RATIONAL DETERMINATION OF PAVEMENT LAYER STRUCTURAL COEFFICIENTS

Final Report No. FHWA/OH-99/006

Principal Investigator: Eddie Y. J. Chou
Co-Investigators: Brian W. Randolph & Andrew G. Heydinger

Prepared in Cooperation with

The Ohio Department of Transportation
and
The U.S. Department of Transportation
Federal Highway Administration

1. Report No. FHWA/OH-99/006	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

RATIONAL DETERMINATION OF PAVEMENT LAYER
STRUCTURAL COEFFICIENTS

5. Report Date

May, 1999

6. Performing Organization Code

8. Performing Organization Report No.

7. Author(s)

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10. Work Unit No. (TRAIS)

9. Performing Organization Name and Address

The University of Toledo
Department of Civil Engineering
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11. Contract or Grant No.

State Job No. 14561(0)

13. Type of Report and Period Covered

Final Report

12. Sponsoring Agency Name and Address

Ohio Department of Transportation
1600 West Broad Street
Columbus, OH 43223

14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

Seven flexible pavements ranging from interstate to state route are selected. Three different approaches are employed. The first two use the resilient modulus of the material to estimate its structural coefficient. In the first approach, cored specimens are obtained from each of the pavement sections and the resilient modulus of in-service 301 and 446/448 materials are determined in the laboratory. The resulting structural coefficient for 301 materials ranges between 0.33 and 0.39 with an average of 0.37. The structural coefficient of 446/448 materials ranges between 0.46 to 0.54 with an average value of 0.49. The second approach back calculates layer elastic modulus from measured pavement deflection. The resulting structural coefficients are 0.44 for 301 materials (range: 0.25~0.53) and 0.55 for 446 materials (range: 0.38~0.60). The third approach determines the structural coefficient from the AASHTO flexible pavement performance equation based on traffic and serviceability history data. When laboratory measured roadbed soil resilient modulus are used, the average coefficient is 0.42 for 301 materials and 0.52 for 446 materials. When back calculated roadbed modulus values (multiplied by a factor 0f 0.33) are used, the average coefficient is 0.30 for 301 and 0.43 for 446 materials. Finally, when the soil modulus is estimated from the group index, the average structural coefficient is 0.39 for 446/448 and 0.26 for 301 materials. The findings of this study indicate that the structural coefficient for 446 materials may be increased from the current value of 0.35 to a value between 0.40 and 0.45. For 301 materials, a structural coefficient of between 0.35 and 0.37 is recommended.

17. Key Words

Structural Coefficient, Flexible Pavements,
Resilient Modulus

18. Distribution Statement

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National Technical Information Service,
Springfield, Virginia 22161

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

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ACKNOWLEDGMENTS

The authors would like to thank the Ohio Department of Transportation and the Federal Highway Administration for supporting the study. The assistance of a number of ODOT engineers is most appreciated, especially Mr. Roger Green, Mr. Aric Morse, and Mr. Ken Corns.

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LIST OF SYMBOLS

a_i	Structural Coefficient of the i^{th} Layer
D_i	Thickness of the i^{th} Layer
δ_H	Horizontal Elastic Deformation
ΔPSI	Difference in PSI values
E	Resilient Modulus of Elasticity
M_R	Roadbed Soil Resilient Modulus
ν	Poisson's Ratio of the Asphalt Mixture
P	Magnitude of the Load
R	Reliability level
S_o	Overall Standard Deviation
SN	Structural Number
t	Specimen Thickness
W_{18}	Number of Repetition of 18-kip (80-kN) Equivalent Single Axle Load
Z_R	Standard Normal Deviates

EXECUTIVE SUMMARY

The objective of this research is to determine whether the structural coefficient of asphalt concrete materials used by ODOT in flexible pavement thickness design are appropriate and whether the structural coefficient can be increased to reflect improved specifications. Increasing the structural coefficient would reduce required pavement thickness and could save substantial materials and construction costs.

Currently, ODOT uses a structural coefficient value of 0.35 for all asphalt concrete materials (including 446, 448, 301, and 302 bituminous aggregate base.) This value came from a study conducted by Coffman et al., (1968), in which the structural coefficient was defined as the "thickness equivalence factor" and was determined using layered elastic theory by varying layer thickness to achieve the same critical strain or deflection. The structural coefficient was found to vary significantly with thickness of the base layer and the failure criterion chosen, the final value reported was based on the "average" condition.

Seven flexible pavements ranging from interstate to state route are selected for the current study. Three different approaches are employed. The first two use the resilient modulus of the material to estimate its structural coefficient. In the first approach, cored specimens are obtained from each of the pavement sections and the resilient modulus of in-service 301 and 446/448 materials are determined in the laboratory. The resulting

structural coefficient for 301 materials ranges between 0.33 and 0.39 with an average of 0.37. The structural coefficient of 446/448 materials ranges between 0.46 to 0.54 with an average value of 0.49.

The second approach back calculates layer elastic modulus from measured pavement deflection. The resulting structural coefficients are 0.44 for 301 materials (range: 0.25~0.53) and 0.55 for 446 materials (range: 0.38~0.60).

The third approach determines the structural coefficient from the AASHTO flexible pavement performance equation based on traffic and serviceability history data. This approach is considered the most direct estimate of the structural coefficient; however, the results are very sensitive to the input parameters, especially the roadbed soil resilient modulus and the present serviceability index. When laboratory measured roadbed soil resilient modulus are used, the average coefficient is 0.42 for 301 materials and 0.52 for 446 materials. When back calculated roadbed modulus values (multiplied by a factor Of 0.33) are used, the average coefficient is 0.30 for 301 and 0.43 for 446 materials. Finally, when the soil modulus is estimated from the group index, the average structural coefficient is 0.39 for 446/448 and 0.26 for 301 materials.

The findings of this study indicate that the structural coefficient for 446 materials may be increased from the current value of 0.35 to a value between 0.40 and 0.45. For 301 materials, a structural coefficient of between 0.35 and 0.37 is recommended.

CHAPTER ONE

INTRODUCTION

1.1 Problem Description

The flexible pavement design procedure currently used by the Ohio Department of Transportation (ODOT) is based on the AASHTO flexible pavement performance equation. In this procedure, a flexible pavement's structural capacity is represented by the structural number (SN), which is expressed as the summed products of the individual layer thickness and the corresponding layer structural coefficients. The design pavement layer thickness is therefore directly affected by the values of structural coefficients chosen. Selecting a smaller layer structural coefficient means a thicker pavement and vice versa. Guidelines in selecting the structural coefficients for various paving materials have been provided by AASHTO (AASHTO, 1993). However, since each state has its own material specifications, AASHTO recommends that each state department of transportation should determine the specific structural coefficients for the materials specified by that state.

Currently, a structural coefficient of 0.35 is assumed by ODOT engineers for all asphalt concrete materials including 446/448, both types I and II, asphalt concrete mixes and 301 bituminous aggregate base. In contrast, the AASHTO Design Guide assumes a structural coefficient of 0.44 for the hot mix asphalt materials used during the AASHO road test. Most states use a structural coefficient value of between 0.30 to 0.44 for their hot mix asphalt concrete materials (Van Til, et al, 1972). Interestingly, in the above reference (NCHRP report 128), Ohio was reported as using a structural coefficient of 0.40 for all plant mix asphalt concrete materials.

The current study was initiated to investigate whether the currently assumed structural coefficient value of 0.35 is too conservative for ODOT 301 bituminous aggregate base and 446/448 asphalt concrete materials. The specifications for these materials are considered to produce higher quality materials than specifications from the past. Therefore, the assumed structural coefficient may possibly be increased to reflect such improvements in material quality. An increase of the structural coefficient would reduce the layer thickness. Because ODOT has observed mainly functional rather than structural failures on its flexible pavements, an excessive build-up of pavement thickness may not necessarily extend the useful pavement life. There is concern that ODOT's structural coefficient assumption may be too conservative. Therefore, ODOT may be able to save substantial materials cost if the structural coefficient can be increased.

1.2 Objective

The objective of this research study is to determine the most appropriate structural coefficients, for ODOT 301 bituminous aggregate base and 446/448 asphalt concrete materials, to be used in flexible pavement thickness design.

1.3 Background

The structural coefficient is a measure of the relative ability of the material to function as a structural component of the pavement. Since the structural coefficient itself is not a directly measurable material property, its value must be estimated from other measurable material characteristics or empirically from the material's actual contribution to pavement performance as defined by the AASHTO design equation.

In the current ODOT flexible pavement design procedure, which is based on the AASHTO design procedure, a pavement's overall structural capacity is represented by the Structural Number (SN). SN is defined as the summed product of the structural coefficients and layer thickness:

$$SN = \sum_{i=1}^{n} a_i D_i \qquad (1)$$

where i is the number of pavement layers above roadbed soil, $\mathbf{a}_i$ and D_i are the structural coefficient and layer thickness, respectively, of each layer.

The structural coefficients can be considered as thickness ratios between the various materials of interest to a standard crushed stone base material. The structural coefficients ($\mathbf{a}_i$-values) can vary considerably depending upon a number of factors (AASHTO, 1986b) such as:

1. layer thickness,
2. material type,
3. material properties,
4. layer location (base, subbase),
5. traffic level, and
6. failure criterion.

Therefore, the structural coefficient should be considered as an average value.

Pavement layer structural coefficients are needed because any design procedure based on the AASHTO flexible pavement performance equation, including the ODOT procedure, requires the structural coefficients in order to determine pavement layer thickness. The structural coefficients may be obtained empirically or derived from layered elastic theory by equating the deflection or critical strains of two pavements having different layer thickness or materials. The latter approach is necessary when no sufficient performance data is available. Since the AASHTO equation is an empirical relationship between pavement performance and pavement structure, using actual pavement structure and performance data to estimate layer structural coefficients seems to be a reasonable approach when such data are available.

When detailed pavement performance data are not available to allow accurate estimation of the structural coefficients of various paving materials, estimating the structural coefficient from other material constants may be the only reliable way. A material's resilient (elastic) modulus has been accepted as the most important property for it to function as a paving material. The resilient modulus of asphalt-aggregate mixtures can be determined directly using the procedure outlined in ASTM D4123 (Indirect Tension Test for Resilient Modulus of Bituminous Mixtures).

AASHTO developed the relationships between resilient modulus (E) and layer coefficients (**a**) using layered elastic theory. Thickness ratios established on the basis of equal strain or deflection criteria were used to translate the AASHO Road Test conditions to different materials (based on modulus). Correlation charts for estimating the structural coefficient of dense-graded asphalt concrete and bituminous treated bases based on their resilient modulus are shown in Figure 1 and 2 (Van Til, et al. 1972). These relationships are recommended for an annual average pavement temperature of 68°F (or 20°C).

The relationship may be express as the following formula:

(1) for surface course (e.g., 446/448 asphalt concrete materials):

$$a = 0.40405*LOG(E)-1.8447$$

(2) for bituminous base (e.g., 301 base):

$$a = =0.3261*LOG(E)-1.5117$$

where a is the structural coefficient and E is the elastic (resilient) modulus of the material.

As stated in the AASHTO Guide, caution is recommended for extrapolating structural coefficient for elastic modulus values above 450,000 lb/in^2; because even though higher modulus asphalt concrete materials are stiffer and more resistant to bending, they are also more susceptible to thermal and fatigue cracking. Therefore, an asphalt concrete material with a very high elastic modulus may not provide very durable service; therefore, it should not be assigned a very high structural coefficient.

The rest of the report is outlined as follows: Chapter two describes the test sections selected and the study methods used, Chapter three presents the finding of the study, and Chapter four contains the conclusion and

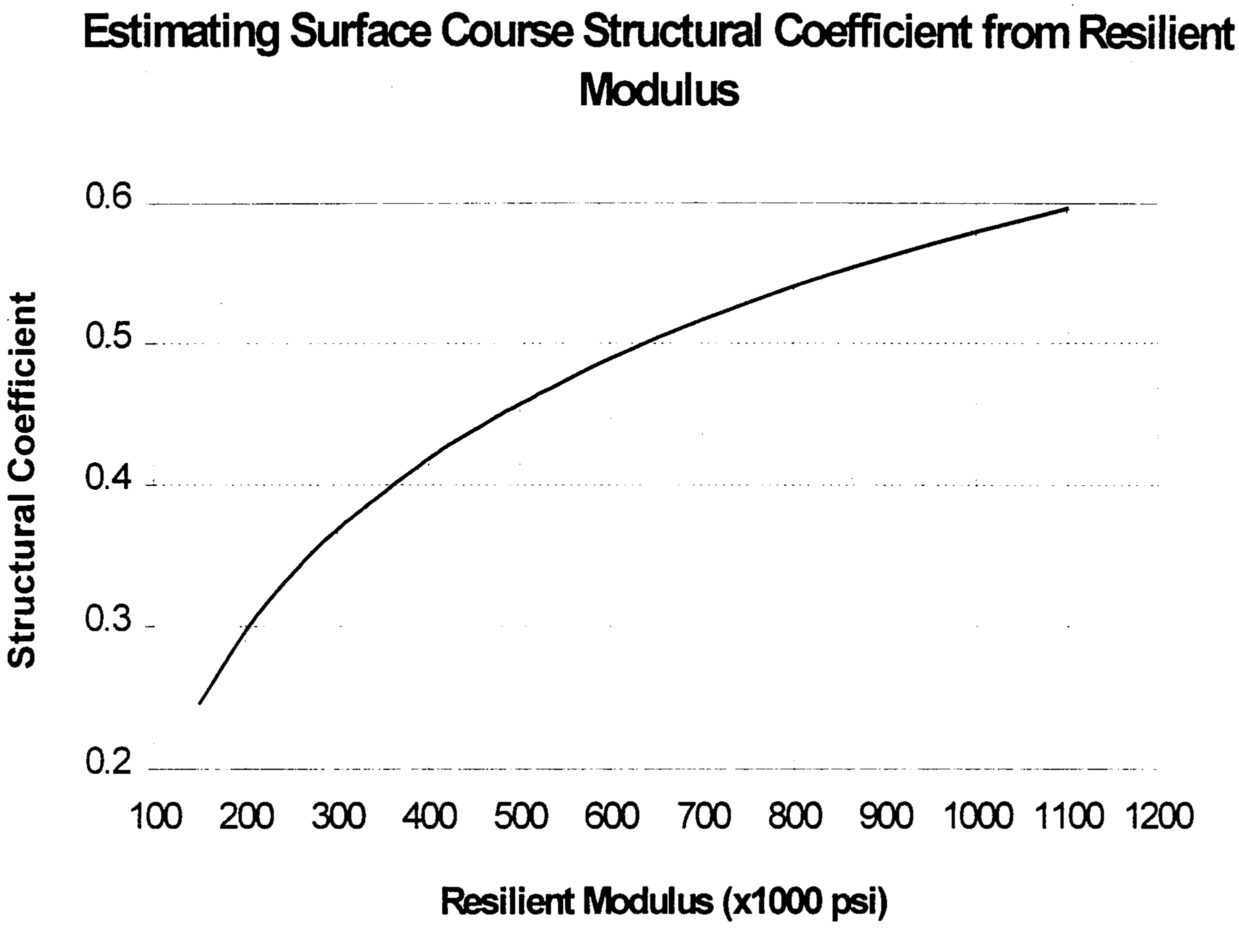

Figure 1. Correlation Chart to Estimate Structural Coefficient from Resilient Modulus for Hot Mix Asphalt Surface Course for an Average Pavement Temperature of 68°F

(Based on data from Van Til, et al, 1972)

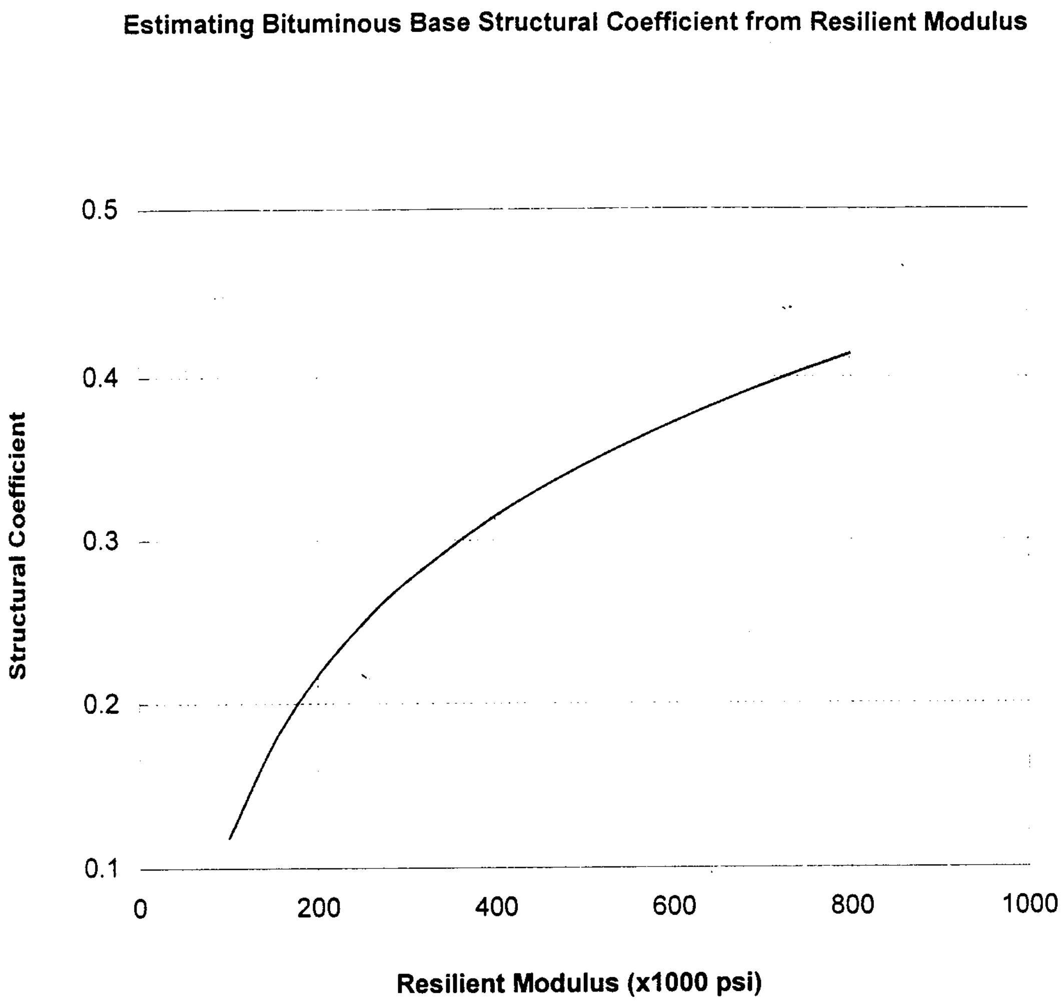

Figure 2. Correlation Chart to Estimate Structural Coefficient from Resilient Modulus for Hot Mix Asphalt Base Course for an Average Pavement Temperature of 68°F

(Based on data from Van Til, et al, 1972) recommendations. Appendix A contains cross sections of the selected test sections. Appendix B presents detailed laboratory test data. Appendix C includes traffic and pavement performance data used in the analysis.

CHAPTER TWO

RESEARCH APPROACH

A number of pavement sections are selected for study based on the following criteria:

(1) The structure must be a flexible pavement; that is, no concrete or cement stabilized layer(s).

(2) The pavement must contain a 301 base layer or a 446/448 asphalt concrete layer.

(3) History of traffic and the present serviceability index (PSI) value of the section must be available.

(4) The PSI must have a monotonically decreasing trend for a period of not less than 5 to 8 years and no rehabilitation work was performed during that period.

The sections selected and the respective structures are shown in Table 1. Drawings showing the cross section of each section are included in appendix A. These sections are selected to represent diverse geographic locations within the state. Both high and low traffic volumes are represented. Figure 3 shows the locations of the test sections.

Table 1. Test Sections Selected

Section ID (1)	County (2)	Route (3)	Beginning Log (4)	Ending Log (5)	Pavement Structure (6)
1	Athens	US-50R	3.20	3.40	**1.25 in. 446** +**1.75 in. 448** (1990) 1.25 in. 848R +0.75 in. 848R (1983) 1.25 in. 404+1.25 in. 402 + **8 in. 301** +4 in. 304 (1969)
2	Columbiana	SR-11R	16.30	16.50	**1.25 in. 446** + **1.75 in. 446** + **3 in. 301** (1991) 1 in. 848 + 1.25 in. 848 (1983) 1.25 in. 404 +2.75 in. 302 + 6in. 824 +6 in. 304 (1968)
3	Crawford	US-30R	7.78	7.98	***3 in. 446*** *(1990?)* **1 in. 848+1 in. 848** (1983) 1.25 in. 404 +1.25 in. 402 + **8 in. 301**+9.5 in." 310 base (1968)
4	Franklin	I-270R	35.00	35.20	**1.25 in. 846** +**1.75 in. 846**+**10 in. 301** (1987)
5	Jackson	US-35R	1.80	2.00	1.25 in. 404+ 1.75 in. 402 + **9" 301**+6 in. 304 (1992)
6	Marion	US-23R	3.00	3.20	**1.25 in. 446**+**0.75 in. 448** (1992) 1 in. 404+0.5 in. 403 (1982) 1.25 in. 404+ 1.25 in. 402+**9" 301**+6 in 310 base (1967)
7	Wood	SR-795R	2.49	2.69	1 in. 404 +0.75 in. 403 (1981) 1.25 in. 404 +1.25 in. (402) +**7" 301**+6 in. 310 subbase (1967)

Figure 3. Test Site Locations

Three different approaches are employed to estimate the structural coefficients of 301 and 446/448 materials. These approaches are: (1) correlating with resilient modulus obtained by laboratory testing of in service materials, (2) correlating with elastic modulus back calculated from pavement deflections, and (3) computing structural coefficient directly from the AASHTO performance equation based on roadbed soil resilient modulus, traffic, and performance history data. These three approaches are described in this chapter.

2.1 Laboratory Testing

Cored specimens containing material of interest are obtained from the test sections. The cores are 4-inch (101 mm) in diameter. They are taken randomly within the test sections. The labeled specimens are brought back to the laboratory and each layer material is carefully identified with the assistance of construction history data provided by ODOT. The cores are then sawed to thickness required for resilient modulus testing (from a minimum of 2.5-in. (64 mm) to a maximum of 4 in. (101 mm).

The resilient modulus of each specimen is measured following the procedures described in ASTM D4123: Indirect Tension Test for Resilient Modulus of Bituminous Mixtures. A test set up similar to the indirect tension test is used. A 4-in. (101-mm) diameter disk specimen is secured between the top and bottom loading strips and stands on its side. A repeated impulse loading with a haversine waveform load having a load duration of 0.1 s and a rest period of 0.9 s at a frequency of 1 Hz is applied vertically on the specimen. The load applied is dependent on the specimen thickness at about 100 lb./in. (17.5 N/mm). Two linear variable differential transducers (LVDT) measure the radial (horizontal) displacements. Preconditioning of the specimens is achieved by applying the load for 150 repetitions. The average horizontal deformations over five loading cycles are then measured. Each specimen is tested twice. The specimen is rotated 90 degrees before the second test. All tests are performed at room temperature (72°F or 22°C).

Figure 4 shows the test configuration. A function generator board and corresponding software installed in the first computer allows the operator to control the load level, duration, frequency, and waveform. The signal is then sent to a servo hydraulic amplifier, which controls the hydraulic valves and load actuator. A load cell reports the actual load being applied. This information is fed back to the servo control to ensure desirable level of loading. The second computer records all load and deformation data through a high-speed data acquisition system.

The resilient modulus of elasticity, E, is calculated by:

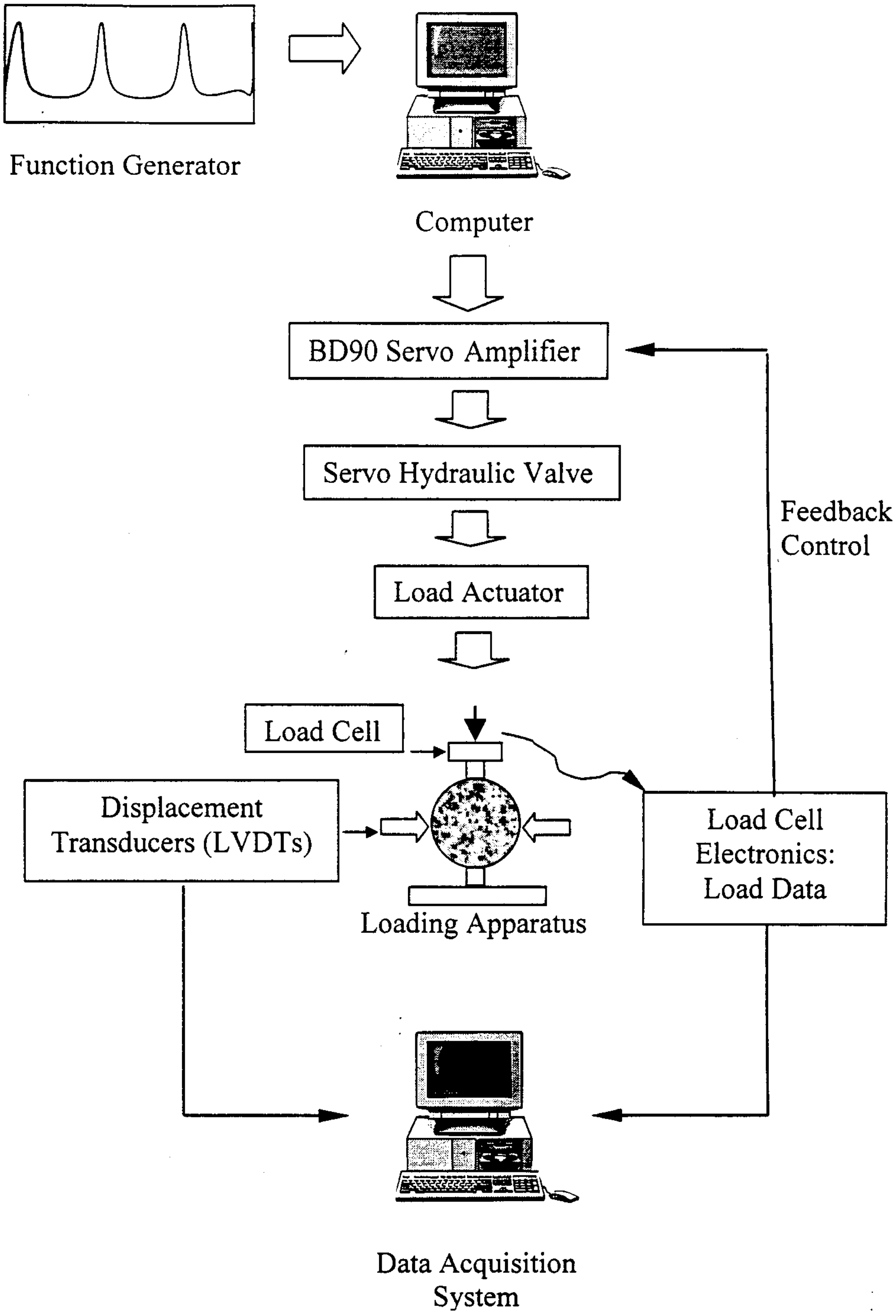

Figure 4. Laboratory Setup for Measuring Resilient Modulus of Elasticity

$$E = \frac{P(\nu + 0.2734)}{\delta_H t} \qquad (2)$$

where:

E = total resilient modulus of elasticity, psi (or MPa),

P = magnitude of the repeated load, lb. (or N),

ν = Poisson's ratio of the asphalt mixture,

δ_H = the total recoverable horizontal deformation, in. (or mm.), and

t = thickness of specimen, in. (or mm).

A Poisson's ratio value of 0.35 has been recommended by ASTM to be reasonable for asphalt mixtures at 77°F (25°C).

The layer structural coefficient is obtained from the laboratory measured elastic modulus with the correlation chart provided by the AASHTO Design Guide. Although the laboratory tests are performed at a room temperature of 72°F (22°C), while the correlation chart is based upon a temperature of 68°F (20°C), the difference is considered insignificant.

Note that a designation of 301 or 446 materials mainly indicates the allowable aggregate gradation ranges. Within each type of material, significant variations in actual gradation, aggregate texture, angularity, asphalt and air void content can exist. Therefore, substantial variability of the resilient modulus may be expected for materials conforming to the same specification. Distributions of asphalt cement and air voids are often uneven within the specimen; as a result, specimen size can affect the measured resilient modulus value.

2.2 Back Calculation of Layer Elastic Modulus

In this approach, nondestructively (NDT) measured surface deflections are used to back calculate layer elastic modulus. Pavement deflection data at chosen pavement sections are obtained using the Falling Weight Deflectometer (FWD). The deflection basin measured at each location and the known layer thickness information are major input to the back calculation program MODULUS. The MODULUS program searches for the best combination of layer modulus that minimizes the differences between the calculated and measured deflection basin. About 30 deflections are measured at each site to account for the spatial variation of underlying materials. Each deflection basin back calculates a set of layer elastic modulus and roadbed soil modulus. An average elastic modulus is obtained for the materials of interest. The structural coefficient is then estimated using the correlation chart shown in Figure 1 and 2.

2.3 Estimation Based on AASHTO Performance Equation

The third approach determines the "effective" structural number (SN) of a pavement section using the AASHTO flexible pavement performance equation based on known roadbed soil resilient modulus and performance history (traffic loading and serviceability loss). The structural coefficient is then estimated from the effective SN and the layer thickness. The AASHTO flexible pavement performance equation is:

$$\log W_{18} = Z_R S_O + 9.36 \log(SN + 1) - 0.20 + \frac{\log\left[\Delta PSI /(4.2 - 1.5)\right]}{0.4 + 1094 /(SN + 1)^{5.19}} + 2.32 \log M_R - 8.07 \quad (3)$$

where:

W_{18} = the number of 18-kip (80-kN) single-axle load applications,

Z_R = the normal deviate for a given reliability R,

S_O = the overall standard deviation,

SN = structural number of pavement, which is computed by equation (1),

ΔPSI = the reduction in serviceability,

M_R = the effective roadbed soil resilient modulus

The AASHTO equation simply indicates that the number of 18-kip (80-kN) single-axle load repetitions that pass through a pavement can be related to its performance in terms of the serviceability loss, ΔPSI, when the pavement's structural number, SN, and the effective roadbed soil resilient modulus, M_R, are known. Because we are interested in finding the average value of structural coefficient, a reliability level of 50% applies. The standard normal deviates, Z_R, equals zero when R equals 50%. Therefore, the reliability term is zero and need not be considered.

Change in Pavement Serviceability Index (ΔPSI)

The AASHTO performance equation uses the present serviceability index (PSI) as the measure for performance. A well-constructed new asphalt surfaced pavement is assumed to have a PSI value of about 4.5. PSI value generally decreases with increasing cumulative traffic, unless rehabilitation is performed to restore the PSI value to a higher level. Depending on the highway category, PSI data are collected yearly or every other year for all highways in Ohio. These PSI data are available from the ODOT Pavement Management Database.

The PSI value is primarily a function of ride smoothness. To a much smaller extent, the PSI is also affected by surface distresses such as cracking, rutting, and patching. Because adding the surface distress data only improves the PSI estimation by about 5%, (Zaniewski et al., 1985), many agencies (including ODOT) use only pavement roughness to estimate PSI.

Roughness data vary with the type of equipment used for measurement. Mays ridemeter, a popular response type road roughness meter (RTRRM), was used by ODOT for years. However, ODOT has since adopted the more advanced technology of laser profilometer. Proliometer results are less dependent upon the specific vehicle suspension, tire pressure, speed, and other factors that affect vehicle response. ODOT currently converts profilometer data back to Mays ridemeter results, then correlates Mays ridemeter results to PSI values. Therefore, the PSI values available from ODOT are only as good as such conversion and correlation.

Equivalent Single Axle Load (ESAL) Applications, W_{18}

Once a serviceability loss between two specific dates is obtained from PSI record, the number of equivalent 18-kip (80-kN) single axle load applications during the same time period is needed. The ESAL value is estimated using the ESAL99 program provided by ODOT. This program uses historical truck counts as well as historical ESAL values to generate a regression equation which predicts future ESAL for a specific route. The independent variable is the year and the cumulative ESAL up to that year is computed. The specific equations for each test section are shown in Appendix C. These equations allow interpolation of specific date when the PSI is measured. For example, August 30 of 1985 may be expressed by the number 1985.67 and the cumulative ESAL up to that date can be computed using the ESAL99 regression equation.

Resilient modulus of roadbed soils

Roadbed soil characteristics can significantly affect flexible pavement responses. The AASHTO flexible pavement design equation uses roadbed soil resilient modulus (M_r) to characterize the structural contribution of roadbed soil. The design structural number (SN) and the pavement thickness are highly sensitive to the value of roadbed soil resilient modulus. Therefore, accurate roadbed soil resilient modulus estimation is important.

To obtain the effective roadbed soil resilient modulus values, in-situ samples of soil underneath the pavement are obtained by pushing 4-in. (101-mm) diameter Shelby tubes into the roadbed soil. The soil specimens are then extruded from the tubes. Each specimen is trimmed down to about 8 inches (202 mm) long and stored in sealed glass jars before resilient testing. The moisture content and the liquid and plastic limits for each soil sample are obtained. Wet sieve analyses are also performed to obtain the percent passing no. 200 sieve.

The "saturated" resilient modulus is measured using the same soil specimen, but after the soil specimen has been back pressured in water in an attempt to recreate saturated or nearly-saturated condition. Soils are not remolded to minimize disturbance; however, the pore water pressure needed to reach near-saturation condition within reasonable amount of time is high enough to cause some disturbance of the soil structure.

The resilient modulus of the roadbed soil is determined by the repeated load triaxial test as specified in AASHTO T274-82: Resilient Modulus of Subgrade Soils. The specimen is 4-in (101-mm) in diameter and 8 in. (203 mm) in height. A confining air pressure (σ_3) of 6 psi (41 kPa) and a deviator stress (σ_d) of 10 psi (69 kPa) are applied to the soil specimen. The average recoverable vertical deformations measured by two LVDTs after 200 repetitions are recorded. The recoverable strain (ε_r) is obtained by dividing the average recoverable deformation by the LVDT clamps. The resilient modulus, M_R, is computed by:

$$M_R = \frac{\sigma_d}{\varepsilon_r}$$

The specimen is then back pressured with water to obtain near saturation conditions. The time required depends on the soil's permeability, moisture content, and the water pressure applied. On average, about 12 hours of back-pressuring period is needed for each specimen. This is very time consuming, because only one specimen can be tested at a time.

Due to the equipment and time requirements, determination of soil resilient modulus in the laboratory is not always feasible. Other methods have been used to estimate the soil resilient modulus. One is to back calculate soil resilient modulus from measured pavement surface deflections. The back calculation method is described earlier. The soil elastic modulus obtained from back calculation may be correlated with that from laboratory testing.

Another method of estimating soil resilient modulus is by using traditional, easier to obtain, soil parameters. The AASHTO soil classification system uses the group index, which is a function of the percentage passing no. 200 sieve, the liquid limit, and the plasticity index, to classify the roadbed soils. The group index ranges from 0 to 20 and can be determined using the following formula.

$$GI = 0.2a + 0.005ac + 0.01bd \qquad (4)$$

where a = that portion of the percentage passing No. 200 sieve greater than 35 percent and not exceeding 75 percent, expressed as a positive integer (0 to 40)

b = that portion of the percentage passing No. 200 sieve greater than 15 percent and not exceeding 55 percent, expressed as a positive integer (0 to 40)

c = that portion of the numerical liquid limit greater than 40 and not exceeding 60, expressed as a positive integer (0 to 20)

d = that portion of the numerical plasticity index greater than 10 and not exceeding 30, expressed as a positive integer (0 to 20)

Since the Group Index can be obtained using equipment available in most soil laboratory, it is used by ODOT to estimate the effective roadbed soil resilient modulus for routine pavement design. The Group Index ranges between 0 to 20 with higher values corresponding to lower resilient modulus. ODOT uses the Group Index to estimate the California Bearing Ratio (CBR), then use the CBR to estimate the resilient modulus. This procedure is also used to estimate the soil resilient modulus for comparison.

Most roadbed soils in Ohio may be classified as A-6 or A-7 and have a Group Index between 5 and 10. The roadbed soil resilient modulus would typically range from 5,000 psi (34.5 MPa) to 10,000 psi (69 MPa).

Once the effective soil resilient modulus (M_R), the PSI loss during a specific time period, and the ESAL (W18) during that time period have been determined for a pavement section, the SN value can be solved from equation (3) by trial and error. With known SN and pavement layer thickness, structural coefficient of a specific layer can be estimated. When both 301 and 446 materials are present at the same time duration, their structural coefficients may be dependent upon each other; that is, choosing one value would determine the other. In these cases, an iteration process may be needed to find the most reasonable values for both materials.

Figure 5 shows a summary of the three approaches described in this chapter.

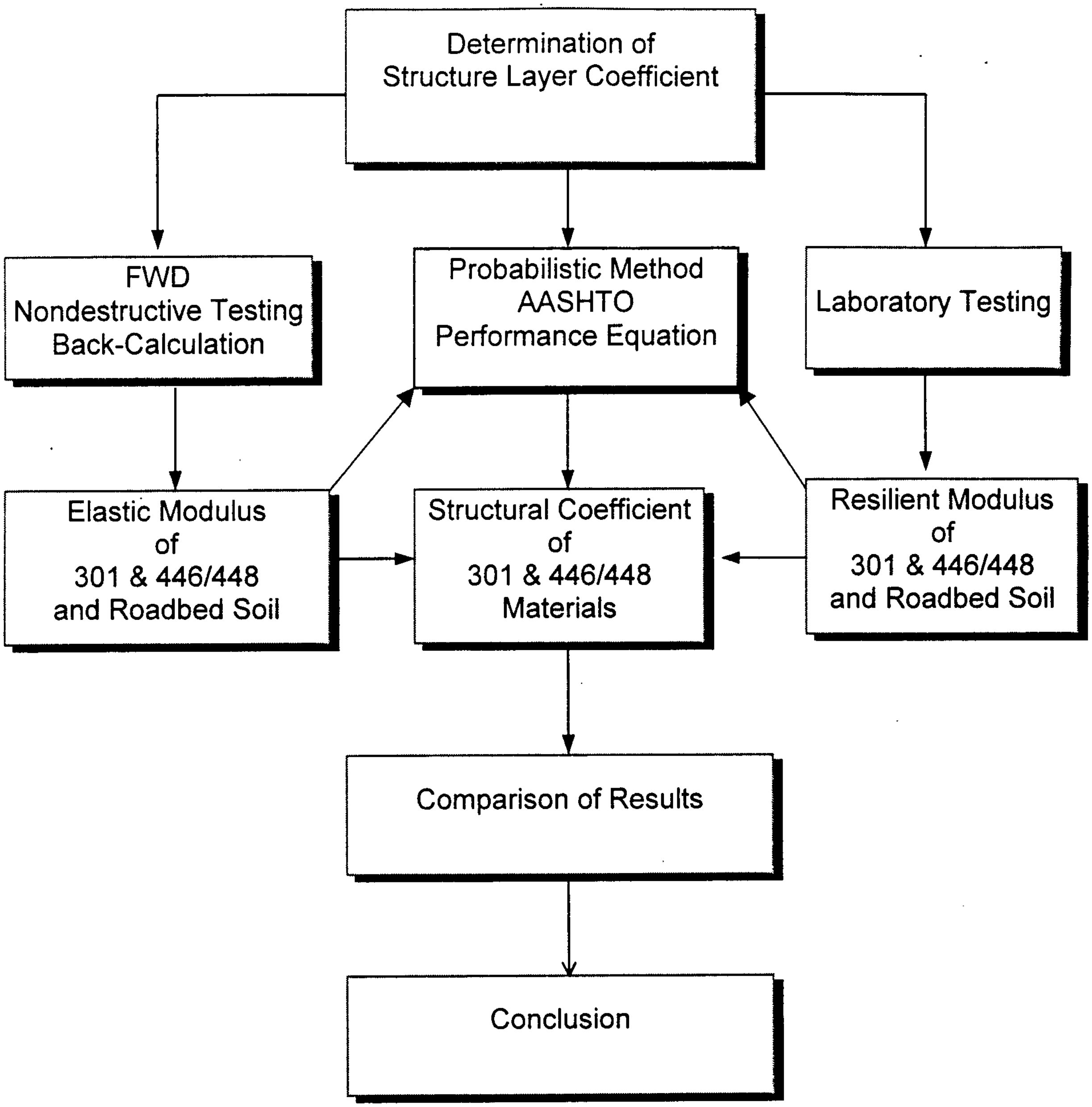

Figure 5. Summary of Study Approach

CHAPTER THREE

FINDINGS

3.1 Resilient Modulus of Cored Asphalt Materials

The following observations can be made from the cored samples of 301 and 446/448 materials:

1. The 301 materials have much larger maximum aggregate size and sometimes contain large air voids.
2. Materials from the Athens US-50 and Jackson US-35 test sites consist mostly of uncrushed river gravel for both 301 and 446/448, while aggregates from other sections are mainly crushed limestone.
3. Cracks, some of which may be caused by the coring operation, are found in some 301 layers. In order to perform laboratory resilient modulus measurement, cored specimens are sawed so that only materials that have no visible cracks are retained.
4. Several layers of asphalt concrete materials may be included in the 446/448 material specimen in order to have sufficient specimen thickness (minimum 2.5 in. or 63.5 mm) for resilient modulus test.

The resilient modulus and the corresponding structural coefficient for 301 bituminous aggregate base specimens are summarized in Table 2 and those for 446 asphalt concrete are shown in Table 3. The structural coefficients are obtained using the correlation chart shown in Figure 1 and 2. A more detailed account of each specimen's resilient modulus and the corresponding structural coefficients are included in Appendix B.

The average layer structural coefficient for 301 materials based on 46 specimens is 0.37 while the average value for 446/448 materials based on a total of 20 specimens is 0.49. The range for 301 materials is 0.33 to 0.43 and for 446 materials is 0.46 to 0.55. The latter is based on only 20 specimens; therefore, the structural coefficient of 446 materials may not be as reliable as that of 301 materials.

Notice that the average resilient modulus of 446 materials is only slightly higher than that of 301 materials, but the resulting structural coefficients show much greater difference. This is due to the fact that the structural coefficients are estimated using different correlation charts (Figure 1 and 2). Given the same resilient modulus, Figure 1 would give a higher structural coefficient than Figure 2.

Resilient modulus is not the only parameter that influences the structural coefficient value. Locations within the pavement structure, layer thickness, traffic loading, and vehicle speed can all affect the structural coefficient. The correlation charts used here represent only the average conditions.

Table 2. Average Resilient Modulus of 301 Bituminous Aggregate Base

Pavement Section (1)	Number of Data (2)	Average Resilient Modulus (x10^3 psi) (6.895MN/m^2) (3)	Coefficient of Variation (%) (4)	Estimated Structural Coefficient (5)	Overall Resilient Modulus (x10^3 psi) (6.895MN/m^2) (6)	Overall Structural Coefficient (7)
Athens US-50	14	702.7	33.3	0.37	608.8	0.37
Crawford US-30	3	421.0	4.1	0.33		
Franklin I-270	7	656.7	24.2	0.38		
Jackson US-35	7	576.6	21.7	0.37		
Marion US-23	4	729.0	32.1	0.39		
Wood SR-795	11	567.0	18.3	0.37		

Table 3. Average Resilient Modulus of 446/448 Asphalt Concrete

Pavement Section (1)	Number of Data (2)	Average Resilient Modulus ($\times 10^3$ psi) ($6.895MN/m^2$) (3)	Coefficient of Variation (%) (4)	Estimated Structural Coefficient (5)	Overall Resilient Modulus ($\times 10^3$ psi) ($6.895MN/m^2$) (6)	Overall Structural Coefficient (7)
Athens US-50	11	572.3	31.2	0.48	646.4	0.49
Franklin I-270	5	525.8	11.7	0.46		
Marion US-23	3	841.0	19.3	0.55		

3.2 Back Calculated Layer Modulus

The layer elastic modulus back calculated from pavement deflections and the corresponding structural coefficients are shown in Table 4. Currently available back calculation procedures still have difficulties converging to a set of reasonable layer modulus values when the number of layer is great than 3 and when relatively thin layers, say, less than 4 or 5 inches, are present. Therefore, combining adjacent thin layers is necessary to obtain reasonable back calculation results.

Using the correlation charts again in Figure 1 and Figure 2, the resulting average structural coefficients are 0.44 for 301 materials and 0.55 for 446/448 materials. These values are higher than those obtained from laboratory testing. The back calculated elastic modulus values for surface layers are usually higher than those obtained from laboratory testing. This may be attributed, at least partly, to the multi-layer elastic model in general and the MODULUS back calculation procedure in particular.

The resilient modulus determined from laboratory testing is likely more accurate than that obtained from back calculation, because the latter involves significant assumptions and approximations. Nevertheless, back calculation from nondestructively measured deflections remains the only practical tool for network-level pavement structural evaluation.

Table 4. Back Calculated Layer Modulus Result

Section ID (1)	Pavement Structure (2)	Assumed Thickness (in.) (3)*	Average Modulus E (psi) (4)	Layer Coefficient a_i (5)
Athens US-50	3"AC (1990) 4.5"AC (1983) 8"301 4"304 base	Surface: 7.5 Base: 8.0 Subbase: 4.0 Subgade: 122.9	E_1=1,116,000 E_2= 555,900 E_3= 74,700 E_{subg}= 17,800	$a_{446/448}$=0.57 a_{301}=0.48
Columbiana-11	3"AC (1991) 3"301 6.25"AC (1983) 6"824 6"304 base	Pavement: 6.0 Base: 12.5 Subbase: 6.0 Subgade: 82.4	E_1=1,850,000 E_2= 530,300 E_3= 92,300 E_{subg}= 17,500	$a_{446/301}$=0.60
Crawford-30	4.5"AC (1983) 8"301 9.5"310 base	Pavement: 4.5 Base: 8.0 Subbase: 9.5 Subgade: 56.6	E_1= 323,000 E_2= 236,000 E_3= 28,100 E_{subg}= 7,900	a_{848}=0.38 a_{301}=0.25
Franklin-270	3"AC (1987) 10"301	Pavement: 3.0 Base: 9.0 Subgade: 272.8	E_1=1,573,000 E_2= 317,400 E_{subg}= 27,900	a_{846}=0.60 a_{301}=0.37
Jackson-35	3"AC (1992) 9"301 6"304 base	Pavement: 3.0 Base: 9.0 Subbase: 6.0 Subgade: 268.5	E_1=1,444,000 E_2= 762,000 E_3= 71,900 E_{subg}= 23,000	a_{301}=0.53
Marion-23	6"AC (1992&82) 9"301 6"310 base	Pavement: 6.0 Base: 9.0 Subbase: 6.0 Subgade: 123.4	E_1=1,235,000 E_2= 486,700 E_3= 69,700 E_{subg}= 16,200	$a_{446/448}$=0.60 a_{301}=0.45
Wood-795	4.25"AC (1981) 7"301 6"310 base	Pavement: 4.25 Base: 7.0 Subbase: 6.0 Subgade: 75.4	E_1=1,068,000 E_2= 379,200 E_3= 18,300 E_{subg}= 9,400	a_{301}=0.40

Note: * The AC layer may include 404/402 as well as 446/448 materials.
** 1 in. = .0254 m = 2.54 mm; 1 psi = 6.895 kN/m^2.

3.3 Structural Number in AASHTO Performance Equation

Given the cumulative ESAL (W_{18}), PSI loss (ΔPSI), and roadbed soil resilient modulus (M_R), the structural number of the pavement can be calculated from the AASHTO performance equation. The structural coefficient can then be estimated from the known structural number given pavement layer thickness. However, the result of this method is very sensitive to the input parameters, especially ΔPSI and M_R.

The exact test location, the actual wheel path, and test equipment may all affect PSI measurement, which is primarily a function of pavement smoothness. Therefore, PSI values may remain the same or even increase slightly between adjacent years. The longer the time period, however, the more reliable the ΔPSI value is. The PSI data between 1985 and 1995 are obtained from ODOT database for the test sections. An initial PSI value of 4.5 is assumed for pavement sections constructed before 1985.

The characteristics of the roadbed soils at the test sites, including group index and laboratory measured resilient modulus, are shown in Table 5. Correlation between the group index and laboratory measured resilient modulus is very poor. This indicates there could be a problem in estimating soil resilient modulus from its group index as suggested in the current ODOT design manual. Laboratory measured resilient modulus values are

Table 5. Characteristics of Roadbed Soils from Laboratory Testing

Sample ID	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Passing No. 200 (%)	Group Index	AASHTO Class.	In Situ Mr (psi)	Saturated Mr (psi)
A1A	12.9	32.0	21.6	10.4	99.9	8.2	A-6	3418	2138
A4A	18.0	28.0	17.4	10.6	75.8	8.2	A-6	2351	2285
A5A	14.4	27.5	17.6	10.0	56.7	4.3	A-6	4024	3630
A5C	10.9	24.0	14.9	9.1	47.5	2.5	A-4	3084	4488
A6A	18.0	31.9	22.1	9.8	92.0	8.0	A-6	3226	---
A6B	10.7	32.0	21.1	10.9	66.4	6.6	A-6	4177	---
A6C	31.6	32.0	21.1	10.9	98.0	8.4	A-6	3164	2288
A7A	15.3	32.0	21.6	10.4	79.5	8.2	A-6	3418	1516
A7B	15.9	25.0	18.0	7.0	52.9	3.6	A-4	4150	4057
A7C	28.8	35.0	22.5	12.5	61.9	6.4	A-6	---	---
C2	12.5	24.3	14.3	10.0	69.6	6.9	A-6	4474	2117
C3	12.7	21.8	15.4	6.4	46.6	2.3	A-4	3237	1452
C4	10.8	22.0	17.0	5.0	58.7	4.7	A-4	---	---
C5	8.9	34.5	21.5	13.0	26.2*	9.2	A-6	3238	1488
C6	7.8	20.5	16.0	4.5	24.2*	8.0	A-6	---	1679
C9	12.5	23.0	17.0	6.0	29.1*	8.0	A-6	4253	1673
F2	8.6	26.5	17.6	8.9	72.7	7.5	A-4	1793	---
F4	15.8	35.0	22.0	13.0	54.6	5.1	A-6	2160	1708
F6	14.0	26.0	21.0	5.0	68.2	6.6	A-4	---	---
F7	16.9	32.0	18.0	14.0	45.6	3.3	A-6	---	---
F8	15.3	32.0	19.0	13.0	64.8	7.2	A-6	---	---
F9	13.7	31.3	20.0	11.3	65.1	6.5	A-6	6250	4874

Sample ID	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Passing No. 200 (%)	Group Index	AASHTO Class.	In Situ Mr (psi)	Saturated Mr (psi)
J7	16.8	28.0	19.0	9.0	70.8	7.2	A-4	---	---
J8	15.6	30.8	20.0	10.8	73.1	7.9	A-6	2604	2749
J9	13.9	30.0	18.9	11.1	68.9	7.2	A-6	2324	1307
M10	16.9	26.0	14.9	11.2	67.4	6.9	A-6	1795	2009
M11	12.4	26.7	17.4	9.3	68.1	6.6	A-4	2102	2198
M12	33.5	36.0	26.0	10.0	74.3	7.9	A-6	---	---
M13	10.1	33.5	21.1	12.5	88.4	9.0	A-6	1936	1115
M14	9.0	24.8	17.5	7.3	84.1	8.0	A-6	1641	1440
M15	9.1	27.3	15.9	11.4	60.6	5.7	A-6	4134	3099
M16	13.0	26.0	16.2	9.8	67.0	6.4	A-4	3180	3396
M17	9.7	28.0	16.7	11.3	67.1	6.9	A-6	1866	1309
M18	12.6	21.5	14.8	6.7	48.3	2.7	A-4	1226	1618
W1A	12.6	32.5	18.0	14.5	84.9	9.8	A-6	4689	2109
W1B	15.5	32.5	18.0	14.5	76.1	9.8	A-6	3088	---
W1C	8.7	32.5	18.0	14.5	84.9	9.8	A-6	6176	3597
W2A	16.4	27.0	16.0	11.0	74.1	8.2	A-6	---	---
W2B	13.1	28.0	15.4	12.6	80.9	9.0	A-6	5390	4226
W2C	13.3	28.0	15.4	12.6	78.9	9.0	A-6	4562	3602
W3A	12.7	25.0	18.0	7.0	81.4	8.0	A-6	6665	3700
W3B	16.6	34.0	23.5	10.5	74.4	8.1	A-6	3431	3185
W3C	23.4	48.5	25.6	22.9	95.7	14.9	A-6	3528	2476
W5A	12.5	35.0	18.1	16.9	82.8	10.8	A-6	2671	2914
W5B	15.7	33.1	20.4	12.7	70.8	8.2	A-6	2123	2708
W5C	17.3	32.5	23.0	9.5	79.6	8.0	A-6	4987	3526
W6A	23.8	25.8	14.9	10.8	84.4	8.3	A-6	4136	2275

generally very low. The low values may be due to the confining and deviator stress levels applied which corresponds to the worst-case conditions. Some specimens failed during resilient modulus testing. Actual roadbed soil resilient modulus is likely to be higher than the laboratory value through most of the year. Further investigation should be conducted to determine the relationship between the group index and the laboratory resilient modulus.

Table 6 compares the laboratory measured soil resilient modulus, modulus estimated from the group index, and the back calculated modulus. The value from back calculation is divided by a factor of 3 to obtain the comparable design value as suggested by the AASHTO Design Guide. The correlation between modulus estimated from the group index and the back calculated modulus is good (R = 0.70). Back calculated roadbed soil modulus is more accurate than back calculated surface or base layer modulus, because roadbed soil has a much higher thickness. The laboratory resilient modulus test for roadbed soil is less reliable than resilient modulus test for asphalt mixtures, because specimens are less stable and can be disturbed easily during handling and testing. A number of soil specimens have to be discarded because they collapsed before testing.

Table 6. Average Roadbed Soil Resilient Modulus

Section ID (1)	Average Roadbed Soil Resilient Modulus* (psi)		
	Laboratory Measured (2)	Estimated from Group Index (3)	Back Calculated from Deflection (4)
Athens US-50	3400	9100	6000
Columbinana SR-11	3800	9000	5800
Franklin I-270	4200	9300	9200
Jackson US-35	2300	8400	7700
Marion US-23	2300	8900	5400
Wood SR-795	4300	7300	2900

*Rounded to the nearest 100.

As a result, the roadbed soil modulus range of between 6,000 to 10,000 psi ($41.37 MN/m^2$ to $68.95 MN/m^2$) is considered more reasonable.

The structural coefficient computation is shown in Table 7. Typically two SN values are computed, one before overlay and one after. The difference in SN divided by the overlay thickness gives the structural coefficient of the overlay material (typically 446/448-asphalt concrete). For 301 materials, some have been in the field for decades and some were built more recently (for example, Columbiana SR-11 in 1991 and Franklin I-270 in 1987).

Using lower soil resilient modulus would produce a higher estimation of the structural coefficient. Table 8 shows the structural coefficients computed based on the soil resilient modulus determined from laboratory testing, the group index, and back calculation. For 446 materials, the average structural coefficient is 0.52, 0.39, and 0.43, respectively. For 301 materials, the values is 0.42, 0.26, and 0.30, respectively. For reasons stated previously, the latter two numbers are considered more reliable.

Variations among the pavement test sites are significant. For 446 materials, the high value is at Marion US-23 (0.57) and low is at Athens US-50 (0.25), with Franklin I-270 (0.36) and Columbiana SR-11 (0.39) in the middle. For

Table 7. Structure Number (SN) and Layer Coefficient Calculation Using AASHTO Performance Equation

Section ID (1)	Date (2)	Cumulative W_{18} (3)	M_R^* (psi) (4)	PSI (5)	ΔPSI (6)	SN^{**} (7)	D_1 (in.) (8)	D_2 (in.) (9)	D_3 (in.) (10)	a_1^{**} (446) (11)	a_2^{**} (301) (12)
Athens US-50	8/1995	1,640,794	3,446	3.52	0.33	5.27	7.5	8	4		
	6/1991	1,265,187	(6,000)	3.85		(3.54)				0.51	0.34
	6/1990	1,228,540		2.87		3.74				(0.25)	(0.22)
	6/1985	892,361		3.63	0.76	(2.77)	4.5	8	4		
Columbia. SR-11	8/1995	5,955,347		3.84	0.12	6.83	6	12.25	6	0.47	0.40
	9/1994	5,628,080	3,801	3.96		(5.71)				(0.39)	(0.35)
	6/1990	4,261,652	(5,833)	2.96		4.23					
	6/1985	2,858,487		4.11	1.15	(3.51)	6.25	6	6		
Crawford US-30	8/1995	12,329,034		3.96	0.40	7.21	7.5	8	9.5	-----	-----
	6/1990	9,941,423	-----	4.36		(7.45)				(0.58)	(0.42)
	5/1983	6,781,056	(2,700)	2.89		5.11					
	8/1968	1,857,499		4.50	1.61	(5.29)	2.5	8	9.5		
Franklin I-270	9/1995	16,649,036	3,401	3.57		6.35				0.57	0.46
			(9,233)		0.93	(4.39)	3	10	0	(0.36)	(0.33)
	9/1987	7,333,583		4.50							

Conti.

Section ID (1)	Date (2)	Cumulative W_{18} (3)	M_R^* (psi) (4)	PSI (5)	ΔPSI (6)	SN^{**} (7)	D_1 (in.) (8)	D_2 (in.) (9)	D_3 (in.) (10)	A_1^{**} (446) (11)	a_2^{**} (301) (12)
Jackson US-35	7/1995 7/1993	7,817,184 7,135,910	2,464 (7,667)	3.69 4.09	0.40	6.42 (3.37)	3	9	6	----	0.50 (0.16)
Marion US-23	8/1995 8/1993 6/1989 6/1986	13,747,998 12,44878 9,838501 8,178332	2235 (5400)	4.03 4.21 3.44 3.75	0.18 0.31	9.38 (7.13) 8.17 (6.08)	7 4	9 9	6 6	0.62 (0.57)	0.54 (0.32)
Wood SR-795	9/1995 9/1993 7/1991 7/1985	1,247,813 1,108,311 967,799 627,485	4,287 (2,900)	3.09 3.25 2.93 3.76	0.16 0.83	5.54 (6.56) 3.24 (3.99)	4.25	7	6	----	0.27 (0.31)

Note: * M_R values are laboratory determined resilient modulus, the values in the parenthesis are back calculated $E_{sub}/3$.
** The values in parenthesis are based on back calculated roadbed soil $E_{sub}/3$.

1 in. = .0254 m = 2.54 mm; 1 psi = 6.895 kN/m^2.

Table 8. Summary of Structure Coefficient Computed from AASHTO Performance Equation

	446/448 Asphalt Concrete			301 Bituminous Aggregate Base		
Pavement Section (1)	Based on Laboratory Measured Modulus (2)	Based on Group Index Estimated Modulus (3)	Based on Back Calculated Modulus (4)	Based on Laboratory Measured Modulus (5)	Based on Group Index Estimated Modulus (6)	Based on Back Calculated Modulus (7)
Athens US-50	0.51	0.24	0.25	0.34	0.15	0.22
Columbiana SR-11	0.47	0.38	0.39	0.40	0.35	0.35
Crawford US-30	---	---	0.58	---	---	0.42
Franklin I-270	0.55	0.36	0.36	0.46	0.33	0.33
Jackson US-35	---	---	---	0.50	0.23	0.16
Marion US-23	0.57	0.58	0.57	0.54	0.29	0.32
Wood SR-795	---	---	---	0.27	0.23	0.31
Average	0.52	0.39	0.43	0.42	0.26	0.30

301 materials, the high value is Crawford US-30 (0.42), followed by Columbiana SR-11 (0.35) and Franklin I-270 (0.33). The low values are Athens US-50 (0.15/0.22) and Jackson US-35 (0.23/0.16).

ODOT currently assumes a structural coefficient of 0.23 for existing asphalt layer. The values for some older 301 materials in Table 8 indicate that this assumption is fairly accurate.

The present method is based on the premise that the structural number, roadbed soil modulus, and cumulative traffic loading affect pavement performance. One important parameter that can significantly affect pavement performance is climate, specifically, temperature and moisture. This parameter is not considered explicitly, but is reflected in the present serviceability index measurement.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

Seven pavements test sites throughout the State of Ohio are selected for this study. The purpose is to determine the structural coefficient for 301 bituminous aggregate base and 446/448 asphalt concrete materials.

Three different approaches are employed. In the first approach, core specimens of in-service 301 and 446/448 materials are obtained from the test sites. The resilient modulus of the asphalt mixture is determined in the laboratory. The structural coefficient is then estimated from the resilient modulus using previously established correlation chart. For 301 materials, the resulting structural coefficient ranges between 0.33 and 0.39 with an average of 0.37. This result is very close to the currently assumed value of 0.35. The structural coefficient of 446/448 materials ranges between 0.46 to 0.54 with an average value of 0.49, which is much higher than the currently assumed value of 0.35.

The second approach uses pavement deflections to back calculate layer elastic modulus. The resulting average structural coefficients are 0.44 for 301 materials (range: 0.25~0.53) and 0.55 for 446 materials (range:

0.38~0.60). This result is not as reliable as the previous one, as evident by the much wider ranges.

The third approach uses the AASHTO flexible pavement performance equation to determine the layer structural coefficient based on actual traffic loading history and serviceability history data. This approach is considered the most direct estimate of the structural coefficient; however, the results are very sensitive to the input parameters. When laboratory measured roadbed soil resilient modulus are used, the average coefficient is 0.42 for 301 materials and 0.52 for 446 materials. When back calculated roadbed modulus values (multiplied by a factor Of 0.33) are used, the average coefficient is 0.30 for 301 and 0.43 for 446 materials. Finally, when the soil modulus is estimated from the group index, the average structural coefficient is 0.39 for 446/448 and 0.26 for 301 materials.

A study sample of seven pavements is not a statistically significant size. Therefore, simply averaging the structural coefficient values obtained would not be appropriate. However, since the test sites do represent a good variety of traffic volumes and geographic locations, an estimation of the structural coefficient can be made. A design structural coefficient should be chosen after carefully considering the risk of pavement structural failure versus initial material cost.

Based on the results from each method and considering the potential cost of pavement structural failure, the following structural coefficient values are recommended for state-wide flexible pavement design purpose: 0.35 to 0.37 for 301 bituminous aggregate base and 0.40 to 0.45 for 446/448 asphalt concrete materials.

Since flexible pavement thickness is very sensitive to the design effective roadbed soil resilient modulus chosen, further study is warranted to validate the current method of estimating soil modulus using group index.

The structural number approach of thickness design, which necessitates the selection of structural coefficient for each layer materials, does not always provide the same level of resistance to different types of distress. For example, a pavement structure may be adequate for resisting rutting distress throughout its design life, but may be inadequate for resisting fatigue cracking.

The structural coefficient as defined in the AASHTO flexible pavement design equation is not exactly a material property, but an equivalence factor. Therefore, estimating structural coefficient from correlating it with elastic modulus is an approximation at best. Ultimately, the Long Term Pavement Performance (LTPP) monitoring program should provide sufficient pavement performance data to ensure transition from a layer coefficient concept to a mechanistic design concept which does not need layer coefficients at all (i.e., the design is based on providing sufficient thickness to prevent specific types of distress).

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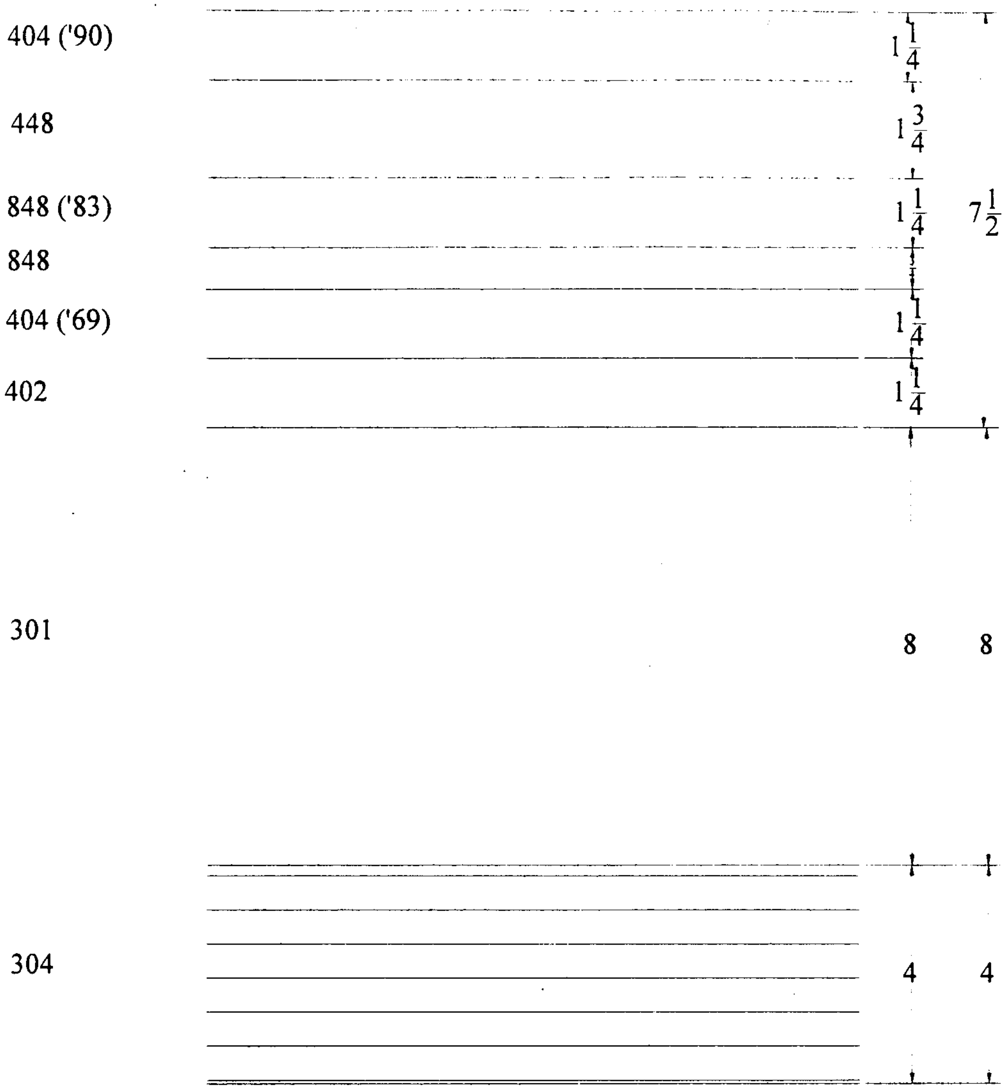
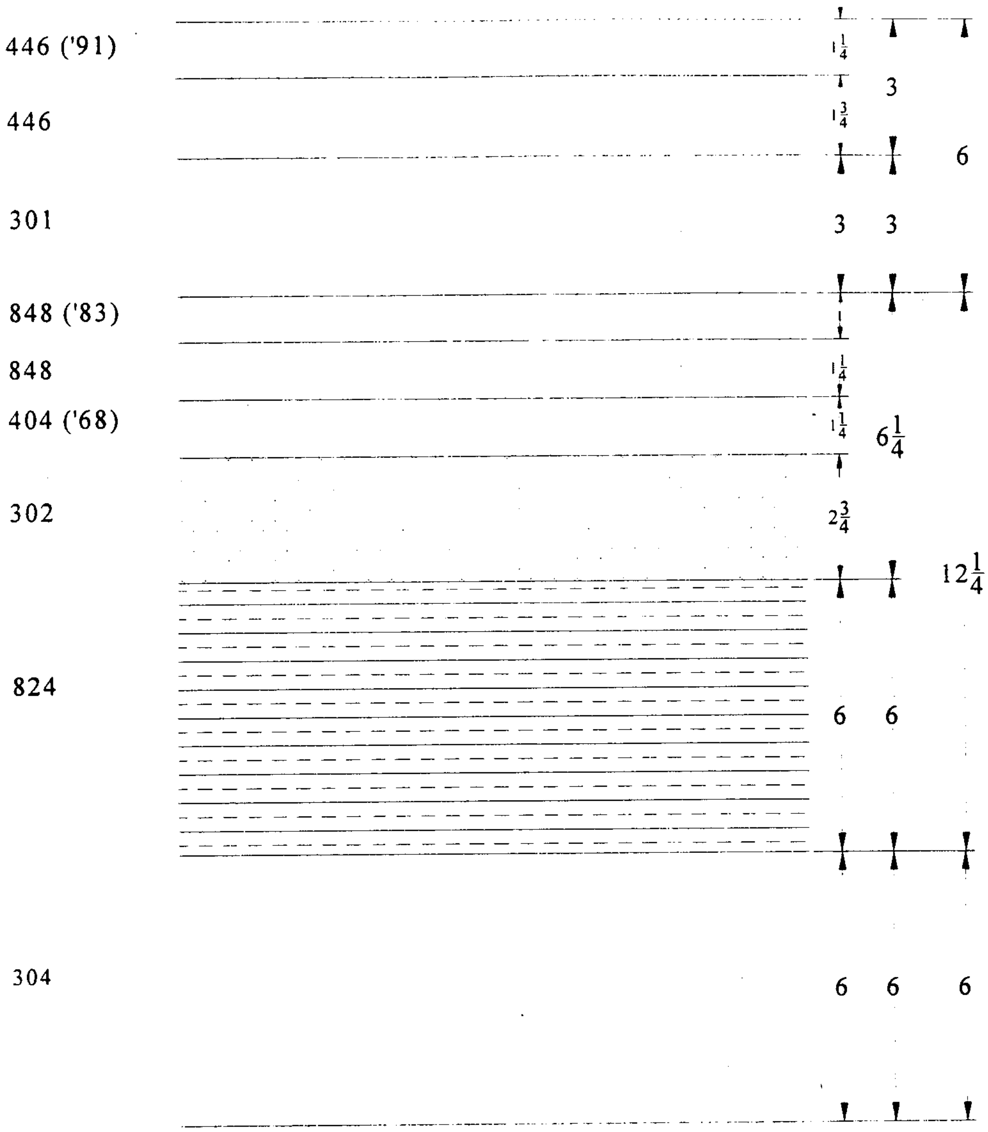
APPENDIX A. Cross Section of Tested Pavement Sections

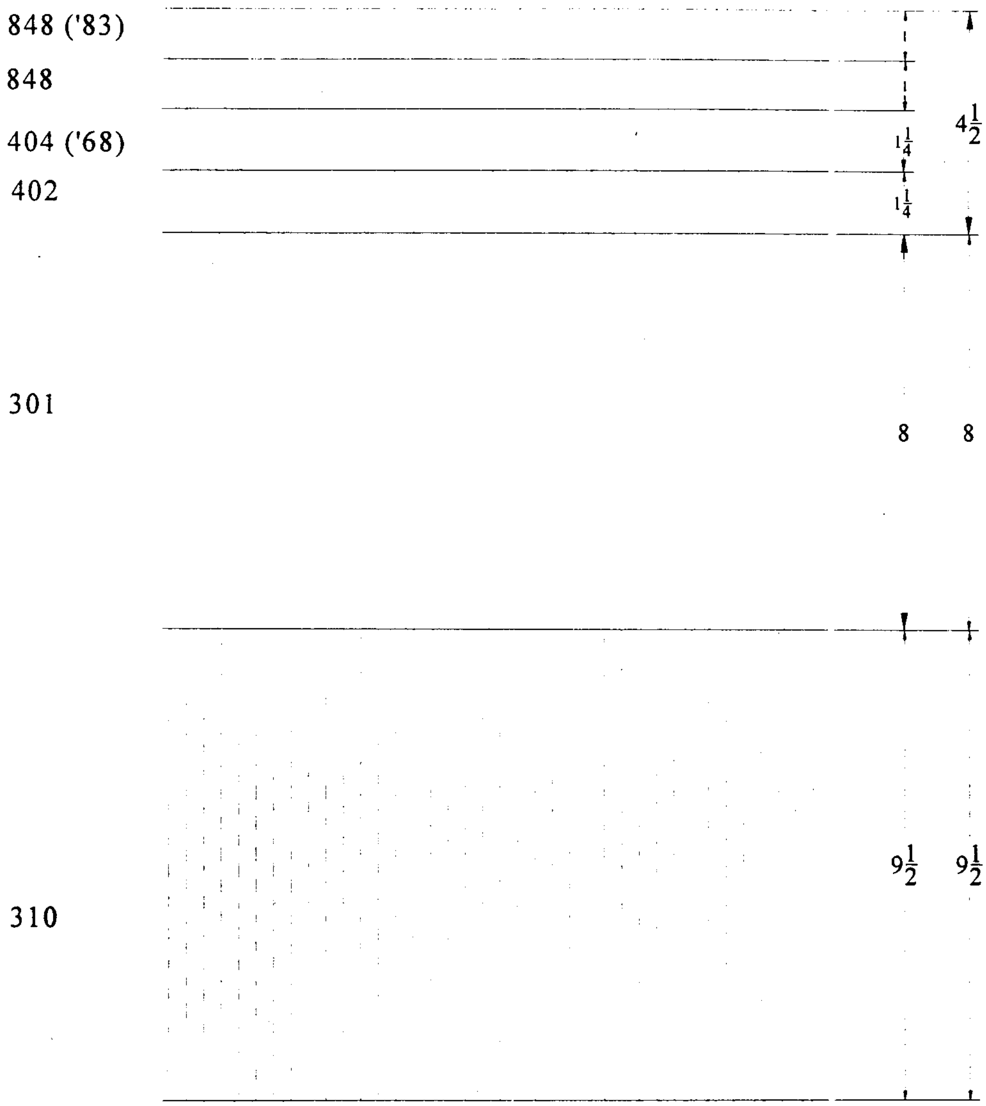
Cross Section of Athen US-50R



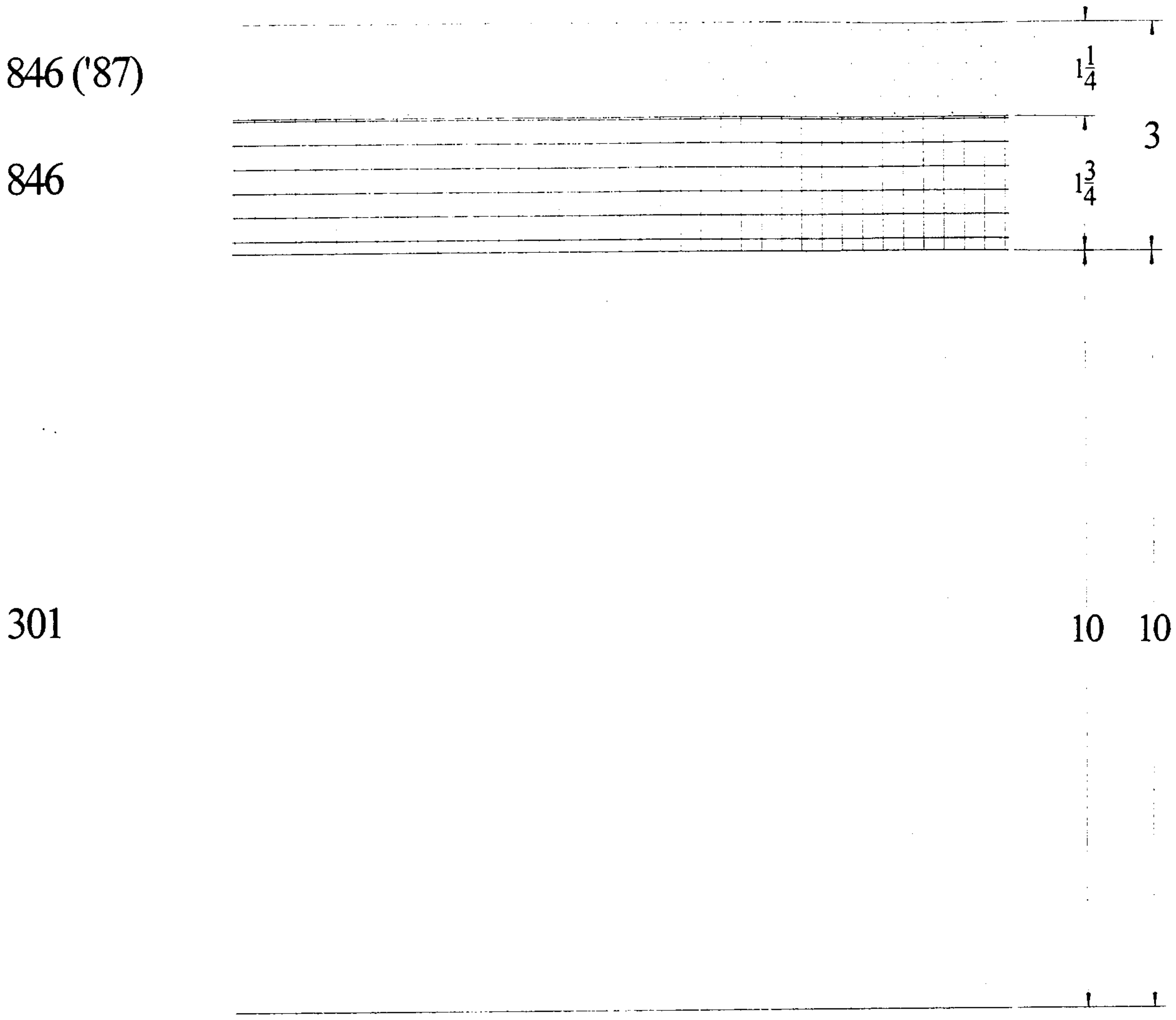
Cross Section of Columbiana SR-11R



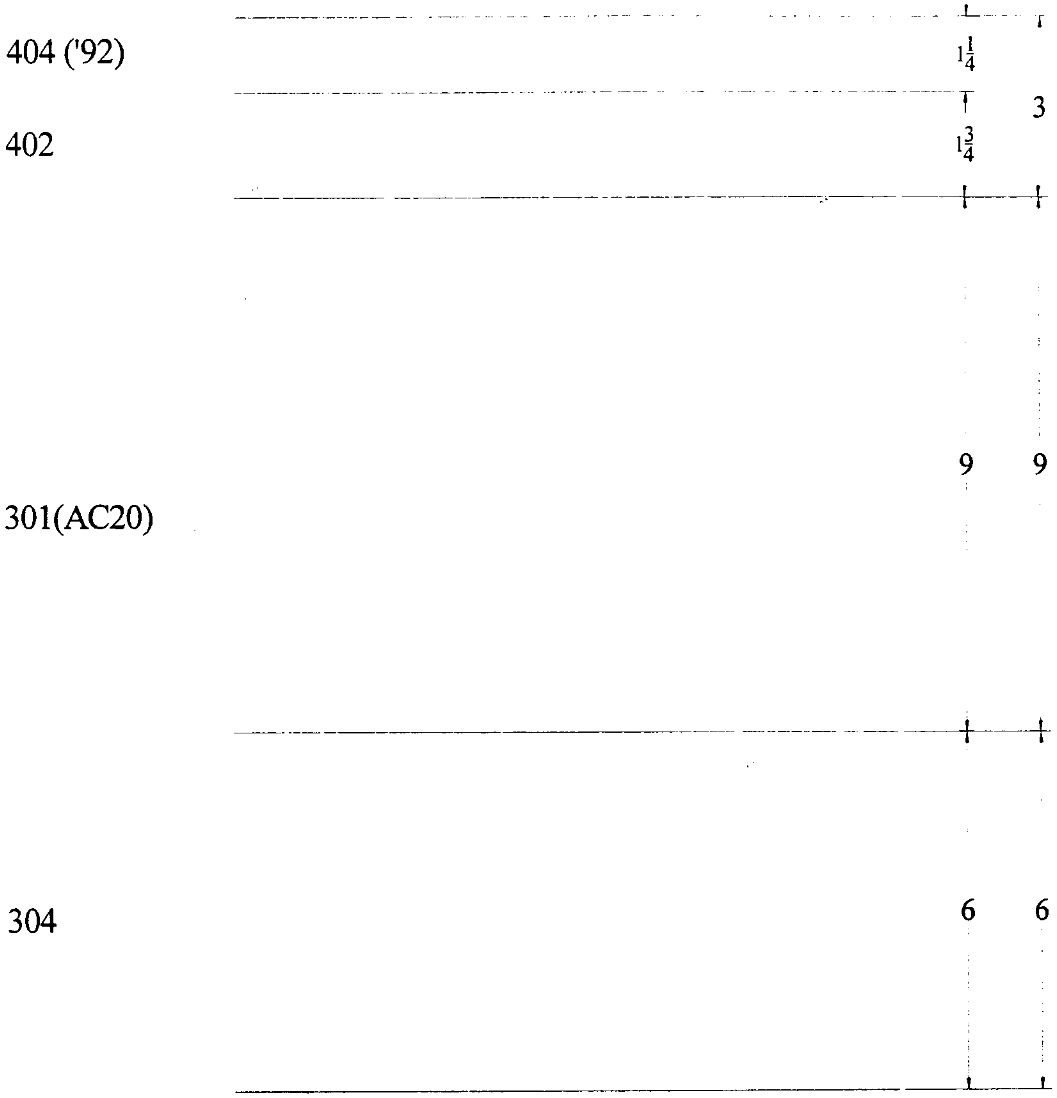
Cross Section of Crawford US-30R



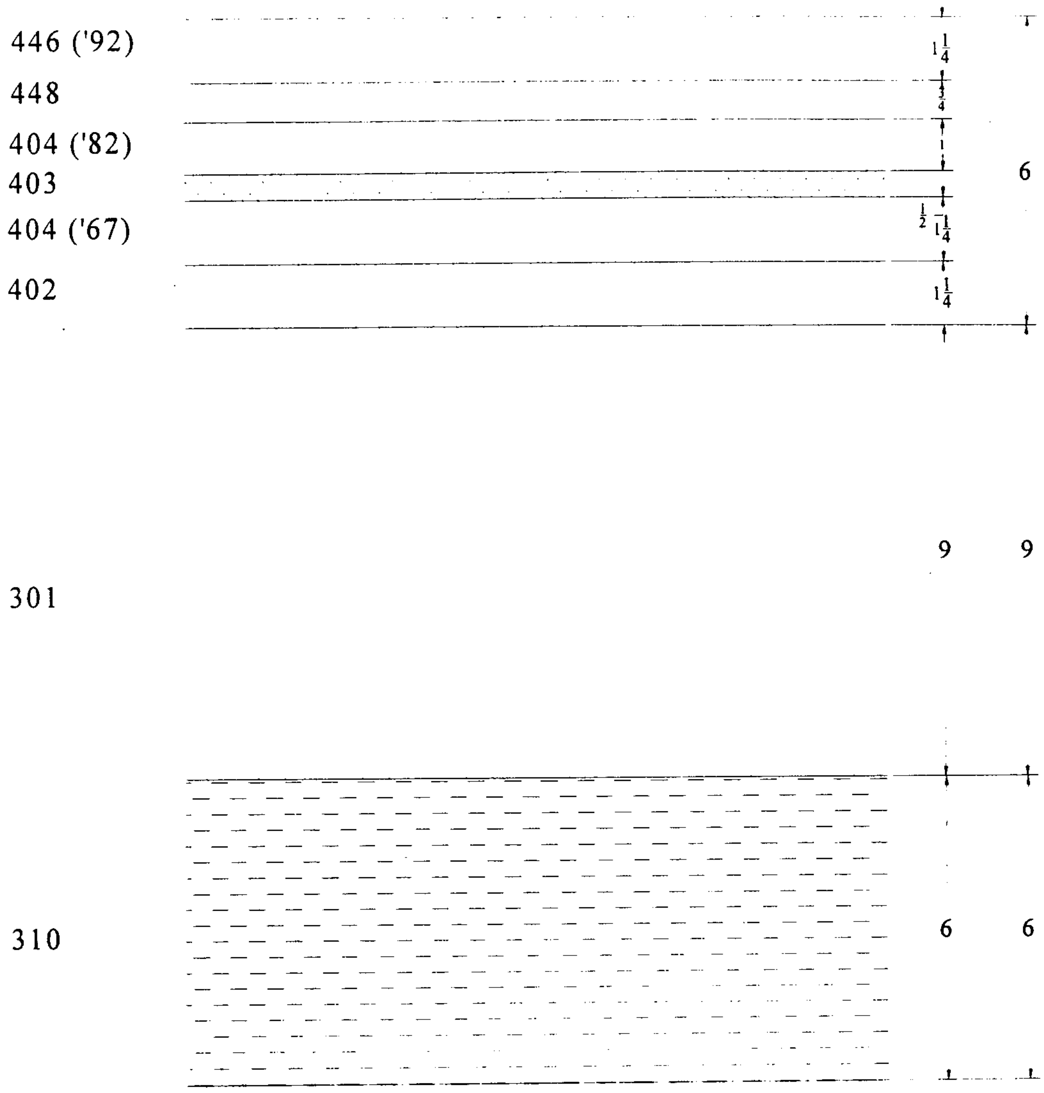
Cross Section of Franklin I-270R



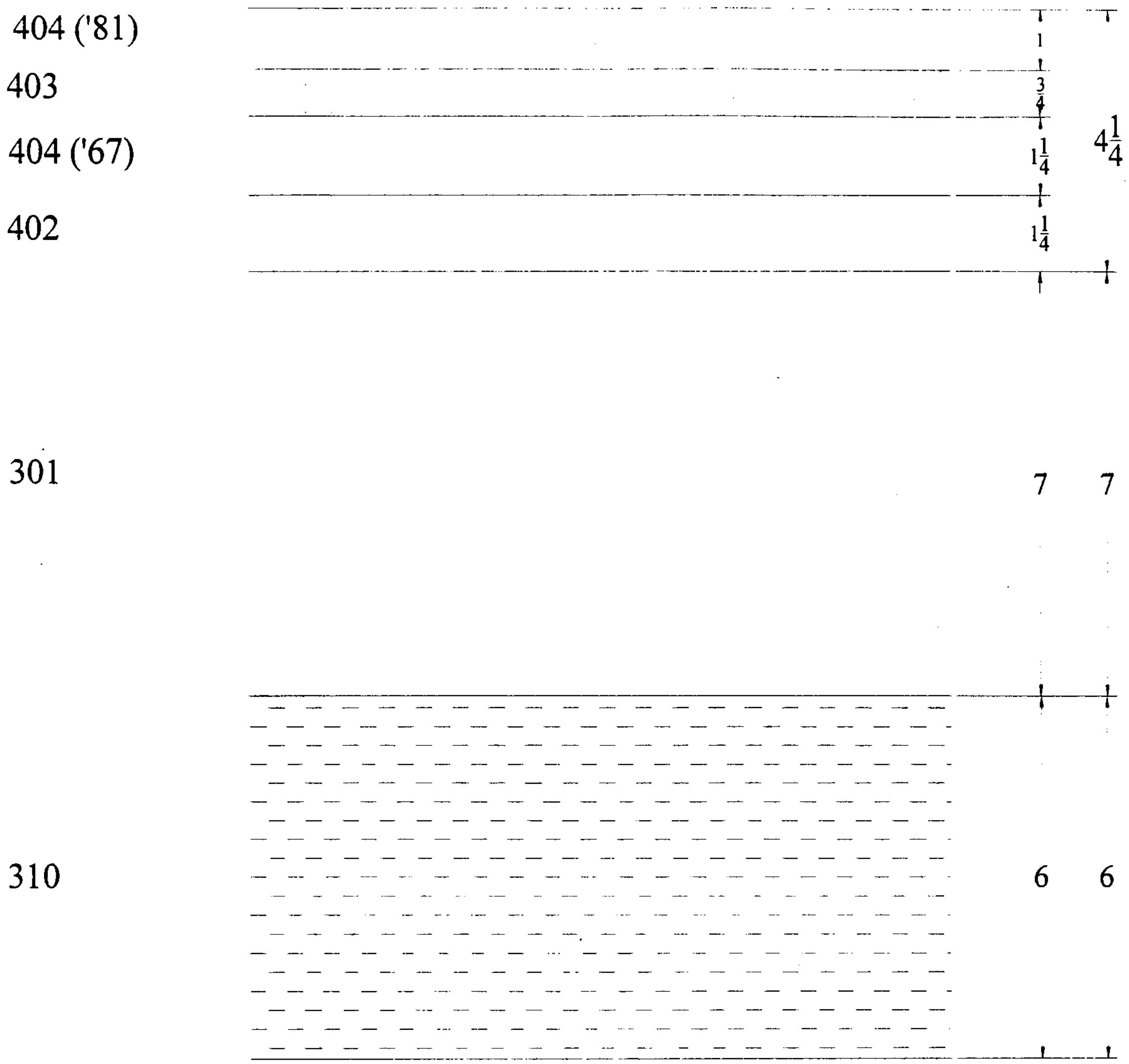
Cross Section of Jackson US-35



Cross Section of Marion US-23R



Cross Section of Wood SR-795R



APPENDIX B. Laboratory Resilient Modulus Test Results

Table B1. Laboratory Resilient Modulus of 301 Base Materials

Section ID (1)	Sample ID (2)	Material (3)	Sample Thickness (in.) (4)	Vertical Load (lbs.) (5)	Horizontal Displacement		E ($\times 10^3$psi) (8)	Avg. E ($\times 10^3$psi) (9)
					LVDT #1 ($\times 10^{-5}$in.) (6)	LVDT #2 ($\times 10^{-5}$in.) (7)		
Athens US-50	A-1a	301	3	431.9	1.4095	4.6379	1,238	1,215
		301	3	361.6	1.2827	3.9765	1,192	
	A-1b	301	3	270.1	5.0522	6.5507	403	361
			3	255.7	5.9434	7.4502	331	
			3	258.9	5.8723	7.0520	347	
	A-1c	301	2 1/2	219.6	4.6169	4.6542	493	519
			2 1/2	216.9	4.2363	5.2219	477	
			2 1/2	221.1	4.2291	4.0740	554	
			2 1/2	221.7	4.0533	4.3070	552	
	A-2a	301	2 7/8	268.8	2.3217	2.8412	942	855
		301	2 7/8	273.3	2.2795	4.1576	768	
	A-2b	301	2 5/8	276.9	1.8982	4.1041	914	1,091
		301	2 5/8	322.8	1.6681	3.3755	1,268	
	A-2c	301	2 7/8	336.2	1.0148	3.7093	1,287	1,141
		301	2 7/8	331.4	2.0016	4.0280	994	
	A-4a	301	2 13/16	330.8	5.2949	2.2077	815	756
		301	2 13/16	297.2	3.3645	4.5203	697	
	A-4b	301	2 7/8	414.6	3.0113	2.8178	1,287	1,216
		301	2 7/8	401.6	3.2242	3.1181	1,145	
	A-5a	301	2 1/4	475.9	8.1399	16.9160	439	441
			2 1/4	492.5	9.6339	16.0780	443	

Cont.

Section ID (1)	Sample ID (2)	Material (3)	Sample Thickness (in.) (4)	Vertical Load (lbs.) (5)	Horizontal Displacement		E ($\times 10^3$psi) (8)	Avg. E ($\times 10^3$psi) (9)
					LVDT #1 ($\times 10^{-5}$in.) (6)	LVDT #2 ($\times 10^{-5}$in.) (7)		
Athens US-50	A-6a	301	2 3/8	268.5	5.8391	6.3642	482	468
		301	2 3/8	268.9	3.0594	9.8940	454	
	A-6b	301	2 7/8	344.6	7.9768	7.9306	392	420
		301	2 7/8	297.5	6.5306	5.4554	449	
	A-7a	301	2 1/2	202.6	4.1885	4.1412	506	518
			2 1/2	198.4	4.3280	3.4670	529	
	A-7b	301	2 3/4	233.6	2.6390	2.6748	831	702
			2 3/4	295.9	6.4298	3.3283	573	
	A-7c	301	2 3/4	268.3	3.3949	3.7230	713	634
		301	2 3/4	255.0	3.9308	4.7394	556	
Crawford US-30	C-1	301	2 3/4	274.8	4.1153	8.5592	410	401
		301	2 3/4	280.2	5.8394	7.6624	392	
	C-2	301	2 3/8	269.3	7.4711	5.3724	459	430
		301	2 3/8	263.7	9.6602	4.7442	401	
	C-3	301	3	199.6	5.9020	2.2721	423	432
			3	190.5	5.1980	2.2888	441	
Franklin I-270	F-1	301	2 3/4	259.0	4.5689	3.0307	644	685
			2 3/4	236.8	3.2944	2.8753	726	
	F-2	301	3	207.4	3.9098	2.9986	520	543
			3	207.9	3.0877	3.3217	562	
			3	208.0	3.5031	3.0814	547	

Cont.

Section ID (1)	Sample ID (2)	Material (3)	Sample Thickness (in.) (4)	Vertical Load (lbs.) (5)	Horizontal Displacement		E ($\times 10^3$psi) (8)	Avg. E ($\times 10^3$psi) (9)
					LVDT #1 ($\times 10^{-5}$in.) (6)	LVDT #2 ($\times 10^{-5}$in.) (7)		
Franklin I-270	F-3	301	2 7/8	436.3	5.7528	5.1171	726	848
		301	2 7/8	399.1	4.5643	2.8833	969	
	F-4	301	2 7/8	291.5	2.9848	6.8327	537	580
		301	2 7/8	287.8	2.3199	6.0312	623	
	F-5	301	2 5/8	214.2	5.4580	5.3570	392	428
			2 5/8	222.1	4.1182	5.3874	463	
			2 5/8	224.9	5.3350	5.5046	411	
			2 5/8	223.4	4.6933	5.1908	448	
	F-7	301	3	287.8	0.8206	5.5647	781	863
		301	3	297.6	2.0557	3.4097	944	
	F-9	301	2 5/8	332.9	5.2250	4.2001	700	650
			2 5/8	330.3	5.3760	5.5210	600	
Jackson US-35	J-1	301	2 3/4	364.0	3.6430	5.7025	736	746
		301	2 3/4	384.8	4.1768	5.4483	756	
	J-2	301	2 15/16	356.6	7.4346	4.5721	527	659
		301	2 15/16	341.8	2.6494	5.0151	791	
	J-4	301	2 3/4	281.5	3.8320	7.2880	479	507
			2 3/4	266.4	3.3716	6.0420	535	
	J-5	301	3	283.6	4.6341	5.4555	487	400
			3	276.1	5.8108	6.9332	376	
			3	281.1	4.9498	8.0250	376	
			3	276.0	5.9423	7.3158	361	

Cont.

Section ID (1)	Sample ID (2)	Material (3)	Sample Thickness (in.) (4)	Vertical Load (lbs.) (5)	Horizontal Displacement		E (x10^{3}psi) (8)	Avg. E (x10^{3}psi) (9)
					LVDT #1 (x10^{-5}in.) (6)	LVDT #2 (x10^{-5}in.) (7)		
Jackson US-35	J-6	301	2 7/8	269.5	5.1974	5.1350	472	479
			2 7/8	269.4	5.1065	4.9190	486	
	J-7	301	2 1/2	313.1	6.4579	4.4504	597	558
		301	2 1/2	328.3	7.1600	5.9843	519	
	J-9	301	2 3/4	299.4	3.9101	4.5256	671	687
			2 3/4	319.2	3.9360	4.6450	703	
Marion US-23	M-13	301	2 3/4	291.9	3.6486	3.4663	776	803
		301	2 3/4	281.1	2.5235	3.8868	829	
	M-14	301	2 7/8	177.1	1.6916	4.8620	489	553
			2 7/8	191.5	1.4031	5.1430	529	
			2 7/8	189.0	4.3790	1.3399	598	
			2 7/8	186.2	4.2350	1.4046	597	
	M-17	301	2 7/8	378.3	3.4686	3.5009	982	1,028
		301	2 7/8	329.2	2.9811	2.5630	1,074	
	M-18	301	3	205.4	4.5193	2.5894	511	532
			3	208.7	5.4025	1.9086	505	
			3	210.1	5.3267	1.7277	527	
			3	204.7	4.3220	1.8923	583	
Wood SR-795	W-1b	301	3 1/16	316.2	4.3155	4.8623	585	578
			3 1/16	302.4	3.9830	5.4081	547	
			3 1/16	299.3	3.6429	4.7755	604	
	W-2a	301	2 1/2	312.4	5.3940	2.0966	867	684
		301	2 1/2	312.8	6.0338	6.9399	502	

Cont.

					Horizontal Displacement			
Section ID (1)	Sample ID (2)	Material (3)	Sample Thickness (in.) (4)	Vertical Load (lbs.) (5)	LVDT #1 ($x10^{-5}$in.) (6)	LVDT #2 ($x10^{-5}$in.) (7)	E ($x10^3$psi) (8)	Avg. E ($x10^3$psi) (9)
Wood SR-795	W-1c	301	3	212.0	2.8870	2.5008	682	600
			3	204.1	2.5830	3.3198	599	
			3	212.2	2.9860	3.3859	577	
			3	212.3	2.8820	3.9072	542	
	W-2b	301	3	268.5	4.8150	4.8679	481	524
			3	289.2	4.6010	4.6295	543	
			3	265.9	4.7560	4.5803	494	
			3	316.6	4.4505	4.4892	614	
			3	304.0	5.1430	5.6780	487	
	W-2c	301	3	210.4	2.3540	2.2542	791	775
			3	212.5	2.2603	2.3077	806	
			3	208.9	2.1731	2.6636	749	
			3	214.0	2.6777	2.2313	756	
	W-3a	301	3	307.9	3.4057	5.5543	596	518
		301	3	293.3	5.6048	5.9167	441	
	W-3b	301	3	561.5	9.3455	11.9883	456	466
		301	3	460.9	6.9902	9.7826	476	
	W-5a	301	3 1/4	546.9	5.6725	16.8360	389	396
			3 1/4	532.0	7.5619	13.9585	396	
			3 1/4	514.9	6.6293	13.7298	405	
	W-5b	301	3 1/4	492.5	4.4641	9.7034	556	622
		301	3 1/4	451.3	5.1153	5.3924	687	
	W-5c	301	3 1/4	447.9	11.1381	5.1600	440	513
		301	3 1/4	414.3	8.4013	2.9219	585	

Cont.

Section ID (1)	Sample ID (2)	Material (3)	Sample Thickness (in.) (4)	Vertical Load (lbs.) (5)	Horizontal Displacement LVDT #1 ($x10^{-5}$in.) (6)	Horizontal Displacement LVDT #2 ($x10^{-5}$in.) (7)	E ($x10^3$psi) (8)	Avg. E ($x10^3$psi) (9)
Wood SR-795	W-6a	301	2 7/8	342.0	5.7908	7.2689	474	561
			2 7/8	375.9	6.5530	8.7215	445	
			2 7/8	348.9	4.7682	6.1013	581	
			2 7/8	349.9	4.7682	5.9663	590	
			2 7/8	345.5	7.2147	1.2441	739	
			2 7/8	364.6	4.4902	6.9232	578	
			2 7/8	338.6	5.5861	7.2689	476	
			2 7/8	347.6	4.5689	5.7637	608	

Note: 1 in. = .0254 m = 2.54 mm; 1 lb. = 4.448 N; 1psi = 6.895 kN/m^2.

Table B2. Laboratory Resilient Modulus of 446/846 Asphalt Concrete

Section	Sample ID	Material	Sample Thickness	Vertical Load	Horizontal Displacement		E	Avg. E
					LVDT #1	LVDT #2		
			(in.)	(lbs.)	($x10^{-5}$in.)	($x10^{-5}$in.)	($x10^3$psi)	($x10^3$psi)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Athens US-50	A-1a	446	2 5/8	205.8	4.0984	8.5761	322	315
			2 5/8	208.3	4.6841	8.7158	308	
			2 5/8	207.7	4.5257	8.7087	311	
			2 5/8	204.4	4.7050	7.9892	319	
	A-1b	446	2 1/4	218.0	7.5688	1.3520	565	577
			2 1/4	203.7	5.4484	2.5270	590	
	A-2a	446	3	205.7	9.2920	2.9625	291	302
			3	204.0	10.4450	2.7696	268	
			3	207.0	7.8472	2.4348	349	
	A-2b	446	2 3/4	364.2	4.9649	3.2697	836	788
		446	2 3/4	327.8	3.7306	4.6450	740	
	A-2c	446	3	426.8	4.4639	4.2439	850	793
		446	3	358.0	6.6525	1.7635	737	
	A-4a	446	2 1/2	313.5	3.3991	5.9492	698	691
		446	2 1/2	291.3	2.5169	6.3344	685	
	A-4c	446	2 1/4	213.9	7.6550	1.2270	557	543
			2 1/4	214.9	8.5570	0.8320	529	
	A-5c	446	2 1/4	204.1	8.3298	5.1980	349	432
			2 1/4	201.6	6.3956	2.9121	501	
			2 1/4	201.5	5.7851	4.6533	446	
	A-6b	446	3	428.8	4.8526	7.9763	579	577
		446	3	395.4	5.9191	6.0166	574	

Cont.

					Horizontal Displacement			
Section ID (1)	Sample ID (2)	Material (3)	Sample Thickness (in.) (4)	Vertical Load (lbs.) (5)	LVDT #1 (x10^{-5}in.) (6)	LVDT #2 (x10^{-5}in.) (7)	E (x10^{3}psi) (8)	Avg. E (x10^{3}psi) (9)
Athens US-50	A-4c	446	2 1/4	213.9	7.6550	1.2270	557	543
			2 1/4	214.9	8.5570	0.8320	529	
	A-5c	446	2 1/4	204.1	8.3298	5.1980	349	432
			2 1/4	201.6	6.3956	2.9121	501	
			2 1/4	201.5	5.7851	4.6533	446	
	A-6b	446	3	428.8	4.8526	7.9763	579	577
		446	3	395.4	5.9191	6.0166	574	
	A-7a	446	2 1/2	265.2	2.2219	4.5576	814	781
		446	2 1/2	248.9	3.0946	3.8314	748	
	A-7b	446	2 1/4	201.0	2.4008	7.4729	470	496
			2 1/4	204.4	5.7332	3.6434	504	
			2 1/4	210.5	5.4028	4.0476	515	
Marion US-23	M-14	446	1 7/8	169.4	3.3383	1.2407	1,026	1,020
			1 7/8	162.0	3.2866	1.1429	1,014	
	M-17	446	1 15/16	262.0	6.2297	2.9129	769	801
			1 15/16	237.5	5.4260	2.2226	833	
	M-18	446	2 1/8	250.0	4.0984	4.2639	732	702
			2 1/8	241.0	4.8604	3.5997	697	
			2 1/8	239.9	4.4491	4.2117	678	
Franklin I-270	F-1	846	2 1/2	215.3	3.7257	6.3281	445	422
			2 1/2	213.1	4.6569	6.1163	411	
			2 1/2	210.5	6.1628	4.5427	409	

Cont.

					Horizontal Displacement			
Section ID (1)	**Sample ID** (2)	Material (3)	Sample Thickness (in.) (4)	Vertical Load (lbs.) (5)	LVDT #1 ($x10^{-5}$in.) (6)	LVDT #2 ($x10^{-5}$in.) (7)	E ($x10^{3}$psi) (8)	Avg. E ($x10^{3}$psi) (9)
Franklin I-270	F-4	846	2 3/8	371.9	8.9410	7.0048	511	521
		846	2 3/8	337.8	7.4695	6.4528	531	
	F-6	846	2 3/4	186.6	3.1419	3.3150	546	574
			2 3/4	185.2	3.1780	2.6971	596	
			2 3/4	187.4	2.9770	2.8880	604	
			2 3/4	186.5	3.1277	3.2940	549	
	F-8	846	2 7/8	280.4	3.3919	5.6939	558	550
		846	2 7/8	274.2	3.4261	5.7322	542	
	F-9	846	2 5/8	213.7	4.7751	3.3150	523	562
			2 5/8	210.6	4.0083	3.3450	567	
			2 5/8	212.6	4.1474	3.0160	588	
			2 5/8	207.7	3.0980	4.1082	571	

Note: 1 in. = .0254 m = 2.54mm; 1 lb. = 4.448 N; 1 psi = 6.895 kN/m^2.

Table B3. Summary of Structural Coefficient from Laboratory Testing

Section ID (1)	Material (2)	Sample ID (3)	Modulus (x10^{3}psi) (4)	Layer Coefficient $a_{301/446/846}$ (5)	Average Value (6)
Athens US-50	301	A-1a	1,215	0.40	Avg. Modulus E_2 = 738 ksi Avg. Coefficient a_{301} = 0.37
		A-1b	361	0.29	
		A-1c	519	0.36	
		A-2a	855	0.40	
		A-2b	1,091	0.40	
		A-2c	1,141	0.40	
		A-4a	756	0.40	
		A-4b	1,216	0.40	
		A-5a	441	0.34	
		A-6a	468	0.34	
		A-6b	420	0.33	
		A-7a	518	0.36	
		A-7b	702	0.40	
		A-7c	634	0.39	
	446	A-1a	315	0.36	Avg. Modulus E_1 = 572 ksi Avg. Coefficient a_{446} = 0.47
		A-1b	577	0.48	
		A-2a	302	0.36	
		A-2b	788	0.54	
		A-2c	793	0.54	
		A-4a	691	0.51	
		A-4c	543	0.47	
		A-5c	432	0.42	
		A-6b	577	0.48	
		A-7a	781	0.54	
		A-7b	496	0.45	
Crawford US-30	301	C-1	401	0.32	Avg. Modulus E_2 = 421 ksi Avg. Coefficient a_{301} = 0.33
		C-2	430	0.33	
		C-3	432	0.33	

Continue.

Section ID (1)	Material (2)	Sample ID (3)	Modulus ($\times 10^3$psi) (4)	Layer Coefficient $a_{301/446/846}$ (5)	Average Value (6)
Franklin I-270	301	F-1	685	0.40	Avg. Modulus E_2 = 657 ksi Avg. Coefficient a_{301} = 0.38
		F-2	543	0.37	
		F-3	848	0.40	
		F-4	580	0.37	
		F-5	428	0.32	
		F-7	863	0.40	
		F-9	650	0.39	
	846	F-1	422	0.41	Avg. Modulus E_1 = 526 ksi Avg. Coefficient a_{446} = 0.46
		F-4	521	0.46	
		F-6	574	0.49	
		F-8	550	0.47	
		F-9	562	0.48	
Jackson US-35	301	J-1	746	0.40	Avg. Modulus E_2 = 577 ksi Avg. Coefficient a_{301} = 0.37
		J-2	659	0.39	
		J-4	507	0.36	
		J-5	400	0.32	
		J-6	479	0.35	
		J-7	558	0.38	
		J-9	687	0.40	
Marion US-23	301	M-13	803	0.40	Avg. Modulus E_2 = 729 ksi Avg. Coefficient a_{301} = 0.39
		M-14	553	0.38	
		M-17	1,028	0.40	
		M-18	532	0.37	
	446	M-14	1,020	0.57	Avg. Modulus E_1 = 841 ksi Avg. Coefficient a_{446} = 0.54
		M-17	801	0.54	
		M-18	702	0.51	

Continue

Section ID (1)	Material (2)	Sample ID (3)	Modulus (x10^3psi) (4)	Layer Coefficient $a_{301/446/846}$ (5)	Average Value (6)
Wood SR-795	301	W-1b	578	0.38	Avg. Modulus E_2 = 567 ksi Avg. Coefficient a_{301} = 0.37
		W-2a	684	0.40	
		W-1c	600	0.39	
		W-2b	524	0.37	
		W-2c	775	0.40	
		W-3a	518	0.36	
		W-3b	466	0.34	
		W-5a	396	0.31	
		W-5b	622	0.39	
		W-5c	513	0.36	
		W-6a	561	0.38	

Note: 1 psi = 6.895 kN/m^2.

APPENDIX C. Traffic and Performance History Data

ESAL99 REGRESSION ANALYSIS

PROJECT INFORMATION

PROJECT NAME: ATH-50-3.20
FUNCTION CLASSIFICATION: URBAN PRIMARY
PAVEMENT TYPE: FLEXIBLE PAVEMENT

REGRESSION ANALYSIS RESULT

LINEAR MODEL:

ESAL = 0.04146761 * YEAR – 81.41363613
R Squared: 0.93462559

NON-LINEAR MODEL:

ESAL = 0.00110133 * YEAR^2 – 4.31163252 *YEAR + 4219.98467962
R Squared: 0.99164037
*ESAL = 0.00110134 * YEAR^2 – 4.31169198 *YEAR + 4220.04295066
R Squared: 0.99164016

TRAFFIC DATA

#	YEAR	B	C	DAILY ESAL	CUMULATIVE ESAL
1	1960	110	170	63.55	0.00000
2	1964	110	230	70.27	0.09776
3	1968	120	240	75.44	0.20420
4	1969	120	240	77.17	0.23207
5	1971	100	130	57.47	0.28124
6	1973	84	156	52.84	0.32153
7	1976	123	227	108.53	0.40995
8	1980	98	182	86.62	0.55250
9	1984	161	299	197.06	0.75972
10	1988	221	409	229.50	1.07133
11	1992	252	468	225.18	1.40347

ESAL99 REGRESSION ANALYSIS

PROJECT INFORMATION

PROJECT NAME: COL-11-16.30
FUNCTION CLASSIFICATION: URBAN PRIMARY
PAVEMENT TYPE: FLEXIBLE PAVEMENT

REGRESSION ANALYSIS RESULT

LINEAR MODEL:

$$ESAL = 0.22140923 * YEAR - 436.60738947$$

R Squared: 0.98600297

NON-LINEAR MODEL:

$$ESAL = 0.00441957 * YEAR^2 - 17.29156521 * YEAR + 16912.37268196$$

R Squared: 0.99909938

$$*ESAL = 0.00441920 * YEAR^2 - 17.29010432 * YEAR + 16910.94506771$$

R Squared: 0.99909980

TRAFFIC DATA

#	YEAR	B	C	DAILY ESAL	CUMULATIVE ESAL
1	1971	550	160	272.69	0.00000
2	1973	1,233	247	510.39	0.28602
3	1976	1,000	200	496.35	0.83758
4	1980	1,117	223	559.30	1.60873
5	1984	692	138	564.34	2.42955
6	1988	1,050	210	818.96	3.44004
7	1992	1,417	283	993.32	4.76391

ESAL99 REGRESSION ANALYSIS

PROJECT INFORMATION

PROJECT NAME: CRA-30-7.83
FUNCTION CLASSIFICATION: URBAN PRIMARY
PAVEMENT TYPE: FLEXIBLE PAVEMENT

REGRESSION ANALYSIS RESULT

LINEAR MODEL:

$$ESAL = 0.33622734 * YEAR - 659.92351245$$

R Squared: 0.98274953

NON-LINEAR MODEL:

$$ESAL = 0.00445408 * YEAR^2 - 17.26889481 * YEAR + 16736.10467808$$

R Squared: 0.99766459

$$*ESAL = 0.00445414 * YEAR^2 - 17.26916168 * YEAR + 16736.36384926$$

R Squared: 0.99766461

TRAFFIC DATA

#	YEAR	B	C	DAILY ESAL	CUMULATIVE ESAL
1	1960	970	420	439.47	0.00000
2	1964	1,280	350	557.04	0.72795
3	1968	1,360	360	590.53	1.56625
4	1969	1,460	300	683.01	1.79883
5	1971	1,600	260	741.79	2.31924
6	1973	2,000	500	944.33	2.93509
7	1976	1,656	414	1,112.77	4.06212
8	1980	1,600	400	1,075.14	5.66039
9	1984	1,440	360	1,117.95	7.26244
10	1988	1,544	386	925.89	8.75546
11	1992	1,904	476	1,178.10	10.29243

ESAL99 REGRESSION ANALYSIS

PROJECT INFORMATION

PROJECT NAME: FRA-270-35.00
FUNCTION CLASSIFICATION: URBAN PRIMARY
PAVEMENT TYPE: FLEXIBLE PAVEMENT

REGRESSION ANALYSIS RESULT

LINEAR MODEL:

$$ESAL = 0.91508724 * YEAR - 1811.06569716$$

R Squared: 0.98036050

NON-LINEAR MODEL:

$$ESAL = 0.02149458 * YEAR^2 - 84.46137521 * YEAR + 82967.07501622$$

R Squared: 0.99247645

$$*ESAL = 0.02149460 * YEAR^2 - 84.46145686 * YEAR + 82967.15475275$$

R Squared: 0.99247665

TRAFFIC DATA

#	YEAR	B	C	DAILY ESAL	CUMULATIVE ESAL
1	1978	1,946	324	853.76	0.00000
2	1982	2,614	436	1,317.31	1.58596
3	1986	3,686	614	4,341.72	5.71988
4	1990	2,983	497	1,756.27	10.17447
5	1994	6,429	1,071	3,490.86	14.00749

ESAL99 REGRESSION ANALYSIS

PROJECT INFORMATION

PROJECT NAME: JAC-35-1.80
FUNCTION CLASSIFICATION: URBAN PRIMARY
PAVEMENT TYPE: FLEXIBLE PAVEMENT

REGRESSION ANALYSIS RESULT

LINEAR MODEL:

ESAL = 0.20957345 * YEAR – 411.29532263
R Squared: 0.96669378

NON-LINEAR MODEL:

ESAL = 0.00379320 * YEAR^2 – 14.79121105 *YEAR + 14419.02998317
R Squared: 0.99647071
*ESAL = 0.00379320 * YEAR^2 – 14.79119669 *YEAR + 14419.01618205
R Squared: 0.99647061

TRAFFIC DATA

#	YEAR	B	C	DAILY ESAL	CUMULATIVE ESAL
1	1960	750	300	402.44	0.00000
2	1964	940	360	502.15	0.66080
3	1968	340	250	198.39	1.17254
4	1969	910	290	453.47	1.29159
5	1970	870	340	439.24	1.45462
6	1972	992	348	496.78	1.79650
7	1975	984	346	420.10	2.29884
8	1978	903	317	463.81	2.78311
9	1982	1,095	385	562.50	3.53283
10	1986	1,147	403	1,023.27	4.69124
11	1990	1,547	543	633.69	5.90164
12	1994	1,598	562	1,471.81	7.43971

ESAL99 REGRESSION ANALYSIS

PROJECT INFORMATION

PROJECT NAME: MAR-23-3.00
FUNCTION CLASSIFICATION: URBAN PRIMARY
PAVEMENT TYPE: FLEXIBLE PAVEMENT

REGRESSION ANALYSIS RESULT

LINEAR MODEL:

$$ESAL = 0.37430942 * YEAR - 735.27246865$$

R Squared: 0.95458300

NON-LINEAR MODEL:

$$ESAL = 0.00838852 * YEAR^2 - 32.79937752 *YEAR + 32061.45034377$$

R Squared: 0.99966209

$$*ESAL = 0.00838851 * YEAR^2 - 32.79932609 *YEAR + 32061.40016134$$

R Squared: 0.99966211

TRAFFIC DATA

#	YEAR	B	C	DAILY ESAL	CUMULATIVE ESAL
1	1960	410	190	223.64	0.00000
2	1964	740	270	393.43	0.45077
3	1968	1,270	180	635.55	1.20244
4	1969	1,270	180	612.44	1.43035
5	1970	1,690	400	829.56	1.69370
6	1972	1,840	460	904.59	2.32710
7	1975	1,824	456	758.62	3.23833
8	1978	2,160	540	1,085.00	4.24840
9	1982	1,920	480	964.44	5.74552
10	1986	2,328	582	1,981.17	7.89728
11	1990	2,256	564	889.06	9.99399
12	1994	3,064	766	2,719.68	12.63017

ESAL99 REGRESSION ANALYSIS

PROJECT INFORMATION

PROJECT NAME: WOO-795-2.49
FUNCTION CLASSIFICATION: URBAN PRIMARY
PAVEMENT TYPE: FLEXIBLE PAVEMENT

REGRESSION ANALYSIS RESULT

LINEAR MODEL:

ESAL = 0.03284474 * YEAR – 64.53583283
R Squared: 0.90080370

NON-LINEAR MODEL:

ESAL = 0.00105951 * YEAR^2 – 4.15716355 *YEAR + 4077.85995654
R Squared: 0.98894182
*ESAL = 0.00105951 * YEAR^2 – 4.15716407 *YEAR + 4077.86053844
R Squared: 0.98894200

TRAFFIC DATA

#	YEAR	B	C	DAILY ESAL	CUMULATIVE ESAL
1	1960	60	110	44.23	0.00000
2	1964	40	100	33.22	0.05658
3	1968	50	130	42.22	0.11169
4	1969	50	140	36.19	0.12601
5	1971	40	90	26.96	0.13754
6	1973	120	280	81.72	0.17723
7	1976	60	140	38.51	0.24311
8	1980	66	154	48.56	0.29081
9	1984	105	245	77.25	0.38272
10	1988	174	406	295.12	0.65473
11	1992	102	238	72.88	0.92356
12	1994	150	350	235.80	1.14905

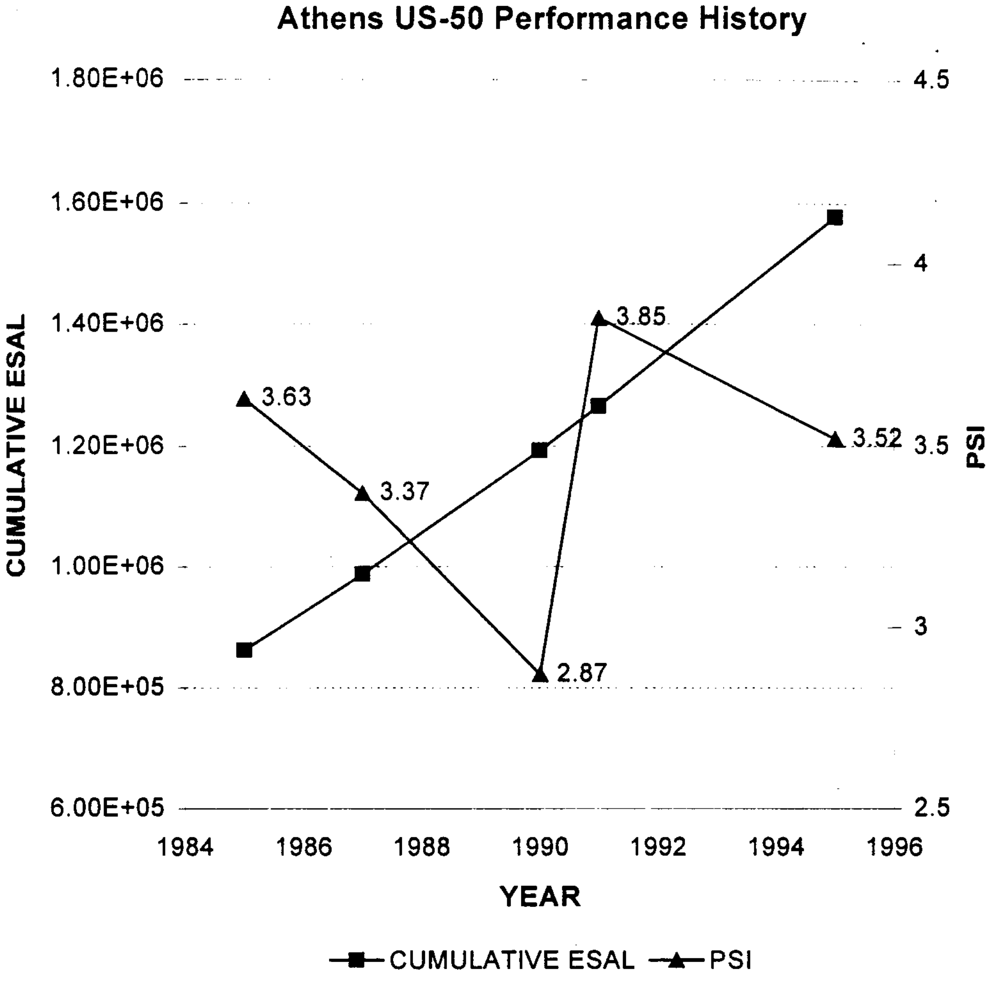


Figure C1. Traffic and PSI History of Test Section on Athens US-50

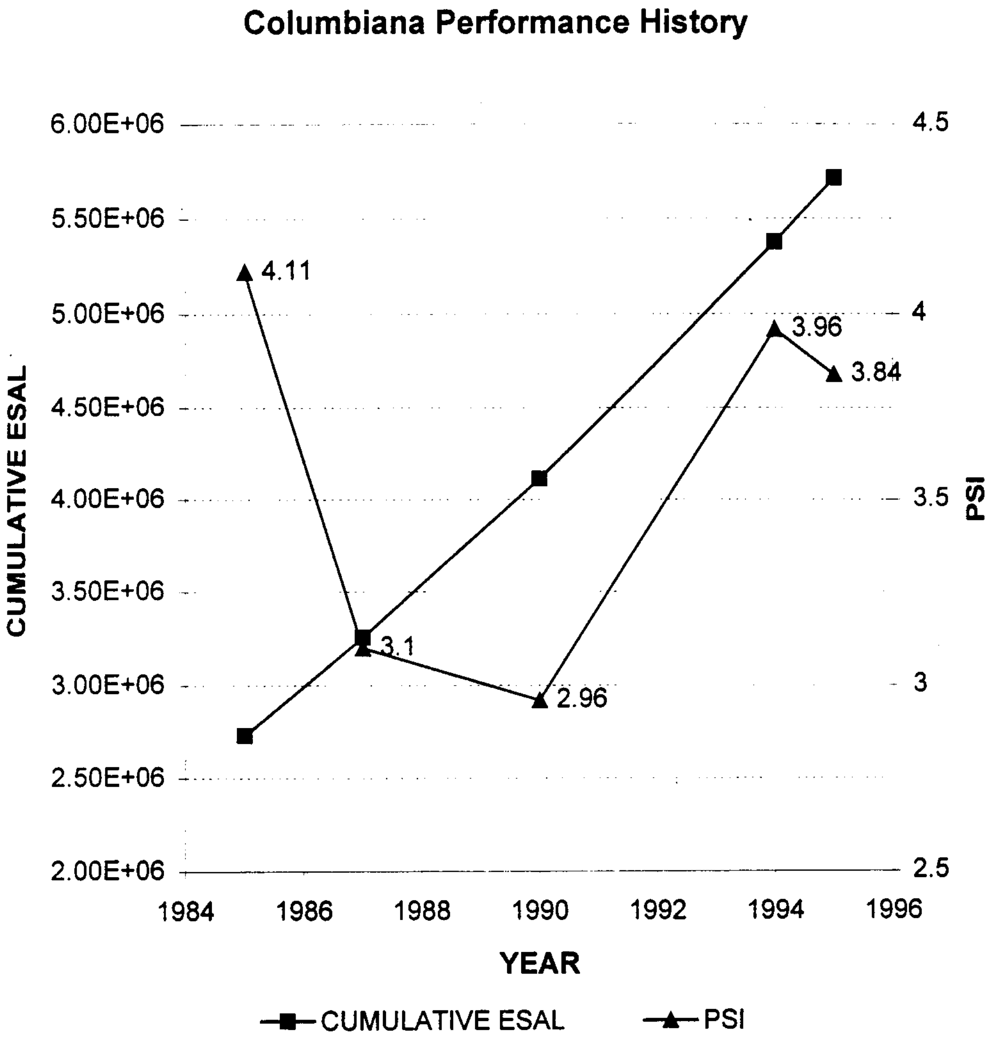


Figure C2. Traffic and PSI History of Test Section on Columbiana SR-11

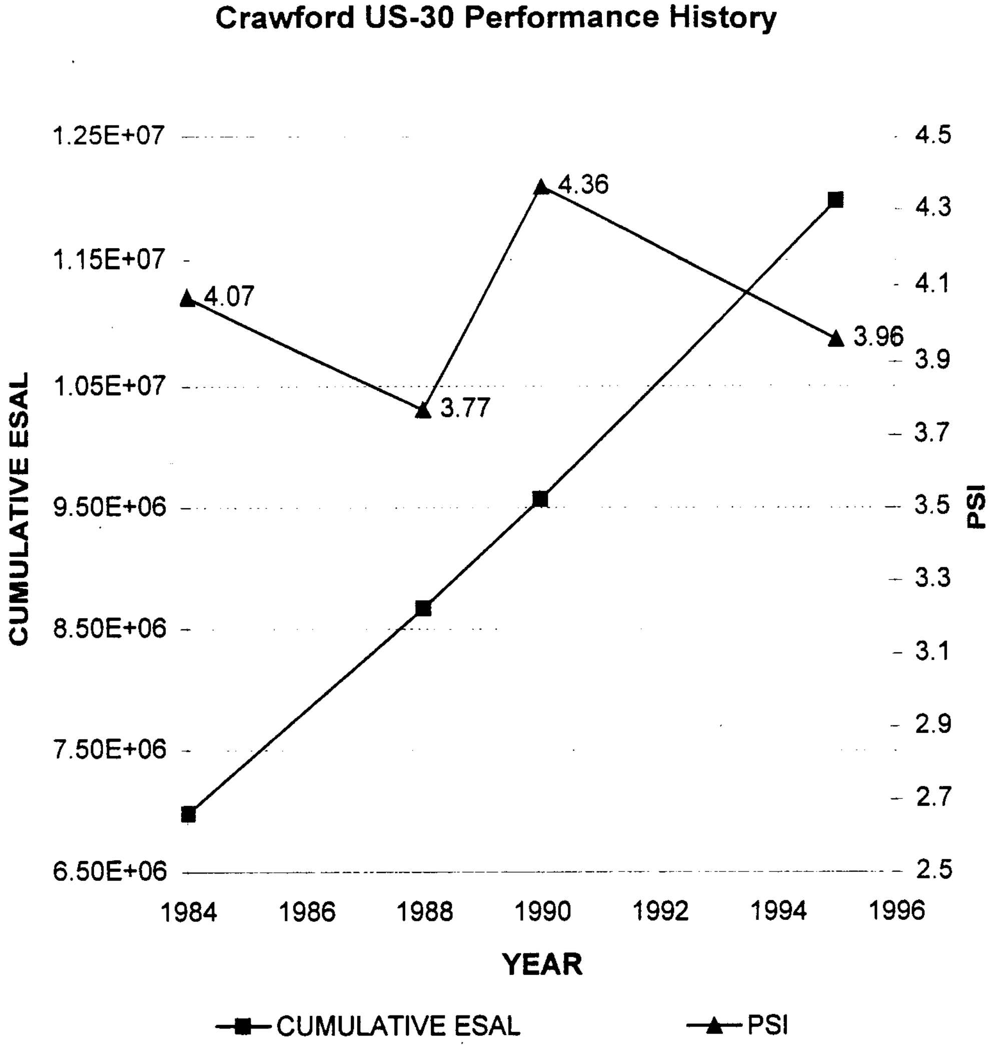


Figure C3. Traffic and PSI History of Test Section on Crawford US-30

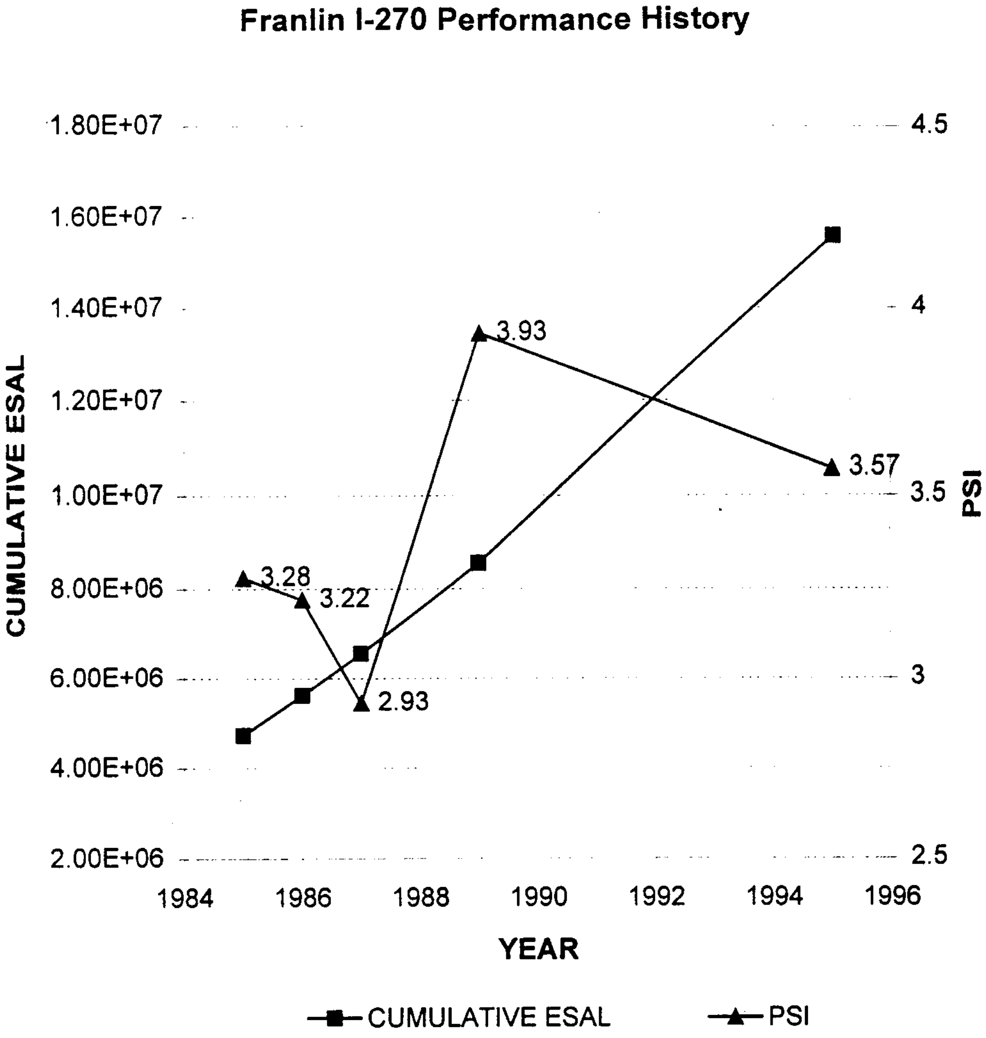


Figure C4. Traffic and PSI History of Test Section on Franklin I-270

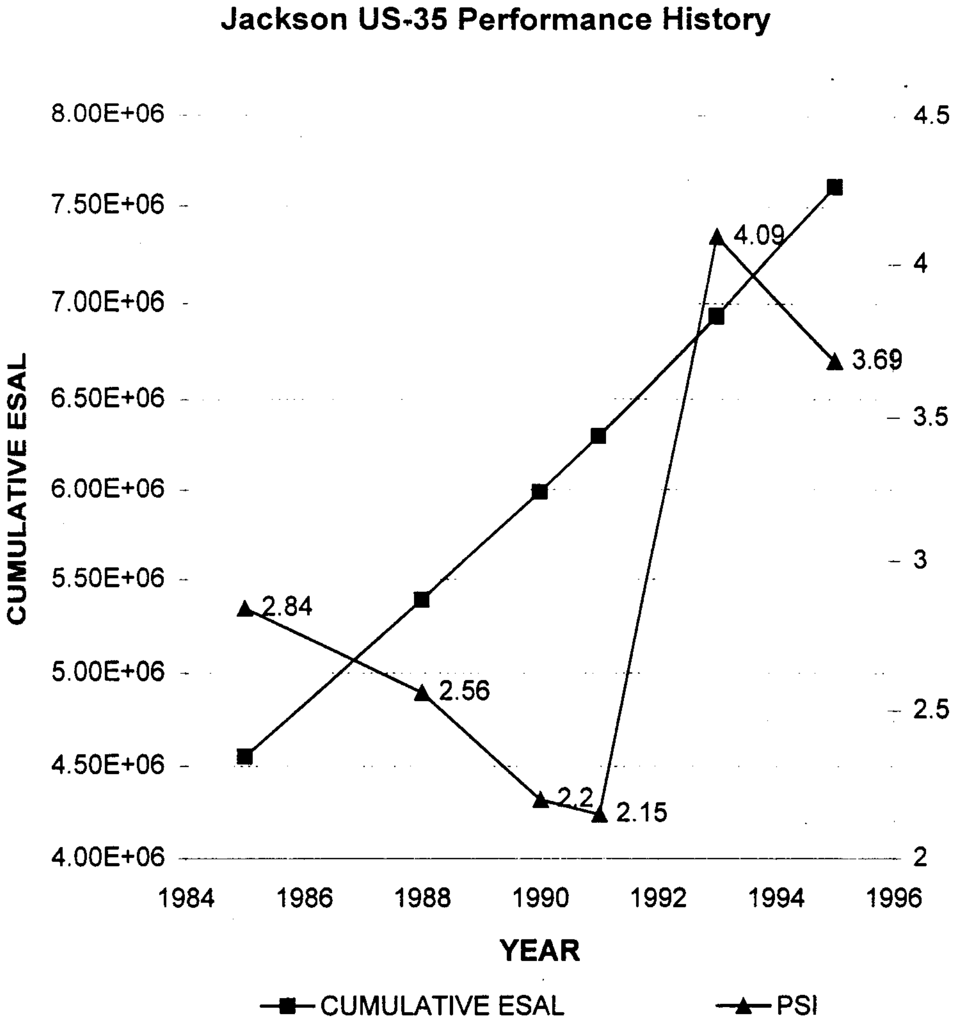


Figure C5. Traffic and PSI History of Test Section on Jackson US-35

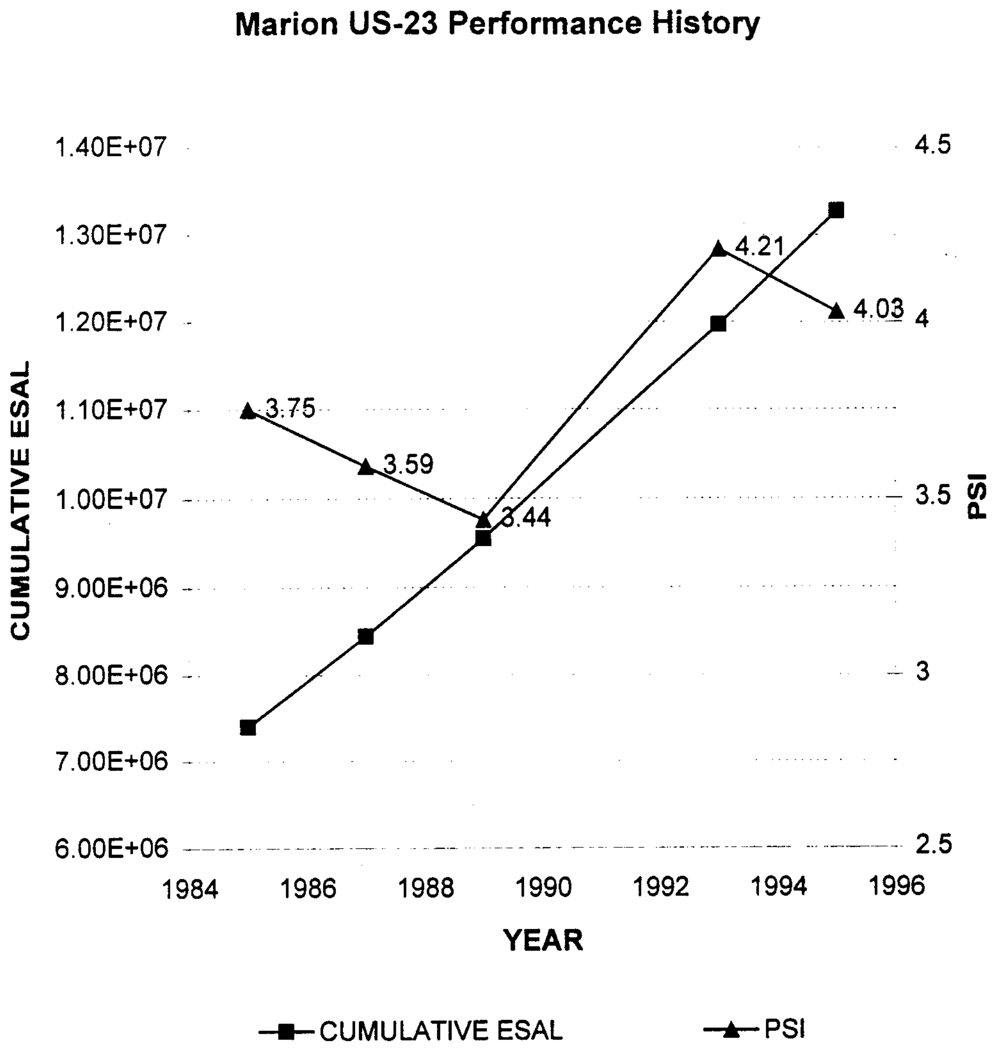


Figure C6. Traffic and PSI History of Test Section on Marion US-23

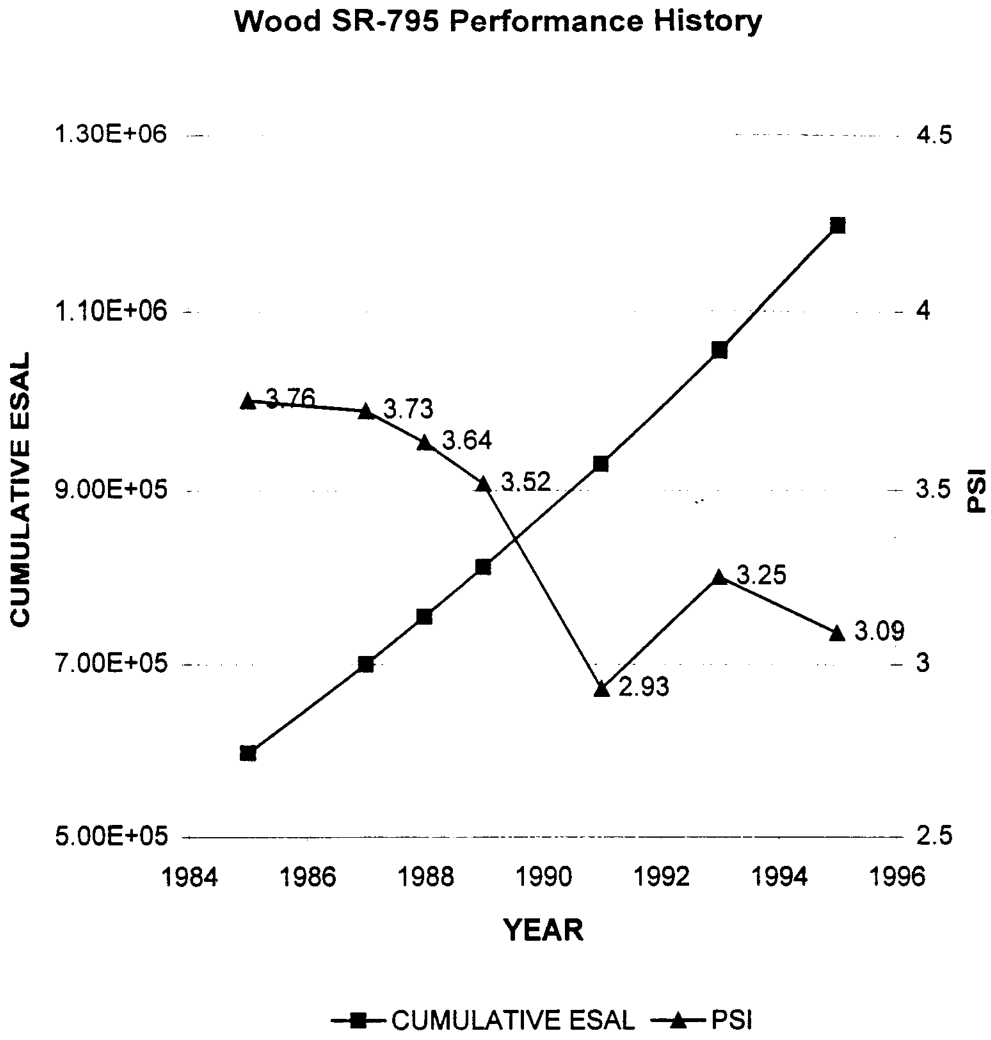


Figure C7. Traffic and PSI History of Test Section on Wood SR-795