FINAL REPORT

PREDICTING MOISTURE-INDUCED DAMAGE TO ASPHALTIC CONCRETE
- FIELD EVALUATION PHASE -

by

G. W. Maupin, Jr.
Research Scientist

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

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

Charlottesville, Virginia

August 1981

VHTRC 82-R11

BITUMINOUS RESEARCH ADVISORY COMMITTEE

R. L. ALWOOD, Chairman, District Materials Engineer, VDH&T

A. D. BARNHART, District Materials Engineer, VDH&T

P. F. CECCHINI, District Engineer, VDH&T

J. L. CORLEY, Assistant District Engineer — Construction, VDH&T

W. R. DAVIDSON, Assistant Maintenance Engineer, VDH&T

W. A. DENNISON, District Materials Engineer, VDH&T

C. E. ECHOLS, Asst. Prof. of Civil Engineering, U. Va.

R. V. FIELDING, Materials Engineer, VDH&T

C. S. HUGHES III, Highway Research Senior Scientist, VH&TRC

A. B. JOHNSON, Assistant Construction Engineer, VDH&T

J. T. LOVE, Materials Engineer, Materials Division, VDH&T

H. E. MARSHALL, District Engineer, FHWA

T. W. NEAL, JR., Chemistry Lab.Supvr., Materials Div., VDH&T

R. S. THOMAS, Bituminous Engineer — Maintenance Div., VDH&T

R. D. WALKER, Chairman, Dept. of Civil Engineering, VPI & SU

ABSTRACT

Virginia was one of seven agencies that participated in the evaluation of a stripping test developed under National Cooperative Highway Research Program Project 4-8(3). The test was used to predict stripping of a field test section and the test results were compared to stripping that occurred in the test section over a 5-year period.

The stripping test predicted that a significant amount of stripping would occur over a long time period. Strength tests and visual examination of field cores indicated a significant amount of stripping had occurred at 22 months; however, subsequent corings did not reveal significant additional stripping. Although considerable stripping has developed, the absence of pavement distress is believed to be related to a low traffic volume. Strength tests indicate that stripping is continuing; therefore, more time might be necessary to reach the predicted level of damage.

FINAL REPORT

PREDICTING MOISTURE-INDUCED DAMAGE TO ASPHALTIC CONCRETE
– FIELD EVALUATION PHASE –

by

G. W. Maupin, Jr.
Research Scientist

INTRODUCTION

A tentative stripping test was developed under National Cooperative Highway Research Program Project 4-8(3) "Predicting Moisture Induced Damage to Asphaltic Concrete". A field evaluation of the new test was initiated in 1974, with Virginia being one of seven state and federal agencies participating.

Each participant installed, tested, and monitored the performance of a 1,000-ft. (300-m) test section of bituminous pavement over a 5-year period. The tentative test method was used to obtain data on laboratory prepared specimens and on cores taken periodically from the test section. The performance of the test section was documented along with traffic and weather data. The NCHRP contractor was responsible for examining the data on all test sections to evaluate the test method and suggest criteria for acceptance of mixes, if possible.

A detailed description of the Virginia test section and testing program was included in the first interim report on the project.(1) The present report presents a brief description of the test section and a summary of the data that have been collected over the 5-year period since its installation.

PURPOSE AND SCOPE

The purpose of this project was to provide lab and field data for the evaluation of a newly developed stripping test. The test was performed on laboratory specimens and on cores from a field test section. Also, the test section was inspected periodically for evidence of stripping failures and other forms of distress.

TEST INSTALLATION

On May 6, 1976, a 950-ft. (290-m) test section was constructed on Greenwood Drive in Portsmouth, Virginia, using an asphaltic concrete mix containing a granitic aggregate known to be susceptible to stripping. The pavement consisted of 1.5 in. (3.8 cm) of S-5 asphaltic concrete surface mix, 5.5 in. (14.0 cm) of I-2 asphaltic concrete base mix, 6 in. (15.0 cm) of crushed stone, and a 6 in. (15.0 cm) cement-stabilized subgrade. The location of the test section and description of the materials are given in the interim report cited above. The bottom 2.5 in. (6.4 cm) of the I-2 base mix was analyzed in this study because, generally, the bottom layer of the asphaltic concrete is the first portion affected by stripping.

The traffic loading for the test section was approximately 5,000 18-kip (80 KN) equivalent single-axle loads per year. The annual precipitation and freezing index (degrees Fahrenheit days below 32°F) were approximately 40 in. (102 cm) and 160°F days (89°C days below 0°C), respectively.

LABORATORY PROCEDURE

While tests on pavement cores would allow more accurate predictions of the tendency of a mix to strip than would tests on lab specimens, in practical design situations the stripping test would be performed on lab specimens containing aggregate and asphalt cement to be used in the pavement. The testing would be performed prior to the initiation of paving to determine the need for an antistripping additive in the mix. For the field evaluation, both laboratory specimens and cores were tested to allow a comparison of the results.

Laboratory Specimens

Specimens were prepared in the laboratory with aggregate and asphalt cement obtained from the plant during the construction of the test section. The specimens, prepared with a permeable void content of 5.5% to duplicate field mixes, were tested after preconditioning as described later and after storage for 2, 5, and 10 months. It was thought that tests on the stored specimens might allow a closer prediction of stripping in the field than would the tests on freshly made specimens.

Cores

Cores were obtained immediately after construction, at 4-month intervals for 2 years, and at 6-month intervals for the remaining 3 years. Some of the first cores taken were stored in the laboratory and tested after 2, 5, and 10 months to allow comparison with the test results from the laboratory specimens stored for the same periods. The average permeable void content of all cores was 5.6%, and periodic coring has indicated no significant decrease in voids as a result of densification by traffic.

Test Procedure

Two types of moisture preconditioning were used for the initial tests on the lab specimens and cores in an attempt to duplicate the stripping that occurs in the field. One set of specimens were preconditioned by vacuum saturation; another set, hereinafter referred to as freeze-thaw specimens, were vacuum saturated, frozen, and placed in a 140°F (60°C) water bath; and a third set were tested dry (unconditioned). The preconditioning by vacuum saturation supposedly simulates short-term stripping, and the saturation, freezing, and 140°F (60°C) soak preconditioning was expected to simulate long-term stripping.

Resilient modulus tests were performed at 72°F (22°C) and 55°F (13°C), and indirect tensile tests at 55°F (13°C). A detailed description of the preconditioning and testing procedure is given in the previously cited interim report.

All cores taken periodically were desiccated to constant weight before any further testing. After desiccation, one set of cores were tested dry (unconditioned) and another set in a vacuum-saturated condition.

RESULTS

Resilient Moduli and Tensile Strength of Unconditioned Cores

Figures 1 and 2 illustrate the resilient modulus at 72°F (22°C) and 55°F (13°C), respectively, of cores taken periodically and tested dry (unconditioned). The moduli for both test temperatures tripled during the first 16 months, but then suddenly decreased at 22 months following a severely cold winter. The moduli increased from 22 months to 46 months, and then decreased significantly from 46 months to 58 months. The 58-month moduli were approximately 40% greater than the initial moduli. The changes in the modulus, especially for the cores tested at 72°F (22°C), appear to be cyclic, displaying decreases during the winter when the pavement is wet and increases during the summer when the pavement dries.

Figure 3 illustrates the tensile strength of the dry (unconditioned) cores. Although the trend is similar to those in Figures 1 and 2, it is not as pronounced.

The curves in Figures 1 through 3 could possibly be represented by the summation of the hypothetical stiffening and stripping curves depicted in Figure 4. Stripping was visually observed to be minor, as indicated by a small strength loss in curve C, during the first 16 months; however, the mix stiffened considerably, as evidenced by the test results. As observed visually, stripping became major and began to overshadow stiffening gains at 22 months. Because of the lack of foresight, data were not gathered to help determine the cause of the pavement stiffening. It is likely that the asphalt cement stiffened through natural aging or through some mechanism connected with the stripping phenomenon. This hypothesis is discussed subsequently in an attempt to explain the comparison of core ratios with the predicted ratios.

Resilient Modulus and Strength Ratios of Lab Specimens and Cores

The resilient modulus and tensile strength ratios are the ratios of the test values obtained on preconditioned specimens to those from dry specimens. Lottman has suggested that the ratio of the preconditioned value to the unconditioned value might be used to predict the stripping susceptibility of a mix.(2) It is thought that a ratio of greater than approximately 0.7 indicates a durable mix.

Specimens fabricated in the laboratory and cores taken immediately after construction were tested to predict the stripping that would ultimately occur, with the vacuum-saturation and freeze-thaw preconditioning being used to simulate short-term and long-term stripping, respectively.

Figures 5, 6, and 7 illustrate the effect of storage time on the resilient modulus ratio at 72°F (22°C), the resilient modulus ratio at 55°F (13°C), and the tensile strength ratio at 55°F (13°C), respectively. The vacuum-saturation preconditioning simulating short-term stripping produced ratios slightly less than 1.0, see 0 storage time. Therefore, the test predicted the negligible short-term stripping that was observed in cores taken from the test section.

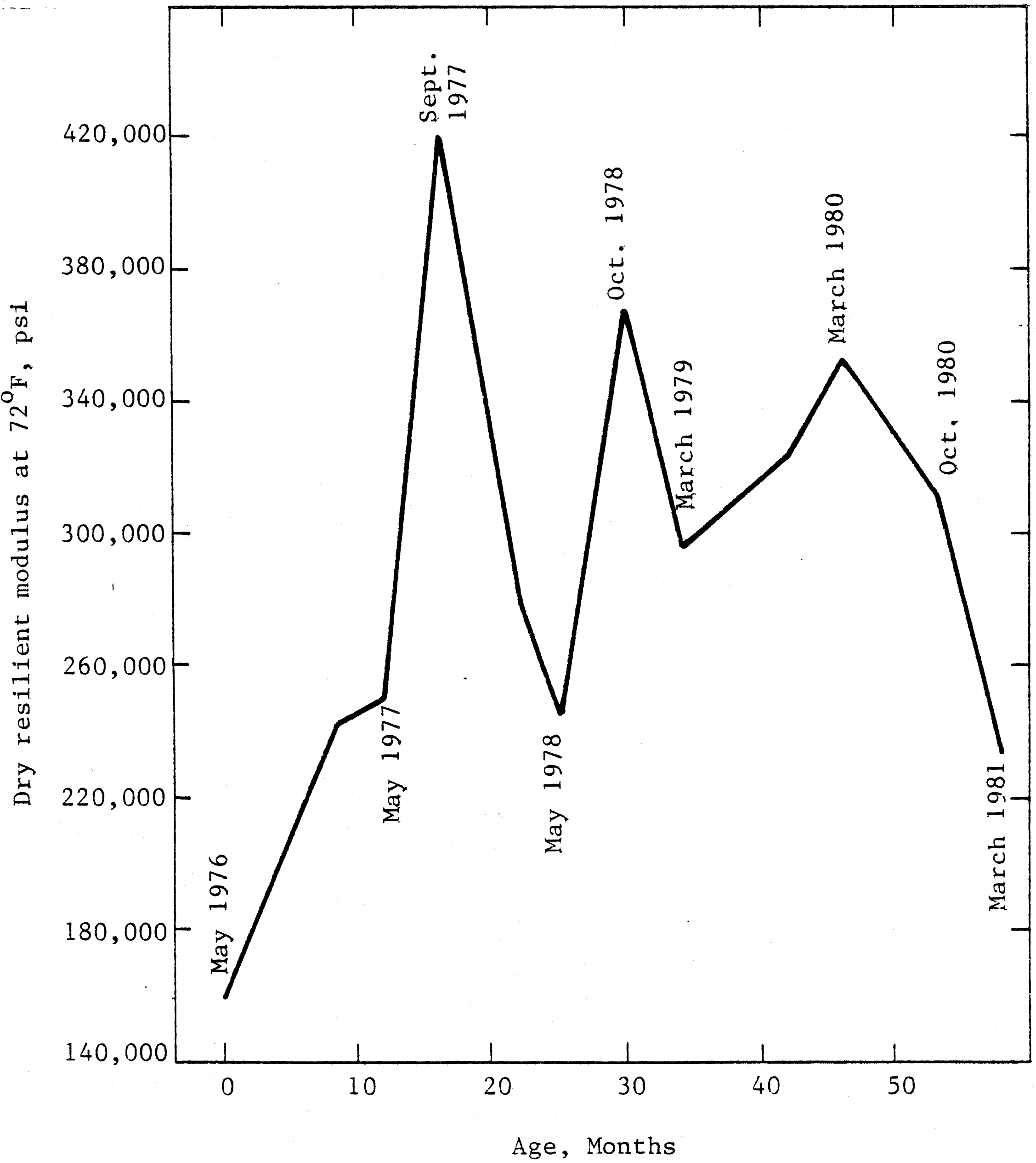

Figure 1. Resilient modulus at 72°F (22°C) vs. age for dry cores taken periodically.
1 psi = 6.89 kPa

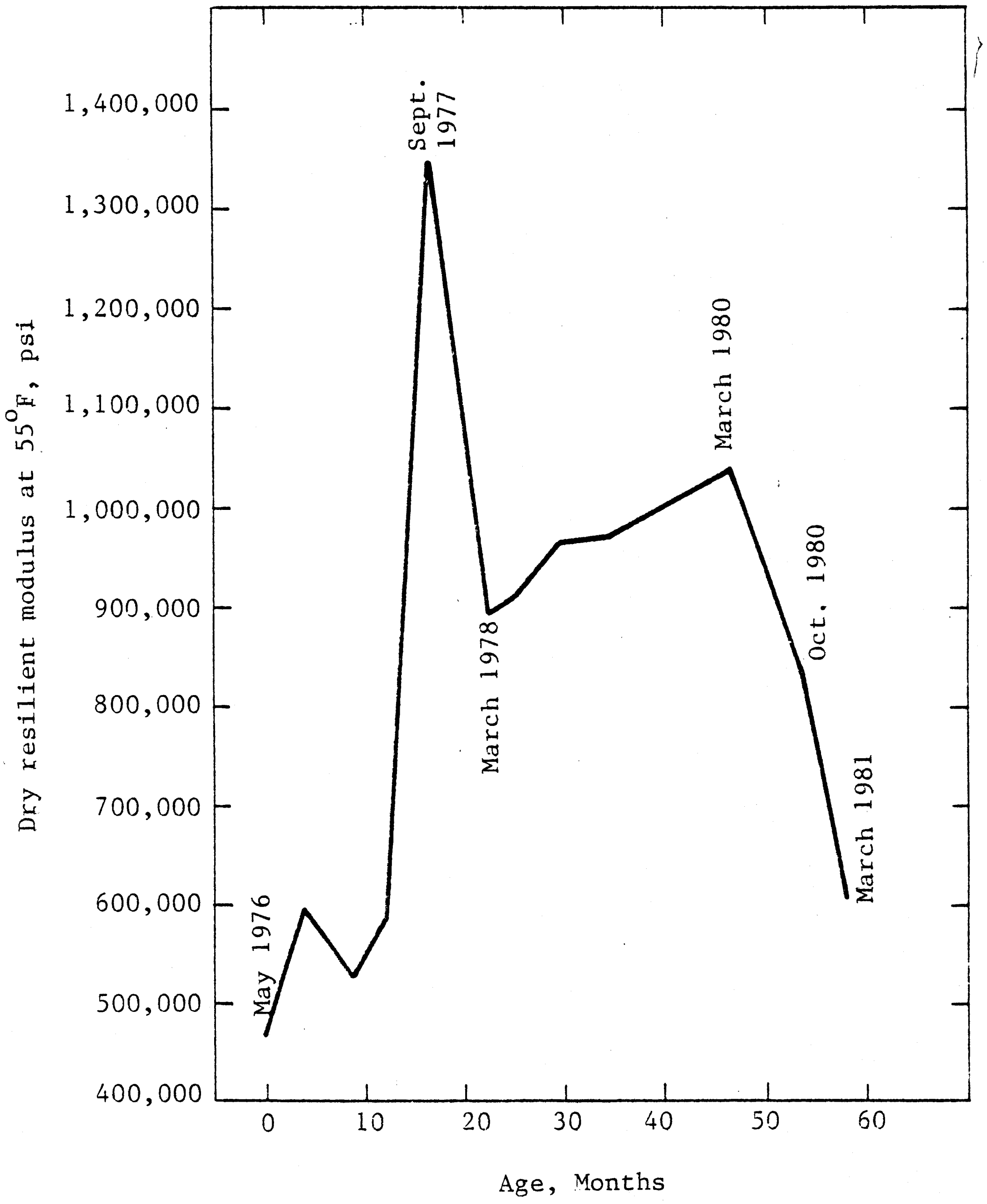

Figure 2. Resilient modulus at 55°F (13°C) vs. age for dry cores taken periodically.
1 psi = 6.89 kPa

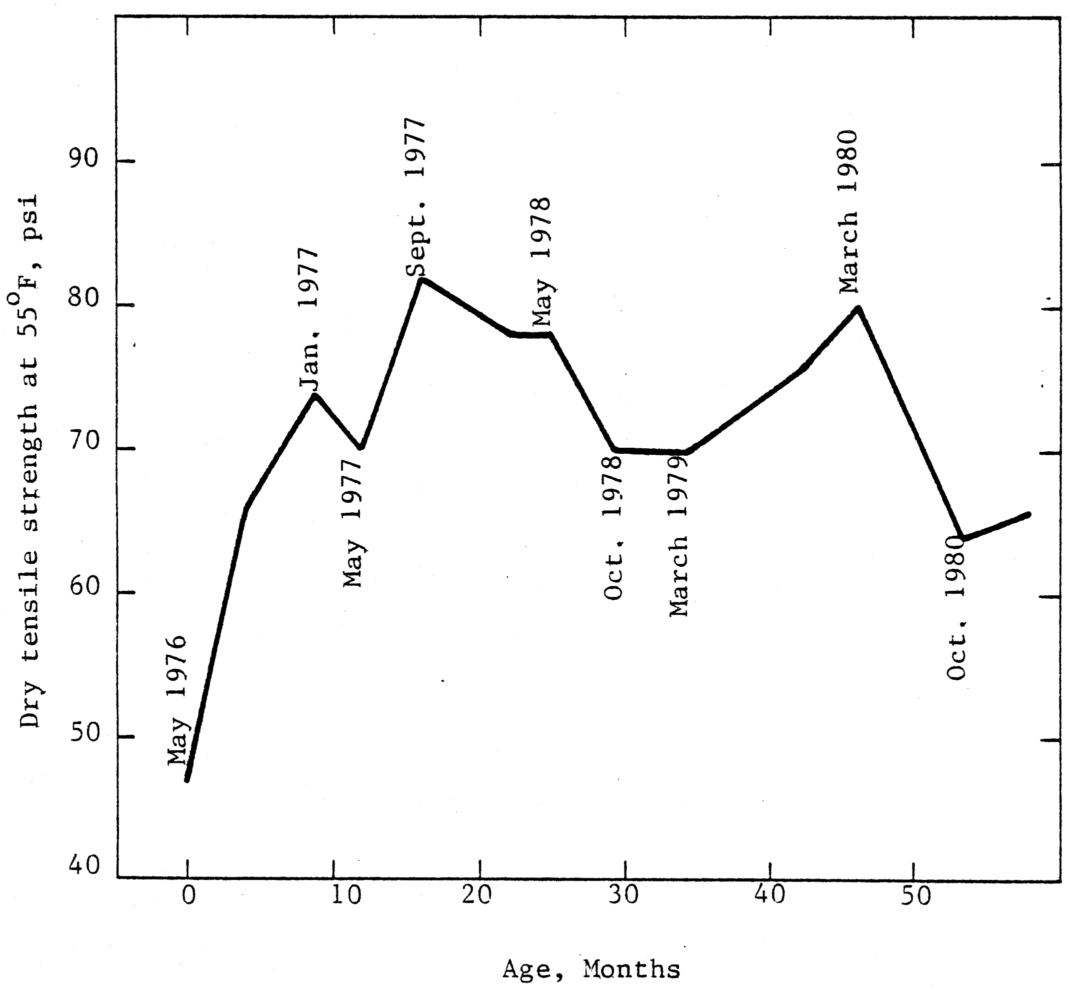

Figure 3. Dry tensile strength at 55°F (13°C) vs. age for dry cores taken periodically.
1 psi = 6.89 kPa

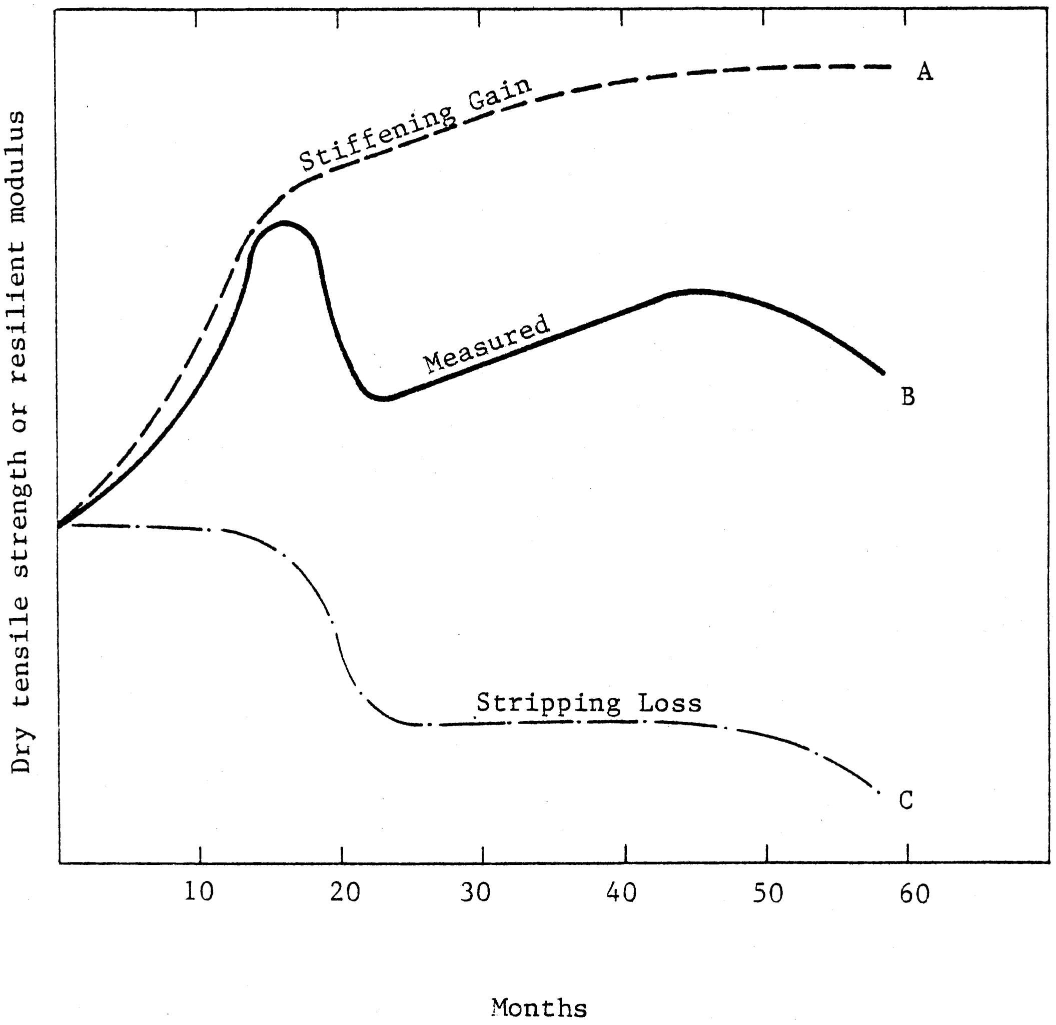

Figure 4. Hypothetical dry tensile strength of cores.

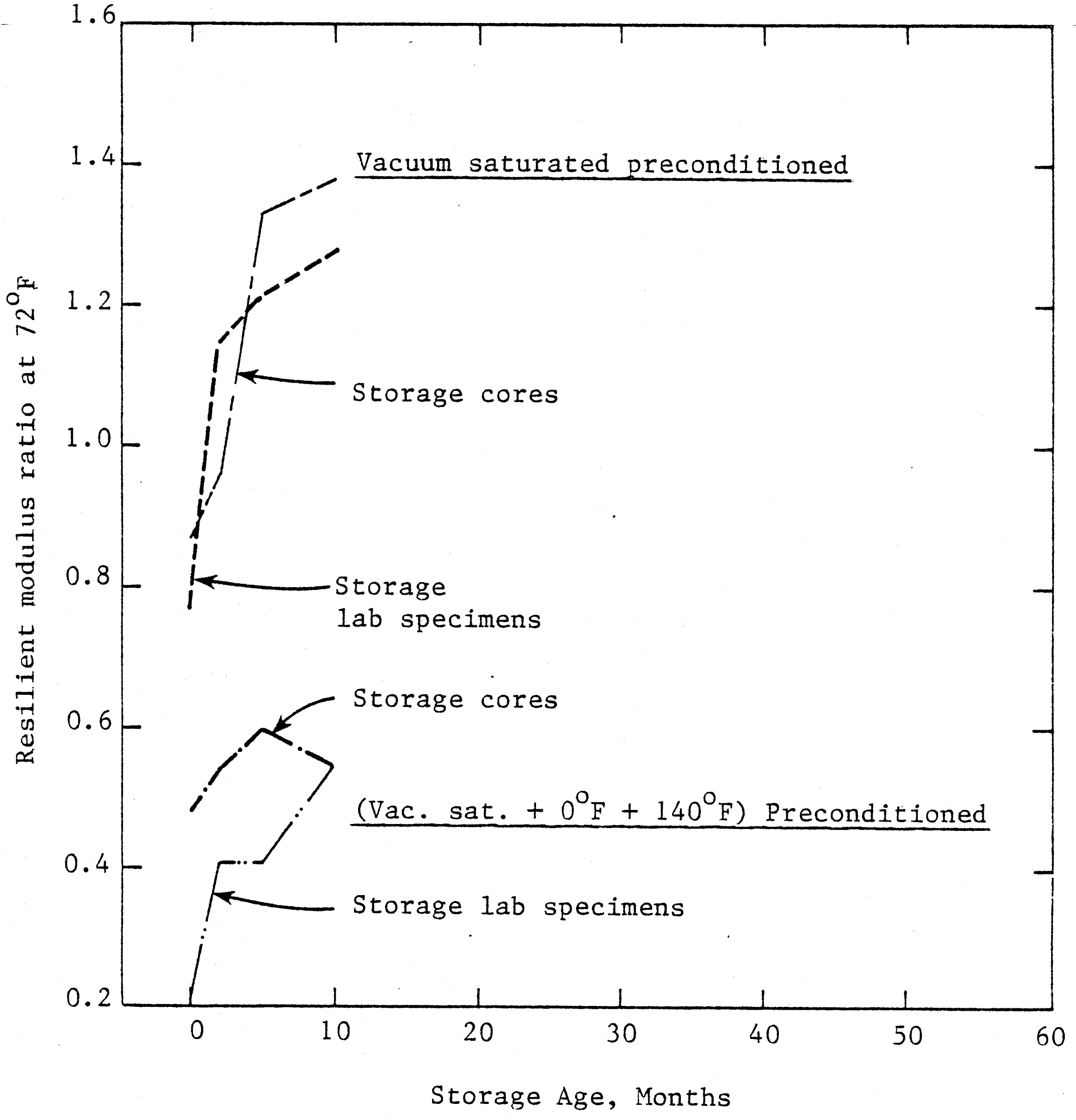

Figure 5. Resilient modulus ratio at 72°F (22°C) vs. storage age for cores and lab specimens.

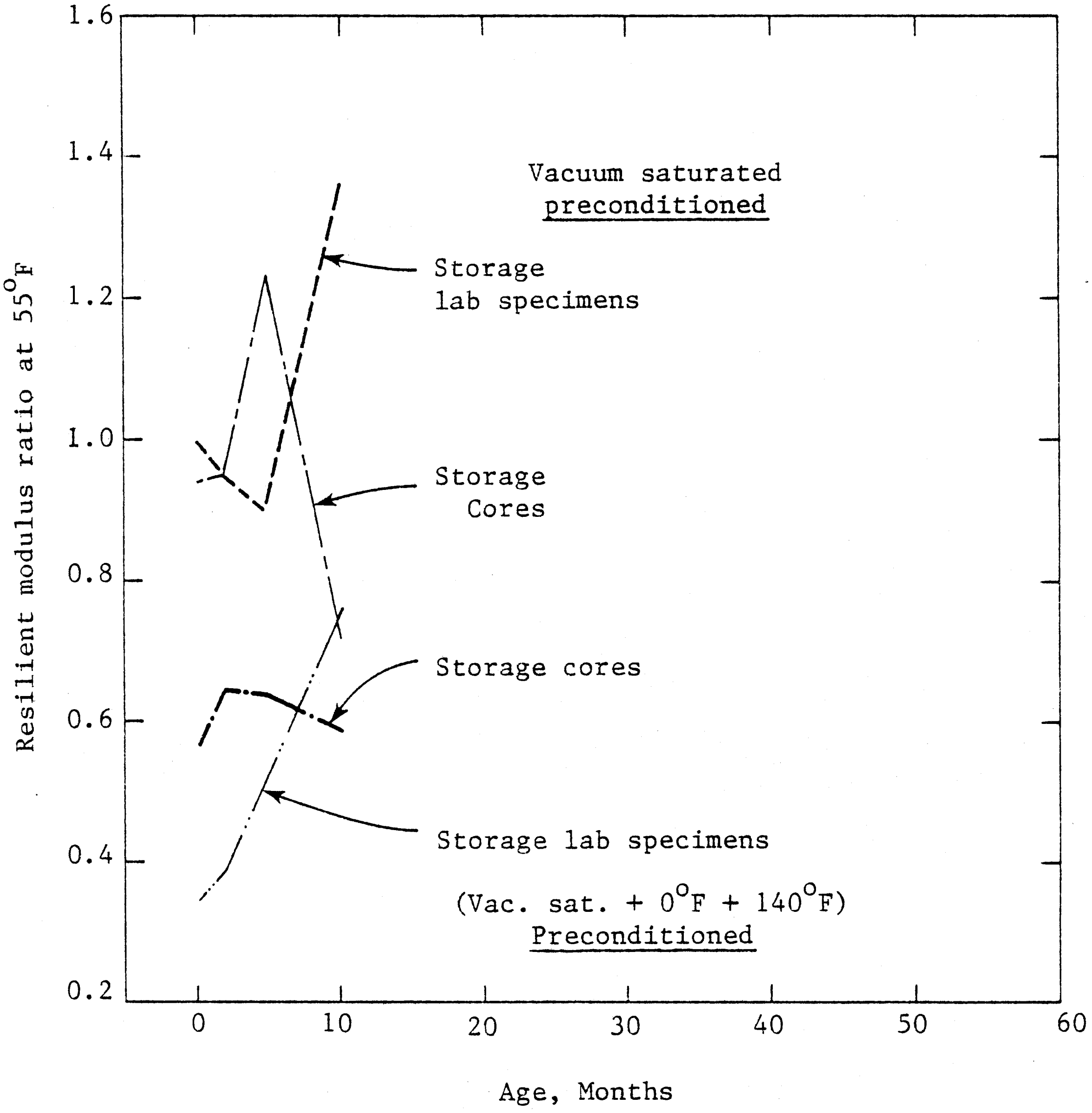

Figure 6. Resilient modulus ratio at 55°F (13°C) vs. storage age for cores and lab specimens.

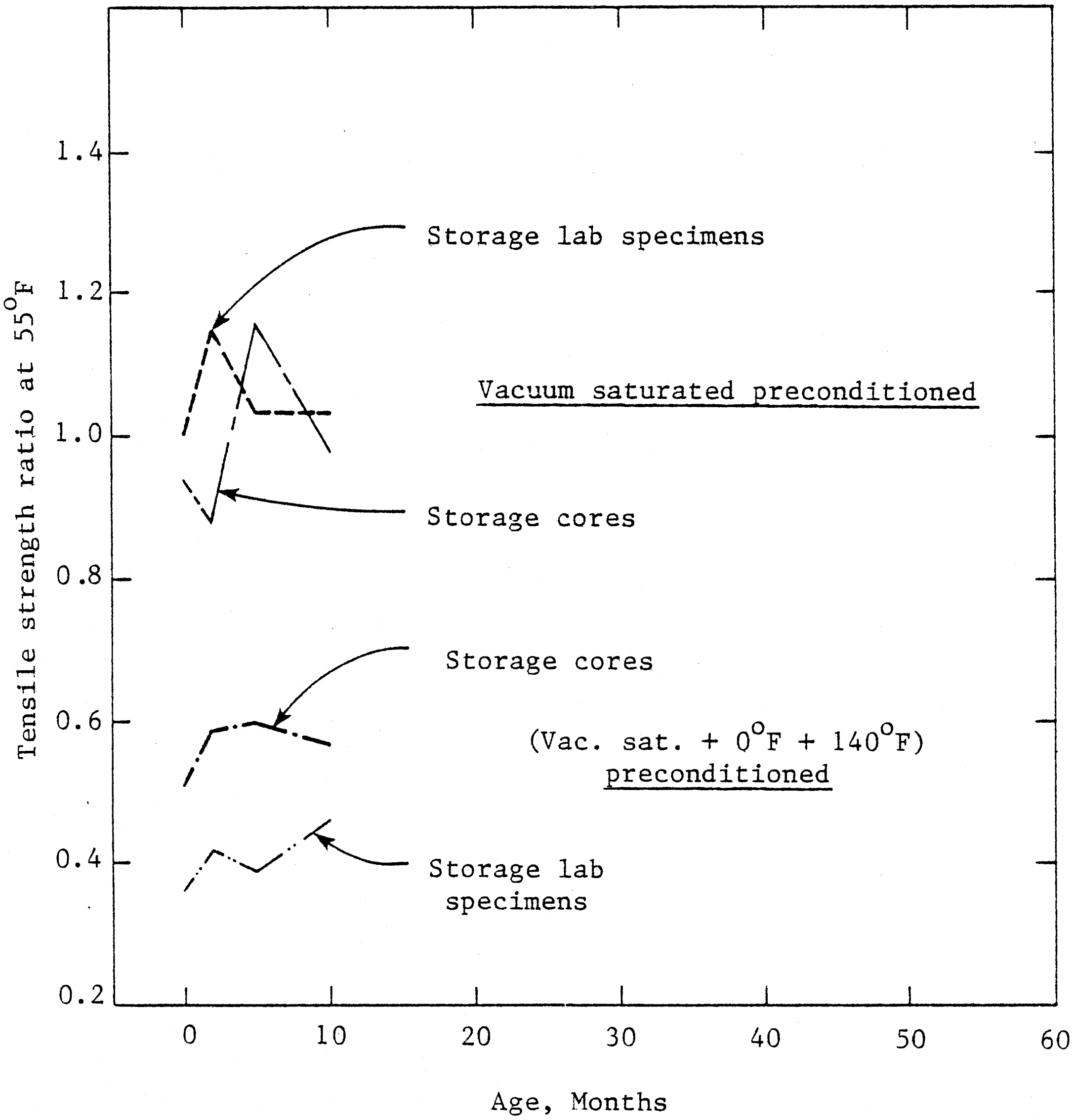

Figure 7. Tensile strength ratio at 55°F (13°C) vs. storage age for cores and lab specimens.

Specimens and cores were tested after storage times of 0, 2, 5, and 10 months to determine if stripping can be predicted more accurately by allowing specimens to age before testing. When it was observed that normal testing variability seemed to overshadow any effect of storage time, it was concluded that storing the specimens did not result in more accurate predictions.

The strength ratios from the initial tests (0 months) of the laboratory specimens given freeze-thaw preconditioning were approximately 0.2 less than the ratios for the cores, which means that the former indicated a potential for more severe stripping than did the latter. Therefore, if the predictive test is used to accept or reject a mix, an allowance should be made for the apparently lower values obtained on lab specimens.

Figures 8 and 9 illustrate the effects of aging and stripping on the resilient modulus ratio at 72°F (22°C) and 55°F (13°C), respectively. There was an increase during the first 9 months and then a fluctuating decrease through 53 months. There was a significant increase at 58 months, which might have been caused by several months of very dry weather prior to coring. The 58-month ratios are 1.0+, which indicate no damage compared to approximately 0.5 for the predicted values.

Figure 10 illustrates the effects of aging and stripping on the tensile strength ratio (TSR) at 55°F (13°C). There was an increase through 9 months, a decrease through 22 months, no change through 46 months, a sudden decrease at 53 months, and an increase to approximately 1.0 for the final 58-month tests. The final ratio of 1.0 is much higher than the predicted long-term ratio of 0.5. As previously noted, the 22-month cores were taken following a severely cold winter and the 58-month cores following a very dry period of several months, which might explain the decrease and increase.

All cores taken periodically during the 5-year study to determine stripping degradation were desiccated to constant weight before testing. The desiccation often required 6 weeks, and it was possible that the properties of the asphalt changed during this period and affected the test results, especially those for the cores tested in the saturated condition. Therefore, several additional 58-month cores were tested immediately in a saturated condition to investigate this possibility. The test results plotted in Figures 5 through 7 indicate that a lower ratio was obtained on the specimens tested immediately. These results verify that there is probably some healing of the stripping degradation during desiccation.

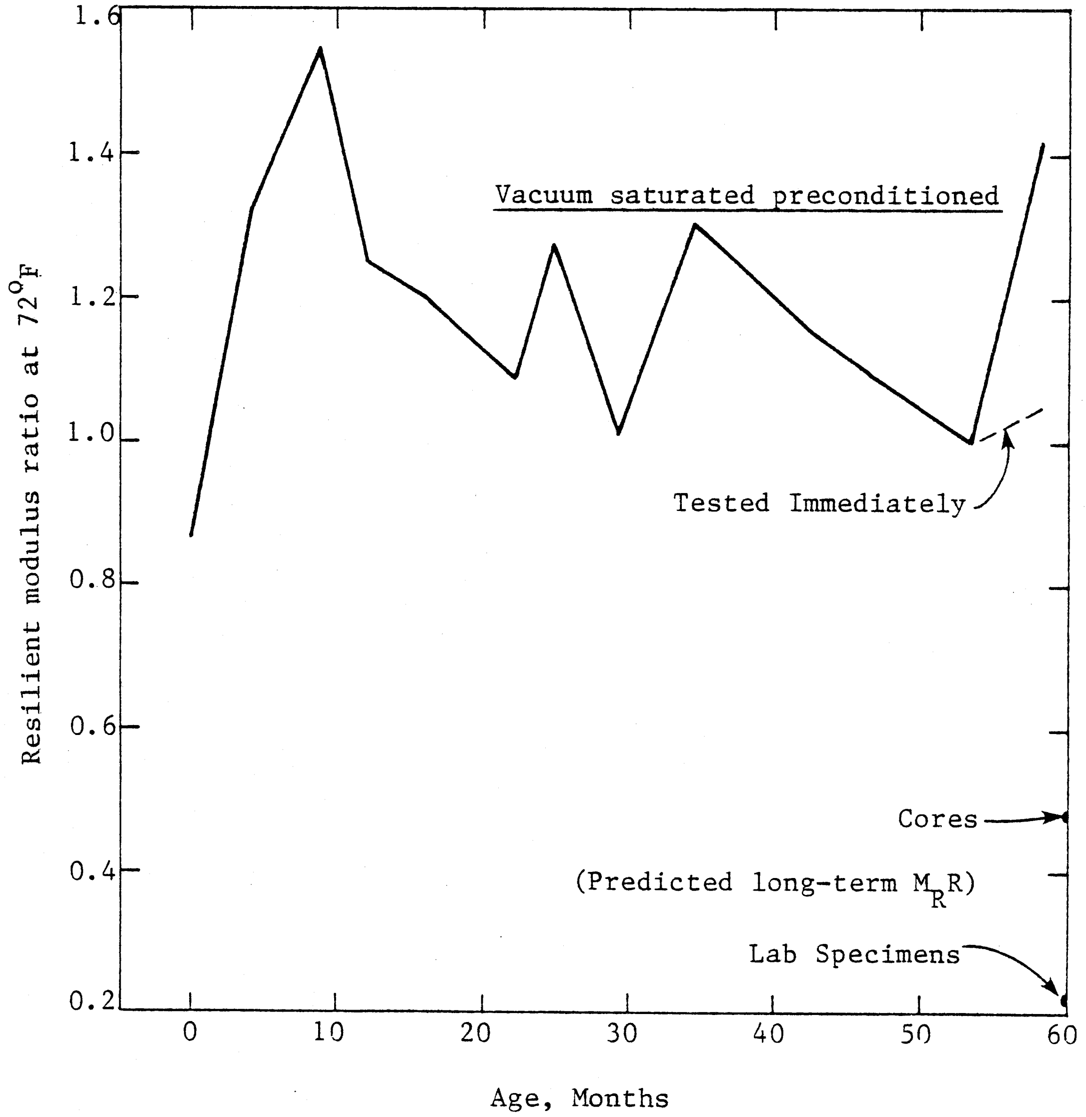

Figure 8. Resilient modulus ratio of periodic cores at 72°F (22°C) vs. age.

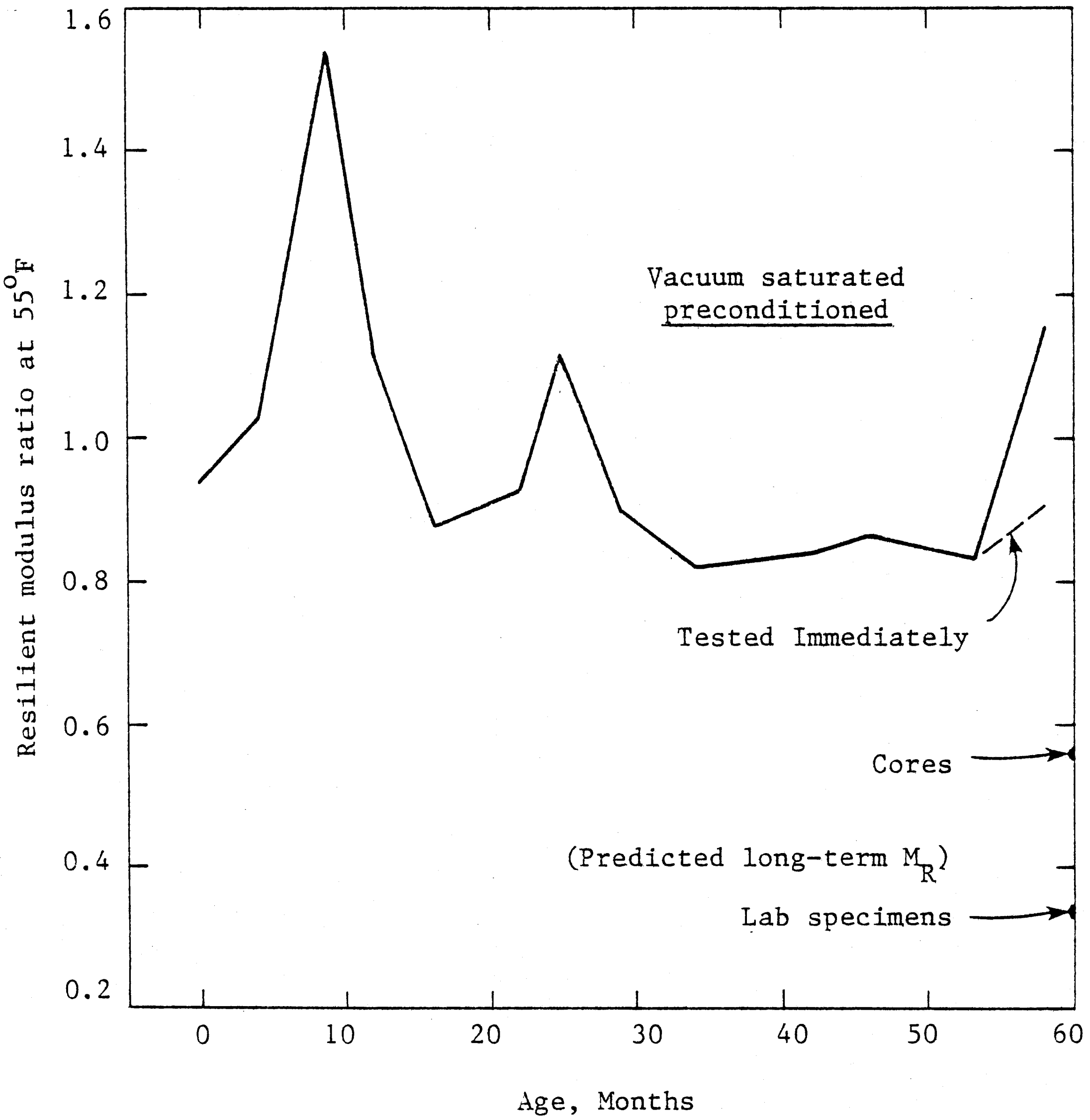

Figure 9. Resilient modulus ratio of periodic cores at $55^{o}F$ ($13^{o}C$) vs. age.

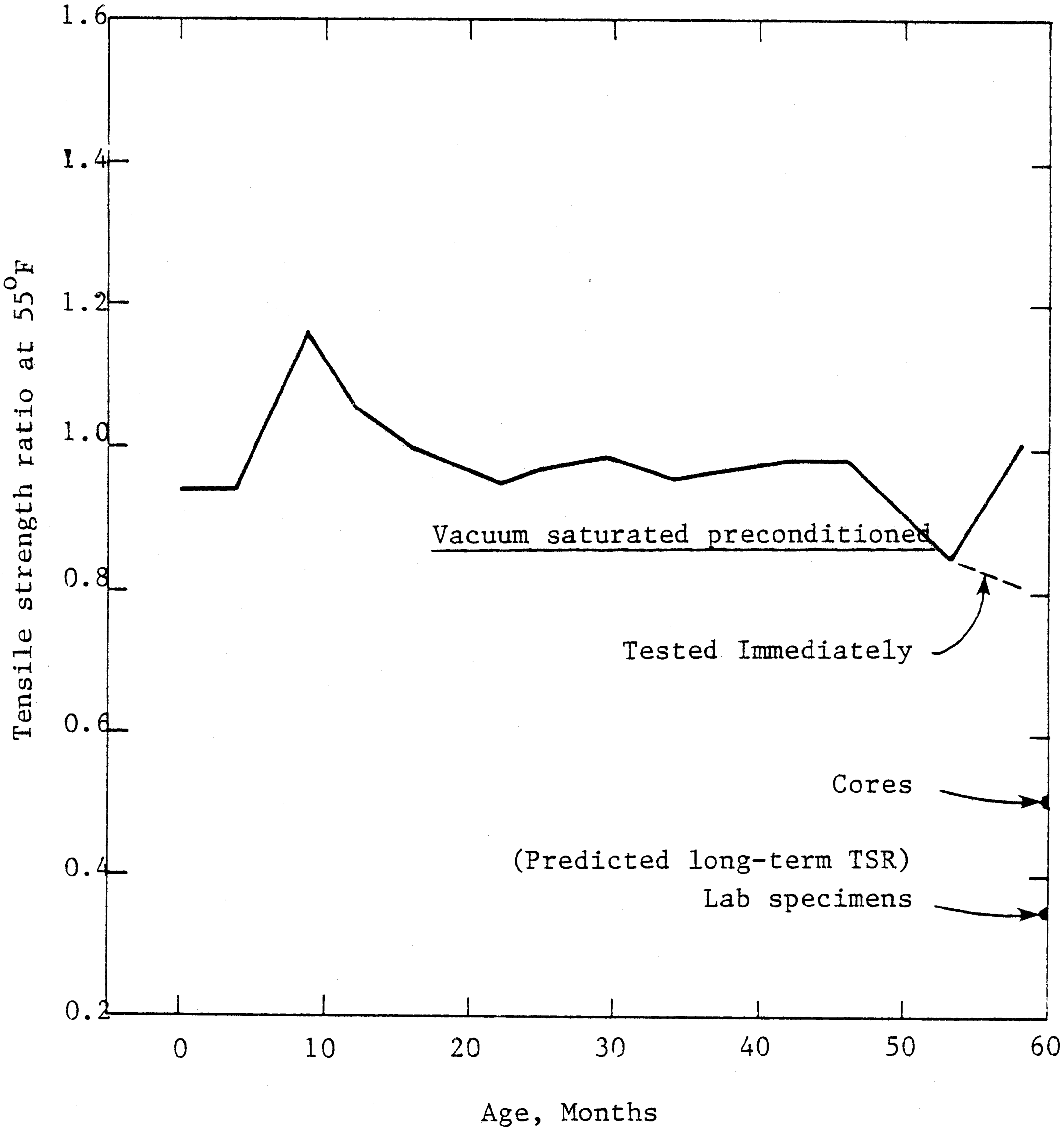

Figure 10. Tensile strength ratio of periodic cores at 55^oF (13^oC) vs. age.

It was proposed in the final report on NCHRP Project 4-8(3) that stripping in the test sections would be indicated by the ratio of the vacuum-saturated tensile strength or modulus to the dry tensile strength or modulus of the pavement cores. The ratios of 5-year cores were expected to approach the predicted long-term ratios; however, ratios of most of the pavements studied in the field evaluation phase remain greater than the predicted long-term ratios. The ratio for the final pavement core should not necessarily coincide with predicted values, because the predicted value represents the dry strength of undamaged pavement whereas the ratio for the cores taken periodically uses the dry strength of a pavement damaged by stripping.

Another complication involves the stiffening of the asphalt. The ratios for the cores would probably be closer to the predicted ratios, if the strength loss of the dry cores caused by stripping could be eliminated. As already discussed, Figure 4 illustrates the possible effects of stiffening and stripping on the measured tensile strength or resilient modulus. The summation of curve A and curve C should equal curve B. Ideally, the ratio for a pavement core should be computed using the appropriate values of curve A, which includes no stripping damage; however, it is not possible to obtain curve A. The remaining alternative is to base the ratio for the 58-month core on the measured maximum dry value (curve B), which occurs at 16 months. The measured dry strength at 16 months reflects only minor stripping damage, as was discussed previously.

The following analysis of field data compares the computation of the TSR of the 58-month cores using the 58-month dry core strength (specified method) and the 16-month dry core strength (modified method) as discussed above.

58-month dry strength, psi = 66 (460 kPa)
58-month saturated strength, psi = 54 (370 kPa)
(tested immediately)
16-month dry strength, psi = 82 (570 kPa)

$$\mathrm{TSR} = \frac{\text{saturated strength}}{\text{dry strength}}$$

Specified method: TSR = 54/66 = 0.82
Modified method : TSR = 54/82 = 0.66

As illustrated in Figure 10, the predicted core TSR was 0.52 as compared to the 0.82 and 0.66 values calculated above. The author believes that 0.66 is a logical computation of the stripping damage that occurred at 58 months.

Pavement Performance

A visual examination of the 12-month cores revealed some stripping, and the 22-month cores, which were taken following a severe winter, revealed a significant amount of stripping, primarily on the large aggregates. Subsequent corings, however, have revealed no significant additional stripping.

The pavement continues to perform well, with no indications of distress. The traffic loading is very low and it is the author's opinion that stripping damage would have been more severe under heavy traffic.

SUMMARY

The testing of laboratory specimens and cores taken immediately after placement of the test section predicted that stripping would reduce the strength by more than 50%; i.e., it would result in a tensile strength ratio and resilient modulus ratio of less than 0.5. Periodic corings revealed significant stripping after 22 months; however, an apparent stiffening of the asphalt binder restored part of the strength loss resulting from the stripping. The values for dry strength and resilient modulus of 58-month cores were higher than the initial values because of the apparent stiffening of the binder.

The tensile strength and resilient modulus ratios of cores have not approached the predicted values; however, the ratios for the pavement cores should not necessarily coincide with the predicted values. A modification to the method of computing the ratios yielded values closer to the predicted values.

While the test pavement is performing well and the stripping noted at 22 months has not progressed, it is believed that the distress would now be greater had the traffic loading been heavier.

CONCLUSIONS

1. The stripping test predicted that the loss in strength induced by stripping would be 50% or more.
2. Significant stripping was visible in cores after 22 months.
3. The resilient modulus and indirect tensile strength of dry cores continue to decrease, which indicates stripping is still causing a loss of strength.

4. The good performance of the test section is believed to be related to the absence of heavy traffic.

STATUS AND RECOMMENDATIONS

Prior to the initiation of this study it was realized that a reliable stripping test was badly needed. After some of the test data had been gathered locally and nationally, it appeared that the test warranted additional study. Participation in the national study was beneficial from an economical viewpoint because the Virginia Department of Highways and Transportation was able to utilize data from the other participating states.

Concurrent work by the author resulted in the development of a modified stripping test that was adaptable for use in field materials testing laboratories at minimal expense.(3) The modified test was recommended for use by the Virginia Department of Highways and Transportation's materials division and is being implemented.

The test is being used to determine if a mix needs an antistripping additive, and it is hoped that in the future it will also be used to ascertain that additives are used effectively. Its adoption should result in savings to the Department because it will reveal cases in which antistripping additives might otherwise be needlessly used and assure that a pavement will not fail prematurely from the use of an ineffective additive.

ACKNOWLEDGEMENTS

Appreciation is expressed to J. H. Dillard and H. H. Newlon, Jr. for their support during the study, and to C. S. Hughes for his professional advice. Also, the cooperation of R. L. Alwood in the conduct of the field work is greatly appreciated. Thanks are extended to L. E. Wood for the excellent testing program and to Ann McDaniel for typing the report.

REFERENCES

1. Maupin, G. W., Jr., Interim Report, Predicting Moisture-Induced Damage to Asphaltic Concrete – Field Evaluation Phase, August 1977.

2. Lottman, Robert P., "Predicting Moisture-Induced Damage to Asphaltic Concrete", National Cooperative Highway Research Program Report 192, 1978.

3. Maupin, G. W., Jr., "Implementation of Stripping Test for Asphaltic Concrete", Transportation Research Record No. 712, Transportation Research Board, 1979.