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Utilizing the Falling Weight Deflectometer in Evaluating Soil Support Values of Pavement Layers

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By
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16. Abstract

Soil Support Value (SSV) is one of the subgrade parameters that are needed for pavement rehabilitation. It is an empirical measure of the stiffness value of the foundation soil. It is similar to the modulus of subgrade reaction except that the SSV is a dimensionless property like the LBR and the CBR measures that are occasionally being used for pavement design. The SSV used to be obtained from the Dynaflect testing technique. Since the Florida Department Of Transportation decided to discontinue the use of the Dynaflect test for pavement evaluation and replace it with the Falling Weight Deflectometer, it was necessary to establish an operational procedures for the FWD to include the testing setup as well as the selection of a proper backcalculation analysis to determine subgrade stiffnesses. There are different types of FWD setups. The one that the FDOT is using (DYNATEST 8000) has certain dropping load capacities and sensor distances. This configuration is not necessarily similar to those FWDs used by other states. At the beginning, the concern was the configuration of the FWD and its suitability for Florida roads. Another concern was the reasonableness of the subgrade moduli values (MR) obtained from the FWD and the comparison with the SSV obtained from the Dynaflect test. On the other hand, If the FWD is well calibrated, the reasonableness of the FWD to predict the MR values is governed by the analytical back calculation method that is used to estimate these values. The AASHTO formula is among these methods. It is simple and practical and can even be used to obtain MR values from Dynaflect tests. Unlike the other analytical methods, the AASHTO formula has to be adjusted to obtain a comparable MR value. The C factor is needed for this adjustment.

In this study, several sources of FWD and Dynaflect data were pursued. Among these sources were, field tests on selected sites, data from previous studies such as the SAP project, the FDOT 300 mile test sites, the LTPP database, and the FDOT water table and moisture study. Data from these resources were analyzed using AASHTO, MODULUS, and Dynaflect methods. Moduli values from these methods were compared with each other. The C factor was obtained from all of these tests and found to be in the range of 0.28 to 0.3 for the FWD tests.

The characteristics of the deflection basins were investigated and relationships was obtained to predict the FWD deflections from any dropping load. These relationships are site specific, which means each site has its own parameters that are different than the others and these parameters have to be used in these relationships. The water table was found to greatly affect the moduli values of the subgrade. Shallow ground water tables resulted in lower moduli values. The same was found for the effect of moisture content. The higher the moisture content is the lower the moduli values. An analytical model was developed in this study to signify these effects.

The finite element analysis gave a close look at the pavement behavior during FWD testing. FEA was found to be a useful tool as a backcalculation analysis. It is a genuine mechanistic approach for estimating the moduli values. However, it is not a simple approach and not practical for frequent use by nonspecialists. The FEA results indicated that the stiffer subgrade moduli values required shorter sensor distances. Selecting the deflection values of D6 was found reasonable for most of the pavement sections in Florida. The FEA suggested lower distances in cases of higher stiffness values or shallow bedrock depths.

The LTPP database holds a large mount of entries on pavement testing. It contains about 98,000 FWD deflection basin. These basins were used in the study to develop the relationship between the FWD deflections and the dropping load for each testing section. The α, β, , and ζ parameters signify the section properties. These parameters varied based on the geometry and properties of the pavement layers.

The FWD deflection measurements were found to be sufficient to obtain MR values, providing the selection of the proper backcalculation method. The AASHTO formula, after correction, and the EVERCALC, were found to be reasonable methods for estimating the MR values. Unlike widely used MODULUS 5.0, the EVERCALC method has better sensitivity of the selected seed values. Also it notifies the user of any irregular FWD deflection measurements. The repetition of these irregularities is a good indiction of the need for sensor calibration. Also EVERCALC can be used with different operating systems. The lack of history records from the FWD has confined the use of this device to the estimation of the moduli values. If the time-amplitude records are captured, there is a great chance that other pavement parameters can be estimated. The analytical techniques to estimate these additional parameters are available; however, the capability of the current FWD units has to be upgraded more to capture and store all of these records. In general, the FWD testing technique is suitable for most of the pavement cross sections in Florida except for the thick and rigid surface layers. A great caution must be exercised when back-calculating the moduli values of these sections. It is recommended that more than one backcalculation method be used for these cases. Also the current backcalculation methods are not sensitive enough to predict the effect of temperature variation and the depth of the bedrock. The database that is being gathered from all around the state along with the use of DCP will be of great benefit to provide necessary information about the temperature and layering setup of the Florida pavements. This data base should supplement the results of the backcalculation analysis.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

DISCLAIMER

The opinions findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Florida Department of Transportation and the Federal Highway Administration.

Prepared in cooperation with the Florida Department of Transportation and the Federal Highway Administration.

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EXECUTIVE SUMMARY

Soil Support Value (SSV) is one of the subgrade parameters that are needed for pavement rehabilitation. It is an empirical measure of the stiffness value of the foundation soil. It is similar to the modulus of subgrade reaction except that the SSV is a dimensionless property like the LBR and the CBR measures that are occasionally being used for pavement design. The SSV used to be obtained from the Dynaflect testing technique. Since the Florida Department of Transportation decided to discontinue the use of the Dynaflect test for pavement evaluation and replace it with the Falling Weight Deflectometer, it was necessary to establish an operational procedure for the FWD to include the testing setup as well as the selection of a proper backcalculation analysis to determine subgrade stiffnesses. There are different types of FWD setups. The one that the FDOT is using (DYNATEST 8000) has certain dropping load capacities and sensor distances. This configuration is not necessarily similar to those FWDs used by other states. At the beginning, the concern was the configuration of the FWD and its suitability for Florida roads. Another concern was the reasonableness of the subgrade moduli values (MR) obtained from the FWD and the comparison with the SSV obtained from the Dynaflect test. On the other hand, If the FWD is well calibrated, the reasonableness of the FWD to predict the MR value is governed by the analytical backcalculation method that is used to estimate these values. The AASHTO formula is among these methods. It is simple and practical and can even be used to obtain MR values from Dynaflect tests. Unlike the other analytical methods, AASHTO formula has to be adjusted to obtain a comparable MR value. The C factor is needed for this adjustment. In this study, several sources of FWD and Dynaflect data were pursued. Among these sources were, field tests on selected sites, data from previous studies such as the SAP project, the FDOT 300 mile test sites, the LTPP database, and a previous study by FDOT on the effect of water table and moisture content on resilient modulus values. Data from these resources were analyzed using AASHTO, MODULUS, and Dynaflect methods. Moduli values from these methods were compared with each other. The C factor was obtained from all of these tests and found to be in the range of 0.28 to 0.3 for the FWD tests.

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Chapter 1

1.1 Introduction

The Florida Department of Transportation (FDOT) manages 39,780 lane miles of highways in the state. More than 2,200 lane miles of asphalt pavement of the Florida highway network are rehabilitated every year. To facilitate managing this demanding task and to efficiently allocate resources, the FDOT pavement evaluation engineers and technicians are relying more and more on nondestructive testing (NDT) techniques to assess the structural integrity of the existing highways and to provide the data base needed for improving design and construction techniques of a new generation of pavements and pavement overlays. Among the primary parameters needed for pavement evaluation are the soil support values of pavement layers.

In this regard, the Florida Department of Transportation has been using various nondestructive testing techniques including Dynaflect and Falling Weight Deflectometer (FWD). These techniques utilize the deflection basin of the pavement surface produced by dynamically applied loads to predict elastic parameters of the pavement layers. Accordingly, in the deformation methods appreciable surface loads are applied to induce measurable deflections in the pavement layers. Large deflections can be attained from large impact loads. In many cases, it is preferable to apply forces comparable to those of the actual service loads on pavements.

The differences between the Dynaflect and FWD methods are mainly in the type and magnitude of applied loads. In the Dynaflect method, a static weight of 8.89 kN to 9.34 kN (2000 lb to 2100 lb) is applied to the pavement through a pair of rigid steel wheels and a steady-state half-sine dynamic force of 4.45 kN (1000 lb) peak-to-peak is then superimposed using a pair of unbalanced flywheels rotating in opposite directions at a constant frequency of 8 Hz. The surface deflection is measured by using five velocity transducers (geophones). The falling weight deflectometer (FWD) technique, on the other hand, uses a transient impulse load to produce the deflection basin on the pavement surface. Typical loads generated by FWD are in the range of 7 kN to 120 kN (1,500 lb to 27,000 lb force). The frequency content of the impact load is usually between 1Hz to 100Hz, and the impulse load form is approximately a half-sine shaped with a duration of 25-35 msec.

The popularity of the FWD method over other testing techniques is due to various factors including technical aspects of the procedure as well as the acceptance of the technique as a research and production tool. Several studies have shown that impact loads produced by FWD are similar to those produced by actual traffic loads. For instance, a truck running at 70 km/h produces a load duration of about 30 milliseconds and an equivalent peak load of 65 kN. Additionally, knowing that pavement material properties are function of the deflection amplitude, light load applications of some NDT techniques such as seismic and Dynaflect methods may not convey the actual pavement parameters. Another aspect for selecting the FWD is the wide acceptance of the testing technique as an important tool for research into pavement design for more than a decade. Also, the device has earned a major role in pavement management. The Strategic Highway Research Program (SHRP) adopted the FWD as a key piece of equipment for assessing the structural capacity of long-term pavement performance (LTPP) test sections. Under the LTPP program, FWD testing is used at all General Pavement Studies (GPS) and Specific Pavement Studies (SPS) test sites. Most sections are tested about once every five years. At selected sections, FWD tests are performed 12 to 14 times a year, every second year, to check for seasonal changes in the pavement strength.

Recent research studies found that back calculated subgrade resilient modulus values should be adjusted by a correction factor C that is between 0 and 1.0. The AASHTO design guide recommends that the values of C should be adjusted to reflect local soil conditions. The adjusted resilient modulus values will be consistent with those values obtained at the AASHO road test. The FDOT has replaced the Dynaflect units with the DYNATEST FWD units which can better simulate the traffic loads. Therefore, a research study is needed on the FWD to insure that reliable modulus values can be obtained with the FWD for typical soil conditions in Florida. In addition, the effect of the water table level and temperature on deflection measurements and back calculated resilient modulus values can be evaluated. The ultimate goal is to fully implement the FWD to obtain resilient modulus values for subgrade layers.

1.2 Study Objectives

For about two decades, the FDOT utilized the Dynaflect test for back calculating resilient modulus values of subgrade. Currently, the FDOT as well many other state highway agencies have replaced their Dynaflect systems with the FWD. As compared to the Dynaflect, the FWD can better simulate the actual traffic loads on pavement. Shifting the emphasis in pavement evaluation from using the Dynaflect method to the FWD method requires that the vast amount of measurements that were taken using the Dynaflect be converted to the FWD method. The simplest procedure to convert the Dynaflect measurements to those of the FWD is to establish a direct correlation between measurements obtained at the same pavement sections and under the same conditions. If a rational relationship does not exist, more parameters such as the geometry of the layers have to be considered in the analysis. Also, to include parameters to such correlation requires a large amount of measurements from both techniques. A study was recently performed at the State Materials Office to statistically correlate modulus values obtained with the Dynaflect and the FWD [1]. That study resulted in an evaluation procedure which produces FWD modulus values consistent with those obtained with the Dynaflect.

The main objectives of this study are to further refine the developed procedure and to insure that the backcalculated modulus values are consistent with the AASHTO design guide.

1.3 Study Organization

The following lists all the tasks that were conducted in this study:

Task 1: Literature Search

Task 2: Selection of Test Sections

Task 3: Data Collection

Task 4: Laboratory Testing

Task 5: Data Analysis and Report Preparation

Task 6: Developing Implementation Guidelines

Through careful coordination with the FDOT pavement evaluation section, these tasks were successfully conducted. Task # 1 involved a literature search of the state of the art practice of the FWD. Also in Task # 1 a comprehensive national survey was conducted to identify practices of other state DOTs related to NDT. The results from this survey will help in determining national trends and insure that FDOT practices are consistent with the national standards. Findings from this survey were published in the research report FL/DOT/SMO/01-452.

Task # 2 involved identification of possible test sections, and identification of test locations. Some of the test locations were selected by the FDOT and the rest of the sections were obtained from the Long Term Pavement Performance (LTPP) program database. Test locations from previous studies were also selected, including those sections of the SPA study and the FDOT 300 mile test sections.

Task # 3 was carried out with Task # 2. However, Task # 3.4.3 "Surface Distress Survey" as it was described in the proposal has only been done on the sections that were tested by the FDOT. No significant cracking was noticed in these sections. Therefore, this factor was not considered during the backcalculation analysis of the subgrade moduli. Sample coring was also part of Task # 3 and was done on a limited basis. Most of the coring information was taken from the previous SPA project. The determination of the in situ density and moisture content was part of the 300 mile measurements. These measurements and the depth of the water table were taken by FDOT materials office at different times. Laboratory measurements of representative subgrade samples were taken from previous studies. The measurements were selected for those sections used for the FWD and the Dynaflect tests. Also for the same cross sections, some laboratory measurements were extracted from the LTPP database.

Task 3.4.7 involved the use of the FDOT DCP. This testing technique was used on May 3, 2001 in a local airport, Brevard County. A total of 25 test locations were used in this segment of the study. Measurements from this test included, penetration vs. number of blows, CBR, LBR and Moduli values of the pavement layers. A set of FWD test were also conducted at the same locations of the DCP. Thickness verification in Task 3.4.8 was done based on the cores obtained, LTPP data as well as the FDOT 300 mile tests.

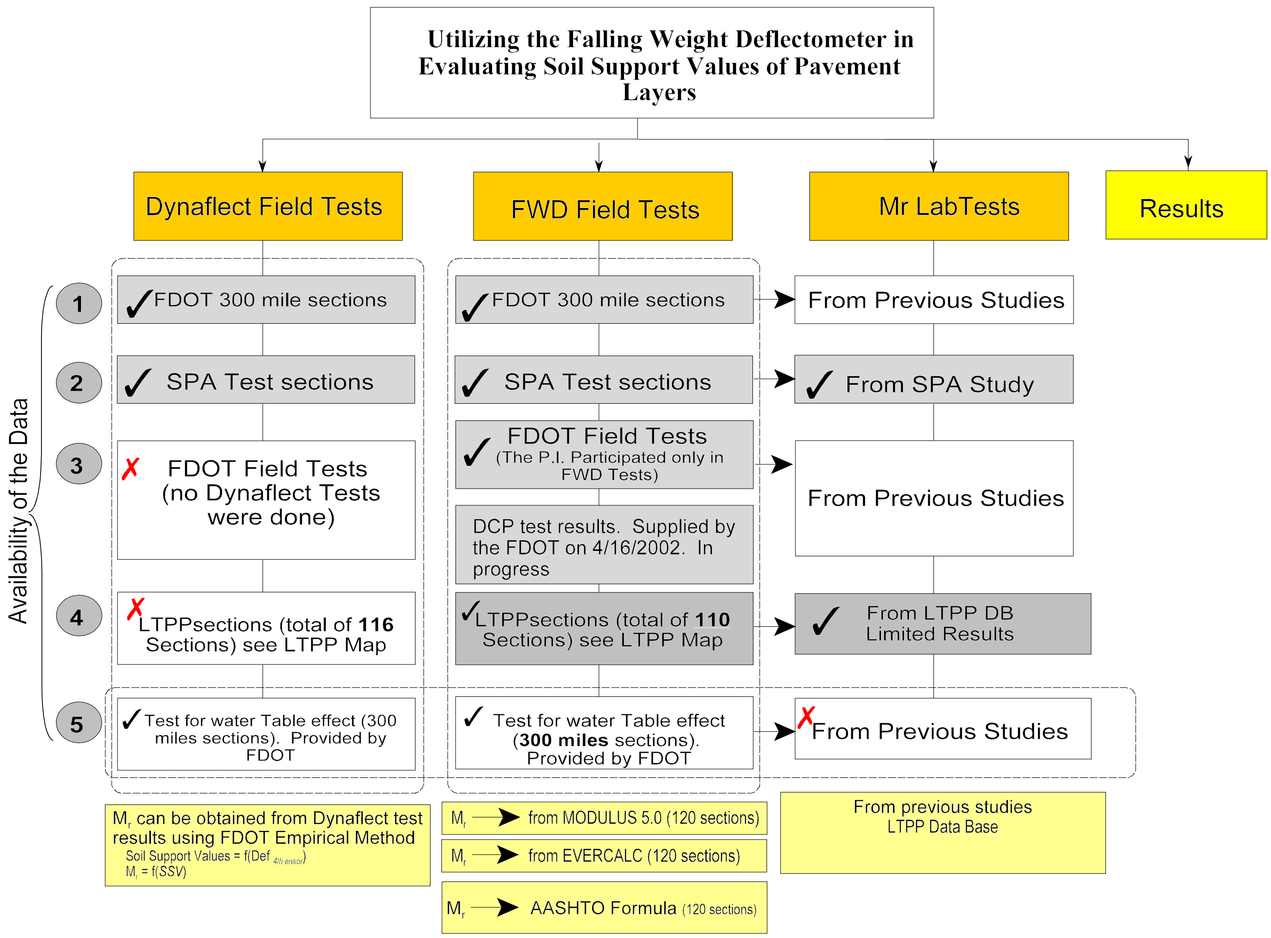
Resilient modulus measurements in Task 4.0 were done using the FWD and the Dynaflect tests. Four backcalculation methods were used for this part including the FDOT empirical procedure for the Dynaflect, MODULUS 5.1, EVERCALC, and AASHTO semi-empirical method for calculating MR from FWD test. Results from the four methods were compared with the extracted MR values from the LTPP database. The final conclusion of the study summarizes in detail the correlations obtained and the proposed testing setup for the FWD.

Since the use of the Dynaflect test has been discontinued by the FDOT pavement evaluation section, the calculated Soil Support Values, SSV, that were obtained in this study were used only to compare with the moduli values estimated from the FWD. Correlations between the SSV vs. MR can be used to convert some of the SSV measurements that were compiled during the last two decades.

In addition to the field and the database measurements of the FWD deflections basin, an attempt was done to simulate the pavement layers using three dimensional (3D) nonlinear finite element modeling. The 3D models developed in this study were limited to a pavement section on US 441. Using these models, it was possible to visualize and measure the three dimensional deflection basins as well as the influence zones of the FWD. The variable parameters used in the finite element analysis were the subgrade and base stiffness values. Unlike the conventional backcalculation methods, the depth of the bedrock in the 3D FEA has a great influence on the characteristics of the deflection basins.

The schematic diagram shown in **Figure 1.1** shows all the tasks that were performed in this study. Additional details as related to these tasks are present in the report. The inclusion of the finite element analysis is not shown in the schematics. Chapter 3 in this study will describe the models used in the analysis. Results of the study are presented in Chapter 4.

Figure 1.1 Schematic showing the sequence of activities on the current study. Activities marked by T have been completed.



Chapter 2

2.1 Introduction

The highway network is the backbone of America's transportation system, making it possible to meet the mobility and economic needs of communities, regions, and the nation as a whole. Americans use the highway system to make more than 90 percent of their passenger trips and move 69 percent of the total freight value. In addition, highways accommodate buses, bicycles, and pedestrians. Also, highways provide vital links among all modes of transportation; thus the influence of their physical and operational condition extends well beyond the impacts experienced directly by highway users. In its 2001 report, the Future Strategic Highway Research Program (F-SHRP) Committee emphasized the use of advanced technology in solving the critical highways' infrastructure and operations problems. Among the advanced technologies that the F-SHRP called for was utilization of equipment and sensing technologies and advanced data collection, storing, and analysis for assessing the conditions of pavements.

On the other side of the world, the Finnish philosophy in pavement design presumes that any treatment to the subgrade should last from 60 to 100 years, the base and subbase should last from 30 to 50 years, and the surface should have a life of from 15 to 20 years. This "bottom-up" approach to pavement design reflects the relative cost of rehabilitation associated with each of these layers and the importance of engineering in characterizing the soil and selecting materials for the lower pavement layers. Consequently, a great deal of attention should be paid to laboratory and field testing of subgrade soils. Techniques for measuring the soil characteristics and conditions, predictions of soil behavior, and methods for subgrade improvements are given top priority in research, design, and construction (Finnish National Road Administration, 1998).

Like any other structure, pavements deteriorate with time. The reasons for the deterioration may be excessive traffic load, climate and environment, pavement layer thickness, pavement distress development, pavement structure materials and subgrade characteristics, geometric design, construction practices (QA & QC), and distress maintenance. If the pavement shows signs of structural deficiencies, rehabilitation may be deemed necessary to improve the existing conditions. In order to select the appropriate rehabilitation procedures, the structural capacity of the existing pavement should be evaluated first. Considerable savings in rehabilitation costs can be procured if accurate prediction of the strength of the existing pavement is made. The magnitude of stresses and strains in pavement layers are the indicators of the structural capacity of a pavement system. In simple words, if an applied load started to cause large deformations, the pavement structure is considered weak.

Soil strength or stiffness is among the primary inputs to any pavement design procedure. In the past, this input for flexible pavements was routinely the R-values, Limerock Bearing Ratio (LBR), or CBR. These values are taken from the laboratory testing on materials in saturated conditions.
For concrete pavements, the practice was to use a modulus of subgrade reaction (k-value) estimated either from past experience or from correlations with other material properties. The value was generally adjusted to reflect the quality and thickness of base materials overlying the subgrade. Although it was widely acknowledged that the geological characteristics of pavement sites changed more frequently than the soil sampling frequency, engineers believed that laboratory testing in a

weakened state would ensure a conservative value for design purposes.

Advances in technology and the recent application of geophysical techniques to subgrade characterization have given pavement engineers greater ability to measure, analyze, and account for subsurface moisture and temperature conditions than at any previous time; however, there does not seem to be a widespread application or acceptance for much of the new technology. Instrumentation is available for measuring subsurface environmental conditions such as temperature, moisture content, and state of moisture. Techniques such as ground-penetrating radar and resistivity tomography provide indications of moisture conditions without the intrusiveness of more traditional methods, such as time-domain reflectometry or potentiometers. These methods are very useful in understanding the temporal changes in subsurface moisture conditions, which dictate the strength or stiffness of subgrade materials. The application of in situ strength or stiffness measurements is somewhat more widely accepted than measurements of in situ moisture content and state. Measurements of deflections date back to the plate bearing test (2) and the Benkleman beam procedure (3). Currently, falling weight deflectometers (FWD) are commonly used to characterize the stiffness of pavements, due to the significant research findings of the Strategic Highway Research Program (SHRP) in the late 1980s (4). Other in situ strength or stiffness measurement techniques for pavements, such as the dynamic cone penetrometer (DCP) or spectral analysis of surface waves (SASW), are not as well known, but they are gaining in some popularity. In the future, it is expected that rolling wheel deflectometers (RWD) will gain some acceptance for its advantages in continuously measuring pavement properties and at higher speed.

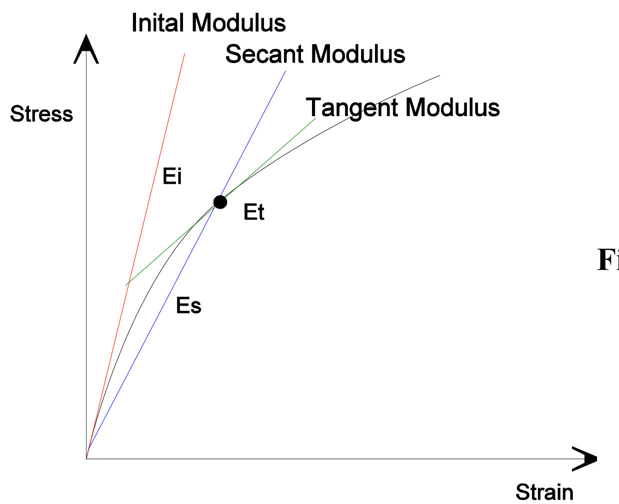


Figure 2.1 Definition of Static Elastic Modulus

2.2 Definitions

A great deal of ambiguity exists regarding the terminology associated with the material characterization used for pavement design. To provide some consistency, at least within this document, the following terms are defined:

1- **Dynamic Modulus** —The maximum axial stress applied to a material in sinusoidal loading, divided by the maximum axial strain occurring during that dynamic loading.

2- **Elastic Modulus** —The applied axial stress divided by the resulting axial strain, within the linear range of stress-strain behavior of a material.

3- **Modulus of Subgrade Reaction** —The applied stress imposed by a loaded plate of a specified dimension acting on a soil mass divided by the displacement of the plate within the linear portion of the stress-deformation curve.

4- **Resilient Modulus** —The stress generated by an impulse load divided by the resulting recoverable strain after loading.

5- **Shear Strength** —A combination of a material's inter-particle friction and its cohesion in resisting deformation from an applied stress. The term strength is generally applicable to the upper limit of the stress-strain relationship.

6- **Stiffness**—A qualitative term meaning a general resistance to deformation. This term is often used interchangeably with elastic modulus, modulus of subgrade reaction, and resilient modulus. Stiffness largely determines the strains and displacements of the subgrade as it is loaded and unloaded.

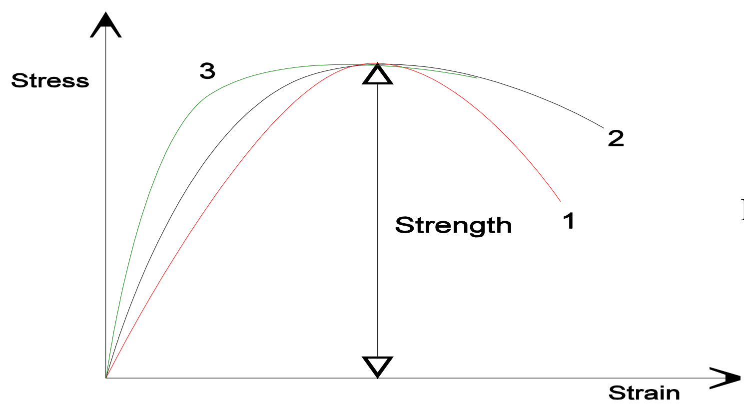


Figure 2.2 Soil Strength

Using these definitions in the right place is very important to characterize material properties. For example, some subgrade materials may possess the same strength but different stiffness values **(Figure 2.2)**. Therefore, any correlation between soil stiffness and soil strength (e.g. M_R vs. LBR) should describe the stress path that the material goes through when it is tested. The variation of the stress path can easily be attained by altering either the deviator stresses or the bulk stresses or even by changing the environmental conditions (moisture content, density, etc.).

Various attempts have been made in the past to correlate the laboratory or field resilient modulus, M_R, of subgrade materials to the LBR values. The M_R values represent the elastic recovered modulus and the LBR signifies the penetration strength of the subgrade material. Since the stress path vary from one testing technique to another, the large scatter in the correlated data (M_R vs. LBR) is unavoidable. Although investigating such correlations is not one of the objectives of this study, a modest attempt will be presented to demonstrate the possibility of predicting M_R values from a strength test such as a dynamic cone penetrometer (DCP) test.

Alternatively, it is crucial to have representative M_R values of the actual field subgrade layers. Without these accurate values it would be very inefficient to use any developed correlations. The laboratory M_R measurements are usually used as control data to the field $_{ME}$ predicted values.

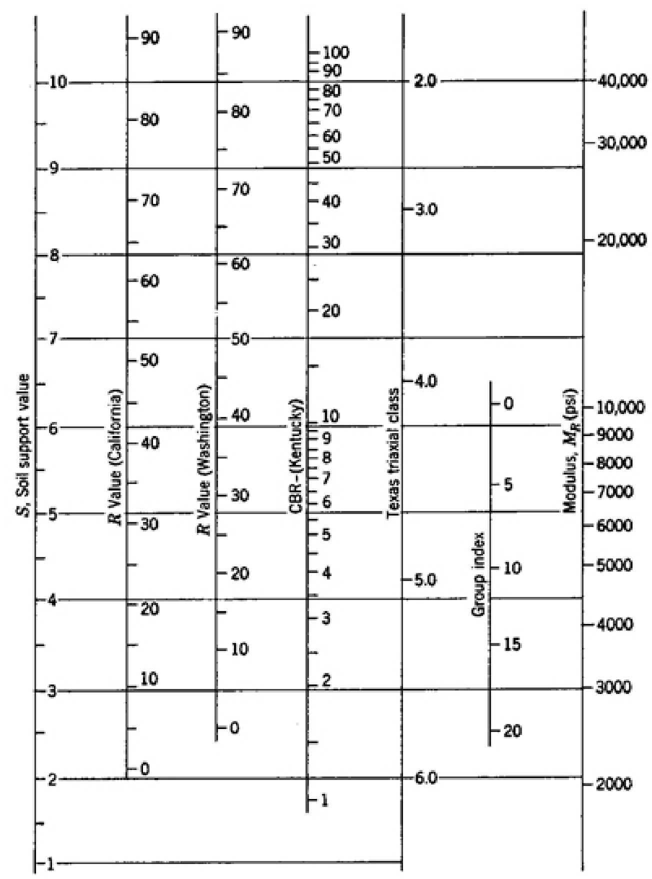


Figure 2.3 Correlation chart for estimating resilient modulus from strength tests of subgrade soils

According to AASHTO guidelines, field values obtained from backcalculating the FWD deflections should be reduced by a factor C to match those obtained from laboratory testing. This factor should be no more than 0.33.

Accordingly, the field moduli values if they were determined from the FWD tests should be:

$$\text{Design } M_R = C\,[(0.24\ P)/(d_r\,.\,r)] \qquad 2.1$$

where P = applied load, pounds; dr = measured deflection at radial distance r, inches; r = radial distance at which the deflection is measured, inches.

However, it should be noted that special attention must be given when preparing and testing representative samples in the laboratory. Material disturbance during sampling and testing produce results which underestimate the material properties especially in cases of anisotropic materials such as soil or gravel. Moreover, laboratory tests are performed under controlled conditions where the effect of other layers, moisture/water table, and other environmental conditions are not considered.

To better understand the concept of the FWD and its role in pavement evaluation, the following sections will describe in some detail the on going evolution of the technique and its increasing implementation in pavement design and rehabilitation.

2.3 FWD at a glance

The French originally developed the concept of a falling-weight pavement test device during the 1960s. Intensive testing of a Danish version of the French FWD was performed in 1967 and several Danish prototypes were developed and tested during the 1970s **(Figure 2.4)**. Since then the FWD has become an important tool in the structural evaluation of pavement sections. A group of engineers and technicians who combined science, technology and business into the development and manufacturing of highly specialized equipment and methodology for pavement engineering founded Dynatest in 1976 in Denmark. The first product, the Falling Weight Deflectometer (FWD), was introduced the same year and has since then become a product acknowledged as the leader in quality and reliability.

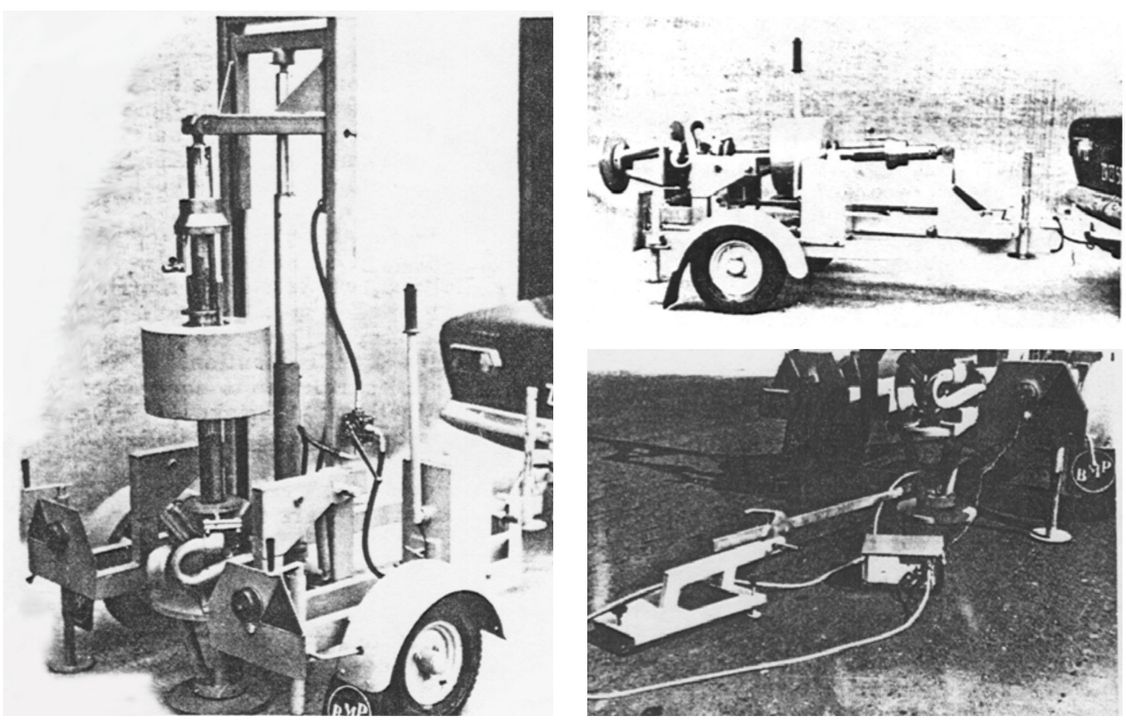


Figure 2.4 The first Danish version of the French Falling Weight Deflectometer

Using the Danish version of the FWD, Bohn, et al. (1972) proved that the stress strain curves obtained from FWD at various depths in a pavement structure were similar to those obtained from traffic load (Figure 2.5).

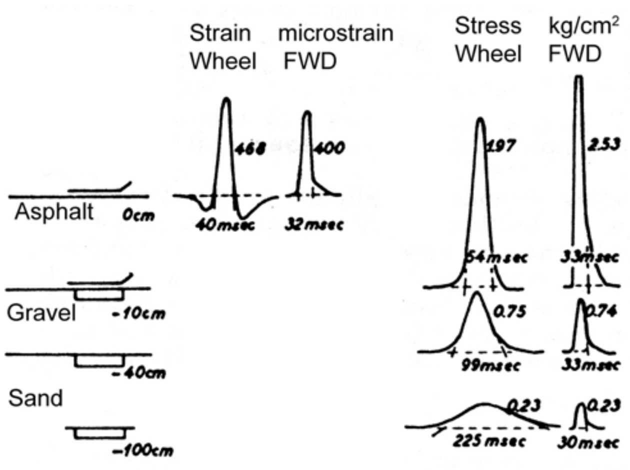


Figure 2.5 Stress-Strain curves of FWD and Traffic Load (Bohn, et al. 1972)

At that time the Chevron layered system software was used to backcalculate the moduli values for subgrade layers.

Since the 1960s, more advanced versions of the FWD setup were developed. The main features that were considered in the modified versions were (1) loading magnitude, (2) calibration procedure, (3) loading pads, (4) data acquisition system, and (5) software for backcalculation analysis. Recently, some FWD devices were equipped with the Global Positioning System (GPS) to accurately identify test point locations.

However, the degree of the improvement of the FWD hardware has exceeded the improvement of the software needed to backcalculate the moduli values. Although there are various methods to backcalculate the moduli values the most usable by the state highway agencies are as follows:

	Evaluation/Network	Overlay Design
DARWIN	X	X
AASHTO	X	X
MODULUS	X	X
EVERCALC	X	X
ELMOD	X	X
EVERPAVE	X	X
WESDEF	X	X
PADAL	X	X
ILL-BACK	X	X
ELCON	X	X
PEDMOD	X	X
DAMA	X	X
MICHBACK	X	
MICHPAVE	X	
Other in-house programs	X	X
KENLAYER		

Most of these programs were developed based on the theory of elasticity solution of the multilayered system. Some of them like ILL-BACK and KENLAYER are based on numerical solutions using the finite element analysis (FEA). In her nationwide survey, Kestler (1997) published the results of the type and the use of different backcalculation methods by the all state transportation departments in the United States (Figure 2.6)

Table 1.2 shows in detail the properties of some of the above listed backcalculation programs. More sophisticated methods were also used to backcalculate pavement moduli values. These methods are based on the finite element modeling of the pavement layers. The advantage of using the finite element method is the realistic three dimensional simulation of the pavement structure and the capability of using more representative constitutive relationships for the nonlinear behavior of

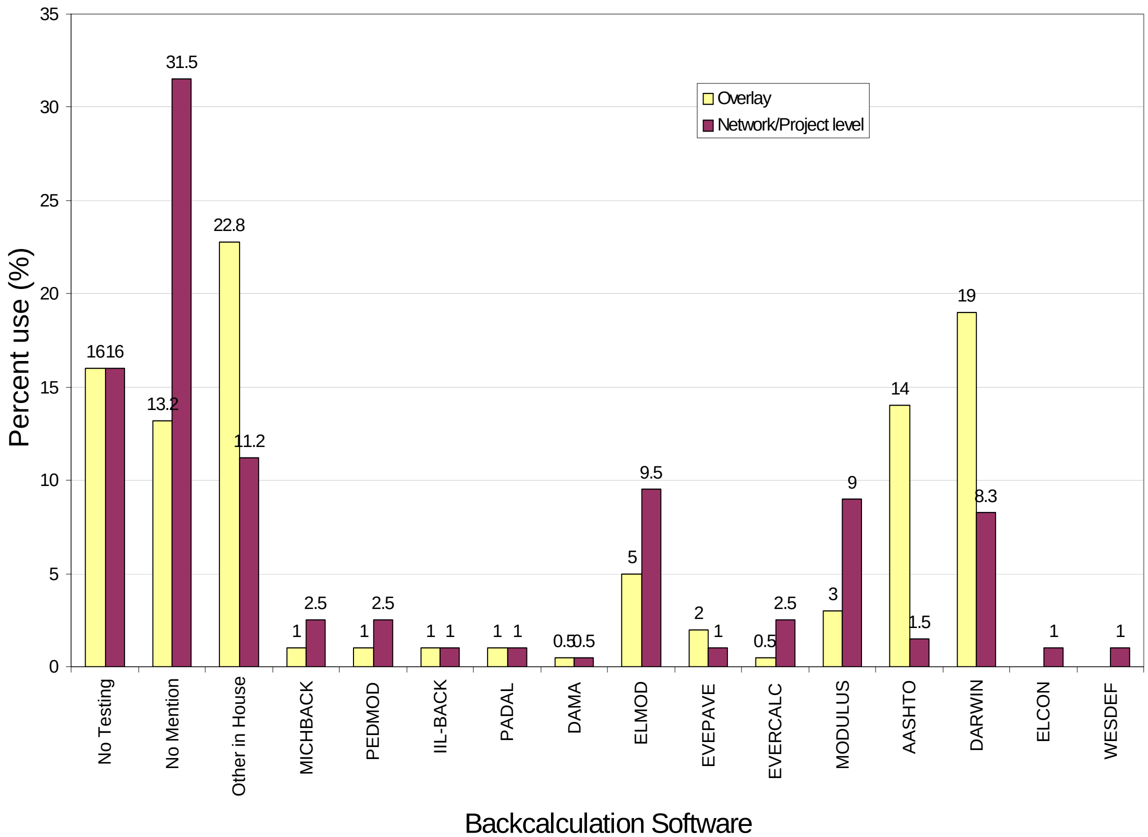


Figure 2.6 Backcalculation software used in the United States, a. Overlay; b. Network/Project Levels(Maureen A. Kestler, 1997)

pavement materials. Attempts of using such a sophisticated method are still limited to research efforts. Using it at the project or network levels may not be feasible in the near future. The disadvantage of the FEA method is simply the lack of the practical aspects in the procedure. To routinely backcalculate the moduli values, the need is always confined to a quick and reliable method. The FEA method at this moment can not provide the speed needed to analyze large amounts of field data.

Currently, most of the efforts spent by the state highways agencies that are utilizing the FWD in their pavement evaluations are essentially concentrated at:

1- Applicability of the FWDs at network and/or project levels. This involves the development of guidelines for the use of FWDs including setup configurations and test point locations.

2- Developing calibration protocols for the FWD setups and requirements for FWD calibration stations.

3- Post-processing FWD data which includes the selection of specific guidelines for the FWD data post-processing and backcalculation procedures.

Efforts were equally spent to develop more representative and practical correlations between the backcalcuated moduli values and other pavement parameters including laboratory measured values.

2.4 Methodology of the Falling Weight Deflectometer (FWD)

The FWD is a nondestructive testing device that induces surface deflections that are in a close match with those induced by traffic loading. The shape and magnitude of the impact force is governed by the configuration of the device, amount of load imposed, and the pavement structure. For practical reasons, the characteristics of the input load is signified by the magnitude of the dropping load only. The duration, frequency content, and contact area are not of a great importance to the backcalculation procedures that are usually performed to estimate the theoretical deflection basins of the pavement surface. The backcalculation procedures are basically centered around producing theoretical deflection basins similar to those produced in the field. Once the theoretical matched the field curves, the assumed pavement moduli are considered correct. This is also another oversight of the problem, because the theoretical solution is not unique. In other words, there might be other sets of pavement moduli that may produce the same deflections. However, the judgment has to be through reference values. These values should come from the laboratory testing on representative samples of the pavement structure. The laboratory resilient modulus test should always be used to verify the field results before concluding any relationships of the pavement deflection vs. pavement moduli values.

The understanding of pavement behavior and correct interpretation of data obtained from a FWD test are key factors for correct rehabilitation procedures. Dropping a rigid set of steel weights on rubber cushions that rest on a steel loading plate generates the FWDs impulsive load. The rigid circular loading plate has a 5.91-inch radius and is separated from the pavement surface by a thin rubber pad. Changing the drop height, with the same total weight used for all tests, varies the maximum peak values. In standard practice, peak loads are controlled by the total weight, the drop height, and the impedance (or stiffness) of a pavement profile. For common pavement profiles the range of possible peak impact loads is approximately 2 to 25 kips. Net effective contact pressures for such loads are between 18 and 245 psi. Dynatest literature for the Model 9000 FWD stated that the peak load was measured with an accuracy of 2 percent ±280 Ibs; thus, for a 9,000-lb load the expected maximum error was 5 percent. Bentson, Nazarian, and Harrison, reported an independent comparison of a Dynatest FWD's internal load measurement with load cells placed under the loading pad. They found approximately 4.3 percent error at a 7.8-kip load, and 3.0 percent error at a 25-kip load. Based on these findings, it seems reasonable to expect the FWD to provide a load measurement accuracy of about 4 percent for typical operations.

2.5 FWD Testing technique

The FWD method is listed in the ASTM standards under a fixed designation D 4694. The scope of the method was stated as follows: The test method describes the measurement of vertical deflection response of the surface to an impulse load applied to the pavement surface. The vertical deflections are measured on the load axis and at the points spaced radially outward from the load axis. The applied impulse loads closely represent the moving vehicle loads applied to prototype pavements.

During the test, a force pulse generated by a weight dropped on a spring system is transmitted through a steel plate resting on the pavement surface. Standard loading plates are 300 and 450 mm (12 and 18 in.) in diameter. The loading plate has an opening in the center to allow a deflection-measuring sensor to be installed. The weight is lifted to a known height by the guided system so that, when dropped, it will impart the desired force on the pavement. When the weight is dropped, the resulting vertical movement of the pavement surface is measured at the specified location using deflection sensors. A schematic drawing of the FWD setup is shown in **Figure 2.7.** By varying the mass or the drop height, the impact on the pavement surface can be varied to account for different loading conditions, i.e., vehicle weights. For the nondestructive evaluation of highway pavements, a load equal to the single axle load is frequently used. The FWD equipment induces a small static preload on the pavement surface in the range of 3 to 14% of the maximum dynamic load. Due to the small magnitude of the pre-load compared with the maximum dynamic amplitude, the weight of the equipment is excluded during the evaluation of the results. The impact load pulse has an approximate shape of a half-sine wave and duration of 20 to 60 ms. The rise time, as a time from the beginning of the loading till the peak value, varies between 10 and 30 ms.

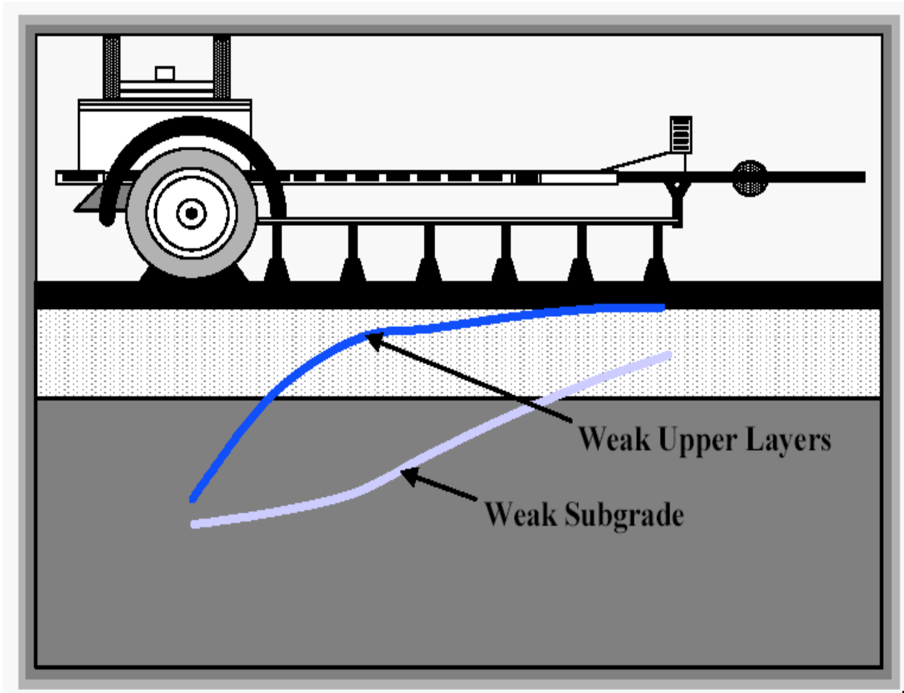


Figure 2.7 FWD setup.

The surface deflections are usually measured by up to seven or 9 sensors transducers mounted on a holding bar lowered automatically with the loading plate. The transducers are usually spaced one foot apart and placed on the pavement surface in the direction of traffic. The Florida Department of Transportation recommends that the sensor distance should be followed at 0, 8, 12, 18, 24, 36, and 60 inches from the center of the loading plate. Transducers may be of several types such as geophones (absolute measurement transducers), velocity transducers, or accelerometers. A load cell is used to measure the applied load on each impact. During each test, variations in the load and surface deflections with the time are recorded and stored for future evaluations. To evaluate the pavement moduli of different layers, peak deflection values are extracted and used in the construction of the deflection basin presented in **Figure 2.8.**

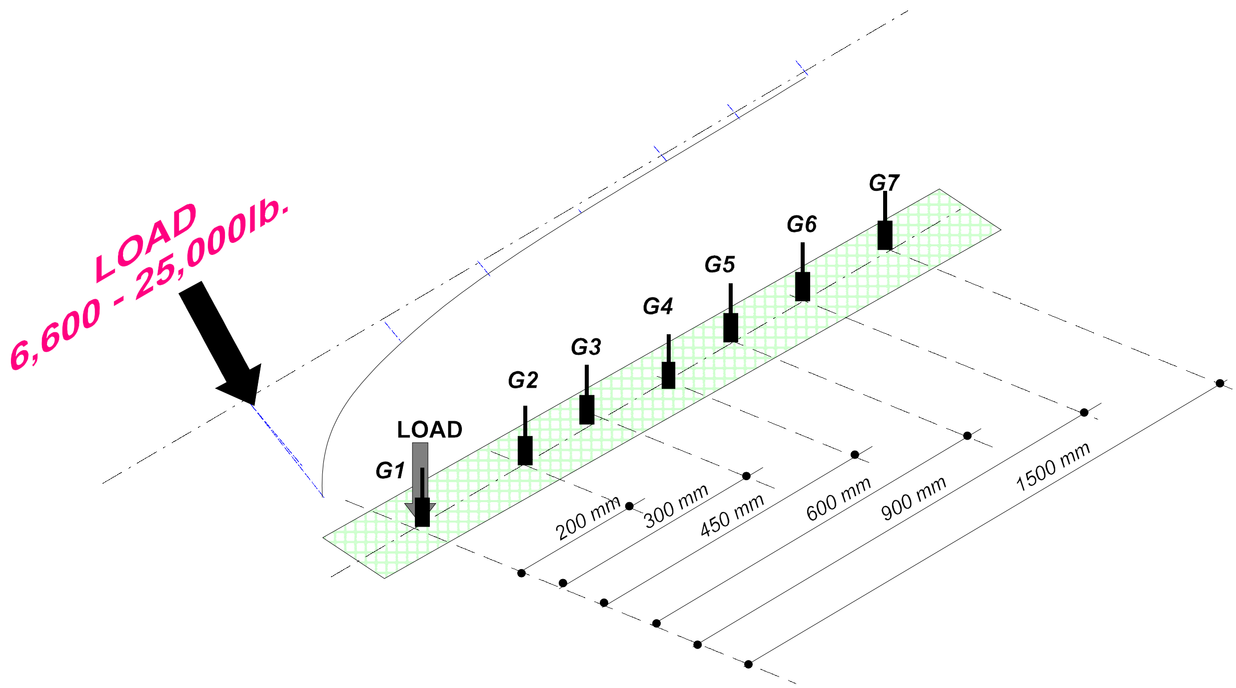


Figure 2.8 Geophones layout for the FWD

Based on the results of the test, decisions are made about rehabilitation procedures and overlay design for highway and airfield pavements. Errors made during interpretation of test data may result in making inappropriate rehabilitation decisions at great economical losses. Therefore, the correct evaluation of the test results is very important from an economical point of view.

2.6 Florida Department of Transportation Practices

The FDOT has extensive experience in using NDT techniques to evaluate pavement properties. One of the first techniques used was the Dynaflect test. For two decades, a large amount of data was collected using this technique. From the Dynaflect and the plate bearing tests, the FDOT developed a statistical correlation to predict the soil support values (SSV) of the subgrade material. Using the SSV, the resilient modulus (MR) of the subgrade can be obtained (**Figure 2.9**). In the meanwhile, the FWD, continued to gain acceptance by the pavement engineers until it was decided that FWD will replace the Dynaflect at both research and project levels.

In an attempt to draw a meaningful comparison between the different state highways agencies and what is being practiced by the FDOT, a survey questionnaire to 51 state departments of transportation, including Puerto Rico, and to three Canadian provinces highway agencies including British Columbia, Ontario, and Quebec was initiated in May of 2001. The main objective of this survey was to gather some related facts and figures of interest to FWD users and to shed light on the differences in the pavement evaluation procedures in different states. The questionnaire targeted three FWD related program areas including field operations, pavement design parameters, and program management.

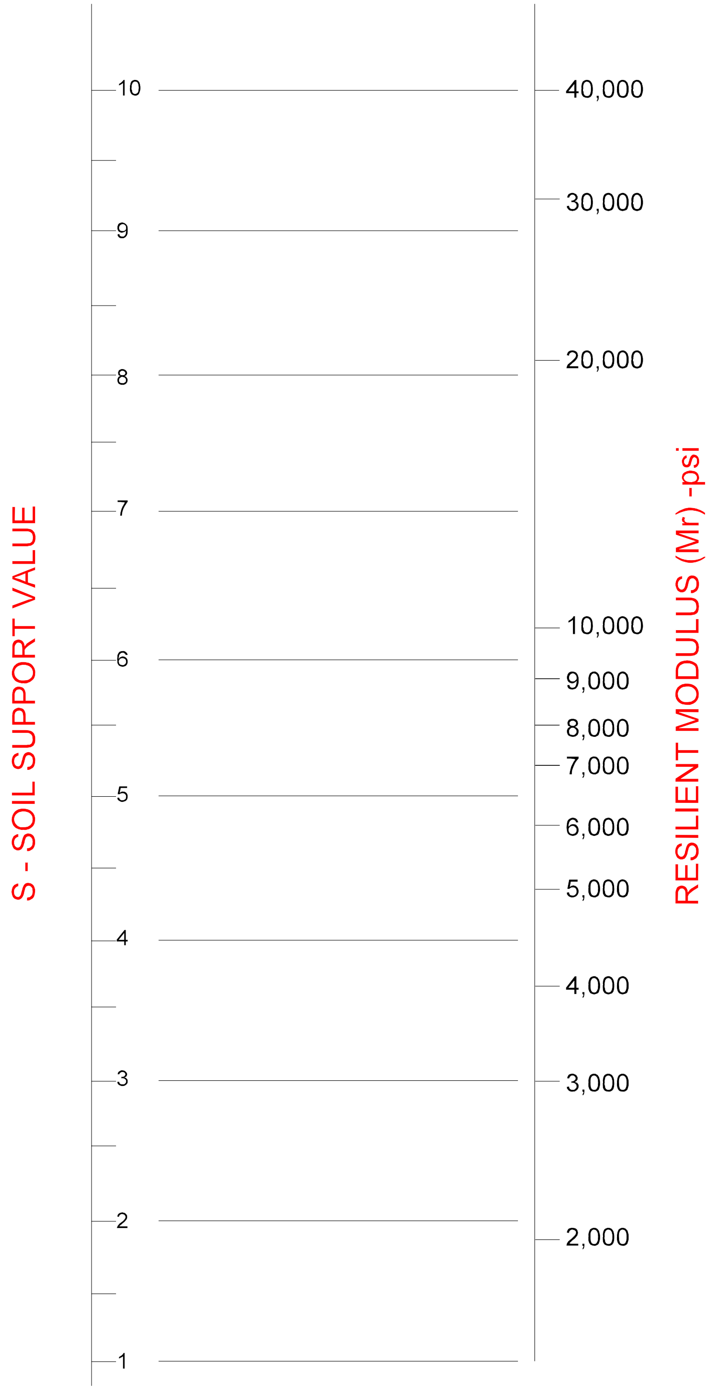


Figure 2.9 AASHTO Resilient Modulus and SSV correlation from AASHTO Guide for Design Pavement Structures (1993)

A total of 39 responses were received representing a 71% response rate. The survey results show 81% of the responding agencies manage their FWD testing program in-house, and the rest of the agencies out-source their work. Seventy percent of the agencies use Dynatest units, 11% use JILS units, 8% use KUWAB units, and 8% own and operate a combination of units. Seventy eight percent of the respondents use the FWD at the project level, while 19% use it at both project and network levels.

As an average percent of FWD program areas, 63% of the testing is dedicated to structural evaluation, 16% for investigative, 18% for research, and the rest for other type of work. Seventy two percent of the agencies have a quality control or quality assurance plan in effect. Fifty seven percent use one crewmember per unit, 16% use two crewmembers, and 22% reported that the number varies. Seventy percent of the agencies typically use a seven-sensor configuration during testing, 23% use nine sensors, and 3% use six sensors. Sixty nine percent of the FWD units operate under DOS, and 22 % operate under a Windows environment. Sixty nine percent of the agencies use the Resilient Modulus from the FWD data to estimate subgrade strength, while 25% use some other means. Twenty eight percent of the agencies reported using a seasonal and/or temperature adjustment factor(s) in determining the effective subgrade modulus, and 64 % did not.

Table 2.1 - Partial List of Layer Moduli Backcalculation Programs [Rada et al]

#	Program Name	Developed By	Forward Calculation Method	Forward Calculation Subroutine	Back-calculation Method	Non-Linear Analysis	Rigid Layer Analysis	Layer Interface Analysis	Maximum Number of Layers	Seed Moduli	Range of Acceptable Modulus	Ability to Fix Modulus	Convergence Routine	Error Conver-gence Function
1	BISDEF	USACE-WES	Multi-LayerElastic Theory	BISAR(Proprietary	Iterative	No	Yes	Variable	Cannot Exceed No. of Deflec., Works Best For 3 Unknowns	Required	Required	Yes	Sum of Squares of Absolute Error	Yes
2	BOUSDEF	ZHOU, et.al. OREGON STATE UNIV.	Odemark-Boussinesq	Odemark- Boussinesq	Iterative	Yes	Yes	Fixed(Rough)	5, Works Best for 3 Unknowns	Required	Required	Yes	Sum of Percent Errors	Yes
3	CHEVDEF	USACE-WES	Multi-Layer Elastic Theory	CHEVRON	Iterative	No	Yes	Fixed(Rough)	Cannot Exceed No. of Deflec., Works Best For 3 Unknowns	Required	Required	Yes	Sum of Squares of Absolute Error	Yes
4	ELMOD/ELCON	P. ULLIDTZ DYNATEST	Odemark-Boussinesq	Odemark- Boussinesq	Iterative	Yes(Subgrade Only)	Yes(variable)	Fixed(Rough)	Up to 4, Exclusive of Rigid Layer	None	No	Yes	Relative Error on 5 Sensors	No
5	ELSDEF	TEXAS A&M UNIV.,USACE-WES	Multi-Layer Elastic Theory	ELSYM5	Iterative	No	Yes	Fixed(Rough)	Cannot Exceed No. of Deflec., Works Best For 3 Unknowns	Required	Required	Yes	Sum of Squares of Absolute Error	Yes
6	EMOD	PCS/LAW	Multi-Layer Elastic Theory	CHEVRON	Iterative	Yes(Subgrade Only)	No	Fixed(Rough)	3	Required	Required	Yes	Sum of Relative Squared Error	No
7	EVERCALC	J. MAHONEY, et.al.	Multi-Layer Elastic Theory	CHEVRON	Iterative	Yes	Yes	Fixed(Rough)	3 Exclusive of Rigid Layer	Required	Required	Yes	Sum of Absolute Error	No
8	FPEDD1	W. UDDIN	Multi-Layer Elastic Theory	BASINPT	Iterative	Yes	Yes(Variable)	Fixed(Rough)	Unknown	Program Generated	Unknown	Unknown	Unknown	No
9	ISSEM4	R. STUBSTAD	Multi-Layer Elastic Theory	ELSYM5	Iterative	Yes(Finite Cylinder Concept)	No	Fixed(Rough)	4	Required	Required	Yes	Relative Deflec. Error	No
10	MODCOMP3	L. IRWIN, SZEBENYI	Multi-Layer Elastic Theory	CHEVRON	Iterative	Yes	Yes	Fixed(Rough)	2 to 15 layers, Max 5 Unknown Layers	Required	Required	Yes	Relative Deflec. Error at Sensors	No
11	MODULUS	TEXAS TRANS. INSTITUTE	Multi-Layer Elastic Theory	WESLEA	Data Base	No	Yes(Variable)	Fixed?	Up to 4 Unknown plus Stiff Layer	Required	Required	Yes	Sum of Relative Squared Error	Yes
12	PADAL	S.F. BROWN,	Multi-Layer Elastic Theory	UNKNOWN	Iterative	Yes(Subgrade Only)	Unknown	Fixed?	Unknown	Required	Unknown	Unknown	Sum of Relative Squared Error	Unknown
13	WESDEF	USACE-WES	Multi-Layer Elastic Theory	WESLEA	Iterative	No	Yes	Variable	Up to 5 Layers	Required	Required	Yes	Sum of Squares of Absolute Error	Yes
15	MICHBAK	MICHIGAN STATE	i-Layer Elastic Th	CHEVRON	Iterative	No	Yes	Fixed	Up to 4 Unknown plus Stiff Layer	Required	Optional	Yes	of Relative Squared	Yes

Chapter 3

Data Collection and Field Tests

3.1 Data Collection

The major part of this study is to collect the correct data related to Dynaflect & FWD tests and their evaluation purposes. The collected data included (1) Dynaflect raw field data, (2) FWD raw field data and LTPP database, (3) layer thickness of pavement, (4) laboratory and field resilient modulus test data including water table and moisture levels in the subgrade layers.

Several trips were made to obtain the needed field data. Test point locations were chosen by the FDOT pavement evaluation office in Gainesville. Initial Dynaflect test results were collected from different sources. In-situ FWD test data were collected at several locations. The FWD data from LTPP sections were originally collected from the FHWA DATAPAVE 2.0. Later on, a new database was used (DATAPAVE 3.0) on the project to extract sections that were not available in the previous version. Because of the large amount of data that needed to be extracted from the software, the corresponding tables were observed directly. About fourteen large capacity tables were dealt with. A total of five million data entries were extracted for the MS Access tables, converted to MS Excel files and than sorted by the following:

1- STATE

2- SHRP _ ID

3- POINT _ LOCATION

4- DATE

5- TEST _ TIME

Most Florida sections were covered in the tables. However, not all sections contain the same information. That means some Florida sections have more field measurements than others. Also, some were tested at different time points while others were limited to one testing date. The biggest advantage of using the LTPP data was the information about the layering structure of the cross sections. They are presented in great detail of the geometry and the properties of the different materials. All the layering properties were included in the analysis of this study.

Some results were obtained from the dynamic cone penetrometer test for a runway with 6 in of AC layer and 36 in of base layer. Data from that site were analyzed and compared with those obtained from the FWD tests. The backcalculation results will be presented in the following sections.

The most comprehensive Dynaflect and FWD data that was used in this study came from the 300 mile sections that were tested by the FDOT pavement evaluation division.   A total of 58 sections from 10 counties were involved in this set. Measurements were taken for the air and pavement temperatures as well as the water table and moisture content levels in the subgrade layers.

Data from previous studies were also included in the analysis. Although most of this type of data may have been collected from different sections, some laboratory resilient moduli values were utilized to correlate with those obtained from the FWD.

Table 3.1 FWD/Dynaflect test sections analyzed in this study.

Pavement Sections From Different Databases							
LTPP Sections			300 Miles Sections		FWD Test Sections		SPA Sections
12-1030	12-0103	12-0506	3010n	87003	200	26	Lee County Site 1B
12-1060	12-0104	12-0547	3010s	87005	200	26	Lee County Site 2B
12-1370	12-0105	12-0507	12070	87005	200	26	Polk County,Site 1A
12-3804	12-0106	12-0508	12070	87020	200	26	Polk County,Site 2A
12-3811	12-0107	12-0508	16070	87020	200	26	Alachua County,Site 3
12-3995	12-0108	12-0509	16160	87030	200	26	Alachua County,Site 4
12-3996	12-0109	12-0509	17010	87030	200	26	Clay County,Site 5
12-3997	12-0110	1 2-0900*	17010	87140	200	26	Clay County,Site 6
12-3997	12-0111	12-0901*	29002	87200	200	26	Jefferson County,Site 1A
12-4000	12-0112	12-0901*	29002	87200	200	26	Jefferson County,Site 2A
12-4051	12-0500	12-0902*	29010	93230	200	207	Gadsden County,Site 2B
12-4059	12-0501	12-0902*	29010	93290	200	207	Gadsden County,Site 3B
12-4096	12-0502	12-0903*	29180	93290	16	207	Dade County,Site 1
12-4097	12-0502	12-0903*	29180	29010	16	207	Dade County,Site 2
12-4099	12-0503	12-A300	35040	29010	16	207	Martin County,Site 3
12-4100	12-0503	12-A310	37130	87020	16	207	Martin County,Site 4
12-4101	12-0504	12-A310	37130	87020	16	207	Seminole County,Site 1
12-4101	12-0504	12-A320	37530	93290	16	72	Seminole County,Site 2
12-4102	12-0505	12-A320	38010		16	72	Osceola County,Site 3
12-4103	12-0102	12-A330	38010		16	72	Osceola County,Site 4
12-4105	12-0103	12-A350	38501		16	72	
12-4106	12-0104	12-A350	49010		24	72	
12-4107	12-0105	12-B300	49010		24	72	
12-4108	12-0106	12-B310	49030		24	72	
12-4109	12-0107	12-8310	50010		24	72	
12-4135	12-0108	12-B320	55002		200	62	
12-4135	12-0109	12-B320	70220		200	62	
12-4135	12-0110	12-B330	72018		200	62	
12-4136	12-0111	12-B350	72018		200	62	
12-4136	12-0112	12-B350	72040		200	62	
12-4136	12-0500	12-0300	72040		200	62	
12-4137	12-0501	12-C310	72280		200	62	
12-4137	12-0502	12-C310	72280		200	62	
12-4137	12-0502	12-0320	72291		200		
12-4138	12-0503		72291		200		
12-4153	12-0503		74040		200		
12-4154	12-0504		76050		200		
12-9054	12-0504		76050		200		
12-0100	12-0505		87001		26		
12-0101	12-0505		87001		26		
12-0102	12-0506		87003				

3.2 Back-calculation of Pavement Moduli

The deflection data collected from the field and from the LTPP sections were analyzed using the following methods:

1- MODULUS 5.0

2- EVERCALC

3- AASHTO Formula

4- Finite Element Modeling

Moduli values from all these procedures are presented in this study. Recommendations on the advantages and disadvantages of each method will be described in the conclusion. Comparison between all the results from these methods showed promising relationships where one can convert one set of data to another with reasonable accuracy. The empirical formula by AASHTO has proven to be very valuable for the first estimate of the subgrade modulus. With the proper sensor distance this method can be used to estimate moduli values that need longer time to be obtained from other sophisticated methods. The correction factor (C) necessary for this formula has been determined from the field and laboratory results collected in this study.

3.2.1 MODULUS Program

MODULUS is a PC software for backcalculating layer moduli (Uzan et al., 1988, 1989; Scullion et al., 1990). It can be applied to a two, three or four-layer system with or without a rigid bedrock layer. A linear elastic program is used to generate a data base of deflection bowls by assuming different modulus ratios. Once the data base is generated for a particular pavement, the linear elastic program is not called again, no matter how many bowls are to be analyzed. In the case of a four-layer system, the elastic layer program is automatically run at least 27 times (3 surface x 3 base x 3 subbase modulus ratios). A pattern search routine is used to fit measured and calculated bowls.

The objective function to be minimized can be expressed as

$$\varepsilon^2 = \sum_{i=1}^{S} \left(\frac{w_i^m - w_i^c}{w_i^m}\right)^2 = \sum_{i=1}^{S} \left(1 - \frac{w_i^c}{w_i^m}\right)^2 \qquad 3.1$$

in which ε^2 is the squared error, w^m is the measured deflection, w^c is the computed deflection, and i is a sensor number from 1 to s. The original equation contains a weighting factor for each sensor i. Because the same weighting factors are usually used, they are not shown in Eq. 3.1. The computed deflection can be expressed as a function of modulus ratios:

$$w_i^c = \frac{qa}{E_n} f_i\left(\frac{E_1}{E_n}, \frac{E_2}{E_n}, \ldots\ldots, \frac{E_{n-1}}{E_n}\right) \qquad 3.2$$

This equation is similar to the well known equation for the deflection of two-layer systems:

$$w_o = \frac{1.18qa}{E_2} F_2 \qquad \ldots\ldots\ldots \text{ for flexible pavement}$$

$$w_o = \frac{1.5qa}{E_2} F_2 \qquad \ldots\ldots\ldots \text{ for rigid pavement}$$

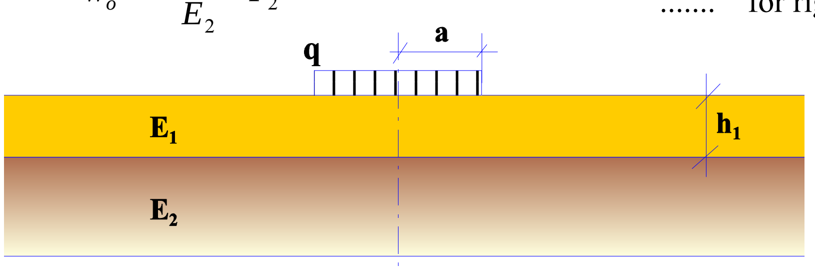


Figure 3.1 Deflection of elastic layers.

in which q is the contact pressure, a is the contact radius, E is the elastic modulus with a subscript indicating the layer number, and F_2 is the deflection factor. The deflection factor is a function of E_1/E_2 and h_1/a. The value of f_i, for sensor i can be obtained from the layer system program and used as a data base. By assuming n - 1 modulus ratios, w_1^c can be obtained from Eq. 3.2 and γ^2 from Eq. 3.1. As in any other back-calculation program, a set of seed moduli is required for the first trial. The following procedure is used to determine the seed modulus of subgrade E_n. When E_n and the modulus ratios are known, the modulus of each layer can be determined.

For a fixed set of modulus ratios, functions f_i can be considered as constants. To minimize the error, the value of E_n can be determined by taking derivative of γ^2 with respect to E_n and setting the result to zero:

$$\frac{\delta \varepsilon^2}{\delta E_n} = \sum_{i=1}^{S} 2\left(1 - \frac{w_i^c}{w_i^m}\right)\left(\frac{1}{w_i^m}\right)\left(\frac{\delta w_i^c}{\delta E_n}\right) = 0 \tag{3.3}$$

From Eq 3.2

$$\frac{\delta w_i^c}{\delta E_n} = -\frac{qaf_i}{E_n^2} = -\frac{w_i^c}{E_n} \tag{3.4}$$

so Eq. 3.3 can be reduced to

$$\sum_{i=1}^{S} \left(1 - \frac{w_i^c}{w_i^m}\right)\left(\frac{w_i^c}{w_i^m}\right) = 0$$

or

$$\sum_{i=1}^{S} \frac{f_i}{f_i \, w_i^m} = \sum_{i=1}^{S} \frac{qaf_i^{\,2}}{f_1 (w_i^m)^2 E_n} \tag{3.5}$$

When both sides are divided by w_i^c with w_i^c = qaf_1/E_n and w_i^c/w_i^c = f_i/f_1, Eq. 3.5 becomes

$$\sum_{i=1}^{S} \frac{w_i^c}{w_i^m} = \sum_{i=1}^{S} \left(\frac{w_i^c}{w_i^m}\right)^2 \qquad 3.6$$

or

$$E_n = \frac{qaf_1 \sum_{i=1}^{S} \left(\frac{f_i}{f_i w_i^m}\right)^2}{\sum_{i=1}^{S} \left(\frac{f_i}{f_i w_i^m}\right)^2} \qquad 3.7$$

where the functions of f_i, are taken from the generated data base. The squared error $\mathbf{g}^2$ is computed using the subgrade modulus from Eq. 3.7 and the modulus ratios of the data base points. A pattern search routine is used to find the optimum set of modulus ratios so that a minimum $\mathbf{g}^2$ is obtained.

3.2.2 EVERCALC Program

This backcalculation program uses a WESLEA layered elastic analysis program for forward analysis and a modified Augmented Gauss-Newton algorithm for optimization. WESLEA was first developed by the U.S. Army Engineer Waterways Experiment Station (WES). EVERCALC program can handle up to 5 layers, 10 sensors, and 12 drops per station. Options for estimating apparent depth to stiff layer and temperature corrections for AC moduli are included. The optimization routine is used to determine a set of modulus values that provide the best fit between a measured deflection basin and the computed deflection basin when given an initial estimate of the elastic modulus values and a limiting range of moduli. Also, the number of deflections on the basin must be greater than the number of layer moduli to be determined. A set of E values is assumed and the deflections at each sensor are computed and compared with the measured deflections. Each unknown E is varied individually, and a new set of deflections is computed for each variation. For each layer and each sensor, the intercept A_{ji}, and the slope S_{ji}, as shown in Figure 3.2, are determined. For multiple deflections and layers, the solution is obtained by developing a set of equations that define the slope and intercept for each deflection and each un-known modulus:

$$\log(\text{deflection}_j) = A_{ji} + S_{ji} (\log E_i) \quad 3.8$$

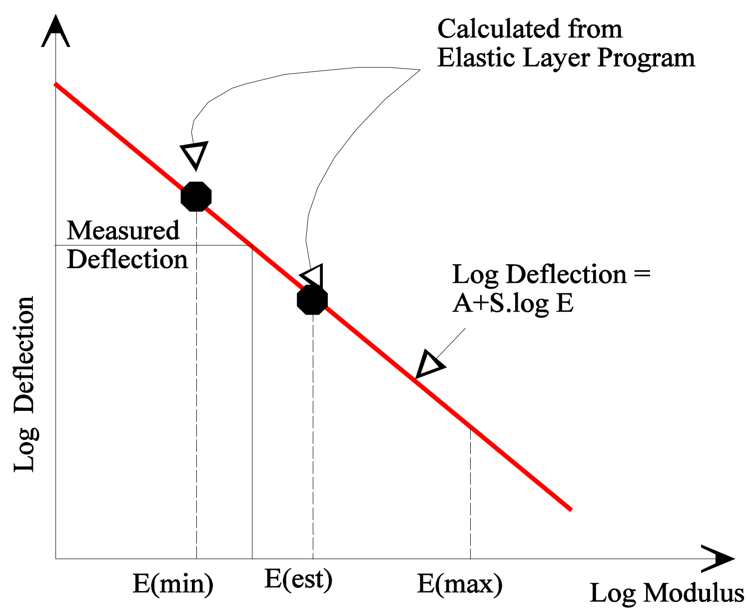


Figure 3.2 Relationship between deflection and modulus

One of the main advantages of using EVERCALC vs. MODULUS is that the measured deflection basin has to be consistent. This means, the deflections at corresponding sensors should decrease as the sensor distance increases. An error massage will notify the user if this provision is violated. In such cases it is preferable not to drop out the data but rather correct to the best estimate the corrupted sensor measurements. The repetition of these errors in the EVERCALC analysis is a good indication that the FWD sensors need to be calibrated. Such cases were encountered in some of the SPA project data, LTPP section 4108 data, and the dynamic cone penetration project data.

3.2.3 AASHTO Method

Figure 3.3 shows a three-layer system with the surface deflections measured by sensors at five locations, arbitrarily assuming that the load is distributed through the various layers according to the broken lines. Because sensors 4 and 5 are outside the stress zone of the surface and base layers, the deflections at sensors 4 and 5 depend on the modulus of the subgrade only and are independent of the moduli of the surface and base layers.

The above explanation on how the layer moduli affect surface deflections is over simplified. In reality, the deflection at any given sensor is affected by the moduli of all layers, each to a different degree. However, for a three-layer system, the following general principles always apply:

1- the deflections of the sensors far away from the load are matched by adjusting the modulus of the bottom layer

2- those at intermediate distances from the load are matched by adjusting the modulus of the middle layer

3- those near the load are matched by adjusting the modulus of the top layer.

Of significance is the radial distance ($r = a_{3e}$) in which the stress zone intersects the interface of the subbase and subgrade layers. When the deflection basin is measured (via geophones or other measurement devices), any surface deflection obtained at or beyond the a_{3e} value is due only to stresses (deformations) within the subgrade itself. Thus, the outer readings of deflection basin, under dynamic load, primarily reflect the in situ modulus properties of the lower (subgrade) soil. This is the fundamental concept used in either approach to establish the value of the pavement support condition from FWD or any other NDT evaluation. Equally important is the fact that there exists an ideal minimum distance for each pavement type and FWD device to ensure that the deflection response is not being influenced by upper pavement layers. If the outer geophone is placed beyond this point, predictive estimation errors in the subgrade support or response will occur.

According to AASHTO, the design subgrade modulus MR may be determined from:

$$M_R = C\ (0.24\ P/d_r\ r) \qquad 3.9$$

where Mr = backcalculated subgrade resilient modulus, psi; P = applied load, pounds; dr = measured deflection at radial distance r, inches; r = radial distance at which the deflection is measured, inches. AASHTO recommends that a correction factor (C) be used to obtain consistent subgrade values. A value for C should not exceed 0.33. It is preferable that laboratory MR values be used to obtain value for C that reflects the local pavement conditions.

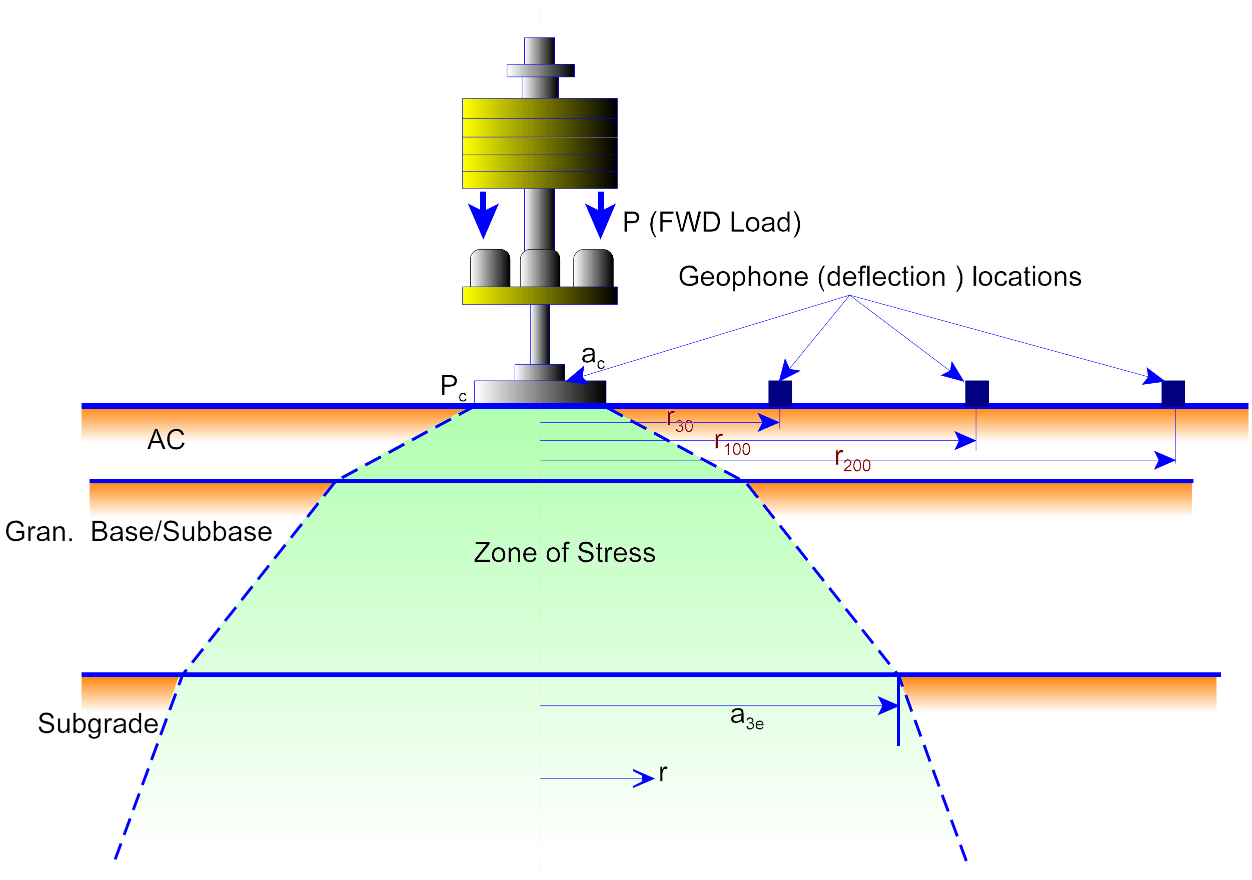


Figure 3.3 Schematic of stress zone within pavement structure under the FWD load.

3.2.4 Finite Element Modeling

Pavement cross section models were created using ANSYS 5.3 finite element program. This program was chosen because of its versatility and capability of modeling nonlinear behavior of pavement materials. Its advantage is that once the model is successfully built and validated, many types of loading conditions can be applied, stress and strain distribution can be tracked and the extent of the deflection basin in the vertical and horizontal directions can be traced. For example, the influence of having a rigid layer (bed rock) is not well represented in the traditional backcalculation procedures. The depth of this layer is usually estimated by some programs. In many situations, this estimation is not accurate. In fact the depth of the rigid layer is not one of the sensitive parameters in the closed-form backcalculation methods. This factor is an important one, and most pavement engineers assert that from their practical experience in the field. The characteristics of the deflection basin is very much affected by the rigid layer. The finite element analysis can easily demonstrate the effect of this layer on the deflection basin. Also the influence depth and the effect of the boundary conditions of the FWD testing can clearly be observed from the three dimensional modeling.

The pavement models used for this part of the study were typical of those at US 441. They consist of three layers; AC, base and subgrade layers. The dimensions of each layer are shown Figures 3.4 a and b, and Table 3.2.

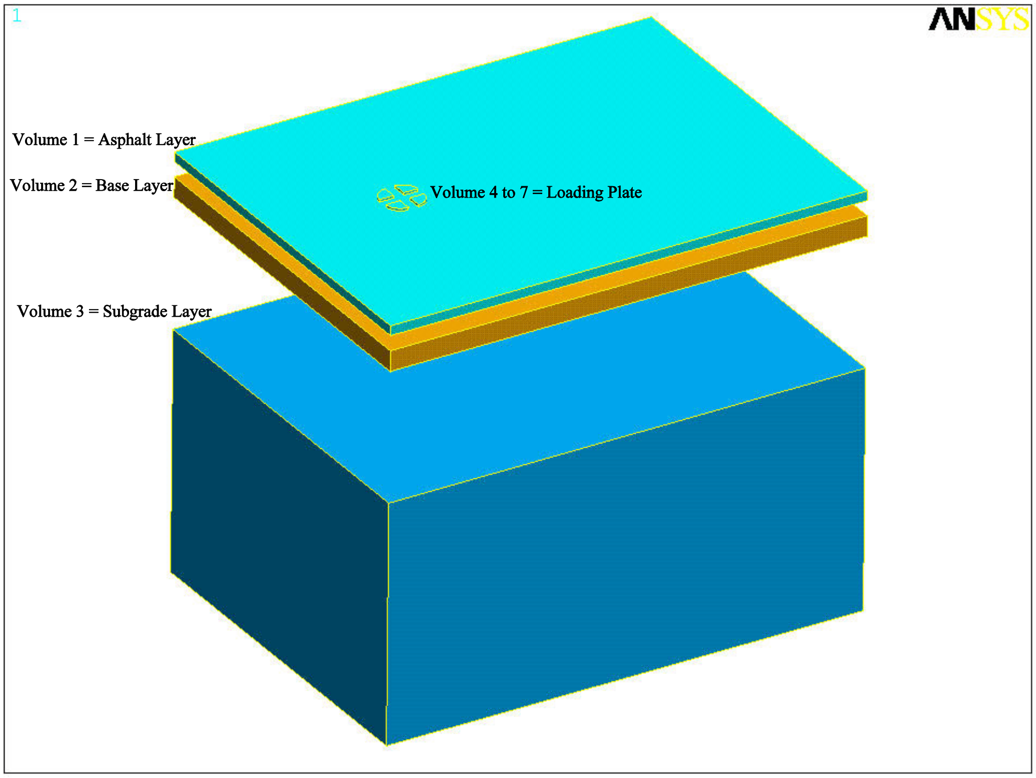


Figure 3.4a. Three dimensional model of US411

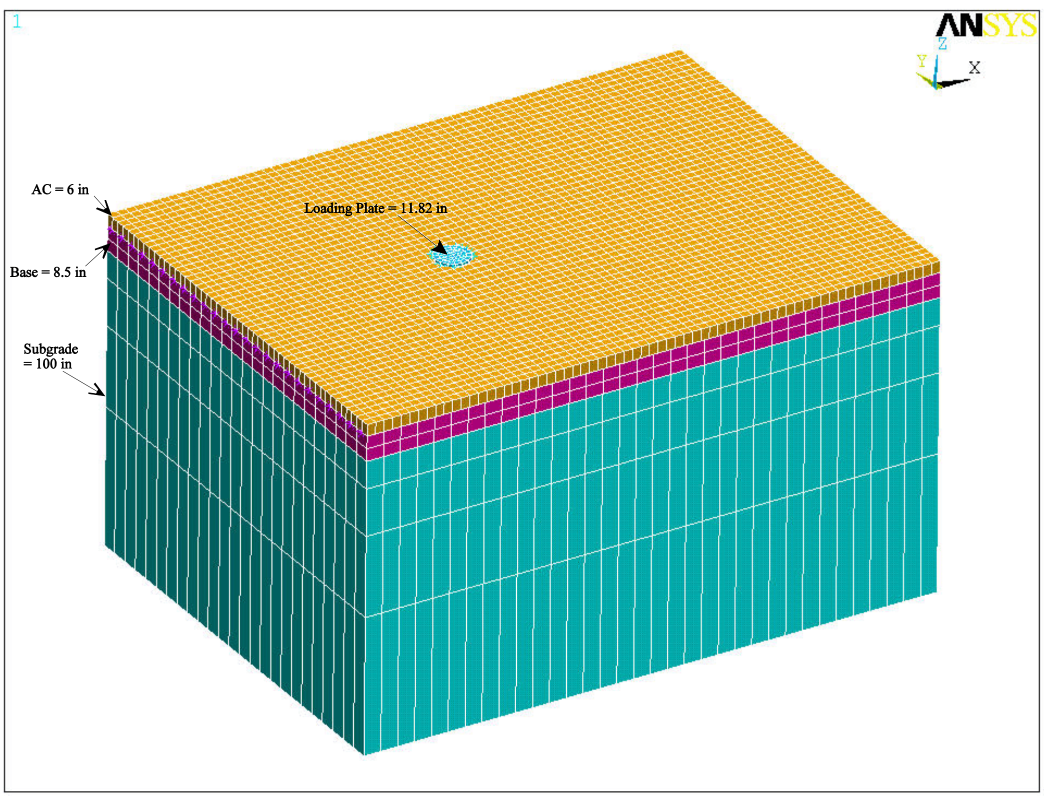


Figure 3.4b. Finite element model of US 411

3.2.4.1 Model Generation

The pavement section was modeled using three different volumes. The loading plate was also modeled to simulate the FWD contact area. The three pavement volumes were attributed based on material stiffnessnes measured from the backcalculation of the field tests. The asphalt layer was taken to be linear elastic, the base and subgrade layers were simulated using the Drucker-Prager model with different cohesion, friction and flow angels. The material properties used in modeling are listed below:

Table 3.2 Model properties of US441

Volume #	Layer	Length x Width	Thickness	Material	Initial Material Properties
1	Asphalt	150" x 200"	6"	Linear Elastic	320 Ksi
2	Base	150" x 200"	8.5"	Nonlinear Elastic	36 Ksi
3	Subgrade	150" x 200"	100"	Nonlinear Elastic	10 Ksi
4,5,6,7	Plate	R = 5.91"	1"	Elastic	29000 Ksi
-	Friction layer	AC&Base	-	Nonlinear	$\mu = 0.7$

Each layer is a volume and was created separately and was then joined by either gluing or by adding a friction element in between. The boundary conditions were selected to restrict deformations in the transverse directions x & y. The asphalt, base and subgrade layers were allowed to deform vertically only. The bottom of the model was restrained in all the three directions i.e., X, Y, Z. The dropping load was simulated using two schemes. The first one was a real drop of the loading pad to produce a predetermined impact load of 9000 lb in peak value with a duration of 1 second. The second scheme consisted of adding a static load of 9000 lb on the loading plate. Deflections in both cases were obtained with very minor differences at the peak values. Because of its shorter processing time, the static loading condition was used in the rest of the analysis. One of the interesting findings was that the addition of the gravitational acceleration (32.2 in/sec^2) to the mass density of the materials have produced stress distribution levels different than assuming weightless materials. These results show that the traditional closed form solutions using the regular backcalculation methods may overestimate the stress distribution in the pavement layers.

Chapter 4

Test Results and Discussion

To meet the objectives of this study, it was necessary to conduct field tests using both Dynaflect and the FWD testing techniques. Also, some of the existing data were collected along with those extracted from the FHWA LTPP data base. The combinations of the gathered test results in this study have given a unique opportunity to obtain a general pattern for the deflection characteristics of the pavement layers in Florida. If the test results are sorted according to the environmental and geometric conditions of the tested pavements, more reliable correlations can be obtained to estimate the soil support values or the resilient moduli values of the subgrade layers.

To start presenting and discussing the obtained results, the following sections are organized so that each individual effort will be presented in a separate section. The final conclusions of this study will include recommendations to the Florida Department of Transportation for using the Falling Weight Deflectometer to estimate the subgrade moduli values in the state.

4.1 Results from the Field Tests for FWD and Dynaflect

A total of 20 sites were used to test pavement sections using the FWD and the Dynaflect tests. This effort was done under a previous FDOT contract related to pavement evaluation **(Figure 4.1)**. A complete set of figures for this part of the study is presented in Volume 2, Appendix A. In this effort three different NDT techniques were simultaneously utilized to determine moduli values of pavement layers as well other pavement parameters. The most important technique to the current study was the FWD and Dynaflect results as related to the subgrade layers. In the previous study, little was done to determine the moduli values of the subgrade layers. The reasons for bypassing the subgrade was the use of the Seismic Pavement Analyzer (SPA) setup in conjunction with the FWD and Dynaflect techniques. The SPA technique proved to be ineffective in determining the subgrade moduli values. It was more suited to estimate values for the surface layer and for less extent the base layer. Therefore, it was not advisable to include results from this testing technique to compare with results obtained from the FWD and the Dynaflect on the subgrade layers.

4.1.1 Dynaflect Results of the SPA Test Sites

In the current study, the gathered results from the FWD and the Dynaflect were extracted from the SPA project database and were analyzed with regard to the moduli values of the subgrade layers at 20 testing sites. The amount of information was enormous, especially for the Dynaflect test results where surface deflections were of primary concern. Although the surface deflections obtained from the Dynaflect tests were much less than those obtained from the FWD, the moduli values were found to be closer.

Surface deflections from the 20 test sites are shown in **Figure 4.2 to 4.3**. To determine the subgrade moduli values of the tested sections, the following procedures were used:

1- FDOT Method: The current FDOT procedure to determine the subgrade modulus is based on an empirical correlation where the deflection of sensor # 4 is used to directly predict the embankment modulus

$$\log E_R = 4.0419 - 0.5523 \log D_4 \qquad 4.1$$

Where: E_R = Embankment modulus, in psi; and D_4 = Deflection measured at 36 inches away from the load, in mils.

2- AASHTO formula:

$$M_R = \frac{0.24\,P}{d_r\ r} \qquad 3.10$$

This formula can be used to predict the subgrade moduli values from the deflection basins of any of the NDT that produces large loads. In this study, equation 3.10 was also used to estimate the subgrade moduli values of the 20 sites of the SPA project.

The procedure in the FDOT method was originally developed based on the plate bearing tests that were conducted at 31 locations in different counties around the state. The plate bearing test results were correlated with the Dynaflect deflections at sensor # 4 and a range of values that correlate between the sets of results was obtained. Based on this relationship another correlation was obtained between Dynaflect sensor # 4 deflections and the Soil Support Values (SSV). Once the SSVs are obtained, the embankment modulus can be figured out using AASHTO resilient modulus correlation with the SSV.

As can be seen, the FDOT method has the advantage of being simple and practical. However, the limited testing results involved in the D4 deflection vs. SSV correlation may cause some error in the estimated moduli values. In other words, the FDOT procedure is not sensitive enough to the variations in the sensor D4 measurements. This insensitivity in the relationship makes it even harder to detect the effect of environmental and geometric conditions on surface deflection from the Dynaflect test. When inspecting the deflection basins from the Dynaflect tests **(Figures 4.2 and 4.3)** one can distinguish the variations in the deflections at D4 at all of the testing sites **(Figure 4.4)**.

Also, part of the shortcomings of this method may be inherent in the testing technique itself. The Dynaflect is known for its low load magnitude (1000 lb) which contributes to the insensitivity of D4 in picking the variations in the deflection measurements. Reducing the distance to a lower value (less than 36 in) may cause a large error in estimating the subgrade moduli values. In this case the effect of the base and pavement surface stiffness will mask the stiffness of the subgrade.

In general, the variations in the moduli values obtained from the FDOT backcalculation method are small as compared to the variations obtained from more complicated backcalculation methods such as MODULUS 5.0. **Figure 4.5,** for instance, shows the large variations of the MR values estimated using MODULUS 5.0. Results from the 20 testing sites of the SPA project exhibit that the standard deviation of the Plate Bearing tests was the highest (18,033 psi), followed by the FWD (13,607 psi) and the Dynaflect (473 psi).

The soil support values (SSV) from Dynaflect testing for all the 20 tested sites were also found to have small variations. According to the data obtained from the Dynaflect results, it was found that the average SSV was about 8.6 with a maximum obtained value of 10.5 and a minimum value of 7.4 **(Figure 4.6)**. The average resilient modulus value using the **FDOT** method **(Equation 4.1)** was found to be 25,587 psi with a maximum value of 65,160 psi and and a minimum value of 20,644 psi **(Figure 4.7)**. The two sites in Dade county produced the lowest deflections at D4 and hence the largest moduli values. A detailed description of the pavement cross sections at the SPA test sites is presented in **Table 4.1.**

When using the AASHTO formula along with the deflections at D4 (Equation 3.10), the maximum modulus was found to be 166,667 psi and the minimum is about 20,833 psi **(Figure 4.8)**. The average value of the 20 test sites was 25,587 psi. These figures clearly show that the AASHTO method has overestimated the maximum moduli values as compared with the FDOT method. Surprisingly, both methods estimated almost the same minimum value. The average value of AASHTO was higher than the one obtained from the FDOT method.

The judgment of the suitability of any or both of these methods is basically a matter of local experience. Both procedures are empirical, but the FDOT data was obtained based on local pavement conditions especially as related to the field plate bearing tests for typical Florida embankments.

Therefore, it can be concluded that the confidence level in using the FDOT method should be higher than utilizing the AASHTO to obtain subgrade MR values from Dynaflect testing.

4.1.2 FWD Results of the SPA Test Sites

Back calculating the subgrade modulus MR from the FWD tests was more time intensive. The reason is the variety of methods that can be used to obtain these values. A method such as the AASHTO formula needs only the deflection values at a selected sensor and the load magnitude to estimate the MR values. The most common distances that are usually used in this method are located between sensor # 6 and sensor # 7. In Florida, the FWD distances for D6 and D7 are 36 in and 60 in, respectively. Lower distances may deem necessary when the curvatures of the deflection basins are steep at the point load. A sharp curvature deflection basin, as opposed to a deep deflection basin, is an indication of a stiff pavement structure. This may arise from either high stiffness of the pavement layers, or due to the proximity of the bedrock layer. In most of the sites where the FWD was used, sensors D6 and D7 were found to properly reflect the surface deformations. In this study the D6 was selected to determine the MR values using AASHTO formula. Also, for the 20 testing sites MODULUS 5.0 software was used to estimate the subgrade moduli values. FWD analysis of all the sites are tabulated in **Table 4.3.**

Figure 4.18 shows the relationship between values obtained from both methods. If the data from all the testing sites are used, the relationship would have an R^2 of 0.46 indicating a weak correlation between the two methods. This correlation, however, can be improved if certain sets of data were selected based on either the geometry of the pavement layers or the soil materials involved. In general, MR values from the AASHTO formula are higher than those estimated using MODULUS 5.0, and the ratio is 1 : 1.57.

The same was found for the relationship between MR values from MODULUS 5.0 vs. FWD deflections at sensor #6 **(Figure 4.9)**. When all the deflection measurements for all the testing sites were plotted together the correlation was found to be low. By plotting D6 vs. $MR_{MODULUS5.0}$ for each testing site, the correlations started to show strong relationships. **Figure 4.10** show these correlations. A complete set of figures is presented in **Volume 2, Appendix B**. The reason for these strong relationships is simply because pavement cross sections for each testing site posses similar geometric and material properties. Therefore, variables that affect these correlations were avoided. However, the variation in pavement properties for all the tested sections (SPA project) are manifested in the following parameters:

$$MR_{MODULUS5.0} = \alpha .\ e^{-\beta(D6)} \qquad 4.2$$

Where $MR_{MODULUS5.0}$ (Ksi) is the resilient modulus from MODULUS 5.0 software, α and β are pavement parameters, and D6 is the deflection at sensor # 6 (mil). **Table 4.4** shows all the values of α and β from the different sites. These parameters as mentioned above indicate the pavement characteristics of each testing site.

The MR vs. D6 relationship in **Figure 4.9** can be enveloped between the upper and the lower bounds of the relationship. Therefore, if the general relationship (Equation 4.2) is to be used then, the user can select between the following α and β values:

$\alpha = 0.4$

$\beta = 35$ to 80

If the user is interested in more specific site, then α and β for that site have to be used in Equation 4.2.

To facilitate the distinction between the deflection properties of the testing sites (SPA project), Figures 4.10 in volume 1 and Figures 4.10 to 4.10Y in volume 2 of this study show the deflection basins for the 20 tested sites. Combining all the deflection basins in one plot was found to give an overall idea of the FWD deflection ranges in the state. As can be seen from the figure, the maximum deflection at the point load was about 26.15 mil and the minimum deflection at the same point was 2.99 mil. If D6 was considered, then the maximum deflection was 5.08 mil and the minimum value was 0.49 mil. Sensor # 7 has a smaller range where the maximum and minimum values were 3.31 mil and 0.24 mil, respectively. However, the lower deflection values are associated with cross sections with thick surface layers or with unknown thicknesses of pavement overlays. The history of the added layers could not be retrieved in this study. As a final check on the subgrade moduli values from different NDT techniques, an attempt was made to compare MR values from the Dynaflect and FWD for the 20 testing sites (SPA project). **Tables 4.5 and 4.6 and Figures 4.12 to 4.13** show values that were obtained from both techniques. A complete set of figures are presented in Volume 2, Appendix C. As can be seen from these figures, the variations in the results between the two techniques are in general not large, except for some sites such as those for Dade and Martin counties. Also, at some sites like Alachua, Jefferson and Gadsden counties, MR values from Dynaflect tests were higher than those of the FWD. **Figure 4.5** was composed to draw a conclusion for the overall relationship of MR values from both techniques. This figure clearly states that a strong correlation does not exist. The fluctuation in the MR values from the FWD is much higher than those from the Dynaflect. This large variation made it difficult to assert any relationship between values from both techniques. It should be mentioned, however, that MR from FWD can be obtained using different methods (MODULUS 5.0, EVERCALC, AASHTO and others). In one of these cases a relationship could be established, providing the variation in the results from one method does not have the pattern in **Figure 4.5.** Another attempt to group certain sites and eliminating others from the relationship was relatively more successful. **Figure 4.14** shows that when MR values were averaged, then the 20 testing points together provided a better relationship between MR_{Dyna} and $MR_{MODULUS}$:

$$\mathbf{MR_{MODULUS5.0} = 1.865\ (MR_{Dyna})} \quad [R^2 = 0.74] \qquad 4.3$$

For the moduli values from Dynaflect and AASHTO formula, the relationship is estimated to be **(Figure 4.15)**:

$$\mathbf{MR_{AASHTO} = 2.15\ (MR_{Dyna})} \quad [R^2 = 0.83] \qquad 4.4$$

The relationship between laboratory MR and MR from MODULUS 5.0 was found to be weak. This relationship can be expressed as **(Figure 4.16)**:

$$\mathbf{MR_{Laboratory} = 6.78\ e^{0.01\ (MR)}{}_{FWD}} \quad [R^2 = 0.5] \qquad 4.5$$

Also the relationship between laboratory MR and MR from AASHTO Formula was weak. This relationship is **(Figure 4.17)**:

$$\mathbf{MR_{Laboratory} = 7.52\ e^{0.01\ (MR)}{}_{PASHTO}} \quad [R^2 = 0.3] \qquad 4.6$$

The estimated subgrade moduli values from AASHTO formula were found to be similar to those obtained from the MODULUS 5.0 backcalculation analysis **(Figure 4.18)**. The MR values used in

Figures 4.14 to 4.20 were the representative averaged values for each of the 20 testing sites. That means the MR values for each method were averaged for that particular site. Also the adjusted laboratory MR values were manually done by calculating the overburden pressure at depths similar to where the laboratory samples were extracted. A typical relationship that shows how the adjusted values were determined is shown in **Figure 4.19**.

From **Table 4.7**, one can distinguish the ratio between the laboratory resilient modulus and MR values from either MODULUS or AASHTO backcalculation methods. The ratios of $MR_{laboratory}$ vs. $MR_{MODULUS}$ or MR_{AASHTO} averaged about 0.3 in both cases. This is an indication that the factor C in the AASHTO formula (Equation 3.10) should always be corrected to reflect local pavement conditions. Based on the field testing it was found that **C = 0.3.**

4.1.3 FWD Results of the FDOT 300-Mile Sites

As was mentioned previously, this study was targeted at obtaining as much FWD data as possible from the current and the previous testing efforts. Part of the study included the analysis of the FWD and Dynaflect data obtained from the FDOT 300 mile test sites. All the properties of the tested sections are presented in **Tables 4.7 to 4.11.**

Results from these sections have provided a closer look at the relationships between different NDT and backcalculation methods. From the Dynaflect test results, it can be shown that the SSV for all the testing sites ranged from 18 to 4 at an average value of about 10.7. **Figure 4.23** shows the relationship of the Dynaflect deflections at sensor # 4 and the SSV. The relationship can be represented by:

$$SSV = 5.5362 (D)^{-0.3414} \qquad [R^2 = 0.95] \qquad 4.7$$

Where D is the deflection at sensor #4. When the deflection measurements from field tests were analyzed using MODULUS, EVERCALC and AASHTO backcalculation methods, the relationships of laboratory MR and MR from these methods were very weak **(Figure 4.24 to 4.26)**. However, categorizing the test sections according to pavement thickness, for example, could improve the relationships. **Figure 4.27** shows an improved correlation between laboratory MR and MR from MODULUS analysis. Also better relationships were found between MR from MODULUS 5.0, MR from AASHTO formula vs. laboratory MR for three different pavement thicknesses **(Figures 4.28 to 4.30)**.

In general MR AASHTO formula correlated very well with both methods, MODULUS 5.0 and EVERCALC. Also the AASHTO **C reduction factor** from the 300 mile test sites was found to be between 0.33 to 0.27 depending on what method was used to obtain the stiffness. On an average the C factor can be taken as 0.30 which is identical to the C factor obtained from the SPA test sites.

4.1.4 FWD Results of the LTPP Sites

A total of 37 LTPP Florida sections were originally analyzed in this study **(Figure 4.40)** . Because some of the sections were only mentioned in the data base but no measurements were found in the database tables, only 31 sections were considered. Upon the release of the new DATAPAVE version, the rest of the sections were added to the analysis. Among all the LTPP data only one showed some irregular FWD results (Section 4108).

The LTPP database contains the most complete measurements of the pavement section used in this study. Although, not a user friendly system, the data included in the software (DATAPAVE 2.0 and 3.0) can be extracted without the need to execute the program. In fact the program itself is a graphic interface for the MS ACCESS program. For the purpose of this study, it was easier to pull out the data directly for the attached files. Certain files that contain the NDT data were identified and the corresponding measurements were extracted and transferred to a spreadsheet. The vast amount of data contained in both CDs showed that there are about five million entries, including measurements from the State of Florida (State ID = 12). Also the data base contains 10,824 definitions of pavement parameters. The needed parameter has to be identified from the database dictionary first before scrolling through the data fields. Once all data was transferred to a spreadsheet, the needed measurements could be sorted out, analyzed and tabulated. To facilitate the process a special macro was written in Excel to sort and tabulate the measurements. A total of 98,152 rows of data was obtained from the data base. The data involve all the deflection basins for the 37 sections starting from 12/7/1989 to 2/18/2000.

Similar to the FDOT 300 mile testing site, the LTPP sections were also sorted based on the pavement thicknesses **(Table 4.12)**. All measurements related to FWD were plotted in **Figures 4.48 to 4.49.**

These figures encompass the FWD MR values. In these figures the maximum, the minimum and the MR values are presented for each LTPP section. The average FWD MR of all the Florida LTPP sections showed a subgrade modulus value of about 45 ksi. MR values were also determined separately. Both MODULUS5.0 and EVERCALC methods along with the AASHTO formula were used to independently determine the moduli values. Some of these values are presented in **Tables 4.13 and 4.14**.

An interesting finding from the LTPP measurements indicated that the deflection basin from the FWD test can be estimated if the test cross section is known. For example, deflections at LTPP Section 0101 can be predicted if the dropping height and the sensor spacing are specified. For that particular section the deflection at any point on the deflection basin can be obtained from the following (**Figures 4.87 and 4.97**):

$$\Delta\ (\text{mil}) = \gamma\ (q)^{\zeta}\ (\beta)^{S} \qquad 4.8$$

where Δ is the deflection in mil; γ, ζ, and β are the section parameters; and q is the dropping load of the FWD. Values of section parameters (Section 0101), γ, ζ, and β, can be obtained from the following ranges

γ = 0.00114

ζ = 0.966 to 0.885

β = 0.946 to 0.935

The differences between the Section 0101 parameters are due to the variation in the characteristics of the deflection basins. The deflection basins obtained during summer testing are different than winter time testing. Also deflection basins obtained from testing the same section at different time levels generate some variations in the γ, ζ, and β parameters.

In this study, several LTPP sections were investigated using the same concept described above. Results from LTPP Section B310 show that Equation 4.7 is valid for all of these sections (Figures 4.97 and 4.99). This conclusion can be generalized to involve all Florida LTPP sections.

4.2. Effect of Moisture and Water Table on the Moduli Values

The effect of water table levels and soil moisture levels has been referenced in the literature. The State of Florida is known for its shallow ground water table especially in areas close to the coastal line. On some road sections the ground water table has many times surfaced to cover segments of these roads. This fluctuation in the water table has weakened the pavement structure especially the subgrade layer.

Figures 4.69 to 4.86 show the effect of changes in both water table levels and changes in soil moisture content. As seen from these figures, the moisture has an adverse effect on deflections. When Sensor # 7 was selected, it was found that as the soil moisture content increases the deflection value at D7 increases. That was true for all the sensors and at all the testing sites used in this study. The relationship between deflection and moisture content can be signified as:

$$\mathbf{\Delta = \alpha \,.\, (Mc)^{\beta}} \qquad 4.9$$

Where Δ = deflection at any sensor, α and β = section parameters and can be obtained from Table 4.18, Mc = moisture content.

Also the effect of the water table depth was clear enough from the field measurements. The deflection at all the sensors decreased as the water table level dropped. This pattern was true for all the sensors and all the tested sites. As for the moisture content another relationship was developed to signify these changes. The FWD deflection can be predicted at a particular section by using the following:

$$\mathbf{\Delta = \alpha \, . \, (Dw)^{\beta}} \qquad 4.10$$

Where Δ is the deflection at any sensor, α and β can be obtained from Table 4.17A&B, Dw is the depth of water surface.

The effects of moisture content and the water table levels on the moduli values were similar to the effect of these parameters on the deflection measurements. Common trends were found between moisture content vs. FWD moduli values and water table vs. moduli values. The relationships of the moisture content and water table levels are presented in **Figures 4.72 to 4.78.**

4.3 Finite Element Results

The advantage of the finite element analysis is that the pavement behavior can be examined at a closer distance than using any other analytical method. In this study, the deflection basins, stress distribution and strains at any point in the pavement structure could be predicted. The first step in the FEA modeling is the validation of the constructed model. The model was validated by comparing the calculated vs. the measured deflections. Using the same dropping load, the surface deflection of US441 was found to be close to the field measurements **(Figure 4.119)**. When the subgrade modulus was assumed as 10 Ksi the deflection basin showed the same maximum deflection as of the measured one. Immediately after the maximum deflection the FEA model exhibited higher deflection values. The values are a reflection of the shape of the FWD loading plate. D6 deflection for MR = 10 ksi was identical to the measured D6 deflection. When the modulus value was assumed as 20 ksi the produced maximum deflection was less than the measured one.

Additionally, findings indicate that the higher the subgrade modulus value is the larger the extent of the surface deflections (**Figures 4.120 to 4.126**). This conclusion indicted that the effective distance has to be adjusted so that shorter distances have to be chosen to capture the surface deflections. The same conclusion is applied when the depth of the bedrock is shallower. The closer the bedrock to the pavement layer the steeper is the deflection basin. **Table 4.2** shows the distances to the loading point for 10%, 5% and 1% of the maximum imposed stress due to 9000 lb dropping load.

Table4.1 Description of the SPA test sites:

County Name	Site #	Pavement type/ thickness(in)	Base layer type/ thickness(in)	Subgrade	Embankment
Jefferson	Site # 1A	Asphalt (4.2)	Limerock(6.5)	Silty Clay (6.5)	Silty Clay
	Site # 2A	Asphalt (5)	Limerock(7.5)	SiltyClay(11.5)	Silty Clay
Gadsden	Site # 2B	Asphalt (4.5)	Limerock(9.6)	SiltySand(10.5)	Clay
	Site # 3B	Asphalt (4.2)	Limerock(8.5)	Fine Sand (23)	Clay
Alachua	Site # 3	Asphalt (5.5)	Limerock(9.5)	Silty Clay(12)	Clay
	Site # 4	Asphalt (4.4)	Limerock (9)	Fine Sand (8)	Fine Sand
Clay	Site # 5	Asphalt (7.5)	Limerock (8)	Fine Sand(12)	Silty Sand
	Site # 6	Asphalt (8)	Limerock (7)	Fine Sand (14)	Fine Sand
Seminole	Site # 1	Asphalt (5.3)	Limerock(12)	Silty Sand (12)	Silty Sand
	Site # 2	Asphalt (5.5)	Limerock (12)	Silty Sand(13.5)	Find Sand
Osceola	Site # 3	Asphalt (3.4)	Coquina (8)	Fine Sand (18)	Fine Sand
	Site # 4	Asphalt (4.7)	Coquina (11)	Fine Sand (18)	Fine Sand
Dade	Site # 1	Asphalt (3.6)	Limerock(13)	Limerock (13)	Limerock
	Site # 2	Asphalt (3.8)	Limerock (13)	Limerock(12.5)	Limerock
Martin	Site # 3	Asphalt (3)	Limerock(11)	Fine Sand (16)	Fine Sand
	Site # 4	Asphalt (3)	Limerock (11)	Fine Sand (12)	Fine Sand
Polk	Site # 1A	Asphalt (5)	Limerock (9)	Silty Sand (14)	Fine Sand
	Site # 2A	Asphalt (5)	Limerock (9)	Silty Sand (13)	Fine Sand
Lee	Site # 1B	Asphalt (1.8)	Limerock(11.5)	Fine Sand (12)	Fine Sand
	Site # 2B	Asphalt (1.6)	Limerock(9.52)	Fine Sand (12)	Fine Sand

Table 4.2 Influence line due to the Load Plate of the Falling Weight Deflectometer is in finite analysis

Type	Stress bulb (Radial distances in inches)			Extent of Deflections in the horizontal distance (inches)
Subgrade	10%	5%	1%	Radial effect
200000 psi(US441-2)	27.47	33.41	48.32	24.48
20000 psi(US441)	36.05	42.04	56.98	62.95
10000 psi(US441-1)	45	54.02	71.93	57
5000 psi(US441-3)	50.74	62.68	80.59	63.56
Bed Rock at 52.98 in(US441-5)	47.76	59.7	68.65	41.79
Bed Rock at 24 in(US441-4)	38.8	44.77	65.67	29.85
Bed Rock at 9.8 in(US441-6)	29.85	35.82	56.71	17.96
Bed Rock at subgrade(US441-7)	23.88	32.83	47.76	11.94

Table 4.3 Relationship Between Subgrade MR (ksi) from MODULUS 5.0 vs. Deflections (mil) at D6 and D7

County: JEFFERSON; SITE # 1A			County: JEFFERSON; SITE # 2A			County: GADSDEN; SITE#2B			County: GADSDEN; SITE#3B			County: MARTIN; SITE # 3		
36	60	MR	36	60	MR	36	60	MR	36	60	MR	36	60	MR
R6	R7	Subgrade	R6	R7	Subgrade	R6	R7	Subgrade	R6	R7	Subgrade	R6	R7	Subgrade
1.06	0.64	21.30	1.35	0.60	12.50	1.67	0.60	11.90	1.06	0.44	15.40	2.00	1.29	33.00
1.27	0.72	17.70	1.31	0.52	10.30	1.51	0.64	12.10	0.69	0.40	19.00	1.84	1.05	32.70
1.31	0.56	18.10	1.67	0.76	9.60	1.71	0.64	11.10	1.02	0.36	15.80	1.39	0.84	43.10
1.27	0.64	17.50	1.96	0.93	9.40	1.71	0.60	11.50	0.82	0.48	16.30	1.31	0.80	50.20
1.39	0.68	14.80	1.88	0.80	9.80	1.80	0.72	10.50	1.06	0.48	14.30	1.22	0.68	50.30
1.10	0.68	20.20	1.43	0.60	11.90	1.80	0.72	11.50	1.06	0.48	15.00	1.35	0.76	45.80
1.10	0.60	21.60	0.90	0.44	15.80	1.39	0.64	11.80	0.90	0.48	16.40	1.18	0.64	49.20
2.33	1.01	9.40	0.82	0.44	15.40	1.80	0.64	10.60	0.86	0.48	16.70	1.14	0.72	53.90
2.45	1.09	8.60	0.94	0.48	14.60	1.84	0.64	10.40	0.73	0.36	18.40	1.06	0.68	58.00
1.92	0.97	11.20	0.94	0.44	15.30	1.71	0.60	11.00	0.82	0.40	17.90	1.14	0.72	56.80
2.08	1.05	9.80	0.98	0.52	14.10	1.80	0.64	11.50	0.82	0.48	17.10	1.18	0.72	53.60
1.63	0.93	15.00	0.90	0.52	16.10	1.59	0.60	12.50	1.18	0.56	14.90	1.14	0.72	57.30
1.51	0.89	15.90	1.10	0.52	13.00	1.88	0.80	11.60	1.31	0.60	14.70	1.80	1.05	35.50
1.55	0.89	15.20	2.37	1.21	7.80	1.71	0.68	11.80	0.94	0.48	16.40	1.96	1.13	32.20

County: DADE; SITE # 1			County: DADE; SITE # 2			County: LEE; SITE # 1B			County: LEE; SITE # 2B			County: POLK; SITE # 1A		
36	60	MR	36	60	MR	36	60	MR	36	60	MR	36	60	MR
R6	R7	Subgrade	R6	R7 S	Subgrade	R6	R7	Subgrade	R6	R7	Subgrade	R6	R7	Subgrade
2.00	1.29	55.70	0.61	0.32	55.30	2.45	1.09	20.70	3.06	1.69	20.50	1.10	0.48	38.10
1.84	1.05	54.30	0.49	0.24	68.40	2.33	1.05	21.00	2.37	1.01	22.40	0.94	0.40	43.20
1.39	0.84	44.80	0.61	0.32	56.10	2.69	1.25	19.10	2.37	1.01	21.70	1.43	0.68	30.60
1.31	0.80	48.00	0.57	0.28	59.20	2.29	1.13	21.80	2.04	0.93	25.90	2.37	1.37	20.30
1.22	0.68	51.10	0.53	0.28	63.00	2.45	1.13	20.70	1.88	0.89	26.80	1.88	1.13	25.50
1.35	0.76	53.80	0.61	0.28	62.50	2.33	1.17	21.80	2.57	1.25	20.50	1.84	1.09	26.30
1.18	0.64	52.00	0.57	0.32	62.10	2.29	1.13	22.30	2.74	1.25	19.20	1.96	1.17	24.70
1.14	0.72	59.50	0.57	0.32	60.40	2.41	1.05	20.30	2.08	0.93	25.30	2.25	1.33	22.10
1.06	0.68	62.70	0.73	0.40	47.50	2.41	1.09	20.90	2.04	0.93	26.30	2.00	1.17	23.30
1.14	0.72	56.50	0.73	0.40	51.30	1.96	0.93	25.70	2.00	0.76	26.10	1.92	1.17	23.30
1.18	0.72	44.60	0.94	0.48	43.00	2.49	1.09	19.80	1.67	0.76	29.70	2.08	1.21	22.50
1.14	0.72	43.70	0.69	0.36	48.80	2.65	1.33	19.90	1.67	0.80	29.60	1.88	1.13	26.10
1.80	1.05	48.80	0.57	0.28	58.10	2.49	1.29	21.00	1.67	0.76	30.30	1.92	1.09	23.00
1.96	1.13	52.40	0.57	0.28	64.10	2.33	1.17	22.50	1.63	0.76	31.60	1.55	0.97	29.60

Table 4.4 Values for Alpha and Beta for the $MR_{MODULUS\ 5.0}$ vs. FWD Deflections at D6 (SPA Project)

$$y = \alpha e^{-\beta(D6)}$$

Testing Site	Alpha	Beta
Jefferson, Site 1A	22.666	0.465
Fefferson, Site 2A	41.828	0.6609
Gadesden; Site 3B	17.214	0.2413
Martin, Site 3	24.713	0.4423
Dade, Site 2	112.66	0.6434
Lee, Site 1B	111.36	1.0756
Lee, Site 2B	53.57	0.3508
Polk, Site 1A	66.889	0.5175
Polk, Site 2A	66.128	0.4485
Osceola, Site 3	67.634	0.3771
Osceola, Site 4	50.7	0.3671
Seminole, Site 1	48.455	0.4242
Seminole, Site 2	77.351	0.615
Jackson, Highway/Road: I10-150	37.918	0.2438
Jackson, Highway/Road: I10-148	90.211	0.4708
Alachua, Site 3	48.878	0.5492
Alachua, Site 4	23.111	0.3711
Clay, Site 5	45.08	0.3499
Clay, Site 6	68.551	0.5112
Average Values	56.57458	0.480247

Table 4.5 MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)

District: 3			MODULI RANGE(psi)		
County: JEFFERSON; SITE # 1A		Thickness(in)	Minimum	Maximum	Poisson Ratio Values
Highway/Road: U.S.27	Pavement:	4.00	70,000	4,500,001	H1: õ = 0.30
	Base:	6.50	30,000	2,000,000	H2: õ = 0.35
	Subgrade:	98.80		12,400	H4: õ = 0.40

Station	Load	Measured deflections (Mils)							Calculated young's moduli (ksi)			Absolute	Depth to
		0	8	12	18	24	36	60					
#	(lbs)	R1	R2	R3	R4	R5	R6	R7	Surface	Base	Subgrade	ERR/Sens	Bedrock
0.01	9,015	11.90	7.96	5.47	3.18	1.95	1.06	0.64	261	79.90	21.30	9.76	40.87
0.02	9,135	11.86	8.32	6.07	3.83	2.40	1.27	0.72	317	98.70	17.70	7.53	44.10
0.03	9,255	9.64	6.79	5.19	3.50	2.40	1.31	0.56	319	198.90	18.10	6.47	64.35
0.04	9,007	12.11	8.36	6.03	3.75	2.44	1.27	0.64	269	101.30	17.50	7.80	50.13
0.05	8,863	13.22	9.29	6.83	4.40	2.85	1.39	0.68	270	92.50	14.80	5.98	50.50
0.06	9,015	12.93	8.68	5.91	3.30	2.07	1.10	0.68	252	67.30	20.20	10.04	39.82
0.07	9,175	10.67	7.07	5.10	3.09	2.03	1.10	0.60	255	124.10	21.60	8.73	50.81
0.08	8,767	17.67	12.50	9.45	6.43	4.47	2.33	1.01	166	101.80	9.40	5.92	64.08
0.09	8,647	19.81	14.31	10.81	7.16	4.76	2.45	1.09	190	68.30	8.60	5.77	57.70
0.10	8,799	17.26	12.18	8.92	5.70	3.70	1.92	0.97	203	71.50	11.20	7.08	51.18
0.11	8,711	18.57	13.51	10.13	6.47	4.19	2.08	1.05	247	57.00	9.80	5.79	51.03
0.12	8,943	14.66	9.81	7.03	4.27	2.81	1.63	0.93	182	90.10	15.00	9.77	52.01
0.13	9,031	14.04	9.65	6.87	4.15	2.64	1.51	0.89	236	80.60	15.90	9.59	45.77
0.14	9,055	13.47	9.33	6.79	4.27	2.81	1.55	0.89	234	101.30	15.20	8.40	52.54
Mean:		**14.13**	**9.84**	**7.19**	**4.54**	**2.97**	**1.57**	**0.81**	**243**	**95.20**	**15.40**	**7.76**	**50.11**
Std. Dev		**3.08**	**2.37**	**1.88**	**1.35**	**0.93**	**0.46**	**0.18**	**46**	**34.80**	**4.30**	**1.63**	**6.88**
Var Coeff(%)		**21.83**	**24.07**	**26.13**	**29.66**	**31.46**	**29.17**	**22.57**	**19**	**36.50**	**28.20**	**21.01**	**13.73**

Table. 4.6A Comparison of Subgrade layer Properties

Asphalt pavement

Jefferson County;

Site # 1A **Poisson's Ratio = 0.40**

TEST #	DATA SET #	YOUNG'S MODULUS (MPa)		DYNAFLECT RESILIENT MODULUS (MPa)	SPA/FWD RATIO
		SPA	FWD		
1	840-41	459.47	146.97	134.39	3.13
2	842-43-44	601.55	122.13	134.39	4.93
3	845	445.74	124.89	134.39	3.57
4	847-48	407.77	120.75	134.39	3.38
5	849	195.17	102.12	134.39	1.91
6	850-52	433.89	139.38	134.39	3.11
7	854-55	196.00	149.04	134.39	1.32
8	856-58	406.42	64.86	129.61	6.27
9	859-60	500.35	59.34	129.61	8.43
10	861-62	452.73	77.28	129.61	5.86
11	863-64	228.31	67.62	134.39	3.38
12	865-66	233.31	103.50	129.61	2.25
13	867-68	248.87	109.71	134.39	2.27
14	869	231.84	104.88	129.61	2.21
Average:		360.10	106.61	132.68	3.71

Table. 4.6B Comparison of Subgrade layer Properties
Asphalt pavement
Jefferson County
Site # 2A

Poisson's Ratio = 0.40

TEST #	DATA SET #	YOUNG'S MODULUS (MPa)		DYNAFLECT RESILIENT MODULUS (MPa)	RESILIENT MODULUS (MPa)	SPA/FWD RATIO
		SPA	FWD			
1	870-71	445.74	86.25	134.39	161.74	5.17
2	872	331.56	71.07	134.39	161.74	4.67
3	874-75	269.47	66.24	134.39	161.74	4.07
4	876	351.86	64.86	129.61	161.74	5.42
5	877-78	284.24	67.62	129.61	161.74	4.20
6	879-80-81	302.30	82.11	134.39	161.74	3.68
7	883-84	426.08	109.02	134.39	161.74	3.91
8	885-86	435.86	106.26	134.39	161.74	4.10
9	887	416.42	100.74	134.39	161.74	4.13
10	889-90	153.78	105.57	134.39	161.74	1.46
11	891-92	356.31	97.29	129.61	161.74	3.66
12	894-96	354.82	111.09	129.61	161.74	3.19
13	897-99	419.78	89.70	129.61	161.74	4.68
14	900-01	320.22	53.82	129.61	161.74	5.95
Average:		347.74	86.55	132.34	161.74	4.16

Table 4.7 Laboratory Resilient Modulus at Field condition,available Dynaflect & FWD resilient modulus and their ratio (SPA Project)

Counties Project Site	Confining Pressure in Field Condition(psf)	Confining Pressure in Field Condition(kpa)	Lab Resilient Modulus (Mpa)	Lab resilient Modulus (ksi)	Dynaflect Resilient Modulus (ksi)	Ratio of M_R(lab) and Dynaflect	FWD Resilient Modulus(ksi)	Ratio of M_R(lab) and FWD	Average Deflection (D6) mil	AASHTO MR (Ksi)	Ratio of M_R(lab) and FWD
Lee County Site 1B	142.29	6.811	60.95	8.83	22.29	0.40	30.65	0.29	2.27	26.4	0.33
Lee County Site 2B	115.83	5.545	53.51	7.75	24.3	0.32	30.65	0.25	2.27	26.4	0.29
Polk County,Site 1A	127.5	6.103	58.38	8.46	19.913	0.42	27.05	0.31	1.79	33.5	0.25
Polk County,Site 2A	127.5	6.103	67.40	9.77	22.131	0.44	29.97	0.33	1.78	33.7	0.29
Alachua County,Site 3	143.95	6.891	56.49	8.19	23.9	0.34	21.26	0.39	2	30.0	0.27
Alachua County,Site 4	133.125	6.373	71.57	10.37	23.249	0.45	25.6	0.41	1.73	34.7	0.30
Clay County,Site 5	145.2	6.951	53.27	7.72			22.43	0.34	3.09	19.4	0.40
Clay County,Site 6	129.16	6.183	44.69	6.48			22.43	0.29	2.2	27.3	0.24
Jefferson County,Site 1A	118.33	5.664	79.40	11.51	25.983	0.44	40.12	0.29	1.57	38.2	0.30
Jefferson County,Site 2A	131.56	6.298	45.77	6.63	27.3	0.24	52.9	0.13	1.32	45.5	0.15
Gadsden County,Site 2B	143.875	6.887	57.18	8.29	25.76	0.32	61.17	0.14	1.71	35.1	0.24
Gadsden County,Site 3B	127.91	6.123	64.50	9.35	29.9	0.31	67.96	0.14	0.95	63.2	0.15
Dade County,Site 1	171.41	8.205	153.51	22.25	47.417	0.47	102.32	0.22	0.61	98.4	0.23
Dade County,Site 2	132.7	6.352	135.45	19.63	45.65	0.43	102.32	0.19	0.61	98.4	0.20
Martin County,Site 3	149.16	7.140	86.14	12.48	23.459	0.53	46.56	0.27	1.41	42.6	0.29
Martin County,Site 4	127.5	6.103	76.53	11.09	18.64	0.59	46.56	0.24	1.42	42.3	0.26
Seminole County,Site 1	192.5	9.215	87.73	12.72	19.04	0.67	33.08	0.38	1.67	35.9	0.35
Seminole County,Site 2	192.5	9.215	83.94	12.17	20.233	0.60	28.07	0.43	1.9	31.6	0.39
Osceola County,Site 3	118.2	5.658	106.46	15.43	18.25	0.85			2.59	23.2	0.67
Osceola County,Site 4	176.45	8.447	112.70	16.34	19.54	0.84			3.44	17.4	0.94
Average	140.54	6.73	75.94	11.01	25.73	0.46	43.95	0.3	1.73	41.3	0.3
STDEV	23.282	1.115	29.452	4.270	8.331	0.171	25.180	0.093	0.718	22.313	0.181

Table 4.8 Data Collection for different field FWD and Dynaflect test (FDOT 300 Mile Test Sites)

File Name	District	County sec	County	Mile Post		Temperature		Typical Cross Section			SSV
				Begin	Finish	Air	Pavement	AC/PCC	Base	Subgrade	
a03010nt	1	3010	Collier	3.041	5.91	86	92	3.5	Assumed		8.78
a03010st	1	3010	Collier	3.041	5.91	86	92	3.5	Assumed		9.43
a12070et	1	12070	Lee	2.96	3.814	90	99	3	Assumed		10.93
a12070wt	1	12070	Lee	2.96	3.814	90	99	3	Assumed		10.48
a16070nt	1	16070	Polk	14.64	22.08	86	91	*Assumed	*Assumed		8.89
a16160nt	1	16160	Polk	6.787	10.07	98	116	*Assumed	10		8.75
a17010nt	1	17010	SARASOTA	0	4.314	91	101	1.25	8		10.38
a17010st	1	17010	SARASOTA	0	4.314	81	90	7	10		9.88
a29002et	2	29002	COLUMBIA	0	3.494	102	120	3	10		9.85
a29002wt	2	29002	COLUMBIA	0	3.494	102	120	3	10		9.77
a29010et	2	29010	COLUMBIA	6.975	8.047	73	79	1	8		11.27
a29010wt	2	29010	COLUMBIA	6.975	8.047	76	84	0.5	8		9.43
a29180nt	2	29180	COLUMBIA	26	30.45	87	93	*Assumed	10		11.08
a29180st	2	29180	COLUMBIA	26	30.45	98	118	*Assumed	10		11.04
a35040nt	2	35040	Madison	0.229	12.38	80	83	3	6		10.71
a37130nt	2	37130	SWANNEE	0	3.585	93	105	4	10		10.58
a37130st	2	37130	SWANNEE	0	3.585	95	113	4	10		10.68
a37530et	2	37530	SWANNEE	0	11.22	76	82	3.75	6		10.04
a38010nt	2	38010	TAYLOR	24.84	27.46	94	122	*Assumed	8		9.77
a38010st	2	38010	TAYLOR	24.84	27.46	91	109	*Assumed	8		9.58
a38501et	2	38501	TAYLOR	0	1.346	79	84	nothing	nothing		8.57
a49010et	3	49010	FRANKLIN	7.33	8.113	61	76	*Assumed	*Assumed		7.9
a49010wt	3	49010	FRANKLIN	29.62	30.26	65	81	*Assumed	*Assumed		8.12
a49030nt	3	49030	FRANKLIN	0	5.42	58	67	2.5	8		7.87
a50010et	3	50010	GADSDEN	0.009	2.158	67	70	nothing	8		9.59
a55002nt	3	55002	LEON	0	8.019	51	53	*Assumed	8		8.97
a70220nt	5	70220	BREVARD	0	31.25	61	60	3	10		9.9
a72018et	2	72018	Duval	2.731	5.737	84	94	2	10		9.16
a72018wt	2	72018	Duval	2.731	5.737	84	94	2	10		8.94
a72040nt	2	72040	Duval	1.72	5.01	85	90	1.75	8		9.85
a72040st	2	72040	Duval	1720	5010	82	89	2	8		9.82
a72280nt	2	72280	Duval	0.001	4.806	75	76	9	10(pcc)		10.06
a72280st	2	72280	Duval	0	4.806	85	87	9	10(pcc)		10.17
a72291nt	2	72291	Duval	0	2.89	89	101	1.5	8		9.37
a72291st	2	72291	Duval	0	2.89	89	101	1.5	8		9.22
a74040nt	2	74040	NASAU	15.64	27.33	87	101	*Assumed	9		8.04
a76050et	2	76050	Putnam	20.31	24.24	84	87	*Assumed	8		8.68
a76050wt	2	76050	Putnam	23.74	24.24	89	100	*Assumed	8		8.03
a87001et	6	87001	DADE	9.882	10.65	87	127	3	8		12.54
a87001wt	6	87001	DADE	9.882	10.65	87	127	3	8		14.44
a87003et	6	87003	DADE	0.546	3.171	82	89	3	9		15.15
a87003wt	6	87003	DADE	0.403	3.13	82	89	3	9		14.91
a87005nt	6	87005	DADE	0	7.153	74	76	2.5	8		16.32
a87005st	6	87005	DADE	0	7.153	87	103	2.5	8		16.71
a87020nt	6	87020	DADE	12.01	16.25	86	104	2.5	8		18.43
a87020st	6	87020	DADE	12.01	16.25	81	84	8	8		13.99
a87030nt	6	87030	DADE	6.507	8.225	87	115	2.5	8		17.03
a87030st	6	87030	DADE	6.507	8.225	87	115	2.5	8		17.17
a87140nt	6	87140	DADE	0	0.727	72	78	2.5	8		14.2
a87200et	6	87200	DADE	0	10.34	75	78	3	9		16.94
a87200wt	6	87200	DADE	0.031	10.34	83	94	2.5	8		16.94
a93230nt	4	93230	PALMBEACH	0.002	2.183	85	104	5	nothing		4.44
a93290nt	4	93290	PALMBEACH	0	9.44	77	82	nothing	6		5.35
a93290st	4	93290	PALMBEACH	10.84	12.07	85	96	nothing	6		5.49
b29010et	2	29010	COLUMBIA	9.208	10.09	73	79	*Assumed	*Assumed		9.88
b29010wt	2	29010	COLUMBIA	9.208	10.09	76	84	*Assumed	*Assumed		9.86
b87020nt	6	87020	DADE	7.012	11.93	85	91	8	8		
b87020st	6	87020	DADE	7.012	11.93	85	91	2.5	8		
b93290nt	4	93290	PALMBEACH	9.44	12.07	82	93	*Assumed	6		5.08

*** Typical cross section test data have been collected from the DOT main frame computer. Most of the thickness data are not exactly match with the FWD test mile post location.In this regards,some of the thicknesses data assumed based on the same route.

Table 4.9 Data Collection for different field FWD and Dynaflect test (FDOT 300 Mile Test Sites)

File Name	Modulus 5.1 M_R	EVERCAL M_R	Ratio of (0.23/0.24)	AASHTO M_R	AASHTO M_R (for 0.23)	DYNAFLECT M_R	***Lab M_R	AASHTO (R5)	AASHTO (R6)	AASHTO (R7)	Mr(lab)/Mr(Modulus 5.0)	Mr(lab)/Mr(Ever)	Mr(lab)/Mr(AASHTO)	Mr(lab)/Mr(DYNA)
a03010nt	22.51	25.24	0.979	23.99	23.49	15.6	12.81	21.78	22.3	23.99	0.57	0.51	0.53	0.82
a03010st	24.22	30.63	0.979	28.4	27.80	15.516	12.81	27.57	27.87	28.4	0.53	0.42	0.45	0.83
a12070et	29.3	37.48	0.979	40.71	39.86	23.48	12.81	34.54	36.62	40.71	0.44	0.34	0.31	0.55
a12070wt	29.26	34.37	0.979	35.85	35.10	23.39	12.81	32.61	33.42	35.85	0.44	0.37	0.36	0.55
a16070nt	27.69	27.77	0.979	26.15	25.60	19.572	10.13	21.26	24.11	26.2	0.37	0.36	0.39	0.52
a16160nt	24.4	39.9	0.979	24.51	24.00	19.272	10.13	25.22	25.53	24.73	0.42	0.25	0.41	0.53
a17010nt	27.58	34.79	0.979	34.98	34.25	20.457	12.81	33.32	31.81	32.57	0.46	0.37	0.37	0.63
a17010st	27.4	39.86	0.979	31.83	31.16	20.176	12.81	28.44	29.22	32.38	0.47	0.32	0.40	0.63
a29002et	30.1	37.2	0.979	30.59	29.95	18.831	10.51	37.93	34.23	30.54	0.35	0.28	0.34	0.56
a29002wt	31.36	43.77	0.979	30.13	29.50	18.743	10.51	34.7	32.3	29.64	0.34	0.24	0.35	0.56
a29010et	36.05	30.33	0.979	41.61	40.74	26.605	10.51	41	41.16	42.245	0.29	0.35	0.25	0.40
a29010wt	28.05	35.47	0.979	28.88	28.27	21.617	10.51	28.76	28.35	28.72	0.37	0.30	0.36	0.49
a29180nt	58.6	69.23	0.979	40.64	39.79	22.404	10.51	51.8	45.93	41.11	0.18	0.15	0.26	0.47
a29180st	35.93	44.15	0.979	38.1	37.30	22.419	10.51	47.26	43.37	38.09	0.29	0.24	0.28	0.47
a35040nt	34.64	42.98	0.979	38.93	38.11	21.024		24.97	36	38.78				
a37130nt	34.7	39.54	0.979	36.42	35.66	22.21	10.51	44.04	39.91	36.42	0.30	0.27	0.29	0.47
a37130st	31.81	32.79	0.979	36.37	35.61	22.197	10.51	42.59	38.5	36.37	0.33	0.32	0.29	0.47
a37530et	32.35	36.42	0.979	33.56	32.86	18.538	10.51	28.89	29.91	33.74	0.32	0.29	0.31	0.57
a38010nt	31.15	35.56	0.979	30.86	30.21	21.083	10.51	33.69	32.13	31.19	0.34	0.30	0.34	0.50
a38010st	28.41	25.2	0.979	29.86	29.23	21.244	10.51	32.94	31.66	30.22	0.37	0.42	0.35	0.49
a38501et	21.7	20.84	0.979	23.69	23.19	16.447	10.51	21.52	22.74	23.48	0.48	0.50	0.44	0.64
a49010et	22.88	24.07	0.979	20.16	19.74	12.827	7.11	17.08	15.52	18.18	0.31	0.30	0.35	0.55
a49010wt	22.16	21.7	0.979	20.54	20.11	14.624	7.11	21.75	19.88	19.85	0.32	0.33	0.35	0.49
a49030nt	26.61	30.94	0.979	20.26	19.83	13.501	7.11	18.24	17.32	20.09	0.27	0.23	0.35	0.53
a50010et	31.99	24.84	0.979	29.79	29.16	17.658	16.1	25.86	26.91	30.09	0.50	0.65	0.54	0.91
a55002nt	23.03	34.22	0.979	25.84	25.30	17.754	16.1	19.38	22.14	25.79	0.70	0.47	0.62	0.91
a70220nt	30.79	27.02	0.979	31.73	31.06	23.03	9.52	29.85	30.8	31.75	0.31	0.35	0.30	0.41
a72018et	22.13	27.63	0.979	25.6	25.06	23.058	11.74	25.17	28.78	31.99	0.53	0.42	0.46	0.51
a72018wt	21.56	40.38	0.979	24.77	24.25	16.577	11.74	21.59	23.57	30.97	0.54	0.29	0.47	0.71
a72040nt	36.31	37.23	0.979	30.3	29.66	21.019	11.74	36.24	34.59	37.84	0.32	0.32	0.39	0.56
a72040st	30.84	36.29	0.979	30.23	29.60	20.896	11.74	33.84	33.78	37.81	0.38	0.32	0.39	0.56
a72280nt	34.61	44.02	0.979	32.59	31.91	23.147	11.74	33.12	33.83	40.91	0.34	0.27	0.36	0.51
a72280st	28.88	32.22	0.979	32.69	32.00	22.63	11.74	33.09	33.63	40.81	0.41	0.36	0.36	0.52
a72291nt	27.41	31.44	0.979	28.75	28.15	14.925	11.74	28.01	27.87	28.67	0.43	0.37	0.41	0.79
a72291st	27.02	35.42	0.979	27.98	27.39	15.703	11.74	26.95	27.48	28.01	0.43	0.33	0.42	0.75
a74040nt	18.24	26.13	0.979	20.78	20.34	14.04	7.77	16.43	17.62	20.81	0.43	0.30	0.37	0.55
a76050et	23.22	29.59	0.979	23.57	23.08	18.627	10.51	23.24	23.48	29.49	0.45	0.36	0.45	0.56
a76050wt		72.57	0.979		0.00	16.499	10.51					0.14		0.64
a87001et	49.72	63.44	0.979	54.97	53.82	36.385	7.4	65.16	66.55	68.08	0.15	0.12	0.13	0.20
a87001wt	64.84	91.5	0.979	71.53	70.03	41.536	7.4	114.09	83.72	89.79	0.11	0.08	0.10	0.18
a87003et	69.62	81.75	0.979	78.09	76.45	41.612	7.4	76.46	84.16	97.77	0.11	0.09	0.09	0.18
a87003wt		100.92	0.979	74.55	72.98	37.539	7.4	76.96		93.95		0.07	0.10	0.20
a87005nt	72.62	106	0.979	91.15	89.24	46.56	7.4	116.44	115.76	114.64	0.10	0.07	0.08	0.16
a87005st	82.23	96.91	0.979	96.41	94.39	49.323	7.4	122.56	122.28	120.82	0.09	0.08	0.08	0.15
a87020nt	79.65	89.35	0.979	120.67	118.14	50.78	7.4	114.05	143.95	150.94	0.09	0.08	0.06	0.15
a87020st	67.12	78.26	0.979	71.16	69.67	50.858	7.4	61.07	68.35	88.87	0.11	0.09	0.10	0.15
a87030nt	93.12	110.28	0.979	103.82	101.64	49.641	7.4	136.68	139.08	129.77	0.08	0.07	0.07	0.15
a87030st	94.43	103.73	0.979	102.87	100.71	51.303	7.4	157.03	122.77	128.45	0.08	0.07	0.07	0.14
a87140nt	60.02	86.49	0.979	66.74	65.34	42.872	7.4	59.58	76.96	83.43	0.12	0.09	0.11	0.17
a87200et	86.38	101.83	0.979	74.18	72.62	47.631	7.4	113.19	113.31	125	0.09	0.07	0.10	0.16
a87200wt			0.979	67.54	66.12	46.884	7.4						0.11	0.16
a93230nt	5.06		0.979		0.00	4.894	9.6							1.96
a93290nt			0.979	10.45	10.23	7.254	9.6							1.32
a93290st			0.979	9.25	9.06	8.749	9.6							1.10
b29010et			0.979	31.54	30.88	20.718	10.51						0.33	0.51
b29010wt			0.979	31.81	31.14	20.851	10.51						0.33	0.50
			0.979		0.00									
			0.979		0.00									
Average			0.979		0.00						0.33	0.27	0.31	0.53

*** Mr Lab measurement were obtained from the LTPP DB.

Table 4.10 Categorizing the 300 mile test sections based on the pavement thickness

For 300 miles Sections at surface Thickness 2-2.5 inches

Thickness	Evercalc	Lab MR
2-2.5 inches	25	12.67
2-2.5 inches	26	12.47
2-2.5 inches	27	12.29
2-2.5 inches	28	12.12
2-2.5 inches	29	11.96
2-2.5 inches	30	11.80
2-2.5 inches	31	11.65
2-2.5 inches	32	11.51
2-2.5 inches	33	11.38
2-2.5 inches	34	11.25
2-2.5 inches	35	11.12
2-2.5 inches	36	11.00
2-2.5 inches	37	10.88
2-2.5 inches	38	10.77
2-2.5 inches	39	10.67
2-2.5 inches	40	10.56
2-2.5 inches	41	10.46

For 300 miles Sections at surface Thickness 2-2.5 inches

Thickness	Modulus 5.1	Lab MR
2-2.5 inches	25	11.85
2-2.5 inches	26	11.67
2-2.5 inches	27	11.50
2-2.5 inches	28	11.34
2-2.5 inches	29	11.19
2-2.5 inches	30	11.04
2-2.5 inches	31	10.91
2-2.5 inches	32	10.77
2-2.5 inches	33	10.64
2-2.5 inches	34	10.52
2-2.5 inches	35	10.41
2-2.5 inches	36	10.29
2-2.5 inches	37	10.18
2-2.5 inches	38	10.08
2-2.5 inches	39	9.98
2-2.5 inches	40	9.88
2-2.5 inches	41	9.79

For 300 miles Sections at surface Thickness 2-2.5 inches

Thickness	AASHTO	Lab MR
2-2.5 inches	25	12.01
2-2.5 inches	26	11.84
2-2.5 inches	27	11.68
2-2.5 inches	28	11.52
2-2.5 inches	29	11.38
2-2.5 inches	30	11.24
2-2.5 inches	31	11.10
2-2.5 inches	32	10.97
2-2.5 inches	33	10.85
2-2.5 inches	34	10.73
2-2.5 inches	35	10.62
2-2.5 inches	36	10.51
2-2.5 inches	37	10.41
2-2.5 inches	38	10.31
2-2.5 inches	39	10.21
2-2.5 inches	40	10.11
2-2.5 inches	41	10.02

For 300 miles Sections at surface Thickness 2-2.5 i

Thickness	Dynaflect	Lab MR
2-2.5 inches	25	10.89
2-2.5 inches	26	10.65
2-2.5 inches	27	10.43
2-2.5 inches	28	10.22
2-2.5 inches	29	10.02
2-2.5 inches	30	9.83
2-2.5 inches	31	9.65
2-2.5 inches	32	9.48
2-2.5 inches	33	9.31
2-2.5 inches	34	9.16
2-2.5 inches	35	9.01
2-2.5 inches	36	8.87
2-2.5 inches	37	8.73
2-2.5 inches	38	8.60
2-2.5 inches	39	8.48
2-2.5 inches	40	8.36
2-2.5 inches	41	8.24

For 300 miles Sections at surface Thickness 3 inches

Thickness	Evercalc	Lab MR
3 inches	25	14.23
3 inches	26	13.94
3 inches	27	13.67
3 inches	28	13.41
3 inches	29	13.17
3 inches	30	12.93
3 inches	31	12.71
3 inches	32	12.51
3 inches	33	12.31
3 inches	34	12.11
3 inches	35	11.93
3 inches	36	11.76
3 inches	37	11.59
3 inches	38	11.43
3 inches	39	11.28
3 inches	40	11.13
3 inches	41	10.99

For 300 miles Sections at surface Thickness 3 inches

Thickness	Modulus 5.1	Lab MR
3 inches	25	13.55
3 inches	26	13.21
3 inches	27	12.90
3 inches	28	12.60
3 inches	29	12.32
3 inches	30	12.05
3 inches	31	11.80
3 inches	32	11.56
3 inches	33	11.34
3 inches	34	11.12
3 inches	35	10.91
3 inches	36	10.72
3 inches	37	10.53
3 inches	38	10.35
3 inches	39	10.18
3 inches	40	10.02
3 inches	41	9.86

For 300 miles Sections at surface Thickness 3 inches

Thickness	AASHTO	Lab MR
3 inches	25	13.94
3 inches	26	13.62
3 inches	27	13.32
3 inches	28	13.03
3 inches	29	12.76
3 inches	30	12.50
3 inches	31	12.26
3 inches	32	12.03
3 inches	33	11.81
3 inches	34	11.60
3 inches	35	11.40
3 inches	36	11.21
3 inches	37	11.03
3 inches	38	10.85
3 inches	39	10.69
3 inches	40	10.53
3 inches	41	10.37

For 300 miles Sections at surface Thickness 3 inch

Thickness	Dynaflect	Lab MR
3 inches	25	10.30
3 inches	26	10.04
3 inches	27	9.80
3 inches	28	9.57
3 inches	29	9.35
3 inches	30	9.15
3 inches	31	8.95
3 inches	32	8.77
3 inches	33	8.60
3 inches	34	8.43
3 inches	35	8.28
3 inches	36	8.13
3 inches	37	7.98
3 inches	38	7.85
3 inches	39	7.71
3 inches	40	7.59
3 inches	41	7.47

Table 4.11 Dynaflect MR vs. SSV

File Name	DYNAFLECT M_R	DYNAFLECT Deflections	SSV
a03010nt	15.6	0.26	8.78
a03010st	15.516	0.23	9.43
a12070et	23.48	0.13	10.93
a12070wt	23.39	0.134	10.48
a16070nt	19.572	0.192	8.89
a16160nt	19.272	0.194	8.75
a17010nt	20.457	0.172	10.38
a17010st	20.176	0.1814	9.88
a29002et	18.831	0.2	9.85
a29002wt	18.743	0.1994	9.77
a29010et	26.605	0.1137	11.27
a29010wt	21.617	0.153	9.43
a29180nt			
a29180st	22.419	0.1458	11.04
a35040nt	21.024	0.1722	10.71
a37130nt	22.21	0.1492	10.58
a37130st	22.197	0.1492	10.68
a37530et	18.538	0.2061	10.04
a38010nt	21.083	0.1663	9.77
a38010st	21.244	0.1597	9.58
a38501et	16.447	0.2457	8.57
a49010et	12.827	0.4378	7.9
a49010wt	14.624	0.3037	8.12
a49030nt	13.501	0.3536	7.87
a50010et	17.658	0.2318	9.59
a55002nt	17.754	0.2178	8.97
a70220nt	23.03	0.1383	9.9
a72018et	23.058	0.2265	9.16
a72018wt	16.577	0.2476	8.94
a72040nt	21.019	0.1634	9.85
a72040st	20.896	0.1646	9.82
a72280nt	23.147	0.1384	10.06
a72280st	22.63	0.1418	10.17
a72291nt	14.925	0.3042	9.37
a72291st	15.703	0.2757	9.22
a74040nt	14.04	0.3498	8.04
a76050et	18.627	0.2019	8.68
a76050wt			
a87001et	36.385	0.0746	12.54
a87001wt	41.536	0.0637	14.44
a87003et	41.612	0.055	15.15
a87003wt			
a87005nt	46.56	0.0471	16.32
a87005st	49.323	0.04523	16.71
a87020nt	50.78	0.04459	18.43
a87020st			
a87030nt	49.641	0.05	17.03
a87030st	51.303	0.04346	17.17
a87140nt	42.872	0.0552	14.2
a87200et	47.631	0.04806	16.94
a87200wt	46.884	0.04954	16.94
a93230nt	4.894	2.88	4.44
a93290nt	7.254	1.37	5.35
a93290st	8.749	0.8089	5.49
b29010et	20.718	0.164	9.88
b29010wt	20.851	0.1646	9.86

Table 4.12 Catagorizing Florida LTPP Sections According to Pavement Thicknesses

For LTPP Sections at surface Thickness 4-5 inches

Thickness	Evercalc	Lab MR
4-5 inches	25	5.35
4-5 inches	26	5.58
4-5 inches	27	5.82
4-5 inches	28	6.06
4-5 inches	29	6.30
4-5 inches	30	6.54
4-5 inches	31	6.78
4-5 inches	32	7.02
4-5 inches	33	7.27
4-5 inches	34	7.51
4-5 inches	35	7.76
4-5 inches	36	8.00
4-5 inches	37	8.25
4-5 inches	38	8.49
4-5 inches	39	8.74
4-5 inches	40	8.99
4-5 inches	41	9.24

For LTPP Sections at surface Thickness 4-5 inches

Thickness	Modulus 5.1	Lab MR
4-5 inches	25	8.25
4-5 inches	26	8.57
4-5 inches	27	8.90
4-5 inches	28	9.22
4-5 inches	29	9.54
4-5 inches	30	9.87
4-5 inches	31	10.19
4-5 inches	32	10.51
4-5 inches	33	10.83
4-5 inches	34	11.15
4-5 inches	35	11.47
4-5 inches	36	11.79
4-5 inches	37	12.12
4-5 inches	38	12.44
4-5 inches	39	12.76
4-5 inches	40	13.08
4-5 inches	41	13.40

For LTPP Sections at surface Thickness 4-5 inches

Thickness	AASHTO	Lab MR
4-5 inches	25	7.06
4-5 inches	26	7.29
4-5 inches	27	7.52
4-5 inches	28	7.75
4-5 inches	29	7.98
4-5 inches	30	8.20
4-5 inches	31	8.43
4-5 inches	32	8.65
4-5 inches	33	8.87
4-5 inches	34	9.09
4-5 inches	35	9.31
4-5 inches	36	9.53
4-5 inches	37	9.75
4-5 inches	38	9.97
4-5 inches	39	10.18
4-5 inches	40	10.40
4-5 inches	41	10.61

For LTPP Sections at surface Thickness 2.5 - 3.5 inches

Thickness	Evercalc	Lab MR
2.5-3.5 inches	25	10.88
2.5-3.5 inches	26	11.04
2.5-3.5 inches	27	11.20
2.5-3.5 inches	28	11.36
2.5-3.5 inches	29	11.51
2.5-3.5 inches	30	11.66
2.5-3.5 inches	31	11.81
2.5-3.5 inches	32	11.95
2.5-3.5 inches	33	12.09
2.5-3.5 inches	34	12.23
2.5-3.5 inches	35	12.37
2.5-3.5 inches	36	12.50
2.5-3.5 inches	37	12.63
2.5-3.5 inches	38	12.76
2.5-3.5 inches	39	12.89
2.5-3.5 inches	40	13.02
2.5-3.5 inches	41	13.14

For LTPP Sections at surface Thickness 2.5 - 3.5 inches

Thickness	Modulus 5.1	Lab MR
2.5-3.5 inches	25	12.39
2.5-3.5 inches	26	12.59
2.5-3.5 inches	27	12.77
2.5-3.5 inches	28	12.96
2.5-3.5 inches	29	13.14
2.5-3.5 inches	30	13.32
2.5-3.5 inches	31	13.49
2.5-3.5 inches	32	13.66
2.5-3.5 inches	33	13.83
2.5-3.5 inches	34	13.99
2.5-3.5 inches	35	14.15
2.5-3.5 inches	36	14.31
2.5-3.5 inches	37	14.46
2.5-3.5 inches	38	14.62
2.5-3.5 inches	39	14.77
2.5-3.5 inches	40	14.91
2.5-3.5 inches	41	15.06

For LTPP Sections at surface Thickness 2.5 - 3.5 inches

Thickness	AASHTO	Lab MR
2.5-3.5 inches	25	11.53
2.5-3.5 inches	26	11.68
2.5-3.5 inches	27	11.83
2.5-3.5 inches	28	11.97
2.5-3.5 inches	29	12.11
2.5-3.5 inches	30	12.25
2.5-3.5 inches	31	12.38
2.5-3.5 inches	32	12.51
2.5-3.5 inches	33	12.64
2.5-3.5 inches	34	12.76
2.5-3.5 inches	35	12.89
2.5-3.5 inches	36	13.01
2.5-3.5 inches	37	13.12
2.5-3.5 inches	38	13.24
2.5-3.5 inches	39	13.35
2.5-3.5 inches	40	13.47
2.5-3.5 inches	41	13.58

For LTPP Sections at surface Thickness 6 - 7 inches

Thickness	Evercalc	Lab MR
6-7 inches	25	9.31
6-7 inches	26	9.51
6-7 inches	27	9.71
6-7 inches	28	9.90
6-7 inches	29	10.09
6-7 inches	30	10.28
6-7 inches	31	10.47
6-7 inches	32	10.65
6-7 inches	33	10.83
6-7 inches	34	11.01
6-7 inches	35	11.19
6-7 inches	36	11.36
6-7 inches	37	11.53
6-7 inches	38	11.70
6-7 inches	39	11.87
6-7 inches	40	12.03
6-7 inches	41	12.20

For LTPP Sections at surface Thickness 6 - 7 inches

Thickness	Modulus 5.1	Lab MR
6-7 inches	25	11.40
6-7 inches	26	11.84
6-7 inches	27	12.28
6-7 inches	28	12.72
6-7 inches	29	13.16
6-7 inches	30	13.60
6-7 inches	31	14.04
6-7 inches	32	14.48
6-7 inches	33	14.91
6-7 inches	34	15.35
6-7 inches	35	15.79
6-7 inches	36	16.22
6-7 inches	37	16.66
6-7 inches	38	17.10
6-7 inches	39	17.53
6-7 inches	40	17.97
6-7 inches	41	18.40

For LTPP Sections at surface Thickness 6 - 7 inches

Thickness	AASHTO	Lab MR
6-7 inches	25	10.13
6-7 inches	26	10.40
6-7 inches	27	10.67
6-7 inches	28	10.94
6-7 inches	29	11.20
6-7 inches	30	11.46
6-7 inches	31	11.72
6-7 inches	32	11.97
6-7 inches	33	12.23
6-7 inches	34	12.48
6-7 inches	35	12.72
6-7 inches	36	12.97
6-7 inches	37	13.21
6-7 inches	38	13.45
6-7 inches	39	13.69
6-7 inches	40	13.93
6-7 inches	41	14.16

For LTPP Sections at surface Thickness 2 - 2.5 inches

Thickness	Evercalc	Lab MR
2-2.5 inches	25	4.49
2-2.5 inches	26	4.63
2-2.5 inches	27	4.78
2-2.5 inches	28	4.92
2-2.5 inches	29	5.07
2-2.5 inches	30	5.21
2-2.5 inches	31	5.35
2-2.5 inches	32	5.49
2-2.5 inches	33	5.63
2-2.5 inches	34	5.77
2-2.5 inches	35	5.91
2-2.5 inches	36	6.05
2-2.5 inches	37	6.18
2-2.5 inches	38	6.32
2-2.5 inches	39	6.46
2-2.5 inches	40	6.59
2-2.5 inches	41	6.73

For LTPP Sections at surface Thickness 2 - 2.5 inches

Thickness	Modulus 5.1	Lab MR
2-2.5 inches	25	5.58
2-2.5 inches	26	5.72
2-2.5 inches	27	5.86
2-2.5 inches	28	5.99
2-2.5 inches	29	6.12
2-2.5 inches	30	6.26
2-2.5 inches	31	6.38
2-2.5 inches	32	6.51
2-2.5 inches	33	6.64
2-2.5 inches	34	6.76
2-2.5 inches	35	6.89
2-2.5 inches	36	7.01
2-2.5 inches	37	7.13
2-2.5 inches	38	7.25
2-2.5 inches	39	7.37
2-2.5 inches	40	7.48
2-2.5 inches	41	7.60

For LTPP Sections at surface Thickness 2 - 2.5 inches

Thickness	AASHTO	Lab MR
2-2.5 inches	25	4.72
2-2.5 inches	26	4.86
2-2.5 inches	27	5.01
2-2.5 inches	28	5.15
2-2.5 inches	29	5.29
2-2.5 inches	30	5.43
2-2.5 inches	31	5.56
2-2.5 inches	32	5.70
2-2.5 inches	33	5.84
2-2.5 inches	34	5.97
2-2.5 inches	35	6.10
2-2.5 inches	36	6.24
2-2.5 inches	37	6.37
2-2.5 inches	38	6.50
2-2.5 inches	39	6.63
2-2.5 inches	40	6.76
2-2.5 inches	41	6.89

Table 4.13 Data information, Back calculation and ratio with Lab MR for LTPP sections

	LTPP section	Surface (in)	Base (in)	Subbase (in)	Subgrade	Modulus (ksi)	Evercalc (ksi)	AASHTO (ksi)	Lab Resilient (ksi)	Ratio 1	Ratio 2	Ratio 3	D7
Zone 1	1030	3.3	9.8	17.1	sand	28.55	40.35	36.1	8.31	0.29	0.21	0.23	1.24
	1370	1.7	10.7	14.8	SP-SM	27.13	41.15	34.81	9.52	0.35	0.23	0.27	1.09
	3804	12	6.7		SP	29.28	38.19	31.79	9.078	0.31	0.24	0.29	1.76
	3811	9.4	6.4	16.8	SC	44.87	67.41	65.38	16.1	0.36	0.24	0.25	
	4059	6.4	8		SP	24.81	37.74	33.55	8.73	0.35	0.23	0.26	1.58
	4099	3.6	10.5	11.2	SP	41.79	55.3	51.1	12.81	0.31	0.23	0.25	0.86
	9054	2.5	10	12	SP	22.95	36.18	26.44	7.77	0.34	0.21	0.29	1.54
										0.33	0.23	0.26	
Zone 2	1060	4	11		GW	48.98	77.96	59.87					0.76
	4057	13.3	7.8		SP	24.9	38.01	32.21	11.93	0.48	0.31	0.37	1.54
	4096	1.3	8.6	13.4	SP-SM	15.75	19.04	17.21	7.11	0.45	0.37	0.41	2.57
	4106	8.2	10	14.5	SP	21.86	30.78	26.66	10.28	0.47	0.33	0.39	1.52
	4135	1.4	3.3	12	SP	27.73	42.5	32.48	11.83	0.43	0.28	0.36	1.18
	4138	8	4.8		SM	22.86	23.35	21.01	10.58	0.46	0.45	0.50	2.33
										0.46	0.35	0.41	
Zone 3	3995	5	12.8	12	SP	28.1	37.05	33.16					1.3
	4097	5	9	6.3	SM	54.69	66.31	55.33	9.26	0.17	0.14	0.17	0.77
	4101	1.3	9.7	13.2	SP-SM	27.88	39.36	34.05	5.855	0.21	0.15	0.17	1.2
	4102	1.2	9.3	7.5	SP-SM	41.02	41.9	50.14	6.88	0.17	0.16	0.14	0.97
	4107	2.7	12		SP-SM	29.15	34.81	31.66					1.38
	4109	7.1	9.4		SP	16.11	24.94	22.09	4.05	0.25	0.16	0.18	2.26
	4153	1.4	11.6		SP	39.71	38.77	44.95	7.31	0.18	0.19	0.16	0.89
	4154	1.3	8.8		SP-SM	29.14	37.84	34.93	7.28	0.25	0.19	0.21	1.21
										0.21	0.17	0.17	
Zone 4	3811	9.4	6.4	16.8	SC	44.87	67.41	65.38	16.1	0.36	0.24	0.25	1.12
	3996	1.5	8	14.2	SP-SM	21.96	30.72	25.42	12.54	0.57	0.41	0.49	1.7
	3997	3.1	11.6	15	SP-SM	17	23.76	22.43	10.51	0.62	0.44	0.47	1.62
	4105	2.3	10.1	13.3	SP	20.76	29.6	23.64	11.74	0.57	0.40	0.50	1.92
	1060	4	11		GW	48.98	77.96	59.87		0.00	0.00	0.00	0.76
	3995	5	12.8	12	SP	28.1	37.05	33.16	11.75	0.42	0.32	0.35	1.3
	4103	2.9	21.7	5.7	SM	175.1	200	195.76		0.00	0.00	0.00	0.22
	4107	2.7	12		SP-SM	29.15	34.81	31.66		0.00	0.00	0.00	1.38

Table 4.14A Data information, Backcalculations and ratio with Lab M_R for LTPP sections

LTPP section	Surface Thick	Base Thick (in)	Subbase (in)	Subgrade Material	Mr Ksi (From MODULUS 5.0)	Mr Ksi (From EVERCALC)	AASHTO (From Equation using D7)	Mr (Laboratory from LTPP DB)	Mr (lab) / Mr Modulus 5.0	Mr (lab) / Mr Evercalc	Mr (lab) / Mr AASHTO Formula	SSV	Water table(ft)
1030	3.3	9.8	17.1	sand	28.55	40.35	36.1	8.31	0.29	0.21	0.23	10.05	
1060	4	11		GW	48.98	77.96	59.87	5.21	0.11	0.07	0.09	12.70	
1370	1.7	10.7	14.8	SP-SM	27.13	41.15	34.81	9.52	0.35	0.23	0.27	10.70	8
3804	12	6.7		SP	29.28	38.19	31.79	9.078	0.31	0.24	0.29	8.49	
3811	9.4	6.4	16.8	SC	44.87	67.41	65.38	16.1	0.36	0.24	0.25	11.02	
3995	5	12.8	12	SP	28.1	37.05	33.16	11.75	0.42	0.32	0.35	9.83	
3996	1.5	8	14.2	SP-SM	28.5	30.72	25.42	12.54	0.44	0.41	0.49	8.54	11
3997	3.1	11.6	15	SP-SM	17	23.76	22.43	10.51	0.62	0.44	0.47	8.97	
4057	13.3	7.8		SP	37.75	38.01	32.21	11.93	0.32	0.31	0.37	9.01	
4059	6.4	8		SP	24.81	37.74	33.55	8.73	0.35	0.23	0.26	8.75	
4096	1.3	8.6	13.4	SP-SM	26.6	19.04	17.21	7.11	0.27	0.37	0.41	7.01	4
4097	5	9	6.3	SM	54.69	66.31	55.33	9.26	0.17	0.14	0.17	12.70	
4099	3.6	10.5	11.2	SP	41.79	55.3	51.1	12.81	0.31	0.23	0.25	11.88	
4101	1.3	9.7	13.2	SP-SM	27.88	39.36	34.05	5.855	0.21	0.15	0.17	10.27	
4102	1.2	9.3	7.5	SP-SM	41.02	41.9	50.14	6.88	0.17	0.16	0.14	11.44	
4103	2.9	21.7	5.7	SM	175.1	200	195.76	9.59	0.05	0.05	0.05	20.06	
4105	2.3	10.1	13.3	SP	23.9	29.6	23.64	11.74	0.49	0.40	0.50	8.09	10
4106	8.2	10	14.5	SP	21.86	30.78	26.66	10.28	0.47	0.33	0.39	9.13	
4107	2.7	12		SP-SM	29.15	34.81	31.66	7.57	0.26	0.22	0.24	9.50	11
4109	7.1	9.4		SP	16.11	24.94	22.09	4.05	0.25	0.16	0.18	7.51	
4135	1.4	3.3	12	SP	27.73	42.5	32.48	11.83	0.43	0.28	0.36	10.28	
4136	1.4	8.1	11.8	SP-SM	27.91	40.72	34.48	8.26	0.30	0.20	0.24	10.31	15
4137	2.8	10	17.4	SP	66.7	79.72	80.56	10.31	0.15	0.13	0.13	15.96	
4138	8	4.8		SM	32.77	29.48	21.01	10.58	0.32	0.36	0.50	7.41	
4153	1.4	11.6		SP	39.71	38.77	44.95	7.31	0.18	0.19	0.16	11.78	
4154	1.3	8.8		SP-SM	29.14	37.84	34.93	7.28	0.25	0.19	0.21	8.00	
9054	2.5	10	12	SP	22.95	36.18	26.44	7.77	0.34	0.21	0.29	9.08	20
101	2	4.8	8.1	SM-GM			203.55	6.77				23.23	
									0.30	0.24	0.28		

Table 4.14B Data information, Backcalculation and ratio with Lab MR for LTPP sections

	LTPP section	Surface	Base	Subbase	Subgrade	Modulus	Evercalc	AASHTO	Lab Resilient	Ratio 1	Ratio 2
District 1	3804	12	6.7		SP	29.28	38.19	31.79	9.078	0.31	0.24
	4099	3.6	10.5	11.2	SP	41.79	55.3	51.1	12.81	0.31	0.23
	4135	1.4	3.3	12	SP	27.73	42.5	32.48	11.83	0.43	0.28
	4136	1.4	8.1	11.8	SP-SM			34.48	8.26	#DIV/0!	#DIV/0!
	4137	2.8	10	17.4	SP			80.56	10.31	#DIV/0!	#DIV/0!

	LTPP section	Surface	Base	Subbase	Subgrade	Modulus	Evercalc	AASHTO	Lab Resilient	Ratio 1	Ratio 2
District 2	3997	3.1	11.6	15	SP-SM	17	23.76	22.43	10.51	0.62	0.44
	4105	2.3	10.1	13.3	SP	20.76	29.6	23.64	11.74	0.57	0.40
	9054	2.5	10	12	SP	22.95	36.18	26.44	7.77	0.34	0.21

	LTPP section	Surface	Base	Subbase	Subgrade	Modulus	Evercalc	AASHTO	Lab Resilient	Ratio 1	Ratio 2
District 3	3811	9.4	6.4	16.8	SC	44.87	67.41	65.38	16.1	0.36	0.24
	4096	1.3	8.6	13.4	SP-SM	15.75	19.04	17.21	7.11	0.45	0.37
	4097	5	9	6.3	SM	54.69	66.31	55.33	9.26	0.17	0.14

	LTPP section	Surface	Base	Subbase	Subgrade	Modulus	Evercalc	AASHTO	Lab Resilient	Ratio 1	Ratio 2
District 4	1030	3.3	9.8	17.1	sand	28.55	40.35	36.1	8.31	0.29	0.21
	3995	5	12.8	12	SP	28.1	37.05	33.16	11.75	0.42	0.32
	4106	8.2	10	14.5	SP	21.86	30.78	26.66	10.28	0.47	0.33
	4107	2.7	12		SP-SM	29.15	34.81	31.66	7.57	0.26	0.22
	4153	1.4	11.6		SP	39.71	38.77	44.95	7.31	0.18	0.19
	101	2	4.8	8.1	SM-GM			203.55	6.77	#DIV/0!	#DIV/0!

	LTPP section	Surface	Base	Subbase	Subgrade	Modulus	Evercalc	AASHTO	Lab Resilient	Ratio 1	Ratio 2
District 5	1370	1.7	10.7	14.8	SP-SM	27.13	41.15	34.81	9.52	0.35	0.23
	4059	6.4	8		SP	24.81	37.74	33.55	8.73	0.35	0.23
	4101	1.3	9.7	13.2	SP-SM	27.88	39.36	34.05	5.855	0.21	0.15
	4102	1.2	9.3	7.5	SP-SM	41.02	41.9	50.14	6.88	0.17	0.16
	4109	7.1	9.4		SP	16.11	24.94	22.09	4.05	0.25	0.16
	4138	8	4.8		SM	22.86	23.35	21.01	10.58	0.46	0.45
	4154	1.3	8.8		SP-SM	29.14	37.84	34.93	7.28	0.25	0.19

	LTPP section	Surface	Base	Subbase	Subgrade	Modulus	Evercalc	AASHTO	Lab Resilient	Ratio 1	Ratio 2
District 6	1060	4	11		GW	48.98	77.96	59.87	5.21	0.11	0.07
	4103	2.9	21.7	5.7	SM	175.1	200	195.76	9.59	0.05	0.05

	LTPP section	Surface	Base	Subbase	Subgrade	Modulus	Evercalc	AASHTO	Lab Resilient	Ratio 1	Ratio 2
District 7	3804	12	6.7		SP	29.28	38.19	31.79	9.078	0.31	0.24
	3996	1.5	8	14.2	SP-SM	21.96	30.72	25.42	12.54	0.57	0.41
	4057	13.3	7.8		SP	24.9	38.01	32.21	11.93	0.48	0.31

Table 4.15 Backcalculated MR for Most of the Florida LTPP Sections (Results Obtained from LTPP CD)

SHRP_ID	Date	Layer No.	Drop Hight	ave_MR(psi)	STD_MR (psi)	Min MR psi	Max MR psi	No. of Basins
1030	12/5/1989	4	1	36.7	6.5	27.3	50.0	33
1030	12/5/1989	4	2	34.6	6.6	26.3	47.7	30
1030	12/5/1989	4	3	32.6	5.3	24.7	45.0	36
1030	12/5/1989	4	4	34.6	6.0	26.8	46.8	33
1030	7/26/1994	4	1	43.1	10.4	31.6	63.1	15
1030	7/26/1994	4	2	39.2	8.1	29.4	56.7	20
1030	7/26/1994	4	3	38.9	7.8	29.3	52.6	18
1030	7/26/1994	4	4	38.3	6.6	30.9	51.2	16
1060	12/1/1989	4	1	58.9	5.8	49.6	71.5	26
1060	12/1/1989	4	2	59.6	4.3	52.5	68.7	39
1060	12/1/1989	4	3	58.3	5.0	48.3	68.0	42
1060	12/1/1989	4	4	60.4	4.9	50.9	69.3	44
1060	8/3/1994	4	1	74.4	6.4	61.8	85.3	29
1060	8/3/1994	4	2	70.7	7.0	58.7	90.6	39
1060	8/3/1994	4	3	69.1	6.9	56.9	93.8	39
1060	8/3/1994	4	4	67.3	5.8	56.6	78.0	39
1370	12/14/1989	4	1	76.8	30.9	30.9	152.3	35
1370	12/14/1989	4	2	135.3	163.6	44.5	749.8	37
1370	12/14/1989	4	3	198.3	225.5	45.0	925.3	35
1370	8/23/1994	4	3	142.2	115.6	52.5	601.9	23
3804	10/8/1989	4	2	96.1	64.9	45.8	293.0	12
3804	10/8/1989	4	3	80.2	34.2	36.7	158.1	17
3804	10/8/1989	4	4	80.0	33.8	32.3	153.7	18
3804	8/16/1994	4	2	53.9	12.6	24.9	78.3	19
3804	8/16/1994	4	3	52.8	12.7	24.5	78.0	18
3804	8/16/1994	4	4	49.3	12.5	23.1	71.5	16
3811	10/9/1989	4	2	74.7	57.6	28.1	223.4	9
3811	10/9/1989	4	3	48.0	14.3	27.3	65.3	5
3811	10/9/1989	4	4	54.8	11.1	30.9	73.7	14
3811	8/31/1994	4	2	84.7	85.8	36.4	326.3	10
3811	8/31/1994	4	3	92.5	90.6	47.6	345.2	10
3811	8/31/1994	4	4	196.7	249.7	38.1	662.8	12
3995	11/30/1989	4	1	52.7	20.8	19.7	92.7	42
3995	11/30/1989	4	2	43.3	17.4	23.5	98.0	42
3995	11/30/1989	4	3	49.5	22.8	23.2	135.0	44
3995	11/30/1989	4	4	77.2	100.9	16.4	596.1	44
3995	8/1/1994	4	1	42.9	15.2	15.5	89.6	40
3995	8/1/1994	4	2	36.1	9.7	23.6	80.9	42
3995	8/1/1994	4	3	35.3	11.6	19.7	76.9	41
3995	8/1/1994	4	4	36.4	9.8	20.9	57.0	42
3996	11/22/1989	4	1	41.1	6.3	33.4	65.3	40
3996	11/22/1989	4	2	37.9	4.2	30.0	48.2	44
3996	11/22/1989	4	3	38.3	3.5	31.6	53.7	44
3996	11/22/1989	4	4	38.0	2.8	29.0	42.4	41
3996	12/4/1995	4	1	35.8	4.6	27.3	51.6	27
3996	12/4/1995	4	2	34.9	4.0	26.3	46.6	35
3996	12/4/1995	4	3	32.8	3.1	24.4	39.2	41
3996	12/4/1995	4	4	31.6	2.4	24.8	36.1	41

Table 4.15 continue

3997	12/21/1989	4	2	21.5	2.2	18.4	27.1	28
3997	12/21/1989	4	3	20.0	1.4	17.5	22.3	35
3997	12/21/1989	4	4	20.6	1.5	18.7	23.2	34
3997	7/31/1990	4	1	38.0	3.0	34.7	40.6	3
3997	7/31/1990	4	2	39.0	9.6	32.3	50.0	3
3997	7/31/1990	4	3	34.6	2.8	31.6	38.3	4
3997	7/31/1990	4	4	34.5	1.6	31.8	36.0	5
3997	11/8/1990	4	1	39.4	4.2	32.8	44.4	5
3997	11/8/1990	4	2	34.4	1.9	31.6	37.0	8
3997	11/8/1990	4	3	33.2	2.9	29.2	38.7	8
3997	11/8/1990	4	4	33.7	2.3	30.7	38.1	8
3997	5/28/1991	4	1	30.2	2.6	25.2	35.7	17
3997	5/28/1991	4	2	27.0	2.1	23.1	31.9	28
3997	5/28/1991	4	3	26.6	2.7	22.5	32.9	30
3997	5/28/1991	4	4	25.1	2.5	20.9	30.6	33
3997	11/23/1993	4	1	30.5	2.3	27.3	34.5	8
3997	11/23/1993	4	2	28.7	1.8	25.7	30.7	7
3997	11/23/1993	4	3	28.1	2.4	24.2	32.2	9
3997	11/23/1993	4	4	26.0	2.0	23.1	29.4	8
4000	9/28/1989	4	2	111.2	147.5	40.6	638.2	19
4000	9/28/1989	4	3	42.9	4.8	33.1	51.6	22
4000	9/28/1989	4	4	56.8	24.4	38.9	150.8	20
4000	7/19/1994	4	2	59.7	51.6	35.5	275.6	20
4000	7/19/1994	4	3	69.3	63.9	34.8	335.0	20
4000	7/19/1994	4	4	55.6	28.0	34.1	158.1	20
4057	10/7/1989	4	2	179.4	307.0	31.3	934.0	8
4057	10/7/1989	4	3	37.9	11.2	21.3	61.5	19
4057	10/7/1989	4	4	49.7	17.8	30.5	100.4	13
4057	8/15/1994	4	2	34.9	5.9	28.6	49.2	14
4057	8/15/1994	4	3	34.6	6.0	24.2	47.6	20
4057	8/15/1994	4	4	35.7	10.4	26.0	60.9	18
4096	11/20/1989	4	1	16.4	2.8	9.4	21.9	35
4096	11/20/1989	4	2	14.0	3.9	6.5	18.9	22
4096	11/20/1989	4	3	15.1	3.1	6.8	19.9	40
4096	11/20/1989	4	4	15.8	3.7	6.8	22.6	39
4096	9/8/1994	4	1	14.6	3.3	5.4	21.3	33
4096	9/8/1994	4	2	14.0	2.5	8.1	19.9	37
4096	9/8/1994	4	3	14.9	2.7	7.1	20.3	41
4096	9/8/1994	4	4	15.3	2.2	8.0	19.3	40
4097	11/21/1989	4	1	68.5	9.6	52.5	83.4	13
4097	11/21/1989	4	2	60.4	14.6	26.0	76.3	9
4097	11/21/1989	4	3	60.8	15.0	36.1	79.3	12
4097	11/21/1989	4	4	59.9	16.1	32.8	83.5	20
4097	9/1/1994	4	1	80.0	14.4	58.2	99.8	11
4097	9/1/1994	4	2	74.0	11.4	51.1	99.8	38
4097	9/1/1994	4	3	71.1	12.4	23.9	93.8	40
4097	9/1/1994	4	4	71.5	9.1	50.9	93.1	41
4099	11/27/1989	4	1	51.0	3.3	45.5	54.8	10
4099	11/27/1989	4	2	48.7	2.9	43.1	54.2	29
4099	11/27/1989	4	3	47.4	2.0	43.9	50.5	22
4099	11/27/1989	4	4	47.6	3.2	40.6	52.1	35

Table 4.15 continue

4100	11/15/1989	4	1	21.3	2.9	15.8	28.3	35
4100	11/15/1989	4	2	19.1	2.4	12.5	22.2	23
4100	11/15/1989	4	3	18.0	2.1	11.5	21.6	42
4100	11/15/1989	4	4	19.4	2.3	14.9	24.7	41
4100	9/9/1994	4	1	19.2	2.4	14.6	26.3	36
4100	9/9/1994	4	2	19.0	1.9	15.2	22.5	35
4100	9/9/1994	4	3	19.2	1.8	14.5	22.8	40
4100	9/9/1994	4	4	19.0	1.3	16.7	21.6	40
4101	12/18/1989	4	1	30.1	3.0	25.5	41.8	25
4101	12/18/1989	4	2	29.8	3.1	24.7	37.4	22
4101	12/18/1989	4	3	27.8	2.3	24.1	34.8	28
4101	12/18/1989	4	4	29.8	2.9	24.9	37.6	23
4101	5/21/1991	4	1	30.9	2.5	24.8	34.5	12
4101	5/21/1991	4	2	27.2	1.7	23.6	29.3	12
4101	5/21/1991	4	3	27.1	2.5	22.5	31.9	17
4101	5/21/1991	4	4	26.9	2.8	21.3	35.2	17
4103	11/28/1989	4	1	208.9	36.8	166.8	235.0	3
4103	11/28/1989	4	2	208.9	45.3	153.7	264.0	5
4103	11/28/1989	4	3	209.2	60.1	161.0	295.9	4
4103	11/28/1989	4	4	190.3	32.3	169.7	246.6	5
4103	8/2/1994	4	1	243.7	14.4	233.5	253.8	2
4103	8/2/1994	4	2	267.6	11.3	259.6	275.6	2
4103	8/2/1994	4	3	297.8	21.8	272.7	311.8	3
4103	8/2/1994	4	4	289.4	40.0	261.1	317.6	2
4105	9/6/1990	4	1	37.7	5.7	25.1	51.9	33
4105	9/6/1990	4	2	32.6	4.0	25.5	44.1	43
4105	9/6/1990	4	3	30.3	3.4	24.1	43.9	44
4105	9/6/1990	4	4	31.4	4.4	24.4	45.0	43
4106	12/4/1989	4	1	21.0	2.3	15.4	25.2	43
4106	12/4/1989	4	2	20.2	1.6	16.8	24.7	43
4106	12/4/1989	4	3	19.8	1.8	17.5	23.9	44
4106	12/4/1989	4	4	20.8	1.5	18.7	24.2	44
4106	7/28/1994	4	1	26.6	2.8	23.5	35.2	35
4106	7/28/1994	4	2	25.0	2.6	22.0	33.2	41
4106	7/28/1994	4	3	24.6	2.4	21.3	30.9	41
4106	7/28/1994	4	4	23.6	2.4	20.6	29.4	40
4107	12/7/1989	4	1	34.5	4.3	26.3	41.8	42
4107	12/7/1989	4	2	33.9	4.0	26.7	39.6	42
4107	12/7/1989	4	3	34.5	4.3	26.8	40.2	39
4107	12/7/1989	4	4	35.5	4.6	28.4	42.9	26
4107	7/25/1994	4	1	35.0	5.6	27.0	43.8	22
4107	7/25/1994	4	2	31.9	5.0	26.1	40.3	10
4107	7/25/1994	4	3	31.6	4.0	26.8	41.2	10
4107	7/25/1994	4	4	31.3	2.6	28.4	36.3	8
4108	11/16/1989	4	1	14.0	3.4	4.9	20.7	32
4108	11/16/1989	4	2	13.5	4.9	6.4	23.6	11
4108	11/16/1989	4	3	12.5	2.9	5.2	16.5	40
4108	11/16/1989	4	4	13.0	2.8	6.5	20.0	34
4108	9/12/1994	4	1	18.1	4.8	10.9	30.0	33
4108	9/12/1994	4	2	17.3	2.9	12.8	26.4	38
4108	9/12/1994	4	3	17.4	2.3	13.5	22.8	38

Table 4.15 continue

4108	9/12/1994	4	4	17.3	2.1	12.6	22.2	41
4109	10/4/1989	4	2	37.3	4.1	30.3	42.9	8
4109	10/4/1989	4	3	38.7	6.8	25.5	51.8	19
4109	10/4/1989	4	4	41.0	13.0	29.0	84.8	18
4135	12/13/1989	4	1	-	-	0.0	0.0	0
4135	12/13/1989	4	2	-	-	0.0	0.0	0
4135	12/13/1989	4	3	-	-	0.0	0.0	0
4135	12/13/1989	4	4	-	-	0.0	0.0	0
4135	5/15/1991	4	1	-	-	0.0	0.0	0
4135	5/15/1991	4	2	-	-	0.0	0.0	0
4135	5/15/1991	4	3	-	-	0.0	0.0	0
4135	5/15/1991	4	4	-	-	0.0	0.0	0
4136	12/12/1989	4	1	53.0	13.2	36.7	101.1	29
4136	12/12/1989	4	2	46.4	8.9	33.9	77.0	30
4136	12/12/1989	4	3	40.1	6.2	29.7	58.6	36
4136	12/12/1989	4	4	41.6	6.2	32.6	59.9	39
4136	5/15/1991	4	1	88.1	26.8	63.8	116.9	3
4136	5/15/1991	4	2	66.5	16.3	46.8	82.5	5
4136	5/15/1991	4	3	60.1	17.1	40.6	89.8	8
4136	5/15/1991	4	4	56.4	22.7	35.1	127.3	14
4137	12/11/1989	4	1	64.7	11.4	38.7	77.3	14
4137	12/11/1989	4	2	69.3	11.0	45.3	87.3	14
4137	12/11/1989	4	3	72.2	8.4	42.4	86.6	28
4137	12/11/1989	4	4	70.6	22.7	33.5	97.2	18
4137	5/16/1991	4	1	48.4	2.9	46.4	50.5	2
4137	5/16/1991	4	2	74.1	23.9	42.5	93.7	5
4137	5/16/1991	4	3	76.0	25.6	39.0	93.8	4
4137	5/16/1991	4	4	79.7	22.7	36.8	99.5	6
4138	10/2/1989	4	2	23.5	5.9	15.5	37.7	17
4138	10/2/1989	4	3	19.1	3.6	15.2	27.1	18
4138	10/2/1989	4	4	22.5	7.1	15.1	47.7	20
4154	12/19/1989	4	1	25.3	3.8	19.7	29.3	6
4154	12/19/1989	4	2	23.9	3.0	19.3	28.6	11
4154	12/19/1989	4	3	24.3	3.9	18.4	31.9	15
4154	12/19/1989	4	4	24.7	4.9	16.4	33.9	24
4154	8/6/1990	4	1	-	-	0.0	0.0	0
4154	8/6/1990	4	2	29.6	-	29.6	29.6	1
4154	8/6/1990	4	3	37.7	9.4	31.0	44.4	2
4154	8/6/1990	4	4	26.7	9.2	16.2	41.5	6
4154	11/9/1990	4	1	-	-	0.0	0.0	0
4154	11/9/1990	4	2	-	-	0.0	0.0	0
4154	11/9/1990	4	3	23.9	-	23.9	23.9	1
4154	11/9/1990	4	4	26.0	-	26.0	26.0	1
4154	5/22/1991	4	1	20.9	1.6	19.7	22.0	2
4154	5/22/1991	4	2	23.0	4.1	18.9	27.7	4
4154	5/22/1991	4	3	23.2	8.6	16.8	37.3	5
4154	5/22/1991	4	4	17.7	3.5	15.5	22.9	4
4154	11/23/1993	4	1	-	-	0.0	0.0	0
4154	11/23/1993	4	2	-	-	0.0	0.0	0
4154	11/23/1993	4	3	-	-	0.0	0.0	0
4154	11/23/1993	4	4	29.0	29.0	29.0	0.1	1/15/1997

Table 4.15 continue

4154	6/16/1996	4	1	23.4	-	23.4	23.4	1
4154	6/16/1996	4	2	29.4	4.9	23.6	35.8	5
4154	6/16/1996	4	3	25.7	4.2	21.9	30.7	5
4154	6/16/1996	4	4	25.3	5.1	20.9	32.6	5
9054	9/26/1989	4	1	34.0	3.3	28.1	38.6	13
9054	9/26/1989	4	2	32.5	2.3	27.8	36.4	17
9054	9/26/1989	4	3	30.0	3.6	22.3	35.5	16
9054	9/26/1989	4	4	31.3	3.1	24.1	36.1	16
9054	7/25/1990	4	1	39.3	39.3	39.3	0.1	1/15/1997
9054	7/25/1990	4	2	-	-	0.0	0.0	0
9054	7/25/1990	4	3	40.0	-	40.0	40.0	1
9054	7/25/1990	4	4	41.9	-	41.9	41.9	1
9054	5/30/1991	4	1	34.5	0.7	33.9	35.2	3
9054	5/30/1991	4	2	32.1	32.1	32.1	0.1	1/15/1997
9054	5/30/1991	4	3	32.2	-	32.2	32.2	1
9054	5/30/1991	4	4	31.1	1.7	29.9	32.3	2
9054	2/10/1993	4	1	28.1	2.2	26.0	30.2	4
9054	2/10/1993	4	2	26.0	2.5	24.2	27.7	2
9054	2/10/1993	4	3	26.0	1.9	24.7	27.4	2
9054	2/10/1993	4	4	26.3	1.3	25.4	27.3	2
A330	7/25/1990	4	1	-	-	0.0	0.0	0
A330	7/25/1990	4	2	-	-	0.0	0.0	0
A330	7/25/1990	4	3	-	-	0.0	0.0	0
A330	7/25/1990	4	4	-	-	0.0	0.0	0
A330	2/10/1993	4	1	28.0	2.3	26.4	29.6	2
A330	2/10/1993	4	2	26.7	-	26.7	26.7	1
A330	2/10/1993	4	3	26.0	-	26.0	26.0	1
A330	2/10/1993	4	4	25.5	-	25.5	25.5	1
A330	6/19/1996	4	1	33.8	33.8	33.8	0.1	
A330	6/19/1996	4	2	36.4	3.3	32.6	38.6	3
A330	6/19/1996	4	3	33.9	3.3	30.6	37.1	3
A330	6/19/1996	4	4	33.0	2.9	30.2	36.0	3
A350	7/26/1990	4	1	43.6	5.8	37.3	54.7	8
A350	7/26/1990	4	2	38.7	2.9	34.1	43.8	8
A350	7/26/1990	4	3	38.9	4.7	32.6	47.1	9
A350	7/26/1990	4	4	39.4	3.3	33.1	43.8	8
C350	8/7/1990	4	1	-	-	0.0	0.0	0
C350	8/7/1990	4	2	-	-	0.0	0.0	0
C350	8/7/1990	4	3	43.1	43.1	43.1	0.1	
C350	8/7/1990	4	4	50.4	0.3	50.2	50.6	2
			Average	**44.9**	**14.1**	**31.8**	**78.3**	
				ave	std	min	max	

Table 4.17A α & β for Water Table - Deflection Relationship

FWD Deflection $d_n = \alpha (D_w)^{\beta}$ where $\alpha = \zeta e^{\psi Rn}$ and $\beta = \upsilon(R_n)+c$

Dw = Depth of Water Table (ft) Rn = FWD Redial Diatance (in)

Road 200 Section 71030			$\alpha = 23e^{-0.05Rn}$ $\beta = -0.0009*(Rn)-0.3682$		
Sensor Distance	Alpha	Beta	Sensor Distance	Theoretical Alpha	Theoretical Beta
0.0	23.4580	-0.3846	0.0	22.999	-0.3682
8.0	15.7030	-0.3382	8.0	15.417	-0.3754
12.0	11.5210	-0.3383	12.0	12.623	-0.3790
18.0	6.3197	-0.3485	18.0	9.351	-0.3844
24.0	4.5977	-0.4830	24.0	6.927	-0.3898
36.0	2.9054	-0.4452	36.0	3.802	-0.4006
60.0	1.9810	-0.3826	60.0	1.145	-0.4222

Road 200 Section 28010			$\alpha = 11.789e^{-0..0245Rn}$ $\beta =-0.0056*(Rn)-0.477$		
Sensor Distance	Alpha	Beta	Sensor Distance	Theoretical Alpha	Theoretical Beta
0.0	8.2171	-0.1631	0.0	11.789	-0.3682
8.0	9.8439	-0.4591	8.0	9.691	-0.3754
12.0	10.1660	-0.5962	12.0	8.786	-0.3790
18.0	10.3480	-0.8285	18.0	7.585	-0.3844
24.0	7.7737	-0.8643	24.0	6.548	-0.3898
36.0	3.9157	-0.6774	36.0	4.880	-0.4006
60.0	2.5575	-0.6354	60.0	2.711	-0.4222

Road 207 Section 78050			$\alpha =23.27e^{-0.045Rn}$ $\beta = 0.002(Rn)-0.385$		
Sensor Distance	Alpha	Beta	Sensor Distance	Theoretical Alpha	Theoretical Beta
0.0	24.6110	-0.2263	0.0	23.999	-0.3850
8.0	20.4900	-0.3652	8.0	16.478	-0.3690
12.0	16.8570	-0.4558	12.0	13.654	-0.3610
18.0	9.9913	-0.5035	18.0	10.299	-0.3490
24.0	5.3165	-0.3603	24.0	7.768	-0.3370
36.0	2.9053	-0.2279	36.0	4.420	-0.3130
60.0	2.2089	-0.2444	60.0	1.431	-0.2650

Road 62 Section 06020			$\alpha = 24.502e^{-0.0154Rn}$ $\beta =-0.0222*(Rn)-0.5382$		
Sensor Distance	Alpha	Beta	Sensor Distance	Theoretical Alpha	Theoretical Beta
0.0	25.4440	-0.4369	0.0	24.505	-0.5380
8.0	20.1270	-0.4884	8.0	21.665	-0.7156
12.0	24.1060	-0.7891	12.0	20.370	-0.8044
18.0	24.8350	-1.2199	18.0	18.572	-0.9376
24.0	11.4950	-1.0284	24.0	16.933	-1.0708
36.0	11.4500	-1.6772	36.0	14.076	-1.3372
60.0	11.4500	-1.6272	60.0	9.727	-1.8700

Table 4.17B α & β for Water Table - Deflection Relationship

FWD Deflection $d_n = \alpha (D_w)^{\beta}$ where $\alpha = \zeta e^{\psi Rn}$ and $\beta = \upsilon(R_n)+c$

Dw = Depth of Water Table (ft) Rn = FWD Redial Diatance (in)

Road 24 Section 26050					
Sensor Distance	Alpha	Beta			
0.0	no water table	no water table	no water table	no water table	no water table
8.0	no water table	no water table	no water table	no water table	no water table
12.0	no water table	no water table	no water table	no water table	no water table
18.0	no water table	no water table	no water table	no water table	no water table
24.0	no water table	no water table	no water table	no water table	no water table
36.0	no water table	no water table	no water table	no water table	no water table
60.0	no water table	no water table	no water table	no water table	no water table

Road 26 Section 31010			Alpha = $17e^{-0.022Rn}$ Beta=0.0011*(Rn)-0.2467		
Sensor Distance	Alpha	Beta	Sensor Distance	Theoretical Alpha	Theoretical Beta
0.0	17.8970	-0.2456	0.0	17.000	-0.2467
8.0	15.5280	-0.2393	8.0	14.257	-0.2379
12.0	13.1850	-0.2332	12.0	13.056	-0.2335
18.0	11.0610	-0.2393	18.0	11.441	-0.2269
24.0	8.6552	-0.2146	24.0	10.026	-0.2203
36.0	6.3121	-0.1880	36.0	7.700	-0.2071
60.0	4.9390	-0.1862	60.0	4.541	-0.1807

Road 72 Section 17070			Alpha =$15.517e^{-0.0303Rn}$ Beta=-0.0048*(Rn)-0.3214		
Sensor Distance	Alpha	Beta	Sensor Distance	Theoretical Alpha	Theoretical Beta
0.0	14.7680	-0.2331	0.0	15.510	-0.3214
8.0	12.6310	-0.3063	8.0	12.171	-0.3598
12.0	12.2320	-0.4070	12.0	10.782	-0.3790
18.0	9.1254	-0.4554	18.0	8.990	-0.4078
24.0	7.3995	-0.5495	24.0	7.495	-0.4366
36.0	4.2365	-0.5194	36.0	5.211	-0.4942
60.0	2.7811	-0.5342	60.0	2.518	-0.6094

Road 16 Section 71050			Alpha = $29.762e^{-0.0473Rn}$ Beta=-0.002(Rn)-0.5189		
Sensor Distance	Alpha	Beta	Sensor Distance	Theoretical Alpha	Theoretical Beta
0.0	31.7310	-0.3723	0.0	29.759	-0.5189
0.0	26.9070	-0.4689	8.0	20.433	-0.5349
12.0	23.0380	-0.5583	12.0	16.931	-0.5429
18.0	15.0800	-0.6604	18.0	12.771	-0.5549
24.0	7.5870	-0.5578	24.0	9.633	-0.5669
36.0	3.3370	-0.3679	36.0	5.480	-0.5909
60.0	2.2806	-0.3433	60.0	1.774	-0.6389

Table 4.18 α & β for Moisture - Deflection Relationship

$$d_n = \alpha \cdot (M_c)^{\beta}$$

Road 200 Section 71030

Alpha	Beta
8.0980	0.2153
5.5458	0.2253
4.9143	0.1503
3.5607	0.0328
1.2223	0.2558
0.3990	0.5296
0.2389	0.6086

Road 24 Section 26050

Alpha	Beta
1.8910	0.8134
0.4299	1.2060
0.0928	1.6166
0.0205	1.9359
0.0364	1.5095
0.0477	1.2947
0.0323	1.3422

Road 200 Section 28010

Alpha	Beta
3.9223	0.2093
1.7218	0.4451
1.1024	0.5594
0.4880	0.7672
0.3495	0.7609
0.3316	0.6117
0.2807	0.5296

Road 26 Section 31010

Alpha	Beta
7.5819	0.1944
4.9995	0.3009
2.8066	0.4701
2.2080	0.4879
2.0347	0.4390
1.7832	0.3829
1.5533	0.3429

Road 207 Section 78050

Alpha	Beta
0.5731	1.2314
0.1461	1.5828
0.0438	1.8964
0.0135	2.1070
0.0494	1.4900
0.0128	1.0025
0.0854	1.0392

Road 72 Section 17070

Alpha	Beta
2.8380	0.5071
3.1840	0.3504
2.0843	0.4419
1.1886	0.5199
1.0698	0.4183
0.7590	0.3530
0.5681	0.2947

Road 62 Section 06020

Alpha	Beta
5.6043	0.3732
3.7880	0.4060
1.6177	0.6499
0.3866	1.0022
0.3424	0.8418
0.1013	1.1505
0.0402	1.3641

Road 16 Section 71050

Alpha	Beta
Data Not Applicable	

dn = Deflection at any FWD Sensor (mil)

Mc = Moisture Content (%)

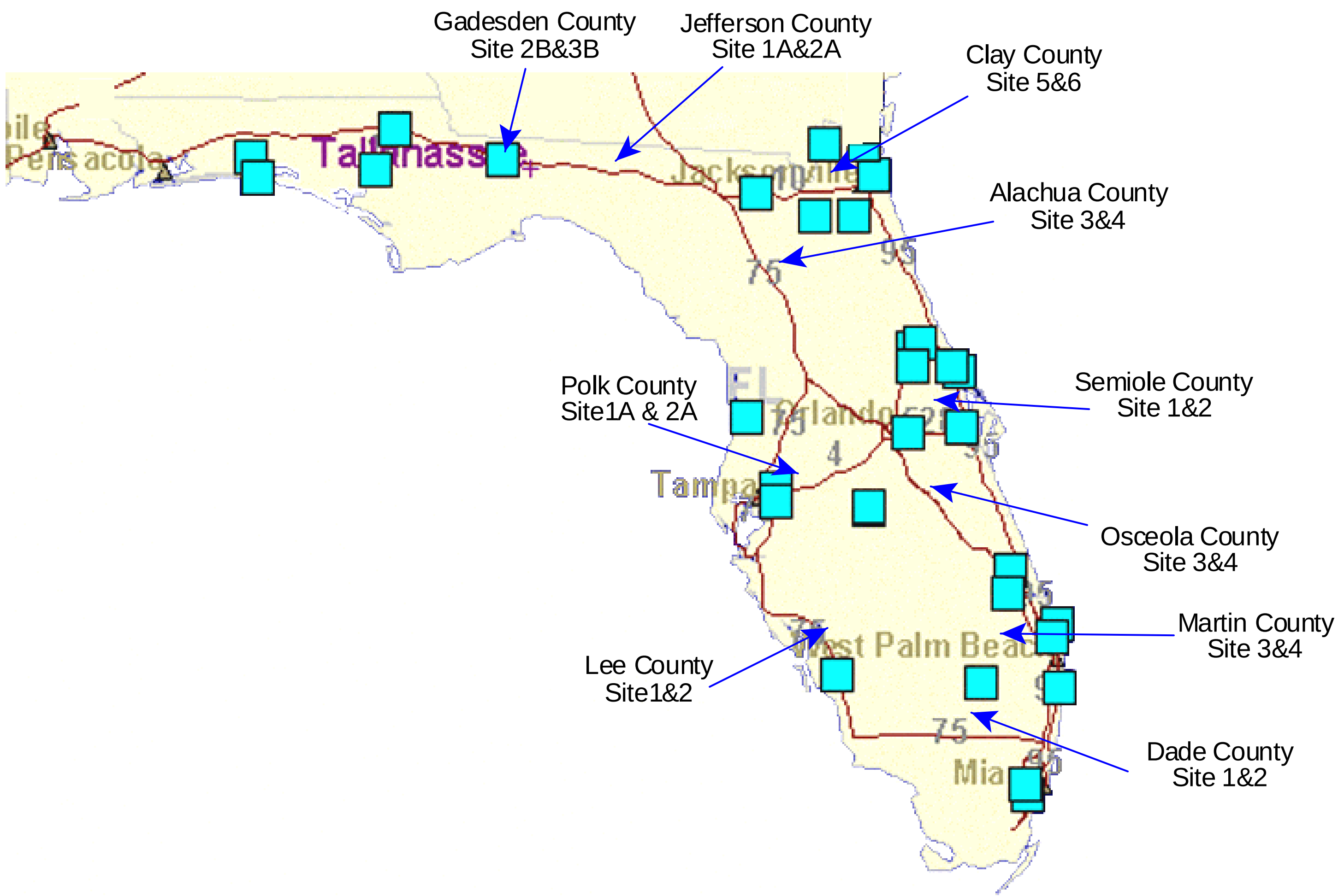


Figure 4.1 Site Locations of FWD and Dynaflect Tests

Figure 4.2 Dynaflect Deflection Basins at Osceola County - Site # 3

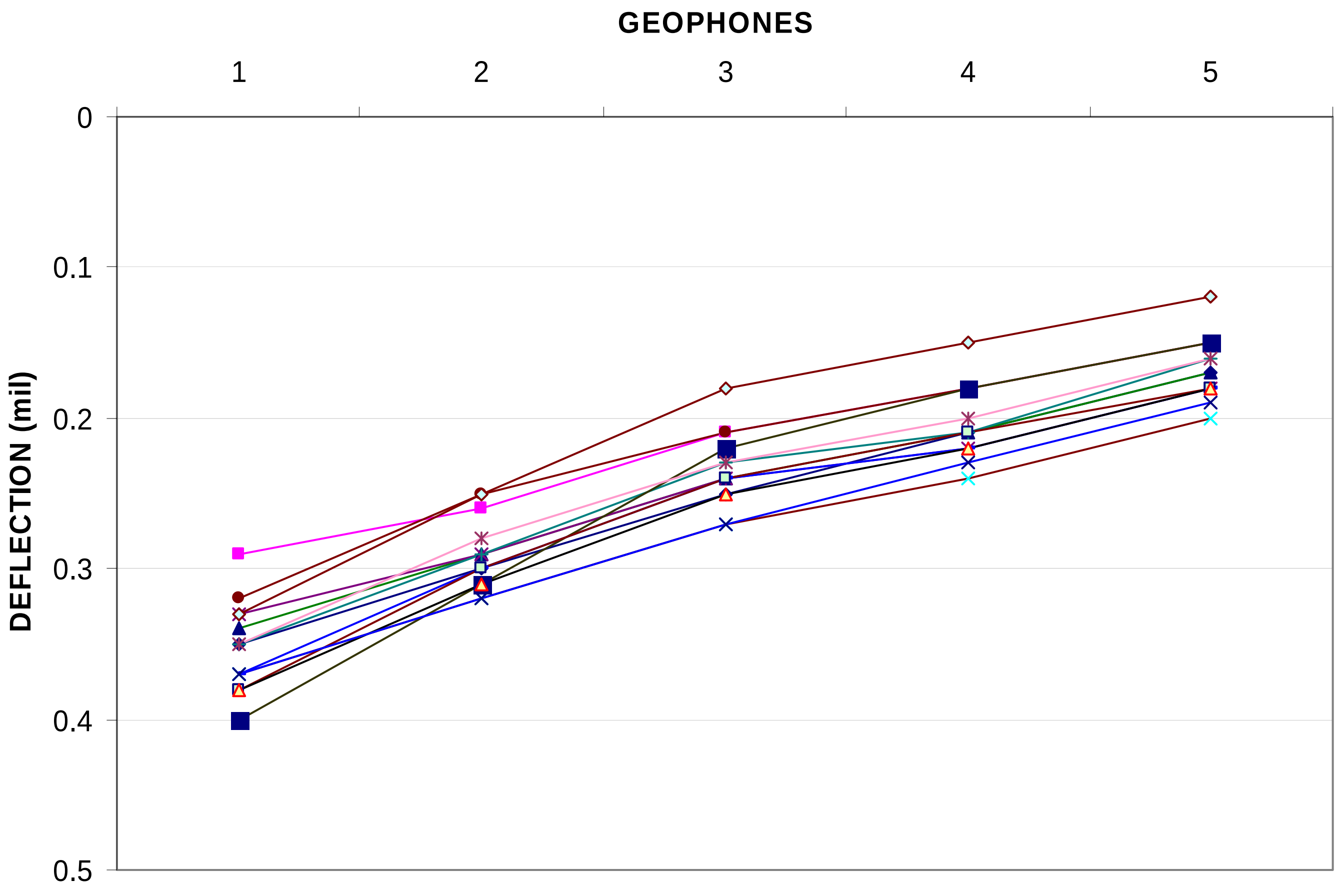


Figure 4.3 Dynaflect Deflection Basins at Osceola County - Site # 4

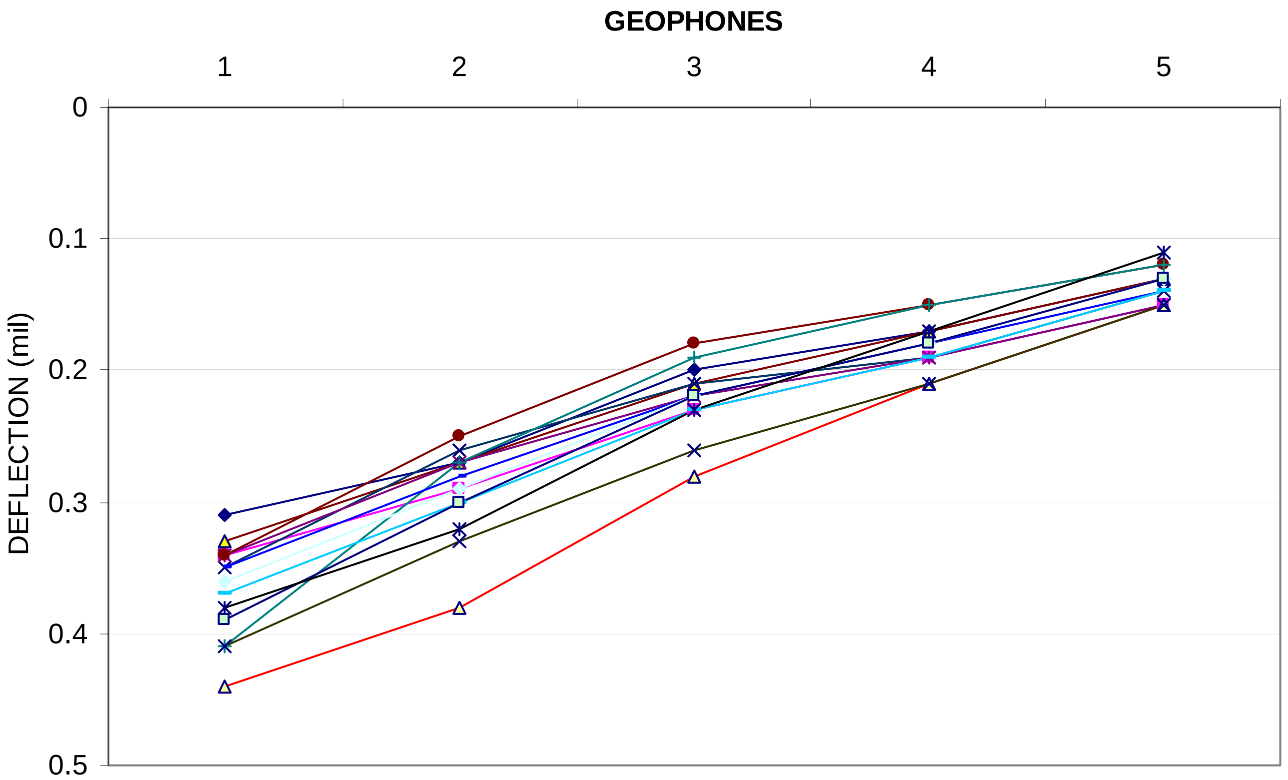


Figure 4.4 Range of Dynaflect Deflections of Sensor # 4 for all Tested Sites

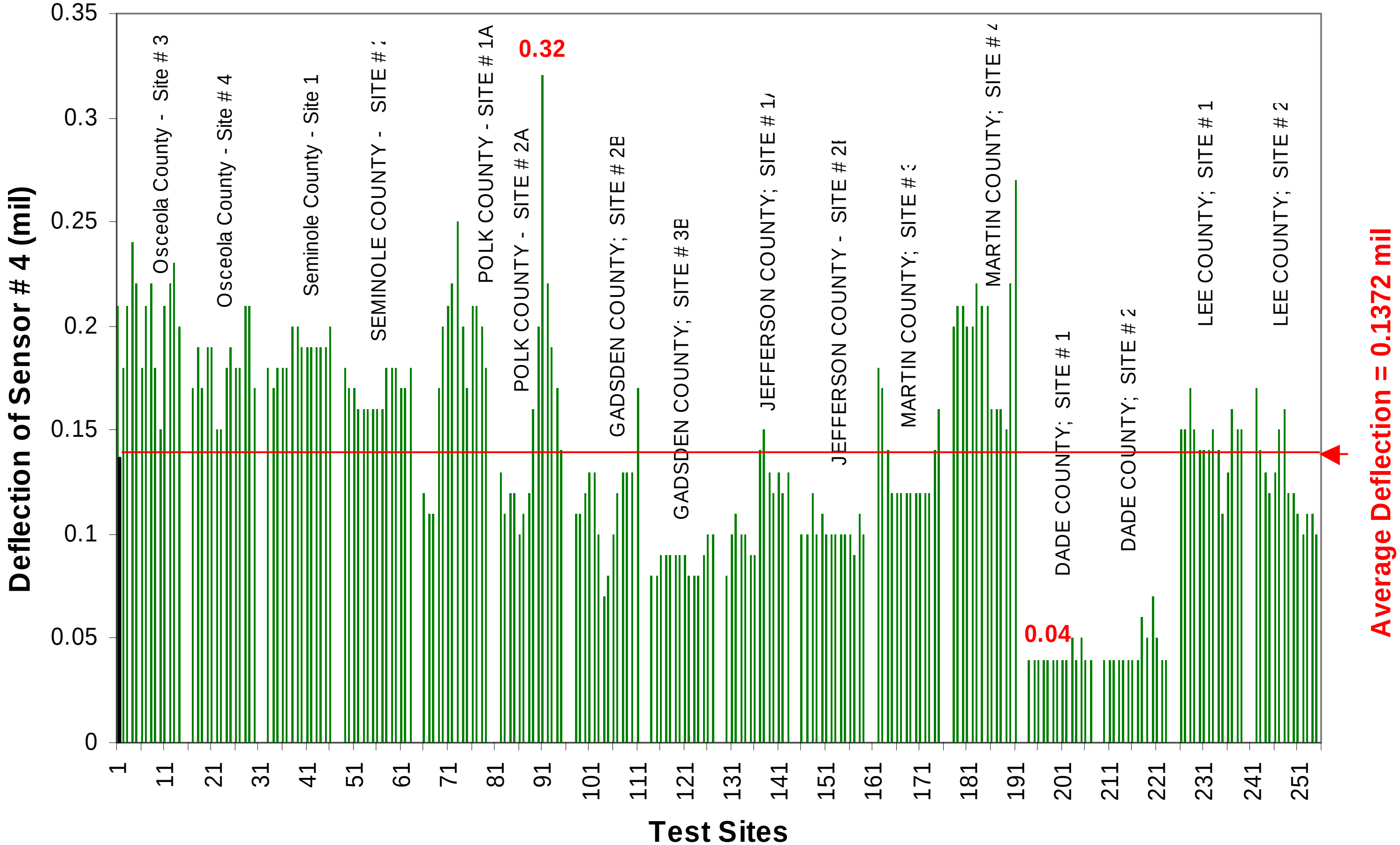


Figure 4.5 Subgrade Modulus From FWD and Dynaflect Tests

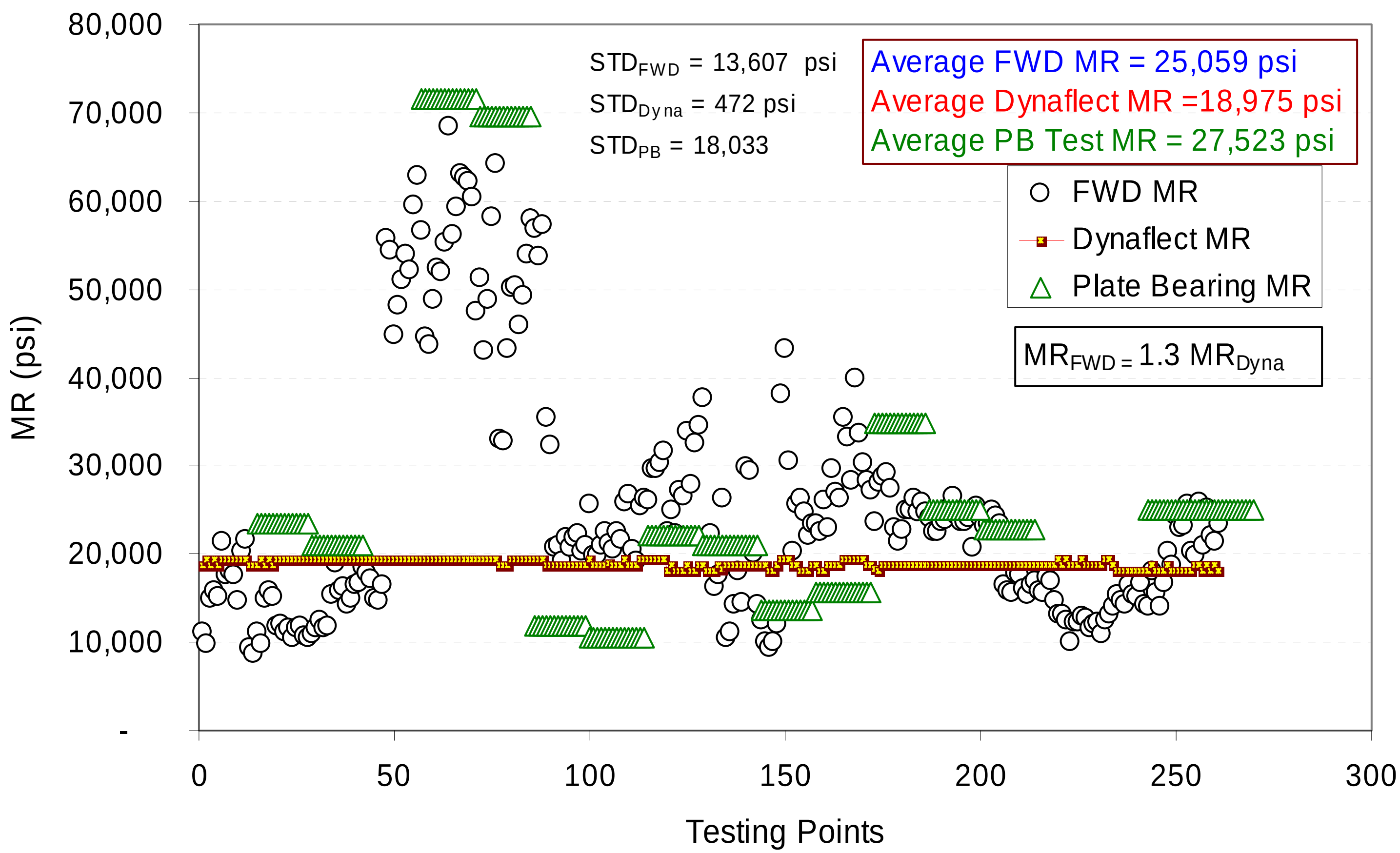
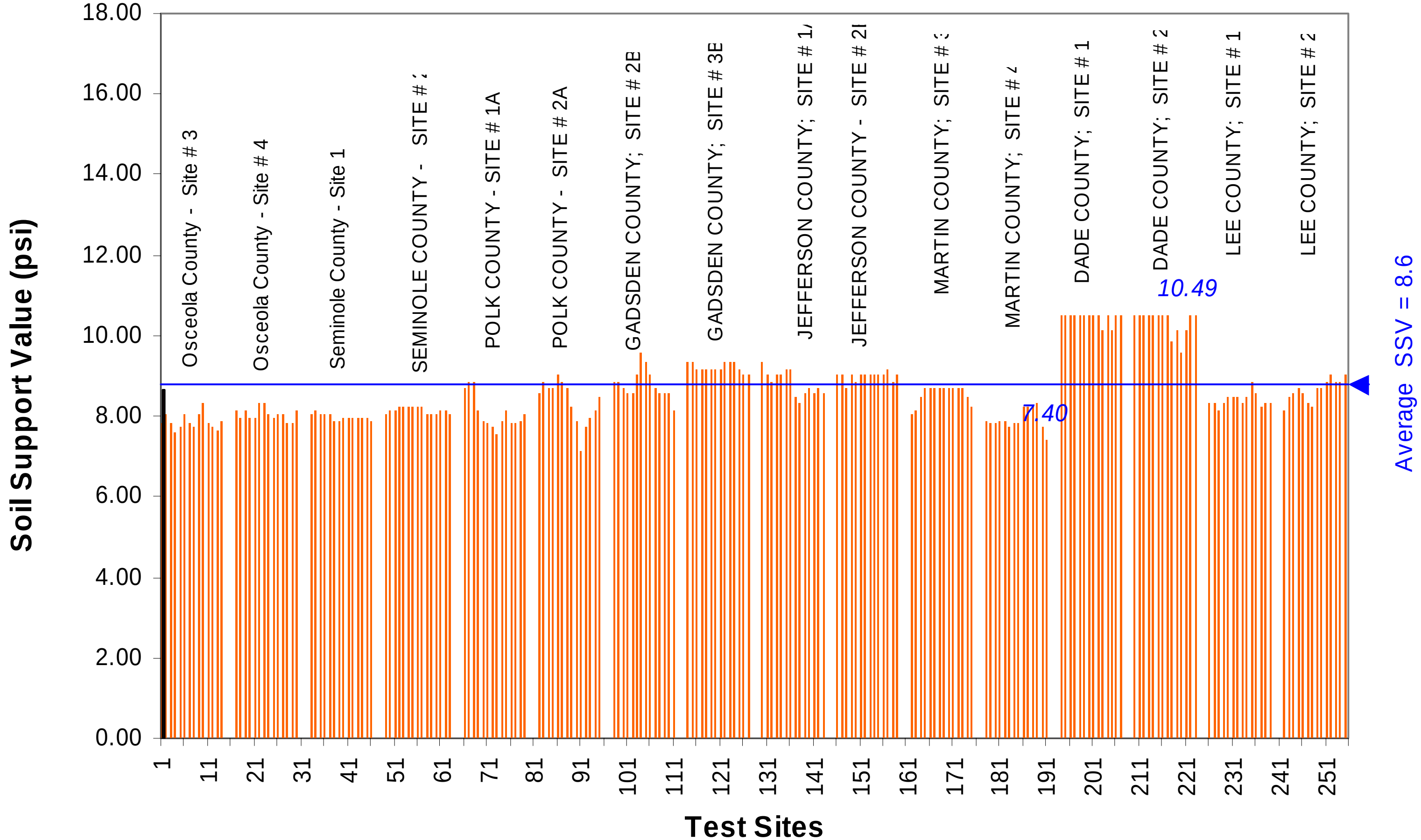


Figure 4. 6 Range of Dynaflect Soil Support Values (SSV) Obtained from Sensor # 4 for all Tested Sites



$\log E_r = 4.0419 - 0.5523 \log D_4$ where Er = Embankment modulus, in psi; and d4 = Deflection measured at 36 inches away

Figure 4.7 Range of Dynaflect Moduli Values (M_R) Obtained from FDOT Formula for Sensor # 4 - for all Tested Sites

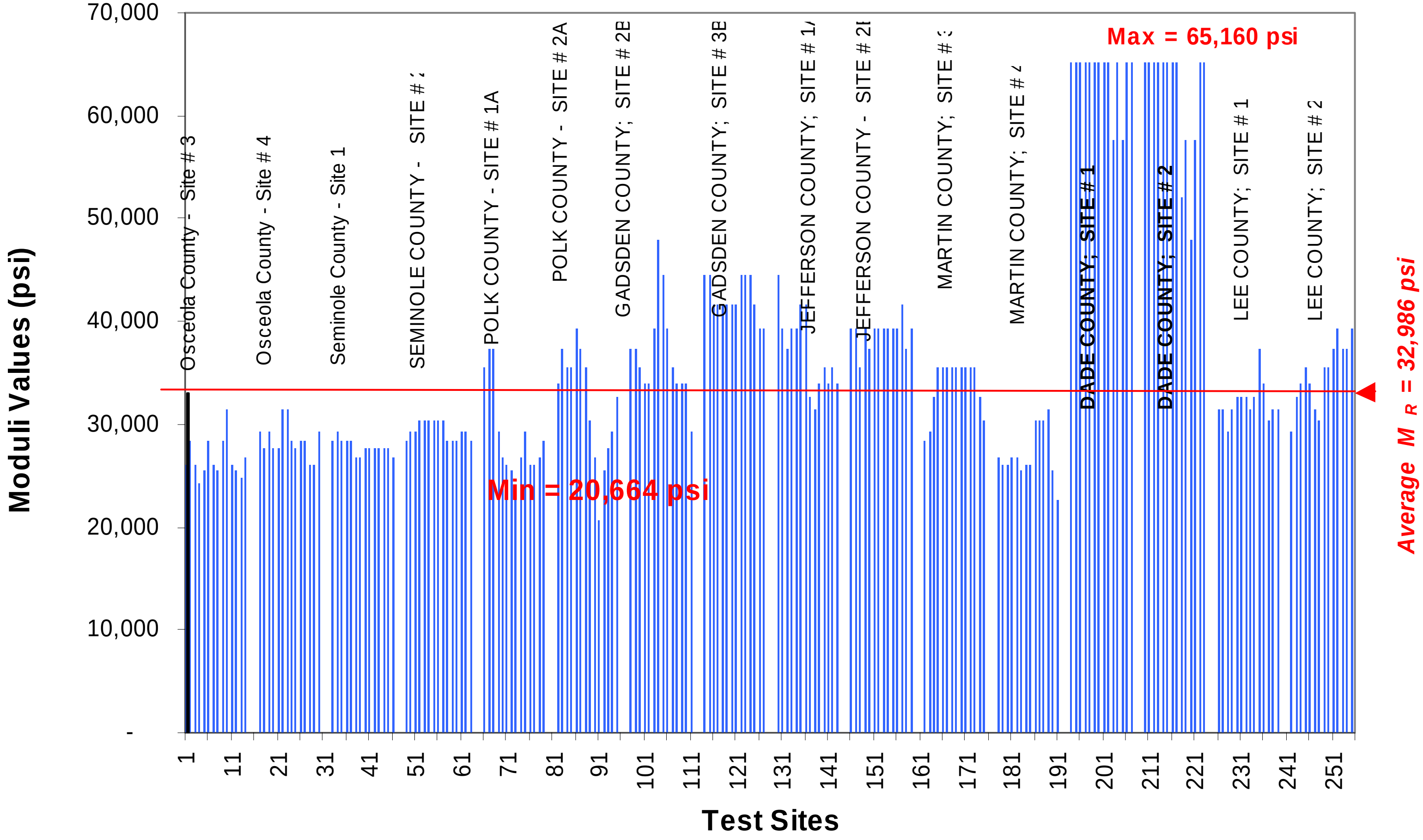


Figure 4.8 Range of Dynaflect Moduli Values (M_R) Obtained from AASHTO Formula for Sensor # 4 - All Tested Sites

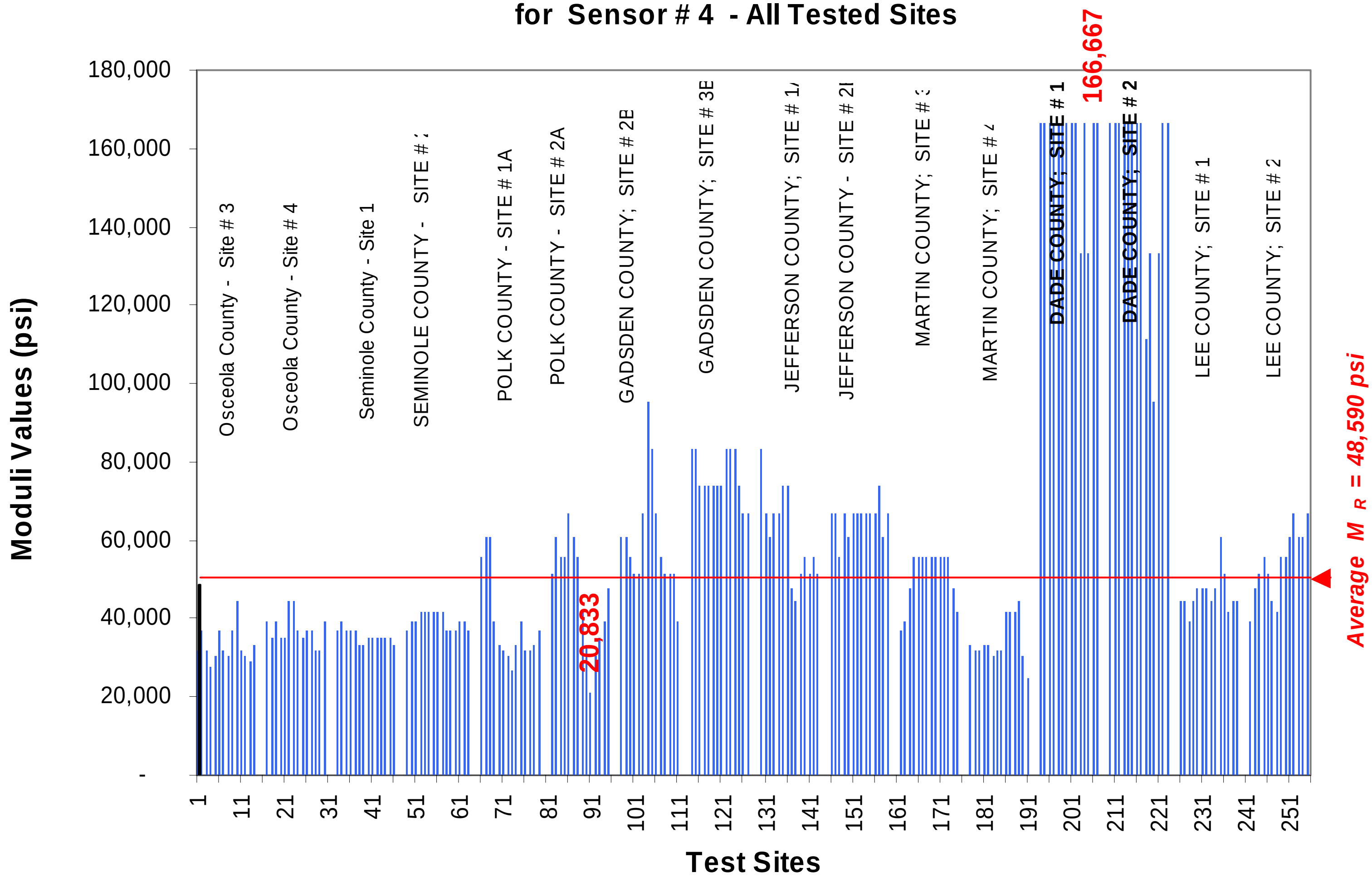


Figure 4.9 MR from MODULUS 5.0 vs. Deflections at D6 of FWD Tests for Ten Counties

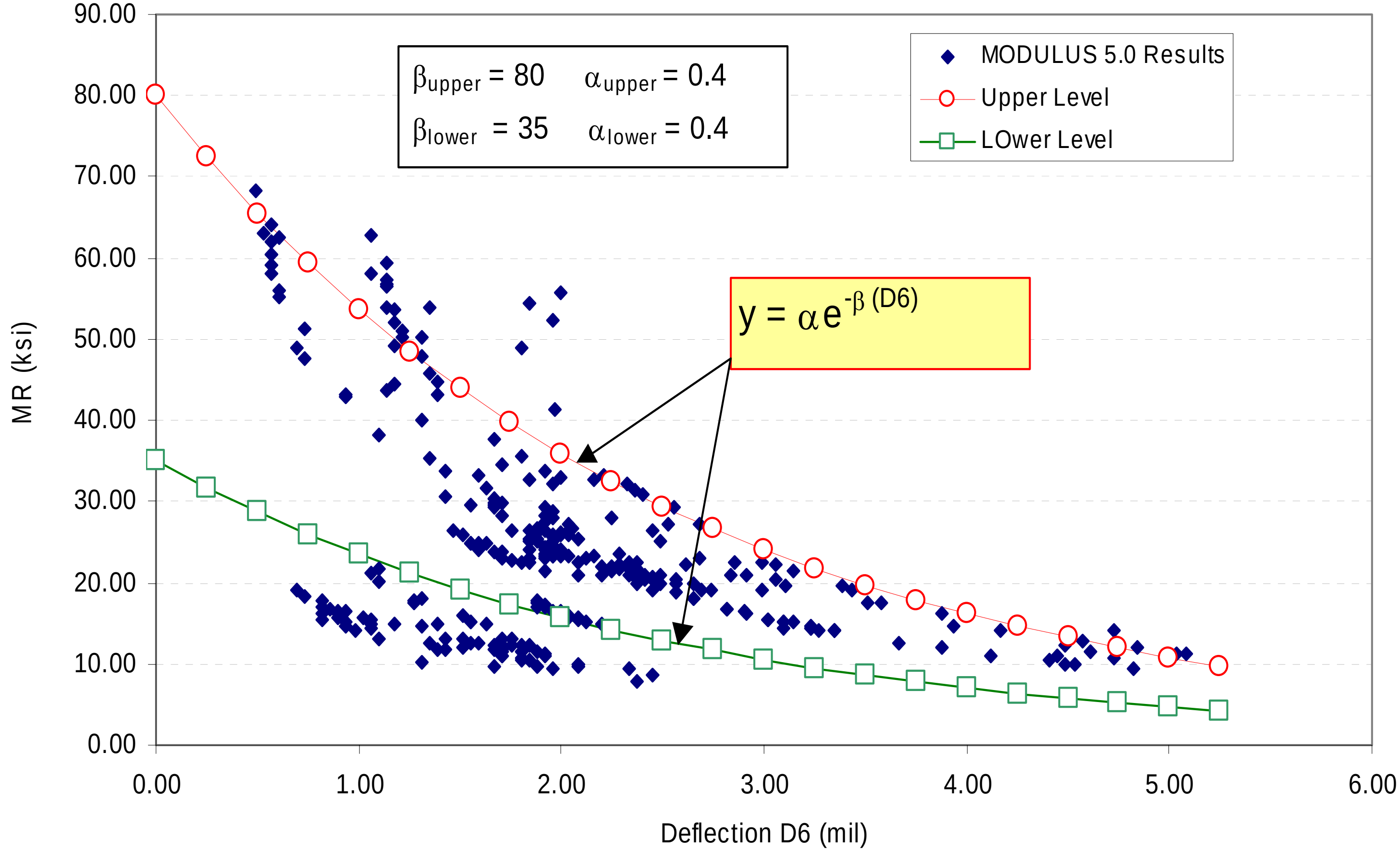


Figure 4.10 MR from MODULUS 5.0 vs. Deflections at D6 at 36 in
County: JEFFERSON; SITE # 2A

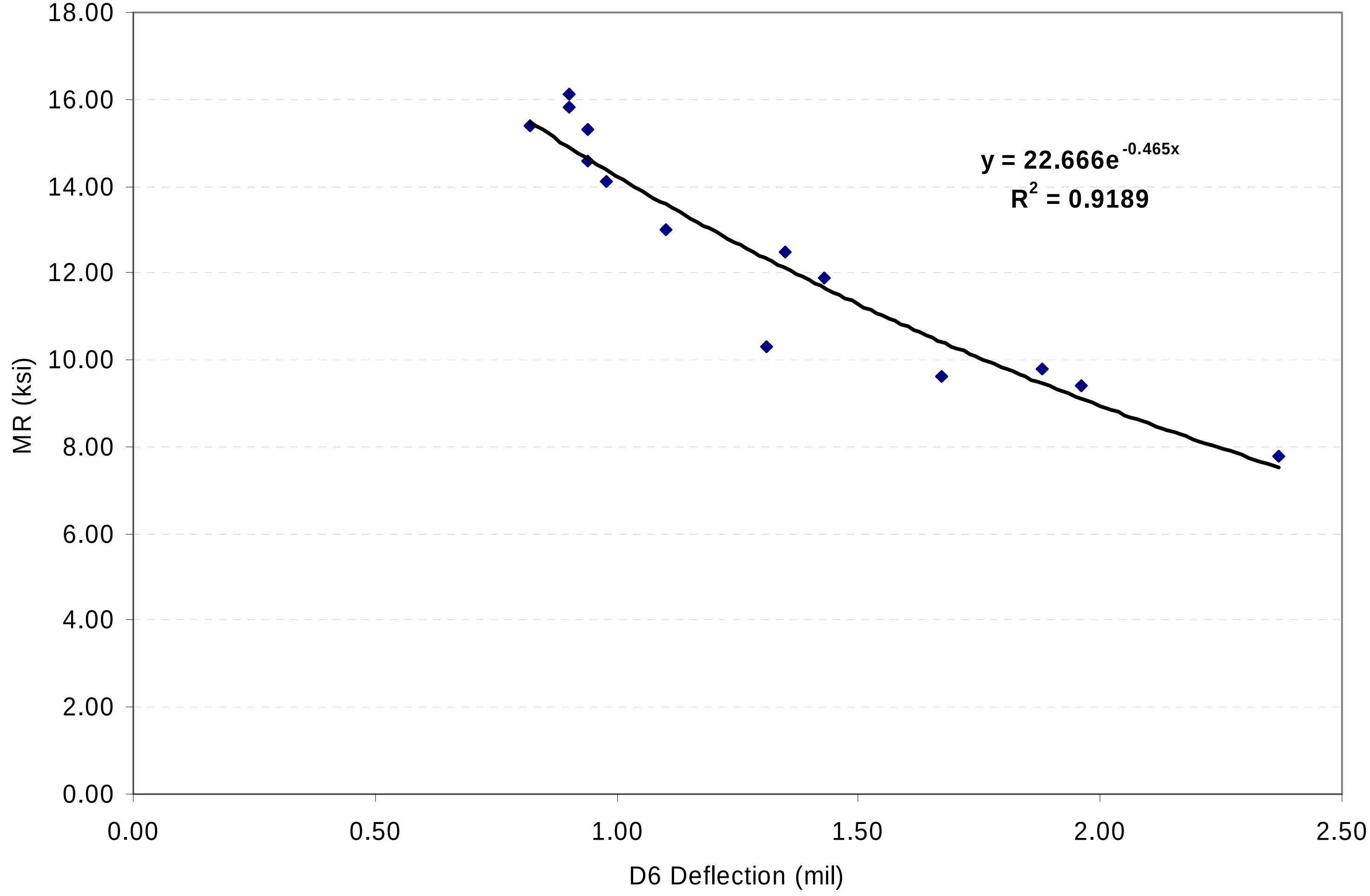


Figure 4.11 FWD DEFLECTION BASINS JEFFERSON COUNTY; SITE # 1A

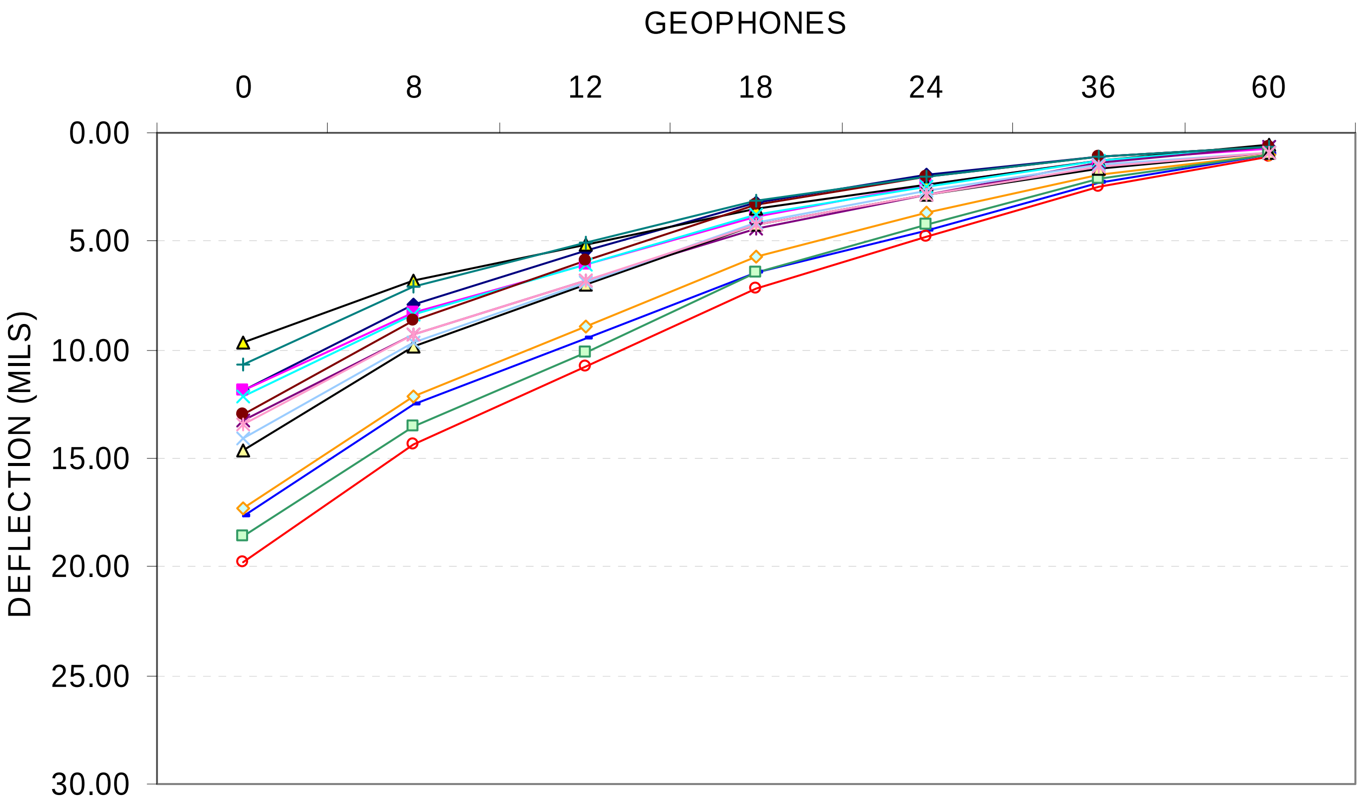
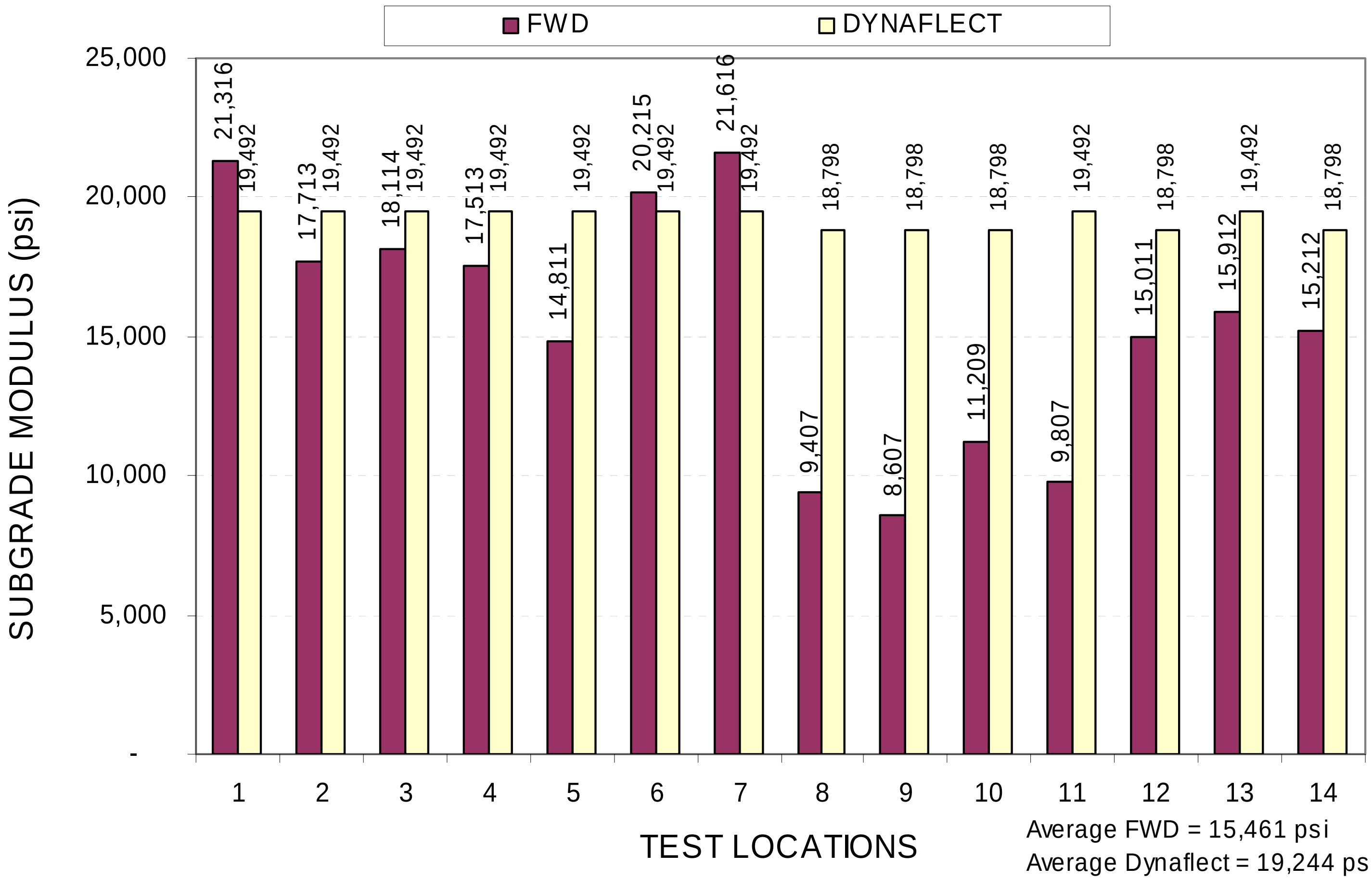


FIGURE: 4.12 COMPARISON OF SUBGRADE MODULI
ASPHALT PAVEMENT; JEFFERSON COUNTY; SITE # 1A



Average FWD = 15,461 psi
Average Dynaflect = 19,244 psi
Laboratory MR = 23,458 psi

FIGURE: 4.13 COMPARISON OF SUBGRADE MODULI
ASPHALT PAVEMENT; CLAY COUNTY; SITE # 6

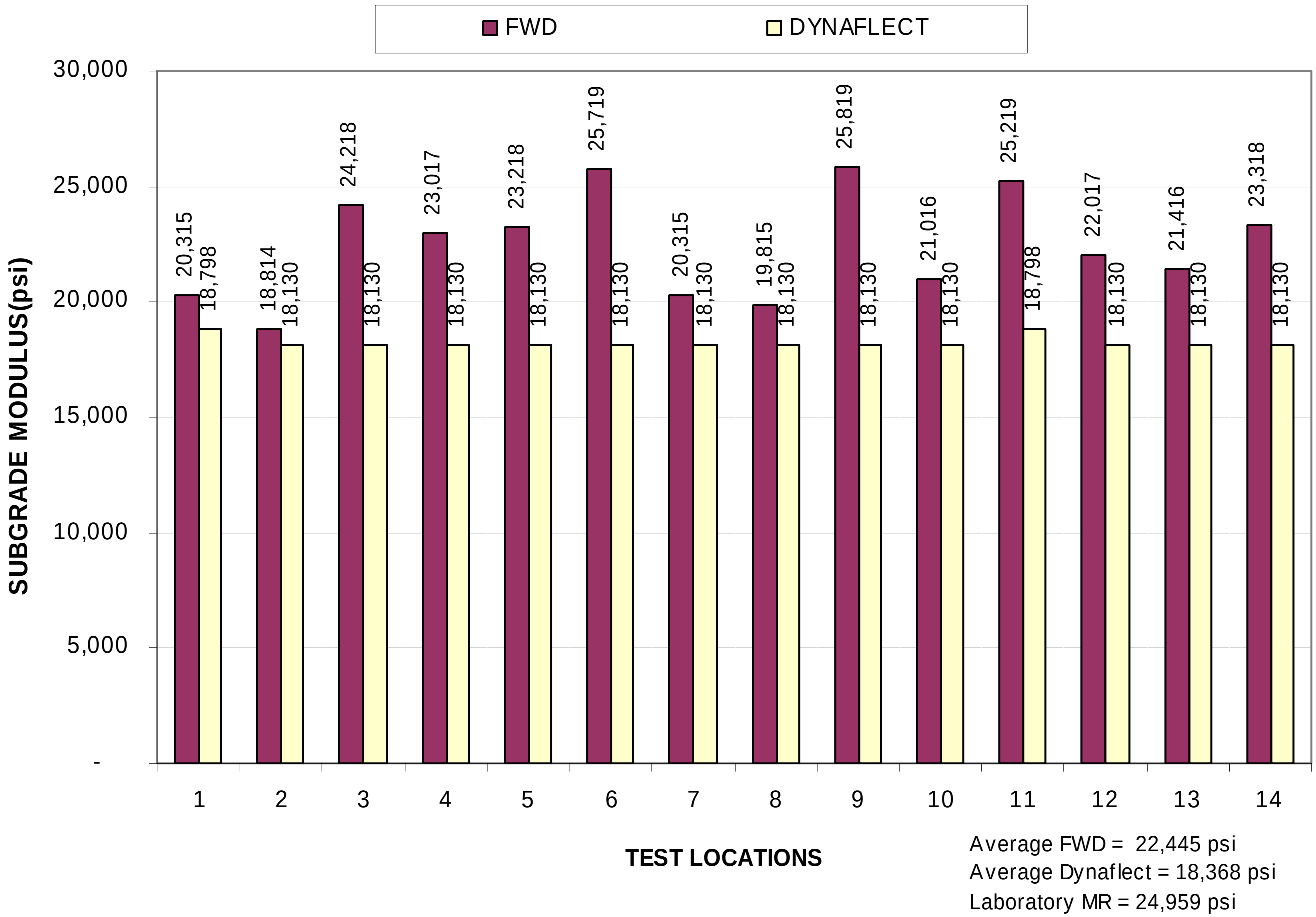


Figure 4.14 Relationship Betweem MR_{FWD} and $MR_{Dynaflect}$

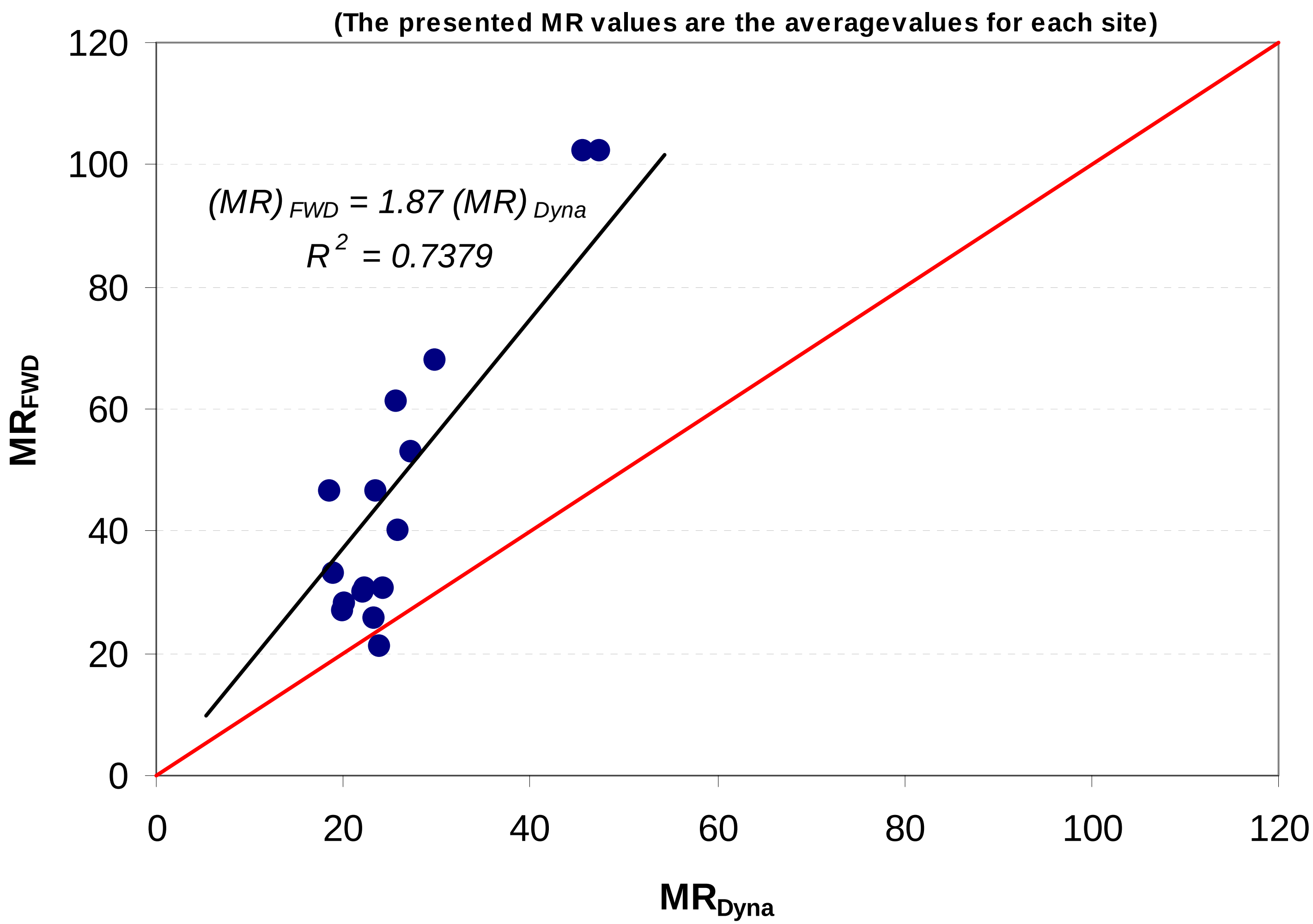


Figure 4.15 Subgrade Modulus from FWD, AASHTO and Dynaflect

(The presented MR values are the averagevalues for each site)

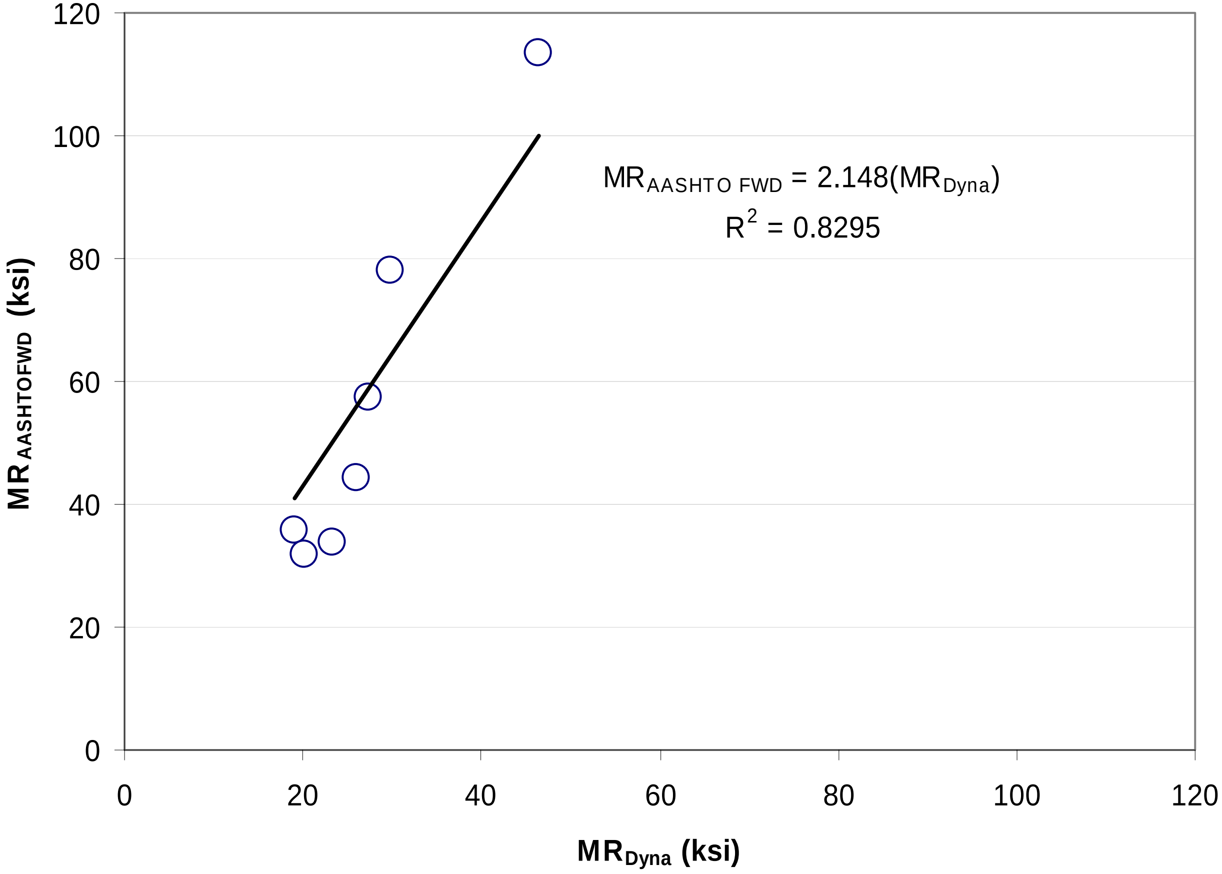


Figure 4.16 FWD Modulus vs. Adjusted Laboratory M_R form 20 Sites Project

(The presented MR values are the averagevalues for each site)

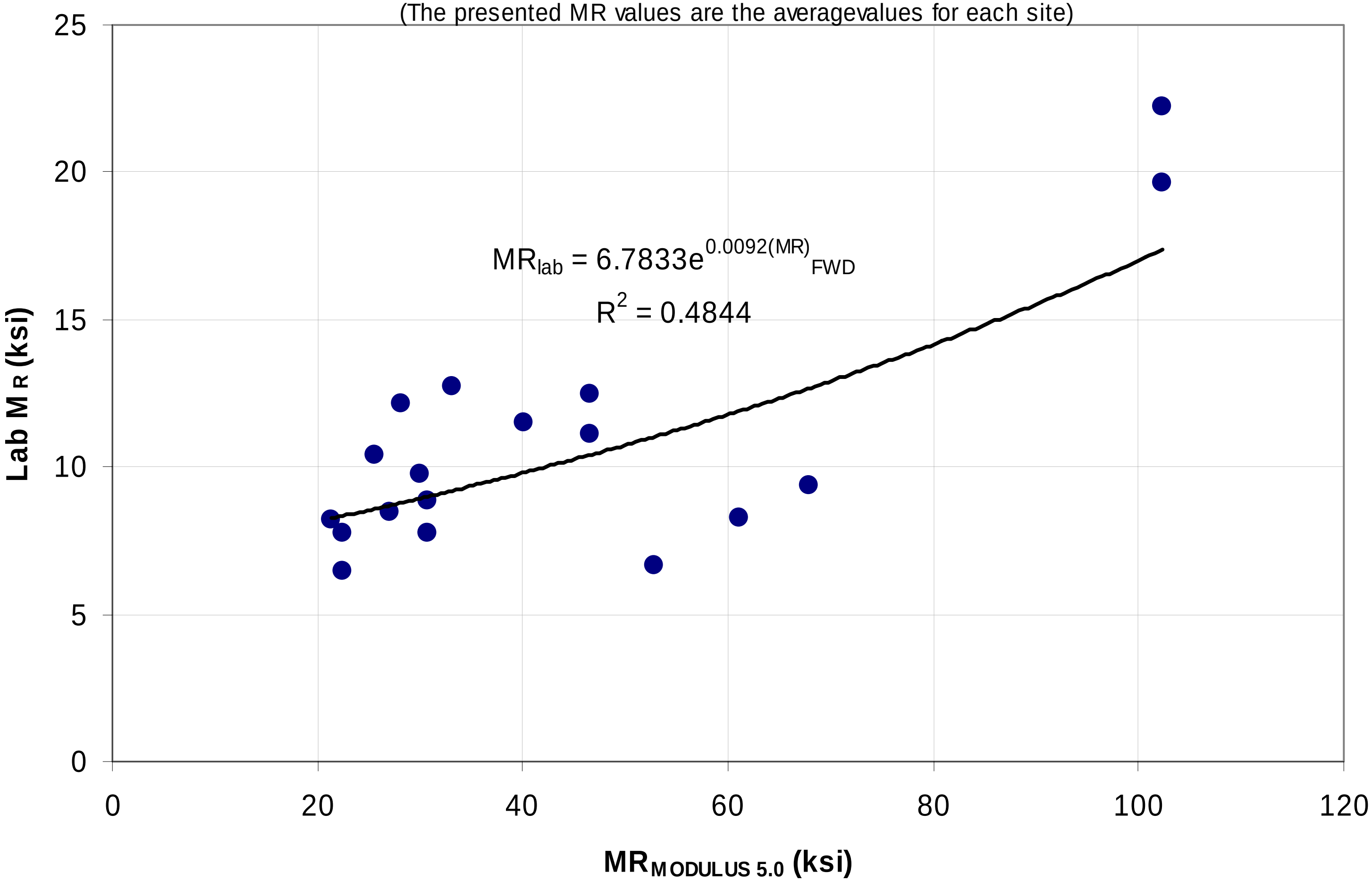


Figure 4.17 FWD Modulus vs. Adjusted Laboratotry M_R form 20 Sites Project
(The presented MR values are the averagevalues for each site)

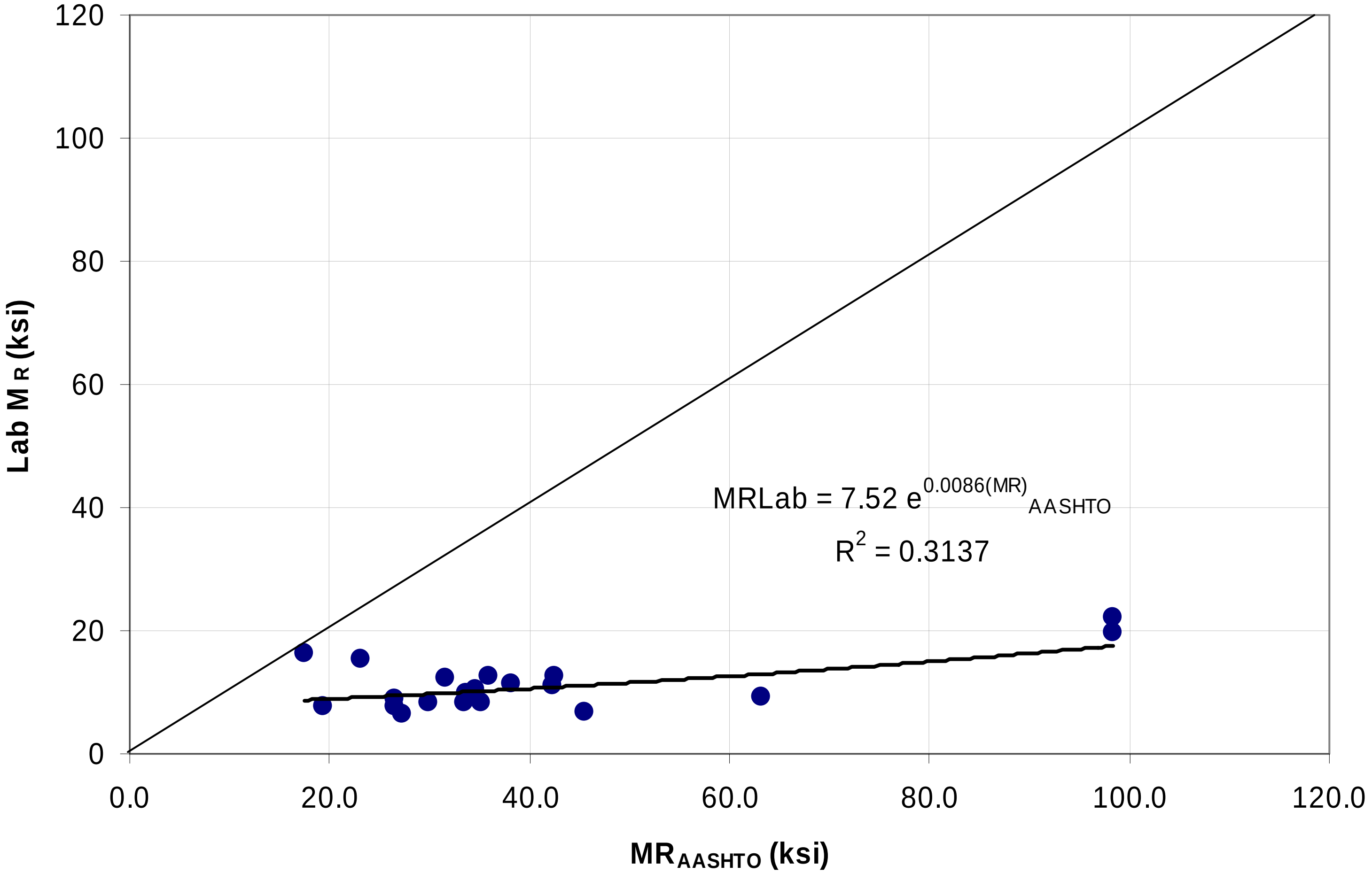


Figure 4.18 $MR_{MODULUS}$ vs. MR_{AASHTO} form 20 Sites Project (SPA project)
(The presented MR values are the averagevalues for each site)

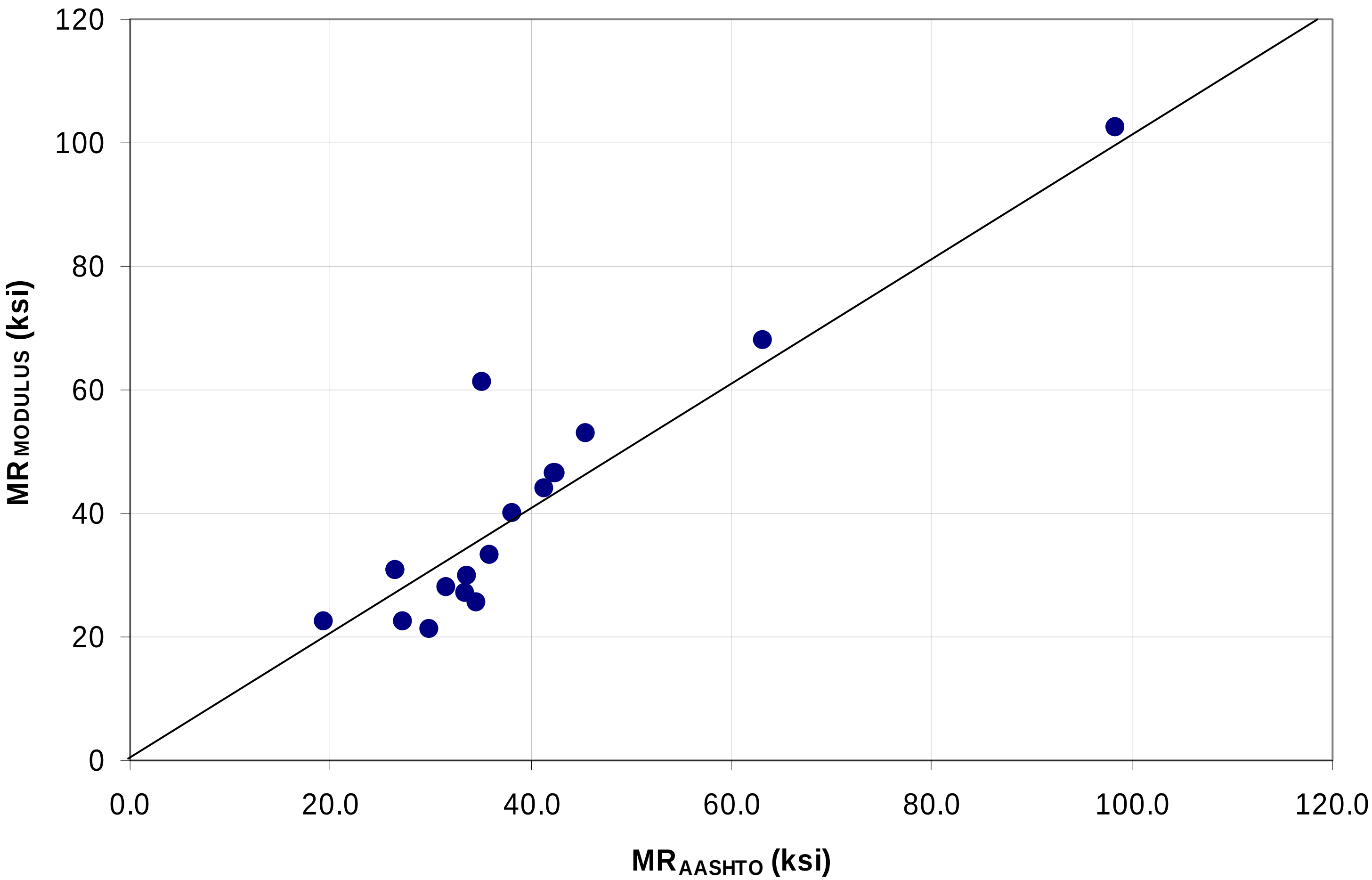


Figure 4.19 An Example of How the MRLaboratory was Adjusted
Lab M_R vs Confining Pressure at Lee County - site 1B

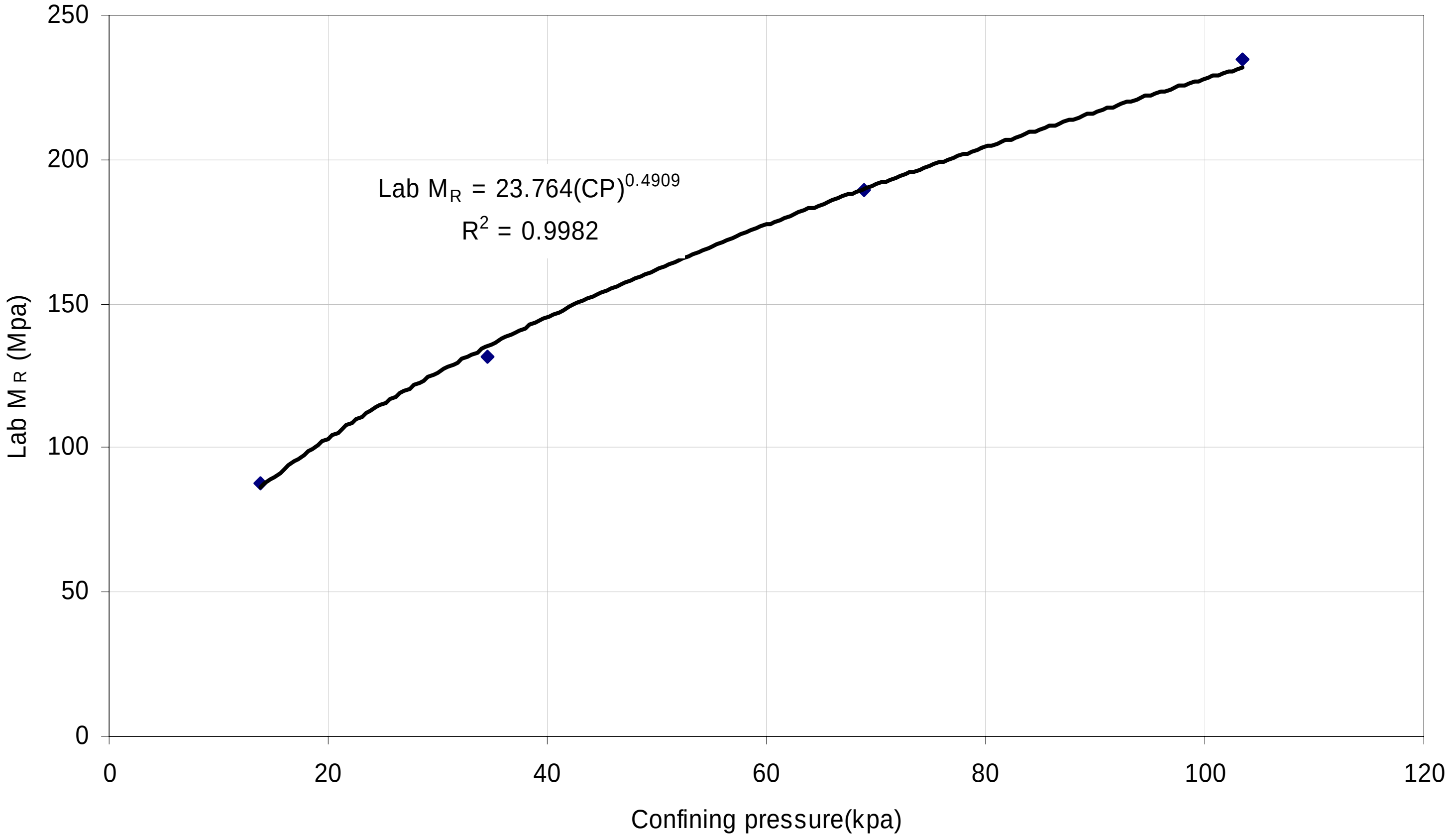


Figure 4.20 Field Plate Bearing Test (FPBT) vs Modulus 5.1,Dynaflect & AASHTO Resilient Modulus from SPA Project

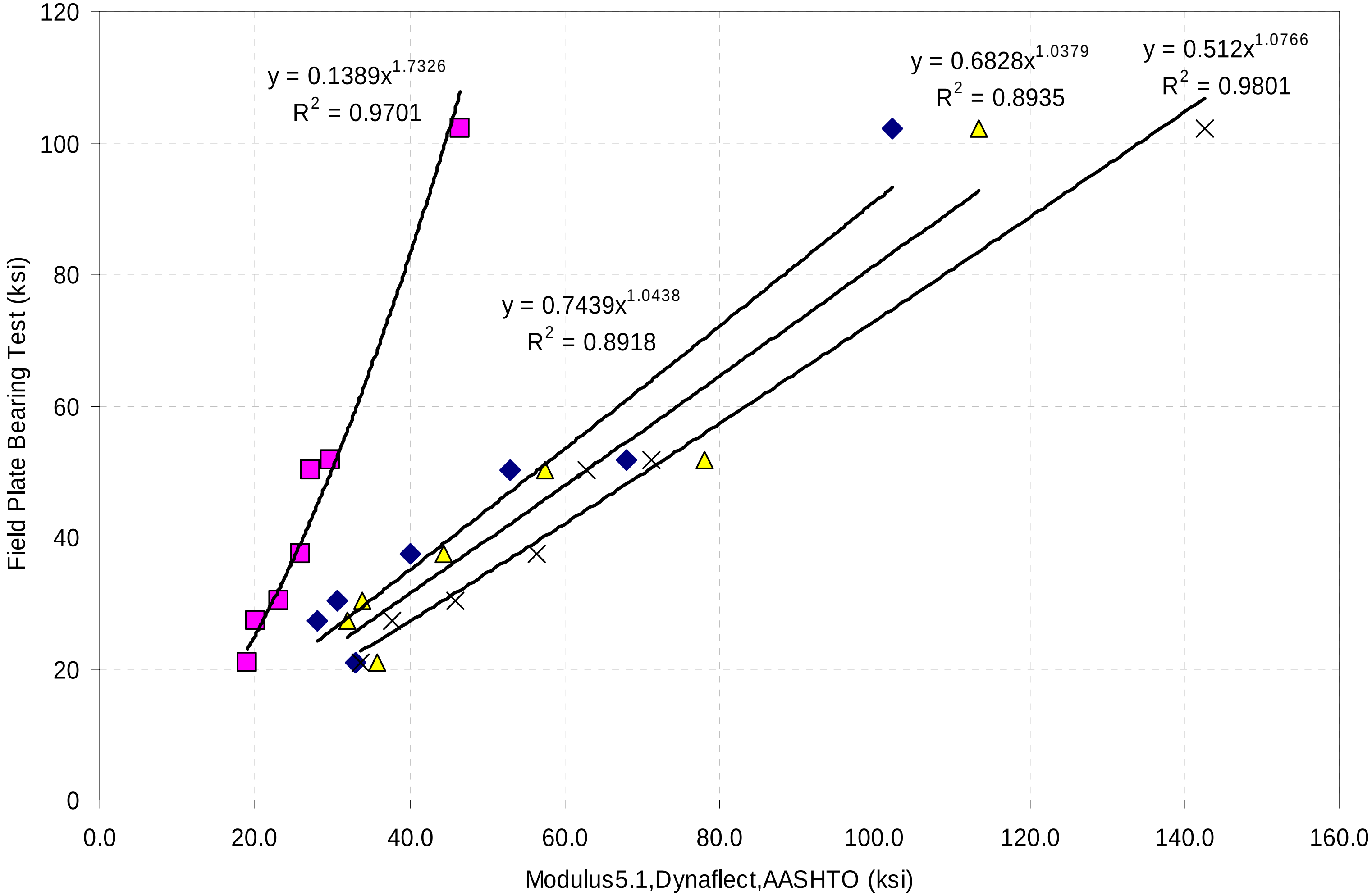


Figure 4.21 Comparison with Field Plate Bearing Resilient Modulus

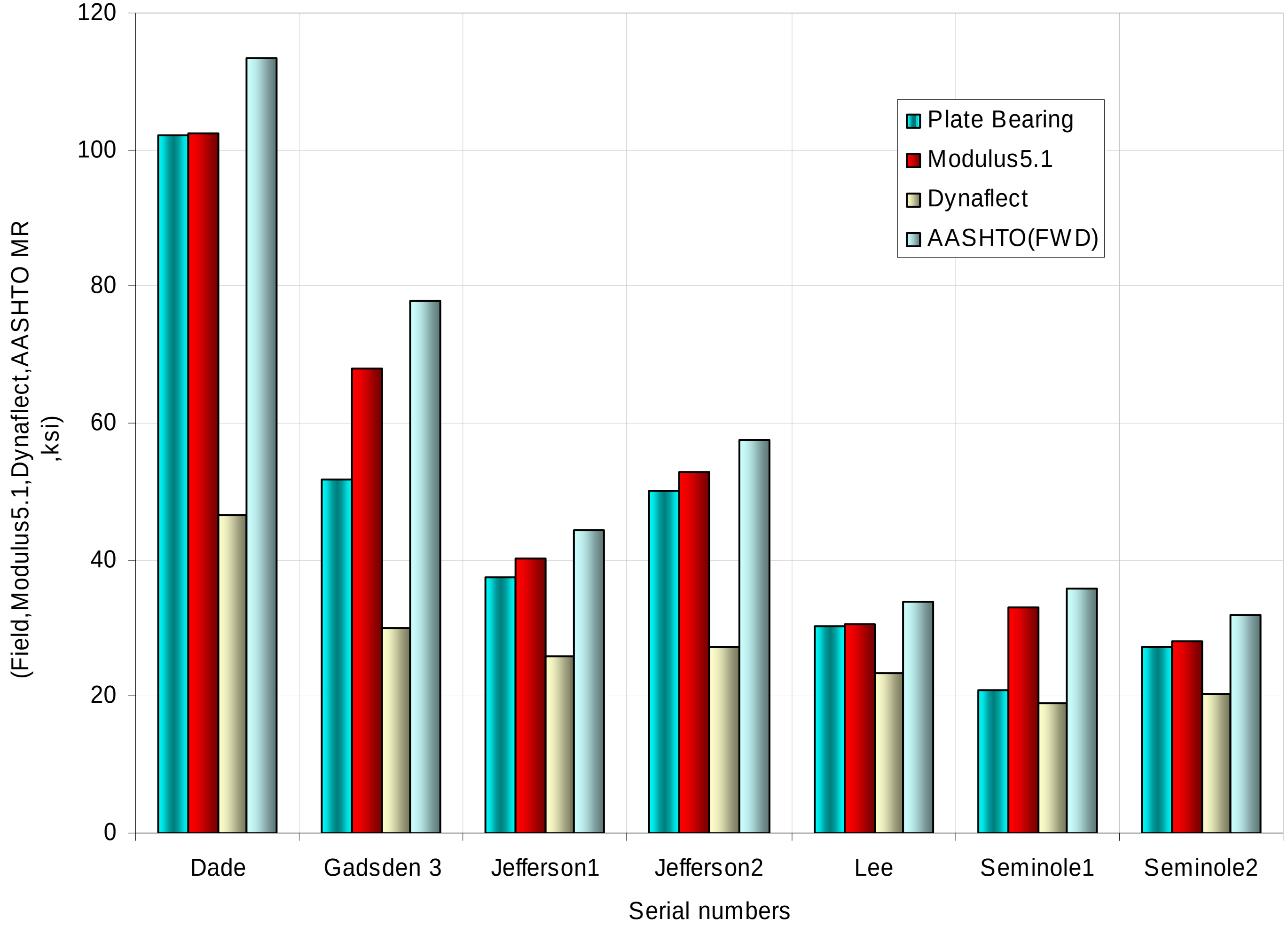


Figure 4.22 SSV at the FDOT 300 Mile Testing Sites

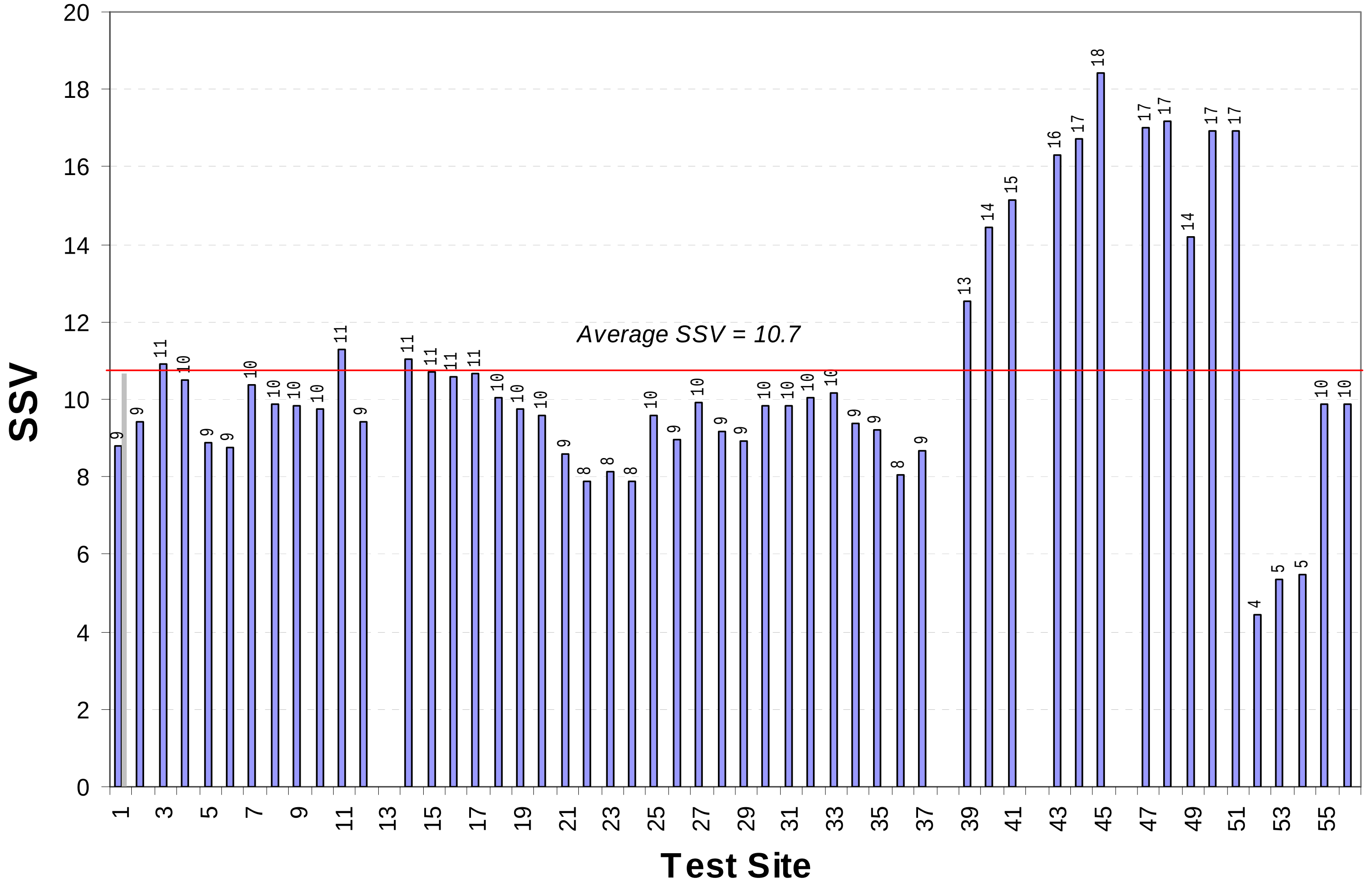


Figure 4.23 Dynaflect Deflection (4th Sensor) vs. Soil Support Value

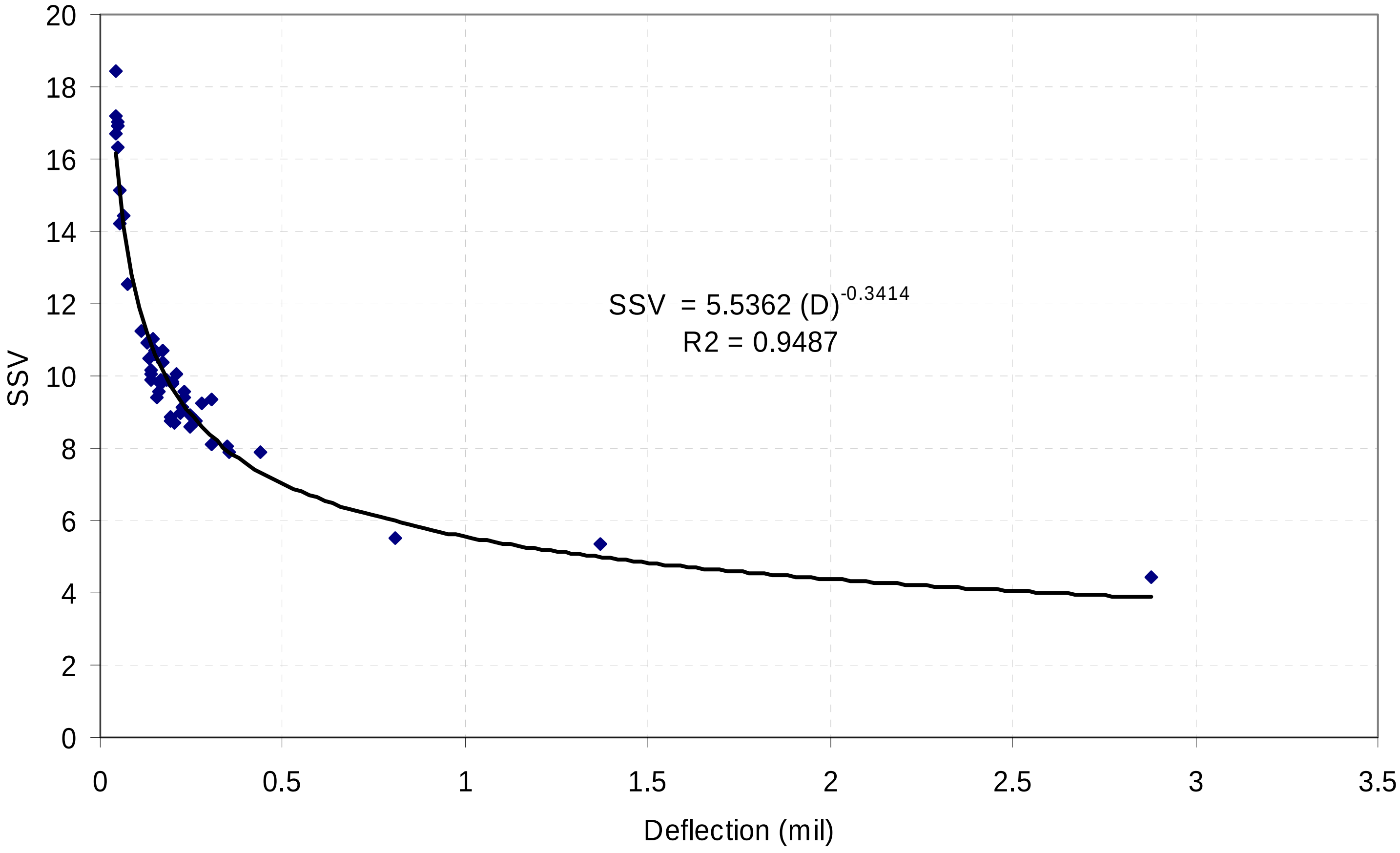


Figure 4.24 AASHTO Resilient Modulus values from FWD and Laboratory Results Using All the data in the 300 mile Sections

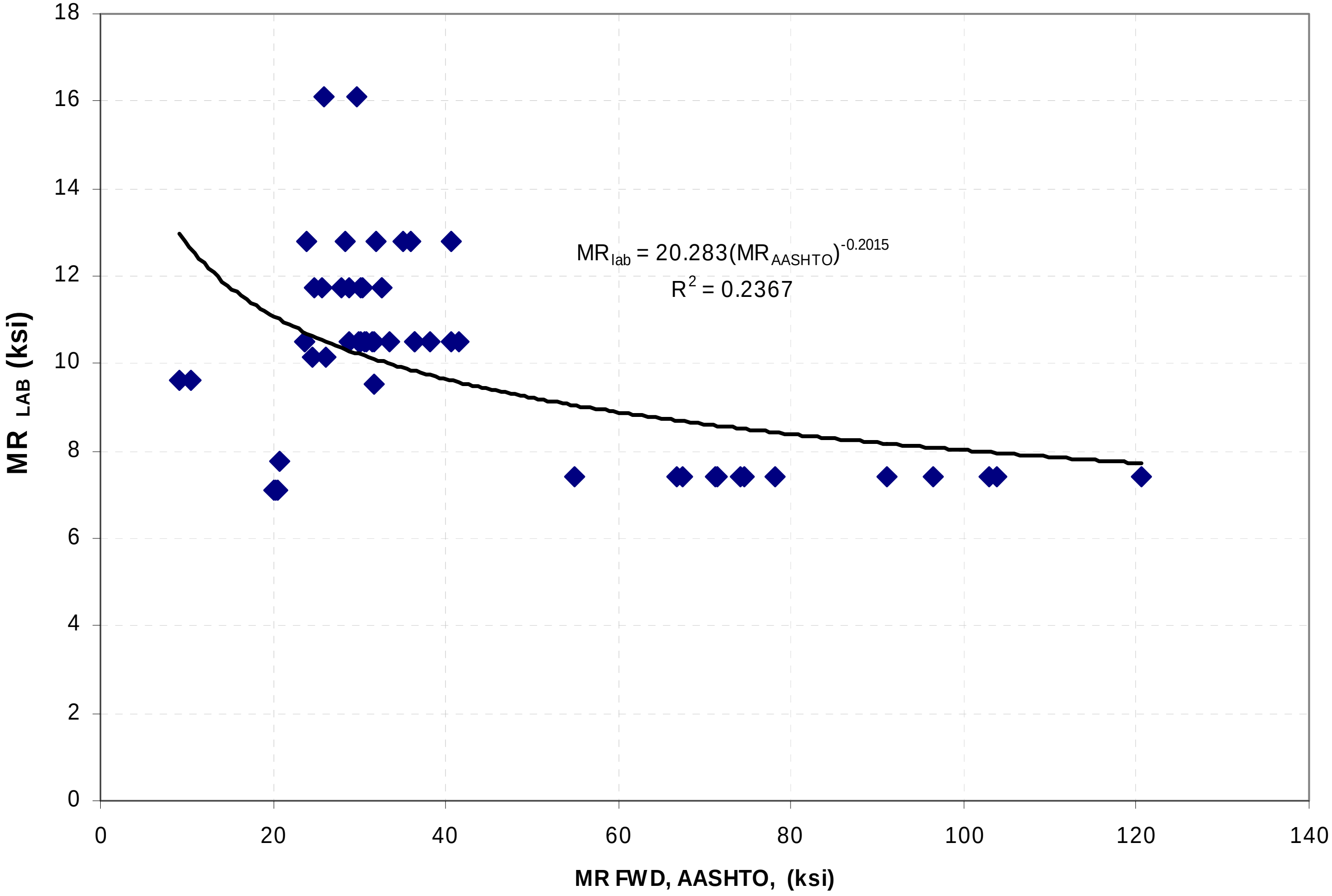


Figure 4.25 MODULUS 5.0 Resilient Modulus values from FWD and Laboratory Results Using All the data in the 300 mile Sections

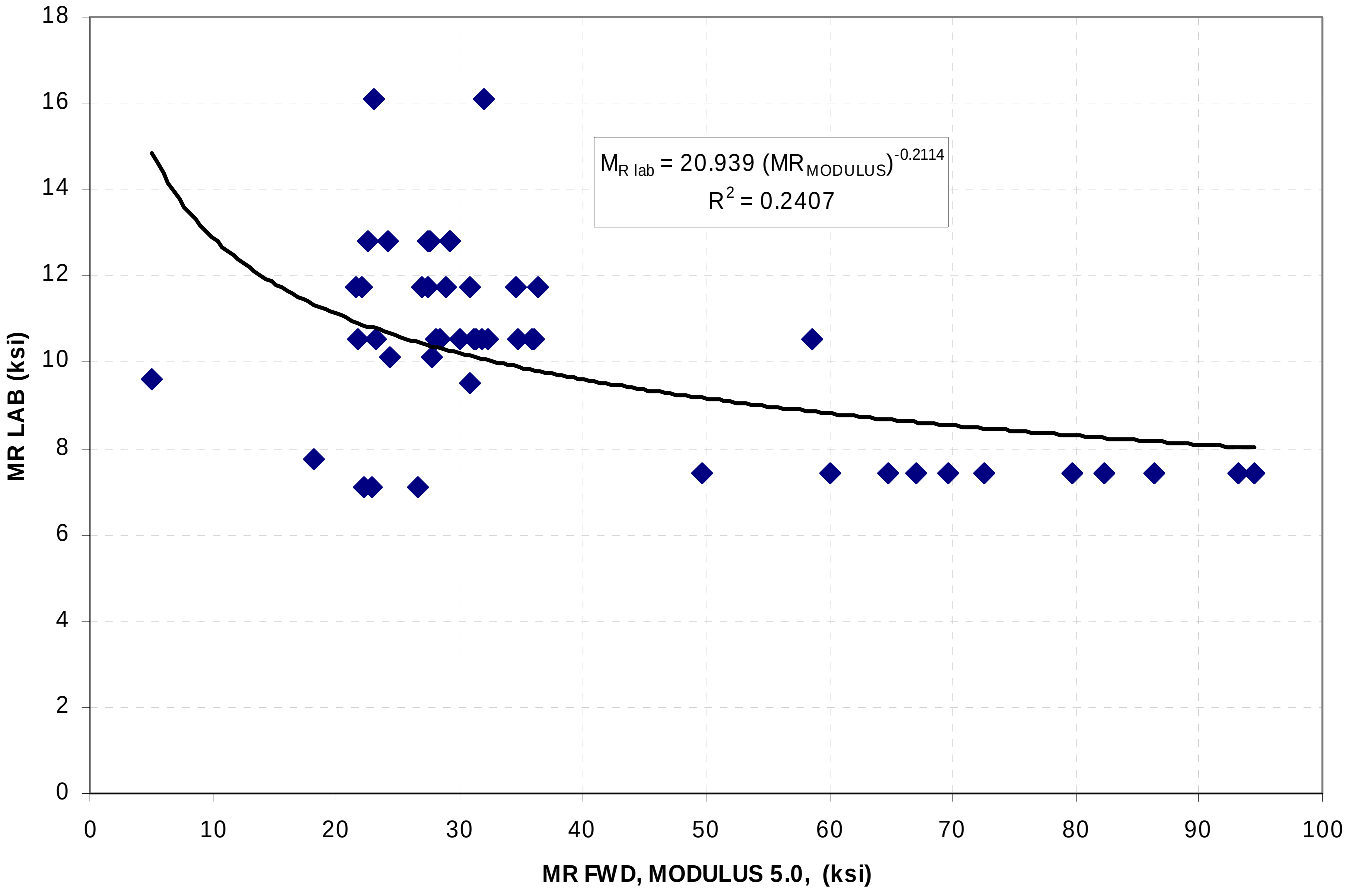


Figure 4.26 EVERCALC Resilient Modulus values from FWD and Laboratory Results Using All the data in the 300 mile Sections

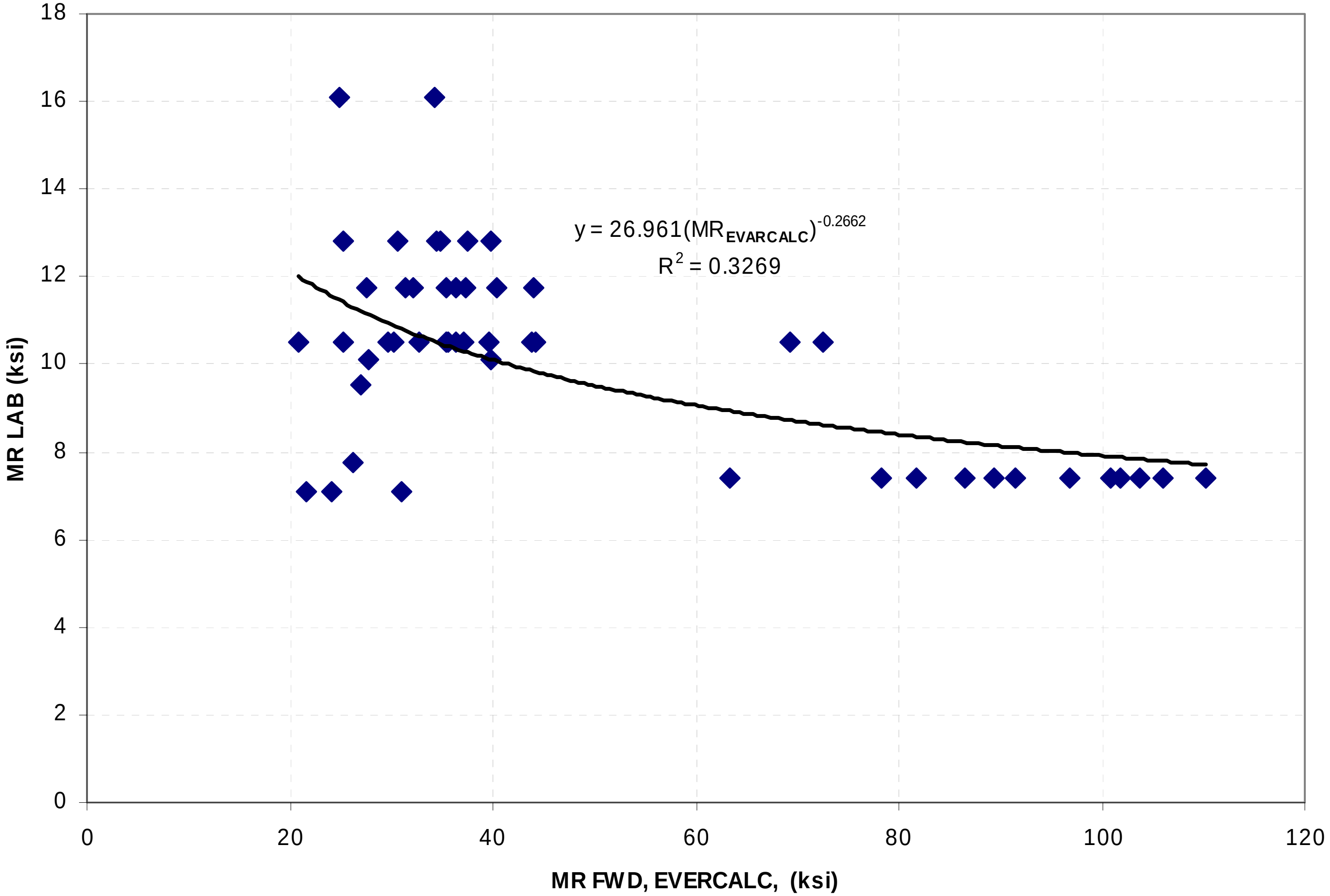


Figure 4. 27 Resilient Modulus values from FWD and Laboratory Results For Sections with 3 in. Thickness

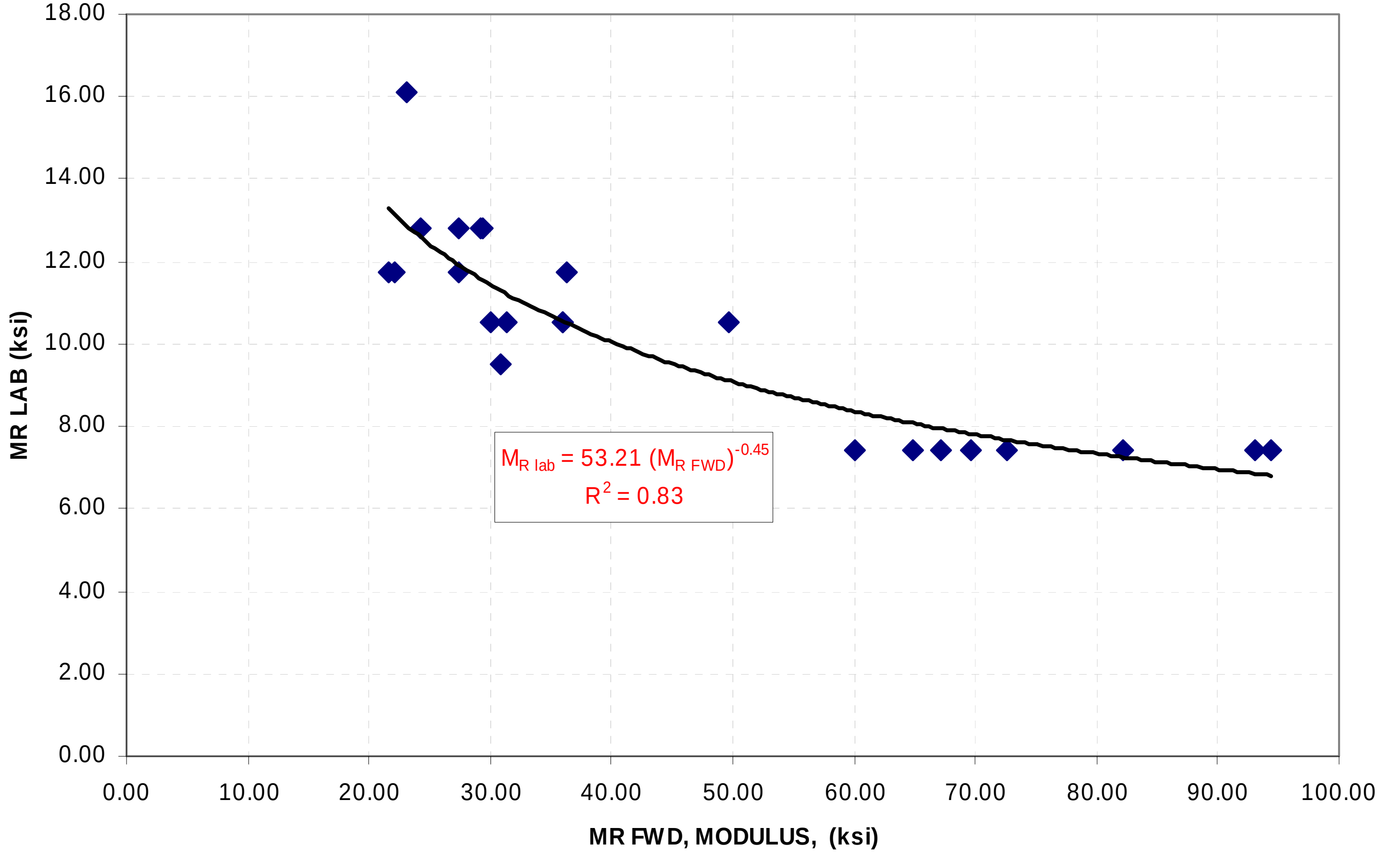


Figure 4.28 M_R MODULUS, AASHTO, DYNAFLECT vs. Laboratory M_R for 3 inch surface layer of 300 miles

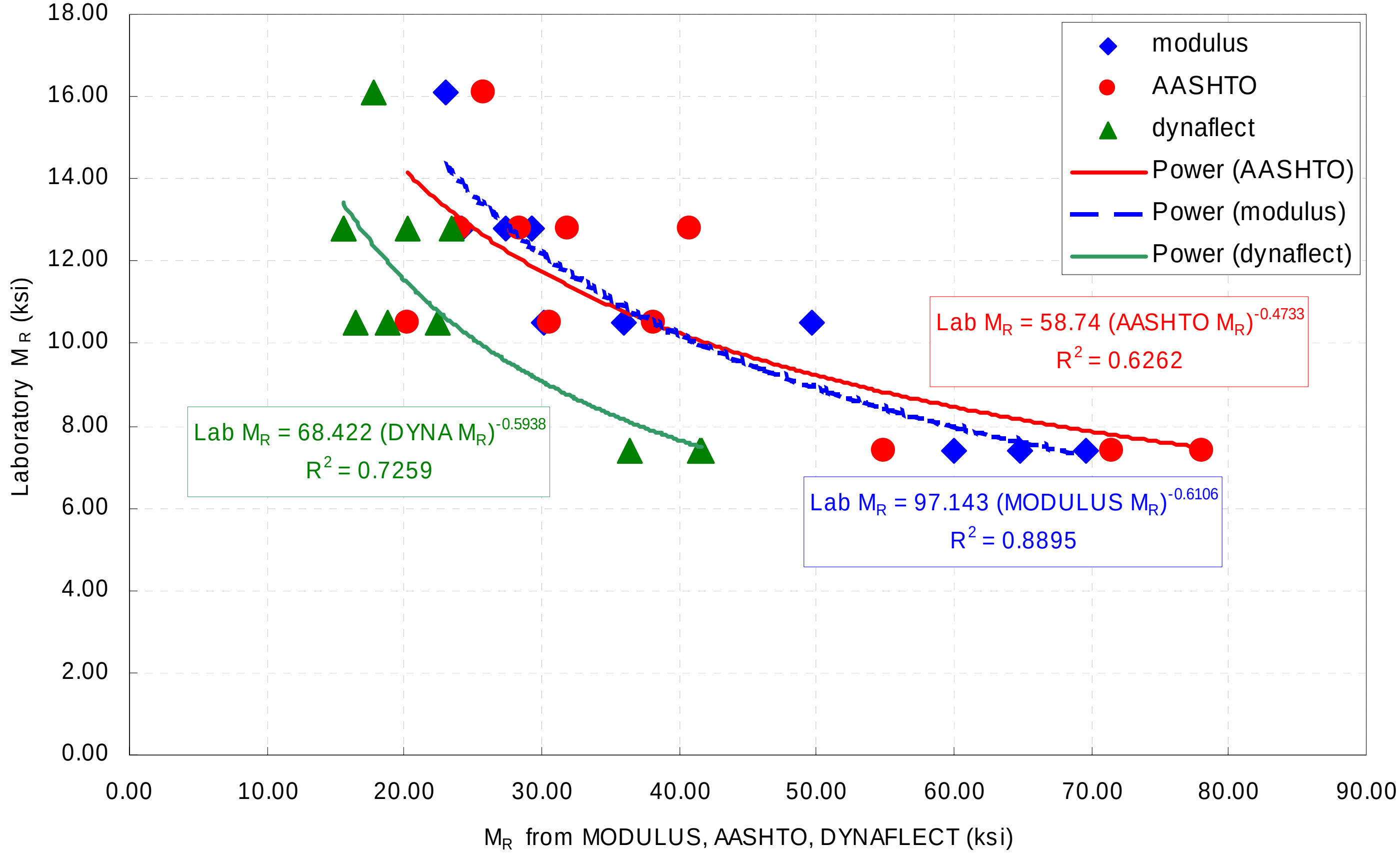
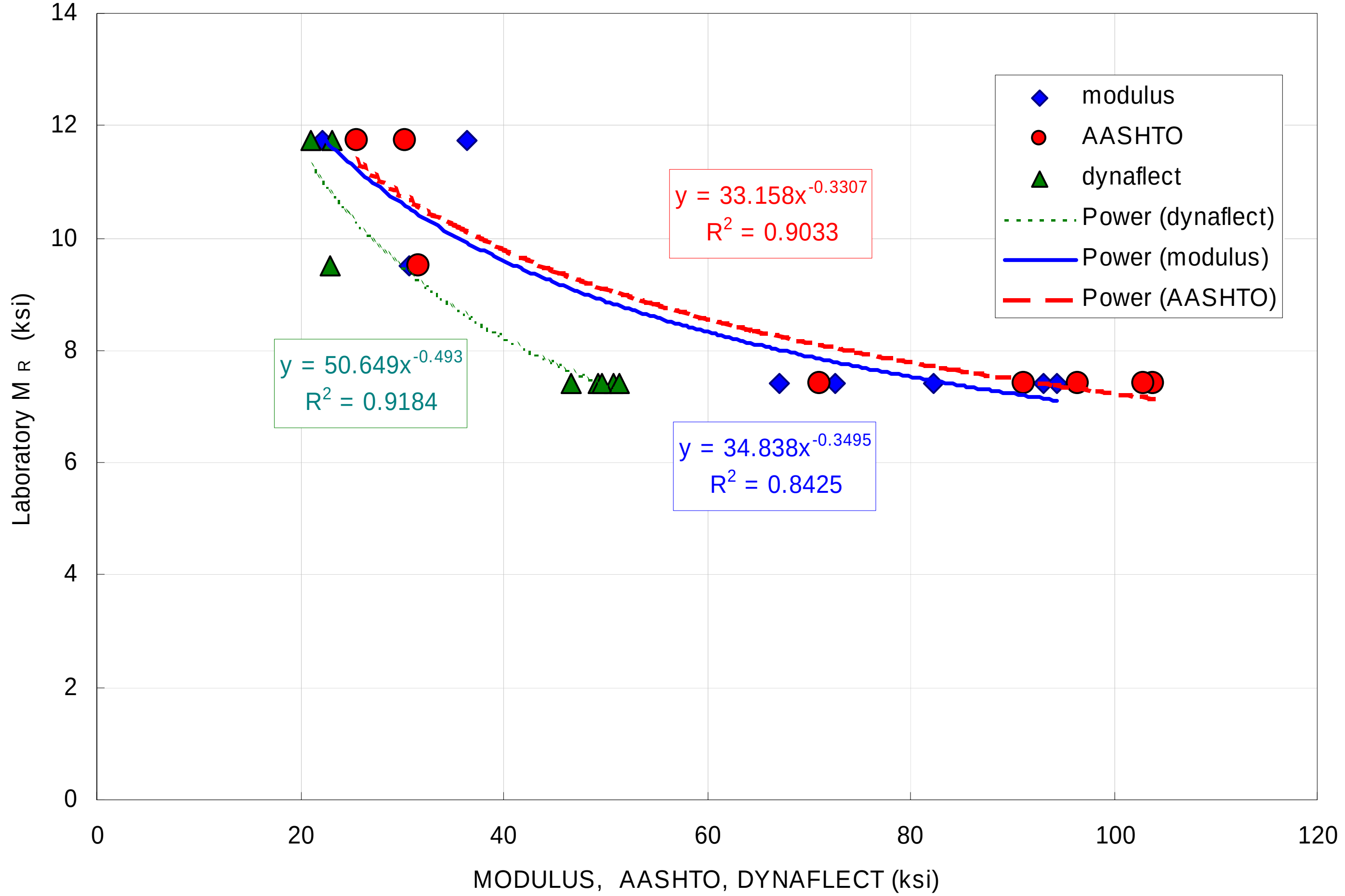


Figure 4.29 M_R MODULUS, AASHTO, DYNAFLECT vs. Laboratory M_R

2 - 2.5 inches surface layer of 300 miles



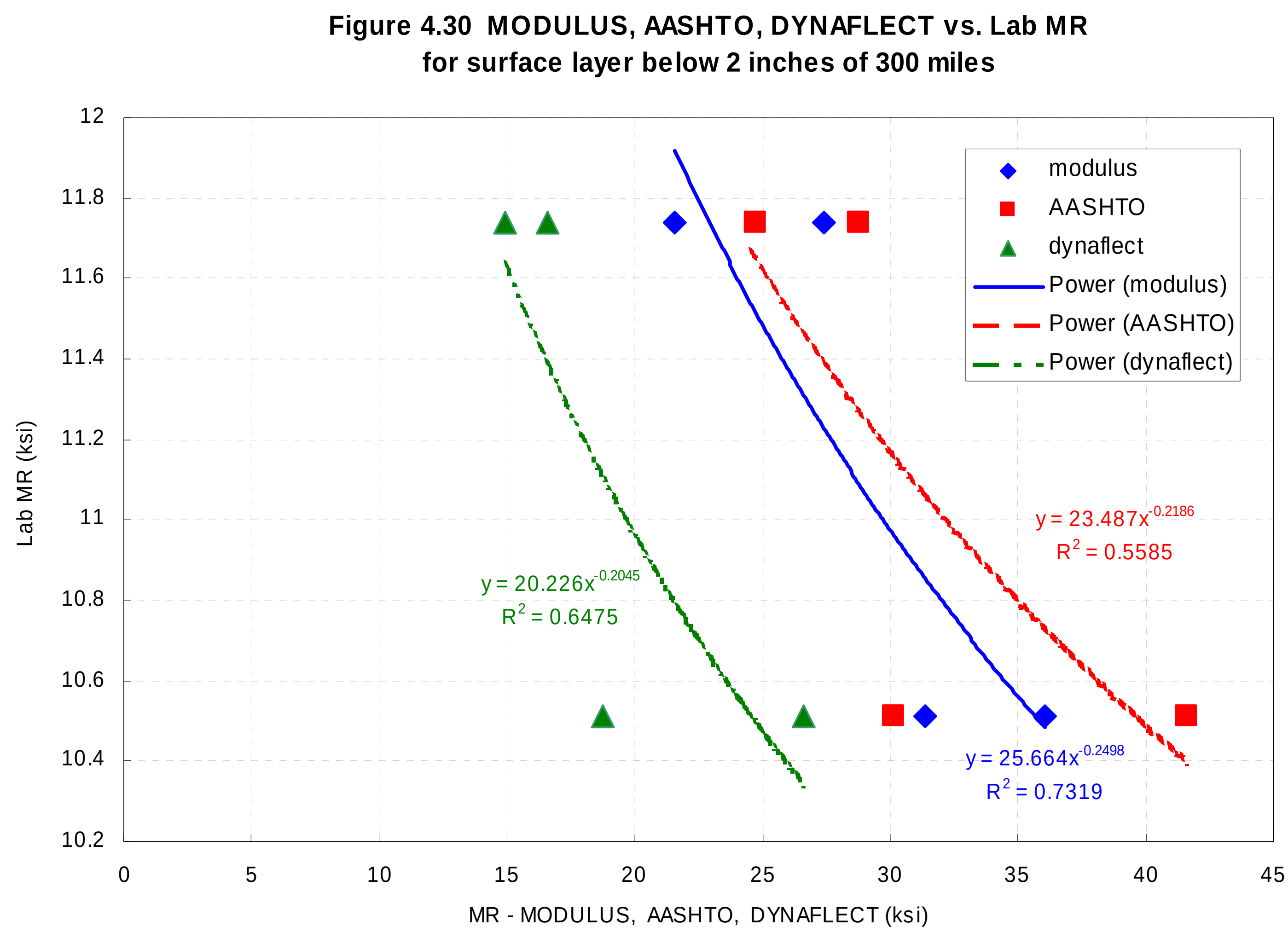


Figure 4.30 MODULUS, AASHTO, DYNAFLECT vs. Lab MR
for surface layer below 2 inches of 300 miles
Lab MR (ksi)
MR - MODULUS, AASHTO, DYNAFLECT (ksi)
modulus
AASHTO
dynaflect
Power (modulus)
Power (AASHTO)
Power (dynaflect)
y = 23.487x^-0.2186
R^2 = 0.5585
y = 20.226x^-0.2045
R^2 = 0.6475
y = 25.664x^-0.2498
R^2 = 0.7319
12
11.8
11.6
11.4
11.2
11
10.8
10.6
10.4
10.2
0
5
10
15
20
25
30
35
40
45

Figure 4.31 Correlation of MODULUS MR vs. DYNAFLECT MR for 300 miles and all surface layers thicknesses

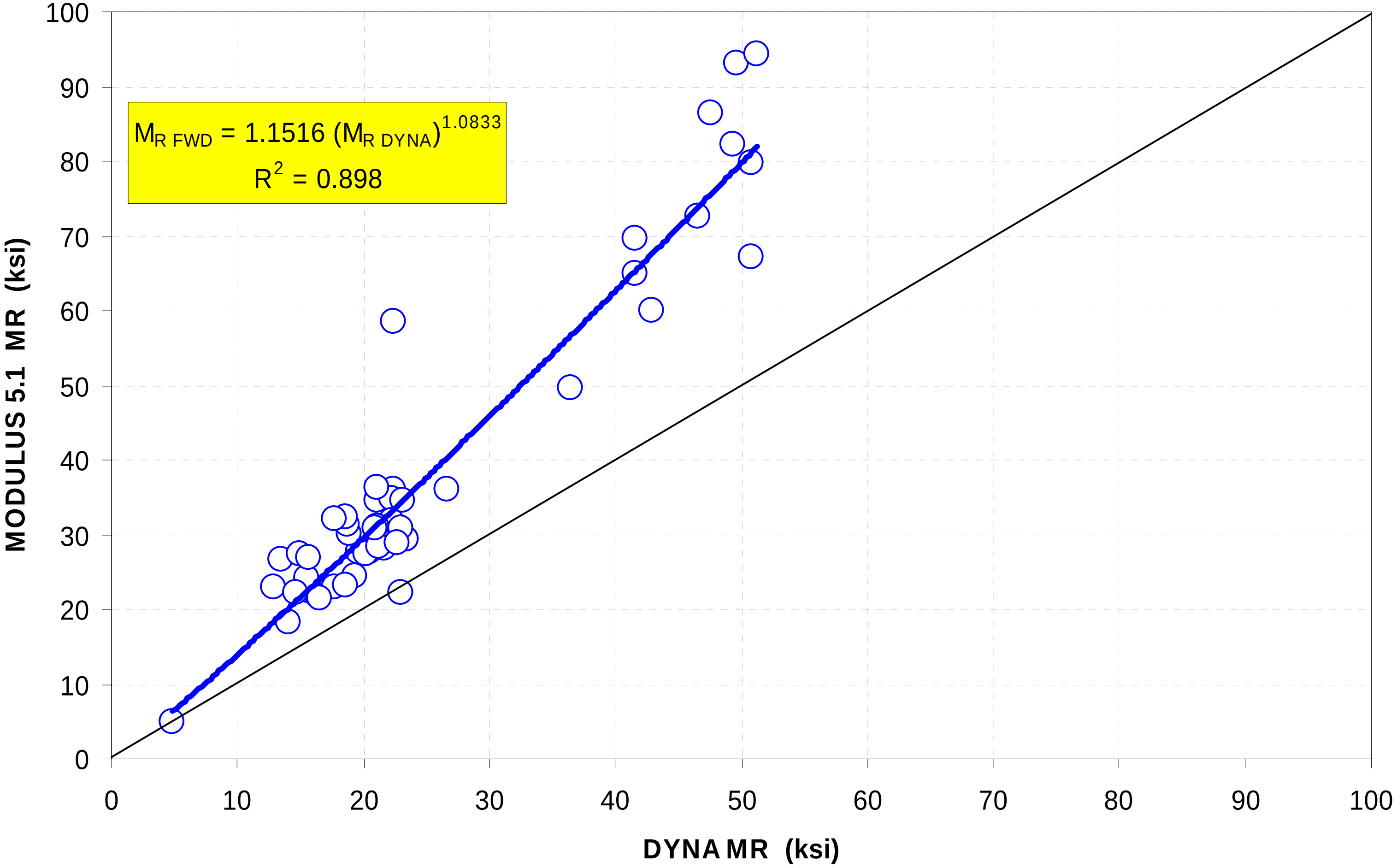


Figure 4.32 Chart for Resilient Modulus values from FWD using Modulus 5.1vs. Dynaflect for 300 miles obtained from LTPP data

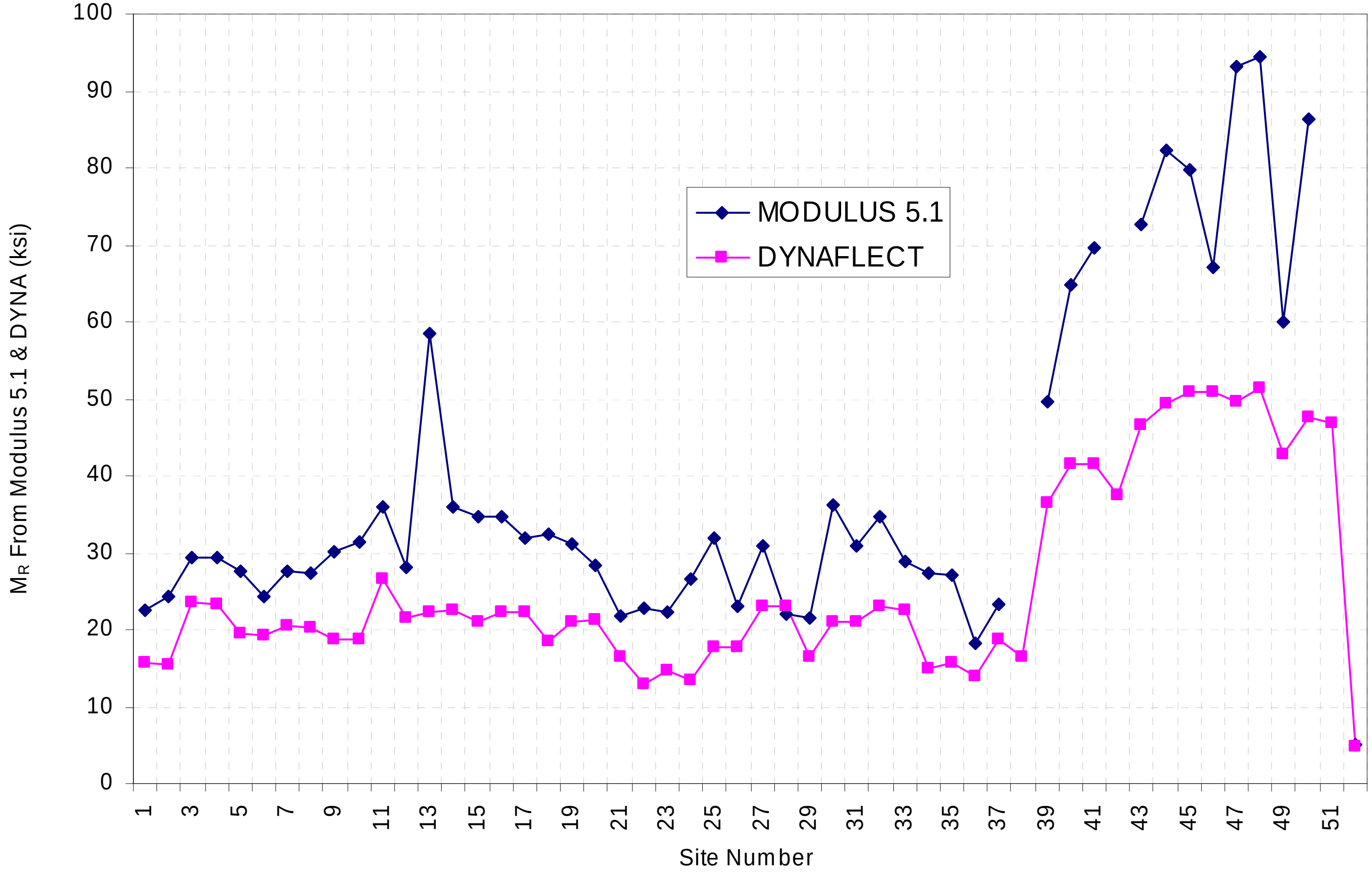


Figure 4.33 Chart for Resilient Modulus from FWD (EVERCALC) and DYNAFLECT for 300 miles

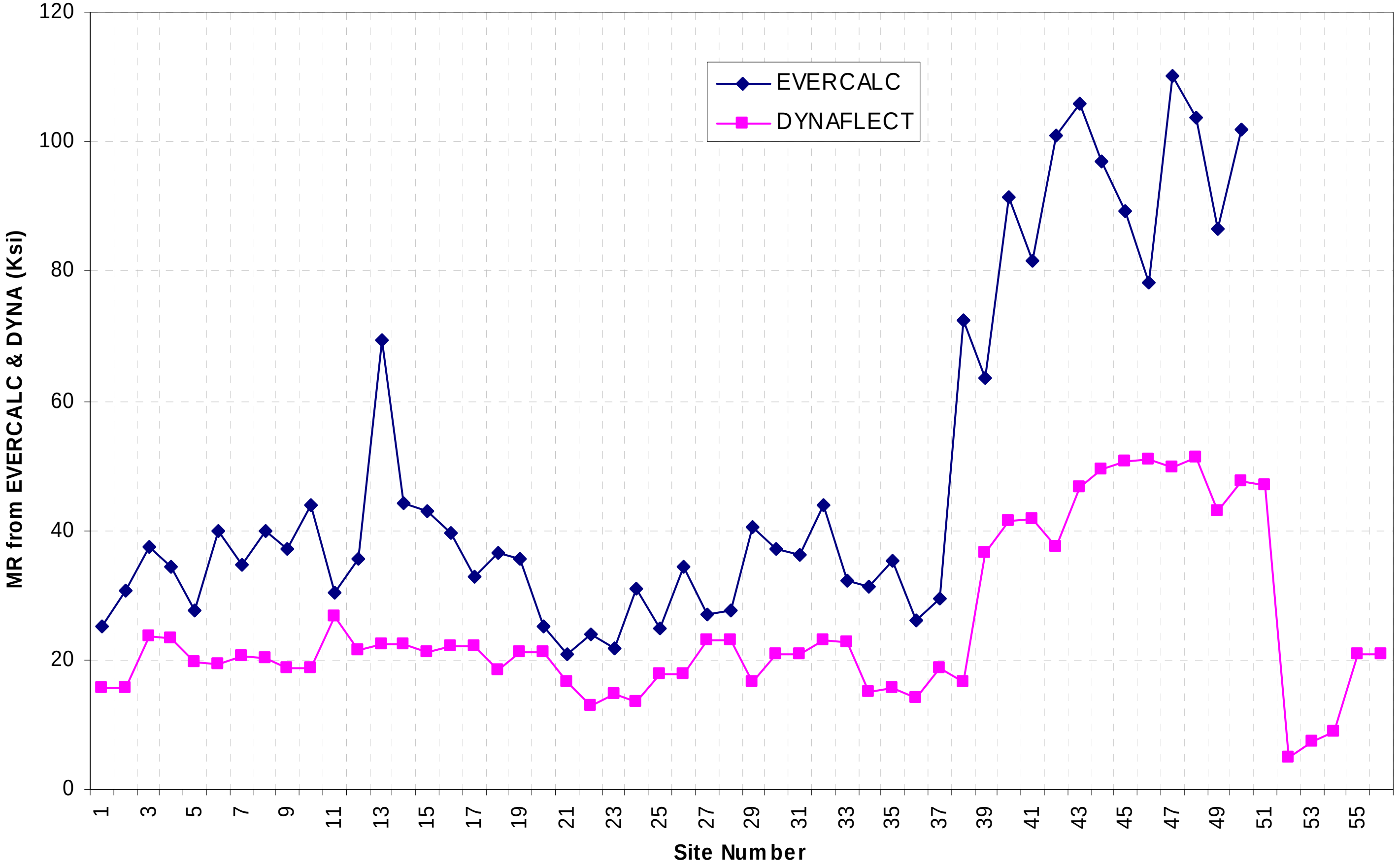


Figure 4.34 Correlation of Resilient Modulus Values between AASHTO vs. FWD (MODULUS5.1) for 300 miles

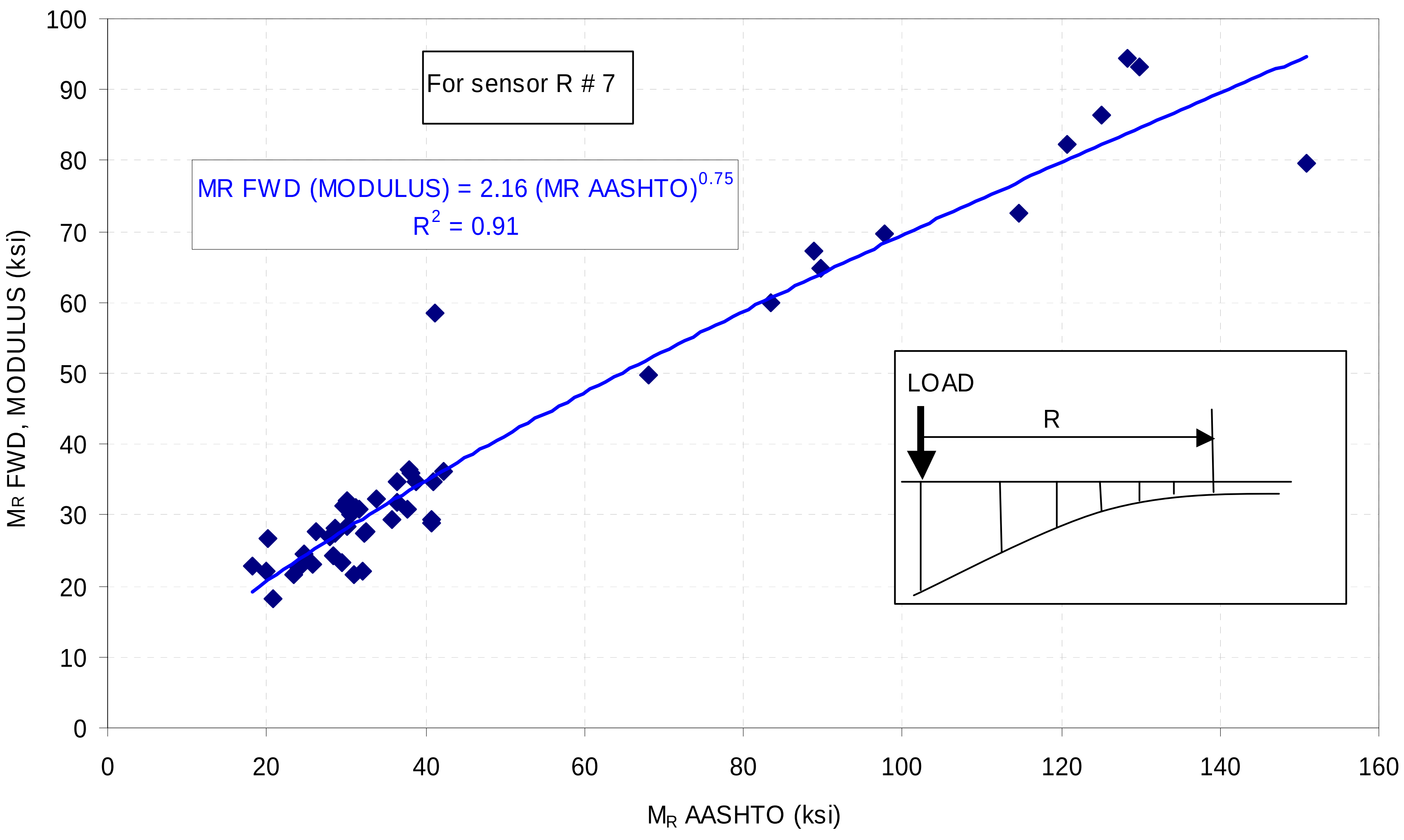


Figure 4.35 Correlation of Resilient Modulus Values between AASHTO vs. FWD (EVERCALC) for 300 miles

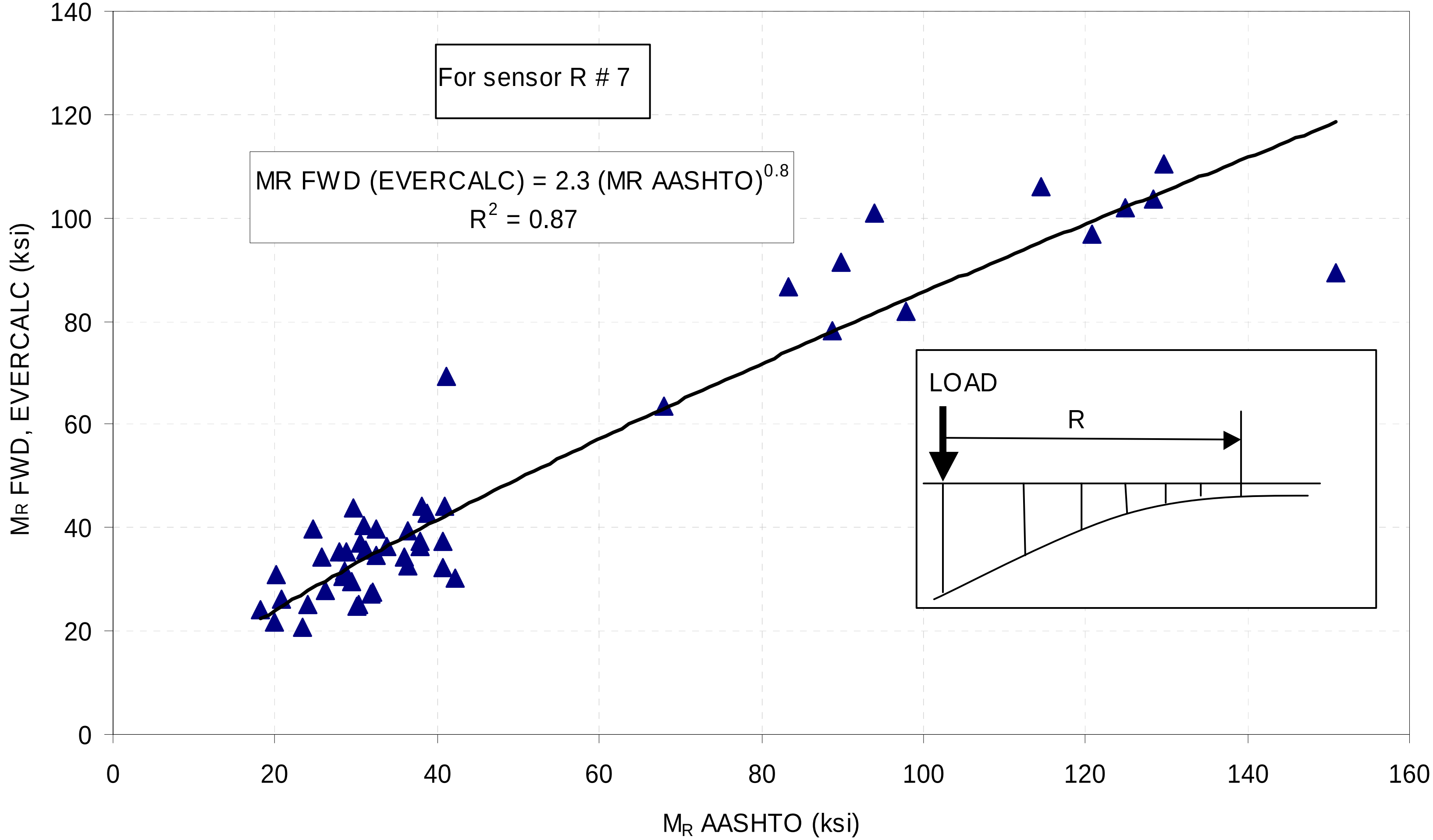


Figure 4.36 Correlation of Resilient Modulus Values between AASHTO vs. FWD (EVERCALC) for 300 miles

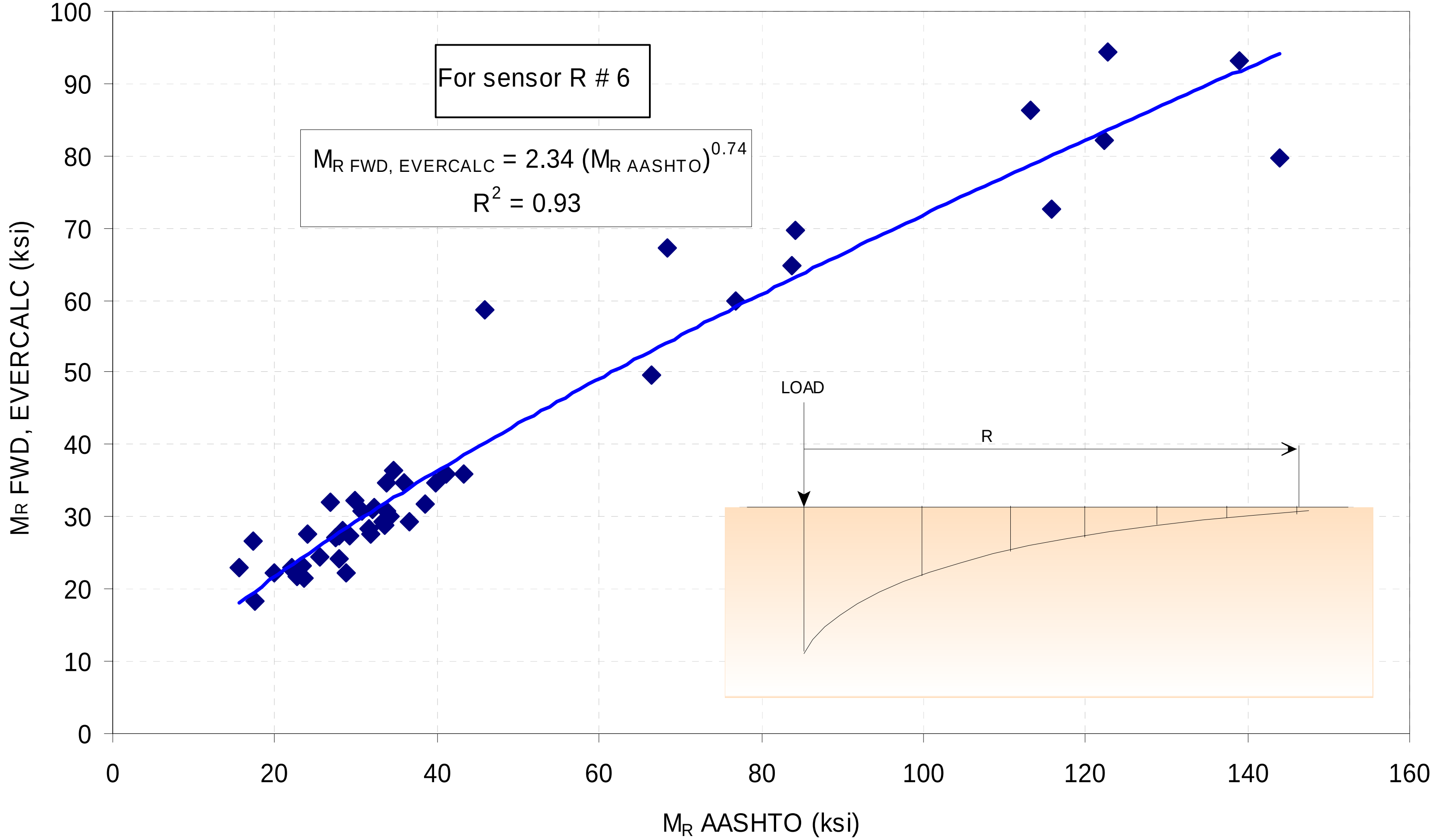


Figure 4.37 Chart for MODULUS, AASHTO & DYNAFLECT for 300 miles

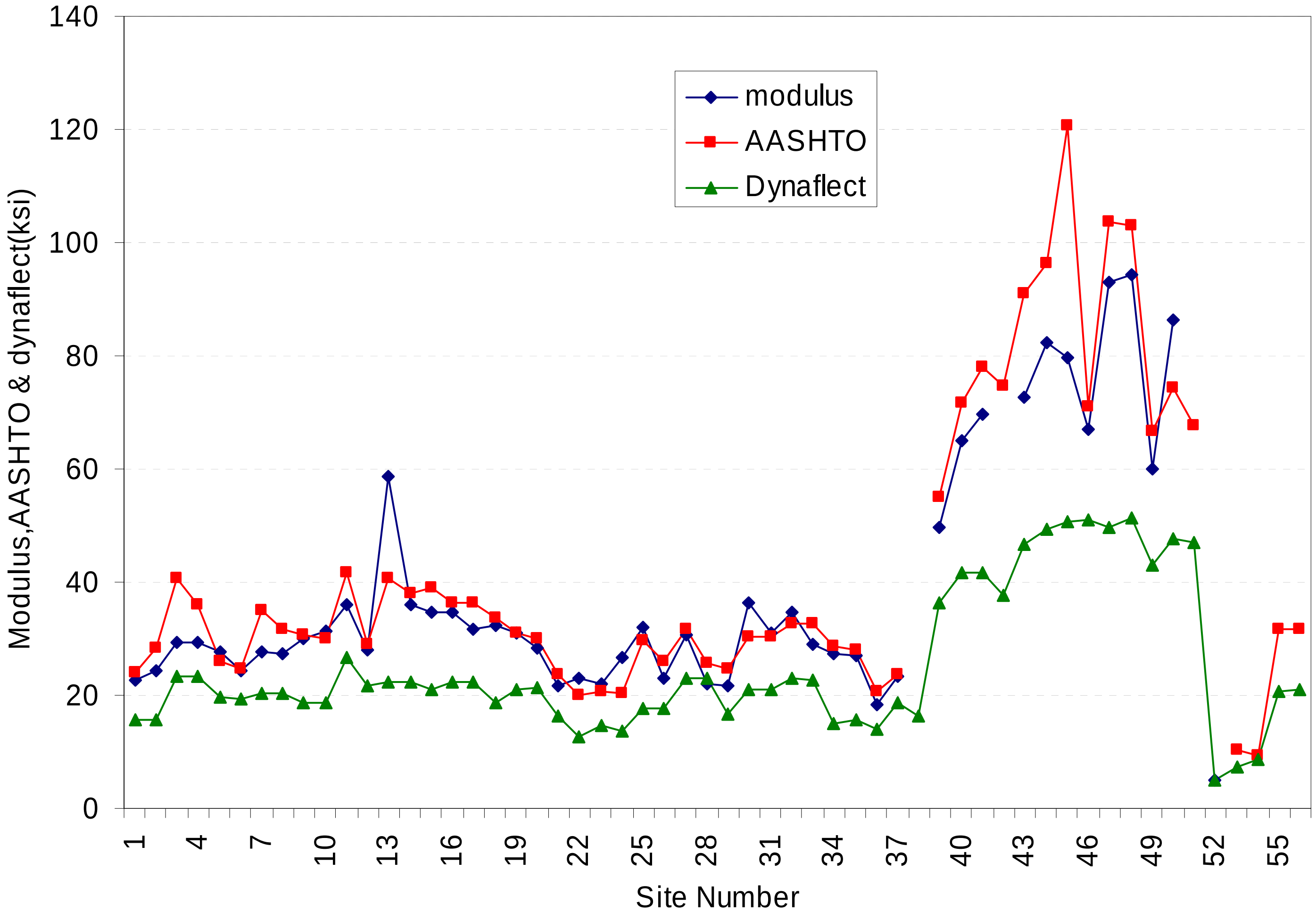


Figure 4.38 Modulus,Evercalc and AASHTO resilient modulus vs Dynaflect for 300 miles sections

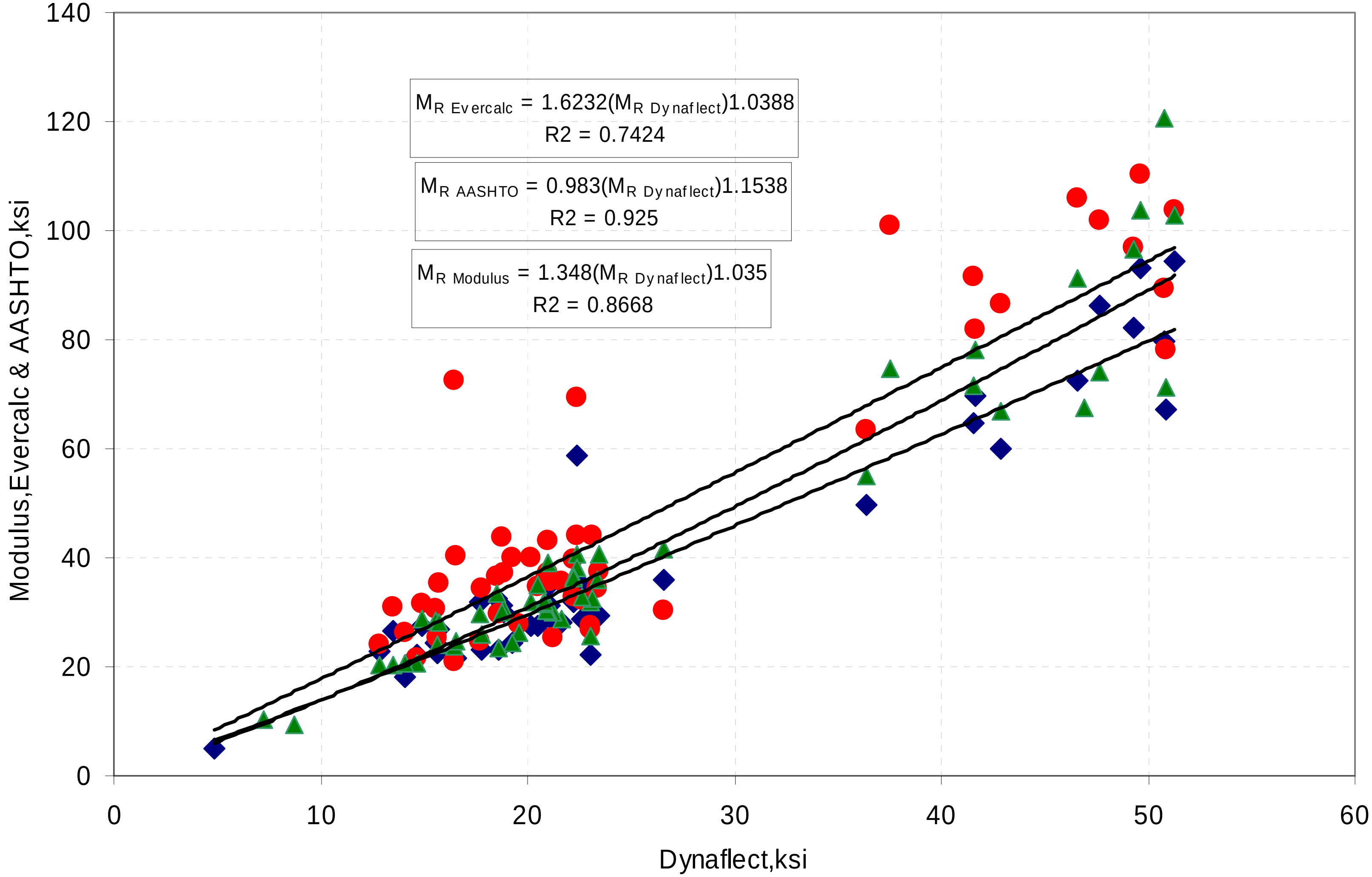
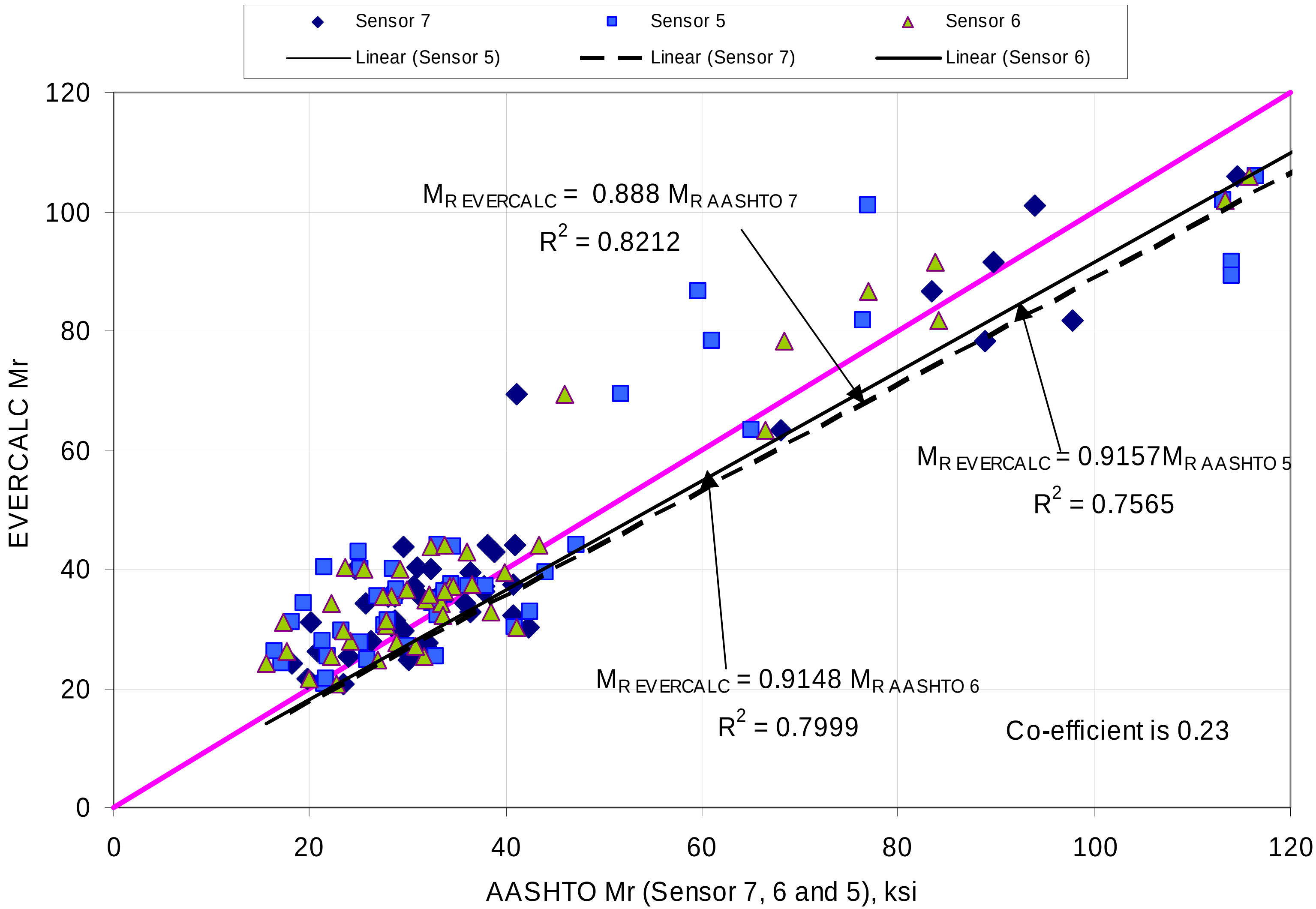


Figure 4.39 AASHTO Mr based on d7 d6, d5 vs. EVERCALC



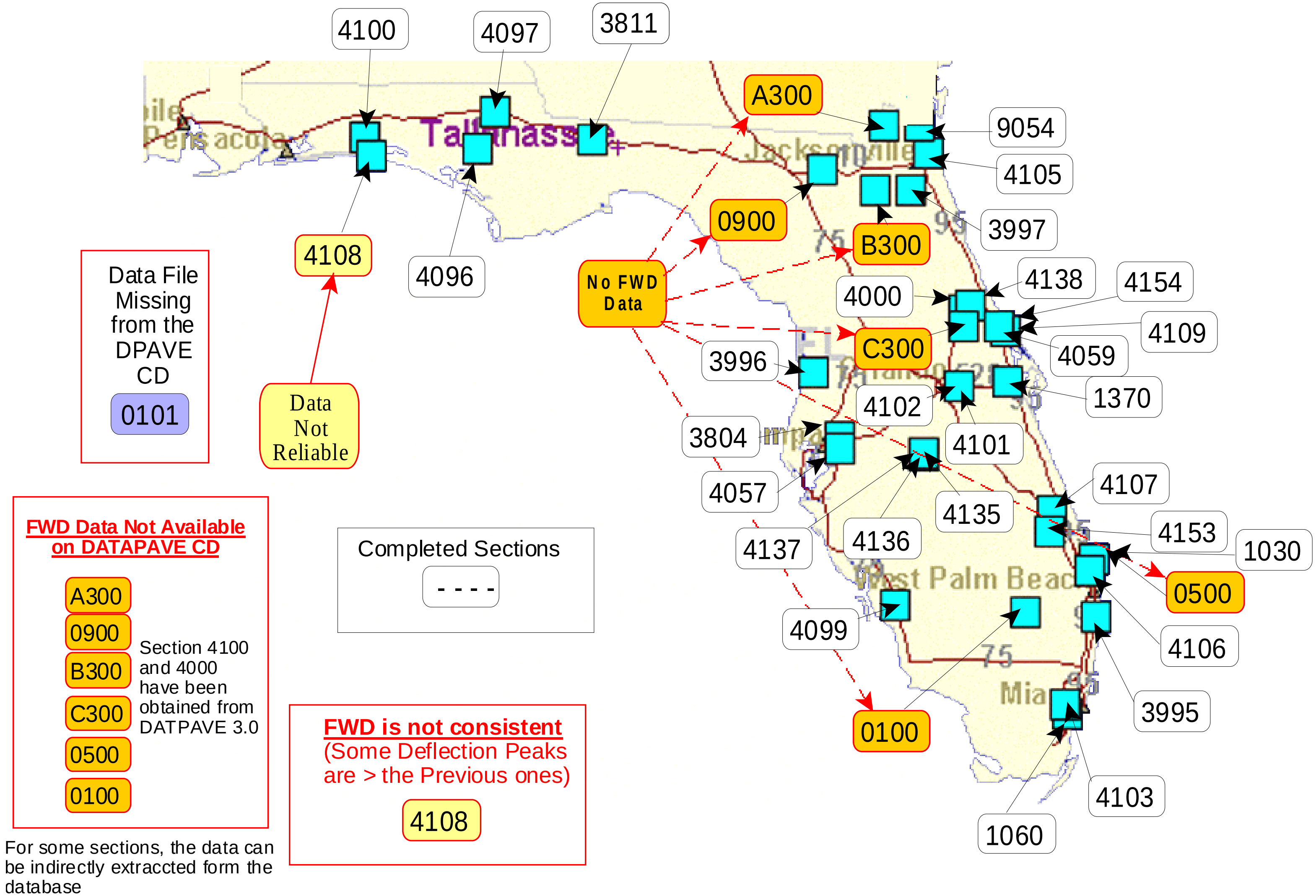


Figure 4.40 LTPP road sections used in this study

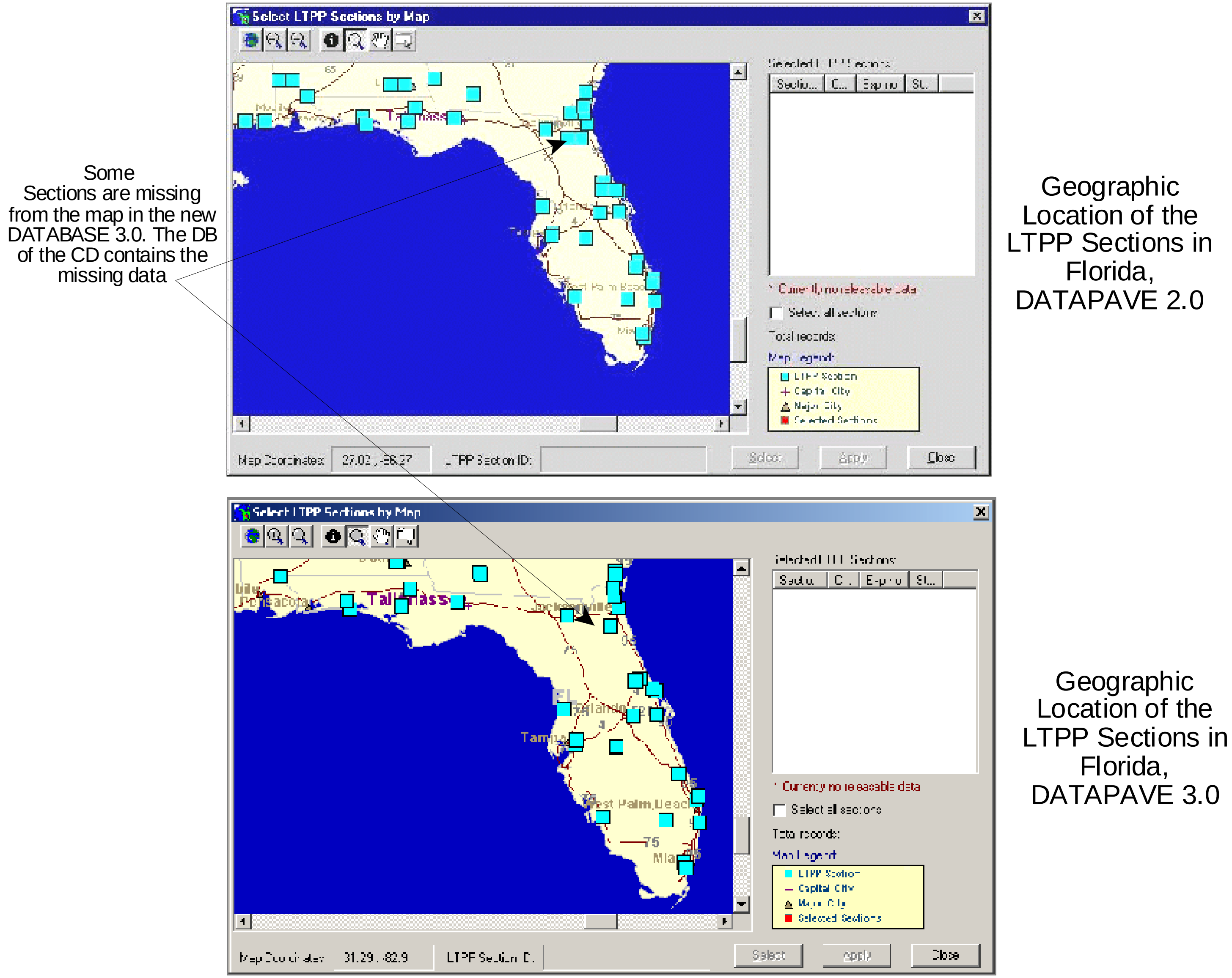
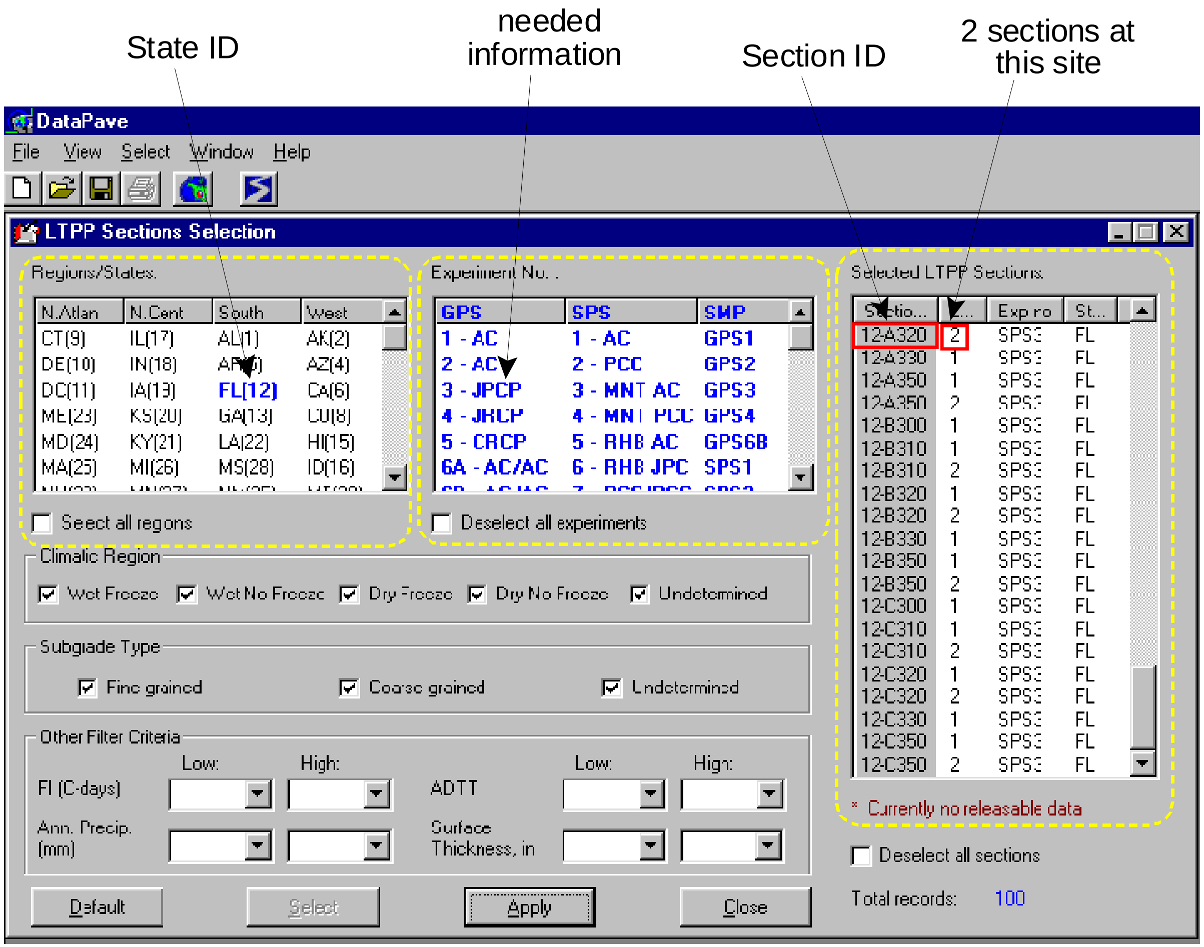


Figure 4.41 Interface of DATA PAVE 2.0



Figur 4.42 Data Pave Selection of the LTPP by State (Florida =12) and by Section ID

File Names of the LTPP Database

12-1030	12-4154	12-0501	12-B320
12-1060	12-9054	12-0502	12-B330
12-1370	12-0100	12-0502	12-B350
12-3804	12-0101	12-0503	12-B350
12-3811	12-0102	12-0503	12-0300
12-3995	12-0103	12-0504	12-C310
12-3996	12-0104	12-0504	12-C310
12-3997	12-0105	12-0505	12-0320
12-3997	12-0106	12-0505	
12-4000	12-0107	12-0506	
12-4051	12-0108	12-0506	
12-4059	12-0109	12-0547	
12-4096	12-0110	12-0507	
12-4097	12-0111	12-0508	
12-4099	12-0112	12-0508	
12-4100	12-0500	12-0509	
12-4101	12-0501	12-0509	
12-4101	12-0502	1 2-0900*	
12-4102	12-0502	12-0901*	
12-4103	12-0503	12-0901*	
12-4105	12-0503	12-0902*	
12-4106	12-0504	12-0902*	
12-4107	12-0504	12-0903*	
12-4108	12-0505	12-0903*	
12-4109	12-0102	12-A300	
12-4135	12-0103	12-A310	
12-4135	12-0104	12-A310	
12-4135	12-0105	12-A320	
12-4136	12-0106	12-A320	
12-4136	12-0107	12-A330	
12-4136	12-0108	12-A350	
12-4137	12-0109	12-A350	
12-4137	12-0110	12-B300	
12-4137	12-0111	12-B310	
12-4138	12-0112	12-8310	
12-4153	12-0500	12-B320	

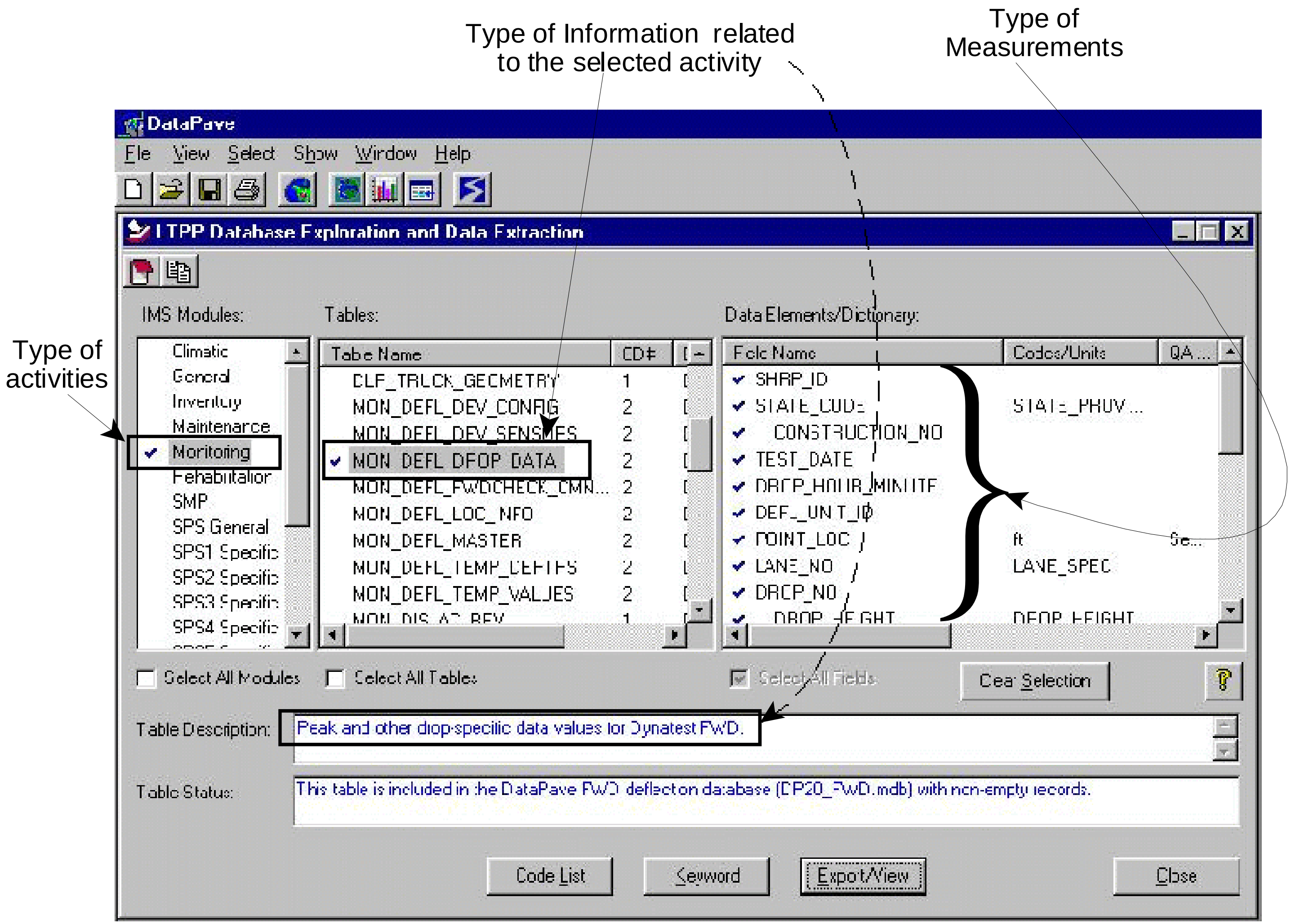


Figure 4.43   LTPP activities for the selected section

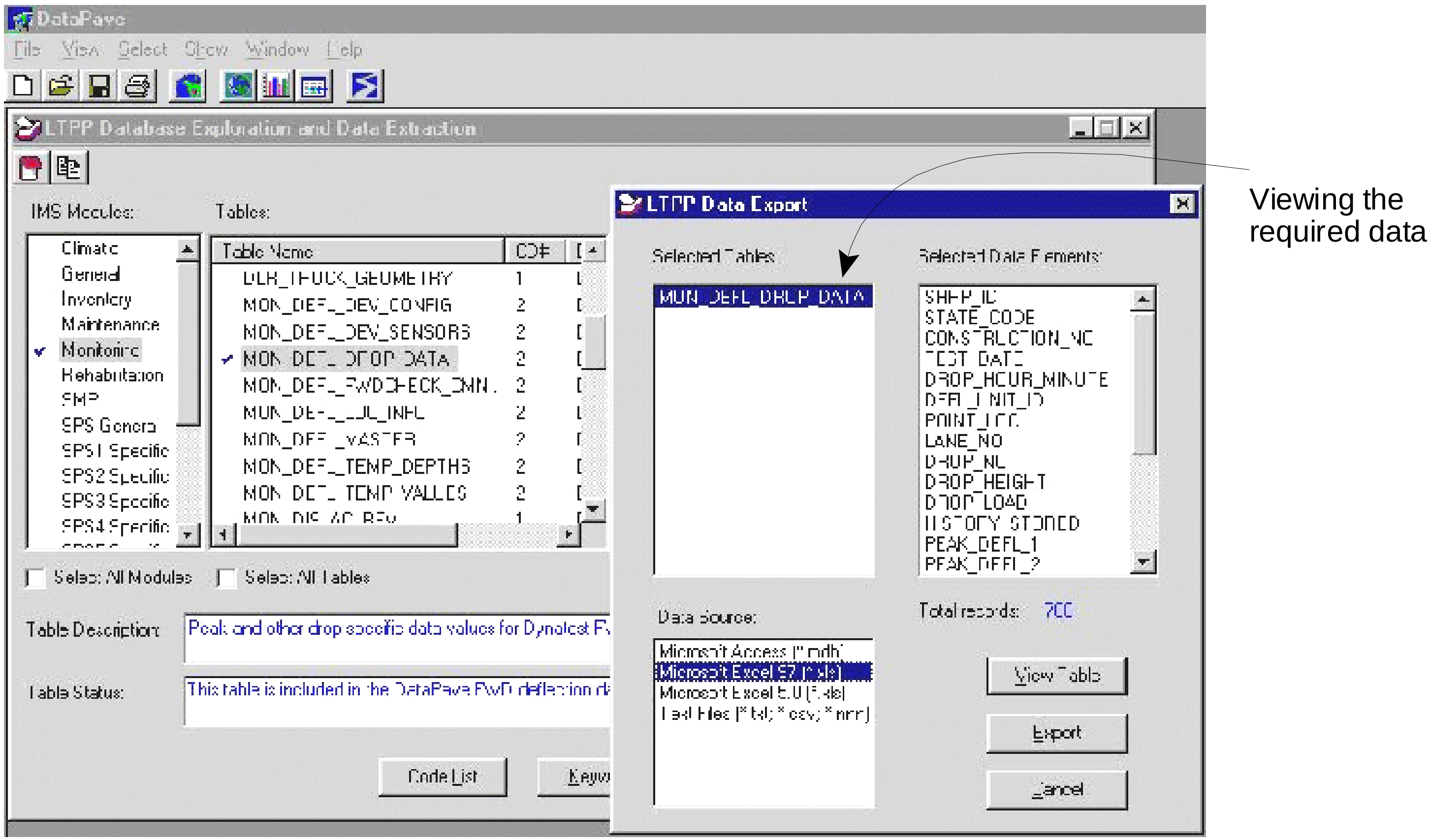


Figure 4.44 Viewing or exporting the data base

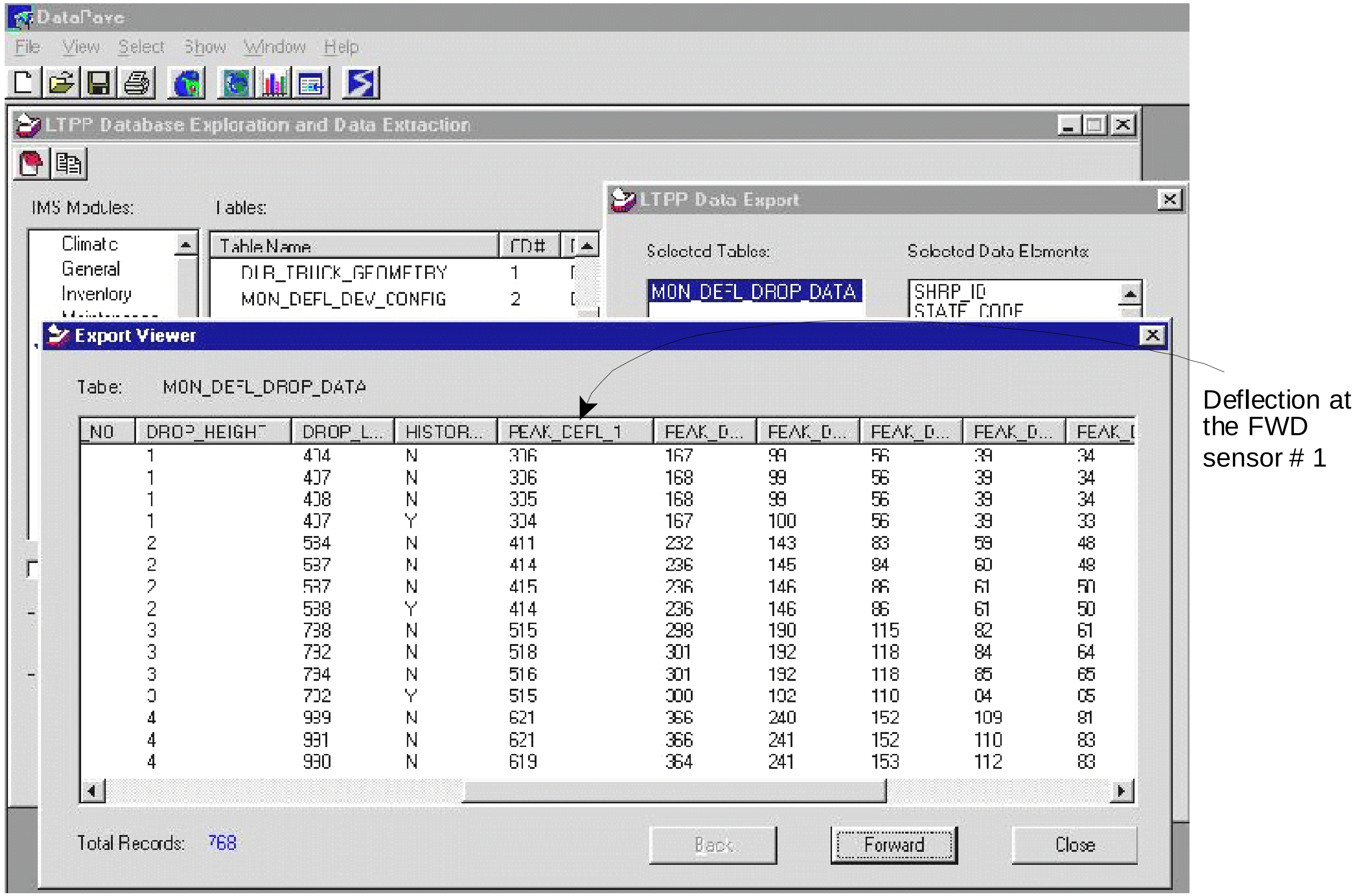


Figure 4.45 Viewing data base file for the selected section

Figure 4.46 Deflection of Sensor # 1 for LTPP Section 4097

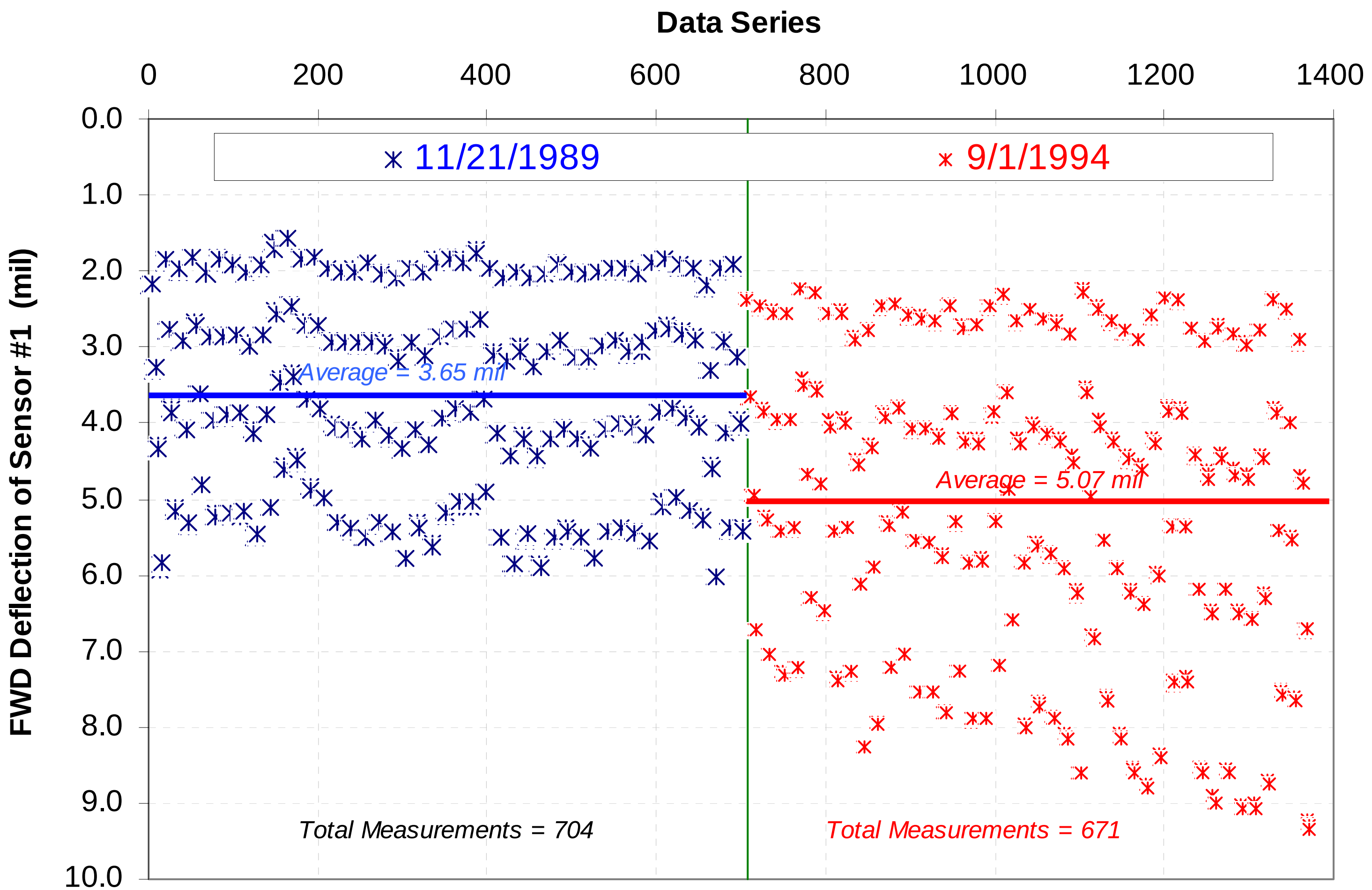


Figure 4.47 Deflection of Sensor # 7 for LTPP Section 4097

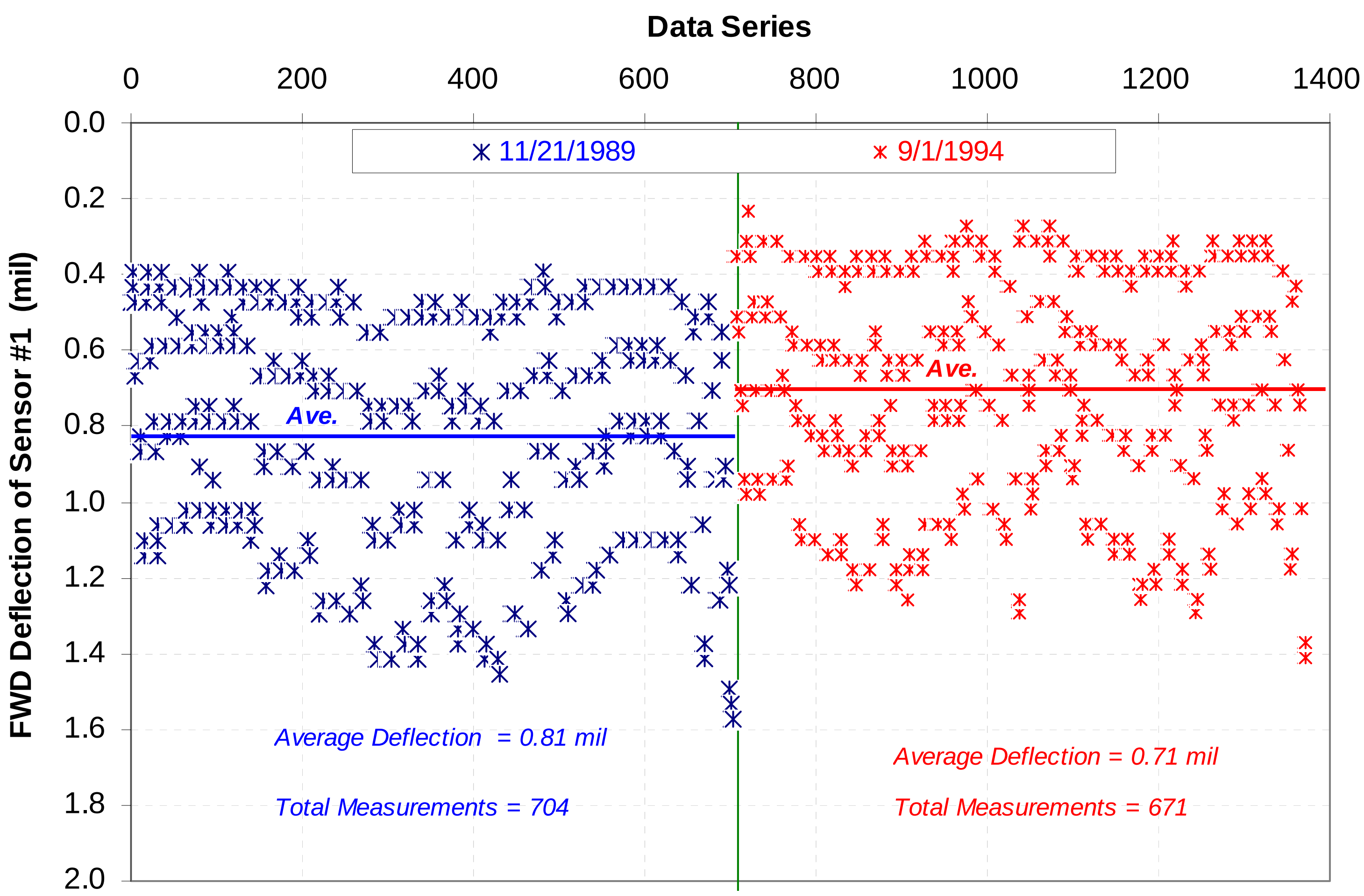


Figure 4.48 Maximum and Minimum Deflections at LTPP Section 4097

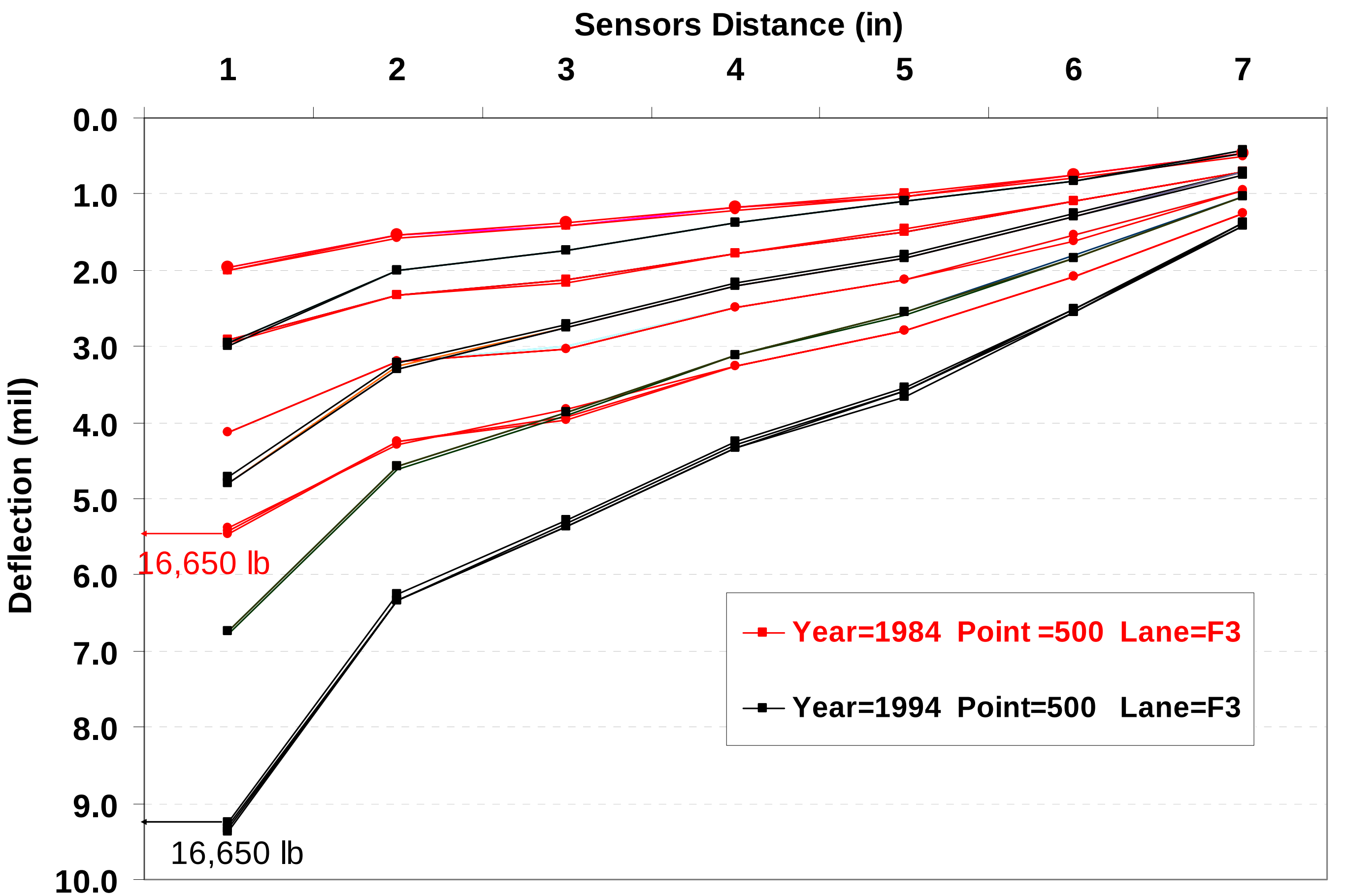


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Figure 4.49 Maximum and Minimum Deflections at LTPP Section 4097

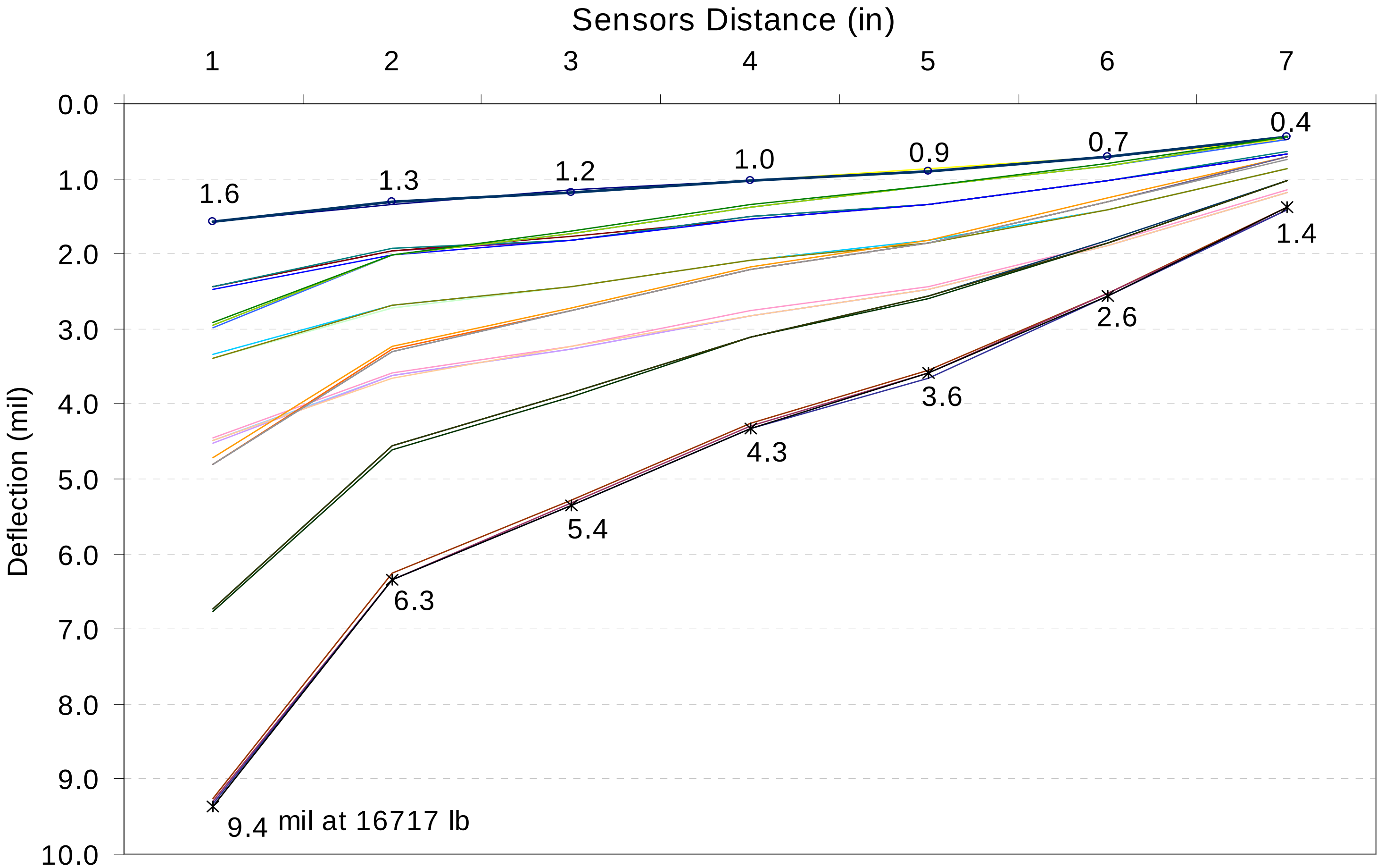
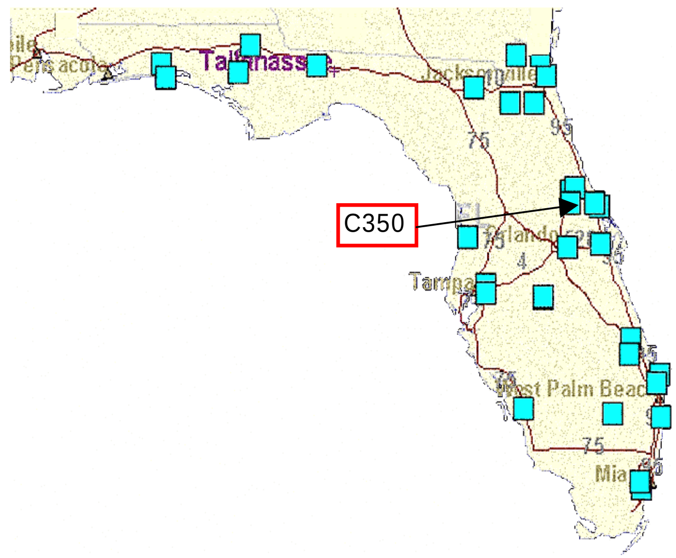


Figure 4.50 Subgrade Modulus (M_R) for LTPP Section # C350

County: VOLUSIA
Route Number: 442
Org. Construction Date: .....
Latitude (deg.) = 28.95
Longitude (deg.) = 80.94
Elevation (ft) = 11
Avg. Daily Truck Traffic = 119
Days above 90 (F) = 66
Precipitation (inch) = 1338.9



Layers

1-Original Surface Layer (Layer type: AC) 1.3 inch
Hot Mixed, Hot Laid AC, Dense Graded
2- Base Layer (Layer type: GB) 8.8 inch
Fine-grained Soils
3- Subgrade (Layer type: SS)
Coarse-Grained Soils: Poorly Graded Sand with Silt

Figure 4.51 Average Subgrade Modulus (M_R) for LTPP Section # C350

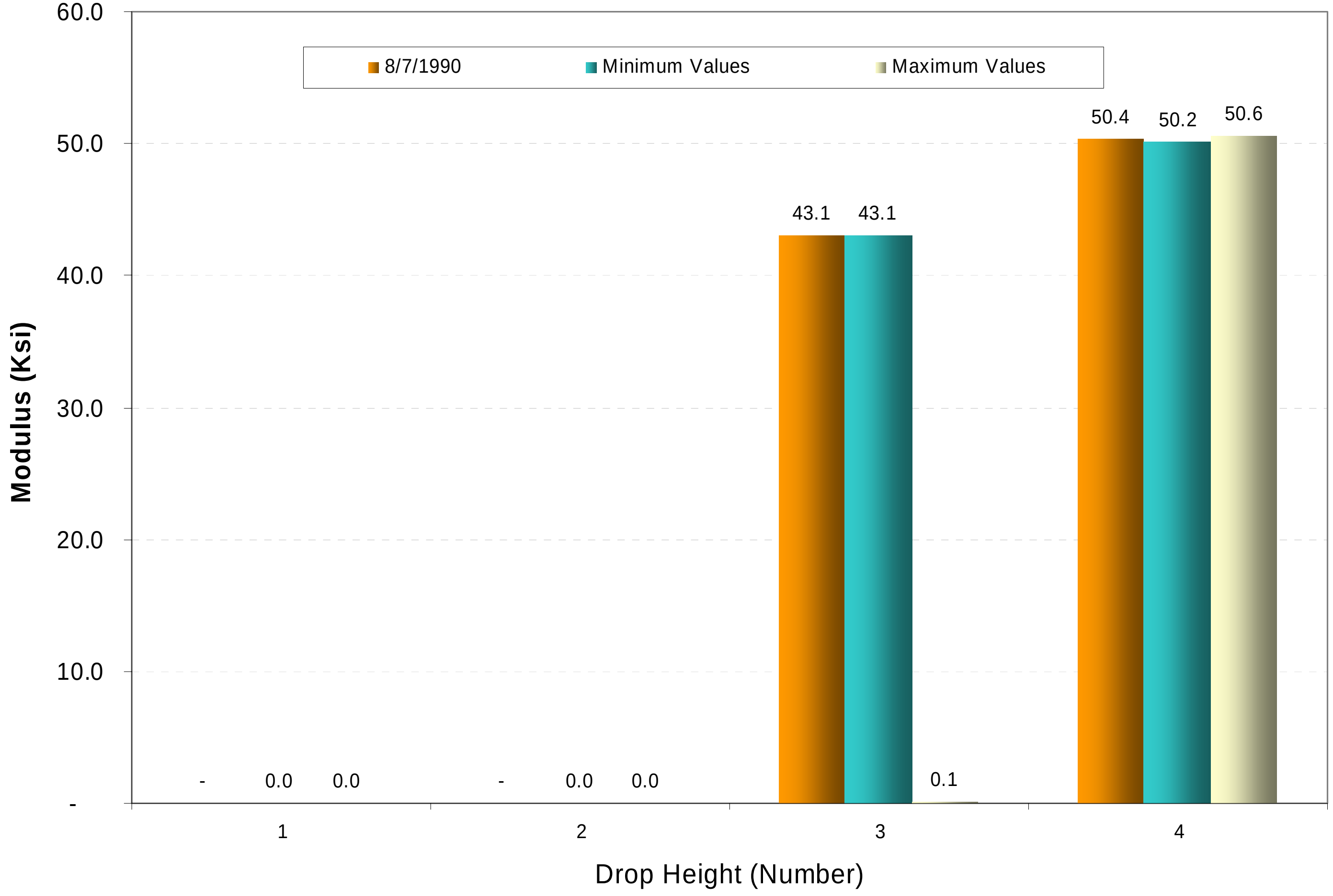
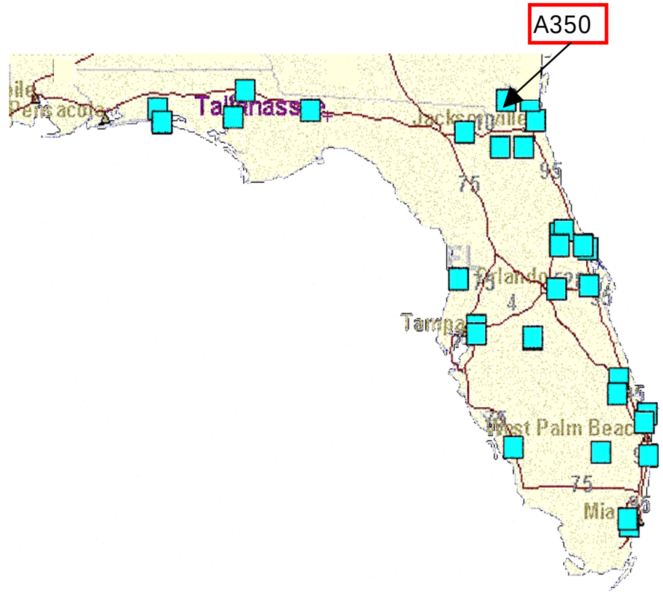


Figure 4.52 Subgrade Modulus (M_R) for LTPP Section # A350



County: NASSAU
Route Number: 200
Org. Construction Date:
Latitude (deg.) = 30.62
Longitude (deg.) = 81.63
Elevation (ft) = 25
Avg. Daily Truck Traffic = 476
Days above 90 (F) = 55
Precipitation (inch) = 1311.5

Layers
1-Original Surface Layer (Layer type: AC) 2.5 inch
Hot Mixed, Hot Laid AC, Dense Graded
2- Base Layer (Layer type: GB) 10 inch
Limerock, Caliche
3- Subbase Layer (Layer type: GS) 12 inch
Fine-grained Soils
4- Subgrade (Layer type: SS)
Coarse-Grained Soils: Poorly Graded Sand

This section has the same properties as LTTP Section A330

Figure 4.53 Average Subgrade Modulus (M_R) for LTPP Section # A350

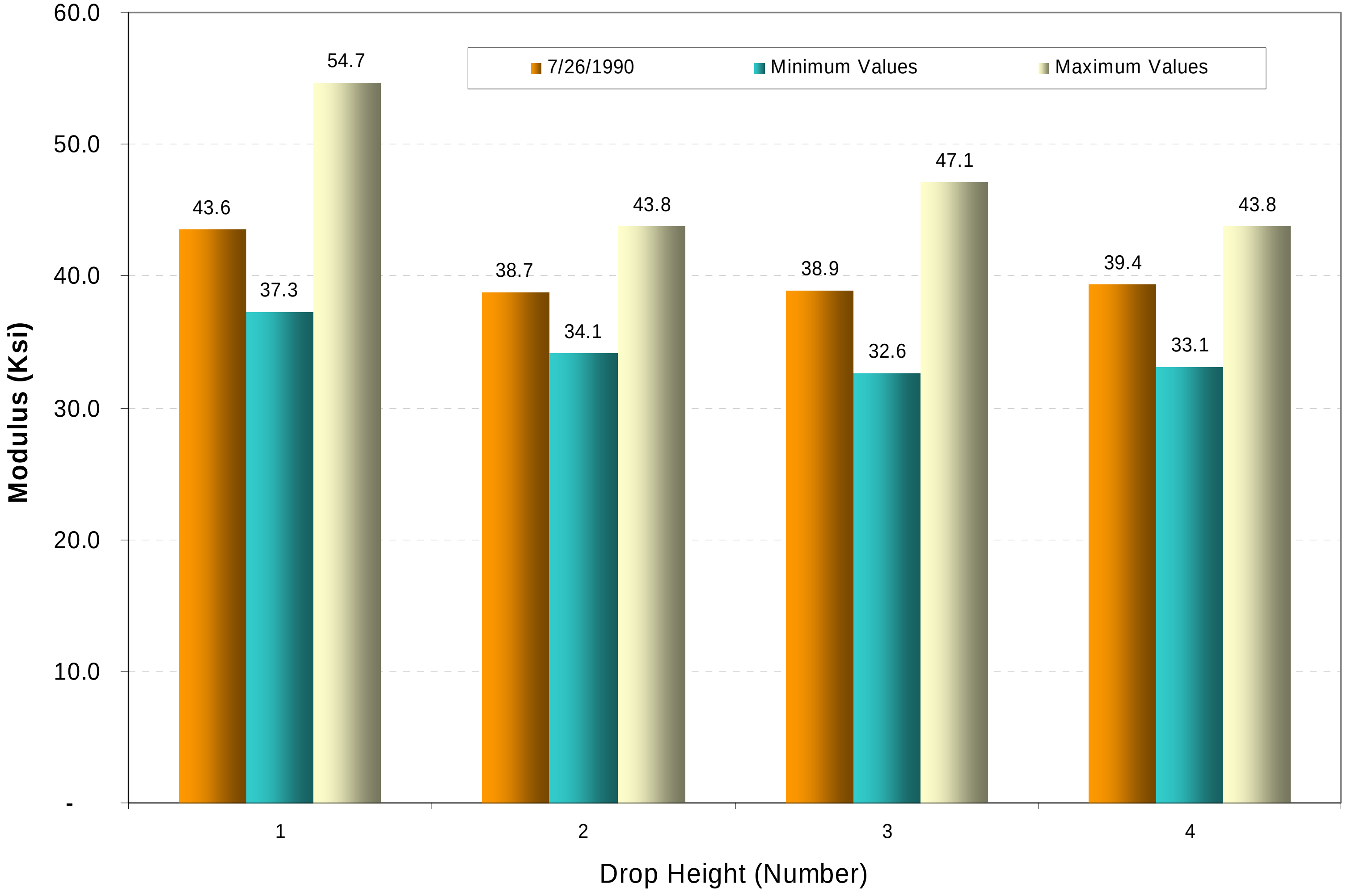


Figure 4.54 Subgrade Modulus (M_R) for LTPP Section # A330

County: NASSAU
Route Number: 200
Org. Construction Date:
Latitude (deg.) = 30.62
Longitude (deg.) = 81.63
Elevation (ft) = 25
Avg. Daily Truck Traffic = 476
Days above 90 (F) = 55
Precipitation (inch) = 1311.5

Layers

1-Original Surface Layer (Layer type: AC) 2.6 inch
Hot Mixed, Hot Laid AC, Dense Graded
2- Base Layer (Layer type: GB) 10 inch
Limerock, Caliche
3- Subbase Layer (Layer type: GS) 12 inch
Fine-grained Soils
4- Subgrade (Layer type: SS)
Coarse-Grained Soils: Poorly Graded Sand

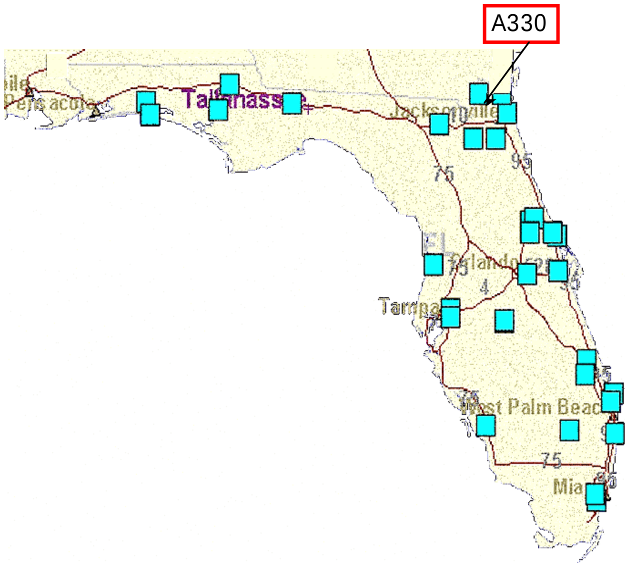


Figure 4.55 Average Subgrade Modulus (M_R) for LTPP Section # A330

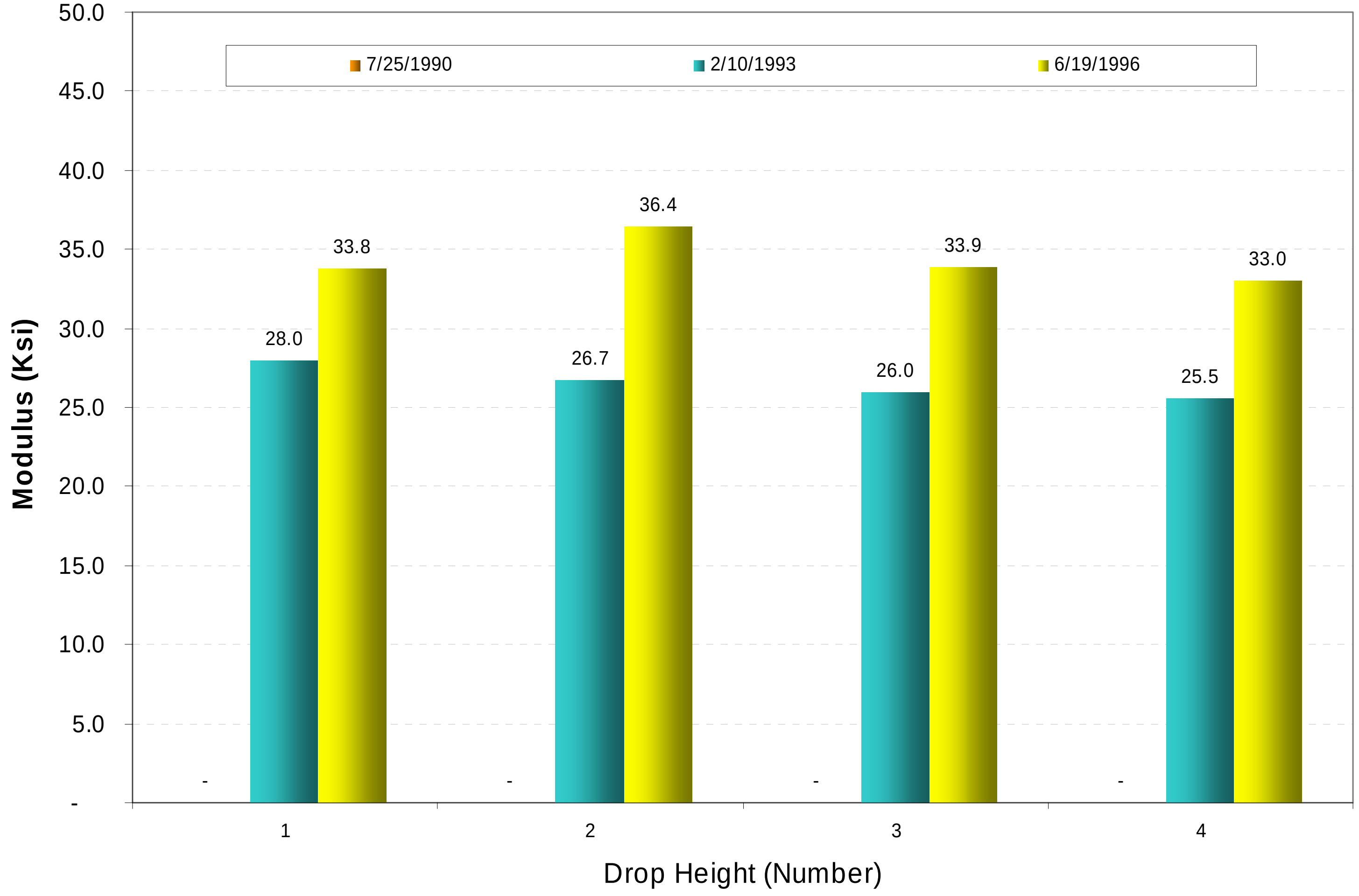


Figure 4.56 Minimum Subgrade Modulus (M_R) for LTPP Section # A330

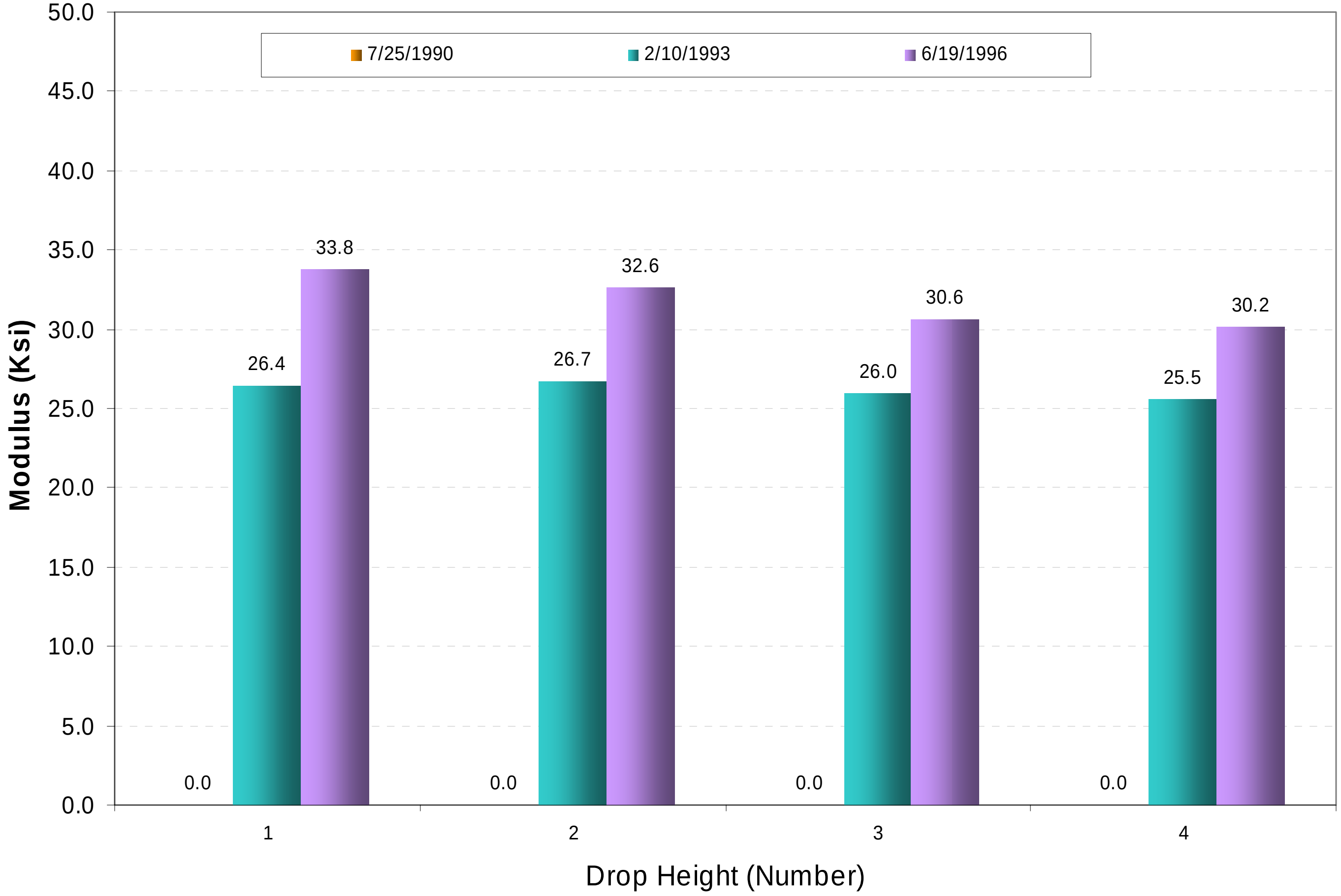


Figure 4.57 Maximum Subgrade Modulus (M_R) for LTPP Section # A330

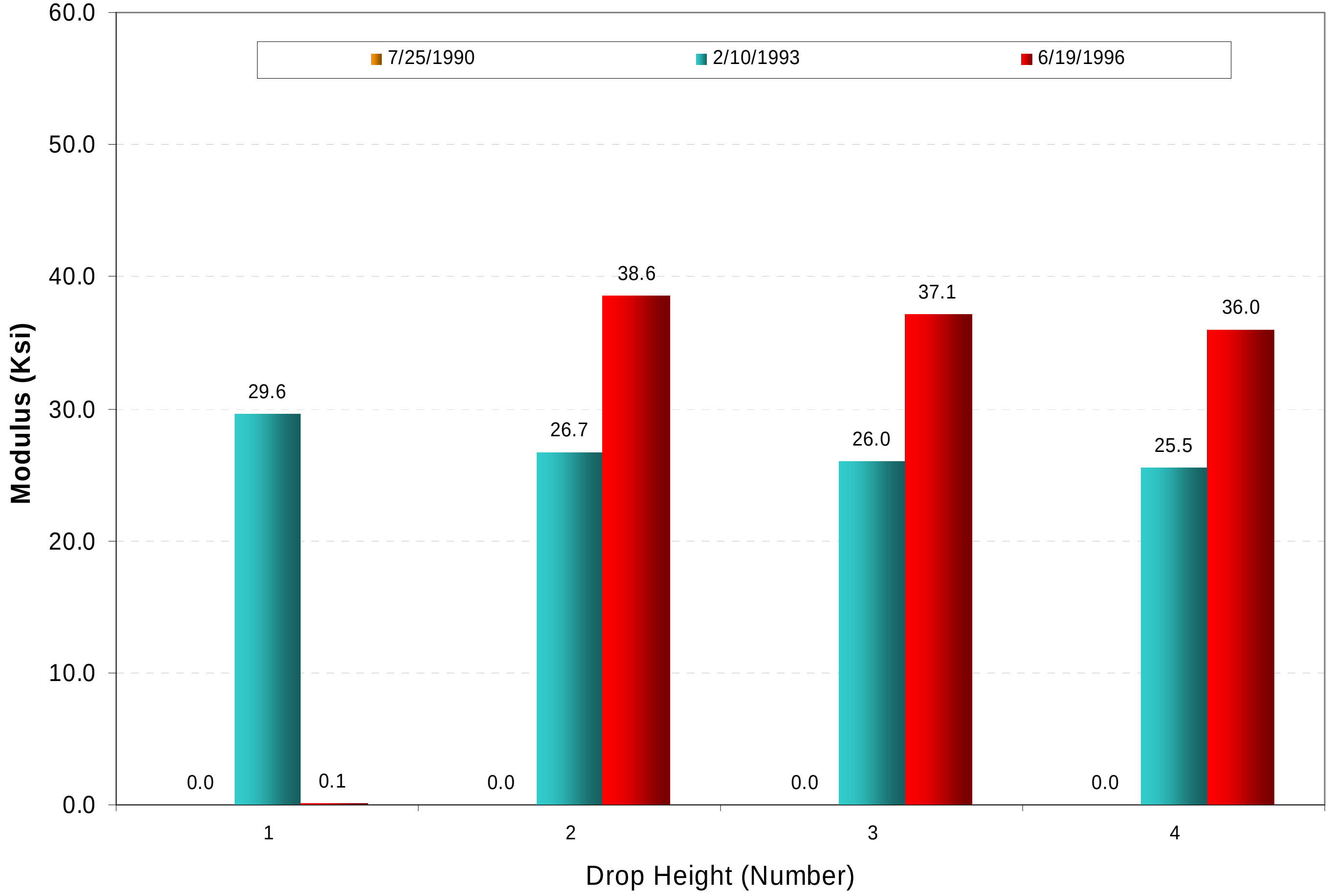


Figure 4.58 LTPP Backcalculated Subgrade Moudulus for Some Sections in Florida

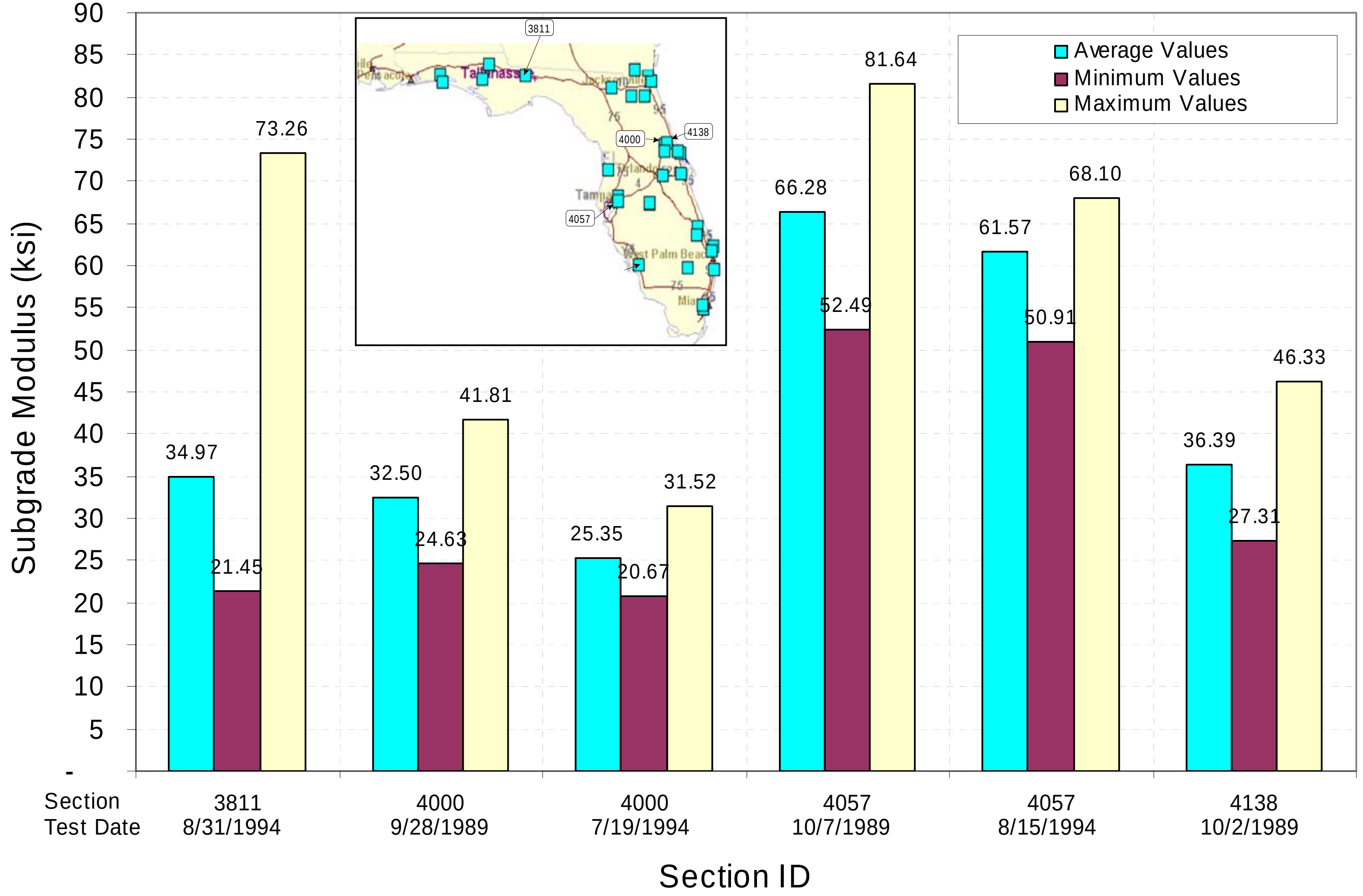


Figure 4.59 Average values of Subgrade Modulus (M_R) from LTPP Data Pave Section

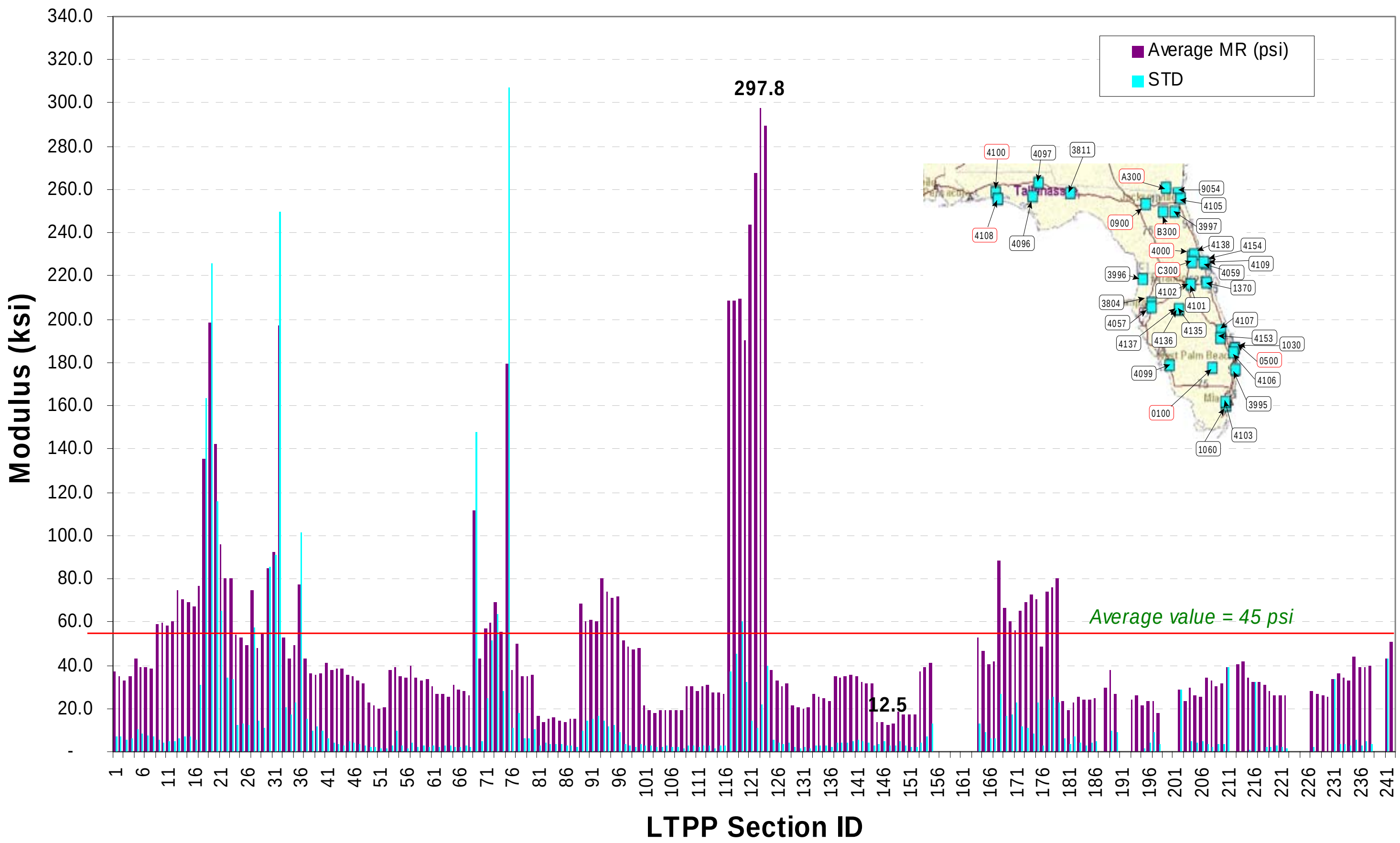


Figure 4.60 Minimum values of Subgrade Modulus (MR) from LTPP Data Pave Section

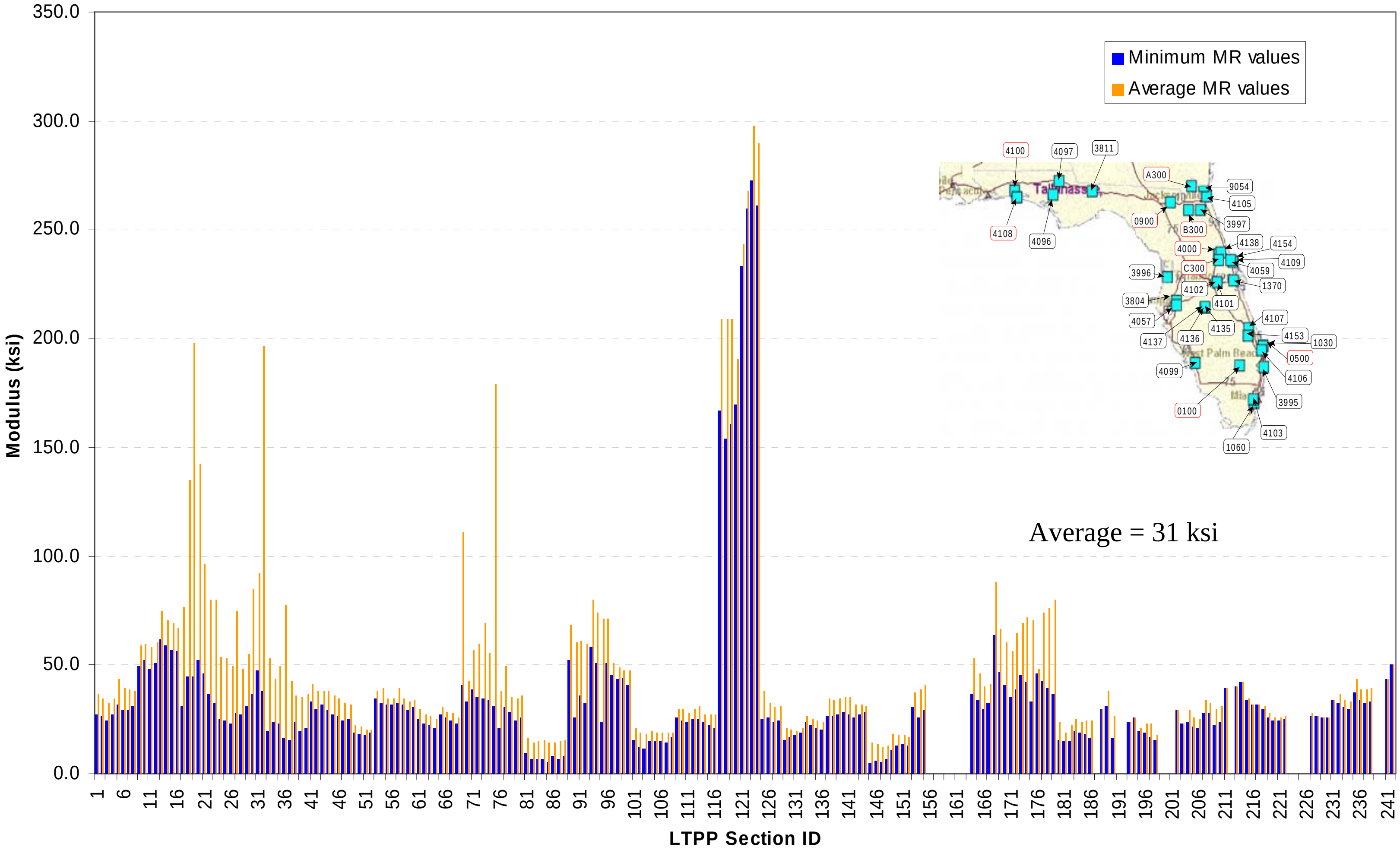


Figure 4.61 Maximum values of Subgrade Modulus (MR) from LTPP Data Pave Section

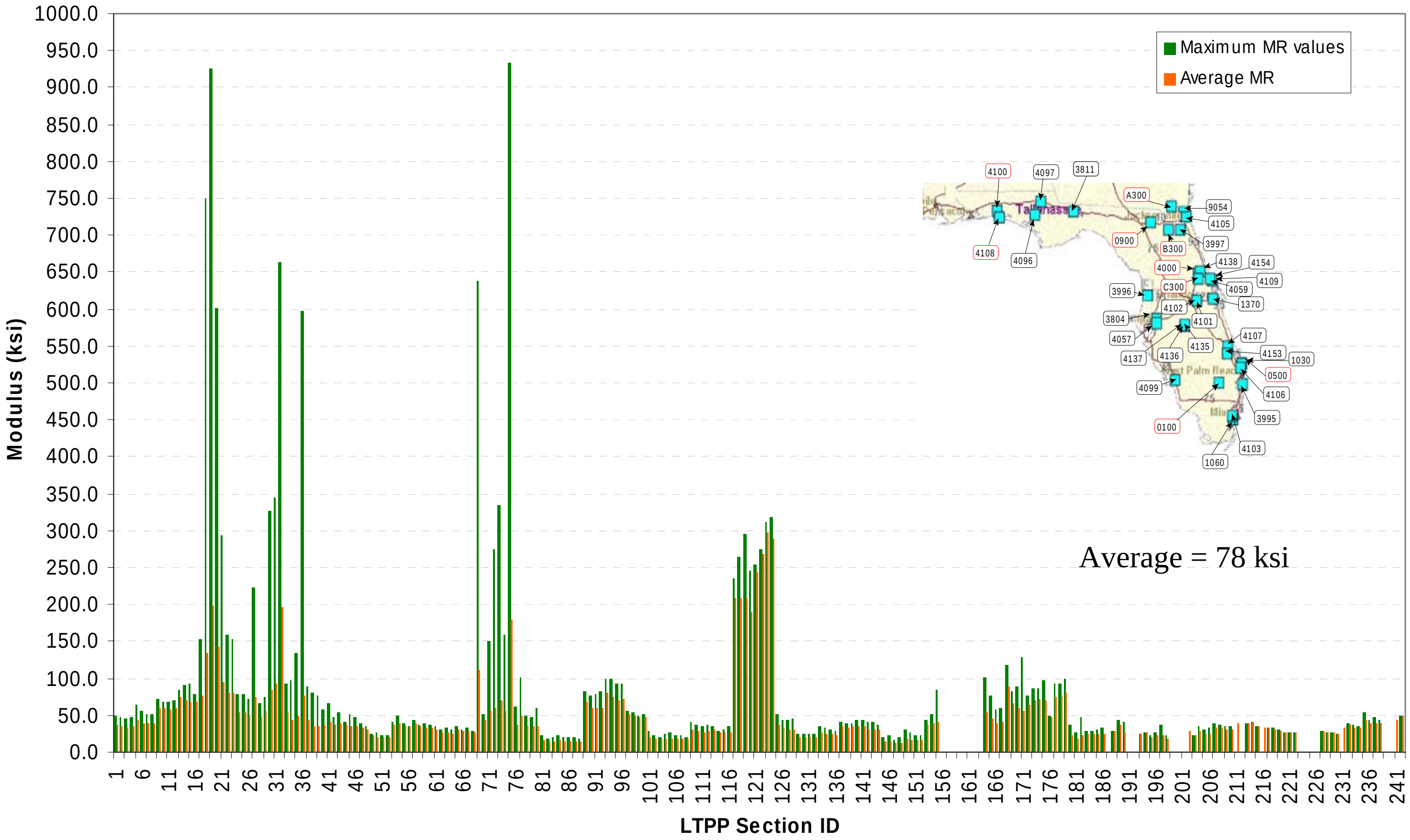


Figure 4.62 Moduli Values at LTPP Section # 3804

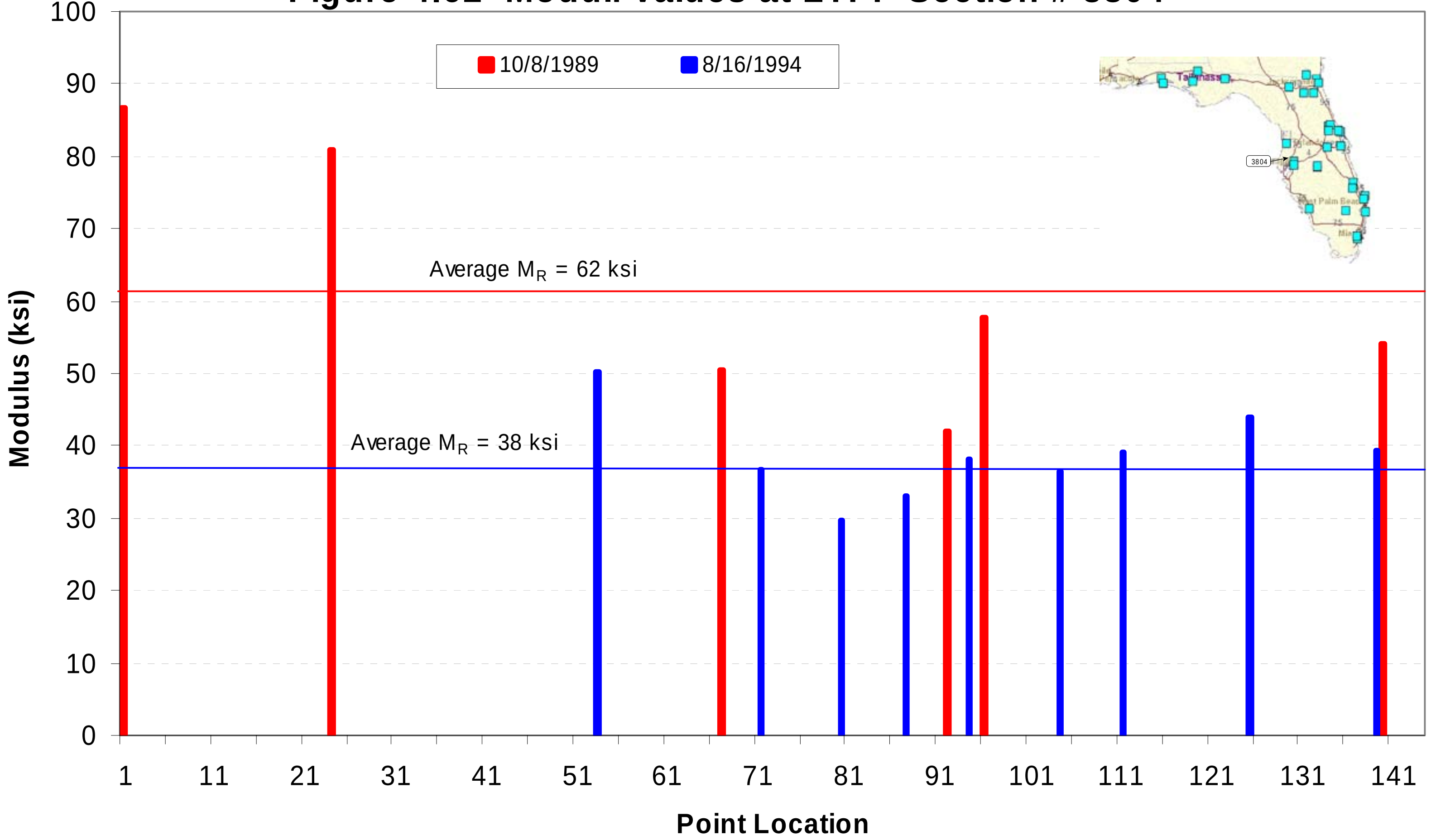


Figure 4.63 Backcalculated MR for LTPP Section 3811

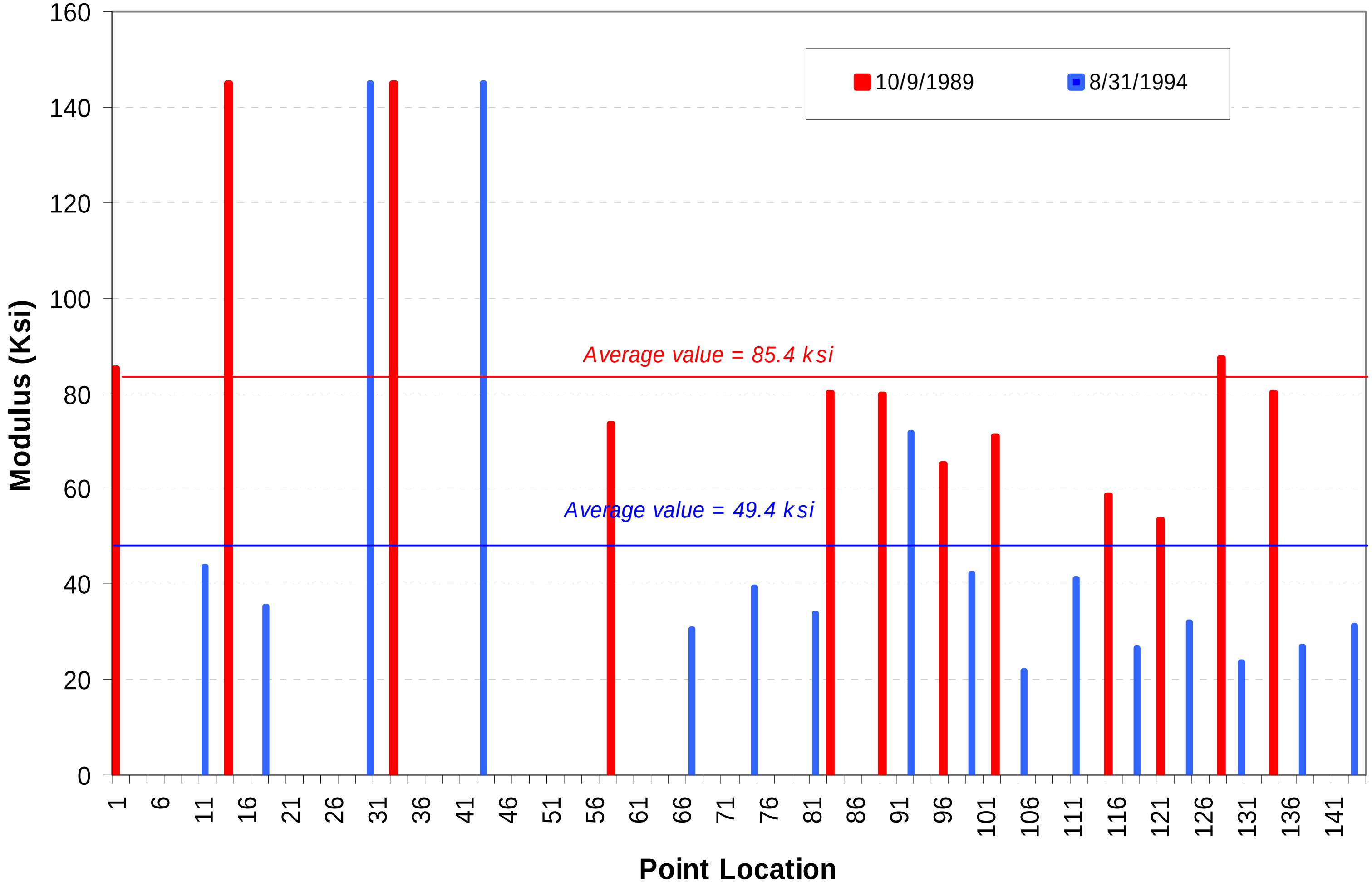


Figure 4.64 Lab MR vs Modulus,Evercalc & AASHTO backcalculation resilient modulus of 28 LTPP sections in Florida

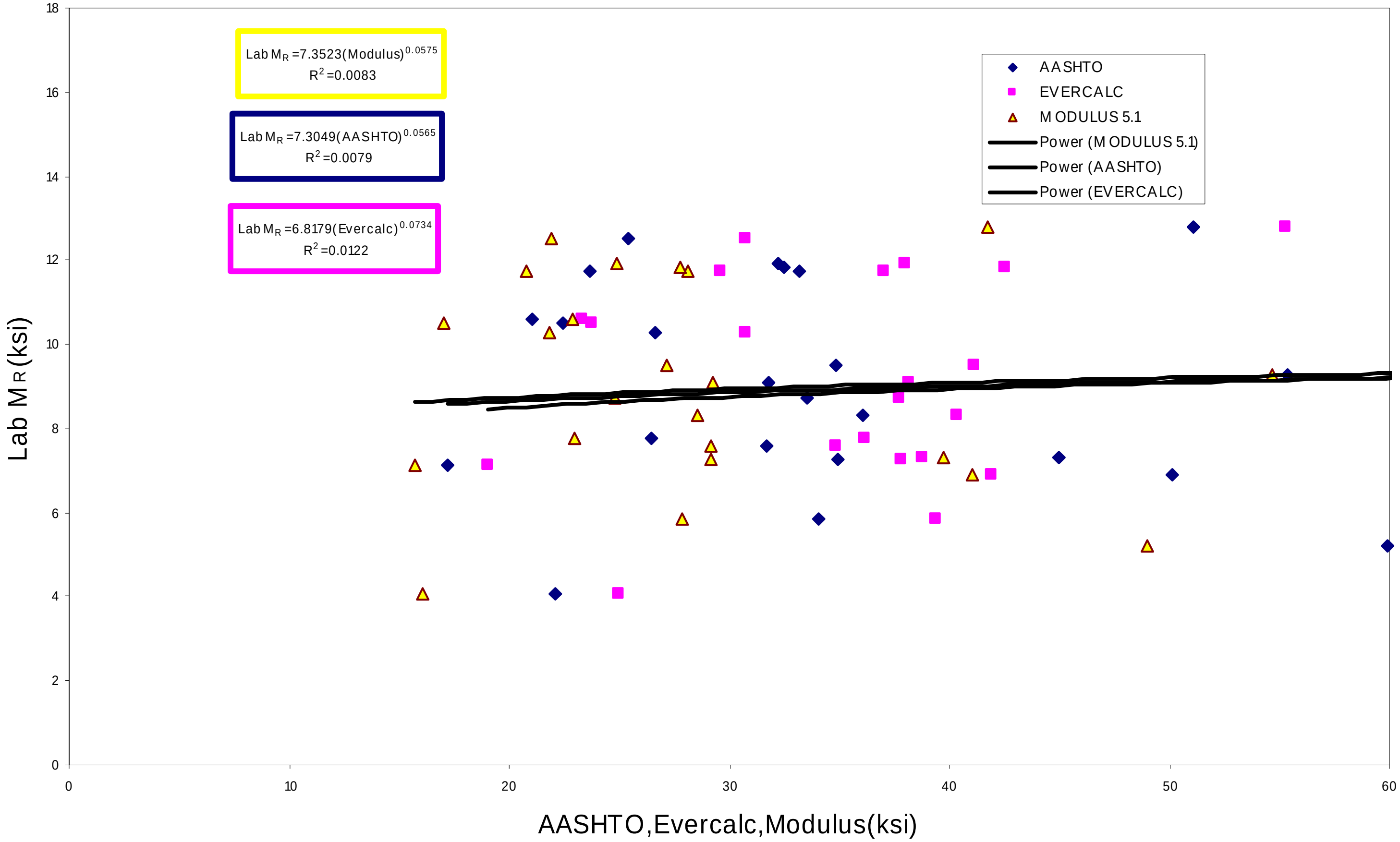


Figure 4.65 Lab MR vs Modulus,Evercalc & AASHTO Resilient Modulus based on 2.5 inches AC thickness(average) from LTPP section

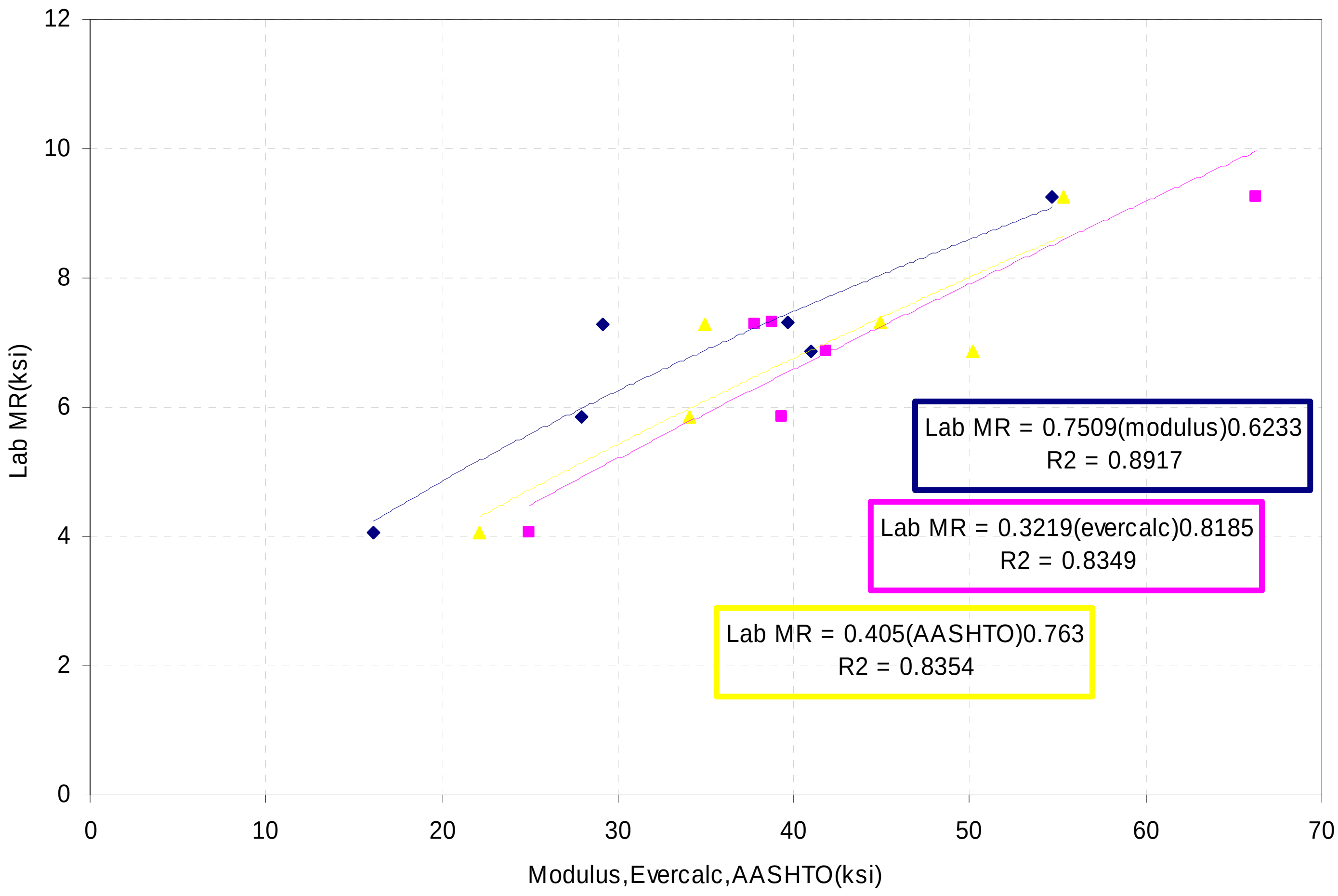


Figure 4.66: MR values According to AASHTO Method for All LTPP Section in Florida (Sensor # 6 at 36 in)

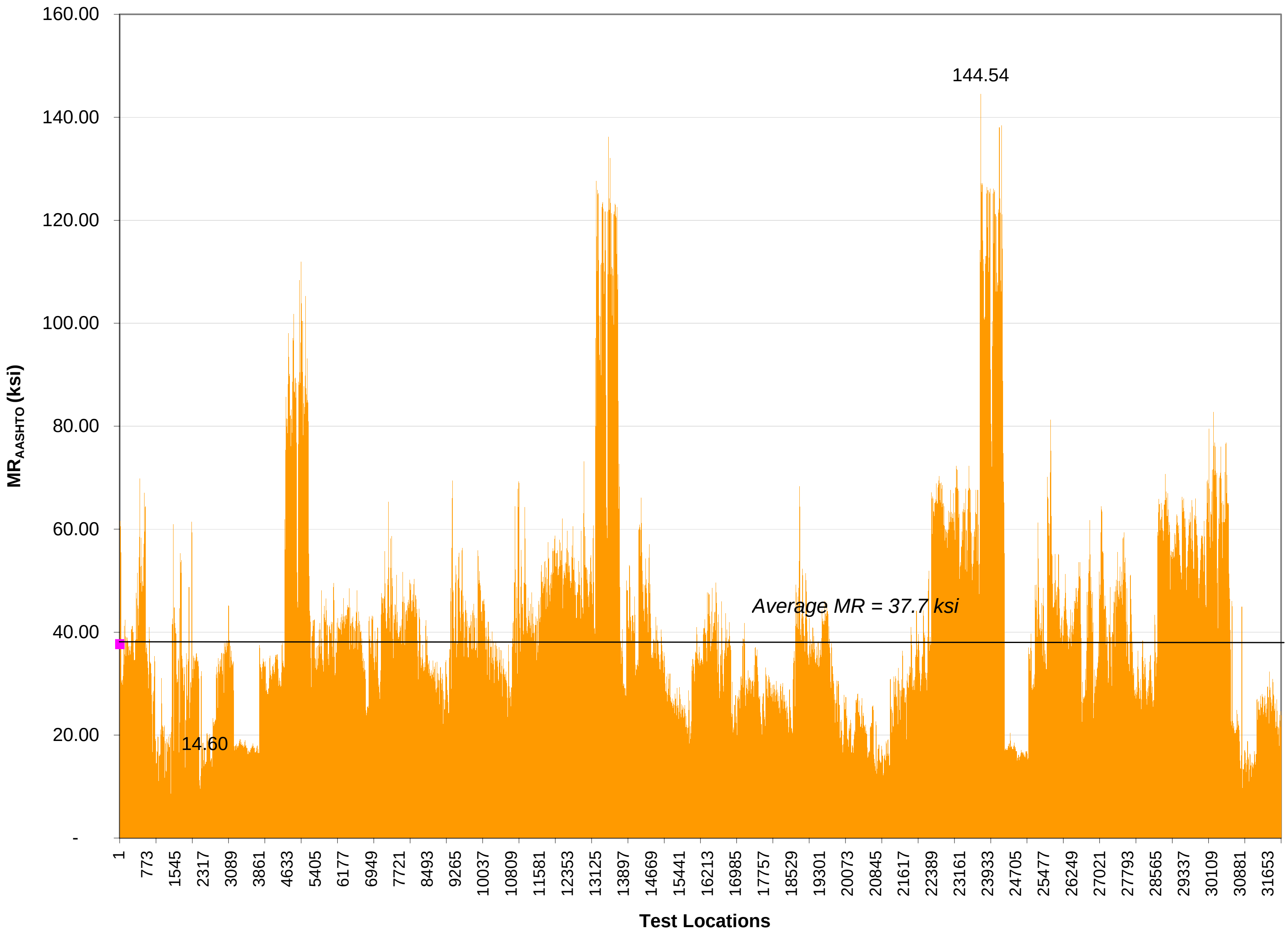


Figure 4.67: MR values According to AASHTO Method for All LTPP Section in Florida

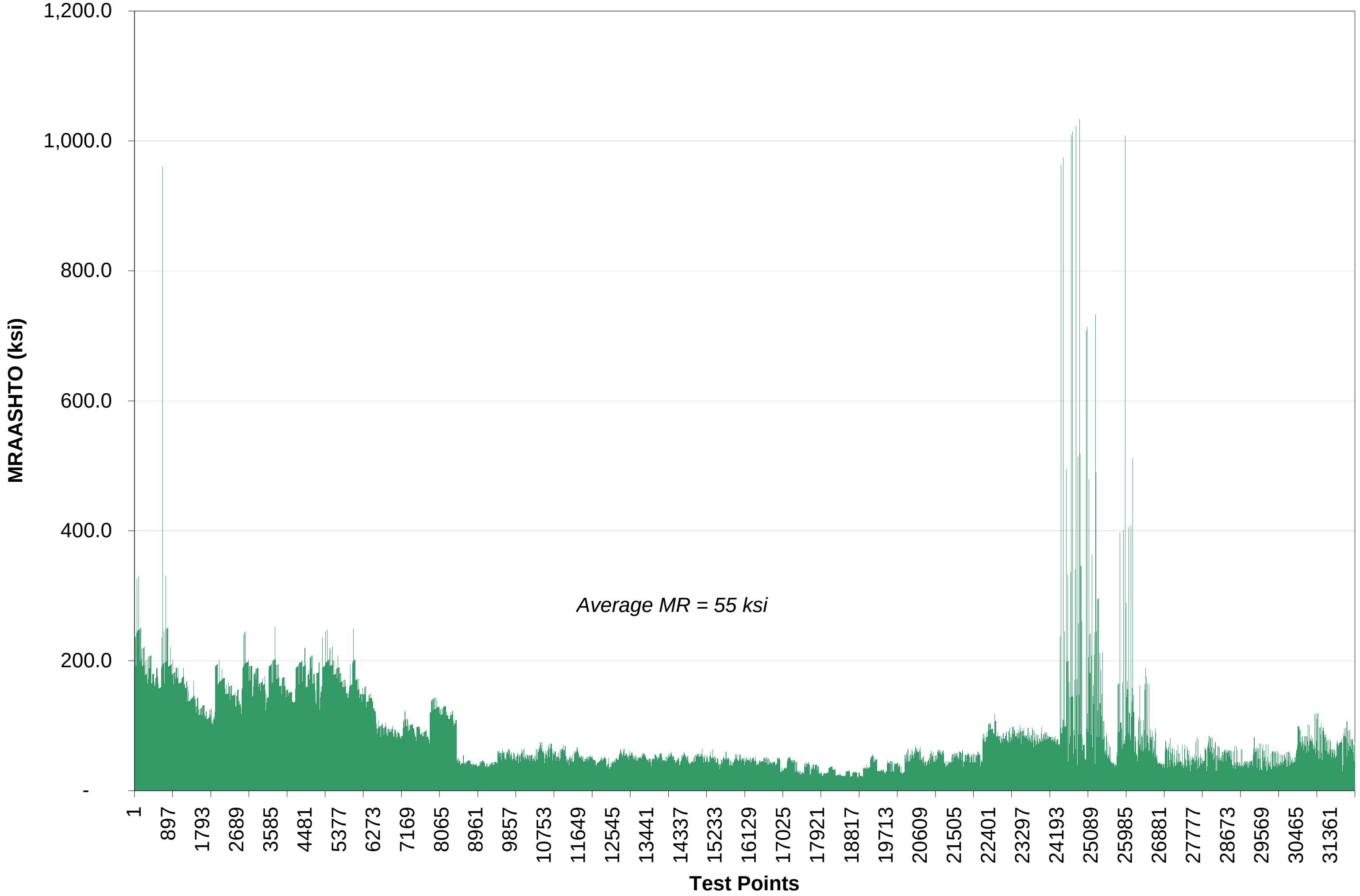


Figure 4.68: DR values According to AASHTO Method for All LTPP Section in Florida

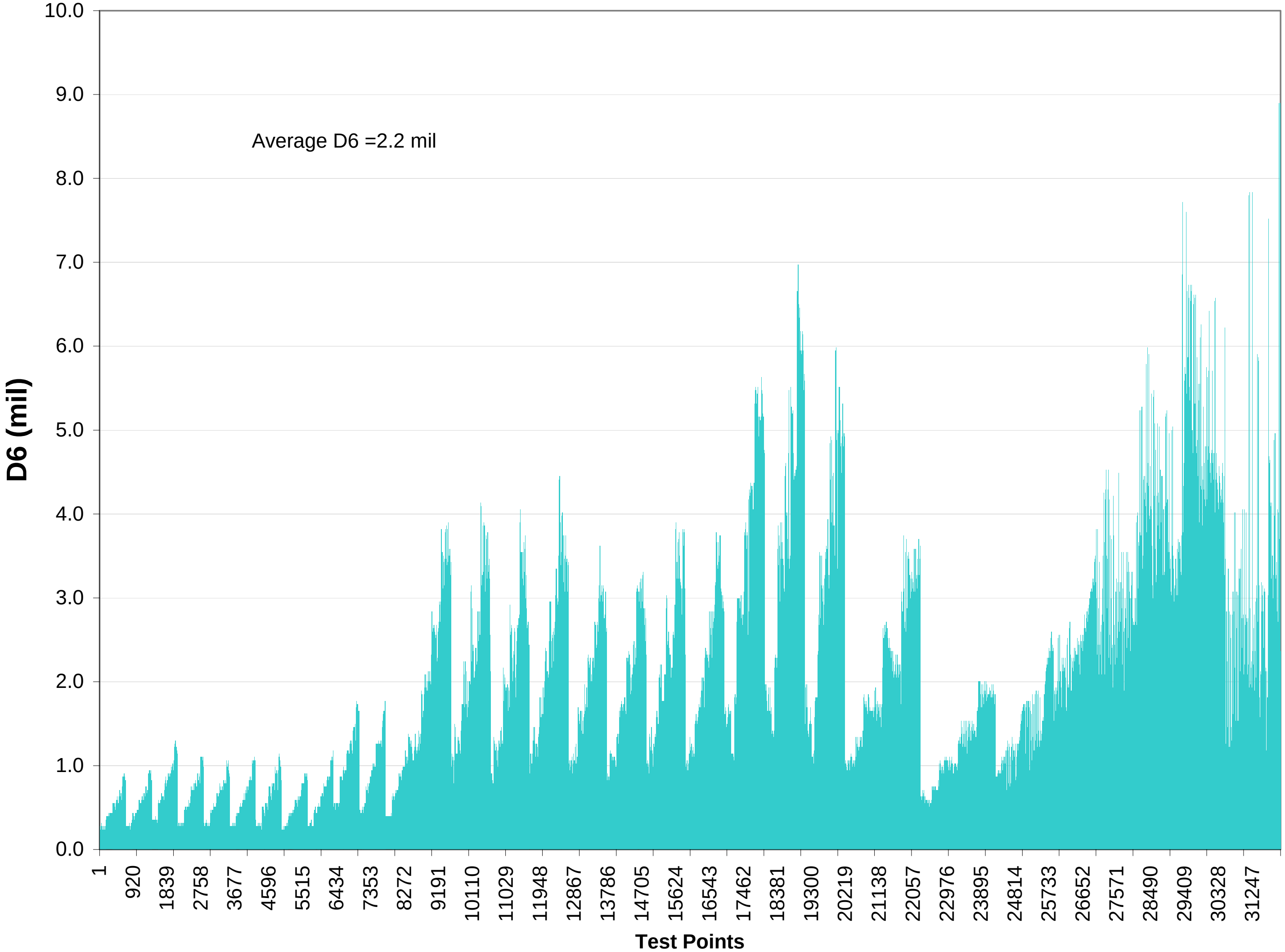


Figure 4.69 Effect of Water Table on the Moduli Values For Different Pavement Thickness Ratio

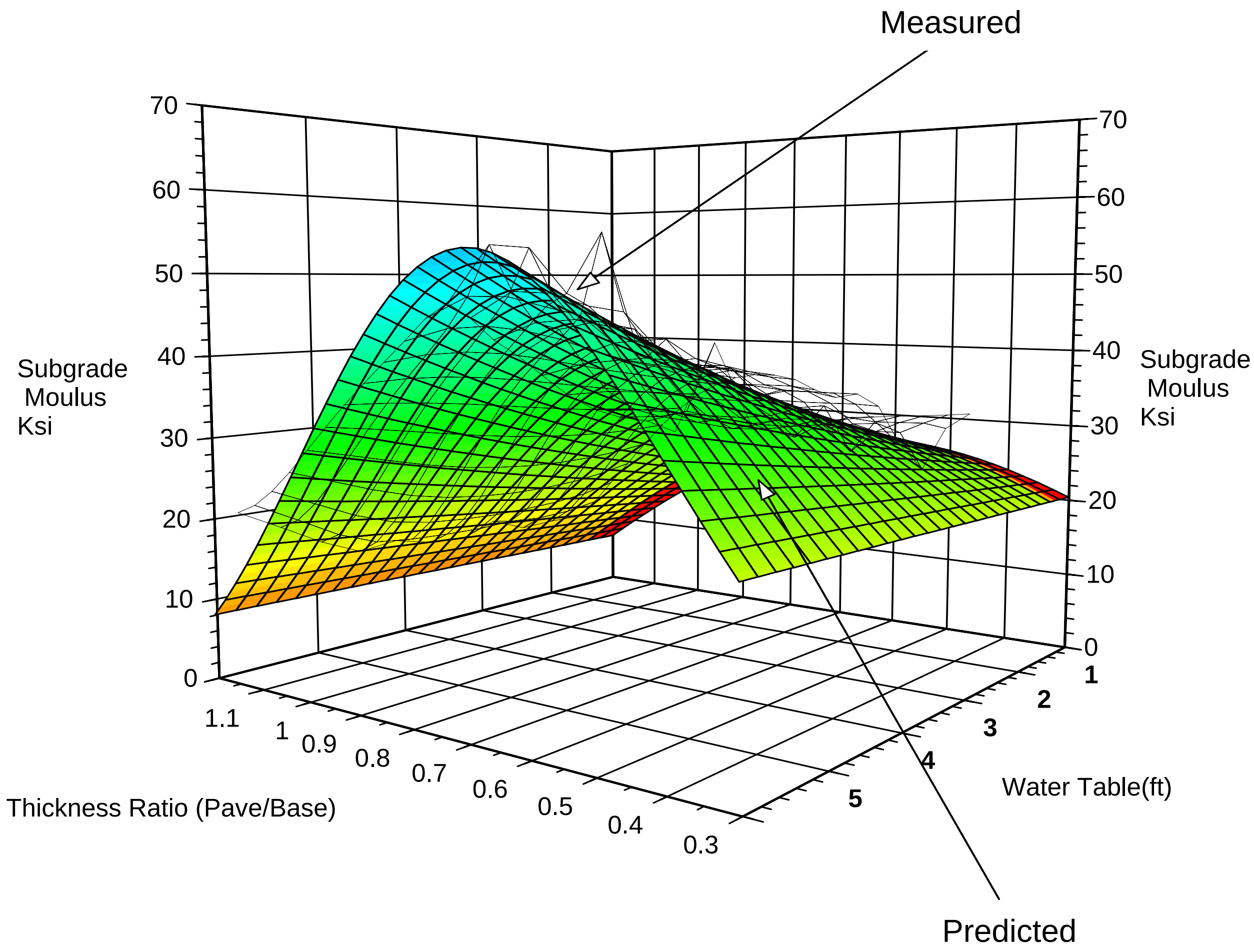


Figure 4.70 Effect of Water Table on the Moduli Values For Different Pavement Thicknesses

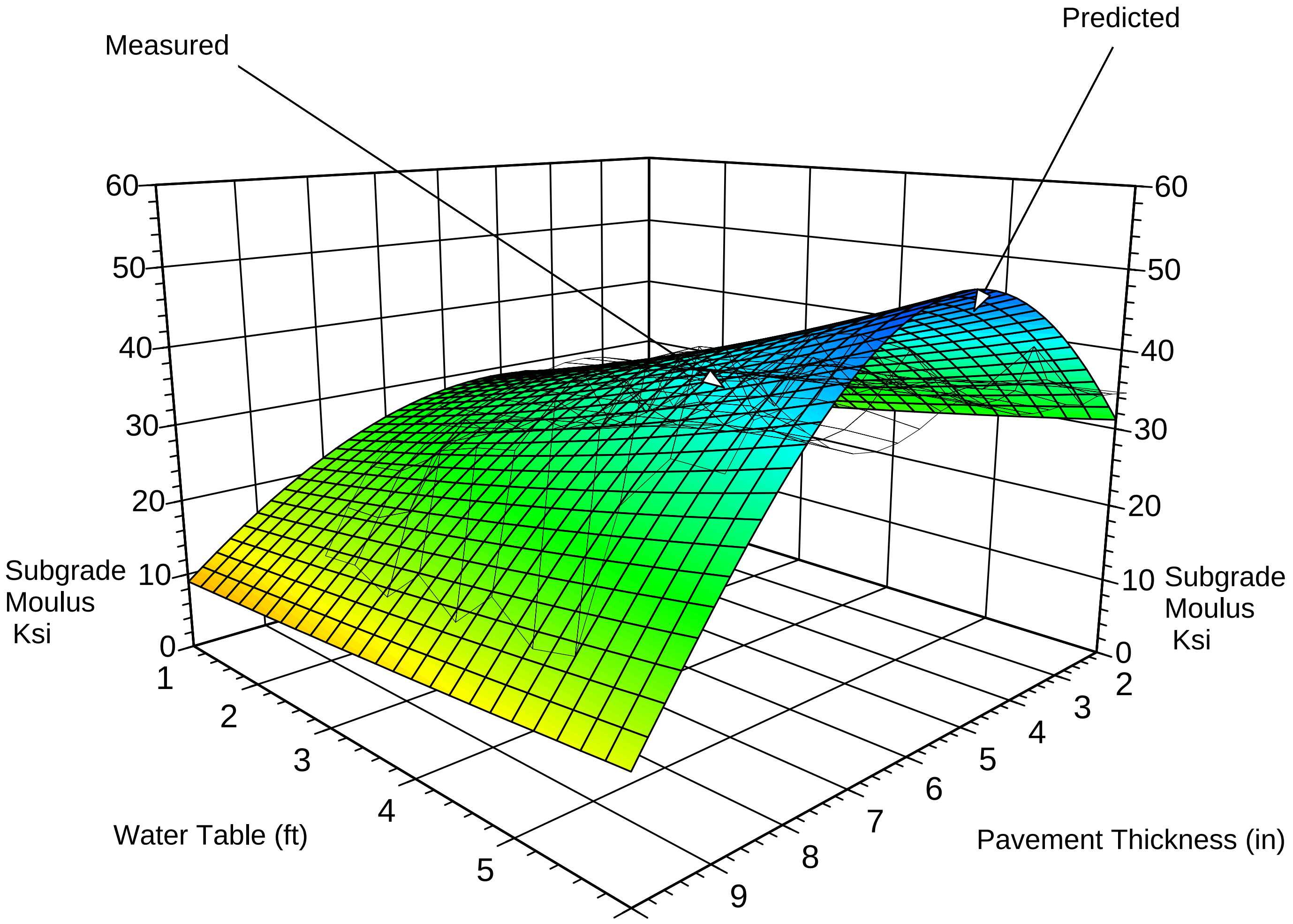


Figure 4.71 Effect of Water Table on the Moduli Values For Different Pavement Thickness Ratio (Pavement/Base)

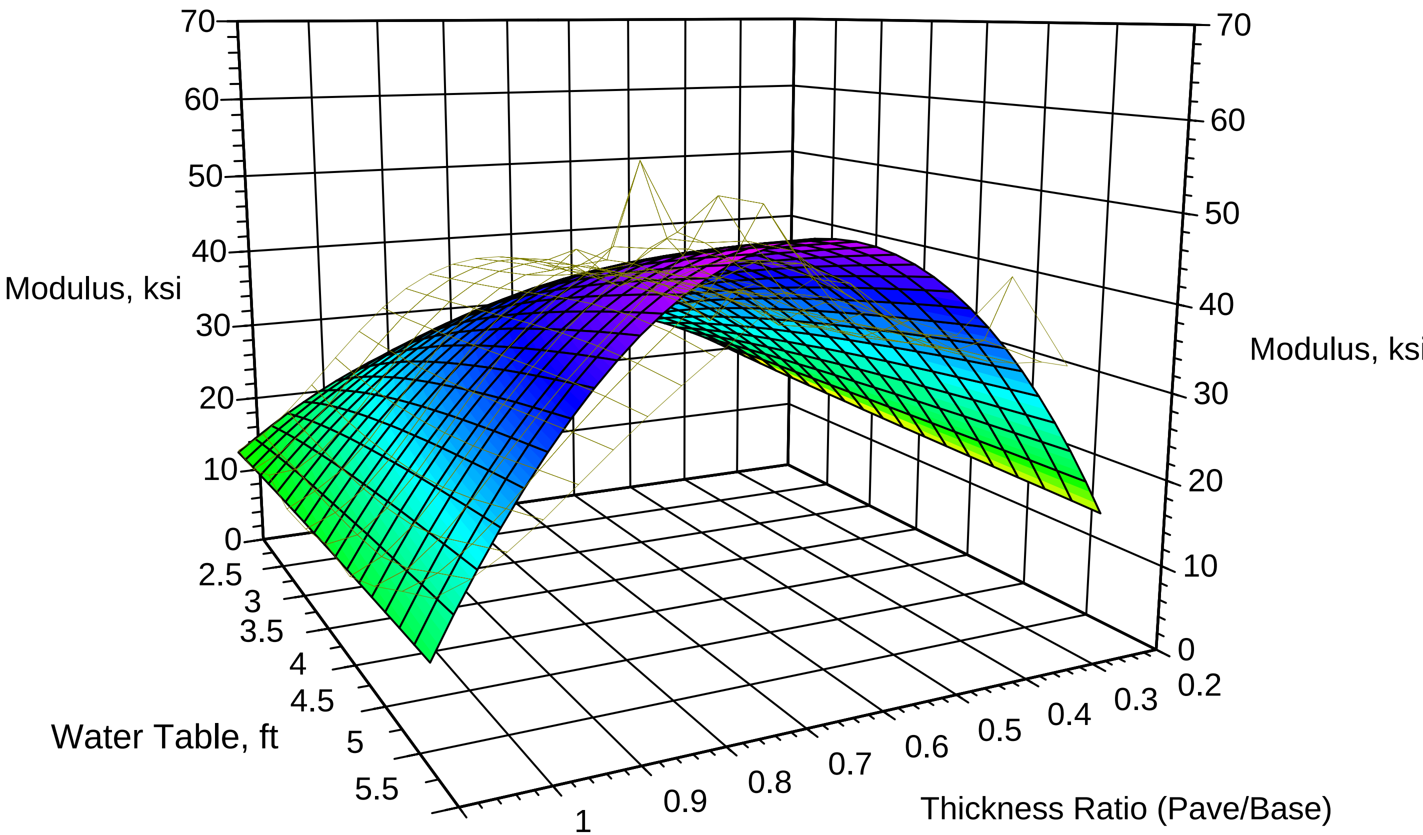
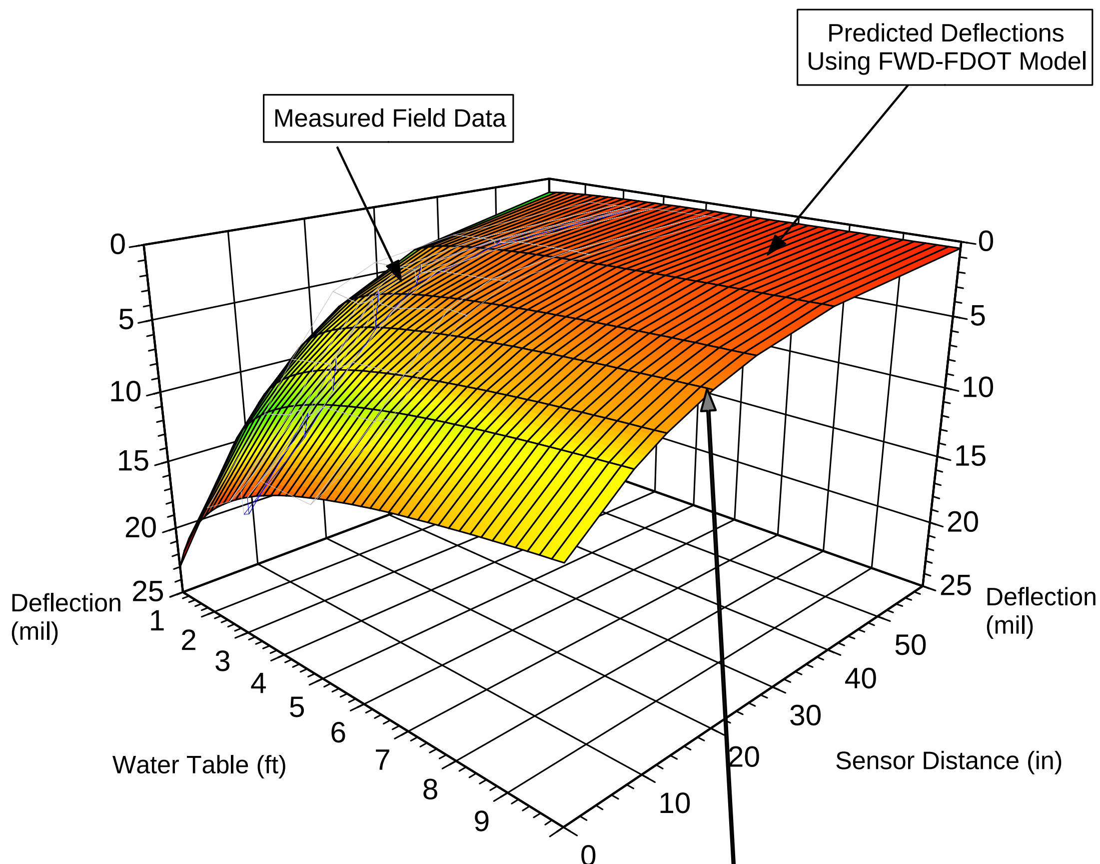


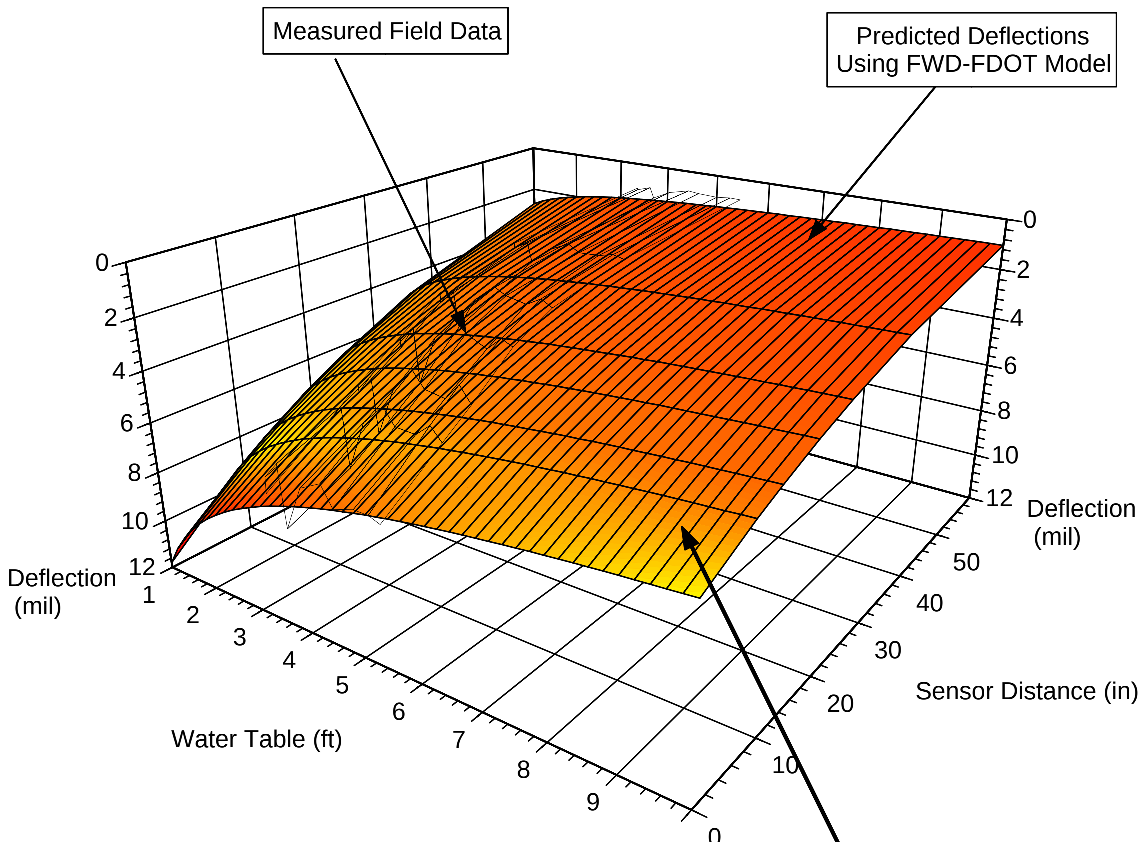
Figure 4.72 Measured vs. Predicted FWD Deflections at Different Water Table Levels at Road 200 Section 71030



dn = Sensor Deflection (in)
Dw = Depth of Water Table (ft)
Rn = Redial Distance of the sensor (in)
C = Constant

$$d_n = \zeta\, e^{\psi R_n} (D_w)^{\upsilon R_n + c}$$

Figure 4.73 Measured vs. Predicted FWD Deflections at Different Water Table Levels at Road 200 Section 28010



dn = Sensor Deflection (in)
Dw = Depth of Water Table (ft)
Rn = Redial Distance of the sensor (in)
C = Constant

$$\mathbf{d}n = \zeta\ \mathbf{e}^{\psi Rn} (\mathbf{D}w)^{\upsilon Rn + c}$$

Figure 4. 74 Measured vs. Predicted FWD Deflections at Different Water Table Levels at Road 26 Section 31010

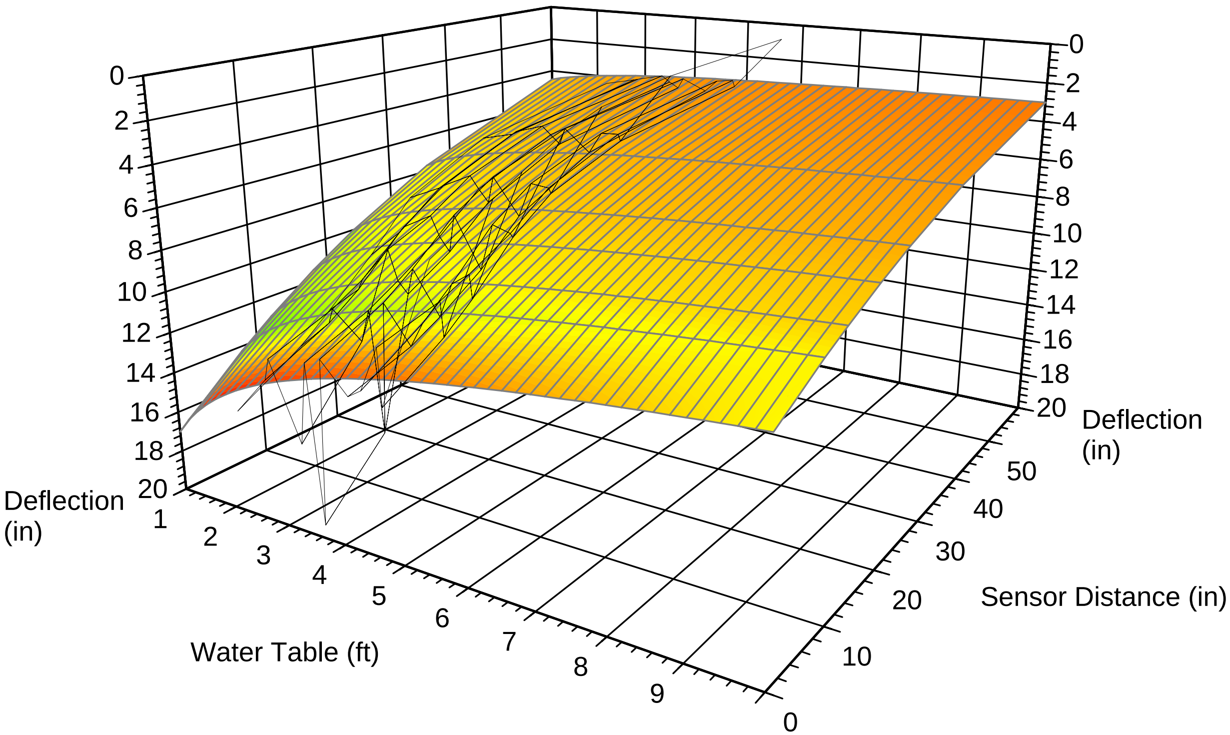


Figure4. 75 Measured vs. Predicted FWD Deflections at Different Water Table Levels
at Road 207 Section 78050

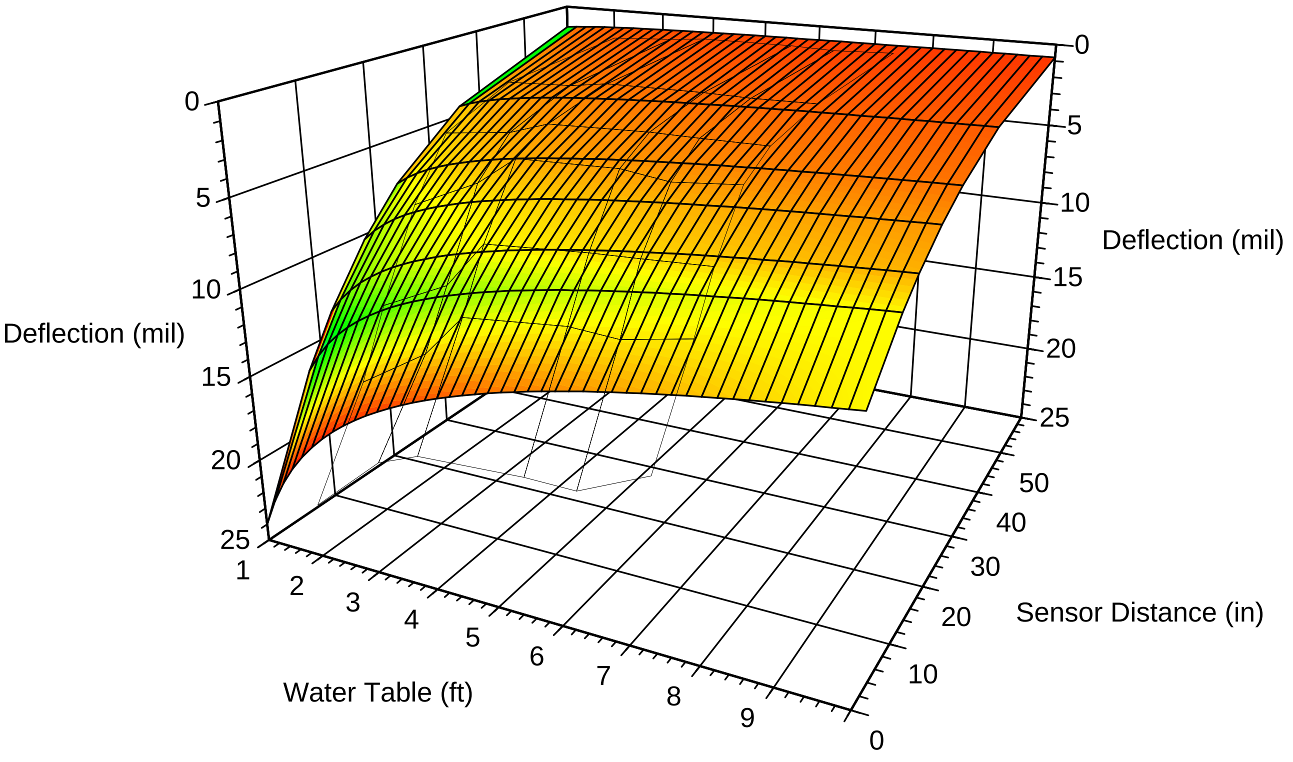


Figure4.76 Measured vs. Predicted FWD Deflections at Different Water Table Levels at Road 62 Section 06020

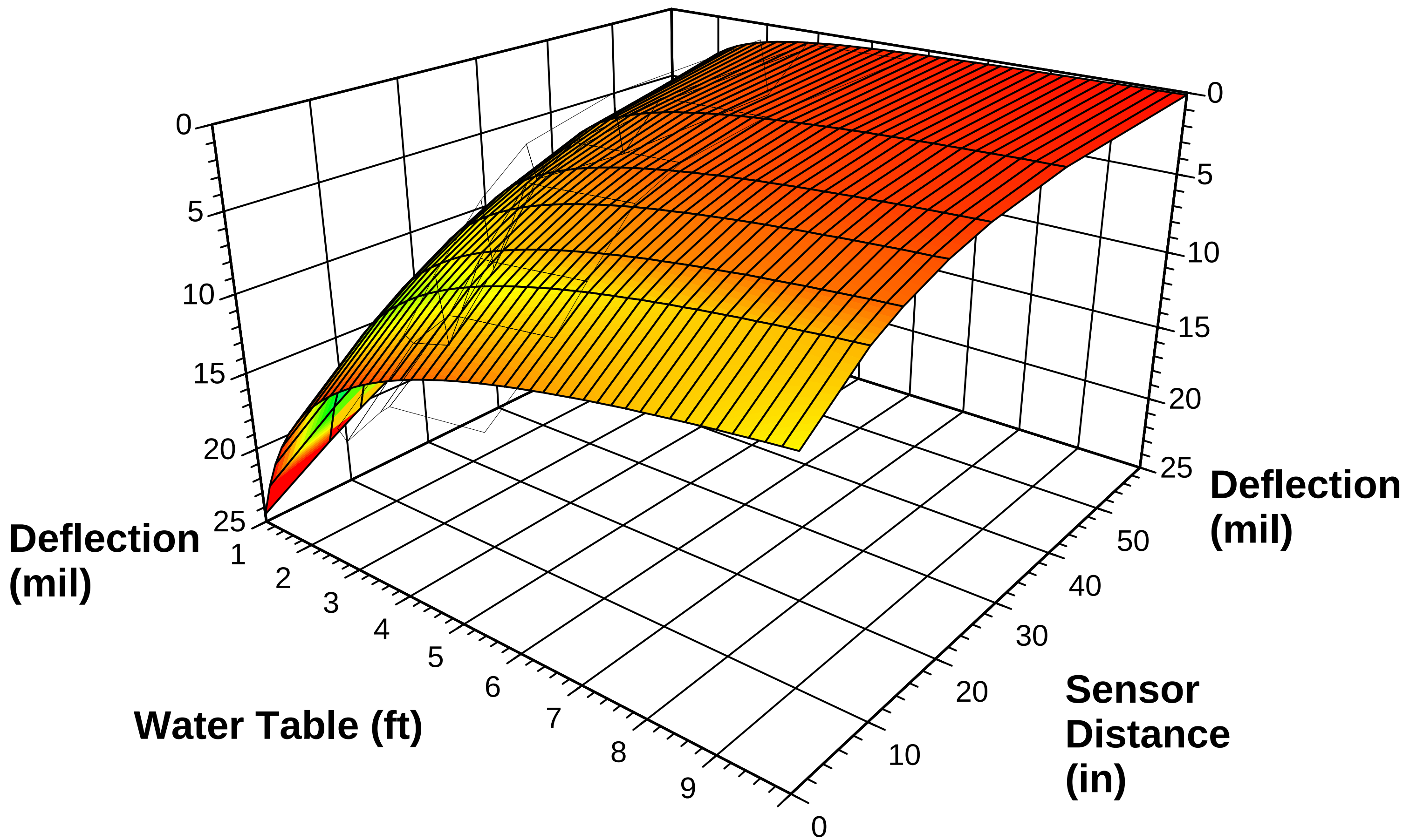


Figure 4.77: Measured vs. Predicted FWD Deflections at Different Water Table Levels at Road 72 Section 17070

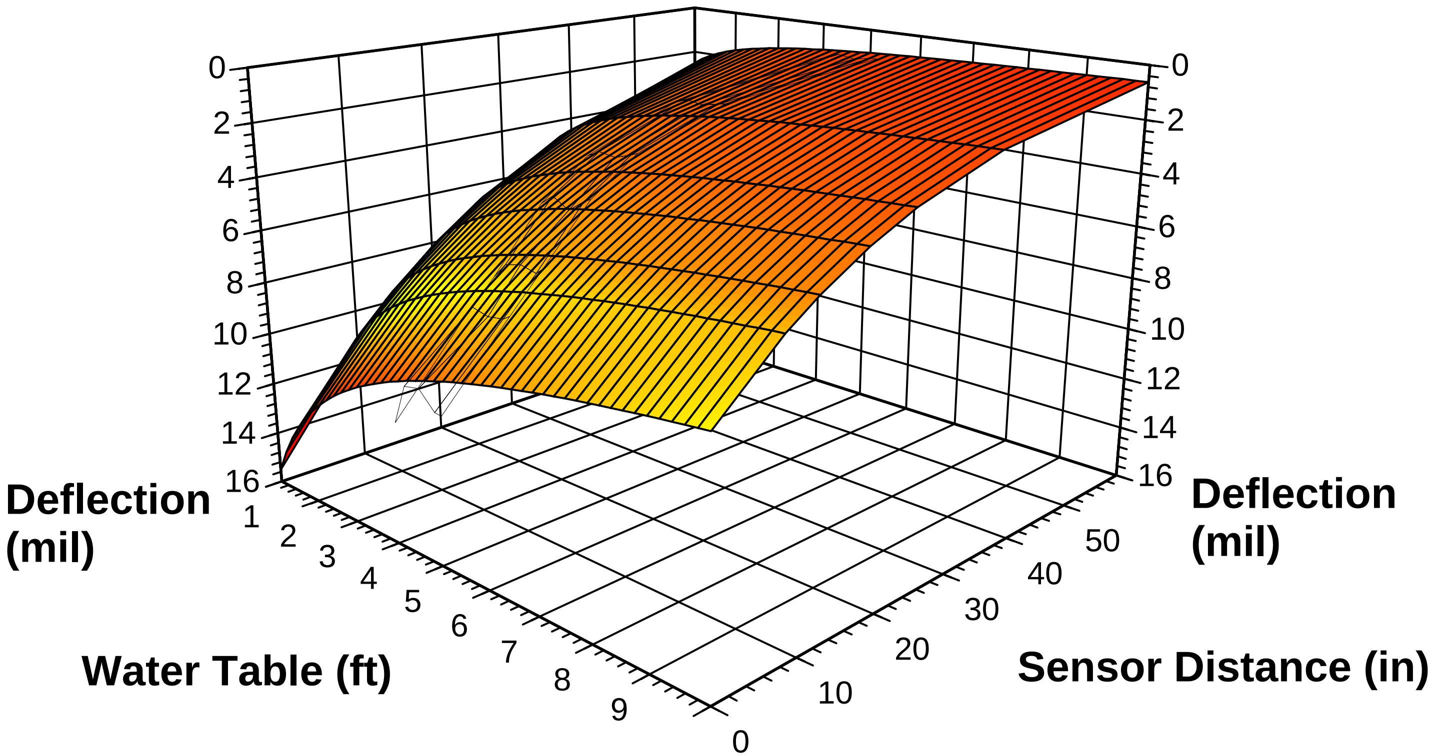


Figure 4.78 Measured vs. Predicted FWD Deflections at Different Water Table Levels at Road 16 Section 71050

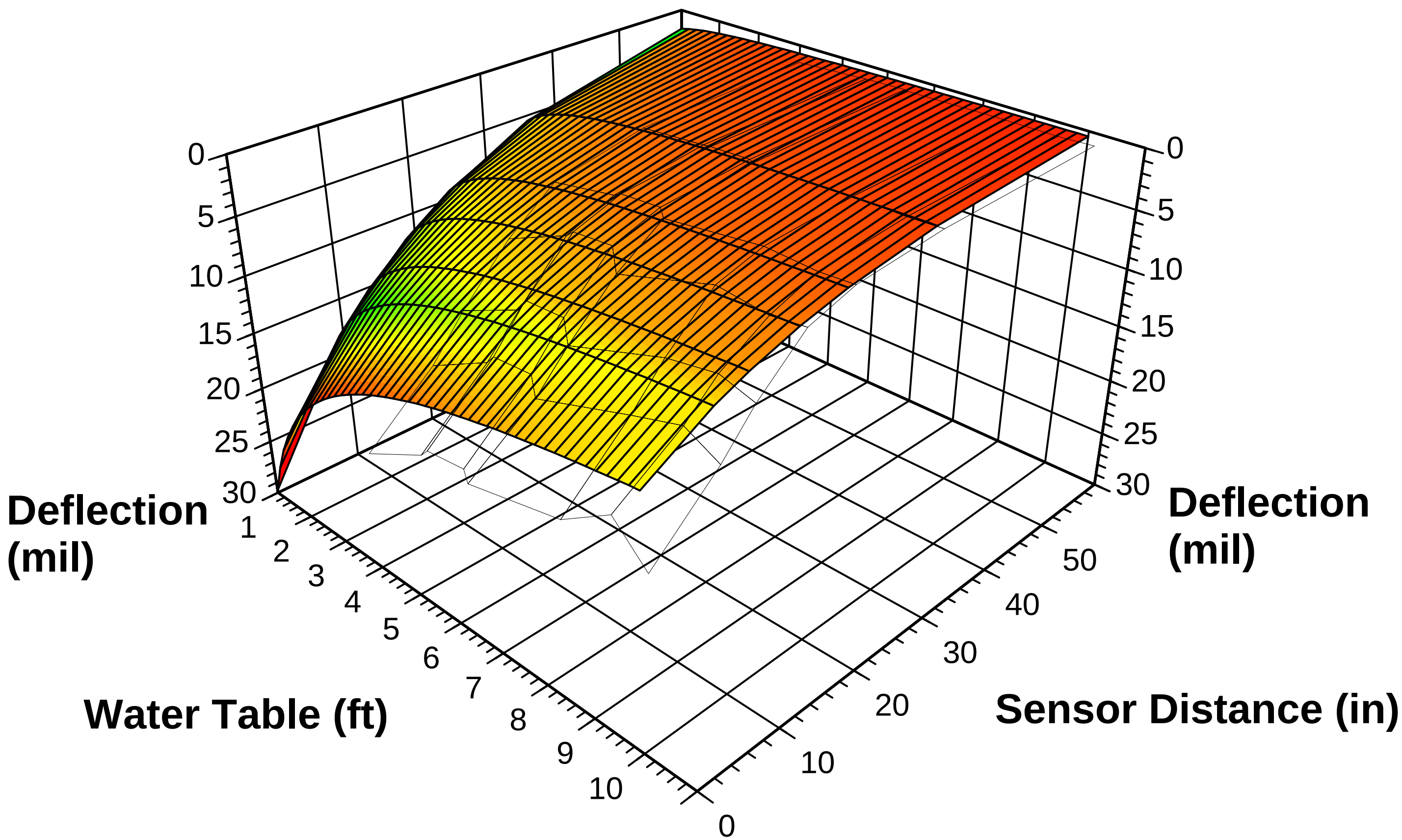


Figure 4.79 Moisture Content (%) Road 200 Section 71030

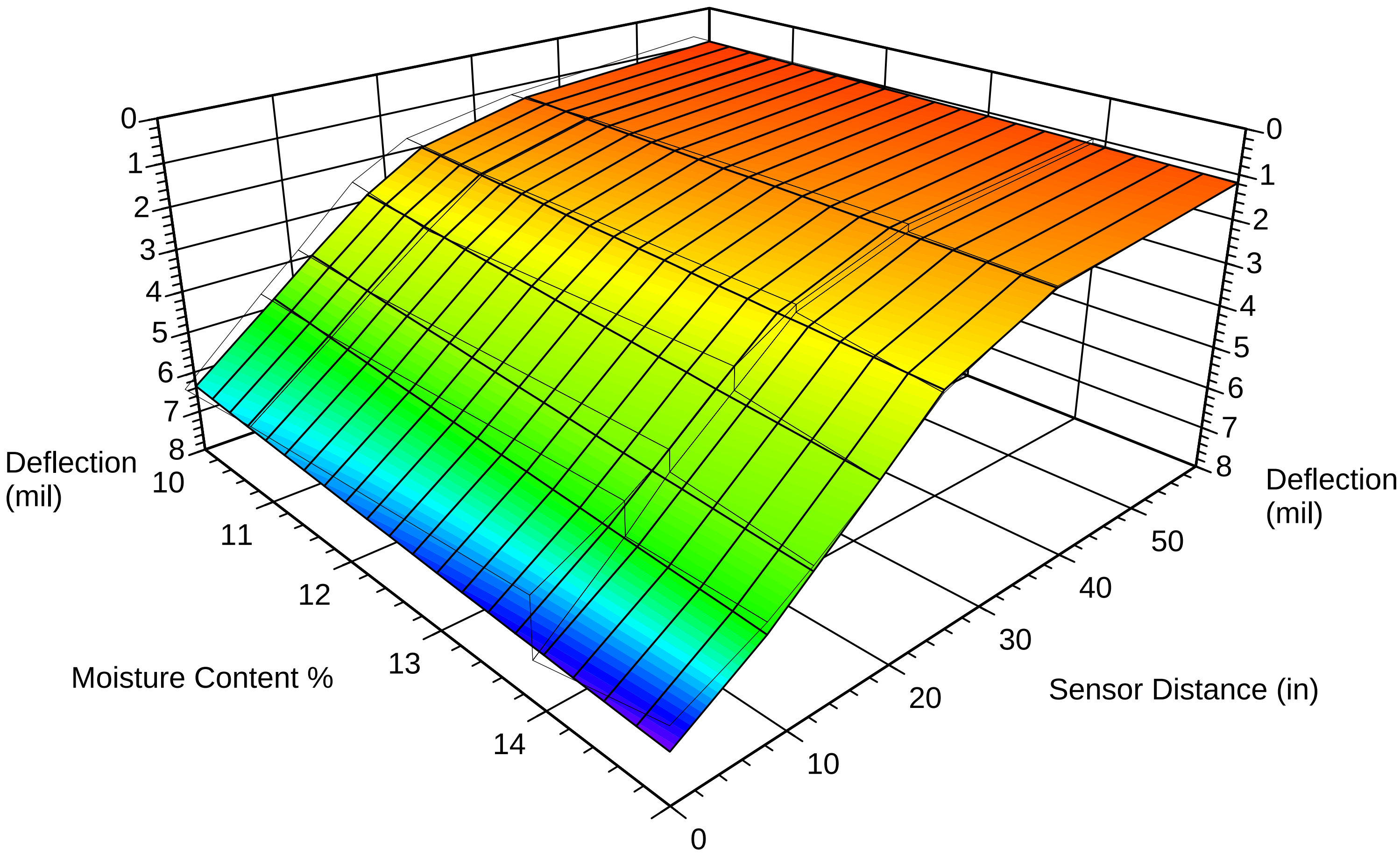
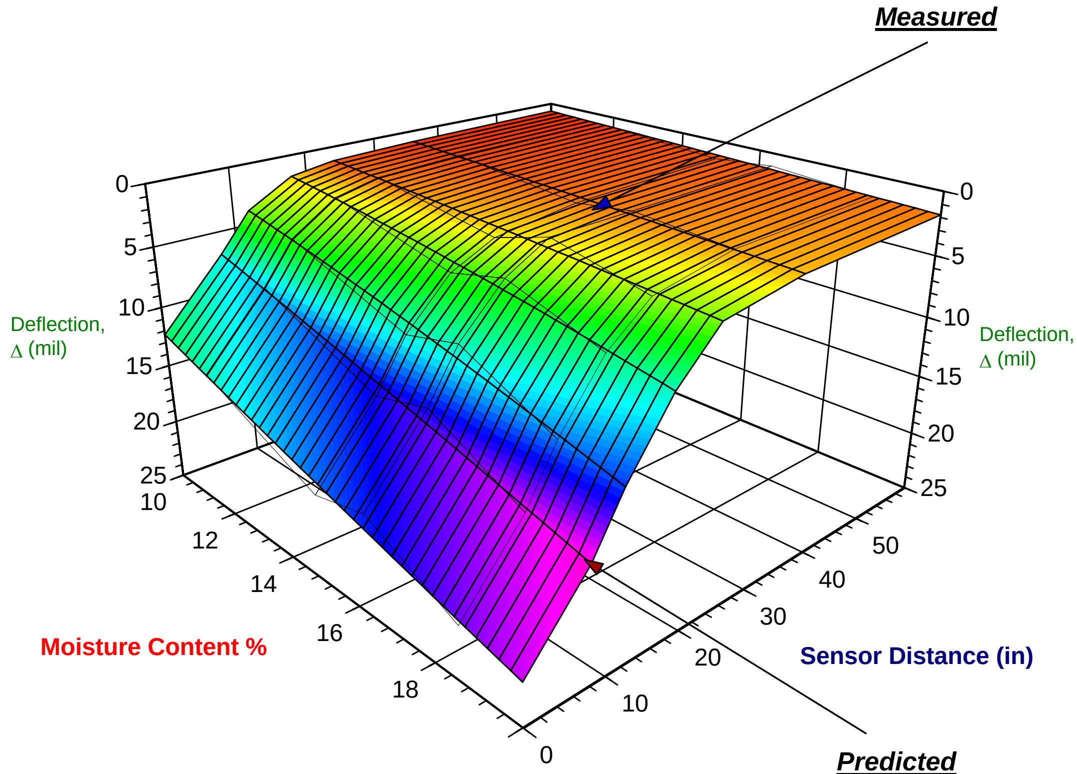


Figure 4.80 Effect of Moisture Content on FWD Deflection

Road 24 Section 26050



$$\Delta = \alpha \cdot (Mc)^{\beta}$$

Mc = moisture content (%)

Δ = Deflection at any distance (mil)

Figure 4.81 Moisture Content (%) Road 26 Section 06020

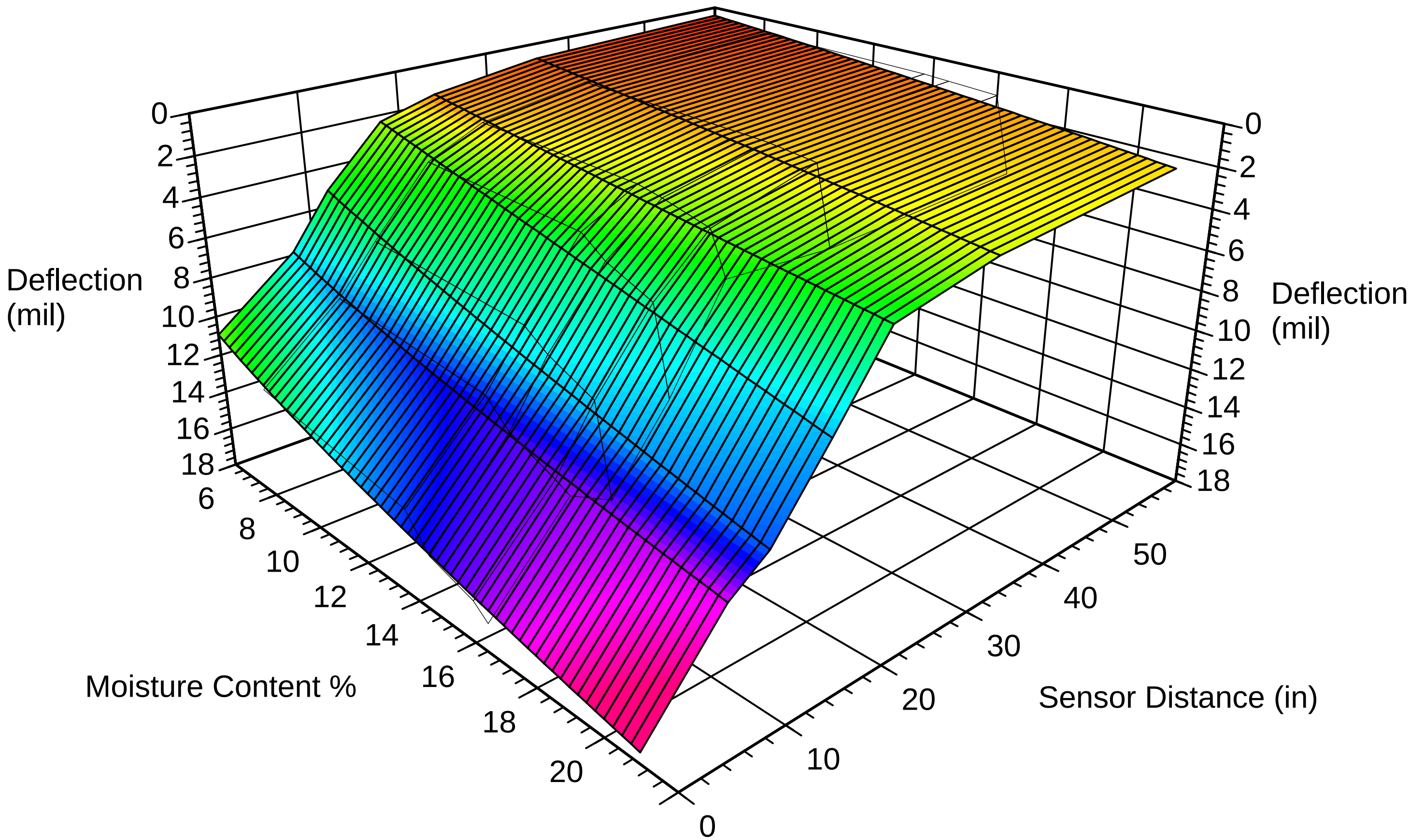


Figure 4.82 Moisture Content (%) Road 26 Section 31010

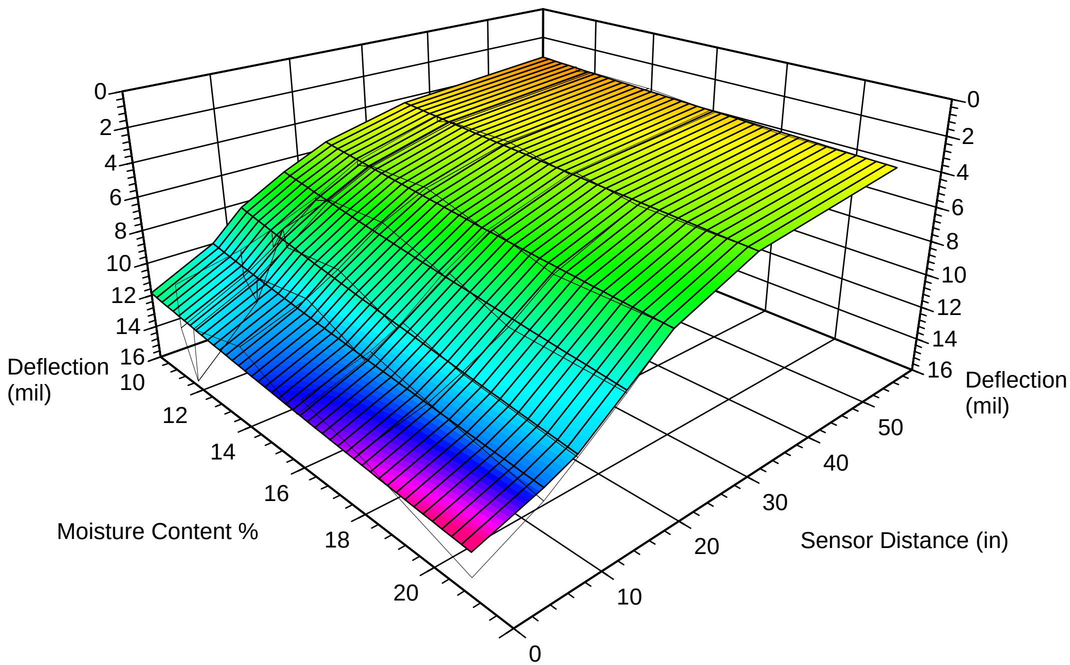


Figure4.83 Moisture Content (%) Road 207 Section 78050

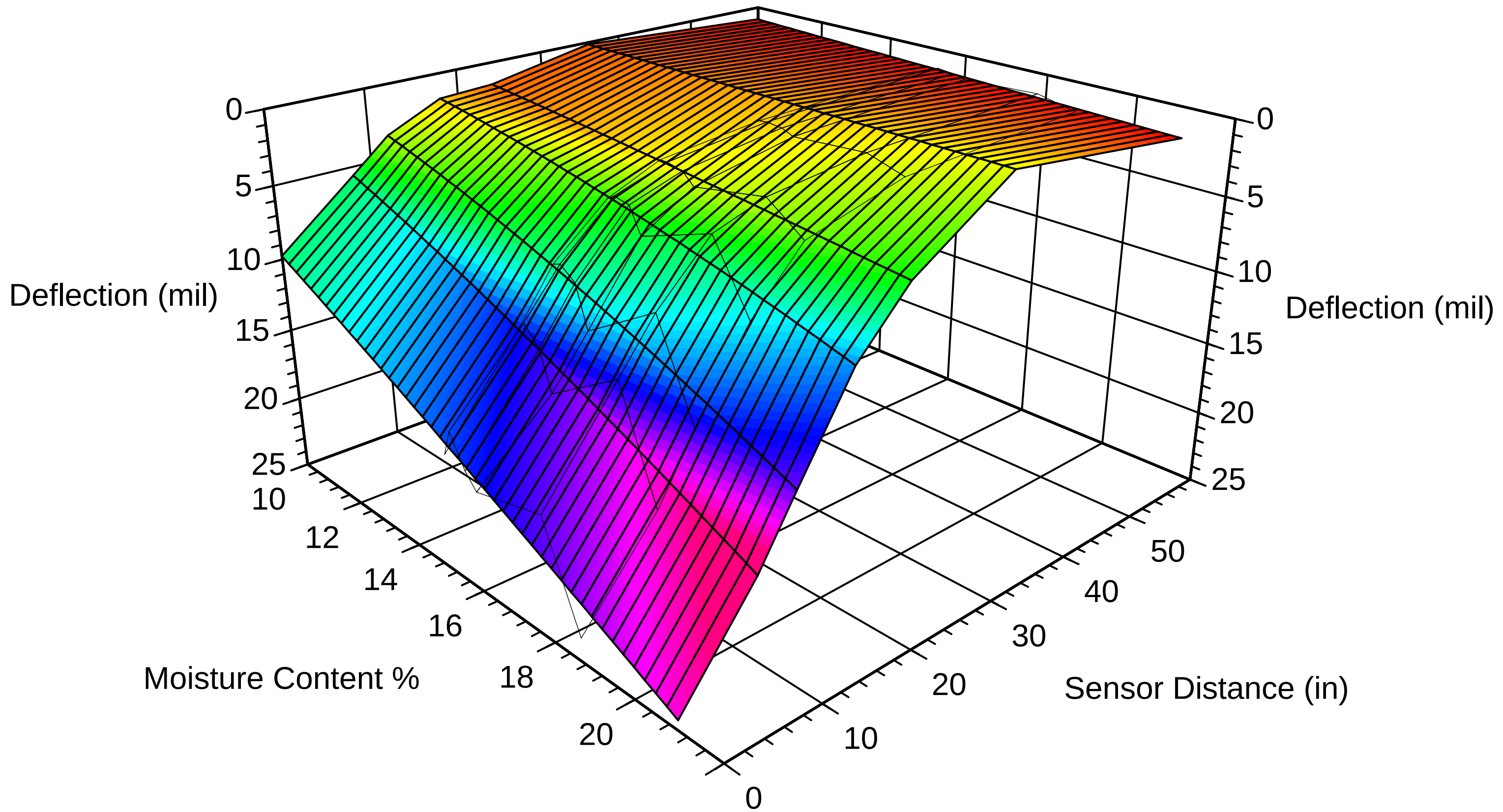


Figure 4.84 Moisture Content (%) Road 72 Section 17070

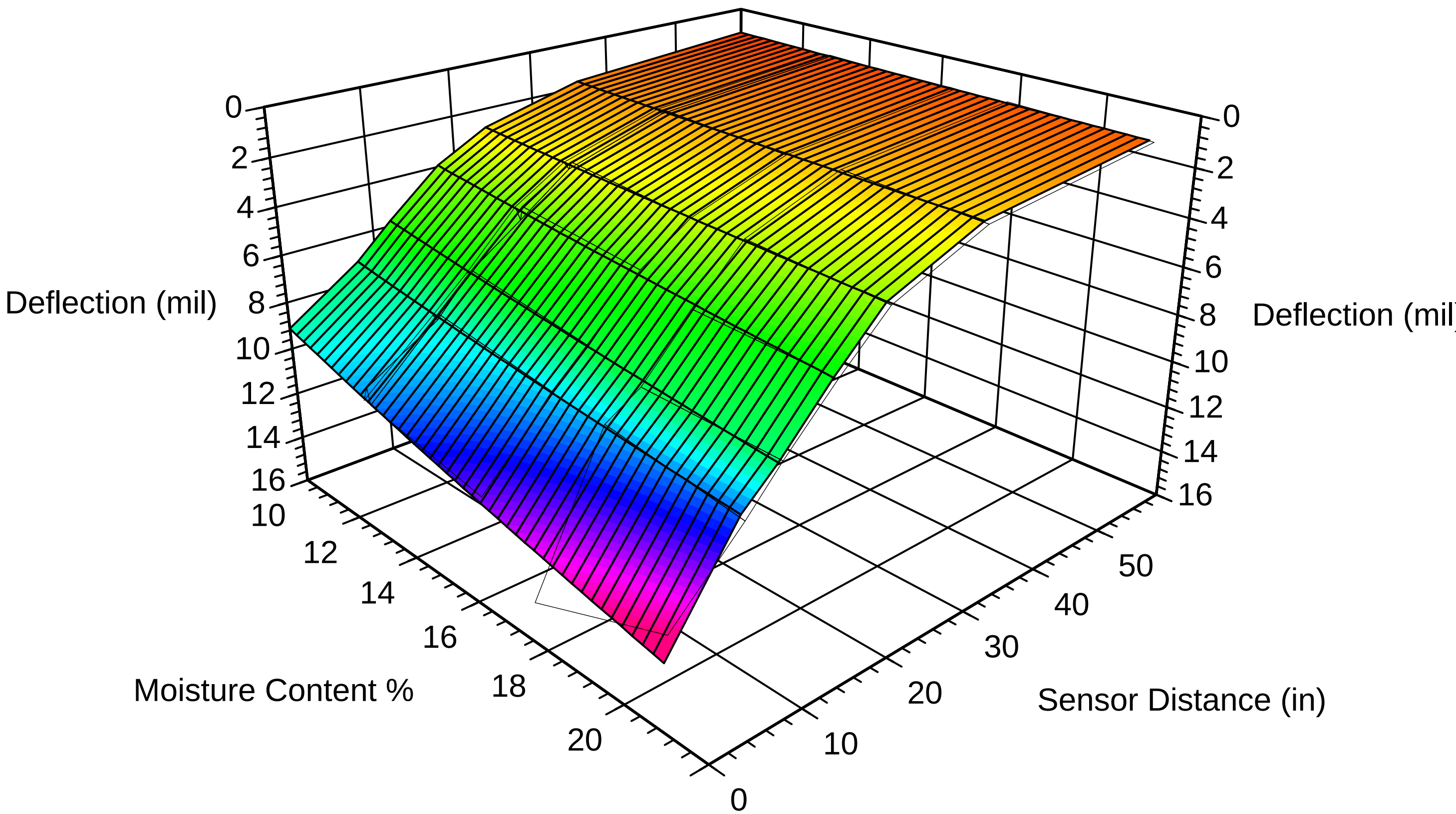


Figure 4.85 Moisture Content (%) Road 62 Section 06020

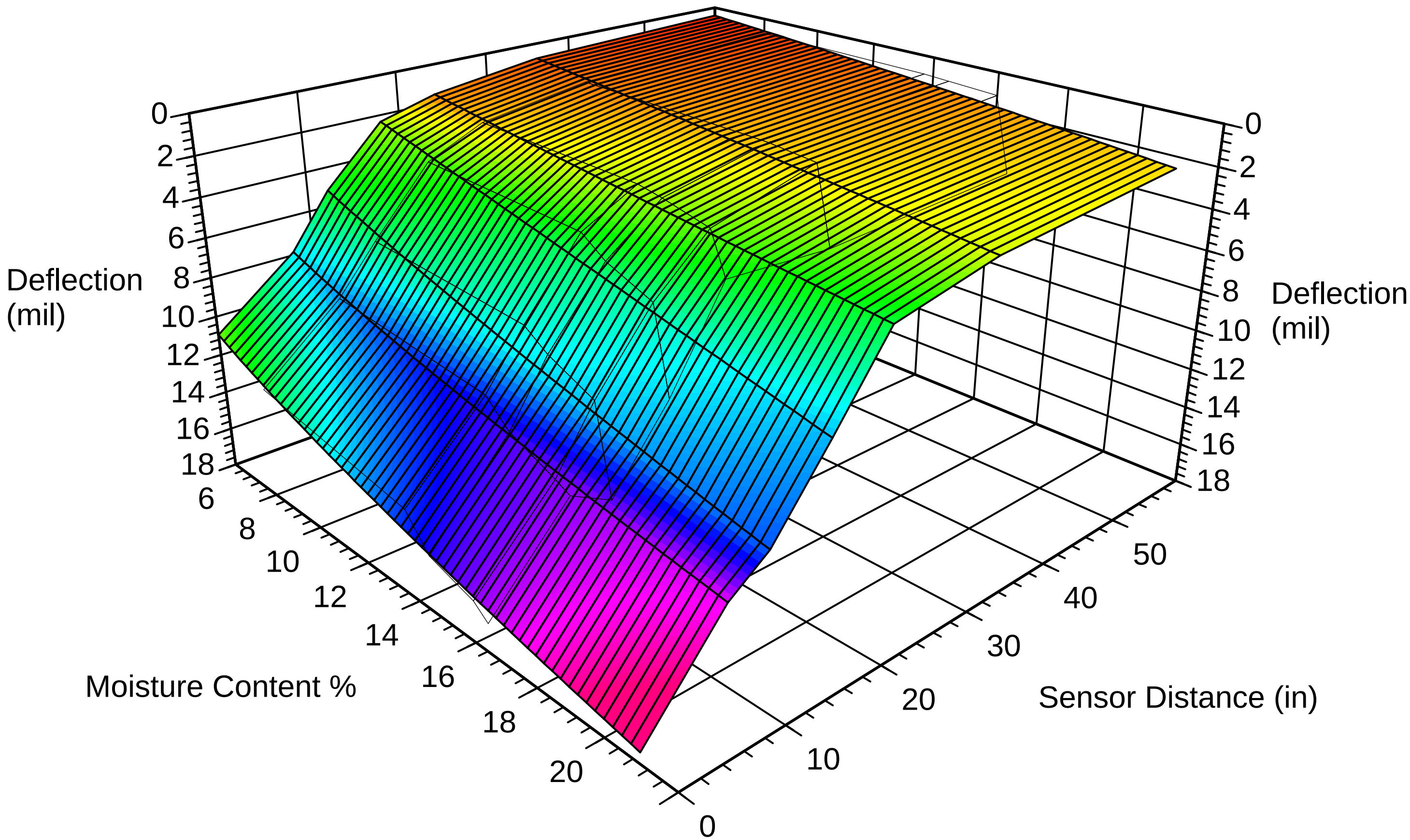


Figure 4.86 Effect of Moisture Content on Moduli Values for Different Pavement Thicknesses

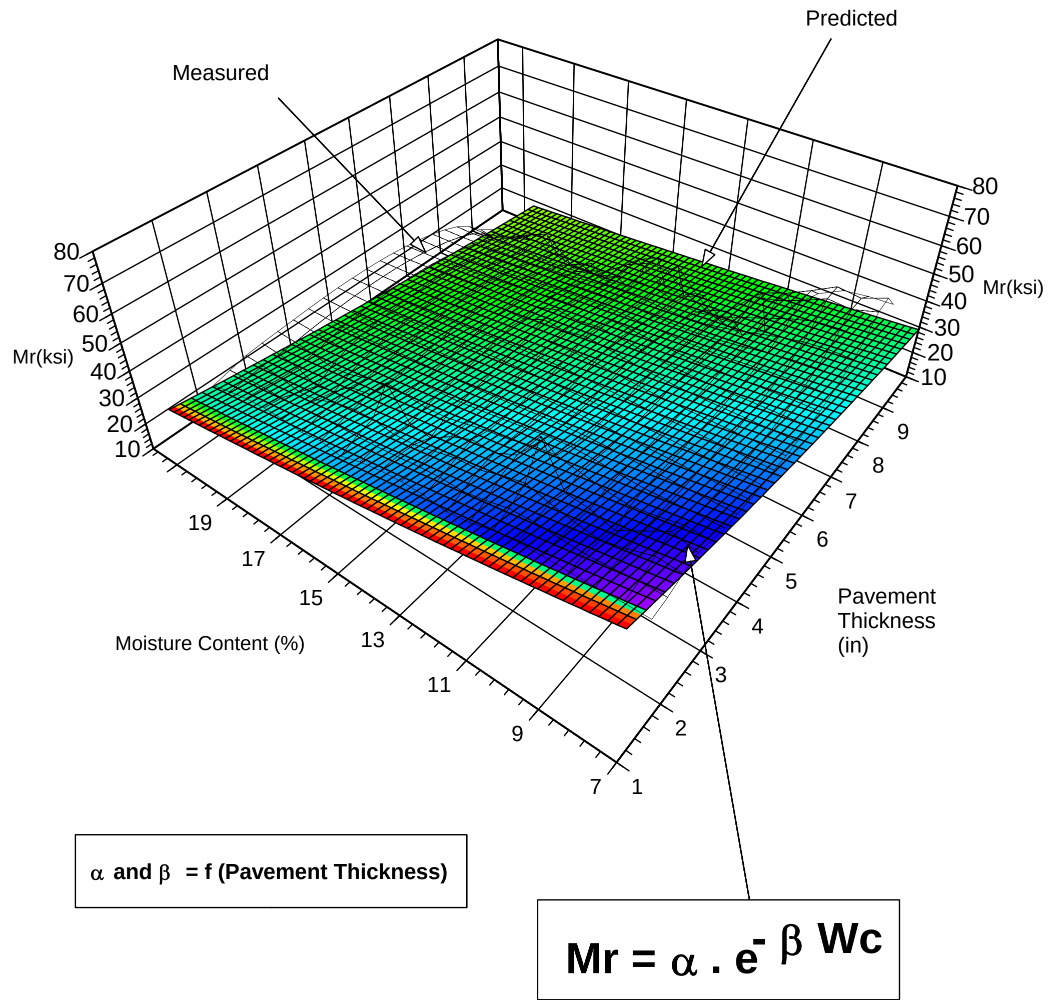


Table 4.19 Average Measured values of
Sensor Deflections, Sensor Spacing, and Dropping Load

for LTPP B310

Results Date:7/31/1990

(All averages values were measured in the field and were obtained from DATPAVE 3.0)

Load (lb)	Drop#1	Drop#2	Drop#3	Drop#4
Spacing (in)	5802	9217	12070	15490
0	9.35	13.45	16.62	20.33
8	5.08	7.92	10.01	12.56
12	3.35	5.52	7.16	9.12
18	2.12	3.6	4.8	6.18
24	1.59	2.68	3.6	4.61
36	1.13	1.84	2.45	3.13
60	0.72	1.21	1.65	2.1

Average Measured values of
Sensor Deflections, Sensor Spacing, and Dropping Load

for LTPP 310

Results Date:5/28/1991

(All averages values were measured in the field and were obtained from DATPAVE 3.0)

Load (lb)	Drop#1	Drop#2	Drop#3	Drop#4
Spacing (in)	6226	9029	12320	15912
0	11.5	16.03	20.6	25.13
8	6.66	9.69	12.84	15.93
12	4.37	6.68	9.17	11.63
18	2.74	4.39	6.24	8.11
24	1.98	3.2	4.61	6.05
36	1.45	2.3	3.25	4.26
60	0.99	1.55	2.16	2.83

Average Measured values of
Sensor Deflections, Sensor Spacing, and Dropping Load

for LTPP 310

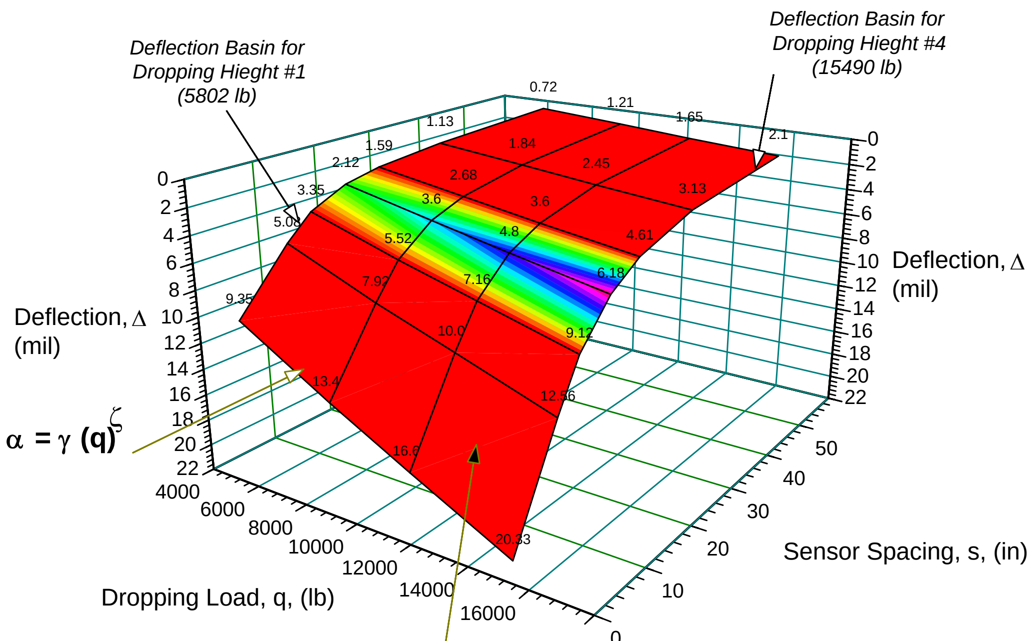
Results Date: 11/22/1993

(All averages values were measured in the field and were obtained from DATPAVE 3.0)

Load (lb)	Drop#1	Drop#2	Drop#3	Drop#4
Spacing (in)	5795	8723	11890	16075
0	7.38	11.03	14.76	19.6
8	5.43	8.27	11.21	14.96
12	4.27	6.62	9.06	12.23
18	2.83	4.52	6.32	8.74
24	2.06	3.29	4.67	6.57
36	1.32	2.09	2.97	4.25
60	0.85	1.31	1.84	2.6

Figure 4.87 AverageMeasured values of
Sensor Deflections, Sensor Spacing, and Dropping Load
for LTPP B310
Results Date: 7/31/1990

(All averages values were measured in the field and were obtained from DATPAVE 3.0)



3D Surface Equation

$$\Delta\ (\text{mil}) = \gamma\ (q)^{\zeta}\ (\beta)^{s}$$

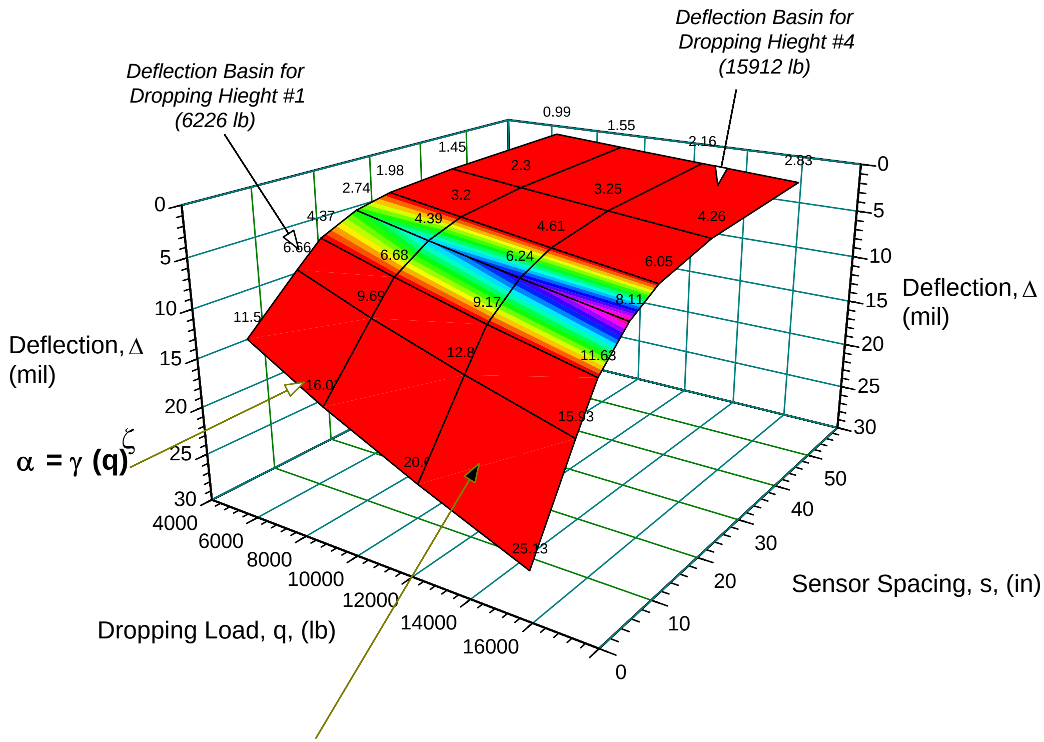
s = Sensor Spacing

Parameters For Section 0101

γ = 0.00825
ζ = 0.81
β = 0.95

Figure 4.88 AverageMeasured values of
Sensor Deflections, Sensor Spacing, and Dropping Load
for LTPP B310
Results Date: 5/28/1991

(All averages values were measured in the field and were obtained from DATPAVE 3.0)



3D Surface Equation

$$\Delta\ (\text{mil}) = \gamma\ (q)^{\zeta}\ (\beta)^{s}$$

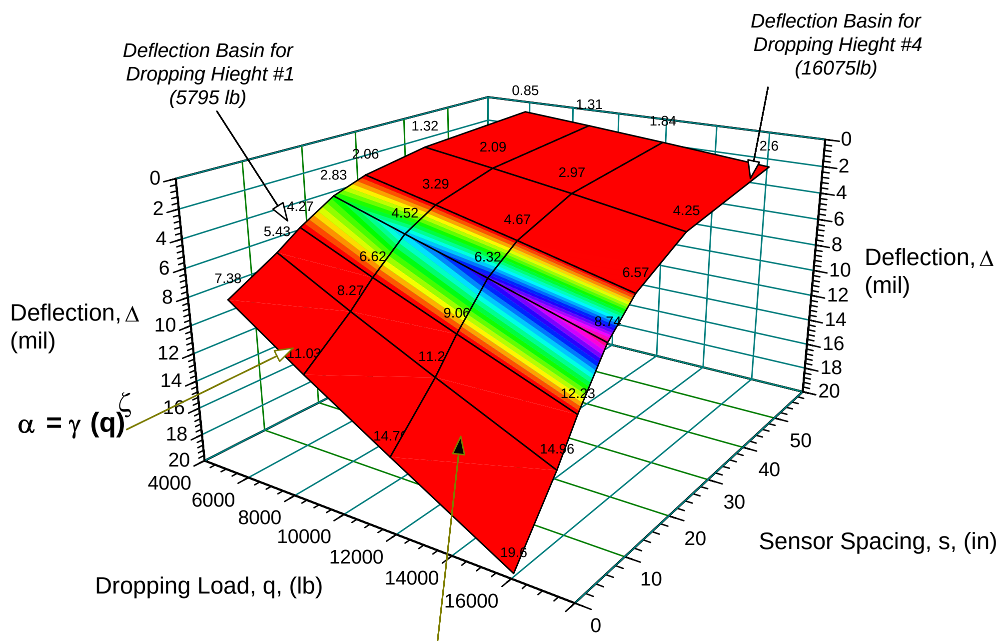
s = Sensor Spacing

Parameters For Section 0101

γ = 0.0160
ζ = 0.754
β = 0.95

Figure 4.89 AverageMeasured values of
Sensor Deflections, Sensor Spacing, and Dropping Load
for LTPP B310
Results Date: 11/22/1993

(All averages values were measured in the field and were obtained from DATPAVE 3.0)



3D Surface Equation

$$\Delta\,(\text{mil}) = \gamma\,(q)^{\zeta}\,(\beta)^{s}$$

s = Sensor Spacing

Parameters For Section B310

$\gamma = 0.00044$
$\zeta = 1.1$
$\beta = 0.95$

Figure 4.90 Sensors Spacing vs. Average Deflection

LTPP Section B310 7/31/1990

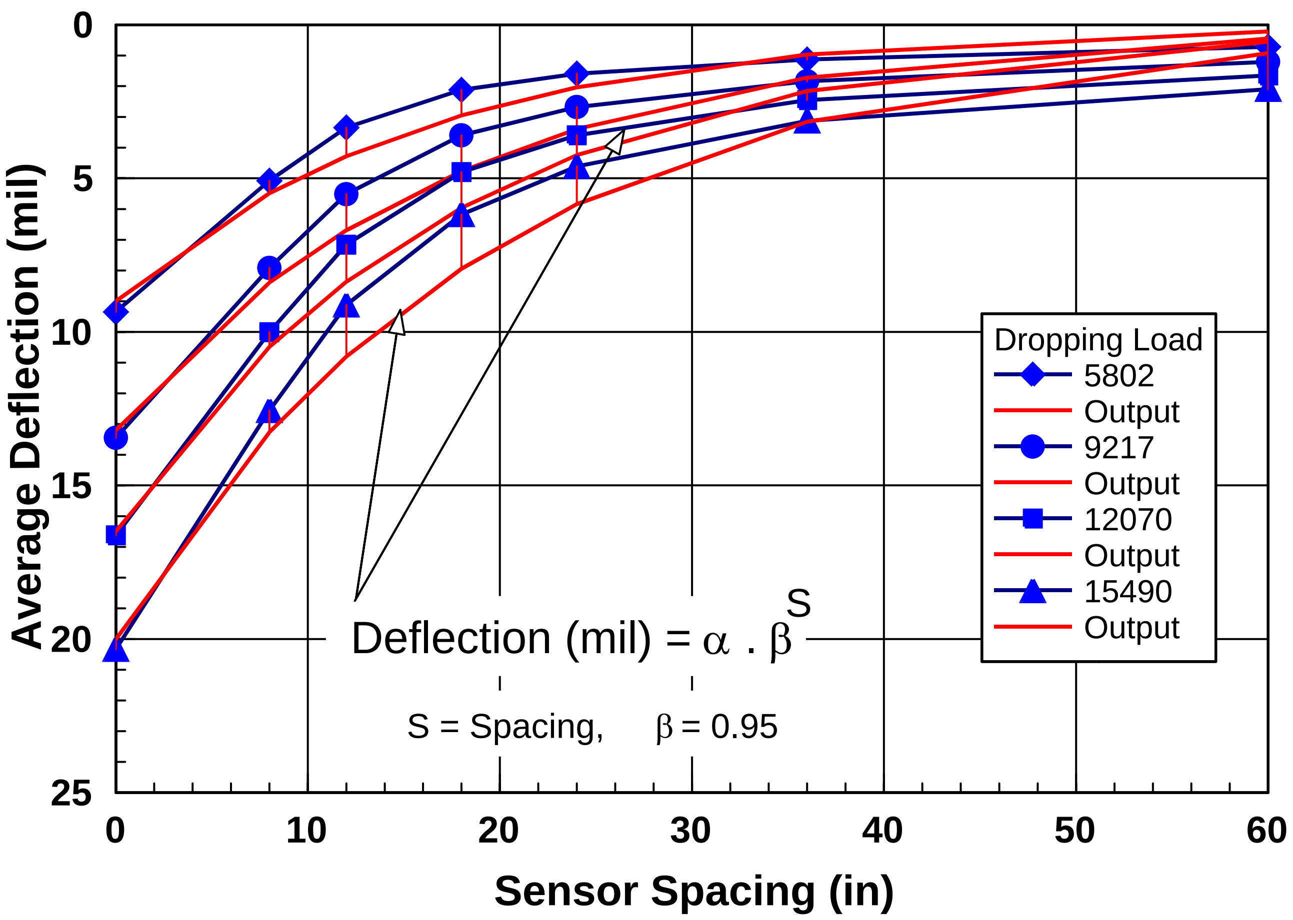


Figure **4.91 LTPP Section B310 (5/28/1991)**

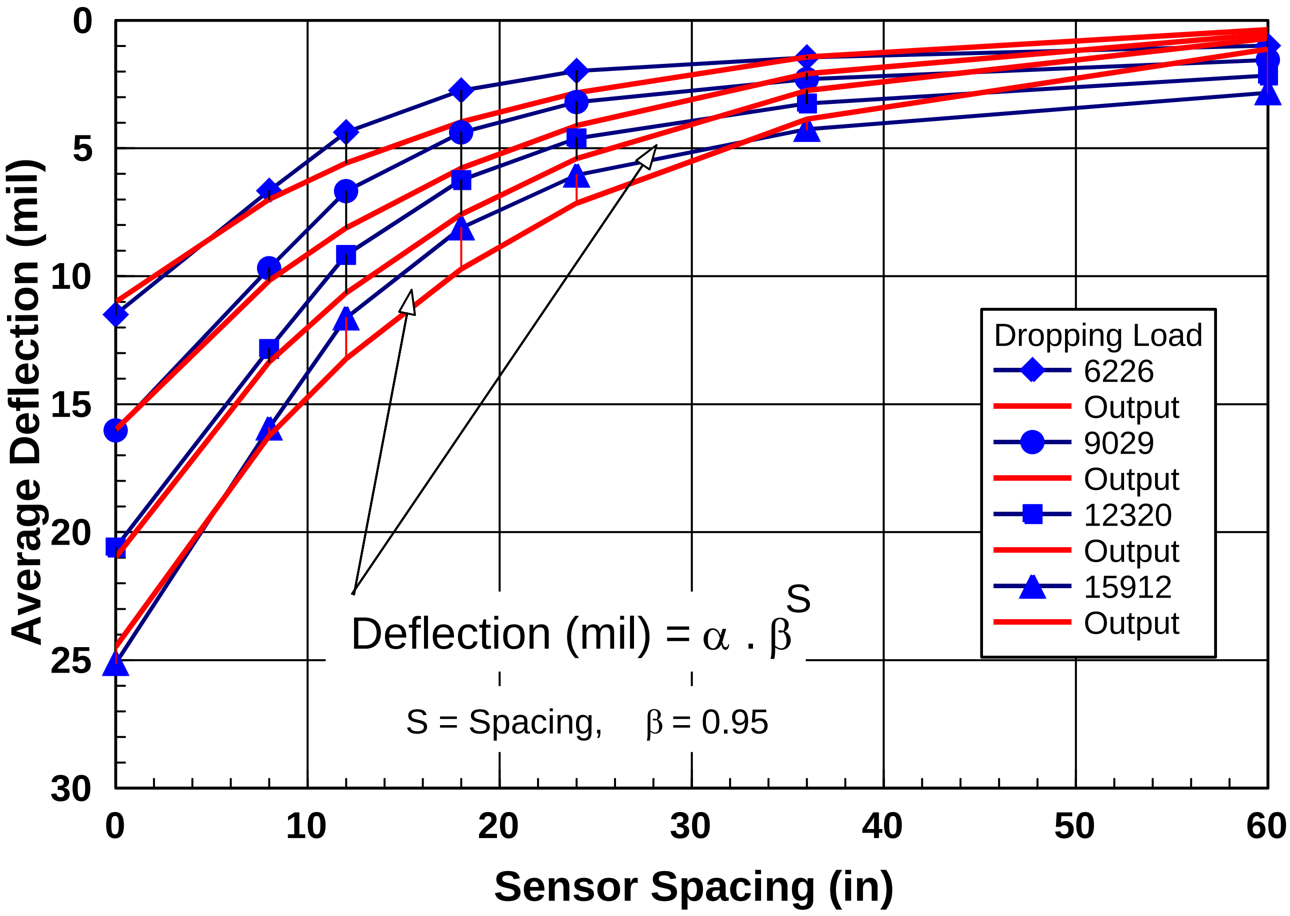


Figure 4.92 Sensors Spacing vs. Average Deflection
LTPP Section B310 (11/22/1993)

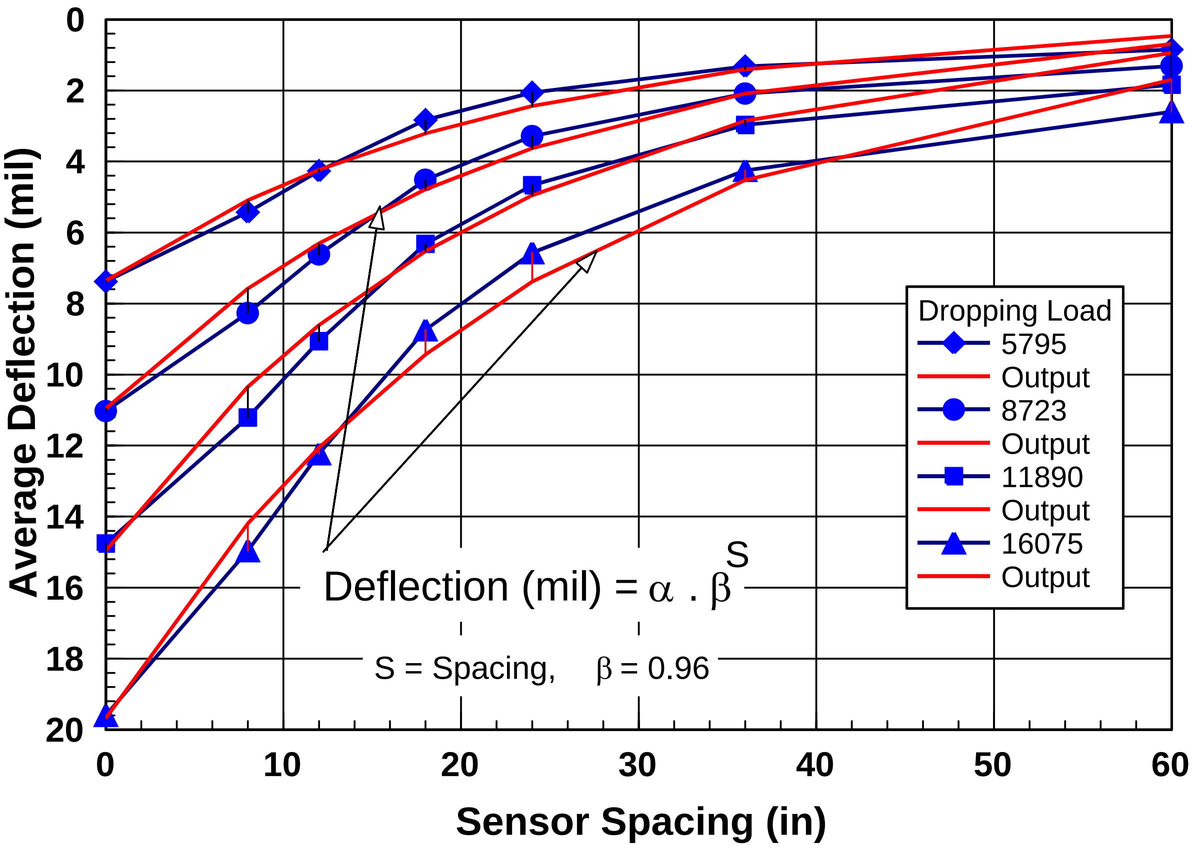


Figure 4.93: α vs. Dropping Load q for FWD Surface
LTPP Section B310 (7/31/1990)

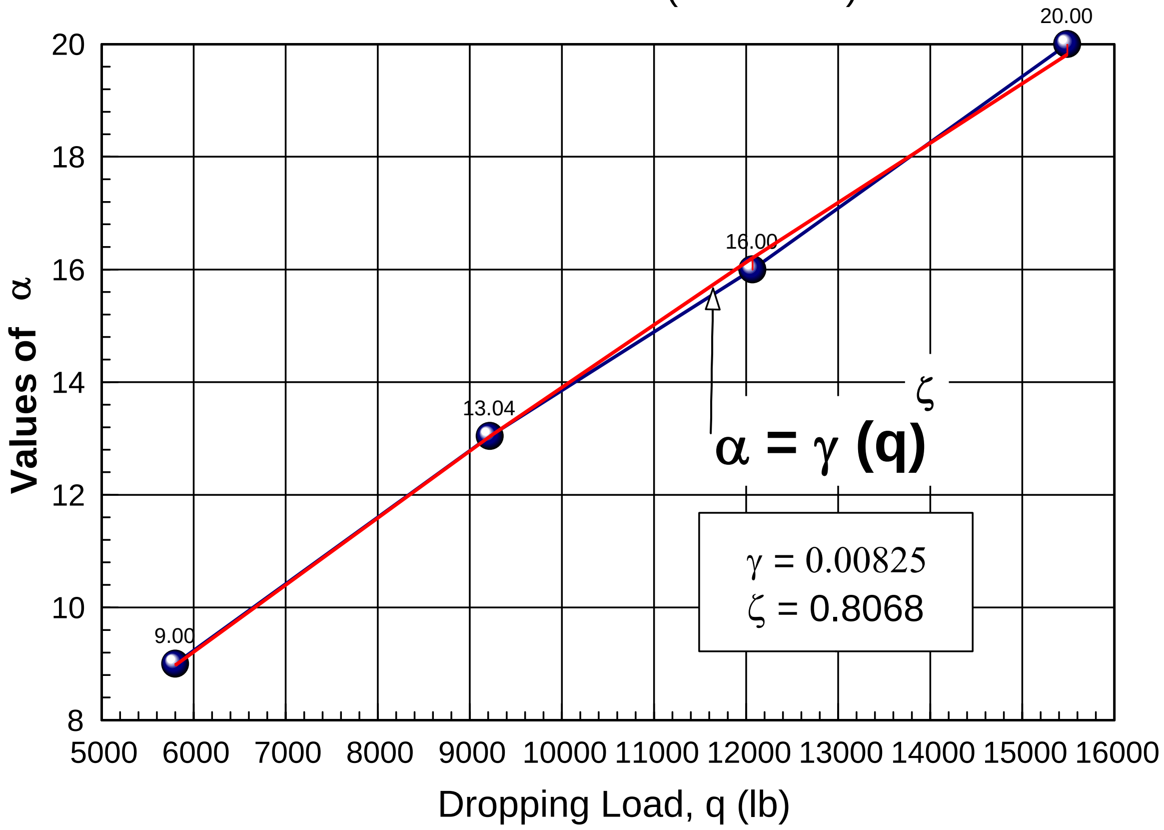


Figure 4.94 α vs. Dropping Load q for FWD Surface
LTPP Section B310 (5/28/1991)

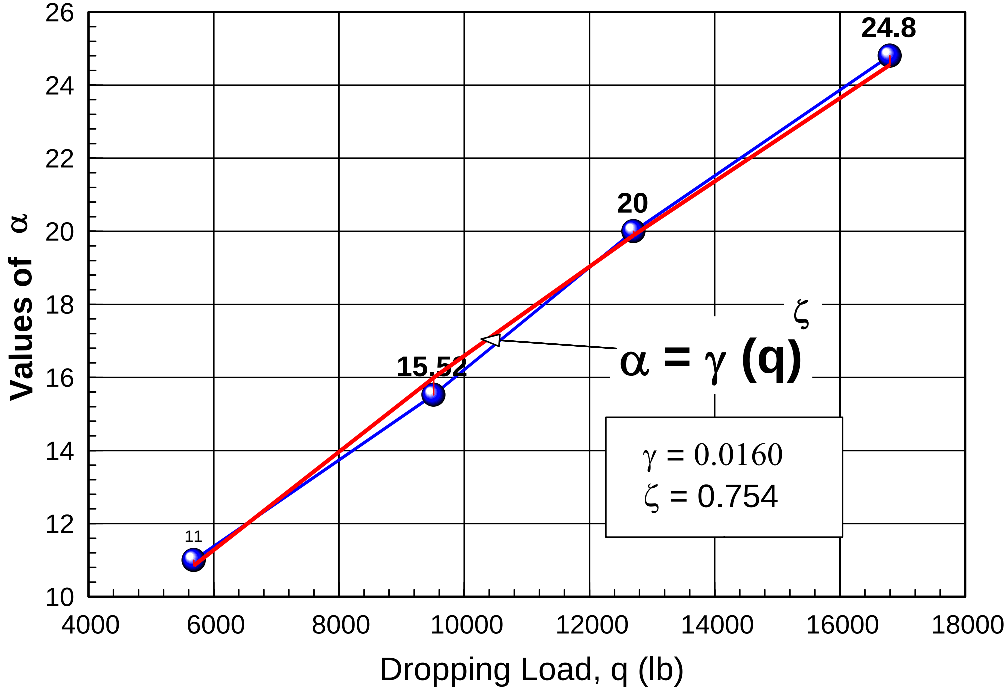


Figure 4.95 α vs. Dropping Load q for FWD Surface
LTPP Section B310 (11/22/1993)

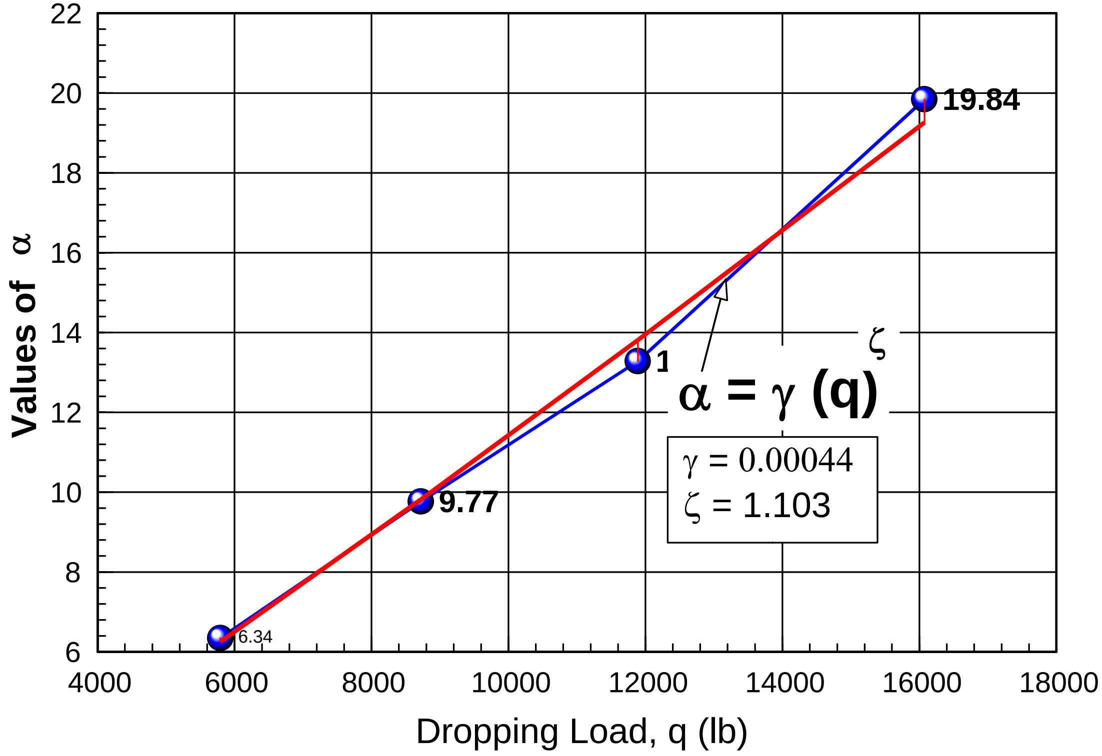


Table 4.20 Average Measured values of
Sensor Deflections, Sensor Spacing, and Dropping Load
for LTPP 0101
Results Date:12/18/1996
(All averages values were measured in the field and were obtained from DATPAVE 3.0)

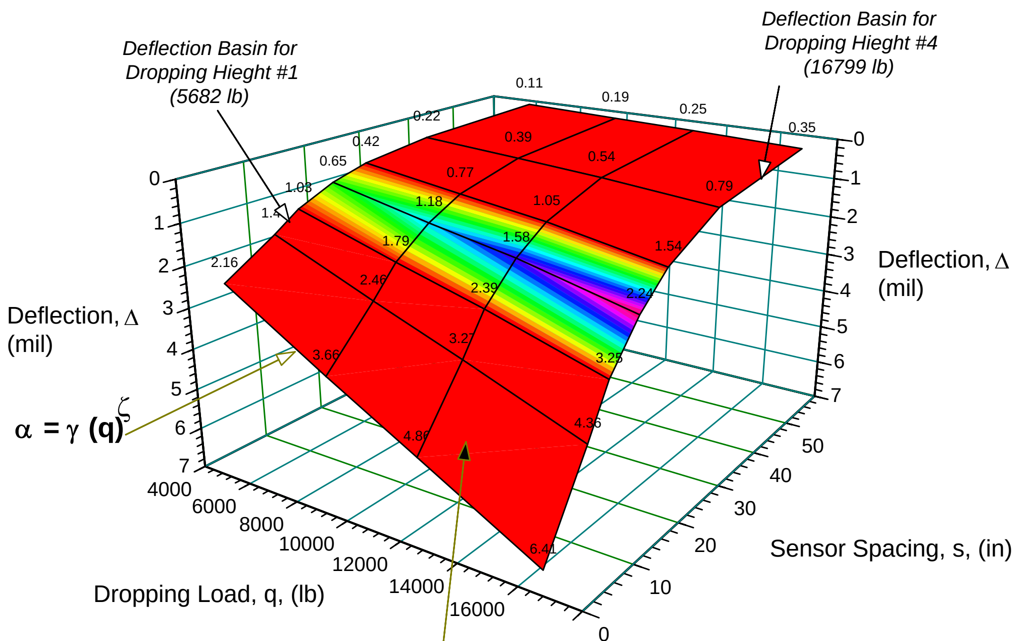
Load (lb)	Drop#1	Drop#2	Drop#3	Drop#4
Spacing (in)	5682	9511	12705	16799
0	2.16	3.66	4.86	6.41
8	1.44	2.46	3.27	4.36
12	1.03	1.79	2.39	3.25
18	0.65	1.18	1.58	2.24
24	0.42	0.77	1.05	1.54
36	0.22	0.39	0.54	0.79
60	0.11	0.19	0.25	0.35

Average Measured values of
Sensor Deflections, Sensor Spacing, and Dropping Load
for LTPP 0101
Results Date:2/15/2000
(All averages values were measured in the field and were obtained from DATPAVE 3.0)

Load (lb)	Drop#1	Drop#2	Drop#3	Drop#4
Spacing (in)	5863	9069	12212	14386
0	2.36	3.66	4.89	5.85
8	1.36	2.14	2.87	3.41
12	1	1.6	2.14	2.57
18	0.6	0.98	1.33	1.65
24	0.39	0.65	0.9	1.14
36	0.21	0.34	0.47	0.6
60	0.14	0.22	0.31	0.38

Figure 4.96: AverageMeasured values of
Sensor Deflections, Sensor Spacing, and Dropping Load
for LTPP 0101
Results Date: 12/18/1996

(All averages values were measured in the field and were obtained from DATPAVE 3.0)



3D Surface Equation

$$\Delta\ (mil) = \gamma\ (q)^{\zeta} (\beta)^{s}$$

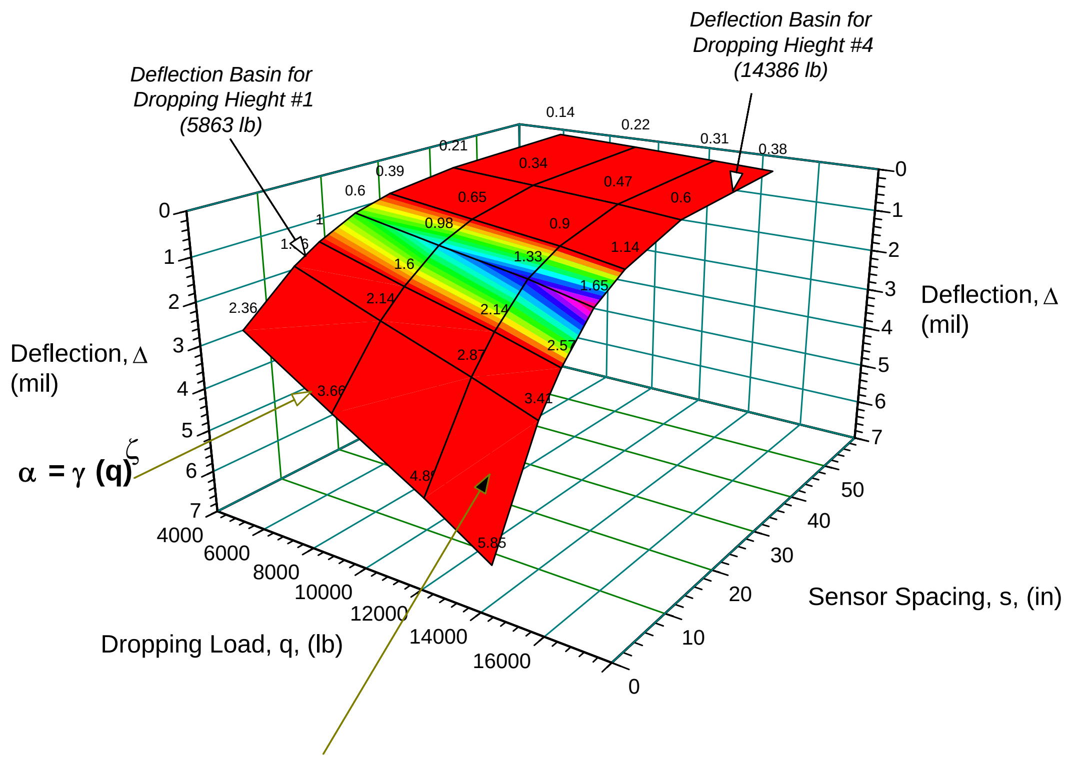
s = Sensor Spacing

Parameters For Section 0101

γ = 0.00114
ζ = 0.986
β = 0.946

Figure 4.97: AverageMeasured values of
Sensor Deflections, Sensor Spacing, and Dropping Load
for LTPP 0101
Results Date: 2/15/2000

(All averages values were measured in the field and were obtained from DATPAVE 3.0)



3D Surface Equation

$$\Delta\ (\text{mil}) = \gamma\,(q)^{\zeta}\,(\beta)^{s}$$

s = Sensor Spacing

Parameters For Section 0101

$\gamma = 0.00114$
$\zeta = 0.885$
$\beta = 0.935$

Figure 4.98 Sensors Spacing vs. Average Deflection

LTPP Section 0101 (12/18/1996)

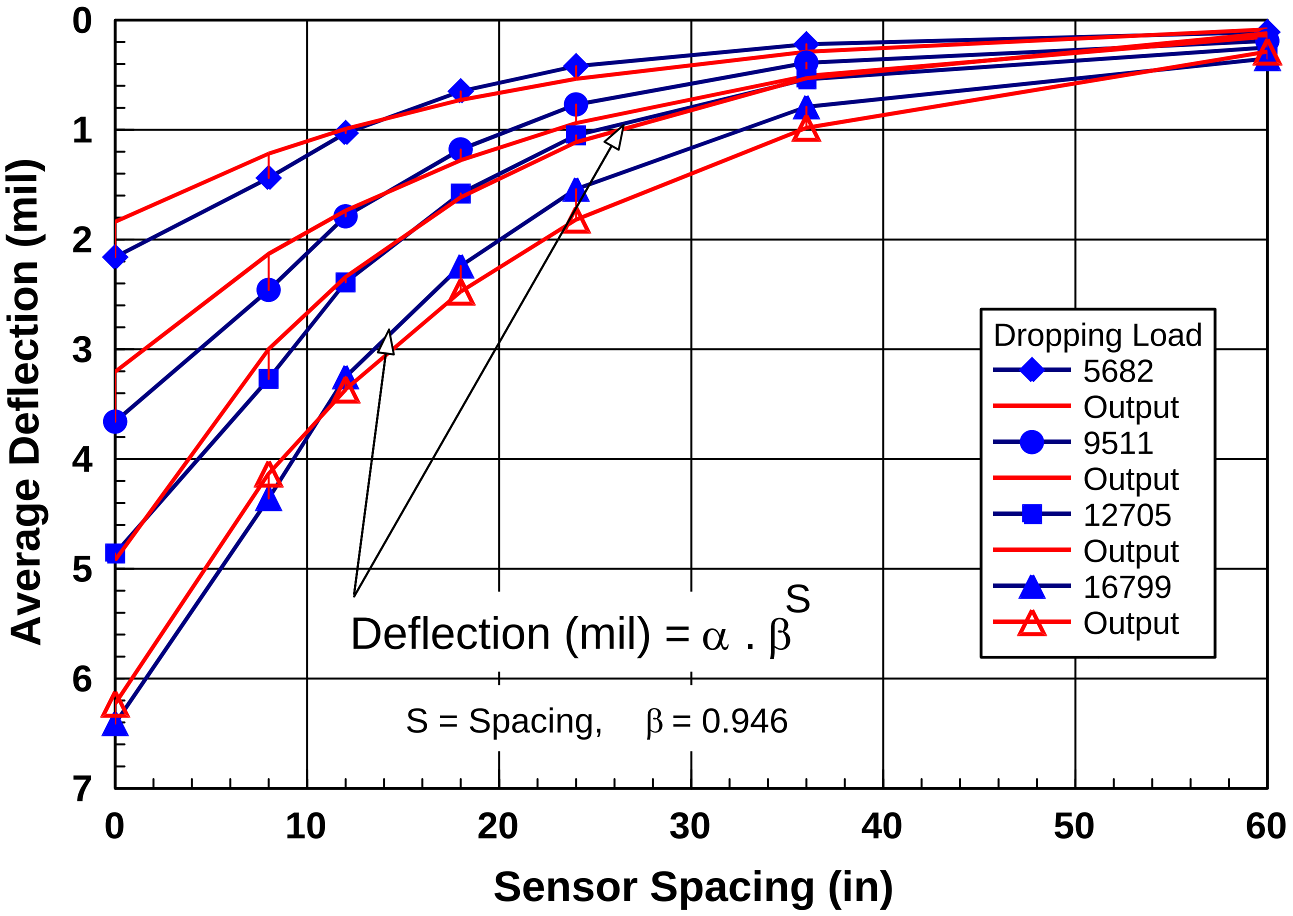


Figure 4.99 Sensors Spacing vs. Average Deflection

LTPP Section 0101 (2/15/2000)

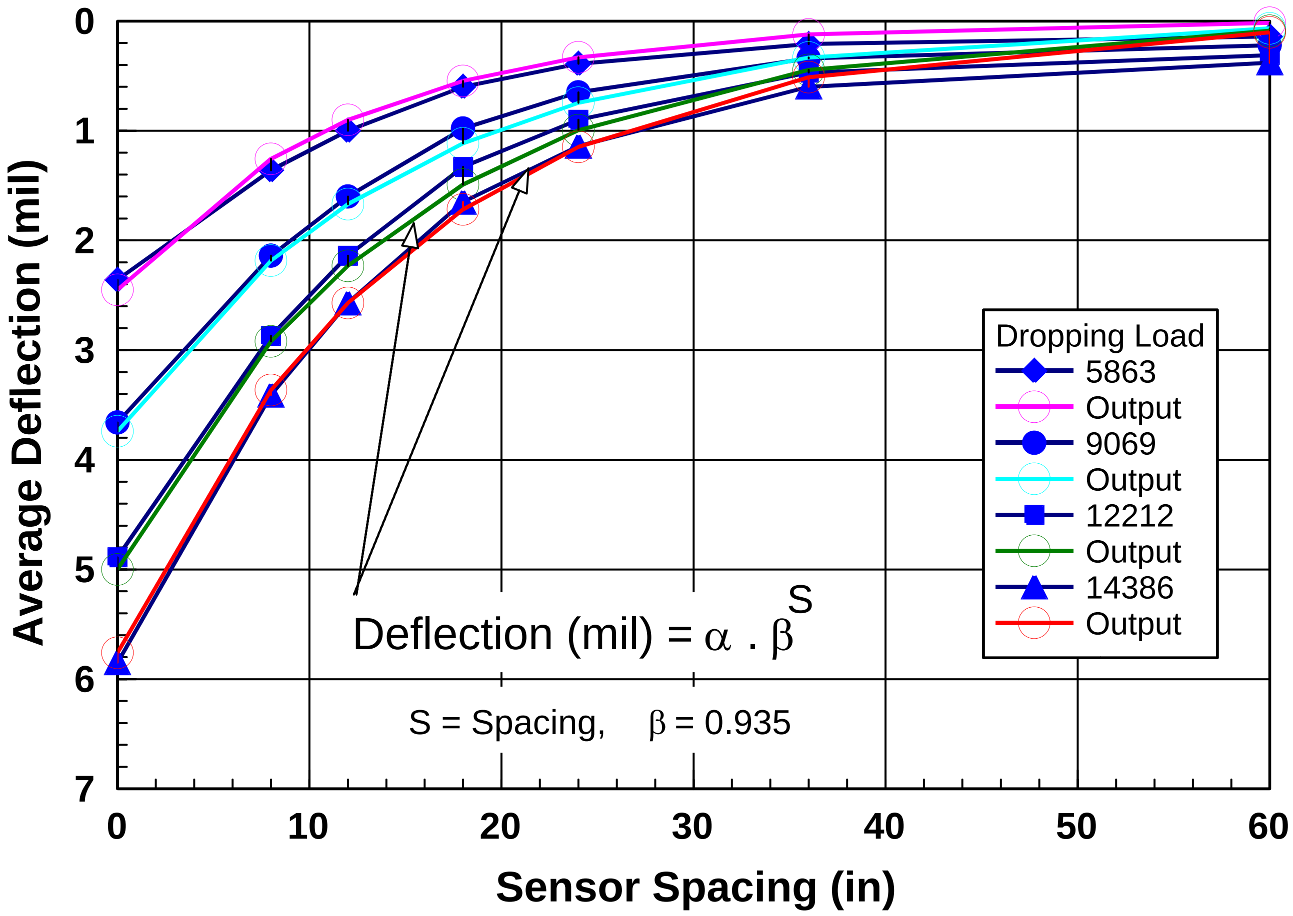


Figure 4.100: α vs. Dropping Load q for FWD Surface
LTPP Section 0101 (12/18/1996)

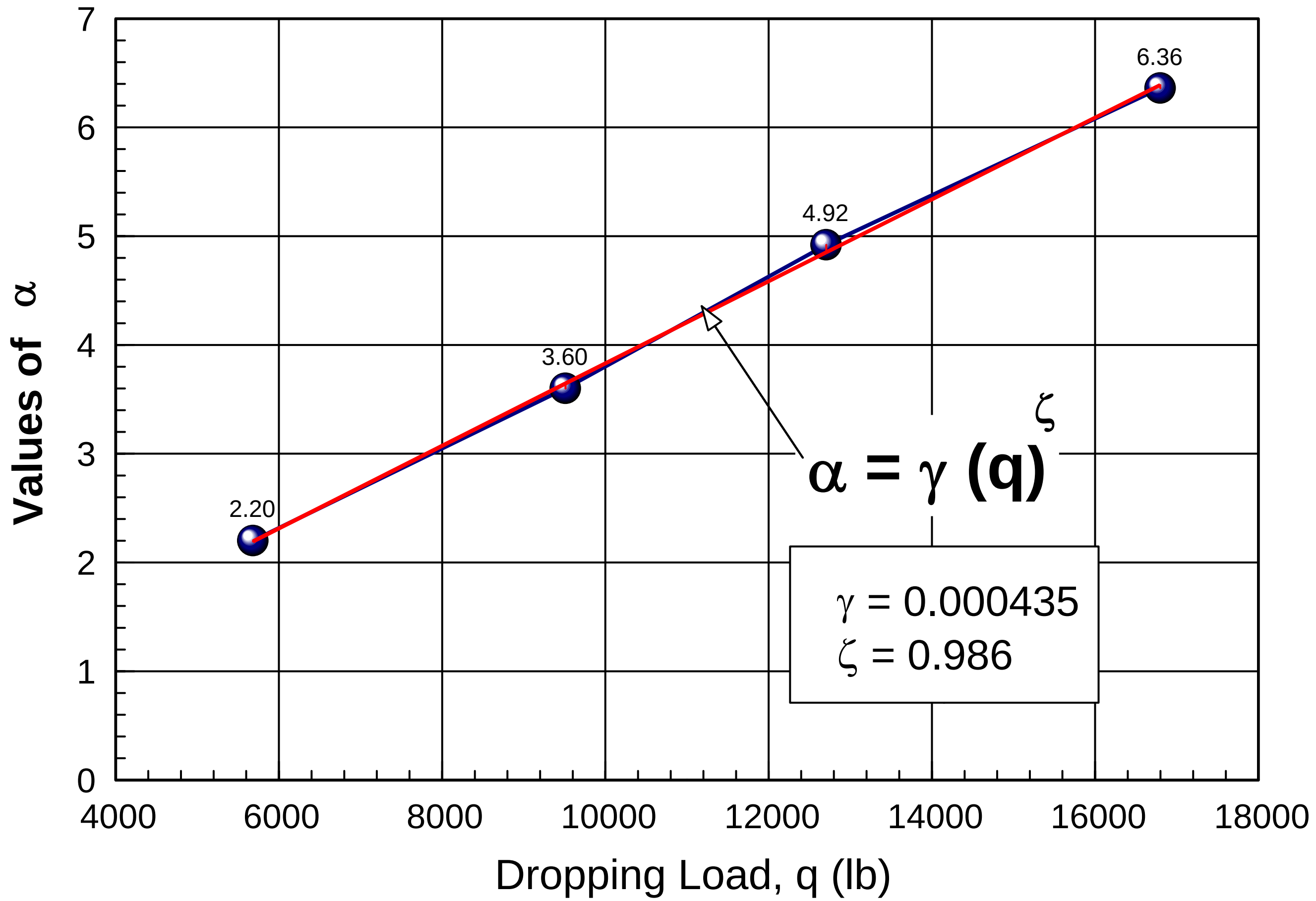


Figure 4.101: α vs. Dropping Load q for FWD Surface
LTPP Section 0101 (2/15/2000)

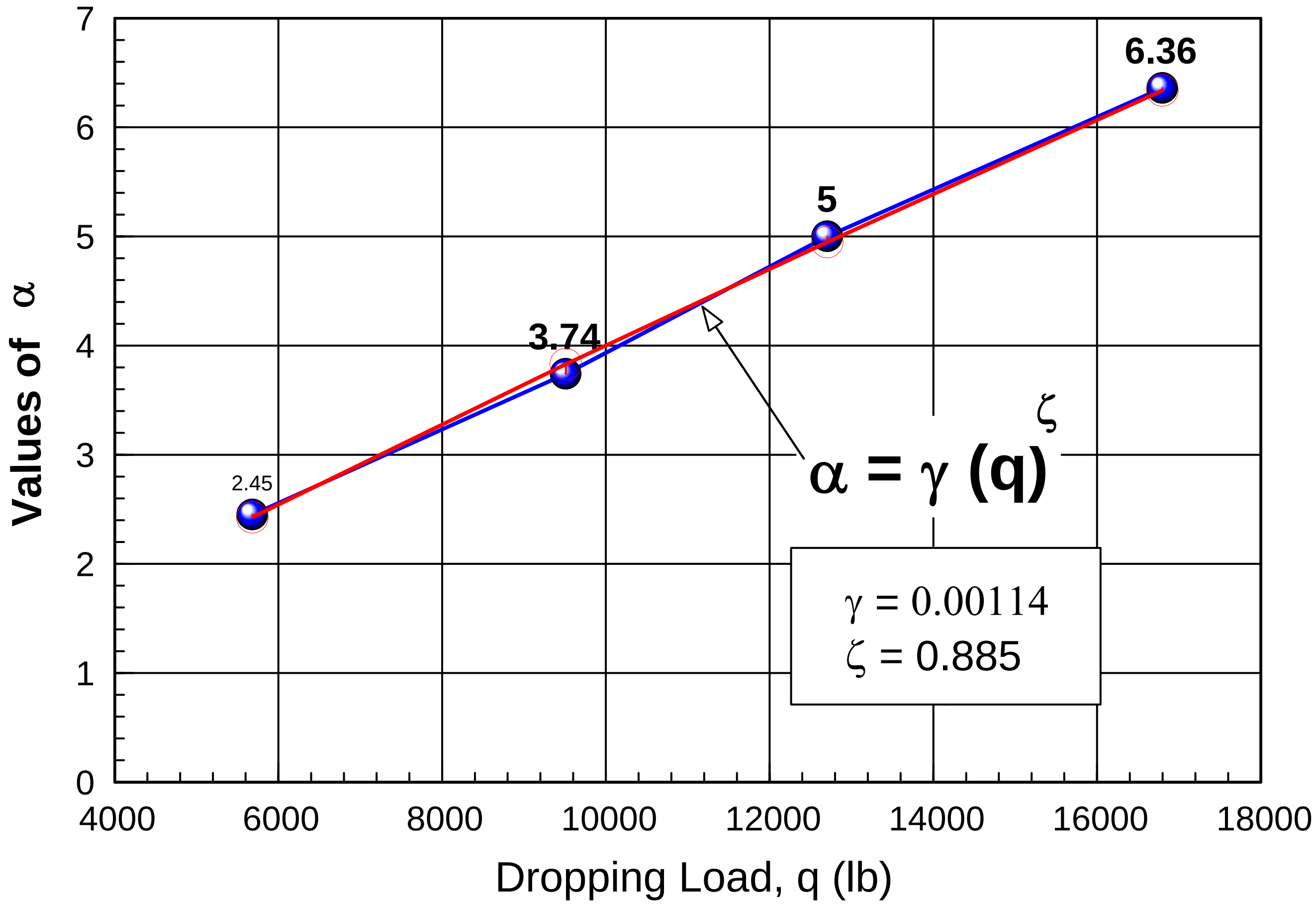


Figure 4.102: Sensors Spacing vs. Average Deflection
LTPP Section 4097 (11/21/1989)

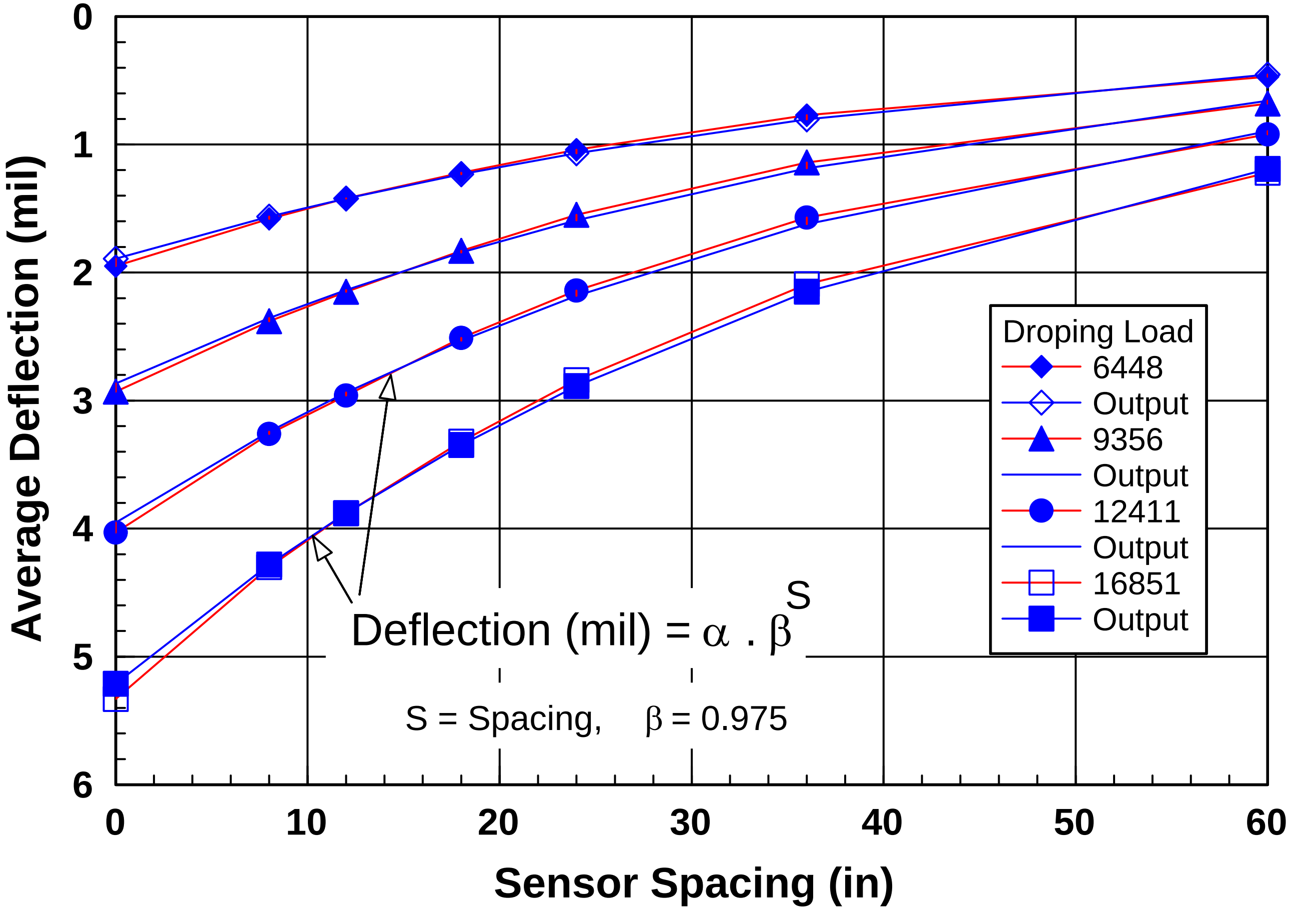


Figure 4.103: α vs. Dropping Load q for FWD Surface
LTPP 4097

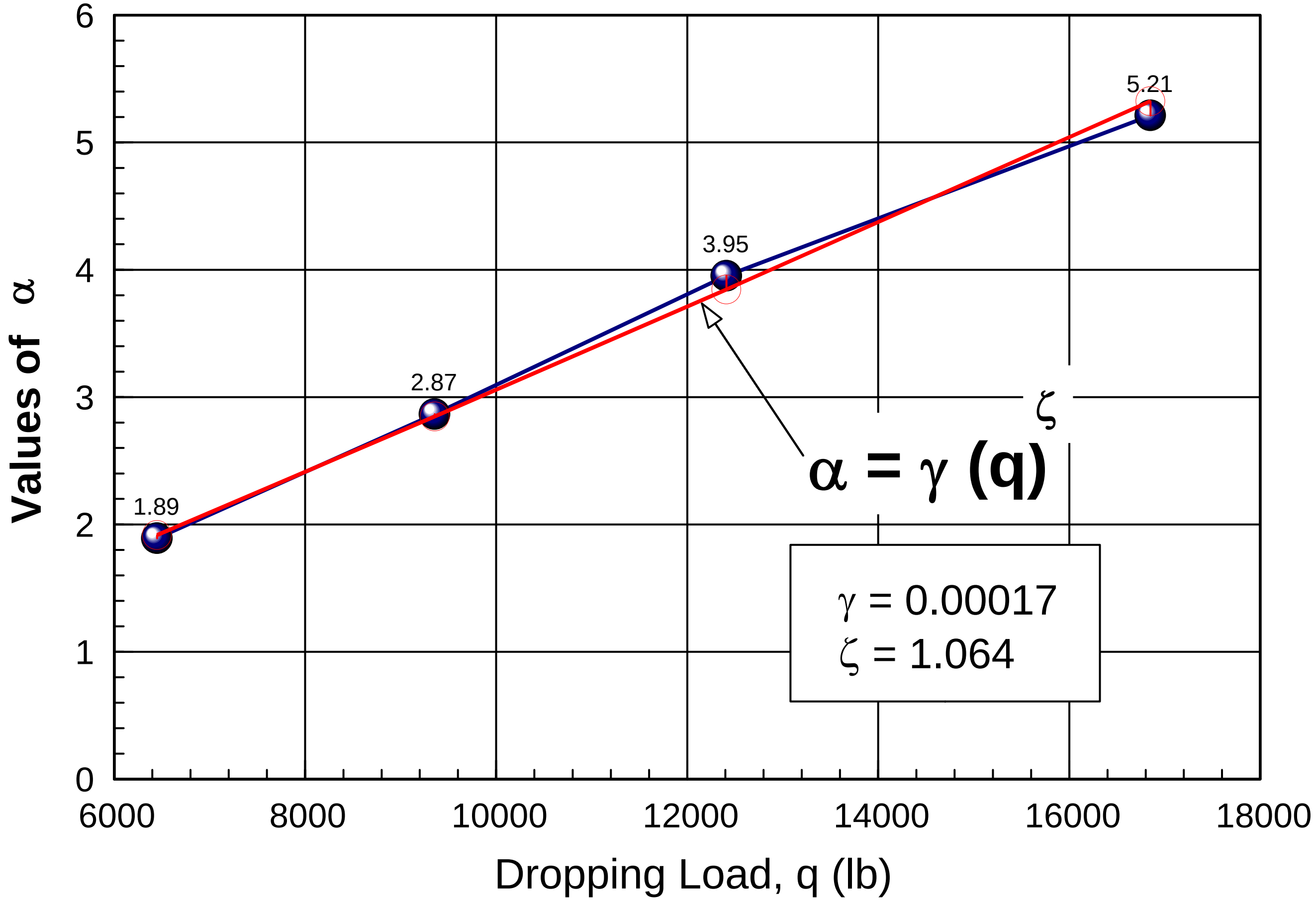


Figure 4.104: Average Deflection at Sensors 1 to 7 vs. Average Dropping Load
LTPP Section 4097 (11/21/1989)

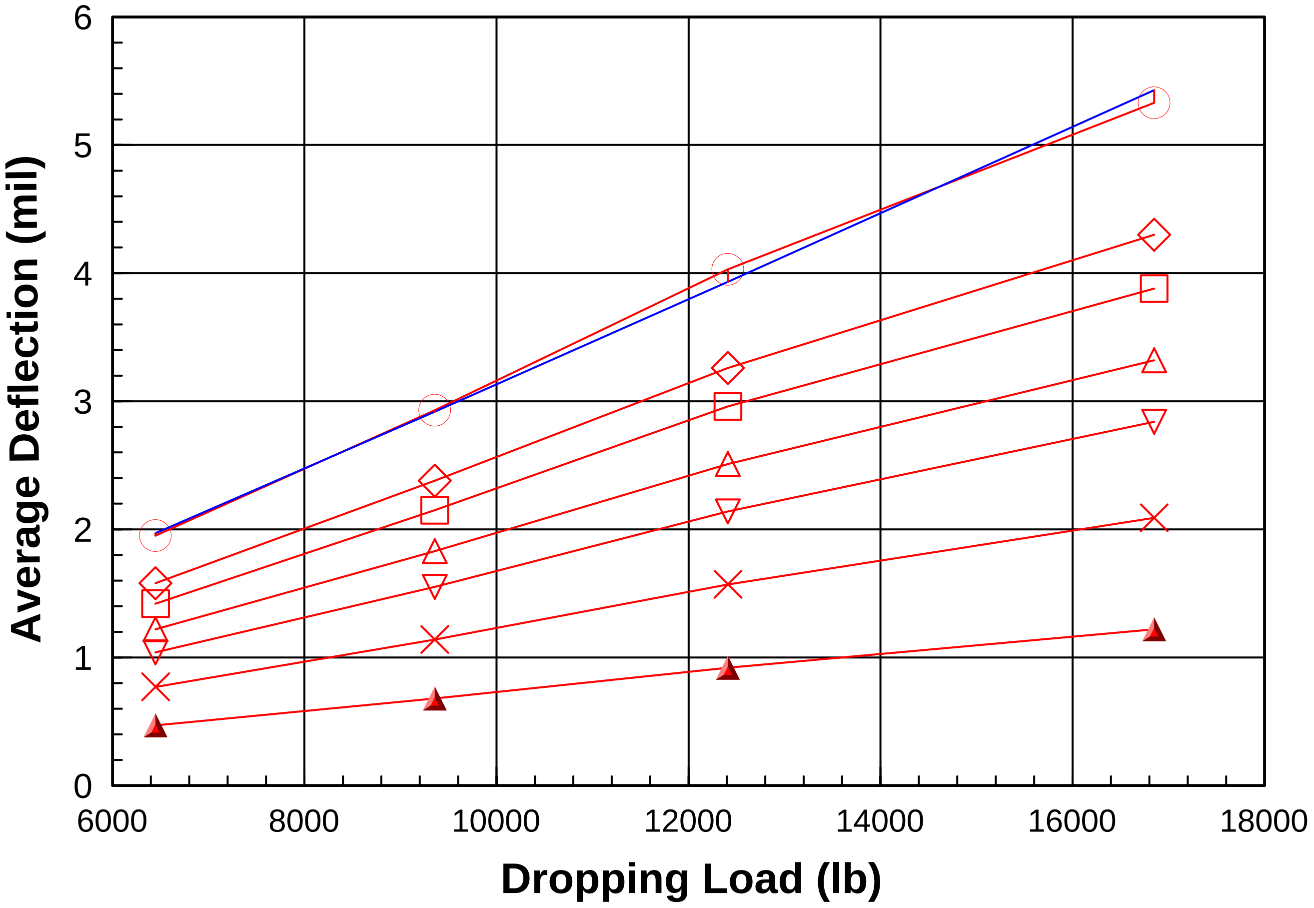


Figure 4.105: Predicted Deflections for LTPP Section 4097

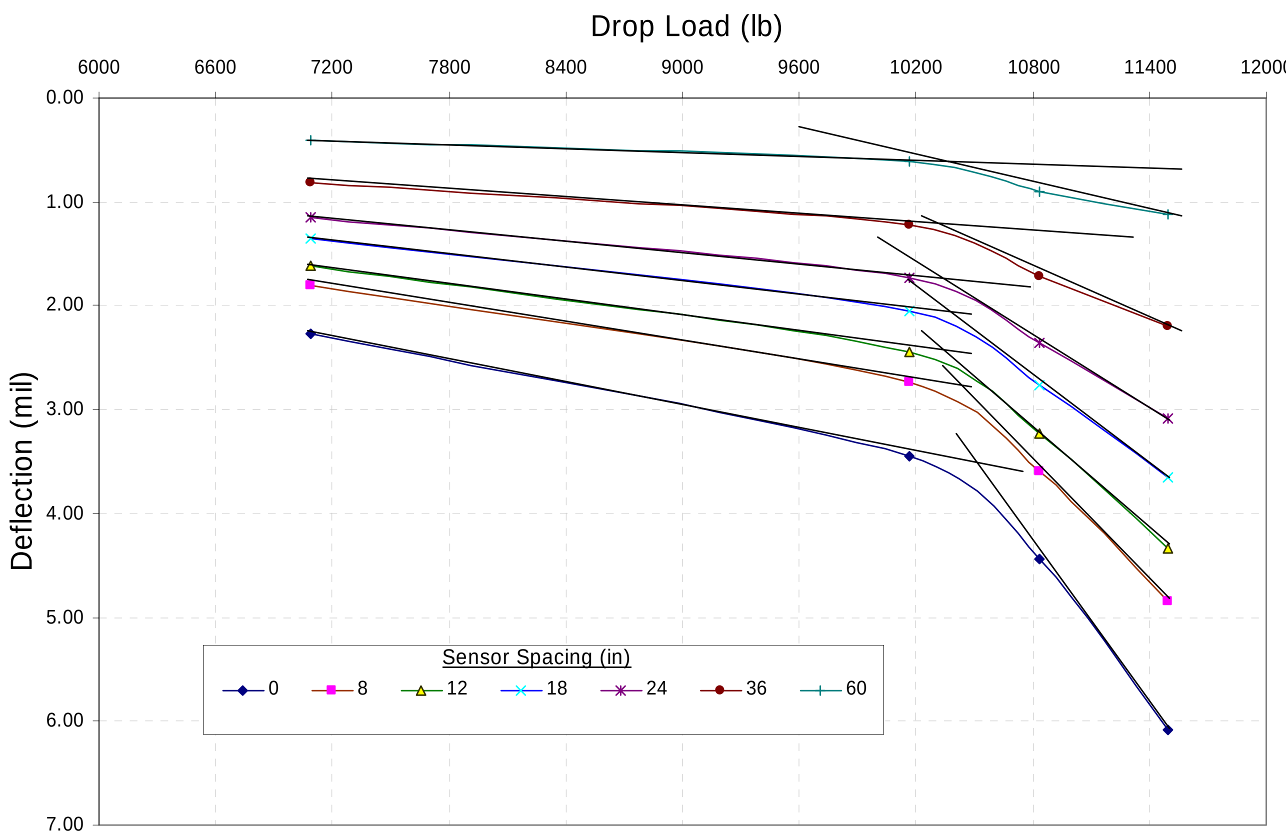


Figure 4.106: Maximum and Minimum Deflections at LTPP Section 4097

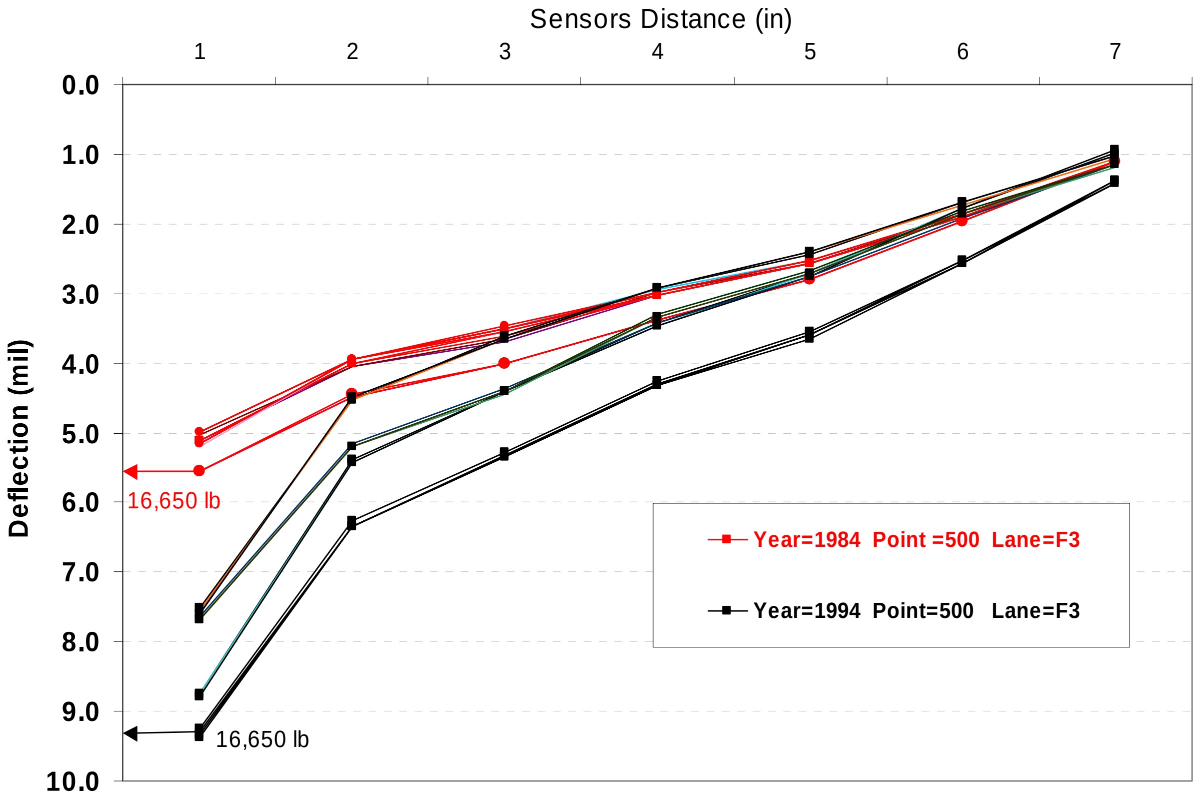


Figure 4.107: Deflection of Sensor # 1 for LTPP Section 4097

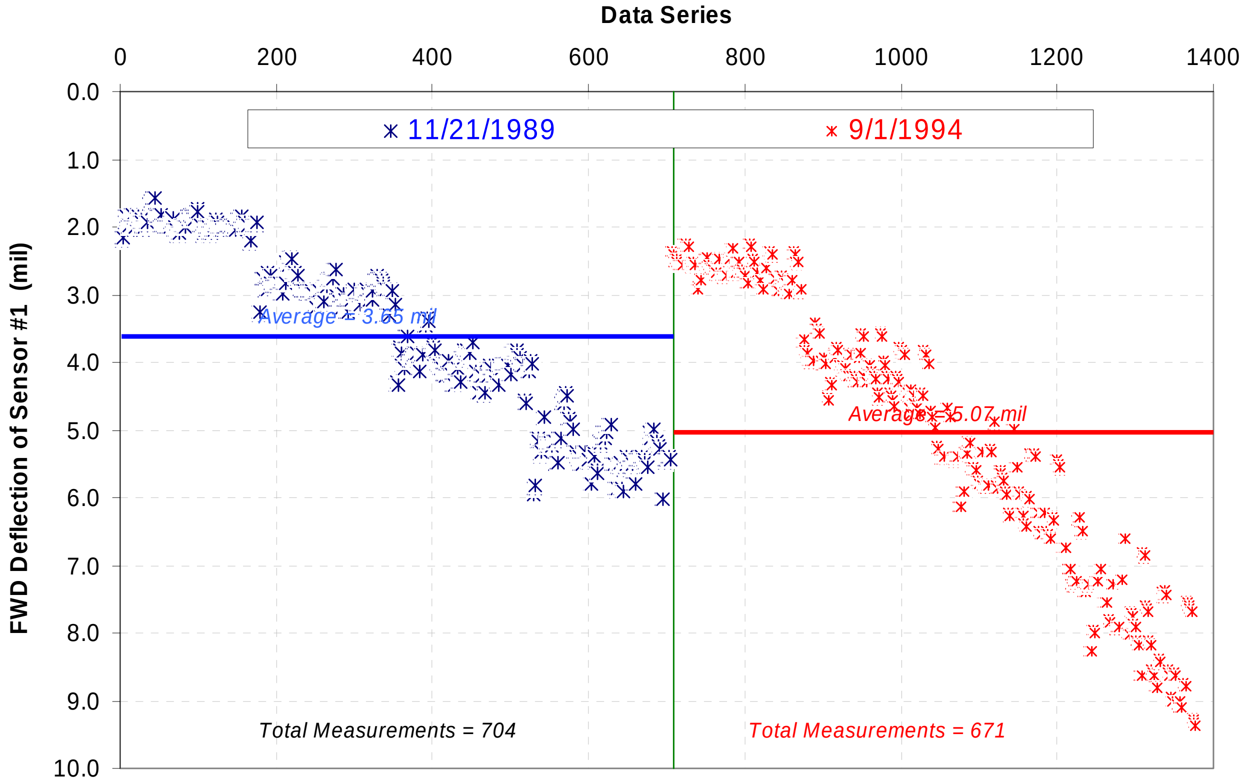


Figure 4.108: Deflection of Sensor # 7 for LTPP Section 4097

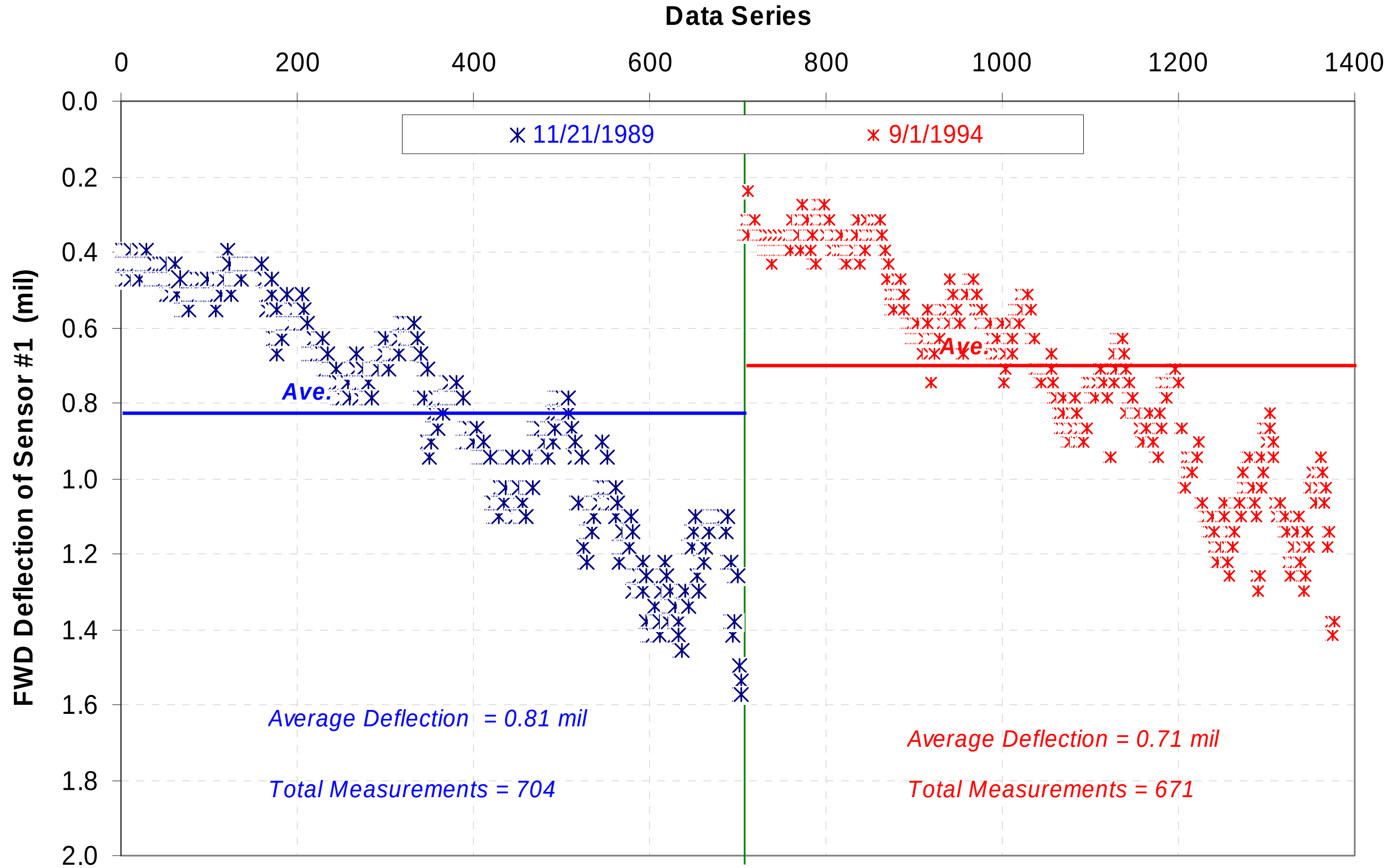


Figure 4.109: Deflection in FWD Sensors for LTPP Section 4097, Results Date 9/1/1994
Dropping Load = 6144.82 lb
Average of each sensor was ploted vs. average loads (See SG 3D chart)

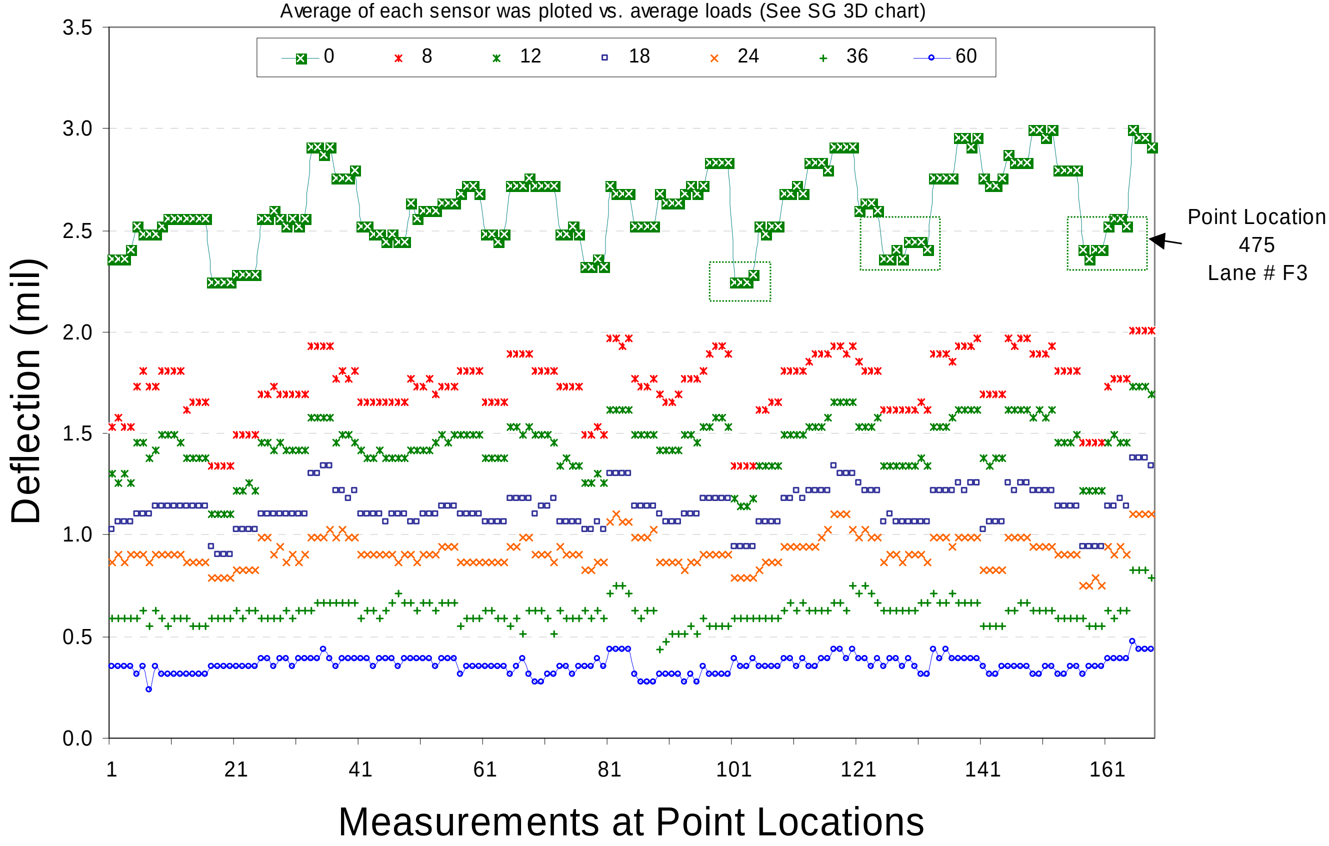


Figure 4.110: Deflection in FWD Sensors for LTPP Section 4097, Results Date 9/1/1994
Dropping Load = 16536 lb

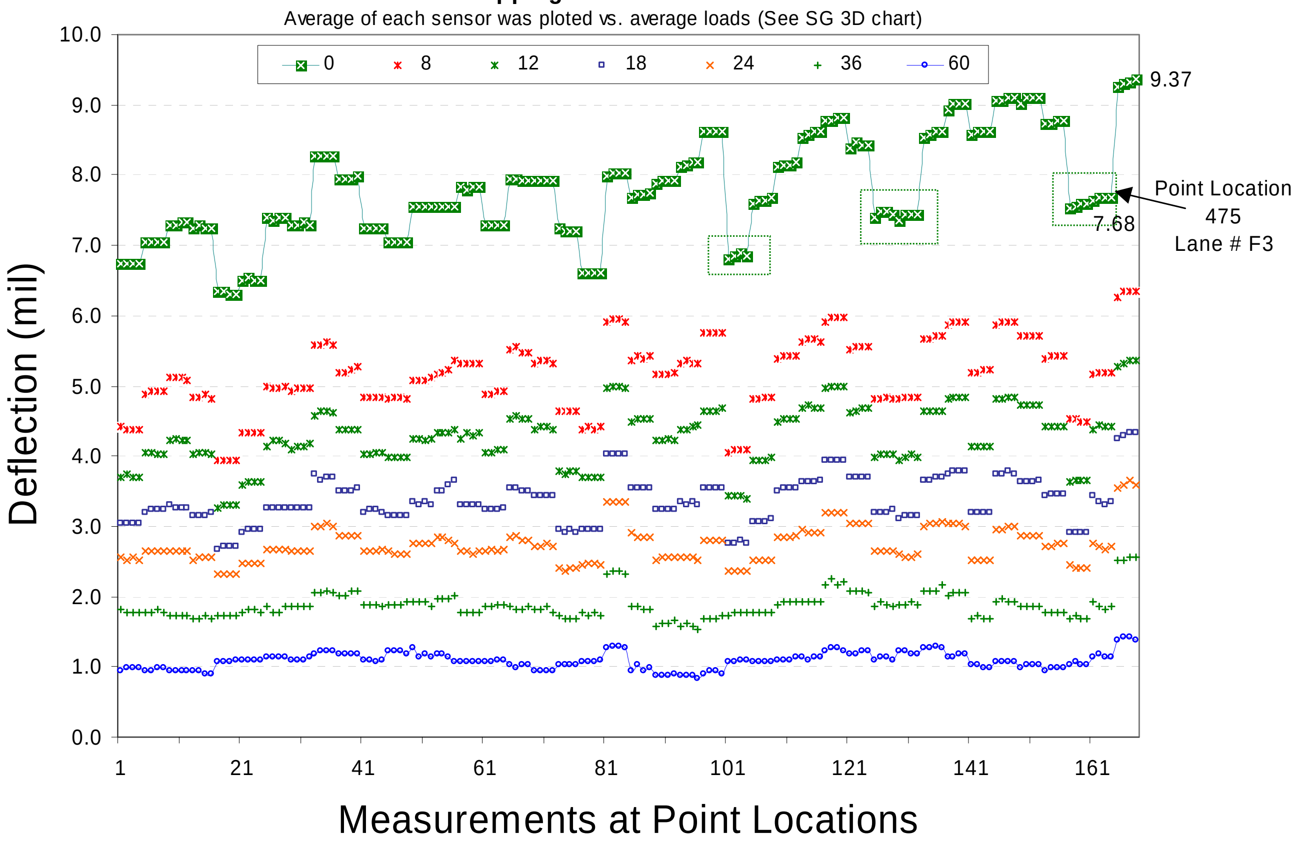


Figure 4.111: **Deflection in FWD Sensors for LTPP Section 4097, Results Date 11/21/1989**
Dropping Load = 16851 lb

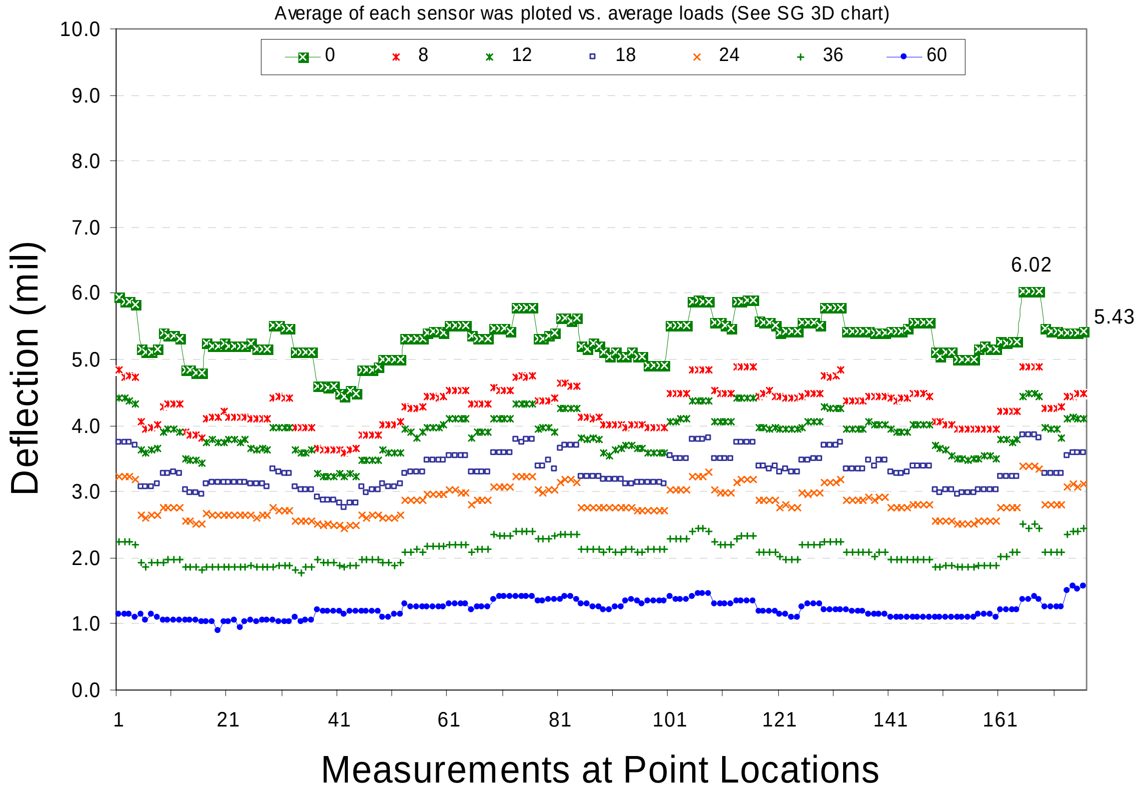


Figure 4.112: Deflection in FWD Sensors for LTPP Section 4097, Results Date 11/21/1989
Dropping Load = 6447.69 lb

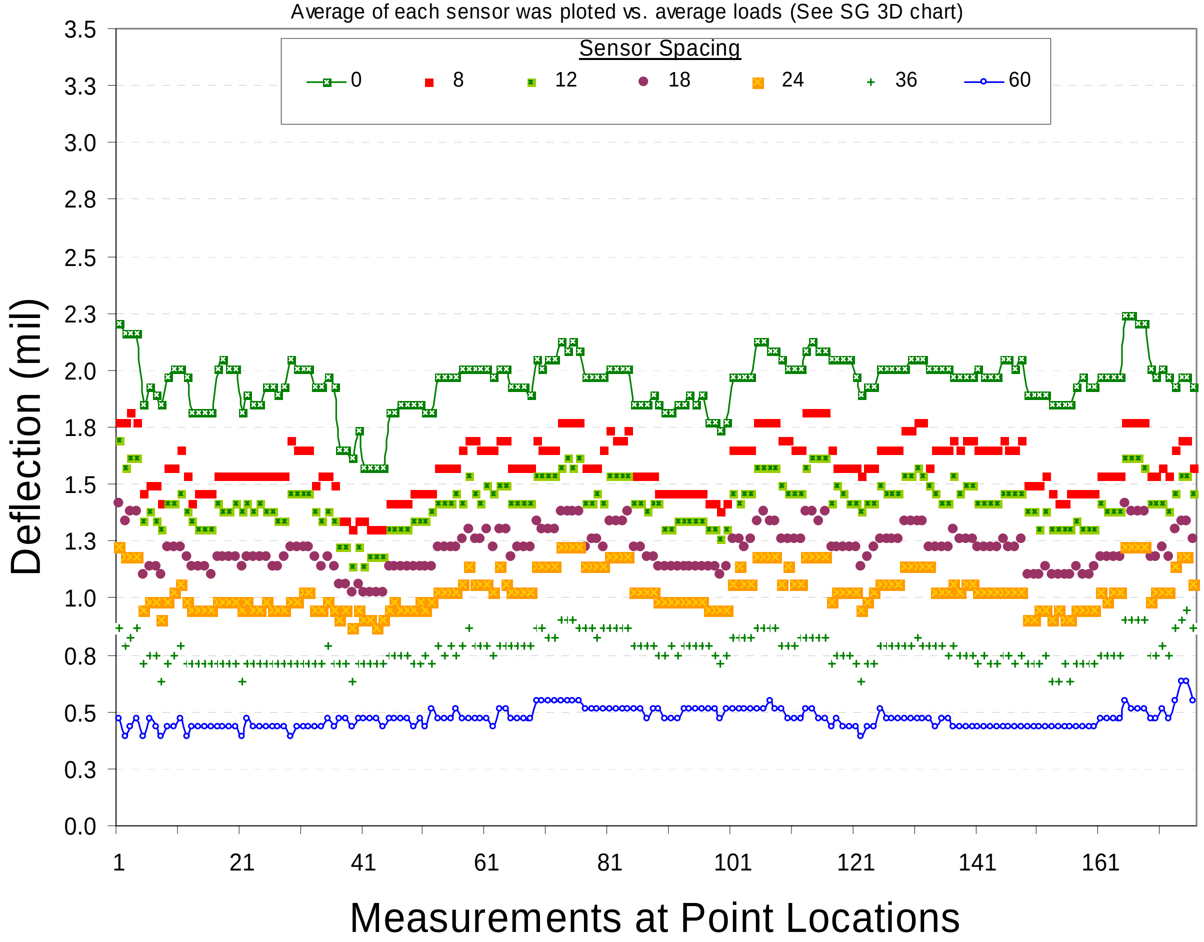


Figure 4.113: Road 200 Section 71030

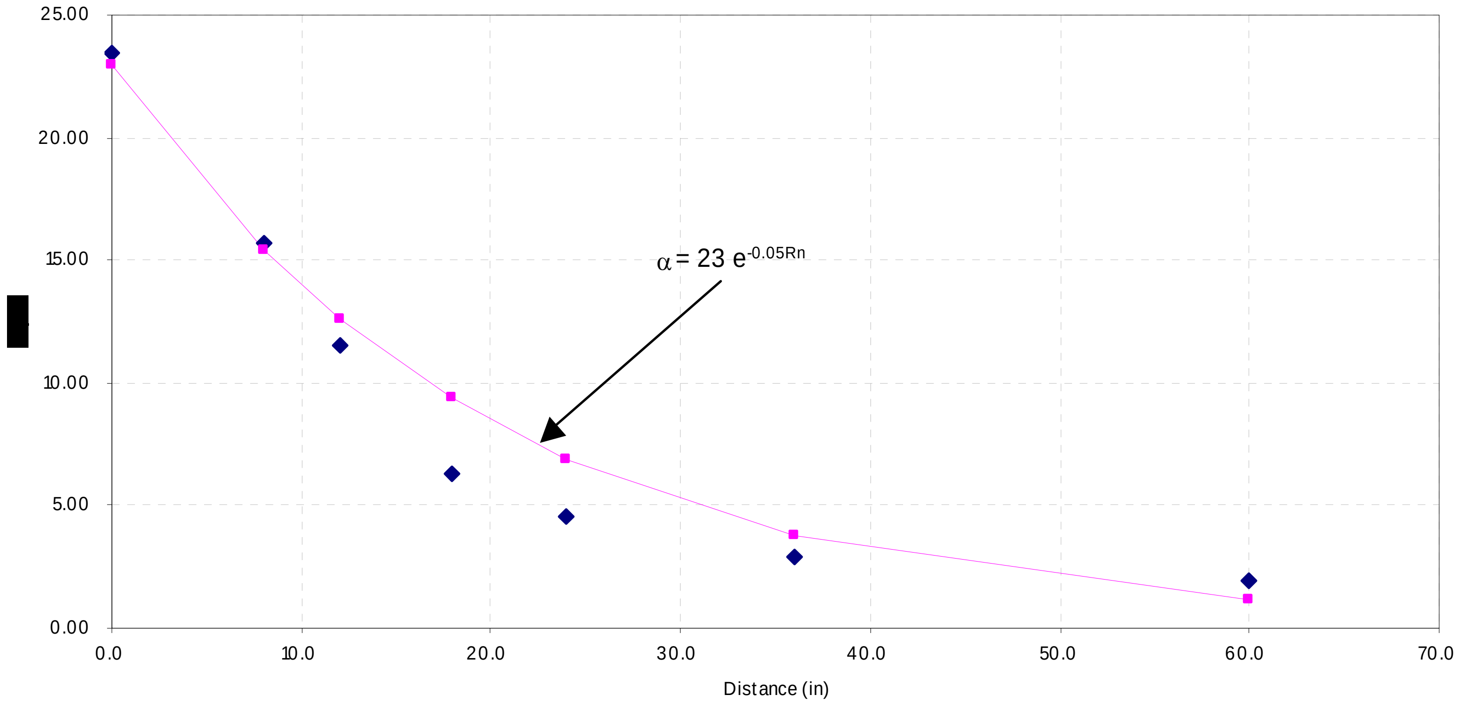


Figure 4.114: Road 200 Section 71030

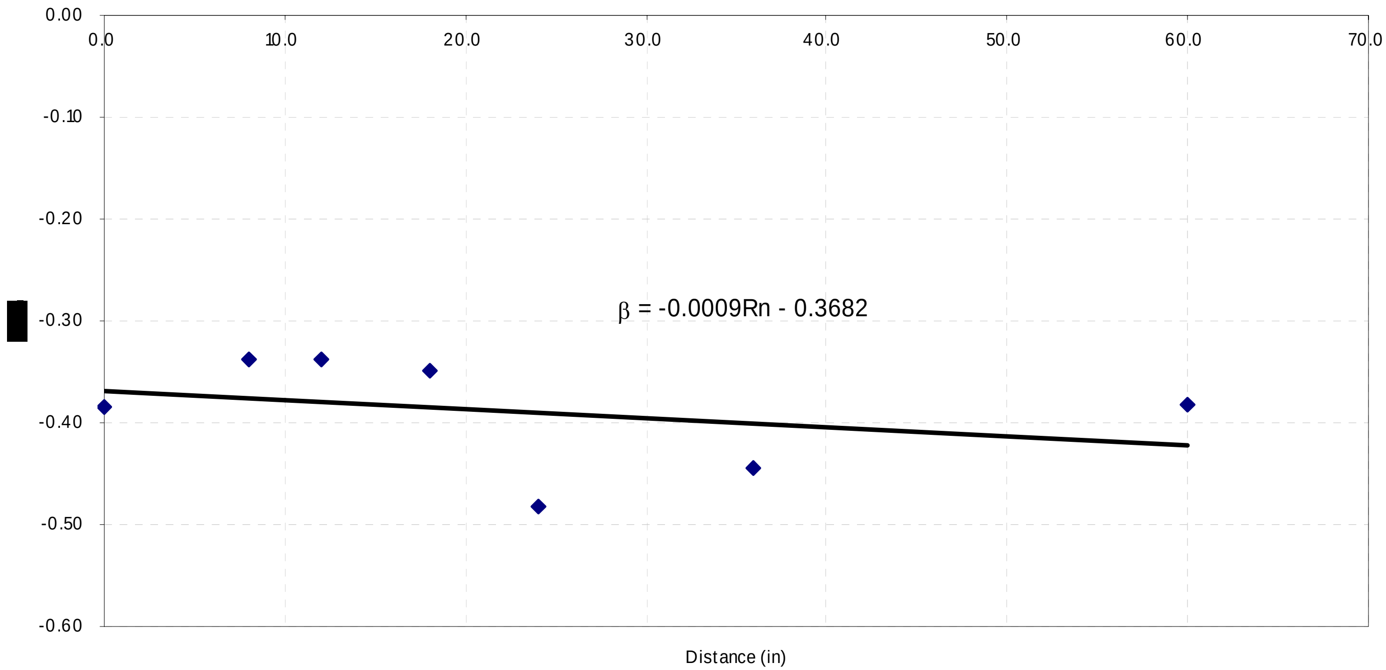


Figure 4.115: Range of Deflection Basins at Florida LTPP Sections

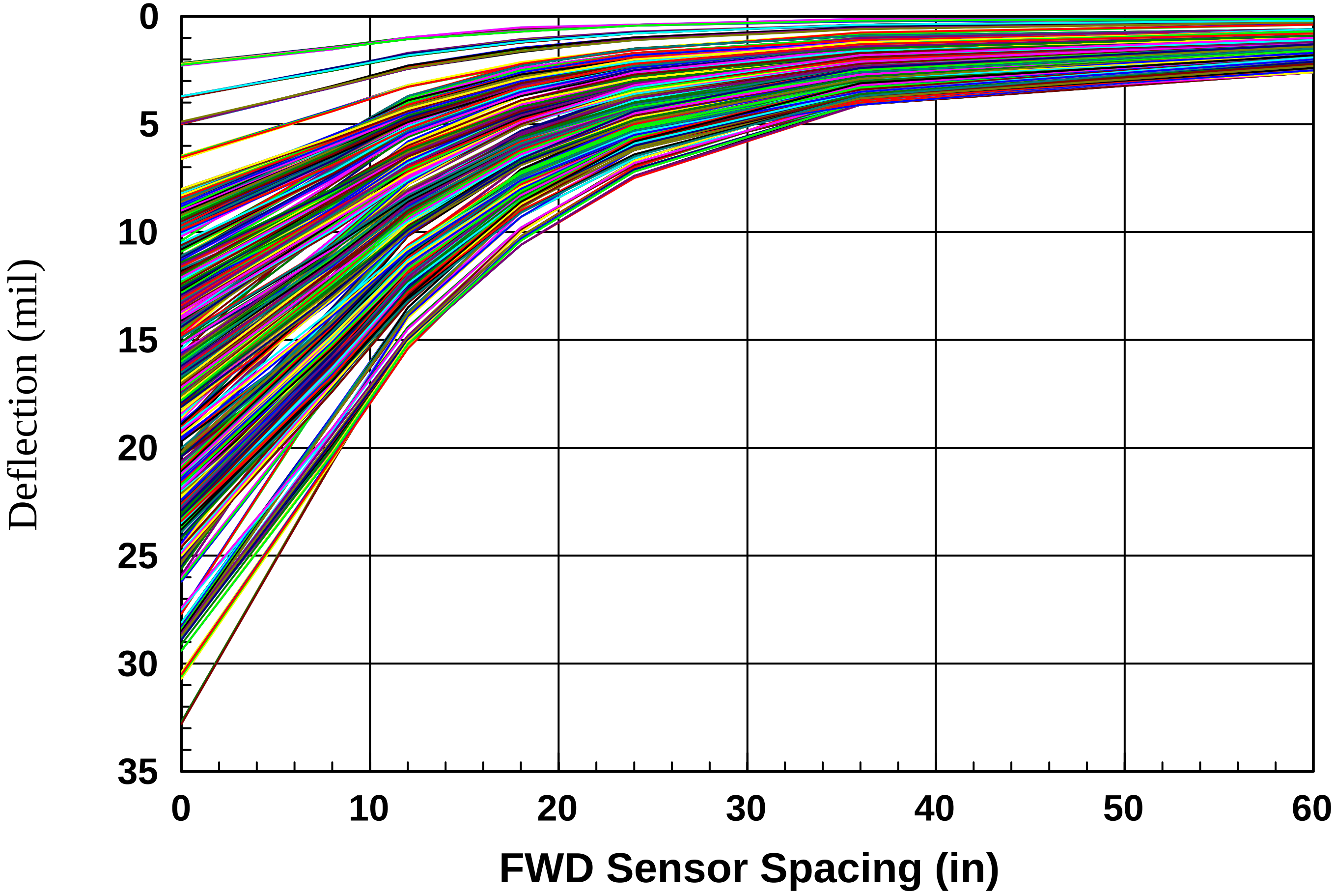


Figure 4.116: Water Table vs. Sensor Deflections for State Road 16 Section 71050

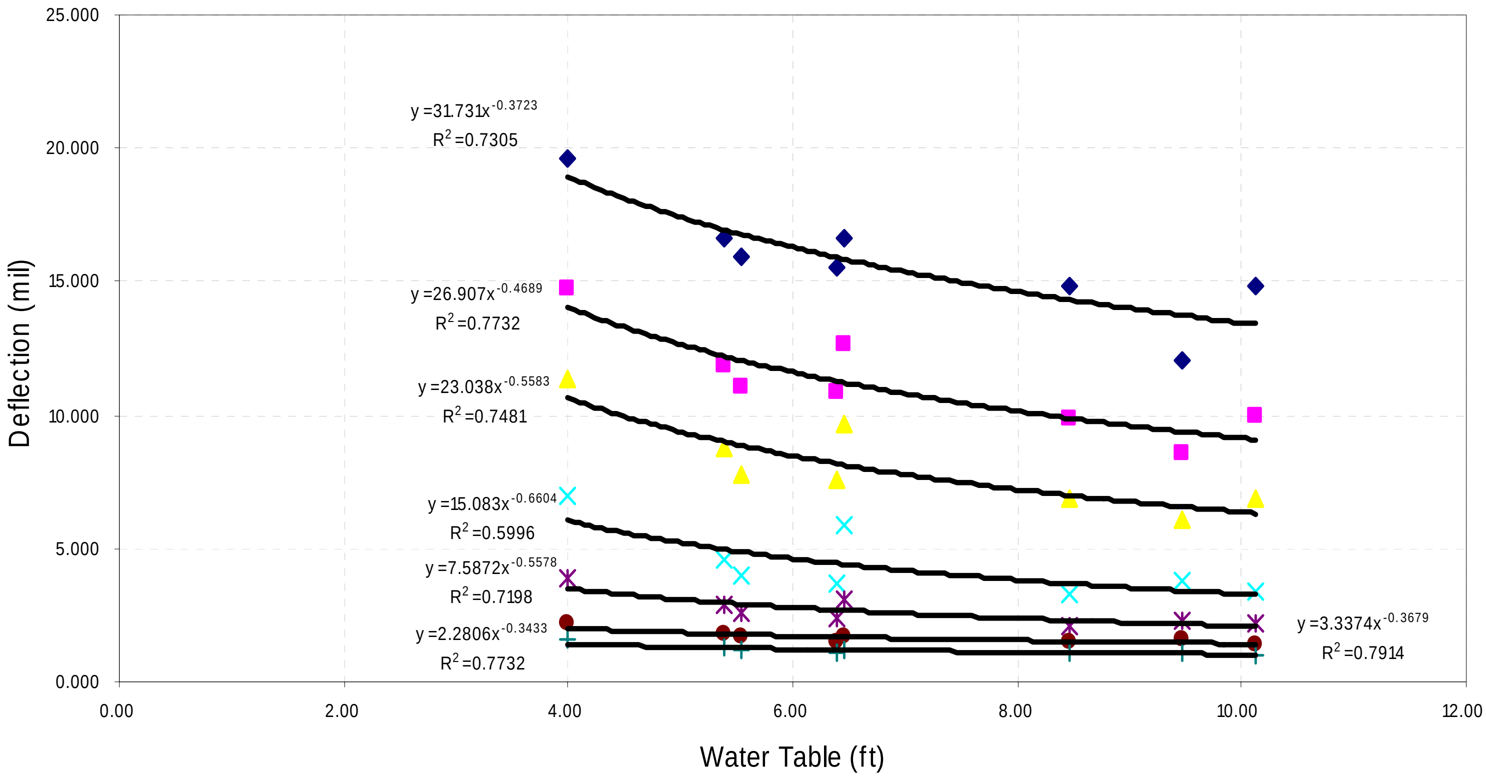


Figure 4.117: Water Table vs. Sensor Deflection for State Road 200 Section 28010

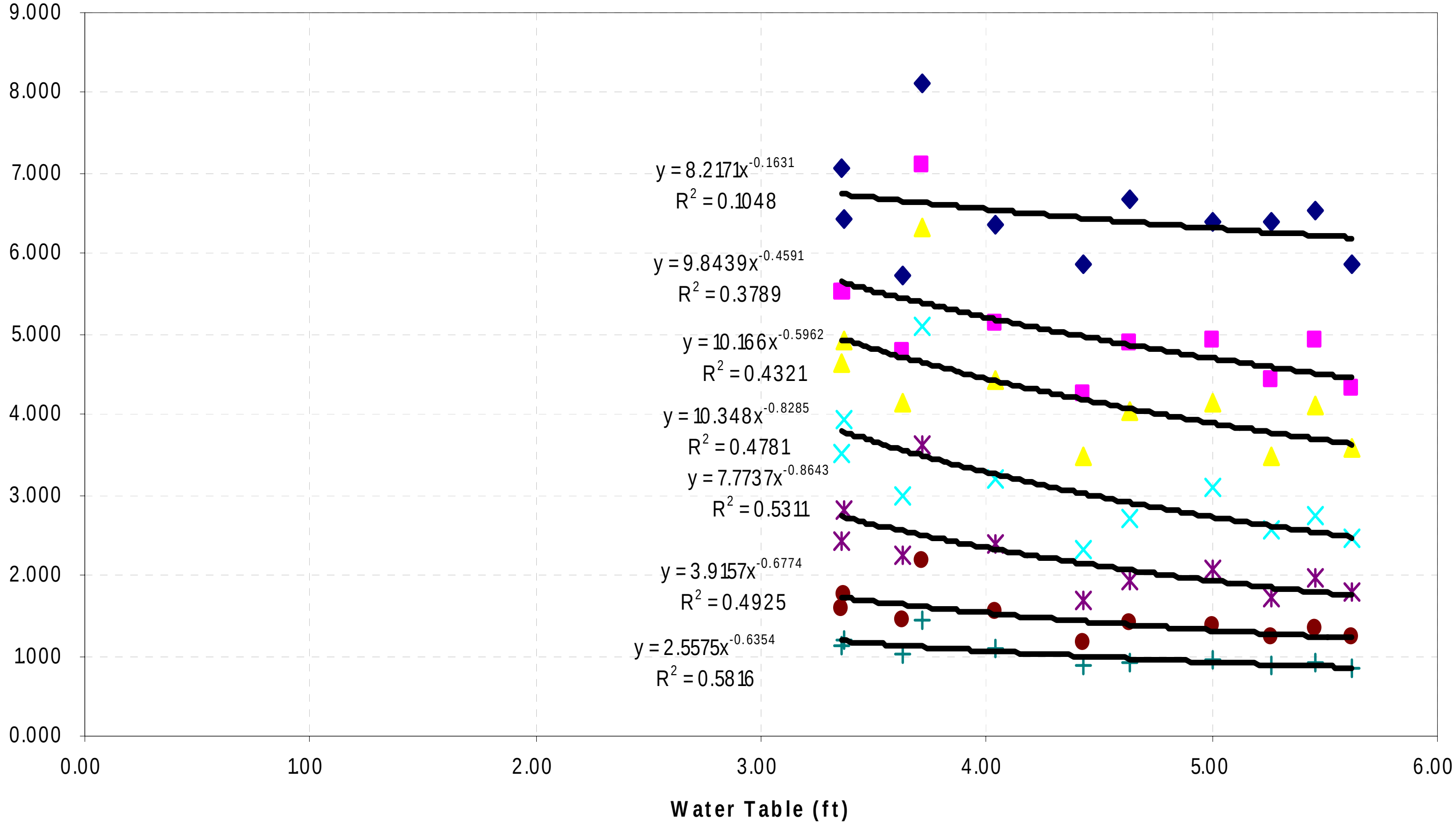


Figure 4.118 Deflection Basins Rock Layer at Different Depths

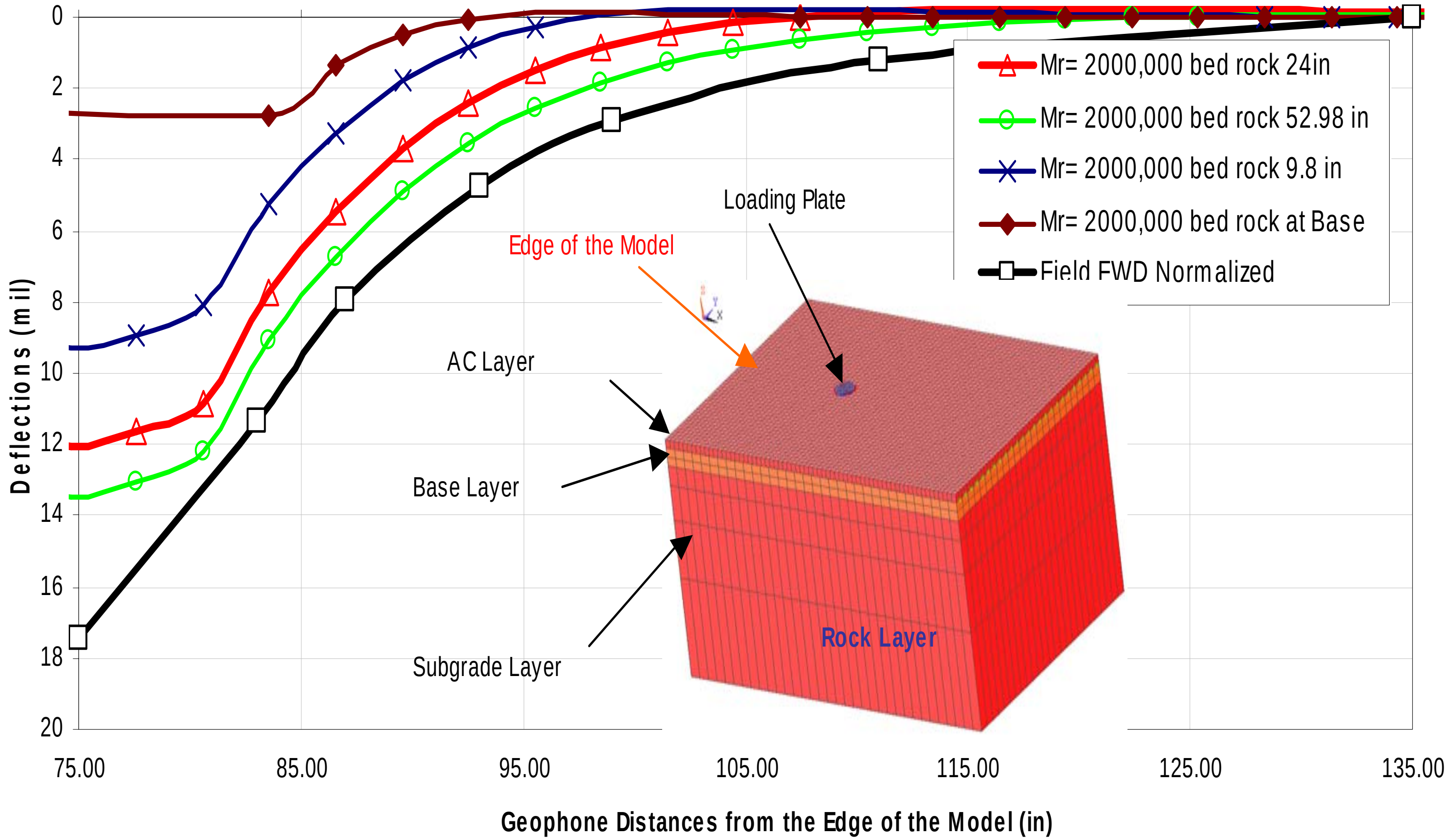
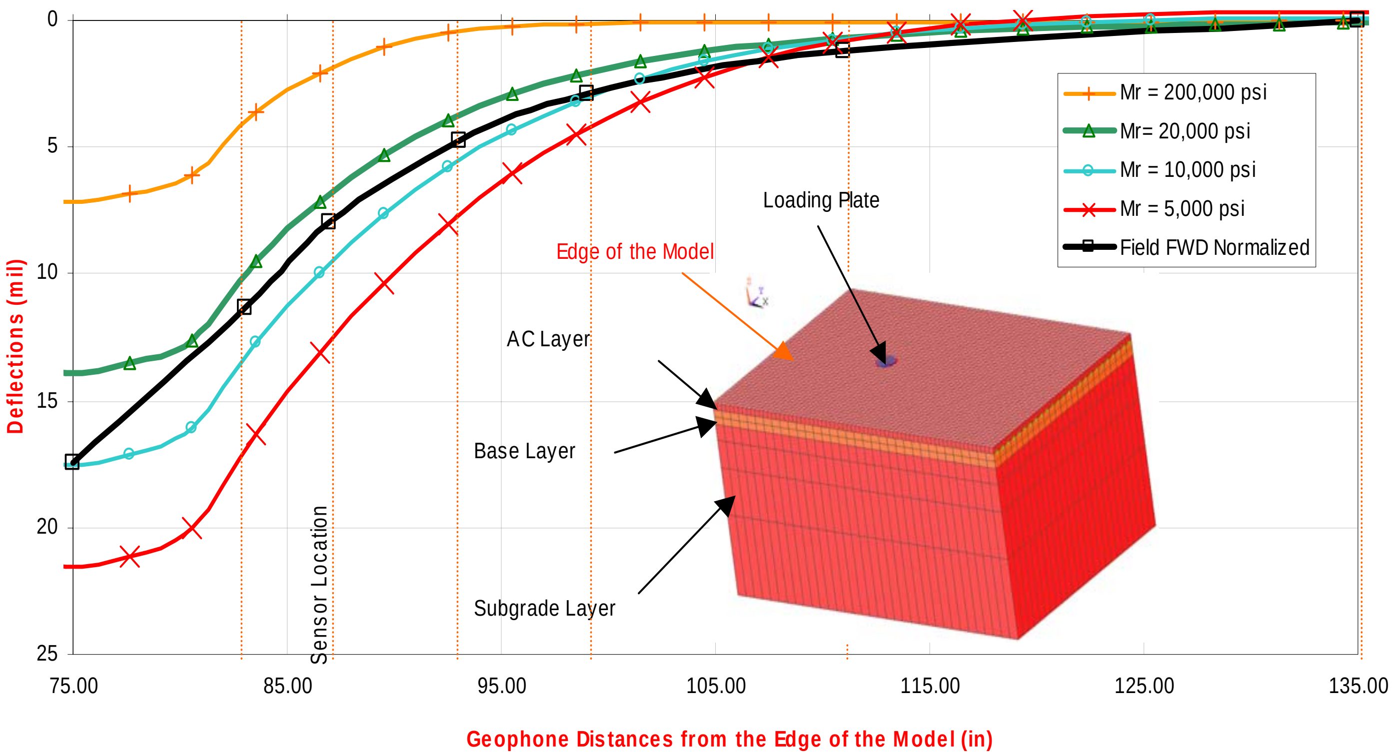


Figure 4.119: Deflection Basins For Different Subgrade MR Values



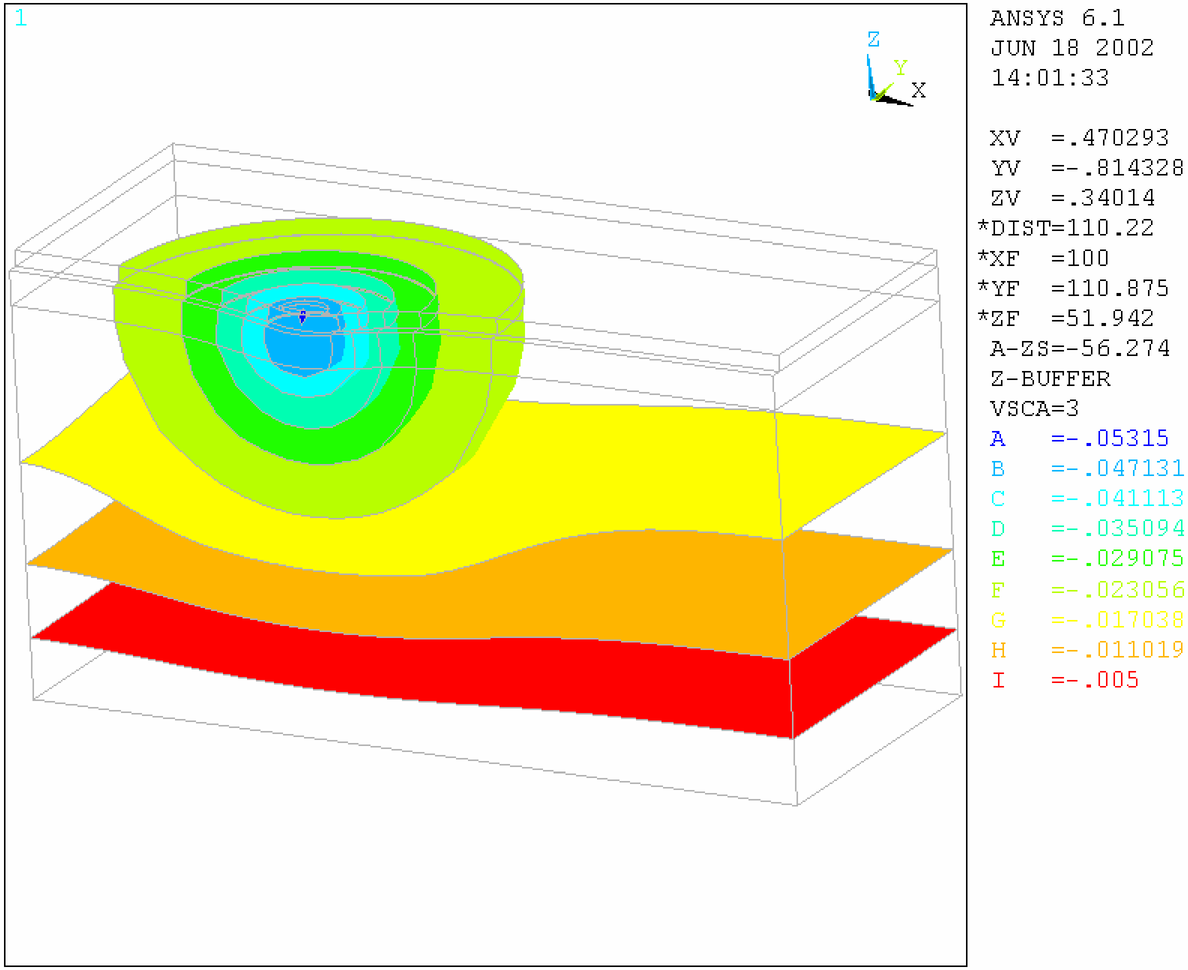


Figure 4.120: Deflection Basin from FEA Model for Subgrade Modulus = 50,000 psi Showing the influence depth of the 9000 lb Dropping Load. The Depth to 1% Maximum Deflection Under the Load is at 10 in from the bottom of the Model.

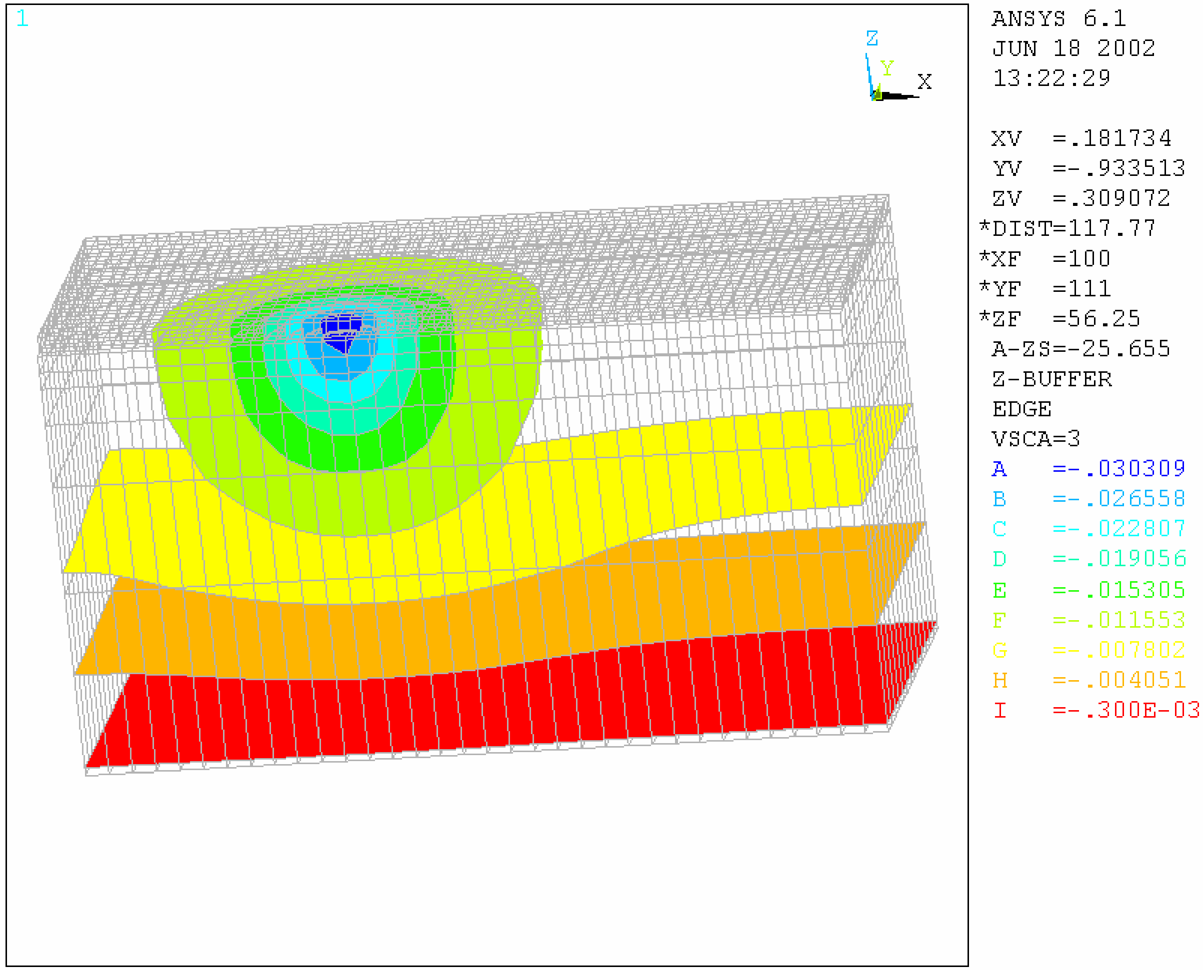


Figure 4.121: Deflection Basin from FEA Model for Subgrade Modulus = 10,000 psi
Showing the influence depth of the 9000 lb Dropping Load. The Depth to 1% Maximum Deflection Under the Load is at 1 in From the Bottom of the Model.

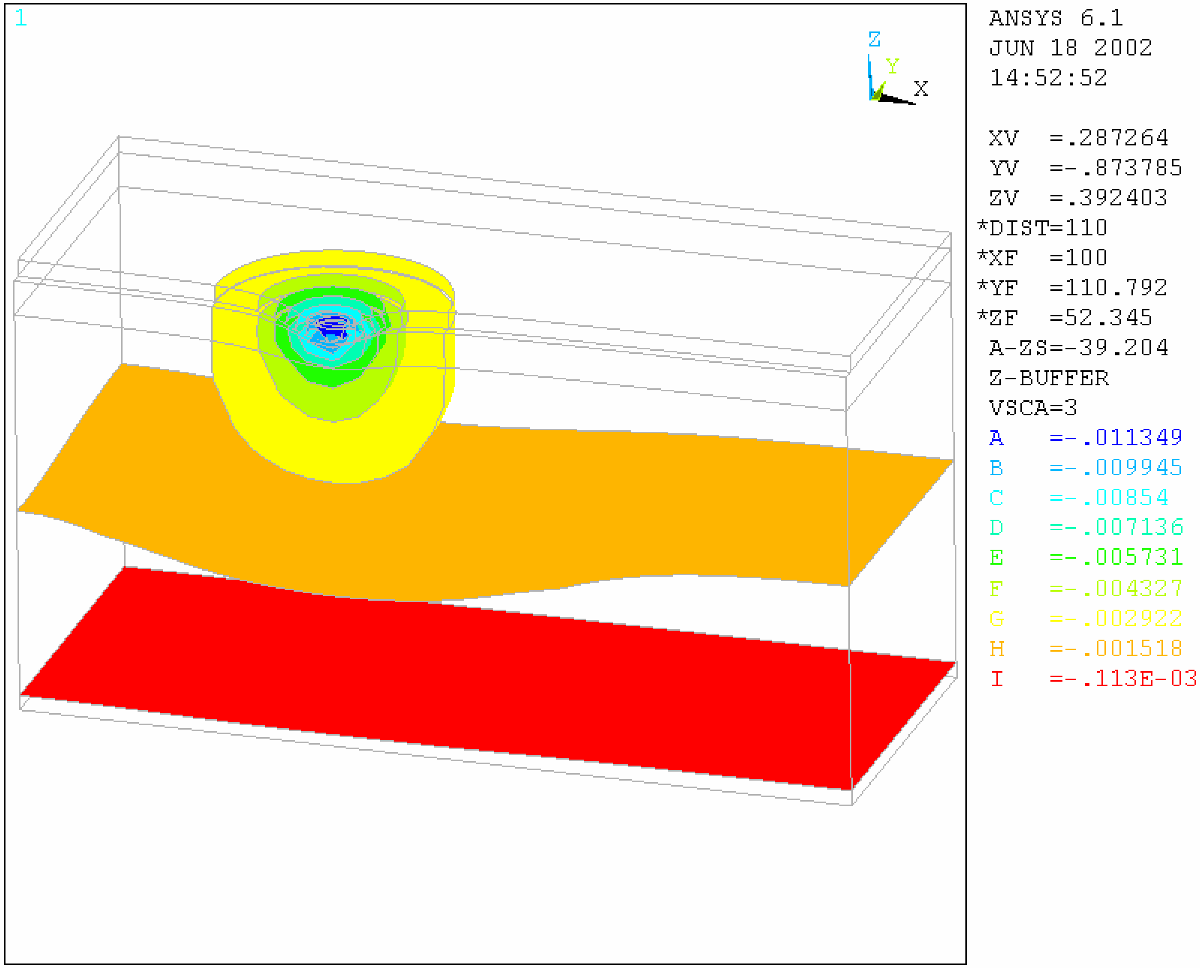


Figure 4.122: Deflection Basin from FEA Model for Subgrade Modulus = 50,000 psi
Showing the influence depth of the 9000 lb Dropping Load. Notice the Reduction of the Deflection Basin

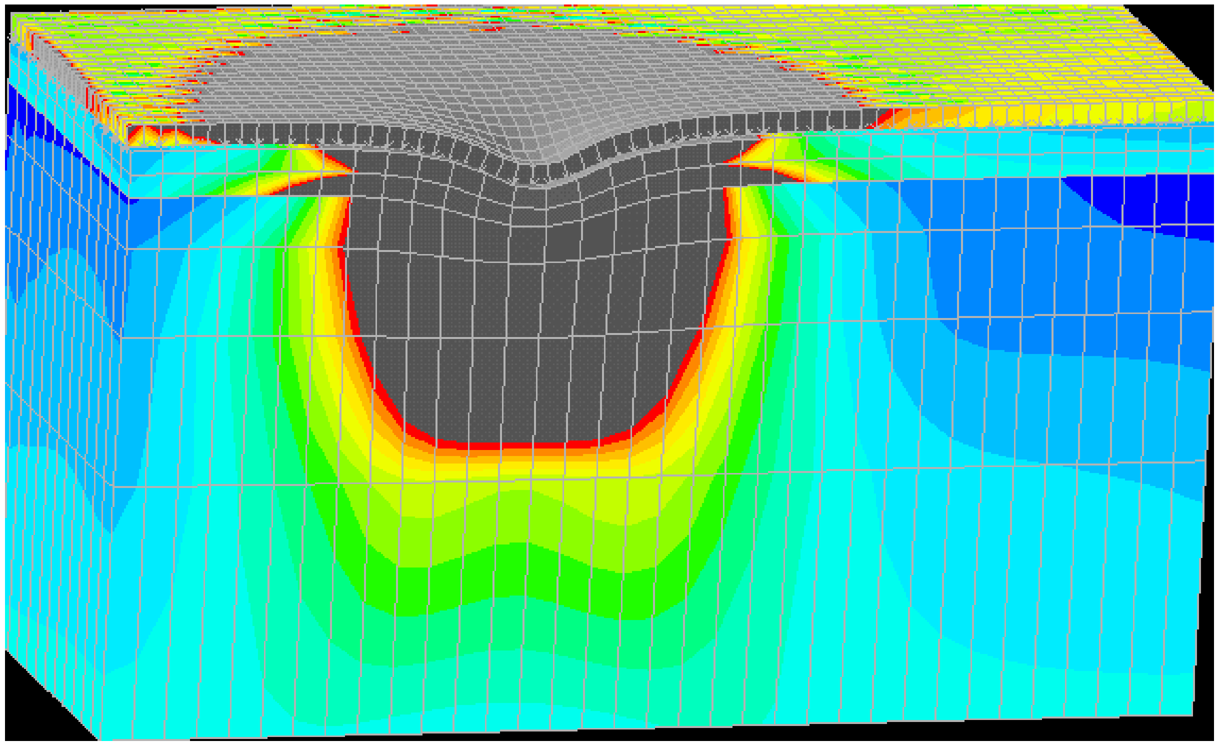


Figure 4.123: Stress bulb at 1% of the applied stress at US 441at subgrade stiffness 20000 psi.

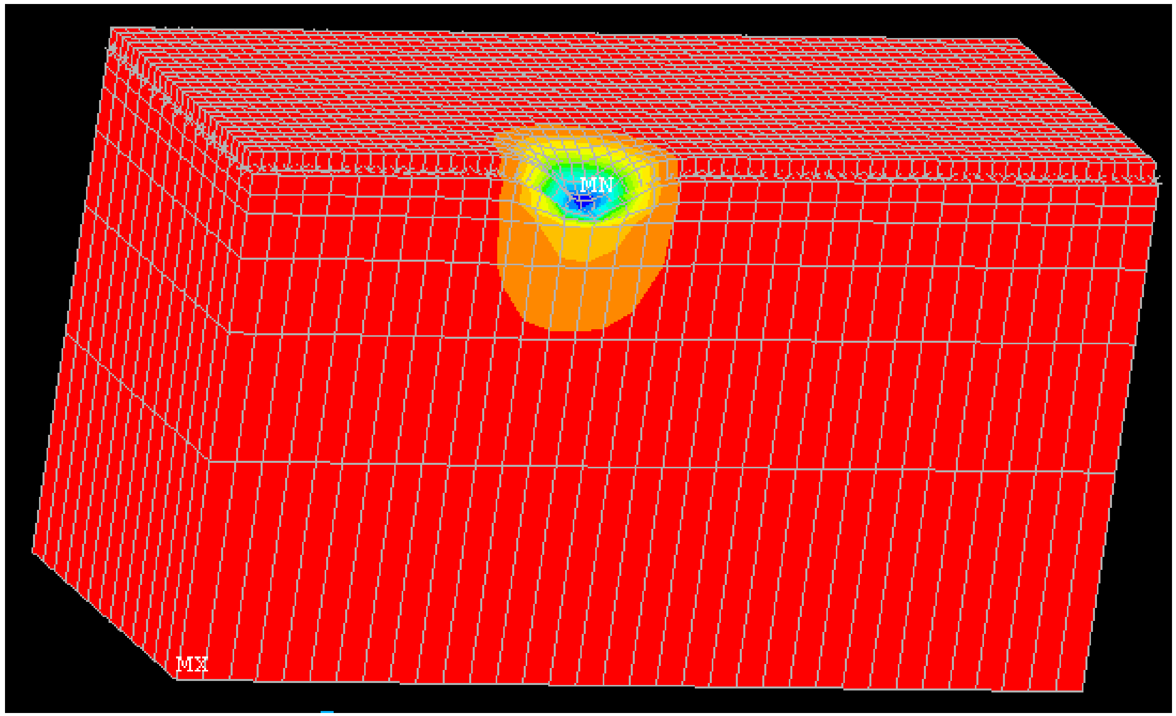


Figure 4.124: Deflection basin at US 441 at subgrade stiffness 200000 psi.

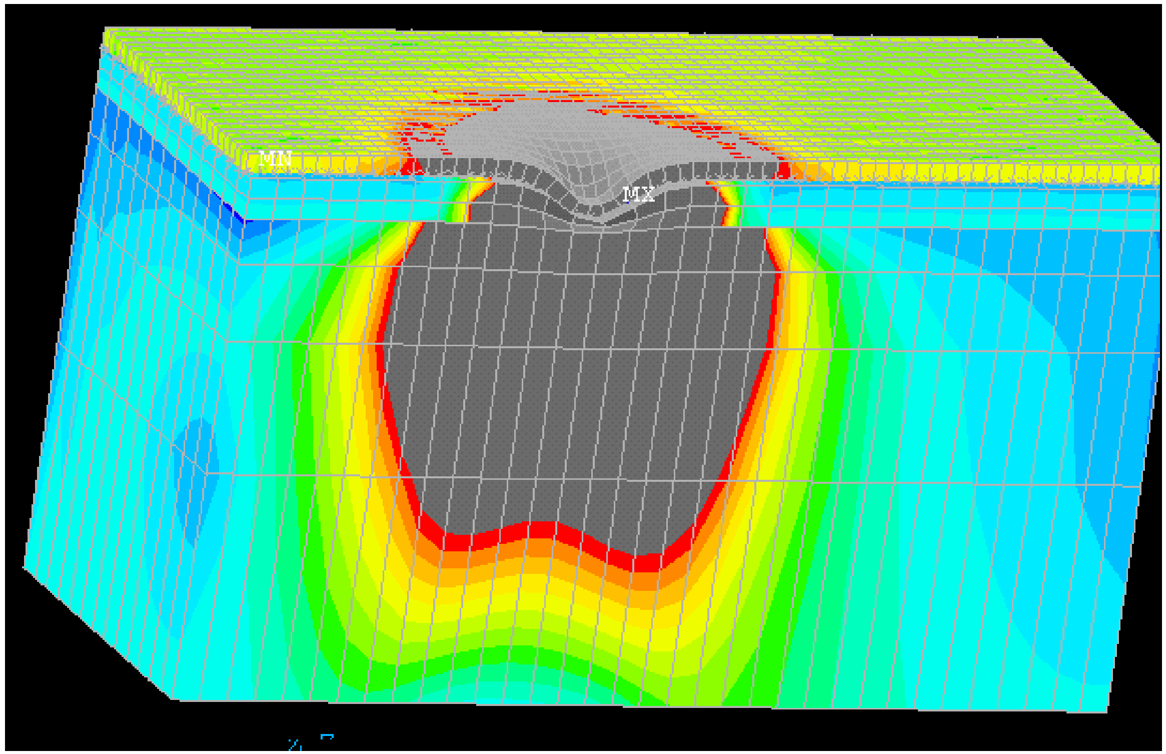


Figure 4.125: Stress bulb at 1% of the applied stress at US 441 at subgrade stiffness 200000 psi.

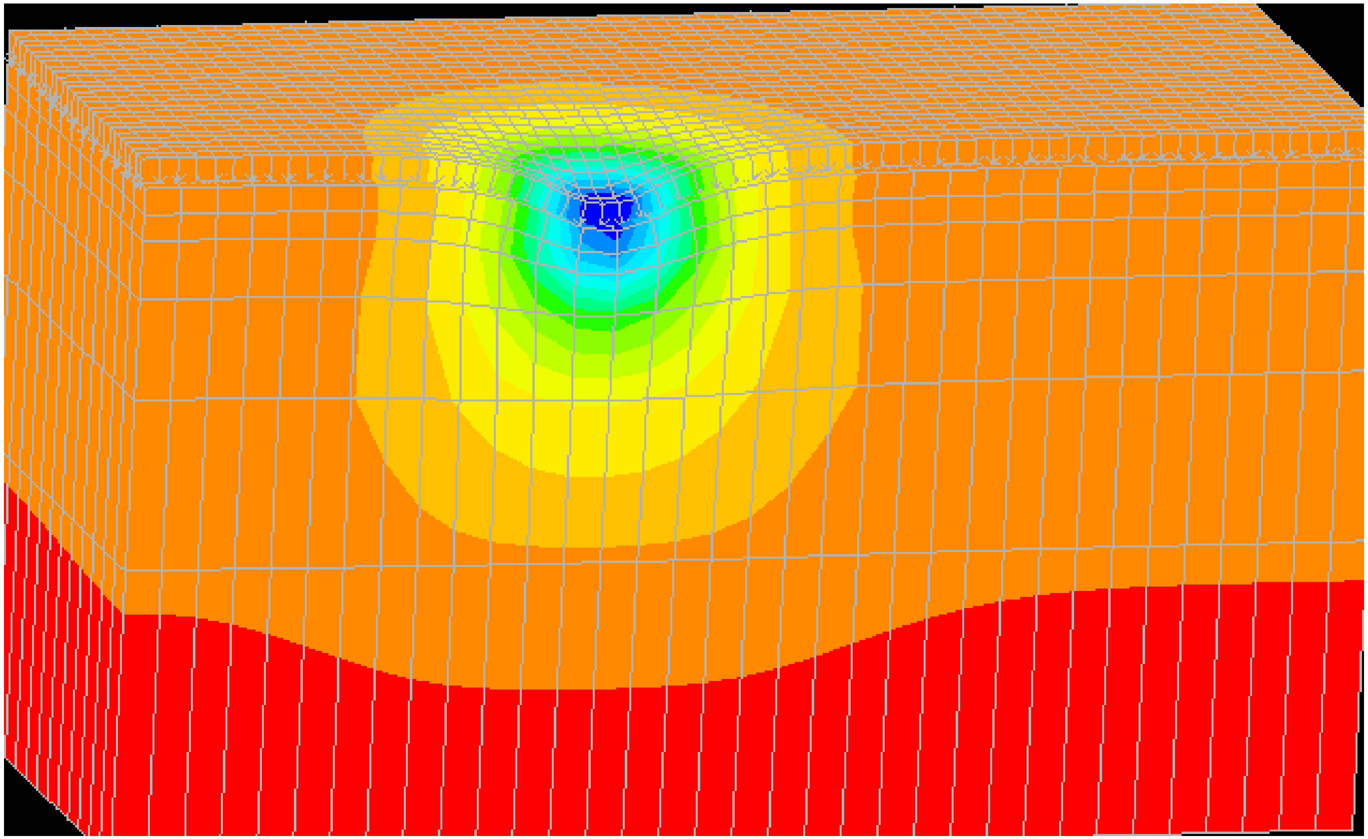


Figure 4.126: Deflection basin at US 441 at subgrade stiffness 10000 psi.

Chapter 5

Conclusion

The following describes the main items that could be considered either conclusive or nonconclusive. Also the best practice for the use of Falling Weight Deflectometer in determining moduli values of subgrade may be considered as suggested recommendations. This is simply because the best practice is governed by the continuous use of this important device and the continuous gathering of the database. In this study, the LTPP was found to be the best database available to deduce general patterns of the pavement behavior during field testing. The large amount of data available on DATPAVE 3.0 software and the continuous feed of the data every season in the year provide an opportunity to plan for the future testing and may be set strategies for pavement rehabilitation and maintenance. The FDOT 300 mile test sites included some detailed FWD results that were utilized in this study. Another valuable database was the measurements that were compiled by the FDOT pavement evaluation section on the water table and moisture content. This small database was so effective and precise that it should definitely be enlarged to include more pavement sections with better measurements of temperature. Also this data base should be part of the LTPP DATAPAVE. Unfortunately, the LTPP tables are poor as to the information about the ground water table levels and moisture content for Florida sections. These provisions are available as fields but measurements are missing. In general, the itemized conclusion is as follows:

1- FWD provide the best simulation of the shape and magnitude of the traffic impact load on pavement.

2- Several NDT techniques have been introduced in the recent years. Although the methodology is advanced , these new NDT devices such as SPA lack one of the most important parameters; the simulation of the actual loading conditions. These devices are confined to certain magnitudes and frequency content of the signals that are far away from the real traffic loads.

3- FWD is a relatively fast testing technique, and with well trained operators it compares with the practical and popular Dynaflect device.

4- Utilizing FWD for AC pavement assessment has proven to be effective. However, certain conditions must be satisfied before attempting to start the backcalculation analysis. These conditions are simply related to pavement geometry and stiffness. A thick or a very thin AC pavement may not produce a realistic analysis. Also, shallow bedrock may be missed in the analysis. The same can be said about concrete pavement. Heavier loads must be used in cases of thick and stiff surface layers. Large loads will induce appreciable deformations at sensors # 6 (36 in) and 7 (60 in) of the FWD.

5- If the FWD is well calibrated, the above shortcomings to the recommendation should only be true for the accompanied methods of analysis.

6-FWD calibration is crucial. Some test sections indicated malfunction in some geophones. Such malfunctions were noticeable from the succession of measurements that form the deflection basin.

To continue the backcalculation analysis, the pavement engineer had to adjust some sensor measurements or else the obtained moduli values would be wrong.

7- When MODULUS 5.0 and EVERCALC were used to back-calculate pavement moduli values, the first software program did not give any warning about the invalidity of the measured deflections. EVERCALC on the other hand, informs the program operator of such irregularities and the data has to be fixed before concluding the analysis.

8- As a conclusion it was found that MODULUS 5.0 and EVERCALC give similar results for most of the sections, with an advantage of EVERCALC over MODULUS 5.0 in the following functions:

  a- MODULUS 5.0 in a DOS operating program. Computers with the version of Windows may not accept the program. An error massage appears of the screen once the analysis started.

  b- EVERCALC was tested using DOS and all versions of Windows (95, 98, Me, 2000, NT and XP) and was found to function well on all these operating systems.

  c- The sensitivity of the seed moduli values (surface layer, base and subgrade) is more pronounced when EVERCALC is used. MODULUS 5.0 may produce the same results if the ranges of the seed values were increased or decreased.

d- MODULUS 5.0 is faster in the analysis time. However, the incompatibility of some operating systems may deem this advantage as useless.

e- Both software programs are considered public domain and are available without any charge. MODULUS 5.0 has to be ordered form TTI in Texas while EVERCALC can be downloaded from the web directly.

f- Supporting documents of EVERCALC are poor if they ever existed. The operator has to contact the developer to get more information about the software.

g- EVERCALC has two additional programs with it. These programs can be used for pavement overlay design and to estimate stress and strain levels in pavement layers.

9- When adjusted, the AASHTO formula is as effective in determining the subgrade moduli values as any other sophisticated computer program. This adjustment is by using the C factor.

10- This study showed that the C factor for Florida pavements ranged from 0.28 to 0.3. About 80% of the sections tested showed 0.3 C factor. About 15% showed C factor of 0.28, and for few sites the C factor exceeded 0.33.

11- Sensor # 6 was found to have a better representation of the subgrade response than sensor # 7. The reason was simply the shorter distance to the loading point. However, this should not be the criteria, because long distances are needed to capture the effect of the subgrade deflection. Some state highway agencies use a distance of 48 in. This distance lays between sensor # 6 and 7. In Florida the use of the 36 in and 60 in distances are reasonable. Many sections did not show any variation in the analysis of how D6 or D7 are used. However, several sections did exhibit variations between the two sensors, giving moduli values with a C factor exceeding 0.33. These results necessitated the use of D6 as the standard distance to estimate subgrade moduli values in Florida.

12- The finite element analysis, have demonstrated the above facts. But some sections were tested using ANSYS 6.0 where the bedrock or the subgrade moduli was increased. In these cases, D6 was out of range and D5 or a certain distance between D6 and D7 must be considered.

13- The effects of water table and soil moisture content have to be taken into account when back calculating subgrade moduli values. Unfortunately, conventional backcalculation analysis methods do not consider these factors. Any consideration for water table levels and moisture content has to be in reducing the seed moduli values of the subgrade. But the reduction of the moduli values may not signify the water table and moisture content.

14- The effect of the bedrock on deflection basin predictions is very important. The current backcalculation methods are not sensitive to the depth of the bedrock. Therefore, the depths of the bedrock, if they are known, have to be recorded during testing. Unfortunately, these depths are not well documented and pavement engineers depend on the backcalculation analysis to figure them out. In such cases, it is advisable that FEA analysis be run rather than speculating the depths from the conventional backcalculation methods.

15- The FEA is not practical when the expertise is not available. However, if a certain FEA software is in use, some typical pavement cross sections can be modeled and later on can be used to run them for similar situations by a trained engineer. The mechanistic approach for pavement design or rehabilitation necessitate the use of more sophisticated software/hardware technology. Relying on the conventional method may be practical; but the state of the knowledge of these methods will not further advance the predictions of the mechanistic behavior pavements.

16- To advance the prediction capability in pavement evaluation, the FWD records have to go beyond just recording the sensor deflections. It is advisable that the complete history records be stored for further analysis. With the advancement in seismic methods, it is possible that additional pavement parameters can be deduced from the FWD testing. These parameters include, layer thicknesses, and to a large extent the depth of the bedrock.

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