Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-92+1222-1F		

4. Title and Subtitle	5. Report Date
ESTABLISHMENT OF ACCEPTANCE LIMITS FOR 5-CYCLE MSS AND MODIFIED WET BALL MILL TESTS FOR AGGREGATES USED IN SEAL COATS AND HMAC SURFACES	November 1991
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Sibty Hasan, Alvin H. Meyer, and David W. Fowler	Research Report 1222-1F

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075	
	11. Contract or Grant No. Research Study 3-9-90/1-1222

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Transportation Planning Division P. O. Box 5051 Austin, Texas 78763-5051	Final
	14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Research Study Title: "Establishment of Acceptance Limits for the 5-Cycle MSS and Modified Wet Ball Mill Tests for Aggregates Used in Seal Coats and HMAC Surfaces"

16. Abstract

This research report evaluates the performance of aggregates from several sources commonly used throughout Texas. The aggregate selection was primarily based on the magnesium sulfate soundness (MSS) loss. Aggregates used in the project had a range of MSS values, with a large fraction of the total having mid-range MSS loss (more than 10.0 but less than 25.0). Included in the study were hot-mixed asphalt concrete (HMAC), seal coat, and micro-seal pavement surfacing. Pavement test sites were selected to provide a range of traffic. Other laboratory tests performed for this study include Texas degradation, Los Angeles abrasion, and polish value.

Evaluation of the pavement surfaces included frictional resistance, macro-photographs, surface texture, and condition rating. Regression equations have been developed to predict performance of different aggregates in pavement surfaces. A mini-texture meter was used for surface texture measurements. Micro- and macro-textural measurements were integrated in an attempt to forecast attendant frictional resistance.

17. Key Words	18. Distribution Statement
performance, aggregates, sources, magnesium sulfate soundness (MSS) loss, hot-mixed asphalt cement (HMAC), seal coat, micro seal pavement surfacing, frictional resistance, texture	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	104	

ESTABLISHMENT OF ACCEPTANCE LIMITS FOR 5-CYCLE MSS AND MODIFIED WET BALL MILL TESTS FOR AGGREGATES USED IN SEAL COATS AND HMAC SURFACES

by

Sibty Hasan
Alvin H. Meyer
David W. Fowler

Research Report 1222-1F

Research Project 3-9-90/1-1222

Establishment of Acceptance Limits for the 5-Cycle MSS and Modified Wet Ball Mill Tests for Aggregates Used in Seal Coats and HMAC Surfaces

sponsored by

Texas Department of Transportation

in cooperation with

U.S. Department of Transportation
Federal Highway Administration

by

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

November 1991

NOT INTENDED FOR CONSTRUCTION,
PERMIT, OR BIDDING PURPOSES

Alvin H. Meyer, P.E. (Texas No. 31410)
David W. Fowler, P.E. (Texas No. 27859)
Research Supervisors

ABSTRACT

This research report evaluates the performance of aggregates from several sources commonly used throughout Texas. The aggregate selection was primarily based on the magnesium sulfate soundness (MSS) loss. Aggregates used in the project had a range of MSS values, with a large fraction of the total having mid-range MSS loss (more than 10.0 but less than 25.0). Included in the study were hot-mixed asphalt concrete (HMAC), seal coat, and micro-seal pavement surfacing. Pavement test sites were selected to provide a range of traffic. Other laboratory tests performed for this study include Texas degradation, Los Angeles abrasion, and polish value.

Evaluation of the pavement surfaces included frictional resistance, macro-photographs, surface texture, and condition rating. Regression equations have been developed to predict performance of different aggregates in pavement surfaces. A mini-texture meter was used for surface texture measurements. Micro- and macro-textural measurements were integrated in an attempt to forecast attendant frictional resistance.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the help extended by individuals and organizations at different stages of this project. We would like to express appreciation to all seven districts that participated in this project. Our gratitude goes to Mr. Harold Albers of the Division of Materials and Tests (D-9) of the Texas Department of Transportation for his advice and assistance. Special thanks go to Mr. Chryssis G. Papaleontiou for his valuable advice.

Finally, the authors would like to thank David Whitney, Joy Swann, Rose Rung, and the entire staff of the Center for Transportation Research for continuous assistance in preparing this report.

ABBREVIATION GUIDE

AGTY	Aggregate type	CUTR	Cumulative traffic
SPGR	Specific gravity	ADT	Annual average daily traffic
ABSP	Absorption	DP	Deduct point
PV	Polish value	BLD	Bleeding
MSS	Magnesium sulfate soundness	LC	Longitudinal crack
TDT	Texas degradation test	TC	Transverse crack
LAABR	Los Angeles abrasion	BLC	Block crack
AGGR	Aggregate gradation	ASPC	Asphalt percentage
SFTY	Surface type	STAB	Stability
AGSR	Aggregate spread rate	BPN	British pendulum number
ASSR	Asphalt spread rate	MTM	Mini-texture meter
HMAC	Hot-mix asphaltic concrete	FN	Friction number
CUPP	Cumulative precipitation	SMTD	Sensor-measured texture depth
CUFT	Cumulative freeze-thaw cycles	SPTD	Sand-patch texture depth

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

In the past few years, the Texas Department of Transportation (TxDOT) has undertaken a number of research studies to evaluate the performance of aggregates used in pavement surface courses. Results from laboratory tests have been used to predict field performance of aggregates. The predictions provided different levels of success for different aggregates and regions.

This study is a continuation of an earlier study, "Evaluation of the 4-Cycle Magnesium Sulfate Soundness Test"[20]. In the previous study, different laboratory tests were investigated, with particular concentration on the magnesium sulfate soundness (MSS) test. The MSS test identifies soft porous aggregates. It was reasonably successful in predicting the performance of most of the aggregates that were included in the research study. Based on the results of that study, 4-cycle MSS maximum values were recommended as follows:

Type of surface	*Allowable MSS Loss*
Hot-mix asphalt concrete (HMAC)	30 percent
Asphaltic seal coat	25 percent

Several districts in Texas reported improved pavement surface performance, resulting from the elimination of unsound aggregate sources, following the recommended allowable MSS loss limits. Because the aggregates used in the previous study had either high (greater than 30) or low (less than 15) MSS loss, this research study was initiated to evaluate more aggregates in the mid-range of MSS loss and to incorporate more field performance data to determine whether the values recommended in the previous study were valid.

After the study was initiated, TxDOT chose to replace the 4-cycle MSS test with the 5-cycle MSS test. Hence, the 5-cycle MSS test was used for the remainder of the study.

Surface type is an important factor that influences the aggregate performance. In HMAC, the aggregates are coated with asphaltic material and compacted (densified). Therefore, a lower-quality aggregate may be adequate, because the individual aggregate particle is somewhat protected. In addition to the type of surface, construction methods, environment, average daily traffic (ADT), and type of traffic also affect the performance of aggregates.

Pavement performance in this study is estimated through a pavement serviceability measurement, a pavement condition rating, and a pavement frictional resistance measurement. Although each of the above observations is indicative of pavement performance, all of them are not affected by the same pavement constituents or external influence. Since aggregates are the largest constituent in the pavement surface, aggregate properties affect each of the measurements. The effect may be generated directly by the physical and chemical properties of the aggregate or indirectly by influencing the mix design or construction methods. Therefore, the measure of pavement performance is also indicative of aggregate performance

1.2 OBJECTIVE

The objective of this study is to establish acceptance limits for the 5-cycle magnesium sulfate soundness (MSS) test and the Texas degradation test (TDT) (modified wet ball mill test).

1.3 SCOPE OF STUDY

The evaluation of aggregate performance in pavement surfaces is difficult in part because of the typical service life of a seal coat (5 to 7 years) and that of an HMAC surface (8 to 15 years). In addition, for a better understanding of the deterioration process, each surface has to be evaluated frequently, at least twice each year. But if aggregate quality, according to one particular laboratory test or combination of laboratory tests evaluating different aggregate properties, can be related to aggregate performance, then the performance of other aggregates can be estimated based on their laboratory quality evaluation.

Acceptance levels for the 4-cycle MSS test and the TDT were recommended in the previous study. The present study was undertaken with particular concentration on aggregates with 4-cycle MSS values between 15 and 30. The present study is expected to affirm and further extend the earlier conclusions.

The selected aggregate sources and the road sections constructed with them are located in seven districts and in two environmental zones. As in most other studies, the selections were made with consideration for practical constraints. This study included three types of pavement surfacing and various levels of average daily traffic (ADT) to provide broad coverage over the inference region. Data supplied by the districts regarding constructional practice, weather condition during construction, and application rates were also included in the study.

Pavement performance measurements were made with existing conventional equipment. Friction measurements, pavement condition ratings, and macro-photographs were taken to evaluate pavement performance in this study. Visual surveys and physical measurements with conventional measuring tools were used to rate pavement condition. Pavement macro-textural measurements, friction measurements with the portable British pendulum, and skid trailer measurements were part of pavement friction measurements. For macro-textural measurement, the sand-patch method and the mini-texture meter were used. The mini-texture meter is a lawnmower-like piece of equipment, equipped with a laser sensor, which measures surface texture. Its functional mechanism is explained in Chapter 6. The measurement made with this machine compares very well with that of the sand patch. The repeatability of the results is very good, and the results are more representative of surface texture because the machine averages the texture over a strip of pavement rather than at a particular location on the pavement surface.

Many factors affecting aggregate performance were included in the study, including the surfacing type, cumulative traffic, percentage commercial traffic, and weather data.

Chapter 2 includes a literature review on pavement performance evaluation. The literature reviewed includes the pavement frictional performance evaluation for each of the three types of road surfacing studied in this project. Literature involving pavement condition rating is also discussed.

Chapter 3 consists of brief details of the laboratory test methods used by TxDOT and used in this study and includes a broader discussion of the MSS loss test. Interrelationships among these test results, and an explanation for interdependency and independency of the tests, are briefly discussed.

Chapters 4 and 5 deal with the field study of the project. Selection of pavement test sections, criteria, and constraints, as well as detailed descriptions of the particular districts and their participation, are included in Chapter 4. Field test and field-related data and their relationships are discussed in Chapter 5.

The mini-texture meter—including related equipment, the theoretical background of such measurements, the advantages of this method of measurement, and future prospects of usage of this type of equipment—is discussed in Chapter 6.

Chapter 7 discusses the performance evaluation procedures and the results that were obtained by following these procedures. Statistical models to predict pavement friction performance are established in Chapter 8.

Chapter 9 presents the conclusions and recommendations that have been derived from this study.

CHAPTER 2. LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, literature relating to pavement performance evaluation is reviewed, with particular concentration on frictional resistance measurement and pavement condition rating.

2.2 PAVEMENT FRICTIONAL STUDY

Measuring friction is one of the three means of evaluating pavement performance. The friction requirement of pavement is based on safety needs. In these days of high-volume traffic commuting at a high speed, the need for adequate pavement friction has increased. Pavements are considered to be in good condition if they have adequate serviceability or condition rating and adequate friction.

The frictional resistance of a pavement surface depends on its characteristics. Important among these are the macro- and micro-texture of the pavement surface. Development of friction between the vehicle tire and pavement consists of two components: (1) adhesion and (2) hysteresis. Adhesion is the shear stress developed along the 'actual area' of contact between the tire and pavement surface. On the other hand, the damping losses within rubber caused by the tire rolling over and around the aggregate particles result in hysteresis and adhesion.

Pavement surface texture is divided into two components—first, micro-texture, with asperities less than 0.5 mm; and, second, macro-texture, with asperities greater than 0.5 mm. The factor that generates micro-texture is the surface texture of individual aggregate particles, whereas the macro-texture, the large-scale texture, is generated by gradation and maximum size of the coarse aggregate.

Micro-texture helps in the development of low-speed skid resistance. Both micro-texture and macro-texture contribute to high-speed skid resistance. Recently, attempts have been made to develop quantitative models to predict skid resistance from surface textural measurements. The developed predictive models include more than the textural measurements. Factors governing surface layer design and laboratory test results are not necessarily related to textural measurement, but both have been found to contribute to the predictive quantitative models. Models that consider different aspects of pavement surface and were developed for different types of surfacing are discussed below.

2.2.1 Hot-Mix Asphaltic Surface

Other researchers have described the major influence that the surface texture has in predicting frictional performance(4,14). Researchers through the years have also attempted to correlate laboratory test results with frictional performance. Other variables used include polish value (PV), Los Angeles abrasion, mix design properties, cumulative traffic volume, annual average daily traffic, and percent commercial traffic.

A study conducted by the Ontario Ministry of Transportation and Communication during 1974, involving 17 asphaltic concrete test sections, led to the development of a strong predictive equation. Factors related to mix design, particularly mix-design stability and accumulated traffic (emphasizing commercial vehicles), were found to be the most significant parameters.

$$SN_{100} = 0.714\ (MS) + 0.356\ (FLOW) + 1.048\ (VOID) + 40.904/(E) - 17.323$$

Abbreviations for parameters shown in the equation are:

SN_{100} = skid number at 100 km/hr,

MS = Marshall stability,

FLOW = flow of the mix,

VOID = void content in the mix,

E = $[EQT\ (36)]^{0.081}$, and

EQT = an equivalent traffic factor.

The equation has a correlation coefficient (R^2) of 0.86.

Further investigation under the same research study led to the development of another equation. However, only the mix parameters were significant in this model, and the equation had a somewhat lower R^2 value of 0.77. The equation was:

$$SN_{80} = 2.155\ (MS) + 0.192\ (FLOW) + 4.418\ (VOID) - 8.57$$

where

SN_{80} = skid number at 80 km/hr

Following the Ontario study, another study was undertaken by the U.K. Transport and Road Research Laboratory (TRRL). It led to the development of a predictive model for sideways measured skid resistance. The model included only two variables, polish value (PV) and traffic volume. The polish value was only for the coarse aggregate. The model had a very high correlation coefficient (R^2).

$$SFC_{50} = 0.024 - 0.663 \times 10^{-4}\ q_{cv} + 1 \times 10^{-2}\ (PV)$$

where

SFC_{50} = sideways force coefficient at 50 km/hr, and

q_{cv} = flow of commercial vehicles per lane per day.

The opinion of researchers involved with this study was that the low speed during the test contributed significantly to obtaining a high correlation coefficient, because the skid resistance at low speed is primarily governed by surface microtexture.

Additionally, it should be noted that the test speed and some of the other parameters were different during the studies. The method of skid resistance measurement was also different. In Europe (particularly in the U.K.), a sideways force coefficient routine investigation machine (SCRIM) is used for skid measurement. In North America, friction is measured according to the ASTM standard E-274, using a locked wheel skid trailer.

The models developed in the U.K. were found to have poor correlation with Ontario site data. With the inclusion of additional parameters like Marshall stability, flow, and void content, associated with the ability of the mixes to resist consolidation under traffic, excellent agreement between model and site data was obtained.

2.2.2 Asphaltic Seal Coats

An asphaltic seal coat is a surface layer in which the aggregate particles, precoated or uncoated, are spread over a thin application of asphalt on an existing base. Seal coats have been used for years, and they are considered an effective means of pavement surface restoration. Seal coats are used particularly to enhance pavement friction properties and/or to improve pavements that have deteriorated. The designer can obtain different amounts of macro-texture by the choice of a maximum size aggregate.

The literature examined showed that the factors that influence the seal coat performance are micro- and macro-texture, angularity, and gradation of the aggregate. The gradation dictates the initial performance of the surface. Polish and wear resistance, strength and toughness, and resistance to weathering dictate the long-term performance of the seal coat. Because the aggregates are at the surface, the aggregates have direct exposure to traffic loads and environmental conditions and require higher aggregate quality for equal performance.

The effect of the external loads on the aggregates (e.g., polish, wear, split) and the surface condition (e.g., bleeding, cracking) should be simple to detect and easy to measure. It is reasonable to assume that it should be easy to obtain predictive equations for skid resistance for this type of surfacing, but research studies have produced mixed results.

One such study conducted by the Center for Transportation Research, The University of Texas at Austin, has generated some interesting results (15). A generalized predictive equation was produced which included cumulative traffic, polish value, insoluble residue, and aggregate spread rate as variables. The equation had an R^2 value of 0.56. Higher R^2 values were produced with equations for individual aggregate types.

2.2.3 Micro-Surface

Micro-surfacing is a relatively new method of pavement surfacing. It is a special type of surface layer, usually used to renovate a worn or slick surface layer. It is recommended for restoring flexible pavements that have adequate structural capacity but low values of skid resistance and/or condition rating requirements. The limited data obtained from various states indicate that this method of surfacing succeeds in increasing skid resistance. In a number of cases it has not improved the condition rating, particularly that related to surface cracking.

Micro-surfacing is a matrix of asphaltic cement, mineral aggregate, water, modifiers, and other additives. Its constituents are very similar to those of a dense-graded asphalt mix. The laboratory test methods used to evaluate this mix are the same as those used to evaluate a dense-graded asphalt mix. Field test results indicate that its micro- and macro-texture measures are similar to those of lightweight aggregate of asphaltic seal coats, and consequently the mix shows a very high skid resistance.

The literature available on micro-surface is very limited. A study on slurry seal undertaken by the New Jersey Department of Transportation indicates that the slurry seal surface (micro-surfacing is a form of slurry seal) improved the average skid resistance of a pavement surface from 40 to 52[(2)], a 30 percent improvement over the original value. After three and a half years, the inner lanes showed only a 13 percent reduction below the improved value. For the outer lane, the skid resistance value was reduced to the original value.

2.3 PAVEMENT CONDITION RATING

2.3.1 Visual Condition Survey

A surface condition analysis involves presenting distress manifestations on the pavement surface numerically. Several studies have been carried out in an effort to provide a method for evaluating pavement condition. A study done by the Texas Transportation Institute produced a method for pavement condition rating that was used by TxDOT until 1990[(7)]. This method assumed that a pavement can be considered to be in sound condition if it has:

1. Sufficient structural capacity.
2. Good riding condition and low roughness.
3. Sufficient skid resistance to fulfill safety aspects.

Mechanical means are available for direct measurement of the pavement condition for each of the aspects mentioned. But mechanical means involve expensive equipment and highly-skilled personnel to operate them. On the other hand, if the condition is measured by visual observation of distress, the total process becomes simple and inexpensive. Different types of distress manifest pavement deterioration. Each distress type may manifest the deterioration of one or more particular aspects of pavement condition. The distress types relating to the three aspects of pavement condition are:

Structural Capacity –	Alligator cracking, patching, rutting, block cracking, longitudinal and transverse cracking, etc.
Riding Quality –	Rutting, raveling, shoving, corrugation, etc.
Skid Resistance –	Rutting, bleeding, polished aggregate, pavement slope, etc.

A visual survey is usually conducted manually, although a semi-mechanical method is also available. The pavement surface of interest is continuously photographed and, later, evaluated from these photographs. The advantages this method offers are that it is fast, does not interfere with traffic flow, and is very accurate. Moreover, it offers hard documentation of the surface condition and can be used for future reference. This method of condition rating has not gained much popularity, and manual inspection is commonly used.

The ultimate goal of making a visual survey is to obtain a pavement rating score (PRS). All types of distresses are measured in numerical terms. For each type of distress, severity and density are also measured and are used to assign a numerical value to the distress existing on the test section. For most of the distress types, severity and density are considered to have three levels. In most of the cases, the higher degrees of severity and density accompany each other. Care should be taken, nevertheless, to make sure that the appropriate level is determined separately for each.

The mathematical expression for the PRS model is:

$$PRS = 100 - D,$$
$$D = f\text{ (distress type, severity, density), and}$$
$$D = \text{Deduct point.}$$

CHAPTER 3. LABORATORY TESTS

3.1 INTRODUCTION

Laboratory tests are instrumental in assessing the quality of aggregates to be used in a pavement. This assessment should include determination of aggregate properties and petrographic character evaluation. To the pavement designer, the engineering properties are of particular interest. In most cases, the engineering properties give an indication of the aggregate behavior during the service life of the pavement. Various laboratory tests are available to evaluate those properties. Several of those laboratory tests are part of this study.

A quality pavement surfacing should be durable; dense; resistant to crushing, abrasion, polishing, and stripping; and well-textured. Different laboratory tests are conducted on the aggregates to ensure that they comply with specific requirements.

Laboratory tests are grouped according to the engineering properties that they evaluate. Researchers usually classify the properties in five categories as listed below. In the listing below, the appropriate tests that are included in this study to evaluate a particular property of aggregates are shown.

1. Particle size and shape:
   a) particle size distribution or grading
2. Physical properties:
   a) bulk specific gravity and absorption
3. Mechanical properties:
   a) Los Angeles abrasion value (LAABR)
   b) polish value (PV)
   c) Texas degradation test (TDT)
4. Soundness or weather:
   a) magnesium sulfate soundness (MSS)
5. Adhesion of bitumen to: None

The other test that can also be included in this list is that of the soundness of basic igneous rock aggregate. The most common methods of testing the soundness of basic igneous rock aggregate are: a) soundness by ethylene glycol, and b) soundness by methylene blue absorption. The present study included only one igneous rock source; therefore, this test was not used.

3.2 PARTICLE SIZE AND SHAPE

3.2.1 Particle Size Distribution or Grading

Gradation or particle size distribution of aggregates is determined by shaking the aggregates in sieves with different opening sizes. The process should comply with ASTM C-136 or TEX 200-F, "Sieve Analysis of Fine and Coarse Aggregates." TEX 200-F is a modified version of ASTM C-136.

The sieves used during the test are usually 8, 12, or 18 inches in diameter and have square openings. The sieves are expected to meet the TEX 907-K test method requirement. The usual sizes of the openings used for grading dense asphaltic mixes are 1 in., 7/8 in., 5/8 in., 3/8 in., No. 4, No. 10, No. 40, No. 80, and No. 200. All of the sizes are not necessarily used for all mixes; the size chosen depends on the type of the mix. For the seal coats, very few large-opening sieves are used. The microsurface material, on the other hand, requires the smaller sizes, starting from No. 4.

The aggregate gradation results are expressed by weight. The results are shown in terms of cumulative percentage: 100 percent for the largest sieve, and then the percentage of aggregate retained on each immediately smaller sieve is subtracted from the cumulative percentage of the immediately larger one.

Proper gradation ensures a higher stability for the dense-graded asphaltic mixes and consequently affects the performance of the pavement surface. For a seal coat, proper gradation contributes to the macro-texture of the surface, which influences pavement performance.

3.3 PHYSICAL PROPERTIES

3.3.1 Specific Gravity and Absorption

Specific gravity is determined by displacement of water following the submergence of test aggregate particles according to Test Method TEX 403-A, "Saturated Surface Dry Specific Gravity and Absorption of Aggregates." Water absorption is usually a part of the process of determining specific gravity. The specified test method is TEX 433-A, and the test values are affected by pores and by the composition of the aggregate. Since these properties vary among samples from the same source, it is necessary to try to keep other variables the same—including sample size and gradation—among tests for the same aggregate.

High absorption and low specific gravity indicate high porosity of the aggregate. An extremely porous aggregate can be detrimental to an asphaltic mix, because it affects asphalt demand and aggregate drying properties, which can then lead to stripping, poor frost resistance, and poor durability. The mineral constituents of the aggregate should be investigated before deriving conclusions from these test results.

3.4 MECHANICAL PROPERTIES

3.4.1 Los Angeles Abrasion Test

The test procedure of the Los Angeles (LA) abrasion test involves a specially designed rotary drum, a test aggregate sample of required mass and size, and steel balls of appropriate size. Aggregate attrition by impact and abrasion force, resulting from the rotation of the drum and from the grinding and impact of the steel balls, helps to determine the aggregate's resistance to those forces. Details of this method are described in Test Method TEX 410-A.

The LA abrasion test results indicate the tendency of aggregates to break up during mixing and placing.

3.4.2 Texas Degradation Test

The Texas degradation test (TDT) subjects aggregate samples to impact, abrasion, and to grinding forces exerted by steel balls in a rotary drum in the presence of water. The mechanical degradation resulting from this process reflects an aggregate's lack of resistance to impact, abrasion, and grinding and weathering forces. This test is a modification of the wet ball mill test (TEX 116-E), "Ball Mill Method for Determination of the Disintegration of Flexible Base Material" [20]. Basically, the only difference between the test procedures of the LA abrasion and those of the TDT is that the latter test is carried out in the presence of water.

TDT results can be considered reflective of aggregate deterioration from:

1. Impact loads during mixing and construction and those due to heavy axle loads during the service life.
2. Abrasion and grinding, to which the aggregate is subjected during its service life from repeated traffic load.
3. Disintegration and weathering in the presence of water.

3.4.3 Polish Value

In this test method, sample aggregate particles are bonded together in a mold. The mold is then mounted on the periphery of a standard wheel and subjected to polishing, which simulates the polish resulting from rubber tires of passing vehicles. The entire procedure is carried out using water and abrasive grits in order to accelerate the polishing. Details of this test procedure can be found in Test Method TEX 438-A.

The polish value (PV) of aggregate should not be confused with the skid resistance capacity of a road surface. The PV is only one of the factors that govern the skid resistance of a pavement surface. PV indicates the nature and extent of change in aggregates used in the pavement surface layer when they are subjected to repeated traffic load.

3.5 SOUNDNESS OR WEATHER RESISTANCE

The physical degradation of aggregates while subjected to the forces of nature, including wind, rain, and temperature, is termed weathering. The forces of nature act directly or indirectly. These forces cause temperature gradients and other adverse conditions, which result in stresses that lead to aggregate degradation.

3.5.1 Magnesium Sulfate Soundness Test

The magnesium sulfate soundness (MSS) test is the primary laboratory test that has been used to predict performance of the aggregates included in this study. In this test method an aggregate sample is submerged in a saturated magnesium sulfate solution for 16 to 18 hours. This step is followed by a 6 to 8 hour oven drying at (110 ± 5)°C. These two steps make up a cycle. At the beginning of the study, the 4-cycle MSS test was considered the standard for aggregate quality control for HMAC and seal coats. The standard is now the 5-cycle MSS test. Data from both the 4-cycle MSS and the 5-cycle MSS test are included in this study.

The MSS test is considered indicative of aggregate resistance to weathering. The mechanism that causes aggregate degradation consists of crystallization during the submergence period, followed by dehydration during the drying period. The aggregates degrade primarily due to the internal stress resulting from the crystal formation. This action is considered to simulate the weathering action.

3.6 INTERRELATION AMONG TEST RESULTS

Earlier in the chapter, it was described how the laboratory test results help in evaluating the different properties of aggregates. These aggregate properties are also indicative of aggregate performance. While detailing the test methods used in this study, interrelationships among them have also been discussed. Most of the prior discussions were based on the previous study results. The following analysis, however, deals exclusively with the data used for this research study. Laboratory test results for the aggregates used in this study are listed in Table 3.1. Data used from other studies have been identified clearly.

The correlation analysis helps evaluate the ability of each test to predict field performance of the aggregates better. This analysis also helps in understanding how well each test indicates the aggregate properties.

The correlation among test results was studied following the same format for each test. An attempt was made to correlate the test results irrespective of any common relation among them. This attempt was followed by correlating aggregates with common properties. In most cases, the common factor considered was the aggregate type.

Correlation among test results has been fairly low. A low correlation was expected because each of the tests evaluated a different property of aggregate. But for a particular type of aggregate, some of the properties may interact, which is reflected through good to fair correlation among the test results.

A noteworthy outcome from the analysis of the test results was the fairly strong correlation between TDT and MSS test results. But the strong correlation that was obtained between TDT and MSS was expected because, as previously explained, they evaluate some of the similar properties of aggregates. A comparatively lower correlation for the SS (sandstone) group may have occurred due to the fact that there were a few outliers included in this group. Earlier study results showed the same trend.

3.6.1 Polish Value vs MSS Test

The polish value test evaluates mechanical properties, whereas the MSS test evaluates weathering resistance characteristics of the aggregates. Therefore, a low correlation between the two tests was expected. A low correlation coefficient (R^2= 0.21) was obtained for the Research Study 1222 data (Fig 3.1a). When Research Study 438 data were included no significant change was observed (Fig 3.1b).

Disregarding the low correlation that was obtained from the previous two analyses with all aggregate types included at a time, an additional analysis was performed to determine if any particular aggregate type showed a higher correlation between the two test results (Fig 3.1c). An improvement was observed for the SS and SG (siliceous gravel) type of aggregate but for the LS (limestone) group a reduction in correlation coefficient was observed. This reduction may be caused by the reduced amount of data, but may result from other factors. Additional data should help to find out the actual cause.

Another analysis was performed to correlate 5-cycle MSS loss with the polish value: the results showed a slight, although practically insignificant, improvement in their relationship (Fig 3.2). However, this improvement may be caused by the amount of the data. The amount of the data that was used for this analysis was much smaller than that for the 4-cycle MSS loss.

Table 3.1 Laboratory test results for all selected aggregates

Aggregate Type	Section	Aggregate Mix Type	Aggregate Gradation	Specific Gravity	Absorption	Polish Value	MSS 5-Cycle	MSS 4-Cycle	Texas Degradation Test	Los Angeles Abrasion
SG	L-1	A	4			30.0	25.0	19.00	7.60	22.0
SG	L-2	D		2.425	2.510	42.0	31.9	28.60	9.50	23.0
SG	L-3	D		2.599	1.250	22.0	8.3	5.40	1.63	20.0
SG	L-4	D		2.548	2.290	25.0	12.5	10.50	5.88	20.0
LS	L-5	B	4			41.0		22.10	9.50	26.0
SG	L-6	C		2.603	1.210	36.0	6.9	5.50	6.70	19.0
RY*	L-7		2	2.459	4.380	37.0	11.2	6.90	4.81	17.0
RY	L-8		2	2.459	4.380	37.0	11.2	6.90	4.81	17.0
LS	OD-1	D				43.0	31.0	28.80	9.97	30.0
RY	OD-2	D		2.465	2.460	38.0	9.3	4.10	3.53	13.0
LS	OD-3	D		2.562	2.800	36.0	30.3	28.30	10.60	28.0
LS	SA-1	PB	4			37.0	21.1	16.85	10.16	27.0
LS	SA-4	PB	4			37.0		20.64	10.63	27.0
LS	SA-6	PB	4			35.0		18.37	7.89	21.0
LS	SA-16	PB	4			35.0	25.7	23.60	8.47	29.0
LS	SA-17	PB	4			37.0		18.40	7.89	21.0
LS	SA-19	PB	4			37.0		18.90	9.25	38.0
LS	SA-27	D		2.629	1.700	37.0		21.20	8.04	31.0
LS	SA-30	PB	4			37.0		20.63	8.91	27.0
LS	A-1	PB	4			39.0		16.30	7.60	27.0
LS	A-2	D				42.0		30.80	11.90	39.0
LS	A-4	D		2.357	1.810	33.0		18.10	8.10	29.0
LS	A-5	D		2.357	1.810	33.0		18.10	8.10	29.0
LS	W-1	D		2.394	3.700	34.0	29.1	26.00	10.11	39.0
LS	W-2	D		2.443	2.600	40.0	12.7	11.20	6.07	30.0
LS	W-3	D		2.443	2.600	40.0	12.7	11.20	6.07	30.0
LS	W-4	D		2.460	3.200		36.0	23.60	6.03	34.0
LS	W-5	D		2.505	2.600	30.0	12.4	11.00	6.44	27.0
LS	W-6	D		2.394	3.700	34.0	29.1	26.00	10.11	39.0
SS	W-7		2	2.570	2.700	43.0	24.9	18.70	22.90	21.0

*Rhyolite

3.6.2 LA Abrasion vs MSS Test

The Los Angeles abrasion and the MSS test results are indicative of aggregate mechanical and weathering resistance properties respectively. Correlation analysis results show a low R^2 value of 0.20 (Fig 3.3). This low correlation between the two test results agrees with the findings from a previous study [15].

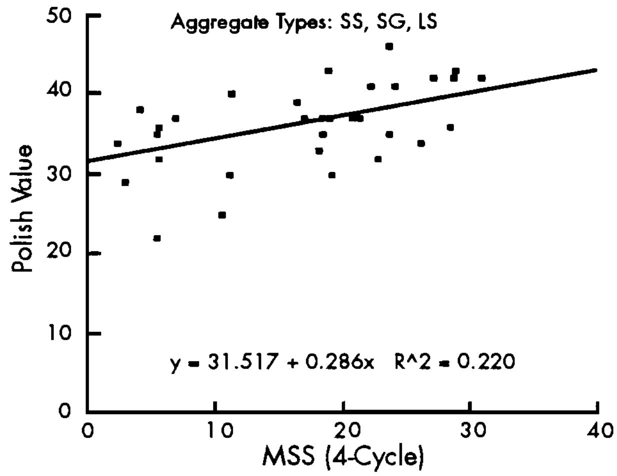

Figure 3.1a Correlation between the MSS and PV test results

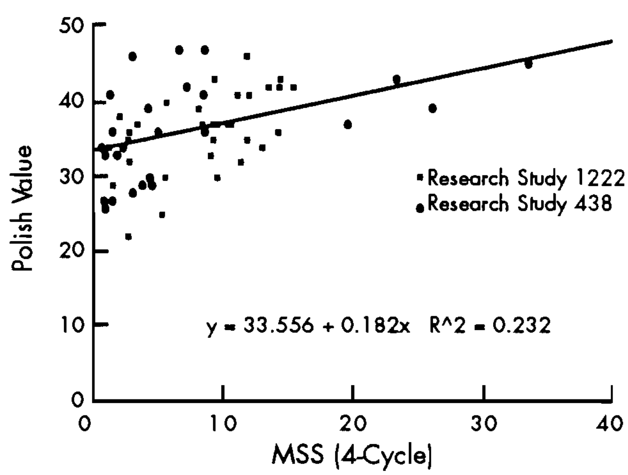

Figure 3.1b Correlation between the MSS and PV test results for Research Study 1222 and Research Study 438 data

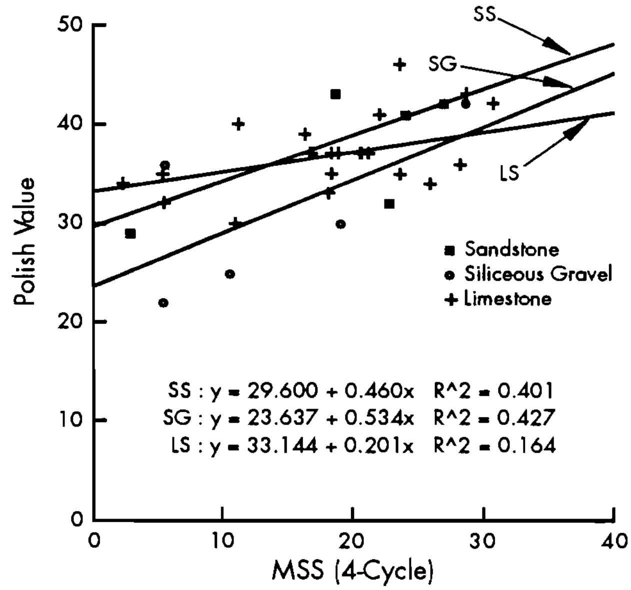

Figure 3.1c Correlation between the MSS and PV test results for different aggregate types

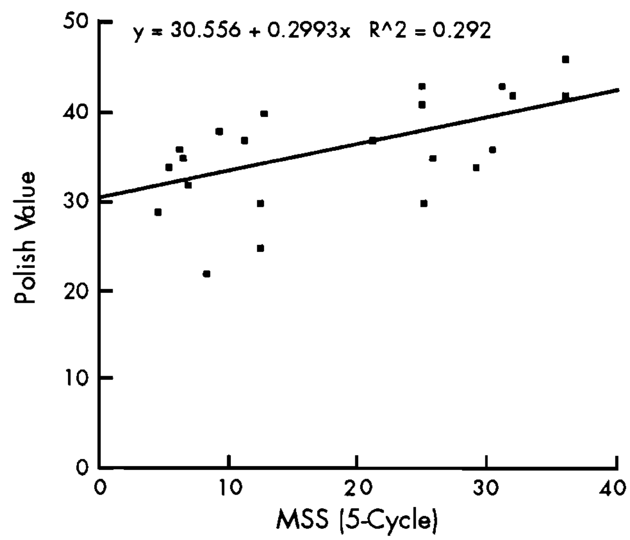

Figure 3.2 Correlation between the MSS (5-cycle) and PV test results

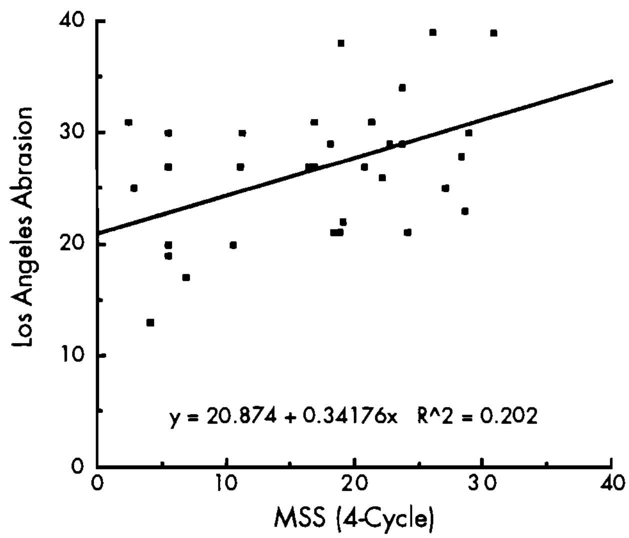

Figure 3.3 Correlation between the MSS and LA abrasion test results for all aggregates

3.6.3 4-Cycle MSS Test vs TDT

An earlier study (Research Study 438) conducted at CTR proposed the idea of the TDT. The 4-cycle MSS test was also part of that study. Therefore, a large amount of data, on a large variety of aggregates with a wide range of losses, was available from that study. The 4-cycle MSS and Texas degradation test results from this study also had a wide range of losses, with particular concentration on mid-range MSS loss.

At first, the correlation coefficient obtained from the analysis of Research Study 1222 data was only 0.25 (Fig 3.4a). A detailed statistical analysis revealed that this low value was due to the three outliers that showed abnormally high TDT values. It was found that these values were for aggregates from the same source. They were tested on the same day and no reason could be detected for this abnormal outcome. Therefore, the data could not be eliminated outright. However, a second analysis that disregarded the TDT values for the aggregate from that source obtained a fairly good R^2 of 0.72 (Fig 3.4b). The possible reason for this correlation was discussed earlier.

Aggregate types often have great influence over the test results. Hence, it was necessary that an analysis should be done to find the strength of correlation between MSS and TDT values for each aggregate type. The analysis results showed equal R^2 values for the LS and SG groups; a comparatively lower value for the SS group was primarily due to the outliers (Fig 3.5).

The data from Research Study 438 revealed a fair correlation between the TDT and MSS test results with a correlation coefficient of 0.57 (Fig 3.6a). At the same time, an analysis conducted with data from Research Studies 1222 and 438 combined showed a correlation coefficient of 0.56. This value was similar to that obtained for the Research Study 438 data only. However, the higher R^2 value that was obtained for the Research Study 1222 data alone was not reflected through this result. Therefore, an extensive statistical analysis was conducted on the data. The analysis outcome suggested that a better correlation can be obtained if aggregates with very high MSS loss were not included in the analysis.

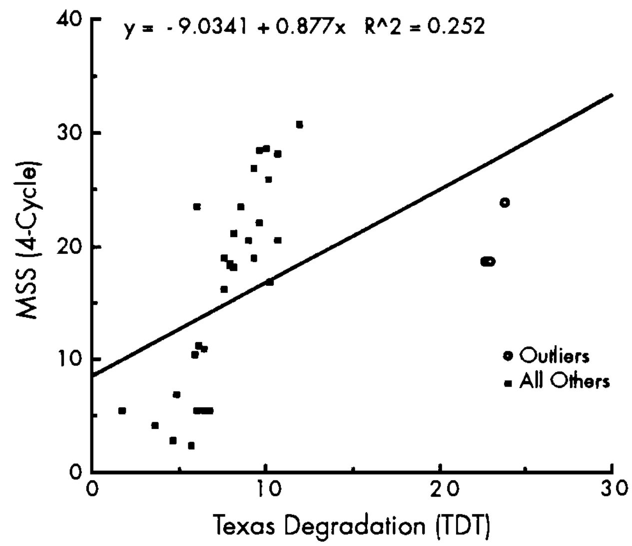

Figure 3.4a Correlation between the TDT and MSS (4-cycle) test results for all aggregate types

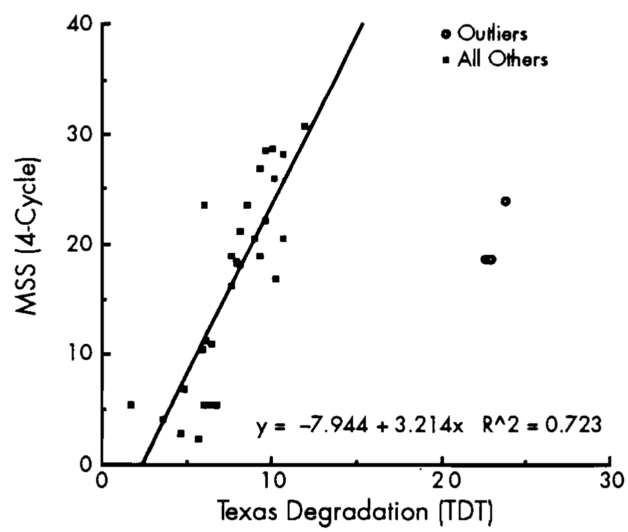

Figure 3.4b Correlation between the TDT and MSS (4-cycle) test results without including the outliers for the equation

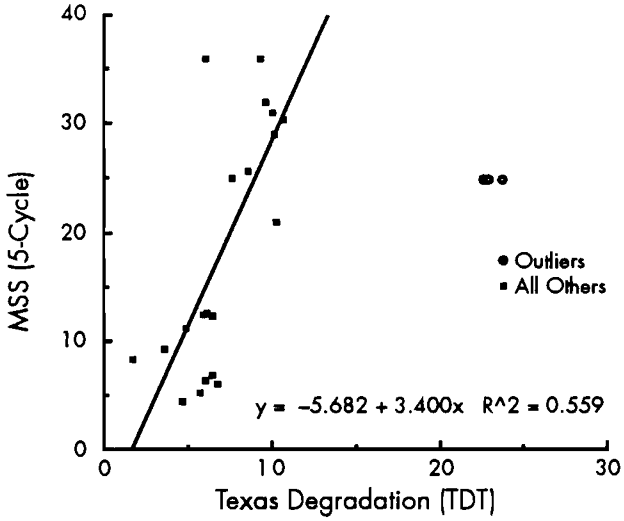

Figure 3.5 Correlation between the TDT and MSS (5-cycle) test results without including the outliers for the equation

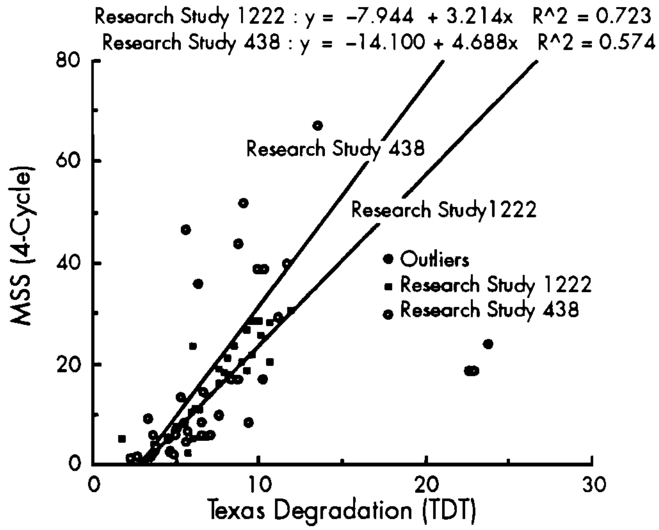

Figure 3.6a Correlation between the TDT and MSS (4-cycle) test results for Research Studies 1222 and 438 separately

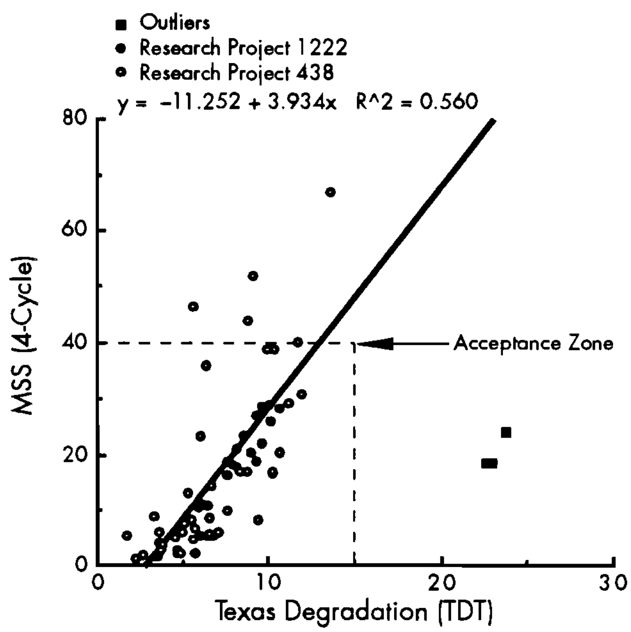

Figure 3.6b Correlation between the TDT and MSS (4-cycle) test results for Research Studies 1222 and 438 together

At the present time, most of the TxDOT districts do not use aggregates with MSS loss greater than 40. For TDT that limit is about 15. If only the data in this "acceptance zone" are used for this analysis, a fairly good correlation coefficient of 0.74 is obtained (Fig 3.6b). The linear regression equation obtained from this analysis is:

4-cycle MSS loss = -5.846 + 2.766 (TDT loss)

3.6.4 5-Cycle MSS Test vs TDT

The possibility of replacing the 4-cycle MSS loss values with the 5-cycle MSS loss values was explored during this study. With that goal in view, a 5-cycle MSS test was conducted on all the aggregates that were made available to CTR by the districts. Aggregates used in 26 out of 39 test sections were available; several of the test sections were constructed using the same material.

The outcome of the analysis using the 5-cycle MSS loss and the TDT loss data was a linear predictive equation with an R^2 of 0.585.

5-cycle MSS loss = -6.545 + 3.518 (TDT loss)

The lower correlation between 5-cycle MSS and TDT values is likely to be due to the smaller amount of data that was used for this analysis. Consequently, it is anticipated that with a larger data set the correlation will become stronger.

3.6.5 4-Cycle MSS vs 5-Cycle MSS

An analysis was conducted to correlate 5-cycle and 4-cycle MSS loss because of a special request made by the Division of Material and Tests (D-9). The data used in the analysis were primarily supplied by D-9. The data generated for Research

Study 1222 were later merged with the D-9 data. Initially the analysis was done with D-9 data only, and later the Research Study 1222 data were merged with those of D-9. The result did not change significantly from what was obtained initially. Initial analysis with D-9 data resulted in a linear regression equation with an R^2 of 0.93 (Fig 3.7a). The addition of Research Study 1222 data and subsequent analysis produced a simple linear predictive equation having an R^2 of 0.943, which indicates a very strong correlation between 4-cycle and 5-cycle MSS loss (Fig 3.7b).

5-cycle MSS loss = 1.481 + 1.111 (4-cycle MSS loss)

The possible effect of aggregate type on this relationship was also investigated, but the outcome showed this effect to be insignificant.

3.6.6 Polish Value vs TDT

Both the polish value and the Texas degradation test are used to evaluate the mechanical properties of aggregate, but the outcome of the analysis showed a very low correlation between the PV and TDT test results (Fig 3.8a). This finding is also consistent with previous findings. A second analysis was conducted to explore the possibility of better correlation between these test results for a particular aggregate type. The results are shown in Figure 3.8b. For the SS and SG groups the correlation coefficient values were fairly high with R^2 values of 0.56 and 0.72, respectively; for the LS group, it was very low.

For further examination, the data from Research Study 438 were merged with those of Research Study 1222. The result was a poor R^2 of 0.25 with all types of aggregates included in the analysis (Fig 3.9a). In order to investigate the reason for high R^2 values for the SS and SG groups and the extremely low value for the LS group, an analysis was conducted for each aggregate type separately from the merged data (Fig 3.9b). The analysis indicated that the higher R^2 values obtained from the previous analyses most likely were due to the small amount of the data used.

3.6.7 Polish Value vs Absorption

An attempt was made to correlate absorption with the PV (Fig 3.10). The analysis used the combined data from Research Studies 1222 and 438. The result was not very encouraging. The analysis was conducted for each aggregate type separately and the correlations were fairly low.

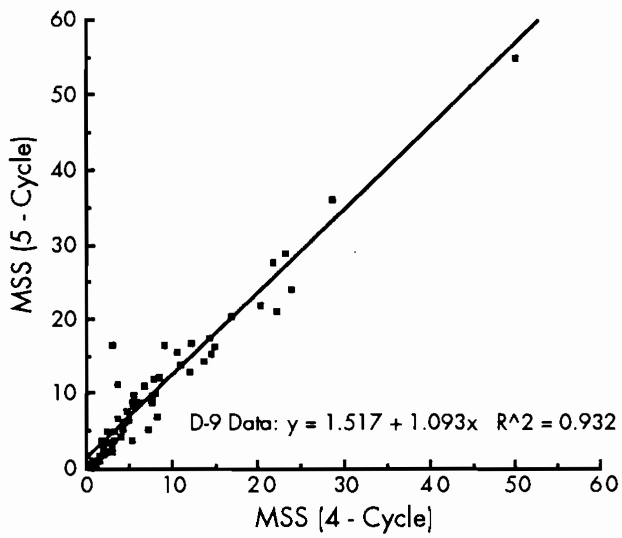

Figure 3.7a Correlation between 4-cycle and 5-cycle MSS loss for the data provided by D-9

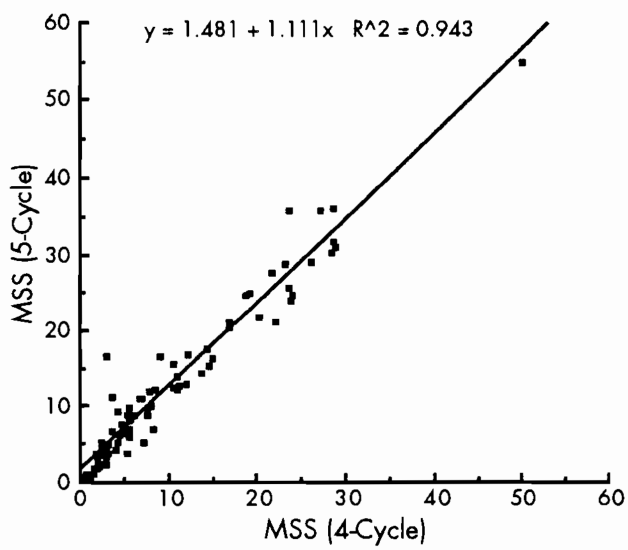

Figure 3.7b Correlation between 4-cycle and 5-cycle MSS loss for Research Study 1222 and D-9 data

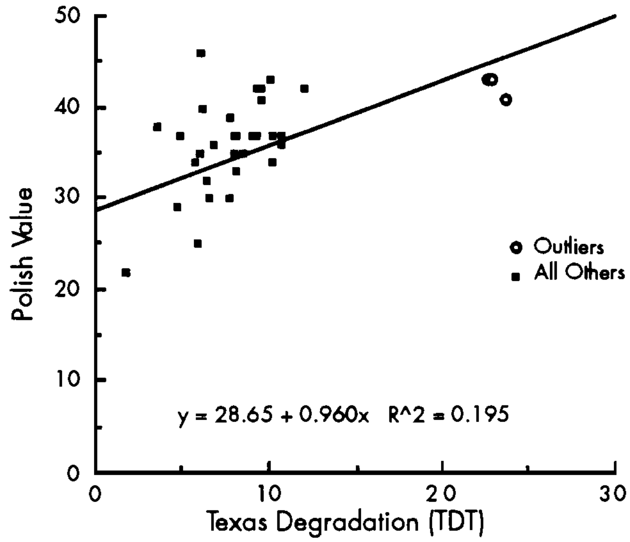

Figure 3.8a Correlation between the TDT and PV test results for Research Study 1222 data

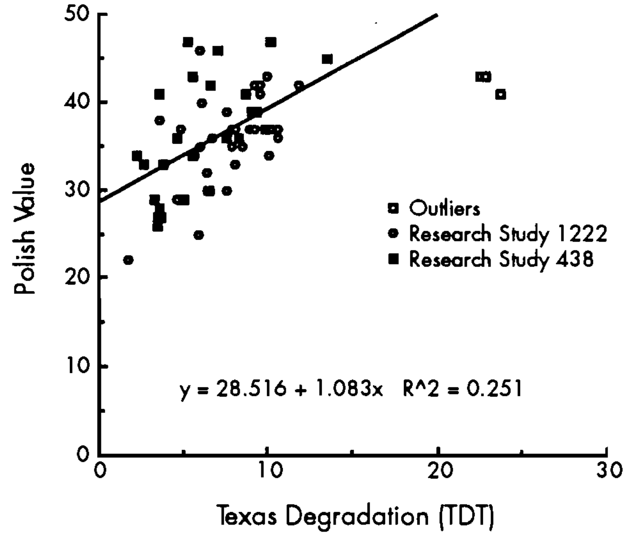

Figure 3.9a Correlation between the TDT and PV test results for Research Studies 1222 and 438 data

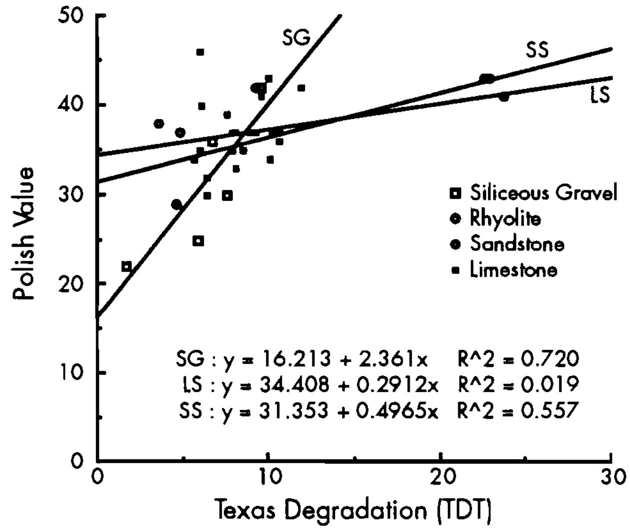

Figure 3.8b Correlation between the TDT and PV test results for different aggregate types

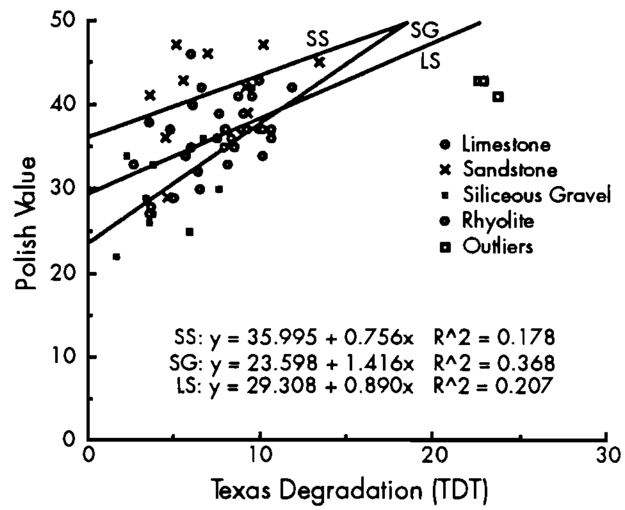

Figure 3.9b Correlation between the TDT and PV test results for Research Studies 1222 and 438 by aggregate type

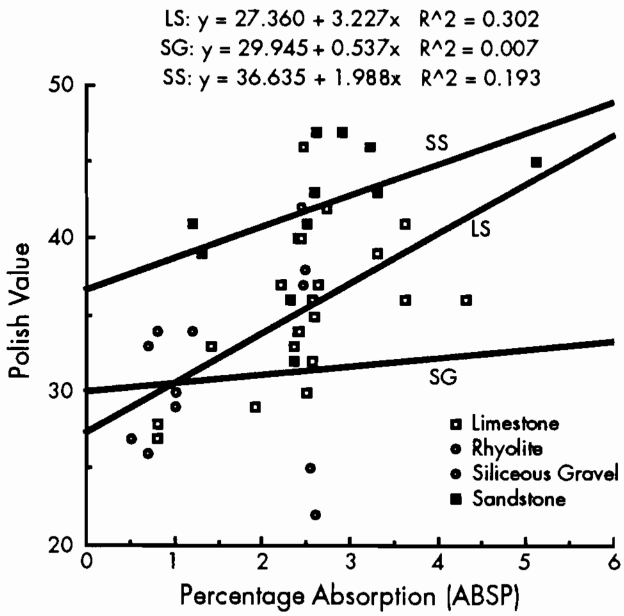

Figure 3.10 Correlation between the absorption and PV test results for Research Studies 1222 and 438 data

CHAPTER 4. FIELD TEST SECTIONS

4.1 INTRODUCTION

One phase of this study was designed to evaluate the performance of aggregates in the field and to relate the performance to the commonly used laboratory tests. The laboratory tests in question were the 5-cycle MSS test and the TDT. This study was basically an extension of Research Study 438, "Evaluation of the 4-Cycle MSS Test." This study concentrated on evaluating the performance of aggregates having mid-range MSS losses.

Test sections constructed with materials from the selected aggregate sources were established in seven districts. Four out of the seven districts participating in this study had also taken part in the previous study. All of the participating districts normally require the MSS test in evaluating aggregate quality. Therefore, they have experience with the performance of aggregates in relation to their soundness loss.

4.2 CRITERIA FOR SELECTION

The typical criteria used to select a test section were:

1. Test sections should be tangent;
2. Test sections should have less than 2% grade;
3. Test sections should be at least 1,000 feet from any major intersection;
4. When the pavement has four or more lanes, the test section should be located in the outer-most lane; and
5. Test sections should be about 1,000 feet in length.

4.3 ENVIRONMENTAL CONSIDERATIONS

The primary components of climatic description are precipitation, temperature, evaporation, and wind. Climate is the long-term average of these descriptive variables. It may also be defined as the history of weather. The four components of climatic description are interrelated, and, therefore, only two of the factors, precipitation and temperature, are needed for consideration. Precipitation variation among the regions is divided into wet and dry. In a wet region, the annual rainfall exceeds the annual evaporation, and in a dry region, the annual rainfall is less than the annual evaporation. East Texas is wet and West Texas is dry. Temperature variation in this study is classified as either "no freezing" or "freeze-thaw cycling." In a "no freezing" region, freezing temperatures are not sustained long enough to freeze the ground. In a "freeze-thaw cycling" region, freezing temperatures are of short duration but of frequent occurrence, which results in freezing and thawing cycles for the ground and the pavement surface layer.

Of the four climatic regions[13,19] identified in Texas, two are included in this study. These are:

Region	*Characteristics*
IV	Dry and no freezing
V	Dry and freeze-thaw cycling

District 16 is in region IV, and all of the other districts in this study are in region V. The two primary environmental factors for this study are the rainfall and the number of freezing and thawing cycles.

4.4 STATISTICAL CONSIDERATIONS

This research study was designed to evaluate the predictive ability of laboratory tests. It also studied the effect of a number of variables related to the field performance of aggregates. The following illustrate some considerations made during the collection of field performance data.

1. For each data set, five skid test measurements were taken along the test sections. This procedure was necessary in order to obtain a representative average and to test whether the variance of the readings was homogeneous and normally distributed.

2. Aggregates having similar properties were used to construct test sections in different districts in an attempt to evaluate the effect of rainfall and freeze-thaw cycles.
3. Where appropriate, replicate test sections were established in order to evaluate the possible variation in the response of material from the same source.

4.5 TEST SECTIONS

For this study, three types of surface layers were included. These were seal coats, HMAC, and micro-surface. Seal coats and HMAC sections were located in all seven participating districts with a variety of traffic levels. Four districts provided micro-surface test sections.

A complete overview of the test sections can be obtained from Tables 4.1 and 4.2. Aggregate quality in each table has been shown in three categories: high quality (MSS loss <10), medium quality (MSS loss 10-20), and low quality (MSS loss >20). The test sections have been grouped into three classes based on their traffic volume or ADT. A test section with an ADT of 750 or less is considered to be a very low-volume road; a test section having an ADT of 750-2,000 is considered a low-volume road; a test section with an ADT of 2,000-5,000 is considered a medium-volume road; a test section with an ADT of 5,000-10,000 is considered a high-volume road; and a test section with a traffic volume above 10,000 is considered a very high-volume road.

4.6 PARTICIPATING DISTRICTS

A total of seven districts participated in this study. All of the participating districts required aggregates used in seal coats and HMAC to satisfy a 4-cycle MSS loss requirement. At the present time, 16 out of 24 districts require the aggregates to satisfy a 4-cycle MSS loss requirement. Most of the participating districts also perform the TDT.

The participating districts were District 5 – Lubbock, District 6 – Odessa, District 7 – San Angelo, District 8 – Abilene, District 9 – Waco, District 14 – Austin, and District 16 – Corpus Christi.

Table 4.1 Overview of the test sections

Traffic Volume	Surface Type			MSS Loss		TDT	
Category (ADT)	HMAC	Micro	Seal	<25%	>25%	<10.0	>10.0
1 (0-750)	2	0	3	4	1	5	0
2 (750-2,000)	0	0	7	6	1	6	1
3 (2,000-5,000)	6	2	2	8	2	5	5
4 (5,000-10,000)	5	2	1	5	3	5	2
5 (10,000-50,000)	8	1	0	9	0	7	1

Table 4.2 Test sections and aggregate sources

District	Section	County	Surfacing Type	Aggregate Mix Type	Aggregate Type	Grade	Producer	Pit	Highway	Region
Lubbock	L-1	Lubbock	Seal	A	SG	4	Janes Gravel	Wood	FM 1294	V
5	L-2	Lubbock	HMAC	D	SG		El Paso Sand Product	Turner	US 62-82	V
	L-3	Lubbock	HMAC	D	SG		Appian Corp.	Thrasher	US 62-82	V
	L-4	Lubbock	HMAC	D	SG		Janes Gravel	Wood	US 62-82	V
	L-5	Lynn	Seal	B	LS	4	CSA Materials	Gordon-Cox	US 380	V
	L-6	Lubbock	HMAC	C	SG		Appian Corp.	Campbell	US 84	V
	L-7	Lubbock	Micro		RY	2	Trans Pecos Materials	Hoban	US 84	V
	L-8	Lubbock	Micro		RY	2	Trans Pecos Materials	Hoban	US 84	V
Odessa	OD-1	Midland	HMAC	D	LS		South Texas Lime Stone	Counts	IH 20	V
6	OD-2	Ector	HMAC	D	RY		Trans Pecos Materials	Hoban	Loop 338	V
	OD-3	Andrews	HMAC	D	LS		Grimmett Brothers	Gordon-Cox	US 385	V
San	SA-1	Runnels	Seal	PB	LS	4	CSA Materials	Willeke	US 83	V
Angelo	SA-4	Menard	Seal	PB	LS	4	CSA Materials	Willeke	US 83	V
7	SA-6	Irion	Seal	PB	LS	4	CSA Materials	Willeke	US 67	V
	SA-16	Glasscock	Seal	PB	LS	4	CSA Materials	Willeke	SH 158	V
	SA-17	Coke	Seal	PB	LS	4	CSA Materials	Willeke	US 277	V
	SA-19	Concho	Seal	PB	LS	4	CSA Materials	Willeke	FM 380	V
	SA-27	Tom Green	HMAC	D	LS		CSA Materials	Willeke	US 277	V
	SA-30	Tom Green	Seal	PB	LS	4	CSA Materials	Willeke	FM 388	V
Abilene	A-1	Howard	Seal	PB	LS	4	Prace Construction	Clements	FM 33	V
8	A-2	Howard	HMAC	D	LS		Prace Construction	Tubb	FM 700	V
	A-4	Callahan	HMAC	D	LS		Strain & Sons	Hutcheson	IH 20	V
	A-5	Callahan	HMAC	D	LS		Strain & Sons	Hutcheson	IH 20	V
Waco	W-1	McLennan	HMAC	D	LS		Bandas Industries	Nolanville	Loop 340	V
9	W-2	Falls	HMAC	D	LS		Redland Worth Materials	Ainsworth	US 77	V
	W-3	Falls	HMAC	D	LS		Redland Worth Materials	Ainsworth	US 77	V
	W-4	McLennan	HMAC	D	LS		Young Brothers	Atkins	IH 35	V
	W-5	Bell	HMAC	D	LS		Odell Geer	Prairie Dell	IH 35	V
	W-6	Bell	HMAC	D	LS		Bandas Industries	Nolanville	Loop 363	V
	W-7	McLennan	Micro		SS	2	Delta Capitol Aggregate	Brownlee	Spur 299	V
Austin	AUS-1	Williamson	Seal	B	SS	3	Delta Capitol Aggregate	Wood	FM 1660	V
14	AUS-2	Williamson	HMAC	C	LS		Texas Crush Stone	Georgetown	FM 620	V
	AUS-3	Travis	HMAC	C	LS		Colorado Materials	Hunter	IH 35	V
	AUS-4	Travis	Micro		SS	2	Delta Capitol Aggregate	Brownlee	Bus 290	V
Corpus	C-1	San Patricio	HMAC	D	SS		South Texas Construction	Rabe	IH 37	IV
Christi	C-2	Nueces	Seal	PB	SS	3	Bay Incorporated	Lindholm	FM 666	IV
16	C-3	San Patricio	HMAC	D	LS		Redland Worth Materials	Beckman	SH 361	IV
	C-4	Refugio	Seal	PB	LS	4	Vulcan Materials	Uvalde	US 77	IV
	C-5	Jim Wells	Micro		SS	2	Delta Capitol Aggregate	Brownlee	US 281	IV

CHAPTER 5. FIELD TEST AND OTHER RELATED DATA

5.1 INTRODUCTION

To evaluate the performance of each aggregate, data were obtained from the various field test locations. The data included both single-occurrence variables, such as mix design or spread rate, and time-dependent variables, such as traffic, skid measurements, and weather. This chapter provides a description of the methods of performance measurement and the data obtained for each method.

5.2 FIELD TEST DATA

Field tests were conducted to evaluate the effect of recurring variables. Usually, recurring variables cause most of the deterioration of the aggregate. Hence, in evaluating aggregate performance, these variables are of primary interest.

The field data were typically collected twice every year. As the study spanned two years, a total of four sets of data were collected. The skid data, however, were collected three times over the two-year period. Some of the test sections, in particular the micro-surface sections, were included during the last year. Therefore, fewer sets of test data were collected for those sections. One data set for a particular test section consisted of data from all the tests conducted on that section during a site visit. The skid trailer data were collected independently of the site visits made by the researchers.

In addition to the data collected at each field test site, traffic data and weather data were also collected as a part of each data set. Each type of measurement is described in the following sections and the data obtained are summarized in tabular form.

5.2.1 Direct Measurement of Skid Resistance

A TxDOT skid trailer was used to obtained a direct measurement of the frictional resistance of the pavement surfacing. Complete details of this test method can be obtained from a standard test method for skid resistance of paved surfaces using a full scale tire (ASTM E 274-79). (Skid resistance data are provided in Table A.1 of Appendix A.)

5.2.2 British Pendulum Tester

This test is designed to measure the micro-texture of pavement surface. It measures the roughness contributed by individual small asperities on the exposed surface of individual aggregate particles. The equipment and test method are detailed under ASTM standard method, designated E 303-83, titled "Measuring Surface Frictional Properties Using the British Pendulum Tester." (British pendulum number (BPN) data are shown in Table A.2 of Appendix A.)

5.2.3 Sand-Patch Method

This test gives a measure of the macro-texture of a pavement surface. The details of this test method are given in TEX 436-A, titled "Measurement of Texture Depth by Sand Patch Method." According to this test method, a fixed volume of fine sand is spread over a circular area; the diameter of the circle is then used to calculate the average texture depth of the area over which the sand was spread.

$$T = 4V/D$$

where T = average texture depth;
V = fixed volume of test sand (1.50 cubic inch is standard); and
D = diameter of the circular area.

(Sand-patch data are shown in Table A.3 of Appendix A.)

5.2.4 Mini-Texture Meter

The mini-texture meter (MTM) and its results are discussed in detail in Chapter 6. (MTM data are shown in Table A.4 of Appendix A.)

5.3 PAVEMENT RATING SCORE

Two existing methods of visual condition survey were considered for this study. One is the method developed by the United States Army (31,32). This method is referred to as method 1. The second method is the one developed for TxDOT and used until very recently; it is referred to as method 2.

Since most of the test sections were relatively new, and the time between condition surveys was relatively short, these observations did not identify any significant change in the condition of the test sections during this study. It is anticipated that, as the sections age and as subsequent condition surveys are made, differences in the performance of the pavement surface will be observed. (Condition survey results are shown in Table A.5 of Appendix A.)

5.4 MACRO-PHOTOGRAPH RECORDS

In addition to the other methods of evaluation in this study, a macro-photograph evaluation was also included. Under this method of evaluation, several photographs were taken for each test section during each visit. For each test section, the photographs were taken at the same location or close to the same location during all of the four visits. During each visit for each section, at least four photographs were taken at a preselected location or within the close vicinity of the selected location. The first picture was taken about four feet from the surface, the second one about two feet from the surface, and the third and fourth pictures about 6 inches from the surface.

5.5 CONSTRUCTION DATA

The construction data for each test section were provided by the district in which the test section was located. No attempt was made by the researchers to verify that these were the actual as-placed data. (The construction data are summarized in Tables A.6 and A.7 of Appendix A.)

5.6 TRAFFIC DATA

Traffic data were obtained from the Transportation Planning Division (D-10) and are summarized in Tables A.8 through A.10 in Appendix A. When traffic data for a highway segment containing a test section were not directly available, a best estimate was made using the values from the nearest available highway segments.

5.6.1 Annual Average Daily Traffic Projection

The annual average daily traffic (ADT) is the number of vehicles, irrespective of number of axles and weight, passing through a particular point on the pavement during a period of a 24 consecutive hours averaged over a period of 365 days (one year). The primary source of these data for this study was the district traffic maps and the district traffic engineers. Years accounted for were 1984-1991. The control section, at which the counts are made, closest to the test section was selected to obtain ADT for each test section. The traffic map is published by the Transportation Planning Division of TxDOT. The maps of a particular year become available in the last quarter of the following year.

The district traffic maps for years 1990 and 1991 were not available at the time of this writing. Hence, an estimate of the ADT for those years was obtained based on the ADT of the previous three years (1987-89). This projection of traffic data was obtained as follows:

A. The change of average annual daily traffic from 1987-88 and 1988-89 was calculated based on the ADT for 1987-88 and 1988-89.
B. The calculated rate of change of ADT was summed. If the summation was positive, the subsequent steps were followed, but if it were negative, the ADT for 1990 for that particular test section was considered to have remained the same as for 1989.
C. If the sum of the rate of change was positive, it was averaged to obtain the expected rate of change from 1989 to 1990. The rates of change were averaged, because, statistically, the most probable value of a series of data derived from the same source is the mean if an estimate of the variance is not available.
D. After obtaining the most probable rate of change of traffic volume for 1990 over that of 1989, the change of traffic volume was calculated and summed with the ADT of 1989 to obtain the projected ADT for 1990.
E. The projected ADT for 1991 was considered to be the same as that of 1990.

Two test sections were located on highway frontage or service roads. District traffic maps show only the total volume of traffic on the highway or total traffic on the highway and the service road. The traffic analysis section of TxDOT provided a traffic count for 1990, the traffic on both the main road and the service road. Based on those one-year data, the data for the other years were generated considering the same percentage of traffic on the main road and the service road every year.

5.6.2 *Directional and Lane Distribution of Traffic*

ADT values are the total count of traffic passing over chosen segments of the selected roads, but the test sections are only located in a particular lane. Hence, only some fraction of the total ADT passes over the test section. For two-lane highways, the directional traffic distribution was based on information from a permanent automatic traffic recorder (PATR). If PATR information was not available, then a distribution factor of 0.5 was used. For highways with four lanes, either a manual count or a distribution factor of 0.6 was used.

5.6.3 *Percent Truck*

The primary source of information on percentage of truck traffic data was the manual count in the annual report published by TxDOT. It is a yearly publication based on a single count of traffic at designated manual count stations. During the count, traffic is also classified into different types depending on weight. Data were available through 1990, and hence they had to be projected for 1991 only. The manual count station locations were not necessarily near each test section. Hence, sections with similar ADTs were used to estimate the percentage of trucks on a given section.

5.7 WEATHER DATA

Temperature and precipitation data for each test section were collected starting from the day of construction and through the last day of the field test. The primary source of weather-related information was the publication "Climatological Data of Texas" published by National Oceanic and Atmospheric Administration. The secondary source was the copy of field records furnished by districts.

5.8 RELATIONSHIPS AMONG FIELD TEST DATA

5.8.1 *Friction Number vs BPN*

A moderate correlation between friction number and British pendulum number (BPN) had been identified in other studies. This study produced similar results as shown in Figure 5.1 (R^2 = 0.48). A similar correlation was also observed when the data were separated by surface type as shown in Figures 5.2 through 5.4 except for micro-surfaces.

The equations for the combined data and for the HMAC data were very nearly the same, but the equation for seal coats was slightly different from the other two.

For the micro-surfaces, the correlation coefficient is 0.90. However, this high R^2 may be due to the very small amount of the data. Therefore, only with additional data can a reliable predictive equation be obtained. Another possible reason for this high correlation may be that the micro-surfaces tend to maintain a very high frictional resistance all the time. Therefore, the friction number (FN) and BPN values tend to remain within a very small range.

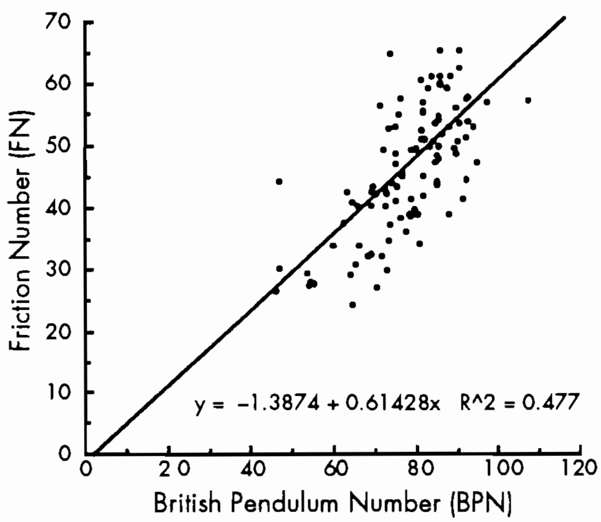

Figure 5.1 Correlation between the BPN and FN for seal coat and HMAC surfaces

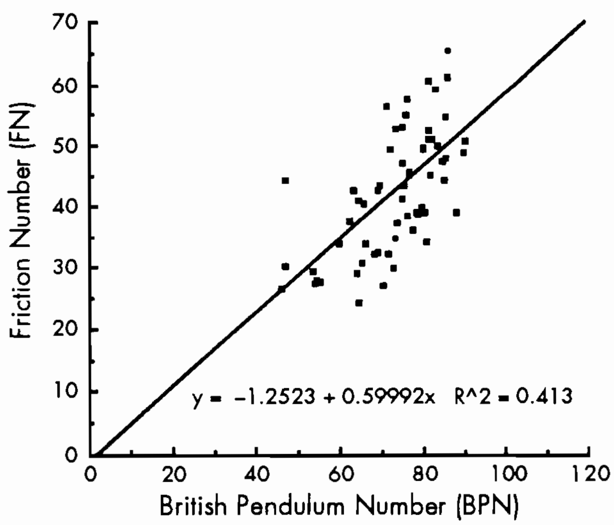

Figure 5.2 Correlation between the BPN and FN for HMAC surfaces

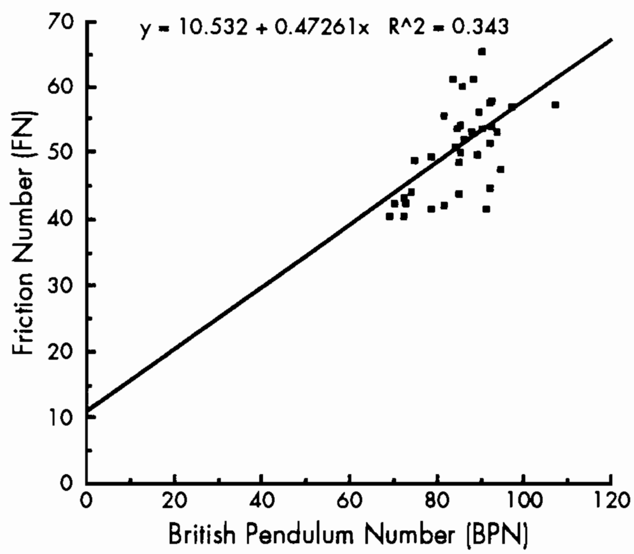

Figure 5.3 Correlation between the BPN and FN for asphaltic seal coats

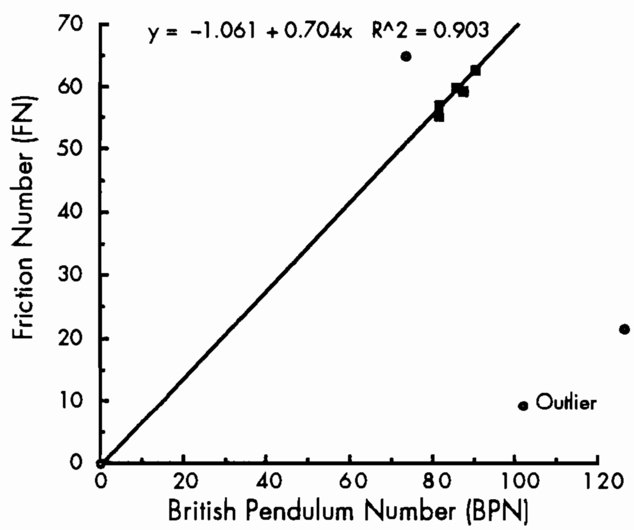

Figure 5.4 Correlation between the BPN and FN for micro-surfaces (one data point omitted for correlation equation)

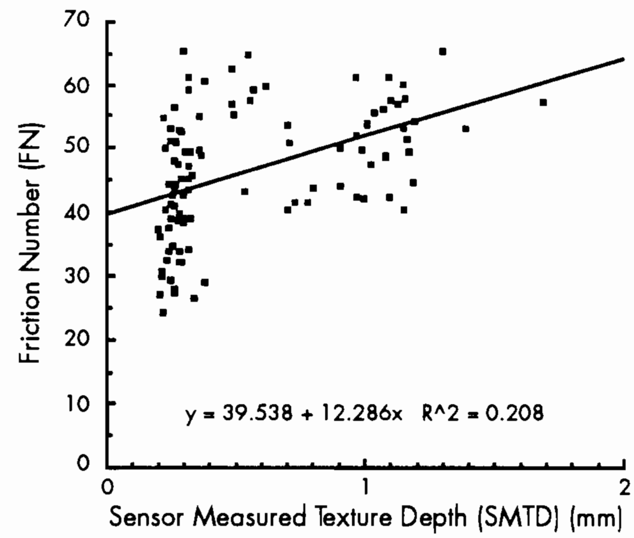

Figure 5.5 Correlation between the SMTD and the FN

5.8.2 Friction Number vs SMTD

As shown in Figure 5.5, there is a low correlation between the friction number and the texture depth. According to the earlier studies, the SPTD (sand-patch texture depth) had shown a low correlation with the friction number. The SMTD maintained the same trend.

The method of measuring texture depth using the MTM is relatively new, but the measurements obtained using this method are very stongly correlated with those of the sand patch method. This strong correlation gave rise to a low R^2 value between FN and SMTD. An analysis based on different surface types did not improve the strength of the correlation. Therefore, it can be said that this result was expected, and it is consistent with previous findings.

5.8.3 Friction Number vs BPN and SMTD

The attempt to correlate FN with BPN and SMTD simultaneously did not meet with much success. The variability of FN, which could not be explained by the BPN, was not explained further by the inclusion of the texture depth data. An attempt was made for each surface and aggregate type, but none of them met with much success.

CHAPTER 6. MINI-TEXTURE METER

6.1 INTRODUCTION

A part of the study involved the measurement of the average texture depth or macro-texture of the surface. For the macro-texture measurements the traditional sand-patch method and a mini-texture meter (MTM) were used.

The MTM uses a contactless laser sensor to measure surface macro-texture. This method of measurement offers various advantages over the sand patch method. As a part of this study the researchers were assigned the task of determining the repeatability and, consequently, the reliability of the MTM data and to determine if the MTM method was a suitable replacement for the sand patch method.

6.2 FUNCTIONAL MECHANISM

From a functional standpoint, the MTM consists of four parts, as shown schematically in Figure 6.1.

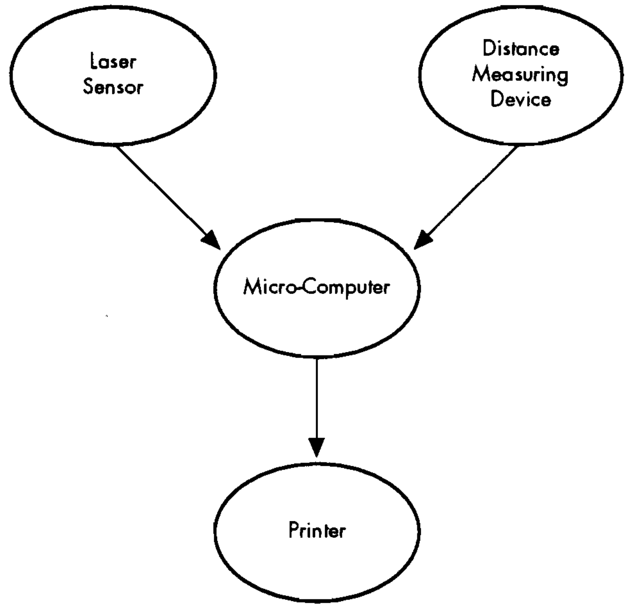

Figure 6.1 Schematic diagram of mini-texture meter functional mechanism

1. Laser sensor
2. Distance measuring device
3. Micro-computer
4. Printer

1. *Laser Sensor:* The contactless laser sensor consists of laser light projection and receiving units. It is mounted on a frame that allows its adjustment to an optimum height from the road surface. The projection unit projects the laser light generated with a laser diode pulser and a laser diode, through a projector onto the pavement surface. The receiving unit collects a fraction of the scattered light and focuses it onto a linear array of photosensitive diodes. The laser diode pulser produces laser light able to measure 500 displacement samples per second. The sensor has a vertical working range of 20 mm with a resolution of 0.01 mm. The laser is projected over a surface area of approximately 0.132 mm^2. The sensor is illustrated schematically in Figure 6.2.

2. *Distance Measuring Device:* The MTM is designed in such a way that the micro-computer only collects data when the equipment is moving. A device measures the rotation of the wheels and thus measures the distance traveled. This information is fed into the micro-computer. Using this information, the printer output gives a macro-textural measurement every 10 m and an average texture measurement after 50 m.

3. *Micro-Computer:* The constituent parts of the micro-computer are the on and off switch, program selector and an Intel 8085 processor. The processor controls the system. Programs needed for texture meter operation are stored in 2 K × 8 bits of RAM. For the storage of data and processed intermediate results, 256 × 8 bits of RAM are available. The micro-computer serves as the control processing unit. It gathers the data from the laser sensor and the distance measuring device, modifies and corrects the data from the sensor, and

then correlates the data from the two sources. Finally, it sends commands to the printer to generate a hard copy of the data.

4. *Printer:* The MTM is equipped with a 20-column thermal printer. The printer is mounted on the handle shaft. It is the only output device fitted into the texture meter. On receiving a command from the micro-computer, it prints out the output data. The printing paper is about 1.75 in. wide and prints two column headings. The first column heading reads 'Dist', with distance traveled listed in meters, and the second column reads 'SMTD' (sensor measured texture depth) with macro-texture listed beneath in millimeters.

The axes of the projection and receiving unit are orthogonal. The surface area illuminated by the laser moves along the axis of the projection beam due to vertical displacement of the pavement surface relative to the sensor. Depending on the vertical displacement of the surface, the spot of light projected focuses on different diodes along the diode array after being collected by the receiving lens. Five hundred laser pulses are shot onto the pavement surface and each time the number of diodes illuminated by the pulse is stored into the memory. These data are later used for assessment and correction.

Data generated for the first 300 mm of travel are disregarded. Beyond that distance each diode number illuminated by laser pulse is stored in the memory for the next 300 mm; immediately after, the statistical computation begins for the data collected over the 300-mm distance. During the computation time, the data for the next 300-mm section are collected.

The vertical displacement measured by the mini-texture meter is the larger oscillatory trend produced as the trailer suspension that supports the sensor moves along the pavement surface. The micro-texture appears as small random variations superimposed on the much larger oscillatory trends produced as mentioned above. The oscillatory vertical movement is compensated by a piecewise parabolic (quadratic) curve fitting procedure. The standard deviation of the residual displacements is the measured texture depth. This measurement is made for every 300-mm distance traveled. The result is a printout for every 10-m distance traveled.

6.3 SAND PATCH VS MINI-TEXTURE METER

6.3.1 Data Comparison

The sensor measured texture depth obtained by the MTM and the texture depth measured by the sand patch method were collected. They covered a wide range of values. The primary factor leading to this wide range of values was that there were three types of pavement surface layers included in this study. The asphaltic seal coat surfaces generated the high texture depth values. The micro-surfaces had medium to high texture depths. The lower values were obtained from the hot mix asphaltic surfaces. The texture depth measured by the sand patch method and the mini-texture meter

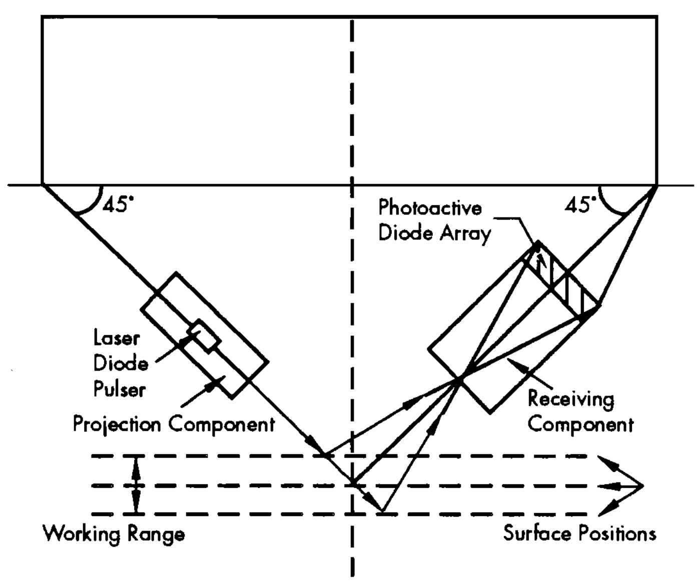

Figure 6.2 Principle of laser displacement transducer

showed a high correlation irrespective of surface type, as illustrated in Figure 6.3.

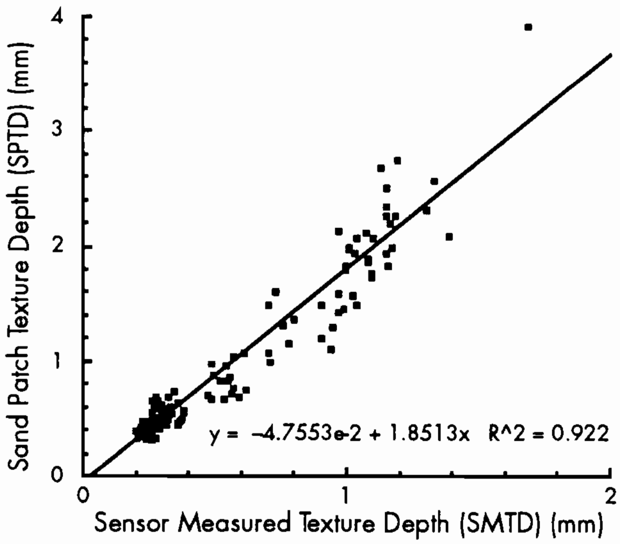

Figure 6.3 Graph showing correlation between SMTD and SPTD

In order to conduct this comparative study, data were collected from the selected test sections during each visit. The collected data used for the analysis have been compiled in Table A-4 in Appendix A. For each test section, during each visit, the sand-patch test was conducted at five locations pre-selected along the test sections. Similarly, five average texture values were obtained from the MTM. The data show a strong linear relationship with a very high correlation coefficient of 0.922. The regression equation obtained from the analysis is:

$$SPTD = -4.755 \times 10^{-2} + 1.8513(SMTD)$$

It should be noted that SMTD yields a better representative measure of surface texture because the MTM measures the texture depth over a long, continuous, although narrow, portion of the pavement surface.

6.3.2 Advantages

1. The MTM method of measurement is not as labor intensive as the sand-patch method.
2. It obtains data from continuous measurements over a series of representative samples in a relatively short period of time.
3. The MTM provides a more precise measurement of average texture depth.

A few precautionary measures that should be followed before operating the MTM are:

1. The equipment should not be operated under wet conditions.
2. The pneumatic tires should be inflated to 10 psi ± 1 psi, to get rid of the excessive bump that may occur while rolling the MTM over the pavement surface.
3. The equipment should be given at least 10 minutes to warm up, particularly before the first measurements of the day.
4. The drop out percentage (DO%) should be calculated at the beginning; the average of five consecutive readings should remain in the range of 40% ± 3%.
5. While rolling the meter on the surface, a walking speed between 3 to 8 km/hr should be maintained.

CHAPTER 7. PERFORMANCE EVALUATION

7.1 INTRODUCTION

In this study six methods were used to evaluate different aspects of pavement performance. The means of evaluation were: 1) skid resistance measurement, 2) British pendulum number measurement, 3) sand-patch texture depth, 4) sensor measured texture depth, 5) visual condition survey, and 6) macro-photograph records. Attempts were made to correlate the results with the aggregate quality evaluation laboratory test results. Different manipulation techniques were used to develop a good correlation and consequently an inexpensive, less time-consuming evaluation method.

7.2 CONDITION SURVEY

Collected condition survey data have been compiled in Table A.3 (Appendix A). The data show that the condition ratings for the test sections were high even as the project expired. The main reasons for the virtually unchanged values of the condition rating were: 1) the study span was only two years, and 2) the test sections included in the study were fairly new (except for a few) at the beginning of the study. A considerable change in the rating was observed only for the comparatively older test sections. A correlation analysis of the aggregate quality with the condition rating did not produce a significant result. The most likely reasons for this low correlation have already been discussed.

Some of the sections actually had their condition ratings improved at times due to the maintenance work carried out during the time between consecutive visits. As the monitoring of the test sections continues, it is anticipated that the pavement condition rating will better indicate the pavement performance.

7.3 TEXTURE MEASUREMENT

Among the objective evaluations done for this study was measurement of the texture depth. Sand-patch texture depth and sensor measured texture depth were obtained for this study. It was expected, particularly for seal coat surfaces, that a trend in aggregate wear rate depending on the aggregate quality would be found. Unfortunately no such trend was obtained when percentage loss in the texture depth was plotted against the MSS loss and the TDT loss. The traffic volume for each test section was also considered, in order to find out if the traffic volume along with the aggregate quality tests could produce some trend.

The primary reason for the absence of a trend may be that the sections are fairly new and therefore a trend is not yet apparent. It may also be that the wear rate is not directly related to texture depth alone. Again, the causes of texture depth loss may be other than those related to aggregate wearing, such as aggregate embedment, aggregate stripping, or shelling.

7.4 FRICTION NUMBER

The friction number measured by a skid trailer showed a trend for most of the test sections for the data available. The data available are for a very short part of the pavement life. Therefore, the trends were established by extending the trend curves to the expected (desired) life span of the pavements.

Two types of trend curves were considered. First, a linear trend curve was considered. It usually gives a conservative estimate of the possible trend. A second, nonlinear trend was also considered. If a pavement friction number trend shows that the pavement is going to maintain a satisfactory friction number through at least 80 percent of its life span for both projections, a 'good' friction performance is assigned to that pavement. A pavement showing 'good' performance according to the nonlinear projection, but less than 'good' according to the linear projection is designated a 'fair' performer. A test section failing to show 'good' performance according to either method of projection is designated a 'poor' performer. For any other case, the performance rating should be 'inconclusive.' Figures 7.1, 7.2, 7.3 and 7.4 show how the pavement performance related to friction may be rated as described above. One should note that although the rating is subjective, it is completely based upon objective evaluation and analysis.

In order to obtain the trend projection, it was necessary to assign the pavement service life over which the projection will be made. Based on interviews with TxDOT district personnel it was estimated that the service life of an asphaltic seal coat surface is usually 5 to 7 years, on average 6 years, and for a hot-mix asphaltic surface, the span is 8 to 12 years, on average 10 years.

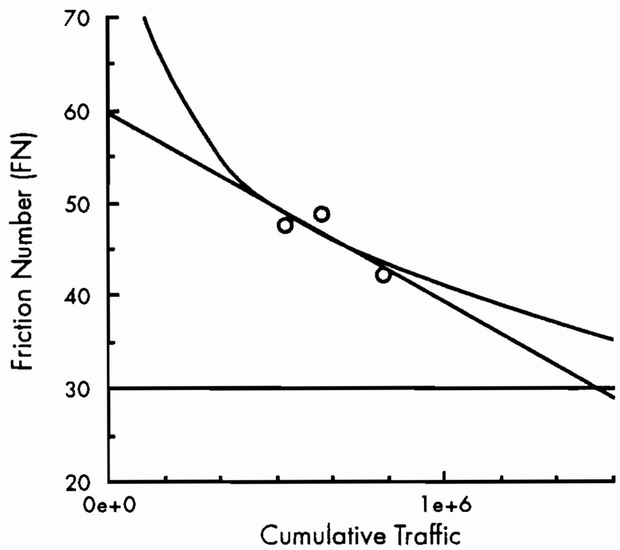

Figure 7.1 Diagram showing a category-2 pavement with a 'good' performance according to the 'rating procedure'

The traffic volume varied from 105 to 50,000 ADT for the test sections included in this study. The traffic volume is the single most dominant factor that affects friction performance. Therefore, evaluating all of the test sections under the same category is not fair. Hence, the test sections were divided into five categories based on ADT as shown below.

Category	*ADT*
1	0 - 750
2	750 - 2,000
3	2,000 - 5,000
4	5,000 - 10,000
5	10,000 - 50,000

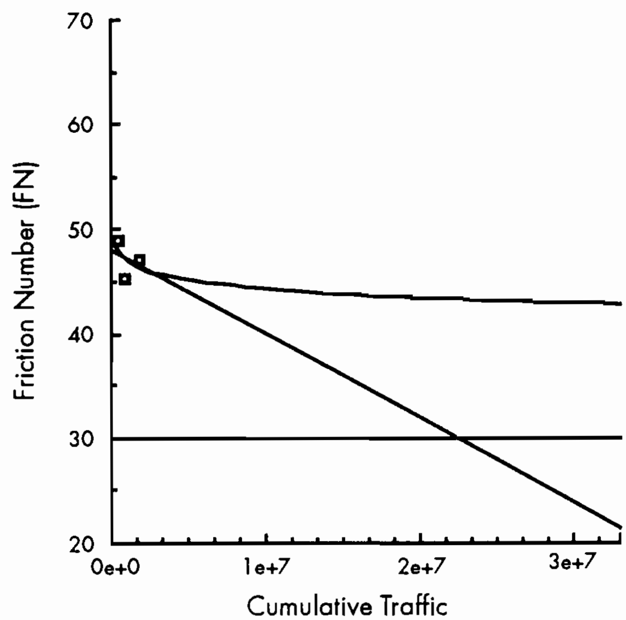

Figure 7.2 Diagram showing a category-5 pavement with a 'fair' performance according to the 'rating procedure'

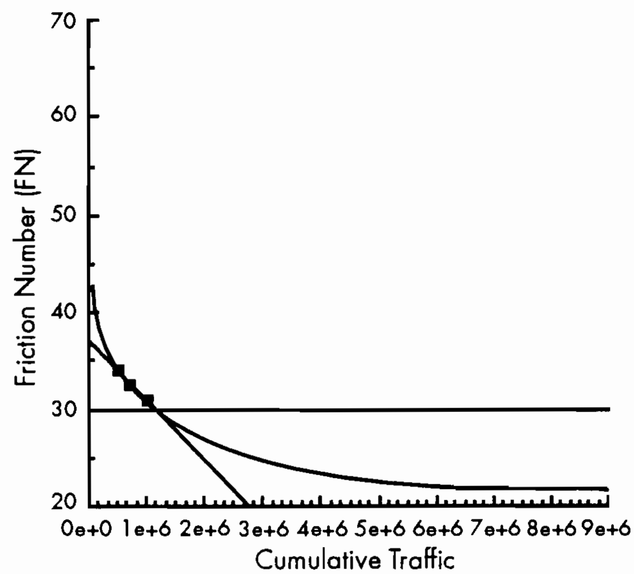

Figure 7.3 Diagram showing a category-4 pavement with a 'poor' performance according to the 'rating procedure'

Each test section, under each category, was expected to be subjected to an average daily traffic equal to the mean ADT for each category, over the service life of the pavement. Each test section, under each category, was assumed to have a directional distribution of 0.5. It was also assumed that the pavements in categories 1, 2, and 3 are two-lane roads (one lane in each direction). Categories 4 and 5 are four-lane roads (two lanes in each direction) with sixty percent of the traffic in the outer lanes. This assumption is conservative, but it was implemented in order to generalize for all the roads under a particular category.

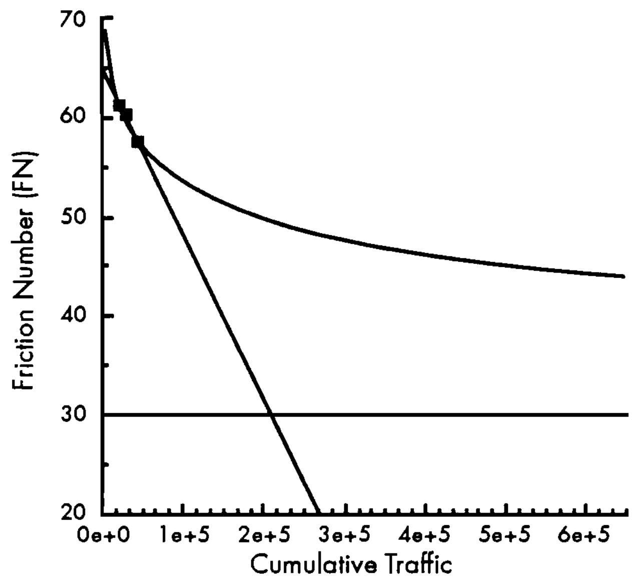

Figure 7.4 Diagram showing a category-1 pavement with an 'inconclusive' performance according to the 'rating procedure'

The friction performance analysis using these criteria showed that out of the 39 test sections, 14 were rated 'good,' 8 were rated 'fair,' 7 were rated 'poor' and 10 were rated 'inconclusive.' Only one of the seal coat surfaces was rated 'poor.' Out of the six hot-mix surfaces that were rated 'poor,' two of them were in category 4 and the other four were in category 5. The two test sections under category 4 that were rated 'poor,' had failed the TDT quality control test and one of them had failed the MSS loss quality control test, i.e., the recommended values were exceeded. It should be noted that of the four aggregates that had failed the TDT, two of them were used for HMAC sections and two for seal coat sections. Both of the aggregates used in seal coat sections (both aggregates were from the same source) had shown 'fair' performance. There were other sections that used aggregates from the same source that passed the TDT test; each of them showed a 'good' performance.

Of the four sections that were rated 'poor' under category 5, as already stated, two of these sections were constructed with material from the same source. Therefore, apparently three 'poor' performers could not be detected by either quality control test. But it should be noted that out of the 10 sections in category 5; none of them rated 'good,' two of them rated 'fair,' four of them rated 'poor,' and for the other four, the performance rating was 'inconclusive.' A very important note regarding these four 'poor' performers is that all of them had relatively low friction numbers (very close to 30) to start with.

7.5 MACRO-PHOTOGRAPH RECORDS

In addition to the other methods of evaluation used in this study, the macro-photograph evaluation was also used. Under this method of evaluation, several photographs were taken for each test section during each visit. For each of the test sections, the photographs were taken at the same location or close to the same location during all of the four visits. During each visit, for each section, at least four photographs were taken at the preselected locations or within the close vicinity of the selected locations. The first picture was taken about 4 feet from the ground, the second one was taken about 2 feet from the ground, and the third and the fourth one were about six inches from the ground.

The macro-photographs were expected to provide evidence of aggregate degradation and polishing with time. A comparative study of photographs taken during subsequent visits was expected to portray the continuous degradation and polishing of the aggregates and, therefore, provide a visual representation of the aggregate quality.

Experienced individuals were asked to evaluate the aggregates based on the impressions that they had from viewing the first and the last photographs. They were asked to rate the aggregates separately for polishing and degradation by noticing the change in the aggregate over the two-year time period. This subjective evaluation was expressed in numerical terms by selecting a rating scale with a value range of 0-10. Better performance is reflected through a higher numerical value. The evaluation was done for seal coat aggregates only.

The plots of the average rating value for degradation against the MSS loss and the TDT values are shown in Figures 7.5a and 7.5b. Two of the aggregates, which were used to surface test sections SA-17 and C-4, have performed poorly. The rest of the aggregates have performed well. In general, the aggregates with comparatively higher MSS loss and TDT values performed slightly worse than the aggregates with very low values. No specific relationship could be developed or groups could be formed to segregate the aggregates based on their quality. It should be noted that in Figure 7.5b, section C-4 data is not present because the TDT value was not available for that section.

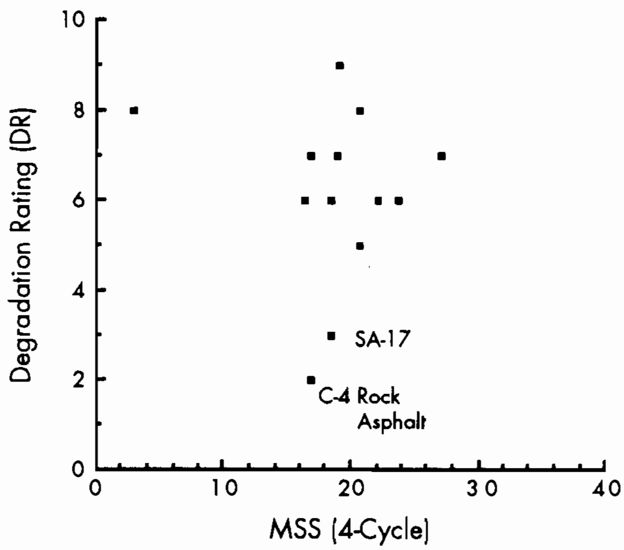

Figure 7.5a Correlation between the MSS (4-cycle) and the macro-photograph degrada-tion ratings for the seal coat surfaces

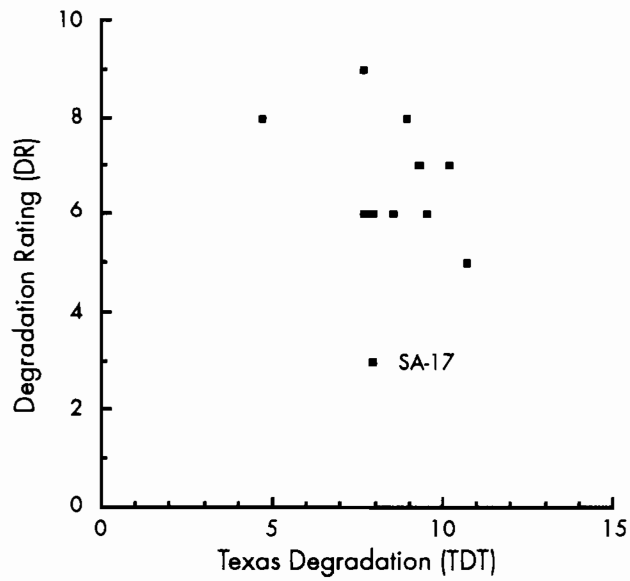

Figure 7.5b Correlation between the TDT results and the macro-photograph degradation ratings for the seal coat surfaces

Similar plots of the average polish rating against the MSS loss and the TDT values are shown in Figures 7.6a and 7.6b. Only two of the aggregates seemed to have performed poorly. No apparent trend could be detected in this case either. Neither could groups be formed based on the aggregate quality, as indicated by the laboratory tests.

Overall, it becomes apparent from the plots that the raters have not been able to differentiate among aggregates of different quality at this stage of the aggregate life span. With the availability of photographs from the section monitoring, representing the later part of the service life of the sections, a difference in quality among the aggregates may become more apparent from this method of evaluation.

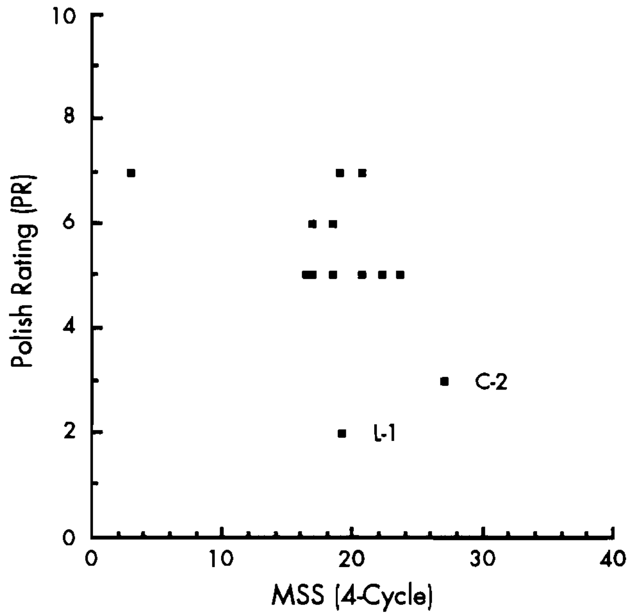

Figure 7.6a Correlation between the MSS (4-cycle) and the macro-photograph polish ratings for the seal coat surfaces

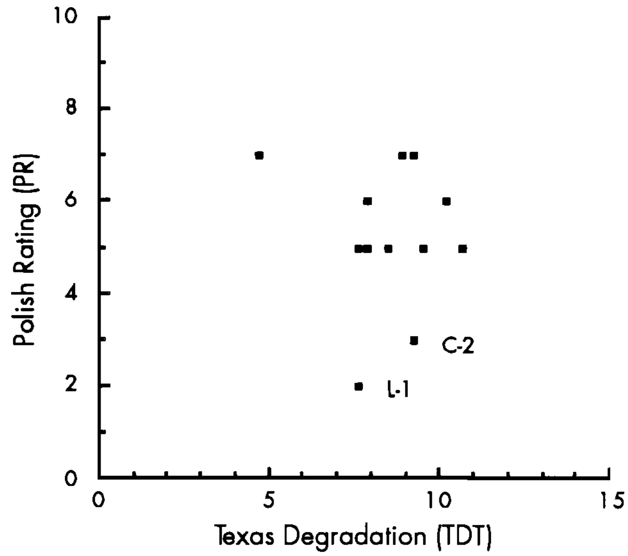

Figure 7.6b Correlation between the TDT results and the macro-photograph polish ratings for the seal coat surfaces

CHAPTER 8. REGRESSION MODELS

8.1 MULTIVARIATE ANALYSIS

Multivariate analysis is the study of linear representations of relations among variables. For this study, regression equations with multiple variables were developed with the existing data.

The analyses were conducted separately for the HMAC and the seal coat surfaces. Due to insufficient data, the analysis was not conducted for the micro-surfaces. The independent variables included in the analysis were related with construction, traffic, environment and laboratory test. Four types of laboratory test data were available for this analysis. Each of the analyses involved no more than two laboratory test data and all of the other data. The intent was to determine how each of the laboratory tests influenced the prediction of the dependent variable. The dependent variable for this analysis was friction number (FN).

Qualitative variables were also used in the analysis. They are included in the models as dummy variables. The aggregate type, environmental region and aggregate coating characteristics were the qualitative variables considered in the analysis. Four aggregate types were considered: limestone (LS), sandstone (SS), siliceous gravel (SG) and rhyolite (RY). The test sections were located in two environmental regions, region four (WR) and region five (CD). The aggregate coating characteristics were pre-coated type B(PB), type A and type B.

The Statistical Analysis System (SAS) was used for the analysis. A detailed analysis was conducted for each case. The results have been compiled in the following sections. The final computer outputs have been compiled in Appendix B. For each of the models only the REG SAS command outputs have been shown, except for the analysis with the PV data and the 'other data'; for that particular case, comparatively more detailed output has been attached.

While the equations obtained represent the best estimate for the available data, it should be clearly recognized that the values generated by these equations are very conservative. This is due to the fact that the equations are linear representations of a phenomenon which is not linear. As additional data are collected, the equations will be modified to be more representative of the real process.

Use of these equations for a short term projection (less than three years) is better than for a long term projection (six or more years).

8.2 REGRESSION MODELS FOR HMAC SURFACES

Many models were developed for HMAC surfaces. The seven models that were considered significant have been compiled in Table 8.1. The data used for each model have been shown below. It should be noted that the term 'other data' refers to all data except for the laboratory test results (see Table 8.1).

Model	*Data Included*
HA or SA	'Other data' only
HB or SB	PV and other data
HC or SC	MSS and other data
HD or SD	TDT and other data
HE or SE	LAABR and other data
HF or SF	PV, MSS, and other data
HG	MSS, TDT, and other data

Table 8.1 The 'other data' for the model generated in Chapter 8

Variable Abbreviation	Variable Explanation
CUTR	Cumulative traffic (see section 5.6)
LCUTR	Natural logarithm of cumulative traffic
CUPP	Cumulative precipitation (Table A.1)
CUFT	Cumulative freeze-thaw cycles (Table A.1)
CD	Cold region (Region V); if the region is V, then CD is 1; otherwise it is zero
ASPC	Asphalt content as a percentage (HMAC only)
ABSP	Aggregate absorption as percentage
SPGR	Aggregate specific gravity
STAB	Mix stability (HMAC only)
ASSR	Asphalt spread rate as gallon per yd^2 (seal coat only)
AGSR	Aggregate spread rate yd^2 per yd^3 (seal coat only)
LS	Limestone; if the aggregate type is limestone then LS is 1; otherwise it is zero
SG	Siliceous gravel; if the aggregate type is siliceous gravel then SG is 1; otherwise it is zero
PB	Precoated type B aggregate; if the aggregate is precoated type B, then PB is 1; otherwise it is zero

The noteworthy aspects of the multi-variable regression equations that have been developed are (Table 8.2):

1. The construction, environment, traffic, aggregate, and physical properties explain 69 percent of the variability associated with the friction number.
2. The inclusion of a laboratory test result improved the R^2 value. The PV, the MSS, and the TDT values individually improved the R^2 values.
3. The LA abrasion test failed to explain the variability over that already explained by the 'other data.' As shown in the model HE, although it was included as a independent variable, its contribution was insignificant.
4. Two test results, the PV and the MSS values along with 'other data' (Model HF) explained about 82 percent of the variability. This is the maximum R^2 obtained.
5. The TDT and the MSS values together (Model HE) explained 78 percent of the variabilities, which is a slight improvement over the percentage that they were explaining individually.

8.3 REGRESSION MODELS FOR SEAL COATS

Six models have been compiled for this surface type. The models are listed in Table 8.3. For the model names in this table, refer to the short list in the previous section. The terms bear the same meaning, although some of the variables included under the 'other data' (particularly construction related variables) are different.

The important aspects of the models in Table 8.3 are:

1. The construction, traffic, environment and aggregate physical properties explained 60 percent of the variability in predicting the friction number.
2. Among the laboratory test results, the MSS along with the 'other data' produced an R^2 value of 0.70 (Model SC).
3. The polish value was the second best individual test; it explained 68 percent of the variability (Model SB).
4. The LA abrasion and the TDT values failed to explained any additional amount of the variability over that already explained by the 'other data.'
5. The PV and the MSS values together with the 'other data' explained 72 percent of the variability. This is a slight improvement in R^2 value over that achieved by the MSS values alone.

8.4 REGRESSION MODELS FOR MICRO-SURFACES

It has already been stated that due to insufficient data, regression models could not be developed for the micro-surfaces. With the availability of more data, the models can be developed in the future. The general observation at this point is that these surfaces tend to maintain a very high FN. The test section W-7, which is about 3 years old, has an FN of 64.8. The newer sections also have high FN's too.

Table 8.2 Regression equations for HMAC surfaces

Model	Regression Equation	R^2
HA	FN= 121.4 + 4.54 ASPC – 7.77 LCUTR + 0.16 CUPP – 0.024 (ABSP*CUFT) + 6.3 X 10^{-6} (SG*CUTR)	0.69
HB	FN= 117.3 + 3.08 ASPC + 0.97 PV + 0.21 CUFT + 0.052 (ABSP*CUPP) – 9.32 LCUTR – 0.093 (ABSP*CUFT)	0.78
HC	FN= 142.8 – 7.31 LCUTR – 0.058 CUFT + 0.19 CUPP + 6.82 X 10^{-6} (CD*CUTR) – 0.06 (ABSP*MSS) – 6.9 X 10^{-6} (LS*CUTR)	0.74
HD	FN= 76.45 + 8.33 ASPC + 0.76 TDT – 6.22 LCUTR + 23.99 LS + 4.2 X 10^{-6} (SG*CUTR) – 3.3 (LS*TDT)	0.76
HE	FN= 117.9 + 5.28 ASPC – 0.24 LAABR – 7.34 LCUTR + 0.16 CUPP – 0.022 (ABSP*CUFT) + 5.2 X 10^{-6} (SG*CUTR)	0.71
HF	FN= 96.64 + 4.43 ASPC + 0.91 PV – 8.01 LCUTR + 0.16 CUFT + 0.0424 (ABSP*CUPP) – 0.069 (ABSP*CUFT) – 0.264 (LS*MSS)	0.82
HG	FN= 47.33 – 0.59 STAB + 2.90 MSS – 0.34 (TDT*MSS) + 18.82 CD + 0.61 (ABSP*TDT) – 6.94 X 10^{-8} (STAB*CUTR)	0.78

Note: 4-cycle MSS values are used in the equations. If 5-cycle MSS values are available these should be converted to 4-cycle values using equation in section 3.6.5 before using the predictive.

Table 8.3 Regression equations for seal coat surfaces

Model	Regression Equation	R^2
A	FN= 195.1 – 76.48 ASSR – 16.81 CD – 7.945 LCUTR	0.60
B	FN= 225.6 – 0.702 (ASSR*AGSR) – 0.72 PV – 8.53 LCUTR – 12.69 CD	0.68
C	FN= 171.4 – 71.05 ASSR – 7.15 LCUTR – 0.24 CUFT – 12.24 LS + 8.82 PB + 0.01127 (MSS*CUFT)	0.70
D	FN= 210.7 – 8.51 LCUTR – 13.81 LS – 10.07 SG – 0.95 (ASSR*AGSR) – 0.00446 (TDT*CUPP)	0.62
E	FN= 226.08 – 102.34 ASSR – 16.46 CD – 9.40 LCUTR – 0.16 (LS*LAABR)	0.63
F	FN= 133.1 – 1.89 PV – 0.60 CUPP – 16.86 CD + 13.96 LS – 1.053X10^{-6} (MSS*CUTR) + 0.03 (MSS*CUPP)	0.72

CHAPTER 9. CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

Based on the results of this study the following conclusions are made:

1. The mini-texture meter (MTM) is an accurate and reliable device for surface texture measurement. A high correlation (R^2 = 0.92) between the sensor-measured texture depth (SMTD) and the texture depth measured by the sand-patch method (SPTD) indicates that the SMTD is an equivalent measure of the surface texture depth. The SMTD should be considered a better representative measurement of surface texture as explained in Chapter 6.
2. The texture measurement may be an important element of pavement evaluation, but it is not a good indicator of the pavement friction performance.
3. The 4-cycle and 5-cycle MSS loss data indicate that the two tests measure the same aggregate properties, as they correlate very strongly with a correlation coefficient of 94 percent. A regression equation is provided to generate either value if the other is known.
4. From the correlation equation for the 4-cycle and 5-cycle MSS tests it can be stated that a 29 percent and a 35 percent MSS loss with 5-cycle provides the same quality indication as a 25 percent and a 30 percent MSS loss do for 4-cycle.
5. For the Texas degradation test (TDT), an allowable loss of 10 percent indicates that good quality aggregates are not discriminated against. In most cases, this allowable limit ensures that only high quality aggregates are included.
6. The MSS loss values along with the 'other data' considered in this research study explain 74 percent of the variability associated with the prediction of the friction number (FN) for the hot-mix asphaltic concrete (HMAC) surfaces. For the seal coat surfaces they explained about 70 percent of the variability.
7. The TDT results along with the 'other data' explained 76 percent of the variability associated with the prediction of the friction number (FN) for the HMAC surfaces and 62 percent of the variability for the seal coat surfaces.
8. The MSS loss values and the TDT results, together with the 'other data' explained 78 percent of the variability in predicting FN values for the HMAC surfaces. For the seal coat surfaces, the correlation coefficient was about 70 percent.
9. The Los Angeles abrasion (LAABR) test values with the 'other data' explained 71 and 63 percent of the variabilities associated with the prediction of FN for the HMAC and the seal coat surfaces respectively. Hence, the LAABR provided no additional information over other tests in predicting the frictional performance.
10. HMAC surfaces on high volume roads (ADT >10,000 vpd) will not provide 'good' performance for the estimated average life of ten years for the aggregates included in this study.

9.2 RECOMMENDATIONS

Based on the results of this study the following recommendations are made:

1. TxDOT should collect 5-cycle MSS loss and TDT test data for all the aggregates used in the HMAC and seal coat surfaces.
2. In order to ensure a good quality pavement surface, through the selection of good quality aggregate, the following allowable losses are recommended for the 5-cycle MSS test:

Surface Type	*Maximum Allowable % Loss*
HMAC	35
Seal Coat	29

3. For the TDT the allowable percentage losses recommended to ensure good quality aggregates are:

Surface Type	*Maximum Allowable % Loss*
HMAC	10
Seal Coat	10

4. For the micro-surfaces, it is recommended that the 5-cycle MSS and the TDT maximum allowable losses be the same as those for seal coats.
5. Whenever it is necessary to measure surface texture, the mini-texture meter should be used in order to obtain a reliable, accurate and more representative measure of the surface texture depth.
6. All test sections should continue to be monitored in order to obtain information regarding long term performance of the aggregates.

REFERENCES

1. Annual Book of ASTM Standards, "Road, Paving, Bituminous Materials; Traveled Surface Characteristics," Part 15, 1980.

2. Button, J. W., and D. N. Little, "Additives Have Potential to Improve Pavement Life," *Roads and Bridges*, May 1988, pp 68-72.

3. "Climatological Data, Texas," National Oceanic and Atmospheric Administration, Years 1984-1991.

4. Colony, D. C., "Skid Resistance of Bituminous Surfaces in Ohio," University of Toledo, March 1984.

5. Construction Bulletin C-14, TxDOT, Construction Division, April 1984.

6. "District Pavement Data Collection: Coordinator's Guide to PES Reports and Scores," TxDOT, Pavement Management (D-18), May 1991.

7. Epps, J. A., A. H. Meyer, I. E. Larrimore, Jr., and H. L. Jones, Research Report 151-2, "Roadway Maintenance Evaluation User's Manual," Texas Transportation Institute, September 1974.

8. Heaton, B. S., J. J. Emery, and N. A. Kamel, "Prediction of Pavement Skid Resistance Performance," *Australian Road Research Board Proceedings*, Vol 9, Part 3, 1978, pp 122-126.

9. Henry, J. J., J. C. Wambold, and X. Huihua, "Evaluation of Pavement Texture," Pennsylvania Transportation Institute, October 1984.

10. Hosking, J. R., P. G. Roe, and L. W. Tubey, "Measurement of Macro-texture of Roads, Part 2: A Study of the TRRL Mini Texture Meter," *Research Report 120,* Transport and Road Research Laboratory, 1987.

11. Hosking, J. R., "The Effect of Aggregate on the Skidding Resistance of Bituminous Surfacing: Factors Other than Resistance to Polishing," Transport and Road Research Laboratory, 1973.

12. Jordan, P. G., "Measurement of Road Surface Shape Using a Laser Sensor," Institute of Civil Engineers, London, 1981.

13. Larkin, T. J., and G. W. Bomar, "Climatic Atlas of Texas," Texas Department of Water Resources, December 1983, pp 1-20.

14. Lees, G., I. D. Katekhda, R. Bond, and A. R. Williams, "The Design and Performance of High Friction Dense Asphalts," *Transportation Research Record*, TRR-624, 1978.

15. Malak, M. U. A., D. W. Fowler, and A. H. Meyer, "Implication of Aggregates in the Construction and Performance of Seal Coat Pavement Overlays," *Informal Report 490-2,* The University of Texas at Austin, August 1990.

16. Manual Count Annual Report, TxDOT, Locations and 24-Hour Vehicle Classification, Transportation Planning Division (D-10), Years 1988-1990.

17. O'Flaherty, C. A., "Highways, Volume 2: Highway Engineering," 3rd Edition, 1988, pp 489-506.

18. Orchard, D. F., *Concrete Technology, Volume 3: Properties and Testing of Aggregates*, John Wiley and Sons, 1976, pp 146-168.

19. Orton, R. B., "The Climate of Texas," Texas Department of Water Resources, December 1983, pp 877-882.

20. Papaleontiou, C. G., A. H. Meyer, and D. W. Fowler, "Evaluation of the 4-Cycle Magnesium Sulfate Soundness Test," *Research Report 438-1F,* Project 3-9-85-438, November 1987.

21. "Pavement Evaluation System Rater's Manual," TxDOT, Pavement Management (D-18), May 1990.

22. Pederson, C. M., W. J. Schuller, and C. D. Hixon, "Microsurfacing with Natural Latex Modified Asphalt Emulsion: A Field Evaluation," *Transportation Research Record* 1171, pp 108-112.

23. Permanent Traffic Recorder Record, TxDOT, Transportation Planning Division, Years 1988-1990.

24. Pike, D. C., "Standards for Aggregates," Ellis Horwood, 1990, pp 203-241.

25. Reczon, F., "Specifier's Guide to Asphalt Modifiers," *Roads and Bridges*, May 1988, pp 68-72.

26. "SAS / FSP User's Guide," Version 5, Edition 1985, SAS Institute Inc.

27. "SAS User's Guide: Statistics," Version 5, Edition 1985, SAS Institute Inc.

28. "SAS User's Guide: Basics," Version 5, Edition 1982, SAS Institute Inc.

29. "SAS Procedure Guide for Personal Computers," Version 6, Edition 1985, SAS Institute Inc.

30. "SAS Introductory Guide," Version 6, Edition 1985, SAS Institute Inc.

31. Shahin, M. Y., and S. D. Kohn, "Development of a Pavement Condition Rating Procedure for Roads, Streets and Parking Lots; Volume 1: Condition Rating Procedure," July 1979, pp 9-19.

32. Shahin, M. Y., and S. D. Kohn,"Development of a Pavement Condition Rating Procedure for Roads, Streets and Parking Lots; Volume: Distress Identification Manual," July 1979.

33. "Standard Nomenclature and Definitions for Pavement Components and Deficiencies," *Special Report 113,* Highway Research Board, 1970, pp 6-16.

34. "Standard Specifications for Construction of Highways, Streets, and Bridges," TxDOT, September 1982.

35. Texas State Department of Transportation, "Standard Specification, Item - 3553, 3557, 3649, Slurry Seal."

36. Tons, E., and A. Lau, "Study of Road Surfaces by Photographic Method," Massachusetts Institute of Technology, June 1963, pp 1-2.

37. "TRRL Mini-Texture Meter Operating/Maintenance Manual," Transportation and Road Research Laboratory.

38. Wright, P. H., and R. J. Paquete, *Highway Engineering,* 4th Edition, John Wiley and Sons, 1979.

APPENDIX A. FIELD TEST RESULTS AND OTHER DATA

Table A.1 Skid resistance test and related data

SEC	SET	CONT. DATE	FN1	FN2	FN3	FN4	FN5	FN	AGE	CUTR	CUFT	CUPP
L1	SET1	05JUN90	48	48	48	47	48	47.4	705	1050170	146	27.89
L1	SET2	17OCT90	48	48	48	50	50	48.8	839	1260550	146	36.04
L1	SET4	11JUN91	43	43	44	39	43	42.4	1076	1632640	224	43.72
L2	SET1	05JUN90	44	42	45	43	44	43.6	796	5599540	147	32.64
L2	SET2	17OCT90	51	49	50	49	55	50.8	930	6616600	147	40.79
L2	SET4	11JUN91	41	40	42	46	44	42.6	1167	8415430	225	48.47
L3	SET1	05JUN90	47	49	49	48	48	48.2	978	6782540	228	35.30
L3	SET2	17OCT90	49	50	51	48	50	49.6	1112	7799600	228	43.45
L3	SET4	11JUN91	39	45	45	45	44	43.6	1349	9598430	306	51.13
L4	SET1	05JUN90	61	59	61	64	62	61.4	340	41580	89	13.33
L4	SET2	17OCT90	61	64	56	61	60	60.4	474	58330	89	21.48
L4	SET4	11JUN91	58	57	57	59	57	57.6	711	87955	167	29.16
L5	SET1	05JUN90	41	41	42	42	42	41.6	370	751360	82	18.66
L5	SET2	17OCT90	43	40	40	43	42	41.6	504	1047500	84	25.76
L5	SET4	12JUN91	42	37	42	38	44	40.6	741	1573480	167	35.22
L6	SET1	05JUN90	45	48	47	43	39	44.4	370	4201720	89	18.31
L6	SET2	17OCT90	48	48	46	47	48	47.4	504	572100	89	26.46
L6	SET4	12JUN91	47	45	44	47	46	45.8	741	8505760	167	34.14
L7	SET4	12JUN91	58	60	56	57	54	57.0	285	1975050	69	7.37

Table A.1 Skid resistance test and related data (cont.)

SEC	SET	CONT. DATE	FN1	FN2	FN3	FN4	FN5	FN	AGE	CUTR	CUFT	CUPP
L8	SET4	12JUN91	58	55	56	57	59	57.0	285	1975050	69	7.37
OD1	SET1	07JUN90	35	35	37	45	43	39.0	381	69130	66	10.81
OD1	SET2	12OCT90	37	38	36	41	40	38.4	508	157480	66	20.04
OD1	SET4	04JUN91	36	31	35	35	38	35.0	743	230330	125	24.26
OD2	SET1	07JUN90	47	49	51	53	45	49.0	118	1321600	20	4.35
OD2	SET2	12OCT90	44	46	42	45	50	45.4	245	2744000	20	11.05
OD2	SET4	04JUN91	45	46	48	50	47	47.2	480	5824000	80	18.51
OD3	SET1	07JUN90	44	44	44	40	41	42.6	1345	11507300	258	69.99
OD3	SET2	12OCT90	24	28	34	26	34	29.2	1472	12510600	258	76.15
OD3	SET3	04JUN91	20	26	26	33	28	26.6	1707	14367100	313	84.29
SA1	SET2	18OCT90	56	56	56	54	56	55.6	476	1076300	57	33.69
SA1	SET3	01MAY91	42	43	45	43	46	43.8	671	1524800	97	45.34
SA1	SET3	01MAY91	42	43	45	43	46	43.8	671	1524800	97	45.34
SA4	SET1	30MAY90	53	53	51	52	49	51.6	391	789500	52	26.66
SA4	SET2	08OCT90	48	42	40	49	42	44.2	522	1058050	52	43.26
SA4	SET4	06JUN91	45	40	48	49	32	42.8	814	1656650	103	60.52
SA6	SET1	31MAY90	52	51	51	52	51	51.4	346	830400	49	19.33
SA6	SET2	18OCT90	47	51	50	47	52	49.4	486	1166400	49	33.15
SA6	SET3	02MAY91	39	44	42	43	43	42.2	682	1636800	90	48.13

Table A.1 Skid resistance test and related data (cont.)

SEC	SET	CONT. DATE	FN1	FN2	FN3	FN4	FN5	FN	AGE	CUTR	CUFT	CUPP
SA16	SET1	29MAY90	54	57	54	52	53	54.0	417	750600	74	16.60
SA16	SET2	12OCT90	54	51	54	55	52	53.2	553	995400	74	30.87
SA16	SET3	02MAY91	51	44	54	51	50	50.0	755	1359000	129	39.21
SA17	SET1	29MAY90	54	50	55	57	55	54.2	365	474500	62	16.10
SA17	SET2	18OCT90	60	61	61	59	60	60.2	507	659100	64	31.65
SA17	SET3	01MAY91	51	57	53	52	56	53.8	702	912600	117	41.89
SA19	SET1	30MAY90	62	59	59	64	63	61.4	365	102200	43	20.30
SA19	SET2	19OCT90	64	64	67	65	68	65.6	507	141960	62	37.36
SA19	SET3	02MAY91	55	56	59	62	57	57.8	702	196560	64	46.56
SA27	SET1	31MAY90	50	50	48	50	57	51.0	607	2217050	49	13.38
SA27	SET2	19OCT90	57	56	52	51	60	55.2	748	2745800	49	27.20
SA27	SET3	01MAY91	36	41	38	44	37	39.2	942	3473300	90	42.18
SA30	SET1	30MAY90	58	53	58	59	57	57.0	364	258440	49	19.33
SA30	SET2	19OCT90	59	55	59	58	57	57.6	506	359260	49	33.15
SA30	SET3	01MAY91	56	55	58	56	56	56.2	700	497000	90	48.13
A1	SET1	04JUN90	46	44	46	44	44	44.8	355	319500	54	16.71
A1	SET2	17OCT90	48	50	50	47	48	48.6	490	441000	54	29.81
A1	SET3	03MAY91	43	39	40	45	45	42.4	688	619200	97	34.66
A2	SET1	04JUN90	36	37	35	31	32	34.2	334	1649700	54	12.70

Table A.1 Skid resistance test and related data (cont.)

SEC	SET	CONT. DATE	FN1	FN2	FN3	FN4	FN5	FN	AGE	CUTR	CUFT	CUPP
A2	SET2	17OCT90	33	31	31	36	32	32.6	469	2338200	54	25.80
A2	SET3	03MAY91	32	28	30	34	31	31.0	667	3348000	97	30.65
A4	SET1	08JUN90	33	34	33	31	30	32.2	728	9267350	43	28.84
A4	SET2	18OCT90	28	32	25	22	31	27.6	860	11029550	43	44.32
A4	SET3	29APR91	30	28	26	28	28	28.0	1053	13606100	77	54.28
A5	SET1	08JUN90	31	33	34	33	31	32.4	668	8529350	43	20.09
A5	SET2	18OCT90	30	30	29	30	29	29.6	800	10291550	43	35.57
A5	SET3	29APR91	27	27	28	28	29	27.8	975	12868100	77	45.53
W1	SET1	05JUN90	38	38	42	39	39	39.2	778	3527000	57	76.37
W1	SET2	27SEP90	34	40	37	35	48	38.8	892	4017200	57	86.31
W1	SET3	29MAR91	41	39	39	42	42	40.6	1045	4675100	76	110.75
W2	SET1	05JUN90	50	49	52	50	49	50.0	715	2711100	56	71.70
W2	SET2	26SEP90	52	49	48	55	52	51.2	829	3129200	56	81.82
W2	SET3	29MAR91	54	54	52	50	54	52.8	982	3699000	74	103.98
W3	SET1	05JUN90	51	53	49	51	52	51.2	715	2711100	56	71.70
W3	SET2	26SEP90	53	53	52	54	51	52.6	829	3129200	56	81.82
W3	SET3	29MAR91	54	54	53	51	53	53.0	982	3699000	74	103.98
W4	SET1	05JUN90	36	36	36	37	36	36.2	678	21188600	47	55.08
W4	SET2	27SEP90	35	37	42	40	33	37.4	792	24905000	47	64.36

Table A.1 Skid resistance test and related data (cont.)

SEC	SET	CONT. DATE	FN1	FN2	FN3	FN4	FN5	FN	AGE	CUTR	CUFT	CUPP
W4	SET3	29MAR91	41	40	39	41	44	41.0	945	29892800	63	82.41
W5	SET1	05JUN90	24	22	23	26	27	24.4	664	32098000	47	55.08
W5	SET2	25SEP90	34	36	34	33	33	34.0	776	37474000	47	64.36
W5	SET4	03JUL91	29	31	30	32	30	30.4	1027	49522000	63	89.79
W6	SET1	05JUN90	42	43	42	39	40	41.2	778	5889640	47	44.00
W6	SET2	25SEP90	41	46	44	45	51	45.4	890	6784520	47	53.28
W6	SET4	03JUL91	46	46	44	43	43	44.4	1141	8790010	63	78.71
W7	SET3	29MAR91	63	63	65	66	67	64.8	876	3509800	76	95.79
AUS1	SET2	25SEP90	55	58	58	56	60	57.4	55	34650	0	4.11
AUS1	SET4	03JUL91	39	43	42	38	40	40.4	337	212310	20	30.23
AUS2	SET2	25SEP90	67	64	66	67	64	65.6	57	723900	0	2.09
AUS2	SET4	03JUL91	58	60	59	60	59	59.2	339	4305300	8	25.30
AUS3	SET2	25SEP90	43	39	37	39	42	40.0	58	3103000	0	2.09
AUS3	SET4	03JUL91	37	38	38	37	39	37.8	340	18190000	8	25.30
AUS4	SET4	03JUL91	60	60	61	59	60	60.0	763	35861000	23	53.44
C1	SET1	24MAY90	53	53	53	56	59	54.8	2276	25355800	14	179.46
C1	SET2	15NOV90	57	59	59	53	55	56.6	2451	27595800	14	192.44
C1	SET3	13MAR91	49	47	53	51	49	49.8	2569	29106200	36	195.97
C2	SET1	24MAY90	50	54	51	52	59	53.2	2215	2548010	14	178.91

Table A.1 Skid resistance test and related data (cont.)

SEC	SET	CONT. DATE	FN1	FN2	FN3	FN4	FN5	FN	AGE	CUTR	CUFT	CUPP
C2	SET2	15NOV90	45	56	62	58	47	53.6	2390	2765010	14	191.89
C2	SET3	13MAR91	48	50	48	54	49	49.8	2508	2911330	36	195.42
C3	SET1	24MAY90	29	27	32	31	32	30.2	569	5264640	15	42.85
C3	SET2	15NOV90	34	30	33	32	41	34.0	744	6762640	15	50.18
C3	SET3	13MAR91	28	26	29	26	28	27.4	862	7772720	20	56.32
C4	SET2	15NOV90	62	60	60	63	62	61.4	76	650560	0	4.15
C4	SET3	13MAR91	52	50	48	53	52	51.0	194	1660640	8	10.96
C5	SET2	15NOV90	59	58	59	61	60	59.4	7	34020	0	0.00
C5	SET3	13MAR91	65	62	62	62	63	62.8	125	604500	4	3.53

Table A.2 British Pendulum Test and related data

SEC	SET	TEST DATE	BPN1	BPN2	BPN3	BPN4	BPN5	BPN	AGE	CUTR	CUFT	CUPP
L1	SET1	14-Mar-90	93	96	95	94	93	94.2	622	3780	137	24.43
L1	SET2	24-Oct-90	75	72	80	75	72	74.8	846	149310	146	36.04
L1	SET3	6-Mar-91	74	78	75	73	77	75.4	979	224280	211	39.44
L1	SET4	10-Jul-91	74	73	77	70	69	72.6	1105	101600	217	44.99
L2	SET1	14-Mar-90	75	75	76	76	73	75.0	713	3035300	138	29.18
L2	SET2	24-Oct-90	75	71	67	76	69	71.6	937	4546600	147	40.79
L2	SET3	6-Mar-91	68	70	70	67	69	68.8	1070	642000	212	44.19
L2	SET4	9-Jul-91	65	60	65	60	59	61.8	1196	13000500	218	49.74
L3	SET1	15-Mar-90	87	85	85	86	82	85.0	895	19367000	219	31.84
L3	SET2	24-Oct-90	80	78	78	80	83	79.8	1119	31208000	228	43.45
L3	SET3	6-Mar-91	70	71	72	79	73	73.0	1252	36801000	293	47.62
L3	SET4	9-Jul-91	66	69	70	70	72	69.4	1378	159040	299	53.17
L4	SET1	15-Mar-90	83	87	88	85	86	85.8	258	338670	80	9.87
L4	SET2	24-Oct-90	81	81	81	85	77	81.0	481	430970	89	21.48
L4	SET3	6-Mar-91	75	81	80	76	79	78.2	614	517590	154	24.88
L4	SET4	9-Jul-91	72	75	76	80	76	75.8	740	595200	160	30.43
L5	SET1	15-Mar-90	90	89	93	94	90	91.2	288	1202400	73	13.13
L5	SET2	25-Oct-90	80	80	75	78	80	78.6	512	1514400	84	25.76
L5	SET3	6-Mar-91	71	71	73	65	73	70.6	644	1807200	157	28.74
L5	SET4	10-Jul-91	70	71	75	71	74	72.2	770	579600	167	34.10

Table A.2 British Pendulum Test and related data (cont.)

SEC	SET	TEST DATE	BPN1	BPN2	BPN3	BPN4	BPN5	BPN	AGE	CUTR	CUFT	CUPP
L6	SET1	15-Mar-90	86	85	83	85	84	84.6	288	3252980	80	14.85
L6	SET2	25-Oct-90	84	86	85	80	86	84.2	512	5844660	89	26.46
L6	SET3	6-Mar-91	81	80	80	82	81	80.8	644	7371900	158	30.68
L6	SET4	10-Jul-91	75	78	75	79	75	76.4	770	8829720	167	34.14
L7	SET3	7-Mar-91	97	95	95	94	94	95.0	188	1302840	78	10.83
L7	SET4	10-Jul-91	81	80	80	81	85	81.4	314	2176020	78	10.83
L8	SET3	7-Mar-91	87	92	82	89	87	87.4	188	1302840	78	10.83
L8	SET4	10-Jul-91	82	79	80	85	82	81.6	314	2176020	78	10.83
OD1	SET1	13-Mar-90	85	88	87	89	89	87.6	295	91450	59	6.7
OD1	SET2	26-Oct-90	75	75	76	77	76	75.8	522	161820	66	21.41
OD1	SET3	5-Mar-91	75	75	75	75	70	74.0	652	202120	118	23.48
OD1	SET4	9-Jul-91	74	73	75	70	74	73.2	778	241180	125	27.64
OD2	SET1	13-Mar-90	86	90	91	89	90	89.2	32	358400	13	1.09
OD2	SET2	26-Oct-90	80	84	83	82	77	81.2	259	2900800	20	12.5
OD2	SET3	5-Mar-91	80	79	83	83	80	81.0	389	4356800	73	15.25
OD2	SET4	9-Jul-91	72	77	77	75	72	74.6	515	5768000	80	20.84
OD3	SET1	13-Mar-90	63	63	62	64	62	62.8	1523	13339550	253	64.88
OD3	SET2	26-Oct-90	70	60	65	64	60	63.8	1750	15132850	258	77.3
OD3	SET3	5-Mar-91	59	55	54	57	60	57.0	1880	16159850	308	79.18
OD3	SET4	9-Jul-91	49	46	45	44	44	45.6	2006	17155250	313	84.29

Table A.2 British Pendulum Test and related data (cont.)

SEC	SET	TEST DATE	BPN1	BPN2	BPN3	BPN4	BPN5	BPN	AGE	CUTR	CUFT	CUPP
SA1	SET1	21-Feb-90	86	86	84	92	83	86.2	238	528800	53	10.28
SA1	SET2	2-Nov-90	84	80	83	75	84	81.2	372	1113000	57	33.69
SA1	SET3	12-Mar-91	87	81	84	85	87	84.8	622	1412000	93	38.69
SA1	SET4	11-Jul-91	75	75	78	76	72	75.2	743	1690300	97	49.03
SA4	SET2	2-Nov-90	71	74	76	74	75	74.0	546	1107300	55	46.15
SA4	SET3	12-Mar-91	65	64	76	68	68	68.2	676	1373800	97	52.31
SA4	SET4	12-Jul-91	75	69	76	72	69	72.2	797	1621580	103	61.57
SA6	SET1	21-Feb-90	90	93	91	94	92	92.0	248	595200	45	10.32
SA6	SET2	1-Nov-90	79	77	79	79	79	78.6	382	1202400	49	33.15
SA6	SET3	11-Mar-91	80	85	79	79	85	81.6	632	1514400	86	39.12
SA6	SET4	11-Jul-91	75	74	74	75	71	73.8	753	1807200	90	61.95
SA16	SET1	22-Feb-90	98	97	86	92	88	92.2	322	579600	69	13.05
SA16	SET2	1-Nov-90	90	87	88	85	89	87.8	574	1033200	70	31.65
SA16	SET3	11-Mar-91	87	87	81	81	89	85.0	704	1267200	124	36.1
SA16	SET4	11-Jul-91	76	78	75	78	71	75.6	826	1486800	129	40.05
SA17	SET1	22-Feb-90	85	80	82	88	90	85.0	189	245700	58	7.53
SA17	SET2	2-Nov-90	84	84	89	86	86	85.8	441	574600	57	32.75
SA17	SET3	11-Mar-91	90	90	92	90	89	90.2	571	742300	113	36.47
SA17	SET4	11-Jul-91	75	74	80	80	74	76.6	693	900900	117	46.27
SA19	SET1	21-Feb-90	88	90	89	86	88	88.2	226	63000	40	12.59

Table A.2 British Pendulum Test and related data (cont.)

SEC	SET	TEST DATE	BPN1	BPN2	BPN3	BPN4	BPN5	BPN	AGE	CUTR	CUFT	CUPP
SA19	SET2	2-Nov-90	94	86	90	90	91	90.2	478	134120	44	37.36
SA19	SET3	12-Mar-91	86	90	96	96	93	92.2	608	710520	77	45.2
SA19	SET4	11-Jul-91	88	85	88	81	81	84.6	730	204400	80	54.77
SA27	SET1	22-Feb-90	91	85	93	90	90	89.8	524	189905	45	4.37
SA27	SET2	1-Nov-90	80	76	75	72	75	75.6	776	2844050	49	33.17
SA27	SET3	11-Mar-91	80	82	79	78	82	80.2	906	3331550	86	45.2
SA27	SET4	12-Jul-91	71	71	72	74	71	71.8	1028	3789050	90	56
SA30	SET1	21-Feb-90	100	96	94	97	98	97.0	552	159040	45	10.32
SA30	SET2	1-Nov-90	92	92	93	89	94	92.0	476	338670	49	33.15
SA30	SET3	11-Mar-91	90	85	92	90	89	89.2	606	430970	86	39.12
SA30	SET4	11-Jul-91	81	78	80	75	78	78.4	728	517590	90	61.95
A1	SET1	3-Apr-90	88	94	91	89	97	91.8	293	263700	54	13.9
A1	SET2	30-Oct-90	84	84	80	85	90	84.6	503	452700	54	16.71
A1	SET3	4-Mar-91	68	70	69	71	72	70.0	628	565200	92	34.63
A1	SET4	8-Jul-91	70	74	74	73	72	72.6	54	678600	97	38.32
A2	SET1	3-Apr-90	78	80	79	84	81	80.4	272	1333500	54	9.89
A2	SET2	30-Oct-90	69	69	70	66	71	69.0	482	2404500	54	12.7
A2	SET3	4-Mar-91	61	69	68	68	60	65.2	607	3042000	92	30.62
A2	SET4	8-Jul-91	60	60	65	66	63	62.8	733	3684600	97	34.31
A4	SET1	3-Apr-90	74	71	72	69	70	71.2	662	8386250	43	23.49

Table A.2 British Pendulum Test and related data (cont.)

SEC	SET	TEST DATE	BPN1	BPN2	BPN3	BPN4	BPN5	BPN	AGE	CUTR	CUFT	CUPP
A4	SET2	30-Oct-90	49	52	57	54	56	53.6	872	11189750	43	44.32
A4	SET3	4-Mar-91	55	54	55	52	54	54.0	997	12858500	72	53.91
A4	SET4	8-Jul-91	54	51	51	50	50	51.2	1123	14540600	77	64.61
A5	SET1	3-Apr-90	66	69	68	68	69	68.0	600	7648250	43	14.74
A5	SET2	30-Oct-90	55	53	50	53	55	53.2	810	10451750	43	35.57
A5	SET3	4-Mar-91	55	57	54	55	54	55.0	935	12120500	72	45.16
A5	SET4	8-Jul-91	50	50	50	50	49	49.8	1061	13802600	77	55.86
W1	SET1	29-Mar-90	74	80	81	78	78	78.2	685	3131100	57	66.16
W1	SET2	11-Oct-90	82	76	78	81	75	78.4	881	3973900	57	84.31
W1	SET3	18-Mar-91	65	65	66	64	67	65.4	1039	4653300	76	110.75
W1	SET4	17-Jul-91	62	67	64	66	65	64.8	1160	5173600	76	122.69
W2	SET1	5-Apr-90	82	82	85	81	85	83.0	6647	2497400	56	64.63
W2	SET2	11-Oct-90	80	83	81	82	79	81.0	843	3196700	56	81.82
W2	SET3	18-Mar-91	71	72	73	75	73	72.8	1001	3781300	74	103.98
W2	SET4	17-Jul-91	71	75	73	74	75	73.6	1122	4229000	74	111.77
W3	SET1	5-Apr-90	84	83	82	81	80	82.0	647	2092800	56	64.63
W3	SET2	11-Oct-90	85	78	82	80	79	80.8	843	2697600	56	.81.82
W3	SET3	18-Mar-91	77	76	72	73	75	74.6	1001	3203200	74	103.98
W3	SET4	17-Jul-91	73	70	69	69	75	71.2	1122	5390400	74	111.77
W4	SET1	5-Apr-90	78	77	77	76	79	77.4	611	19152000	47	47.93

Table A.2 British Pendulum Test and related data (cont.)

SEC	SET	TEST DATE	BPN1	BPN2	BPN3	BPN4	BPN5	BPN	AGE	CUTR	CUFT	CUPP
W4	SET2	11-Oct-90	74	78	71	71	74	73.6	807	25313400	47	64.36
W4	SET3	18-Mar-91	65	65	60	66	65	64.2	965	30464200	63	82.41
W4	SET4	17-Jul-91	60	59	58	60	58	59.0	1086	34408800	63	92.16
W5	SET1	5-Apr-90	63	61	65	66	65	64.0	597	29830000	47	47.93
W5	SET2	11-Oct-90	71	65	65	63	65	65.8	793	35902000	47	64.36
W5	SET3	18-Mar-91	55	58	55	56	54	55.6	951	43486000	63	82.41
W5	SET4	17-Jul-91	48	48	46	45	46	46.6	1072	49294000	63	92.16
W6	SET1	5-Apr-90	75	75	74	74	75	74.6	685	5200050	47	36.85
W6	SET2	11-Oct-90	74	78	78	74	78	76.4	881	6710160	47	53.28
W6	SET3	18-Mar-91	65	66	65	63	64	64.6	1039	7972580	63	71.33
W6	SET4	17-Jul-91	48	48	46	45	46	46.6	1160	8939370	63	81.08
W7	SET3	18-Mar-91	73	73	74	75	73	73.6	865	3465800	76	95.79
W7	SET4	17-Jul-91	82	84	80	84	80	82.0	986	3949800	76	107.73
AUS1	SET2	7-Aug-90	110	108	101	110	107	107.2	6	3780	0	0
AUS1	SET3	26-Mar-91	81	75	76	74	79	77.0	237	149310	20	20.22
AUS1	SET4	24-Jul-91	70	69	69	68	69	69.0	356	224280	20	35.14
AUS2	SET2	7-Aug-90	80	87	86	88	86	85.4	8	101600	0	0
AUS2	SET3	26-Mar-91	82	83	84	82	82	82.6	239	3035300	8	16.98
AUS2	SET4	24-Jul-91	80	84	83	86	81	82.8	358	4546600	8	28.44
AUS3	SET2	8-Aug-90	77	84	79	84	73	79.4	12	642000	0	0

Table A.2 British Pendulum Test and related data (cont.)

SEC	SET	TEST DATE	BPN1	BPN2	BPN3	BPN4	BPN5	BPN	AGE	CUTR	CUFT	CUPP
AUS3	SET3	26-Mar-91	68	72	70	65	69	68.8	243	13000500	8	16.98
AUS3	SET4	24-Jul-91	62	65	60	64	60	62.2	362	19367000	8	28.44
AUS4	SET3	26-Mar-91	83	81	85	85	85	83.8	664	31208000	23	45.13
AUS4	SET4	24-Jul-91	80	84	87	85	91	85.4	783	36801000	23	56.59
C1	SET1	20-Mar-90	90	85	83	82	85	85.0	2210	24513200	14	172.61
C1	SET2	15-Nov-90	76	68	71	70	70	71.0	2450	27585200	14	192.44
C1	SET3	14-Mar-91	84	82	82	74	77	79.8	2569	29108400	36	195.97
C2	SET1	20-Mar-90	95	97	94	91	91	93.6	2149	2466310	14	172.06
C2	SET2	15-Nov-90	82	90	81	83	85	84.2	2389	2763910	14	191.89
C2	SET3	14-Mar-91	90	87	89	85	93	88.8	2508	2911470	36	195.42
C3	SET1	20-Mar-90	71	72	73	75	72	72.6	504	4833850	15	38.19
C3	SET2	16-Nov-90	60	59	59	59	60	59.4	745	7280000	15	51.52
C3	SET3	14-Mar-91	71	75	69	70	66	70.2	863	8477700	20	56.32
C3	SET4	15-Jul-91	52	55	55	53	54	53.8	986	9726150	20	64.84
C4	SET2	15-Nov-90	93	80	81	80	83	83.4	1111	642000	0	4.15
C4	SET3	14-Mar-91	85	86	90	75	84	84.0	1229	1403840	8	10.96
C4	SET4	15-Jul-91	73	78	75	73	74	74.6	1352	2456720	8	19.48
C5	SET2	15-Nov-90	90	87	85	90	85	87.4	7	34020	0	0
C5	SET3	14-Mar-91	87	86	93	93	93	90.4	126	612360	4	3.53
C5	SET4	15-Jul-91	91	91	88	87	90	89.4	249	1210140	4	10.59

Table A.3 **Sand patch test and related data**

SET	SET	TEST DATE	SP1	SP2	SP3	SP4	SP5	SP	SPTD	SMTD	M1 DP	M1 BLD	M2 DP	M2 BLD
L1	SET1	14-Mar-90	5.00	5.50	6.00	5.50	5.75	5.55	1.574	1.022	0	0	0	0
L1	SET2	24-Oct-90	4.85	5.05	5.15	5.35	5.15	5.11	1.857	1.076	7	5	19	2
L1	SET3	6-Mar-91	6.00	5.50	5.88	6.00	5.75	5.83	1.429	0.962	7	5	19	2
L1	SET4	10-Jul-91	5.12	5.00	6.00	6.00	7.00	5.83	1.429	0.964	8	5	19	2
L2	SET1	14-Mar-90	9.00	9.40	9.50	9.25	10.00	9.43	0.545	0.256	0	0	0	0
L2	SET2	24-Oct-90	9.50	9.40	9.30	9.85	10.40	9.69	0.516	0.300	8	0	15	0
L2	SET3	6-Mar-91	10.62	10.62	10.50	10.75	10.50	10.60	0.432	0.254	10	0	8	0
L2	SET4	9-Jul-91	9.88	9.50	9.25	9.75	10.00	9.68	0.518	0.284	11	0	8	0
L3	SET1	15-Mar-90	8.50	9.00	8.00	8.75	8.50	8.55	0.663	0.260	0	0	0	0
L3	SET2	24-Oct-90	8.40	8.35	8.15	8.40	8.70	8.40	0.687	0.320	7	0	15	0
L3	SET3	6-Mar-91	9.00	9.38	9.00	8.88	8.50	8.95	0.605	0.294	8	0	8	0
L3	SET4	9-Jul-91	10.00	8.62	8.62	9.00	9.00	9.05	0.592	0.312	8	0	8	0
L4	SET1	15-Mar-90	10.50	8.75	10.25	10.00	10.00	9.90	0.495	0.318	0	0	0	0
L4	SET2	24-Oct-90	9.20	9.15	9.70	9.00	9.65	9.34	0.556	0.380	0	0	0	0
L4	SET3	6-Mar-91	10.62	9.75	10.00	9.00	10.00	9.88	0.497	0.372	0	0	0	0
L4	SET4	9-Jul-91	7.00	8.00	7.75	7.50	7.00	7.45	0.874	0.552	0	0	0	0
L5	SET1	15-Mar-90	5.50	5.25	5.50	5.75	5.50	5.50	1.603	0.724	0	0	0	0
L5	SET2	25-Oct-90	6.90	6.70	6.45	6.10	6.25	6.48	1.155	0.774	4	4	0	0
L5	SET3	6-Mar-91	8.75	8.06	8.00	8.94	8.12	8.38	0.691	0.590	4	4	0	0
L5	SET4	10-Jul-91	6.88	6.50	6.25	7.50	6.50	6.72	1.072	0.696	6	6	2	2

Table A.3 Sand patch test and related data (cont.)

SET	SET	TEST DATE	SP1	SP2	SP3	SP4	SP5	SP	SPTD	SMTD	M1 DP	M1 BLD	M2 DP	M2 BLD
L6	SET1	15-Mar-90	8.25	9.00	11.00	10.50	10.00	9.75	0.510	0.264	0	0	0	0
L6	SET2	25-Oct-90	7.45	8.60	8.50	8.10	9.15	8.36	0.694	0.274	0	0	0	0
L6	SET3	6-Mar-91	7.12	9.00	9.00	9.12	9.00	8.65	0.648	0.278	0	0	0	0
L6	SET4	10-Jul-91	8.75	9.00	8.88	9.00	9.00	8.93	0.609	0.328	0	0	0	0
L7	SET3	7-Mar-91	7.75	7.62	7.88	7.12	7.75	7.62	0.834	0.520	10	0	17	0
L7	SET4	10-Jul-91	7.12	7.00	7.38	7.75	7.62	7.38	0.892	0.492	11	0	27	0
L8	SET3	7-Mar-91	7.12	6.75	6.12	6.88	6.75	6.72	1.072	0.608	6	0	13	0
L8	SET4	10-Jul-91	7.00	6.88	6.75	7.62	7.00	7.05	0.976	0.482	18	0	18	0
OD1	SET1	13-Mar-90	10.00	10.50	9.50	9.75	9.95	9.94	0.491	0.320	0	0	0	0
OD1	SET2	26-Oct-90	10.85	10.75	10.25	9.65	9.25	10.15	0.471	0.296	0	0	0	0
OD1	SET3	5-Mar-91	12.75	10.50	10.62	10.12	9.50	10.70	0.424	0.266	1	0	5	0
OD1	SET4	9-Jul-91	11.00	10.00	10.50	9.00	9.50	10.00	0.485	0.250	1	0	5	0
OD2	SET1	13-Mar-90	12.00	10.00	9.00	10.50	9.00	10.10	0.475	0.364	0	0	0	0
OD2	SET2	26-Oct-90	10.45	8.55	8.75	8.95	9.55	9.25	0.567	0.318	0	0	0	0
OD2	SET3	5-Mar-91	10.88	11.00	10.75	10.62	10.75	10.80	0.416	0.288	0	0	0	0
OD2	SET4	9-Jul-91	10.75	9.50	9.50	9.50	9.50	9.75	0.510	0.316	0	0	0	0
OD3	SET1	13-Mar-90	9.25	9.00	9.75	8.75	9.25	9.20	0.573	0.294	0	0	0	0
OD3	SET2	26-Oct-90	9.15	9.40	9.30	8.80	9.25	9.18	0.575	0.376	7	0	17	0
OD3	SET3	5-Mar-91	10.00	9.62	10.88	10.62	10.12	10.25	0.462	0.360	10	0	17	0
OD3	SET4	9-Jul-91	9.00	9.25	9.75	9.00	10.00	9.40	0.549	0.338	21	0	27	0

Table A.3 Sand patch test and related data (cont.)

SET	SET	TEST DATE	SP1	SP2	SP3	SP4	SP5	SP	SPTD	SMTD	M1	M1	M2	M2
											DP	BLD	DP	BLD
SA1	SET1	21-Feb-90	5.25	4.90	4.20	4.40	5.10	4.77	2.131	0.962	0	0	0	0
SA1	SET2	2-Nov-90	4.25	5.10	4.95	4.95	4.95	4.84	2.070	1.036	0	0	0	0
SA1	SET3	12-Mar-91	6.00	6.00	5.88	5.88	6.00	5.95	1.370	0.794	3	3	3	3
SA1	SET4	11-Jul-91	6.00	6.88	6.50	5.50	5.50	6.08	1.314	0.756	5	5	5	2
SA4	SET2	2-Nov-90	7.10	5.20	5.75	7.50	6.25	6.36	1.199	0.902	5	5	2	2
SA4	SET3	12-Mar-91	7.75	8.75	7.12	8.88	8.88	8.28	0.708	0.472	17	17	7	7
SA4	SET4	12-Jul-91	8.00	8.00	6.00	11.00	9.50	8.50	0.671	0.530	20	20	7	7
SA6	SET1	21-Feb-90	4.50	4.75	5.00	4.75	4.50	4.70	2.195	1.160	0	0	0	0
SA6	SET2	1-Nov-90	4.50	4.75	4.75	5.90	4.75	4.93	1.995	1.166	0	0	0	0
SA6	SET3	11-Mar-91	5.88	5.12	5.00	5.00	5.00	5.20	1.793	0.992	0	0	0	0
SA6	SET4	11-Jul-91	5.50	5.00	5.50	7.00	5.50	5.70	1.492	1.036	2	2	0	0
SA16	SET1	22-Feb-90	4.50	4.50	5.00	5.25	5.50	4.95	1.979	1.006	0	0	0	0
SA16	SET2	1-Nov-90	3.80	4.40	4.55	4.85	4.40	4.40	2.505	1.150	2	2	0	0
SA16	SET3	11-Mar-91	5.62	5.50	6.00	5.75	5.62	5.70	1.492	0.900	2	2	0	0
SA16	SET4	11-Jul-91	5.50	6.00	7.00	6.00	6.00	6.10	1.303	0.946	3	3	0	0
SA17	SET1	22-Feb-90	4.10	4.20	4.30	4.20	4.20	4.20	2.749	1.186	0	0	0	0
SA17	SET2	2-Nov-90	4.45	4.40	4.55	4.50	4.80	4.54	2.353	1.150	0	0	0	0
SA17	SET3	11-Mar-91	4.50	5.00	5.00	5.00	5.12	4.92	1.999	1.008	0	0	0	0
SA17	SET4	11-Jul-91	5.00	5.00	5.00	5.00	5.00	5.00	1.940	1.030	0	0	0	0
SA19	SET1	21-Feb-90	5.75	5.25	5.15	5.80	5.70	5.53	1.586	0.968	0	0	0	0

Table A.3 Sand patch test and related data (cont.)

SET	SET	TEST DATE	SP1	SP2	SP3	SP4	SP5	SP	SPTD	SMTD	M1 DP	M1 BLD	M2 DP	M2 BLD
SA19	SET2	2-Nov-90	4.70	4.15	4.70	5.00	4.35	4.58	2.312	1.302	0	0	0	0
SA19	SET3	12-Mar-91	5.00	5.12	5.12	5.50	5.00	5.15	1.828	1.154	0	0	0	0
SA19	SET4	11-Jul-91	4.00	4.75	4.50	5.00	4.88	4.62	2.267	1.146	0	0	0	0
SA27	SET1	22-Feb-90	9.00	10.00	9.00	9.25	8.00	9.05	0.592	0.266	0	0	0	0
SA27	SET2	1-Nov-90	9.00	8.35	9.70	8.40	8.10	8.71	0.639	0.358	0	0	0	0
SA27	SET3	11-Mar-91	10.00	10.00	9.75	9.75	8.00	9.50	0.537	0.292	0	0	0	0
SA27	SET4	12-Jul-91	9.00	9.50	9.00	9.00	8.75	9.05	0.592	0.282	0	0	0	0
SA30	SET1	21-Feb-90	4.10	4.25	4.50	4.10	4.30	4.25	2.685	1.128	0	0	0	0
SA30	SET2	1-Nov-90	4.80	5.05	4.80	4.95	4.60	4.84	2.070	1.100	0	0	0	0
SA30	SET3	11-Mar-91	4.62	4.62	4.62	4.62	5.38	4.78	2.127	1.072	0	0	0	0
SA30	SET4	11-Jul-91	5.00	5.00	5.00	5.75	5.00	5.15	1.828	0.990	0	0	0	0
A1	SET1	3-Apr-90	4.30	4.25	4.10	5.25	5.25	4.63	2.262	1.180	0	0	0	0
A1	SET2	30-Oct-90	5.10	5.15	4.95	5.15	4.90	5.05	1.901	1.076	11	11	5	5
A1	SET3	4-Mar-91	5.50	4.75	5.75	4.94	5.50	5.29	1.734	1.092	11	11	5	5
A1	SET4	8-Jul-91	7.00	7.50	6.75	5.88	6.00	6.62	1.105	0.940	13	13	5	5
A2	SET1	3-Apr-90	9.75	11.50	10.25	9.75	10.25	10.30	0.457	0.316	0	0	0	0
A2	SET2	30-Oct-90	10.20	10.82	9.25	10.75	9.75	10.15	0.470	0.228	0	0	10	0
A2	SET3	4-Mar-91	11.50	12.00	11.00	11.25	10.75	11.30	0.380	0.208	0	0	8	0
A2	SET4	8-Jul-91	11.00	11.00	10.50	10.00	10.00	10.50	0.440	0.222	6	0	22	0
A4	SET1	3-Apr-90	9.25	9.75	9.75	9.50	10.00	9.65	0.521	0.288	0	0	0	0

Table A.3 Sand patch test and related data (cont.)

SET	SET	TEST DATE	SP1	SP2	SP3	SP4	SP5	SP	SPTD	SMTD	M1 DP	M1 BLD	M2 DP	M2 BLD
A4	SET2	30-Oct-90	8.40	9.10	9.60	9.25	10.00	9.27	0.564	0.260	0	0	0	0
A4	SET3	4-Mar-91	11.30	10.50	10.50	10.50	10.75	10.71	0.423	0.260	0	0	8	0
A4	SET4	8-Jul-91	11.00	11.12	10.50	10.12	10.00	10.55	0.436	0.242	1	0	12	0
A5	SET1	3-Apr-90	9.50	9.50	10.20	10.25	9.75	9.84	0.501	0.282	0	0	0	0
A5	SET2	30-Oct-90	9.15	9.90	10.75	10.30	10.40	10.10	0.475	0.246	0	0	0	0
A5	SET3	4-Mar-91	10.75	11.12	11.12	10.75	10.75	10.90	0.408	0.258	0	0	8	0
A5	SET4	8-Jul-91	10.06	10.75	11.50	11.00	10.75	10.81	0.415	0.236	2	0	12	0
W1	SET1	29-Mar-90	10.25	10.25	10.30	9.75	10.00	10.11	0.474	0.246	0	0	0	0
W1	SET2	11-Oct-90	13.75	8.85	9.05	9.20	9.70	10.11	0.474	0.270	0	0	0	0
W1	SET3	18-Mar-91	12.00	11.50	11.25	12.00	12.00	11.75	0.351	0.222	0	0	0	0
W1	SET4	17-Jul-91	10.00	10.00	10.00	10.00	10.00	10.00	0.485	0.250	0	0	0	0
W2	SET1	5-Apr-90	10.00	10.00	10.25	10.00	10.00	10.05	0.480	0.224	0	0	0	0
W2	SET2	11-Oct-90	11.00	11.50	10.00	9.50	9.75	10.35	0.453	0.268	0	0	0	0
W2	SET3	18-Mar-91	10.00	10.75	10.62	10.00	10.00	10.28	0.459	0.282	0	0	0	0
W2	SET4	17-Jul-91								0.270	0	0	0	0
W3	SET1	5-Apr-90	10.00	9.50	10.25	10.25	11.00	10.20	0.466	0.244	0	0	0	0
W3	SET2	11-Oct-90	8.80	9.15	9.75	11.50	10.25	9.89	0.496	0.284	0	0	0	0
W3	SET3	18-Mar-91	10.75	10.62	10.88	11.00	11.00	10.85	0.412	0.244	0	0	0	0
W3	SET4	17-Jul-91								0.262	0	0	0	0
W4	SET1	5-Apr-90	10.25	11.25	10.25	11.50	12.50	11.15	0.390	0.204	0	0	0	0

Table A.3 Sand patch test and related data (cont.)

SET	SET	TEST DATE	SP1	SP2	SP3	SP4	SP5	SP	SPTD	SMTD	M1 DP	M1 BLD	M2 DP	M2 BLD
W4	SET2	11-Oct-90	11.00	10.50	10.50	11.00	12.00	11.00	0.401	0.196	0	0	0	0
W4	SET3	18-Mar-91	11.50	12.12	13.00	12.00	12.62	12.25	0.323	0.256	0	0	0	0
W4	SET4	17-Jul-91								0.178	2	0	13	0
W5	SET1	5-Apr-90	10.75	10.00	11.00	11.00	11.00	10.75	0.420	0.220	0	0	0	0
W5	SET2	11-Oct-90	10.25	10.50	10.50	10.00	10.50	10.35	0.453	0.282	0	0	0	0
W5	SET3	18-Mar-91	12.00	11.25	10.88	10.88	11.00	11.20	0.387	0.244	0	0	0	0
W5	SET4	17-Jul-91								0.212	0	0	0	0
W6	SET1	5-Apr-90	10.50	9.75	9.75	9.75	10.25	10.00	0.485	0.248	0	0	0	0
W6	SET2	11-Oct-90	9.00	10.50	10.00	9.00	10.00	9.70	0.515	0.290	0	0	0	0
W6	SET3	18-Mar-91	12.00	12.00	11.00	10.00	11.00	11.20	0.387	0.242	0	0	0	0
W6	SET4	17-Jul-91								0.236	0	0	0	0
W7	SET3	18-Mar-91	7.00	7.00	8.25	7.75	8.00	7.60	0.840	0.542	34	0	45	0
W7	SET4	17-Jul-91	7.00	7.00	7.00	7.50	7.00	7.10	0.962	0.540	36	0	30	0
AUS1	SET2	7-Aug-90	3.70	3.60	3.60	3.40	3.30	3.52	3.914	1.682	0	0	0	0
AUS1	SET3	26-Mar-91	4.75	4.38	4.50	4.12	4.00	4.35	2.563	1.328	5	0	5	0
AUS1	SET4	24-Jul-91	5.00	5.12	5.00	5.00	4.88	5.00	1.940	1.150	9	0	5	0
AUS2	SET2	7-Aug-90	10.00	8.00	9.00	8.50	8.50	8.80	0.626	0.296	0	0	0	0
AUS2	SET3	26-Mar-91	12.00	10.00	9.50	9.75	10.75	10.40	0.448	0.272	0	0	0	0
AUS2	SET4	24-Jul-91	9.25	9.50	9.00	9.00	8.75	9.10	0.586	0.316	0	0	0	0
AUS3	SET2	8-Aug-90	8.80	8.25	9.00	8.25	8.50	8.56	0.662	0.280	0	0	0	0

Table A.3 Sand patch test and related data (cont.)

SET	SET	TEST DATE	SP1	SP2	SP3	SP4	SP5	SP	SPTD	SMTD	M1 DP	M1 BLD	M2 DP	M2 BLD
AUS3	SET3	26-Mar-91	9.50	9.50	9.50	9.50	10.25	9.65	0.521	0.262	0	0	0	0
AUS3	SET4	24-Jul-91	10.00	10.00	10.50	9.88	10.00	10.07	0.478	0.240	0	0	0	0
AUS4	SET3	26-Mar-91	7.50	9.00	8.00	9.00	7.50	8.20	0.721	0.558	0	0	0	0
AUS4	SET4	24-Jul-91	8.00	8.00	8.00	8.00	8.00	8.00	0.758	0.612	0	0	5	0
C1	SET1	20-Mar-90	10.25	10.50	10.75	11.00	10.75	10.65	0.428	0.216	0	0	0	0
C1	SET2	15-Nov-90	10.15	10.30	11.30	11.35	11.05	10.83	0.413	0.256	2	0	17	0
C1	SET3	14-Mar-91	8.88	10.12	10.62	10.88	11.00	10.30	0.457	0.358	15	0	22	0
C2	SET1	20-Mar-90	4.75	4.80	5.50	4.50	4.50	4.81	2.096	1.382	0	0	0	0
C2	SET2	15-Nov-90	6.70	7.05	4.95	5.25	4.50	5.69	1.498	0.700	5	5	2	2
C2	SET3	14-Mar-91	5.88	5.88	5.25	6.75	5.12	5.78	1.454	0.988	6	6	2	2
C3	SET1	20-Mar-90	11.50	10.50	12.00	12.00	12.00	11.60	0.360	0.210	0	0	0	0
C3	SET2	16-Nov-90	11.45	11.50	13.40	13.30	11.75	12.28	0.322	0.240	0	0	0	0
C3	SET3	14-Mar-91	12.00	12.00	12.50	12.00	12.00	12.10	0.331	0.202	0	0	0	0
C3	SET4	15-Jul-91	12.00	12.00	12.00	12.00	12.00	12.00	0.337	0.276	0	0	0	0
C4.	SET2	15-Nov-90	5.75	4.70	5.20	5.30	5.20	5.23	1.773	1.088	0	0	0	0
C4	SET3	14-Mar-91	7.00	7.25	7.00	6.75	7.00	7.00	0.990	0.708	7	7	2	2
C4	SET4	15-Jul-91	8.50	8.00	8.00	7.50	7.75	7.95	0.767	0.564	30	30	10	10
C5	SET2	15-Nov-90	6.05	6.20	7.20	7.55	6.95	6.79	1.052	0.564	0	0	0	0
C5	SET3	14-Mar-91	9.00	8.62	9.12	8.00	7.62	8.47	0.675	0.482	8	0	27	0
C5	SET4	15-Jul-91	7.50	8.00	8.50	8.00	8.50	8.10	0.739	0.346	10	0	27	0

Table A.4 Sensor measured texture depth and related data

SEC	SET	TESTDATE	SMTD1	SMTD2	SMTD3	SMTD4	SMTD5	SMTD	SPTD
L1	SET1	14-Mar-90	1.130	1.200	1.000	0.830	0.950	1.022	1.574
L1	SET2	24-Oct-90	1.190	1.020	0.980	1.070	1.120	1.076	1.857
L1	SET3	6-Mar-91	0.940	1.080	1.060	0.950	0.780	0.962	1.429
L1	SET4	10-Jul-91	1.070	1.040	0.850	0.900	0.960	0.964	1.429
L2	SET1	14-Mar-90	0.180	0.280	0.240	0.250	0.330	0.256	0.545
L2	SET2	24-Oct-90	0.240	0.260	0.260	0.370	0.370	0.300	0.516
L2	SET3	6-Mar-91	0.230	0.280	0.250	0.260	0.250	0.254	0.432
L2	SET4	9-Jul-91	0.400	0.260	0.240	0.260	0.260	0.284	0.518
L3	SET1	15-Mar-90	0.150	0.260	0.250	0.360	0.280	0.260	0.663
L3	SET2	24-Oct-90	0.250	0.300	0.450	0.330	0.270	0.320	0.687
L3	SET3	6-Mar-91	0.270	0.260	0.300	0.360	0.280	0.294	0.605
L3	SET4	9-Jul-91	0.360	0.310	0.300	0.340	0.250	0.312	0.592
L4	SET1	15-Mar-90	0.370	0.300	0.290	0.320	0.310	0.318	0.495
L4	SET2	24-Oct-90	0.350	0.430	0.370	0.410	0.340	0.380	0.556
L4	SET3	6-Mar-91	0.360	0.380	0.320	0.450	0.350	0.372	0.497
L4	SET4	9-Jul-91	0.590	0.540	0.570	0.530	0.530	0.552	0.874
L5	SET1	15-Mar-90	0.740	0.810	0.680	0.600	0.790	0.724	1.603
L5	SET2	25-Oct-90	0.790	0.810	0.890	0.700	0.680	0.774	1.155
L5	SET3	6-Mar-91	0.520	0.570	0.650	0.500	0.710	0.590	0.691
L5	SET4	10-Jul-91	0.640	0.650	0.600	0.680	0.910	0.696	1.072

Table A.4 Sensor measured texture depth and related data (cont.)

SEC	SET	TESTDATE	SMTD1	SMTD2	SMTD3	SMTD4	SMTD5	SMTD	SPTD
L6	SET1	15-Mar-90	0.190	0.230	0.300	0.270	0.330	0.264	0.510
L6	SET2	25-Oct-90	0.320	0.230	0.240	0.300	0.280	0.274	0.694
L6	SET3	6-Mar-91	0.280	0.270	0.280	0.280	0.280	0.278	0.648
L6	SET4	10-Jul-91	0.330	0.360	0.290	0.310	0.350	0.328	0.609
L7	SET3	7-Mar-91	0.490	0.570	0.530	0.540	0.470	0.520	0.834
L7	SET4	10-Jul-91	0.520	0.490	0.510	0.480	0.460	0.492	0.892
L8	SET3	7-Mar-91	0.640	0.580	0.650	0.590	0.580	0.608	1.072
L8	SET4	10-Jul-91	0.510	0.470	0.480	0.480	0.470	0.482	0.976
OD1	SET1	13-Mar-90	0.280	0.300	0.310	0.380	0.330	0.320	0.491
OD1	SET2	26-Oct-90	0.360	0.260	0.270	0.300	0.290	0.296	0.471
OD1	SET3	5-Mar-91	0.250	0.250	0.250	0.260	0.320	0.266	0.424
OD1	SET4	9-Jul-91	0.220	0.200	0.260	0.310	0.260	0.250	0.485
OD2	SET1	13-Mar-90	0.320	0.360	0.340	0.400	0.400	0.364	0.475
OD2	SET2	26-Oct-90	0.230	0.390	0.320	0.370	0.280	0.318	0.567
OD2	SET3	5-Mar-91	0.240	0.240	0.310	0.280	0.370	0.288	0.416
OD2	SET4	9-Jul-91	0.220	0.360	0.280	0.340	0.380	0.316	0.510
OD3	SET1	13-Mar-90	0.340	0.250	0.260	0.310	0.310	0.294	0.573
OD3	SET2	26-Oct-90	0.460	0.280	0.310	0.300	0.530	0.376	0.575
OD3	SET3	5-Mar-91	0.410	0.390	0.320	0.320	0.360	0.360	0.462
OD3	SET4	9-Jul-91	0.460	0.270	0.260	0.310	0.390	0.338	0.549

Table A.4 Sensor measured texture depth and related data (cont.)

SEC	SET	TESTDATE	SMTD1	SMTD2	SMTD3	SMTD4	SMTD5	SMTD	SPTD
SA1	SET1	21-Feb-90	0.870	0.880	1.050	1.060	0.950	0.962	2.131
SA1	SET2	2-Nov-90	0.990	1.160	1.010	0.960	1.060	1.036	2.070
SA1	SET3	12-Mar-91	0.680	0.730	0.970	0.740	0.850	0.794	1.370
SA1	SET4	11-Jul-91	0.890	0.780	0.620	0.830	0.660	0.756	1.314
SA4	SET2	2-Nov-90	0.740	1.140	0.840	0.860	0.930	0.902	1.199
SA4	SET3	12-Mar-91	0.500	0.500	0.430	0.500	0.430	0.472	0.708
SA4	SET4	12-Jul-91	0.590	0.470	0.620	0.440	0.530	0.530	0.671
SA6	SET1	21-Feb-90	0.990	1.270	1.170	1.250	1.120	1.160	2.195
SA6	SET2	1-Nov-90	1.090	1.220	1.100	1.130	1.290	1.166	1.995
SA6	SET3	11-Mar-91	1.020	1.050	1.030	0.900	0.960	0.992	1.793
SA6	SET4	11-Jul-91	1.150	1.100	0.980	0.980	0.970	1.036	1.492
SA16	SET1	22-Feb-90	1.080	1.210	0.950	0.750	1.040	1.006	1.979
SA16	SET2	1-Nov-90	1.110	1.340	0.880	1.240	1.180	1.150	2.505
SA16	SET3	11-Mar-91	0.940	0.900	0.770	0.930	0.960	0.900	1.492
SA16	SET4	11-Jul-91	0.950	0.710	1.020	1.030	1.020	0.946	1.303
SA17	SET1	22-Feb-90	1.220	1.360	1.130	1.020	1.200	1.186	2.749
SA17	SET2	2-Nov-90	1.110	1.350	1.070	1.100	1.120	1.150	2.353
SA17	SET3	11-Mar-91	1.130	1.080	1.040	0.910	0.880	1.008	1.999
SA17	SET4	11-Jul-91	0.990	1.200	1.030	0.930	1.000	1.030	1.940
SA19	SET1	21-Feb-90	1.020	1.070	0.920	0.800	1.030	0.968	1.586

Table A.4 Sensor measured texture depth and related data (cont.)

SEC	SET	TESTDATE	SMTD1	SMTD2	SMTD3	SMTD4	SMTD5	SMTD	SPTD
SA19	SET2	2-Nov-90	1.410	1.480	1.130	1.250	1.240	1.302	2.312
SA19	SET3	12-Mar-91	1.240	1.220	0.950	1.150	1.210	1.154	1.828
SA19	SET4	11-Jul-91	1.300	1.280	0.920	1.010	1.220	1.146	2.267
SA27	SET1	22-Feb-90	0.310	0.220	0.250	0.300	0.250	0.266	0.592
SA27	SET2	1-Nov-90	0.350	0.400	0.300	0.360	0.380	0.358	0.639
SA27	SET3	11-Mar-91	0.290	0.280	0.330	0.360	0.200	0.292	0.537
SA27	SET4	12-Jul-91	0.260	0.230	0.290	0.290	0.340	0.282	0.592
SA30	SET1	21-Feb-90	1.240	1.040	0.980	1.150	1.230	1.128	2.685
SA30	SET2	1-Nov-90	1.100	1.000	1.050	1.100	1.250	1.100	2.070
SA30	SET3	11-Mar-91	1.070	1.020	1.130	1.100	1.040	1.072	2.127
SA30	SET4	11-Jul-91	1.080	0.870	1.030	0.960	1.010	0.990	1.828
A1	SET1	3-Apr-90	1.050	1.190	1.270	1.170	1.220	1.180	2.262
A1	SET2	30-Oct-90	1.040	0.920	1.120	1.150	1.150	1.076	1.901
A1	SET3	4-Mar-91	1.250	0.960	1.170	1.140	0.940	1.092	1.734
A1	SET4	8-Jul-91	1.100	0.650	1.040	1.040	0.870	0.940	1.105
A2	SET1	3-Apr-90	0.290	0.300	0.310	0.260	0.420	0.316	0.457
A2	SET2	30-Oct-90	0.270	0.180	0.230	0.230	0.230	0.228	0.470
A2	SET3	4-Mar-91	0.220	0.220	0.160	0.240	0.200	0.208	0.380
A2	SET4	8-Jul-91	0.270	0.180	0.260	0.180	0.220	0.222	0.410
A4	SET1	3-Apr-90	0.350	0.270	0.260	0.350	0.210	0.288	0.521

Table A.4 Sensor measured texture depth and related data (cont.)

SEC	SET	TESTDATE	SMTD1	SMTD2	SMTD3	SMTD4	SMTD5	SMTD	SPTD
A4	SET2	30-Oct-90	0.290	0.300	0.200	0.250	0.260	0.260	0.564
A4	SET3	4-Mar-91	0.280	0.210	0.290	0.270	0.250	0.260	0.423
A4	SET4	8-Jul-91	0.270	0.240	0.190	0.240	0.270	0.242	0.436
A5	SET1	3-Apr-90	0.390	0.310	0.220	0.250	0.240	0.282	0.501
A5	SET2	30-Oct-90	0.300	0.230	0.210	0.230	0.260	0.246	0.475
A5	SET3	4-Mar-91	0.230	0.230	0.370	0.220	0.240	0.258	0.408
A5	SET4	8-Jul-91	0.240	0.250	0.220	0.230	0.240	0.236	0.415
W1	SET1	29-Mar-90	0.210	0.270	0.260	0.290	0.200	0.246	0.474
W1	SET2	11-Oct-90	0.290	0.280	0.250	0.280	0.250	0.270	0.474
W1	SET3	18-Mar-91	0.250	0.240	0.270	0.160	0.190	0.222	0.351
W1	SET4	17-Jul-91	0.290	0.240	0.220	0.250	0.250	0.250	0.485
W2	SET1	5-Apr-90	0.240	0.220	0.220	0.160	0.280	0.224	0.480
W2	SET2	11-Oct-90	0.260	0.280	0.220	0.310	0.270	0.268	0.453
W2	SET3	18-Mar-91	0.290	0.290	0.290	0.260	0.280	0.282	0.459
W2	SET4	17-Jul-91	0.270	0.310	0.230	0.270	0.270	0.270	
W3	SET1	5-Apr-90	0.300	0.270	0.250	0.250	0.150	0.244	0.466
W3	SET2	11-Oct-90	0.240	0.200	0.340	0.400	0.240	0.284	0.496
W3	SET3	18-Mar-91	0.260	0.260	0.240	0.210	0.250	0.244	0.412
W3	SET4	17-Jul-91	0.220	0.260	0.270	0.300	0.260	0.262	
W4	SET1	5-Apr-90	0.220	0.220	0.360	0.160	0.060	0.204	0.390

Table A.4 Sensor measured texture depth and related data (cont.)

SEC	SET	TESTDATE	SMTD1	SMTD2	SMTD3	SMTD4	SMTD5	SMTD	SPTD
W4	SET2	11-Oct-90	0.230	0.220	0.190	0.200	0.140	0.196	0.401
W4	SET3	18-Mar-91	0.290	0.290	0.270	0.220	0.210	0.256	0.323
W4	SET4	17-Jul-91	0.150	0.180	0.170	0.210	0.180	0.178	
W5	SET1	5-Apr-90	0.190	0.300	0.220	0.210	0.180	0.220	0.420
W5	SET2	11-Oct-90	0.340	0.220	0.260	0.330	0.260	0.282	0.453
W5	SET3	18-Mar-91	0.240	0.240	0.230	0.260	0.250	0.244	0.387
W5	SET4	17-Jul-91	0.190	0.220	0.240	0.200	0.210	0.212	
W6	SET1	5-Apr-90	0.250	0.280	0.210	0.220	0.280	0.248	0.485
W6	SET2	11-Oct-90	0.310	0.280	0.350	0.260	0.250	0.290	0.515
W6	SET3	18-Mar-91	0.260	0.260	0.230	0.240	0.220	0.242	0.387
W6	SET4	17-Jul-91	0.270	0.230	0.190	0.250	0.240	0.236	
W7	SET3	18-Mar-91	0.610	0.610	0.560	0.430	0.500	0.542	0.840
W7	SET4	17-Jul-91	0.580	0.550	0.500	0.530	0.540	0.540	0.962
AUS1	SET2	7-Aug-90	1.590	1.590	1.680	1.740	1.810	1.682	3.914
AUS1	SET3	26-Mar-91	1.200	1.200	1.410	1.310	1.520	1.328	2.563
AUS1	SET4	24-Jul-91	1.060	1.090	1.180	1.270	1.150	1.150	1.940
AUS2	SET2	7-Aug-90	0.290	0.320	0.290	0.310	0.270	0.296	0.626
AUS2	SET3	26-Mar-91	0.250	0.280	0.270	0.290	0.270	0.272	0.448
AUS2	SET4	24-Jul-91	0.340	0.340	0.310	0.280	0.310	0.316	0.586
AUS3	SET2	8-Aug-90	0.270	0.370	0.190	0.310	0.260	0.280	0.662

Table A.4 Sensor measured texture depth and related data (cont.)

SEC	SET	TESTDATE	SMTD1	SMTD2	SMTD3	SMTD4	SMTD5	SMTD	SPTD
AUS3	SET3	26-Mar-91	0.290	0.250	0.260	0.230	0.280	0.262	0.521
AUS3	SET4	24-Jul-91	0.310	0.260	0.180	0.260	0.190	0.240	0.478
AUS4	SET3	26-Mar-91	0.600	0.350	0.540	0.610	0.690	0.558	0.721
AUS4	SET4	24-Jul-91	0.620	0.590	0.570	0.550	0.730	0.612	0.758
C1	SET1	20-Mar-90	0.210	0.260	0.240	0.190	0.180	0.216	0.428
C1	SET2	15-Nov-90	0.240	0.230	0.360	0.180	0.270	0.256	0.413
C1	SET3	14-Mar-91	0.300	0.300	0.440	0.370	0.380	0.358	0.457
C2	SET1	20-Mar-90	1.100	1.190	1.390	1.630	1.600	1.382	2.096
C2	SET2	15-Nov-90	0.650	0.690	0.960	0.630	0.570	0.700	1.498
C2	SET3	14-Mar-91	0.920	0.920	0.990	1.040	1.070	0.988	1.454
C3	SET1	20-Mar-90	0.200	0.290	0.200	0.230	0.130	0.210	0.360
C3	SET2	16-Nov-90	0.180	0.250	0.190	0.330	0.250	0.240	0.322
C3	SET3	14-Mar-91	0.220	0.180	0.190	0.220	0.200	0.202	0.331
C3	SET4	15-Jul-91	0.370	0.200	0.190	0.260	0.360	0.276	0.337
C4	SET2	15-Nov-90	1.110	1.000	1.250	0.980	1.100	1.088	1.773
C4	SET3	14-Mar-91	0.710	0.690	0.710	0.770	0.660	0.708	0.990
C4	SET4	15-Jul-91	0.660	0.520	0.540	0.580	0.520	0.564	0.767
C5	SET2	15-Nov-90	0.650	0.560	0.540	0.520	0.550	0.564	1.052
C5	SET3	14-Mar-91	0.470	0.610	0.470	0.390	0.470	0.482	0.675
C5	SET4	15-Jul-91	0.400	0.380	0.330	0.310	0.310	0.346	0.739

Table A.5 Visual survey results and related data

SEC	SET	TEST DATE	METH - 1 DP	METH - 1 BLD	METH - 1 BLC	METH - 1 LC	METH - 1 TC	METH - 2 DP	METH - 2 BLD	METH - 2 BLC	METH - 2 LC	METH - 2 TC	CUMM. TRAFF.
L1	SET1	14MAR90	0	0	0	0	0	0	0	0	0	0	919860
L1	SET2	24OCT90	7	5	0	0	2	19	2	0	5	12	1271540
L1	SET3	06MAR91	7	5	0	0	2	19	2	0	5	12	1480350
L1	SET4	10JUL91	8	5	0	0	3	19	2	0	5	12	1678170
L2	SET1	14MAR90	0	0	0	0	0	0	0	0	0	0	4969570
L2	SET2	24OCT90	8	0	0	8	0	15	0	0	15	0	6669730
L2	SET3	06MAR91	10	0	0	10	0	8	0	0	8	0	7679200
L2	SET4	09JUL91	11	0	0	11	0	8	0	0	8	0	8635540
L3	SET1	15MAR90	0	0	0	0	0	0	0	0	0	0	6160160
L3	SET2	24OCT90	7	0	0	7	0	15	0	0	15	0	7852730
L3	SET3	06MAR91	8	0	0	8	0	8	0	0	8	0	8862200
L3	SET4	09JUL91	8	0	0	8	0	8	0	0	8	0	9818540
L4	SET1	15MAR90	0	0	0	0	0	0	0	0	0	0	31330
L4	SET2	24OCT90	0	0	0	0	0	0	0	0	0	0	59210
L4	SET3	06MAR91	0	0	0	0	0	0	0	0	0	0	75830
L4	SET4	09JUL91	0	0	0	0	0	0	0	0	0	0	91580
L5	SET1	15MAR90	0	0	0	0	0	0	0	0	0	0	570140
L5	SET2	25OCT90	4	4	0	0	0	0	0	0	0	0	1065180
L5	SET3	06MAR91	4	4	0	0	0	0	0	0	0	0	1356900

Table A.5 Visual survey results and related data (cont.)

SEC	SET	TEST DATE	METH - 1					METH - 2					CUMM. TRAFF.
			DP	BLD	BLC	LC	TC	DP	BLD	BLC	LC	TC	
L5	SET4	10JUL91	6	6	0	0	0	2	2	0	0	0	1635360
L6	SET1	15MAR90	0	0	0	0	0	0	0	0	0	0	3252980
L6	SET2	25OCT90	0	0	0	0	0	0	0	0	0	0	5844660
L6	SET3	06MAR91	0	0	0	0	0	0	0	0	0	0	7371900
L6	SET4	10JUL91	0	0	0	0	0	0	0	0	0	0	8829720
L7	SET3	07MAR91	10	0	0	1	9	17	0	0	5	12	1302840
L7	SET4	10JUL91	11	0	1	2	8	27	0	5	10	12	2176020
L8	SET3	07MAR91	6	0	0	4	2	13	0	0	8	5	1302840
L8	SET4	10JUL91	18	0	4	4	10	18	0	5	5	8	2176020
OD1	SET1	13MAR90	0	0	0	0	0	0	0	0	0	0	91450
OD1	SET2	26OCT90	0	0	0	0	0	0	0	0	0	0	161820
OD1	SET3	05MAR91	1	0	0	1	0	5	0	0	5	0	202120
OD1	SET4	09JUL91	1	0	0	1	0	5	0	0	5	0	241180
OD2	SET1	13MAR90	0	0	0	0	0	0	0	0	0	0	358400
OD2	SET2	26OCT90	0	0	0	0	0	0	0	0	0	0	2900800
OD2	SET3	05MAR91	0	0	0	0	0	0	0	0	0	0	4356800
OD2	SET4	09JUL91	0	0	0	0	0	0	0	0	0	0	5768000
OD3	SET1	13MAR90	0	0	0	0	0	0	0	0	0	0	13339550
OD3	SET2	26OCT90	7	0	0	0	7	17	0	0	5	12	15132850

Table A.5 Visual survey results and related data (cont.)

SEC	SET	TEST DATE	METH - 1					METH - 2					CUMM. TRAFF.
			DP	BLD	BLC	LC	TC	DP	BLD	BLC	LC	TC	
OD3	SET3	05MAR91	10	0	0	2	8	17	0	0	5	12	16159850
OD3	SET4	09JUL91	21	0	0	12	9	27	0	0	15	12	17155250
SA1	SET1	21FEB90	0	0	0	0	0	0	0	0	0	0	528800
SA1	SET2	02NOV90	0	0	0	0	0	0	0	0	0	0	1113000
SA1	SET3	12MAR91	3	3	0	0	0	3	3	0	0	0	1412000
SA1	SET4	11JUL91	5	5	0	0	0	5	2	0	0	3	1690300
SA4	SET2	02NOV90	5	5	0	0	0	2	2	0	0	0	1107300
SA4	SET3	12MAR91	17	17	0	0	0	7	7	0	0	0	1373800
SA4	SET4	12JUL91	20	20	0	0	0	7	7	0	0	0	1621580
SA6	SET1	21FEB90	0	0	0	0	0	0	0	0	0	0	595200
SA6	SET2	01NOV90	0	0	0	0	0	0	0	0	0	0	1202400
SA6	SET3	11MAR91	0	0	0	0	0	0	0	0	0	0	1514400
SA6	SET4	11JUL91	2	2	0	0	0	0	0	0	0	0	1807200
SA16	SET1	22FEB90	0	0	0	0	0	0	0	0	0	0	579600
SA16	SET2	01NOV90	2	2	0	0	0	0	0	0	0	0	1033200
SA16	SET3	11MAR91	2	2	0	0	0	0	0	0	0	0	1267200

Table A.5 Visual survey results and related data (cont.)

SEC	SET	TEST DATE	METH - 1					METH - 2					CUMM. TRAFF.
			DP	BLD	BLC	LC	TC	DP	BLD	BLC	LC	TC	
SA16	SET4	11JUL91	3	3	0	0	0	0	0	0	0	0	1486800
SA17	SET1	22FEB90	0	0	0	0	0	0	0	0	0	0	245700
SA17	SET2	02NOV90	0	0	0	0	0	0	0	0	0	0	574600
SA17	SET3	11MAR91	0	0	0	0	0	0	0	0	0	0	742300
SA17	SET4	11JUL91	0	0	0	0	0	0	0	0	0	0	900900
SA19	SET1	21FEB90	0	0	0	0	0	0	0	0	0	0	63000
SA19	SET2	02NOV90	0	0	0	0	0	0	0	0	0	0	134120
SA19	SET3	12MAR91	0	0	0	0	0	0	0	0	0	0	710520
SA19	SET4	11JUL91	0	0	0	0	0	0	0	0	0	0	204400
SA27	SET1	22FEB90	0	0	0	0	0	0	0	0	0	0	189905
SA27	SET2	01NOV90	0	0	0	0	0	0	0	0	0	0	2844050
SA27	SET3	11MAR91	0	0	0	0	0	0	0	0	0	0	3331550
SA27	SET4	12JUL91	0	0	0	0	0	0	0	0	0	0	3789050
SA30	SET1	21FEB90	0	0	0	0	0	0	0	0	0	0	159040
SA30	SET2	01NOV90	0	0	0	0	0	0	0	0	0	0	338670
SA30	SET3	11MAR91	0	0	0	0	0	0	0	0	0	0	430970
SA30	SET4	11JUL91	0	0	0	0	0	0	0	0	0	0	517590
A1	SET1	03APR90	0	0	0	0	0	0	0	0	0	0	263700

Table A.5 Visual survey results and related data (cont.)

SEC	SET	TEST DATE	METH - 1					METH - 2					CUMM. TRAFF.
			DP	BLD	BLC	LC	TC	DP	BLD	BLC	LC	TC	
A1	SET2	30OCT90	11	11	0	0	0	5	5	0	0	0	452700
A1	SET3	04MAR91	11	11	0	0	0	5	5	0	0	0	565200
A1	SET4	08JUL91	13	13	0	0	0	5	5	0	0	0	678600
A2	SET1	03APR90	0	0	0	0	0	0	0	0	0	0	1333500
A2	SET2	30OCT90	0	0	0	0	0	10	0	0	5	5	2404500
A2	SET3	04MAR91	0	0	0	0	0	8	0	0	5	3	3042000
A2	SET4	08JUL91	6	0	0	4	2	22	0	0	10	12	3684600
A4	SET1	03APR90	0	0	0	0	0	0	0	0	0	0	8386250
A4	SET2	30OCT90	0	0	0	0	0	0	0	0	0	0	11189750
A4	SET3	04MAR91	0	0	0	0	0	8	0	0	5	3	12858500
A4	SET4	08JUL91	1	0	0	0	1	12	0	0	5	7	14540600
A5	SET1	03APR90	0	0	0	0	0	0	0	0	0	0	7648250
A5	SET2	30OCT90	0	0	0	0	0	0	0	0	0	0	10451750
A5	SET3	04MAR91	0	0	0	0	0	8	0	0	5	3	12120500
A5	SET4	08JUL91	2	0	0	0	2	12	0	0	5	7	13802600
W1	SET1	29MAR90	0	0	0	0	0	0	0	0	0	0	3131100
W1	SET2	11OCT90	0	0	0	0	0	0	0	0	0	0	3973900

Table A.5 Visual survey results and related data (cont.)

SEC	SET	TEST DATE	METH - 1					METH - 2					CUMM. TRAFF.
			DP	BLD	BLC	LC	TC	DP	BLD	BLC	LC	TC	
W1	SET3	18MAR91	0	0	0	0	0	0	0	0	0	0	4653300
W1	SET4	17JUL91	0	0	0	0	0	0	0	0	0	0	5173600
W2	SET1	05APR90	0	0	0	0	0	0	0	0	0	0	2497400
W2	SET2	11OCT90	0	0	0	0	0	0	0	0	0	0	3196700
W2	SET3	18MAR91	0	0	0	0	0	0	0	0	0	0	3781300
W2	SET4	17JUL91	0	0	0	0	0	0	0	0	0	0	4229000
W3	SET1	05APR90	0	0	0	0	0	0	0	0	0	0	2092800
W3	SET2	11OCT90	0	0	0	0	0	0	0	0	0	0	2697600
W3	SET3	18MAR91	0	0	0	0	0	0	0	0	0	0	3203200
W3	SET4	17JUL91	0	0	0	0	0	0	0	0	0	0	5390400
W4	SET1	05APR90	0	0	0	0	0	0	0	0	0	0	19152000
W4	SET2	11OCT90	0	0	0	0	0	0	0	0	0	0	25313400
W4	SET3	18MAR91	0	0	0	0	0	0	0	0	0	0	30464200
W4	SET4	17JUL91	2	0	0	2	0	13	0	0	10	3	34408800
W5	SET1	05APR90	0	0	0	0	0	0	0	0	0	0	29830000
W5	SET2	11OCT90	0	0	0	0	0	0	0	0	0	0	35902000
W5	SET3	18MAR91	0	0	0	0	0	0	0	0	0	0	43486000
W5	SET4	17JUL91	0	0	0	0	0	0	0	0	0	0	49294000

Table A.5 Visual survey results and related data (cont.)

SEC	SET	TEST DATE	METH - 1					METH - 2					CUMM. TRAFF.
			DP	BLD	BLC	LC	TC	DP	BLD	BLC	LC	TC	
W6	SET1	05APR90	0	0	0	0	0	0	0	0	0	0	5200050
W6	SET2	11OCT90	0	0	0	0	0	0	0	0	0	0	6710160
W6	SET3	18MAR91	0	0	0	0	0	0	0	0	0	0	7972580
W6	SET4	17JUL91	0	0	0	0	0	0	0	0	0	0	8939370
W7	SET3	18MAR91	34	0	13	5	16	45	0	10	20	15	3465800
W7	SET4	17JUL91	36	0	14	4	18	30	0	12	8	10	3949800
AUS1	SET2	07AUG90	0	0	0	0	0	0	0	0	0	0	3780
AUS1	SET3	26MAR91	5	0	5	0	0	5	0	5	0	0	149310
AUS1	SET4	24JUL91	9	0	9	0	0	5	0	5	0	0	224280
AUS2	SET2	07AUG90	0	0	0	0	0	0	0	0	0	0	101600
AUS2	SET3	26MAR91	0	0	0	0	0	0	0	0	0	0	3035300
AUS2	SET4	24JUL91	0	0	0	0	0	0	0	0	0	0	4546600
AUS3	SET2	08AUG90	0	0	0	0	0	0	0	0	0	0	642000
AUS3	SET3	26MAR91	0	0	0	0	0	0	0	0	0	0	13000500
AUS3	SET4	24JUL91	0	0	0	0	0	0	0	0	0	0	19367000
AUS4	SET3	26MAR91	0	0	0	0	0	0	0	0	0	0	31208000

Table A.5 Visual survey results and related data (cont.)

SEC	SET	TEST DATE	METH - 1					METH - 2					CUMM. TRAFF.
			DP	BLD	BLC	LC	TC	DP	BLD	BLC	LC	TC	
AUS4	SET4	24JUL91	0	0	0	0	0	5	0	0	5	0	36801000
C1	SET1	20MAR90	0	0	0	0	0	0	0	0	0	0	24513200
C1	SET2	15NOV90	2	0	0	0	2	17	0	0	5	12	27585200
C1	SET3	14MAR91	15	0	0	6	8	22	0	0	12	10	29108400
C2	SET1	20MAR90	0	0	0	0	0	0	0	0	0	0	2466310
C2	SET2	15NOV90	5	5	0	0	0	2	2	0	0	0	2763910
C2	SET3	14MAR91	6	6	0	0	0	2	2	0	0	0	2911470
C3	SET1	20MAR90	0	0	0	0	0	0	0	0	0	0	4833850
C3	SET2	16NOV90	0	0	0	0	0	0	0	0	0	0	7280000
C3	SET3	14MAR91	0	0	0	0	0	0	0	0	0	0	8477700
C3	SET4	15JUL91	0	0	0	0	0	0	0	0	0	0	9726150
C4	SET2	15NOV90	0	0	0	0	0	0	0	0	0	0	642000
C4	SET3	14MAR91	7	7	0	0	0	2	2	0	0	0	1403840
C4	SET4	15JUL91	30	30	0	0	0	10	10	0	0	0	2456720
C5	SET2	15NOV90	0	0	0	0	0	0	0	0	0	0	34020
C5	SET3	14MAR91	8	0	0	2	6	27	0	5	10	12	612360
C5	SET4	15JUL91	10	0	1	4	5	27	0	5	10	12	1210140

Table A.6 Summary of construction related data (HMAC and micro-surface)

SEC	CONST DATE	SFTY	AGTY	LANE O/I	ASPC	ASPHALT TYPE	MXTY	ADMIX	PERCENT ADMIX
L-2	4/1/88	HMAC	SG	O	5.65	AC-10	D		
L-3	10/1/87	HMAC	SG	O	6.30	AC-10	D		
L-4	7/1/89	HMAC	SG	.	5.40	AC-10	D		
L-6	6/1/89	HMAC	SG	O	4.70	AC-10	C	Latex	3.0
L-7	9/1/90	MICRO	RY	O	8.00	RALUMAC		Latex/Cement	2.0
L-8	9/1/90	MICRO	RY	O	8.00	RALUMAC		Latex/Cement	2.0
OD-1	5/22/89	HMAC	LS	.	6.65	AC-20	D		
OD-2	2/9/90	HMAC	RY	O	6.30	AC-20	D		
OD-3	1/10/86	HMAC	LS	I	5.40	AC-20	D		
SA-27	9/16/88	HMAC	LS	.	5.50	AC-10	D		
A-2	7/5/89	HMAC	LS	O	5.50	AC-10	D		
A-4	6/10/88	HMAC	LS	O	5.52	AC-10	D		
A-5	8/9/88	HMAC	LS	O	5.52	AC-10	D		
W-1	5/13/88	HMAC	LS	.	6.95	AC-20	D	Anti-Strip/Lime	
W-2	6/20/88	HMAC	LS	.	6.35	AC-20	D	Latex/Lime	
W-3	6/20/88	HMAC	LS	.	6.35	AC-20	D	Latex/Lime	
W-4	7/26/88	HMAC	LS	O	6.10	AC-10	D	Latex/Lime	
W-5	8/9/88	HMAC	LS	O	5.50	AC-10	D	Latex/Lime	1.5

Table A.6 Summary of construction related data (HMAC and micro-surface) (cont.)

SEC	CONST DATE	SFTY	AGTY	LANE O/I	ASPC	ASPHALT TYPE	MXTY	ADMIX	PERCENT ADMIX
W-6	5/13/88	HMAC	LS	O	6.95	AC-20	D	Anti-Strip/	
W-7	11/3/88	MICRO	SS	O	7.50	RALUMAC	D	Latex/Cement	2.0
AUS-2	7/30/90	HMAC	LS	O	6.10	AC-20	C		
AUS-3	7/26/90	HMAC	LS	O	5.30	AC-20	C		
AUS-4	6/1/89	MICRO	SS	.	7.50	RALUMAC		Latex/Cement	2.0
C-1	3/1/84	HMAC	SS	O	6.10	AC-10	D		
C-3	11/1/88	HMAC	LS	O	5.30	AC-20	D	Pave bond Spe./ Lime	1.0
C-5	11/8/90	MICRO	SS	.	7.50	RALUMAC		Latex/Cement	2.0

Table A.7 Summary of construction related variables (asphalt seal coats)

SEC	CONST DATE	SFTY	AGTY	AGG GRADE	LANE I/O	AGSR	ASPH. TYPE	ASSR	ADMIX TYPE	PCR ADMIX
L-1	7/1/88	SEAL	SG	4	.	115	AC-5	0.360	Latex	2
L-5	6/1/89	SEAL	LS	4	.	119	AC-5	0.360	Latex	2
SA-1	6/29/89	SEAL	LS	4	.	115	AC-5	0.305	Latex	3
SA-4	5/4/89	SEAL	LS	4	.	115	AC-5	0.320	Latex	3
SA-6	6/19/89	SEAL	LS	4	.	109	AC-5	0.308	Latex	3
SA-16	4/7/89	SEAL	LS	4	.	110	AC-5	0.328	Latex	3
SA-17	8/18/89	SEAL	LS	4	.	113	AC-5	0.347	Latex	3
SA-19	7/12/89	SEAL	LS	4	.	118	AC-5	0.360	Latex	3
SA-30	7/13/89	SEAL	LS	4	.	108	AC-5	0.387	Latex	3
A-1	6/14/89	SEAL	LS	4	.	110	AC-5	0.400		
AUS-1	8/1/90	SEAL	SS	3	.	125	AC-20	0.600		
C-2	5/1/84	SEAL	SS	3	.	80		0.400		
C-4	9/1/90	SEAL	LS	4	O	100		0.400		

Table A.8 Average annual daily traffic data

DIST	SEC	CONST DATE	HWY	LANE	SHLD	ADT 1991	ADT 1990	ADT 1989	ADT 1988	ADT 1987
5 LUBBOCK	L-1	7/1/88	FM 1294	2	Y	1570	1570	1450	1500	1250
	L-2	4/1/88	US 62-82	4	Y	7590	7590	7200	6500	6500
	L-3	10/1/87	US 62-82	4	Y	7590	7590	7200	6500	6500
	L-4	7/1/89	US 62-82	2	Y	125	125	120	105	105
	L-5	6/1/89	US 380	2	Y	2210	2210	1900	2170	1500
	L-6	6/1/89	US 84	4	Y	11570	11570	11200	10500	10500
	L-7	9/1/90	US 84	4	Y	6930	6930	6600	6100	6000
	L-8	9/1/90	US 84	4	Y	6930	6930	6600	6100	6000
6 ODESSA	OD-1	5/22/89	IH 20	2	Y	310	310	310	320	310
	OD-2	2/9/90	LOOP 338	4	Y	11200	11200	11200	11700	11700
	OD-3	1/10/86	US 385	4	N	7900	7900	7900	8400	9400
7 SAN ANGELO	SA-1	6/29/89	US 83	2	Y	2300	2300	2200	2100	2000
	SA-4	5/4/89	US 83	2	Y	2050	2050	2000	1900	1900
	SA-6	6/19/89	US 67	2	Y	2400	2400	2400	2450	2700
	SA-16	4/7/89	SH 158	2	Y	1800	1800	1800	1900	1950
	SA-17	8/18/89	US 277	2	Y	1300	1300	1300	1250	1350

Table A.8 Average annual daily traffic data (cont.)

DIST	SEC	CONST DATE	HWY	LANE	SHLD	ADT				
						1991	1990	1989	1988	1987
	SA-19	7/12/89	FM 380	2	N	280	280	280	320	280
	SA-27	9/16/88	US 277	2	Y	3750	3750	3700	3300	3700
	SA-30	7/13/89	FM 388	2	N	710	710	710	790	730
8	A-1	6/14/89	FM 33	2	N	900	900	900	950	980
ABILENE	A-2	7/5/89	FM 700	4	Y	5100	5100	4800	5000	4600
	A-4	6/10/88	IH 20	4	Y	13350	13350	12700	12300	11500
	A-5	8/9/88	IH 20	4	Y	13350	13350	12700	12300	11500
9	W-1	5/13/88	LOOP 340	2	Y	4300	4300	4300	5100	5200
WACO	W-2	6/20/88	US 77	2	Y	3700	3700	3700	4100	3800
	W-3	6/20/88	US 77	2	Y	3200	3200	3200	3200	3300
	W-4	7/26/88	IH 35	4	Y	32600	32600	31000	30000	28000
	W-5	8/9/88	IH 35	6	Y	48000	48000	48000	50000	50000
	W-6	5/13/88	LOOP 363	4	Y	7990	7990	7400	7500	6400
	W-7	11/3/88	SPAR 299	4	N	4000	4000	4000	4100	4300

Table A.8 Average annual daily traffic data (cont.)

DIST	SEC	CONST DATE	HWY	LANE	SHLD	ADT				
						1991	1990	1989	1988	1987
14	AUS-1	8/1/90	FM 1660	2	N	630	630	630	640	800
AUSTIN	AUS-2	7/30/90	FM 620	6	Y	12700	12700	12700	14400	15600
	AUS-3	7/26/90	IH 35	6	Y	53500	53500	52000	50500	49000
	AUS-4	6/1/89	BUS 290	2	Y	47000	47000	47000	47000	48000
16	C-1	3/1/84	IH 37	4	Y	12800	12800	11900	11500	10300
CORPUS	C-2	5/1/84	FM 666	2	N	1240	1240	1150	1200	1000
CHRISTI	C-3	11/1/88	SH 361	4	Y	10150	10150	9600	8800	8600
	C-4	9/1/90	US 77	4	Y	8560	8560	8300	8000	7800
	C-5	11/8/90	US 281	2	Y	4860	4860	4700	4600	4400

Table A.9 Directional distribution of traffic from permanent station

SEC	DIST	PERMN. STATION	1988			1989			1990		
			APR	JUN	OCT	APR	JUN	OCT	APR	JUN	OCT
L-2	5	S-138 W	0.499	0.501	0.501	0.601	0.501	0.501	0.501	0.501	0.500
L-3	5	S-138 E	0.501	0.499	0.499	0.499	0.499	0.499	0.499	0.499	0.500
L-7	5	S-128 E	0.506	0.504	0.507	0.504	0.504	0.505	0.503	0.504	0.507
L-8	5	S-128 W	0.494	0.496	0.493	0.496	0.496	0.495	0.497	0.496	0.493
OD-1	6	S-195 E	0.507	0.498	0.495	0.501	0.496	0.495	0.503	0.498	0.494
OD-3	6	S-212 N		0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.483
SA-1	7	S-018 S	0.501	0.503	0.495	0.502	0.500	0.503	0.502	0.502	0.506
A-4	8	S-153 E	0.504	0.498	0.494	0.502	0.498	0.495	0.502	0.497	0.495
W-4	9	S-197 S	0.495			0.496	0.506	0.491	0.503	0.504	0.510
W-5	9	S-215 S	0.507	0.510	0.480	0.506	0.500	0.495		0.497	0.493
AUS-3	14	S-004 S	0.498	0.503	0.502	0.518	0.501	0.503	0.499	0.500	0.503
C-1	16	S-054 N	0.496	0.496	0.495	0.500	0.499	0.495	0.500	0.498	0.492
C-4	16	S-074 S	0.485	0.515	0.529	0.492	0.508	0.530	0.489	0.506	0.527
C-5	16	S-097 S	0.485	0.515	0.541	0.485	0.508	0.528	0.480	0.504	0.526

Table A.10 Percentage truck data based on 24 hr. manual count

SEC	MANUAL STATION	HIGHWAY	BOUND	T & B	LT	(T&B-LT)	TOTAL TRAFF	PERCENT T&B	PERECNT (TB-LT)
L-2	M-1265	US 62-82	SW	3348	2458	890	7167	0.467	0.124
L-3	M-1265	US 62-82	NE	2961	2113	848	6408	0.462	0.132
L-5	M-952	US 380	E	1305	838	467	2034	0.642	0.230
L-6	M-951A	US 84	NDD	5429	3490	1939	11558	0.470	0.168
L-7	M-951A	US 84	NDD	5429	3490	1939	11558	0.470	0.168
L-8	M-951A	US 84	NDD	5429	3490	1939	11558	0.470	0.168
OD-1	MS-195		NDD	8172	3964	4208	13611	0.600	0.309
OD-3	M-176A	LOOP 338	NDD	3378	2161	1217	6277	0.538	0.194
SA-1	MS-18	US 385	SW	1374	969	405	2722	0.505	0.149
SA-4	M-1002		N	1310	801	509	2603	0.503	0.196
SA-6	MS-6	US 83	NE	4194	3315	879	7608	0.551	0.116
SA-16	M-1103	US 83	W	1503	903	600	2383	0.631	0.252
SA-17	M-943	US 67	S	1767	1110	657	3119	0.567	0.211
SA-27	MS-511	US 277	NDD	2118	1659	459	3789	0.559	0.121
A-3	MS-153		NDD	7700	3586	4114	13847	0.556	0.297
A-4	MS-153	FM 33	NDD	7700	3586	4114	13847	0.556	0.297
W-2	M-111	IH 20	S	1940	1411	529	3833	0.506	0.138
W-3	M-111	IH 20	S	1940	1411	529	3833	0.506	0.138
W-4	MS-197		NDD	14905	10187	4718	35790	0.416	0.132
W-5	L-351	LOOP 340	NDD	19014	12965	6049	4299	4.423	1.407

APPENDIX B. PREDICTION MODEL COMPUTER OUTPUTS

Table B.1 Model A for HMAC surfaces

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	5	4180.99654	836.19931	22.900	0.0001
Error	51	1862.27223	36.51514		
C Total	56	6043.26877			

Root MSE	6.04278	R-square	0.6918
Dep Mean	42.68070	Adj R-sq	0.6616
C.V.	14.15810		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	121.404775	14.38125519	8.442	0.0001
ASPC	1	4.540893	1.50990749	3.007	0.0041
LCUTR	1	-7.766470	0.81223599	-9.562	0.0001
CUPP	1	0.159823	0.02632460	6.071	0.0001
ABFT	1	-0.023734	0.00534201	-4.443	0.0001
SGTR	1	0.000006299	0.00000113	5.593	0.0001

Table B.2 Model B for HMAC surfaces

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	6	4745.94218	790.99036	30.485	0.0001
Error	50	1297.32659	25.94653		
C Total	56	6043.26877			

Root MSE	5.09377	R-square	0.7853
Dep Mean	42.68070	Adj R-sq	0.7596
C.V.	11.93461		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	117.309261	12.00829839	9.769	0.0001
ASPC	1	3.081036	1.31646204	2.340	0.0233
PV	1	0.974627	0.16233829	6.004	0.0001
CUFT	1	0.210974	0.02465642	8.557	0.0001
ABPP	1	0.052094	0.00589495	8.837	0.0001
LCUTR	1	-9.323516	0.74793459	-12.466	0.0001
ABFT	1	-0.093326	0.01042224	-8.954	0.0001

Table B.2 Model B for HMAC surfaces (cont.)

Collinearity Diagnostics

Number	Eigenvalue	Condition Number	Var Prop INTERCEP	Var Prop ASPC	Var Prop PV	Var Prop CUFT
1	5.90296	1.00000	0.0001	0.0002	0.0004	0.0013
2	0.64155	3.03333	0.0001	0.0002	0.0004	0.0394
3	0.36707	4.01014	0.0007	0.0011	0.0033	0.0058
4	0.06860	9.27636	0.0002	0.0005	0.0201	0.3486
5	0.01267	21.58175	0.0171	0.2182	0.5132	0.1810
6	0.00523	33.58767	0.0738	0.4528	0.3906	0.2852
7	0.00191	55.63867	0.9080	0.3270	0.0720	0.1387

Number	Var Prop ABPP	Var Prop LCUTR	Var Prop ABFT
1	0.0035	0.0001	0.0013
2	0.1041	0.0001	0.0187
3	0.3117	0.0007	0.0203
4	0.0679	0.0014	0.3854
5	0.0764	0.0055	0.1530
6	0.0321	0.2777	0.2528
7	0.4042	0.7145	0.1685

Table B.2 Model B for HMAC surfaces (cont.)

Obs	Dep Var FN	Predict Value	Std Err Predict	Residual	Std Err Residual	Student Residual
1	31.0000	26.1912	2.442	4.8088	4.470	1.076
2	34.2000	40.3445	1.560	-6.1445	4.849	-1.267
3	32.6000	40.8459	1.449	-8.2459	4.883	-1.689
4	32.2000	32.6338	1.255	-0.4338	4.937	-0.088
5	27.6000	32.4703	1.246	-4.8703	4.939	-0.986
6	28.0000	32.7978	1.157	-4.7978	4.961	-0.967
7	32.4000	32.5824	1.273	-0.1824	4.932	-0.037
8	29.6000	32.2910	1.262	-2.6910	4.935	-0.545
9	27.8000	32.4927	1.172	-4.6927	4.957	-0.947
10	59.2000	48.5020	1.167	10.6980	4.958	2.158
11	65.6000	60.7116	2.008	4.8884	4.681	1.044
12	37.8000	31.7233	1.459	6.0767	4.880	1.245
13	40.0000	45.3126	1.461	-5.3126	4.880	-1.089
14	49.8000	53.7724	2.776	-3.9724	4.271	-0.930
15	56.6000	53.7432	2.690	2.8568	4.326	0.660
16	54.8000	51.8277	2.452	2.9723	4.465	0.666
17	27.4000	35.5160	1.334	-8.1160	4.916	-1.651
18	34.0000	36.2290	1.335	-2.2290	4.916	-0.453
19	30.2000	37.4181	1.305	-7.2181	4.924	-1.466
20	43.6000	42.8217	1.406	0.7783	4.896	0.159
21	42.6000	39.2395	1.856	3.3605	4.744	0.708
22	50.8000	42.3313	1.390	8.4687	4.900	1.728
23	48.2000	46.5632	2.411	1.6368	4.487	0.365
24	43.6000	51.0027	2.990	-7.4027	4.124	-1.795
25	49.6000	45.7912	2.413	3.8088	4.486	0.849
26	61.4000	62.3378	2.650	-0.9378	4.350	-0.216
27	57.6000	53.2747	2.506	4.3253	4.435	0.975
28	60.4000	60.4130	2.508	-0.0130	4.434	-0.003
29	44.4000	43.7705	1.715	0.6295	4.796	0.131

Table B.2 Model B for HMAC surfaces (cont.)

Obs	Dep Var FN	Predict Value	Std Err Predict	Residual	Std Err Residual	Student Residual
30	45.8000	43.5164	2.010	2.2836	4.680	0.488
31	47.4000	41.4672	1.685	5.9328	4.807	1.234
32	47.2000	41.6017	1.292	5.5983	4.927	1.136
33	49.0000	54.0114	1.696	-5.0114	4.803	-1.043
34	45.4000	48.0044	1.493	-2.6044	4.870	-0.535
35	26.6000	29.7252	2.886	-3.1252	4.197	-0.745
36	29.2000	32.6009	2.310	-3.4009	4.540	-0.749
37	39.2000	48.5078	1.406	-9.3078	4.896	-1.901
38	55.2000	47.9047	1.196	7.2953	4.951	1.473
39	51.0000	48.6751	1.229	2.3249	4.943	0.470
40	39.2000	44.4329	1.567	-5.2329	4.847	-1.080
41	38.8000	45.3229	1.541	-6.5229	4.855	-1.344
42	40.6000	44.3747	1.679	-3.7747	4.809	-0.785
43	50.0000	50.6824	1.172	-0.6824	4.957	-0.138
44	51.2000	51.2352	1.201	-0.0352	4.950	-0.007
45	52.8000	50.6967	1.281	2.1033	4.930	0.427
46	51.2000	50.6824	1.172	0.5176	4.957	0.104
47	52.6000	51.2352	1.201	1.3648	4.950	0.276
48	53.0000	50.6967	1.281	2.3033	4.930	0.467
49	36.2000	39.6395	1.642	-3.4395	4.822	-0.713
50	37.4000	39.7377	1.653	-2.3377	4.818	-0.485
51	41.0000	38.2941	1.634	2.7059	4.824	0.561
52	30.4000	24.2634	1.833	6.1366	4.753	1.291
53	24.4000	24.6391	1.773	-0.2391	4.775	-0.050
54	34.0000	24.5857	1.789	9.4143	4.769	1.974
55	44.4000	42.3653	1.670	2.0347	4.812	0.423
56	41.2000	39.1527	1.821	2.0473	4.757	0.430
57	45.4000	39.7976	1.739	5.6024	4.788	1.170

Table B.3 Model C for HMAC surfaces

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	6	4483.96682	747.32780	23.964	0.0001
Error	50	1559.30196	31.18604		
C Total	56	6043.26877			

Root MSE	5.58445	R-square	0.7420
Dep Mean	42.68070	Adj R-sq	0.7110
C.V.	13.08424		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	142.776640	12.15193786	11.749	0.0001
LCUTR	1	-7.311182	0.93332838	-7.833	0.0001
CUFT	1	-0.057908	0.01328746	-4.358	0.0001
CUPP	1	0.190380	0.02459522	7.741	0.0001
CDTR	1	0.000006820	0.00000112	6.072	0.0001
ABMS	1	-0.058554	0.01857537	-3.152	0.0027
LSTR	1	-0.000006914	0.00000100	-6.889	0.0001

Table B.4 Model D for HMAC surfaces

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	6	4280.39307	713.39885	24.815	0.0001
Error	47	1351.20693	28.74908		
C Total	53	5631.60000			

Root MSE	5.36182	R-square	0.7601
Dep Mean	42.06667	Adj R-sq	0.7294
C.V.	12.74600		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	76.450980	13.15377885	5.812	0.0001
ASPC	1	8.325257	1.35376977	6.150	0.0001
TDT	1	0.764675	0.54948556	1.392	0.1706
LCUTR	1	-6.222345	0.80382369	-7.741	0.0001
LS	1	23.988961	5.49387466	4.366	0.0001
SGTR	1	0.000004208	0.00000158	2.670	0.0104
LSTD	1	-3.300839	0.71449685	-4.620	0.0001

Table B.5 Model E for HMAC surfaces

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	6	4273.79110	712.29852	20.127	0.0001
Error	50	1769.47767	35.38955		
C Total	56	6043.26877			

Root MSE	5.94891	R-square	0.7072
Dep Mean	42.68070	Adj R-sq	0.6721
C.V.	13.93818		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	117.933570	14.31923536	8.236	0.0001
ASPC	1	5.280041	1.55496132	3.396	0.0013
LAABR	1	-0.242806	0.14994627	-1.619	0.1117
LCUTR	1	-7.341322	0.84162039	-8.723	0.0001
CUPP	1	0.156842	0.02598098	6.037	0.0001
ABFT	1	-0.021534	0.00543162	-3.965	0.0002
SGTR	1	0.000005196	0.00000130	3.993	0.0002

Table B.6 Model F for HMAC surfaces

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	7	4968.18273	709.74039	32.348	0.0001
Error	49	1075.08604	21.94053		
C Total	56	6043.26877			

Root MSE	4.68407	R-square	0.8221
Dep Mean	42.68070	Adj R-sq	0.7967
C.V.	10.97468		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	96.641897	12.81033724	7.544	0.0001
ASPC	1	4.425034	1.28211706	3.451	0.0012
PV	1	0.911538	0.15059149	6.053	0.0001
LCUTR	1	-8.010184	0.80207271	-9.987	0.0001
CUFT	1	0.160063	0.02774825	5.768	0.0001
ABPP	1	0.042485	0.00620487	6.847	0.0001
ABFT	1	-0.068765	0.01230470	-5.589	0.0001
LSMS	1	-0.263748	0.08287078	-3.183	0.0025

Table B.7 Model G for HMAC surfaces

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	6	4396.86656	732.81109	27.894	0.0001
Error	47	1234.73344	26.27092		
C Total	53	5631.60000			

Root MSE	5.12552	R-square	0.7807
Dep Mean	42.06667	Adj R-sq	0.7528
C.V.	12.18427		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	47.333651	7.53822692	6.279	0.0001
STAB	1	-0.586862	0.17297684	-3.393	0.0014
MSS	1	2.903489	0.43266475	6.711	0.0001
TDMS	1	-0.336454	0.04220685	-7.972	0.0001
CD	1	18.818410	3.28052126	5.736	0.0001
ABTD	1	0.607755	0.10369080	5.861	0.0001
STTR	1	-6.944189E-8	0.00000001	-7.409	0.0001

Table B.8 Model A for seal coats

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	977.64182	325.88061	16.618	0.0001
Error	33	647.11710	19.60961		
C Total	36	1624.75892			

Root MSE	4.42827	R-square	0.6017
Dep Mean	50.79459	Adj R-sq	0.5655
C.V.	8.71800		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	195.096364	21.30709922	9.156	0.0001
ASSR	1	-76.475742	15.83717668	-4.829	0.0001
CD	1	-16.808761	3.01299844	-5.579	0.0001
LCUTR	1	-7.948548	1.15718795	-6.869	0.0001

Table B.9 Model B for seal coats

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	4	1097.25710	274.31428	16.641	0.0001
Error	32	527.50182	16.48443		
C Total	36	1624.75892			

Root MSE	4.06010	R-square	0.6753
Dep Mean	50.79459	Adj R-sq	0.6348
C.V.	7.99318		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	225.599023	23.78957921	9.483	0.0001
ASAG	1	-0.702061	0.11885424	-5.907	0.0001
PV	1	-0.718635	0.25582044	-2.809	0.0084
LCUTR	1	-8.530827	1.07670816	-7.923	0.0001
CD	1	-12.687298	2.40323536	-5.279	0.0001

Table B.10 Model C for seal coats

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	6	1145.55480	190.92580	11.953	0.0001
Error	30	479.20412	15.97347		
C Total	36	1624.75892			

Root MSE	3.99668	R-square	0.7051
Dep Mean	50.79459	Adj R-sq	0.6461
C.V.	7.86832		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	171.397355	21.71488735	7.893	0.0001
ASSR	1	-71.049285	20.48253211	-3.469	0.0016
LCUTR	1	-7.150036	1.13262604	-6.313	0.0001
CUFT	1	-0.236879	0.07191446	-3.294	0.0025
LS	1	-12.242836	2.67132123	-4.583	0.0001
PB	1	8.819484	2.38992250	3.690	0.0009
MSFT	1	0.011272	0.00362334	3.111	0.0041

Table B.11 Model D for seal coats

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	5	942.63353	188.52671	9.655	0.0001
Error	29	566.26933	19.52653		
C Total	34	1508.90286			

Root MSE	4.41888	R-square	0.6247
Dep Mean	50.48571	Adj R-sq	0.5600
C.V.	8.75274		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	210.697235	25.94161994	8.122	0.0001
LCUTR	1	-8.506312	1.30003452	-6.543	0.0001
LS	1	-13.813751	6.71323467	-2.058	0.0487
SG	1	-10.066174	6.74269325	-1.493	0.1463
AGAS	1	-0.949028	0.22575993	-4.204	0.0002
TDPP	1	-0.004463	0.00562358	-0.794	0.4338

Table B.12 Model E for seal coats

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	4	1021.35262	255.33816	13.541	0.0001
Error	32	603.40630	18.85645		
C Total	36	1624.75892			

Root MSE	4.34240	R-square	0.6286
Dep Mean	50.79459	Adj R-sq	0.5822
C.V.	8.54894		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	226.077719	29.16545687	7.752	0.0001
ASSR	1	-102.341519	23.01738557	-4.446	0.0001
CD	1	-16.462028	2.96333442	-5.555	0.0001
LCUTR	1	-9.395823	1.48028580	-6.347	0.0001
LSLA	1	-0.162004	0.10640476	-1.523	0.1377

Table B.13 Model F for seal coats

Dependent Variable: FN

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	7	1242.43382	177.49055	17.984	0.0001
Error	27	266.46903	9.86922		
C Total	34	1508.90286			

Root MSE	3.14153	R-square	0.8234
Dep Mean	50.48571	Adj R-sq	0.7776
C.V.	6.22262		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-1047.780092	219.86378903	-4.766	0.0001
AGSR	1	10.107066	1.73591773	5.822	0.0001
ASSR	1	-118.881579	27.21130338	-4.369	0.0002
MSS	1	6.016169	1.53817164	3.911	0.0006
TDT	1	142.909773	24.47487128	5.839	0.0001
AGTD	1	-1.156990	0.19102736	-6.057	0.0001
LCUTR	1	-9.001044	0.92204286	-9.762	0.0001
TDMS	1	-0.640864	0.18490974	-3.466	0.0018