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Correlating Responses of Portable Field Instruments Used for Testing Aggregate and Soil Pavement Layers

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CORRELATING RESPONSES OF PORTABLE FIELD INSTRUMENTS

USED FOR TESTING AGGREGATE AND

SOIL PAVEMENT LAYERS

by

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ABSTRACT

CORRELATING RESPONSES OF PORTABLE FIELD INSTRUMENTS

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SOIL PAVEMENT LAYERS

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This research examined correlations among the responses of five portable aggregate and soil testing devices, including the nuclear density gauge (NDG), dynamic cone penetrometer (DCP), heavy Clegg impact soil tester (CIST), soil stiffness gauge (SSG), and portable falling-weight deflectometer (PFWD). Readings were analyzed from 41 project sites on treated and untreated base, subbase, and subgrade layers representing 15 different material types in Iowa, Louisiana, Utah, and Wyoming. Analyses of the data revealed statistically significant correlations for all six of the possible two-way comparisons involving the DCP, CIST, SSG, and PFWD, and a nomograph was developed for correlating responses among these different devices. No statistically

significant correlations between data from the NDG and that of any other instrument were identified, however. The correlations developed in this research will be useful to pavement engineers needing to compare different types of strength and/or stiffness measurements for quality control/quality assurance purposes.

Additionally, repeatability with respect to operator effects was additionally investigated for the CIST and SSG at 27 sites on treated and untreated base layers in Utah. Analyses of these data indicated that the CIST data exhibited a significant operator effect at 7.4 percent of the test sites, whereas no operator effects were detected at any test site for the SSG data. Thus, the SSG data appear to be less susceptible to operator effects than the CIST data.

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CHAPTER 1

INTRODUCTION

1.1 PROBLEM STATEMENT

When designing roads, engineers must specify the mechanical and physical properties of each pavement layer required for the completed facility to withstand traffic and weathering effects (*1*). Successful design requires knowledge of the properties of each material proposed for use as a surface, base, or subbase layer, as well as the properties of the original soil, or subgrade. Then, successful construction requires adequate compaction of each layer to ensure that excessive consolidation and/or cracking do not occur under loading. In addition, to more economically construct some pavements, many engineers utilize base, subbase, and subgrade stabilization techniques to improve local materials of marginal quality; common stabilization agents used for this purpose include portland cement, fly ash, lime, and bituminous materials (*2*).

Although roadway stability depends largely on the degree to which subsurface pavement layers meet the engineer's quality control/quality assurance (QC/QA) specifications, measuring specific in-situ qualities of these layers, such as strength or stiffness, can be difficult due to instrument limitations. Traditionally, the nuclear density gauge (NDG) has been used for QC/QA measures associated with construction of new aggregate and soil layers in the field; however, use of the NDG requires specialized training and is accompanied by strict licensing, including travel restrictions (*3*, *4*).

Furthermore, density is not an input in pavement design (*1*). For these reasons, the use of other devices for testing subsurface pavement materials is an attractive alternative. Such other devices include but are not limited to the dynamic cone penetrometer (DCP), Clegg impact soil tester (CIST), soil stiffness gauge (SSG), and portable falling-weight deflectometer (PFWD).

Research studies investigating useful stabilization techniques in conjunction with the DCP, CIST, SSG, and PFWD are being conducted across the United States. Such studies include development of CIST thresholds related to rutting of cement-treated base (CTB) materials and procedures for determining when to stop the pre-cracking of CTB materials using the SSG (5, *6*). Unfortunately, the instruments utilized by these researchers may not be accessible to many transportation agencies for on-site implementation. Therefore, mathematical or graphical correlations quantifying relationships among the outputs of these and other devices would be extremely useful for pavement engineers. Understanding the correlation between any two devices would allow an engineer to quickly convert the values associated with one instrument to those associated with another as needed, saving time and money. Additionally, correlations would allow instituting QC/QA programs such as certifying assumed design properties after construction and comparing construction practices and pavement layer properties, including seasonal variations, at regional, national, and/or global levels. No formal attempt to simultaneously develop correlations among all of these devices, however, has yet been published.

While mean values from multiple test measurements obtained using one device may be correlated to mean values obtained using another device, an operator may need to conduct more testing with one instrument than with another if the former is less repeatable. Repeatability in the context of this research is an evaluation of the variability of test data collected using a given instrument from within a common testing location. Several factors can affect the repeatability of an instrument, including the spatial variability of the soil due to heterogeneous soil properties, moisture content, and deviation in the measurement process with respect to a given operator. While overall repeatability has been investigated for many of the instruments (*7*, *8*, *9*), research specifically investigating operator effects on repeatability have not been found in the literature. However, knowing the extent to which instrument output is affected by an operator would be useful in selecting equipment and determining the degree of operator training that may be required to ensure consistent data collection techniques.

1.2 SCOPE

The primary objective of this research was to compile and analyze available data for the purpose of developing working correlations between data sets associated with the NDG, DCP, CIST, SSG, and PFWD. Readings were analyzed from 41 project sites on treated and untreated base, subbase, and subgrade layers representing 15 different soil types in Iowa, Louisiana, Utah, and Wyoming. As a secondary objective, repeatability with respect to operator effects was additionally investigated for the CIST and SSG at 27 sites on treated and untreated base layers in Utah.

1.3 OUTLINE OF REPORT

This report contains five chapters. Chapter 1 introduces the problem statement associated with this research and describes the scope of the work. Chapter 2 provides instrument descriptions and reviews of existing correlations and repeatability evaluations as reported in the literature. Chapter 3 explains the data collection and analysis procedures, and Chapter 4 presents the results. Chapter 5 provides a conclusion summarizing the research findings and recommendations.

CHAPTER 2

BACKGROUND

2.1 OVERVIEW

At the beginning of this study, the literature was searched for background information concerning the function of the NDG, DCP, CIST, SSG, and PFWD. Descriptions, existing correlations, and information about the repeatability of these devices are given in the following sections.

2.2 INSTRUMENT DESCRIPTIONS

The following sections outline the functions of the NDG, DCP, CIST, SSG, and PFWD.

2.2.1 Nuclear Density Gauge

The NDG is a measuring device used to derive in-situ dry density and moisture content of aggregate and soil layers by means of radioactive particles emitted into the ground. As depicted in Figure 2.1, a typical device consists of a 20- or 30-cm (8- or 12-in.) retractable rod, Geiger-Muller detector, and display screen. For measurement of density, the isotope source fixed upon the end of the retractable rod emits photons, usually gamma rays, which interact with electrons in the base material and are counted

FIGURE 2.1 Nuclear density gauge.

upon return by the Geiger-Muller detector situated opposite from the handle and rod (*4*, *10*, *11*). The lower the number of photons measured by the detector, the higher the material density.

For measurement of moisture content, "fast" neutrons emitted by the radioactive source are thermalized by contact with hydrogen atoms. Thermalization is the loss of kinetic energy to the degree that further collisions with hydrogen or other materials will not continue to slow the neutron. Because the neutron detector in the NDG is sensitive only to thermalized neutrons, the returning neutron count obtained by the detector is directly proportional to the hydrogen count and subsequently to the water content of the material (*4*).

Two modes of operation for the NDG exist: direct transmission and backscatter. Direct transmission was utilized in the collection of data analyzed in this report and involves insertion of the retractable rod into the aggregate or soil surface prior to the emission of radioactive particles (*10*). The NDG is a quick, virtually non-destructive method of obtaining dry density and moisture content. However, as mentioned previously, licensing is required for the operator of the NDG because of the radiation emitted during testing (*3*, *4*, *10*).

2.2.2 Dynamic Cone Penetrometer

The DCP is used to measure the bearing capacity and uniformity of compacted base, subbase, and subgrade layers. As shown in Figure 2.2, the DCP consists of a 12-mm- (0.47-in.-) diameter metal rod. A standard metal cone at the end of the rod is driven into the ground by repeated blows of a 4.6- or 8.0-kg (10.0- or 17.5-lb) slide hammer dropped from a height of 575 mm (22.5 in.) (*12*). The 8.0-kg (17.5-lb) hammer is more useful for penetrating stronger soils, such as CTB. The penetration of the cone into the ground is measured after each set of blows to enable calculation of a penetration index having units of mm/blow (in./blow) (*12*, *13*).

Because of its comparatively small size, ease of use, and affordability, the DCP is utilized globally. Many studies have been conducted on the DCP to correlate penetration rate with other measurement indices (*14*, *15*, *16*). Most common is the correlation between the penetration index and the California bearing ratio presented as Equation 2.1 (*12*, *17*).

FIGURE 2.2 Dynamic cone penetrometer.

$$CBR = \frac{292}{DCP^{1.12}} \quad (2.1)$$

where CBR = California bearing ratio (%)

DCP = penetration index (mm/blow)

2.2.3 Heavy Clegg Impact Soil Tester

The CIST is a device used to evaluate the strength or stiffness of base, subbase, or subgrade material used in pavement construction. It consists of a slide hammer, a guide tube, and an electronic display (*18*, *19*). The CIST is available in four possible hammer masses: 4.5-kg (9.9-lb) standard Clegg hammer, 0.5-kg (1.1-lb) light Clegg hammer, 2.25-kg (5.0-lb) medium Clegg hammer, and 20-kg (44-lb) heavy Clegg hammer (*14*). Data from the CIST analyzed in this report were all collected using the heavy CIST, which was specially developed for testing stiff aggregates and soils, including stabilized subsurface layers (*19*). A heavy CIST is shown in Figure 2.3.

To operate the heavy CIST, the user drops the hammer four times at each test point from a height of 300 mm (11.8 in.). An accelerometer mounted at the top of the hammer measures the peak deceleration of the hammer when it impacts the soil surface. The electronic display shows the highest deceleration value at each point as a Clegg impact value (CIV), where 1 CIV is equivalent to 10 times the acceleration rate of gravity (*18*, *19*, *20*). The Clegg hammer elastic modulus of aggregate and soil layers may be computed for a given CIV using Equation 2.2 (*19*).

FIGURE 2.3 Heavy Clegg impact soil tester.

$$CHM = 0.23 \cdot (CIV)^2 \tag{2.2}$$

where *CHM* = Clegg hammer elastic modulus (MPa)

CIV = Clegg impact value obtained using a heavy CIST

2.2.4 Soil Stiffness Gauge

Shown in Figure 2.4, the SSG is a compact cylinder, weighing 10 kg (22 lb), with a digital display and keypad. It imparts very small displacements created by a harmonic oscillator to the aggregate or soil through a ring-shaped foot. Because a minimum of 60 percent of the instrument foot must be in contact with the ground for accurate measurements, the SSG is often seated on a 6-mm (0.25-in.) layer of moist sand (*21*). Stiffness is then determined from the deflections of the soil caused by the vibrations (*7*). The SSG measures the stiffness modulus of underlying soil to an average depth of 220 to

FIGURE 2.4 Soil stiffness gauge.

310 mm (9 to 12 in.) from the ground surface (*21*). The stiffness force/displacement ratio is described by Equation 2.3 (*21*, *22*).

$$SSG = \frac{F}{d} \quad (2.3)$$

where SSG = stiffness (MN/m)

F = force on the aggregate or soil surface (MN)

d = displacement of the aggregate or soil surface (m)

Soil properties measured using the SSG can be presented as layer stiffness in MN/m (klbf/in.) or as Young's modulus in MPa (ksi) with a given Poisson's ratio for the soil. The viability of the SSG in determining road base stiffness has been ascertained both in laboratory settings and in the field (*23*). Laboratory tests have also shown that SSG measurements can yield satisfactory elastic moduli and stiffness calculations when compared to such tests as the static plate load and dynamic load penetration tests (*24*).

2.2.5 Portable Falling-Weight Deflectometer

The PFWD is a device used to determine the elastic modulus in MPa (ksi) of aggregate and soil layers. To perform a PFWD test, the operator manually lifts and then releases a drop weight that falls onto a loading plate; the response of the surface layer is automatically measured by the PFWD through the use of deflection sensors positioned at specified radial distances from the center of the loading plate. These measurements are recorded and entered into a back-analysis computer program such as MODULUS to evaluate the in-situ stiffness of the pavement layers (*25*). The PFWD is depicted in Figure 2.5.

The PFWD uses fewer sensors than a traditional falling-weight deflectometer and is easily transportable due to its significantly lower weight. Some identified weaknesses of the PFWD are measurement variability on heterogeneous surfaces, such as mixed sand and gravel, and the need to use the appropriate loading plate size for a given modulus (*26*). Though the accuracy of the device may be questionable in these instances, the PFWD has proven to be an effective tool for the rapid analysis of pavement properties by experienced operators (*25*, *26*).

FIGURE 2.5 Portable falling-weight deflectometer.

2.3 EXISTING CORRELATIONS

Few attempts have been made to correlate responses of the NDG, DCP, CIST, SSG, and PFWD. The literature review on this topic began with searching for correlations involving the NDG. Because density is often considered by transportation agencies to be a suitable estimate of strength, the NDG is regularly used for QC/QA measures (*27*). The QC/QA evaluation is conducted by determining in the laboratory the optimum moisture content (OMC) and corresponding maximum dry density (MDD) of the given base, subbase, or subgrade material. Specimens are prepared using a specified compaction effort, usually either the standard or modified Proctor procedure. The strength and/or stiffness of the specimens are then measured. In the field, the pavement layer is ideally compacted at or near the OMC to some high percentage of the MDD; the NDG is then used to evaluate the quality of actual compaction achieved. The ratio between the NDG dry density reading at some point and the MDD reflects the relative compaction, usually presented as a percentage, at that location.

In theory, a high percent compaction in the field will result in a relatively high aggregate and soil strength consistent with laboratory testing, which is generally performed on specimens compacted at or near the given MDD. While this may be true for a number of untreated materials (*28*), research has indicated that relative compaction is not strongly correlated to relative strength for many stabilized aggregates and soils (*3*, *27*). Furthermore, relative compaction is not consistently correlated to strength or stiffness across a range of material types, meaning that a laboratory-determined percent compaction needed for achieving a desired strength or stiffness for one material type may be either insufficient or excessive for another material type (*27*).

One study developed an empirical relationship between dry density and stiffness for several untreated materials (*29*); however, further investigation of this relationship indicated that it cannot be used without information about the moisture content and zero-voids density of the tested material. A study investigating the application of this empirical relationship for QC/QA purposes using the NDG and SSG indicated that it is sensitive to both construction methods and site conditions (*30*). No meaningful correlation between the NDG and the other instruments was identified in the literature.

Although no equations correlating the outputs of the CIST to the SSG, the CIST to the PFWD, or the SSG to the PFWD were found in the literature review performed in this research, correlations between the DCP and the other devices were identified. Equations 2.4 to 2.7 represent correlations between the DCP and the CIST (*3*), the SSG (*31*), and the PFWD (*9*, *31*). The reported coefficient of determination, or R^2 value, is given in each case. The R^2 value describes the fraction of variation in the dependent, or response, variable that can be explained by variation in the independent variable (*5*, *32*, *33*).

$$CIV = 0.6194 \cdot DCP_{BLOW} + 13.883 \quad (\mathrm{R}^2 = 0.65) \tag{2.4}$$

where CIV = Clegg impact value obtained using a heavy CIST

DCP_{BLOW} = number of DCP blows required to reach a depth of 15.25 cm (6 in.)

$$SSG = 755.2 \cdot DCP^{-0.671} \quad (\mathrm{R}^2 = 0.52) \tag{2.5}$$

where SSG = stiffness (MPa)

DCP = penetration index (mm/blow)

$$PFWD = \frac{2191.4}{DCP} \quad (R^2 = 0.72) \tag{2.6}$$

where *PFWD* = modulus (MPa)

DCP = penetration index (mm/blow)

$$PFWD = \frac{5301.54}{(8.31 + DCP^{1.44})} \quad (R^2 = 0.87) \tag{2.7}$$

where *PFWD* = modulus (MPa)

DCP = penetration index (mm/blow)

Equation 2.4 is based on the results of testing performed on lime-treated subgrade soil at ten sites in Indiana. The comparably small sample size and focus on a single material may limit the general applicability of this relationship. The nine treated and untreated aggregates and soils used for developing Equations 2.5 and 2.6 represent a wider range of base materials commonly used for pavement construction, but these materials were compacted and tested exclusively in a laboratory setting, potentially limiting the utility of these equations in field applications. Testing conducted to develop Equation 2.7 was performed at 27 stations representing three highways and two controlled trench sections with 14 different treated and untreated aggregate and soil types in Louisiana. Based on such a wide range of materials and a large sample size, this equation may be applicable to a broad range of pavement materials.

2.4 EXISTING REPEATABILITY EVALUATIONS

Two investigations quantifying and comparing the repeatability of specific instruments included in this research were identified in the literature, in addition to precision statements published for each instrument in American Society for Testing and Materials (ASTM) standards. In Utah, the repeatability of the CIST, SSG, and PFWD was evaluated on two pavement reconstruction projects employing CTB (*7*). Between two and three instrument readings were obtained at each of six stations within each of three sites on each project at time intervals corresponding to various CTB ages over the course of several days. With spatial variability assumed to be constant for each instrument from station to station within each test site, statistical analyses were then performed. In particular, the coefficient of variation (CV) was computed for the station means at each incremental curing time for each site for each instrument. The station CVs for the CIST and SSG ranged from 5.3 to 20.3 percent and 3.4 to 30.1 percent, respectively, on the first project and from 3.9 to 24.6 percent and 6.5 to 40.0 percent, respectively, on the second project. The station CVs for the PFWD, which were computed for only the second site, ranged from 12.8 to 68.2 percent. In the analyses, the significance of the differences in the CVs computed for the station means at each incremental curing time was evaluated for each site for each instrument. The results of *t*-tests utilized to analyze the collected data indicated that the CIST was the most repeatable instrument, followed by the SSG and the PFWD, in that order.

In Louisiana, the repeatability of the SSG and PFWD was evaluated at 27 stations on highway and trench sections representing treated and untreated base and subbase layers (*8*, *9*). Five instrument readings were taken within a 300-mm (1-ft) radius at each station, with the close proximity of multiple readings intended to minimize spatial variability in the layer properties, and the CV was then computed for each set of five readings. The CVs calculated for the SSG were determined to vary between 0.4 and 11.4 percent, with the majority of the values falling between 1 and 7 percent (*8*), while those calculated for the PFWD were determined to vary between 2.1 and 28.1 percent. Thus, these data also show the SSG to be more repeatable overall than the PFWD.

To various degrees, the repeatability of the NDG, DCP, CIST, SSG, and PFWD is also addressed in ASTM D 6938-08 (Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)), ASTM D 6951-03 (Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications), ASTM D 5874-02 (Standard Test Method for Determination of the Impact Value (IV) of a Soil), ASTM D 6758-08 (Standard Test Method for Measuring Stiffness and Apparent Modulus of Soil and Soil-Aggregate In-Place by an Electro-Mechanical Method), and ASTM E 2583-07 (Standard Test Method for Measuring Deflections with a Light Weight Deflectometer (LWD)), respectively. However, the precision statements in some of these standards address spatial variability associated with typical construction projects rather than repeatability of the individual instruments.

As stated previously, several factors can affect the repeatability of a given instrument, with one possible factor being operator effects; devices that require more participation by the user may be more susceptible to variable results due to deviations in the measurement process by different operators. However, while the results of the Utah and Louisiana studies provide insights as to the overall repeatability of these instruments, neither study was designed to investigate operator effects. Furthermore, none of the ASTM standards governing the use of these devices provides information about the effect of different operators on instrument responses.

2.5 SUMMARY

Several devices exist for testing subsurface pavement materials, including but not limited to the NDG, DCP, CIST, SSG, and PFWD. A few attempts have been made to correlate the output of some of these instruments, but no endeavors to simultaneously develop correlations among all of these devices for base, subbase, and subgrade materials have yet been published. Furthermore, while the repeatability of the CIST, SSG, and PFWD has been evaluated, the relative influence of operator effects on test results obtained from the different devices has not been quantified.

CHAPTER 3

EXPERIMENTAL METHODOLOGY

3.1 OVERVIEW

The following sections present the methods utilized in this research for collection and analysis of correlation and operator effects data.

3.2 CORRELATIONS

The procedures used to collect and analyze data for the correlation analyses are described in the following sections.

3.2.1 Data Collection

Test results from 41 project sites in four states, namely Iowa, Louisiana, Utah, and Wyoming, were compiled for the purpose of performing correlation analyses on the NDG, DCP, CIST, SSG, and PFWD instrument readings. Data collected in Utah and Wyoming by Brigham Young University researchers were combined with data previously published or collected by various researchers in Iowa and Louisiana (*26*, *34*). A summary of project locations, names, material descriptions, soil types, and numbers of tests is given in Table 3.1, and the original data are included in Appendix A.

Aggregate and/or soil samples were collected from over 800 test locations by the various researchers and classified according to Unified Soil Classification System

TABLE 3.1 Summary of Correlation Data

State	Project Name	Material Description	Unified Soil Classification	Number of Tests
Iowa	Project 1 - Eddyville Bypass	Hydrated Fly Ash-Stabilized Subbase	GP-GM	33
	Project 2 - Highway 330	Untreated Subgrade	SM	33
	Project 3 - Knapp Street	Untreated Subgrade	SC	51
	Project 5 - 35th Street and I-235 Westbound Ramp	Untreated Subgrade	CL	130
	Project 6 - 35th Street and I-235 Westbound Ramp	Granular Subbase	GP-GM	24
	Project 7 - Highway 34 Eastbound Lane East of Fairfield	Untreated Subgrade	SM	85
	Project 8 - Highway 218 Southbound Lane South of Mount Pleasant	Untreated Subgrade	CL	85
	Project 9 - I-35 Northbound Lane by Highway 20	Untreated Subgrade	CL-ML	85
	Project 10 - Lot S1 before Fly Ash Stabilization	Untreated Subgrade	SC	18
	Project 11 - Lot S1 after Fly Ash Stabilization	Class C Fly Ash-Stabilized Subgrade	SM	18
	Project 12 - University-Guthrie Avenue	Granular Subbase	GP-GM	30
Louisiana	Seyman - Clay	Compacted Base	CL	9
	Seyman - Clay + 2% Cement Content by Weight of Clay	CTB	CL	5
	Seyman - Clay + 4% Cement Content by Weight of Clay	CTB	CL	4
	Seyman - Sand Clay Gravel Base Course	Compacted Base	GC	1
	Seyman - Limestone	Compacted Base	GC	1
	Seyman - Crushed Limestone	Compacted Base	GW	1
	Seyman - RAP	RAP Base	GP	1
	Seyman - Clayey Silt	Compacted Base	CL-ML	3
	Seyman - Sand	Compacted Base	SP	3
Utah	I-84 Site 1 - 2% Cement Blended with 50% RAP	CTB	SW-SM	43
	I-84 Site 2 - 2% Cement Blended with 50% RAP	CTB	SW-SM	35
	I-84 Site 3 - 2% Cement Blended with 50% RAP	CTB	SW-SM	36
	I-84 Site 4 - 2% Cement Blended with 50% RAP	CTB	SW-SM	6
	US-91 Site 1 - 2% Cement	CTB	GW	54
	US-91 Site 2 - 2% Cement	CTB	GW	42
	US-91 Site 3 - 2% Cement	CTB	GW	36
	Orem - 16% RAP	RAP Base	SW	12
Wyoming	Black Butte Road - 1	Compacted Base	SP	2
	Black Butte Road - 2	Untreated Subgrade	CL-ML	2

(USCS). Additives applied to some of these soils include hydrated fly ash, Class C fly ash, cement, and reclaimed asphalt pavement (RAP). MDDs were determined in the laboratory for the aggregate samples from Utah and Wyoming in order to evaluate percent compaction. Compaction of these test specimens was achieved by using the modified Proctor procedure.

To ensure more accurate correlations between instrument readings, only those data sets including measurements obtained using at least three of the five instruments were selected for use in this research. To reduce the probability of variation between instrument readings due to spatial differences in material properties, only NDG, DCP, CIST, SSG, and PFWD tests performed within a 0.5-m (1.5-ft) radius at each location were used for analysis. Additionally, the target depth for each reading was 200 to 450 mm (8 to 18 in.), which is considered to be within the range of typical road base or subbase layer thicknesses and is acceptable for subgrade measurement (*1*).

3.2.2 Data Analysis

Regression analysis was performed by plotting each instrument reading comparatively with another at the same site and location. Percent compaction values, computed by dividing NDG dry density readings by the respective MDD values, were also plotted comparatively for examination. Several transformations of the *x*- and/or *y*-axes were performed as necessary to linearize the data trends to enable the visual evaluation of residuals. A simple linear regression analysis was then completed on the transformed data sets to quantify the results as linear regression equations.

For each regression analysis, the R^2 value was computed, and a *t*-test was also performed on the slope of the regression line. The null hypothesis was that the slope of the regression line was zero, while the alternative hypothesis was that the slope of the regression line was non-zero. When the resulting *p*-value was less than or equal to a Type I error rate of 0.05, the null hypothesis was rejected and the alternative hypothesis accepted. Transformations that resulted in high R^2 values, low *p*-values, and balanced residuals were ultimately selected for use in the correlation analyses. Specifically, correlations resulting in R^2 values greater than or equal to 0.50 in conjunction with *p*-values less than or equal to 0.05 were considered satisfactory for the purposes of this research.

Satisfactory correlations were then used to develop a nomograph for correlating responses among the different devices. The ranges selected for each instrument were those associated with the properties of the treated and untreated base, subbase, and subgrade pavement layers analyzed in this research.

3.3 OPERATOR EFFECTS

The procedures used to collect and analyze data for determining operator effects are described in the following sections.

3.3.1 Data Collection

For investigation of operator effects in this research, the CIST and SSG devices were chosen over the NDG, DCP, and PFWD because of their low cost, mobility, and simplicity (*5, 7*). Concerning simplicity in particular, neither the CIST nor the SSG requires specialized operator training like the NDG, nor do these instruments return output requiring additional analysis like the DCP and PFWD, which may attach uncertainty to the study unrelated to operator effects. For these reasons, the CIST and SSG were used in this research to examine repeatability with respect to operator effects.

Data were collected at 27 test sites on six types of treated and untreated aggregate base material in Utah. A summary of project names, material descriptions, and USCS soil classifications associated with data collected for the analysis of operator effects is given in Table 3.2, and the original data are included in Appendix B. Individual test locations were configured at each site by marking nine points evenly spaced within a square having a side length of 1 m (3 ft) square. Data collection was then completed by randomly selecting and assigning each of three operators to test three locations within the square as shown as Figure 3.1. The operators then deployed the SSG device row by row at their assigned location, consistently working left to right and top to bottom at each test site. Thus, after the testing was complete, each operator had measured the stiffness of the test site three times. Following the SSG testing, CIST measurements were collected using the same pattern described for the SSG. The CIST testing was performed last so that any consolidation of the aggregate surface caused by the falling weight would not influence SSG readings, which are entirely non-destructive. The data collection process is illustrated in Figures 3.2 to 3.4.

TABLE 3.2 Summary of Operator Effects Data

Project Name	Material Description	Unified Soil Classification	Square Number
Pleasant Grove - 2008	Untreated Base	SP	1
	Untreated Base	SP	2
	Untreated Base	SP	3
	CTB	SP	4
	CTB	SP	5
	CTB	SP	6
	Cement + Enzyme	SP	7
	Cement + Enzyme	SP	8
	Cement + Enzyme	SP	9
	Enzyme	SP	10
	Enzyme	SP	11
	Enzyme	SP	12
	Enzyme	SP	13
	Enzyme	SP	14
	Enzyme	SP	15
	Surfactant	SP	16
	Surfactant	SP	17
	Surfactant	SP	18
US-91 - 2004	CTB	GW	19
	CTB	GW	20
	CTB	GW	21
	CTB	GW	22
	CTB	GW	23
I-84 - 2005	CTB	SW-SM	24
	CTB	SW-SM	25
US-91 - 2005	CTB	GW	26
	CTB	GW	27

1	2	3
3	1	2
2	3	1

FIGURE 3.1 Layout of operator test locations.

FIGURE 3.2 Marking of operator test locations.

FIGURE 3.3 Testing with SSG to assess operator effects.

FIGURE 3.4 Testing with CIST to assess operator effects.

3.3.2 Data Analysis

Data collected for investigating operator effects were tabulated by square, and CVs for both the CIST and SSG were computed for each square. The data were then evaluated using a one-way analysis of variance (ANOVA). One ANOVA was completed for each instrument for each of the 27 test sites. The null hypothesis of the ANOVA was that the mean CIV or soil stiffness values were equal among the different operators. The alternative hypothesis was that the means were different between at least two of the operators. As in the regression analysis, a Type I error rate of 0.05 was specified. Thus, when the *p*-value was less than or equal to 0.05, the null hypothesis was rejected and the alternative hypothesis accepted, meaning that the variation in output between operators was high.

3.4 SUMMARY

Test results from 44 sites in Iowa, Louisiana, Utah, and Wyoming were compiled for performing a series of statistical regression analyses to evaluate correlations among NDG, DCP, CIST, SSG, and PFWD instrument readings. Regression analysis was performed by plotting each instrument reading comparatively with another at the same site and location. Analyses were also performed to compare percent compaction to DCP, CIST, SSG, and PFWD readings. Correlations resulting in R^2 values greater than or equal to 0.50 and *p*-values less than or equal to 0.05 were considered satisfactory. Operator effects associated with the CIST and SSG were evaluated at 27 sites in Utah using an ANOVA. Operator effects were considered to be statistically significant when the resulting *p*-value was less than or equal to 0.05.

CHAPTER 4

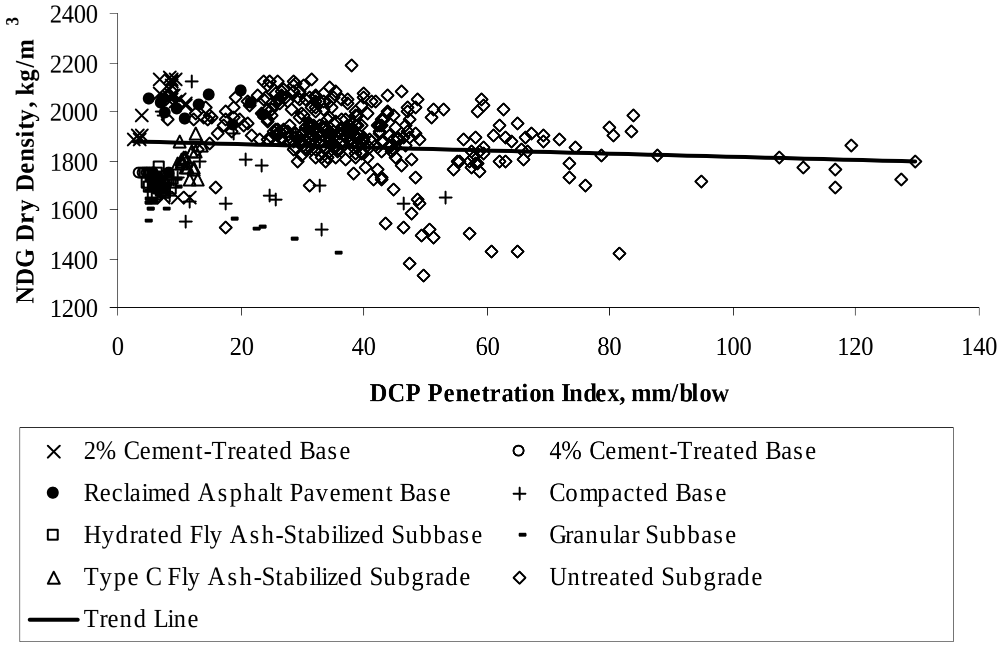
RESULTS

4.1 OVERVIEW

The following sections present summaries of the instrument correlations and analyses of the operator effects investigated in this research.

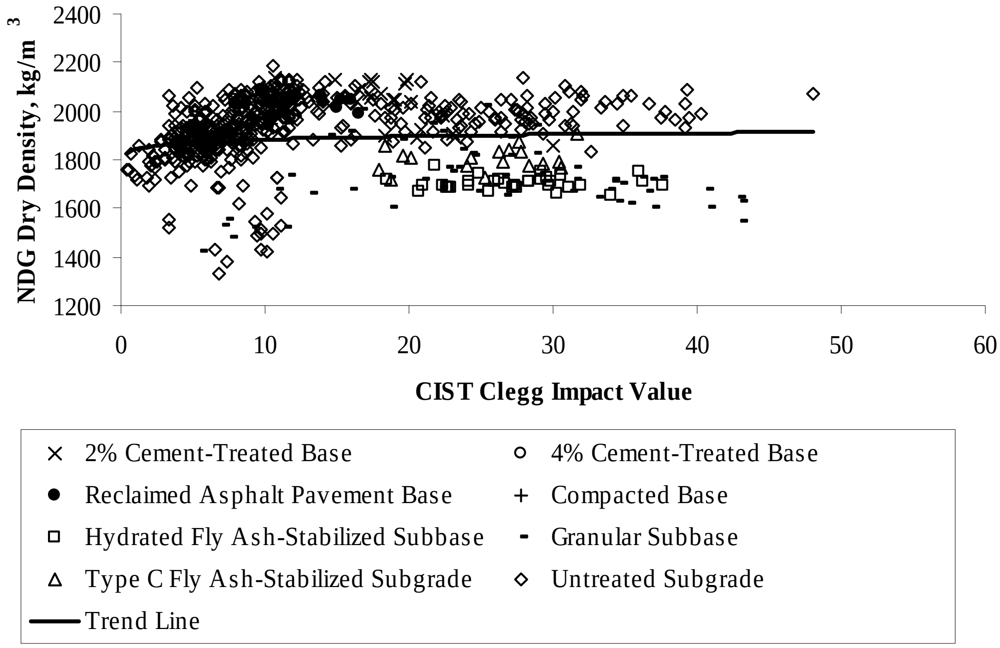
4.2 CORRELATIONS

The ten possible scatter plots of two-way instrument data comparisons for the given treated and untreated base, subbase, and subgrade material types are shown in Figures 4.1 to 4.10. Corresponding NDG, DCP, CIST, SSG, and PFWD measurement readings are given as dry density (kg/m^3), penetration index (mm/blow), CIV, stiffness (MN/m), and modulus (MPa), respectively. To further investigate correlations between the NDG and the DCP, CIST, SSG, and PFWD instruments, NDG dry density readings were replaced with NDG percent compaction (NDGPC) and were again plotted as shown in Figures 4.11 to 4.14. A summary of R^2 and *p*-value statistical results for each two-way analysis is given in Table 4.1. Displayed trend lines indicate the best overall regressions for the given data sets.



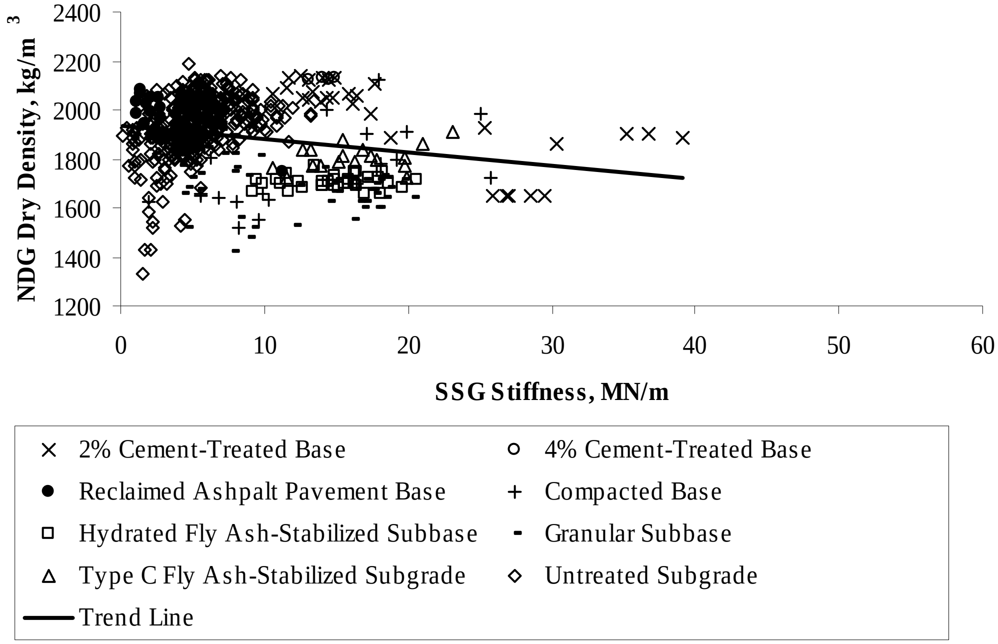
NOTE: 1 pcf = 16.02 kg/m^3
1in./blow = 25.4 mm/blow

FIGURE 4.1 Correlation between NDG dry density and DCP penetration index.



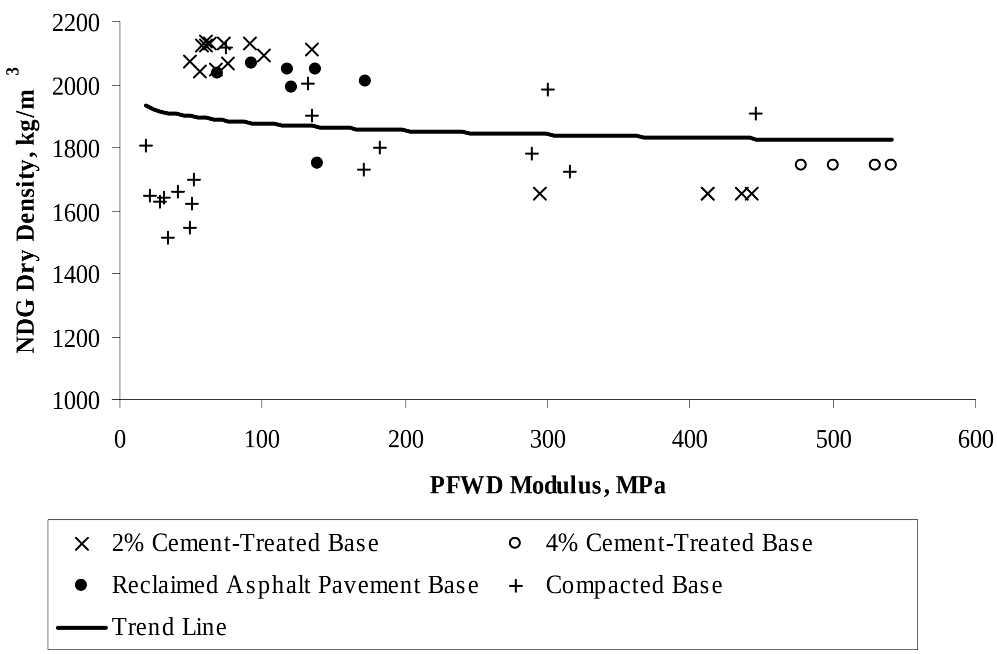
NOTE: 1 pcf = 16.02 kg/m^3

FIGURE 4.2 Correlation between NDG dry density and CIST Clegg impact value.



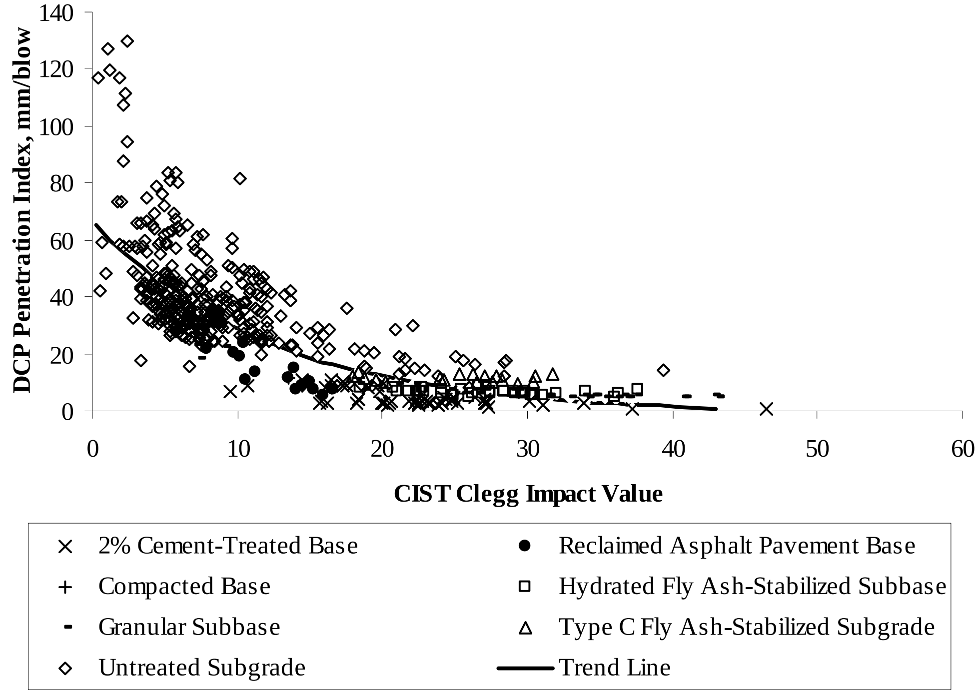
NOTE: 1 pcf = 16.02 kg/m^3
1 klbf/in. = 0.175 MN/m

FIGURE 4.3 Correlation between NDG dry density and SSG stiffness.



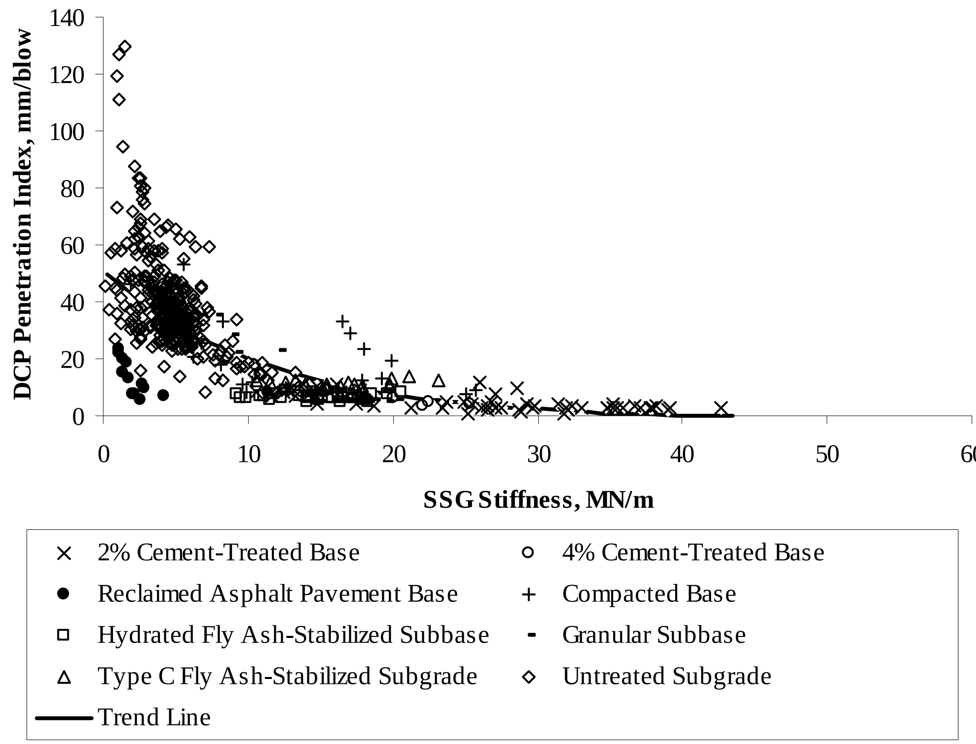
NOTE: 1 pcf = 16.02 kg/m^3
1 ksi = 6.89 MPa

FIGURE 4.4 Correlation between NDG dry density and PFWD modulus.



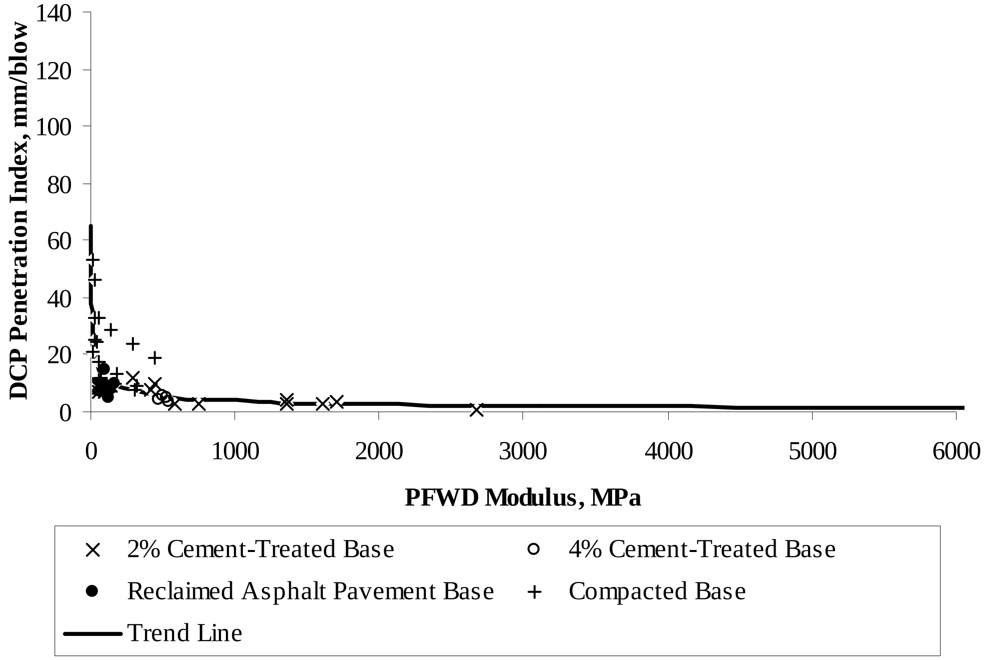
NOTE: 1in./blow = 25.4 mm/blow

FIGURE 4.5 Correlation between DCP penetration index and CIST Clegg impact value.



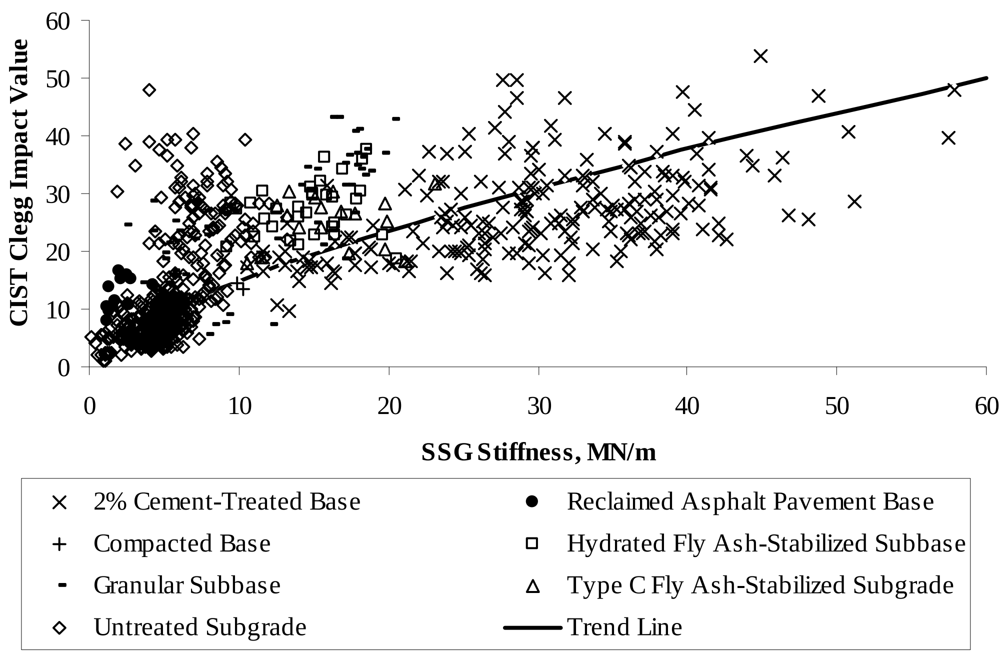
NOTE: 1in./blow = 25.4 mm/blow
1 klbf/in. = 0.175 MN/m

FIGURE 4.6 Correlation between DCP penetration index and SSG stiffness.



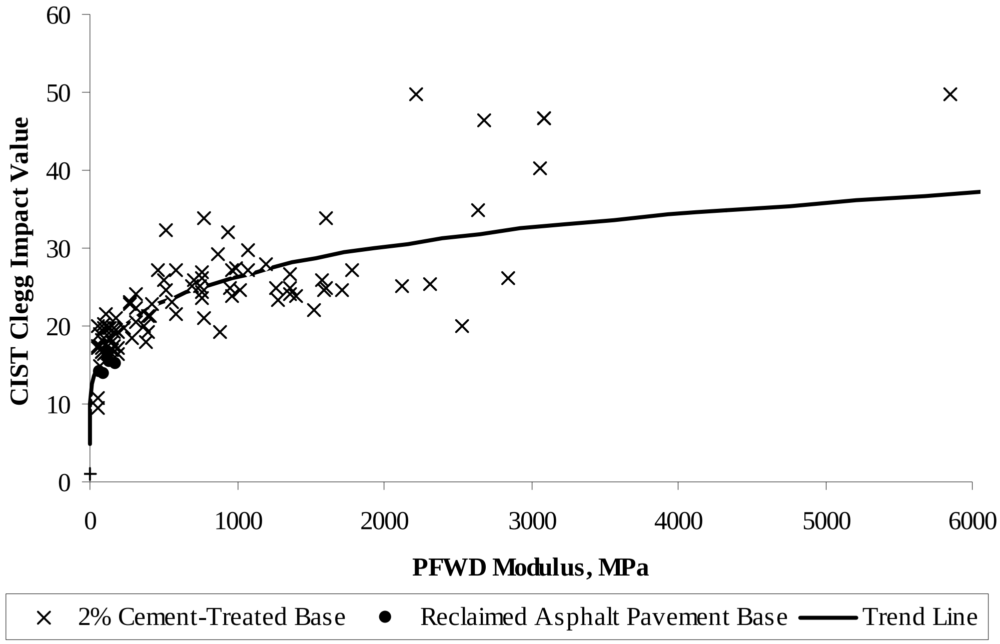
NOTE: 1in./blow = 25.4 mm/blow
1 ksi = 6.89 MPa

FIGURE 4.7 Correlation between DCP penetration index and PFWD modulus.



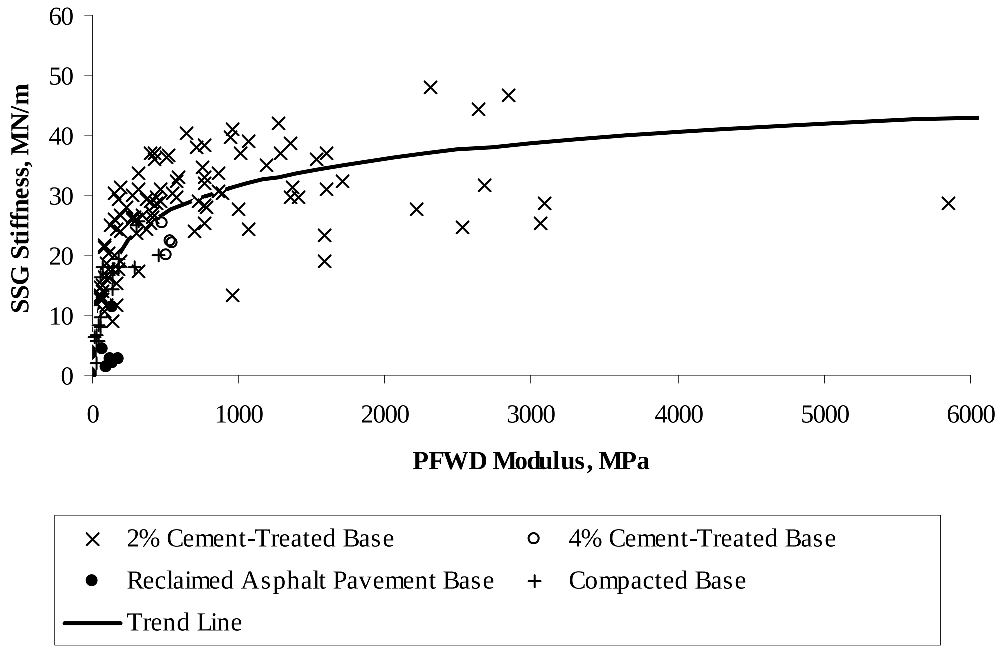
NOTE: 1klbf/in. = 0.175 MN/m

FIGURE 4.8 Correlation between CIST Clegg impact value and SSG stiffness.



NOTE: 1 ksi = 6.89 MPa

FIGURE 4.9 Correlation between CIST Clegg impact value and PFWD modulus.



NOTE: 1klbf/in. = 0.175 MN/m
1 ksi = 6.89 Mpa

FIGURE 4.10 Correlation between SSG stiffness and PFWD modulus.

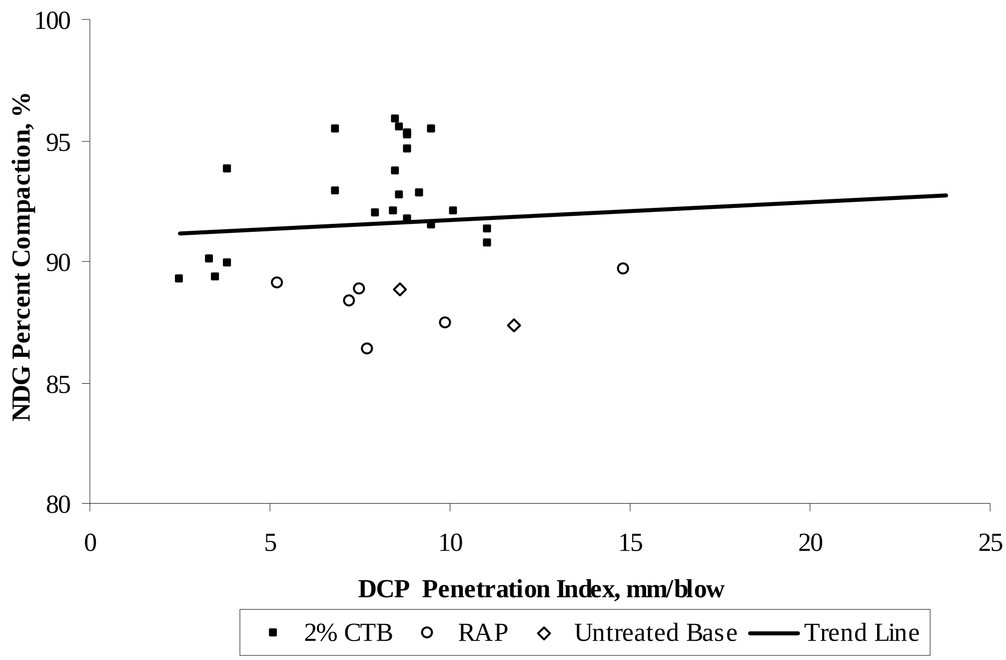


FIGURE 4.11 Correlation between NDG percent compaction and DCP penetration index.

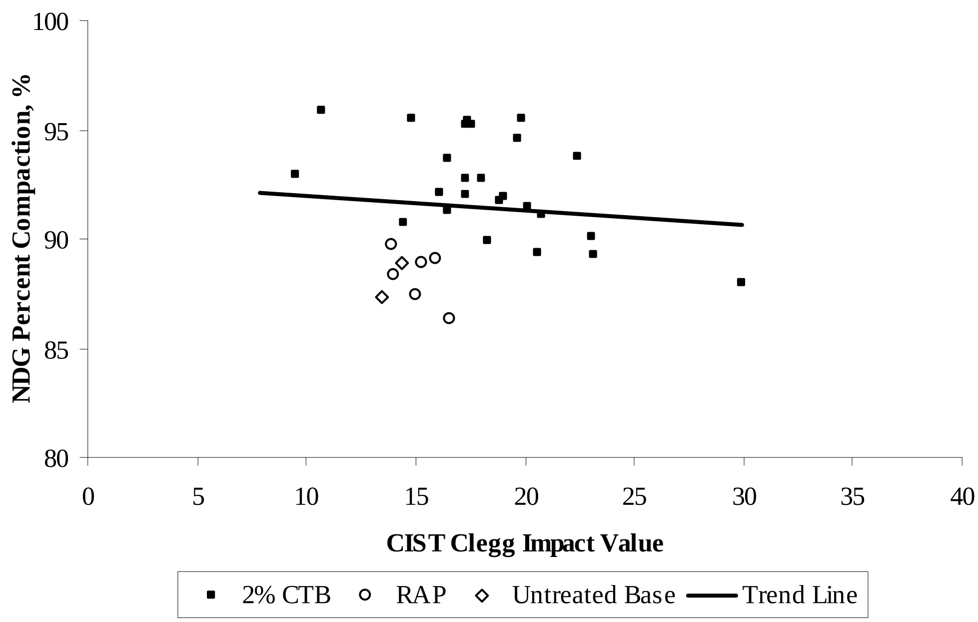
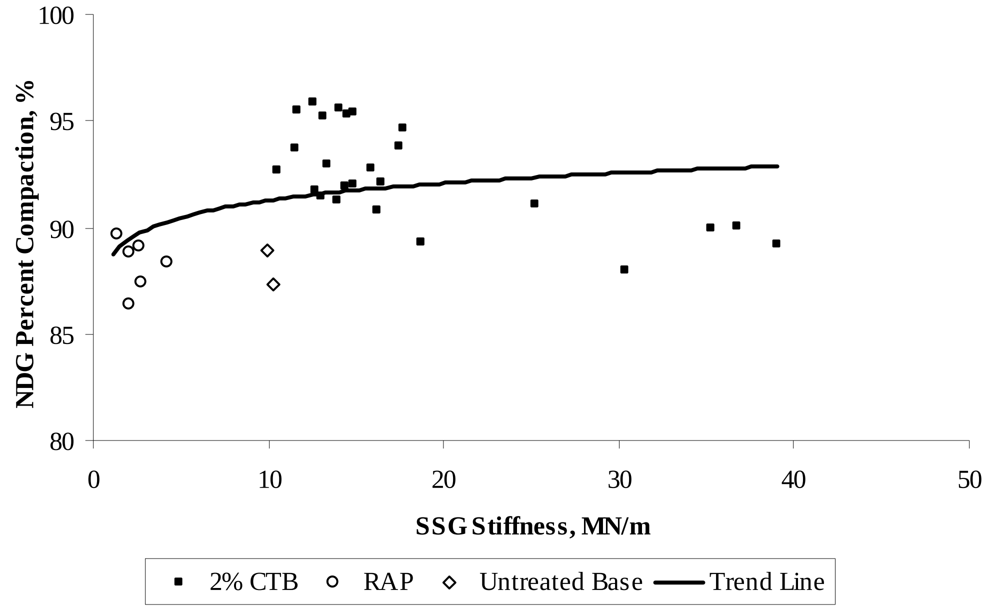
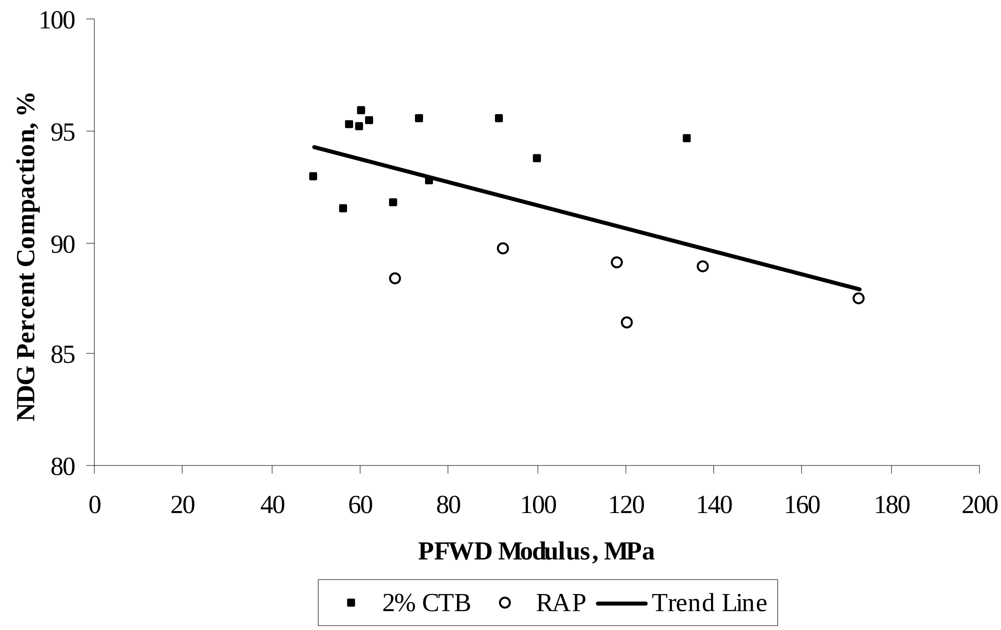


FIGURE 4.12 Correlation between NDG percent compaction and CIST Clegg impact value.



NOTE: 1klbf/in. = 0.175 MN/m

FIGURE 4.13 Correlation between NDG percent compaction and SSG stiffness.



NOTE: 1 ksi = 6.89 MPa

FIGURE 4.14 Correlation between NDG percent compaction and PFWD modulus.

TABLE 4.1 Statistical Evaluations of Correlation Data

y-axis	*x*-axis	R^2	*p*-value
NDG	DCP	0.01	0.035
NDG	CIST	0.00	0.970
NDG	SSG	0.04	<0.001
NDG	PFWD	0.12	0.020
NDGPC	DCP	0.00	0.700
NDGPC	CIST	0.01	0.599
NDGPC	SSG	0.13	0.041
NDGPC	PFWD	0.32	0.015
DCP	CIST	0.72	<0.001
DCP	SSG	0.74	<0.001
DCP	PFWD	0.54	<0.001
CIST	SSG	0.59	<0.001
CIST	PFWD	0.66	<0.001
SSG	PFWD	0.59	<0.001

According to these results, statistically significant correlations exist between DCP and CIST, DCP and SSG, DCP and PFWD, CIST and SSG, CIST and PFWD, and SSG and PFWD instrument measurements. Poor correlations between the NDG and all other instrument readings strongly suggest that no satisfactory relationships exist between dry density or percent compaction and road base, subbase, or subgrade soil properties measured by the DCP, CIST, SSG, or PFWD for the materials investigated in this study. These poor correlations are further evidence that density cannot be generally correlated to strength or stiffness independent of soil type, as previously stated.

For the six satisfactory relationships identified from the data in Table 4.1, regression equations were modeled according to the original data plots and trend lines. For example, the trend line in Figure 4.1 relating DCP penetration index to CIV is a logarithmic type and therefore produced the logarithmic-based relationship presented as

Equation 4.1. In several data sets, the numerical values were increased by a value of one to avoid taking the log of zero. The relationships resulting from this process, repeated for each two-way comparison, are presented as Equations 4.1 to 4.6. No regression equations were developed for data plotted with the NDG due to unsatisfactory R^2 and *p*-values.

$$\log(DCP+1) = 1.83 - 0.0356 \cdot CIV \quad (R^2 = 0.72) \tag{4.1}$$

where DCP = penetration index (mm/blow)

CIV = Clegg impact value

$$\log(DCP+1) = 1.72 - 0.0396 \cdot SSG \quad (R^2 = 0.74) \tag{4.2}$$

where DCP = penetration index (mm/blow)

SSG = stiffness (MN/m)

$$\log(DCP+1) = 1.92 - 0.413 \cdot \log(PFWD) \quad (R^2 = 0.54) \tag{4.3}$$

where DCP = penetration index (mm/blow)

$PFWD$ = modulus (MPa)

$$\log(CIV) = 0.442 + 0.704 \cdot \log(SSG+1) \quad (R^2 = 0.59) \tag{4.4}$$

where CIV = Clegg impact value

SSG = stiffness (MN/m)

$$\log(CIV) = 0.846 + 0.192 \cdot \log(PFWD) \ \ (R^2 = 0.66) \tag{4.5}$$

where CIV = Clegg impact value

$PFWD$ = modulus (MPa)

$$SSG = 15.1 \cdot \log(PFWD) - 13.8 \ \ (R^2 = 0.59) \tag{4.6}$$

where SSG = stiffness (MN/m)

$PFWD$ = modulus (MPa)

The R^2 values in Equations 4.1 to 4.6 are comparable to those associated with correlations established by other researchers as documented in Equations 2.4 to 2.7. Equations 4.1 and 4.2 are actually characterized by higher R^2 values than the corresponding Equations 2.4 and 2.5; however, the R^2 values reported for Equations 2.6 and 2.7, which both relate DCP to PFWD data, exceed the R^2 value computed for the corresponding Equation 4.3 developed in this study. Although an engineer may therefore consider substituting Equation 2.8 for Equation 4.3 when relating DCP and PFWD data, the engineer should consider the fact that the equations developed in this research are based on a comparatively larger sample size and are therefore more applicable to a wider variety of aggregate and soil materials.

Because all six equations generated in this research were considered satisfactory, additional criteria were necessarily applied to develop the correlation nomograph. The chosen approach was to select a reference instrument that exhibited a range in data sufficiently large to encompass the data sets associated with the other devices and that was also characterized by uniformly high R^2 values in the regression analyses performed in this study. The purposes of these criteria were to ensure that the full ranges of all the data available for the other instruments could be correlated to the reference instrument data and to uniformly distribute the correlation errors throughout the nomograph to the extent possible. In this approach, the equations relating the output of the reference instrument to that of the other instruments would be exclusively used in developing the nomograph. Application of these criteria in this manner also ensured that a maximum of two equations would be involved in relating the output of any two instruments included in the nomograph; the objective in involving a minimum number of equations was to reduce the propagation of errors associated with numerous sequential calculations.

With the additional criteria in place, the data given in Table 4.2 were considered in the process of selecting a reference instrument. Although the DCP exhibited the highest average R^2 value, it also had the highest standard deviation, indicating that this set of correlations was characterized by the least uniformity in statistical quality. On the other hand, while the PFWD exhibited the lowest standard deviation, it also had the lowest average R^2 value, which was likewise undesirable. Consequently, with an average R^2 value very close to the maximum and a standard deviation very close to the minimum, the CIST was selected as the reference instrument for development of the nomograph.

In the process of nomograph creation, a linear scale was drawn to represent CIST values ranging from 1 to 50, and then subsequent scales were drawn to relate the CIST values to corresponding values associated with the DCP, SSG, and PFWD based on Equations 4.1, 4.4, and 4.5, respectively. Figure 4.15 displays the end product, which may used for correlating the responses of the different devices. A horizontal line drawn through the chart intersects the vertical lines at equivalent strength/stiffness values for

TABLE 4.2 Coefficients of Determination from Correlation Analyses

	R^2 Value			
Instrument	DCP	CIST	SSG	PFWD
DCP	-	0.72	0.74	0.54
CIST	0.72	-	0.59	0.66
SSG	0.74	0.59	-	0.59
PFWD	0.54	0.66	0.59	-
Average	0.67	0.66	0.64	0.60
Standard Deviation	0.11	0.07	0.09	0.06

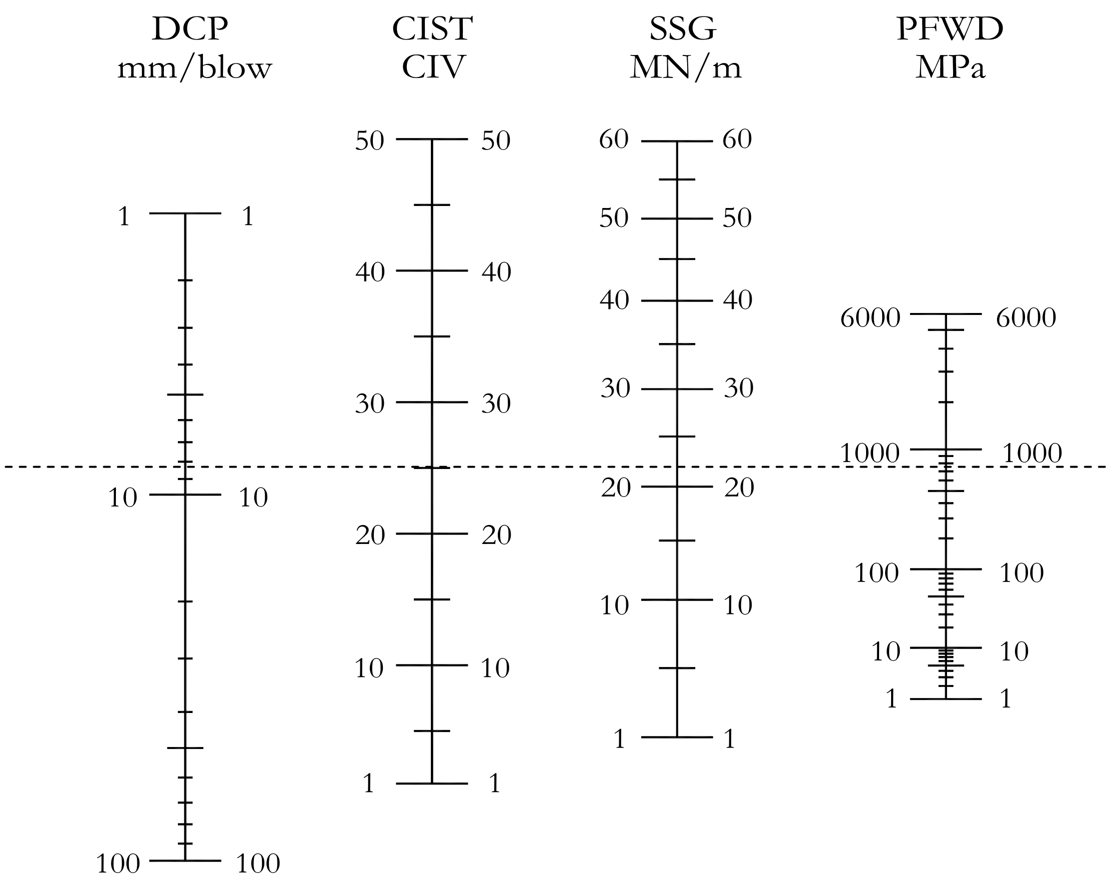


FIGURE 4.15 Correlation nomograph.

each instrument. For example, the recommended threshold CIV at which CTB layers may be opened to early trafficking to prevent excessive rutting is 25 (*5*); however, in the case that testing was limited to only an SSG, an engineer or contractor could readily determine from Figure 4.15 that the SSG reading equivalent to a CIV of 25 is approximately 22 MN/m. Scatter plots comparing the relationships embodied in the nomograph with each of the individual equations developed in this research for correlating instrument responses are provided in Appendix C.

4.3 OPERATOR EFFECTS

The results of the analyses performed to evaluate operator effects are presented in Table 4.3, which includes average CIST CIV and SSG stiffness values for each operator and CVs and *p*-values for each instrument at each test site. The CVs for the CIST and SSG range from 4.6 to 36.6 percent and from 6.9 to 34.0 percent, respectively; these data are very similar to those reported by other researchers as discussed previously.

According to the table, two of the 27 CIST data analyses returned *p*-values less than or equal to 0.05, signifying a statistically significant operator effect for 7.4 percent of the CIST test sites. Operator variability at square 24 was statistically significant between operators one and three. A 95 percent confidence interval of -5.7 to -0.1 indicates that the difference between operators is also of practical importance. Similarly, statistically significant differences occurred at square 27 between operator one and both operators two and three, with 95 percent confidence intervals of 1.4 to 8.4 and 2.0 to 9.0, respectively.

No operator effects were detected at any square for the SSG data, as indicated by *p*-values greater than 0.05 in every case. Thus, to the extent that the experimental design was successful in equalizing the effects of spatial variability on each operator, the SSG data appear to be less susceptible to operator effects than the CIST data.

TABLE 4.3 Statistical Evaluations of Operator Effects Data

Square	Average CIST (CIV)			Average SSG (MN/m)			CV (%)		*p* -value	
	Operator			Operator						
Number	1	2	3	1	2	3	CIST	SSG	CIST	SSG
1	8.3	8.5	7.8	7.3	7.4	6.85	9.5	10.1	0.610	0.730
2	8.4	7.8	8.7	10.7	9.5	9.74	23.6	28.4	0.862	0.872
3	10.1	10.5	10.0	15.6	14.6	16.76	7.4	13.4	0.801	0.577
4	13.4	12.9	13.9	12.4	14.2	15.56	6.9	8.7	0.464	0.101
5	14.6	15.7	14.4	16.3	15.9	13.42	5.4	10.9	0.208	0.184
6	11.4	12.8	11.4	11.8	15.0	12.18	6.3	20.7	0.176	0.444
7	13.2	13.5	14.3	10.7	13.4	10.69	16.0	22.3	0.828	0.445
8	16.5	16.1	15.7	15.9	21.2	16.05	13.0	19.3	0.906	0.231
9	12.6	12.9	12.9	12.0	15.7	13.14	4.6	12.7	0.808	0.095
10	7.6	8.2	7.9	7.2	7.6	7.45	13.8	15.5	0.809	0.892
11	10.2	10.4	9.1	10.1	10.2	10.68	10.0	8.7	0.338	0.774
12	9.4	9.4	8.9	10.7	10.8	10.04	14.7	19.9	0.909	0.887
13	8.1	8.5	7.7	8.2	7.3	7.42	23.0	23.7	0.886	0.808
14	8.7	8.3	9.3	10.9	11.0	11.35	19.4	22.4	0.791	0.978
15	10.3	10.5	10.2	13.4	11.2	11.68	12.2	19.8	0.972	0.713
16	3.8	3.7	3.4	6.4	5.4	5.05	36.6	26.2	0.922	0.559
17	10.9	10.2	9.9	15.6	12.5	12.18	7.8	22.4	0.430	0.375
18	6.0	5.7	6.2	9.9	9.7	10.38	29.0	34.0	0.940	0.972
19	24.6	25.5	28.6	37.4	37.5	40.48	10.9	11.2	0.332	0.651
20	25.3	26.6	25.2	35.9	37.8	33.07	10.9	10.2	0.818	0.415
21	28.4	29.1	29.5	34.0	37.8	36.98	8.6	12.1	0.874	0.633
22	27.5	25.1	25.4	33.7	33.3	32.53	6.1	10.3	0.279	0.925
23	26.4	24.5	25.2	35.2	36.8	37.40	5.4	15.7	0.367	0.899
24	18.1	19.9	21.0	16.6	17.2	17.51	5.6	22.5	0.049	0.957
25	27.5	30.2	33.1	28.9	30.2	33.08	10.8	9.0	0.226	0.336
26	20.5	20.2	20.8	21.1	21.8	18.60	13.0	29.0	0.963	0.821
27	23.0	18.1	17.5	17.4	16.8	17.50	7.0	6.9	0.005	0.755

4.4 SUMMARY

Numerous data analyses were performed in this research to investigate correlations among NDG, DCP, CIST, SSG, and PFWD data and to evaluate operator effects on the output of the CIST and SSG. Regression analyses identified statistically significant correlations between DCP and CIST, DCP and SSG, DCP and PFWD, CIST and SSG, CIST and PFWD, and SSG and PFWD instrument readings; however, no statistically significant correlation between the NDG and any other instrument was observed. Thus, based on specific equations developed from the statistically significant correlations, a nomograph was developed for correlating responses among DCP, CIST, SSG, and PFWD data. According to the ANOVA results obtained in this study, the CIST data exhibited a significant operator effect at 7.4 percent of the test sites, whereas no operator effects were detected at any test site for the SSG data. Thus, to the extent that the experimental design was successful in equalizing the effects of spatial variability on each operator, the SSG data appear to be less susceptible to operator effects than the CIST data.

CHAPTER 5

CONCLUSION

5.1 SUMMARY

The primary objective of this research was to develop working correlations between data sets associated with the NDG, DCP, CIST, SSG, and PFWD that allow pavement engineers to apply QC/QA measures without necessarily acquiring the instruments used to develop the testing procedures of interest. Readings were analyzed from 41 project sites on treated and untreated base, subbase, and subgrade layers representing 15 different soil types in Iowa, Louisiana, Utah, and Wyoming. Scatter plots representing two-way instrument comparisons were prepared, and statistical analyses were then performed to investigate correlations among the data. As a secondary objective, repeatability with respect to operator effects was additionally investigated for the CIST and SSG at 27 sites on treated and untreated base layers in Utah. Operator effects were determined by means of a one-way ANOVA.

5.2 FINDINGS

Regression analyses identified statistically significant correlations between DCP and CIST, DCP and SSG, DCP and PFWD, CIST and SSG, CIST and PFWD, and SSG and PFWD instrument readings; however, no statistically significant correlation between the NDG and any other instrument was observed. Poor correlations between the NDG and all other instrument readings strongly suggest that no satisfactory relationships exist between dry density or percent compaction and road base, subbase, or subgrade soil properties measured by the DCP, CIST, SSG, or PFWD for the materials investigated in this study. Thus, based on specific equations developed from the statistically significant correlations, a nomograph was developed for correlating responses among DCP, CIST, SSG, and PFWD data.

According to the ANOVA results obtained in this study, the CIST data exhibited a significant operator effect at 7.4 percent of the test sites, whereas no operator effects were detected at any test site for the SSG data. Thus, to the extent that the experimental design was successful in equalizing the effects of spatial variability on each operator, the SSG data appear to be less susceptible to operator effects than the CIST data.

5.3 RECOMMENDATIONS

The results obtained from this research suggest that engineers should consider utilizing alternative approaches to the NDG for evaluating the mechanistic properties of aggregates and soils, as density cannot be generally correlated to strength or stiffness independent of soil type. Alternative devices include the DCP, CIST, SSG, and PFWD, which were all evaluated in this study and included in a nomograph developed for correlating responses among these instruments.

Correlations developed from this research will be useful to engineers needing to quickly convert the values associated with one instrument to those associated with another. Specifically, understanding the correlation between any two devices will allow an engineer to more readily certify assumed design properties after construction and compare construction practices and pavement layer properties, including seasonal variations, at regional, national, and/or global levels. Pavement engineers, however, must utilize judgment when applying the equations or correlation chart developed in this research to materials dissimilar to those included in this study.

Additionally, the results of the repeatability study suggest that, at minimum, CIST responses may be sensitive to operator effects. In general, operators utilizing any of the instruments studied in this research should carefully adhere to the operational procedures recommended by the respective instrument manufacturer.

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APPENDIX A

CORRELATION DATA

TABLE A.1 Project 1 - Eddyville Bypass

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1689	6.6	22.6	16.5	-
2	1682	8.9	27.2	12.6	-
3	1748	6.4	29.2	16.2	-
4	1736	5.6	30.5	11.6	-
5	1712	6.5	28.4	9.5	-
6	1681	7.9	22.8	19.6	-
7	1665	7.7	25.5	11.8	-
8	1713	6.7	28.4	10.8	-
9	1714	8.1	18.5	20.6	-
10	1744	5.2	24.9	16.4	-
11	1721	6.5	29.1	17.9	-
12	1667	7.9	20.7	9.2	-
13	1706	4.8	26.0	14.1	-
14	1694	6.3	29.7	15.9	-
15	1684	6.8	22.9	15.1	-
16	1707	5.9	24.1	12.3	-
17	1697	7.6	37.7	18.6	-
18	1696	6.6	22.4	11.1	-
19	1713	6.2	36.3	15.8	-
20	1703	8.6	26.7	14.5	-
21	1750	4.6	36.0	18.3	-
22	1719	6.0	26.3	17.3	-
23	1694	6.0	27.4	10.0	-
24	1696	6.3	32.0	15.6	-
25	1694	7.7	24.1	16.3	-
26	1687	5.3	31.1	14.9	-
27	1686	6.8	27.5	14.1	-
28	1773	6.7	21.8	13.5	-

TABLE A.1 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
29	1713	7.0	29.9	15.0	-
30	1728	6.2	29.6	14.9	-
31	1692	6.5	21.0	14.1	-
32	1655	6.5	34.0	17.0	-
33	1657	5.7	30.3	18.1	-

TABLE A.2 Project 2 - Highway 330

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1929	37.8	10.6	4.3	-
2	1890	47.6	5.6	2.5	-
3	1909	30.0	5.3	2.9	-
4	1938	31.1	7.6	4.1	-
5	1996	32.1	5.9	4.9	-
6	1902	44.3	6.0	1.0	-
7	1944	32.8	5.2	1.9	-
8	1928	38.3	6.0	2.6	-
9	1930	37.0	4.1	0.5	-
10	1898	38.4	5.6	2.9	-
11	1945	38.5	5.2	1.6	-
12	1958	24.5	9.0	3.4	-
13	1904	35.3	10.4	3.4	-
14	1902	37.8	5.3	2.2	-
15	1929	25.5	6.8	3.6	-
16	1928	32.2	4.7	1.2	-
17	1876	41.1	4.9	1.3	-
18	1936	33.7	5.0	2.1	-
19	1946	39.1	9.0	4.4	-
20	1895	45.6	5.3	0.1	-
21	1935	30.5	4.6	2.6	-
22	1941	37.6	7.8	1.9	-
23	1918	27.7	7.7	2.5	-
24	1902	29.9	5.9	2.3	-
25	1920	26.9	5.5	0.8	-
26	1981	30.1	7.1	1.9	-
27	1922	30.5	7.2	2.4	-

TABLE A.2 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
28	1863	34.7	6.7	2.1	-
29	1917	25.3	7.4	2.3	-
30	1873	36.0	5.5	1.0	-
31	1886	44.9	5.6	0.8	-
32	1898	25.8	7.3	4.6	-

TABLE A.3 Project 3 – Knapp Street

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1901	31.8	5.0	2.1	-
2	1716	94.8	2.4	1.4	-
3	1765	54.7	7.5	3.1	-
4	1723	43.0	10.9	3.2	-
5	1724	41.6	10.9	2.5	-
6	1942	62.2	4.9	2.2	-
7	1819	87.8	2.2	2.2	-
8	1858	119.3	1.2	0.9	-
9	1790	58.3	5.1	2.2	-
10	1642	48.9	11.1	1.9	-
11	1526	46.4	11.1	-	-
12	1797	57.2	5.8	2.9	-
13	1790	73.3	2.0	1.0	-
14	1790	58.0	2.5	1.2	-
15	1907	67.3	5.8	2.5	-
16	1429	60.7	9.7	1.6	-
17	1487	51.2	9.4	-	-
18	1874	63.8	4.3	2.8	-
19	1773	57.6	2.1	0.6	-
20	1761	116.6	0.4	-	-
21	1799	63.0	6.0	2.4	-
22	1494	49.3	10.5	-	-
23	1621	49.1	8.2	2.9	-
24	1854	59.3	5.1	2.7	-
25	1720	127.2	1.1	1.0	-
26	1760	42.4	0.6	-	-
27	1904	69.1	5.6	2.6	-

TABLE A.3 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
28	1515	50.6	9.7	2.2	-
29	1694	31.3	8.5	3.2	-
30	1897	63.0	5.5	2.4	-
31	1837	58.7	1.9	0.8	-
32	1692	116.8	1.9	-	-
33	1906	61.2	7.2	3.1	-
34	1422	81.7	10.2	-	-
35	1499	57.2	9.7	-	-
36	1938	80.0	5.9	2.8	-
37	1795	129.5	2.4	1.4	-
38	1727	73.5	1.8	-	-
39	1917	83.5	5.2	2.5	-
40	1334	49.7	6.8	1.5	-
41	1543	43.5	9.3	2.2	-
42	1885	71.8	4.9	2.0	-
43	1734	48.5	1.0	-	-
44	1825	59.3	0.7	-	-
45	1900	80.6	5.4	2.6	-
46	1429	65.0	6.5	2.1	-
47	1581	47.7	10.2	2.0	-
48	1850	74.5	3.8	2.8	-
49	1816	107.5	2.2	-	-
50	1771	111.3	2.3	1.0	-
51	1824	78.5	4.4	2.7	-
52	1377	47.3	7.4	-	-

TABLE A.4 Project 5 - 35th Street and I-235 Westbound Ramp

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1927	36.4	9.8	6.0	-
2	1805	47.8	3.1	4.9	-
3	1772	40.3	5.7	5.3	-
4	1793	29.4	6.3	4.8	-
5	1863	38.7	5.5	4.5	-
6	1813	32.1	5.3	3.6	-
7	1911	36.2	11.3	5.4	-

TABLE A.4 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
8	1850	42.1	4.7	5.5	-
9	1920	42.7	4.0	5.0	-
10	1874	37.7	8.6	7.1	-
11	1856	35.3	8.4	5.2	-
12	1810	45.1	3.6	5.0	-
13	1891	38.7	5.8	4.7	-
14	1894	39.1	6.8	6.4	-
15	1903	31.5	7.6	4.3	-
16	1893	34.4	7.8	4.5	-
17	1882	40.9	13.3	6.2	-
18	1860	46.7	4.4	3.5	-
19	1848	65.5	4.2	5.0	-
20	1885	40.0	8.9	3.4	-
21	1939	39.6	7.0	3.8	-
22	1839	66.8	3.7	4.5	-
23	1838	57.4	3.1	4.1	-
24	1852	44.1	5.6	5.0	-
25	1853	38.4	6.1	4.5	-
26	1826	39.8	4.4	3.9	-
27	1879	41.3	3.9	5.1	-
28	1907	29.0	9.0	5.7	-
29	1794	55.3	4.7	5.6	-
30	1906	36.9	6.7	3.8	-
31	1933	33.1	8.6	6.2	-
32	1863	36.8	12.0	4.8	-
33	1883	39.8	9.2	3.8	-
34	1879	34.4	5.1	5.1	-
35	1826	38.7	4.6	4.1	-
36	1891	29.5	6.1	4.3	-
37	1894	38.7	5.2	5.4	-
38	1909	42.7	7.2	6.2	-
39	1942	43.0	3.3	5.5	-
40	1811	38.5	9.2	5.0	-
41	1891	30.9	6.9	2.7	-
42	1892	66.3	3.3	2.5	-
43	1920	34.4	7.2	6.2	-
44	1890	28.8	7.5	4.9	-
45	1851	30.7	6.3	4.2	-
46	1903	34.0	4.7	3.8	-

TABLE A.4 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
47	1891	39.9	6.3	4.6	-
48	1892	32.0	8.7	4.4	-
49	1895	58.1	3.5	3.8	-
50	1905	29.8	8.8	6.4	-
51	1907	34.5	7.2	2.7	-
52	1803	66.0	3.1	4.3	-
53	1794	55.6	3.8	3.3	-
54	1826	39.5	4.7	5.0	-
55	1876	42.8	4.5	3.7	-
56	1862	44.2	4.3	3.1	-
57	1885	23.1	7.5	4.7	-
58	1807	37.2	4.4	3.7	-
59	1879	69.1	4.3	3.5	-
60	1889	37.7	6.6	5.9	-
61	1912	34.8	8.5	4.6	-
62	1870	32.7	2.8	4.2	-
63	1848	32.2	6.6	4.3	-
64	1888	24.4	8.3	5.7	-
65	1944	28.0	8.2	4.0	-
66	1891	31.1	7.3	5.7	-
67	1940	31.2	7.9	5.9	-
68	1849	33.7	5.9	5.3	-
69	1841	44.8	5.8	3.4	-
70	1845	31.0	8.8	3.9	-
71	1865	35.5	8.7	6.3	-
72	1885	49.2	2.8	2.8	-
73	1888	39.0	3.8	4.4	-
74	1904	33.2	5.8	5.4	-
75	1852	41.1	5.7	4.5	-
76	1941	42.5	4.3	4.4	-
77	1881	31.5	4.2	3.8	-
78	1884	39.6	3.4	5.1	-
79	1862	40.7	3.8	4.1	-
80	1940	42.3	6.6	6.2	-
81	1918	33.8	10.1	4.6	-
82	1810	57.8	3.0	3.5	-
83	1811	35.4	4.5	4.3	-
84	1888	38.2	6.4	4.3	-
85	1880	43.3	4.8	4.1	-

TABLE A.4 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
86	1880	28.7	6.7	4.4	-
87	1923	26.0	6.4	4.3	-
88	1810	34.3	6.3	4.5	-
89	1682	44.8	6.8	5.6	-
90	1843	33.7	8.2	4.8	-
91	1798	33.8	8.4	3.8	-
92	1813	40.5	8.3	4.2	-
93	1874	28.0	5.3	4.6	-
94	1891	26.6	6.1	5.6	-
95	1896	25.0	6.7	4.9	-
96	1927	32.0	6.6	4.7	-
97	1896	27.8	5.7	6.6	-
98	1833	35.8	5.6	5.4	-
99	1729	42.8	3.5	3.4	-
100	1846	35.7	9.7	5.8	-
101	1838	44.6	6.8	6.8	-
102	1865	33.3	6.7	5.3	-
103	1835	37.6	4.1	4.4	-
104	1817	29.9	5.3	4.8	-
105	1856	44.3	4.2	3.5	-
106	1846	31.5	4.1	3.3	-
107	1856	29.1	5.8	5.3	-
108	1860	30.2	5.7	5.6	-
109	1779	46.1	4.6	4.9	-
110	1854	35.2	8.2	6.5	-
111	1970	43.1	7.5	5.7	-
112	1910	30.4	8.7	4.5	-
113	1917	27.0	7.5	4.8	-
114	1841	28.7	7.4	4.4	-
115	1929	37.9	4.8	4.0	-
116	1894	35.0	6.2	5.7	-
117	1920	26.2	6.3	6.2	-
118	1926	27.0	7.3	5.1	-
119	1815	33.1	5.7	5.1	-
120	1886	45.6	7.6	6.7	-
121	1862	44.6	6.2	4.6	-
122	1834	42.8	5.5	4.1	-
123	1867	29.6	7.8	4.0	-
124	1916	26.2	5.4	4.1	-

TABLE A.4 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
125	1922	32.9	6.7	5.0	-
126	1867	31.9	3.9	3.8	-
127	1839	34.6	6.2	4.1	-
128	1882	38.8	6.1	4.2	-
129	1750	38.4	4.0	4.9	-
130	1799	62.0	7.6	5.3	-

TABLE A.5 Project 6 - 35th Street and I-235 Westbound Ramp

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1676	-	16.0	5.5	-
2	1823	-	28.7	7.1	-
3	1764	-	22.6	7.9	-
4	1823	-	24.3	7.8	-
5	1768	-	23.3	4.2	-
6	1747	-	22.9	7.8	-
7	1938	-	28.7	4.2	-
8	1658	-	13.2	4.4	-
9	1737	-	11.7	5.5	-
10	2006	-	16.6	5.6	-
11	1726	-	18.6	4.9	-
12	1918	-	22.2	6.9	-
13	1881	-	19.5	4.9	-
14	1816	-	27.0	9.7	-
15	1892	-	27.0	7.8	-
16	1680	-	10.9	4.7	-
17	1517	-	11.4	4.6	-
18	1899	-	14.5	3.5	-
19	1819	-	24.5	2.4	-
20	1844	-	23.6	5.9	-
21	1946	-	21.5	5.3	-
22	1734	-	26.5	8.8	-
23	2026	-	25.3	5.7	-
24	1915	-	15.9	6.3	-

TABLE A.6 Project 7 - Highway 34 Eastbound Lane East of Fairfield

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1970	19.9	11.7	6.5	-
2	2086	26.9	10.4	5.6	-
3	1938	33.3	8.0	4.5	-
4	1966	24.3	12.2	6.1	-
5	2037	33.5	13.0	9.2	-
6	2052	25.9	10.7	8.9	-
7	2016	32.2	8.9	5.1	-
8	1844	30.6	6.7	4.8	-
9	2084	29.6	12.1	6.0	-
10	2045	26.4	11.5	7.0	-
11	2126	24.5	11.6	8.4	-
12	2103	24.5	12.2	7.0	-
13	1908	26.0	8.0	4.0	-
14	1973	29.4	10.5	5.0	-
15	1981	25.1	11.7	4.8	-
16	2026	25.5	10.8	5.1	-
17	2016	31.6	8.5	6.4	-
18	1926	37.3	7.2	4.7	-
19	2005	28.2	11.0	4.5	-
20	2041	21.1	14.0	8.0	-
21	2056	19.2	15.5	7.7	-
22	2055	26.7	10.2	5.9	-
23	1967	34.0	8.7	6.9	-
24	2040	27.7	8.2	4.7	-
25	2009	24.3	8.4	6.1	-
26	2067	-	12.0	4.8	-
27	2061	-	8.4	4.7	-
28	1937	-	9.3	6.6	-
29	2071	-	11.5	5.5	-
30	2129	-	12.2	7.7	-
31	1981	-	12.1	8.6	-
32	2123	-	9.6	5.9	-
33	2076	-	9.3	5.1	-
34	2092	-	9.9	5.1	-
35	2081	-	11.9	5.8	-
36	2058	-	10.9	6.2	-
37	1945	-	9.8	5.4	-

TABLE A.6 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
38	1949	-	9.5	5.1	-
39	2049	-	8.5	5.7	-
40	2086	-	12.7	7.6	-
41	2073	-	10.6	6.2	-
42	2077	-	8.8	4.2	-
43	2057	-	8.2	4.2	-
44	2051	-	8.4	6.2	-
45	2073	-	14.0	8.2	-
46	2045	-	11.6	5.9	-
47	2032	-	10.0	5.5	-
48	1953	-	9.8	5.7	-
49	1976	-	9.2	4.5	-
50	2095	-	13.7	5.1	-
51	2087	-	11.6	7.4	-
52	1946	-	9.7	5.0	-
53	2007	-	8.2	4.5	-
54	2066	-	10.3	6.1	-
55	2061	-	13.9	5.4	-
56	1983	-	10.0	6.2	-
57	2091	-	11.3	6.3	-
58	2001	-	9.3	4.9	-
59	2050	-	9.9	4.8	-
60	2108	-	10.4	7.4	-
61	2010	-	10.8	6.0	-
62	2045	-	9.8	5.3	-
63	1971	-	11.2	6.5	-
64	2058	-	11.3	8.2	-
65	2052	-	10.1	4.7	-
66	2009	-	10.8	5.0	-
67	2037	-	11.0	5.9	-
68	2053	-	10.7	4.5	-
69	2063	-	8.6	4.0	-
70	2007	-	10.0	6.9	-
71	2045	-	8.4	5.6	-
72	1979	-	10.0	5.1	-
73	2019	-	10.7	4.9	-
74	2046	-	11.7	6.7	-
75	2056	-	10.9	6.3	-
76	2018	-	11.7	6.2	-

TABLE A.6 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
77	1995	-	7.7	4.7	-
78	2019	-	9.6	4.5	-
79	1998	-	11.1	4.9	-
80	1926	-	8.8	5.5	-
81	1960	-	9.2	5.0	-
82	2022	-	10.1	4.5	-
83	2068	-	9.9	6.4	-
84	2043	-	9.1	4.7	-
85	2082	-	10.8	6.1	-

TABLE A.7 Project 8 - Highway 218 Southbound Lane South of Mount Pleasant

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1974	14.0	39.4	5.3	-
2	1993	12.6	23.8	8.2	-
3	1966	8.0	26.0	7.0	-
4	1964	12.5	28.4	11.4	-
5	1885	26.8	16.0	6.2	-
6	1875	-	24.0	8.2	-
7	1976	-	26.4	8.4	-
8	1972	-	26.0	13.3	-
9	1946	-	24.6	8.7	-
10	2028	-	29.4	4.8	-
11	2101	-	30.9	5.8	-
12	2019	-	21.4	4.7	-
13	2001	-	27.6	7.6	-
14	2012	-	33.4	9.2	-
15	1913	-	19.7	7.4	-
16	2002	-	27.5	6.8	-
17	1986	-	40.3	7.0	-
18	2079	-	31.1	6.0	-
19	1984	-	17.7	9.1	-
20	1913	-	24.3	10.2	-
21	1948	-	31.3	8.9	-
22	1925	-	27.8	9.0	-
23	1995	-	27.6	5.8	-

TABLE A.7 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
24	2086	-	39.3	5.8	-
25	1952	-	26.7	8.1	-
26	1930	-	15.3	6.9	-
27	2051	-	21.5	5.7	-
28	1935	-	39.1	4.0	-
29	1964	-	29.7	6.9	-
30	2000	-	22.6	9.7	-
31	1858	-	15.3	7.8	-
32	1943	-	31.4	7.9	-
33	2043	-	23.5	6.9	-
34	1992	-	24.1	8.5	-
35	1961	-	27.8	9.9	-
36	1939	-	34.8	5.9	-
37	1992	-	27.9	7.4	-
38	2046	-	26.4	7.3	-
39	1976	-	18.3	5.0	-
40	2003	-	27.3	9.1	-
41	2044	-	32.0	7.9	-
42	2029	-	20.2	6.3	-
43	2034	-	36.7	5.2	-
44	1971	-	37.5	4.7	-
45	1938	-	30.8	9.5	-
46	1932	-	23.5	10.9	-
47	1947	-	28.6	6.1	-
48	2064	-	34.8	3.1	-
49	2055	-	30.2	1.9	-
50	1954	-	28.1	6.8	-
51	2030	-	34.5	8.9	-
52	2007	-	21.3	4.1	-
53	2080	-	32.0	9.2	-
54	2067	-	35.4	8.5	-
55	1973	-	22.2	9.5	-
56	1940	-	15.4	5.0	-
57	1834	-	32.7	6.1	-
58	1964	-	38.5	2.4	-
59	1995	-	31.4	7.0	-
60	2138	-	27.9	7.0	-
61	2009	-	19.0	6.7	-

TABLE A.7 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
62	1997	-	22.6	7.1	-
63	1997	-	30.0	7.1	-
64	2060	-	28.2	7.4	-
65	1963	-	23.4	8.0	-
66	2010	-	28.2	12.0	-
67	2068	-	48.1	4.1	-
68	1988	-	29.4	6.5	-
69	1909	-	29.3	7.4	-
70	1973	-	11.4	6.2	-
71	1982	-	22.3	6.6	-
72	2041	-	33.6	7.9	-
73	2061	-	32.1	6.2	-
74	2031	-	39.2	10.5	-
75	2028	-	16.0	7.7	-
76	2017	-	18.8	11.3	-
77	1994	-	37.8	6.8	-
78	2042	-	23.6	4.5	-
79	2016	-	19.6	6.2	-
80	2050	-	27.1	9.2	-
81	1957	-	24.9	6.6	-
82	2017	-	12.5	7.5	-
83	2026	-	22.5	5.9	-
84	1939	-	23.6	6.6	-
85	1885	-	22.6	6.0	-

TABLE A.8 Project 9 - I-35 Northbound Lane by Highway 20

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1687	15.9	6.7	2.5	-
2	2079	26.7	12.3	2.5	-
3	2074	25.7	10.4	4.6	-
4	2034	26.2	11.3	5.5	-
5	2030	37.2	5.9	4.2	-
6	2042	34.4	11.7	4.1	-
7	2064	26.7	12.1	5.1	-

TABLE A.8 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
8	1970	42.9	12.0	5.5	-
9	2123	26.1	11.1	5.6	-
10	1969	47.3	8.2	2.8	-
11	1752	58.7	6.9	3.1	-
12	1991	23.2	13.8	5.4	-
13	2085	28.6	7.5	4.3	-
14	2051	29.5	15.6	5.4	-
15	2026	39.5	6.4	4.5	-
16	2075	39.9	7.9	5.0	-
17	2043	42.0	13.6	4.6	-
18	2055	27.3	15.0	5.9	-
19	2122	23.6	11.6	5.1	-
20	2019	48.5	5.1	1.4	-
21	1995	40.7	11.4	4.3	-
22	2059	24.0	15.5	5.8	-
23	2188	38.0	10.5	4.7	-
24	1962	35.6	6.7	4.1	-
25	2083	46.0	11.5	3.4	-
26	1941	46.6	3.7	4.5	-
27	2047	37.3	10.2	4.4	-
28	2084	35.3	8.3	5.0	-
29	2120	24.6	11.7	6.1	-
30	2046	48.8	10.9	3.5	-
31	1882	56.4	7.1	2.3	-
32	2057	31.0	12.1	4.8	-
33	2053	23.7	12.9	5.8	-
34	1979	34.4	9.4	4.7	-
35	2023	59.5	3.6	6.3	-
36	1997	47.3	5.2	5.1	-
37	2044	41.3	12.3	4.2	-
38	2054	29.2	9.4	4.3	-
39	2107	30.4	10.8	5.4	-
40	2117	28.9	14.1	4.3	-
41	2010	52.8	7.9	3.6	-
42	2059	35.0	8.7	5.4	-
43	2011	33.5	9.1	4.4	-
44	2105	28.5	16.3	5.8	-
45	2063	43.8	3.3	5.2	-
46	1993	43.9	3.8	5.9	-

TABLE A.8 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
47	2120	28.7	20.9	6.0	-
48	2127	31.6	11.1	5.1	-
49	2070	33.5	10.1	5.6	-
50	2094	34.4	5.3	4.0	-
51	2005	62.8	5.2	5.9	-
52	1932	45.0	11.6	5.7	-
53	2047	36.3	17.5	7.3	-
54	1995	29.8	22.1	5.1	-
55	2010	51.2	4.1	3.7	-
56	1914	48.4	4.9	4.6	-
57	2054	40.0	11.6	4.7	-
58	2005	25.1	7.8	4.1	-
59	1938	30.5	6.6	4.4	-
60	1696	76.0	4.8	2.7	-
61	1999	43.7	5.9	3.6	-
62	1970	36.5	6.4	5.7	-
63	2020	47.1	11.8	5.5	-
64	1955	31.1	8.7	5.6	-
65	1950	64.8	5.9	3.9	-
66	1980	44.9	10.3	4.2	-
67	2014	34.6	8.5	4.2	-
68	2041	32.2	10.2	4.7	-
69	1915	35.2	11.4	6.2	-
70	1939	31.7	7.9	6.9	-
71	2053	59.0	4.7	7.4	-
72	2045	30.6	7.2	5.2	-
73	1986	38.8	9.6	5.1	-
74	2065	32.0	7.1	4.3	-
75	1975	50.9	5.5	4.2	-
76	1916	47.1	5.4	2.8	-
77	1893	46.3	4.9	4.1	-
78	1998	38.6	13.6	5.4	-
79	1969	37.2	8.1	5.4	-
80	1986	83.8	5.8	2.6	-
81	1940	37.8	5.1	3.8	-
82	2060	32.1	8.4	5.3	-
83	2037	32.7	8.6	5.3	-
84	1981	39.1	7.6	3.7	-
85	1997	58.3	4.6	4.1	-

TABLE A.9 Project 10 - Lot S1 before Fly Ash Stabilization

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	2067	22.9	13.7	8.1	-
2	2013	14.3	22.9	10.4	-
3	1947	21.0	18.8	7.0	-
4	2015	18.7	25.0	10.9	-
5	2028	21.5	18.1	7.7	-
6	1972	15.4	18.8	10.8	-
7	1975	18.9	21.1	9.2	-
8	2001	17.6	25.6	10.4	-
9	1944	17.1	28.4	9.7	-
10	1980	15.0	22.2	13.2	-
11	1946	20.4	19.4	8.6	-
12	1971	14.5	21.5	10.9	-
13	1918	18.6	21.6	10.1	-
14	1901	21.9	16.3	8.7	-
15	1914	16.2	26.4	9.2	-
16	1870	14.9	18.9	11.7	-
17	1846	12.9	21.1	7.8	-
18	1970	17.4	28.5	9.5	-

TABLE A.10 Project 11 - Lot S1 after Fly Ash Stabilization

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1808	10.4	20.2	19.8	-
2	1837	12.0	27.0	16.9	-
3	1812	10.8	24.3	15.5	-
4	1789	10.4	30.4	16.3	-
5	1784	9.8	29.3	15.1	-
6	1861	13.6	18.4	21.1	-
7	1792	10.4	26.5	17.8	-
8	1774	11.0	28.3	19.7	-
9	1874	9.9	27.6	15.4	-
10	1724	13.0	25.3	20.0	-
11	1771	12.5	30.5	13.3	-
12	1910	12.6	31.7	23.2	-
13	1774	11.2	24.0	14.0	-

TABLE A.10 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
14	1719	11.6	18.8	11.5	-
15	1835	12.7	26.3	13.2	-
16	1760	12.5	17.9	10.5	-
17	1813	11.0	19.6	17.4	-
18	1833	12.1	27.8	12.6	-

TABLE A.11 Project 12 - University-Guthrie Avenue

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1557	18.6	7.4	8.3	-
2	1687	9.6	22.2	12.4	-
3	1643	4.6	33.0	18.3	-
4	1764	5.1	31.5	14.1	-
5	1672	5.6	31.3	17.4	-
6	1547	4.5	43.1	16.2	-
7	1525	22.9	7.1	12.2	-
8	1719	9.3	21.0	15.5	-
9	1602	4.8	37.0	17.8	-
10	1714	4.8	36.8	19.6	-
11	1602	4.8	40.9	18.0	-
12	1676	4.5	40.7	17.6	-
13	1519	22.1	9.1	9.2	-
14	1653	6.3	26.7	17.7	-
15	1730	4.8	36.1	18.2	-
16	1722	5.5	37.5	18.5	-
17	1627	4.7	43.1	16.6	-
18	1643	5.6	42.9	20.3	-
19	1421	35.3	5.5	7.8	-
20	1602	7.4	18.7	16.9	-
21	1714	4.8	34.1	15.1	-
22	1671	5.1	36.5	17.3	-
23	1712	4.6	34.1	18.0	-
24	1680	5.4	33.9	18.7	-

TABLE A.11 (Continued)

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
25	1480	28.2	7.7	9.0	-
26	1666	7.1	24.7	15.1	-
27	1698	5.7	34.7	17.7	-
28	1627	5.6	34.5	14.5	-
29	1714	5.3	31.5	16.9	-
30	1621	4.6	35.3	17.0	-

TABLE A.12 Seyman - Clay

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1800	13.3	-	19.3	182.3
2	1911	19.0	-	19.9	445.2
3	1696	32.8	-	16.5	52.5
4	1901	28.8	-	17.1	134.9
5	1547	11.2	-	9.6	48.6
6	1722	9.2	-	25.7	314.9
7	1779	23.5	-	18.0	288.6
8	1516	33.1	-	8.2	34.2
9	1728	9.6	-	18.0	171.4

TABLE A.13 Seyman - Clay + 2% Cement

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1652	11.8	-	26.0	294.2
2	1652	-	-	26.9	412.2
3	1652	9.8	-	28.6	442.7
4	1652	-	-	29.5	435.9
5	1652	7.4	-	27.0	412.4

TABLE A.14 Seyman - Clay + 4% Cement

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1743	5.9	-	20.1	500.0
2	1743	4.8	-	22.5	530.6
3	1743	4.3	-	25.4	477.5
4	1743	3.7	-	22.1	541.6

TABLE A.15 Seyman - Sand Clay Gravel Base Course

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1984	7.5	-	25.0	300.4

TABLE A.16 Seyman - Limestone

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	2120	12.1	-	17.9	74.4

TABLE A.17 Seyman - Crushed Limestone

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	2000	7.2	-	14.4	131.2

TABLE A.18 Seyman - RAP

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1749	8.4	-	11.3	138.3

TABLE A.19 Seyman - Clayey Silt

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1644	25.5	-	6.8	31.4
2	1625	17.6	-	8.1	49.8
3	1626	46.5	-	2.0	28.5

TABLE A.20 Seyman - Sand

Test Number	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1807	20.9	-	6.3	18.0
2	1660	24.7	-	5.5	40.7
3	1648	53.4	-	5.5	20.6

TABLE A.21 I-84 Site 1 - 2% Cement Blended with 50% RAP

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	2114	-	3.1	21.8	37.8	-
2	2114	-	2.2	31.1	28.8	-
3	2114	-	2.2	23.9	39.1	-
4	2114	-	-	28.6	51.2	-
5	2114	-	-	44.0	27.8	-
6	2114	-	-	36.7	29.5	-
7	2114	-	-	38.7	35.9	-
8	2114	-	2.5	18.2	21.3	-
9	2114	1905	3.3	23.0	36.7	-
10	2114	-	2.6	23.2	27.5	-
11	2114	-	-	30.3	37.8	-
12	2114	-	-	32.2	26.3	-
13	2114	-	-	29.0	29.3	-
14	2114	-	-	31.5	40.8	-
15	2114	-	2.4	19.9	23.4	-
16	2114	-	3.2	22.7	38.2	-

TABLE A.21 (Continued)

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
17	2114	-	2.8	22.2	42.6	-
18	2114	-	-	28.4	40.1	-
19	2114	-	-	31.0	27.5	-
20	2114	-	-	29.0	36.5	-
21	2114	-	-	27.2	35.9	-
22	2114	-	2.5	16.3	26.2	-
23	2114	1887	2.5	23.2	39.1	-
24	2114	-	2.5	20.5	37.9	-
25	2114	-	-	23.3	29.4	-
26	2114	-	-	31.5	33.1	-
27	2114	-	-	23.3	37.2	-
28	2114	-	-	26.3	31.5	-
29	2114	-	3.2	15.8	26.5	-
30	2114	1889	3.5	20.6	18.8	-
31	2114	-	2.7	23.1	35.9	-
32	2114	-	-	24.6	24.3	-
33	2114	-	-	40.2	34.5	-
34	2114	-	-	37.0	27.8	-
35	2114	-	-	27.4	33.8	-
36	2114	-	2.6	15.7	32.0	-
37	2114	-	2.2	20.3	26.5	-
38	2114	-	2.6	23.3	34.8	-
39	2114	-	-	30.1	24.9	-
40	2114	-	-	33.3	39.0	-
41	2114	-	-	33.2	22.1	-
42	2114	-	-	32.8	39.7	-

TABLE A.22 I-84 Site 2 - 2% Cement Blended with 50% RAP

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	2114	-	-	29.9	34.2	-
2	2114	1860	-	29.9	30.4	-
3	2114	-	-	47.6	39.7	-
4	2114	-	-	30.0	-	-
5	2114	-	-	33.1	33.0	-
6	2114	-	-	30.8	21.1	-
7	2114	-	2.9	20.0	35.6	-
8	2114	-	-	27.7	32.9	-
9	2114	-	-	37.4	37.9	-
10	2114	-	-	33.4	29.5	-
11	2114	-	-	32.8	33.1	-
12	2114	-	-	31.4	15.9	-
13	2114	-	2.7	22.5	27.0	-
14	2114	-	-	26.7	34.8	-
15	2114	-	-	28.2	36.0	-
16	2114	-	-	40.2	-	-
17	2114	-	-	28.6	28.9	-
18	2114	-	-	31.0	29.7	-
19	2114	1901	3.9	18.3	35.2	-
20	2114	-	-	18.1	32.1	-
21	2114	-	-	38.9	35.8	-
22	2114	-	-	34.6	-	-
23	2114	-	-	31.2	29.4	-
24	2114	-	-	26.2	29.1	-
25	2114	-	2.6	27.1	35.3	-
26	2114	-	-	32.2	23.7	-
27	2114	-	-	36.4	44.0	-
28	2114	-	-	41.6	30.9	-
29	2114	-	-	30.8	41.6	-
30	2114	-	-	34.7	36.1	-
31	2114	-	2.2	22.5	32.2	-
32	2114	-	-	22.7	42.1	-
33	2114	-	-	34.2	41.4	-
34	2114	-	-	41.0	-	-
35	2114	-	-	39.4	31.1	-
36	2114	-	-	41.3	27.1	-

TABLE A.23 I-84 Site 3 - 2% Cement Blended with 50% RAP

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	2114	-	4.2	18.4	14.7	-
2	2114	-	-	31.1	41.6	-
3	2114	-	-	39.5	41.4	-
4	2114	-	-	38.4	-	-
5	2114	-	-	37.7	-	-
6	2114	-	-	46.8	48.8	-
7	2114	1983	3.9	22.4	17.5	-
8	2114	-	-	33.2	31.7	-
9	2114	-	-	40.5	39.0	-
10	2114	-	-	39.8	57.5	-
11	2114	-	-	32.9	45.8	-
12	2114	-	-	47.9	57.9	-
13	2114	-	-	23.4	21.6	-
14	2114	-	-	32.2	33.6	-
15	2114	-	-	33.2	38.5	-
16	2114	-	-	35.4	-	-
17	2114	-	-	43.7	-	-
18	2114	-	-	53.9	44.9	-
19	2114	-	-	21.2	22.3	-
20	2114	-	-	28.5	29.1	-
21	2114	-	-	37.9	29.7	-
22	2114	-	-	39.5	-	-
23	2114	-	-	34.2	-	-
24	2114	-	-	44.5	40.4	-
25	2114	1925	-	20.8	25.3	-
26	2114	-	-	36.0	33.3	-
27	2114	-	-	34.2	30.1	-
28	2114	-	-	36.1	46.3	-
29	2114	-	-	37.0	40.6	-
30	2114	-	-	40.8	50.8	-
31	2114	-	-	19.8	28.6	-
32	2114	-	-	32.1	23.4	-
33	2114	-	-	38.9	28.0	-
34	2114	-	-	33.1	-	-
35	2114	-	-	34.2	-	-
36	2114	-	-	37.8	29.6	-

TABLE A.24 I-84 Site 4 - 2% Cement Blended with 50% RAP

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	-	-	3.7	30.1	29.8	-
2	-	-	4.0	27.0	29.3	-
3	-	-	4.0	24.4	25.5	-
4	-	-	4.6	24.3	24.9	-
5	-	-	4.7	26.4	23.8	-
6	-	-	5.0	24.9	26.8	-

TABLE A.25 US-91 Site 1 - 2% Cement

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	2230	2050	8.0	19.1	14.3	-
2	2230	-	-	19.7	24.9	122.5
3	2230	-	-	21.0	29.5	171.9
4	2230	-	-	22.8	36.0	420.7
5	2230	-	-	-	40.3	646.8
6	2230	-	-	28.0	35.0	1195.8
7	2230	-	-	28.9	37.1	-
8	2230	-	-	26.7	38.6	1355.8
9	2230	-	-	28.0	40.7	-
10	2230	2052	10.1	17.3	14.8	-
11	2230	-	-	21.6	16.4	106.8
12	2230	-	-	17.2	18.9	196.3
13	2230	-	-	24.1	23.7	306.3
14	2230	-	-	-	28.0	772.4
15	2230	-	-	27.5	27.7	999.9
16	2230	-	-	25.4	31.1	-
17	2230	-	3.5	24.7	32.3	1707.8
18	2230	-	1.1	27.3	28.9	-
19	2230	2054	8.5	16.1	16.4	-
20	2230	-	-	18.2	21.6	82.2
21	2230	-	-	19.9	24.5	167.3
22	2230	-	-	19.2	30.3	885.7
23	2230	-	-	-	37.0	394.5
24	2230	-	-	27.0	33.0	759.3
25	2230	-	-	28.9	37.9	-
26	2230	-	-	31.9	39.8	938.7

TABLE A.25 (Continued)

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
27	2230	-	-	26.7	39.5	-
28	2230	2069	9.2	18.0	15.8	-
29	2230	-	-	20.3	18.8	92.6
30	2230	-	-	17.8	20.1	143.8
31	2230	-	-	21.1	25.4	769.1
32	2230	-	-	-	29.0	724.9
33	2230	-	-	27.3	29.1	458.3
34	2230	-	-	25.7	32.3	-
35	2230	-	-	29.1	33.7	865.8
36	2230	-	-	27.3	34.7	-
37	2230	2036	11.1	16.4	13.9	-
38	2230	-	-	16.6	16.3	80.6
39	2230	-	-	17.6	20.3	108.8
40	2230	-	-	19.3	25.3	391.6
41	2230	-	-	-	30.6	859.2
42	2230	-	-	23.7	29.6	1401.2
43	2230	-	-	25.3	26.3	-
44	2230	-	4.4	24.8	31.4	1362.5
45	2230	-	-	25.9	25.1	-
46	2230	2024	11.0	14.5	16.2	-
47	2230	-	-	16.7	21.4	85.1
48	2230	-	-	16.4	23.9	185.1
49	2230	-	-	21.3	29.1	398.5
50	2230	-	-	-	36.9	428.7
51	2230	-	-	24.7	36.8	1016.8
52	2230	-	-	26.1	37.6	-
53	2230	-	-	25.8	38.1	713.7
54	2230	-	-	29.7	22.5	-

TABLE A.26 US-91 Site 2 - 2% Cement

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	2230	2129	6.9	19.9	11.6	91.6
2	2230	-	-	18.5	8.9	132.9
3	2230	-	-	25.0	13.3	951.4
4	2230	-	-	24.5	18.9	1589.9
5	2230	-	-	25.2	-	2127.0
6	2230	-	-	25.8	23.5	1580.4
7	2230	-	-	36.9	24.0	-
8	2230	2090	8.5	16.5	11.6	100.3
9	2230	-	-	17.4	15.2	166.1
10	2230	-	-	25.1	23.9	697.0
11	2230	-	-	24.8	30.9	1602.6
12	2230	-	-	27.2	-	972.6
13	2230	-	2.7	24.2	29.6	1356.2
14	2230	-	0.9	37.2	25.1	-
15	2230	2067	8.6	17.3	10.6	75.8
16	2230	-	-	19.1	11.6	166.1
17	2230	-	-	22.3	17.2	312.2
18	2230	-	-	20.0	24.7	2533.9
19	2230	-	-	22.9	-	268.7
20	2230	-	-	27.2	24.2	1070.6
21	2230	-	-	31.5	30.6	-
22	2230	2040	9.5	20.1	13.0	56.3
23	2230	-	-	17.6	17.8	110.4
24	2230	-	-	21.3	26.5	404.0
25	2230	-	-	23.0	30.2	551.5
26	2230	-	-	24.5	-	520.9
27	2230	-	-	25.8	36.3	500.6
28	2230	-	-	27.0	36.7	-
29	2230	2046	8.9	18.9	12.7	67.6
30	2230	-	-	19.5	17.8	177.0
31	2230	-	-	23.1	26.4	275.1
32	2230	-	-	23.3	37.0	1278.9
33	2230	-	-	26.2	-	758.1
34	2230	-	2.7	25.1	34.8	748.6
35	2230	-	-	37.3	22.7	-
36	2230	2110	8.9	19.7	17.7	133.9
37	2230	-	-	18.6	26.3	282.9

TABLE A.26 (Continued)

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
38	2230	-	-	24.9	42.1	1265.1
39	2230	-	-	26.3	46.8	2844.4
40	2230	-	-	27.1	-	1777.9
41	2230	-	-	25.4	48.1	2307.7
42	2230	-	-	34.6	36.3	-

TABLE A.27 US-91 Site 3 - 2% Cement

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	2230	2072	6.9	9.5	13.3	49.5
2	2230	-	-	16.3	30.5	144.2
3	2230	-	-	-	29.9	269.9
4	2230	-	-	23.6	31.9	765.9
5	2230	-	-	32.2	36.5	515.8
6	2230	-	-	34.9	44.3	2639.3
7	2230	2138	8.5	10.7	12.5	60.6
8	2230	-	-	17.0	25.9	151.1
9	2230	-	-	-	26.7	346.4
10	2230	-	-	24.3	28.3	760.0
11	2230	-	2.7	33.8	37.1	1600.7
12	2230	-	0.9	46.5	31.8	2675.1
13	2230	2130	8.6	14.8	14.1	73.4
14	2230	-	-	19.2	31.5	196.5
15	2230	-	-	-	31.1	314.4
16	2230	-	-	21.5	32.3	580.1
17	2230	-	-	33.9	38.4	768.8
18	2230	-	-	49.7	27.7	2215.6
19	2230	2128	9.5	17.4	14.8	62.4
20	2230	-	-	19.6	28.1	229.3
21	2230	-	-	-	30.9	463.3
22	2230	-	-	20.4	33.7	315.5
23	2230	-	-	29.7	39.0	1070.3
24	2230	-	-	49.7	28.5	5850.0

TABLE A.27 (Continued)

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
25	2230	2122	8.9	17.5	13.1	60.1
26	2230	-	-	20.1	24.2	366.1
27	2230	-	-	-	26.6	195.3
28	2230	-	-	18.0	29.4	374.3
29	2230	-	2.7	27.1	33.0	583.2
30	2230	-	-	40.3	25.4	3061.2
31	2230	2124	8.9	17.3	14.5	57.7
32	2230	-	-	23.2	26.1	275.6
33	2230	-	-	-	29.5	575.1
34	2230	-	-	22.1	36.2	1526.1
35	2230	-	-	23.7	41.0	963.2
36	2230	-	-	46.6	28.6	3084.1

TABLE A.28 Orem - 16% RAP

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	2302	1983	23.8	10.4	1.1	-
2	2302	2030	21.8	7.9	1.1	-
3	2302	2084	20.1	9.8	1.4	-
4	2302	2028	13.4	11.3	1.8	-
5	2302	1969	11.0	10.6	2.7	-
6	2302	1941	18.7	10.2	1.7	-
7	2302	1988	7.7	16.6	2.0	120.7
8	2302	2065	14.8	13.9	1.4	92.7
9	2302	2046	7.5	15.3	2.1	137.6
10	2302	2050	5.2	15.9	2.6	118.2
11	2302	2012	9.9	15.1	2.8	172.7
12	2302	2034	7.2	14.0	4.3	68.3

TABLE A.29 Black Butte Road - 1

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1868	1660	8.6	14.4	9.9	-
2	1868	1631	11.8	13.5	10.3	-

TABLE A.30 Black Butte Road - 2

Test Number	Modified Proctor MDD (kg/m^3)	NDG (kg/m^3)	DCP (mm/blow)	CIST (CIV)	SSG (MN/m)	PFWD (MPa)
1	1868	1524	17.4	3.3	4.2	-
2	1868	1551	-	3.3	4.4	-

APPENDIX B

OPERATOR EFFECTS DATA

TABLE B.1 Pleasant Grove 2008

Repetition	ID	Square 1		Square 2		Square 3	
		CIV-1	SSG-1	CIV-2	SSG-2	CIV-3	SSG-3
1	1	6.6	6.15	6.0	6.86	8.4	15.12
2	1	9.0	7.61	9.8	12.56	11.5	14.62
3	1	9.4	8.04	9.5	12.60	10.5	17.09
1	2	8.8	8.84	8.8	10.09	10.5	15.34
2	2	8.0	6.65	8.6	11.64	10.9	15.34
3	2	8.8	6.83	6.0	6.77	10.2	13.02
1	3	8.2	6.84	9.9	11.69	9.9	19.27
2	3	7.5	6.89	6.1	6.60	9.8	12.39
3	3	7.6	6.83	10.0	10.94	10.4	18.61
Repetition	ID	Square 4		Square 5		Square 6	
		CIV-4	SSG-4	CIV-5	SSG-5	CIV-6	SSG-6
1	1	12.7	9.90	15.6	16.47	11.1	11.67
2	1	14.4	12.46	13.4	14.97	11.8	12.45
3	1	13.2	14.84	14.7	17.53	11.4	11.31
1	2	13.0	14.60	16.1	15.61	13.3	18.16
2	2	13.8	13.48	15.5	16.64	12.4	15.60
3	2	11.8	14.43	15.5	15.44	12.6	11.26
1	3	13.8	15.23	15.2	14.44	11.8	10.62
2	3	13.0	15.70	14.6	15.53	9.9	9.05
3	3	14.8	15.75	13.4	10.28	12.6	16.86

TABLE B.1 (Continued)

Repetition	ID	Square 7		Square 8		Square 9	
		CIV-7	SSG-7	CIV-8	SSG-8	CIV-9	SSG-9
1	1	11.0	8.06	18.2	12.64	12.9	13.06
2	1	14.6	8.89	16.8	20.09	12.1	9.71
3	1	14.1	15.16	14.5	14.96	12.8	13.14
1	2	13.4	10.88	17.9	24.49	13.4	13.45
2	2	15.2	16.41	13.3	23.73	12.3	17.03
3	2	11.8	12.98	17.0	15.32	12.9	16.63
1	3	13.9	11.12	15.7	15.64	13.4	12.91
2	3	11.6	9.49	17.7	17.82	13.3	14.46
3	3	17.5	11.46	13.8	14.70	12.0	12.05
Repetition	ID	Square 10		Square 11		Square 12	
		CIV-10	SSG-10	CIV-11	SSG-11	CIV-12	SSG-12
1	1	6.3	5.71	8.8	9.27	9.0	10.73
2	1	8.9	7.42	10.8	10.98	9.4	8.81
3	1	7.5	8.33	11.0	10.15	9.8	12.67
1	2	9.4	6.61	10.7	11.29	9.3	9.98
2	2	8.2	8.45	11.2	8.40	11.1	12.38
3	2	6.9	7.74	9.2	10.81	7.8	10.18
1	3	7.8	8.10	8.3	10.40	11.2	13.29
2	3	7.3	6.11	9.5	10.89	7.9	9.29
3	3	8.7	8.13	9.6	10.76	7.7	7.53
Repetition	ID	Square 13		Square 14		Square 15	
		CIV-13	SSG-13	CIV-14	SSG-14	CIV-15	SSG-15
1	1	9.5	9.00	9.5	12.38	8.4	19.96
2	1	9.0	9.69	9.7	11.94	10.3	10.86
3	1	5.7	5.96	7.0	8.50	12.3	9.48
1	2	9.7	8.64	8.5	13.04	10.1	11.08
2	2	6.4	5.64	6.9	8.25	11.3	9.65
3	2	9.4	7.63	9.6	11.79	10.0	12.83
1	3	5.7	5.20	6.7	8.22	10.4	11.31
2	3	8.4	8.73	10.4	13.79	9.0	11.85
3	3	9.1	8.34	10.9	12.05	11.2	11.88

TABLE B.1 (Continued)

Repetition	ID	Square 16		Square 17		Square 18	
		CIV-16	SSG-16	CIV-17	SSG-17	CIV-18	SSG-18
1	1	2.5	6.97	12.2	19.07	4.6	7.60
2	1	3.1	5.36	10.9	15.31	7.9	14.19
3	1	5.8	6.87	9.5	12.33	5.4	7.76
1	2	3.2	6.94	10.2	13.58	8.0	12.36
2	2	5.0	6.24	9.6	9.49	4.9	9.09
3	2	2.9	2.99	10.7	14.41	4.3	7.75
1	3	4.1	5.36	9.5	8.76	6.7	7.46
2	3	2.1	3.65	9.6	14.25	4.6	8.61
3	3	3.9	6.15	10.5	13.52	7.4	15.06

TABLE B.2 US-91 2004

Repetition	ID	Square 19		Square 20		Square 21	
		CIV-19	SSG-19	CIV-20	SSG-20	CIV-21	SSG-21
1	1	21.4	41.12	28.2	40.44	26.9	28.07
2	1	25.6	35.32	21.8	35.18	27.9	36.45
3	1	26.7	35.85	26	32.18	30.3	37.37
1	2	27.8	32.93	28.2	43.5	28.6	37.01
2	2	20.1	39.43	28.1	32.39	27.3	39.04
3	2	28.5	40.01	23.4	37.53	31.5	37.25
1	3	29.6	42.83	27.3	32.38	26.9	44.78
2	3	28	44.8	22.6	34.64	27.9	33.78
3	3	28.2	33.82	25.8	32.18	33.6	32.39

Repetition	ID	Square 22		Square 23	
		CIV-22	SSG-22	CIV-23	SSG-23
1	1	29.1	33.66	26.7	39.42
2	1	25.4	36.11	26	29.24
3	1	28	31.3	26.5	37.04
1	2	24.6	35.78	22.5	32.45
2	2	25.5	36.68	26.2	36.13
3	2	25.1	27.36	24.8	41.74
1	3	22.8	35.44	23.6	44.4
2	3	25.9	30.12	27.2	37.83
3	3	27.6	32.03	24.8	29.96

TABLE B.3 I-84 2005

Repetition	ID	Square 24		Square 25	
		CIV-24	SSG-24	CIV-25	SSG-25
1	1	17.8	20.34	30.3	28.4
2	1	16.7	14.63	26.4	30.07
3	1	19.7	14.78	25.7	28.15
1	2	19	13.18	35.08	35.08
2	2	20.3	21.2	30.59	30.59
3	2	20.3	17.26	24.86	24.86
1	3	20	15.61	34.68	34.68
2	3	21.1	14.48	33.87	33.87
3	3	21.9	22.44	30.69	30.69

TABLE B.4 US-91 2005

Repetition	ID	Square 26		Square 27	
		CIV-26	SSG-26	CIV-27	SSG-27
1	1	21.1	28.61	24.1	18.8
2	1	22.6	18.36	21.48	16.3
3	1	17.8	16.31	23.47	17
1	2	17.2	14.67	16.4	16.4
2	2	22	31.49	18.2	18.2
3	2	21.4	19.38	19.81	15.8
1	3	21.8	17.69	17.5	17.5
2	3	17.5	16.14	16.5	16.5
3	3	23.1	21.96	18.5	18.5

APPENDIX C

EQUATION-NOMOGRAPH COMPARISONS

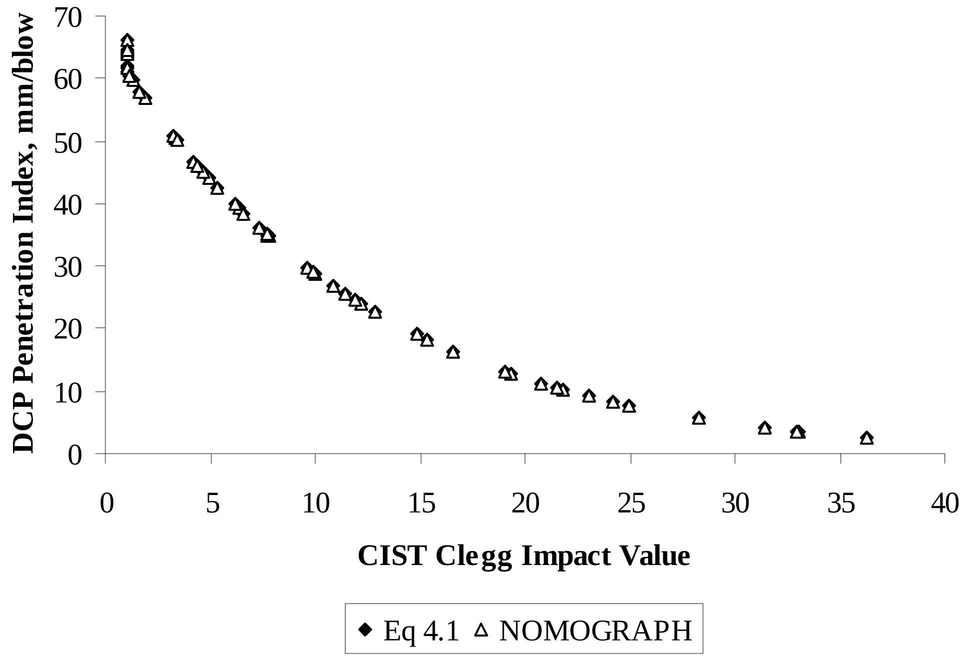

FIGURE C.1 CIST Clegg impact value determined by Equation 4.1 and the correlation nomograph from a given DCP penetration index.

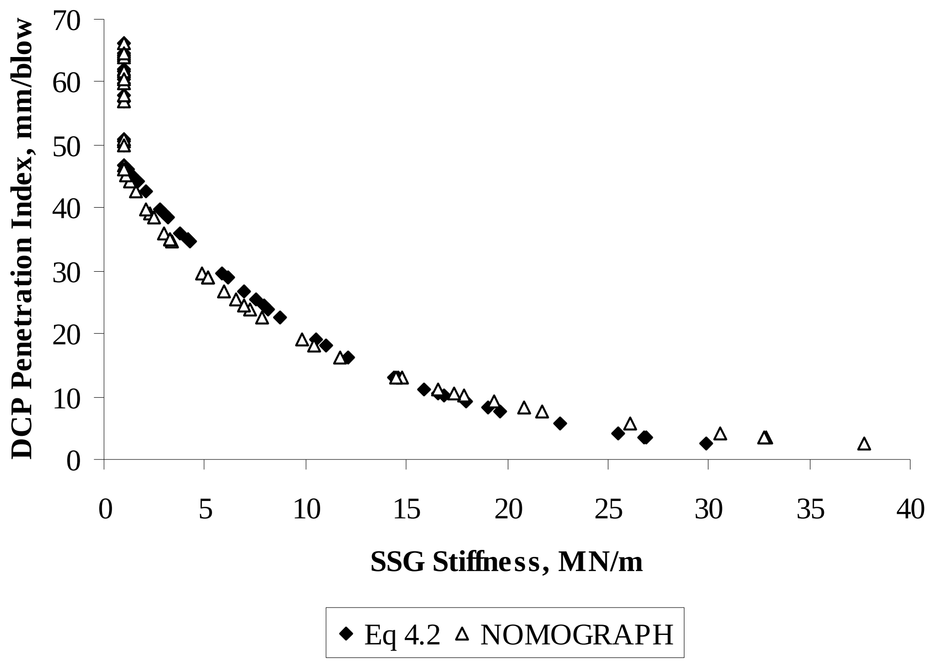

FIGURE C.2 SSG stiffness determined by Equation 4.2 and the correlation nomograph from a given DCP penetration index.

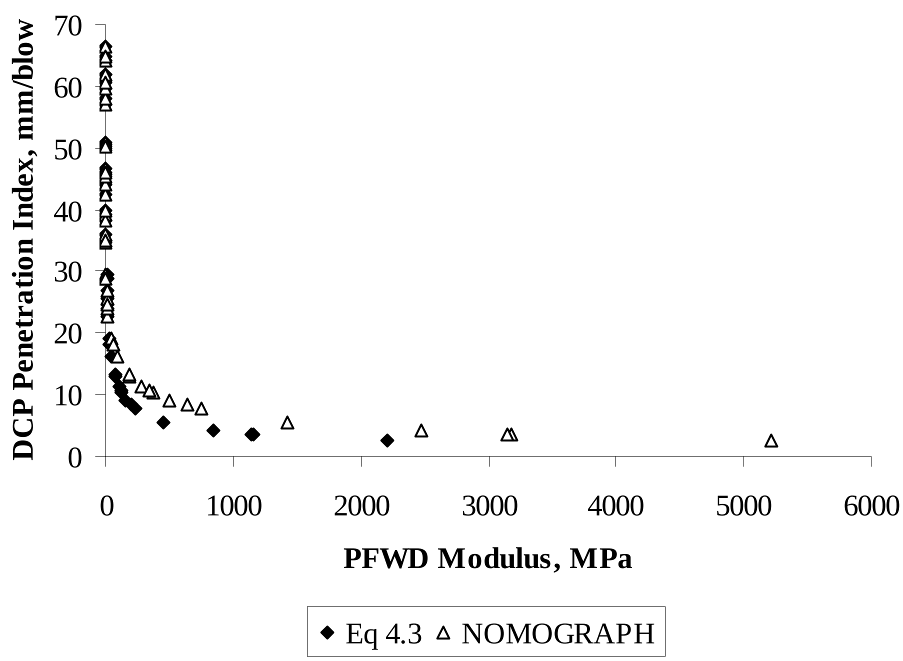

FIGURE C.3 PFWD modulus determined by Equation 4.3 and the correlation nomograph from a given DCP penetration index.

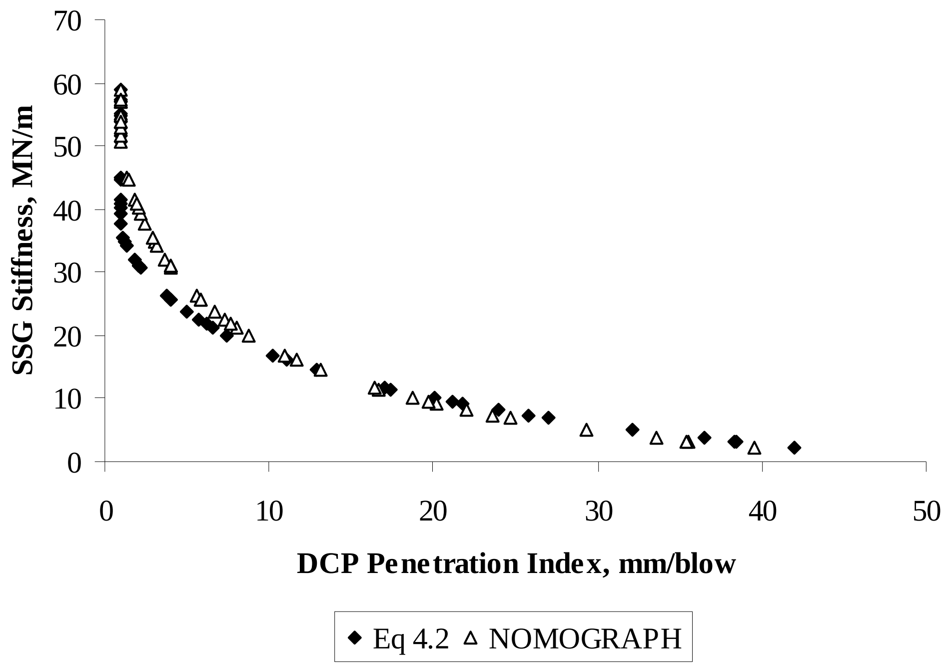

FIGURE C.4 DCP penetration index determined by Equation 4.2 and the correlation nomograph from a given SSG stiffness.

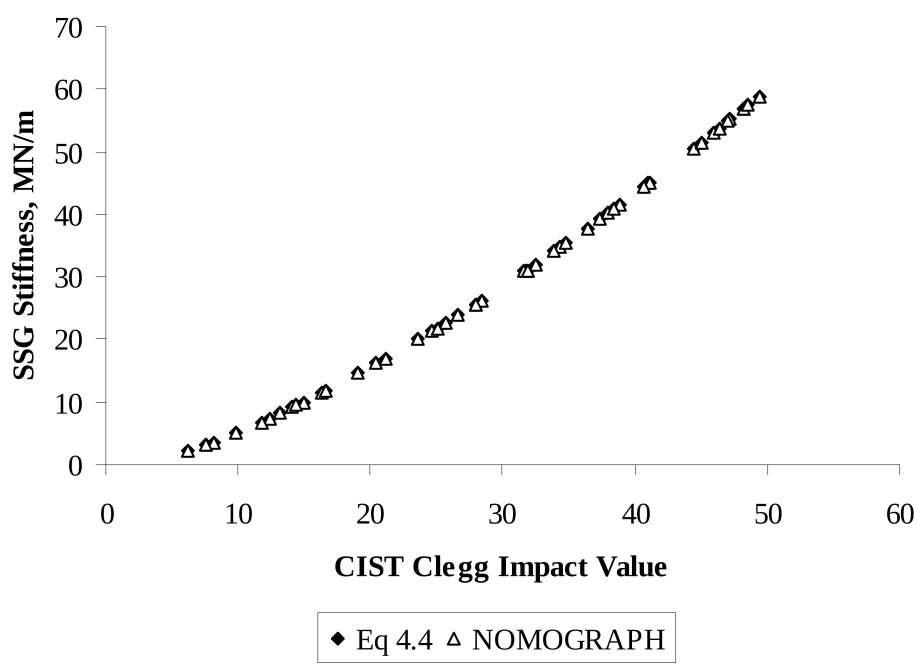

FIGURE C.5 CIST Clegg impact value determined by Equation 4.4 and the correlation nomograph from a given SSG stiffness.

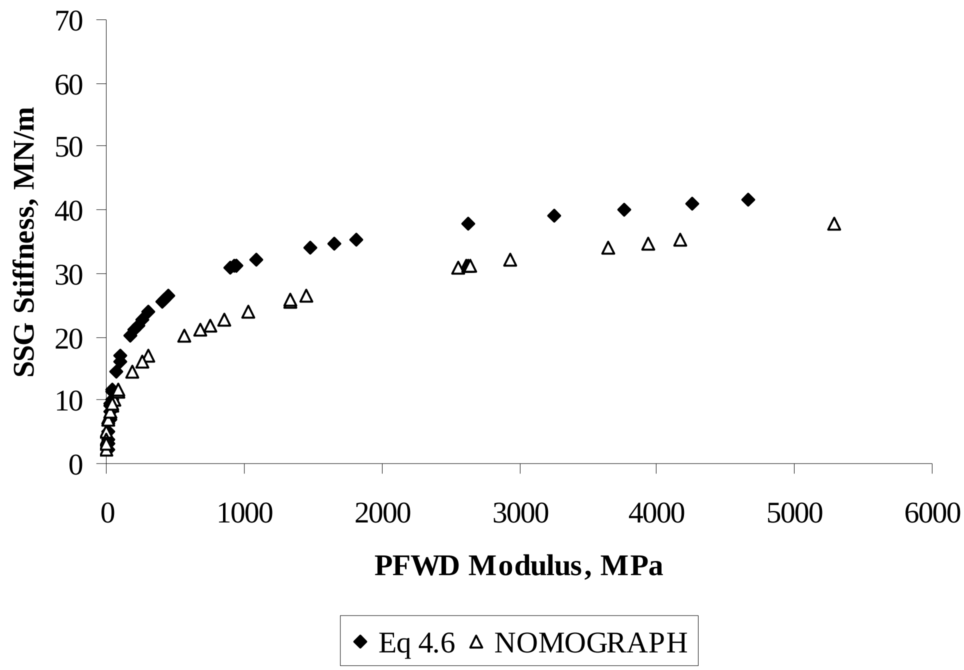

FIGURE C.6 PFWD modulus determined by Equation 4.6 and the correlation nomograph from a given SSG stiffness.

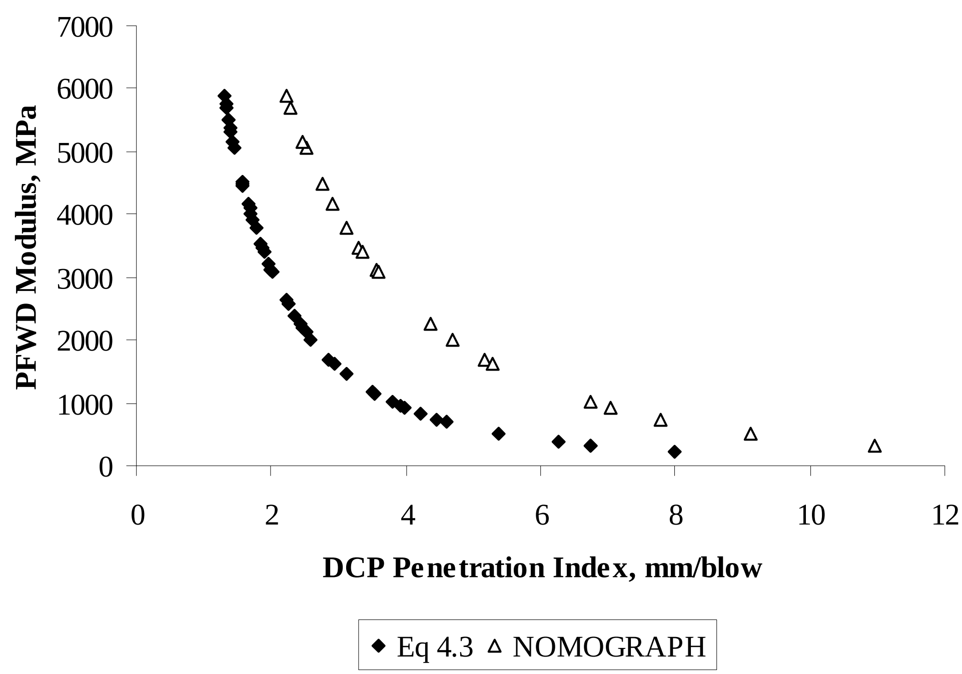

FIGURE C.7 DCP penetration index determined by Equation 4.3 and the correlation nomograph from a given PFWD modulus.

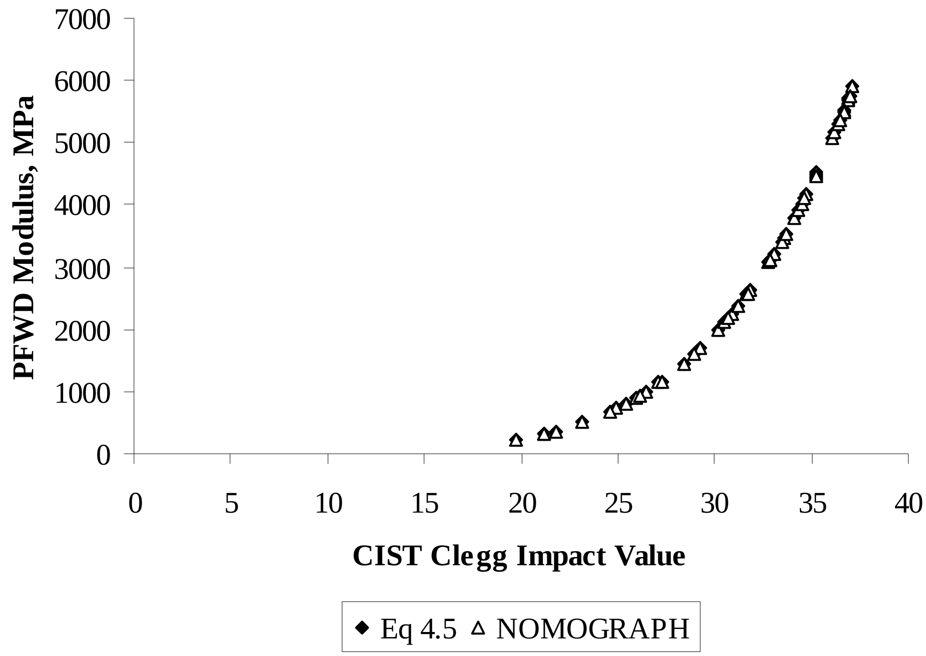

FIGURE C.8 CIST Clegg impact value determined by Equation 4.5 and the correlation nomograph from a given PFWD modulus.

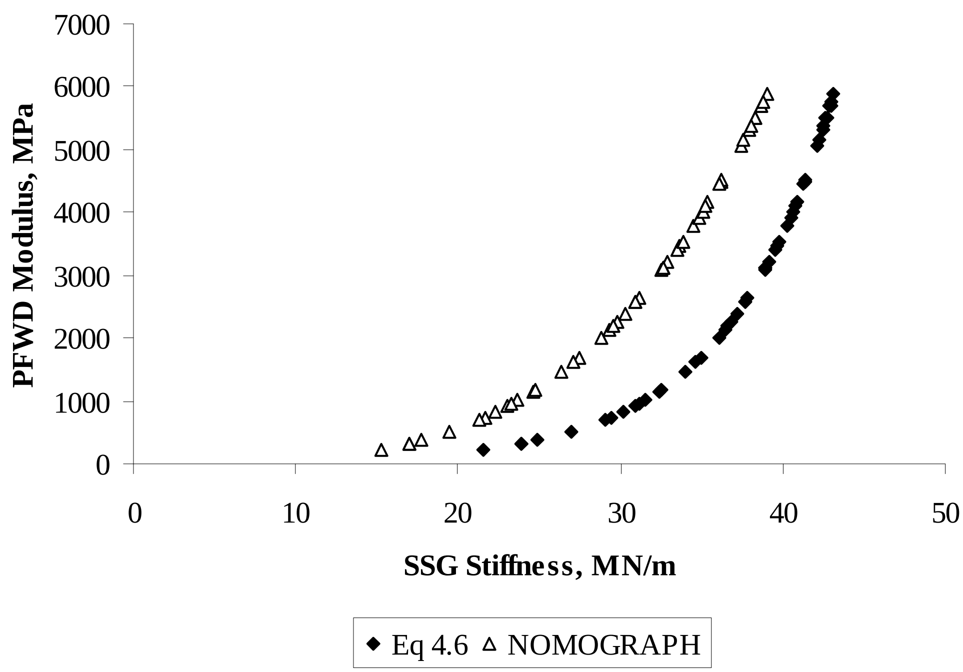

FIGURE C.9 SSG stiffness determined by Equation 4.6 and the correlation nomograph from a given PFWD modulus.