SUBGRADE CHARACTERIZATION FOR HIGHWAY PAVEMENT DESIGN

FINAL REPORT

by

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16. Abstract

Subgrade soil characterization expressed in terms of Resilient Modulus (M_R) has become crucial for pavement design. For a new design, M_R values are generally obtained by conducting repeated triaxial tests on reconstituted/undisturbed cylindrical specimens. Because of the complexities encountered with the test, in-situ tests would be desirable, if reliable correlation can be established. In evaluating existing pavements for rehabilitation selection, subgrade characterization is even more complex. The main focus of this study is to determine subgrade M_R employing a Dynamic Cone Penetrometer (DCP), especially the automated version. In support of the study, side-by-side Falling Weight Deflectometer tests are also conducted.

Twelve as-built test sections reflecting typical subgrade soil materials of Mississippi are selected and tested with DCP and FWD before and after pavement construction. Undisturbed samples are extracted using a Shelby tube, and tested in repeated triaxial machine for M_R. Other routine laboratory tests are conducted to determine physical properties of the soil. In analyzing the data, the soils tested are categorized into two groups, fine-and coarse-grain soils.

DCP results (DCP index, penetration/blow) from tests conducted directly in the prepared subgrade are employed to develop regression models for laboratory M_R prediction. The predictability of the model is substantiated by repeating DCP tests at an independent site. Models for in-situ modulus prediction are also developed in the study. Deflection measurements facilitated the calculation of in-situ modulus, for which three programs were used: MODULUS 5, FWDSOIL and UMPED. The MODULUS 5 –backcalculated subgrade modulus shows good agreement with the laboratory M_R. The FWDSOIL backcalculation program predicts subgrade moduli which are slightly lower than the laboratory M_R. With emplacement of pavement structure (lime treated subgrade, lime fly ash subbase, and several inches of asphalt concrete) atop the subgrade, the subgrade backcalculated moduli are enhanced, coarse-grain soil showing a larger increase than the fine-grain soil. This latter result, namely the enhancement of subgrade moduli, is substantiated employing the data compiled from 20 LTPP pavement sections in Mississippi. In order to analyze the automated DCP results, a software designated Dynamic Cone Penetrometer ANaylsis (DCPAN), has been developed. With the regression equation incorporated in the software, real time laboratory as well as backcalculated subgrade modulus calculations are plausible in the field.

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ABSTRACT

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The objective of pavement design is to provide a structural and economical combination of materials to carry traffic in a given climate over the existing soil conditions for a specified time interval. Soil mechanical properties represent a key factor that affect pavement structural design. As noted by Yoder and Witzack (1), "all pavements derive their ultimate support from the underlying subgrade, therefore, a knowledge of basic soil mechanics is essential".

Characterizing subgrade material is crucial in pavement design/rehabilitation activities. The 1993 AASHTO Guide for design of pavement structures suggested the use of subgrade resilient modules (M_R) for pavement structural design (2). Resilient modulus is a measure of elastic property of the soil that recognizes certain nonlinear characteristics. It is the ratio of deviator stress (σ_d) to the recoverable strain (ε_r),

$$M_R = \sigma_d / \varepsilon_r \tag{1.1}$$

M_R may be estimated directly from laboratory testing, by backcalculation from deflection testing in the field or indirectly through correlation with other standard measures. Laboratory test procedures, though revised/simplified over the years, are judged to be very complex. Because of large spatial variability of soil materials, a large number of samples must be collected and tested to generate results of statistical significance. Also, it is difficult to quantify, much less reproduce, in-situ conditions and environment in the laboratory (3).

Recognizing the importance of in-situ testing, AASHTO Design Guide (2) recommended Falling Weight Deflectometer (FWD) tests for pavement evaluation by deflection measurements. Being a nondestructive test (NDT) that can be conducted in a few minutes, and with the availability of several backcalculation programs, FWD is gaining acceptance among highway engineers. Imposing dynamic loads similar to those resulting from traffic, pavement deflection is measured and subsequently backcalculated to arrive at the modulus of each layer, including subgrade. Since the AASHTO design guide recommends laboratory measured modulus for structural design, the backcalculated subgrade modulus needs to be converted to equivalent laboratory M_R through correlation. The Design Guide recommends that the correction factor be no greater than 0.33 for cohesive soil. This concept may not be valid, as found in this study.

Subgrade resilient modulus by correlation with other known soil properties will be reviewed in the next chapter.

1.2 CRITIQUE OF LABORATORY AND FIELD TESTS

The laboratory-based resilient modulus determination involves the repeated load triaxial test. Only elastic (recoverable) strain is captured during the repeated load application. Earlier methods (AASHTO T274-82 and T292-91I) specify the use of either internally- or externally-mounted LVDTs. The current method, specified by SHRP—SHRP Protocol P46—(alternately known as TP46-94) requires two externally mounted LVDTs for determining axial recoverable deformation. The AASHTO TP 46-94 procedure calls for haversine wave form rather than triangular or rectangular wave form stipulated in the earlier test procedures.

The laboratory resilient modulus test is a tedious, costly, and time consuming procedure. Large numbers of samples need to be collected and tested for reasonably accurate results. Even then, it is difficult to reproduce the in-situ sample conditions (3). Therefore, the cost to characterize subgrade soils for a typical project may become prohibitive. Another difficulty stems from the large variation in subgrade soil properties, both vertically and horizontally. This spatial variability makes it difficult to reproduce M_R values in the laboratory.

Pavement surface deflections measured by FWD are employed for backcalculating layer moduli using backcalculation programs. FWD is a trailer mounted device that delivers a transient force impulse, striking a buffered plate that rests on the pavement surface. Deflections generated in the pavement surface are measured at the center of the load and at six locations away from the loading plate. The traditional backcalculation techniques employ the deflection test conditions (i.e., load plate geometry, layer thickness) and seed layer moduli to generate a theoretical deflection basin. The theoretical deflections are compared with the measured deflections and the error is minimized until the two basins show a good match.

Despite its widespread acceptance, the backcalcuation is a highly indeterminate problem which may generate a non-unique set of moduli. For instance, the depth of rigid bottom, if not guessed properly, would significantly affect the output moduli. So also, would transverse cracks that might intercept the sensors.

1.3 PROBLEM STATEMENT

With the adoption of the 1986/93 AASHTO Design Guide, there is a pressing need to characterize subgrade soil in terms of M_R (2, 4). No clear-cut procedure is suggested, though laboratory M_R is the intended property designated in the Guide. The laboratory test procedure itself is highly complex, not to mention the added difficulties if pavement coring were to be conducted for retrieving samples from the bare subgrade or from an in service pavement. In-situ tests are therefore preferred as they can alleviate sample disturbance and consequent variability. Driven by the desire to characterize subgrade soil in-situ, this study is undertaken with the objective of exploring an automated version of Dynamic Cone Penetrometer (DCP) for this purpose. DCP consists of a steel rod with a cone at one end that is driven into the pavement or subgrade by means of a sliding hammer. The angle of the cone tip is normally 60^o, and its base diameter is 20 mm. The hammer weighs 8 kg, and its sliding height is 575 mm.

A schematic of a fully portable, trailer-mounted device that automates the process of driving the penetrometer, designated automated DCP (ADCP), is shown in *Figure 1.1* (5). Designed and constructed for one-man operation, quick set-up, simple operation, and automatic data collection, the ADCP makes the same measurements as the standard manual DCP in a more efficient and cost-effective manner. The cone penetrometer assembly used in ADCP is substantially similar to a manual dynamic cone penetrometer. The ADCP automates the process of driving the penetrometer, recording the blow count and penetration, extracting the penetrometer, and analyzing the data. Trailer-mounted for portability, the ADCP device can run on a vehicle's power system or from 110-V AC power. User-friendly, Windows-based software running on a standard laptop computer controls the sequencing of operations of the ADCP, acquires the data as the test progresses, and analyzes the data after the test is completed. The material's resistance to

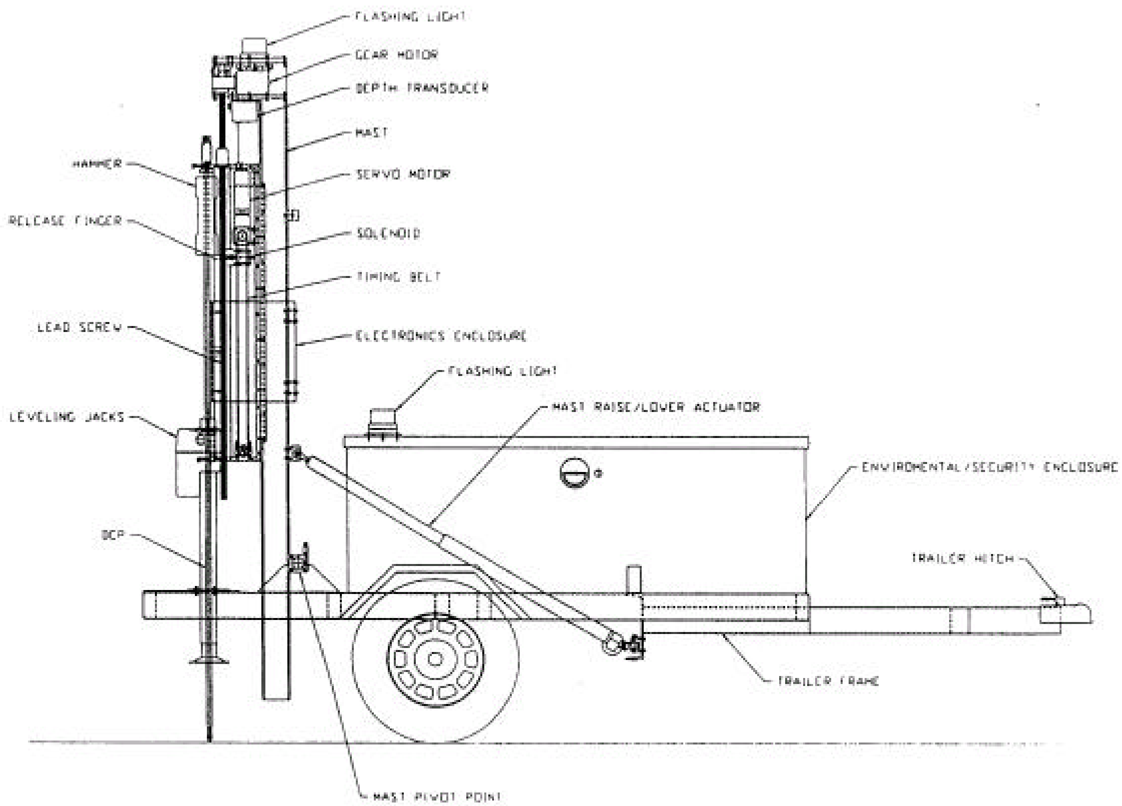


Figure 1.1 Schematic of ADCP trailer

penetration is measured in terms of DCP index (DCPI) millimeters per blow (5). DCP testing appears to be a desirable alternative in characterizing pavement materials if it can be meaningfully correlated with M_R. Studies of this nature are few indeed, however, there is one study that provides a one-to-one relationship between DCP and M_R for fine-grain soil (6). Whether the DCP index can be related to M_R for different types of soil is explored in this study.

Only one study was found relating DCP test results to M_R through a one-to-one relationship (6). It has been reported that the resilient modulus is very sensitive to variations in the soil physical/mechanical properties. Therefore, the usefulness of a one-to-one relationship is questionable. Other material properties, for example density, moisture content, particle size distribution, etc., could have significant effect and should be incorporated in the correlation for reliable M_R prediction.

A non destructive test, namely FWD, has been employed for pavement evaluation with the subgrade moduli calculated using backcalculation programs. Modulus values calculated from FWD deflection data performed on existing pavement surface were recognized to be higher than the corresponding laboratory values, with little consensus on their probable relationship (7, 8, 9). Note that in those studies no consideration has been given to the soil type. Although AASHTO suggests 0.33 as a conversion factor, this ratio needs to be substantiated, especially with respect to soil type.

The possible use of FWD directly on the prepared subgrade for soil characterization is another issue of interest. A Minnesota study addressed this problem reporting difficulties in analyzing the deflection data (10). A reliable method of estimating laboratory M_R from deflection measurements atop the subgrade needs to be pursued as well.

1.4 OBJECTIVES

The primary objective is to explore the feasibility of employing DCP testing for subgrade soil characterization. Since AASHTO design calls for soil resilient modulus, it needs to be correlated to ADCP output, namely, DCPI. Both laboratory and FWD-backcalculated moduli will be correlated.

Since soil characterization is needed for new pavement design and for pavement evaluation, M_R–DCPI correlation applicable to both situations will be sought. Viewed differently, tests need to be conducted on bare subgrade and with the pavement structure atop the subgrade.

A user-friendly program to calculate resilient modulus employing DCPI will be the deliverable product of the study. Correlations for calculating M_R for both new pavement design and evaluation of existing pavements are included in the program.

1.5 SCOPE

In correlating laboratory and in-situ moduli (natural subgrade) with DCPI, the following tests are conducted: laboratory resilient modulus on Shelby tube samples and FWD and DCP tests on the prepared subgrade. Twelve test sections reflecting a range of subgrade soils are selected. Preliminary soil tests are conducted by MDOT and subgrade construction completed in the early part of 1999. The test program including both laboratory tests and field in-place tests is briefly described.

1.5.1 On the prepared subgrade (before emplacement of pavement layers), field and laboratory tests are conducted (*cycle 1,* June – July of 1999).

(a) FWD test is performed on the subgrade from which in-situ elastic modulus is backcalculated. In the vicinity of the FWD loading plate, the DCP test is conducted to determine the DCPI for three feet depth in the subgrade.

(b) Thin wall Shelby tube samples are obtained for laboratory M_R testing, to a depth of three feet of the subgrade. The tested samples are subjected to routine laboratory tests for soil classification.

1.5.2 Side-by-side tests, ADCP and FWD, are conducted in three sections after lime treatment of the subgrade and subsequent lime-fly ash emplacement (*cycle 2*, November 1999).

1.5.3 Field tests are repeated on six test sections in Monroe County following the completion of pavement construction (*cycle 3*, March 2000). The tests include FWD, and ADCP tests in the subgrade, accessing through 102-mm (4-inch) core holes.

1.5.4 Four sections in Rankin County are tested later (*cycle 4*, April, June 2000). Note: the construction of one section in Monroe County (station 260+00 to 266+00), and the section in Leake County (station 522+00 to 530+00) were not completed in time to perform field tests.

During both *cycles 3* and *4*, the DCP test was conducted in the subgrade following coring the entire depth of the pavement structure. The FWD test was performed atop the asphalt surface. Sampling and test sequence, both laboratory and field, and steps for analyzing the results are schematically presented in *Figure 1.2*.

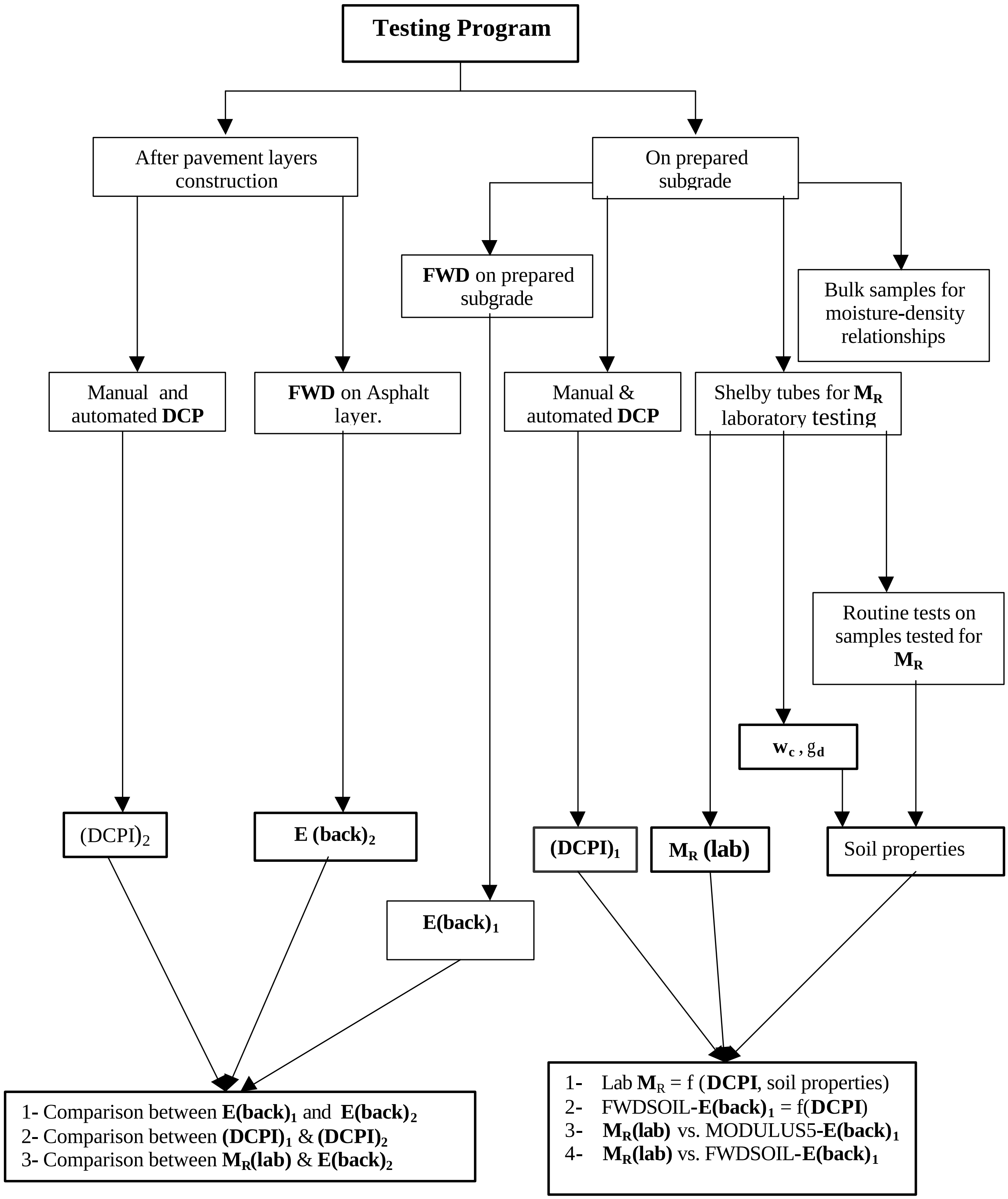


Figure 1.2 Schematic chart showing laboratory and field tests and data analysis.

CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

As resilient modulus characterization is desired by AASHTO, this study explores whether ADCP can be used to estimate this property. Despite laboratory resilient modulus being the necessary input in the AASHTO design, the FWD-based backcalculated modulus has been widely accepted for pavement evaluation purposes. This review, therefore, focuses on the development of DCP/ADCP test and how it can be used to estimate the resilient modulus. Since the FWD backcalculated modulus serves as an independent method for comparison, a critique of the backcalculation procedure will also be included in the latter part of this chapter.

2.2 DYNAMIC CONE PENETROMETER

The Dynamic Cone Penetrometer has been increasingly used in many parts of the world in soil (subgrade), granular material, and lightly stabilized soils through its relationship with in-situ California Bearing Ratio (CBR). Throughout the last two decades, sufficient data have been compiled relating DCP index to CBR, making it possible to estimate the in-situ strength of subgrades and pavement layers.

2.2.1 Early Development

Development of the hand-held DCP is credited to Scala of Australia in the mid-1950's (11). Pavement design procedures in Australia then did not specifically require in-situ strength tests of the subgrade soils because of the time and complexity of available test methods. The device Scala developed included a 9.1-kg (20-lb) drop hammer falling a distance of 508 mm (20 inches). A 15.9 mm (5/8 inch) diameter rod calibrated in 50.8 mm (2 inch) increments was used to determine the penetration. The configuration used a 30 degree included angle cone tip. Scala conducted tests correlating CBR with DCP data and proposed a pavement design procedure based on this correlation. Use of this DCP device was adopted by the Country Roads Board, Victoria, and gained widespread acceptance.

The next generation of DCP equipment was developed by Van Vuuren (12) from South Africa. Basically it was similar to the DCP apparatus developed by Scala except the weight of the drop hammer was changed to 10 kg (22 lbs) and the drop height was changed to 383.5 mm (18.1 inches). The shaft diameter measured 16 mm (0.63 inch) while the apex angle remained at 30 degrees. The development was prompted by the need to alleviate problems associated with performing field CBR tests. In the ensuing study, the CBR/DCP correlation resulted in a better correlation when compared to CBR/CPT correlation. Additionally, Van Vuuren concluded that the DCP is suited for use with soils having CBR values of 1 to 50.

The present version of the DCP used in this study was developed by Kleyn (13) of the Transvaal Roads Department, South Africa. Van Vuuren's basic design was utilized in Kleyn's work; however, the hammer weight was reduced to 8 kg (17.6 lbs) and the height of the drop was increased to 576 mm (22.6 inches). Kleyn studied two cone angle configurations of 30 degrees and 60 degrees. The cone angle utilized in this study was based on the 60 degree included angle. Kleyn's work focused on the development of the generalized DCP/CBR correlation for the full range of materials tested.

2.2.2 Representation of DCP Results

The DCP results, when plotted, describes the number of blows to reach a certain depth affording an instantaneous visual illustration of in-situ material strength (*see Figure 2.1*). The slope of the curve at any point expressed in terms of mm/blow is called the dynamic cone penetration index (DCPI) which represents the resistance offered by the material; the lower the DCPI the stiffer the material, and vice versa.

2.2.3 DCP for Soil Investigation

The DCP was originally designed and used to determine the strength profile of flexible pavements or the subgrade due to its ability to provide a continuous record of relative soil strength with depth. By plotting a graph of penetration index DCPI, expressed in mm/blow (inch/blow), versus depth below the tested surface, one can observe a profile showing layer depths, thicknesses, and strength conditions (*see Figure 2.2*). DCP can be conducted during preliminary soil investigation to quickly map out areas of weak materials and to locate potentially collapsible soils. DCP is an ideal tool for monitoring all aspects of the construction of pavement subgrade and verify the level and uniformity of compaction over a project. Yet, another indirect application of DCP is in the characterization of subgrade and base material properties through its relationship with some other soil properties, for example, CBR and Unconfined Compressive Strength (UCS) (14). Note that DCP tests in coarse gravelly material may be unreliable.

2.2.4 DCP Index in Pavement Design

Kleyn et al. (13) reported the development of a DCP-based pavement design method for thin surfaced unbound gravel pavements in South Africa. A pavement design model was developed and subsequently correlated with the Heavy Vehicle Simulator

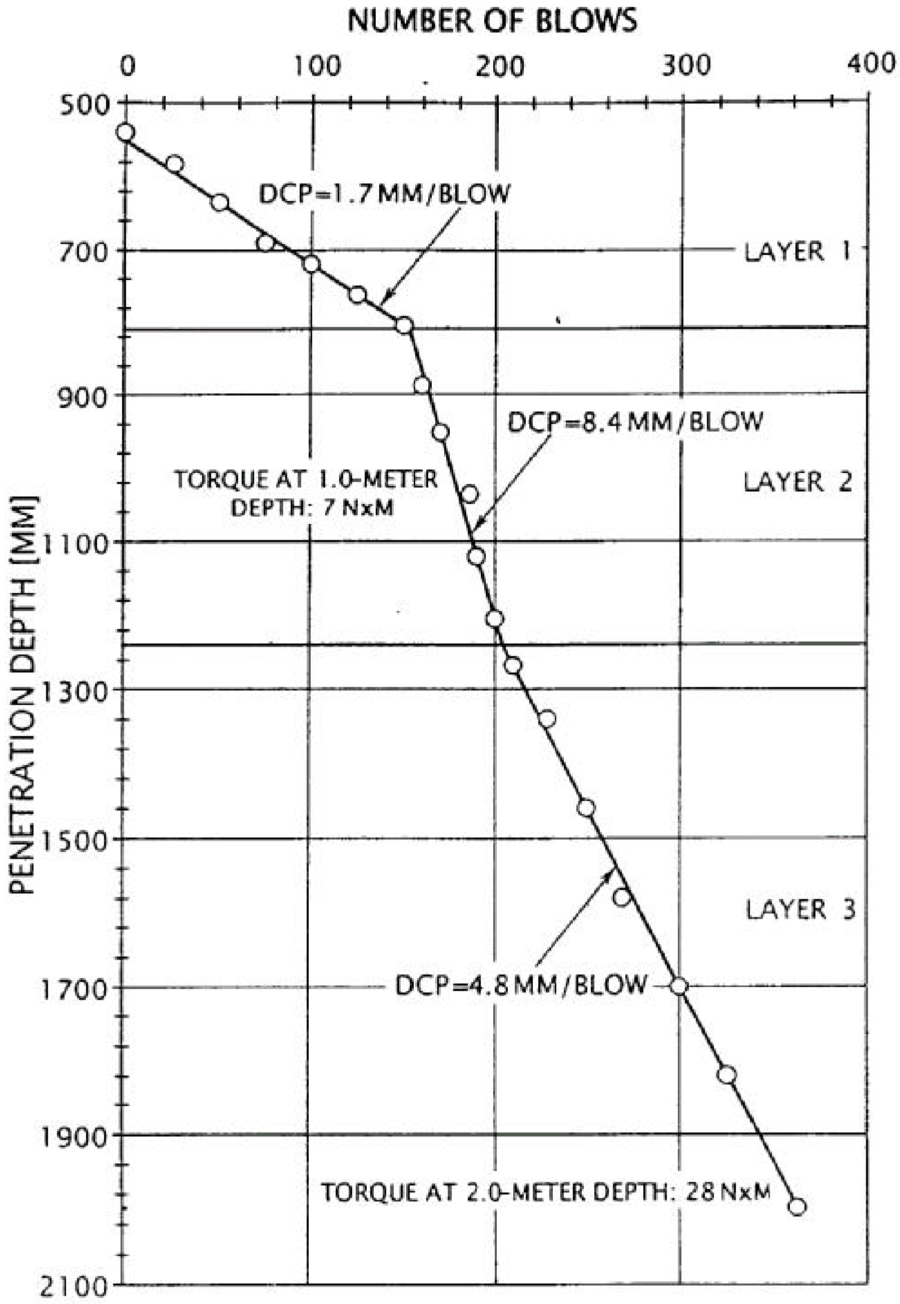


Figure 2.1 Average strength profile of an existing flexible pavement (Note: The boundaries of the layers shown in the figure are those as obtained from the DCP values) (10)

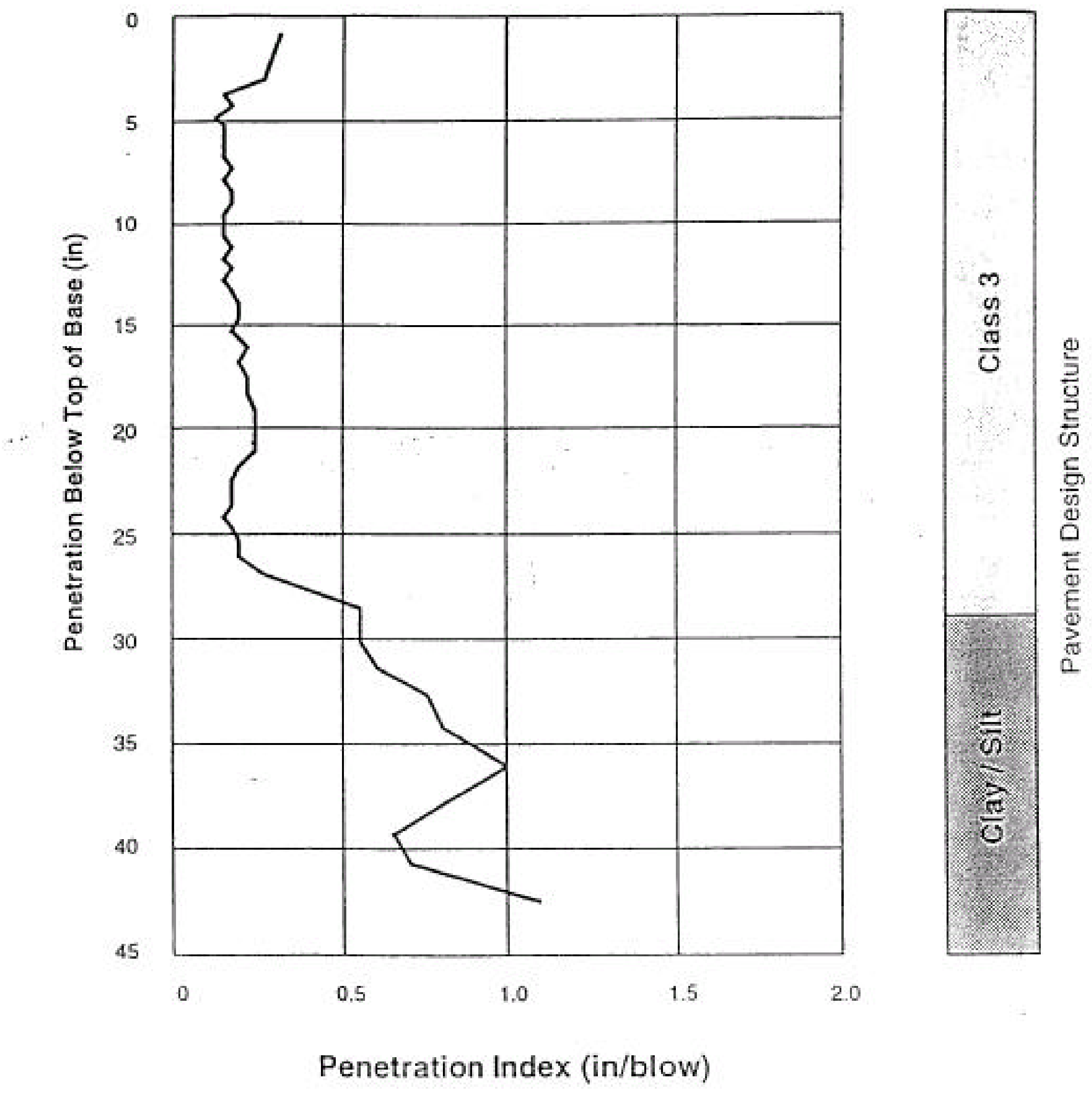


Figure 2.2 Layer strength diagram (10)

(HVS) for a number of pavement sections. The South African development was presented through a paper which introduced the concept of the DCP structural number, called the DSN. The DCP structural number provides the layer thickness through the equation.

$$\text{Layer DSN} = h/DN \qquad (2.1)$$

where h = the layer thickness,

DN = DCP test results in terms of mm/blow.

The DSN is equal to the number of blows to penetrate a layer, while the pavement DSN is the summation of the individual layer DSN values which made up the pavement. The limiting depth for a pavement DSN was determined to be 800 mm (31.5 inches), assuming that stresses at depths greater than 800 mm (31.5 inches) were insignificant. The percent DSN (X-AXIS) was then plotted against the depth (Y-AXIS) to obtain a pavement strength balance (PSB) curve. An example of the PSB curve is shown in *Figure 2.3*. Typical PSB curves used in South Africa are shown in *Figure 2.4*. The PSB curve is then compared to curves obtained from field evaluations of various types of pavement conditions using the HVS. In this case DCP values are used as a direct design input to obtain the pavement thickness using this PSB curve. This procedure is currently restricted to low volume roads in South Africa and has prompted other studies to enhance its applicability. Another procedure incorporating the direct use of DCP values, developed in Victoria, Australia, was also reported but the details were too vague for presentation here (15).

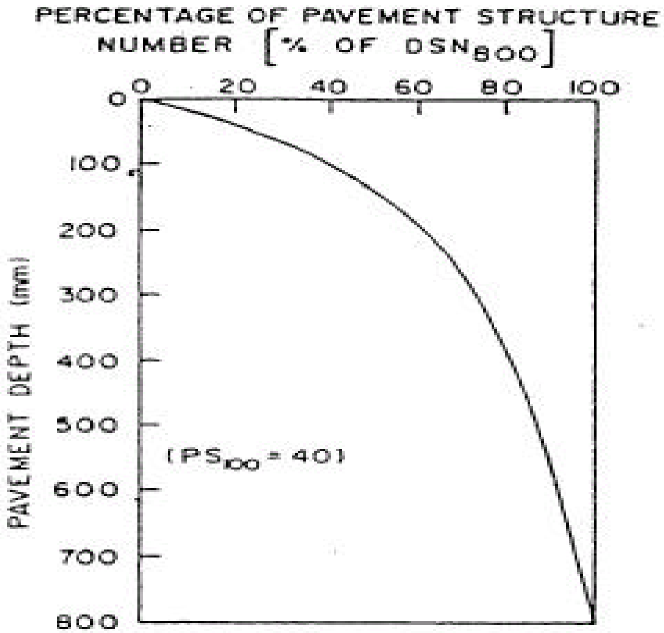


Figure 2.3 Example of a pavement strength-balance curve (13)

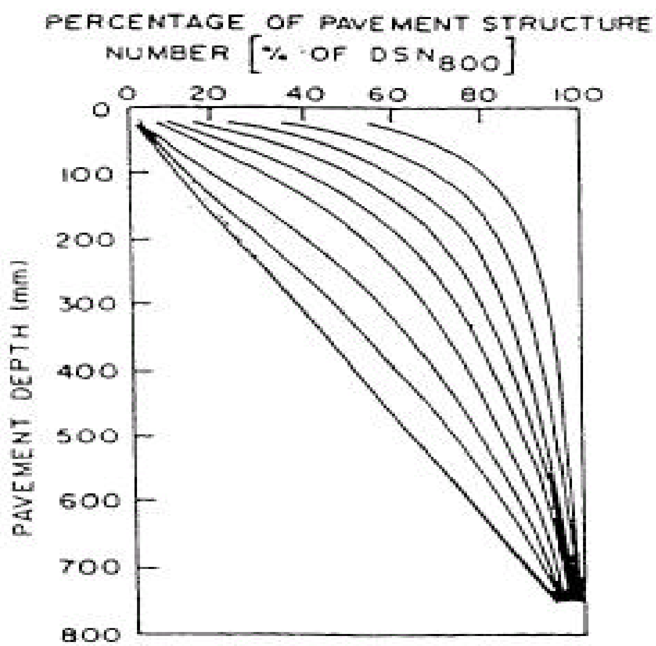


Figure 2.4 Pavement strength-balance curve for typical pavement(13)

2.3 FACTORS AFFECTING DCP TEST RESULTS

Many studies have been conducted to determine the general trends and behavior of the DCP index in regard to various soil and material factors. These factors include soil type, density, gradation, maximum aggregate size, and moisture content.

2.3.1 Material Effects

In his study to investigate the effect of several different variables on DCP index for fine-grained soils, Hassan (6) reported that DCPI is significantly affected by moisture content, AASHTO soil classification, and dry density. Kleyn (13) concluded that gradation, density, moisture content, and plasticity were important material properties affecting the DCP values.

For granular materials, coefficient of uniformity, and maximum size aggregate size are reported to be the primary factors. An increase in the percentage of the fines generally decreases the DCP value for the same target density. Similarly, an increase in the density for a similar gradation or individual material type decreases the DCP value.

2.3.2 Vertical Confinement Effect

Liveneh, et al. (16, 17) investigated the effects of vertical confinement on the DCPI of the subgrade and granular pavement layers reporting the following findings: there was no vertical confinement effect by the upper pavement layers on the DCPI of cohesive subgrade; however, a vertical confinement effect on the DCPI of granular subgrade does exist. Those results are in general agreement with those of Hassan (6).

2.3.3 Side Friction Effect

With the DCP device not being truly vertical while penetrating soil, the penetration resistance would be apparently higher due to side friction. This effect could be more pronounced with a manual DCP. In a recent study conducted by Livneh (16), a correlation factor based on the side friction was developed and used to correct the DCP/CBR correlation equation. The apparent higher resistance may also be caused when penetrating in a collapsible material (granular soil). This effect may be minimal in clay material in which preserving a gap between DCP rod and sides of the hole is not problematical.

2.4 DCPI RELATED TO OTHER PROPERTIES

The direct use of DCPI in pavement design is yet to be established; however, it has been correlated to commonly used soil parameters, for example, CBR.

2.4.1 California Bearing Ratio (CBR)

Liveneh, et al. (17) performed both laboratory and field tests to correlate DCP results to CBR. The laboratory and field testing program resulted in quantitative relationships between the CBR and its DCPI as follows:

$$\text{Log CBR} = 2.2 - 0.71\,(\log \text{DCPI})^{1.5} \qquad (2.2)$$

where DCPI = penetration index, mm/blow

Yet another equation form with good predictability is,

$$\text{Log (CBR)} = 2.4 - 1.2\,(\log \text{DCPI}) \qquad (2.3)$$

From a physics point of view DCP and CBR tests should provide a reasonable correlation since both tests use large strain penetration to measure material strength. *Figure 2.5* is typical, in that DCPI correlates well with the CBR measured on granular base material (17).

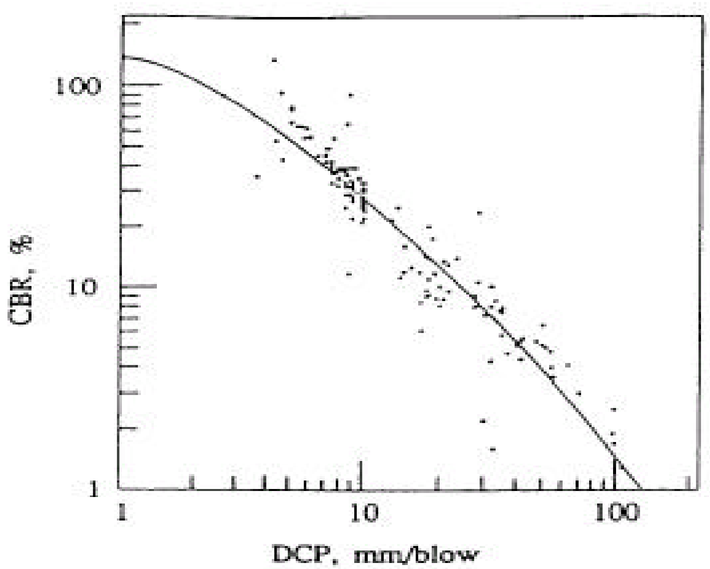


Figure 2.5 Relation between CBR value and DCP Index (17)

2.4.2 Unconfined Compressive Strength (UCS)

Two models for correlating UCS and DCP were examined by McElvancy, et al. (18) for silty clay and sandy clay, and clayey soils stabilized with lime. Two models were examined as follows:

$$UCS = A(DCPI)^{-1} + B \quad (2.4)$$

$$UCS = C(DCPI)^{-D} \quad (2.5)$$

where UCS = unconfined compressive strength (kPa)

A, B, C, D = regression coefficients.

It was stated that DCP could be used to provide a reasonable estimate of the unconfined compressive strength of soil-lime mixtures (18).

2.4.3 Shear Strength of Cohesionless Granular Materials

Ayers et al. (19) conducted a laboratory study to determine relationships between the DCPI and the shear strength properties (cohesion *c*, and angle of internal friction f). Prediction equations for confining pressures of 35, 103, and 207 kPa (5, 15, and 30 psi) were developed in the form:

$$DS = A - B(DCPI) \quad (2.6)$$

where DS = shear strength

A, B = regression coefficients

2.4.4 Resilient Modulus

Only a few studies have attempted to correlate resilient modulus to DCPI. Hassan (6) developed a simple regression model correlating M_R with DCPI for fine-grained soils at optimum moisture content.

$$M_R(psi) = 7013.065 - 2040.783 \ln(DCPI) \quad (2.7)$$

where DCPI expressed in inches/blow

The resilient modulus values calculated using this model are very conservative, however. In the same study Hassan reported that for fine-grained soils, the correlation of M_R values with DCPI is significant at optimum moisture content but less significant at optimum moisture plus 2.0%. Chai, et al. (20) used the results of the DCP tests and CBR-DCP relationships developed in Malaysia during the 1987 National Axle Load study to determine in situ subgrade elastic modulus as follows:

$$E(MN/m^2) = 17.6\ (269/DCP)^{0.64} \ldots\ldots\ldots\ldots\ldots \quad (2.8)$$

where DCP = blows/300mm penetration

In the same study, the backcalculated elastic modulus correlated well with the DCP value through the following relationship:

$$E(_{back}) = 2224 \text{ x } DCP^{-0.996} \ldots\ldots\ldots\ldots\ldots \quad (2.9)$$

where $E(_{back})$ = backcalulated subgrade elastic modulus (MN/m^2)

Jianzhou, et al. (21) analyzed the FWD deflection data and DCP results on six pavement projects of Kansas Department of Transportation (KDOT) to develop a relationship between the DCPI and backcalculated subgrade moduli. The correlation between DCPI and $E(_{back})$ was shown to be significant, with the best model in power form:

$$E(_{back}) = 338(DCPI)^{-0.39} \ldots\ldots\ldots\ldots\ldots \quad (2.10)$$

where $E(_{back})$ = backcalculated elastic modulus, (Mpa)

DCPI expressed in mm/blow

2.5 THEORETICAL ANALYSIS OF DCP

A review of literature reveals that considerable research was conducted investigating the stresses induced by static cone penetration in soil medium (22, 23). For granular materials, the advancement of a static cone was investigated by Meier and Baladi (22). A cone penetration model was developed and was partly verified by laboratory studies. A practical relationship between DCP index (or cone index, CI) and soil properties *c* and *ø* was derived. Since the equations developed and reported by Meier and Baladi were derived for a static cone penetrometer, they are not directly applicable to dynamic cone testing. In a study conducted by Allersma (24) an optical stress/strain analysis in granular material was performed based on the advancement of a static cone penetrometer. Salgado et al. (23) presented a theory based on cavity expansion analysis for determining static cone tip resistance in sands including the relative density and stress state as input parameters.

Cone tip to soil interaction behavior models are variations of models developed to analyze soil failure caused by an air-dropped projectile. Considering the projectiles begin with velocities of several hundred feet per second, DCP tip penetrations are relatively "slow." Notably, Chua (25) utilized the one-dimensional projectile penetration theory, originally developed by Yankelevsky and Adin (26), to relate the DCP test results to CBR and elastic modulus of soils. Chua (25) formulates his modeling solution by considering the penetration of an axisymmetric soil disc with a thickness equal to the height of the cone. Using stresses and strains from the model, Chua developed a correlation of penetration index versus elastic modulus for various types of soils. In a special application, Chua and Lytton (27) developed a technique in which the DCP test is used in conjunction with an accelerometer to enable a signal analysis technique such that the soil damping can be deduced.

2.6 BACKCALCULATION OF PAVEMENT LAYER MODULI

An indirect method of in-situ modulus determination, backcalculation makes use of deflection response of a pavement to a static, dynamic, or impulse load. FWD with impulse load duration of 25 to 30 msec approximates that of a vehicle traversing at 65 to 80 kmh (40 to 50 mph), and therefore is widely used for backcalculating in-situ modulus.

2.6.1 Backcalculation Procedure

The procedure followed by most computer programs is to start with some "seed" values of moduli for each of the pavement layers. The peak applied dynamic load is represented by a static load on the surface, and a static deflection basin is calculated for the pavement model layers (28). A comparison is made of the calculated deflection basin with the measured deflection basin. Differences are used to guide adjustment of moduli in various layers, and another set of deflection is calculated for the model. The comparison-adjustment-recalculation procedure is carried out until the calculated static deflections are within an acceptable tolerance of the measured peak dynamic deflections. The result is a set of moduli for the layers of the model that gives a calculated static deflection basin close to the measured dynamic deflection basin.

2.6.2 Factors Affecting Backcalculated Moduli

Although backcalculation is widely used for ascertaining acceptable modulus values for various layers, it calls for subjective input in most of the available programs. Several parameters influence the backcalculated moduli, for example, seed moduli, number of layers, layer thickness, and depth to rigid layer. In most instances, it is preferred not to analyze a system with more than three or four layers (29, 30, 31).

Sensitivity analyses of the aforementioned parameters have been conducted and the results indicate that, except for seed moduli, all of those parameters have significant effect on backcalculated layer moduli (32).

2.6.3 Comparison of Laboratory and Field Moduli

The published literature is rich with comparisons of moduli measured by laboratory testing with that backcalculated from deflection data. The AASHTO Guide recognizes that the moduli determined from both procedures are not equal. The guide suggests that a subgrade modulus determined from deflection basins be adjusted by a factor of 0.33. However, other ratios have been documented in the literature. Ali and Khosla (7) compared the subgrade soil resilient modulus determined in the laboratory and backcalculated from three pavement sections in North Carolina. The ratio of laboratory measured modulus values to the corresponding backcalculated varied from 0.18 to 2.44. Newcomb (8) reported the results of similar tests for the state of Washington and the ratio was in the range of 0.8 to 1.3. Von Quintus, et al. (9) reported ratios in the range of 0.1 to 3.5, a study based on data obtained from the Long Term Pavement Performance (LTPP) database. Different average ratios were reported based on the type of base layer (granular or stabilized) atop the subgrade layer (9). Laboratory values were consistently higher than the backcalculated values—nearly two times—in a study reported by Chen, et al. (33). It was concluded that the primary cause of the difference between laboratory and field modulus values stems from the different volumes of material tested in the laboratory and in the field (3). Note the previous studies relied solely on backcalculated modulus from deflection measurements atop the pavement surface. Houston, et al. (34) conducted an extensive study investigating the site variability effect, based on NDT test data. It was reported that spatial variability of subgrade materials contributed to the variability in pavement response.

In their study of Minnesota Research Road Project (Mn/ROAD), Newcomb et al. (10) reported difficulties analyzing FWD measurements performed directly on subgrade surface with no direct relation established between laboratory measured and backcalculated elastic moduli.

2.7 CONCLUSION

The survey study indicates that DCP has been increasingly used in many parts of the world for pavement and subgrade evaluation by relating DCPI to CBR. Only a few investigations have attempted a correlation between DCPI and M_R, however. The soil properties affecting DCPI are found to be gradation, plasticity, and uniformity coefficient, especially for granular soils. Moisture content and density also affect DCP index.

In-situ testing by FWD and subsequent backcalculation of layer moduli have become accepted practice despite uncertainties encountered in the backcalculation procedure. There seems to be practically no consensus as to how the backcalculated modulus is related to the laboratory modulus, when the deflection testing is performed on the pavement surface. Not many deflection studies had been carried out on the subgrade directly.

CHAPTER 3

EXPERIMENTAL WORK AND DATA COLLECTED

3.1 INTRODUCTION

The AASHTO pavement-design procedure, primarily based on the AASHO Road Test results, requires the determination of the resilient modulus of subgrade soil. For estimating layer coefficients, moduli of other layers would be needed as well. Asphalt concrete modulus is frequently estimated using indirect tensile test, while the moduli of the granular base course and the soil subgrade are determined from repeated-load triaxial tests.

Due to the complexity and equipment requirements for repeated load testing, it is desirable to develop approximate methods for estimation of M_R. In fact the AASHTO design guide suggests that agencies involved in pavement design establish correlations based on standard soil tests. Also, the guide allows the use of in-situ backcalculated moduli, but recognizes that the moduli determined from deflection basins be adjusted by a factor 0.33 for pavement design. It is recommended that this value be evaluated and adjusted if needed by user agencies for their soil and deflection measurement equipment.

The primary objective of this study is to establish a relationship between the resilient modulus and DCP index for two different type of soils, namely, fine- and coarse-grain soils. The relation between laboratory measured moduli and backcalculated elastic moduli will be examined as well. Four cycles of FWD tests are performed, first directly on prepared subgrade (*cycle 1*), second, the treated subgrade and lime-fly ash subbase in place (*cycle 2*), third and fourth on the pavement surface (*cycle 3/4*). *Table 3.1* presents a summary of the tests in four cycles including the sections tested and dates. Note that test *cycles 3/4* are conducted on the completed pavements with only difference being that they are performed at different dates. A discussion of the laboratory and field testing program is presented in the following sections.

TABLE 3.1 Dates of Different Tests Conducted on Twelve Test Sections

Station	County/ Road	Designation	Date tested			
			Cycle 1[a]	Cycle 2[b]	Cycle 3[c]	Cycle 4[d]
1303-1311	Rankin/ SR25	Sec 1S[e]	6/7/00	NT[f]	3/08/00	NT
1347-1354		Sec 2S	6/8/99	NT	3/08/00	NT
1591-1598[g]		Sec 3S	6/8/99	NT	NT	4/05/00
1696-1704		Sec 4S	6/8/99	NT	NT	4/05/00
522-530	Leake/ SR25	Sec 1N	7/28/99	NT	NT	NT
88-96	Monroe/ US45	Sec 1N/South project	7/27/99	11/03/99	NT	6/26/00
108-116[g]		Sec 2N/South project	7/27/99	11/02/00	NT	6/27/00
170-178[g]		Sec 3N/South project	7/26/99	NT	NT	6/27/00
260-266		Sec 4N/South project	7/26/99	NT	NT	NT
461-469[g]		Sec 1N/North project	7/19/99	11/03/99	3/06/00	NT
490-498[g]		Sec 2N/North project	7/20/99	11/01/99	3/07/00	NT
668-676		Sec 3S/North project	7/14/99	11/02/99	3/07/00	NT

a FWD, MDCP, ADCP, and Shelby tube.
b FWD, ADCP
c FWD, ADCP, MDCP, pavement coring
d FWD, ADCP, MDCP, pavement coring
e Section 1 south bound
f Not tested.
g Sections with erratic deflection basins.

3.2 *CYCLE 1* (SUMMER 1999)

3.2.1 Field Testing

3.2.1.1 FWD on Prepared Subgrade

Twelve as-built test sections reflecting typical subgrade soil materials of Mississippi were selected and tested (see *Table 3.1*). The Mississippi Department of Transportation (MDOT) FWD was used for the deflection testing discussed in this study. The testing pattern for each section was designed for a series of 17 test stations located longitudinally at 16.5 m (50 ft.) intervals. The test locations were 1 m (3 ft.) from the outer lane edge except for section # 3 where it was conducted 1 m (3 ft.) from the outer edge of in the inner lane.

A 300 mm (12 in.) diameter plate was used for all the tests and velocity sensors located at the center of the plate and at offset distances of 200 mm (8 in.), 300 mm (12 in.), 457 mm (18 in.), 600 mm (24 in.), 914 mm (36 in.), and 1524 mm (60 in.) from the center. Three seating loads followed by two load drops each at different drop heights were used. In cases where the station was unsuitable for testing due to loose surface material, wheel ruts, or other reasons, the surface was leveled to eliminate as far as possible erratic sensor deflections. Some sections were bladed and recompacted before FWD testing to ensure surface smoothness. Nonetheless, debris and improper sensor seating resulted in unrealistic deflection basins. In some cases, though the surface appeared smooth, deflections exceeded the sensor's range; those sections were excluded from further analysis. The sections with excessive deflections and/or questionable deflection basins are marked in *Table 3.1*. Typical deflection basins from five stations of each test section are presented in *Appendix A.*

<u>Backcalculation of Elastic Moduli, $E(back)_1$</u> Subgrade elastic modulus $E(back)_1$ was backcalculated using the program MODULUS, developed at the Texas Transportation Institute. It uses a layered elastic computer program called WES5 to generate a database of deflection basins for a range of layer moduli. A pattern search method and interpolation are employed to minimize the error between the measured and calculated deflection basins. That it is being selected by the Strategic Highway Research Program (SHRP) is a testimonial of its perceived performance.

By necessity, the basins with extremely high deflection values or negative slopes were excluded from the analysis. These high deflections might be due to unevenness of the soil surface attributable to either a soft layer or debris present at the surface. Those sections that were bladed prior to FWD testing had many erratic deflection basins. For other sections, it could be due to spatial variation resulting in soft pockets along the road.

Preliminary analysis of DCP data, to be discussed in the next section, showed that the subgrade is naturally layered: three layers 0.3 m (12 in.), 0.3 m (12 in.), and 0.3 m (12 in.). With three laboratory samples retrieved from each test location for resilient modulus determination, this layering facilitated a direct comparison of $E(back)_1$ and laboratory M_R values.

Under the FWD test conditions, the contact pressure under the loading plate was in the range of 207-345 kPa (30-50 psi). This stress level was considered relatively high compared with even the highest stress level experienced in the repeated triaxial test of 50 to 62 kPa (7.2 to 9.0 psi). The backcalculated moduli for the top subgrade layer, therefore, were excluded from further analysis in this part of the study. *Tables 3.2* and *3.3* list the $E(back)_1$ values of layers 2 and 3 for the seven sections with reasonable deflection basins. Note that there was a relatively large variation spatially within the sections regardless of the type of soil. Comparing fine- and coarse-grain soils, the variability for fine soil is higher, however. Another observation, in the case of fine-grain soil, is that the variability within one section exists in the vertical direction as well, with the third layer showing less variability than the second layer. Detailed discussion of these results will be included in *Chapter 5*.

TABLE 3.2. MODULUS-Backcalculated Elastic Moduli from FWD Test on Prepared Subgrade. (fine-grain soil sections)

Section Designation	County/Road/ Project	Station No.	Backcalculated moduli, MPa (psi)	
			Layer 2	Layer 3
South Sec 1	Rankin/SR25/ South project	1303+00	172.5 (25,000)	103.5 (15,000)
		1305+00	207.0 (30,000)	107.0 (15,500)
		1307+00	127.0 (18,400)	74.5 (10,800)
		1309+00	76.0 (11,000)	82.0 (11,900)
		1311+00	60.0 (8,700)	77.0 (11,200)
South Sec 2		1347+00	169.0 (24,500)	101.0 (14,700)
		1349+00	82.0 (11,900)	109.0 (15,800)
		1351+00	187.7 (27,200)	105.0 (15,200)
		1353+00	51.0 (7,400)	66.0 (9,500)
		1354+50	265.7 (38,500)	134.0 (19,400)
South Sec 4		1696+00	85.6 (12,400)	78.7 (11,400)
		1698+00	76.6 (11,100)	74.0 (10,700)
		1700+00	38.0 (5,500)	76.6 (11,100)
		1702+00	157.0 (22,800)	136.0 (19,700)
		1704+00	33.8 (4,900)	76.0 (11,000)
North Sec 1	Leake/SR25/ North project	522+00	145.0 (21,000)	124.0 (18,000)
		524+00	71.0 (10,300)	85.6 (12,400)
		526+00	85.0 (12,300)	133.0 (19,300)
		528+00	276.0 (40,000)	312.6 (45,300)
		530+00	276.0 (40,000)	292.6 (42,400)

3.2.1.2 Dynamic Cone Penetrometer (DCP) Test

The MDOT DCP device was used to conduct penetration testing on prepared subgrade. In four sections manual DCP (MDCP) and Automated DCP (ADCP) were used to conduct the test. When the testing program started in early June of 1999, the ADCP device was not available, so the MDCP was used to conduct testing on sections 1S, 2S, 3S, and 4S in Rankin County. After the ADCP was made available, side-by-side tests were conducted using the MDCP and the ADCP. These sections include, Sec 1N in Leake County, Sec 2N (south project, US45) Monroe County and Sec 1N (south project, US45) and Sec 3S (north project US45) Monroe County. The scheme for DCP investigation consisted of testing at 30 m (100 ft.) intervals approximately in the middle of the FWD loading plate imprint. DCP testing on a given section was performed following FWD test to a depth of 1 m (3 ft.) in the subgrade. *Figure 3.1* presents the ADCP in operation, with the penetration data automatically collected by the laptop computer running the DCP. The DCPI, expressed in mm/blow (in/blow), is logged for each hammer blow.

TABLE 3.3. MODULUS -Backcalculated Elastic Moduli from FWD Test on Prepared Subgrade. (coarse-grain soil sections)

Section Designation	County/Road/ Project	Station No.	Backcalculated Moduli, MPa (psi)	
			Layer 2	Layer 3
Sec 1N	Monroe/US45/ South project	88+00	54.0 (7,800)	85.0 (12,300)
		90+00	42.0 (6,100)	90.4 (13,100)
		92+00	28.0 (4,000)	94.5 (13,690)
		94+00	28.0 (4,000)	30.0 (4,300)
		96+00	29.7 (4,300)	76.6 (11,100)
Sec 4N	Monroe/US45/ South project	260+00	76.0 (11,500)	67.0 (9,700)
		261+50	46.0 (6,700)	83.5 (12,100)
		262+63	69.0 (9,950)	70.4 (10,200)
		264+50	47.0 (6,800)	80.0 (11,600)
		266+00	43.5 (6,300)	56.0 (8,100)
Sec 3N	Monroe/US45/ North project	668+00	79.0 (11,500)	68.0 (9,800)
		670+00	115.0 (16,700)	85.0 (12,300)
		672+00	71.0 (10,300)	67.6 (9,800)
		674+00	91.0 (13,200)	84.0 (12,200)
		676+00	112.0 (16,200)	88.0 (12,800)

The DCP test results for the twelve sections are plotted and presented in *Appendix B*. The subgrade strength in terms of penetration resistance can be expressed in terms of the slope of DCP plot. The DCPI (slope of DCP plot) is calculated manually for each foot of the top three feet of the subgrade layer, matching the Shelby tube samples retrieved from approximately, the same depth. The calculated DCPIs are used for correlation with laboratory measured M_R which will be discussed in detail in *Chapter 5*. *Table 3.4* lists the manually calculated DCPI values for all the twelve sections for the first, second, and third layers. Note that there is no specific trend for most of the sections with some exceptions

Figure 3.1 Automated dynamic cone penetrometer in operation in the field

in which the DCPI increases with depth. This could be attributed to the spatial variation in the subgrade soil both horizontally and vertically. It was expected that for coarse-grain soil, the DCPI would decrease with depth due to lateral confinement. Nonetheless, no clear trend was found in these sections, which could be attributed to the variability effect or to high moisture content in the bottom layers.

TABLE 3.4. Penetration Index at Different Depths in Subgrade Soil in Twelve Test Sections.

Section Designation	County/Road/ Project	Station No.	DCPI, mm/blow (in./blow)		
			1st ft.	2nd ft.	3rd ft.
Sec 1S	Rankin/SR25/South	1303+00	13.9 (0.54)	23.1 (0.91)	30.0 (1.18)
		1305+00	27.3 (1.1)	233.1 (0.91)	30.0 (1.18)
		1307+00	28.9 (1.14)	50 (1.97)	66.7 (2.63)
		1309+00	17.7 (0.70)	30.0 (1.18)	12.0 (0.47)
		1311+00	18.8 (0.74)	30 .0 (1.18)	33.0 (1.30)
Sec 2S		1347+00	5.8 (0.23)	0.35 (8.9)	0.66 (16.7)
		1349+00	0.15 (3.7)	15.9 (0.63)	15.9 (0.63)
		1351+00	4.3 (0.17)	5.5 (0.22)	13.6 (0.54)
		1353+00	10.7 (0.42)	11.7 (0.46)	42.0 (1.65)
		1354+50	5.5 (0.22)	7.7 (0.30)	10.8 (0.43)
Sec 3S		1591+00	27.3 (1.07)	23.3 (0.92)	36.6 (1.44)
		1593+00	41.6 (1.64)	8.3 (0.33)	38.0 (1.50)
		1595+00	12.3 (0.48)	63.7 (2.51)	35.6 (1.40)
		1596+00	13.3 (0.52)	11.0 (0.43)	44.2 (1.74)
		1598+00	14.8 (0.58)	10.6 (0.42)	41.3 (1.63)
Sec 4S		1696+00	8.1 (0.32)	29.1 (1.15)	19.5 (0.77)
		1698+00	9.2 (0.36)	26.0 (1.02)	40.4 (1.60)
		1700+00	12.8 (0.50)	25.1 (1.0)	56.0 (2.2)
		1702+00	8.2 (0.32)	21.3 (0.84)	30.0 (1.20)
		1704+00	9.5 (0.37)	30.8 (1.2)	22.1 (0.87)
Sec 1N	Leake/SR25/North	522+00	12.0 (0.47)	14.6 (0.57)	9.8 (0.40)
		524+00	21.4 (0.84)	22.2 (0.87)	24.0 (0.94)
		526+00	18.8 (0.74)	20.3 (0.8)	14.5 (0.57)
		528+00	8.8 (0.35)	8.9 (0.35)	7.1 (0.28)
		530+00	10.0 (0.40)	8.6 (0.34)	6.8 (0.27)
Sec 1N	Monroe/US45/ South	88+00	10.6 (0.42)	12.5 (0.49)	14.9 (0.59)
		90+00	15.8 (0.62)	13.6 (0.54)	11.1 (0.44)
		92+00	11.6 (0.46)	13.6 (0.54)	12.5 (0.5)
		94+00	8.3 (0.33)	13.6 (0.54)	19.4 (0.76)
		96+00	8.3 (0.33)	23.1 (0.91)	11.0 (0.43)

Table 3.4 (Continued).

Section **Designation**	**County/Road/Project**	**Station No.**	**DCPI, mm/blow (in./blow)**		
			1st ft.	**2nd ft.**	**3rd ft.**
Sec 2N	Monroe/US45/South	108+00	15.0 (0.60)	12.5 (0.5)	12.5 (0.5)
		110+00	20.0 (0.79)	30.0 (1.2)	37.5 (1.48)
		112+00	19.4 (0.77)	20.3 (0.80)	37.5 (1.48)
		114+00	21.4 (0.84)	27.3 (1.07)	25.9 (1.0)
		116+00	18.8 (0.75)	20.2 (0.79)	25.2 (1.0)
Sec 3N		170+00	8.6 (0.34)	64.7 (2.55)	63.3 (2.5)
		172+00	11.5 (0.45)	12.7 (0.5)	63.7 (2.5)
		174+00	6.7 (0.26)	39.5 (1.56)	8.7 (0.34)
		176+00	11.8 (0.46)	23.0 (0.91)	29.0 (1.14)
		178+00	17.2 (0.68)	20.6 (0.81)	9.3 (0.37)
Sec 4N		260+00	28.3 (1.11)	11.2 (0.44)	15.2 (0.6)
		261+50	13.7 (0.54)	9.0 (0.35)	11.9 (0.47)
		262+63	15.8 (0.62)	9.4 (0.37)	12.9 (0.51)
		264+50	14.4 (0.57)	11.7 (0.46)	12.1 (0.48)
		266+00	11.5 (0.45)	10.0 (0.40)	14.6 (0.57)
Sec 1N	Monroe/US45/North	461+00	42.9 (1.69)	27.3 (1.07)	50.0 (1.97)
		463+00	27.3 (1.07)	35.3 (1.39)	34.1 (1.34)
		465+00	36.1 (1.42)	32.6 (1.28)	32.6 (1.28)
		467+00	33.3 (1.31)	30.6 (1.20)	35.7 (1.41)
		469+00	43.5 (1.71)	25.9 (1.0)	22.9 (0.9)
Sec 2N		490+00	50.0 (1.97)	28.6 (1.13)	27.3 (1.07)
		492+00	25.0 (1.0)	50.0 (1.97)	22.6 (0.89)
		494+00	25.4 (1.0)	34.5 (1.36)	25.0 (1.0)
		496+00	33.3 (1.31)	40.0 (1.57)	56.6 (2.230
		498+00	12.5 (0.5)	21.7 (0.85)	29.7 (1.17)
Sec 3S		668+00	13.6 (0.54)	7.8 (0.3)	16.4 (0.65)
		670+00	11.9 (0.47)	6.6 (0.26)	10.4 90.41)
		672+00	16.3 (0.64)	9.1 (0.36)	10.9 (0.43)
		674+00	11.7 (0.46)	5.7 (0.22)	6.3 (0.24)
		676+00	13.8 (0.54)	7.9 (0.31)	15.9 (0.63)

3.2.1.3 Soil Sampling and Tests

Composite bulk samples were collected from every section for laboratory tests and analysis. From along the roadway, Shelby tube samples were obtained at 61 m (200 ft.) intervals to a depth of 1.5 m (5 ft.) except for the middle hole, where the sampling reached a depth of 3 m (10 ft.) exploring the presence of possible water table/rigid bottom. Retrieved from each foot was one sample, 71 mm (2.8 in.) diameter by 142 mm

(5.6 in.) height, with the top three tested for M_R in the laboratory. Upon completion of M_R test, each sample was tested in quick shear. Other data collected from these samples include density and moisture content. On the composite bulk samples, standard proctor test (T99-90) was conducted with the maximum dry density/optimum moisture content listed in *Table 3.5* for the twelve sections.

TABLE 3.5. Locations, Stations, and Other Physical Properties of Tested Sections.

Section Designation	County/Road/Project	Proctor Test on	
		Max. Dry Density, kN/m^3 (pcf)	Optimum Moisture, %
Sec 1S	Rankin/SR25/South	17.4 (111.0)	14.0
Sec 2S		18.2 (116.0)	12.0
Sec 3S		17.1 (109.0)	14.3
Sec 4S		18.0 (114.5)	13.0
Sec 1N	Leake/SR25/North	18.4 (117.0)	14.0
Sec 1N	Monroe/US45/South	16.7 (106.0)	15.0
Sec 2N		16.3 (104.0)	16.0
Sec 3N		17.1 (109.0)	14.5
Sec 4N		15.7 (100.0)	17.5
Sec 1N	Monroe/US45/North	17.4 (111.0)	14.5
Sec 2N		17.1 (108.5)	15.5
Sec 3S		15.7 (100.0)	15.5

3.2.2 Laboratory Testing

3.2.2.1 Laboratory Resilient Modulus Testing

A laboratory M_R test, in accordance with AASHTO TP46 protocol (35), was conducted using the MDOT repeated load triaxial machine furnished by Industrial Process Control (IPC), Boronia, Australia. The load sequence and combination are presented in *Appendix C.*

The deformation in the samples was recorded using two Linear Variable Differential Transducers (LVDTs) mounted outside of the testing chamber. Deformation and applied load readings were digitally recorded, from which the deviator stresses and resilient strains were calculated. The average M_R values for the last five loading cycles of a 100-cycle sequence yielded the resilient modulus. Typical laboratory M_R test results for some of the tested samples are presented in *Appendix D.* As expected for fine-grain soil, laboratory M_R decreases with increase in deviator stress increase while the confining pressure has practically no significant effect. It is different for coarse-grain soil samples, however, where confining pressure is significant. A detailed discussion of the test results will be offered in *Chapter 5*.

3.2.2.2 Routine Laboratory Testing

The samples tested for resilient modulus were kept for further laboratory tests. Based on the visual appearance, dry density values, and resilient modulus for every sample, the samples were grouped, reducing the number of samples for testing. Nonetheless, 110 tests were required from an original pool of 180 samples. These tests included particle size analysis in accordance with AASHTO T88-90, Liquid limit in accordance with AASHTO T-89-90, and Plastic limit T-90-87 (35). This information was used to divide the subgrade soil materials into fine- and coarse-grain soils. *Tables 3.6 – 3.17* list the results of the aforementioned tests for all the samples from the twelve sections included in the study. The actual sample densities are obviously higher than the maximum design dry density especially for fine-grain soil. This could be attributed to disturbance/densification resulting from pushing Shelby tube for sample extraction. Since M_R is significantly affected by sample density, modulus values are expected to be high for these samples. This will make it mandatory to consider dry density as an explanatory variable in the developed regression models.

TABLE 3.6. Properties of Samples Tested for Resilient Modulus. (Sec1S, Rankin County, SR25)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
1303 / #1	18.08 (115.1)	17.3	88.0	45	26	A-7
1303 / #2	18.05 (114.9)	16.5	94.0	42	18	A-6
1303 / #3	17.07 (108.7)	19.6	89.0	40	20	A-6
1305 / #1	17.70 (112.5)	17.7	89.0	45	21	A-7
1305 / #2	17.86 (113.7)	18.4	94.0	42	18	A-6
1305 / #3	17.03 (108.4)	20.1	NA*	NA	NA	NA
1307 / #1	17.92 (114.1)	18.1	89.0	45	21	A-7
1307 / #2	17.30 (110.0)	19.9	91.0	31	10	A-4
1307 / #3	16.24 (103.4)	24.5	35.0	31	12	A-6
1309 / #1	18.05 (114.9)	17.3	82.0	43	28	A-7
1309 / #2	17.55 (111.7)	18.5	91.0	31	10	A-4
1309 / #3	16.78 (106.8)	18.6	35.0	31	12	A-6
1311 / #1	19.34 (123.1)	13.8	82.0	43	28	A-7
1311 / #2	19.20 (122.0)	13.7	72.0	24	18	A-6
1311 / #3	16.92 (107.7)	20.7	89.0	40	20	A-6

* Data not available

TABLE 3.7. Properties of Samples Tested for Resilient Modulus. (Sec 2S, Rankin County SR25)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
1347 / #1	17.25 (109.8)	12.3	78.0	34	18	A-6
1347 / #2	19.68 (125.3)	10.6	80.0	34	16	A-6
1347 / #3	18.62 (118.5)	15.4	78.0	32	16	A-6
1349 / #1	19.75 (125.7)	11.0	78.0	34	18	A-6
1349 / #2	18.22 (116.0)	15.4	81.0	35	16	A-6
1349 / #3	17.17 (109.3)	15.8	88.0	36	16	A-6
1351 / #1	NA*	NA	NA	NA	NA	NA
1351 / #2	19.68 (125.5)	12.1	73.0	34	18	A-6
1351 / #3	18.96 (120.7)	14.8	88.0	36	16	A-6
1353 / #1	18.68 (118.9)	13.2	83.0	38	19	A-6
1353 / #2	17.90 (113.9)	15.5	80.0	34	15	A-6
1353 / #3	17.53 (111.6)	14.9	78.0	32	16	A-6
1355 / #1	19.04 (121.2)	13.5	83.0	38	19	A-6
1355 / #2	19.26 (122.6)	12.9	73.0	34	18	A-6
1355 / #3	19.20 (122.1)	14.2	75.0	31	14	A-6

* Data not available

TABLE 3.8. Properties of Samples Tested for Resilient Modulus. (Sec 3S, Rankin County, SR25)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
1591 / #1	18.54 (118.0)	14.3	77	35	16	A-6
1591 / #2	18.77(119.5)	14.3	66	28	9	A-4
1591 / #3	18.63 (118.6)	15.1	68	28	11	A-6
1593 / #1	16.76 (106.7)	17.3	87	37	17	A-7
1593 / #2	16.01 (101.9)	23.8	98	42	20	A-7
1593 / #3	16.56 (105.4)	21.9	98	57	31	A-4
1595 / #1	16.97 (108.0)	18.2	97	25	4	A-7
1595 / #2	16.61 (105.7)	20.2	98	42	20	A-7
1595 / #3	16.79 (106.9)	20.0	90	49	26	A-6
1596 / #1	17.52 (111.5)	16.1	87	37	17	A-7
1596 / #2	16.17 (102.9)	21.8	99	44	27	A-6
1596 / #3	16.98 (108.1)	19.3	96	33	12	A-6
1598 / #1	17.63 (112.2)	18.5	77	35	16	A-6
1598 / #2	17.61 (112.1)	14.5	89	33	13	A-6
1598 / #3	16.51 (105.1)	20.8	96	33	12	A-6

TABLE 3.9. Properties of Samples Tested for Resilient Modulus. (Sec 4S, Rankin County, SR25)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
1696 / #1	20.0 (127.3)	10.7	79	35	18	A-6
1696 / #2	19.01 (121.0)	12.4	82	31	13	A-6
1696 / #3	18.33 (116.7)	16.9	73	28	12	A-6
1698 / #1	18.57 (118.2)	13.8	76	30	14	A-6
1698 / #2	18.1 (115.1)	17.3	74	34	19	A-6
1698 / #3	18.41 (117.2)	19.8	73	27	11	A-6
1700 / #1	19.51 (124.2)	13.2	78	32	14	A-6
1700 / #2	18.70 (119.0)	14.4	74	38	22	A-6
1700 / #3	17.96 (114.3)	17.4	76	41	24	A-7
1702 / #1	20.17 (128.4)	11.6	63	32	15	A-6
1702 / #2	19.08 (121.5)	13.8	58	30	13	A-6
1702 / #3	18.54 (118.0)	13.4	79	30	12	A-6
1704 / #1	18.79 (119.6)	14.8	76	30	14	A-6
1704 / #2	17.33 (110.3)	17.0	74	34	19	A-6
1704 / #3	15.51 (98.8)	19.2	87	29	3	A-4

TABLE 3.10. Properties of Samples Tested for Resilient Modulus. (Sec 1N, Leake County, SR25)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
522 / #1	20.11 (128.0)	11.0	56	27	12	A-6
522 / #2	18.82 (119.8)	15.5	54	28	10	A-4
522 / #3	18.05 (114.9)	15.4	79	34	13	A-6
524 / #1	19.54 (124.4)	12.2	47	31	16	A-6
524 / #2	19.43 (123.7)	12.9	64	31	16	A-6
524 / #3	18.43 (117.3)	15.2	79	34	13	A-6
526 / #1	19.87 (126.5)	13.0	47	31	16	A-6
526 / #2	19.23 (122.4)	13.4	54	26	12	A-6
526 / #3	19.50 (124.1)	12.8	44	29	14	A-6
528 / #1	20.04 (127.6)	11.4	56	27	12	A-6
528 / #2	19.02 (121.1)	14.0	54	26	12	A-6
528 / #3	18.80 (119.7)	15.4	43	20	2	A-4
530 / #1	19.42 (123.6)	11.1	47	31	16	A-6
530 / #2	19.68 (125.3)	10.6	54	28	10	A-4
530 / #3	19.87 (126.5)	11.5	44	29	14	A-6

TABLE 3.11. Properties of Samples Tested for Resilient Modulus. (Sec 1N, Monroe County, US45, South Project)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
88 / #1	17.27 (109.9)	14.8	18	37	9	A-2-4
88 / #2	16.68 (106.2)	10.1	33	28	0	A-2-4
88 / #3	16.84 (107.2)	19.6	23	27	0	A-2-4
90 / #1	17.01 (108.3)	15.8	23	27	1	A-2-4
90 / #2	17.60 (112.0)	17.8	29	28	4	A-2-4
90 / #3	17.23 (109.7)	17.2	23	27	0	A-2-4
92 / #1	18.76 (119.4)	12.4	28	33	5	A-2-4
92 / #2	18.18 (115.7)	17.6	33	31	14	A-2-6
92 / #3	17.75 (113.0)	15.7	31	30	2	A-2-4
94 / #1	18.58 (118.3)	13.3	30	29	5	A-2-4
94 / #2	18.02 (114.7)	16.8	29	28	4	A-2-4
94 / #3	18.35 (116.8)	17.2	38	32	8	A-4
96 / #1	19.02 (121.1)	14.3	27	29	5	A-2-4
96 / #2	17.19 (109.4)	20.9	29	28	4	A-2-4
96 / #3	18.44 (117.4)	15.1	23	30	3	A-2-4

TABLE 3.12. Properties of Samples Tested for Resilient Modulus. (Sec 2N, Monroe County, US45, South Project)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
108 / #1	17.23 (109.7)	18.1	15	25	0	A-2-4
108 / #2	17.97 (114.4)	17.5	22	27	0	A-2-4
108 / #3	17.75 (113.0)	18.3	32	27	4	A-2-4
110 / #1	17.05 (108.5)	13.8	15	25	0	A-2-4
110 / #2	16.81 (107.0)	21.7	88	54	20	A-7
110 / #3	16.37 (104.2)	23.6	39	48	22	A-7
112 / #1	17.91 (114.0)	16.4	17	26	0	A-2-4
112 / #2	17.22 (109.6)	19.2	22	27	0	A-2-4
112 / #3	16.70 (106.3)	20.1	17	26	0	A-2-4
114 / #1	17.53 (111.6)	17.6	15	25	0	A-2-4
114 / #2	16.90 (107.6)	22.0	26	31	4	A-2-4
114 / #3	17.05 (108.5)	19.3	17	26	0	A-2-4
116 / #1	17.85 (113.6)	16.4	17	26	0	A-2-4
116 / #2	17.85 (113.6)	18.2	21	29	5	A-2-4
116 / #3	17.14 (109.1)	18.9	24	29	8	A-2-4

TABLE 3.13. Properties of Samples Tested for Resilient Modulus. (Sec 3N, Monroe County, US45, South Project)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
170 / #1	20.58 (131.0)	10.9	39	26	8	A-4
170 / #2	19.35 (123.2)	12.4	NA*	29	8	NA
170 / #3	18.02 (114.7)	17.1	NA	40	10	NA
172 / #1	19.42 (123.6)	11.6	68	28	8	A-4
172 / #2	18.30 (116.5)	16.2	23	28	6	A-2-4
172 / #3	17.83 (113.5)	19.2	66	31	13	A-6
174 / #1	19.98 (127.2)	12.3	68	28	8	A-4
174 / #2	18.50 (117.7)	14.7	23	28	6	A-2-4
174 / #3	18.68 (118.9)	16.4	21	23	23	A-2-6
176 / #1	NA	NA	NA	NA	NA	NA
176 / #2	18.43	17.3	32	29	7	A-2-4
176 / #3	NA	NA	NA	NA	NA	NA
178 / #1	19.10 (121.6)	12.6	27	25	3	A-2-4
178 / #2	17.36 (110.5)	20.7	32	29	7	A-2-4
178 / #3	17.60 (112.0)	16.5	21	23	23	A-2-6

* Data not available

TABLE 3.14. Properties of Samples Tested for Resilient Modulus. (Sec 4N, Monroe County, US45, South Project)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
260 / #1	15.76 (100.3)	18.0	10	NP*	NP	A-3
260 / #2	15.66 (99.7)	15.2	7	NP	NP	A-3
260 / #3	NA**	NA	NA	NA	NA	NA
261+50 / #1	17.41 (110.8)	16.1	13	NP	NP	A-2-4
261+50 / #2	17.08 (108.7)	16.8	16	NP	NP	A-2-4
261+50 / #3	16.12 (102.8)	17.5	13	NP	NP	A-2-4
262+63 / #1	17.36 (110.5)	16.6	13	NP	NP	A-2-4
262+63 / #2	17.20 (109.5)	17.2	14	NP	NP	A-2-4
262+63 / #3	16.48 (104.9)	19.1	15	NP	NP	A-2-4
264 / #1	17.41 (110.8)	15.1	15	NP	NP	A-2-4
264 / #2	17.42 (110.9)	17.3	16	NP	NP	A-2-4
264 / #3	16.38 (104.3)	17.2	15	NP	NP	A-2-4
266 / #1	17.47 (111.2)	18.5	13	NP	NP	A-2-4
266 / #2	17.03 (108.4)	15.5	16	NP	NP	A-2-4
266 / #3	16.21 (103.2)	19.4	17	23	NP	A-2-4

* Non plastic

** Data not available

TABLE 3.15. Properties of Samples Tested for Resilient Modulus. (Sec 1N, Monroe County, US45, North Project)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
461 / #1	15.13 (96.3)	31.1	47	49	27	A-7
461 / #2	18.1 (115.2)	17.2	43	35	18	A-6
461 / #3	17.5 (111.4)	18.4	54	37	19	A-6
463 / #1	18.5 (117.7)	16.0	45	35	18	A-6
463 / #2	18.32 (116.6)	16.4	47	32	13	A-6
463 / #3	18.22 (116.0)	17.4	54	37	19	A-6
465 / #1	18.38 (117.0)	15.6	45	35	18	A-6
465 / #2	17.70 (112.6)	19.6	47	32	13	A-6
465 / #3	17.2 (109.3)	19.8	54	36	17	A-6
467 / #1	19.01 (121.0)	14.7	45	35	19	A-6
467 / #2	17.96 (114.3)	18.8	54	38	21	A-6
467 / #3	17.39 (110.7)	15.9	47	36	20	A-6
469 / #1	17.5 (111.4)	19.9	59	43	25	A-7
469 / #2	18.47 (117.4)	16.4	43	35	18	A-6
469 / #3	17.52 (111.5)	15.8	54	37	19	A-6

TABLE 3.16. Properties of Samples Tested for Resilient Modulus. (Sec 2N, Monroe County, US45, North Project)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
490 / #1	16.64 (105.9)	24.7	42	36	18	A-6
490 / #2	19.06 (121.3)	14.2	54	29	12	A-6
490 / #3	17.53 (111.6)	15.9	41	30	12	A-6
492 / #1	18.79 (119.6)	14.4	42	36	18	A-6
492 / #2	17.12 (109.0)	20.0	35	26	5	A-2-4
492 / #3	17.45 (111.1)	17.9	38	30	10	A-4
494 / #1	18.93 (120.5)	15.3	42	36	18	A-6
494 / #2	18.36 (116.9)	18.0	35	26	5	A-2-4
494 / #3	17.5 (111.4)	18.4	41	30	12	A-6
496 / #1	19.17 (122.0)	10.7	35	26	5	A-2-4
496 / #2	18.3 (116.5)	17.7	55	30	10	A-4
496 / #3	17.67 (112.5)	15.4	51	31	12	A-4
498 / #1	19.04 (121.2)	14.5	43	41	24	A-7
498 / #2	18.3 (116.5)	17.7	35	26	5	A-2-4
498 / #3	18.04 (114.5)	11.9	50	36	19	A-6

TABLE 3.17. Properties of Samples Tested for Resilient Modulus. (Sec 3S, Monroe County, US45, North Project)

Station / sample #	Dry density, kN/m^3 (pcf)	Moisture, %	% passing # 200 sieve	Liquid limit, %	Plasticity index	AASHTO classification
668 / #1	16.07 (102.3)	16.3	11	NP*	NP	A-1-a
668 / #2	16.23 (103.3)	17.0	10	NP	NP	A-3
668 / #3	NA**	NA	NA	NA	NA	NA
670 / #1	17.20 (109.5)	15.8	11	NP	NP	A-1-a
670 / #2	16.45 (104.7)	16.2	10	NP	NP	A-3
670 / #3	NA	NA	NA	NA	NA	NA
672 / #1	16.40 (104.4)	18.6	11	NP	NP	A-1-a
672 / #2	16.00 (101.8)	20.3	10	NP	NP	A-3
672 / #3	NA	NA	NA	NA	NA	NA
674 / #1	16.80 (106.9)	18.1	10	NP	NP	A-3
674 / #2	16.43 (104.6)	15.7	10	NP	NP	A-3
674 / #3	16.43 (104.6)	15.6	9	NP	NP	A-3
676 / #1	17.64 (112.3)	16.8	10	NP	NP	A-3
676 / #2	17.40 (110.7)	16.1	10	NP	NP	A-3
676 / #3	16.61 (105.7)	16.7	9	NP	NP	A-3

* Non plastic

** Data not available

3.3 CYCLE 2 (NOVEMBER 1999)

On several test sections the top 152.4 mm (6 in.) of the subgrade was stabilized with lime and then paved with 152.4 mm (6 in.) lime-fly ash (LFA) base. Both these two stabilized layers were still not fully cured by November 1999 and it was possible to conduct automated DCP tests through these layers. Therefore, side-by-side tests with both ADCP and FWD, were conducted on some sections in Monroe County without coring and removing the top two stabilized layers. This second cycle of testing in November 1999 gave a unique opportunity to evaluate the seasonal effects on the stiffness of subgrade soils. Detailed data and results are described in Sections 5.2.1 and 5.2.2. *Figure 3.2* compares the FWD sensor 1 deflection data collected in July 1999 (c*ycle 1*) and November 1999 (c*ycle 2*). As expected, sensor 1 maximum deflection decreased soon after the construction of the LFA base over the lime treated subgrade. It is further noted that the deflection values after the construction of the LFA treated base are within the accuracy range, well below 80 mils.

3.4 CYCLES 3/4 (SPRING/SUMMER 2000)

3.4.1 Field Test

3.4.1.1 FWD on Asphalt Surface

Following the *cycle 1* field test, the subgrade received lime treatment to a depth of 152 mm (6.0 in.), followed by 152 mm (6 in.) lime-fly ash stabilization of a topping material trucked in and mixed in-place. Two asphalt layers, 2.5 in. binder and 3.0 in. base, completed the first stage of construction. During Spring/Summer of 2000, the FWD test was repeated at each location followed by pavement coring for in-situ layer thickness of base and subbase, and moisture of subgrade soil. Those thicknesses served as inputs to backcalculate the layer moduli.

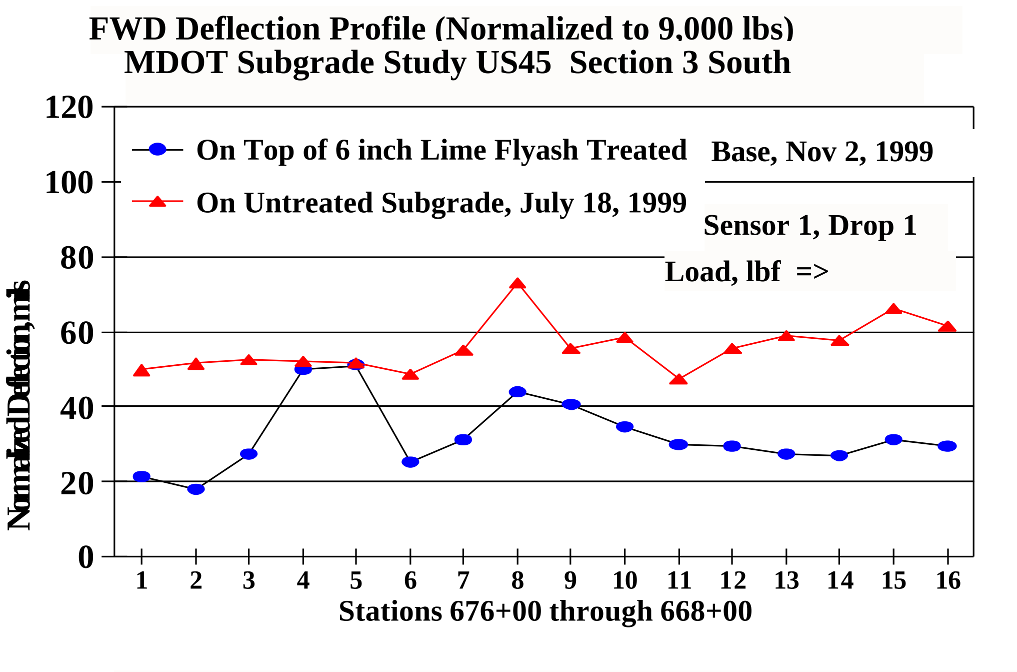


Figure 3.2 Illustration of smaller deflection values on top of the constructed LFA base over lime-treated subgrade, US45 North Project Section 3S, Monroe county.

Backcalculation of Moduli In order to analyze FWD data obtained during the Spring/Summer of 2000, the pavement structure was modeled as a three-layer system. Best results are obtained with MODULUS when not more than three layers with unknown moduli are analyzed (36). From top to bottom are the asphalt layer, the stabilized layers (lime-fly ash and lime-treated) and the subgrade, respectively. Listed in *Table 3.18* are the actual average thicknesses of the layers at each location determined from pavement cores, served as the layers thicknesses in the backcalculation program.

Table 3.19 and *3.20* list the backcalculated values for all the twelve sections included in the study.

TABLE 3.18. Pavement Layers Thicknesses Determined from Pavement Cores Extracted in the Spring/Summer of 2000.

Section Designation	County/Road/Project	Asphalt layer, mm/in.		Treated layer, mm/in.	
		Binder	Base	LFA[a] subbase	Treated subgrade
Sec 1S	Rankin/SR25	61.0 / 2.4	81.0 / 3.2	203.0/ 8.0	114.0 / 4.5
Sec 2S		47.0 / 1.9	86.0 / 3.4	254.0 / 10.0	102.0 / 4.0
Sec 3S		70.0 / 2.8	76.0 / 3.0	216.0 / 8.5	165.0 / 4.5
Sec 4S		68.6 / 2.7	76.0 / 3.0	218.0 / 8.6	152.0 / 6.0
Sec 1N	Leake/SR25	NA[b]	NA	NA	NA
Sec 1N	Monroe/US45/South	63.5 / 2.5	95.0 / 3.7	171.5 / 6.75	203.0 / 8.0
Sec 2N		63.5 / 2.5	83.0 / 3.3	203.0 / 8.0	228.0 / 9.0
Sec 3N		63.5 / 2.5	83.0 / 3.3	203.0 / 8.0	228.0 / 9.0
Sec 4N		NA	NA	NA	NA
Sec 1N	Monroe/US45/North	58.0 / 2.3	84.0 / 3.3	178.0 / 7.0	127.0 / 5.0
Sec 2N		66.0 / 2.6	86.0 / 3.4	152.0 / 6.0	152.0 / 6.0
Sec 3N		58.0 / 2.3	76.0 / 3.0	152.0 / 6.0	152.0 / 6.0

a Lime Fly Ash
b Data not available

The variation of the backcalculated subgrade moduli for both fine- and coarse-grain soils was diminished as compared that for *cycle 1*. This could be attributed in part to the uniformity in deflection data measured atop the finished asphalt surface compared with those measured on the bare subgrade surface.

Extensive analysis of FWD data collected throughout the test program was conducted using a specially developed program based on PEDD backcalculation software. The results are discussed in Sections 5.3.2 and included in *Appendix E*.

3.4.1.2 Dynamic Cone Penetrometer Tests

During *cycle 3/4* ADCP tests were conducted at the same stations as those where *cycle 1* ADCP tests were conducted, with one difference that penetration resistance was measured through core holes. *Figure 3.3* shows the pavement coring through the top

TABLE 3.19. MODULUS 5-Backcalculated Moduli from FWD on Asphalt Surface, SR 25.

Section Designation/County	Station No.	Backcalculated Moduli, MPa (psi)		
		Asphalt layer	Subabse + Treated Subgrade	Subgrade
Sec 1S/Rankin	1303+00	2663 (386,000)	1063 (154,000)	145 (21,000)
	1305+00	2153 (312,000)	996 (144,000)	132 (19,100)
	1307+00	2381 (345,000)	1603 (232,200)	129 (18,700)
	1309+00	3450 (498,000)	1291 (188,200)	139 (20,200)
	1311+00	1732 (251,000)	1368 (198,300)	121 (17,500)
Sec 2S/Rankin	1347+00	1925 (279,000)	1704 (247,000)	183 (26,500)
	1349+00	3105 (450,000)	1132 (164,000)	171 (24,800)
	1351+00	2622 (380,000)	1297 (188,000)	144 (20,900)
	1353+00	2929 (410,000)	1932 (280,000)	161 (23,300)
	1354+50	2415 (350,000)	1484 (215,000)	186 (27,000)
Sec 3S/Rankin	1591+00	2415 (350,000)	338 (49,000)	110 (15,900)
	1593+00	2967 (430,000)	163 (23,600)	105 (15,200)
	1595+00	3802 (551,000)	504 (73,100)	122 (17,700)
	1596+00	3128 (453,000)	350 (50,700)	108 (15,600)
	1598+00	3933 (570,000)	460 (66,700)	108 (15,700)
Sec 4S/Rankin	1696+00	4140 (600,000)	856 (123,600)	121 (17,600)
	1698+00	4002 (580,000)	378 (54,600)	115 (16,700)
	1700+00	4071 (590,000)	684 (99,100)	150 (21,700)
	1702+00	4140 (600,000)	425 (61,600)	126 (21,400)
	1704+00	3933 (570,000)	795 (115,200)	144 (20,800)
Sec 1N/Leake	522+00	NA[a]	NA[a]	NA[a]
	524+00			
	526+00			
	528+00			
	530+00			

a Data not available

layers exposing the subgrade for ADCP testing. Before the penetrometer test, the cored hole was cleaned, removing the debris and excess water. The ADCP operation is captured in *Figure 3.4*.

Since the top 6 in. of the subgrade was stabilized with lime, the penetration resistance of the 'top foot' (as described in *cycle 1*) could not be determined. What was determined was the continuous resistance of the subgrade soil beneath the lime-treated

TABLE 3.20. MODULUS 5-Backcalculated Moduli from FWD on Asphalt Surface, US45.

Section Designation/ County/Project	Station No.	Backcalculated Moduli, MPa (psi)		
		Asphalt layer	Subabse + Treated Subgrade	Subgrade
Sec 1N/Monore/ South	88+00	2139 (310,000)	405 (58,800)	167 (24,200)
	90+00	1967 (285,000)	571 (82,700)	213 (30,900)
	92+00	1456 (211,000)	416 (60,300)	242 (35,100)
	94+00	2215 (321,000)	505 (73,200)	277 (40,100)
	96+00	1932 (280,000)	1877 (272,000)	186 (27,000)
Sec 2N/Monore/ South	108+00	1490 (216,000)	539 (78,100)	161 (23,400)
	110+00	1484 (215,000)	1718 (250,000)	152 (22,000)
	112+00	2594 (376,000)	1007 (146,000)	86 (12,500)
	114+00	2760 (400,000)	717 (104,100)	92 (13,400)
	116+00	2629 (381,000)	602 (87,300)	88 (12,700)
Sec 3N/Monore/ South	170+00	3450 (500,000)	919 (133,200)	144 (20,800)
	172+00	1173 (170,000)	359 (52,000)	127 (18,400)
	174+00	1711 (248,000)	380 (54,500)	169 (24,500)
	176+00	2312 (335,000)	157 (22,800)	77 (11,200)
	178+00	3016 (457,000)	233 (33,800)	105 (15,200)
Sec 4N/Monore/ South	260+00	NA[a]	NA[a]	NA[a]
	261+50			
	262+63			
	264+50			
	266+00			
Sec 1N/Monore/ North	461+00	3174 (460,000)	466 (67,500)	121 (17,400)
	463+00	2967 (430,000)	406 (58,900)	123 (17,800)
	465+00	3381 (490,000)	390 (56,500)	136 (19,700)
	467+00	3002 (435,000)	235 (34,000)	128 (18,500)
	469+00	3209 (465,000)	459 (66,500)	132.5 (19,200)
Sec 2N/Monore/ North	490+00	3105 (450,000)	1070 (155,000)	156 (22,600)
	492+00	3519 (510,000)	709 (102,800)	128 (18,600)
	494+00	3312 (480,000)	549 (79,000)	135 (19,600)
	496+00	3174 (460,000)	413 (59,800)	96 (16,000)
	498+00	2691 (390,000)	621 (90,000)	150 (21,700)
Sec 3S/Monore/ North	668+00	1346 (195,000)	281 (40,700)	129 (18,700)
	670+00	1097 (159,000)	216 (31,300)	137 (19,800)
	672+00	1277 (185,000)	207 (30,000)	130 (18,900)
	674+00	2450 (500,000)	262 (38,000)	131 (19,000)
	676+00	3409 (494,000)	652 (94,500)	154 (22,300)

a Data not available

soil. Accordingly, penetration resistance of the second-foot layer (*cycle 1*) would be comparable to that of the top layer (*cycle 3/4*), and third layer resistance to second layer

Figure 3.3 Drilling through the pavement layers in progress

Figure 3.4 Automated dynamic cone penetrometer test in the cored hole with MDOT FWD in the background

and so forth. The DCPI of each layer is now estimated from a graph of number of blows vs. penetration depth and the results listed in *Table 3.21*.

When the penetration resistance is determined in the subgrade with pavement overburden, it is expected that the confinement effect would be reflected in the DCPI results. That this effect would be the same for both fine- and coarse-grain soil is an issue that will be discussed in more details in the next chapter.

3.4.1.3 Moisture Content of Subgrade Soil

Upon completion of penetration test a representative moisture sample was collected from the subgrade, sealed in plastic bags and shipped to the laboratory for moisture determination. In order to minimize the contamination of the sample by water, that was used during drilling, the samples were extracted intentionally from at least 6 inches from the subgrade surface. Moisture results from two depths in typical cases did not show a large disparity, ensuring that the (drilling) water had not materially affected the subgrade soil. Listed in *Table 3.22* are the moisture content results from some tested locations.

In summary, this chapter dealt with the experimental work conducted in the field as well as in the laboratory. Also, summary results of different tests were presented. The tested samples were then put into two groups, fine- and coarse-grain soils. The data for the two groups was compiled, with M_R as a dependent variable and the other physical properties as independent variables for regression modeling. FWD deflection data from two test cycles (*cycles 1* and *3/4*) were used to backcalculate the subgrade elastic modulus and the moduli of other layers as applicable. In the next chapter, regression analysis will be performed to develop two models for each soil group with M_R as a dependent variable, and DCPI and other material properties as independent variables. Another two simple models, relating M_R to DCPI, will be presented as well. Backcalculated moduli using two programs, FWDSOIL for tests on prepared subgrade and UMPED for tests on the pavement surface are presented. MODULUS 5 program is also used to backcalculate subgrade modulus. Laboratory measured M_R as compared to the backcalculated modulus will be addressed as well in the next chapter.

TABLE 3.21. Manually Calculated DCPI Values for Subgrade after Pavement Construction, C*ycle 3/4*.

Section Designation/ County/Road/ Project	Station No.	DCPI values, mm/blow (in./blow)		
		1st foot	2nd foot	3rd foot
Sec 1S/Rankin/ SR25	1303+00	13.7 (0.5)	13.7 (0.5)	13.7 (0.5)
	1305+00	19.4 (0.8)	9.7 (0.4)	9.7 (0.4)
	1307+00	12.8 (0.5)	18.6 (0.7)	33.0 (1.3)
	1309+00	24.0 (0.95)	18.3 (0.7)	18.3 (0.7)
	1311+00	33.0 (1.3)	25.6 (1.0)	18.3 (0.7)
Sec 2S/Rankin/ SR25	1347+00	6.4 (0.25)	12.3 (0.5)	12.3 (0.5)
	1349+00	12.7 (0.5)	12.7 (0.5)	NA[a]
	1351+00	9.7 (0.4)	17.2 (0.7)	22.2 (0.9)
	1353+00	12.0 (0.5)	15.3 (0.6)	NA[a]
	1354+50	10.0 (0.4)	14.2 (0.6)	9.6 (0.4)
Sec 3S/Rankin/ SR25	1591+00	49.5 (1.95)	15.7 (0.6)	15.7 (0.6)
	1593+00	33.5 (1.32)	7.4 (0.3)	22.4 (0.88)
	1595+00	53.5 (2.1)	26.3 (1.04)	NA
	1596+00	5.0 (0.2)	33.0 (1.3)	53.0 (2.1)
	1598+00	19.5 (0.77)	16.6 (0.65)	27.0 (1.1)
Sec 4S/Rankin/ SR25	1696+00	15.6 (0.6)	24.2 (0.95)	NA
	1698+00	32.2 (1.27)	33.5 (1.30)	23.4 (0.9)
	1700+00	14.4 (0.6)	12.8 (0.5)	31.0 (1.22)
	1702+00	25.8 (1.02)	17.9 (0.7)	33.5 (1.3)
	1704+00	14.0 (0.55)	14.0 (0.55)	9.2 (0.4)
Sec 1S/Leake/ SR25	522+00	NA	NA	NA
	524+00			
	526+00			
	528+00			
	530+00			

a Data not available

Table 3.21. Continued

Section Designation/ County/Road/Project	Station No.	PI, mm/blow (in/blow)		
		1st foot	2nd foot	3rd foot
Sec 1N/Monore/ US45/ South	88+00	13.0 (0.5)	8.4 (0.33)	NA[a]
	90+00	9.8 (0.39)	13.8 (0.54)	7.0 (0.3)
	92+00	16.0 (0.63)	8.0 (0.3)	6.0 (0.24)
	94+00	8.8 (0.35)	15.0 (0.6)	23.3 (0.9)
	96+00	10.0 (0.4)	8.1 (0.32)	NA
Sec 2N/Monore/ US45/ South	108+00	9.3 (0.37)	10.0 (0.4)	NA
	110+00	48.0 (1.9)	41.7 (1.6)	NA
	112+00	10.5 (0.4)	22.3 (0.88)	NA
	114+00	9.2 (0.36)	14.8 (0.6)	21.0 (0.83)
	116+00	9.4 (0.37)	17.0 (0.67)	21.6 (0.85)
Sec 3N/Monore/ US45/ South	170+00	10.0 (0.4)	24.8 (0.98)	NA
	172+00	12.0 (0.47)	24.0 (0.94)	42.5 (1.7)
	174+00	6.1 (0.24)	21.5 (0.85)	8.8 (0.35)
	176+00	9.4 (0.37)	18.5 (0.7)	21.0 (0.8)
	178+00	8.0 (0.3)	8.8 (0.35)	6.4 (0.25)
Sec 4N/Monore/ US45/ South	260+00	NA	NA	NA
	261+50			
	262+63			
	264+50			
	266+00			
Sec 1N/Monore/ US45/ North	461+00	25.2 (1.0)	30.4 (1.2)	30.0 (1.2)
	463+00	20.6 (0.8)	23.0 (0.9)	28.3 (1.1)
	465+00	29.6 (1.2)	29.6 (1.2)	28.0 (1.1)
	467+00	20.0 (0.8)	31.7 (1.25)	28.7 (1.1)
	469+00	33.0 (1.3)	14.5 (0.6)	14.0 (0.6)
Sec 2N/Monore/US45/ North	490+00	19.9 (0.8)	23.4 (0.9)	34.0 (1.3)
	492+00	44.0 (1.7)	15.1 (0.6)	15.4 (0.6)
	494+00	17.0 (0.67)	22.1 (0.9)	29.0 (1.1)
	496+00	18.0 (0.7)	25.0 (1.0)	25.0 (1.0)
	498+00	17.0 (0.67)	21.0 (0.8)	28.0 (1.1)
Sec 3N/Monore/US45/ North	668+00	6.4 (0.25)	6.4 (0.25)	15.5 (0.6)
	670+00	5.0 (0.2)	5.0 (0.2)	11.0 (0.4)
	672+00	7.0 (0.28)	6.3 (0.25)	10.0 (0.4)
	674+00	4.6 (0.18)	4.6 (0.18)	14.0 (0.55)
	676+00	4.3 (0.17)	4.3 (0.17)	4.7 (0.18)

a Data not available

TABLE 3.22. Subgrade Moisture Content Determined during *Cycle 3/4*.

Station	County/Road	Moisture content, %
88+00	Monroe/US45	19.67
89+00		15.93
90+00		17.34
91+00		24.67
92+00		21.88
93+00		22.11
94+00		20.65
95+00		24.67
96+00		19.40
107+95		20.43
108+95		18.12
109+95		25.11
110+95		20.40
112+00		19.22
112+90		18.96
114+00		20.81
114+95		21.34
115+95		18.91
170+00		15.40
171+00		23.95
172+05		18.24
173+05		17.37
174+00		25.05
175+00		29.82
176+00		23.71
177+05		25.95
177+95		23.89

CHAPTER 4

DYNAMIC CONE PENETROMETER TEST RESULTS

4.1 GENERAL

For structural evaluation of unbound pavement layers, both Manual DCP (MDCP) and Automated DCP (ADCP) can be used. The MDCP test calls for recording the number of blows for approximately 25 mm of penetration, whereas ADCP is programmed to record penetration for each blow count. In either case, the data analysis entails computing the DCP index (DCPI) with depth, from which is determined the layering of the pavement foundation. The DCPI-value provides a measure of in situ strength of the layer. From a plot of depth versus penetration (*see Figure 4.1*), depth of layering and corresponding DCPI may be determined. For example, in *Figure 4.1*, three layers of thicknesses 265mm, 160mm, and 325mm are identified. To facilitate the process of determining layering, a software designated Dynamic Cone Penetration ANalysis (DCPAN), is developed. A description of this program is included in the latter part of this chapter. The performance characteristics of MDCP and ADCP is compared in the ensuing section.

4.2 COMPARISON OF MANUAL DCP AND AUTOMATED DCP

MDOT has been using MDCP, and with the acquisition of ADCP in the summer of 1999, it became necessary to conduct a side-by-side comparison of both devices. Livenh (16) reported manual DCP results are affected by the stem not being plumb and side friction effects resulting from collapsing soil, whereas in a Florida study both devices provided identical results (5). For further meaningful comparison verification of this issue, therefore, MDCP and ADCP were tested side-by-side in four sections, though in one section, only four tests were successful owning to ADCP malfunctioning. Typical penetration plots obtained from MDCP and ADCP for one test station section is presented in *Figure 4.2*.

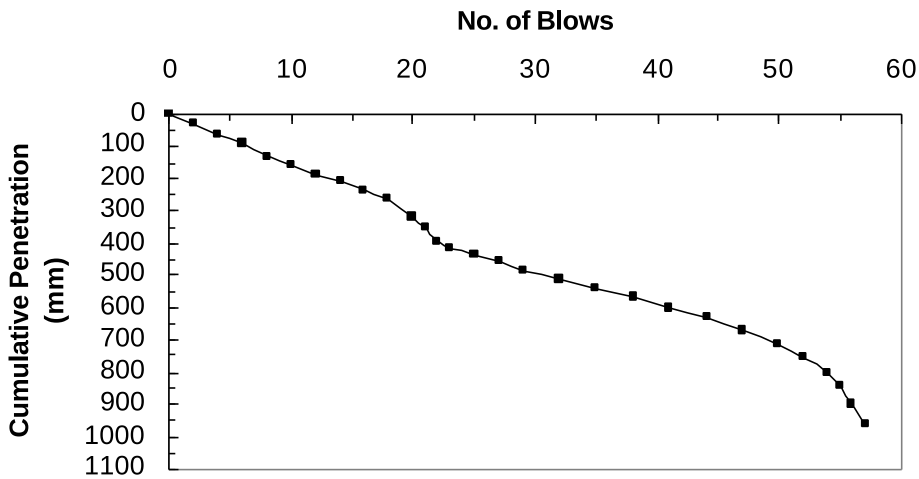


Figure 4.1 Manual Dynamic Cone Penetrometer results of penetration vs. number of blows, station 1598+00, Rankin county

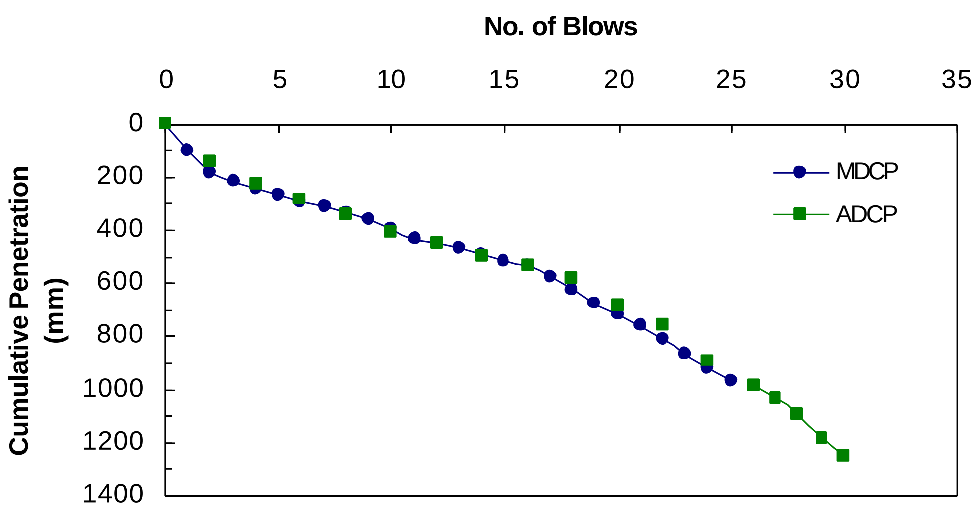


Figure 4.2 Manual vs. Automated DCP, station 461+00, Monroe county

Since a blow-by-blow comparison was not relevant because of unequal cumulative penetration for a given number of blows, only an approximate comparison is possible. Two distinct approaches were employed: first, a comparative study of two populations (independent samples) was conducted employing Mann-Whitney-Wilcoxon (M-W-W) test. In making a comparison, penetration depths resulting from one or more blows were used, as dictated by the MDCP results. Note that MDCP penetration data was collected for 1, 2, 3, or more blows, dictated primarily by the cumulative penetration of 25 mm, a target value adopted by MDOT. That is, if two successive blows result in 25 mm (plus or minus) penetration, it would be recorded. On the other hand, ADCP automatically records penetration for each blow. From MDCP data, DCPI is calculated from each record of approximately 25 mm penetration. ADCP-DCPI at the same depth is now determined graphically, providing a second value for comparison with the MDCP index. This procedure ensures comparison of results in same layers with same characteristics. *Figure 4.2* graphs penetration vs. depth using MDCP as well as ADCP. As listed in *Table 4.1*, the M-W-W test reveals a significant difference in only 5 stations among the 30 tested, that is, 11 percent of the tested stations.

In the second approach, both ADCP and MDCP results were plotted with depth and layering determined based on the slope of the blows versus penetration depth curves. It is important to ensure that we compare the penetration indices of the same sub-layer determined by two devices – MDCP and ADCP. The null hypothesis tested is that the difference in slope is zero. “Test of differences in paired samples” is employed, comparing calculated t-statistic to the tabulated value, accepting or rejecting the null hypothesis. Out of the 30 stations tested only four stations (15 percent) failed the test of equality (see *Table 4.1*).

Table 4.1 Comparison of Manual DCP (MDCP) and Automatic DCP (ADCP) Results Employing (i) Mann-Whitney-Wilcoxon (M-W-W) Test (ii) Test of Difference in Paired Samples. Cycle 1 Test in the Prepared Subgrade.

County	Station No.	Soil Type	M-W-W Test Difference Insignificant at 5% Risk Level	Test of No Difference in Paried Samples at 5% Risk Level
Monroe	461	A-7	yes	accepted
Monroe	462	A-7	yes	accepted
Monroe	463	A-7	yes	accepted
Monroe	464	A-7	yes	accepted
Monroe	465	A-7	yes	rejected
Monroe	466	A-7	yes	accepted
Monroe	467	A-7	no	accepted
Monroe	468	A-7	yes	accepted
Monroe	469	A-7	yes	accepted
Monroe	108	A-2-4	yes	accepted
Monroe	109	A-2-4	no	accepted
Monroe	110	A-2-4	yes	accepted
Monroe	111	A-2-4	yes	accepted
Monroe	112	A-2-4	yes	accepted
Monroe	113	A-2-4	yes	accepted
Monroe	114	A-2-4	no	accepted
Monroe	115	A-2-4	no	accepted
Monroe	116	A-2-4	yes	rejected
Leake	522	A-4	yes	accepted
Leake	523	A-4	yes	accepted
Leake	524	A-4	yes	accepted
Leake	525	A-4	yes	accepted
Leake	526	A-4	yes	accepted
Leake	527	A-4	yes	accepted
Leake	528	A-4	yes	accepted
Leake	529	A-4	yes	rejected
Leake	530	A-4	no	rejected
Monroe	673	A-2-4	yes	rejected
Monroe	674	A-2-4	yes	accepted
Monroe	675	A-2-4	yes	accepted

Two sections in Rankin County (Sec 1S and Sec 2S, SR25) were again chosen for side-by-side tests following the completion of pavement construction. How the overburden of pavement layers affects the MDCP and ADCP was the objective of repeating the tests in *cycle 3/4* tests, during Spring/Summer of 2000. The top layers were cored and both MDCP and ADCP tests were performed atop the subgrade layer. A comparative statistical study for both tests, not presented here for brevity, shows the responses of both devices to be identical.

With approximately 90 percent of the stations tested showing no significant difference, it is concluded that measurements conducted employing MDCP and ADCP are identical. However, special attention should be paid while conducting the test with the MDCP that the rod is maintained in a vertical position, a free drop of the hammer and accurate penetration measurements.

4.3 DCPAN SOFTWARE FOR LAYERING AND MODULUS PREDICTION

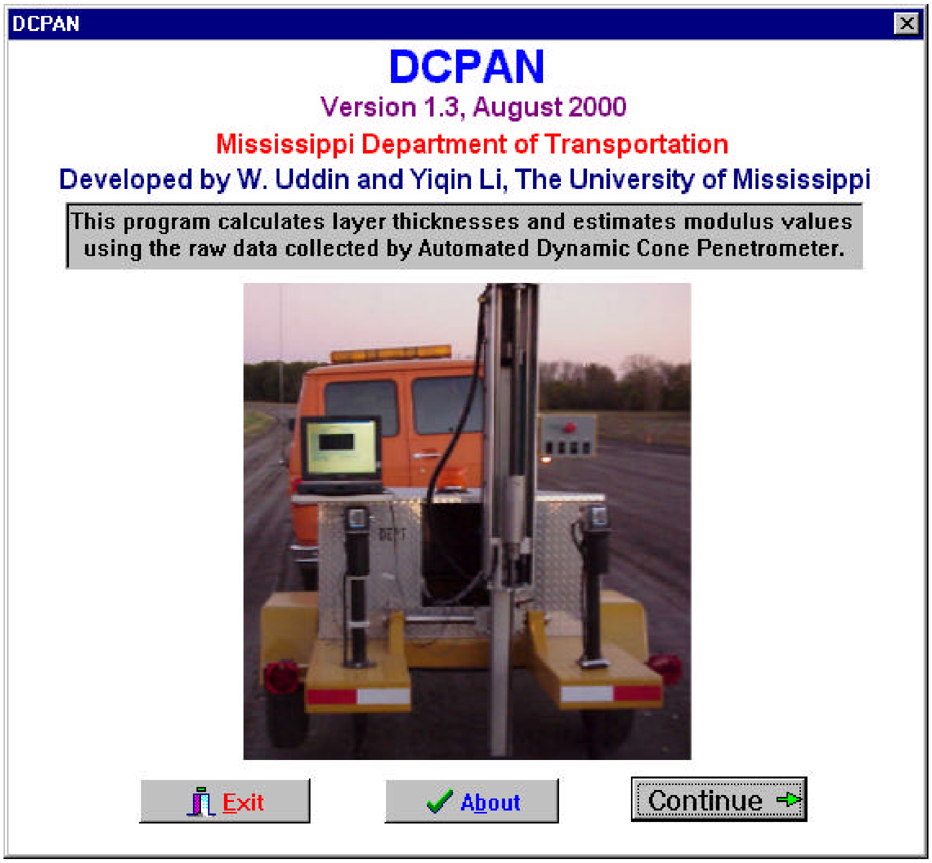
A user friendly object-oriented DCPAN (Dynamic Cone Penetrometer Analysis) software has been developed in this study (44). This program reads the ADCP test data file and generates the following plots on the same screen:

* Cumulative penetration versus blows
* Depth from the surface versus Dynamic Cone Penetrometer Index (DCPI). Where DCPI is penetration per blow.
* Depth from the surface versus Dynamic Stiffness
* Layer Thickness Profile
* Layer Young's Modulus Profile, modulus predicted from a regression relation between DCPI and FWDSOIL-backcalculated field modulus values from *cycle 1* tests.

Note: The DCPAN program only accepts the formatted data file generated by the ADCP.

Figure 4.3 shows the main and information screens of the DCPAN software. *Figure 4.4* shows examples of the input and analysis option screen for input file selection. The final screen plots are shown in *Figure 4.5*. The DCPAN program also provides options to print text file output and reports, as shown at the bottom of *Figure 4.5*. It can also analyze DCPI data and laboratory index properties to predict independent estimates of layer Young's modulus based on the relationships developed using laboratory test data. Further discussion of the DCPAN software is presented in Section 5.2.2.

Presented in this chapter are a comparison of ADCP and MDCP and also the input-output details of DCPAN program. Detailed discussion of the test results and the relations developed between DCPI and modulus are the topics of next chapter.



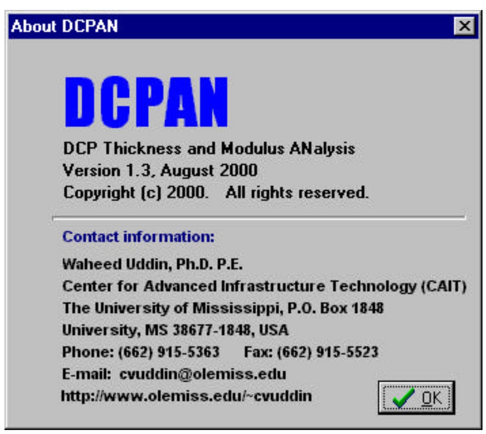


Figure 4.3. Main and information screens of DCPAN.

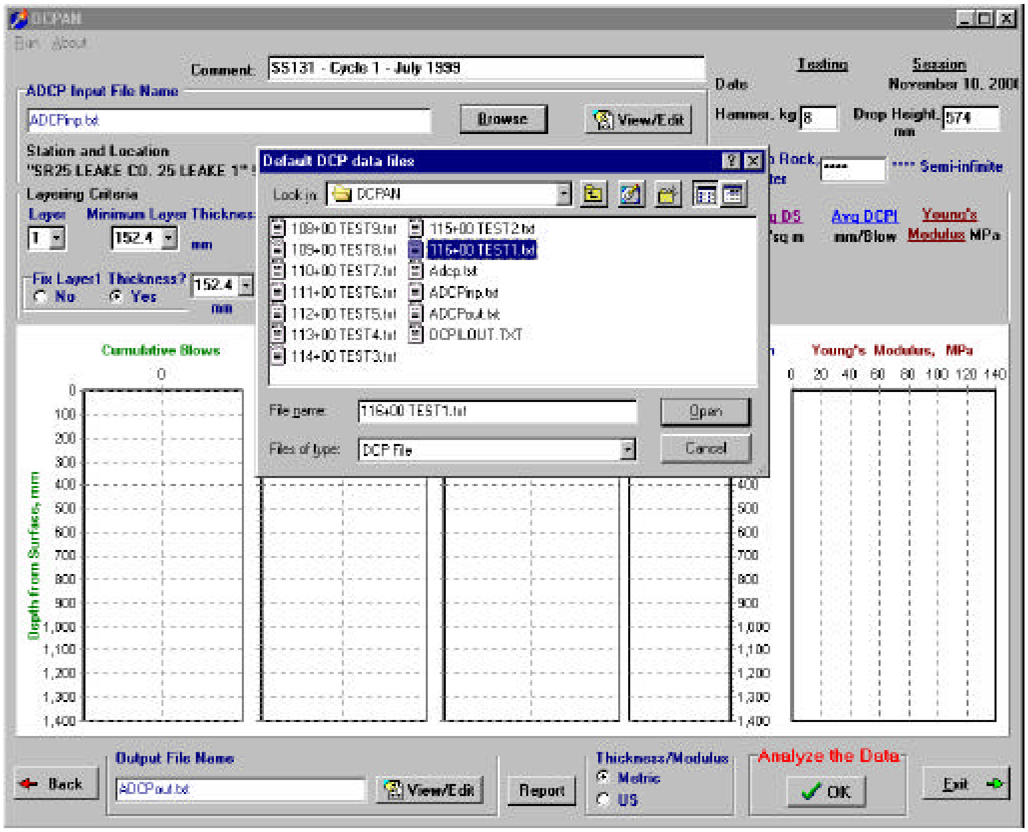


Figure 4.4. Screen capture of input and analysis screen of DCPAN.

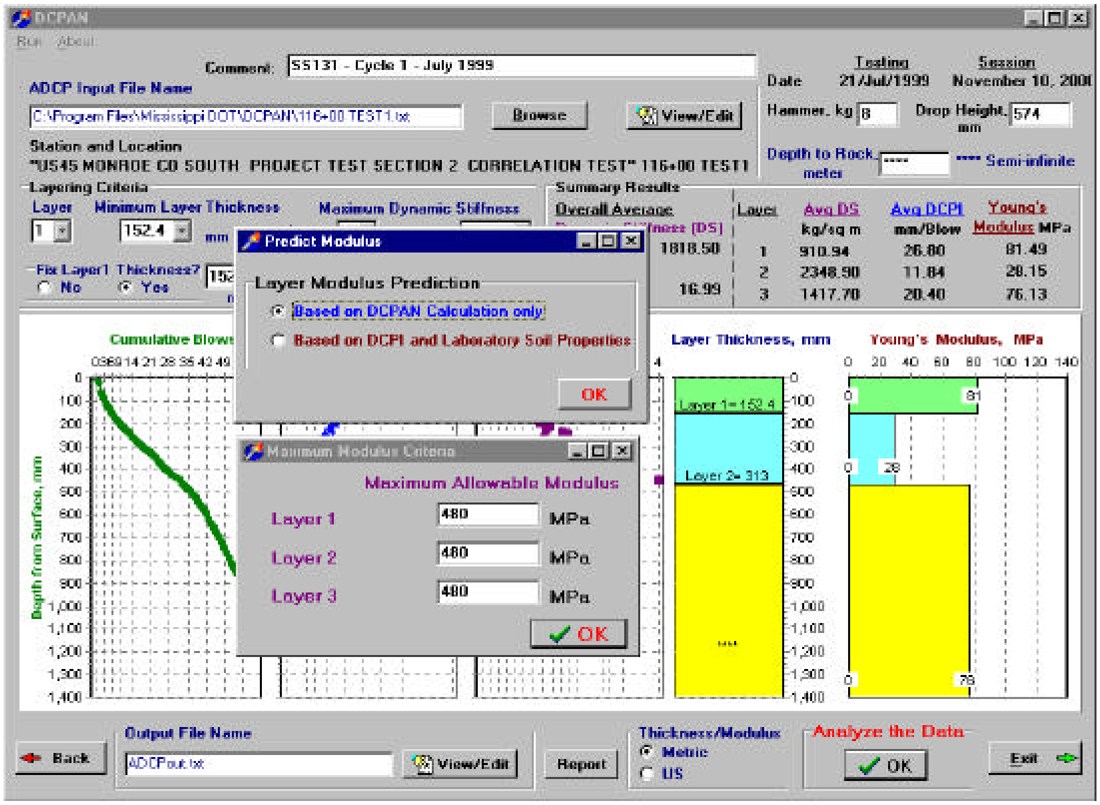


Figure 4.5. Screen capture of all five plots including layer thickness and modulus profile generated by DCPAN using ADCP data files

CHAPTER 5

ANALYSIS AND DISCUSSION OF RESULTS

5.1 INTRODUCTION

The primary objective of this study is to determine subgrade resilient modulus employing Dynamic Cone Penetrometer (DCP) test. That being the objective, this chapter presents the data analyses to establish a relationship between Dynamic Cone Penetration Index (DCPI) and laboratory measured resilient modulus M_R(lab). By necessity, no one relationship could cover all of the soils: accordingly, fine- and coarse-grain soils were investigated separately. M_R, as a dependent variable, is correlated with DCPI in conjunction with other physical and mechanical material properties of soil, as explanatory variables. Next, the correlation between M_R(lab) and FWD-backcalculated elastic moduli E(back) before/after pavement construction is also accomplished. As a third topic, the effect of confinement, offered by pavement layers, on DCP results will be discussed as well.

An exclusive methodology has been developed for automatic determination of layering and layers thicknesses. The DCPAN program reads the Automated DCP data files and generates DCPI plots and layer profiles. The DCPI values have been correlated with the FWD-backcalculated moduli of subgrade soil. These equations are implemented in the DCPAN program to generate in-situ backcalculated moduli of subgrade layers. Another module of the program calculates M_R corresponding to TP-46 test, making use of DCPI estimated by the DCPAN routine.

5.2 CORRELATION ANALYSIS

5.2.1 Resilient Modulus Determination

Shelby tube samples extracted from twelve test sections were tested for M_R in accordance with AASHTO TP46 protocol. Samples, 71 mm (2.8 in) diameter and 142 mm (5.6 in.) height were subjected to fifteen stress combinations determining a set of resilient moduli for a given sample (see *Appendix C*). Since only one laboratory M_R value of each sample representing a location was available to correlate with the corresponding DCPI (in conjunction with possibly other material properties), a modulus at one stress combination had to be calculated. Making use of the average layer thicknesses obtained after pavement coring (see *Table 5.1*), in-situ stress under a wheel load of 20 kN (4500 lb) at a tire pressure of 690 kPa (100 psi) is calculated employing KENLAYER program (37). Stresses due to overburden pressure are then computed and added to the load induced stress. Those calculations yielded 37 kPa (5.4 psi) deviator stress and 14 kPa (2.0 psi) lateral stress which were used for M_R interpolation from laboratory M_R plots similar to those in *Appendix D.* A single M_R value was interpolated for each sample at the stress combination with the results tabulated in *Tables 5.2 – 5.3*.

Generally, the modulus of the first-foot (top) sample was higher than that of the second- and third-foot samples. Desiccation of the top layer could be the primary reason for the selective increase in the top layer modulus. Having dried out and shrunk, it took much larger force to push the Shelby tube into the top layer, which in turn caused densification of the top layer. Resilient modulus is bound to increase with density. Though not reported here, the top sample in general tested high in dry density. Another observation is that M_R values varied with depth, and location along the roadway.

5.2.2 Prediction of Resilient Modulus Using DCP Index

5.2.2.1 General

As was necessary, the 180 samples from 12 test sections were classified into two groups: fine-grain and coarse-grain soil in accordance with AASHTO M145-87 (35). For each group, one model was attempted for M_R-prediction. The regression modeling technique and various steps needed to derive a reliable model form are discussed in detail in the following sections.

TABLE 5.1. Pavement Layer Thickness Measured during Pavement Coring in the Spring/Summer of 2000.

Section Designation	County/Road/Project	Asphalt layer, mm (in.)		Treated layer, mm (in.)	
		Surface	Binder	LFA[a] subbase	Treated subgrade
Sec 1 S	Rankin/SR25	61.0 (2.4)	81.0 (3.2)	203.0 (8.0)	114.0 (4.5)
Sec 2 S		47.0 (1.9)	86.0 (3.4)	254.0 (10.0)	102.0 (4.0)
Sec 3 S		70.0 (2.8)	76.0 (3.0)	216.0 (8.5)	165.0 (6.5)
Sec 4 S		69.0 (2.7)	76.0 (3.0)	218.0 (8.6)	152.0 (6.0)
Sec1 N	Leake/SR25	NA[b]	NA	NA	NA
Sec1 N	Monroe/US45/South	64.0 (2.5)	95.0 (3.7)	171.0 (6.7)	203.0 (8.0)
Sec2 N		64.0 (2.5)	83.0 (3.3)	203.0 (8.0)	228.0 (9.0)
Sec3 N		64.0 (2.5)	83.0 (3.3)	203.0 (8.0)	228.0 (9.0)
Sec4 N		NA	NA	NA	NA
Sec1 N	Monroe/US45/North	58.0 (2.3)	84.0 (3.3)	178.0 (7.0)	127.0 (5.0)
Sec2 N		66.0 (2.6)	86.0 (3.4)	152.0 (6.0)	152.0 (6.0)
Sec3 S		58.0 (2.3)	76.0 (3.0)	152.0 (6.0)	152.0 (6.0)

a Lime-Fly Ash
b Data not available

5.2.2.2 Fine-grain Soil

Since DCP is a field test it may not be realistic to expect a one-to-one relation between laboratory-derived M_R and DCPI. Therefore, other soil properties, namely, dry density (γ_d), moisture content (w_c), liquid limit (LL), and plasticity index (PI) are

TABLE 5.2 Laboratory Resilient Modulus Values of Samples from SR25.
(determined at 37 kPa deviator stress, and 14 kPa confining stress)

Section Designation	County/Road	Station	M_R, MPa (psi)		
			1st foot	2nd foot	3rd foot
Sec1 S	Rankin/SR25	1303+00	NA[a]	213 (30,870)	126 (18,261)
		1305+00	167 (24,203)	233 (33826)	NA
		1307+00	189 (27,391)	98 (14,203)	54 (7,826)
		1309+00	233 (33,768)	163 (23,623)	34 (4,928)
		1311+00	239 (34,638)	235 (34,058)	133 (19,275)
Sec2 S		1347+00	243 (35,217)	265 (38,406)	63 (9,130)
		1349+00	263 (38,116)	76 (11,014)	97 (14,058)
		1351+00	NA	235 (34,058)	107 (15,507)
		1353+00	160 (23,188)	106 (15,362)	64 (9,275)
		1354+50	74 (10,637)	212 (30,725)	138 (20,000)
Sec3 S		1591+00	138 (20,000)	51 (7,391)	51 (7,391)
		1593+00	67 (9,710)	31 (4,493)	96 (13,913)
		1595+00	70 (10,145)	44 (6,377)	189 (27,391)
		1596+00	68 (9,855)	61 (8,841)	56 (8,116)
		1598+00	133 (19,275)	105 (15,217)	49 (7,101)
Sec4 S		1696+00	269 (38,986)	206 (29,855)	60 (8,696)
		1698+00	133 (19,275)	69 (10,000)	47 (6,812)
		1700+00	162 (23,478)	109 (15,797)	32 (4,638)
		1702+00	266 (38,551)	263 (38,116)	120 (17,391)
		1704+00	120 (17,391)	77 (11,159)	70 (10,145)
Sec1 N	Leake/SR25	522+00	201 (29,130)	151 (21,884)	108 (15,652)
		524+00	175 (25,362)	108 (15,651)	121 (17,536)
		526+00	156 (22,609)	82 (11,884)	136 (19,710)
		528+00	199 (28,841)	88 (12,754)	63 (9,130)
		530+00	148 (21,450)	131 (18,986)	130 (18,841)

a Data not available

included in the correlation analysis. *Table 5.4* presents the range of dependent and independent variables.

<u>Selection of Explanatory Variables for Regression</u> A regression equation relates the dependent variable (or response variable), in this case M_R, to one or more independent variables otherwise known as explanatory variables. The variables (explanatory) should be such that there be no strong correlation between them. Explanatory variables, if they

TABLE 5.3 Laboratory Resilient Modulus Values of Samples from US45.
(determined at 37 kPa deviator stress, and 14 kPa confining stress)

Section Designation	County/Road/ project	Station	M_R, MPa (psi)		
			1st foot	2nd foot	3rd foot
Sec1 N	Monroe/US45/South	88+00	85 (12,319)	41 (5,942)	69 (10,000)
		90+00	74 (10,725)	73 (10,580)	56 (8,160)
		92+00	112 (16,232)	126 (18,261)	101 (14,637)
		94+00	141 (20,435)	77 (11,160)	152 (22,029)
		96+00	158 (22,898)	87 (12,609)	82 (11,884)
Sec2 N		108+00	64 (9,275)	62 (8,986)	62 (8,986)
		110+00	66 (9,565)	180 (26,087)	152 (22,029)
		112+00	69 (10,000)	66 (9,565)	43 (6,232)
		114+00	60 (8,696)	28 (4,058)	41 (5,942)
		116+00	67 (9,710)	57 (8,261)	38 (5,507)
Sec3 N		170+00	208 (30,145)	83 (12,029)	NA*
		172+00	132 (19,130)	63 (9,130)	82 (11,884)
		174+00	159 (23,043)	65 (9,420)	73 (10,580)
		176+00	135 (19,565)	51 (7,391)	36 (5,217)
		178+00	72 (10,435)	43 (6,232)	78 (11,304)
Sec4 N		260+00	84 (12,174)	64 (9,275)	NA
		261+50	82 (11,884)	62 (8,986)	51 (7,391)
		262+62	78 (11,304)	81 (11,739)	67 (9,710)
		264+50	88 (12,754)	64 (9,275)	72 (10,435)
		266+00	82 (11,884)	58 (8,406)	53 (7,681)
Sec1 N	Monroe/US45/North	461+00	79 (11,450)	146 (21,160)	143 (20,725)
		463+00	136 (19,710)	106 (15,3620	130 (18,841)
		465+00	220 (31,884)	110 (15,942)	88 (12,754)
		467+00	86 (12,463)	94 (13,623)	110 (15,942)
		469+00	111 (16,087)	137 (19,855)	137 (19,855)
Sec 2 N		490+00	48 (6,928)	165 (23,913)	134 (19,420)
		492+00	153 (22,174)	52 (7,536)	154 (22,319)
		494+00	158 (22,899)	65 (9,420)	70 (10,145)
		496+00	262 (37,971)	60 (8,696)	101 (14,638)
		498+00	215 (31,160)	53 (7,681)	127 (18,405)
Sec3 S		668+00	81 (11,740)	86 (12,464)	NA[a]
		670+00	73 (10,580)	94 (13,623)	NA
		672+00	78 (11,304)	85 (12,319)	NA
		674+00	101 (14,638)	86 (12,463)	75 (10,870)
		676+00	123 (17,826)	69 (10,000)	78 (11,304)

a Data not available

are highly correlated, would weaken the prediction power of the model. This problem, otherwise referred to as multicollinearity, is addressed in this study. A correlation matrix with the six variables is computed and listed in *Table 5.5*. A strong correlation exists between dry density and moisture content, and liquid limit and plasticity index, an indication that one variable from each pair would suffice for regression. As will be shown later multicollinearity effects can be minimized by coining transformed variables.

It is believed that samples from the first-foot of subgrade layer had undergone recompaction resulting in densities that were higher than maximum dry density (γ_{dm}) which, in turn, enhanced modulus values. No definite trend was observed in the second- and third-foot samples, however. Also, because of continuous desicnocation, the moisture content of the top layer was generally lower than the optimum moisture (w_{copt}), whereas, the majority of samples from second- and third-foot layers had moisture contents that were above the w_{copt}. Therefore, in order to consider the effect of density/moisture variation around the maximum/optimum values on M_R, two transformed variables were introduced, namely, density ratio γ_{dr} (γ_d/γ_{dm}) and moisture ratio w_{cr} (w_c/w_{copt}). Another transformed variable, liquid limit/moisture content (LL/ w_c), was also attempted. The correlation matrix of M_R and each of the transformed variables is listed in *Table 5.6*. Being not significant, w_{cr} is not included in the analysis. Clear from *Table 5.6* is that the coefficient of correlation of M_R with each of the transformed variables is now increased compared to that before transformation (see *Table 5.5*). In addition, the correlation coefficients between each pair of transformed variables are lower than those in *Table 5.5* suggesting no strong multicollinearity. The implications of multicollinearity will be discussed in detail in a later section. The transformed variables were, therefore, used for further analysis in developing the regression model.

TABLE 5.4 Ranges of Both Dependent and Independent Variables for Fine-grain Soil Group.

Variable Type	Variable Symbol	Description	Range MPa (psi)
Dependent	M_R	Laboratory measured resilient modulus*, MPa (psi)	31(4,436) – 269 (38,986)
Independent	DCPI	Penetration Index, mm (in.)/blow	3.7 (0.14) – 66.7 (2.63)
	γ_d	Field dry density, kN/m^3 (pcf)	15.1 (96.0) – 20.6 (131)
	w_c	Field moisture content, %	10.6 – 31.1
	LL	Liquid limit, %	20 - 57
	PI	Plasticity index, %	2 - 31

* M_R interpolated at 37 kPa (5.4 psi) deviator stress and 14 kPa (2.0 psi) confining pressure.

TABLE 5.5 Correlation Matrix of Dependent and Independent Variables for Fine-grain Soil Group.

	M_R	DCPI	g_d	w_c	LL	PI
M_R	1	-0.35	0.48	-0.47	0.09	0.19
DCPI	-0.35	1	-0.53	0.57	0.28	0.20
g_d	0.48	-0.53	1	-0.87	-0.50	-0.25
w_c	-0.47	0.57	-0.87	1	0.53	0.30
LL	0.09	0.28	-0.50	0.53	1	0.84
PI	0.19	0.20	-0.25	0.30	0.84	1

TABLE 5.6 Correlation Matrix of Basic and Transformed Variables for Fine-grain Soil Group.

	M_R	DCPI	g_{dr}	LL/w_c	PI
M_R	1	-0.35	0.49	0.62	0.19
DCPI	-0.35	1	-0.33	-0.4	0.2
g_{dr}	0.49	-0.33	1	0.45	-0.17
LL/w_c	0.62	-0.4	0.45	1	0.44
PI	0.19	0.2	-0.17	0.44	1

<u>Development of the Model</u> Models for M_R prediction were developed using regression technique. Initially, scatter plots of the dependent variable versus each of the potential explanatory variables were obtained, determining the likely relationship (see *Figures 5.1-*

5.4). Also, they help in identifying outlier data, if any. Points judged to be outliers were examined carefully before deletion.

The stepwise regression option in Statistical Package for the Social Science (SPSS) was employed to investigate the significance of each of the potential explanatory variables. Based on the stepwise regression analysis, three variables found to be highly significant were, DCPI, γ_{dr}, and LL/w_c.

To select a model, some basic principles are followed: first, minimum Mean Square Error (MSE); the smallest MSE would result in the narrowest confidence intervals and largest test statistics. The model with the smallest MSE involving the least number of independent variables would be the most appropriate. However, a model with the absolute smallest MSE may not provide the best intuitive model. That is, a model providing a slightly larger MSE but with explanatory variables that are more relevant to the problem may be more desirable. Second, the model should be as simple as possible; or in other words, it should have as few explanatory variables as possible. Third, the larger the coefficient of determination, R^2, the better the model is. Fourth, the cause-and-effect relationship between the dependent variable and each of the explanatory variables should be relevant. Fifth, the model should satisfy the physical requirements of the boundary conditions. For example, it is expected that the subgrade resilient modulus will become infinite when the DCPI value approaches zero, and will be zero when the DCPI value is infinite.

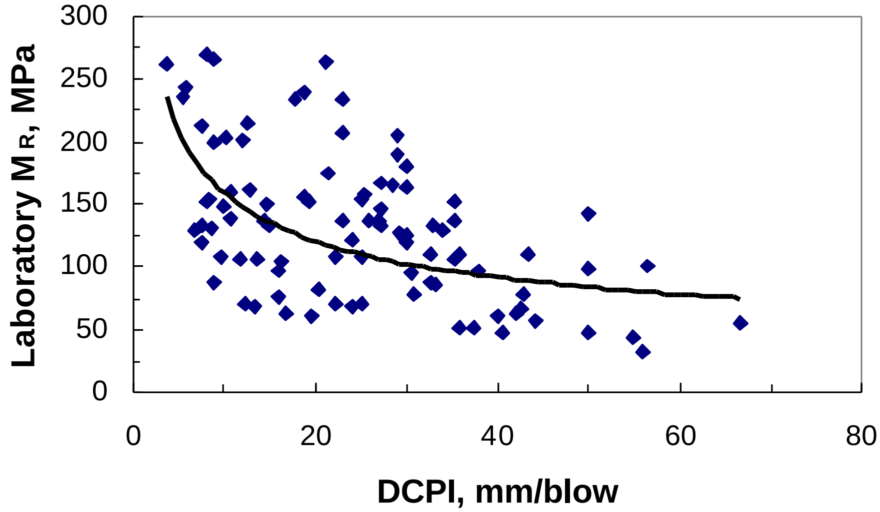


Figure 5.1 Laboratory M_R vs. DCPI for fine-grain soil

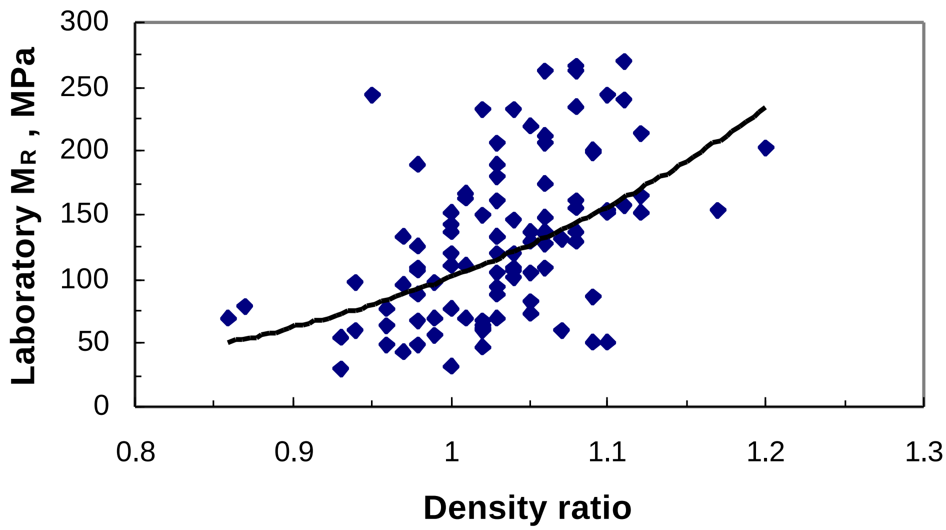


Figure 5.2 Laboratory M_R vs. density ratio for fine-grain soil.

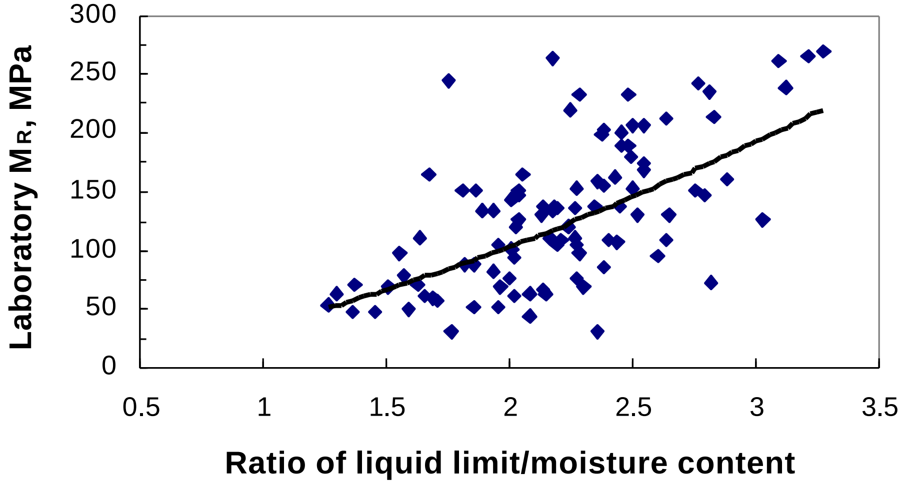


Figure 5.3 Laboratory M_R vs. Liquid limit/moisture content for fine-grain soil

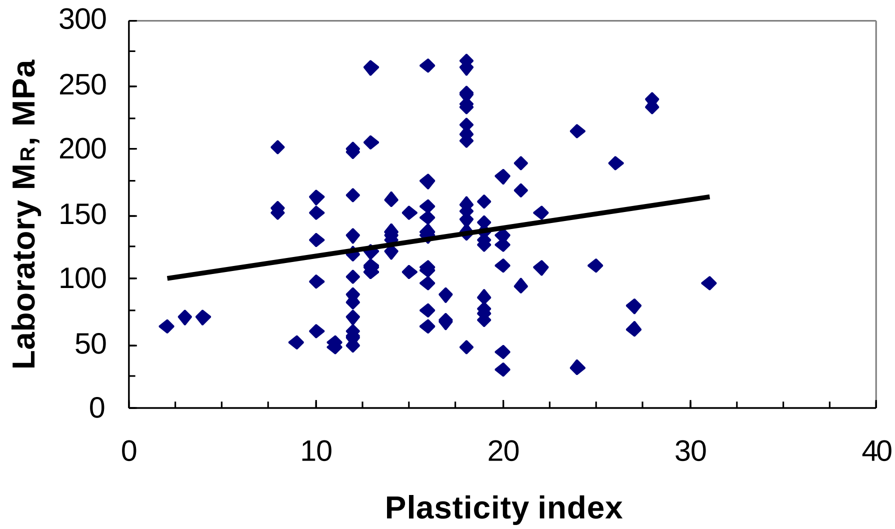


Figure 5.4 Laboratory M_R vs. plasticity index for fine-grain soil

Problems encountered with regression analysis One concern when developing regression models is the likelihood of strong multicollinearity among explanatory variables. When explanatory variables are highly correlated, each one of them may serve as a proxy for the other(s) in the regression equation without affecting explanatory power of the model (38). Multicollinearity, when present, is always associated with unstable estimated regression coefficients and can seriously limit the use of regression analysis for inference and forecasting.

Multicollinearity could be detected based on the simple correlation between each pair of explanatory variables. Strong collinearity does exist between a pair with a high coefficient of correlation (R). A procedure for detecting multicollinearity after developing the regression model entails plotting the residuals against predicted values for scrutiny. A scatter plot with a distinct pattern suggests that strong collinearity is inherent, and so the resulting model is not well specified. This plot can be used to examine the aptness of the regression model as well.

The explanatory variables used in developing M_R-DCPI model were examined initially based on simple correlation coefficients. As discussed in an earlier section, transformed variables were coined (see *Table 5.6*) which helps to minimize multicollinearity.

Yet another concern is the lack of homoscedasticity, or presence of heteroscedasticity in the data used to derive the regression model. One of the standard assumptions of least square theory is the constancy of error variance, which is often referred to as the assumption of homoscedasticity. When the error variance is not constant over all of the observations, the error is said to be heteroscedastic, violating the standard assumption of least square theory. To detect the heteroscedastic error in a regression model, the residuals are plotted against independent variables on the x-axis. If the residuals fall in a band of two lines parallel to the x-axis, there is no evidence of heteroscedasticity, and in turn, no obvious violation of the least square theory assumption.

Regression model The first step towards developing a meaningful/well specified model is to examine the best form of relation between dependent variable and each of the explanatory variables. The curve estimation option in SPSS was employed investigating the best forms, based on R^2, with the results presented in *Table 5.7*. The three explanatory variables were then combined and different model forms were examined. The nonlinear regression option in SPSS was employed for determining the regression coefficients.

TABLE 5.7. Best Relation Based on Multi-correlation.

Dependent Variable	**Explanatory Variables**	**Relation**
$\mathbf{M_R}$	DCPI	Power
	γ_{dr}	Power
	LL/w_c	Power

After an exhaustive search, examining many different forms and interaction terms, the following model form is selected with summary statistics presented in *Table 5.8*:

$$M_R = a_o\,(DCPI)^{a1}\,(\gamma_r^{\,a2} + (LL/w_c)^{a3}) \quad \ldots\ldots(5.1)$$

$R^2 = 0.71$ RMSE = 31.6

where M_R = Resilient modulus, MPa

DCPI = Penetration Index, mm/blow

γ_{dr} = Density ratio, field density/maximum dry density

w_c = Actual moisture content, %

LL = Liquid limit, %

a_o, a_1, a_2, and a_3 = Regression coefficients (see *Table 5.8*)

TABLE 5.8 Summary Statistics for Fine-grain Soil Model

Coefficient	Value	*t**	*F**	*RMSE*	R^2
a_o	27.86	4.33	46.5	31.6	0.71
a_1	-0.114	2.05			
a_2	7.82	4.60			
a_3	1.925	10.81			

What follows is a discussion of the statistical tests undertaken to test the robustness of the model. First, a scatter plot of residual versus predicted M_R values is presented in *Figure 5.5.* No distinct pattern is observed, ruling out multicollinearity among the explanatory variables. The model is well specified, therefore.

Second, to test the model for any possible heteroscedasticity, residuals are plotted against each of the explanatory variables as shown in *Figures 5.6 – 5.8*. The plotted points in each graph form a satisfactory band, suggesting very little evidence of heteroscedasticity in the derived model.

The *F*-test for multiple regression relation is conducted to validate the significance of the relationship between M_R and all of the explanatory variables included in the model (38). That the F^* value of 46.5 greater than $F(0.95, 4, 78) = 2.5$, is indication of a significant relationship between M_R and the chosen independent variables. The significance of individual coefficients is tested employing the *t*-test. That the t^* of each of the coefficients is larger than 1.96 suggests all of them are significant at a confidence level of 95%.

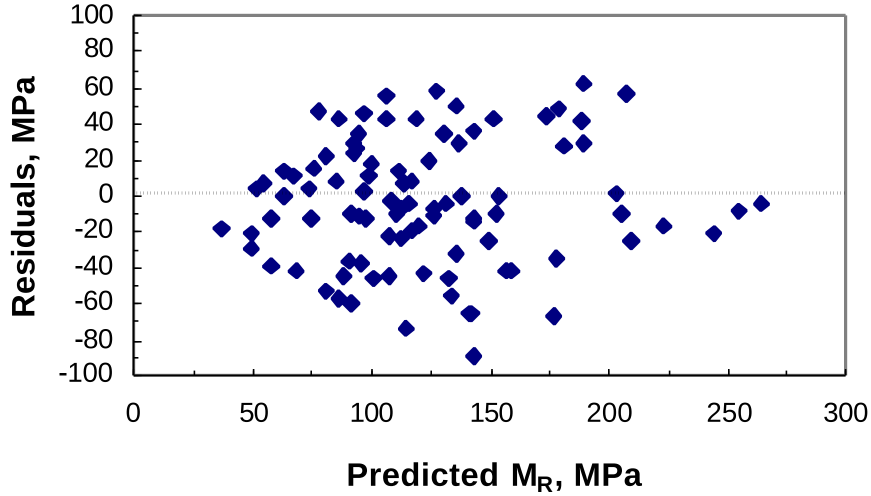


Figure 5.5 Residuals vs. predicted values of M_R for fine-grain soil.

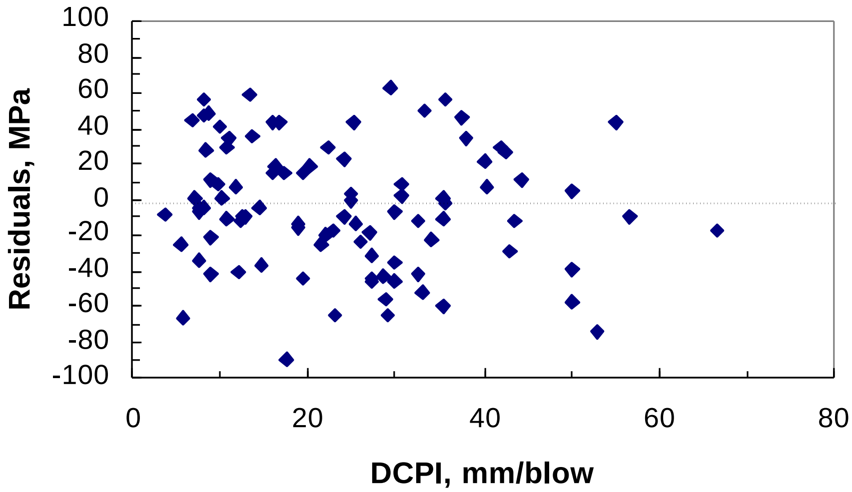


Figure 5.6 Residuals vs. DCPI for fine-grain soil.

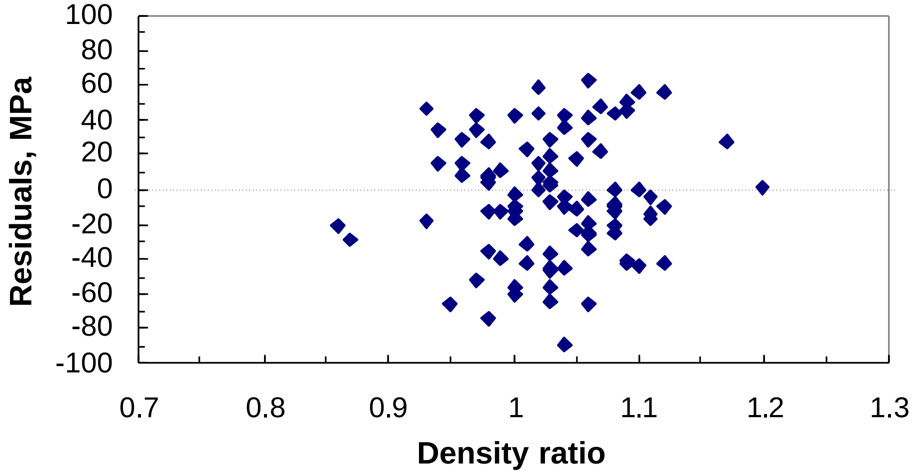


Figure 5.7 Residuals vs. density ratio for fine-grain soil.

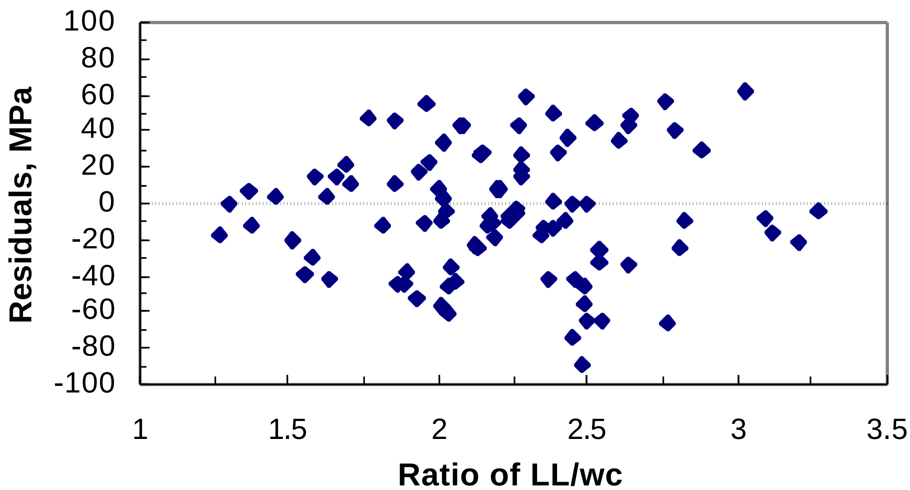


Figure 5.8 Residuals vs. ratio of LL/wc for fine-grain soil.

As a final verification/calibration, the actual M_R values are plotted against predicted values as shown in *Figure 5.9*. The plotted points cluster along the line of equality is an indication of the robustness of the model.

Correlation of Resilient Modulus with DCPI This relationship is mandated by MDOT for the reason that during a DCP survey, in-situ moisture, density, and liquid limit are not available to the field crew, accordingly, they are unable to use Equation 5.1 in real time. Despite sacrificing accuracy of M_R prediction, being able to correlate M_R in real time is considered essential. A one-to-one relation between M_R and DCPI is attempted. Noting that M_R vs. DCPI does not obey a linear relationship, other forms such as semilog and power forms are tried. The best form of the equation is of the power form:

$$M_R = 532.1\ DCPI^{-0.492} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.2)$$

$$R^2 = 0.4 \qquad\qquad RMSE = 35.3$$

where M_R is in Mpa units and DCPI in mm/blow.

That the R^2 is relatively low in comparison to that for Eq. 5.1 is not unexpected. Suppressing the variables such as moisture and/or density and other important physical properties is the primary reason for this low coefficient of determination. Nonetheless, being able to calculate subgrade resilient modulus while the DCP test is in progress somewhat offsets the lack of accuracy.

5.2.2.3 Coarse-grain Soil

Five independent variables, namely, DCPI, γ_d, w_c, uniformity coefficient (c_u), and percent passing #200 sieve, were examined for possible relationship with M_R. *Table 5.9* lists the range of dependent and independent variables. The correlation matrix for both

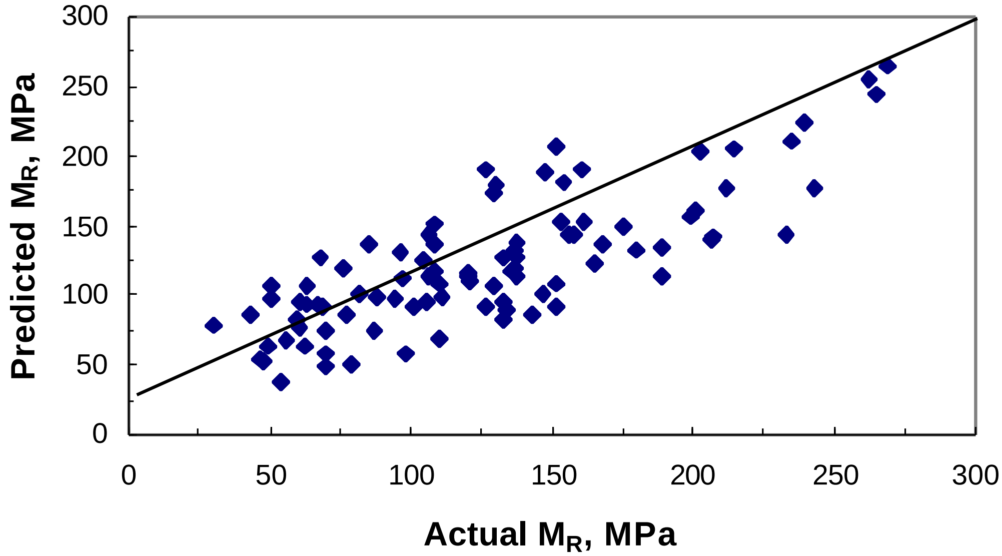


Figure 5.9 Predicted vs. actual M_R values for fine-grain soil

dependent and independent variables were calculated and listed in *Table 5.10*. With a high coefficient of correlation, there is indication that DCPI and Logc_u are correlated. Therefore, these two variables were combined to form a transformed variable, DCPI/Logc_u. As was discussed in the case of fine-grain soil, density ratio and moisture ratio were introduced as explanatory variables developing the correlation matrix shown in *Table 5.11*. Although the correlation coefficients of M_R and each of the transformed variables were not enhanced, the correlation between each pair of explanatory transformed variables decreased suggesting not-so-strong multicollinearity among the explanatory variables. *Figures 5.10 – 5.13* present the likely relationship between M_R and each of the probable explanatory variables.

Upon employing the stepwise regression option in SPSS DCPI/logc_u, density ratio, and moisture ratio were found to be significant. To define the best relationship form of laboratory M_R and each of explanatory variables, curve estimation option in SPSS was employed with the results tabulated in *Table 5.12*. The three significant explanatory variables were incorporated in one model examining different model forms with different interaction terms. After an exhaustive search, employing the nonlinear option in SPSS, the following model was selected with summary statistics listed in *Table 5.13*:

$$M_R = a_o\,(DCPI/\log c_u)^{a1}\,(w_{cr}^{\,a2} + \gamma_{dr}^{\,a3}) \qquad (5.3)$$

$R^2 = 0.72$ RMSE = 12.1

where M_R = Resilient modulus, Mpa

DCPI = Dynamic cone penetration index, mm/blow

c_u = Coefficient of uniformity

w_{cr} = Moisture ratio, field moisture/optimum moisture

γ_{dr} = Density ratio, field density/maximum dry density

a_o, a_1, a_2, and a_3 =Regression coefficients (see *Table 5.13*)

The *F*-test was conducted to test the significance of the relationship between M_R and the explanatory variables included in the model. With F^* value of 31.82, greater than $F(0.95, 4, 48) = 2.55$, there is sufficient evidence that a relationship does exist between

TABLE 5.9 Range of both Dependent and Independent Variables for Coarse-grain Soil Group.

Variable Type	**Variable Symbol**	**Description**	**Range**
Dependent	M_R	Laboratory measured resilient modulus*, MPa (psi)	28 (4,058) – 158 (22,899)
Explanatory	DCPI	Penetration index, mm (in.)	5.6 (0.22) – 40.0 (1.6)
	γ_d	Field dry density, kN/m^3 (pcf)	15.7 (99.7) – 19.1 (121.6)
	w_c	Field moisture content, %	12.4 – 22.0
	Cu	Uniformity coefficient	2.8 - 925
	% passing # 200	Percent passing # 200 sieve	7 - 33

* M_R values calculated at 37 kPa, deviator stress, and 14 kPa, confining pressure.

TABLE 5.10 Correlation Matrix of Dependent and Selected Independent Variables for Coarse-grain Soil.

	M_R	**DCPI**	**g_d**	**w_c**	**Log c_u**	**% #200**
M_R	1	-0.46	0.28	-0.45	0.53	0.11
DCPI	-0.46	1	-0.10	0.39	0.67	0.21
g_d	0.28	-0.10	1	-0.42	0.40	0.62
w_c	-0.45	0.39	-0.42	1	0.13	0.04
Log c_u	0.53	0.67	0.40	0.13	1	0.77
% passing # 200	0.11	0.21	0.62	0.04	0.77	1

TABLE 5.11 Correlation Matrix of Basic and Transformed Variables for Coarse-grain Soil.

	M_R	DCPI/ Log c_u	g_{dr}	w_{cr}	% #200
M_R	1	-0.45	0.35	-0.42	0.11
DCPI/ Log c_u	-0.45	1	-0.20	0.03	-0.39
g_{dr}	0.35	-0.20	1	-0.40	0.12
w_{cr}	-0.42	0.03	-0.40	1	0.33
% passing # 200	0.11	-0.39	0.12	0.33	1

TABLE 5.12 Best Relation Based on Multi-correlation.

Dependent Variable	Explanatory Variables	Relation
M_R	DCPI/logC_u	Power
	γ_{dr}	Power
	w_{cr}	Power

TABLE 5.13 Summary Statistics of Coarse-grain Soil Model

Coefficient	Value	½*t**½	*F**	*RMSE*	R^2
a_o	90.68	9.99	31.82	12.1	0.72
a_1	-0.305	10.48			
a_2	-0.935	1.98			
a_3	0.674	2.17			

M_R and other independent variables. The significance of individual coefficients was tested employing *t*-test. At a confidence level of 95% all of the coefficients are significant, as $t^* > 1.96$ (39).

Presented in *Figure 5.14* is a scatter plot of residuals versus predicted M_R values. No distinct pattern is observed suggesting no strong multicollinearity among the selected

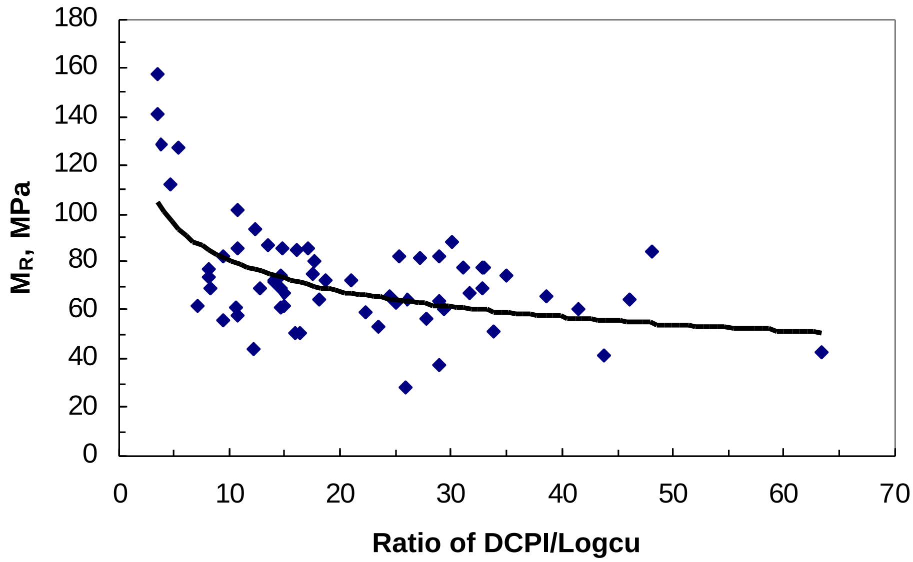


Figure 5.10 Laboratory M_R vs. DCPI/Logcu for coarse-grain soil.

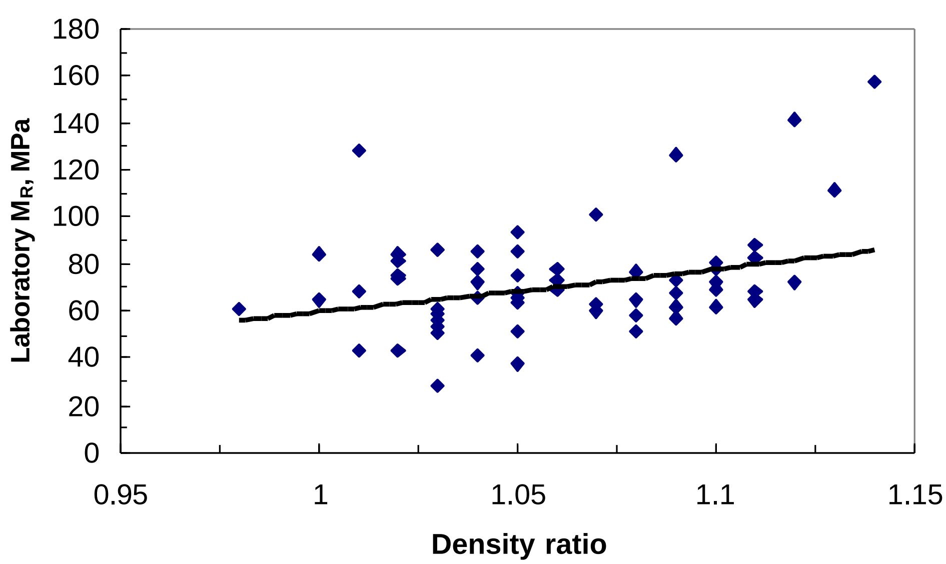


Figure 5.11. Laboratory M_R vs. density ratio for coarse-grain soil.

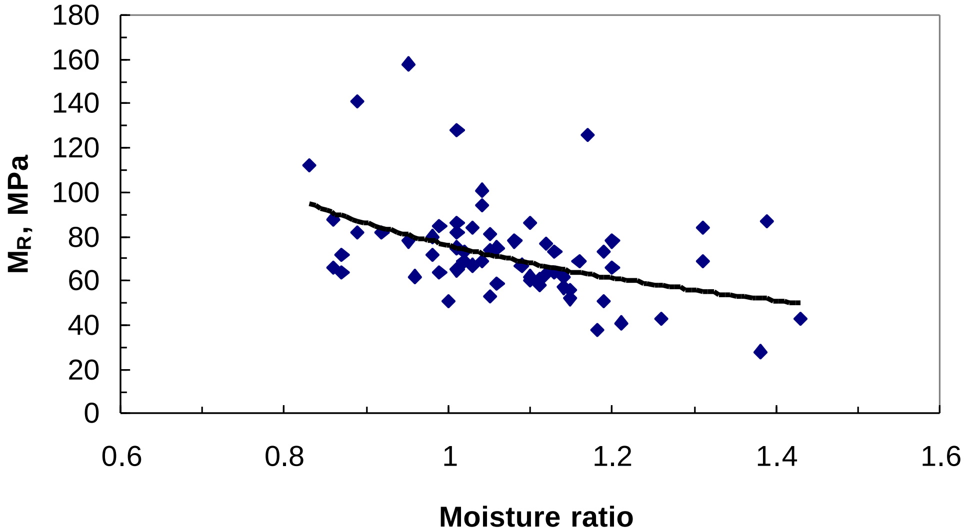


Figure 5.12. Resilient modulus vs. moisture ratio for coarse-grain soil

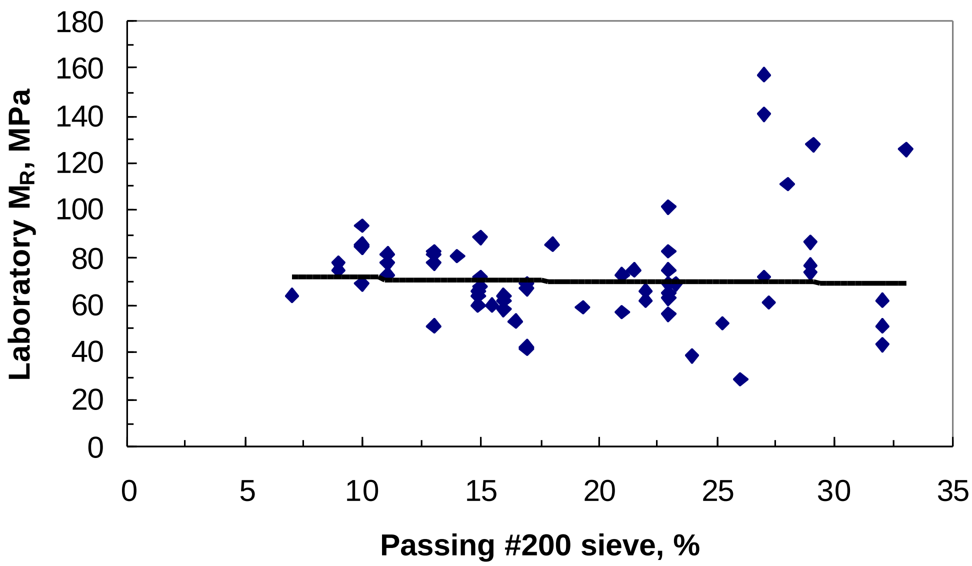


Figure 5.13 Laboratory M_R vs. %passing #200 sieve for coarse-grain soil.

explanatory variables. Also, the random scatter of residuals is an indication of the aptness of the developed regression model.

Figures 5.15 – 5.17 present the relation between the residuals and each of the explanatory variables for investigating heteroscedasticity. In *Figure 5.15* the residuals seem to lie in a band that slightly converges as DCPI/logc_u ratio increases. Residuals in the other two plots lie in a band that is satisfactorily parallel to the *x*-axis. No strong heteroscedasticity exists in the developed model, therefore.

Presented in *Figure 5.18* is the relationship between actual laboratory and predicted M_R values. That the plotted points are parallel to the line of equality is an indication of the robustness of the model.

<u>Correlation of Resilient Modulus with DCPI</u> In order to meet the requirement that subgrade resilient moduli need to be calculated in real time while DCP test is in progress in the field, a one-to-one relation between M_R and DCPI is attempted, resulting in the following power model:

$$M_R = 235.3\ \mathrm{DCPI}^{-0.475} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.4)$$

$$R^2 = 0.4 \qquad \mathrm{RMSE} = 18.5$$

where M_R is in Mpa units and DCPI in mm/blow.

Again, the R^2 of Equation 5.4 is somewhat diminished in comparison to that of Equation 5.3 for the reason that all of the significant explanatory variables are not taken into account in Equation 5.4.

Note that DCPAN program includes all of the four equations (Equations 5.1 – 5.4) by which resilient modulus could be calculated. Equations 5.2 and 5.4 could be used in the field in real time while DCP test is in progress. With density and moisture content of

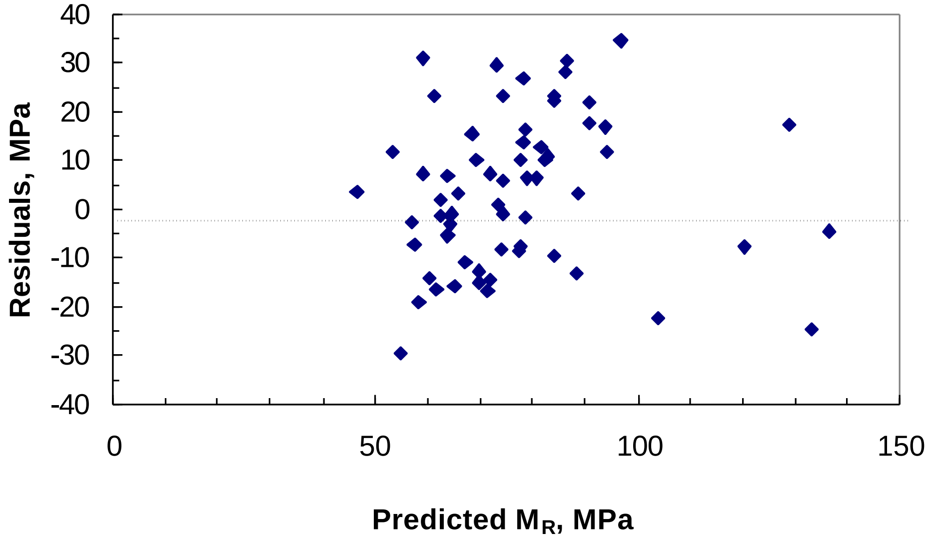


Figure 5.14 Residuals vs. predicted M_R values for coarse-grain soil

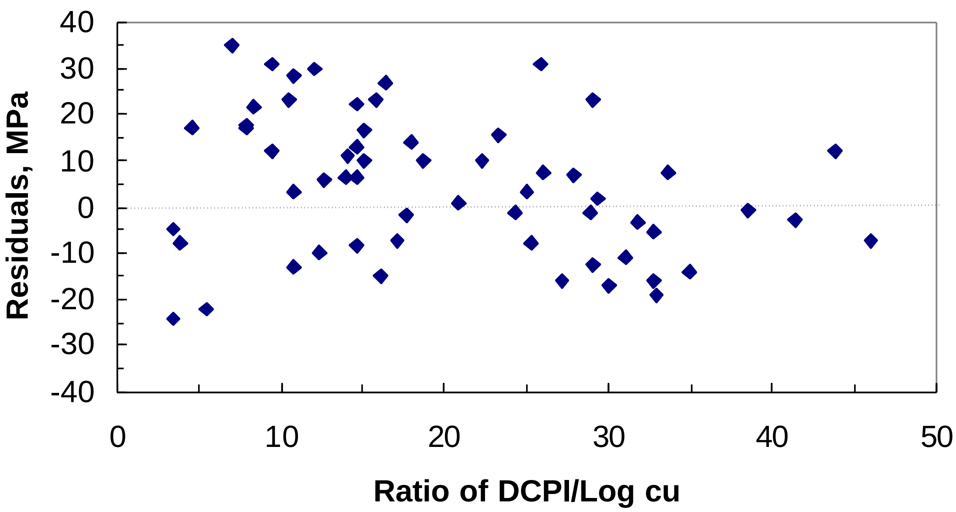


Figure 5.15 Residuals vs. ratio of DCPI/Log cu for coarse-grain soil

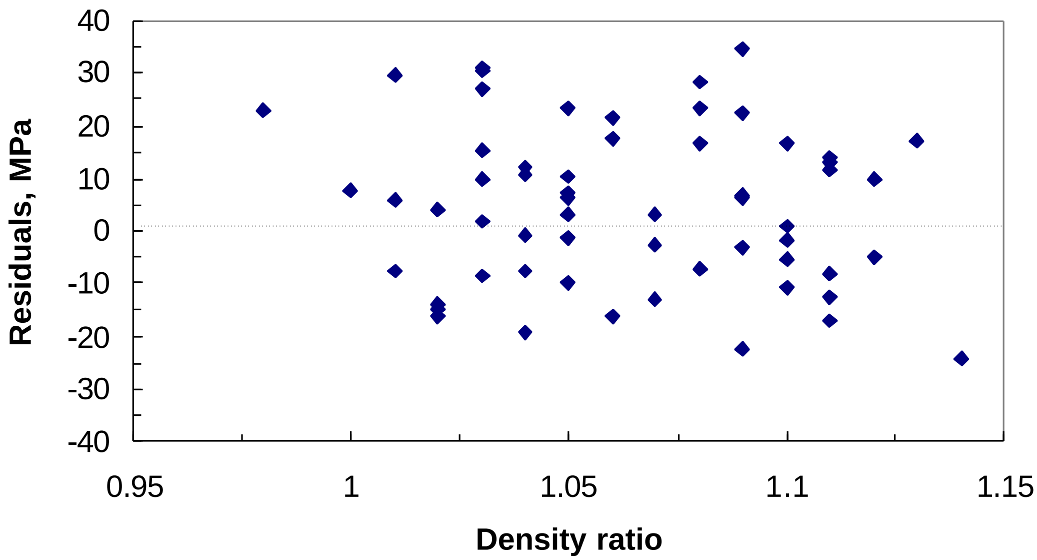


Figure 5.16 Residuals vs. density ratio for coarse-grain soil

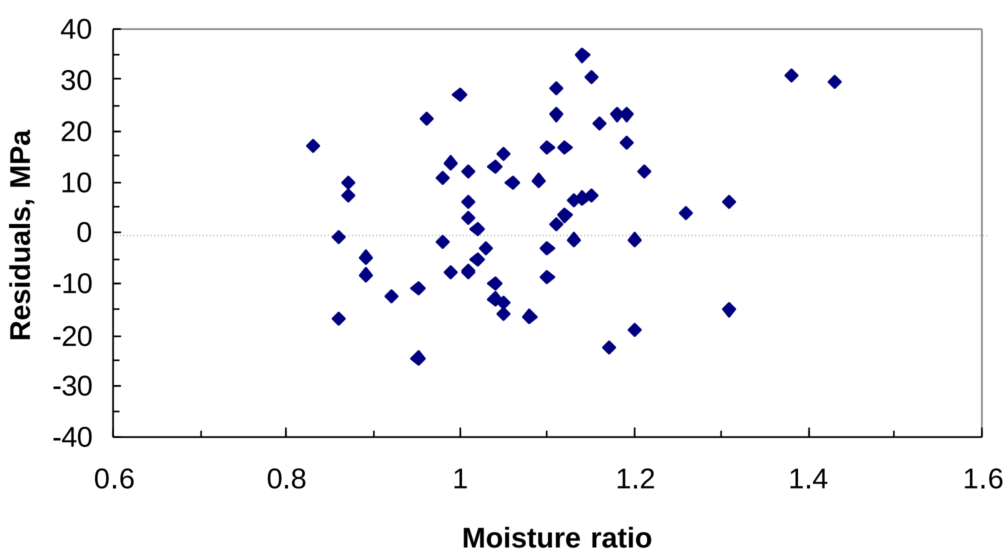


Figure 5.17 Residuals vs. moisture ratio for coarse-grain soil

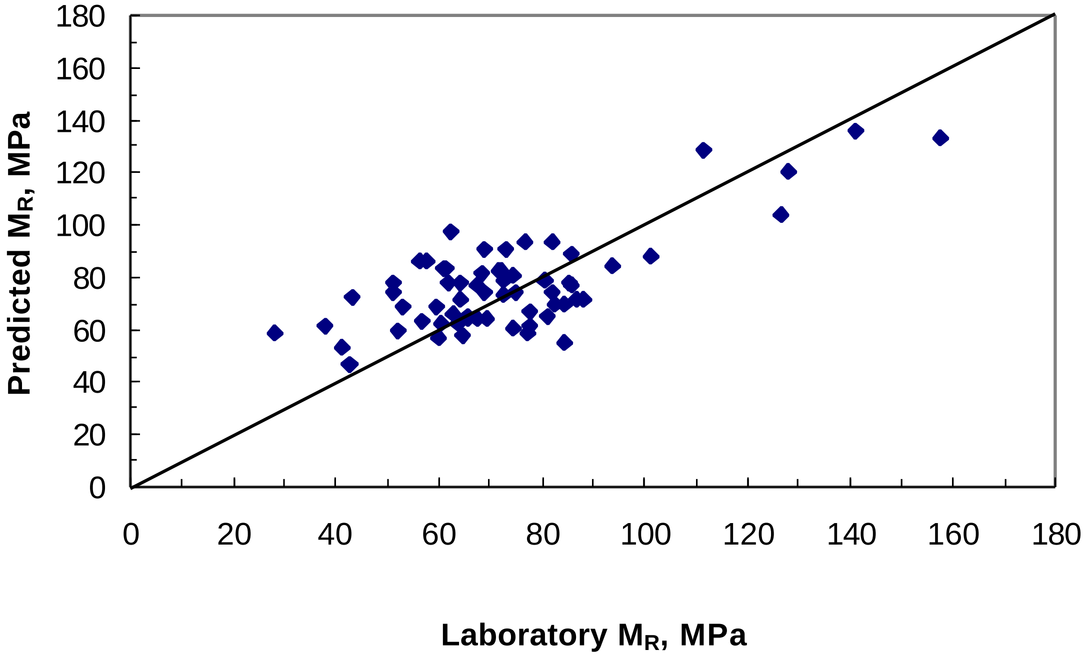


Figure 5.18 Laboratory M_R vs. predicted M_R for coarse-grain soil

in place soil determined in the field, and the optimum moisture content, maximum dry density, the liquid limit and uniformity coefficient determined on bulk samples collected from the field during DCP test, the subgrade resilient modulus may be determined in the office using Equations 5.1 and 5.3.

5.2.3 Model Verification

To verify the predictability of the developed models, the DCP test was conducted at four different locations in a newly constructed embankment in Oxford. The field density was measured employing a sand cone test in accordance with AASHTO T 191-86, and moisture content as well. Bulk soil samples were collected from each of the test locations for resilient modulus determination and other routine tests. Three samples from each location were reconstituted for M_R testing. Atterberg limits test and sieve analysis were conducted on the tested samples. *Table 5.14* lists the physical properties of the tested samples averaged for three samples. Based on AASHTO soil classification, the soil in each of the four tested locations was classified as fine-grain soil.

TABLE 5.14 Physical Properties of Samples Tested for Model Verification.

Location #	Actual Moisture content, %	Dry density, kN/m^3 (pcf)	Moisture ratio	Density ratio	Liquid limit
1	12.6	17.1 (109.0)	0.76	1.05	39.0
2	12.6	17.8 (113.0)	0.76	1.08	37.0
3	15.3	16.8 (107.0)	0.93	1.03	39.0
4	13.0	16.7 (106.5)	0.79	1.02	28.0

The laboratory M_R values were determined for the three samples from each location at stress combinations of 37 kPa deviator stress, and 14 kPa confining pressure. The average of the three M_R values are listed in column 2 of *Table 5.15*. Using the fine soil model in equation 5.1, the M_R values are predicted and compared with the average laboratory measured values, as can be seen in columns 2 and 3 of *Table 5.15*.

To evaluate the difference between predicted and actual M_R values, the test of differences of paired samples was conducted (40). Twelve moduli values (three per each location) form the sample size. The null hypothesis, namely no significant difference between predicted and actual values, is accepted. Simply put, no evidence of significant difference exists between actual and predicted moduli values (t^* = -0.52 compared with $|t_{0.025,11}|$ = 2.593).

TABLE 5.15 Comparison Between Laboratory and Predicted M_R Values.

Location #	**Laboratory M_R, Mpa (psi)**	**Predicted M_R, Mpa (psi)**
1	189 (27,391)	216 (31,304)
2	197 (28,550)	193 (27,971)
3	141 (20,434)	146 (21,260)
4	113 (16,377)	103 (14,928)

5.3 FWD BACKCALCULATED SUBGRADE MODULI

5.3.1 General

The primary use of deflection testing with FWD is in evaluating existing pavement structure for maintenance and rehabilitation purposes. Deflections are normally measured atop asphalt/concrete surface layer and layer moduli calculated using a backcalculation program. The subgrade modulus, backcalculated from FWD deflection measurements E(back), has been reported to be higher than the laboratory measured M_R. Although the 1993 AASHTO Guide suggests a conversion ratio of 0.33 to calculate laboratory moduli from backcalculated values, the Guide left it to highway agencies to evaluate this ratio considering their soil type/conditions. Note that the 0.33 ratio was arrived at using deflection measurements on existing pavements. Another issue is that only one ratio is reported regardless of the type of soil. Therefore, this part of the study evaluates the reasonableness of 0.33 factor, especially for subgrade soil types in

Mississippi. Would FWD conducted directly on prepared subgrade be pertinent for subgrade soil characterization is discussed first.

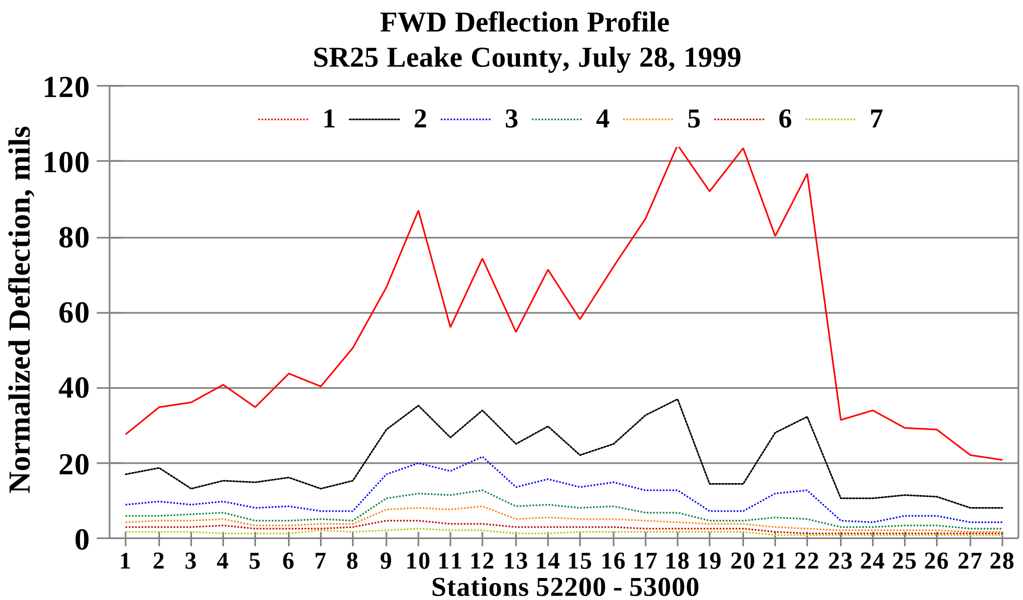
5.3.2 Backcalculation of FWD Moduli Using the FWDSOIL and UMPED Programs

5.3.2.1. Problems with FWD Deflection Data and Modulus Backcalculation Programs

The FWD deflection time history data files collected on the subgrade during the pilot work in March 1999 could not be processed by a few of the available programs (41). The primary reason is that these programs were developed to handle FWD data on paved sections. None of these and many other currently available backcalculation programs are designed to handle large surface deflections and backcalculate layer moduli on compacted subgrade sections. The Pavement Evaluation Based on Dynamic Deflection (PEDD) program (42, 43, 36) and its simplified University of Mississippi version of PEDD (UMPED) program can read the data files, however, the seed modulus values must be entered by users to get reasonable output moduli.

FWD Test Protocol What follows is a test protocol established earlier in the study based on the pilot FWD testing in Monroe county (41). The following test setup was used for FWD tests on base layers and subgrade using routine mass sets: 3 seating drops at drop height 1, one peak test record at drop height 1 and second peak test record at drop height 2, followed by full time history records at drop height1 and drop height 2. Total of four test measurements were, therefore, recorded at each test location. Careful attention was paid for abnormal data due to presence of gravel and improper seating of sensors on the surface. Many deflection measurements on subgrade sections were above the acceptable accuracy range for the geophone sensors. These data were excluded at the time of FWD data analysis.

Peak FWD load could not be produced below 5,000 - 6,000 lbf range at the lowest drop height 1 using the standard test configuration option available on the MDOT FWD model. This has resulted in many instances, particularly at drop height 2, peak sensor 1 deflection exceeding 80 mils in the center of the loading plate on subgrade, as shown in *Figure 5.19.*



Note: Number on the graph represent sensor location (sensor 1 under the load….. sensor 7 farthest away from the load)

Figure 5.19. Examples of abnormally large FWD deflection data measured on unpaved subgrade sections.

These are above the manufacturer's recommended acceptable accuracy range for the FWD geophone sensors. The PEDD program and its simplified version UMPED program (42, 43) are capable of handling such data, however, the predicted modulus values may be unreliable.

1- On many test locations the FWD deflection measurements at sensor 7 and sometime at sensor 6 are less than 0.1 mil or even zero, which is below the acceptable accuracy. These results indicate large attenuation of impact energy. This abnormally low deflection is another problem that can not be generally handled by many backcalculation programs. The UMPED program can handle these extremely low or zero values on sensor 7, however, the backcalculated modulus values may be unreliable (41). It is observed from many iterations (attempted to match the abnormally high measured deflections) that the difference between sensor 1 computed and measured deflections must be ignored to get the best and acceptable match for other sensors.

2- Another problem observed in the data is the presence of non-decreasing deflection values, particularly common to drop height 2 deflection data and time history data. For this and related reasons the FWD data with nondecreasing values are not used in later analysis.

3- Because of the inaccuracies in sensor 1 and occasionally sensor 7 deflection measurements, it became necessary to develop an exclusive modulus backcalculation program that can rely upon only sensors 2 through 6. The questions related to large FWD deflections on subgrade soils and backcalculation of moduli were posted on the International FWD-USER list-server in the Fall of 1999 (41). No positive response was made at that time from FWD users and researchers in North America. Recently one posting mentioned abnormally large FWD sensor 1 deflections during subgrade testing of some new Specific Pavement Study (SPS) test sections, however, the data has not been analyzed so far (41).

4- Having encountered these problems during the processing of *Cycle 1* (June-July FWD data, and subsequent discussion during the second project meeting with the MDOT oversight committee in October 1999, it became imperative to broaden the scope of the study related to in situ modulus backcalculation using FWD data. Development of an exclusive FWDSOIL analysis software using only sensors 2 through 6 deflection data became necessary. This special effort undertaken by Uddin at the end of 1999 (41), is described in the next section.

5.3.2.2 Preliminary Analysis of FWD Data Using the UMPED Backcalculation Program

The FWD deflection time history data files collected on the unpaved subgrade test sections were initially processed using the UMPED backcalculation program which is a simplified version of the PEDD program. The backcalculation analysis subprogram incorporated in PEDD is used for deflection matching algorithm (41, 42). The seed modulus values, however, must be entered in UMPED by users to backcalculate reasonable modulus values for the unpaved subgrade sections. Because of the excessive sensor deflections, particularly at drop height 2, the basin match was poor at many locations. Therefore, these data were further analyzed by conducting manual iterations of modulus changes. The maximum error between measured and final computed deflections reduced considerably, however, only sensors 2 through 6 were used to determine the best deflection basin match and arrive at the best estimates of backcalculated moduli. Subgrade soil layer thicknesses were estimated from the DCP cumulative penetration plots. For self-iterative backcalculation a new program was developed based upon the experience gained from the preliminary results.

Analysis of FWD Data Using the FWDSOIL Backcalculation Program A new FWD data processing program, FWDSOIL, has been developed to process the FWD data collected using the test protocol setup and backcalculate in situ moduli of subgrade layers. This requires the processed DCP data to estimate layer thicknesses from the plots. The preliminary data analysis was conducted first with pre-selected inputs for seed moduli using versions 1 and 2 of the FWDSOIL program. Based on the initial analysis results, many abnormal deflection basins (higher than 80 mils at sensor 1 and 2 or zero mils at sensor 7) were excluded from further analysis using the latest version 3 of the FWDSOIL backcalculation program. This analysis shows an increase in the backcalculated modulus values for Cycle 2 of FWD data soon after the construction of 152 mm (6 in.) LFA base atop 152 mm (6 in.) of lime-treated subgrade. This is supported by the FWD deflection data which shows a decrease in sensor 1 maximum deflection soon after the construction of the LFA base over the lime treated subgrade. The deflection values after the construction of LFA treated base are within the accuracy range, well below 80 mils.

FWD Test Specifications and Sensor Configurations Related to Each Cycle of Test

Cycle 1: Drop 1 analyzed.
Radius of loading plate = 5.91 in; Sensor distances (in): 0.0, 8.0, 12.0, 24.0, 36.0, 48.0, 60.0.

Cycle 2: Drop 1 analyzed.
Radius of loading plate = 5.91 in; Sensor distances (in): 0.0, 8.0, 12.0, 24.0, 36.0, 48.0, 60.0.

Cycle 3: Drop 2 analyzed.
Radius of loading plate = 5.91 in; Sensor distances (in): 0.0, 12.0, 24.0, 36.0, 48.0, 60.0, 72.0. (Note: MDOT adopted this new distance configuration in December 1999 – January 2000)

Cycle 4: Drop 2 analyzed.
Radius of loading plate = 5.91 in; Sensor distances (in): 0.0, 12.0, 24.0, 36.0, 48.0, 60.0, 72.0.

Test Sections

Table 5.16 shows a summary of FWD tests conducted and analyzed in each test cycle.

Pavement Models Used for Backcalculation *Tables 5.17* through *5.20* show the sections and the idealized pavement models used for modulus backcalculation. The last subgrade layer was assumed semi-infinite because of the absence of rock in the first 33 m (100 ft).

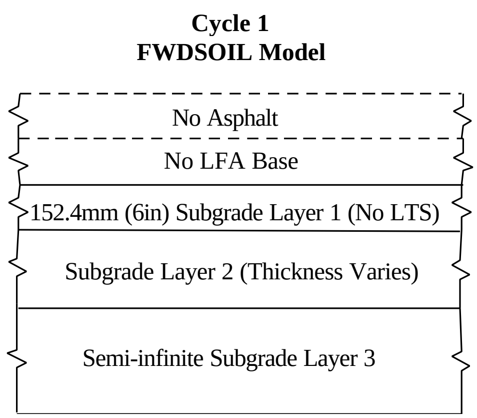
Table 5.16. Summary of Sections Tested by FWD and Analyzed in Each Cycle

Cycle	Monroe County, North Project			Monroe County, South Project				Rankin County				Leake County
	US45N Sec 1	US45N Sec 2	US45S Sec 3	US45N Sec 1	US45N Sec 2	US45N Sec 3	US45N Sec 4	SR25S Sec 1	SR25S Sec 2	SR25S Sec 3	SR25S Sec 4	SR25N Sec 1
1	7/19/1999	7/20/1999	7/14/1999	7/27/1999	7/27/1999	7/26/1999	7/26/1999	6/7/1999	6/8/1999	6/10/1999	6/9/1999	7/28/1999
2	11/3/1999	11/1/1999	11/2/1999	11/3/1999	11/2/1999							
3	3/6/2000	3/7/2000	3/7/2000					3/8/2000	3/8/2000			
4				6/26/2000	6/27/2000	6/27/2000				4/5/2000	4/5/2000	

5.3.2.3 Backcalculation of Subgrade and Pavement Moduli Using FWD Data, (cycles 1, 2 and *3/4)*

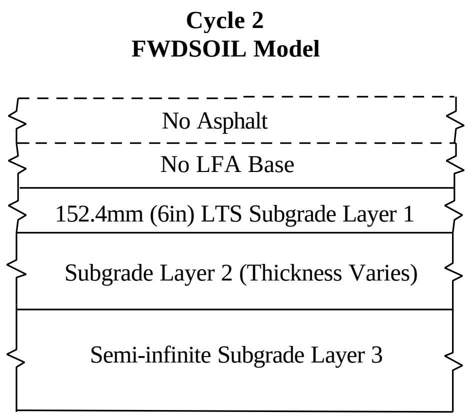
Drop 1 (smallest FWD load) data are analyzed for the tests conducted on subgrade and/or base before asphalt paving. Drop 1 data were used in *cycle 1* and *cycle 2* because the deflection data for Drop 2 is higher than 80 mils, the maximum deflection value within the acceptable accuracy range for the FWD sensors. These high deflection values occur due to the absence of paved surfaces. In c*ycle 1* data, the pavement consisted only of subgrade. The low load level is appropriate in this case because of the nonlinear behavior at higher load level. Moreover, the stresses and strains on the subgrade after construction will be relatively smaller because the wheel load will be on top of the constructed asphalt pavement. The FWDSOIL version 3 backcalculation program was used, as explained in detail in Tech memo TM-WU-4 (41). The detailed final backcalculated modulus results are included in *Appendix E*.

TABLE 5.17. Pavement Model and Cycle 1 Sections Analyzed Using the FWDSOIL Program



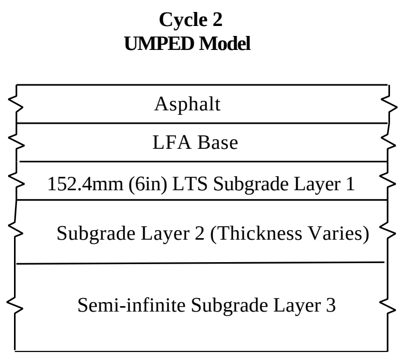
Cycle 1, FWDSOIL Analysis	
Project	**Sections**
Monroe County, North Project	US45N Sec 1
	US45N Sec 2
	US45S Sec 3
Monroe County, South Project	US45N Sec 1
	US45N Sec 2
	US45N Sec 3
	US45N Sec 4
Rankin County	SR25S Sec 1
	SR25S Sec 2
	SR25S Sec 3
	SR25S Sec 4
Leake County	US25N Sec 1

TABLE 5.18. Pavement Model and Cycle 2 Sections Analyzed Using the FWDSOIL Program



Cycle 2, FWDSOIL Analysis	
Project	**Sections**
Monroe County, North Project	US45S Sec 3
Monroe County, South Project	US45N Sec 1
	US45N Sec 2

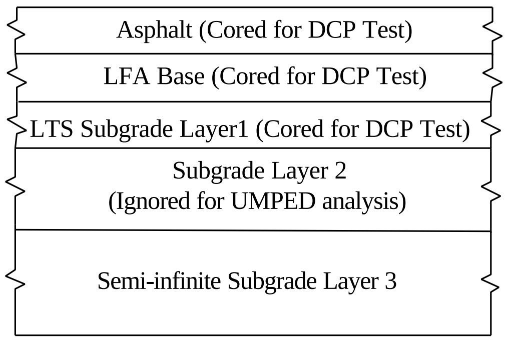
TABLE 5.19. Pavement Model and Cycle 2 Sections Analyzed Using the UMPED Program



Cycle 2, UMPED Analysis	
Project	**Sections**
Monroe County, North Project	US45N Sec 1
	US45N Sec 2

TABLE 5.20. Pavement Model and Cycle 3 and Cycle 4 Sections Analyzed Using the UMPED Program

Cycle 3 and Cycle 4
UMPED Model



Cycle 3, UMPED Analysis	
Project	**Sections**
Monroe County, North Project	US45N Sec 1
	US45N Sec 2
	US45S Sec 3
Rankin County	SR25S Sec 1
	SR25S Sec 2

Cycle 4, UMPED Analysis	
Project	**Sections**
Monroe County, South Project	US45N Sec 1
	US45N Sec 2
	US45N Sec 3
Rankin County	SR25S Sec 3
	SR25S Sec 4

Cycle 2 FWD data was collected after the subgrade was treated with lime to increase its bearing capacity. On two sections, an asphalt layer and LFA (lime-fly ash) base were placed on the top of the lime-treated subgrade (LTS). C*ycle 1* data and *cycle 2* data were analyzed twice. In the first analysis described in TM-WU-4 (41), the subgrade layer thicknesses were constant for all locations in a section. In the final analysis, the layer thicknesses for all eight sections in Monroe and Rankin counties were input using the results of the DCPAN program. The DCPAN program, developed exclusively in this study and described later in Section 5.3.3, is based on the analysis of the automated DCP data files (44).

Drop 2 deflection data were used for *cycle 3/4* analysis because the peak FWD load applied on the loading plate is close to 4,082 kgf (9,000 lbf). In *cycle 3/4* the FWD data were collected after the construction of the LFA base and asphalt layers on the top of the LTS layer. In *cycle 3/4*, the asphalt and LFA base core thicknesses obtained from the field were used for modulus backcalculation. The FWD data collected on the top of the asphalt layers were analyzed using the UMPED backcalculation program and the results are included in *Appendix E*.

FWD Test on Top of Subgrade and Base - FWDSOIL Backcalculation Program The FWDSOIL program has been developed by Uddin, specifically for unpaved sections. This program is developed to process FWD text data files, to enter layer thickness data based on DCP data interpretation, specify seed modulus and Poisson's ratio, provide maximum and minimum modulus for each layer, and generate input files for the FPEDD2 backcalculation program which is based on the PEDD programs (42 and 43). The FWDSOIL default inputs are: seed modulus 159 Mpa (23,000 psi), Poisson's ratio (0.40

or 0.45), maximum modulus 482 MPa (70,000 psi) and minimum modulus 7 Mpa (1,000 psi) for each layer. The FWDSOIL program calls FPEDD2 to automatically iterate and converge to the best moduli (based upon sensors 2 through 6). The moduli from the first analysis for *cycles 1* and *2* (41) were used as the new 'seed' moduli for the final FWDSOIL analysis.

FWD Test on Top of Asphalt Pavement - UMPED Backcalculation Program This program is a simplified version of the PEDD backcalculation program for the backcalculation of Young's moduli for asphalt or concrete pavements. The program now corrects the FWD backcalculated moduli of unbound layers and subgrade using the design wheel load and axle configuration and applying the equivalent linear analysis (42, 43). It does not require any seed modulus value. The UMPED program is used for backcalculation considering all seven sensors.

Appendix E includes the final backcalculated modulus results for the FWD data collected in *cycle 1*, *cycle 2*, and *cycle 3/4*.

5.3.2.4 Coring, In-place Layer Thickness, and Core Testing

Coring through the asphalt layers, LFA base, and LTS layers was made in *cycles 3/4*. The extracted cores were primarily used to measure the in-place layer thickness of these layers. Note very few intact cores could be extracted from the LTS layer, and in a few cases the LTS material had to be removed manually by augering. After clearing the cored hole, automatic DCP test was conducted in each hole.

The LFA and LTS cores extracted from SR25 Section 2 and the LFA core extracted from US 45 Section1N, North Project were capped and tested in compression in the Civil Engineering Laboratory of Mississippi State University. The load-deformation data were analyzed to calculate Young's modulus and compressive strength. *Figure 5.20* shows a typical stress-strain plot. *Table 5.21* shows a summary of the test results and compares the laboratory Young's modulus values with the in situ UMPED backcalculated Young's modulus. Some difference is expected because of :

(a) the different state of stresses on the specimens in the laboratory and in situ,

(b) damaging effects of water flow and coring operation,

(c) water absorption after coring.

The results compare reasonably well for SR25 section. The LFA base cores from US45 section were hardly intact; corroborating significantly lower modulus in the laboratory test.

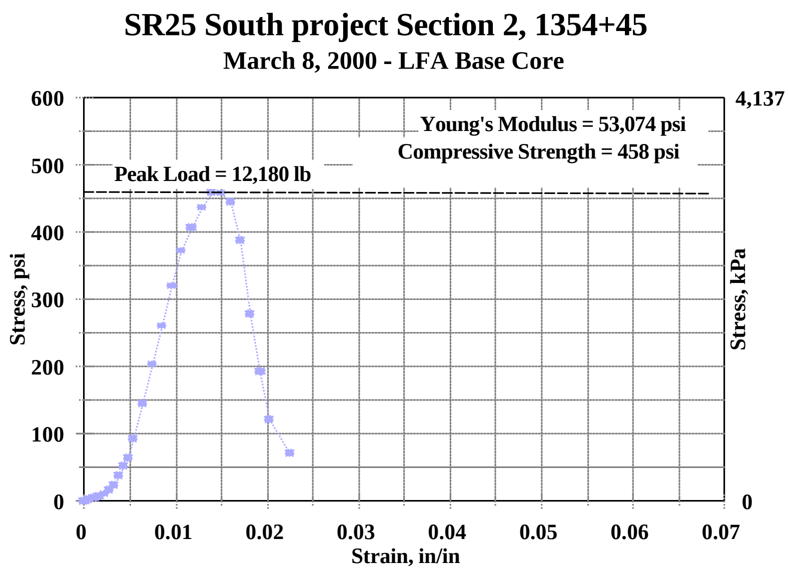


Figure 5.20. Stress-strain plot based on the laboratory compressive strength test of the LFA core

TABLE 5.21. A Summary of Laboratory Compression Test Results on LFA and LTS Cores

Section & Station	Core Type	Material Type	Compressive Strength kPa (psi)	Laboratory Young's Modulus MPa (psi)	UMPED In Situ Backcalculated Young's Modulus MPa (psi)
SR25S Sec 2 1354+45	Base	LFA	3,158 (458)	366 (53,074)	314 (45,600)
SR25S Sec 2 1353+95	Base	LFA	2,696 (391)	157 (22,752)	372 (53,900)
SR25S Sec 2 1353+95	Subgrade	LTS	3,792 (550)	290 (42,041)	224 (32,510)
US45N Sec1 North Project 469+11*	Base*	LFA*	1,489 (216)*	68 (9,857)*	216 (31,400)

* Partially damaged during extraction

5.3.3 Layer Thickness and In-Situ Moduli from Automated DCP Data Analysis

5.3.3.1 Overview of Dynamic Cone Penetrometer (DCP) Data Collection

The DCP test is used to assess in-situ stiffness of subgrade soils. It is easy to test natural soils and subgrade, however, it is difficult on gravelly and stabilized soils. The cumulative penetration versus number of blows data from DCP tests can used to estimate layer thicknesses and empirical stiffness of layers. The DCP test can be done both manually and automatically. Since the Automated DCP (ADCP) test is more precise because of electronically controlled impact force and data acquisition, only the ADCP data files are used for analysis and interpretation (41). *Table 5.22* shows the ADCP data collection frequency and dates of data collection.

TABLE 5.22. ADCP Data Collection Dates

Cycle	US45 Monroe County, North Project			US45 Monroe County, South Project				SR25, Rankin County				SR25 Leake County
	North Sec 1	North Sec 2	South Sec 3	North Sec 1	North Sec 2	North Sec 3	North Sec 4	South Sec 1	South Sec 2	South Sec 3	South Sec 4	North Sec 1
1	7/19/1999	7/20/1999	7/14/1999	7/27/1999	7/21/1999	7/27/1999	7/26/1999					7/28/1999
2			11/02/1999	11/03/1999	11/02/1999							
3	3/06/2000	3/07/2000	3/07/2000					3/09/2000	3/08/2000			
4				6/26/2000	6/27/2000	6/27/2000				4/06/2000	4/05/2000	

5.3.3.2 *The Final DCPAN Results of Subgrade Layer Thickness and Predicted Young's Modulus*

The DCPAN software generates DCPI and layer thickness plots, as introduced earlier in Section 4.3. An extensive study was conducted to develop regression equations for predicting backcalculated modulus using a database of average DCPI value for each of the three layers, layer 2 thickness and the FWD backcalculated modulus values for layers 1, 2 and 3. *Appendix E* presents the *cycle 1* FWD-backcalculated modulus data. The latest version of the DCPAN program includes the following final equations used for FWD-backcalculated modulus predictions, as shown in *Table 5.23*.

TABLE 5.23. Regression Equations Implemented for DCPAN Modulus Prediction

Based on	Layer	Equations	R^2
Average DCPI	Layer 1	$\log E = 4.587 - 0.00683 \cdot DCPI - 0.232 \cdot \log(DCPI)$	0.27
	Layer 2	$\log E = 5.122 + 0.01873 \cdot DCPI - 1.965 \cdot \log(DCPI) + 0.001203 \cdot Thickness\ 2$	0.27
	Layer 3	$\log E = 4.844 - 0.00216 \cdot DCPI - 0.578 \cdot \log(DCPI)$	0.42

E is in psi units and DCPI in mm/blow. R^2 is the coefficient of determination.

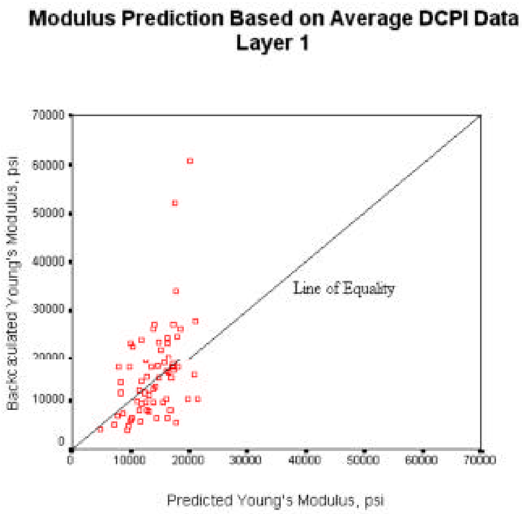
The graphs in *Figure 5.21* show the anorccuracy of these regression models based on average DCPI values (all prediction models based on *cycle 1* total data only, 66 points).

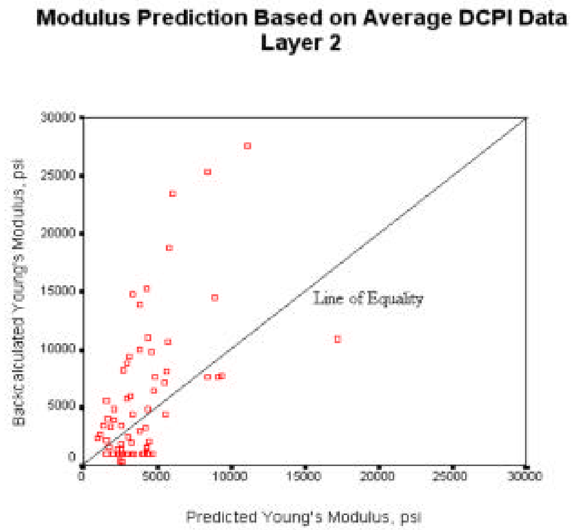
The DCPAN program has been recently modified to include maximum allowable modulus criteria which has been established to ignore any unreasonably large modulus prediction. The criteria are:

In Metric Units: Maximum Allowable Modulus = 480 Mpa (70,000 psi)

Table 5.24 shows an example of the DCPAN results for US45N Section2 North Project, *cycle 1.* The summary tables of final DCPAN results are included in *Appendix F. Figure 5.22* shows a summary of subgrade layer 2 thickness predictions for the same section. Subgrade layer 2 thickness and DCPI results for all three subgrade layers of the same section are compared in *Figure 5.23* for *cycles 1, 2* and *4*. It is noted that layer 1 thickness was fixed at 6 inches because the top 6 inches of the subgrade was supposed to be treated with lime before the placement of LFA base. The results show seasonal effects on the subgrade layers. It will be important to note the date of testing and weather conditions and consider the seasonal effects on subgrade modulus for designing pavement thickness. The overburden of LFA base and asphalt layers is expected to influence the cycle 4 subgrade modulus (increased value) backcalculated from FWD data. However, this should not affect the DCPAN results because these overburden layers were removed before the DCP test during cycle 4. These data can be input to the PADAP mechanistic pavement thickness design program considering load and environment simulations. The PADAP software was developed in State Study 122 (36, 44).

Figure 5.24 shows an example of all five DCPAN plots and a partial capture of the output text file that summarizes all input data and calculations. *Figure 5.25* shows a sample DCPAN report. Table 5.25 shows a section-by-section summary results of layer thickness and DCPI predictions for all four cycles of ADCP test data. *Appendix F* includes detailed results of ADCP data and analysis using the DCPAN software.





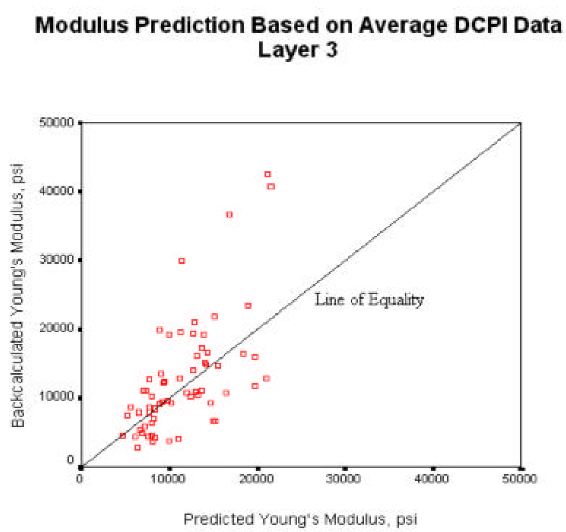


Figure 5.21 Scatter plot of DCPAN predicted versus backcalculated Young's modulus (N = 66, R^2 = 0.2)

TABLE 5.24 An Example of Summary of DCPAN Results of Layer Thickness and Young's Modulus

US45N SECTION 2, SOUTH PROJECT, MONROE COUNTY
Test Date: 07/27/1999, Cycle 1

	DCP station	LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
		Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	116+00	26.80	81.49	313.03	11.84	28.15	20.40	76.13
2	115+00	20.34	96.17	301.06	13.49	22.64	30.38	57.54
3	114+00	19.75	97.74	306.70	11.05	30.63	23.94	68.18
4	113+00	27.08	80.95	322.04	16.95	17.78	32.83	54.36
5	112+00	34.80	67.64	240.20	14.91	16.71	32.42	54.86
6	111+00	22.60	90.57	443.64	18.42	22.54	39.91	46.87
7	110+00	27.14	80.83	536.43	23.05	22.91	23.70	68.66
8	109+00	18.85	100.21	553.38	18.50	30.39	14.20	96.81
9	108+00	20.38	96.06	372.54	11.94	32.83	14.27	96.48
Mean		24.19	96.06	376.56	15.57	24.95	25.78	68.88
S.D		5.20	10.84	110.41	3.98	5.80	8.79	18.08
CV		21.50%	12.32%	29.32%	25.57%	23.23%	34.08%	26.25%

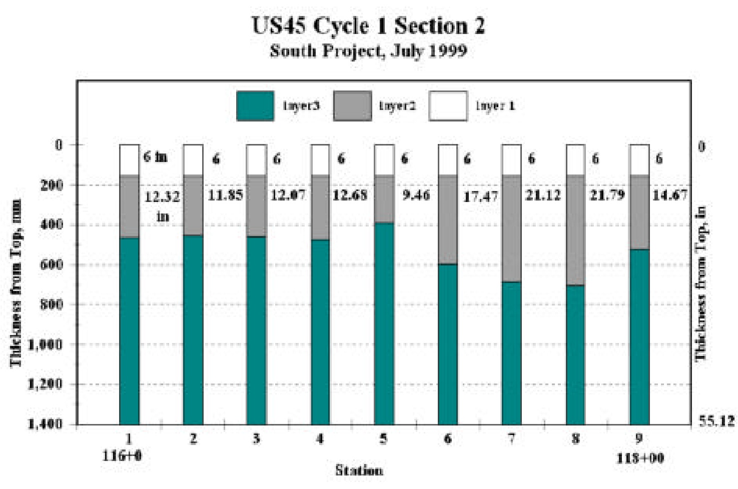


Figure 5.22. A plot of layer thickness predicted by the DCPAN software

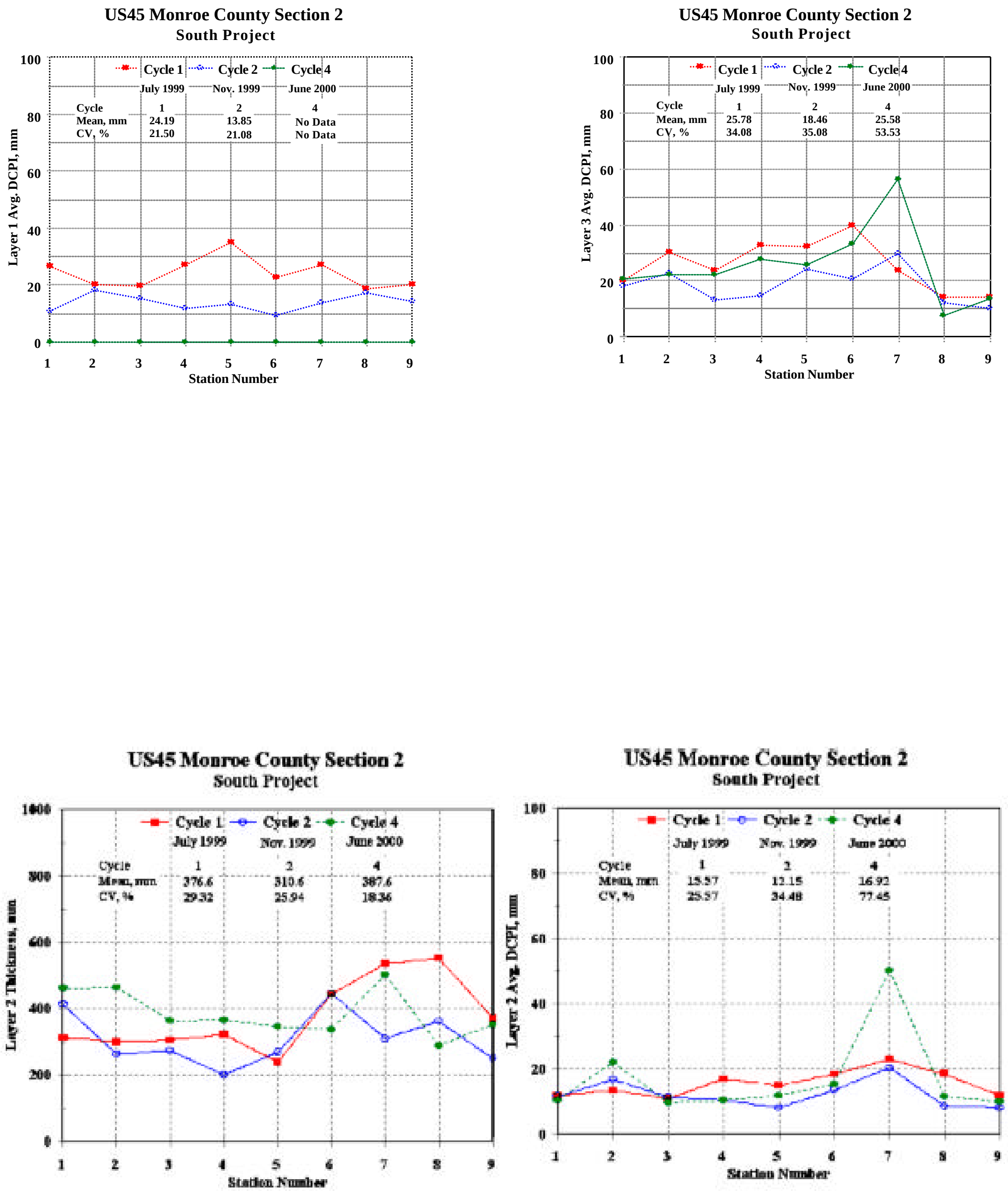
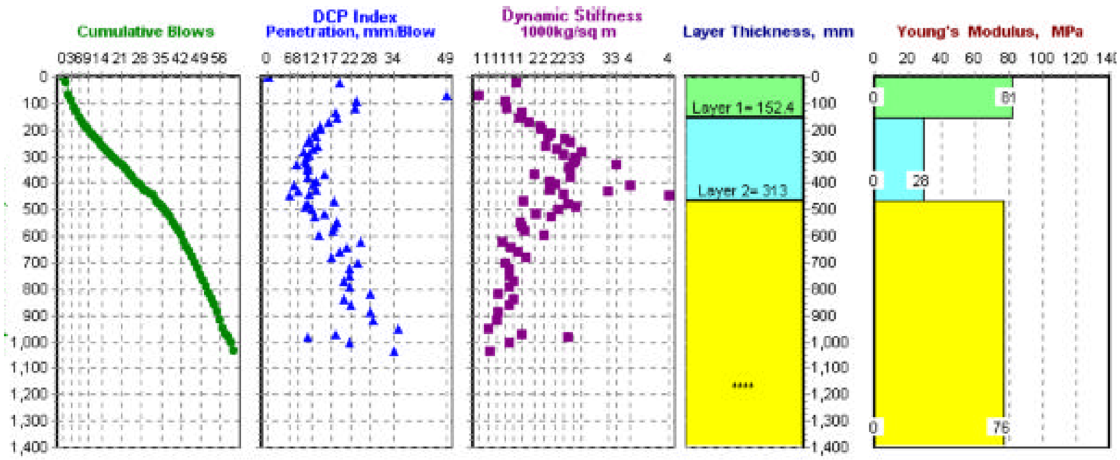
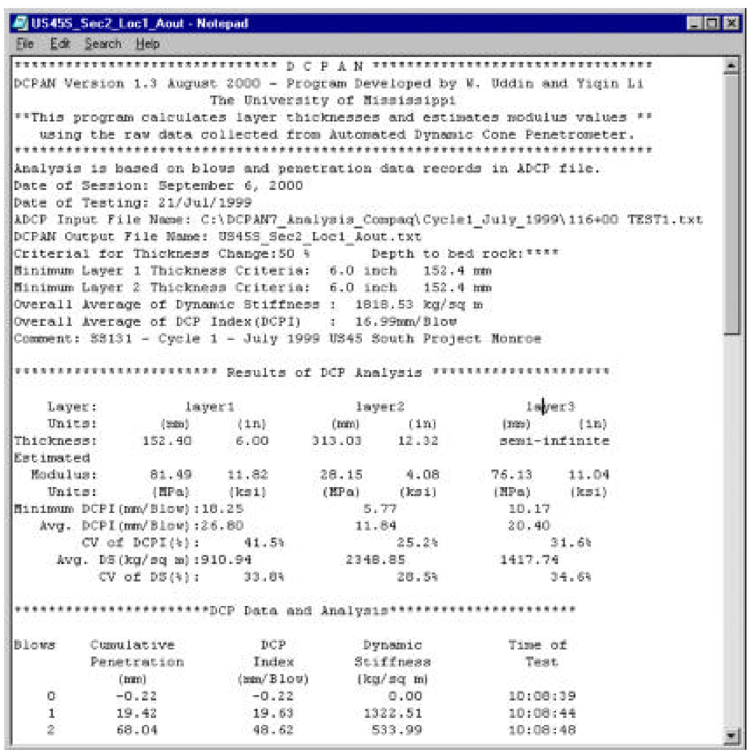


Figure 5.23. Comparison of Layer 2 thickness and DCPI for all subgrade layers predicted by the DCPAN program for different cycles of testing.




US45S_Sec2_Loc1_Aout - Notepad

File Edit Search Help

```
****************************** D C P A N ********************************
DCPAN Version 1.3 August 2000 - Program Developed by W. Uddin and Yiqin Li
                     The University of Mississippi
**This program calculates layer thicknesses and estimates modulus values **
   using the raw data collected from Automated Dynamic Cone Penetrometer.
***************************************************************************
Analysis is based on blows and penetration data records in ADCP file.
Date of Session: September 6, 2000
Date of Testing: 21/Jul/1999
ADCP Input File Name: C:\DCPAN7_Analysis_Compaq\Cycle1_July_1999\116+00 TEST1.txt
DCPAN Output File Name: US45S_Sec2_Loc1_Aout.txt
Criterial for Thickness Change:50 %       Depth to bed rock:****
Minimum Layer 1 Thickness Criteria:  6.0 inch   152.4 mm
Minimum Layer 2 Thickness Criteria:  6.0 inch   152.4 mm
Overall Average of Dynamic Stiffness :  1818.53 kg/sq m
Overall Average of DCP Index(DCPI)   :  16.99mm/Blow
Comment: SS131 - Cycle 1 - July 1999 US45 South Project Monroe

************************ Results of DCP Analysis ********************

    Layer:          layer1              layer2              layer3
    Units:        (mm)      (in)      (mm)      (in)      (mm)      (in)
Thickness:       152.40     6.00     313.03    12.32      semi-infinite
Estimated
  Modulus:        81.49    11.82      28.15     4.08     76.13    11.04
    Units:        (MPa)    (ksi)      (MPa)    (ksi)     (MPa)    (ksi)
Minimum DCPI(mm/Blow):18.25              5.77              10.17
   Avg. DCPI(mm/Blow):26.80             11.84              20.40
        CV of DCPI(%):      41.5%             25.2%              31.6%
     Avg. DS(kg/sq m):910.94           2348.85            1417.74
          CV of DS(%):      33.8%             28.5%              34.6%

***********************DCP Data and Analysis**********************

Blows    Cumulative          DCP         Dynamic          Time of
         Penetration        Index        Stiffness         Test
            (mm)          (mm/Blow)     (kg/sq m)
   0        -0.22            -0.22          0.00          10:08:39
   1        19.42            19.63       1322.51          10:08:44
   2        68.04            48.62        533.99          10:08:48
```

Figure 5.24. Examples of DCPAN plots and text output file

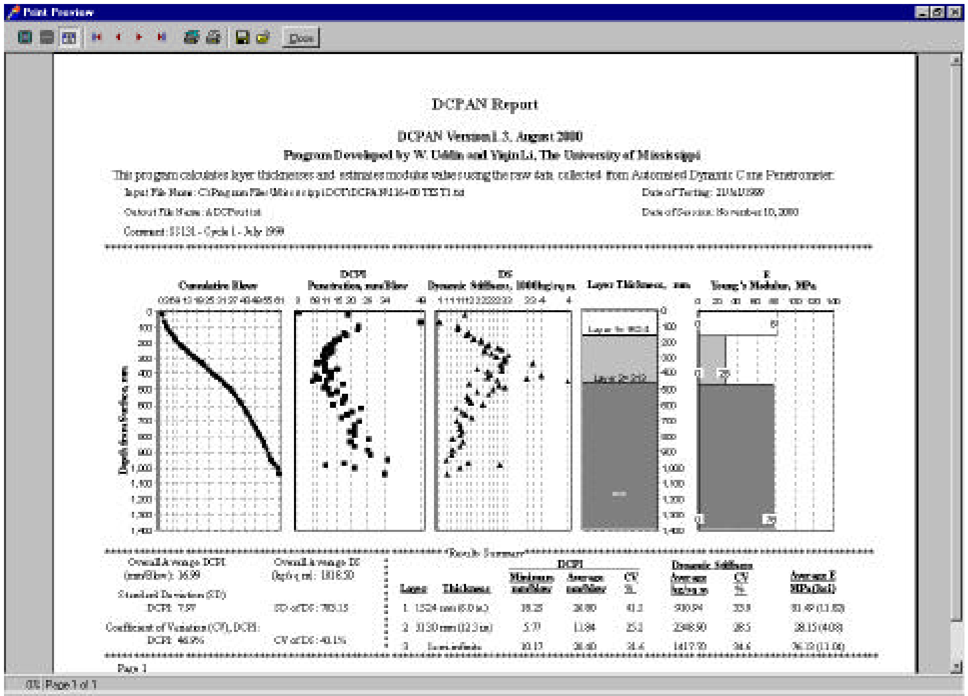


Figure 5.25. An example of DCPAN report showing all five plots and summary statistics

<u>Comparison of DCPAN Modulus Values with the FWD Backcalculated Modulus Results and Laboratory Resilient Modulus Results</u> Table 5.26 compares section averages of the DCPAN predicted modulus with the FWDSOIL backcalculated modulus and laboratory resilient modulus results for *cycle 1* (<u>44</u>). The DCPAN results for only eight sections are shown because four sections were tested by manual DCP and not analyzed by the DCPAN software. The laboratory modulus values represent samples taken: (a) from the top 12 in. for layer 1 (6 in. assumed for DCPAN and FWDSOIL analysis), (b) middle 12 in. for layer 2 (variable thickness of 12 in. to 22 in. from DCPAN analysis), and (c) bottom 12 in. for layer 3 (semi infinite assumed for DCPAN and FWDSOIL analysis). On average, DCPAN modulus values are 29% and 70% less than the average laboratory modulus for layers 1 and 2. The subgrade modulus of layer 1 should be ignored because it will change and increase many times after lime treatment of the top 6 in. Layer 2 modulus calculated by the DCPAN method is conservative. However, the average modulus of subgrade layer 3, from DCPAN and laboratory, agrees. In general both DCPAN and FWD backcalculated modulus agree reasonably. These values are relatively more conservative than the

TABLE 5.25. Section-by-Section Summary of *Appendix F* Results of DCPAN Layer Thickness and DCPI for *Cycles 1, 2, 3* and *4*

Section Information		Layer 1 Average Value		Layer 2 Average Value		Layer 3 Average Value	
		Thickness, mm (CV, %)	DCPI, mm/blow (CV, %)	Thickness, mm (CV, %)	DCPI, mm/blow (CV, %)	Thickness, mm (CV, %)	DCPI, mm/blow (CV, %)
Cycle 1	US45NN Section 1	152.40 (0.0)	39.00 (36.0)	356.39 (26.0)	34.05 (23.2)	Semi-infinite	36.11 (11.6)
	US45NN Section 2	152.40 (0.0)	22.50 (443)	473.91 (20.1)	35.10 (28.75)	Semi-infinite	36.82 (13.0)
	US45SN Section 3	152.40 (0.0)	17.91 (15.6)	304.23 (44.2)	7.57 (12.3)	Semi-infinite	8.87 (26.1)
	US45NS Section 1	152.40 (0.0)	17.7 (65.0)	327.2 (40.0)	13.50 (26.3)	Semi-infinite	16.75 (29.1)
	US45NS Section 2	152.40 (0.0)	24.19 (21.5)	376.56 (29.3)	15.57 (25.6)	Semi-infinite	25.78 (34.1)
	US45NS Section 3	152.40 (0.0)	12.6 (23.3)	374.34 (26.6)	16.30 (17.9)	Semi-infinite	28.76 (68.3)
	US45NS Section 4	152.40 (0.0)	30.57 (35.0)	404.36 (28.0)	11.30 (11.7)	Semi-infinite	18.92 (18.63)
	SR25N Section 1 (Leake County)	152.40 (0.0)	15.37 (35.3)	433.21 (13.2)	14.50 (34.5)	Semi-infinite	13.97 (47.5)
Cycle 2	US45NS Section 1	152.40 (0.0)	18.25 (28.3)	329.55 (32.2)	11.03 (17.1)	Semi-infinite	11.10 (16.3)
	US45NS Section 2	152.40 (0.0)	13.85 (21.1)	310.56 (26.0)	12.15 (34.5)	Semi-infinite	18.46 (35.1)
	US45SN Section 3	152.40 (0.0)	15.28 (37.3)	152.40 (0.0)	8.75 (30.4)	Semi-infinite	5.17 (20.8)
Cycle 3	US45NN Section 1	0.00 (None)	0.00 (None)	462.56 (31.7)	24.10 (13.0)	Semi-infinite	22.52 (15.6)
	US45NN Section 2	0.00 (None)	0.00 (None)	456.38 (47.5)	18.73 (20.5)	Semi-infinite	22.69 (19.1)
	US45SN Section 3	0.00 (None)	0.00 (None)	247.90 (16.0)	5.63 (19.6)	Semi-infinite	6.24 (21.1)
	SR25N Section 1	0.00 (None)	0.00 (None)	401.51 (36.2)	14.84 (42.8)	Semi-infinite	17.85 (32.9)
	SR25N Section 2	0.00 (None)	0.00 (None)	254.48 (46.0)	8.09 (40.1)	Semi-infinite	14.26 (18.1)

laboratory values. This variation may be partially contributed to the difference in the thicknesses of layer 1 and layer 2 used for laboratory testing. However, all three methods agree reasonably for subgrade layer 3.

TABLE 5.25. (continued)Section-by-Section Summary of *Appendix F* Results of DCPAN Layer Thickness and DCPI for *Cycles 1, 2, 3* and *4*.

Section Information		Layer 1 Average Value		Layer 2 Average Value		Layer 3 Average Value	
		Thickness, mm (CV, %)	DCPI, mm/blow (CV, %)	Thickness, mm (CV, %)	DCPI, mm/blow (CV, %)	Thickness, mm (CV, %)	DCPI, mm/blow (CV, %)
Cycle 4	US45NS Section 1	0.00 (None)	0.00 (None)	366.01 (21.3)	13.42 (17.5)	Semi-infinite	10.18 (35.8)
	US45NS Section 2	0.00 (None)	0.00 (None)	387.63 (18.6)	16.92 (77.5)	Semi-infinite	25.58 (53.5)
	US45NS Section 3	0.00 (None)	0.00 (None)	461.84 (27.8)	13.04 (28.3)	Semi-infinite	19.72 (52.9)
	SR25NS Section 3	0.00 (None)	0.00 (None)	294.70 (37.9)	11.38 (92.9)	Semi-infinite	22.99 (29.5)
	SR25NS Section 4	0.00 (None)	0.00 (None)	311.43 (45.2)	16.97 (52.4)	Semi-infinite	21.8 (18.2)

TABLE 5.26. Summary Statistics of Laboratory Resilient Modulus, DCPAN Modulus, and FWD Backcalculated Modulus for Subgrade Layers 1,2 ,3; *Cycle 1* Data

Layer	Laboratory Resilient Modulus	DCPAN Modulus	FWD Backcalculated Modulus
Number of Sections	12	8	12
Layer 1 Thickness	12 inch	6 inch	6 inch
Mean Modulus, MPa	137	96	97
(CV, %)	(34.9)	(46.2)	(64.8)
Layer 2 Thickness	12 inch	Variable	Variable
Mean Modulus, MPa	104	31	46
(CV, %)	(43.5)	(46.0)	(89.2)
Layer 3 Thickness	12 inch	Semi-infinite	Semi-infinite
Mean Modulus, MPa	87	82	80
(CV, %)	(23.9)	(35.0)	(65.3)

5.3.4 Comparison of Laboratory M_R with Backcalculated Values

Direct measurement of resilient modulus in the laboratory is the procedure recommended by AASHTO 1993 Design Guide (2) for subgrade characterization. Due to the complexity of laboratory resilient modulus test procedure, highway agencies have been exploring FWD-backcalculated modulus values for pavement design. The relationship between the laboratory and backcalculated modulus values is explored in the following sections.

5.3.4.1 Backcalculated Moduli from FWD Basins on Prepared Subgrade (Cycle 1)

Parallel to the development of the program FWDSOIL, the deflection basins measured in the subgrade were analyzed employing the MODULUS 5.0 program with a three-layer idealization, namely 0.3 m (12 in.), 0.3 m (12 in.), and 7.6 m (300 in.). Why three 0.3 m (12 in.) layers were adopted needs some explanation. First, the laboratory M_R-values were obtained from three samples at 0.3 m (12 in.) intervals, and, therefore, for meaningful comparison of backcalculated modulus with laboratory $M_{R,}$ the deflection basin analysis should adopt a three-layer system as well. Second, the DCPI determination revealed in general three 0.3 m (12 in.) layers at the top of the subgrade. This layering system was employed since laboratory moduli values were measured on samples retrieved from the first-, second- and third-foot of the subgrade soil. The calculated stress level in the first layer ranged between 207 kPa (30 psi) and (345 kPa) (50 psi), which is unrealistic in relation to typical subgrade under a standard axle load. Therefore, the moduli of samples retrieved from the first-foot layer were excluded from the analysis. In recognition of the stress dependency of subgrade soil, the laboratory modulus of the second and third layers had to be interpolated from plots such as in *Appendix C*, with due consideration to stress induced in FWD test. In fact, the stress state developed in the second and third layers due to FWD loading was calculated assuming subgrade soil as a homogeneous isotropic material (37). The load stress in conjunction with the overburden stress was employed to interpolate the laboratory measured M_R(lab)values, which were then compared with *cycle 1* backcalculated elastic moduli values, E(back)$_1$.

Fine-grain Soil Detailed MODULUS 5 results of FWD backcalculated moduli of seven sections with acceptable deflection basins are presented in *chapter 3*. A summary of M_R(lab) and E(back)$_1$ of fine and coarse soils with their statistics is presented in *Table 5.27*. The section mean M_R(lab) of the second and third layers compare well with the respective backcalculated values. Comparing the fine soil and coarse soil data, we note that the coefficient of variation, CV, of the former group is relatively high. Very large variations in subgrade soil properties, both spatially and vertically, have been reported by Houston and Perera (34). They demonstrated the potential for a high level of variation in subgrade moduli caused by layering and spatial non-homogeneity.

Different statistical tests of comparison were conducted to evaluate the difference between E(back)$_1$ and M_R(lab) values, with the results tabulated in *Table 5.28*. A Mann-Whitney-Wilcoxon test for comparison of two independent populations (39) was performed to test the differences between E(back)$_1$ and M_R(lab) for each section separately. The test revealed no significant difference between the two sets of modulus values. Two other statistical tests, namely, test of differences between means, and test of differences for paired data were conducted (40), and the results presented in *Table 5.28.* These tests again show that statistically, the mean values of E(back)$_1$ and M_R(lab) are identical.

TABLE 5.27 Summary Results of Laboratory and MODULUS-Backcalculated Moduli.

Soil Type	Designation/ Road/ project	2nd layer				3rd layer			
		M_R(lab)		E(back)$_1$[b]		M_R(lab)		E(back)$_1$	
		Mean, Mpa[a]	CV[c] (%)	Mean, MPa	C.V (%)	Mean, MPa	CV (%)	Mean, MPa	CV (%)
Fine-grain soil	Sec1S/SR25	169.0	36.0	146.0	39.0	93.0	59.0	89.0	17.0
	Sec 2S/SR25	148.0	40.0	176.0	43.0	102.0	29.0	103.0	24.0
	Sec 4S/SR25	81.0	51.0	89.0	56.0	81.0	37.0	88.0	30.0
	Sec1N/SR25	88.0	31.0	82.0	59.0	123.0	10.0	114.0	22.0
Coarse-grain soil	Sec1N/US45/South	70.0	32.0	62.0	37.0	86.0	18.0	87.0	8.0
	Sec4N/US45/South	64.0	16.0	57.0	28.0	67.0	14.0	68.0	15.0
	Sec3S/US45/North	90.0	38.0	91.0	23.0	82.0	9.0	94.0	21.0

a MPa = 145.0 psi
b Backcalculated from FWD conducted on prepared subgrade.
c Coefficient of variation

TABLE 5.28 Summary Results of Different Tests of Significance.

Soil Type	Section Designation/ project	M-W-W[a]	Difference Between Means	Test of Differences
		$\lvert Z^* \rvert$[b]	$\lvert t_1 \rvert$	$\lvert t_2 \rvert$
Fine-grain soil	Sec1S/SR25	0.33	1.03[c]	1.10[d]
	Sec 2S/SR25	1.26		
	Sec 4S/SR25	0.0		
	Sec1N/SR25	0.0		
Coarse-grain soil	Sec1N/US45/South	1.26	1.18[e]	0.90[f]
	Sec4N/US45/South	1.66		
	Sec3S/US45/North	0.38		

a Mann-Whitney-Wilcoxon
b $\lvert Z^* \rvert$ is checked against $Z_{(0.025)}$ = 1.960
c t_1 is checked against $t_{(0.025)}$ = 2.473
d t_2 is checked against $t_{(0.025)}$ = 2.262
e t_1 is checked against $t_{(0.025)}$ = 2.752
f t_2 is checked against $t_{(0.025)}$ = 2.510

After having been concluded that no significant difference exists between the E(back)$_1$ and M_R(lab) of each section, all four sections were grouped to give rise to a

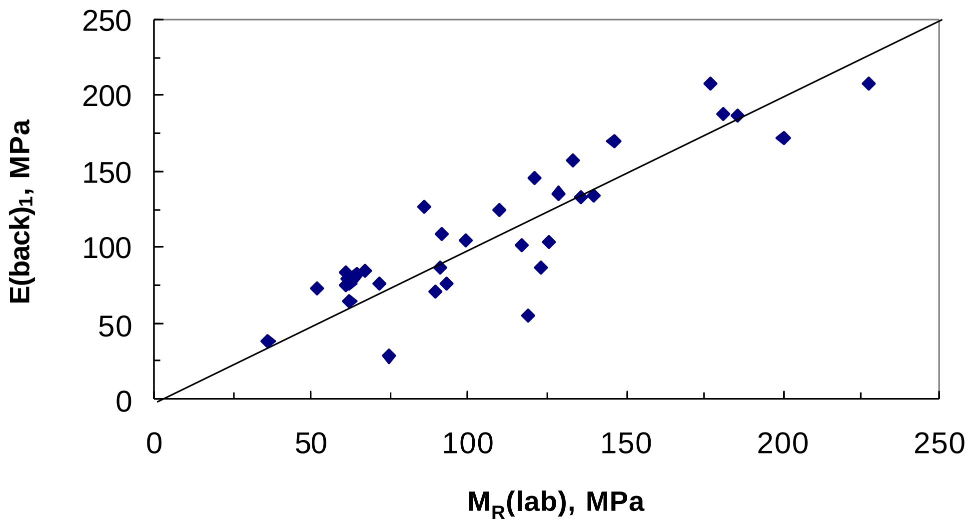


Figure 5.26 $E(back)_1$ compared to laboratory M_R for fine-grain soil.(FWD conducted on prepared subgrade)

single population. The objective here is to test for equality of moduli of the fine-grain soil. Comparing the backcalculated moduli with the laboratory determined moduli for the four fine-grain soil sections (see Figure 5.26), we note satisfactory agreement. It is noteworthy that this group comprises of different soils, exhibiting a range of properties but still belongs to the broad group of fine-grain soils. The question here boils down to whether there could be a relation between $E(back)_1$ and M_R(lab) for the group.

To accomplish this, individual ratios from the 40 data points were grouped and tested for outliers employing Chauvenet's criterion (45). Ten percent of the available data was defined as outliers and therefore excluded from the analysis. *Figure 5.27* presents a frequency distribution, with ratios in the range of 0.8 to 1.3 with an average of 1.1. *Table 5.29* shows summary statistics of fine-grain soil sections.

A close scrutiny of the data from each sample location reveals that the laboratory and field moduli show some discrepancy. Nonetheless, average values for each section are nearly equal. Estimated by two different test methods, that should they be equal is a question that merits some discussion. Besides variability in the prepared subgrade, there are other fundamental differences in the procedural aspects of the two test procedures that may yield different moduli at a given location. Possible factors that contribute

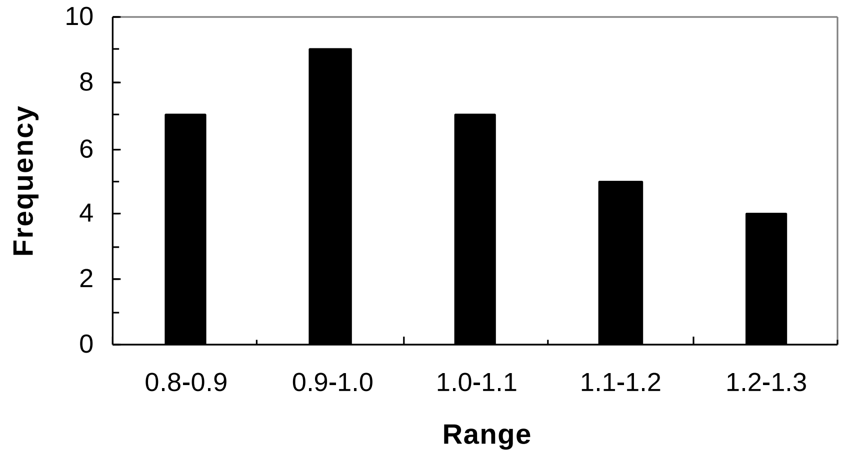


Figure 5.27 Frequency distribuation of $E(back)_1/M_R(lab)$ ratio for fine-grain soil. (FWD measurements on prepared subgrade)

TABLE 5.29 Ratio of Laboratory and Backcalculated Moduli.
(FWD test conducted on prepared subgarde)

Soil type	$E(back)_1 / M_R(lab)$	
	Mean*	**Coefficient of Variation, %**
Fine soil	1.1	16.5
Coarse soil	1.03	18.0

* Mean value based on all of the data after combining four and three sections, respectively, for fine-grain and coarse-grain soils

to different moduli are briefly explained herein. First, volume of material tested in the laboratory is different from that in the field. The size effect phenomenon accordingly should result in the laboratory modulus being larger than the field modulus, granted the material tested is homogenous. Second, the stress state in the two tested volumes are different, the stress level of laboratory sample is generally smaller than in the field counterpart resulting in larger laboratory modulus in the laboratory sample. Third, the confinement in TP46 protocol is generated by pressurized air whereas in the field it is owing to self-induced passive earth pressure. Air medium is compressible and, therefore, the laboratory sample is vulnerable to relatively large lateral, and, in turn, large axial deformation that may result in a smaller resilient modulus as compared to field values

While those three factors are recognized as influencing the resilient moduli, their quantification is somewhat obscure at this time. The results of this study simply show that the effects of those factors offset each other while averaging the results of four test sections resulting in nearly identical values of laboratory and backcalculated moduli.

Coarse-grain Soil Presented in *Table 5.27* is a summary statistics of the three coarse soil sections. Satisfactory agreement between the two sets of moduli is noteworthy. *Table 5.28* lists the different statistical "test for differences" similar to those employed for fine-grain soil. Based on the results, there is insufficient evidence to suggest laboratory M_R-values differ from the backcalculated (field) modului. A comparison between $E(back)_1$ and M_R(lab) for coarse soil is presented in *Figure 5.28*.

Whereas the mean values determined from the two procedures are statistically similar, the $E(back)_1/M_R(lab)$ ratios from each station are in the range of 0.8 to 1.2 with 1.03 on average. Note that 8 percent are identified as outliers for this soil group, according to Chauvenet's criterion. The variability in M_R values for coarse soil is much less than that for fine soil as can be seen in *Table 5.27.* This result is somewhat expected because coarse soil is amenable to uniform compaction. *Figure 5.29* presents a frequency distribution of the calculated ratios for coarse soil.

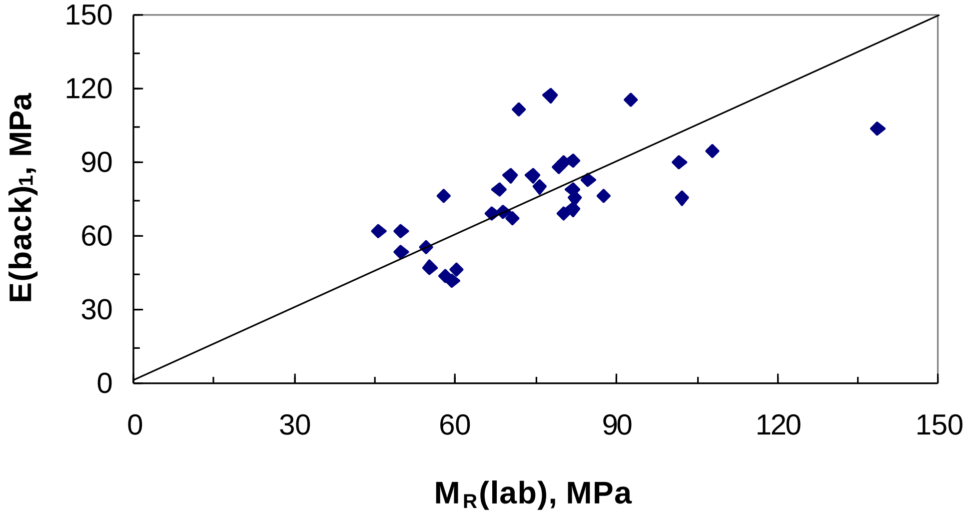


Figure 5.28 Backcalculated modulus (*cycle 1*), $E(back)_1$, compared to laboratory modulus, M_R(lab), for coarse-grain soil. (FWD conducted on prepared subgrade)

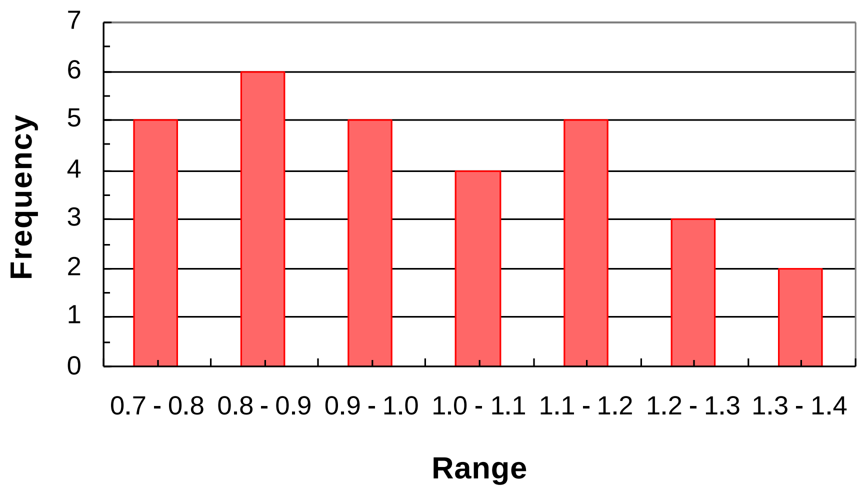


Figure 5.29 Frequency distribution of $E(back)_1/M_R$(lab) ratio for coarse-grain soil. (FWD conducted on prepared subgrade)

A conclusion is in order here that with a carefully executed deflection survey of prepared subgrade employing FWD, in conjunction with a backcalculation program, it is possible to duplicate a resilient modulus equivalent to that generated from TP46 protocol.

5.3.4.2 MODULUS 5 Backcalculated Moduli from FWD Basins on Asphalt Surface (Cycle 3/4)

As originally envisioned, the purpose of the second cycle tests was to estimate backcalculated subgrade moduli with the pavement structure in place, and compare those values with the laboratory M_R determined in soil samples cored from the prepared subgrade. Also, it would be desirable to assess the change (resilient modulus increase) resulting especially from the overburden of three pavement layers. The three layers include a 152.4-mm (6-inch) lime-treated subgrade, 152.4-mm (6-inch) lime-fly ash subbase layer and 152.4 mm (6 inch, average) of asphalt concrete.

For the backcalculation analysis, a three-layer system is devised: the asphalt layer, lime-fly ash subbase plus the lime-treated subgrade, and a (7.62-m) 300-inch subgrade. Note that the thicknesses of asphalt and the second stabilized layer were determined from the layer information compiled during the Spring/Summer 2000 coring operations (see *Table 5.1*).

Now, as the resilient modulus is stress dependent, the approximate stress state needs to be determined for interpolating the laboratory resilient modulus from plots, similar to those in *Appendix C*. FWD load stresses are calculated using KENLAYER program (37) and combined with overburden stresses. Because the first-foot of the original subgrade had been reworked for lime stabilization, the moduli of only the second and third-foot samples are of significance here. Restricted to a three layer system, the entire subgrade needs to be treated as one layer. That is, it becomes necessary to combine the second- and third-foot laboratory sample moduli for comparison with the backcalculated value.

For each soil, two comparisons are now performed and discussed as follows: First, the laboratory moduli of two samples from each sample location are averaged and compared with the backcalculated value. As expected, the backcalculated moduli in *cycle 3/4* are larger than the corresponding laboratory values (as illustrated in *Figures 5.30* and *5.31*) of both fine- and coarse-grain soils, respectively. For fine-grain soils the section specific ratio of $E(back)_2$ to $M_R(lab)$ varies from 0.85 to 2.0 with 1.4 on average. Similar calculations for the coarse-grain soil group resulted in ratios in the range of 0.9 to 2.4 with an average of 2.0. Reference (9) reported a somewhat similar ratio for subgrades under stabilized material. However, only one ratio was reported regardless of the type of soil. The present data suggests two different ratios, one for fine-grain and another for coarse-grain soils.

Second comparison involved the backcalculated values themselves at two instances, namely, moduli from *cycle 1* and *cycle 3/4*, as presented in *Table 5.30*. *Figures 5.32* and *5.33* present a comparison between the two cycles' results of fine- and coarse-grain soils, respectively. Increase in MODULUS 5 backcalculated moduli based on deflections directly on the subgrade (*cycle 1*) to those backcalculated with superimposed pavement structure turns out to be 20 to 60 percent for fine-grain soils, and 60 to 140 percent for coarse-grain soils.

Why are the MODULUS 5 backcalculated moduli larger than their laboratory counterpart? Of the several causal factors for the difference in response, the confinement offered by the overburden (the pavement layers) and the lateral resistance facilitated by

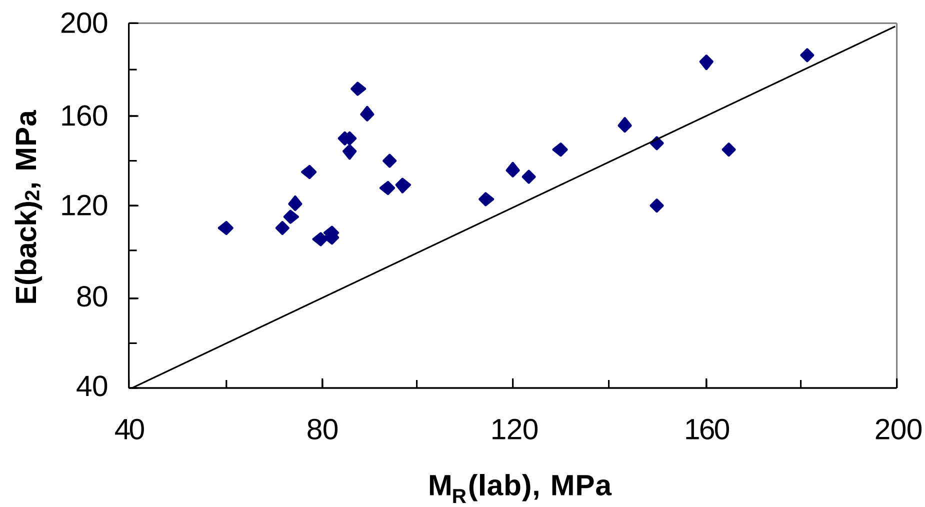


Figure 5.30 Backcalculated modulus (*cycle 3/4*), $E(back)_2$, compared to laboratory modulus, M_R(lab). FWD performed on asphalt surface, fine-grain soil

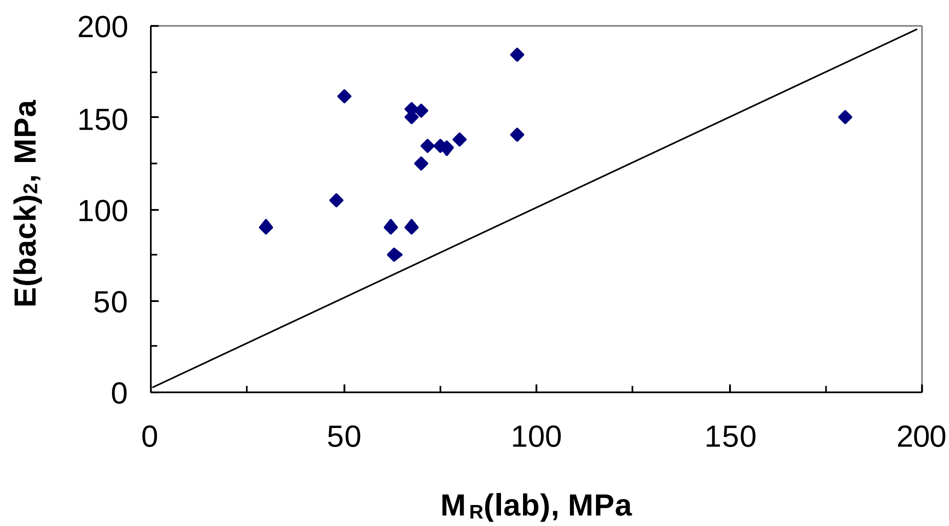


Figure 5.31Backcalculated modulus (*cycle 3/4*), $E(back)_2$, compared to laboratory modulus, M_R(lab). FWD test conducted on asphalt surface, coarse-grain soil.

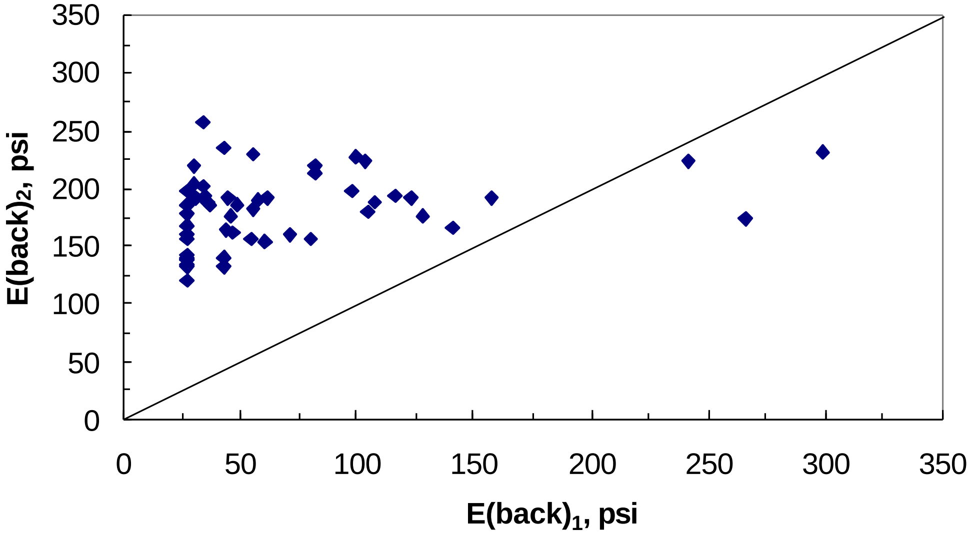


Figure 5.32 Cycle 3/4 backcalculated moduli, E(back)$_2$, compared to those in cycle 1, E(back)$_1$. Fine-grain soil subgrade.

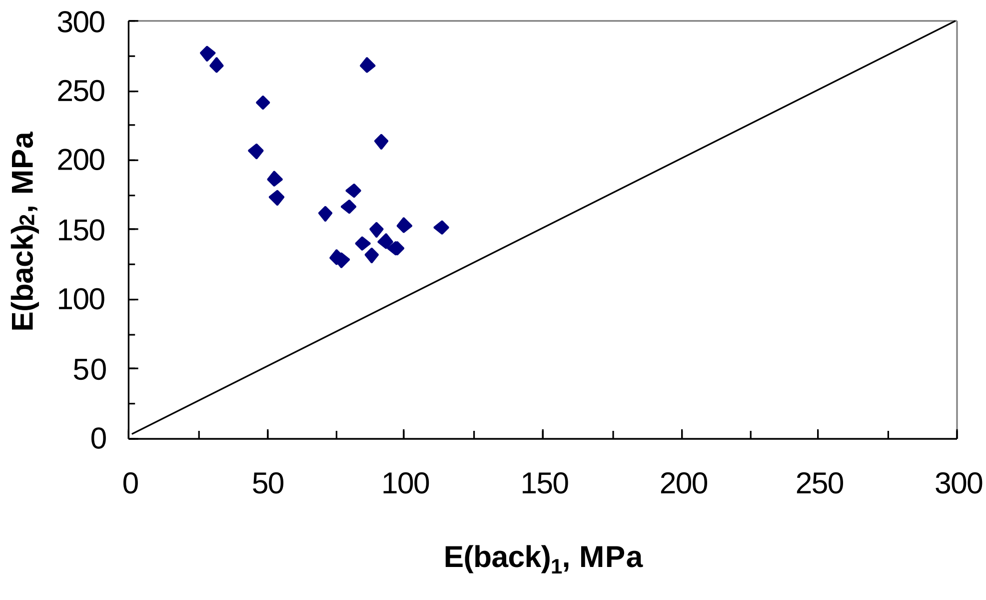


Figure 5.33 Cycle 3/4 backcalculated moduli, E(back)$_2$ compared to those in cycle 1, E(back)$_1$. Coarse-grain soil subgrade.

TABLE 5.30 Summary Statistics of MODULUS E(back). (FWD test conducted on prepared subgrade and subsequently on the asphalt surface**)**

Soil type	Designation/Road/ Project	Cycle 1[a]		Cycle 3/4[b]	
		$E(back)_1$ MPa	CV[c] (%)	$E(back)_2$ MPa	CV (%)
Fine-grain	Sec1S/SR25	111.0	32.0	133.0	7.0
	Sec 2S/SR25	128.0	40.0	169.0	10.0
	Sec 4S/SR25	87.0	39.0	136.0	12.0
	Sec1N/SR25	155.0	65.0	NA[d]	NA
Coarse-grain	Sec1N/US45/South	89.0	29.0	211.0	20.0
	Sec4N/US45/South	62.0	23.0	NA	NA
	Sec3S/US45/North	84.0	8.0	136.0	8.0

a On prepared subgrade
b On asphalt surface.
c Coefficient of variation
d Data not available.

the passive earth pressure seem to be most significant. While the field moduli show increase because of the confinement, laboratory moduli suffers from coring operations and consequent sample disturbance. The net result, therefore, would be for the backcalculated moduli to be larger than the laboratory values.

Previous researchers reported qualitatively similar results in that backcalculated modulus was larger than the laboratory value (7, 8, 9). A unique ratio of ($E(back)_2/M_R(lab)$), however, has been proposed for both coarse- and fine-grain soils although the two types of soils behave differently, warranting different ratios. The Revised Pavement Design Guide (AASHTO 1993) recommends that a factor of 0.33 to be used to convert backcalculated moduli to their laboratory equivalent. This study suggests that ratios in the range of 0.70 to 0.50—with the upper values for fine-grain soil and the lower for coarse-grain soil—are appropriate for conversion from backcalculated to laboratory moduli.

5.3.5 Long Term Pavement Performance Data Analysis

In order to substantiate the MODULUS 5 E(back)/M_R(lab) ratio of the present study, the material testing and deflection data of 20 LTPP sections in Mississippi were compiled from the LTPP database and analyzed. Specific data required for the comparison study are the laboratory resilient modulus of subgrade soil, and FWD deflection data of the pavement structure for in-situ subgrade modulus backcalculation. Based on the soil classification provided in the LTPP database, 13 fine-grain soil sections and 7 coarse-grain soil sections with all the required data were compiled. *Table 5.31* lists the structure of the 20 sections, each 500 ft. long. Laboratory moduli of each section were extracted from LTPP database and included in the table. MODULUS 5 was employed for backcalculating the subgrade moduli relying on FWD deflection basins measured on pavement surface. The backcalculated modulus E(back) and laboratory modulus M_R(lab) are compared in *Figures 5.34* and *5.35*, respectively, for fine- and coarse-grain soils.

Considering each type of soil as one population, and the premise they should have a unique ratio of E(back)/M_R(lab), Chauvenet's Criterion was again employed to identify outliers (45). As shown in *Table 5.32*, the ratio ranges from 0.8 to 2.6, with the mean at 1.7 for fine-grain soil. Similar calculations for coarse-grain soils, which included primarily sandy soils, the ratio ranged from 1.2 to 2.5, a relatively narrow range compared to that of the fine-grain soil, with the average being 1.9. It is encouraging that the ratios from LTPP data, namely 1.7 for fine-grain soils and 1.9 for coarse-grain soils, are comparable with those of the present study where the respective ratios are 1.4 and 2.0. The trend in results in both studies, where the coarse-grain soil showing a larger ratio, is worth mentioning.

TABLE 5.31 Structural Details and Resilient Modulus Values for the 20 LTTP Sections in the State of Mississippi.

SHRP id.	Subgrade type	Subbase		Base		Asphalt layer thick. mm	Average Subgrade $M_{R,}$ MPa
		Type	Thick. (mm)	Type	Thick. mm		
1001	Silty sand	sand	150	Hot mix asphalt	150	100	29
1016	Sandy silt	sand	457	Hot mix asphalt	150	6.3	45
1802	Silty sand	sand	114	Hot mix asphalt	140	7.6	72
2807	Clayey silt	NO*	-----	Cement-aggregate	150	267	20
3801	Silty sand	NO	-----	Soil-cement	150	229	54
3082	Sand	NO	-----	Soil-cement	185	211	80
3083	Sand	NO	-----	Soil-cement	173	46	55
3085	Silty clay	NO	-----	Soil-cement	150	25	118
3087	Silty sand	NO	-----	Soil-cement	150	175	66
3089	Silty clay	Soil-cement	165	Hot mix asphalt	165	119	54
3090	Clay (ll>50)	Soil-aggregate Mix.	178	Soil aggregate mix.	150	50	44
3091	Silty sand	NO	-----	Hot mix asphalt	191	109	69
3093	Silty sand	Lime-treated	150	Hot mix asphalt	165	140	65
3094	Sandy clay	Lime-treated	216	Soil-cement	140	287	68
0503	Lean clay with sand	Lime-treated	84	Hot mix asphalt	180	110	46
0504	Clay with sand	Lime-treated	150	Hot mix asphalt	218	112	110
0506	Lean clay with sand	Lime-treated	114	Hot mix asphalt	198	107	43
0507	Sand lean clay	Lime-treated	234	Hot mix asphalt	185	86	92
0508	Lean inorganic clay	NO	-----	Hot mix asphalt	196	91	49
0509	Silty clay	Lime-treated	100	Hot mix asphalt	193	109	50

* Data not available

TABLE 5.32 Ratio of MODULUS-Backcalculated and Laboratory Measured Moduli for Mississippi LTPP Sections.

Type of soil	E(back)/M_R(lab)			
	Range	**Mean**	**Standard deviation**	**Coefficient of variation, %**
Fine-grain soil	0.8 – 2.6	1.7	0.53	32.0
Coarse-grain soil	1.2 – 2.5	1.9	0.39	21.0

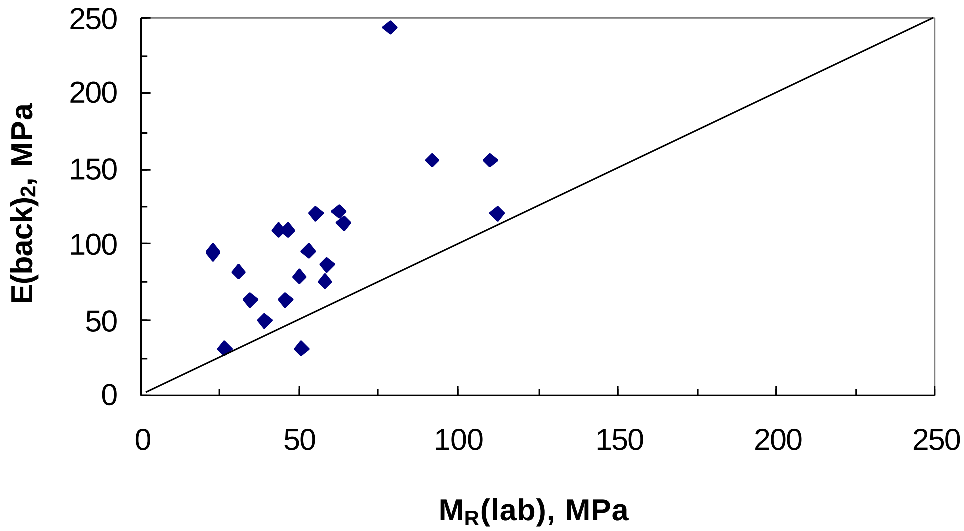


Figure 5.34 Backcalculated modulus, E(back), compared to laboratory M_R(lab) for fine-grain soils. (Mississippi LTPP Sections)

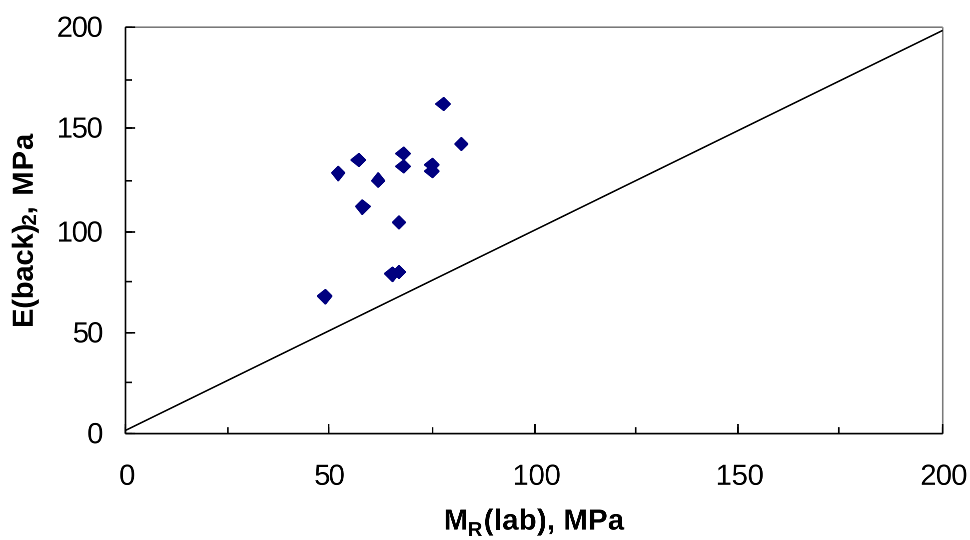


Figure 5.35 Backcalculated modulus, E(back), compared to laboratory modulus, M_R(Lab), for coarse-grain soils.(Mississippi LTPP sections)

5.4 COMPARISON OF DCP RESULTS FROM *CYCLE 1* AND *CYCLE 3/4*

5.4.1 General

As discussed in *Chapter 4*, DCPIs for each foot of the top 0.95 m (3 feet) of the subgrade were calculated from depth vs. penetration plots (see *Tables 3.4, 3.5*). Similar calculations from ADCP tests of *cycle3/4* resulted in DCPIs listed in *Tables 3.33* and *3.34*. The two sets of results are analyzed with respect to the effect of confinement provided by the pavement layers, if any. DCPI values for fine-grain and coarse-grain soils, calculated in *cycle 1* ($DCPI_1$), are compared with those obtained in *cycle 3/4* ($DCPI_2$). For every section, the ratios of ($DCPI_2$/ $DCPI_1$) were calculated. Considering each section as one population with the same soil type/conditions, outliers are defined employing Chauvenet's criterion, and were excluded from further analysis. *Table 5.33* presents summary statistics of individual sections for both soil groups.

5.4.2 Fine-grain Soil

Recall that on average the MODULUS 5 backcalculated moduli increased by 40 percent after pavement layer construction. This increase is partly attributed to apparent subgrade stiffening resulting from confinement offered by the pavement structure. Further investigation is recommended into a possible correlation with DCP results.

Cycle 1 DCP tests were performed on the prepared subgrade, with no overburden whatsoever. In *cycle 3/4*, however, the DCP tests were conducted atop the subgrade following drilling through the entire depth of all pavement layers. These layers include an asphalt concrete surface, stabilized subbase, and lime-treated subgrade. A comparison between $DCPI_2$ and $DCPI_1$ is presented in *Figure 5.36*.

In order to examine the difference between $DCPI_1$ and $DCPI_2$, the test for differences was conducted. The test was employed on data from each section, and subsequently combining data from six sections that belong to fine-grain soil group. The null hypothesis, H_o, (namely, no significant difference between $DCPI_1$ and $DCPI_2$) is rejected in both cases, suggesting that there is a significant difference between $DCPI_1$ and $DCPI_2$.

As listed in *Tables 5.33 and 5.34*, the ratio of $DCPI_2$/ $DCPI_1$ ranges from 0.65 to 1.0 with an average of 0.80 for all sections combined as one group. This corresponds to a 20 percent decrease in DCPI after pavement layer construction, primarily due to the confinement effect. Note that E(back) gained an average of 40 percent after pavement layer construction, a trend that is captured by DCP data as well.

Why the change (increase) from *cycle 1* to *cycle 3/4* in E(back) is different from the change (decrease) in DCPI is discussed. First, the nature of the two tests: while the DCP test is destructive in nature, the FWD test is not. Second, the volume of material sampled in the two tests is different. While a large volume is sampled in FWD, a small annular volume of soil is tested to failure (plastic failure) in DCP test.

5.4.3 Coarse-grain Soil

DCPI ratios of coarse-grain soil sections are listed in *Table 5.33* along with summary statistics. A comparison between DCPI from *cycle 1* and *cycle 3/4* is presented in *Figure 5.37*. The test of differences was employed section-wise and after combining the four sections into one population. The null hypothesis, namely, no significant difference between $DCPI_1$ and $DCPI_2$, was rejected for both cases, suggesting a significant difference between $DCPI_1$ and $DCPI_2$.

TABLE 5.33 Summary Statistics of $DCPI_2$/ $DCPI_1$ for Individual Sections.

Soil Type	Stations	County/ Roadway	No. of Stations	Outliers	$DCPI_2$/ $DCPI_1$	
					Average	CV[a], %
Fine-grain	1303- 1311	Rankin/SR25	9	1	0.65	40
	1347-1355	Rankin/SR25	9	NO[b]	1.0	38
	1591-1598	Rankin/SR25	9	1	0.77	46
	1696-1704	Rankin/SR25	9	NO	0.81	45
	522-530	Leake/SR25	NA[c]	NA	NA	NA
	461-469	Monroe/US45	9	NO	0.81	31
	490-498	Monroe/US45	9	NO	0.67	38
Coarse-grain	88-96	Monroe/US45	9	2	0.8	33
	108-116	Monroe/US45	9	3	0.59	27
	170-178	Monroe/US45	9	1	0.66	41
	260-266	Monroe/US45	NA	NA	NA	NA
	668-676	Monroe/US45	9	1	0.6	35

a Coefficient of variation
b No outliers defined
c Data not available

TABLE 5.34 Summary Statistics of $DCPI_{3/4}$/ $DCPI_1$ for Two Soil Groups.

Soil Type	No. of sections	$DCPI_2$/ $DCPI_1$	
		Average	CV, %
Fine-grain	6	0.80	42
Coarse-grain	4	0.66	39

The section-wise ratios of $DCPI_2$/ $DCPI_1$ range from 0.59 to 0.80 with an average of 0.66 for all the tested sections (see *Tables 5.33 and 5.34*). The percentage decrease in DCPI is approximately 34 percent compared with 20 percent for fine-grain soils. Note that E(back) of coarse-grain soils gained 100 percent from *cycle 1* to *cycle 3/4* (after pavement layer construction) compared with 40 percent for fine-grain soils.

For coarse-grain soil, with larger angle of internal friction in relation to that for fine-grain soil, the confinement due to upper layers is significant. With adequate confinement of coarse-grain soil, the penetration resistance would increase with a corresponding decrease in DCPI.

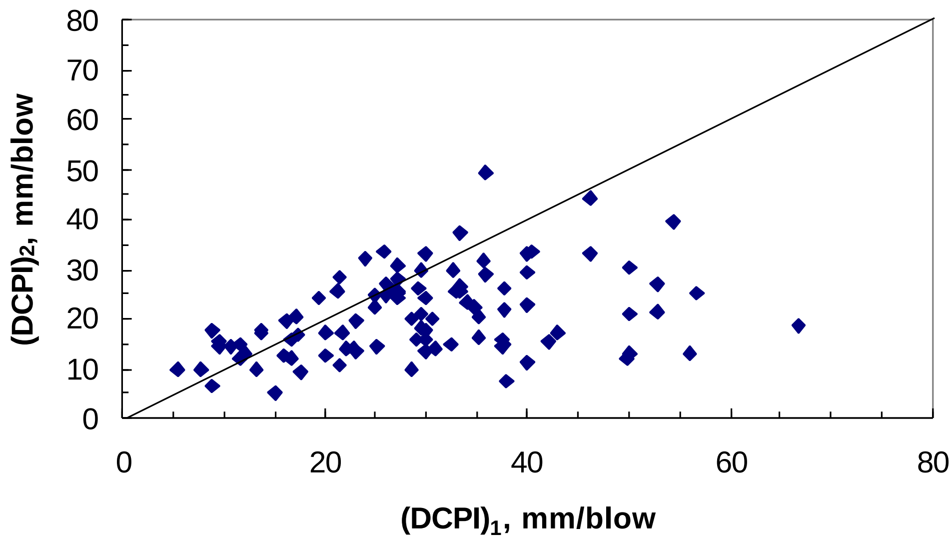


Figure 5.36 Comparison of DCPI from cycle 1, $(DCPI)_1$, and cycle 3/4, $(DCPI)_2$. Fine-grain soil subgrade.

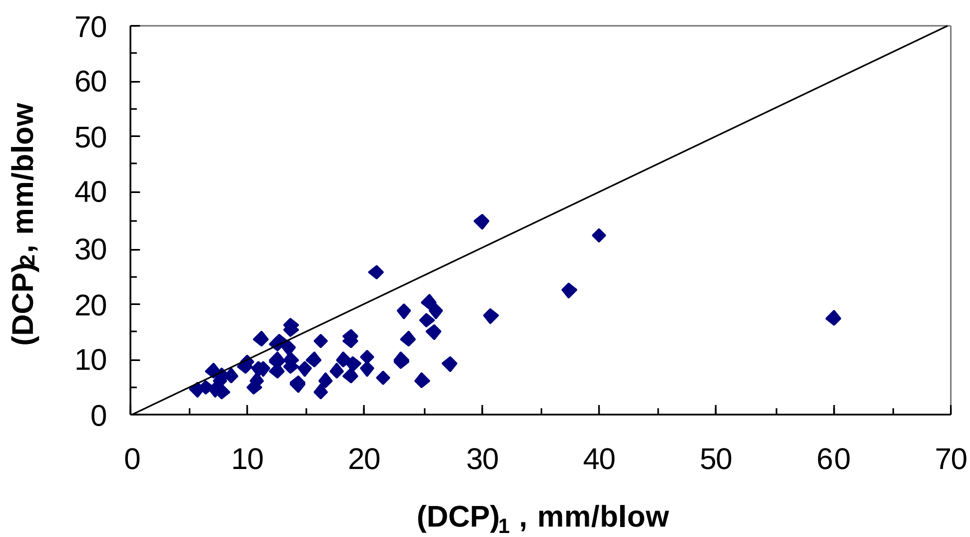


Figure5.37 Comparison of DCPI from cycle 1, $(DCPI)_1$, and cycle 3/4, $(DCPI)_2$. Coarse-grain soil subgrade.

5.5 ADVANCED COMPUTER MODELING AND SIMULATION

5.5.1 Overview

Traditionally, highway and airport pavements have been modeled as static linear elastic systems for structural response analysis. Limitations of these procedures and uncertainties in material properties may lead to incorrect structural response of pavements. Many of these procedures do not appropriately consider the effects of dynamic loading and pavement nonlinearities. Appropriate and accurate material inputs are essential for meaningful advanced finite element modeling and simulation.

Elastic material properties, generally used for pavement response analysis, can not simulate time-dependent viscoelastic behavior of asphalt pavements. Time-dependent behavior is also exhibited by granular layers and unbound subgrade soils in laboratory resilient modulus tests. An advanced material model is therefore formulated at the University of Mississippi to simulate time-dependent behavior and microcracking of these pavement materials.

The User Material (UMAT) routine is based upon a generalized Maxwell viscoelastic model and incorporates microcracking and crack propagation. The UMAT routine is implemented in the ABAQUS finite-element code using FORTRAN subroutines. The required pavement material properties include bulk modulus, shear modulus, Poisson's ratio, mass density, and relaxation time. The required parameters for crack propagation analysis are: initial crack size, stress intensity threshold, crack growth rate, and static coefficient of friction.

5.5.2 UMAT Model Formulation

For the viscoelastic solid, represented by a generalized deviatoric Maxwell model, with the strain being common for all elements of the model and the stresses for the individual elements being additive, i.e.,

$$s_{ij} = \sum_{n=1}^{N} s_{ij}^{(n)} \tag{5.5}$$

where N is the number of elements in the generalized Maxwell model, $s_{ij}^{(n)}$ is the deviatoric stress component for the nth element. The relationship between the deviatoric stress rate and the viscoelastic deviatoric strain rate and deviatoric stress is given by

$$\dot{s}_{ij} = \sum_{n=1}^{N} \left(2G^{(n)} \dot{e}_{ij}^{ne} - \frac{s_{ij}^{(n)}}{t^{(n)}} \right) \tag{5.6}$$

where $G^{(n)}$ and $t^{(n)}$ are the shear modulus and relaxation time, respectively, for the nth Maxwell element, and e_{ij}^{ve} is the viscoelastic deviatoric strain. Equations are formulated for the subroutines CRACK, CRACKR and INTENS which are called from UMAT.

5.5.3 UMAT Implementation

In this study UMAT has been successfully implemented in ABAQUS. Initial Implementation efforts were made using a simple one-layer model of a few soil brick elements. Later in August 1999, the study was terminated because of limited resources allowed to the modeling phase. For brevity these early results are not presented here. The detailed equations and preliminary results are described in Reference 46.

5.6 SUMMARY

The laboratory M_R is successfully correlated with the DCP test result, namely DCPI and other soil properties. Two distinct regression models are developed, one each for fine-grain and coarse-grain soil, respectively. The predicted M_R values compare well with the actual moduli, an indication of the robustness of the model. Modulus values backcalculated employing MODULUS 5, from deflection data of FWD test conducted directly on prepared subgrade, are comparable to the laboratory M_R. As determined from FWD on pavement structure, the subgrade moduli backcalculated by MODULUS 5, E(back), are consistently larger than the corresponding laboratory values. Owing primarily to confinement effect, different ratios ($E(back)_2$ / $M_R(lab)$) are obtained depending on the type of soil being tested. The ratios derived in this study generally agree with those obtained employing the results of 20 LTPP sections in Mississippi.

The subgrade moduli backcalculated by the FWDSOIL program and predicted by regression equation incorporated in the DCPAN program (using deflection basins measured on the subgrade) are lower than the laboratory resilient modulus values for subgrade layers 1 and 2. The laboratory modulus values for subgrade layer 3, however, agree reasonably well with the backcalculated values. Therefore, a factor of 1.0 is recommended if the DCPAN program and FWDSOIL backcalculation program are used.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY

The focus of this study is to investigate the use of Dynamic Cone Penetrometer (DCP) for subgrade soil characterization. In a planned field test program, twelve as-built subgrade sections were tested using the Automated DCP and Falling Weight Deflectometer (FWD). Undisturbed samples were extracted using a thin wall Shelby tube and tested in the laboratory for Resilient Modulus (M_R). Data from DCP test conducted directly on the prepared subgrade facilitated development of regression models for laboratory M_R prediction. Two prediction models were developed one each for fine-grain and coarse-grain soils. A feature of the model is that besides the DCP index, other physical properties of soil were found to be significant in M_R prediction. The models were verified by repeating the tests at another site and comparing the measured and predicted M_R values. Two simpler relations, again, one each for fine-grain and coarse-grain soils, were derived where DCPI is directly correlated to laboratory M_R.

An exclusive backcalculation program, FWDSOIL, was developed to analyze FWD deflection data on the subgrade surface using sensors 2 through 6 only. A methodology has been developed to identify layering in subgrade soil and their thicknesses. The software, designated DCPAN, also calculates in-situ backcalculated modulus of subgrade soil layers, using regression relations developed in the study.

With the plan to investigate the subgrade soil in situ, FWD measurements were conducted, first in the prepared subgrade and subsequently on the surface of the asphalt layer. Moduli of the subgrade in the two cases were backcalculated employing

MODULUS 5, comparing each with the laboratory M_R. The moduli of subgrade and DCP results before and after the emplacement of pavement structure were analyzed, investigating the effect of overburden confinement.

An advanced material model (UMAT) has been formulated for computer simulation of DCP test. This model is based on a generalized Maxwell viscoelastic model incorporating microcracking and crack propagation. The model is implemented in the ABAQUS finite element code. At this stage, this computer simulation effort was terminated in view of the extensive laboratory testing required for material characterization.

6.2 CONCLUSIONS

The analysis of results focused on relating the DCP index (DCPI) to laboratory M_R and FWD-based backcalculated moduli. Summarized herein are the major conclusions of this study.

1- Sample disturbance caused by pushing the Shelby tube sampler into a dessicated top layer resulted in a significant increase in sample densities and, in turn, increased resilient modulus values. Moisture also influenced the resilient modulus.

2- Field as well as laboratory test results show that the subgrade in all the twelve test sections is non-uniform, showing more variation spatially than in the vertical direction

3- The results dictated two relations—one for fine-grain and another for coarse-grain soils—in correlating DCPI to laboratory M_R. For further improvement of the model, soil physical properties are found to be necessary explanatory variables.

4- For the range of soils tested the backcalculated modulus (MODULUS 5), employing direct deflection tests in the subgrade, is in agreement with laboratory M_R.

5- The subgrade “firmed” up with emplacement of pavement structure, as indicated by FWD-backcalculated modulus values. Comparing FWD results before and after pavement construction, a 40 and 100 percent increase are realized in fine-grain and coarse-grain soils, respectively.

6- That the backcalculated subgrade moduli of existing pavements are larger than laboratory measured core sample moduli is confirmed by results from 20 LTPP sections in the State of Mississippi.

7- The FWDSOIL backcalculation program predicts reasonable subgrade modulus values which are generally lower than the laboratory resilient modulus values. This implies that the backcalculated modulus values can be directly used for designing pavement thickness using the AASHTO Design Guide.

8- The DCPAN software facilitates estimating in-situ subgrade layers thicknesses and backcalculated modulus values. The DCPAN software automatically generates the profile and DCP plots from ADCP data files.

9- The Dynamic Cone Penetrometer offers a viable alternative to other more complex and time-consuming procedures in characterizing subgrade soil through its correlation with laboratory resilient modulus and FWDSOIL-backcalculated modulus.

6.3 RECOMMENDATIONS FOR FURTHER RESEARCH

1- Though the ADCP provided satisfactory results in the soils investigated in this study, its performance in coarse soils (sand and gravelly soils) is not yet clear. What is important here is the likely collapse of DCP hole and how it affects penetration results.

2- With the finding that FWD-backcalculated moduli match the laboratory M_R, the viability of direct FWD tests on subgrade needs further investigation. If FWD can provide modulus values replicating laboratory M_R, FWD could indeed be a viable device for subgrade characterization. In order to limit the deflections (less than 80 mils, as recommended by FWD manufacturer), a larger loading plate be designed and used with the lower peak load attainable with the equipment.

6.4 IMPLEMENTATION

Developed from field and laboratory studies are relations between ADCP index and laboratory resilient moduli. DCPAN software on the other hand determines layering in the subgrade, and corresponding layer thicknesses. With the correlation equations incorporated in the software, ADCP becomes a versatile tool for subgrade soil characterization in AASHTO pavement design and/or for rehabilitation design of existing pavements. Alternately, FWD tests, programmed for low-level loads, may be conducted directly on the subgrade for modulus determination. For reliable results from FWD tests, not only should the load intensity be within reasonable limits but ensuring that the deflection measuring sensors are not affected by loose debris is important as well. With some additional work ADCP could well be used for construction quality control of uncemented pavement layers.

6.5 BENEFITS

The principal benefit of the DCP index-laboratory M_R correlation resides in being able to use the ADCP for subgrade soil characterization. Subgrade resilient moduli for new pavement design (in accordance with AASHTO Guide) and also for rehabilitation design can be determined employing the relations developed in this study. The DCPAN software provides real time soil resilient moduli as the investigation is underway in the field. The study results lend support to the use of the Falling Weight Deflectometer directly on the subgrade for determining in-situ subgrade moduli.

Recognition of spatial variability of soil compaction unearthed in this study could lead to better construction control specifications. ADCP could be developed as a tool for compaction control. That the manual and automated DCPs results in statistically identical penetration resistance could lead to the use of manual DCP in remote areas, especially in the preliminary phase of highway alignment and site selection for appurtenant structures.

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APPENDIX A

FWD DEFLECTION BASINS MEASURED IN PREPARED SUBGRADE (*CYCLE 1*)

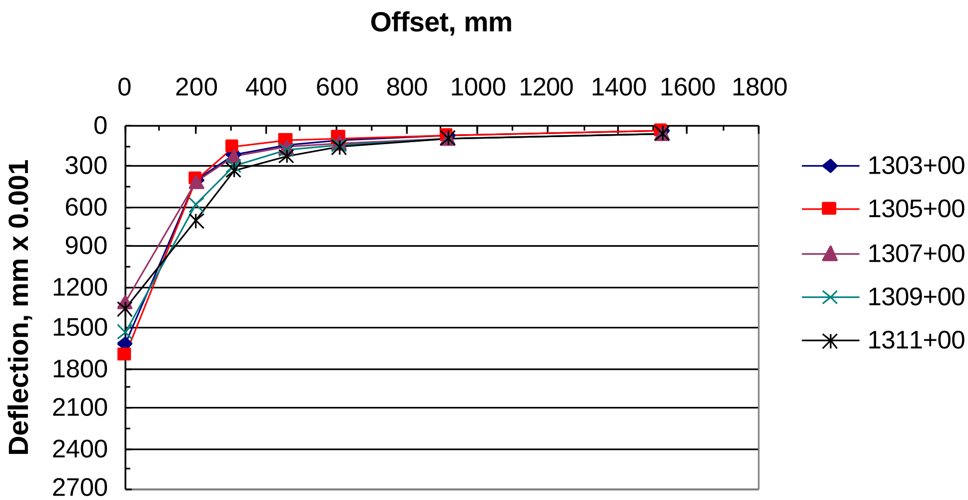

Figure A-1. Deflection basins for five stations in section 1 south bound, rankin county, SR25

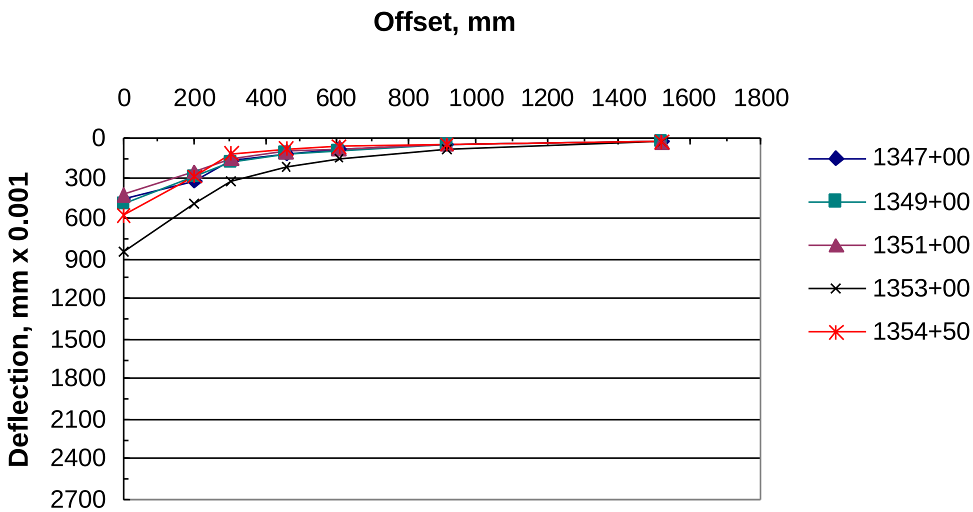

Figure A-2. Deflection basins for five stations in section 2 south bound, Rankin county, SR25

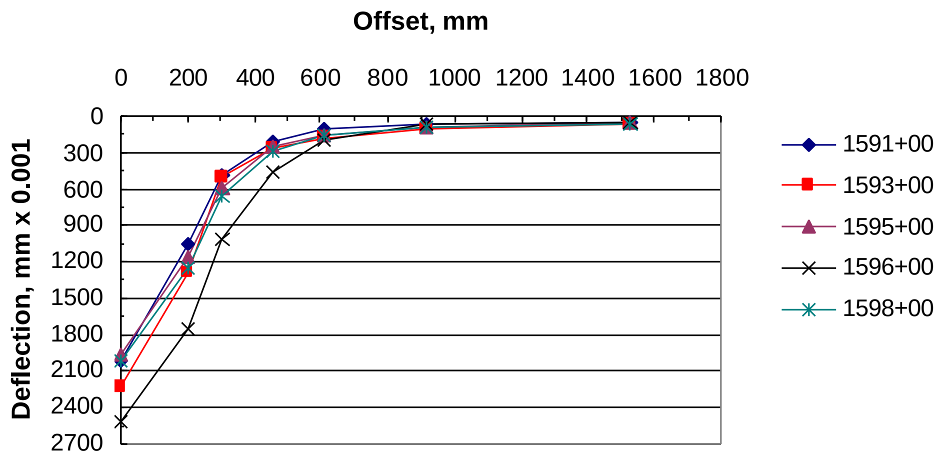

Figure A-3. Deflection basins for five stations in section 3 south bound, Rankin county, SR 25

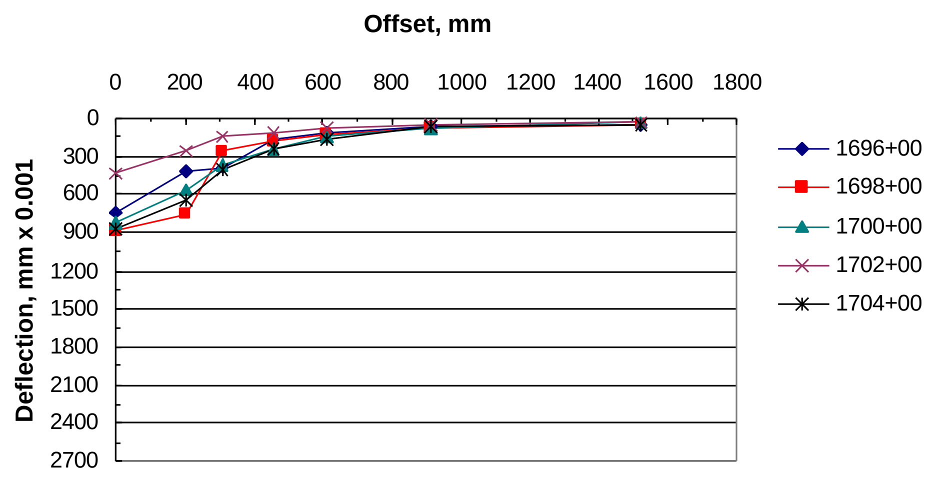

Figure A-4. Deflection basins for five stations in section 4 south bound, Rankin county, SR25

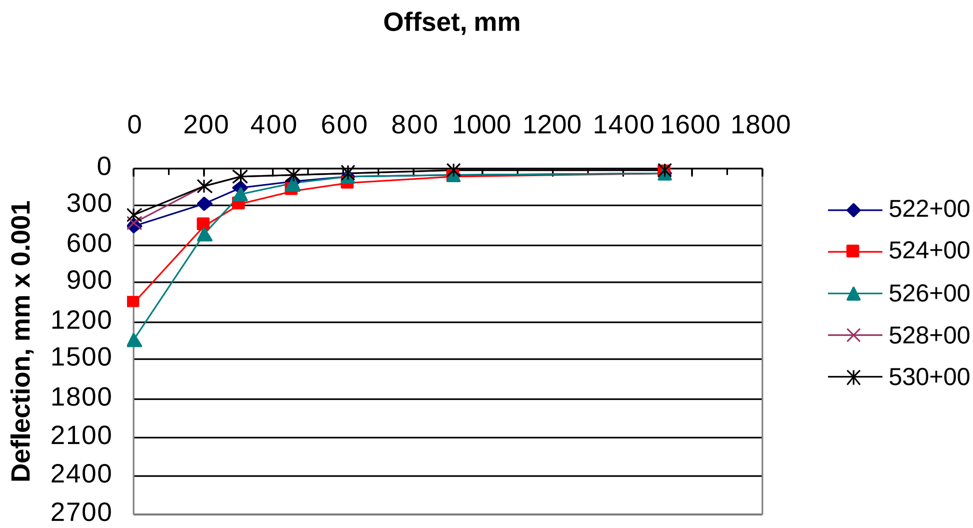

Figure A-5 Deflection basins for five stations in section 5 north bound, Leake county, SR25

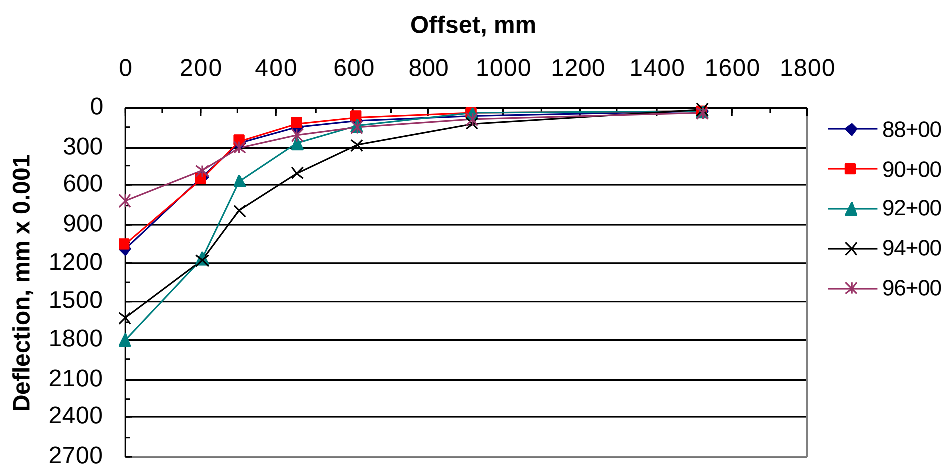

Figure A.6 Deflection basins forfive stations in section 1 north bound, south project, Monroe county, US45

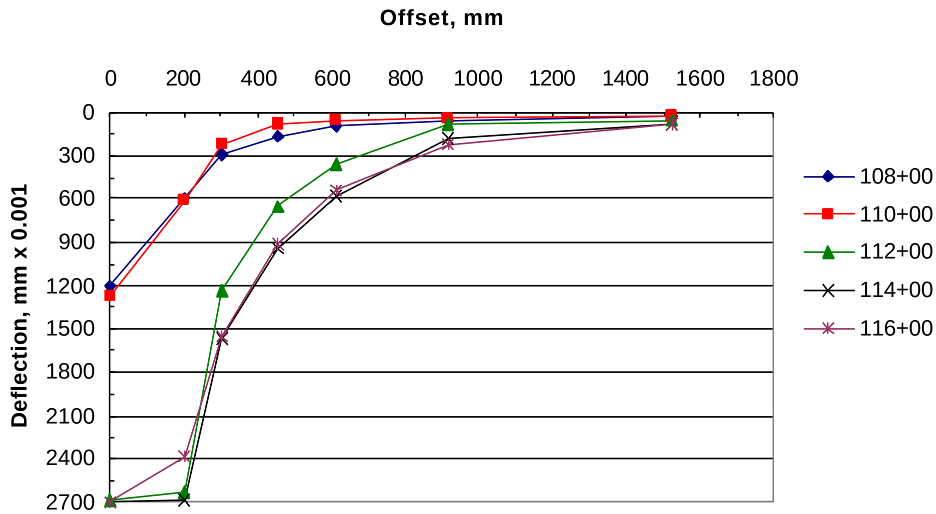

Figure A.7 Deflection basins for five stations in section 2 north bound, south project, Monroe county, US45

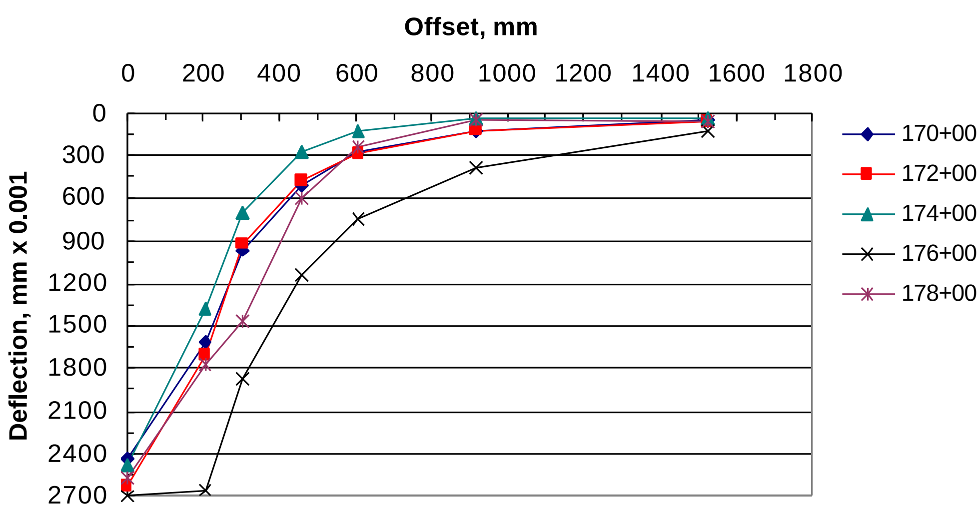

Figure A.8 Deflection basins for five stations in section 3 north bound, south project, Monroe county, US45

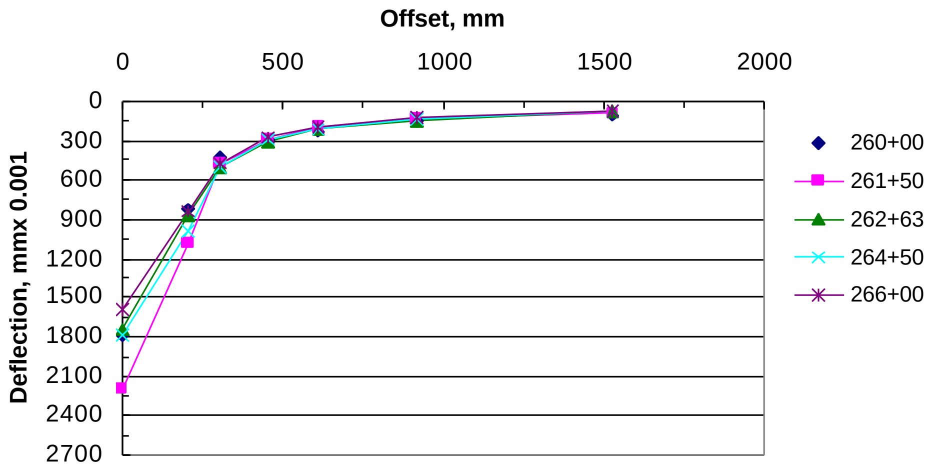

Figure A.9 Deflection basins for five stations on section 4 north bound, south project, Monroe county, US45.

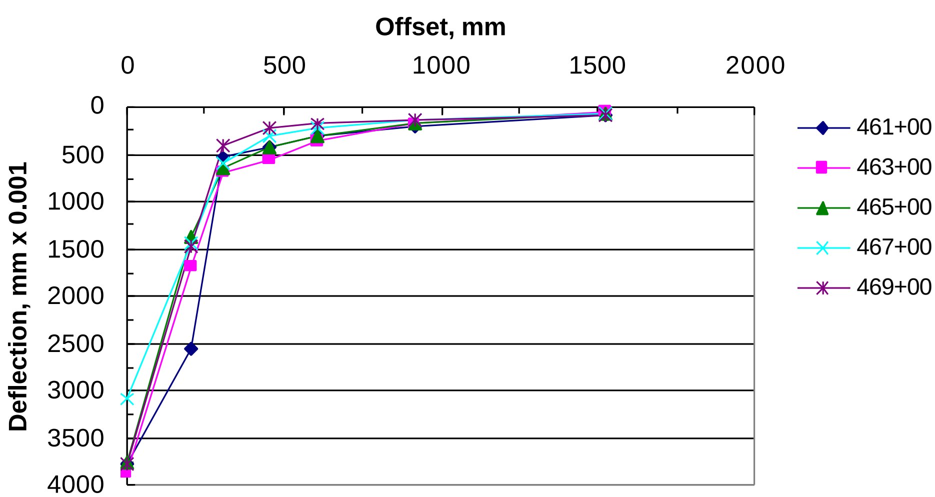

Figure A.10 Deflection basins for five stations on section 1 north bound, north project, Monroe count, US45.

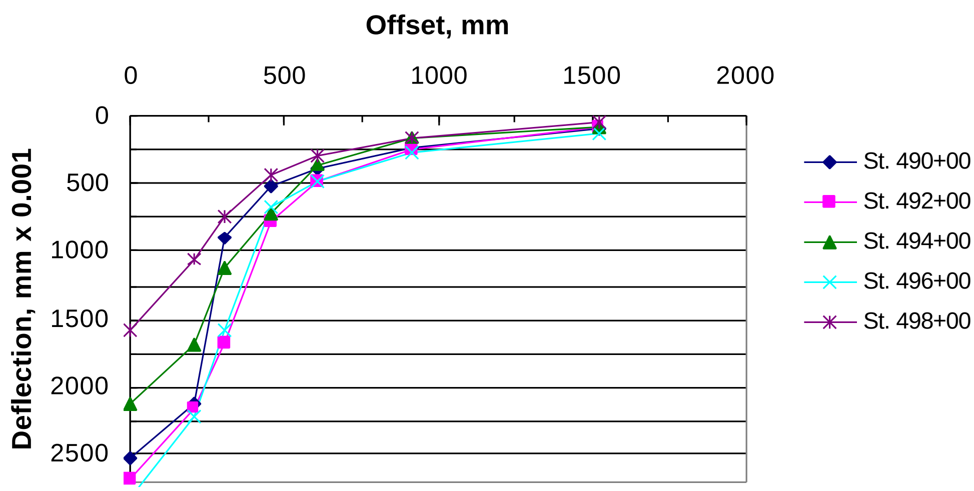

Figure A.11 Deflection basins for five stations on section 2 north bound, north project, Monroe county, US45.

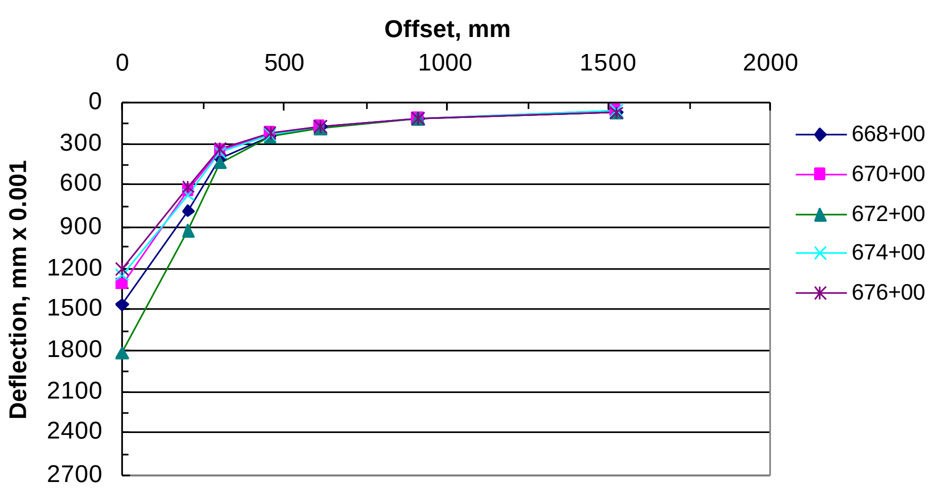

Figure A.12 Deflection basins for five stations on section 3 south, north project, Monroe county, US45.

APPENDIX B

DYNAMIC CONE PENETROMETER PLOTS
(DCP TESTS CONDUCTED IN PREPARED SUBGRADE, *CYCLE 1*)

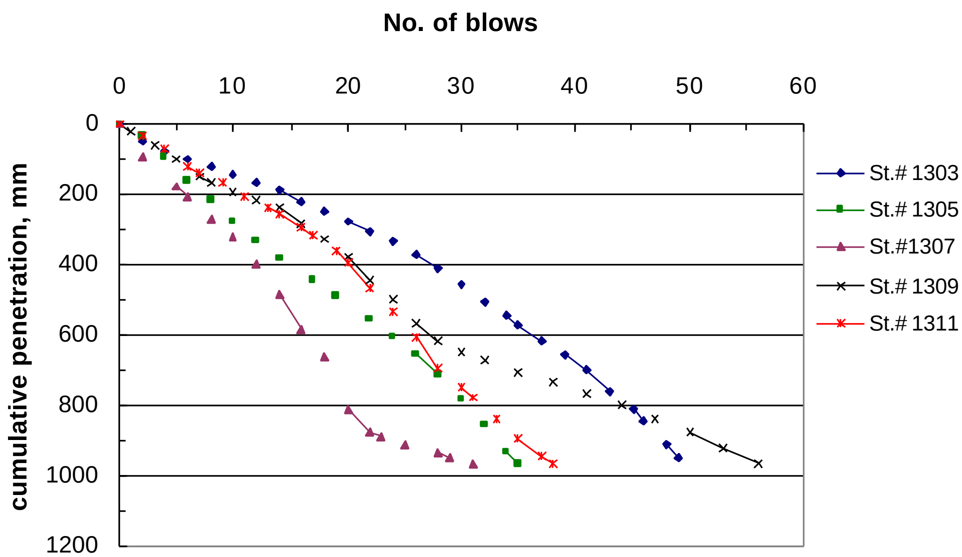

Figure B.1 MDCP test results in section 1 south bound, SR25-Rankin county.

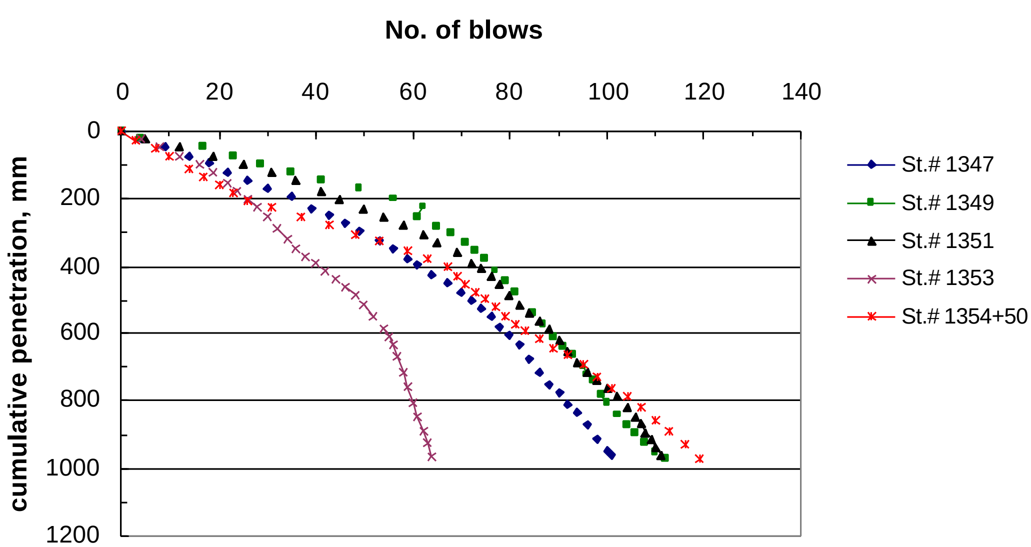

Figure B.2 MDCP test results in section 2 south bound, SR25-Rankin county.

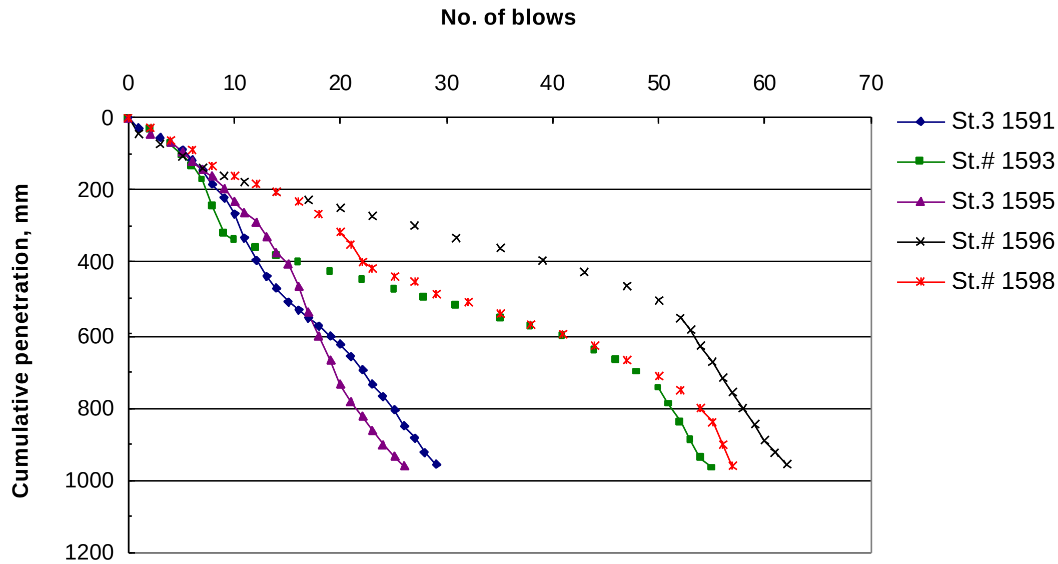

Figure B.3 MDCP test results in section 3 south bound, SR25-Rankin county.

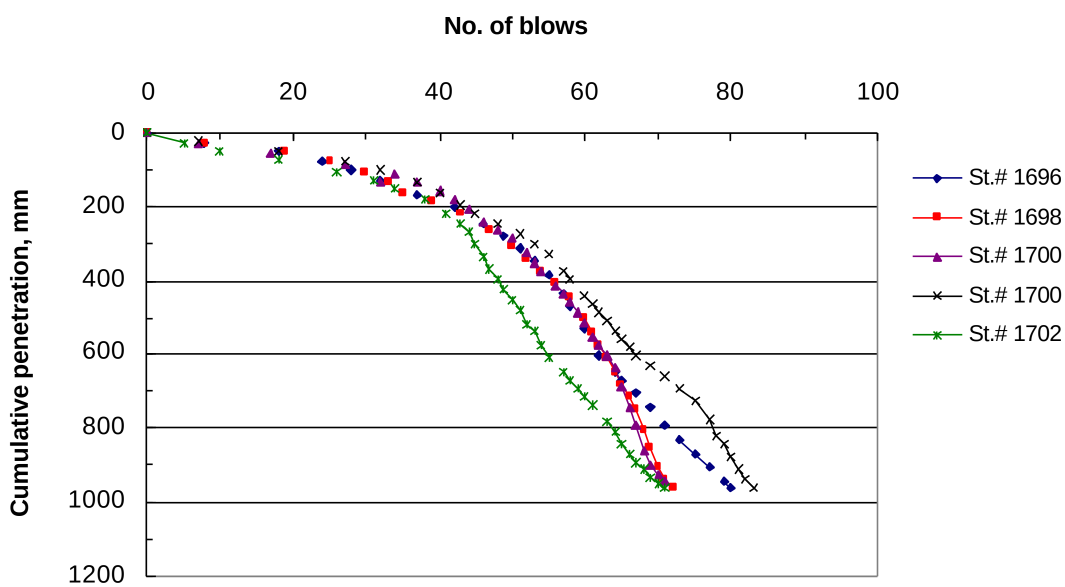

Figure B.4 MDCP test results in section 4 south bound, SR25-Rankin county.

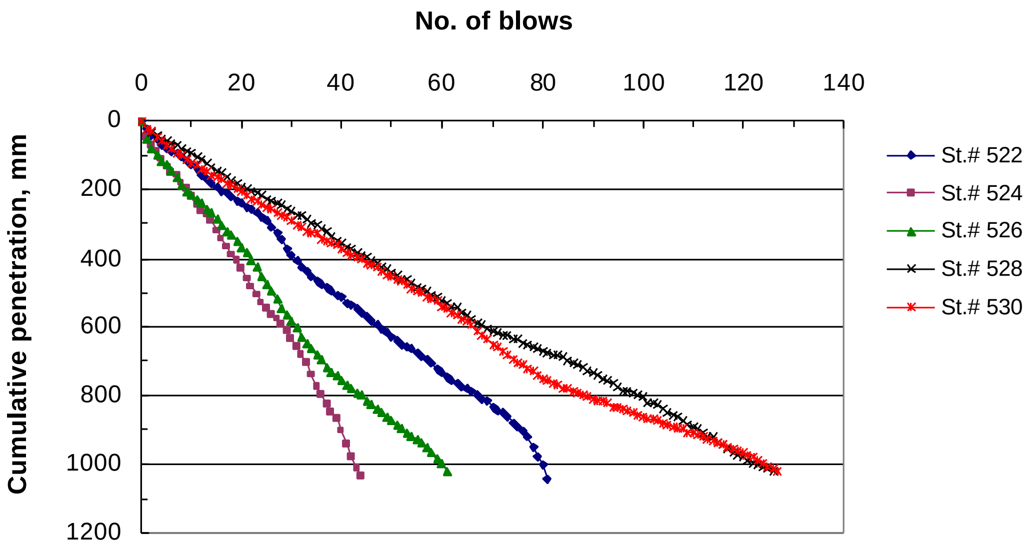

Figure B.5 ADCP test results in section 1 north bound , SR25-Leake county.

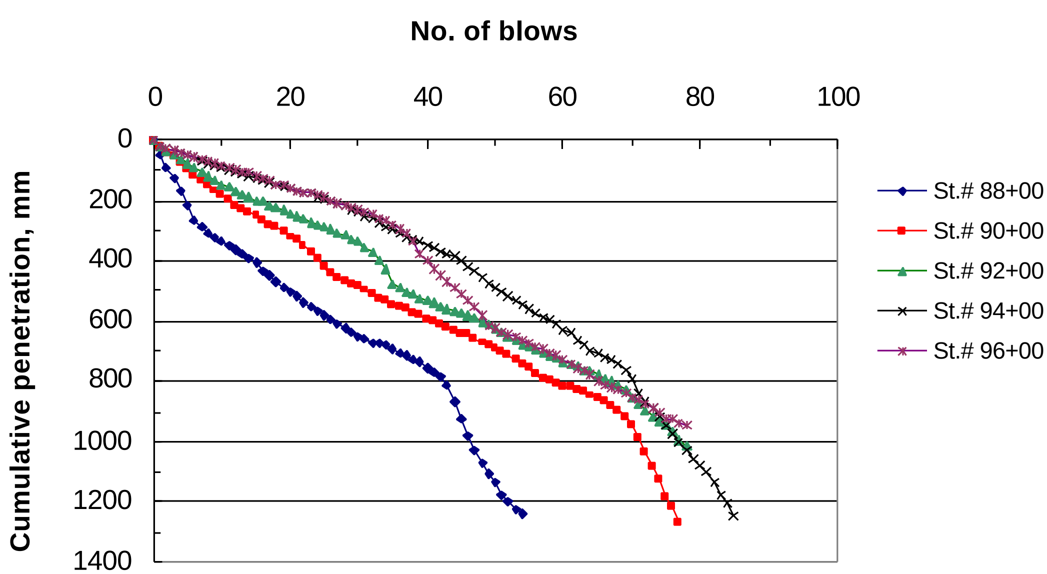

Figure B.6 ADCP test results in section 1 north bound, south project, US45- Monroe county.

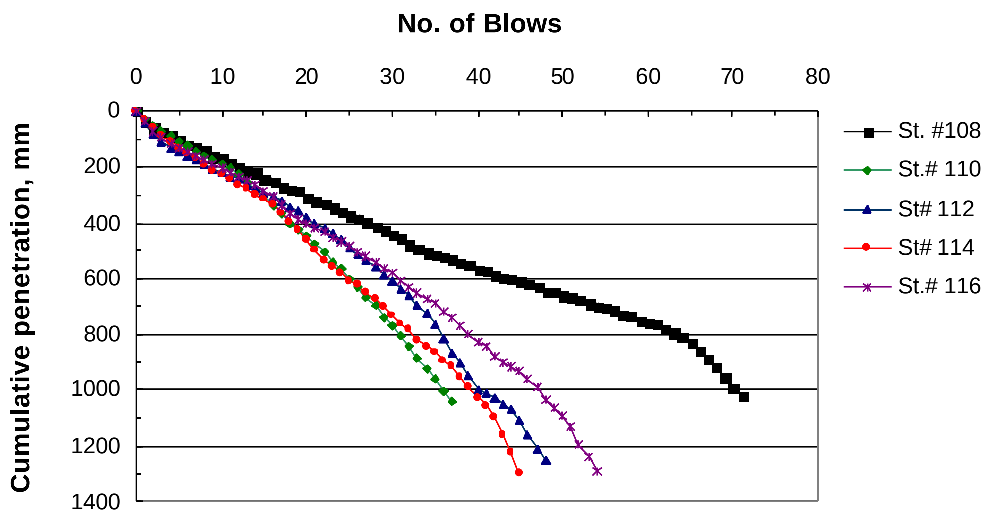

Figure B.7 ADCP test results in section 2 north bound, south project, US45- Monroe county.

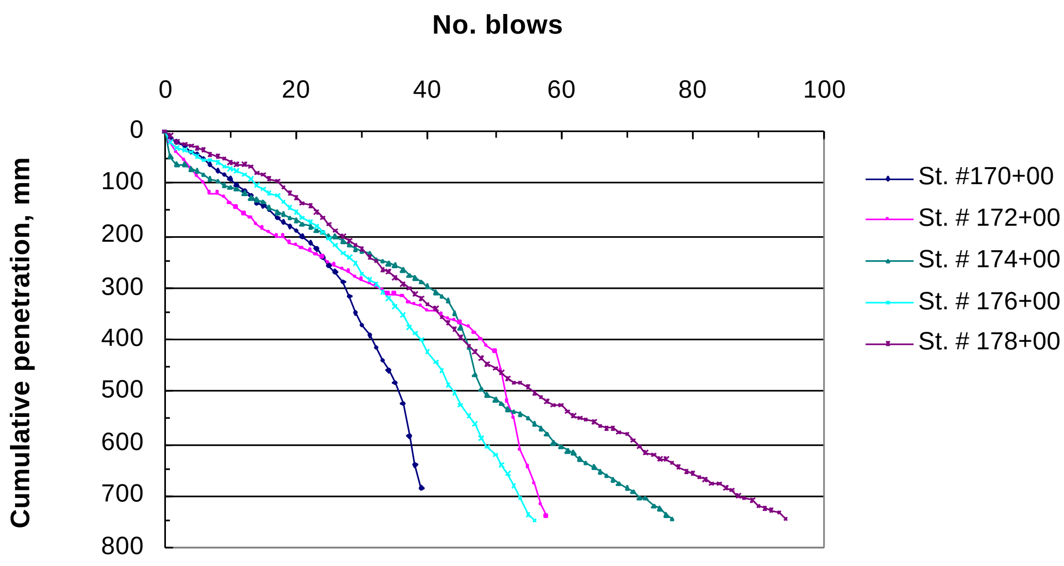

Figure B.8 ADCP test resultsin section 3 north bound, south project, US45-Monroe county.

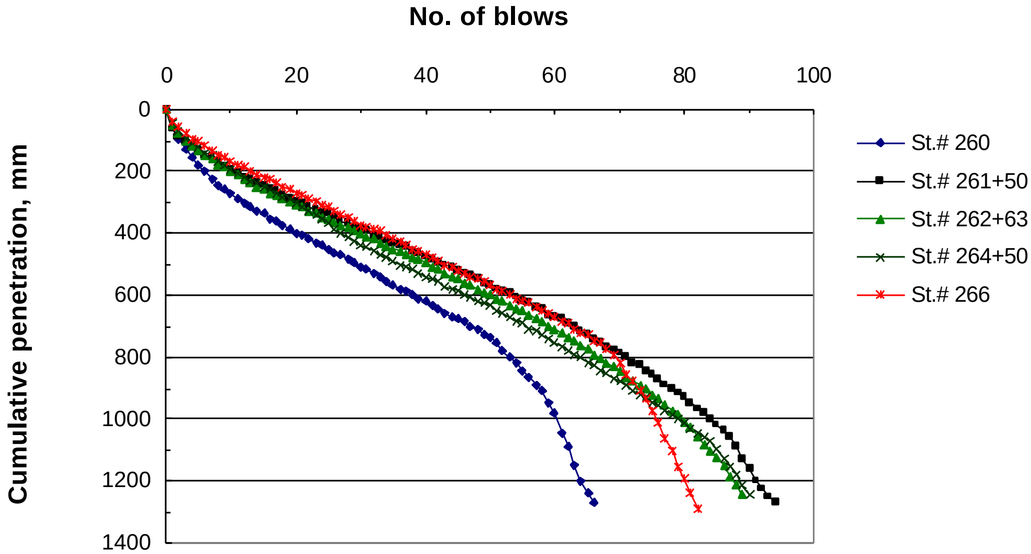

Figure B.9 ADCP test results in section 4 north bound, south project, US45-Monroe county.

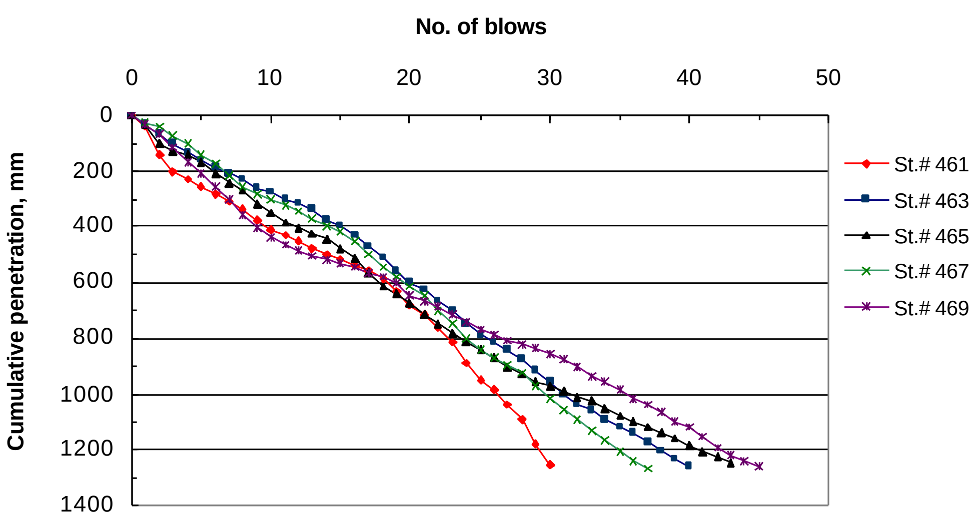

Figure B.10 ADCP test results in section 1, north bound, south project, US45-Monroe county.

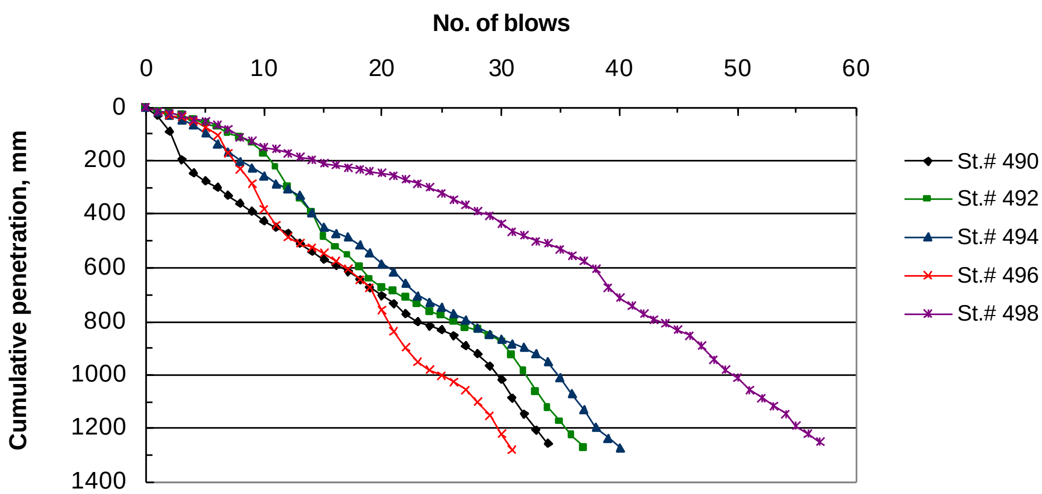

Figure B.12 ADCP test results in section 2, north bound, north project, US45-Monroe county.

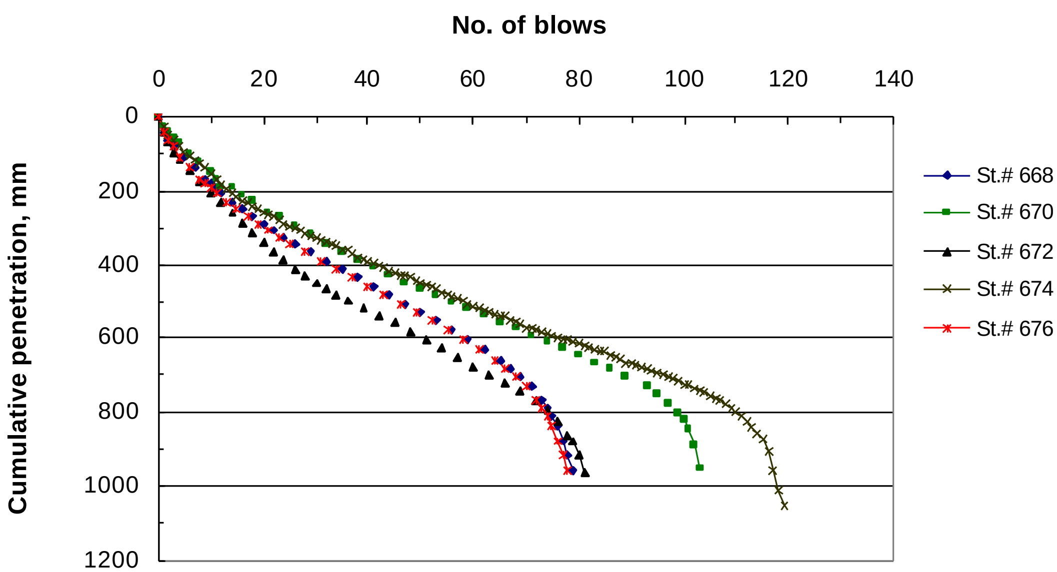

Figure B.12 DCP test results in section 3, south bound, south project, US45-Monroe county.

APPENDEX C

TP46 TEST SEQUENCE FOR SUBGRADE SOIL MATERIALS

TABLE C.1 TP46 Protocol Test Sequence for Subgrade Soil Materials.

Sequence No.	Confining Pressure, σ_3		Max. Axial Stress, σ_{max}		Cyclic Stress, σ_{cyclic}		Constant Stress, 0.1 σ_{max}		No. of Load Application (s)
	kPa	psi	kPa	psi	kPa	psi	kPa	psi	
0	41.4	6	27.6	4	24.8	3.6	2.8	0.4	500-1000
1	41.4	6	13.8	2	12.4	1.8	1.4	0.2	100
2	41.4	6	27.6	4	24.8	3.6	2.8	0.4	100
3	41.4	6	41.4	6	37.3	5.4	4.1	0.6	100
4	41.4	6	55.2	8	49.7	7.2	5.5	0.8	100
5	41.4	6	68.9	10	62	9.0	6.9	1.0	100
6	27.6	4	13.8	2	12.4	1.8	1.4	0.2	100
7	27.6	4	27.6	4	24.8	3.6	2.8	0.4	100
8	27.6	4	41.4	6	37.3	5.4	4.1	0.6	100
9	27.6	4	55.2	8	49.7	7.2	5.5	0.8	100
10	27.6	4	68.9	10	62	9.0	6.9	1.0	100
11	13.8	2	13.8	2	12.4	1.8	1.4	0.2	100
12	13.8	2	27.6	4	24.8	3.6	2.8	0.4	100
13	13.8	2	41.4	6	37.3	5.4	4.1	0.6	100
14	13.8	2	55.2	8	49.7	7.2	5.5	0.8	100
15	13.8	2	68.9	10	62	9.0	6.9	1.0	100

APPENDIX D

TYPICAL PLOTS FROM LABORATORY RESILIENT MODULUS TESTS

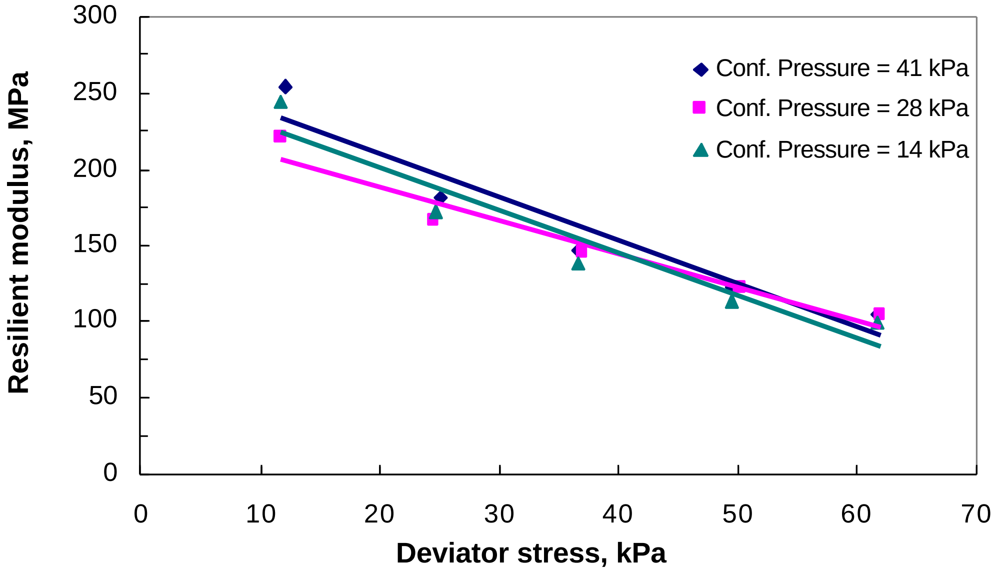

Figure D.1 Resilient Modulus Test results, SR25, Rankin county, Station 1311+00, Sample #3

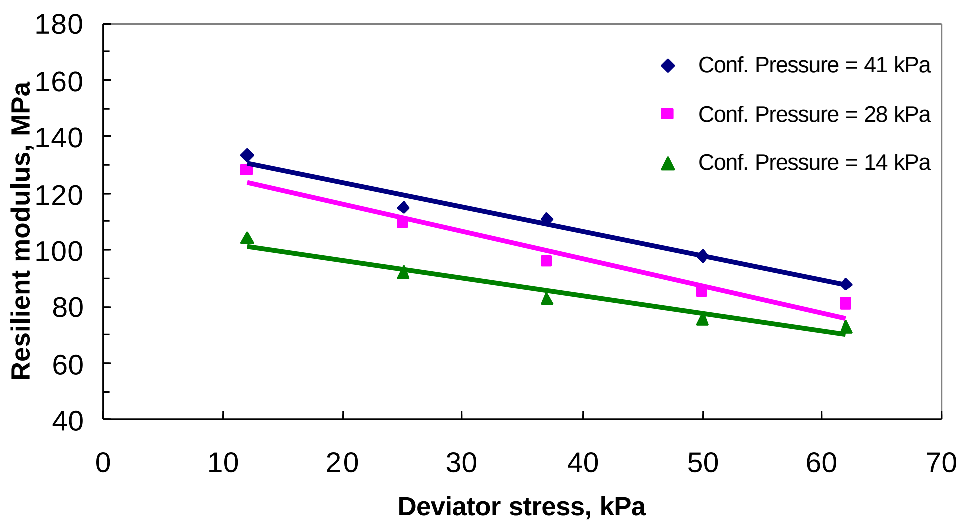

Figure D.2 Resilient Modulus Test results, SR-25, Rankin county, Station 1349+00, Sample #2

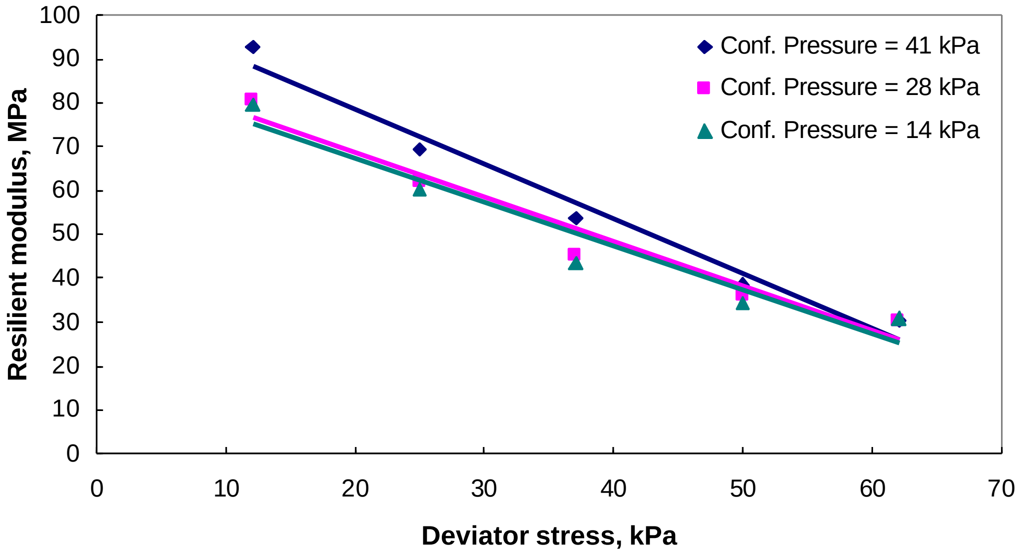

Figure D.3 Resilient modulus test results, SR25, Rankin county, Station 1595+00, Sample #2

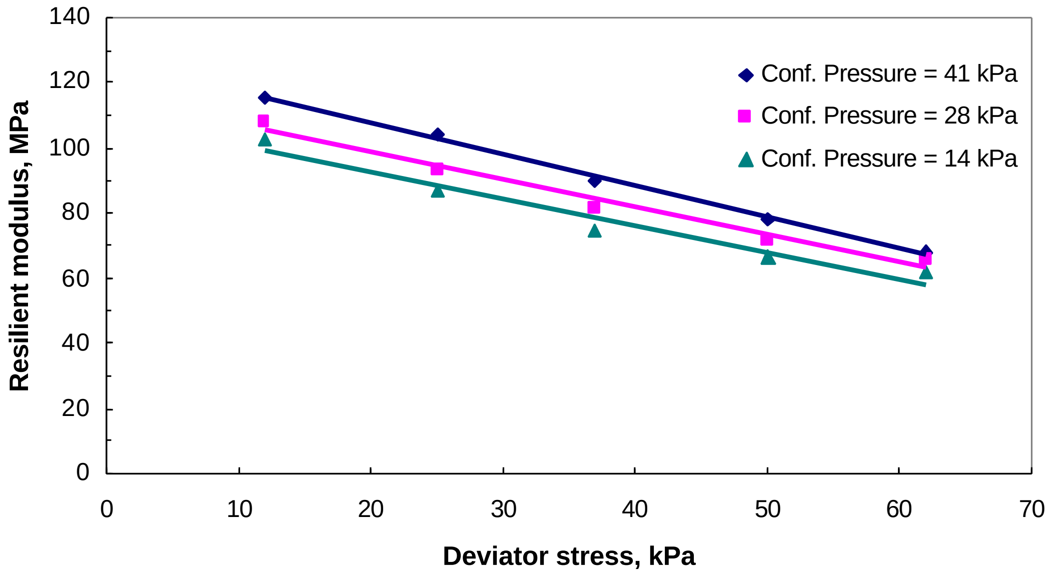

Figure D.4 Resilient Modulus Test results, SR25, Rankin county, Station 1698+00, Sample # 2

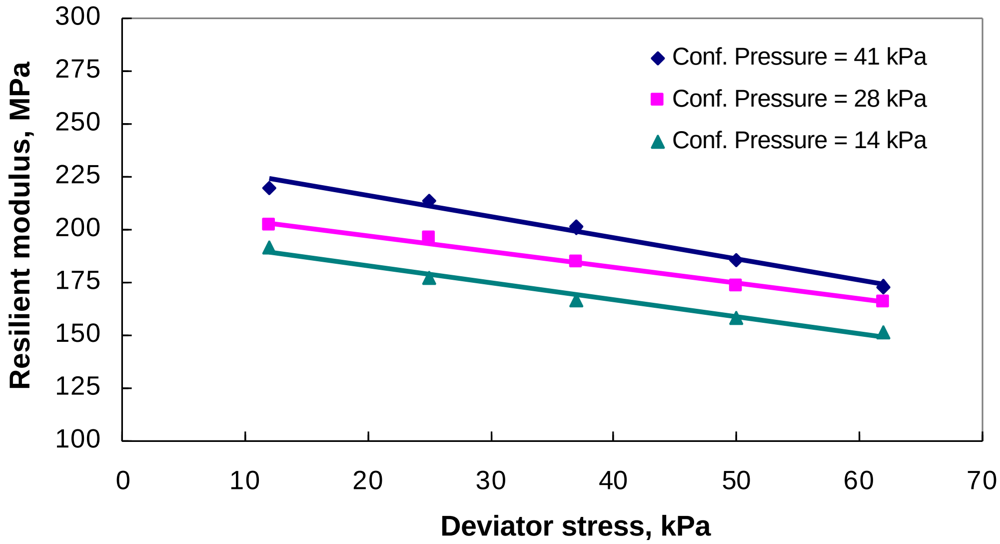

Figure D.5 Resilient Modulus Test results, SR25, Leake county, Station 524+00, Sample #1

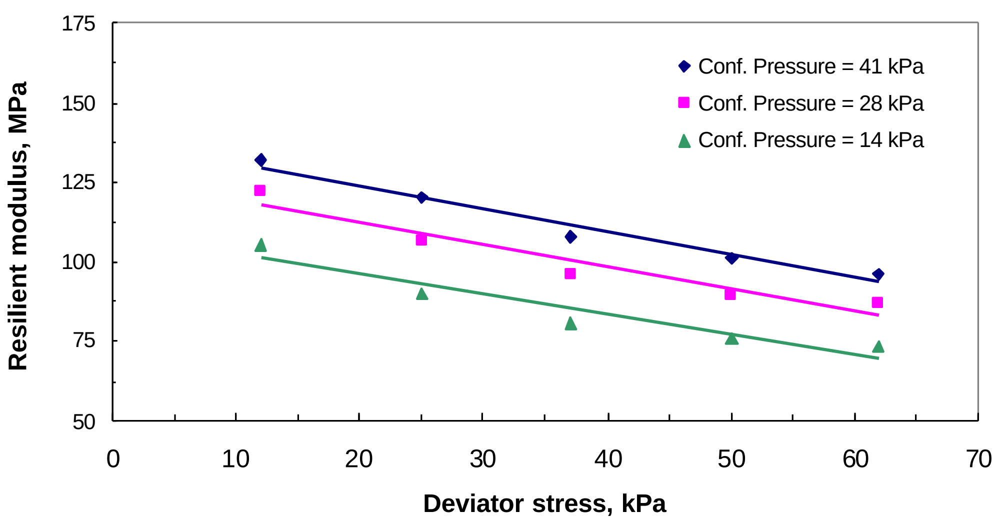

Figure D.6 Resilient modulus test results,US-45, Monroe county, Station 88+00, Sample #1

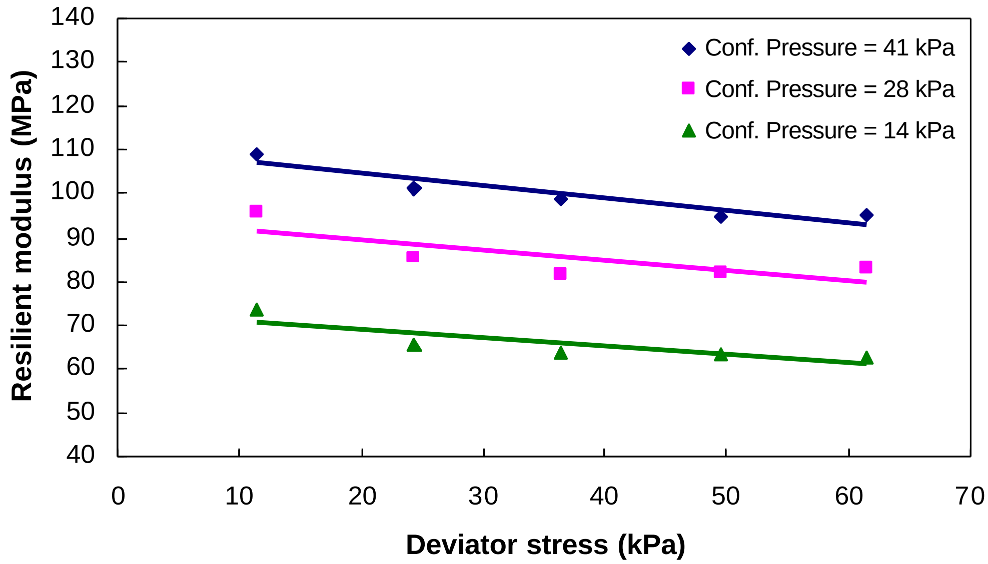

Figure D.7 Resilient Modulus Test results, US45,Monroe County, Station 110+00,Sample#1

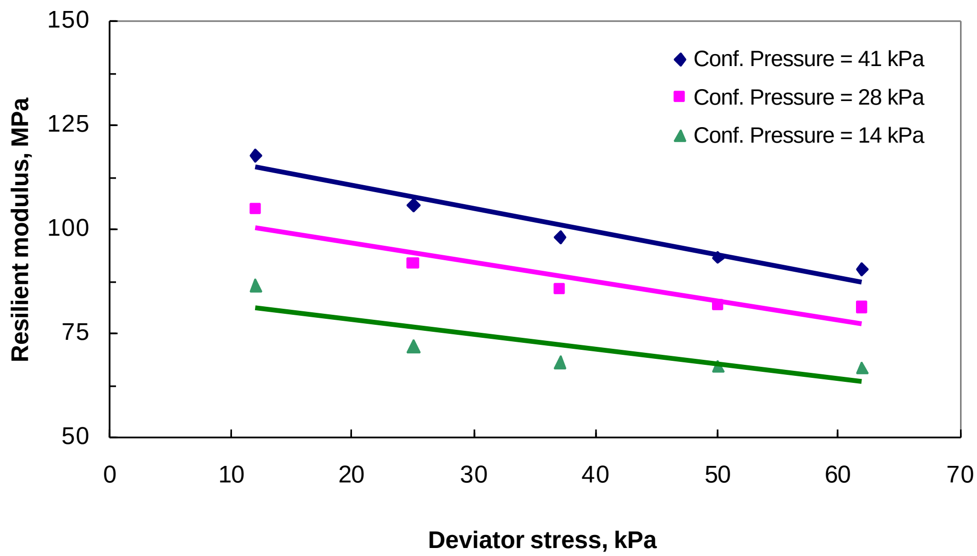

Figure D.8 Resilient Modulus Test results, US45, Monroe county, Station 178+00, Sample #1

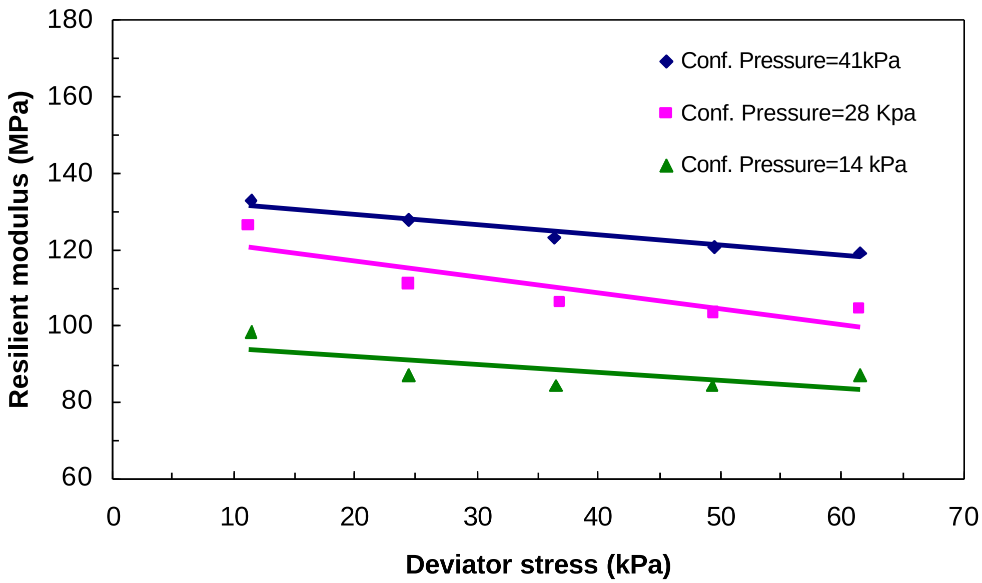

Figure D. 9 Resilient Modulus Test results, US45, Monroe county, Station 264+00, Sample#1

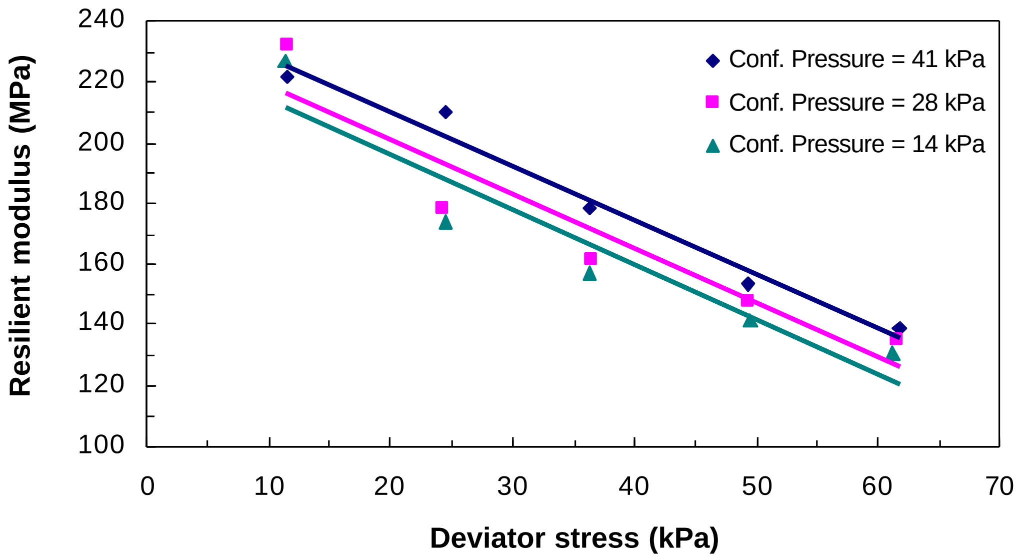

Figure D.10 Resilient Modulus Test results, US45, Monroe county, station 461+00, sample #2

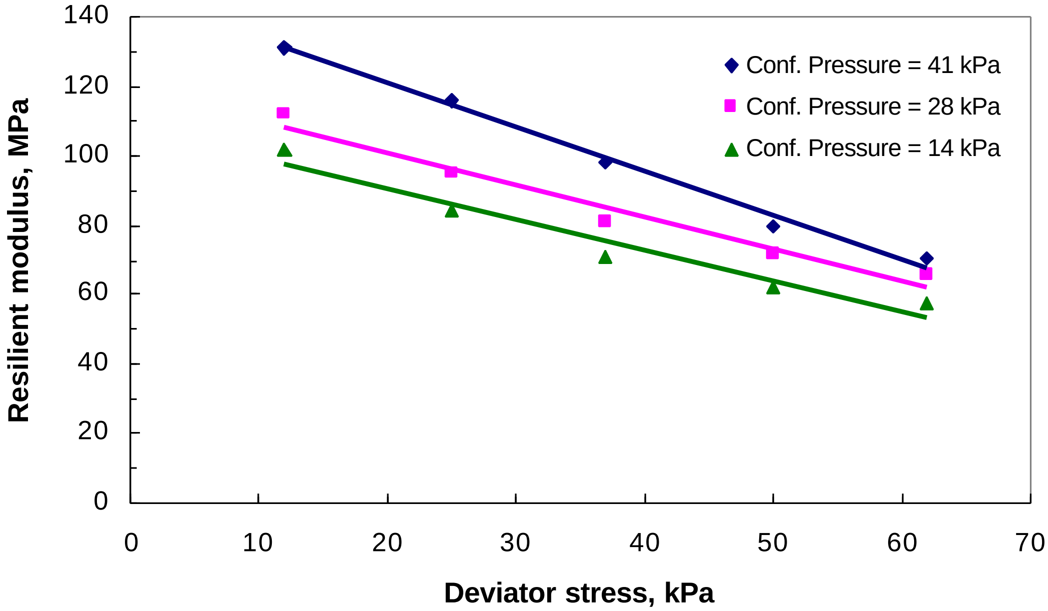

Figure D.11 Resilient Modulus Test results, US45, Monroe county,Station 498+00, Sample #2

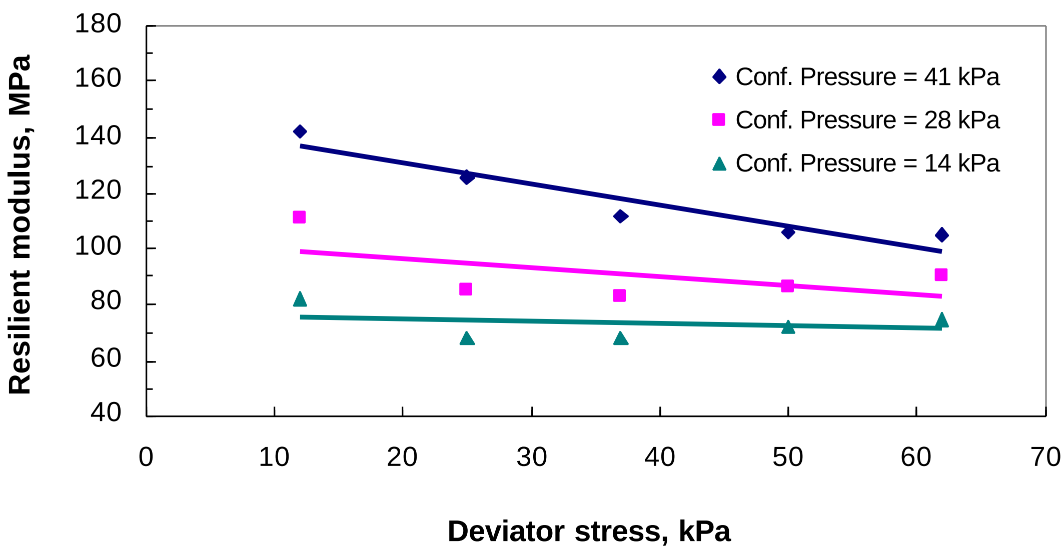

Figure D.12 Resilient Modulus Test results, US45, Monroe county, Station 676+00, Sample #2

APPENDIX E

DETAILED RESULTS OF FWD MODULUS BACKCALCULATED BY THE *FWDSOIL* AND *UMPED* PROGRAMS

SUMMARY OF MODULUS RESULTS FOR CYCLE 1 ANALYSIS, APRIL 2000

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:45S01F6A.INP

***DATE OF TEST   07/27/1999   FPEDD-OUTPUT FILE:DSOILO.OUT

*** SS131 Cycle 1 Second Analysis, US45N SEC1, South Project DROP 1 only, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION   BACKCALCULATED YOUNG'S MODULI (PSI)
THICKNESS(in) + LAYER2   LAYER1   LAYER2   LAYER3

	STATION				THICKNESS(in) + LAYER2
1	88+00	22600.	4500.	17460.	7.89
2	88+50	6100.	4500.	21350.	7.89
3	89+00	7500.	3300.	19890.	20.93
4	89+50	5800.	7500.	22650.	20.93
5	90+00	17100.	6000.	19310.	13.59
6	90+50	17100.	6000.	28580.	13.59
7	91+00	8200.	4500.	16260.	14.96
8	91+50	9800.	7800.	24850.	14.96
9	92+00	15800.	3000.	16790.	8.17
10	92+50	15800.	3000.	16790.	8.17
11	93+00	60700.	1000.	9330.	15.65
12	93+50	27800.	3600.	11180.	15.65
13	94+00	15400.	1500.	19490.	7.73
14	94+50	43000.	3400.	16970.	7.73
15	95+00	27200.	4100.	14110.	8.00
16	95+50	38000.	6800.	13590.	8.00
17	96+00	27800.	9800.	10820.	19.12
	* MEAN :	21500.	4700.	17610.	12.88
	S.D. DEV :	14829.	2322.	5073.	5.15
	C V(%):	69.	49.	29.	39.97

****

Thickness (in) :   6.00   + varies Semi-infinite

Subgrade | Layer1   Layer2   Layer3

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UNIVERSITY, MS 38677,   USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:45S02F9A.IN

***DATE OF TEST   07/27/1999   FPEDD-OUTPUT FILE:DSOILO.OUT

*** SS131 Cycle 1 Second Analysis, US45N SEC2, South Project DROP 1 only, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION		BACKCALCULATED YOUNGS MODULI (PSI)			HICKNESS(in)
		LAYER1	LAYER2	LAYER3	+ LAYER2
1	116+00	14000.	1000.	4190.	12.32
2	115+45	15500.	1000.	4920.	12.32
3	115+00	12400.	1000.	4320.	11.85
4	114+50	22800.	1500.	7280.	11.85
5	114+05	12700.	1000.	3860.	12.07
6	113+50	13300.	1000.	3860.	12.07
7	112+95	24200.	300.	4710.	12.68
8	112+50	24200.	400.	4120.	12.68
9	112+05	17000.	400.	6450.	9.46
10	111+50	26500.	1300.	6780.	9.46
11	111+00	11200.	2000.	4950.	17.47
12	110+50	23000.	4000.	6480.	17.47
13	110+00	5800.	14800.	19200.	21.12
14	109+50	17000.	2600.	9880.	21.12
15	109+00	6500.	4900.	14870.	21.79
16	108+50	5800.	5600.	15460.	21.79
17	108+00	9800.	6500.	17660.	14.67
	* MEAN :	15300.	2900.	8170.	14.83
	STD DEV :	6760.	3621.	5234.	4.35
	C V(%):	44.	125.	64.	29.32

****

Thickness (in) :	6.00	+ varies	Semi-infinite
Subgrade |	Layer1	Layer2	Layer3

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1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED FPEDD-INPUT FILE:45S03F6A.IN

***DATE OF TEST 07/26/1999 FPEDD-OUTPUT FILE:DSOILO.OUT

*** SS131 Cycle 1 Second Analysis, US45N SEC3, South Project DROP 1 only, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION		BACKCALCULATED YOUNGS MODULI (PSI) LAYER1	LAYER2	LAYER3	THICKNESS(in) + LAYER2
1	170+00	15000.	2700.	7970.	10.00
2	170+50	18400.	5500.	8820.	10.00
3	171+00	21300.	1000.	4360.	9.60
4	171+50	20300.	1000.	7170.	9.60
5	172+00	18400.	2100.	8760.	13.96
6	172+50	35400.	18400.	19010.	13.96
7	173+00	8300.	3600.	15120.	14.24
8	173+50	18300.	3100.	14360.	14.24
9	174+05	10500.	2100.	11740.	19.33
10	174+95	16200.	1000.	3690.	15.46
11	175+60	23900.	1000.	2840.	15.46
12	175+95	16900.	1000.	2850.	11.97
13	176+55	15600.	1000.	4630.	11.97
14	176+95	14500.	1000.	6800.	20.95
	* MEAN :	18000.	3100.	8430.	14.74
	STD DEV :	6421.	4584.	4988.	3.93
	C V(%):	36.	148.	59.	26.64

****

Thickness (in) : 6.00 + varies Semi-infinite

Subgrade | Layer1 Layer2 Layer3

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1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED FPEDD-INPUT FILE:45S04F4A.IN

***DATE OF TEST 07/26/1999 FPEDD-OUTPUT FILE:DSOILO.OUT

*** SS131 Cycle 1 Second Analysis, US45N SEC4, South Project DROP 1 only, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION		BACKCALCULATED YOUNGS MODULI (PSI) LAYER1	LAYER2	LAYER3	THICKNESS(in) + LAYER2
1	266+00	23600.	7200.	12940.	13.25
2	265+63	19600.	5600.	11220.	13.25
3	265+25	14800.	5800.	11100.	8.33
4	264+88	11200.	5300.	10300.	8.33
5	264+50	17000.	7600.	10430.	21.83
6	264+13	16200.	7300.	10450.	21.83
7	262+63	18300.	7700.	10740.	21.54
8	262+25	9000.	10100.	8080.	21.54
9	261+88	6900.	8100.	10900.	14.15
10	261+50	9700.	7600.	10190.	19.52
11	261+13	12500.	8600.	9230.	19.52
12	260+74	13600.	13900.	12480.	12.48
13	260+38	24000.	8200.	17580.	12.48
14	260+00	11700.	11000.	9220.	16.26
	* MEAN :	14800.	8100.	11060.	15.92
	STD DEV :	5230.	2284.	2252.	4.46
	C V(%):	35.	28.	20.	28.03

****

	Layer1	Layer2	Layer3
Thickness (in) :	6.00	+ varies	Semi-infinite
			Subgrade

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1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:45N01F1A.IN

***DATE OF TEST   7/19/1999   FPEDD-OUTPUT FILE:DSOILO.OUT

*** SS131 Cycle 1 Second Analysis, US45N SEC1, North Project DROP 1 only, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION		BACKCALCULATED YOUNGS MODULI (PSI)			THICKNESS(in)
		LAYER1	LAYER2	LAYER3	+ LAYER2
1	461+00	4200.	3400.	8590.	15.15
2	461+55	22300.	1700.	7600.	15.15
3	462+00	23400.	1600.	7620.	17.47
4	462+55	10000.	3500.	11810.	17.47
5	463+00	6600.	2200.	12750.	10.86
6	463+50	7300.	2500.	10110.	10.86
7	464+00	6000.	4900.	9170.	18.06
8	464+50	6800.	4800.	10310.	18.06
9	465+00	4900.	2700.	9510.	10.00
10	465+50	5600.	2600.	10800.	10.00
11	466+04	9600.	4000.	11020.	18.80
12	466+46	3900.	4500.	12460.	18.80
13	467+00	8000.	3500.	11050.	11.70
14	467+50	9100.	3500.	11940.	11.70
15	467+90	5000.	2400.	12230.	9.31
16	468+40	8400.	1000.	12140.	9.31
17	469+06	4000.	5600.	9650.	14.92
	* MEAN :	8500.	3200.	10510.	14.03
	STD DEV :	5724.	1281.	1640.	3.65
	C V(%):	67.	40.	16.	26.04

****

Thickness (in) :   6.00   + varies Semi-infinite

Subgrade | Layer1   Layer2   Layer3

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1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED FPEDD-INPUT FILE:45N02F2A.IN

***DATE OF TEST 7/20/1999 FPEDD-OUTPUT FILE:DSOILO.OUT

*** SS131 Cycle 1 Second Analysis, US45N SEC2, North Project DROP 1 only, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION		BACKCALCULATED YOUNGS MODULI (PSI) LAYER1	LAYER2	LAYER3	THICKNESS(in) + LAYER2
1	490+00	17000.	1900.	5030.	21.66
2	490+50	14200.	1000.	5650.	21.66
3	491+01	9900.	1000.	5530.	18.45
4	491+54	22600.	1000.	6000.	18.45
5	492+00	10400.	1000.	5140.	22.07
6	492+50	7400.	1100.	5980.	22.07
7	493+01	20300.	1000.	8640.	12.02
8	493+50	17300.	1900.	9890.	12.02
9	494+00	7800.	1400.	8000.	19.84
10	494+50	5400.	1800.	8260.	19.84
11	495+00	12100.	1000.	4510.	20.63
12	495+50	6300.	1900.	7860.	20.63
13	495+90	22100.	1000.	4430.	15.52
14	496+49	9500.	1000.	6850.	15.52
15	497+00	9800.	1400.	8460.	22.87
16	497+50	6600.	1500.	9900.	22.87
17	498+00	24500.	1000.	10200.	14.85
	* MEAN :	13100.	1200.	7070.	18.66
	STD DEV :	6314.	385.	1956.	3.74
	C V(%):	48.	32.	28.	20.07

****

Thickness (in) :	6.00	+ varies	Semi-infinite	
Subgrade	Layer1	Layer2	Layer3	

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```
1
 DEFLECTION TEST DATA FILE NAME:DEFLECT.PED      FPEDD-INPUT FILE:45N03F1A.IN

  ***DATE OF TEST          7/14/1999           FPEDD-OUTPUT FILE:DSOILO.OUT

  *** SS131 Cycle 1 Second Analysis, US45S SEC3, North Project DROP 1 only, FWDSOIL

  ************ SUMMARY -  MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

  STATION                           BACKCALCULATED YOUNGS MODULI (PSI)   THIRCKNESS(in)
                                          LAYER1   LAYER2   LAYER3         + LAYER2
  1  676+00                                17900.   14500.   12990.          11.92
  2  675+50                                18500.   12700.   13050.          11.92
  3  675+00                                27200.    7600.   12940.           7.11
  4  674+50                                24700.    8100.   14480.           7.11
  5  674+00                                23500.   10900.   14660.          19.36
  6  672+95                                26100.   10700.   16050.          19.36
  7  672+50                                16800.    9900.   14890.           9.52
  8  672+00                                15500.    5400.   13410.           9.52
  9  671+50                                15900.    9300.   17450.           9.52
 10  671+00                                13300.   11100.   12490.                 9.52
 11  670+50                                35200.   10800.   14910.           9.52
 12  670+00                                19000.   12500.   14910.           9.52
 13  669+50                                15700.    7100.   13940.           9.52
 14  669+00                                19700.    8700.   13730.           9.52
 15  668+50                                14300.    8000.   13490.           9.52
 16  668+00                                21900.    7500.   12400.           9.52

           * MEAN  :                       20300.    9600.   14110.               11.98
           STD DEV :                        5815.    2404.    1356.                5.30
           C V( % ):                          29.      25.      10.               44.23
 ************************************************************************
     Thickness (in) :                        6.00    + varies Semi-infinite

                                  Subgrade  Layer1    Layer2    Layer3

    FLEX. PAVEMENT EVALUATION PROGRAM          F P E D D 2  -  Version 2.1
    PROGRAM WRITTEN BY WAHEED UDDIN                        1999
       VERSION : 1.0  APRIL 16,1984                BY DR. WAHEED UDDIN
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```

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED FPEDD-INPUT FILE:LEK01F2A.INP

***DATE OF TEST 7/28/1999 FPEDD-OUTPUT FILE:DSOILO.OUT

*** SS131 Cycle 1 Second Analysis, 25LEAKE CO. DROP 1 only, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

	STATION	BACKCALCULATED YOUNGS MODULI (PSI) LAYER1	LAYER2	LAYER3	THICKNESS(in) + LAYER2
1	522+00	52100.	15300.	21900.	14.80
2	522+50	27800.	16700.	21360.	14.80
3	523+00	24900.	18800.	23570.	18.07
4	523+50	16700.	26800.	17900.	18.07
5	524+00	11400.	3200.	19560.	17.32
6	524+50	25800.	6200.	15910.	17.32
7	525+00	17500.	10000.	21020.	21.20
8	525+50	13600.	7400.	18180.	21.20
9	526+00	8100.	8200.	19270.	14.41
10	526+50	7000.	10400.	20610.	14.41
11	527+00	6600.	9400.	29930.	17.80
12	528+00	19000.	27600.	42550.	18.95
13	528+50	33100.	53900.	44720.	18.95
14	529+00	16000.	23400.	36280.	16.20
15	529+50	26200.	21000.	36800.	16.20
16	530+00	26100.	25300.	40700.	14.76
	* MEAN :	20700.	17700.	26890.	17.06
	STD DEV :	11623.	12438.	9929.	2.25
	C V(%):	56.	70.	37.	13.20
	Thickness (in) :	6.00	+ varies	Semi-infinite	
	Subgrade	Layer1	Layer2	Layer3	

****

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
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1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:25r01f2a.in

***DATE OF TEST   6/7/1999   FPEDD-OUTPUT FILE:DSOILO.OUT

***   SS131 Cycle 1 Second Analysis, SR25 SEC1   DROP 1 ONLY, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION		BACKCALCULATED YOUNGS MODULI (PSI)		
		LAYER1	LAYER2	LAYER3
1	750	20000.	4100.	9860.
2	675	4500.	6700.	15770.
3	650	11100.	15800.	14260.
4	585	5600.	9000.	12860.
5	550	8500.	8900.	14790.
6	500	7300.	6900.	14960.
7	450	6000.	11700.	15980.
8	400	6000.	14700.	12510.
9	350	9400.	6800.	10720.
10	300	10800.	6400.	10620.
11	250	10700.	8000.	12280.
12	200	4400.	12700.	15480.
13	150	6400.	11000.	13970.
14	100	5400.	7500.	12300.
15	50	3900.	13000.	13120.
16	0	5600.	9800.	15850.
	* MEAN :	7800.	9500.	13450.
	STD DEV :	4016.	3306.	1984.
	C V(%):	51.	35.	15.

****

	Layer1	Layer2	Layer3
Thickness (in) :	8.00	20.0	Semi-infinite
	Subgrade Layer1	Layer2	Layer3

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
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```
1
 DEFLECTION TEST DATA FILE NAME:DEFLECT.PED      FPEDD-INPUT FILE:25r02f2a.inP

  ***DATE OF TEST           6/8/1999          FPEDD-OUTPUT FILE:DSOILO.OUT

  ***   SS131 Cycle 1 Second Analysis, SR25 SEC2       DROP 1 ONLY, FWDSOIL

  ************ SUMMARY -  MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

  STATION                      BACKCALCULATED YOUNGS MODULI (PSI)
                                      LAYER1  LAYER2  LAYER3

  1    750                           21200.   24900.   21260.
  2    700                           24400.   34200.   20580.
  3    650                           55700.   19000.   18720.
  4    600                           31900.    4800.   12480.
  5    550                           35500.   22900.   21830.
  6    500                           35500.    7300.   18610.

             * MEAN  :               34000.   18800.   18910.
             STD DEV :               12131.   11131.    3415.
             C V( % ):                  36.      59.      18.
*************************************************************************
      Thickness (in) :                8.00     12.0 Semi-infinite

                           Subgrade |Layer1   Layer2   Layer3

     FLEX. PAVEMENT EVALUATION PROGRAM          F P E D D 2  -  Version 2.1
     PROGRAM WRITTEN BY WAHEED UDDIN                        1999
        VERSION : 1.0  APRIL 16,1984                BY DR. WAHEED UDDIN
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```

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:25r03f2a.inP

***DATE OF TEST   06/10/1999   FPEDD-OUTPUT FILE:DSOILO.OUT

***   SS131 Cycle 1 Second Analysis, SR25 SEC3   DROP 1 ONLY, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION			BACKCALCULATED YOUNGS MODULI (PSI)		
			LAYER1	LAYER2	LAYER3
1	800		7000.	2100.	5530.
2	700		11700.	2700.	7050.
3	650		7900.	4200.	8680.
4	600		5100.	1000.	5230.
5	551		13000.	2000.	5010.
6	500		12100.	4500.	9260.
7	450		13000.	4400.	9610.
8	400		6500.	2500.	6710.
9	250		3700.	2000.	5490.
10	200		4400.	2500.	5010.
11	150		3400.	2000.	6270.
12	100		5000.	1000.	2540.
13	50		15200.	2500.	6420.
14	0		4900.	2400.	7260.
		* MEAN :	8000.	2500.	6430.
		STD DEV :	4069.	1108.	1895.
		C V(%):	51.	44.	29.

****

Thickness (in) :   8.00   20.0 Semi-infinite

Subgrade | Layer1   Layer2   Layer3

FLEX. PAVEMENT EVALUATION PROGRAM   F P E D D 2 - Version 2.1
PROGRAM WRITTEN BY WAHEED UDDIN   1999
VERSION : 1.0 APRIL 16,1984   BY DR. WAHEED UDDIN
CENTER FOR TRANSPORTATION RESEARCH   UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
THE UNIVERSITY OF TEXAS AT AUSTIN   UNIVERSITY, MS 38677,   USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED FPEDD-INPUT FILE:25R04F1A.INP

***DATE OF TEST 6/9/1999 FPEDD-OUTPUT FILE:DSOILO.OUT

*** SS131 Cycle 1 Second Analysis, SR25 SEC4 DROP 1 ONLY, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION		BACKCALCULATED YOUNGS MODULI (PSI)		
		LAYER1	LAYER2	LAYER3
1	800	39000.	4300.	11720.
2	750	20300.	2400.	13560.
3	700	13000.	2000.	8450.
4	650	20500.	3600.	12540.
5	600	42600.	23200.	18010.
6	550	37100.	2700.	7370.
7	500	36000.	14900.	16180.
8	450	50600.	5200.	13510.
9	400	33600.	4900.	12610.
10	349	47300.	4300.	12270.
11	300	28300.	5100.	7780.
12	250	23600.	3400.	11000.
13	200	35600.	6700.	11330.
14	150	25300.	5000.	10480.
15	100	28500.	10400.	11480.
16	50	51700.	14500.	13590.
17	0	22700.	12000.	11580.
	* MEAN :	32600.	7300.	11960.
	STD DEV :	11284.	5782.	2712.
	C V(%):	35.	79.	23.

****

Thickness (in) :	8.00	20.0	Semi-infinite
Subgrade	Layer1	Layer2	Layer3

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
UNIVERSITY, MS 38677, USA

SUMMARY OF MODULUS RESULTS FOR CYCLE 2 ANALYSIS, AUGUST 2000

```
1
 DEFLECTION TEST DATA FILE NAME:DEFLECT.PED      FPEDD-INPUT FILE: 45S1NVD1.IN

  ***DATE OF TEST          11/3/1999           FPEDD-OUTPUT FILE:UMPEDO.OUT

  ***   SS131 Cycle 2 Second Analysis, US45N SEC1, South Project DROP 1 ONLY,
FWDSOIL

  ************ SUMMARY -  MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION            THICKNESS(in)   BACKCALCULATED YOUNGS MODULI (psi)
                     + LAYER2          LAYER1   LAYER2   LAYER3

  1   88+05             8.82           19200.    4900.   18000.
  2   88+55             8.82           14400.    6500.   28180.
  3   89+05            22.24           13300.   12600.   33280.
  4   89+55            22.24           13700.   12700.   30320.
  5   90+05             7.66           14000.   10200.   31420.
  6   90+55             7.66           13300.    6000.   27600.
  7   91+05            14.42           20200.   10700.   26810.
  8   91+55            14.42           18900.   14200.   36150.
  9   92+05            11.65           48900.   19600.   42640.
 10   92+55            11.65           21600.   14600.   39230.
 11   93+05            11.91           12500.   14500.   34500.
 12   93+55            11.91           14000.   11800.   32730.
 13   94+05            11.91           12100.   14600.   36970.
 14   94+55            11.91           44400.   13900.   40880.
 15   95+05            14.01           10400.   14500.   34400.
 16   95+55            14.01            9900.   11800.   34870.
 17   96+05            14.15           42900.   24300.   31750.

           * MEAN  :   12.97           20200.   12700.   32920.
           STD DEV :    4.18           12511.    4714.    5886.
           C V( % ):   32.23              62.      37.      18.
 ************************************************************************
    Thickness (in) :                6.00  + varies Semi-infinite
                                   LTS    Subgrade   Subgrade
                                               Top

     FLEX. PAVEMENT EVALUATION PROGRAM          F P E D D 2  -  Version 2.1
     PROGRAM WRITTEN BY WAHEED UDDIN                        1999
        VERSION : 1.0  APRIL 16,1984                BY DR. WAHEED UDDIN
     CENTER FOR TRANSPORTATION RESEARCH    UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
     THE UNIVERSITY OF TEXAS AT AUSTIN          UNIVERSITY, MS 38677,   USA
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1

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DEFLECTION TEST DATA FILE NAME:DEFLECT.PED      FPEDD-INPUT FILE:45S2NVB1.IN

 ***DATE OF TEST          11/02/1999          FPEDD-OUTPUT FILE:DSOILO.OUT

 ***   SS131 Cycle 2 Analysis, US45N SEC2, South Project DROP 1 ONLY, FWDSOIL

 ************ SUMMARY -  MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

 STATION            THICKNESS(in)   BACKCALCULATED YOUNGS MODULI (PSI)
                     + LAYER2          LAYER1   LAYER2   LAYER3
  1  115+95             16.29           70000.    4700.   11930.
  2  115+40             16.29           49500.    5200.   13430.
  3  114+95             10.43           24300.    1300.    8920.
  4  114+45             10.43           70000.    5600.   13550.
  5  114+00             10.78           53100.    3100.   11920.
  6  113+45             10.78           51900.    3800.   11600.
  7  112+90              7.93           41600.    1400.   12620.
  8  112+45              7.93           70000.    3800.   18390.
  9  112+00             10.63           70000.    2500.   13750.
 10  111+45             10.63           26000.    5100.   21860.
 11  110+95             17.53           70000.   14800.   14470.
 12  110+45             17.53           35500.   10800.   18260.
 13  109+95             12.23           20600.   12100.   19050.
 14  109+45             12.23           49700.    5400.   20180.
 15  108+95             14.29           35500.   11700.   28660.
 16  108+45             14.29           44500.   11900.   30360.
 17  107+95              9.92           35500.   11600.   26720.

          * MEAN  :   12.23             48100.    6700.   17390.
          STD DEV :    3.17             17293.    4359.    6396.
          C V( % ):   25.94                36.      65.      37.
*************************************************************************
   Thickness (in) :                     6.00  + varies Semi-infinite
                                        LTS   Subgrade    Subgrade
                                                Top

    FLEX. PAVEMENT EVALUATION PROGRAM          F P E D D 2  -  Version 2.1
    PROGRAM WRITTEN BY WAHEED UDDIN                          1999
       VERSION : 1.0  APRIL 16,1984                  BY DR. WAHEED UDDIN
    CENTER FOR TRANSPORTATION RESEARCH    UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
    THE UNIVERSITY OF TEXAS AT AUSTIN          UNIVERSITY, MS 38677,   USA
```

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE: 45N3NVB1.IN

***DATE OF TEST   11/2/1999   FPEDD-OUTPUT FILE:DSOILO.OUT

***   SS131 Cycle 2 Analysis, US45S SEC3, North Project DROP 1 ONLY, FWDSOIL

************ SUMMARY - MODULI NOT CORRECTED FOR DESIGN AXLE LOAD *************

STATION		BACKCALCULATED YOUNGS MODULI (PSI) LAYER1	LAYER2	LAYER3
1	675+95	60400.	49500.	18600.
2	675+45	52200.	55900.	19260.
3	674+95	25800.	27200.	19280.
4	674+45	16000.	10900.	19760.
5	673+45	35500.	20500.	20990.
6	672+95	27000.	17500.	23970.
7	672+45	30200.	13000.	24470.
8	671+95	21400.	11600.	22370.
9	671+45	23300.	11500.	24930.
10	670+95	23500.	13700.	21180.
11	670+45	31300.	17500.	19370.
12	669+95	29800.	18800.	19360.
13	669+45	43600.	15700.	22870.
14	668+95	47200.	17000.	19190.
15	668+45	39100.	15800.	18940.
16	667+95	35500.	16000.	18160.
	* MEAN :	33800.	20700.	20790.
	STD DEV :	12077.	13144.	2240.
	C V(%):	36.	63.	11.

****

	Thickness (in) :	6.00	6.00	Semi-infinite
		LTS	Subgrade Top	Subgrade

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
UNIVERSITY, MS 38677,   USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE: 45N1NVB1.IN

***DATE OF TEST   11/3/1999   FPEDD-OUTPUT FILE:UMPEDO.OUT

***   SS131 Cycle 2 Analysis, US45N SEC1, North Project DROP 1 ONLY, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION *********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1	LAYER1	LAYER2	LAYER3	LAYER4	LAYER4
IN SITU	CORRECTED	NONLINEAR	BACKCALCULATED				
1	461+05	339800.	327600.	146700.	42800.	11350.	18830.
2	461+60	386500.	372600.	93100.	29400.	10120.	17820.
3	462+05	274300.	245900.	76900.	31100.	10700.	19170.
4	462+60	240000.	240000.	49100.	31600.	10880.	20180.
5	463+05	374200.	311900.	129100.	41200.	12600.	20780.
6	463+55	345600.	399900.	96000.	38600.	12000.	20470.
7	464+05	341200.	394800.	76700.	38500.	13390.	22860.
8	464+55	269800.	323800.	85500.	35300.	12720.	21930.
9	465+05	307200.	342800.	95100.	38900.	12320.	21020.
10	465+55	410600.	475100.	82100.	25700.	12410.	21370.
11	466+09	316800.	353400.	93300.	39500.	13270.	22390.
12	466+51	290200.	335800.	93300.	32900.	11680.	20260.
13	467+05	264200.	317000.	63800.	29400.	11070.	20060.
14	467+55	363000.	435600.	101200.	40700.	14200.	23470.
15	467+95	291200.	375900.	67900.	31500.	12160.	21490.
16	468+45	336600.	419000.	110200.	39800.	12110.	20400.
17	469+11	414200.	534600.	141700.	47400.	15240.	24140.
	* MEAN :	327300.	365000.	94200.	36100.	12240.	20790.
	STD DEV :	51933.	75241.	26244.	5810.	1296.	1650.
	C V(%):	16.	21.	28.	16.	11.	8.

****

Thickness (in)	3.00	3.00	6.00	6.00	Semi-infinite
	Asphalt		LFA	LTS	Subgrade
				Base	

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
UNIVERSITY, MS 38677,   USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE: 45N1NVC2.IN

***DATE OF TEST   11/3/1999   FPEDD-OUTPUT FILE:UMPEDO.OUT

***   SS131 Cycle 2 Analysis, US45N SEC1, North Project DROP 2 ONLY, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION *********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER4 ACKCALCULATED
1	461+05	332200.	320300.	132500.	40800.	10470.	17740.
2	461+60	264800.	255300.	97600.	31300.	9740.	17390.
3	462+05	375800.	362400.	76000.	21800.	10700.	19100.
4	462+60	238200.	213500.	47700.	29700.	10770.	20110.
5	463+05	334200.	334200.	119900.	37400.	11830.	19920.
6	463+55	350000.	291700.	90800.	39000.	11440.	19720.
7	464+05	297700.	344400.	78000.	35800.	13040.	22460.
8	464+55	279100.	323000.	79000.	34300.	12240.	21350.
9	465+05	287000.	344500.	90000.	37400.	11770.	20380.
10	465+55	256400.	286000.	78000.	31100.	11920.	21010.
11	466+09	284900.	329600.	86900.	34400.	12370.	21370.
12	466+51	284900.	317800.	73300.	18700.	15000.	25440.
13	467+05	240000.	277700.	52100.	26500.	11260.	20780.
14	467+55	325600.	390700.	95500.	36300.	13650.	22930.
15	467+95	271600.	350600.	58900.	28000.	11640.	21050.
16	468+45	305400.	380100.	98600.	43700.	10890.	18780.
17	469+11	343300.	443100.	132400.	41300.	14870.	23960.
	* MEAN :	298300.	327300.	87400.	33300.	11970.	20790.
	STD DEV :	39840.	53828.	24545.	6863.	1462.	2093.
	C V(%):	13.	16.	28.	21.	12.	10.

****

Thickness (in)	3.00	3.00	6.00	6.00	Semi-infinite
		Asphalt	LFA	LTS	Subgrade
				Base	

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
UNIVERSITY, MS 38677,   USA

1
DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE: 45N2NVB1.IN

***DATE OF TEST   11/1/1999   FPEDD-OUTPUT FILE:UMPEDO.OUT

***   SS131 Cycle 2 Analysis, US45N SEC2, North Project DROP 1 ONLY, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3	LAYER4 NONLINEAR	LAYER4 BACKCALCULATED
1	490+05	306700.	368000.	163900.	42500.	18490.	27620.
2	490+60	322900.	448400.	112500.	36700.	13030.	20950.
3	491+00	362600.	503500.	134100.	40200.	13310.	20950.
4	491+55	372700.	499000.	132900.	18300.	13180.	20910.
5	492+03	449700.	602100.	97600.	31900.	12270.	19980.
6	492+55	384700.	534200.	86400.	21800.	14040.	22790.
7	493+05	319200.	443200.	136900.	37800.	15720.	24310.
8	493+55	273800.	366600.	75600.	29200.	15020.	24540.
9	494+05	240600.	310600.	69600.	29100.	14990.	24710.
10	494+55	246800.	342700.	87300.	29800.	14760.	24020.
11	495+05	324200.	450200.	85900.	34000.	15180.	24360.
12	495+55	261200.	325100.	70100.	32500.	14150.	23410.
13	496+00	301300.	418400.	61100.	29000.	8660.	15600.
14	496+55	289500.	402000.	85300.	36500.	15290.	24550.
15	497+05	303100.	326000.	84100.	35500.	16690.	26460.
16	497+55	264400.	274200.	82600.	34100.	16800.	26750.
17	498+05	346100.	358900.	105300.	38900.	15310.	24090.
	* MEAN :	315800.	410100.	98300.	32800.	14520.	23290.
	STD DEV :	54832.	88985.	28586.	6288.	2158.	2918.
	C V(%):	17.	22.	29.	19.	15.	13.

****

Thickness (in)	3.00	3.00	6.00	8.00	Semi-infinite
	Asphalt		LFA Base	LTS	Subgrade

FLEX. PAVEMENT EVALUATION PROGRAM   F P E D D 2 - Version 2.1
PROGRAM WRITTEN BY WAHEED UDDIN   1999
VERSION : 1.0 APRIL 16,1984   BY DR. WAHEED UDDIN
CENTER FOR TRANSPORTATION RESEARCH   UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
THE UNIVERSITY OF TEXAS AT AUSTIN   UNIVERSITY, MS 38677,   USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE: 45N2NVB2.IN

***DATE OF TEST   11/1/1999   FPEDD-OUTPUT FILE:UMPEDO.OUT

***   SS131 Cycle 2 Analysis, US45N SEC2, North Project DROP 2 ONLY, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER4 ACKCALCULATED
1	490+05	339100.	406900.	151200.	43400.	17160.	25930.
2	490+60	277800.	385700.	101900.	33800.	11960.	19740.
3	491+00	444300.	616900.	105700.	32400.	12610.	20330.
4	491+55	262100.	350900.	128900.	31100.	11120.	18330.
5	492+03	254100.	340200.	101400.	30900.	11720.	19520.
6	492+55	238700.	331500.	82200.	29500.	12510.	21000.
7	493+05	344700.	478600.	129500.	26300.	14820.	23260.
8	493+55	258400.	345900.	71400.	27300.	14020.	23310.
9	494+05	284600.	367400.	66900.	33800.	12840.	21560.
10	494+55	284100.	394500.	96400.	28300.	13270.	21730.
11	495+05	312300.	433600.	87800.	30300.	14090.	22920.
12	495+55	246200.	306500.	68800.	29000.	14650.	24240.
13	496+00	214400.	297700.	55900.	26600.	8440.	15600.
14	496+55	276100.	383400.	76200.	33400.	14660.	23950.
15	497+05	318800.	342900.	76800.	32300.	16110.	25840.
16	497+55	320900.	332900.	68800.	34300.	16170.	26060.
17	498+05	424800.	440600.	91700.	29200.	14920.	23790.
	* MEAN :	300000.	385600.	91800.	31200.	13590.	22180.
	STD DEV :	62085.	76933.	25853.	4038.	2140.	2873.
	C V(%):	21.	20.	28.	13.	16.	13.

****

Thickness (in)	3.00	3.00	6.00	8.00	Semi-infinite
	Asphalt		LFA Base	LTS	Subgrade

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
UNIVERSITY, MS 38677,   USA

SUMMARY OF MODULUS RESULTS FOR CYCLE 3 ANALYSIS, AUGUST 2000

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:453NNIA.IN

***DATE OF TEST   3/6/2000   FPEDD-OUTPUT FILE:UMPEDO.OUT

***   SS131 Cycle 3 Analysis, US45N SEC1 NORTH PROJECT   Drop 2 only, UMPED

*********************** SUMMARY OF STRUCTURAL EVALUATION *********************

FINAL VALUES OF YOUNGS MODULI(PSI)

STATION		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER 4 ACKCALCULATED
1	461+05	670700.	1293100.	150800.	15900.	17180.	23240.
2	462+05	574500.	1107700.	80700.	25600.	15700.	23280.
3	463+05	631300.	1262500.	123100.	15100.	16860.	23270.
4	464+05	567600.	1017500.	94400.	21300.	15800.	23760.
5	465+05	530600.	1473400.	108400.	26700.	17730.	25380.
6	466+05	580700.	1612500.	128400.	18100.	18390.	25760.
7	467+05	521000.	1556200.	37200.	19700.	16570.	24530.
8	467+95	681400.	2035400.	67300.	27200.	17440.	25500.
9 *	469+11	492400.	1525400.	91700.	31400.	17340.	24990.
	* MEAN :	583300.	1431500.	98000.	22300.	17000.	24410.
	STD DEV :	65972.	305683.	34353.	5649.	876.	1041.
	C V(%):	11.	21.	35.	25.	5.	4.

****

CORE THICKNESS VALUES(in)

STATION		LAYER1 Asphalt Combined	LAYER2 LFA Base	LAYER3 LTS	LAYER4 Subgrade
1	461+05	6.00	5.81	6.00	Semi-Infinite
2	462+05	4.83	7.00	6.00	Semi-Infinite
3	463+05	5.52	6.50	6.00	Semi-Infinite
4	464+05	4.81	5.63	6.00	Semi-Infinite
5	465+05	5.04	6.85	6.00	Semi-Infinite
6	466+05	4.98	6.50	6.00	Semi-Infinite
7	467+05	5.60	7.00	6.00	Semi-Infinite
8	467+95	5.23	6.00	6.00	Semi-Infinite
9	469+11	5.54	6.54	6.00	Semi-Infinite
	* MEAN :	5.28	6.43	6.00	
	STD DEV :	0.41	0.51	0.00	
	C V(%):	8	8	0	

****

FLEX. PAVEMENT EVALUATION PROGRAM   F P E D D 2 - Version 2.1
PROGRAM WRITTEN BY WAHEED UDDIN   1999
VERSION : 1.0 APRIL 16,1984   BY DR. WAHEED UDDIN
CENTER FOR TRANSPORTATION RESEARCH   UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
THE UNIVERSITY OF TEXAS AT AUSTIN   UNIVERSITY, MS 38677,   USA

Core Test Results	Asphalt	LFA Base	LTS	
* Young's Modulus (psi)	-	9,857	-	(LFA core damaged)

1
DEFLECTION TEST DATA FILE NAME:DEFLECT.PED FPEDD-INPUT FILE: 453NN2A.IN

***DATE OF TEST 3/7/2000 FPEDD-OUTPUT FILE:UMPEDO.OUT
*** 2 SS131 Cycle 3 Analysis, US45N SEC2 NORTH PROJECT Drop 2 only, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER4 ACKCALCULATED
1	490+05	800700.	463300.	274400.	38400.	23990.	30460.
2	491+00	831600.	517600.	219800.	15200.	20870.	26430.
3	492+03	596700.	358100.	138600.	25600.	19110.	25790.
4	493+05	808700.	522000.	297900.	17400.	23120.	28430.
5	494+05	707600.	473700.	138300.	33900.	18130.	24860.
6	495+05	882300.	635400.	152800.	30500.	20260.	26930.
7	496+00	620800.	431100.	110500.	30500.	14340.	20600.
8	497+05	758300.	587400.	178700.	16100.	22040.	28820.
9	498+05	620300.	446700.	181000.	22300.	22050.	29310.
	* MEAN :	736300.	492800.	188000.	25500.	20430.	26840.
	STD DEV :	104510.	83713.	64076.	8346.	2947.	2954.
	C V(%):	14.	17.	34.	33.	14.	11.

****

STATION		CORE THICKNESS VALUES(in)			
		LAYER1 Asphalt Combined	LAYER2 LFA Base	LAYER3 LTS	LAYER4 Subgrade
1	490+05	6.06	6.00	6.00	Semi-infinite
2	491+00	6.27	5.67	6.00	Semi-infinite
3	492+03	6.56	5.67	6.00	Semi-infinite
4	493+05	6.33	6.00	6.00	Semi-infinite
5	494+05	5.92	6.00	6.00	Semi-infinite
6	495+05	6.35	5.73	6.00	Semi-infinite
7	496+00	5.83	6.15	6.00	Semi-infinite
8	497+05	5.15	6.48	6.00	Semi-infinite
9	498+05	5.60	6.00	6.00	Semi-infinite
	* MEAN :	6.01	5.97	6.00	
	STD DEV :	0.44	0.26	0.00	
	C V(%):	7	4	0	

****

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
UNIVERSITY, MS 38677, USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:453SN3A.IN

***DATE OF TEST   3/7/2000   FPEDD-OUTPUT FILE:UMPEDO.OUT

***   SS131 Cycle 3 Analysis, US45S SEC3 NORTH PROJECT   Drop 2 only, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER4 ACKCALCULATED
1	675+95	605100.	1210000.	115100.	34400.	19800.	26890.
2	674+95	615900.	1374000.	112500.	33800.	18140.	25930.
3	673+95	484400.	1080800.	35000.	22400.	15760.	23830.
4	672+90	318100.	736000.	17400.	23200.	16500.	26150.
5	671+95	384400.	922500.	11800.	17000.	14540.	23830.
6	670+95	406000.	1010600.	24400.	23500.	14800.	24200.
7	669+95	314500.	782700.	23600.	27100.	13730.	23140.
8	668+90	399000.	2471600.	29600.	25600.	15220.	24300.
9	667+95	353100.	945400.	45500.	30000.	13010.	22210.
	* MEAN :	431100.	1170400.	46100.	26300.	15720.	24490.
	STD DEV :	113775.	526878.	39597.	5655.	2148.	1527.
	C V(%):	26.	45.	86.	22.	14.	6.

****

STATION		CORE THICKNESS VALUES(in)			
		LAYER1 Asphalt Combined	LAYER2 LFA Base	LAYER3 LTS	LAYER4 Subgrade
1	675+95	5.42	8.04	6.00	Semi-infinite
2	674+95	5.52	5.44	6.00	Semi-infinite
3	673+95	5.79	6.00	6.00	Semi-infinite
4	672+90	5.50	6.00	6.00	Semi-infinite
5	671+95	5.56	3.63	6.00	Semi-infinite
6	670+95	5.42	3.79	6.00	Semi-infinite
7	669+95	4.83	5.83	6.00	Semi-infinite
8	668+90	5.10	6.00	6.00	Semi-infinite
9	667+95	4.77	4.17	6.00	Semi-infinite
	* MEAN :	5.32	5.43	6.00	
	STD DEV :	0.35	1.39	0.00	
	C V(%)	7	26	0.00	

****

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
UNIVERSITY, MS 38677,   USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED FPEDD-INPUT FILE:253SS1A.IN

***DATE OF TEST 3/08/2000 FPEDD-OUTPUT FILE:UMPEDO.OUT

*** SS131 Cycle 3 Analysis, SR25S SEC1 Drop 2 only, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER4 ACKCALCULATED
1	1310+95	247400.	477100.	221700.	30400.	18660.	25140.
2	1309+70	353400.	760300.	394900.	19400.	23820.	28170.
3	1308+80	437000.	940100.	292800.	35900.	21540.	27330.
4	1307+95	396000.	851900.	169000.	40000.	21860.	28750.
5	1306+95	396800.	853600.	518800.	58200.	19760.	25590.
6	1305+95	479500.	1031400.	148600.	15900.	14760.	20530.
7	1304+95	471400.	977700.	147500.	36500.	18470.	25210.
8	1303+95	477400.	1027000.	228100.	41200.	18420.	24320.
9	1302+95	461300.	992200.	174000.	34400.	21780.	28870.
	* MEAN :	413300.	879000.	255000.	34600.	19890.	25990.
	STD DEV :	76170.	176214.	127111.	12417.	2684.	2659.
	C V(%):	18.	20.	50.	36.	13.	10.

****

STATION		CORE THICKNESS VALUES(in)			
		LAYER1 Asphalt Combined	LAYER2 LFA Base	LAYER3 LTS	LAYER4 Subgrade
1	1310+95	5.46	8.19	6.00	Semi-infinite
2	1309+70	5.75	9.90	6.00	Semi-infinite
3	1308+80	5.65	8.29	6.00	Semi-infinite
4	1307+95	5.31	9.02	6.00	Semi-infinite
5	1306+95	5.42	6.52	6.00	Semi-infinite
6	1305+95	5.94	6.52	6.00	Semi-infinite
7	1304+95	5.92	7.13	6.00	Semi-infinite
8	1303+95	5.00	8.63	6.00	Semi-infinite
9	1302+95	5.50	7.79	6.00	Semi-infinite
	* MEAN :	5.55	8.00	6.00	
	STD DEV :	0.30	1.14	0.00	
	C V(%):	5	14	0	

****

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
UNIVERSITY, MS 38677, USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:253SS2A.IN

***DATE OF TEST   3/8/2000   FPEDD-OUTPUT FILE:UMPEDO.OUT

***   SS131 Cycle 3 Analysis, SR25S SEC2   Drop 2 only, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER4 ACKCALCULATED
1	* 1354+45A	1237000.	1150000.	257900.	45600.	31820.	34450.
2	**1353+95	706900.	657200.	1278200.	53900.	31180.	32510.
3	1352+95A	559700.	520400.	750900.	21300.	30410.	31670.
4	1351+95	476400.	442900.	568200.	60200.	29540.	31700.
5	1350+95A	695900.	647000.	260900.	35200.	22970.	28520.
6	1349+95	614400.	571100.	240500.	39300.	22410.	28010.
7	1348+95A	725800.	699800.	240900.	41300.	24250.	30130.
8	1346+95A	567100.	567100.	293600.	38300.	22870.	28080.
9	1346+95A	447400.	447400.	296800.	43300.	25800.	31750.
	* MEAN :	670000.	633600.	465300.	42000.	26800.	30750.
	STD DEV :	234391.	213298.	352938.	11089.	3902.	2223.
	C V(%):	35.	34.	76.	26.	15.	26.

****

STATION		CORE THICKNESS VALUES(in)			
		LAYER1 Asphalt Combined	LAYER2 LFA Base	LAYER3 LTS	LAYER4 Subgrade
1	1354+45A	5.31	9.77	6.00	Semi-infinite
2	1353+95	5.54	9.60	6.00	Semi-infinite
3	1352+95	5.83	10.60	6.00	Semi-infinite
4	1351+95	4.60	10.83	6.00	Semi-infinite
5	1350+95A	5.04	9.48	6.00	Semi-infinite
6	1349+95	5.60	9.17	6.00	Semi-infinite
7	1348+95A	4.73	10.00	6.00	Semi-infinite
8	1347+95	4.76	10.25	6.00	Semi-infinite
9	1346+95A	4.98	9.92	6.00	Semi-infinite
	* MEAN :	5.17	9.96	6.00	
	STD DEV :	0.42	0.53	0.00	
	C V(%):	8	5	0	

****

FLEX. PAVEMENT EVALUATION PROGRAM   F P E D D 2 - Version 2.1
PROGRAM WRITTEN BY WAHEED UDDIN   1999
VERSION : 1.0 APRIL 16,1984   BY DR. WAHEED UDDIN
CENTER FOR TRANSPORTATION RESEARCH   UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
THE UNIVERSITY OF TEXAS AT AUSTIN   UNIVERSITY, MS 38677,   USA

Core Test Results		Asphalt	LFA Base	LTS
*	Young’s Modulus (psi)	-	53,074	-
**	Young’s Modulus (psi)	-	22,752	42,041

SUMMARY OF MODULUS FOR CYCLE 4 ANALYSIS, SEPTEMBER 2000

1
DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:254SS3A.IN

***DATE OF TEST   4/5/2000   FPEDD-OUTPUT FILE:UMPEDO.OUT

***   SS131 Cycle 4 Analysis, SR25S SEC3   Drop 2 only, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER4 ACKCALCULATED
1	1597+94	353600.	676800.	66000.	23800.	13550.	19970.
2	1596+94	350500.	671000.	51000.	18300.	13100.	19760.
3	1595+93	336800.	735200.	43600.	22700.	12270.	18990.
4	1595+93	303200.	706800.	31700.	17200.	11970.	19080.
5	1594+93	386100.	906400.	77700.	15900.	16160.	23200.
6	1594+03	263600.	656000.	50000.	7400.	13100.	19370.
7	1592+98	275800.	733000.	19200.	18300.	10700.	18310.
8	1591+97	183600.	521200.	56000.	16100.	12130.	18250.
9	1590+97	247200.	701500.	39600.	49700.	12420.	19000.
	* MEAN :	300000.	700800.	48300.	21000.	12820.	19540.
	STD DEV :	63687.	100159.	17562.	11718.	1500.	1485.
	C V(%):	21.	14.	36.	56.	12.	8.

****

STATION		CORE THICKNESS VALUES(in)			
		LAYER1 Asphalt Combined	LAYER2 LFA Base	LAYER3 LTS	LAYER4 Subgrade
1	1597+94	5.62	9.00	6.00	Semi-Infinite
2	1596+94	6.11	7.62	6.00	Semi-Infinite
3	1595+93	5.73	8.25	6.00	Semi-Infinite
4	1595+93	5.50	8.50	6.00	Semi-Infinite
5	1594+93	4.90	9.00	6.00	Semi-Infinite
6	1594+03	5.50	8.87	6.00	Semi-Infinite
7	1592+98	5.25	7.50	6.00	Semi-Infinite
8	1591+97	6.40	9.50	6.00	Semi-Infinite
9	1590+97	6.00	8.50	6.00	Semi-Infinite
	* MEAN :	5.67	8.53	6.00	
	STD DEV :	0.46	0.66	0.00	
	C V(%):	8	8	0	

****

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
UNIVERSITY, MS 38677,   USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:253SS4A.IN

***DATE OF TEST   4/5/2000   FPEDD-OUTPUT FILE:UMPEDO.OUT

***   SS131 Cycle 4 Analysis, SR25S SEC4   Drop 2
only, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER4 ACKCALCULATED
1	1703+96	749400.	412000.	160800.	35900.	20400.	26430.
2	1702+96	595700.	327500.	93500.	24700.	18960.	25280.
3	1701+96	633200.	348100.	64100.	28200.	17550.	25080.
4	1700+95	819600.	422000.	106400.	28400.	16050.	22700.
5	1699+95	816800.	449100.	107200.	31700.	20120.	26750.
6	1698+95	558800.	328100.	93800.	23300.	17070.	23620.
7	1697+94	583200.	417000.	59700.	28000.	14740.	21240.
8	1696+94	535300.	382700.	166400.	36500.	18140.	24210.
9	1695+94	809700.	578800.	154500.	31400.	18130.	22890.
	* MEAN :	677900.	407200.	111800.	29700.	17900.	24240.
	STD DEV :	119425.	77655.	40163.	4533.	1825.	1819.
	C V(%):	18.	19.	36.	15.	10.	8.

****

STATION		CORE THICKNESS VALUES(in)			
		LAYER1 Asphalt Combined	LAYER2 LFA Base	LAYER3 LTS	LAYER4 Subgrade
1	1703+96	5.62	8.62	6.00	Semi-Infinite
2	1702+96	6.50	8.00	6.00	Semi-Infinite
3	1701+96	5.00	8.50	6.00	Semi-Infinite
4	1700+95	5.00	8.00	5.00	Semi-Infinite
5	1699+95	5.50	8.50	6.00	Semi-Infinite
6	1698+95	5.90	8.50	5.00	Semi-Infinite
7	1697+94	5.42	9.00	6.00	Semi-Infinite
8	1696+94	5.10	9.00	6.00	Semi-Infinite
9	1695+94	6.50	9.50	6.00	Semi-Infinite
	* MEAN :	5.62	8.62	6.00	
	STD DEV :	0.58	0.48	0.00	
	C V(%):	10	6	0.00	

****

FLEX. PAVEMENT EVALUATION PROGRAM   F P E D D 2 - Version 2.1
PROGRAM WRITTEN BY WAHEED UDDIN   1999
VERSION : 1.0 APRIL 16,1984   BY DR. WAHEED UDDIN
CENTER FOR TRANSPORTATION RESEARCH   UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
THE UNIVERSITY OF TEXAS AT AUSTIN   UNIVERSITY, MS 38677,   USA

1
DEFLECTION TEST DATA FILE NAME:DEFLECT.PED   FPEDD-INPUT FILE:454NS1A.IN

***DATE OF TEST   6/26/2000   FPEDD-OUTPUT FILE:UMPEDO.OUT

***   SS131 Cycle 4 Analysis, US45N SEC1 SOUTH PROJECT   Drop 2 only, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION		FINAL VALUES OF YOUNGS MODULI(PSI)					
		LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4 ACK	LAYER4 CALCULATED
1	88+05	426200.	2366600.	66900.	19600.	22640.	30970.
2	89+05	386300.	2224700.	69300.	25900.	39750.	49630.
3	90+05	402600.	2494400.	73900.	28000.	30420.	39870.
4	91+05	383000.	2372600.	57300.	27100.	25080.	33800.
5	92+05	419200.	2597000.	37600.	26100.	33010.	43620.
6	93+05	398700.	2470200.	62500.	19800.	40360.	49450.
7	94+05	398800.	2470500.	76700.	26100.	39740.	50710.
8	95+05	300100.	1859100.	90200.	27500.	28660.	38240.
9	96+05	308700.	1912500.	393100.	35200.	31030.	36840.
	* MEAN :	380400.	2307500.	103000.	26100.	32290.	41450.
	STD DEV :	45277.	260638.	109718.	4628.	6521.	7278.
	C V(%):	12.	11.	107.	18.	20.	18.

****

STATION		CORE THICKNESS VALUES(in)			
		LAYER1 Asphalt Combined	LAYER2 LFA Base	LAYER3 LTS	LAYER4 Subgrade
1	88+05	6.25	7.00	6.00	Semi-Infinite
2	89+05	6.00	6.75	9.25	Semi-Infinite
3	90+05	6.00	7.00	7.50	Semi-Infinite
4	91+05	6.25	6.50	8.25	Semi-Infinite
5	92+05	6.00	6.75	7.50	Semi-Infinite
6	93+05	6.50	6.50	9.50	Semi-Infinite
7	94+05	6.00	6.00	7.50	Semi-Infinite
8	95+05	6.00	6.00	7.50	Semi-Infinite
9	96+05	6.50	7.50	9.00	Semi-Infinite
	* MEAN :	6.17	6.72	8.00	
	STD DEV :	0.22	0.42	1.11	
	C V(%):	4	6	14	

****

FLEX. PAVEMENT EVALUATION PROGRAM   F P E D D 2 - Version 2.1
PROGRAM WRITTEN BY WAHEED UDDIN   1999
VERSION : 1.0 APRIL 16,1984   BY DR. WAHEED UDDIN
CENTER FOR TRANSPORTATION RESEARCH   UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
THE UNIVERSITY OF TEXAS AT AUSTIN   UNIVERSITY, MS 38677,   USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED FPEDD-INPUT FILE:454NS2A.IN

***DATE OF TEST 6/27/2000 FPEDD-OUTPUT FILE:UMPEDO.OUT

*** SS131 Cycle 4 Analysis, US45N SEC2 SOUTH PROJECT Drop 2 only, UMPED

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION			FINAL VALUES OF YOUNGS MODULI(PSI)					
			LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER4 ACKCALCULATED
1	115+95		518400.	1998900.	223400.	17800.	12900.	17160.
2	114+95		397600.	1589900.	100500.	29400.	9470.	13910.
3	114+00		439200.	1821600.	205900.	25900.	14060.	18810.
4	112+90		313200.	1299200.	53400.	23300.	8920.	13980.
5	112+00		368500.	1834200.	241500.	36700.	12640.	16960.
6	110+95		590200.	3046800.	315600.	47600.	15880.	20000.
7	109+95		373300.	1998700.	214200.	41200.	22930.	29300.
8	108+95		309000.	1914600.	87000.	26100.	23840.	32060.
9	107+95		413100.	2559100.	62500.	31600.	21750.	29650.
		* MEAN :	413600.	2007000.	167100.	31000.	15820.	21310.
		STD DEV :	92034.	516461.	93006.	9345.	5698.	7085.
		C V(%):	22.	26.	56.	30.	36.	33.

****

STATION			CORE THICKNESS VALUES(in)			
			LAYER1 Asphalt Combined	LAYER2 LFA Base	LAYER3 LTS	LAYER4 Subgrade
1	115+95		5.00	7.50	10.00	Semi-Infinite
2	114+95		5.25	9.00	7.50	Semi-Infinite
3	114+00		5.50	7.50	9.00	Semi-Infinite
4	112+90		5.50	10.00	6.00	Semi-Infinite
5	112+00		5.50	8.00	8.50	Semi-Infinite
6	110+95		5.75	7.75	9.00	Semi-Infinite
7	109+95		5.75	7.25	9.00	Semi-Infinite
8	108+95		6.00	8.00	7.00	Semi-Infinite
9	107+95		5.75	8.50	8.50	Semi-Infinite
		* MEAN :	5.56	8.17	8.28	
		STD DEV :	0.30	0.88	1.23	
		C V(%):	5	11	15	

****

FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
UNIVERSITY, MS 38677, USA

1

DEFLECTION TEST DATA FILE NAME:DEFLECT.PED FPEDD-INPUT FILE:454NS3A.IN

***DATE OF TEST 6/27/2000 FPEDD-OUTPUT FILE:UMPEDO.OUT

*** SS131 Cycle 4 Analysis, US45N SEC3 SOUTH PROJECT Drop 2 only, UMPED ***

********************** SUMMARY OF STRUCTURAL EVALUATION ********************

STATION			FINAL VALUES OF YOUNGS MODULI(PSI)					
			LAYER1 IN SITU	LAYER1 CORRECTED	LAYER2	LAYER3 NONLINEAR	LAYER4	LAYER4 ACKCALCULATED
1	170+05		681700.	1135900.	320100.	39400.	21700.	27750.
2	171+05		387600.	645800.	144500.	34100.	17600.	24050.
3	172+05		343600.	552100.	41800.	28000.	14760.	23420.
4	173+05		566300.	943600.	287900.	45900.	29380.	35400.
5	174+10		453800.	784200.	38900.	28400.	22050.	30740.
6	175+00		424900.	734300.	59700.	22100.	14740.	20650.
7	176+00		304500.	526300.	18700.	16300.	9470.	15070.
8	177+00		388100.	721400.	48000.	22300.	19440.	26390.
9	177+85		433700.	836200.	26800.	16300.	14020.	20230.
		* MEAN :	442600.	764400.	109600.	28000.	18120.	24850.
		STD DEV :	116112.	191786.	116360.	10179.	5825.	6063.
		C V(%):	26.	25.	106.	36.	32.	24.

****

STATION			CORE THICKNESS VALUES(in)			
			LAYER1 Asphalt Combined	LAYER2 LFA Base	LAYER3 LTS	LAYER4 Subgrade
1	170+05		5.00	7.00	7.00	Semi-Infinite
2	171+05		5.00	9.00	6.30	Semi-Infinite
3	172+05		4.50	7.00	7.00	Semi-Infinite
4	173+05		4.75	8.25	10.00	Semi-Infinite
5	174+10		5.00	7.00	10.00	Semi-Infinite
6	175+00		6.00	9.00	8.00	Semi-Infinite
7	176+00		6.25	7.50	9.00	Semi-Infinite
8	177+00		6.00	8.00	10.00	Semi-Infinite
9	177+85		6.50	9.00	7.00	Semi-Infinite
		* MEAN :	5.56	8.17	8.28	
		STD DEV :	0.30	0.88	1.23	
		C V(%):	5	11	15	

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FLEX. PAVEMENT EVALUATION PROGRAM
PROGRAM WRITTEN BY WAHEED UDDIN
VERSION : 1.0 APRIL 16,1984
CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

F P E D D 2 - Version 2.1
1999
BY DR. WAHEED UDDIN
UNIVERSITY OF MISSISSIPPI, P.O.BOX:22
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APPENDIX F

DCPAN LAYER THICKNESS AND MODULUS SUMMARY TABLES

US45N SECTION 2, SOUTH PROJECT, MONROE COUNTY
Test Date: 07/27/1999, Cycle 1

Summary of DCPAN Analyze

	DCP STATION	LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
		Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	116+00	26.80	81.49	313.03	11.84	28.15	20.40	76.13
2	115+00	20.34	96.17	301.06	13.49	22.64	30.38	57.54
3	114+00	19.75	97.74	306.70	11.05	30.63	23.94	68.18
4	113+00	27.08	80.95	322.04	16.95	17.78	32.83	54.36
5	112+00	34.80	67.64	240.20	14.91	16.71	32.42	54.86
6	111+00	22.60	90.57	443.64	18.42	22.54	39.91	46.87
7	110+00	27.14	80.83	536.43	23.05	22.91	23.70	68.66
8	109+00	18.85	100.21	553.38	18.50	30.39	14.20	96.81
9	108+00	20.38	96.06	372.54	11.94	32.83	14.27	96.48
	Mean	24.19	96.06	376.56	15.57	24.95	25.78	68.88
	S.D	5.20	10.84	110.41	3.98	5.80	8.79	18.08
	CV	21.50%	12.32%	29.32%	25.57%	23.23%	34.08%	26.25%

US45N SECTION 1, SOUTH PROJECT, MONROE COUNTY
Test Date: 07/27/1999 Cycle 1

Summary of DCPAN Analyze

	DCP STATION	LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
		Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	96+00	8.01	144.93	485.53	15.25	31.99	11.25	112.35
2	95+00	13.16	119.1	203.30	19.10	11.1	16.79	86.73
3	94+00	8.12	144.21	196.24	9.20	29.85	19.93	77.33
4	93+00	9.05	138.58	397.39	12.62	32.45	13.28	101.08
5	92+00	14.51	114.01	207.51	10.21	26.65	14.01	104.7
6	91+00	14.29	114.8	379.93	10.82	38.74	15.90	89.89
7	90+00	18.64	100.81	345.31	15.16	36.04	16.72	79.82
8	89+00	40.69	59.46	529.10	18.03	29.29	27.96	61.1
9	88+00	32.66	70.98	200.35	11.10	32.84	14.91	86.49
	Mean	17.68	111.88	327.18	13.50	29.88	16.75	88.83
	S.D	11.49	30.53	130.76	3.55	7.90	4.87	15.61
	CV	64.98%	27.29%	39.97%	26.29%	26.45%	29.07%	17.57%

*Semi-infinite

US45N SECTION 3, SOUTH PROJECT, MONROE COUNTY
Test Date: 07/26/1999 Cycle 1

Summary of DCPAN Analyze

	DCP STATION	LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
		Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	177+80	18.11	102.34	435.24	19.25	20.93	13.06	102.18
2	176+95	13.80	116.65	532.09	19.03	27.74	12.68	104.09
3	175+95	11.99	123.97	304.00	16.45	17.57	44.32	43.15
4	174+95	13.16	119.11	392.80	19.07	18.81	31.74	55.72
5	174+05	7.59	147.71	490.93	15.85	30.89	8.28	136.18
6	173+00	12.61	121.35	361.76	18.77	17.57	9.29	126.78
7	172+00	13.66	117.16	354.55	12.30	29.91	31.26	56.36
8	171+00	12.48	121.9	243.72	12.96	20.43	65.14	31.15
9	170+00	9.51	136.03	254.00	13.00	19.27	43.03	46.5
	Mean	12.55	122.91	374.34	16.30	22.57	28.76	78.01
	S.D	2.92	12.76	99.73	2.92	5.39	19.65	39.36
	CV	23.28%	10.38%	26.64%	17.92%	23.87%	68.32%	50.46%

US45N SECTION 4, SOUTH PROJECT, MONROE COUNTY
Test Date: 07/26/1999 Cycle 1

Summary of DCPAN Analyze

	DCP STATION	LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
		Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	266+00	18.29	101.8	336.56	10.08	38.25	20.08	76.95
2	265+25	23.79	87.83	211.65	12.29	20.15	15.00	93.39
3	264+50	21.44	93.38	554.45	11.36	58.39	15.75	90.48
4	262+63	24.39	86.52	547.14	10.44	64.96	18.23	82.11
5	261+88	46.37	52.75	359.29	10.35	39.08	16.35	88.25
6	261+50	24.26	86.8	495.77	9.67	63.38	17.28	85.08
7	260+74	43.19	56.37	316.91	12.58	26.09	25.81	64.68
8	260+00	42.80	56.85	413.10	13.65	30.37	22.84	70.46
	Mean	30.57	69.14	404.36	11.30	37.85	18.92	72.38
	S.D	10.70	31.58	113.33	1.32	21.65	3.52	28.72
	CV	35.02%	45.68%	28.03%	11.68%	57.20%	18.63%	39.68%

US45N SECTION 1, NORTH PROJECT, MONROE COUNTY
Test Date: 07/19/1999 cycle 1

Summary of DCPAN Analyze

		LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
	DCP STATION	Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	461+00	72.03	31.81	384.72	28.08	12.68	51.24	38.34
2	462+00	33.91	69.01	443.64	51.16	12.43	57.50	34.77
3	463+00	33.46	69.71	275.89	24.54	10.5	34.50	52.38
4	464+00	34.13	68.66	458.80	31.65	14.36	28.08	60.91
5	465+00	35.69	66.31	254.00	32.57	8.01	27.06	62.55
6	466+04	26.77	81.56	477.54	35.44	14.26	36.97	49.71
7	467+00	27.84	79.47	297.30	28.23	9.92	38.75	47.95
8	467+90	49.99	48.98	236.58	39.85	7.03	26.55	63.4
9	469+06	37.15	64.2	379.01	34.97	10.92	24.36	67.36
	Mean	39.00	64.41	356.39	34.05	11.12	36.11	53.04
	S.D	14.06	15.38	92.80	7.88	2.57	11.58	11.47
	CV	36.04%	23.88%	26.04%	23.15%	23.09%	32.06%	21.62%

US45N SECTION 2, NORTH PROJECT, MONROE COUNTY
Test Date: 07/20/1999 cycle 1

Summary of DCPAN Analyze

	DCP STATION	LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
		Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	490+00	44.70	54.62	550.22	34.07	17.76	39.61	47.15
2	491+00	29.27	76.81	468.70	36.51	13.74	41.71	45.28
3	492+00	15.17	111.67	560.52	44.34	26.22	37.24	37.55
4	493+01	14.37	114.53	305.33	26.25	17.81	34.60	48.26
5	494+00	22.60	90.59	504.03	32.55	35.66	34.31	38.69
6	495+00	27.88	79.39	524.05	35.82	16.14	34.82	52.01
7	495+90	17.16	105.18	394.26	49.34	19.19	45.79	40.85
8	497+00	16.57	107.03	580.99	41.73	18.07	30.47	57.42
9	498+00	14.82	112.88	377.09	15.25	23.69	32.81	54.37
	Mean	22.50	94.74	473.91	35.10	20.92	36.82	46.84
	S.D	10.06	20.77	95.12	10.09	6.69	4.80	6.97
	CV	44.72%	21.92%	20.07%	28.75%	31.99%	13.02%	14.88%

US45S SECTION 3, NORTH PROJECT, MONROE COUNTY
Test Date: 07/14/1999 cycle 1

Summary of DCPAN Analyze

	DCP STATION	LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
		Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	676+00	15.96	108.98	302.76	7.08	61.18	7.45	145.34
2	675+00	20.10	96.79	180.68	8.33	33.48	7.45	145.26
3	674+00	15.07	112.02	491.76	6.49	119.47	12.29	106.23
4	672+95	20.51	95.75	241.78	8.36	39.43	8.30	135.98
	Mean	17.91	103.39	304.25	7.57	63.39	8.87	133.20
	S.D	2.79	8.32	134.58	0.93	39.24	2.31	18.51
	CV	15.60%	8.05%	44.23%	12.33%	61.90%	26.07%	13.90%

SR25 South Direction SECTION 1, LEAKE COUNTY
Test Date: 07/28/1999 cycle 1

Summary of DCPAN Analyze

	DCP	LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
	STATION	Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	522+00	12.93	120.02	375.80	12.86	34.42	12.86	102.28
2	523+00	12.17	123.2	458.88	12.24	40.19	8.93	129.94
3	524+00	25.01	85.18	439.84	20.09	20.21	27.66	61.57
4	525+00	13.16	119.12	538.53	20.20	45.49	16.52	82.1
5	526+00	23.78	87.87	365.96	17.89	18.81	14.67	94.78
6	527+00	15.09	111.93	452.12	19.69	21.38	19.64	78.1
7	528+00	9.56	135.76	481.32	8.31	35.21	7.42	142.43
8	529+00	15.37	110.99	411.51	10.91	41.73	10.73	115.8
9	530+00	11.26	127.27	374.93	8.28	57.88	7.26	147.69
	Mean	15.37	113.48	433.21	14.50	35.04	13.97	106.08
	S.D	5.43	17.03	57.18	5.00	13.10	6.63	30.00
	CV	35.30%	15.01%	13.20%	34.48%	37.39%	47.47%	28.28%

US45S SECTION 3, NORTH PROJECT, MONROE COUNTY
Test Date: 11/02/1999 Cycle 2 Nov' 1999

Summary of DCPAN Analyze

	DCP STATION	LAYER 1 (6 in)		LAYER 2 (6 in)		LAYER 3 (Semi-infinite)	
		Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	675+95	12.32	122.58	5.93	54.51	3.93	214.23
2	675+95ab	15.05	112.09	9.63	49.52	4.10	209.52
3	673+95	30.09	75.33	15.07	12.92	4.85	188.76
4	672+90	11.94	124.22	7.31	38.33	3.81	210.25
5	671+95	16.09	108.56	9.89	23.62	6.54	157.35
6	670+95	13.21	118.92	7.88	33.86	5.06	183.88
7	669+95	13.13	119.24	7.90	33.74	5.68	171.50
8	668+95	12.68	121.05	7.80	34.44	6.18	162.98
9	667+95	13.05	119.56	7.32	38.24	6.39	159.58
	Mean	15.28	113.51	8.75	35.46	5.17	184.23
	S.D	5.71	15.15	2.66	12.41	1.08	22.86
	CV	37.34%	13.35%	30.37%	34.98%	20.84%	12.41%

US45N SECTION 1, SOUTH PROJECT, MONROE COUNTY
Test Date: 11/03/1999 Cycle 2 Nov' 1999

Summary of DCPAN Analyze

	DCP STATION	LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
		Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	96+05	13.58	117.47	359.51	9.64	43.65	9.56	124.46
2	95+05	18.69	100.66	355.85	13.75	25.66	13.64	99.35
3	94+05	26.56	81.97	302.55	11.12	30.01	10.36	118.37
4	93+05	13.49	117.83	302.52	11.79	27.51	10.65	116.35
5	92+05	10.75	129.65	295.91	10.68	31.28	8.65	132.55
6	91+05	19.58	98.18	366.21	11.53	33.91	12.84	103.30
7	90+05	23.94	87.51	194.54	8.14	36.09	10.20	119.57
8	89+05	16.73	106.52	564.88	9.13	83.90	10.42	117.93
9	88+05	20.96	94.57	224.00	13.51	18.25	13.58	99.62
	Mean	18.25	103.82	329.55	11.03	36.70	11.10	114.61
	S.D	5.17	15.52	106.23	1.88	19.06	1.80	11.50
	CV	28.32%	14.95%	32.23%	17.08%	51.93%	16.25%	10.03%

US45N SECTION 2, SOUTH PROJECT, MONROE COUNTY
Test Date: 11/02/1999 Cycle 2 Nov' 1999

Summary of DCPAN Analyze

	DCP STATION	LAYER 1 (6 in)		LAYER 2			LAYER 3 (Semi-infinite)	
		Avg. DCPI (mm/blow)	Modulus (MPa)	Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	115+95	11.02	128.36	413.67	11.74	37.68	18.36	81.73
2	114+95	18.35	101.63	264.91	16.82	15.33	22.66	70.84
3	114+00	15.24	111.43	273.93	11.42	26.65	13.05	102.21
4	112+90	11.93	124.23	201.51	10.56	24.51	14.93	93.67
5	112+00	13.35	118.37	269.95	8.10	44.82	24.44	67.21
6	110+95	9.28	137.28	445.34	13.61	33.35	20.85	74.99
7	109+95	13.75	116.81	310.60	20.39	13.90	29.64	58.59
8	108+95	17.45	104.30	363.01	8.53	53.38	12.02	107.72
9	107+95	14.29	114.79	252.09	8.17	42.13	10.20	119.51
	Mean	13.85	117.47	310.56	12.15	32.42	18.46	86.27
	S.D	2.92	11.32	80.57	4.19	13.45	6.48	20.58
	CV	21.08%	9.64%	25.94%	34.48%	41.49%	35.08%	23.86%

US45N_Sec1 North Project, Monroe County
Test Date: 03/06/2000Cycle 3

Summary of DCPAN Analyze

	DCPI STATION		LAYER2			LAYER3 (Semi-infinite)	
			Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	461+05	No LAYER 1	428.21	26.76	14.85	25.22	65.75
2	462+05		290.83	22.44	11.91	23.51	69.04
3	463+05		594.98	23.94	15.15	26.07	63.01
4	464+05		434.54	25.56	15.71	23.85	68.37
5	465+05		615.52	29.36	13.20	22.84	65.41
6	466+09		278.39	25.31	10.28	20.06	76.99
7	467+05		312.29	19.52	14.66	26.41	63.63
8	467+95		646.00	23.93	15.46	17.98	76.09
9	469+11		562.29	20.08	28.38	16.72	86.98
	Mean		462.56	24.10	15.51	22.52	70.59
	S.D		146.83	3.13	5.16	3.50	7.93
	CV		31.74%	12.98%	33.24%	15.56%	11.24%

US45N_Sec2 North Project, Monroe County
Test Date: 03/07/2000Cycle 3

Summary of DCPAN Analyze

	DCPI STATION		LAYER 2			LAYER 3 (Semi-infinite)	
			Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	490+05	No LAYER 1	388.90	20.47	17.20	28.03	60.99
2	491+00		330.28	14.40	22.46	22.62	66.07
3	492+03		765.28	21.26	15.18	17.55	89.37
4	493+05		767.39	22.57	15.32	16.73	70.49
5	494+05		260.54	17.02	14.92	26.64	63.24
6	495+05		626.37	19.60	34.82	18.81	80.40
7	496+00		488.84	23.28	19.89	22.59	70.99
8	497+00		208.46	11.62	21.66	23.15	69.80
9	498+05		271.34	18.31	14.08	28.12	60.85
	Mean		456.38	18.73	19.50	22.69	70.24
	S.D		216.97	3.84	6.52	4.34	9.42
	CV		47.54%	20.51%	33.43%	19.13%	13.41%

US45S_Sec3 North Project, Rankin County
Test Date: 03/07/2000 Cycle 3

Summary of DCPAN Analyze

	DCPI STATION		LAYER 2			LAYER 3 (Semi-infinite)	
			Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	675+95	No LAYER 1	232.16	4.74	100.23	5.10	183.03
2	674+95		198.01	4.95	84.43	4.72	191.68
3	673+95		242.09	4.89	97.58	6.02	165.56
4	672+90		233.28	4.10	130.11	5.17	181.52
5	671+95		341.33	7.26	65.34	7.09	149.84
6	670+95		269.02	6.21	69.51	5.03	184.65
7	669+95		234.70	5.22	85.32	7.97	139.42
8	668+95		247.79	6.21	65.52	7.02	150.75
9	667+95		232.76	7.08	50.45	8.06	138.49
	Mean		247.90	5.63	83.17	6.24	164.99
	S.D		39.63	1.10	23.97	1.32	20.88
	CV		15.99%	19.61%	28.82%	21.12%	12.65%

SR25S_Sec1 Cycle 3 March 2000 Rankin County
Test Date: 03/08/2000

Summary of DCPAN Analyze

	DCPI STATION		LAYER 2			LAYER 3 (Semi-infinite)	
			Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	1310+95	No LAYER 1	152.40	4.37	92.75	27.13	62.43
2	1309+70		232.23	19.35	16.56	13.33	108.42
3	1308+80		385.32	14.31	26.39	14.86	93.97
4	1307+95		644.41	26.85	8.81	22.45	66.05
5	1306+95		423.83	15.39	26.65	25.03	66.09
6	1305+95		469.10	17.41	25.87	17.84	83.29
7	1304+95		463.78	13.64	34.99	9.35	126.23
8	1303+95		353.72	8.63	51.13	16.69	87.06
9	1302+95		488.76	13.58	37.74	14.01	97.65
	Mean		401.51	14.84	35.65	17.85	87.91
	S.D		145.26	6.35	24.63	5.88	21.35
	CV		36.18%	42.83%	69.07%	32.93%	24.28%

SR25S_Sec2 Rankin County
Test Date: 03/08/2000 Cycle 3

Summary of DCPAN Analyze

	DCPI STATION		LAYER 2			LAYER 3 (Semi-infinite)	
			Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	1354+45	No LAYER 1	282.96	6.03	76.04	11.39	111.52
2	1353+95		227.77	7.22	48.19	11.79	109.07
3	1352+95		233.22	7.09	50.34	14.89	93.83
4	1351+95		228.58	10.43	26.91	15.89	89.93
5	1350+95		226.80	9.86	29.17	16.89	86.40
6	1349+95		546.12	11.56	55.60	15.93	89.79
7	1348+95		152.40	2.87	198.39	12.08	107.42
8	1347+95		240.07	12.67	20.87	17.98	82.87
9	1346+95		152.40	5.06	71.71	11.50	110.79
	Mean		254.48	8.09	64.14	14.26	97.96
	S.D		117.00	3.24	53.88	2.58	11.57
	CV		45.98%	40.08%	84.00%	18.10%	11.81%

US45N_Sec1 South Project, Morone County
Test Date: 06/26/2000Cycle 4

Summary of DCPAN Analyze

	DCPI STATION		LAYER 2			LAYER 3 (Semi-infinite)	
			Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	96+05	No LAYER 1	412.60	12.50	34.31	11.16	112.96
2	95+05		420.11	16.80	23.59	15.89	89.94
3	94+05		356.10	9.97	60.01	10.30	107.10
4	93+05		335.23	11.97	29.47	8.04	138.60
5	92+05		281.26	16.59	16.32	7.64	143.10
6	91+05		406.26	14.56	27.31	9.47	125.21
7	90+05		449.27	14.52	30.89	6.43	158.98
8	89+05		421.17	11.38	40.26	6.63	156.13
9	88+05		212.12	12.48	29.24	16.07	77.10
	Mean		366.01	13.42	32.38	10.18	123.24
	S.D		77.94	2.34	12.30	3.65	28.72
	CV		21.30%	17.45%	37.99%	35.83%	23.30%

US45N_Sec2 South Project, Monroe County
Test Date: 06/27/2000Cycle 4

Summary of DCPAN Analyze

	DCPI STATION		LAYER 2			LAYER 3 (Semi-infinite)	
			Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	115+95	No LAYER 1	462.61	10.53	38.39	20.96	85.88
2	114+95		464.50	22.12	19.55	22.34	71.54
3	114+00		365.11	9.87	35.64	22.45	78.95
4	112+90		367.31	10.49	28.30	27.74	75.64
5	112+00		346.06	11.93	19.83	25.73	64.37
6	110+95		338.44	15.38	19.89	33.23	56.12
7	109+95		501.93	50.27	13.25	56.23	29.68
8	108+95		289.30	11.57	34.50	7.94	91.50
9	107+95		353.44	10.10	47.15	13.59	95.77
	Mean		387.63	16.92	28.50	25.58	72.16
	S.D		71.15	13.10	11.15	13.69	20.31
	CV		18.36%	77.45%	39.12%	53.52%	28.15%

US45N_Sec3 South Project, Monroe County
Test Date: 06/27/2000Cycle 4

Summary of DCPAN Analyze

	DCPI STATION		LAYER 2			LAYER 3 (Semi-infinite)	
			Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	177+85	No LAYER 1	492.70	8.99	70.33	6.44	158.83
2	177+00		504.22	14.01	37.75	17.29	85.05
3	176+00		682.31	18.65	43.04	22.62	70.92
4	175+00		539.50	16.35	33.98	20.70	75.36
5	174+10		533.89	10.27	64.21	8.38	135.16
6	173+05		367.04	11.12	35.86	14.09	97.26
7	172+05		387.49	8.10	62.15	32.21	55.12
8	171+05		233.19	16.71	14.16	17.16	85.50
9	170+05		416.26	13.15	32.27	38.63	48.07
	Mean		461.84	13.04	43.75	19.72	90.14
	S.D		128.18	3.69	18.25	10.44	36.10
	CV		27.76%	28.31%	41.72%	52.93%	40.05%

SR25S_Sec3 Rankin County
Test Date: 4/06/2000 Cycle 4

Summary of DCPAN Analyze

	DCPI STATION		LAYER 2			LAYER 3 (Semi-infinite)	
			Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	1597+95	No LAYER 1	430.40	8.82	61.09	21.19	74.18
2	1596+95		269.60	9.48	34.91	27.17	62.37
3	1595+95		301.96	6.35	73.31	26.48	63.51
4	1595+95B		202.53	5.79	65.22	20.43	76.05
5	1594+95		152.40	3.22	160.96	18.35	81.74
6	1593+95		341.67	13.91	24.29	35.58	51.18
7	1592+95		460.56	11.82	42.51	14.26	96.51
8	1591+95		152.40	4.94	74.74	27.60	61.66
9	1590+95		340.80	38.06	8.60	15.84	90.14
	Mean		294.70	11.38	60.63	22.99	73.04
	S.D		111.77	10.57	43.97	6.78	14.75
	CV		37.92%	92.88%	72.52%	29.51%	20.20%

SR25S_Sec4 Rankin County

Test Date: 4/05/2000 Cycle 4

Summary of DCPAN Analyze

	DCPI STATION		LAYER 2			LAYER 3 (Semi-infinite)	
			Thickness (mm)	Avg. DCPI (mm/blow)	Modulus (MPa)	Avg. DCPI (mm/blow)	Modulus (MPa)
1	1703+95	No LAYER 1	118.67	3.21	147.50	16.43	87.98
2	1702+95		171.26	12.23	18.14	23.54	69.00
3	1701+95		348.77	21.50	14.60	22.36	71.48
4	1700+95		300.63	14.36	20.76	21.21	74.13
5	1699+95		333.96	11.95	29.44	15.02	93.32
6	1698+95		152.40	13.37	15.18	22.80	70.54
7	1697+95		502.54	33.56	15.68	22.65	70.85
8	1696+95		492.35	25.95	18.20	28.18	60.76
9	1695+95		382.25	16.62	21.53	24.12	67.83
	Mean		311.43	16.97	33.45	21.81	73.99
	S.D		140.71	8.90	43.01	3.97	10.22
	CV		45.18%	52.42%	128.59%	18.22%	13.81%

Comparison of The DCPAN and FWD Backcalculated Modulus Results for All Cycles

US45 South Project Section 2 Location 1: 116+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected				3,574 (518,400) 13,781 (1,998,900)
LFA Base	Backcalculated Young's Modulus, MPa (psi)				1,540 (223,400)
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)	152.4 (6.00)		
	Average DCPI, mm/blow (CV, %)	26.80 (41.5)	11.02 (28.6)		
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	81 (11,820)	128 (18,620)		
	Backcalculated Young's Modulus, MPa (psi)	96 (14,000)	483 (70,000) LTS		123 (17,800) LTS
Subgrade Layer 2	DCPAN Thickness, mm (in)	313.03 (12.32)	413.67 (16.29)		301.23 (11.86)
	Average DCPI, mm/blow (CV, %)	11.84 (25.2)	11.74 (33.2)		9.34 (25.0)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	28 (4,080)	38 (5,460)		38 (5,570)
	Backcalculated Young's Modulus, MPa (psi)	6 (1,000)	32 (4,700)		
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite	Semi-infinite		Semi-infinite
	Average DCPI, mm/blow (CV, %)	20.40 (31.6)	18.36 (58.1)		17.04 (36.2)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	76 (11,400)	82 (11,850)		86 (12,460)
	Backcalculated Young's Modulus, MPa (psi)	30 (4,190)	82 (11,930)		118 (17,160)

Note: Data not available in shaded cell(s).

US45N South Project Section 2 Location 2: 115+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected				2,741 (397,600) 10,961 (1,589,900)
LFA Base	Backcalculated Young's Modulus, MPa (psi)				693 (100,500)
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)	152.4 (6.00)		
	Average DCPI, mm/blow (CV, %)	20.34 (22.9)	18.35 (30.8)		
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	96 (14,000)	102 (14,740)		
	Backcalculated Young's Modulus, MPa (psi)	85 (12,400)	168 (24,300) LTS		203 (29,400) LTS
Subgrade Layer 2	DCPAN Thickness, mm (in)	301.06 (11.85)	264.91 (10.43)		464.50 (18.29)
	Average DCPI, mm/blow (CV, %)	13.49 (15.8)	16.82 (22.2)		22.12 (34.0)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	23 (3,280)	15 (2,220)		20 (2,840)
	Backcalculated Young's Modulus, MPa (psi)	69 (1,000)	9 (1,300)		
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite	Semi-infinite		Semi-infinite
	Average DCPI, mm/blow (CV, %)	30.38 (22.8)	22.66 (43.6)		22.34 (26.6)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	57 (8,350)	71 (10,270)		72 (10,380)
	Backcalculated Young's Modulus, MPa (psi)	30 (4,320)	62 (8,920)		96 (13,910)

Note: Data not available in shaded cell(s).

US45N South Project Section 2 Location 3: 114+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected				3,028 (439,200) 12,559 (1,821,600)
LFA Base	Backcalculated Young's Modulus, MPa (psi)				1,420 (205,900)
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)	152.4 (6.00)		
	Average DCPI, mm/blow (CV, %)	19.75 (41.1)	15.24 (48.8)		
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	98 (14,180)	111 (16,160)		
	Backcalculated Young's Modulus, MPa (psi)	88 (12,700)	366 (53,100) LTS		179 (25,900) LTS
Subgrade Layer 2	DCPAN Thickness, mm (in)	306.70 (12.07)	273.93 (10.78)		272.93 (10.75)
	Average DCPI, mm/blow (CV, %)	11.05 (23.6)	11.42 (41.0)		9.41 (45.7)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	31 (4,400)	27 (3,860)		36 (5,170)
	Backcalculated Young's Modulus, MPa (psi)	69 (1,000)	21 (3,100)		
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite	Semi-infinite		Semi-infinite
	Average DCPI, mm/blow (CV, %)	23.94 (20.8)	13.05 (26.9)		19.33 (102.2)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	57 (8,350)	102 (14,820)		79 (11,450)
	Backcalculated Young's Modulus, MPa (psi)	27 (3,860)	82 (11,920)		130 (18,810)

Note: Data not available in shaded cell(s).

US45N South Project Section 2 Location 4: 113+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected				21,594 (313,200) 8,958 (1,299,200)
LFA Base	Backcalculated Young's Modulus, MPa (psi)				3,682 (53,400)
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)	152.4 (6.00)		
	Average DCPI, mm/blow (CV, %)	27.08 (31.5)	11.93 (31.1)		
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	81 (12,000)	124 (18,020)		
	Backcalculated Young's Modulus, MPa (psi)	167 (24,200)	287 (41,600) LTS		161 (23,300) LTS
Subgrade Layer 2	DCPAN Thickness, mm (in)	322.04 (12.68)	201.51 (7.93)		234.66 (9.24)
	Average DCPI, mm/blow (CV, %)	16.95 (16.5)	10.56 (40.1)		10.20 (42.3)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	18 (2,580)	24 (3,550)		28 (9,240)
	Backcalculated Young's Modulus, MPa (psi)	2 (300)	10 (1,400)		
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite	Semi-infinite		Semi-infinite
	Average DCPI, mm/blow (CV, %)	32.83 (52.8)	14.93 (54.0)		20.59 (88.9)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	54 (7,880)	94 (13,590)		76 (10,970)
	Backcalculated Young's Modulus, MPa (psi)	32 (4,710)	87 (12,620)		96 (13,980)

Note: Data not available in shaded cell(s).

US45N South Project Section 2 Location 5: 112+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected				2,541(368,500) 12,646 (1,834,200)
LFA Base	Backcalculated Young's Modulus, MPa (psi)				1,665 (241,500)
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)	152.4 (6.00)		
	Average DCPI, mm/blow (CV, %)	34.8 (34.0)	13.35 (41.5)		
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	68 (10,000)	118 (17,170)		
	Backcalculated Young's Modulus, MPa (psi)	117 (17,000)	483 (70,000) LTS		253 (36,700) LTS
Subgrade Layer 2	DCPAN Thickness, mm (in)	240.20 (9.46)	269.95 (10.63)		255.52 (10.06)
	Average DCPI, mm/blow (CV, %)	14.91 (12.3)	8.10 (29.7)		12.92 (41.3)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	17 (2,420)	45 (6,500)		20 (2,890)
	Backcalculated Young's Modulus, MPa (psi)	3 (400)	17 (2,500)		
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite	Semi-infinite		Semi-infinite
	Average DCPI, mm/blow (CV, %)	32.42 (34.2)	24.44 (47.3)		31.43 (33.7)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	55 (7,960)	67 (9,750)		56 (8,140)
	Backcalculated Young's Modulus, MPa (psi)	44 (6,450)	95 (13,750)		117 (16,960)

Note: Data not available in shaded cell(s).

US45N South Project Section 2 Location 6: 111+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected				4,069 (590,200) 21,006 (3,046,800)
LFA Base	Backcalculated Young's Modulus, MPa (psi)				(315,600)
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)	152.4 (6.00)		
	Average DCPI, mm/blow (CV, %)	22.60 (44.4)	9.28 (41.9)		
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	91 (13,140)	137 (19,910)		
	Backcalculated Young's Modulus, MPa (psi)	77 (11,200)	483 (70,000) LTS		328 (47,600) LTS
Subgrade Layer 2	DCPAN Thickness, mm (in)	443.64 (17.74)	445.34 (17.53)		232.50 (9.15)
	Average DCPI, mm/blow (CV, %)	18.42 (29.4)	13.61 (79.2)		12.92 (41.3)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	23 (3,270)	33 (4,840)		20 (2,890)
	Backcalculated Young's Modulus, MPa (psi)	14 (2,000)	102 (14,800)		
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite	Semi-infinite		Semi-infinite
	Average DCPI, mm/blow (CV, %)	39.91 (38.71)	20.85 (25.4)		31.43 (33.7)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	23 (3,270)	75 (10,880)		56 (8,140)
	Backcalculated Young's Modulus, MPa (psi)	34 (4,950)	100 (14,470)		138 (20,000)

Note: Data not available in shaded cell(s).

US45N South Project Section 2 Location 7: 110+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected				2,574 (373,300) 13,780 (1,998,700)
LFA Base	Backcalculated Young's Modulus, MPa (psi)				1,477 (214,200)
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)	152.4 (6.00)		
	Average DCPI, mm/blow (CV, %)	27.14 (12.9)	13.75 (51.9)		
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	81 (11,720)	117 (16,940)		
	Backcalculated Young's Modulus, MPa (psi)	40 (5,800)	142 (20,600) LTS		284 (41,200) LTS
Subgrade Layer 2	DCPAN Thickness, mm (in)	536.43 (21.12)	310.60 (12.23)		501.93 (19.76)
	Average DCPI, mm/blow (CV, %)	23.05 (39.1)	20.39 (27.8)		50.27 (20.9)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	23 (3,320)	14 (2,020)		15 (2,110)
	Backcalculated Young's Modulus, MPa (psi)	102 (14,800)	83 (12,100)		
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite	Semi-infinite		Semi-infinite
	Average DCPI, mm/blow (CV, %)	23.70 (10.5)	29.64 (30.8)		56.23 (23.6)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	69 (9,960)	59 (8,500)		36 (5,140)
	Backcalculated Young's Modulus, MPa (psi)	132 (19,200)	131 (19,050)		202 (29,300)

Note: Data not available in shaded cell(s).

US45N South Project Section 2 Location 8: 109+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected				2,133 (309,400) 13,200 (1,914,600)
LFA Base	Backcalculated Young's Modulus, MPa (psi)				600 (87,000)
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)	152.4 (6.00)		
	Average DCPI, mm/blow (CV, %)	18.85 (42.8)	17.45 (21.1)		
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	100 (14,530)	104 (15,130)		
	Backcalculated Young's Modulus, MPa (psi)	45 (6,500)	102 (35,500) LTS		180 (26,100) LTS
Subgrade Layer 2	DCPAN Thickness, mm (in)	553.38 (21.79)	363.01 (14.29)		289.30 (11.39)
	Average DCPI, mm/blow (CV, %)	18.50 (40.0)	8.53 (44.0)		11.57 (39.8)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	30 (4,410)	53 (7,740)		27 (3,960)
	Backcalculated Young's Modulus, MPa (psi)	32 (4,900)	81 (11,700)		
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite	Semi-infinite		Semi-infinite
	Average DCPI, mm/blow (CV, %)	14.20 (95.5)	12.02 (75.9)		7.94 (32.2)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	96 (14,000)	108 (15,620)		140 (20,270)
	Backcalculated Young's Modulus, MPa (psi)	103 (14,870)	198 (28,660)		221 (32,060)

Note: Data not available in shaded cell(s).

US45N South Project Section 2 Location 9: 108+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected				2,848 (413,100) 17,644 (2,559,100)
LFA Base	Backcalculated Young's Modulus, MPa (psi)				431 (62,500)
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)	152.4 (6.00)		
	Average DCPI, mm/blow (CV, %)	20.38 (58.4)	14.29 (46.0)		
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	96 (13,930)	115 (16,650)		
	Backcalculated Young's Modulus, MPa (psi)	68 (9,800)	245 (35,500) LTS		218 (31,600) LTS
Subgrade Layer 2	DCPAN Thickness, mm (in)	372.54 (14.67)	252.09 (9.92)		416.40 (16.39)
	Average DCPI, mm/blow (CV, %)	11.94 (22.8)	8.17 (45.5)		10.16 (33.6)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	33 (4,760)	42 (6,110)		47 (6,840)
	Backcalculated Young's Modulus, MPa (psi)	45 (6,500)	80 (11,600)		
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite	Semi-infinite		Semi-infinite
	Average DCPI, mm/blow (CV, %)	14.27 (54.6)	10.20 (64.6)		14.43 (42.7)
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	96 (14,000)	119 (17,330)		96 (13,890)
	Backcalculated Young's Modulus, MPa (psi)	122 (17,660)	184 (26,720)		204 (29,650)

Note: Data not available in shaded cell(s).

US45N North Project Section 1 Location 1: 461+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected		2,343 (339,800) 2,259 (327,600)	4,624 (670,700) 8,915 (1,293,100)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)		1,011 (146,700)	1,040 (150,800)	
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)			
	Average DCPI, mm/blow (CV, %)	72.03 (44.4)			
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	32 (4,610)			
	Backcalculated Young's Modulus, MPa (psi)	30 (4,200)	295 (42,800) LTS	110 (15,900) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)	384.72 (15.15)		428.21 (16.86)	
	Average DCPI, mm/blow (CV, %)	28.08 (32.9)		26.76 (31.1)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	13 (1,840)		15 (2,150)	
	Backcalculated Young's Modulus, MPa (psi)	23 (3,400)			
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite		Semi-infinite	
	Average DCPI, mm/blow (CV, %)	51.24 (35.3)		25.22 (23.1)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	38 (5,560)		66 (9,540)	
	Backcalculated Young's Modulus, MPa (psi)	59 (8,590)	130 (18,830)	160 (23,240)	

Note: Data not available in shaded cell(s).

US45N North Project Section 1 Location 2: 462+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected		1,891 (274,300) 1,695 (245,900)	3,961 (574,500) 7,637 (1,107,700)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)		530 (76,900)	556 (80,700)	
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)			
	Average DCPI, mm/blow (CV, %)	33.91 (22.6)			
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	69 (10,010)			
	Backcalculated Young's Modulus, MPa (psi)	161 (23,400)	214 (31,100) LTS	177 (25,600) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)	443.64 (17.47)		290.83 (11.45)	
	Average DCPI, mm/blow (CV, %)	51.16 (21.0)		22.44 (61.6)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	12 (1,800)		12 (1,730)	
	Backcalculated Young's Modulus, MPa (psi)	11 (1,600)			
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite		Semi-infinite	
	Average DCPI, mm/blow (CV, %)	57.50 (28.4)		23.51 (36.9)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	35 (5,040)		69 (10,010)	
	Backcalculated Young's Modulus, MPa (psi)	53 (7,620)	132 (19,170)	160 (23,240)	

Note: Data not available in shaded cell(s).

US45N North Project Section 1 Location 3: 463+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected		2,580 (374,200) 2,150 (311,900)	4,352 (631,300) 8,704 (1,262,500)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)		890 (129,100)	849 (123,100)	
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)			
	Average DCPI, mm/blow (CV, %)	33.46 (10.2)			
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	70 (10,110)			
	Backcalculated Young's Modulus, MPa (psi)	46 (6,600)	284 (41,200) LTS	104 (15,100) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)	275.89 (10.86)		373.69 (14.71)	
	Average DCPI, mm/blow (CV, %)	24.54 (20.7)		22.19 (30.3)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	11 (1,520)		15 (2,200)	
	Backcalculated Young's Modulus, MPa (psi)	15 (2,200)			
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite		Semi-infinite	
	Average DCPI, mm/blow (CV, %)	34.50 (21.7)		26.78 (26.7)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	52 (7,600)		63 (9,140)	
	Backcalculated Young's Modulus, MPa (psi)	88 (12,750)	143 (20,780)	160 (23,240)	

Note: Data not available in shaded cell(s).

US45N North Project Section 1 Location 4: 464+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected		2,352 (341,200) 2,722 (394,800)	3,913 (567,600) 7,015 (1,017,500)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)		529 (76,700)	650 (94,400)	
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)			
	Average DCPI, mm/blow (CV, %)	34.13 (16.4)			
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	69 (9,960)			
	Backcalculated Young's Modulus, MPa (psi)	41 (6,000)	265 (38,500) LTS	147 (21,300) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)	458.80 (18.06)		434.54 (17.11)	
	Average DCPI, mm/blow (CV, %)	31.65 (35.5)		25.56 (41.3)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	14 (2,080)		16 (2,280)	
	Backcalculated Young's Modulus, MPa (psi)	34 (4,900)			
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite		Semi-infinite	
	Average DCPI, mm/blow (CV, %)	28.08 (27.7)		23.85 (22.0)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	61 (8,830)		68 (9,920)	
	Backcalculated Young's Modulus, MPa (psi)	63 (9,170)	158 (22,860)	164 (23,760)	

Note: Data not available in shaded cell(s).

US45N North Project Section 1 Location 5: 465+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected		2,118 (307,200) 2,364 (342,800)	3,658 (530,600) 10,158 (1,473,400)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)		656 (95,100)	747 (108,400)	
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)			
	Average DCPI, mm/blow (CV, %)	35.69 (49.5)			
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	66 (9,620)			
	Backcalculated Young's Modulus, MPa (psi)	34 (4,900)	268 (38,900) LTS	184 (26,700) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)	254.00 (10.00)		412.08 (16.22)	
	Average DCPI, mm/blow (CV, %)	32.57 (21.4)		29.51 (21.8)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	8 (1,160)		13 (1,910)	
	Backcalculated Young's Modulus, MPa (psi)	19 (2,700)			
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite		Semi-infinite	
	Average DCPI, mm/blow (CV, %)	27.06 (34.1)		25.40 (23.8)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	63 (9,070)		65 (9,490)	
	Backcalculated Young's Modulus, MPa (psi)	66 (9,510)	145 (21,020)	175 (25,380)	

Note: Data not available in shaded cell(s).

US45N North Project Section 1 Location 6: 466+04

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected		2,184 (316,800) 2,437 (353,400)	4,004 (580,700) 6,981(1,612,500)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)		643 (93,300)	885 (128,400)	
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)			
	Average DCPI, mm/blow (CV, %)	26.77 (43.3)			
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	82 (11,830)			
	Backcalculated Young's Modulus, MPa (psi)	66 (9,600)	272 (39,500) LTS	125 (18,100) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)	477.54 (18.80)		278.39 (10.96)	
	Average DCPI, mm/blow (CV, %)	35.44 (25.4)		25.31 (38.2)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	14 (2,070)		10 (1,490)	
	Backcalculated Young's Modulus, MPa (psi)	28 (4,000)			
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite		Semi-infinite	
	Average DCPI, mm/blow (CV, %)	36.97 (39.6)		20.06 (26.1)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	50 (7,210)		77 (11,170)	
	Backcalculated Young's Modulus, MPa (psi)	76 (11,020)	154 (22,390)	178 (25,760)	

Note: Data not available in shaded cell(s).

US45N North Project Section 1 Location 7: 467+00

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected		1,822 (264,200) 2,186 (317,000)	3,592 (521,000) 10,730 (1,556,200)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)		440 (63,800)	256 (37,200)	
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)			
	Average DCPI, mm/blow (CV, %)	27.84 (22.1)			
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	79 (11,530)			
	Backcalculated Young's Modulus, MPa (psi)	55 (8,000)	203 (29,400) LTS	136 (19,700) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)	297.30 (11.70)		312.29 (12.30)	
	Average DCPI, mm/blow (CV, %)	28.23 (26.9)		19.52 (35.4)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	10 (1,440)			
	Backcalculated Young's Modulus, MPa (psi)	24 (3,500)		123 (17,900)	
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite		Semi-infinite	
	Average DCPI, mm/blow (CV, %)	38.75 (22.7)		26.41 (27.8)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	48 (6,950)		64 (9,230)	
	Backcalculated Young's Modulus, MPa (psi)	76 (11,050)	138 (20,060)	168 (24,530)	

Note: Data not available in shaded cell(s).

US45N North Project Section 1 Location 8: 467+90

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected		2,008 (291,200) 2,592 (375,900)	4,698 (681,400) 14,033 (2,035,400)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)		468 (67,900)	464 (67,300)	
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)			
	Average DCPI, mm/blow (CV, %)	49.99 (45.6)			
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	49 (7,100)			
	Backcalculated Young's Modulus, MPa (psi)	34 (5,000)	217 (31,500) LTS	188 (27,200) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)	236.58 (9.31)		410.32 (16.15)	
	Average DCPI, mm/blow (CV, %)	39.85 (43.9)		24.14 (31.1)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	7 (1,020)		15 (2,240)	
	Backcalculated Young's Modulus, MPa (psi)	17 (2,400)			
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite		Semi-infinite	
	Average DCPI, mm/blow (CV, %)	26.55 (38.9)		20.41 (36.6)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	63 (9,200)		76 (11,040)	
	Backcalculated Young's Modulus, MPa (psi)	84 (12,230)	148 (21,490)	176 (25,500)	

Note: Data not available in shaded cell(s).

US45N North Project Section 1 Location 9: 469+06

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected		2,856 (414,200) 3,686 (534,600)	3,394 (492,400) 10,517 (1,525,400)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)		977 (141,700)	632 (917,100)	
Subgrade Layer 1	DCPAN Thickness, mm (in)	152.4 (6.00)			
	Average DCPI, mm/blow (CV, %)	37.15 (16.6)			
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	64 (9,310)			
	Backcalculated Young's Modulus, MPa (psi)	28 (4,000)	327 (47,400)	216 (31,400) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)	379.01 (14.92)		562.29 (22.14)	
	Average DCPI, mm/blow (CV, %)	34.97 (42.1)		20.08 (51.9)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	11 (1,580)		28 (4,120)	
	Backcalculated Young's Modulus, MPa (psi)	39 (5,600)			
Subgrade Layer 3	DCPAN Thickness, mm (in)	Semi-infinite		Semi-infinite	
	Average DCPI, mm/blow (CV, %)	24.36 (30.0)		16.72 (32.2)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)	67 (9,770)		87 (12,610)	
	Backcalculated Young's Modulus, MPa (psi)	67 (9,650)	166 (24,140)	172 (24,990)	

* LFA Base Core Young's Modulus = 68 (9,857). Coring was for Cycle 3 only.

Note: Data not available in shaded cell(s).

SR25S Section 2 Location 1: 1354+45

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected			8,529 (1,237,000) 7,929 (1,150,000)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)			1,778 (257,900) *	
Subgrade Layer 1	DCPAN Thickness, mm (in)				
	Average DCPI, mm/blow (CV, %)				
	DCPAN Modulus based on Avg. DCPI, MPa (psi)				
	Backcalculated Young's Modulus, MPa (psi)			314 (45,600) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)			282.96 (11.14)	
	Average DCPI, mm/blow.0 (CV, %)			6.03 (60.6)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			76 (11,030)	
	Backcalculated Young's Modulus, MPa (psi)				
Subgrade Layer 3	DCPAN Thickness, mm (in)			Semi-infinite	
	Average DCPI, mm/blow (CV, %)			11.39 (36.5)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			112 (16,170)	
	Backcalculated Young's Modulus, MPa (psi)			238 (34,450)	

* LFA Base Core Young's Modulus = 366 (53,074). Coring was for Cycle 3 only.

Note: Data not available in shaded cell(s).

SR25S Section 2 Location 2: 1353+95
* Check with core table

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected			4,874 (706,900) 4,531 (657,200)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)			8,813 (1,278,200) *	
Subgrade Layer 1	DCPAN Thickness, mm (in)				
	Average DCPI, mm/blow (CV, %)				
	DCPAN Modulus based on Avg. DCPI, MPa (psi)				
	Backcalculated Young's Modulus, MPa (psi)			372 (53,400) LTS **	
Subgrade Layer 2	DCPAN Thickness, mm (in)			227.77 (8.97)	
	Average DCPI, mm/blow (CV, %)			7.22 (37.7)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			48 (6,990)	
	Backcalculated Young's Modulus, MPa (psi)				
Subgrade Layer 3	DCPAN Thickness, mm (in)			Semi-infinite	
	Average DCPI, mm/blow (CV, %)			11.79 (35.4)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			109 (15,820)	
	Backcalculated Young's Modulus, MPa (psi)			224 (32,510)	

* LFA Base Core Young's Modulus = 157 (22,752). Coring was for Cycle 3 only.
** LTS Subgrade Core Young's Modulus = 290 (42,041). Coring was for Cycle 3 only.

Note: Data not available in shaded cell(s).

SR25S South Project Section 2 Location 3: 1352+95

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected			3,859 (559,700) 3,933 (520,400)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)			5,177 (750,900)	
Subgrade Layer 1	DCPAN Thickness, mm (in)				
	Average DCPI, mm/blow (CV, %)				
	DCPAN Modulus based on Avg. DCPI, MPa (psi)				
	Backcalculated Young's Modulus, MPa (psi)			147 (21,300) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)			233.22 (9.18)	
	Average DCPI, mm/blow (CV, %)			7.09 (68.7)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			50 (7,300)	
	Backcalculated Young's Modulus, MPa (psi)				
Subgrade Layer 3	DCPAN Thickness, mm (in)			Semi-infinite	
	Average DCPI, mm/blow (CV, %)			14.89 (25.9)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			94 (13,610)	
	Backcalculated Young's Modulus, MPa (psi)			218 (31,670)	

Note: Data not available in shaded cell(s).

SR25S Section 2 Location 4: 1351+95

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected			3,285 (476,400) 3,053 (442,900)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)			3,918 (568,200)	
Subgrade Layer 1	DCPAN Thickness, mm (in)				
	Average DCPI, mm/blow (CV, %)				
	DCPAN Modulus based on Avg. DCPI, MPa (psi)				
	Backcalculated Young's Modulus, MPa (psi)			415 (60,200) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)			228.58 (9.00)	
	Average DCPI, mm/blow (CV, %)			10.43 (34.0)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			27 (3,900)	
	Backcalculated Young's Modulus, MPa (psi)				
Subgrade Layer 3	DCPAN Thickness, mm (in)			Semi-infinite	
	Average DCPI, mm/blow (CV, %)			15.89 (28.1)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			90 (13,040)	
	Backcalculated Young's Modulus, MPa (psi)			219 (31,700)	

Note: Data not available in shaded cell(s).

SR25S Section 2 Location 5: 1350+95

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected			4,798 (695,900) 4,460 (647,000)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)			1,799 (260,900)	
Subgrade Layer 1	DCPAN Thickness, mm (in)				
	Average DCPI, mm/blow (CV, %)				
	DCPAN Modulus based on Avg. DCPI, MPa (psi)				
	Backcalculated Young's Modulus, MPa (psi)			243 (35,200) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)			226.80 (8.93)	
	Average DCPI, mm/blow (CV, %)			9.86 (32.5)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			29 (4,230)	
	Backcalculated Young's Modulus, MPa (psi)				
Subgrade Layer 3	DCPAN Thickness, mm (in)			Semi-infinite	
	Average DCPI, mm/blow (CV, %)			16.89 (33.6)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			86 (12,530)	
	Backcalculated Young's Modulus, MPa (psi)			192 (28,520)	

Note: Data not available in shaded cell(s).

SR25S Section 2 Location 6: 1349+95

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected			4,236 (614,400) 3,938 (571,100)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)			1,658 (240,500)	
Subgrade Layer 1	DCPAN Thickness, mm (in)				
	Average DCPI, mm/blow (CV, %)				
	DCPAN Modulus based on Avg. DCPI, MPa (psi)				
	Backcalculated Young's Modulus, MPa (psi)			271 (39,300) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)			546.12 (21.50)	
	Average DCPI, mm/blow (CV, %)			11.56 (46.9)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			56 (8,060)	
	Backcalculated Young's Modulus, MPa (psi)				
Subgrade Layer 3	DCPAN Thickness, mm (in)			Semi-infinite	
	Average DCPI, mm/blow (CV, %)			15.93 (25.6)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			90 (13,020)	
	Backcalculated Young's Modulus, MPa (psi)			193 (28,010)	

Note: Data not available in shaded cell(s).

SR25S Section 2 Location 7: 1348+95

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected			5,004 (720,200) 4,825 (699,800)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)			1,661 (240,900)	
Subgrade Layer 1	DCPAN Thickness, mm (in)				
	Average DCPI, mm/blow (CV, %)				
	DCPAN Modulus based on Avg. DCPI, MPa (psi)				
	Backcalculated Young's Modulus, MPa (psi)			285 (41,300) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)			152.4	
	Average DCPI, mm/blow (CV, %)			2.87 (92.5)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			198 (28,770)	
	Backcalculated Young's Modulus, MPa (psi)				
Subgrade Layer 3	DCPAN Thickness, mm (in)			Semi-infinite	
	Average DCPI, mm/blow (CV, %)			12.08 (26.8)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			107 (15,580)	
	Backcalculated Young's Modulus, MPa (psi)			208 (30,130)	

Note: Data not available in shaded cell(s).

SR25S Section 2 Location 8: 1347+95

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected			3,910 (567,100) 3,910 (567,100)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)			2,024 (293,600)	
Subgrade Layer 1	DCPAN Thickness, mm (in)				
	Average DCPI, mm/blow (CV, %)				
	DCPAN Modulus based on Avg. DCPI, MPa (psi)				
	Backcalculated Young's Modulus, MPa (psi)			264 (38,300) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)			240.07 (9.45)	
	Average DCPI, mm/blow (CV, %)			12.67 (42.2)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			21 (3,030)	
	Backcalculated Young's Modulus, MPa (psi)				
Subgrade Layer 3	DCPAN Thickness, mm (in)			Semi-infinite	
	Average DCPI, mm/blow (CV, %)			17.98 (27.7)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			83 (12,020)	
	Backcalculated Young's Modulus, MPa (psi)			194 (28,080)	

Note: Data not available in shaded cell(s).

SR25S Section 2 Location 9: 1346+95

Layer Information		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Asphalt	In situ Backcalculated Young's Modulus, MPa (psi); Corrected			3,085 (447,400) 3,085 (447,400)	
LFA Base	Backcalculated Young's Modulus, MPa (psi)			2,046 (296,800)	
Subgrade Layer 1	DCPAN Thickness, mm (in)				
	Average DCPI, mm/blow (CV, %)				
	DCPAN Modulus based on Avg. DCPI, MPa (psi)				
	Backcalculated Young's Modulus, MPa (psi)			299 (43,300) LTS	
Subgrade Layer 2	DCPAN Thickness, mm (in)			152.40 (6.00)	
	Average DCPI, mm/blow (CV, %)			5.06 (38.0)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			72 (10,400)	
	Backcalculated Young's Modulus, MPa (psi)				
Subgrade Layer 3	DCPAN Thickness, mm (in)			Semi-infinite	
	Average DCPI, mm/blow (CV, %)			11.50 (34.2)	
	DCPAN Modulus based on Avg. DCPI, MPa (psi)			111 (16,070)	
	Backcalculated Young's Modulus, MPa (psi)			219 (31,750)	

Note: Data not available in shaded cell(s).