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For the Florida Department of Transportation

Implementing Resilient Modulus Test for Design of Pavement Structures in Florida

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16. Abstract

Past research focused on soil resilient modulus testing for pavement design in Florida. A follow up study in technology transfer is needed to better use the data for implementing the resilient modulus. The purpose of this research is to develop and apply RMDB (Resilient Modulus Database) for pavement design in Florida. The research included the concept and procedure of database development with Microsoft Visual Basic 6.0, and the application of the database for analyzing granular subgrade resilient modulus, such as the influences on the modulus by LVDT position and test method (T292-91I and T294-92). The analysis concentrated on the resilient modulus with liner regression model.

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METRIC CONVERSIONS

inches = 25.4 millimeters

feet = 0.305 meters

square inches = 645.1 millimeters squared

square feet = 0.093 meters squared

cubic feet = 0.028 meters cubed

pounds = 0.454 kilograms

poundforce = 4.45 newtons

poundforce per square inch = 6.89 kilopascals

pound per cubic inch = 16.02 kilograms per meters cubed

DISCLAIMER

“The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or the U.S. Department of Transportation. This publication is prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation.”

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ABSTRACT

Past research focused on soil resilient modulus testing for pavement design in Florida. A follow up study in technology transfer is needed to better use the data for implementing the resilient modulus. The purpose of this research is to develop and apply RMDB (Resilient Modulus Database) for pavement design in Florida. The research included the concept and procedure of database development with Microsoft Visual Basic 6.0, and the application of the database for analyzing granular subgrade resilient modulus, such as the influences on the modulus by LVDT position and test method (T292-91I and T294-92). The analysis concentrated on the resilient modulus with liner regression model.

CHAPTER 1

INTRODUCTION

1.1 Background

The 1986 AASHTO Guide for Design of Pavement Structures has incorporated the resilient modulus of component materials into the design process. Considerable attention has also been given to the development of mechanistic-empirical approaches (e.g., the 2002 AASHTO Pavement Design Guide) for design and evaluation of pavements. Both the 1986 Guide and the mechanistic based design methods use the resilient modulus of each layer in the design process.

In Florida, several research projects in the past ten years have been conducted to study the resilient modulus characteristics of Florida pavement soils. Comparative studies were conducted to evaluate the resilient modulus from laboratory cyclic triaxial tests and field experimental programs such as: field plate bearing test, falling weight deflectormeter (FWD) test, and test-pit test that were developed to simulate field pavement layer behavior subject to dynamic traffic loadings. The resilient modulus was found to be dependent on a number of factors: soil type, test method, specimen density, specimen moisture, specimen size, confining pressure, deviator stress, etc. One soil specimen may have many different resilient modulus values depending on the states of stresses. Conducting the resilient modulus test and selecting an appropriate resilient modulus value for pavement designs are very complex processes. Research studies have also been conducted to correlate resilient modulus with basic soil physical properties, which are relatively easy to measure such as density, moisture, plasticity, and classification. However, no reliable relationships between resilient modulus and these parameters have been found so far.

More than two hundred laboratory triaxial resilient modulus tests on Florida soils have been conducted in the previous studies. These test results have been saved on the computers in Microsoft Excel table format. Difficulties, inconveniences, low efficiency, and mistakes have often been made in such data maintenance activities as updating, editing, or adding new data, to say nothing of search and analysis by treating them as a complete database. In addition, due to the lack of necessary equipment and well-trained technicians to run the resilient modulus test, district laboratories do not have the capability to carry out the MR testing for pavement design. A database for the resilient modulus test results is needed so that the Florida pavement soils can be categorized and a simplified method may be developed to select a reasonable resilient modulus value for pavement design.

1.2 Study Objective

The primary objective of this research is to develop a resilient modulus database (RMDB) of available MR test results for facilitating soil resilient modulus evaluation and pavement design. The research goal is to study the concept and procedures of the database development with Microsoft Visual Basic 6.0, and the application of the database for analyzing the resilient modulus of Florida pavement soils. The influence factors on the resilient modulus by the linear variable differential transducer (LVDT) position, and test method (T292-91I or T294-92) were also evaluated for the possibility of further implementation.

1.3 Scope of Study

To achieve the objectives, the scope of this research study will cover:

- A literature review concerning resilient modulus test

  A comprehensive literature review will be conducted on the resilient modulus test, including the concept, test procedure, and factors, which may affect the test results.

- The development of resilient modulus database

  A resilient modulus database (RMDB) will be developed using Visual Basic 6.0, and Microsoft Access 2000. A database system is established according to the relational database model. The data manipulation and analysis functions are developed with Visual Basic 6.0.

- The application of resilient modulus database

  The RMDB will be applied to determine the resilient modulus adjustment factors, which include the following:

  a. Resilient modulus values based on the LVDT measurements inside the triaxial chamber vs. outside the triaxial chamber

  b. Resilient modulus values based on the LVDT 4-in. measurements vs. 8-in. measurements (inside the triaxial chamber)

1.4 Report Organization

This report summarizes the study to develop the soil resilient modulus database and to apply the database for evaluating the soil resilient modulus test procedures of the T292-91I and T294-92. The resilient modulus database is a part of the effort to implement the 1986 & 1993 AASHTO design guide for pavement structures. As in the first chapter, the background and objectives are introduced. Chapter 2 reviews the basic concepts of the soil resilient modulus test. Chapter 3 presents the basic principle and procedures of the database development. Chapter 4 demonstrates the use of the data manipulation functions of the RMDB, including the data entry, data query, and analysis. Determination of the adjustment factors by using the RMDB is discussed in Chapter 5. Summary, conclusion, and recommendation are presented in Chapter 6. A user manual concerning the RMDB is presented in Appendix.

CHAPTER 2

SOIL RESILIENT MODULUS MEASUREMENT

2.1 Resilient Modulus Concept

Most pavement materials, especially soils, are not pure elastic material, but exhibit elastic-plastic behavior. That means that they act partly elastic under a static load but experience some permanent deformation. However, under repeated loads, they express other important properties. At the beginning, they perform just like they would under a static load. But after certain repetitions, the permanent deformation under each load repetition is almost completely recoverable. By this point, it can be nearly considered elastic, if the repeat load is small enough compared to its strength, otherwise the soil structure would be damaged. Figure 2.1 illustrates the behavior of unbounded material under a sequence of repeating loads.

Resilient modulus (MR) is a measurement of the elastic property of soil recognizing certain nonlinear characteristics. Resilient modulus is defined as the ratio of the axial deviator stress to the recoverable axial strain, and is presented in the following equation:

$$M_R = \sigma_d / \varepsilon_R \tag{2.1}$$

Where σ_d = axial deviator stress

ε_R = axial recoverable strain

As exhibited in Figure 2.1, there are two components to the total deformation, a resilient or recoverable portion and a permanent portion. Only the recoverable portion is included in the measurement of resilient modulus.

2.2 Resilient Modulus Test Procedure

When performing a resilient modulus test, a prepared soil specimen is placed in a triaxial cell and subjected to a confining pressure, usually produced by air pressure. This confining pressure simulates the confinement of the material in the pavement. A dynamic load is applied to the sample, which is intended to simulate the dynamic traffic load on the material in the pavement and is measured using a loading cell. The time-serialized deformation or specimen strain is measured through a set of devices, upon which the resilient modulus is calculated.

In order to measure the resilient modulus, one has to make the sample to become like the elastic characteristics as shown in Figure 2.1. A series of condition loading cycles was conducted before the resilient modulus was measured. At a specific confining pressure and deviator stress, the resilient modulus can be calculated as:

$$M_R = \frac{(\sigma_1 - \sigma_3)}{\varepsilon_R} = \frac{\sigma_d}{\varepsilon_R} \tag{2.2}$$

Where: σ_1 = major principal stress

σ_3 = minor principal stress

σ_d = deviator stress

ε_R = recoverable or elastic strain

Different testing parameters such as sample preparation, sample conditioning, deviator stress and confining pressure, can result in different resilient modulus values.

At the same time AASHTO introduced resilient modulus, it also recommended AASHTO T274-82, the “Standard Method of Testing for Resilient Modulus of Subgrade Soils”, for the measurement. However, since its introduction, it has been widely criticized, including the criticism that the test period of five hours is too long, the required loading conditions are too severe, and therefore a specimen may fail in the conditioning stage.

In 1991 AASHTO modified the T274-82 testing procedure and released the T292-91I testing procedure (AASHTO, 1991). A number of important improvements have been made on the test loading cycles, and the testing period was reduced to two and a half hours. In 1992 AASHTO adopted the Strategic Highway Research Program (SHRP) test method of determining resilient modulus for soils and unbound aggregates SHRP P46, which became AASHTO T294-92 (AASHTO 1994). In 1994 AASHTO refined the SHRP procedure, and proposed AASHTO T P46-94, basically, it shares almost the same mainframe as the T294-92. However, after decades of research on the resilient modulus test procedure, no universally accepted laboratory technique has been developed. In this study, T292-91I and T294-92 were discussed in detail since they represent the major mainframe of the resilient modulus test procedures.

2.3 Test Equipment

For the resilient modulus test, all of these test protocols require the use of a triaxial chamber, in which confining pressure and deviator stress can be controlled. The test method for determining the resilient response of pavement materials is basically a triaxial compression test in which a cyclic axial load is applied to a cylindrical test specimen. The load is measured by a load cell, while the resilient strain was measured. The test is usually conducted by applying a number of stress repetitions over a range of deviator stress levels and confining pressure levels representing variations in depth or location from the applied load.

The major components of these systems are the loading system, digital controller, personal computer, triaxial cell, and linear variable differential transducer (LVDT) deformation measurements system. The resilient modulus testing equipment is schematically shown in Figure 2.2 (a) and (b).

2.4 Deformation Measurement

In this study, four LVDTs were mounted inside the triaxial cell. Two of the LVDTs were positioned in the middle half length of the specimen (10.2-cm) by using 180-degree diametrically-opposed clamps around the axis of the specimen (Figure 2.2 (b)). The other two diametrically opposed LVDTs were attached to the top platen of the test specimen and rested on the top of the cell. All four LVDTs were adjustable and arranged around the specimen evenly.

Calibrations were made periodically during the laboratory-testing program. This setup was used to compare the resilient modulus measurements obtained from the LVDTs at different locations.

2.4.1 LVDT positions

Typically, there are three positions for LVDT placement: middle length LVDT (10.2-cm LVDT measures the deformation of the half length of specimen, placed on the clamps around the specimen), full length LVDT (20.3-cm LVDT measures the deformation of the full length of specimen) inside the chamber, and the full length LVDT outside the chamber. Different positions of LVDTs are shown in Figure 2.3 for both T292-91I and T294-92.

Tests showed a significant difference between the MR values computed from the deformations measured by the 10.2-cm LVDT (measure the deformation of the half length of specimen) measurements and by the 20.3-cm LVDT (measure the deformation of the full length of specimen) measurements. Figure 2.4 and Figure 2.5 show the difference between the 10.2-cm LVDT and 20.3-cm LVDT for A-3 and A-2-4 soils.

2.4.2 Influence of LVDT positions

In general, the 20.3-cm LVDT measurements, especially external measurements (mounted outside the triaxial cell), would induce significant errors to the measurements because of air gaps between the specimen and accessories such as porous stones and platens, and errors such as sample alignment and bedding problems. This is given the term end effect.

The external LVDT suffered from the friction and elastic strain caused by the loading piston, load cell and steel ball, in addition to the top platen, and end effect for the internal LVDT. That generally led to a less accurate and lower resilient modulus value.

The 10.2-cm LVDT measurements, though hard to install, were less influenced by the system compliance of triaxial cell accessories. The results from the 10.2-cm measurements still resulted in higher resilient modulus values than those from the 20.3-cm measurements.

A number of tests were conducted with different positions of the middle LVDTs within the length of specimen as shown in Figure 2.6. Four replicate samples were tested for the four different positions of the middle LVDTs mounted from the bottom to the top of the test specimen.

Figure 2.7 shows that the variations of the resilient modulus of a subgrade sand at different positions of the middle LVDTs were very small. However, the differences were significant when one of the LVDTs was positioned on the top platen (Place 4, Figure 2.6). The figure clearly demonstrates the influence of the end effect on the resilient modulus measurements.

However, even the full length LVDT had a less accurate result, the internal full length LVDT was the most reliable position. The half-length LVDT was hard to install, especially when the soil was weak, and the alignment of the clamps was the most different part in some situation. Figure 2.8 and Figure 2.9 show that there is an excellent relation between them. Thus, the internal full length LVDT measurement is the most recommended LVDT position.

2.5 Comparison of Test Procedures

T292-91I and T294-92 test procedures are summarized as illustrated in Table 2.1. The resilient modulus results from the two test procedures were compared in order to investigate the effect of testing methods. The differences in the two test procedures due to various influence factors were compared in terms of the resilient response of soils from the T292-91I procedure with those of the T294-92, by different LVDT measurement positions. A discussion of the results follows.

Figures 2.10 and 2.11 present the different values of resilient modulus measured by the same procedure but with the reverse stress path in the T292-91I and the T294-92 test procedures, respectively. In both procedures, for an identical sample, the resilient modulus values appeared to increase faster when the confining pressure progressed from low to high, and the rate of increase also depended on the type of soil. This indicated that the stiffening and strengthening effects on the specimen structure were attributed to the higher MR values obtained from the T294-92 test procedure.

2.5.1 Effect of different LVDT positions

As we discussed above, the position of LVDT is very important for the measurement of the resilient modulus. Figure 2.7 shows that the variations of the resilient modulus of a subgrade sand at different positions of the middle LVDTs were very small. However, the differences were significant when the end effect was taken into consideration, i.e., the LVDTs were either positioned on the platen or mounted outside the triaxial cell. The effects of different positions of LVDT measurements for the T292-91I and T294-92 procedures (Figure 2.3) were investigated and are described further in the following sections.

2.5.1.1 T292-91I method

In this study, for the T292-91I procedure, four LVDTs were mounted inside the triaxial cell as illustrated in Figure

2.3(a). Both full length and middle length resilient modulus were measured.

From the test result, the results clearly show the 10.2-cm measurements (Position A in Figure 2.3(a)) had higher resilient modulus values than those from the 20.3-cm measurements (Position B in Figure 2.3(a)). Figures 2.8 and 2.9 illustrate the resilient modulus ratio, MR ratio (A,B), between the 10.2-cm and 20.3-cm measurements for A-3 and A-2-4 soils, respectively. The figures show that the resilient modulus ratios also depend on the type of soil. The average ratios of the resilient modulus values from the 10.2-cm (middle length) and 20.3-cm (full length) measurements are summarized in Table 2.2.

The ratios also depend on the level of confining pressure. The ratios ranged from 1.35 to 1.30 at lower confining pressures and from 1.19 to 1.14 at higher confining pressures for A-3 and A-2-4 soils, respectively. The lower ratios at the higher pressures were probably due to the near perfect contact between the end platen, the porous stone, and the specimen ends. This observation was consistent with the findings by other researcher (Mohammed 1994).

2.5.1.2 T294-92 method

For the T294-92 procedure, two LVDTs were attached to the piston rod outside of the chamber instead of using the LVDTs for the 20.3-cm measurements (Figure 2.3(b)). The results from the externally mounted LVDT measurements (Position 3 in Figure 2.3(b)) showed lower resilient modulus values than those from both the 10.2-cm (LVDT Position 1) and 20.3-cm (LVDT Position 2) measurements.

These average resilient modulus ratios are summarized in Table 2.3. The ratios are also presented in Figures 2.12 through 2.15. The average MR ratio (3,1) ranged from 0.61 to 0.64 at lower confining pressures and from 0.54 to 0.55 at higher confining pressures for A-3 and A-2-4 soils, respectively. The average MR ratio (2,1) ranged from 0.67 at lower confining pressure to 0.83 at higher confining pressure for A-3 soils. The average MR ratio (3,2) ranged from 0.87 at lower confining pressures to 0.69 at higher confining pressures for A-3 soils. The results showed that the resilient modulus from the externally mounted LVDT measurements (LVDT Position 3 in Figure 2.3(b)) were the lowest among the three different positions of LVDT measurements.

2.5.2 Discussion

The T292-91I procedure began with high confining pressures and ended with low confining pressures whereas, the T294-92 test procedure was conducted from low to high confining pressure instead.

Generally, in the construction and service of roadbed soil, the stress history begins with high confining pressures and deviator stresses in the construction as well as compaction. As the subbase, base and pavement layers compacted; the stress goes from high to low, step by step. In their service, the confining pressure and deviator stresses are lower, since the upper layers bear the most traffic load, and give soil confining pressure. From this point, the T292-91I procedure is more representative than the T294-92 test procedure.

In other words, the soil strength, especially granular soil, is more sensitive to the confining pressure; if the confining pressure is high, it can bear a large deviator stress, when the confining pressure is lower, their bearing capacity goes lower too. That means in the T292-91I procedure, soils are more likely to be able to withstand the test sequence, if the deviator stress is limited.

In the T292-91I procedure, the resilient modulus values were a little unstable at high confining pressures, but were stable at low confining pressures. Otherwise, the resilient modulus was unstable at the beginning of the testing sequence and became stable after a high number of load cycles. In the T294-92 procedure, the resilient modulus was stable at high confining pressures but varied a little at low confining pressures. This observation indicated that, after sequences of testing, the resilient modulus value reached a stable status as the result of a stiffening effect of the cyclic stress on the specimen.

However, no significant difference existed between the T292-91I procedure and T294-92 procedure. The results were almost the same; either of them can reach a reasonably accurate result for resilient modulus measurement.

Since the soil works under a lower confining pressure in the pavement, results showed that the T292-91I procedure was obviously more satisfactory for simulating the true condition of the soil in the pavement.

2.6 Typical Resilient Modulus Test Results

The typical resilient modulus test results of a granular soil sample included 14 modulus values corresponding to the various number of confining pressure and deviator stress settings when tested with the T292-91I (Table 2.4). The results contained 15 modulus values when tested with T294-

92 (Table 2.5). The test results only included five modulus values when a clay soil sample was tested with the T292-91I test procedure (Table 2.6).

Table 2.1(a) AASHTO T292-91I and T294-92 test procedures for granular soils

Test Procedure	AASHTO T 292-91I						AASHTO T 294-92		
	Subgrade Soils			Base/Subbase Soils					
	Conf. Pressure	Dev. Stress	Reps.	Conf. Pressure	Dev. Stress	Reps.	Conf. Pressure	Dev. Stress	Reps.
	kPa	kPa		kPa	kPa		kPa	kPa	
Specimen Condition	103.4	82.3	1000	137.8	103.4	1000	103.4	103.4	1000
Testing	103.4	48.2	50	137.8	68.9	50	20.7	20.7	100
	103.4	68.9	50	137.8	137.8	50	20.7	41.3	100
	103.4	103.4	50	137.8	206.7	50	20.7	62	100
	68.9	34.5	50	137.8	275.6	50	34.5	34.5	100
	68.9	48.2	50	103.4	68.9	50	34.5	68.9	100
	68.9	68.9	50	103.4	137.8	50	34.5	103.4	100
	68.9	103.4	50	103.4	206.7	50	68.9	68.9	100
	34.5	20.7	50	103.4	275.6	50	68.9	137.8	100
	34.5	34.5	50	68.9	34.5	50	68.9	206.7	100
	34.5	48.2	50	68.9	68.9	50	103.4	68.9	100
	34.5	68.9	50	68.9	137.8	50	103.4	103.4	100
	13.8	20.7	50	68.9	206.7	50	103.4	206.7	100
	13.8	34.5	50	34.5	34.5	50	137.8	103.4	100
	13.8	48.2	50	34.5	68.9	50	137.8	206.7	100
				34.5	103.4	50	137.8	275.6	100
				20.7	34.5	50			
				20.7	48.2	50			
				20.7	62	50			

Table 2.1(b) AASHTO T292-91I and T294-92 test procedures for cohesive soils

Test Procedure	AASHTO T 292-91I			AASHTO T 294-92		
	Confining Pressure	Deviator Stress	N0. of Repetitions	Confining Pressure	Deviator Stress	No. of Repetitions
	kPa	kPa		kPa	kPa	
Specimen Condition	20.7	20.7	1000	41.3	27.5	1000
		41.3	1000			
Testing	20.7	20.7	50	41.3	13.8	100
	20.7	34.5	50	41.3	27.5	100
	20.7	48.2	50	41.3	41.3	100
	20.7	68.9	50	41.3	55.1	100
	20.7	103.4	50	41.3	68.9	100
				20.7	13.8	100
				20.7	27.5	100
				20.7	41.3	100
				20.7	55.1	100
				20.7	68.9	100
				0	13.8	100
				0	27.5	100
				0	41.3	100
				0	55.1	100
				0	68.9	100

Table 2.2 Average resilient modulus ratios, MR (A,B), from the 10.2-cm and 20.3-cm LVDT measurements (T292-91I method)

Confining Pressure (kPa)	Type of Soil	
	A-3	A-2-4
13.79	1.35	1.30
34.47	1.30	1.25
68.97	1.23	1.18
103.42	1.19	1.14

Table 2.3 Average resilient modulus ratios, MR (3,1), MR (2,1), and MR (3,2) from the 10.2-cm and 20.3-cm (internal and external) LVDT measurements (T294-92 method)

Confining Pressure (kPa)	M_R Ratio (3,1)		M_R Ratio (2,1)	M_R Ratio (3,2)
	A-3 Soils	A-2-4 Soils	A-3 Soils	A-3 Soils
20.68	0.61	0.64	0.67	0.87
34.47	0.60	0.63	0.70	0.84
68.42	0.59	0.61	0.76	0.78
103.42	0.55	0.57	0.79	0.73
137.9	0.54	0.55	0.83	0.69

Table 2.4 Typical soil resilient modulus test results of granular soil with T292-91I

		Summary Resilient Modulus Test Results					
Test Type:	T292-91I				Soil Identification		
Date:	9/7/1995				Embankment (Fine Sand)		
Sample:	2A1AES				U.S.17		
Mold #:	1&3				Polk County, Site #1		
Lab.Moist.	12.4%				Opt.Moist.	12.4%	
Lab.Den.	17.04	kN/m^3			Opt.Den.	16.85	kN/m^3
Compaction Effort:		20 blows/layer					
					Conditioning Information		
					Load Type	Dynamic	
					Dev. σ	82.74	kPa
					Conf. σ	103.42	kPa
					No. Reps.	1000	
Confining Pressure	Axial Load	Dev. Stress	Bulk Stress	Middle Strain	Total Strain	Middle Modulus	Full Length Modulus
kPa	kN	kPa	kPa			MPa	MPa
103.42	0.376	46.328	356.588	0.00019	0.00023	240.408	201.238
103.42	0.545	67.201	377.461	0.00028	0.00033	239.804	203.298
103.42	0.825	101.742	412.002	0.00041	0.00049	245.715	209.453
68.95	0.263	32.400	239.250	0.00016	0.00020	196.625	158.791
68.95	0.377	46.444	253.294	0.00024	0.00029	193.517	158.998
68.95	0.543	67.021	273.871	0.00034	0.00041	195.744	162.041
68.95	0.825	101.778	308.628	0.00049	0.00059	206.651	172.434
34.47	0.152	18.806	122.216	0.00013	0.00018	145.344	106.825
34.47	0.263	32.466	135.876	0.00023	0.00030	142.964	109.151
34.47	0.377	46.441	149.851	0.00032	0.00041	144.087	112.960
34.47	0.545	67.264	170.674	0.00045	0.00056	150.800	119.952
13.79	0.152	18.711	60.081	0.00019	0.00027	98.488	68.722
13.79	0.264	32.579	73.949	0.00031	0.00043	103.852	75.204
13.79	0.383	47.300	88.670	0.00050	0.00063	95.236	75.320

Table 2.5 Typical soil resilient modulus test results of granular soil with T294-92

Summary Resilient Modulus Test Results							
Test Type	T294-92				Soil Identification		
Date	5/7/1996				Subgrade (Silty Sand)		
Sample	4A1ASS				U.S.17		
Mold #	4&5				Polk County, Site #1		
Lab.Moist.	10.10%				Opt.Moist.	10.10%	
Lab.Den.	18.19	kN/m^3			Opt.Den.	18.3	kN/m^3
Compaction Effort		20 blows/layer					
					Conditioning Information		
					Load Type Dynamic		
					Dev. σ	103.42	kPa
					Conf. σ	103.42	kPa
					No.Reps.	1000	
Confining Pressure	Axial Load	Dev. Stress	Bulk Stress	Middle Strain	External Strain	Middle Modulus	External Modulus
kPa	kN	kPa	kPa			MPa	MPa
20.68	0.155	19.168	81.748	0.00015	0.00021	127.430	89.633
20.68	0.325	40.029	102.609	0.00030	0.00042	134.391	94.998
20.68	0.491	60.588	123.168	0.00042	0.00060	145.494	101.510
34.47	0.268	33.106	136.516	0.00017	0.00026	198.495	128.905
34.47	0.548	67.641	171.051	0.00035	0.00053	193.152	128.282
34.47	0.826	101.903	205.313	0.00055	0.00080	185.181	127.466
68.95	0.547	67.486	274.336	0.00024	0.00038	282.521	176.026
68.95	1.106	136.485	343.335	0.00052	0.00079	264.672	173.296
68.95	1.666	205.452	412.302	0.00080	0.00119	255.427	173.093
103.42	0.548	67.629	377.889	0.00020	0.00033	341.028	207.223
103.42	0.828	102.144	412.404	0.00031	0.00049	333.298	207.409
103.42	1.666	205.442	515.702	0.00063	0.00098	325.283	209.555
137.90	0.829	102.258	515.958	0.00026	0.00044	391.018	234.660
137.90	1.107	136.549	550.249	0.00035	0.00058	387.246	236.780
137.90	2.191	270.277	683.977	0.00073	0.00116	369.183	233.745

Table 2.6 Typical soil resilient modulus test results of clay soil

		Summary Resilient Modulus Test Results					
Test Type:	T292-91I				Soil Identification		
Date:	11/13/95				Embankment (Clay)		
Sample:	2B4AEC				U.S.301		
Mold #:	4&6				Alachua County, Site #4		
Lab.Moist.	11.8%				Opt.Moist.	11.7%	
Lab.Den.	12.40	kN/m^3			Opt.Den.	12.50	kN/m^3
Compaction Effort:		215 blows/layer					
					Conditioning Information		
					Load Type	Dynamic	
					Dev. σ	82.74	kPa
					Conf. σ	103.42	kPa
					No. Reps.	1000	
Confining Pressure	Axial Load	Dev. Stress	Bulk Stress	Middle Strain	Total Strain	Middle Modulus	Full Length Modulus
kPa	kN	kPa	kPa			MPa	MPa
20.68	0.162	20.043	82.083	0.00001	0.00005	3055.130	396.232
20.68	0.281	34.713	96.753	0.00002	0.00008	1860.825	423.775
20.68	0.395	48.664	110.704	0.00003	0.00011	1602.866	433.521
20.68	0.564	69.512	131.552	0.00005	0.00016	1508.031	430.211
20.68	0.844	104.113	166.153	0.00008	0.00024	1352.476	428.682

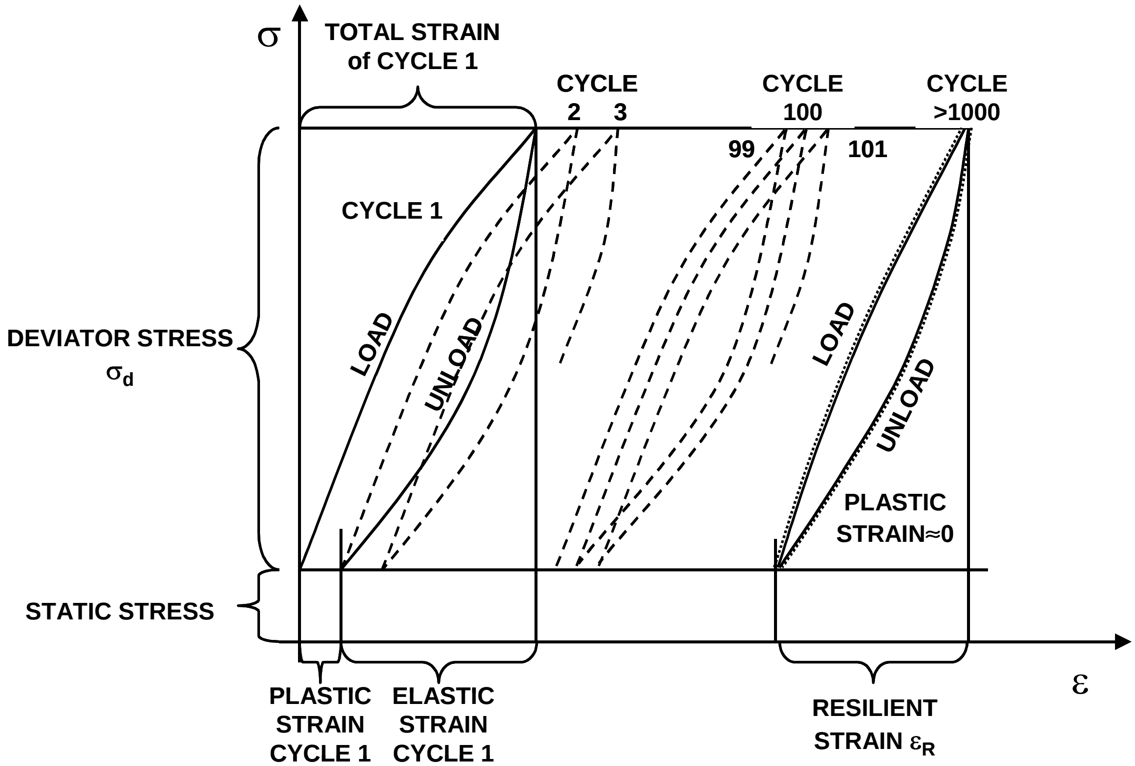


Figure 2.1 Concept of resilient modulus of Soils

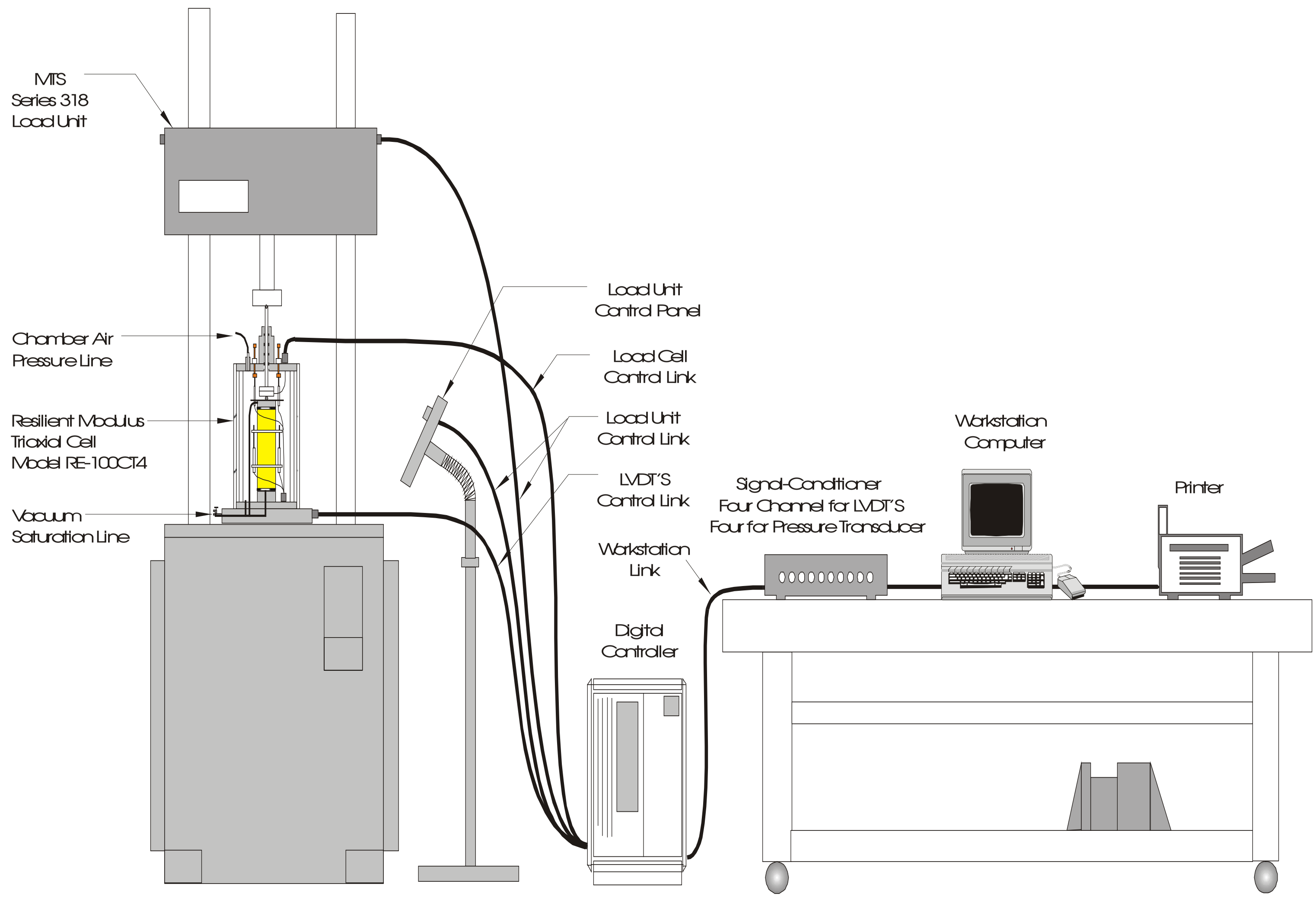


Figure 2.2(a) Sketch of the resilient modulus testing equipment

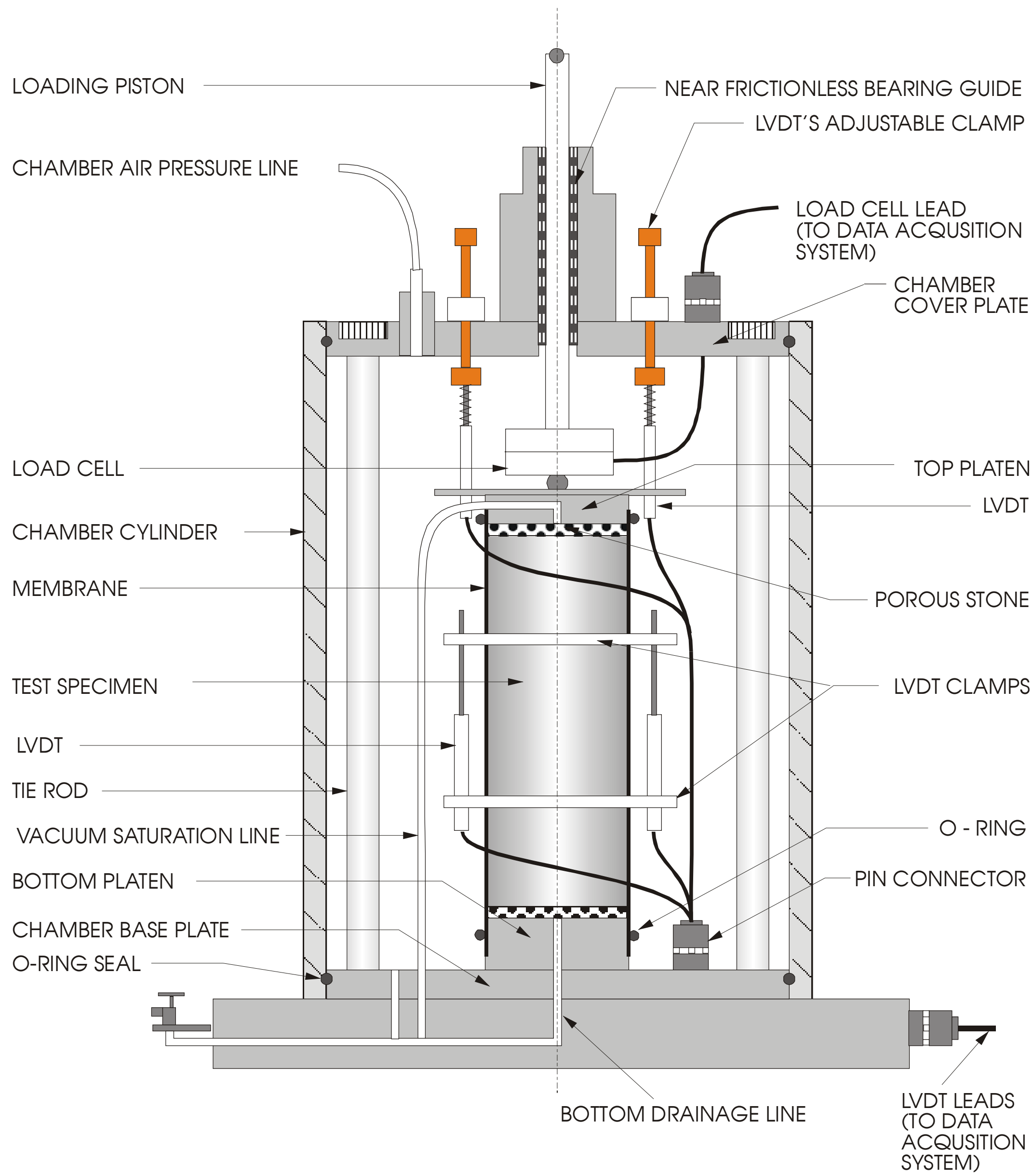
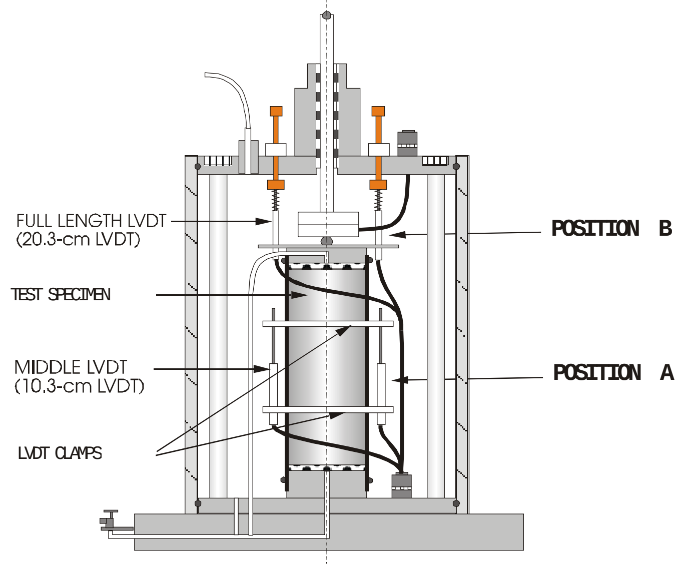
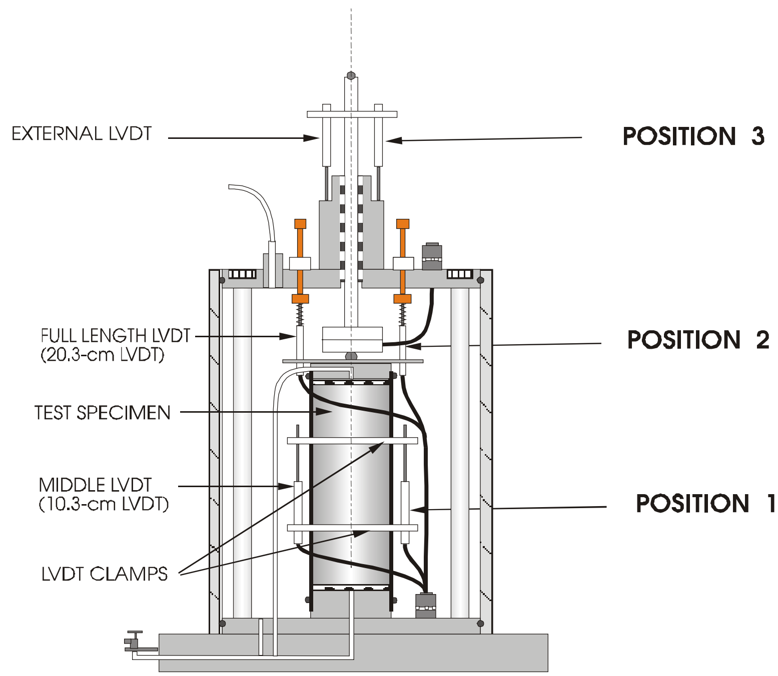


Figure 2.2(b) Triaxial chamber with internal LVDTs and load cell



(a) T 292-91I



(b) T294-92

Figure 2.3 Different positions of LVDTs, T 292-91I and T 294-92

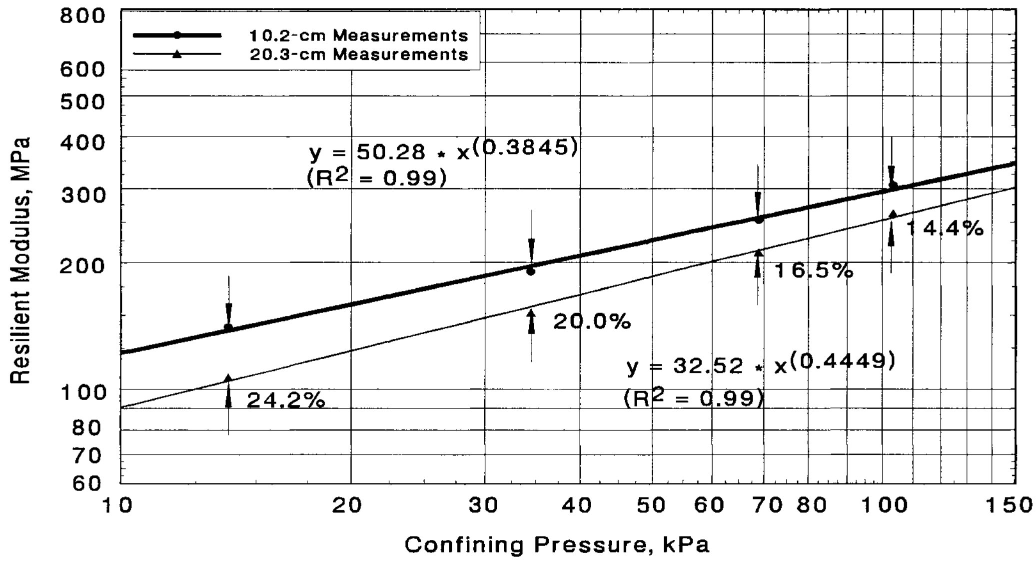


Figure 2.4 Resilient modulus versus confining pressure for A-3 soils

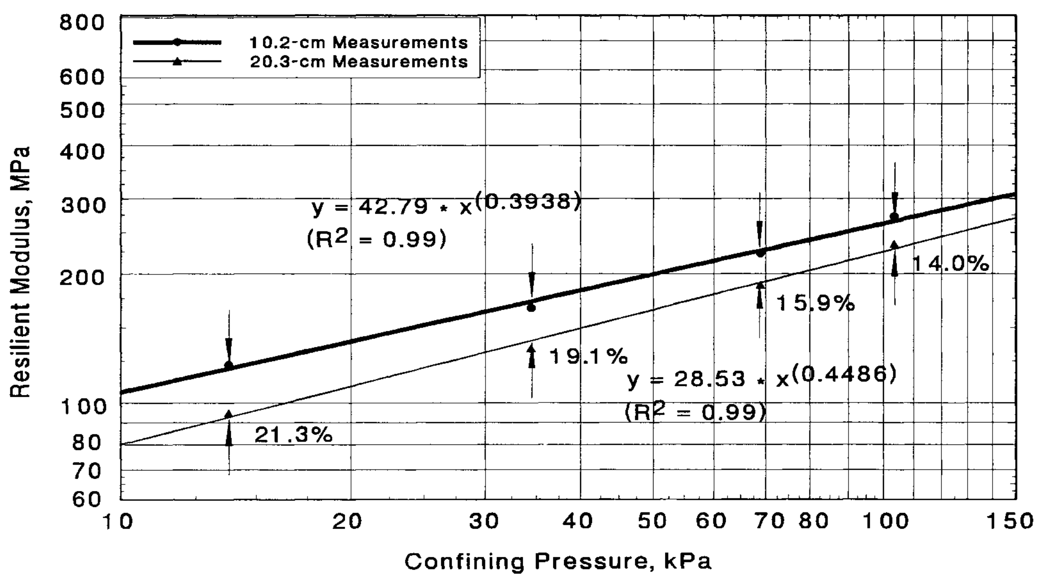


Figure 2.5 Resilient modulus versus confining pressure for A-2-4 soils

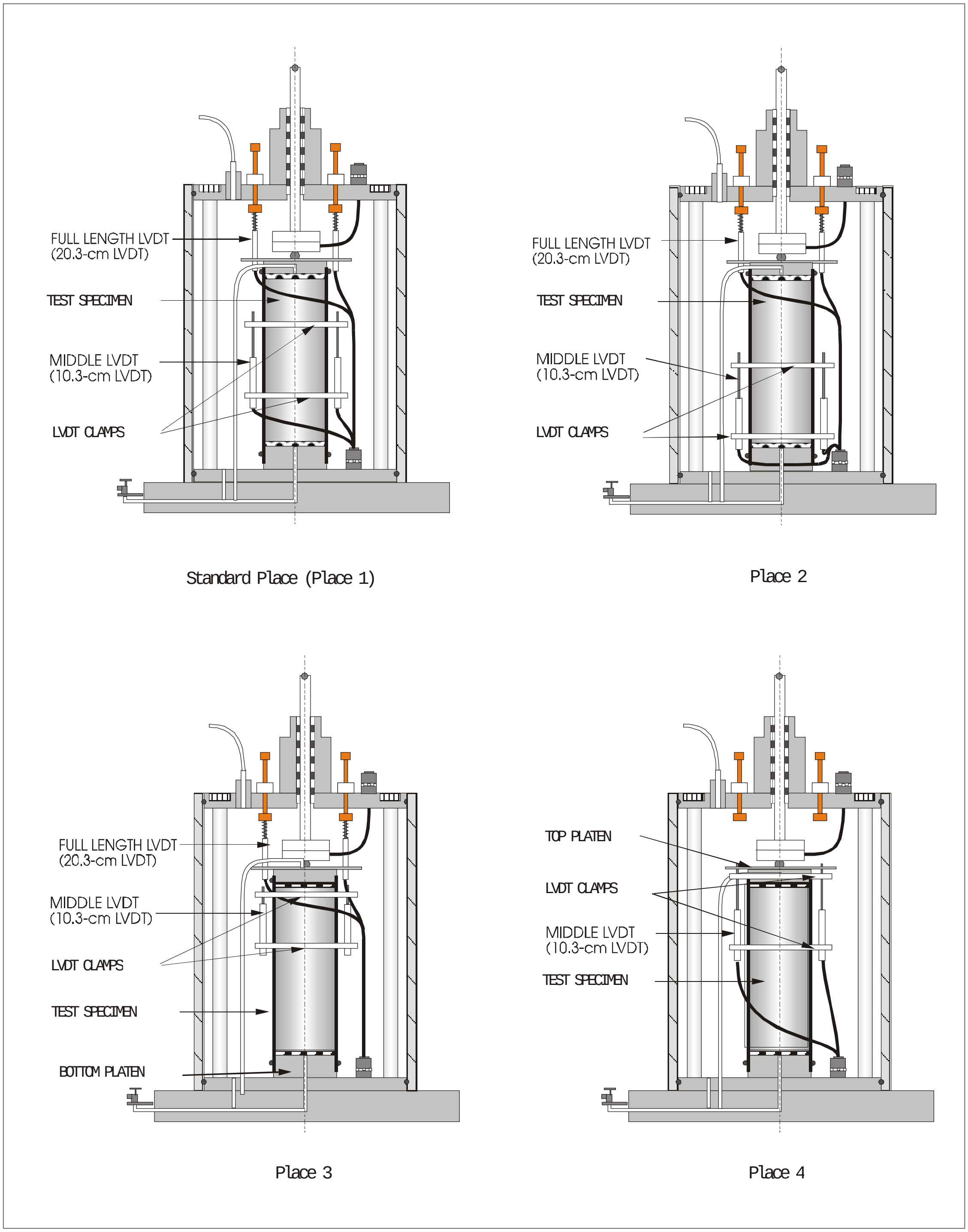


Figure 2.6 Different positions of the middle LVDTs

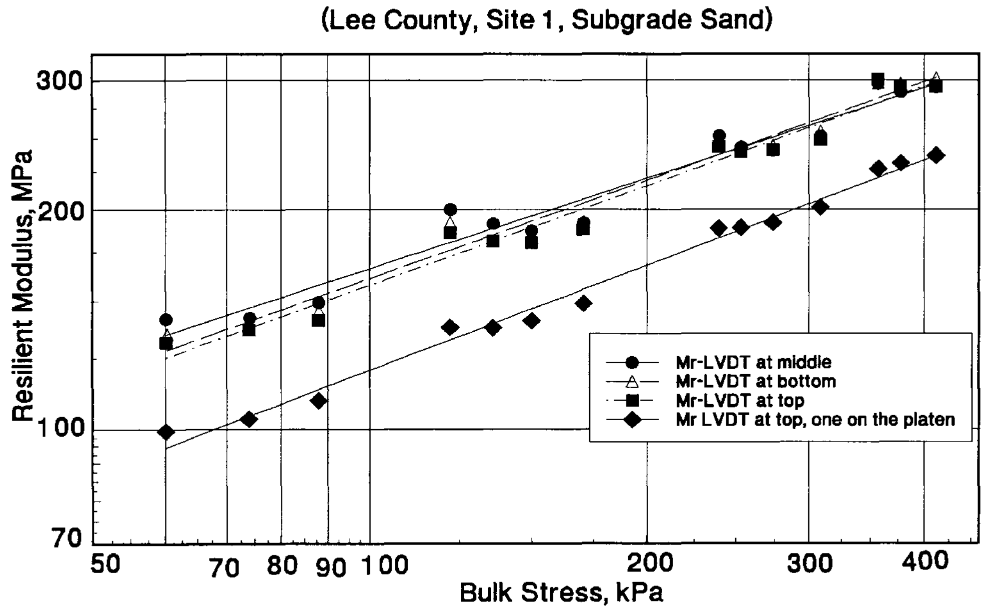


Figure 2.7 Resilient modulus versus bulk stress at different LVDTs' positions for a subgrade sand, T292-91I

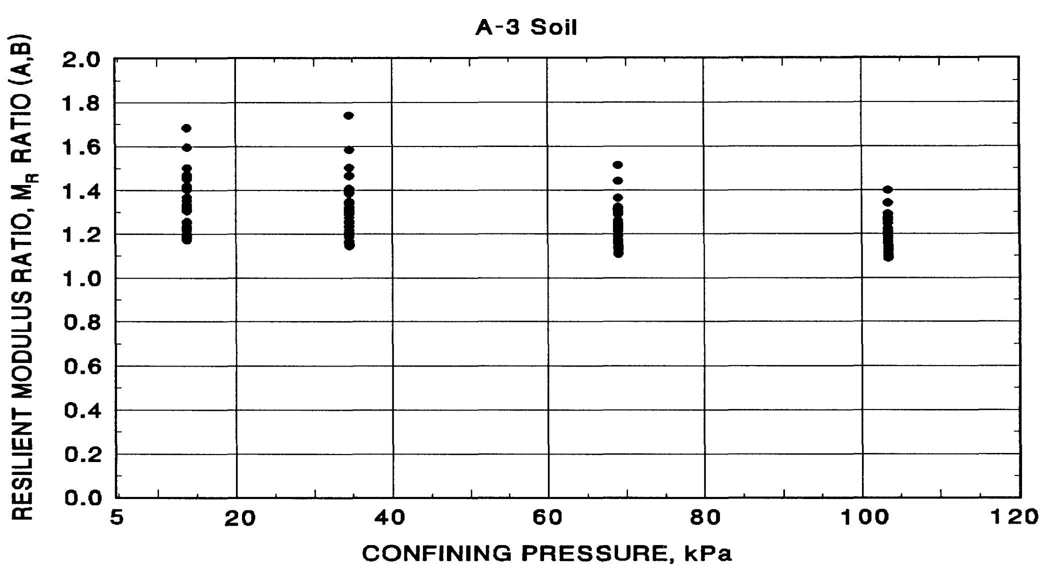


Figure 2.8 Ratio between middle and full length resilient modulus values of T292-91I for A-3 soil

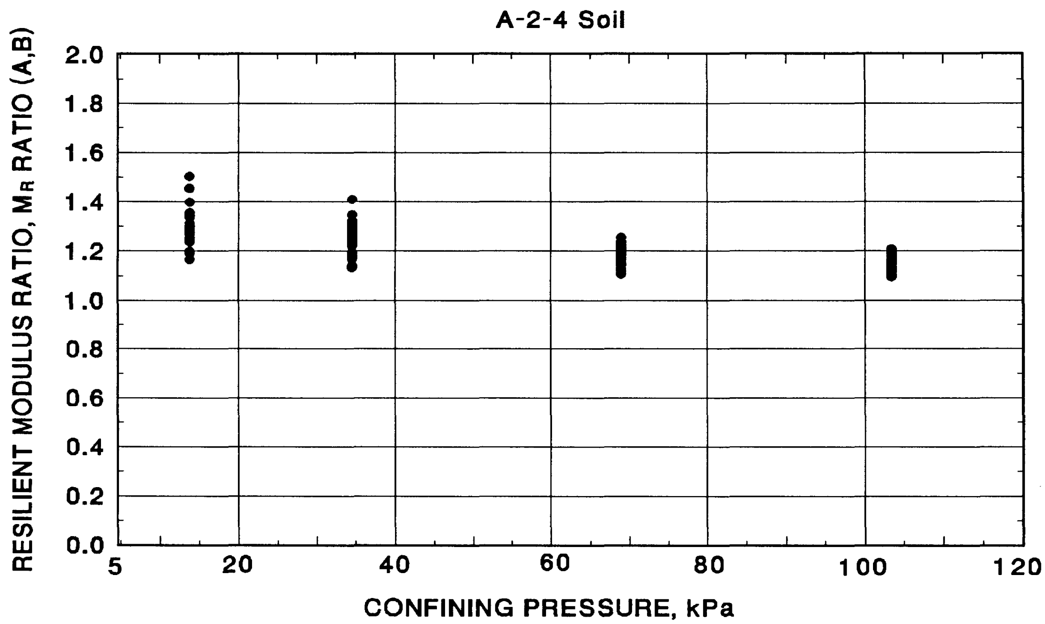


Figure 2.9 Ratio between middle and full length resilient modulus values of T292-91I for A-2-4 soil

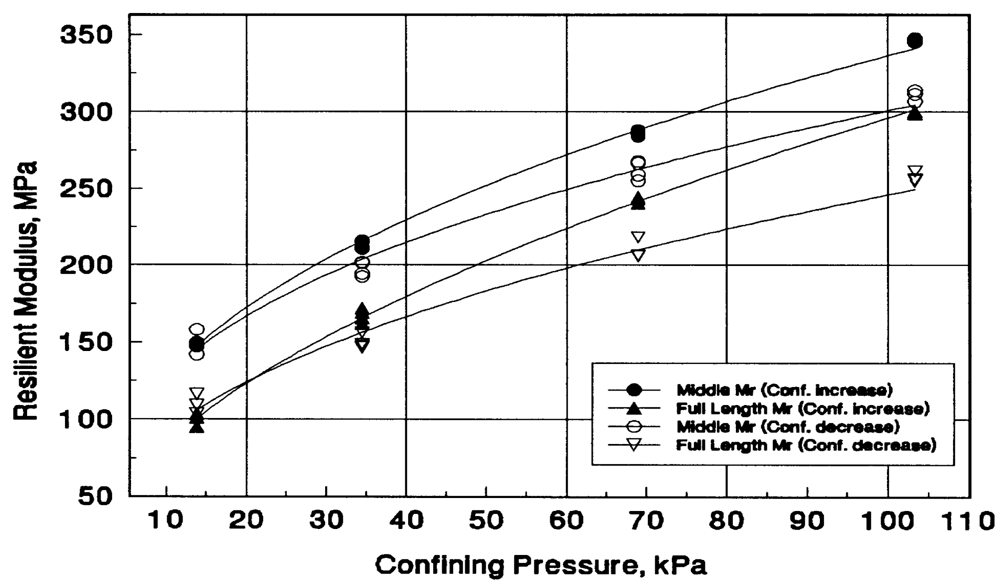


Figure 2.10 Effect of stress paths on resilient modulus versus confining pressure (T292-91I)

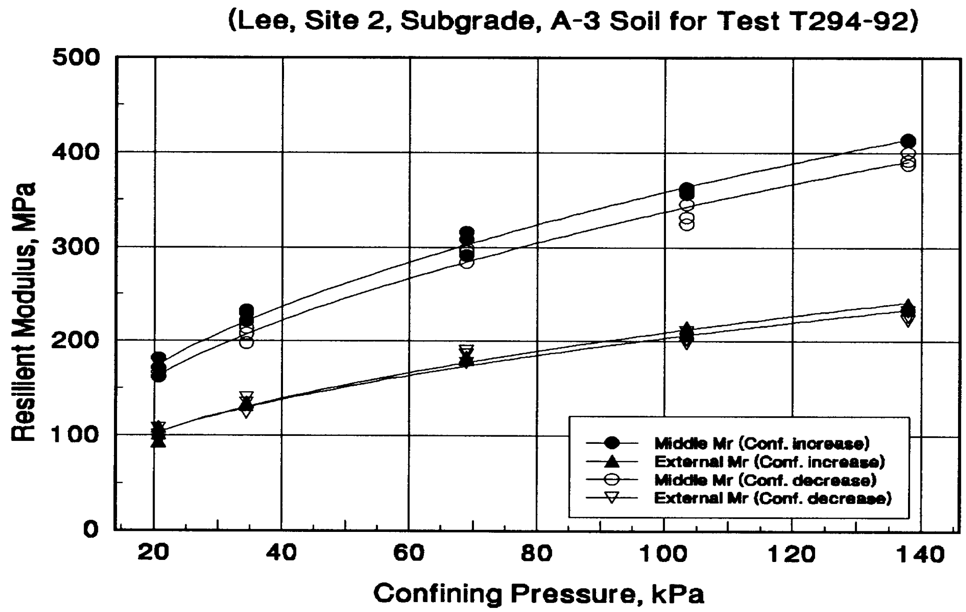


Figure 2.11 Effect of stress paths on resilient modulus versus confining pressure (T294-92)

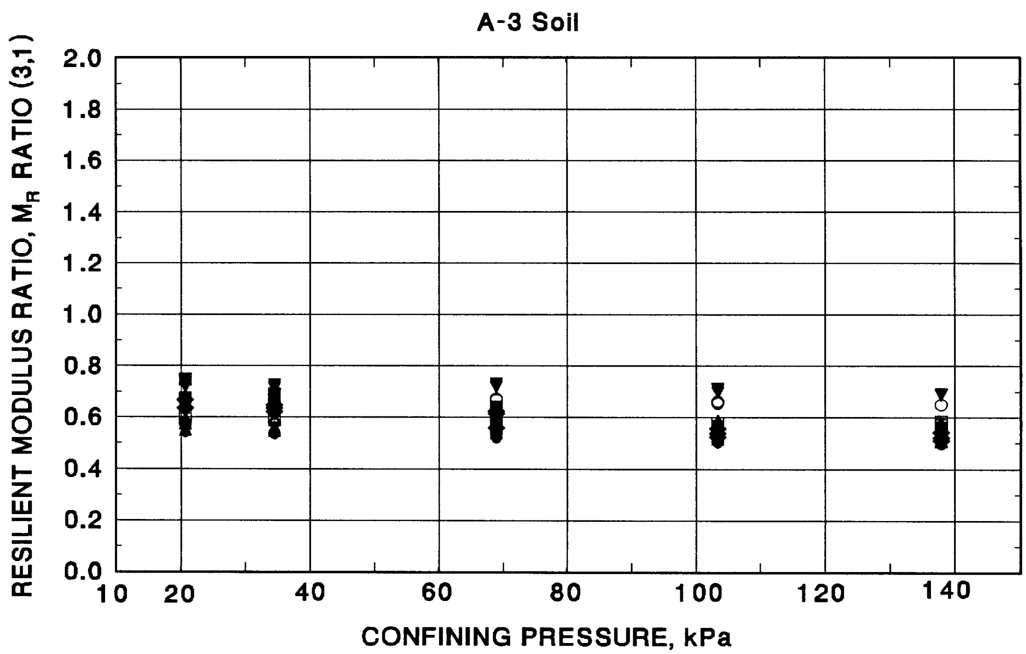


Figure 2.12 Ratio between external and middle resilient modulus values of T294-92 for A-3 soil

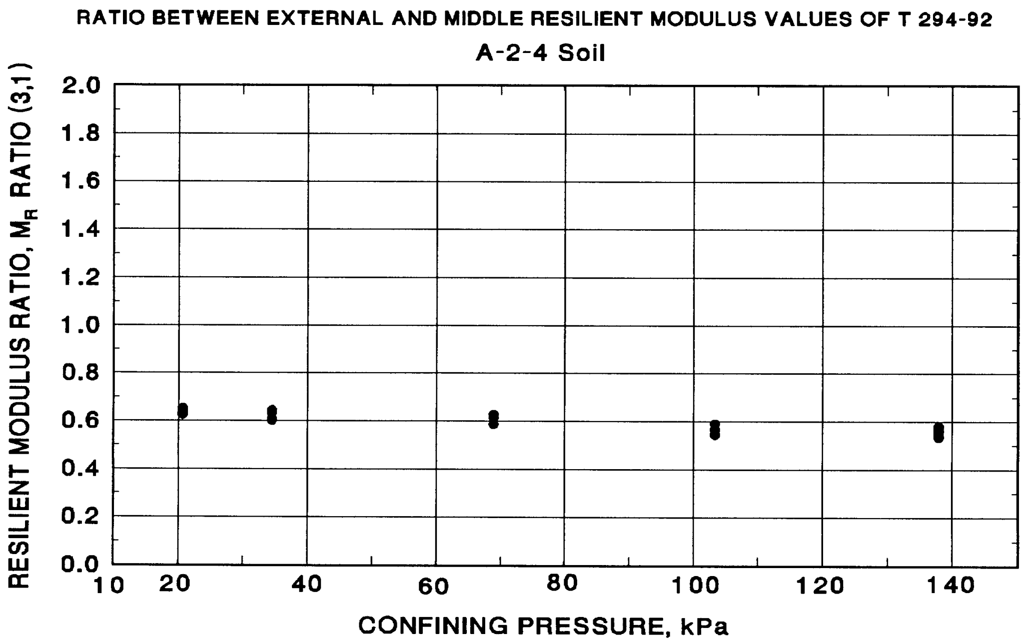


Figure 2.13 Ratio between external and middle resilient modulus values of T294-92 for A-2-4 soil

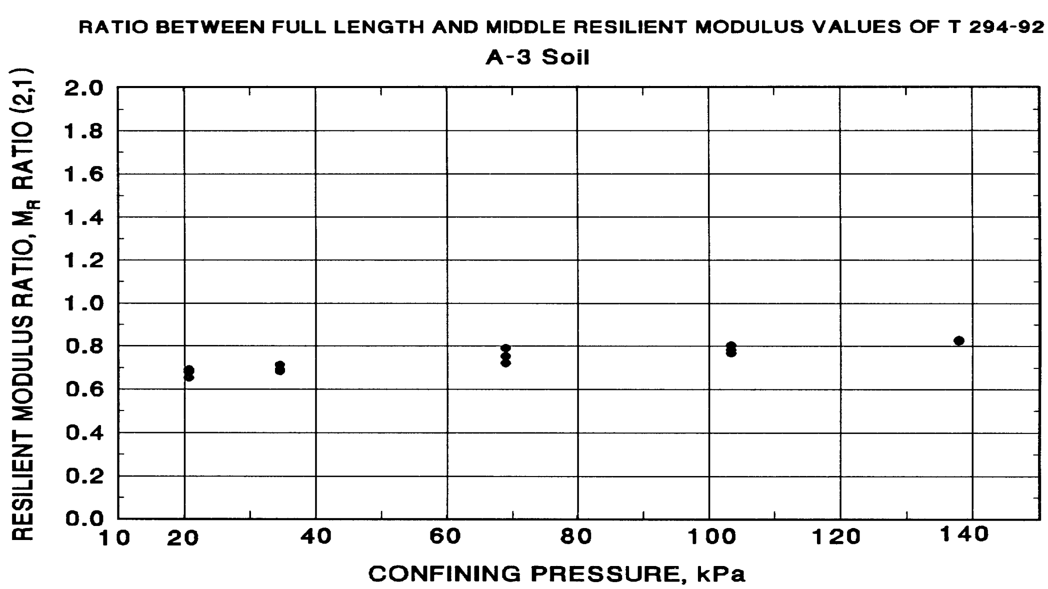


Figure 2.14 Ratio between full length and middle resilient modulus values of T294-92 for A-3 soil

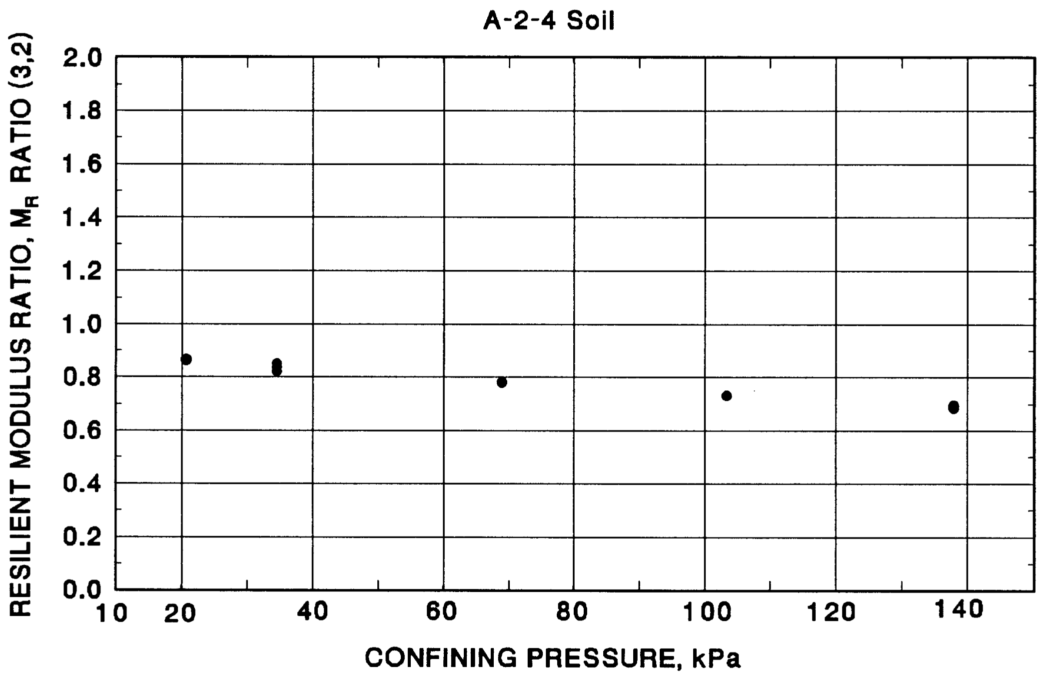


Figure 2.15 Ratio between external and full length resilient modulus values of T294-92 for A-2-4 soil

CHAPTER 3

DATABASE DEVELOPMENT

3.1 General

This chapter of the report describes the development of the database. The development process was started first to clarify the user requirements of the database. Then the entities and relationships were defined for the relational database model. The database was implemented using Microsoft Access.

3.2 Database User Requirements

The user requirements of the database were gathered, and are summarized as the following:

- The final product of the database ought to be a package using Visual Basic 6.0 and Microsoft Access 2000, which can be installed and distributed.
- The database must be capable of dealing with all data categories of a resilient modulus test, including resilient modulus test results, test condition data, sample location information, and other soil properties

related to the test, such as soil classifications, optimum moisture content, maximum dry unit weight.

- Basic data manipulation functions must be incorporated into the database, such as data entry, data query, data editing, and data reporting.
- The automatic data communication function between the database and Microsoft Excel should be a required feature of the database.
- The database should have the capability to analyze the data mathematically, and graphically.
- The database can be switched between the customary unit system and SI unit system.
- The database should be able to differentiate between various sampling locations such as an existing roadway, a developing roadway, or from a plant or pit, as shown in the FDOT Sample Transmittal Card (Figure 3.1).

3.3 Basic Concepts of Relational Database Model

The relational database model represents data in the form of two-dimension tables. Each table represents an entity about which information is collected, and is a set of records, where a record in turn is a set of fields and each field is a paired field-name/field-value. All records in a particular table have the same number of fields with the same field-names. The characteristics of a relational model are as following.

- Values are atomic.
- Column values are of the same kind.
- Each row is unique.
- The sequence of columns is insignificant.
- The sequence of rows is insignificant.
- Each column must have a unique name.
- All values in a column come from the same domain.

3.3.1 Entity and attribute

An entity is a distinguishable objective that exists. Entities are concepts, real or abstract, about which information is collected. Attributes are properties, which describe the entities. A particular instance of an attribute is a value. Each entity has associated with it a set of attributes describing it.

3.3.2 Relationship and key

A relationship is an association between two or more tables. Relationships are expressed in the data values of the primary and foreign keys. A primary key is a column or columns in a table whose values uniquely identify each row in a table. A foreign key is a column or columns whose values are the same as the primary key of another table. A foreign key can be considered as a copy of the primary key from another relational table. The relationship is made between two relational tables by matching the values of the foreign key in one table with the values of the primary key in another. Keys are fundamental to the concept of relational databases because they enable tables in the database to be related with each other. Navigation around a relational database depends on the ability of the primary key to unambiguously identify specific rows of a table. Navigating between tables requires that the foreign key is able to correctly and consistently reference the values of the primary keys of a related table.

3.3.3 Data integrity

Data integrity means, in part, that you can correctly and consistently navigate and manipulate the tables in the database. There are two basic rules to ensure data integrity: entity integrity and referential integrity.

The entity integrity rule states that the value of the primary key can never be a null value (a null value is one that has no value and is not the same as a blank). Because a primary key is used to identify a unique row in a relational table, its value must always be specified and should never be unknown. The integrity rule requires that insert, update, and delete operations maintain the uniqueness and existence of all primary keys.

The referential integrity rule states that if a relational table has a foreign key, then every value of the foreign key must either be null or match the values in the relational table in which that foreign key is a primary key.

3.4 Relational Database Model

The relational database model of the resilient modulus database (RMDB) is illustrated in Figure 3.2. The entity – relation schema of the RMDB, consists of the following nine entities:

- Soil
- MRCondition
- MRResult
- Location
- County-District
- AASHTOClassification
- UnifiedClassification
- SieveAnalysis
- MRRegression

The definition, attributes, and reference of these entities are described as below. The attributes are listed following each entity, and the primary key (PK) and reference attribute are underlined.

3.4.1 Soil

Definition: Any soil sample, which has been tested, and stored in the RMDB

Attributes: <u>SampleID</u>, MaterialNo, LocationNo1, ASHTOClassificationNo, UnifiedClassificationSymbol, StdOMC, StdDryUW, MdfOMC, MdfDryUW, GroupIndex, SpecificGravity, PlasticityIndex, LiquidLimit, MR_LBR, MR_FWD, MR_Dynaflect, MR_PLT, DateSampled, IntendedUse, Re-marks

Reference: Sample ID

A description of the attributes is summarized in Table 3.1.

3.4.2 MRCondition

Definition: The test condition or settings are exclusively applied to identify an individual test. The test is defined with the combination of sample ID, test method, sample size, test date, compaction type, and lab number. Any difference between the sample ID, test method, sample size, compaction type or lab number, would lead to a distinguished test.

Attributes: RecordNo, TestNo, SampleID1, SampleSize, Method, TestDate, MC, DryUW, CompactionType, LabNo

Reference: TestNo, or the combination of SampleID, Method, SampleSize, CompactionType, and LabNo

A description of the attributes is presented in Table 3.2.

3.4.3 MRResult

Definition: MRResult entity is defined with MRRecordNo. Each MRRecordNo corresponds to a set of resilient modulus test data under a particular confining pressure of the test.

Attributes: MRRecord No, TestRecord No, Sequence No, Confining Pressure, Axial Load, Dev. Stress, Bulk Stress, Middle Strain, Total Strain, Middle Modulus, Full Length Modulus

Reference: MRRecordNo, or TestNo plus the test sequence number

A description of the attributes is summarized in Table 3.3.

3.4.4 MRRegression

Definition: The regression parameters, including that of MR versus bulk stress, MR versus confining pressure, as well as MR versus confining pressure plus deviator stress

Attributes: MRRegNo, TestRecordNo1, LVDTPosition, k1, k2, k12Square, k3, k4, k34Square, k5, k6, k7, k567Square

Reference: MRRegNo

A description of the attributes is demonstrated in Table 3.4.

3.4.5 Location

Definition: A location is a site, where soil was sampled, tested, and the test results are stored in the database. There are three major types of location: site of an existing roadway, site of a future roadway project, and a site in a plant or pit.

Attributes: LocationNo, County, ProjectID, StationFrom, StationTo, Offset Distance, OffsetDirection, Mainline, ReferenceLine, PlantOrPitNo Roadway, RoadwayID, RoadwaySide, MP, Layer, Description

Reference: Location is referenced differently with each type of site. Existing roadway type locations use a combination of roadway number, roadway ID, milepost, reference line, offset distance, and roadway side to uniquely define a location.

Roadway project type locations apply project number, station from and station to, reference line, and offset distance as a whole to do so. Plant or pit numbers are used to exclusively determine plant or pit type location.

Scope: Only those sites, where the soil is sampled, tested and the test result data are entered into the soil resilient modulus, are defined as location in this study.

A description of the attributes is summarized in Table 3.5.

3.4.6 AASHTOClassification

Definition: AASHTOClassification is the soil engineering classification used to characterize soil by means of limited general properties in a brief and concise manner, without the necessity of entering into lengthy descriptions and detailed analysis.

Attributes: ClassificationNo, Classification, GroupNo, SoilType, Group Index, Definition

Reference: AASHTO classification is referenced uniquely by eight group classifications from A-1 through A-8 and thirteen sub-groups, such as A-1-a, A-1-b, and A-2-4 and so on.

A description of the attributes is presented in Table 3.6.

3.4.7 UnifiedClassification

Definition: UnifiedClassification is an outgrowth of the airfield soil calssification, which incorporates the textural characteristics of the soil into the engineering classification and utilizes the grain-size classification.

Attributes: GroupSymbols, TypicalName, Major division

Reference: All soils are classified into 15 groups of the system, each group being designated by two letters as named group symbols. Group symbols, GW, GP, GM, for instance, are applied to reference Unified Classification entities in the database exclusively. These letters are abbreviations of certain soil characteristics:

G – gravel	O – organic
W – well graded	S – sand
M – nonplastic or low plasticity fines	P – poorly graded
Pt – peat, humus, swamp	C – plastic fines
L – low liquid limit	H - high liquid limit

A description of the attributes is presented in Table 3.7.

3.4.8 CountyDistrict

Definition: The entity of CountyDistrict is defined as the corresponding relationship between the county and district number. It is established only for reducing the database redundancy by the relational database normalization principal.

Attributes: County1, CountyNo, District

Reference: The unique county name is used as the reference.

A description of the attributes is presented in Table 3.8.

3.4.9 SieveAnalysis

Definition: Soil sieve analysis results

Attributes: SampleID2, SieveNo, PassingPer

Reference: SampleID2

A description of the attributes is summarized in Table 3.9.

3.5 Entity Relationship

Seven major relationships relate the entities with each other, which are demonstrated in Figure 3.3, and are described as the following:

(1) Relationship 1: Soil vs. Location

This is a one to many relationship. One location may be sampled many times, but one sample has to be from only one single location.

(2) Relationship 2: Soil vs. MRCondition

This also is a one to many relationship. One sample may be tested more than one time with different test numbers, but one test needs to be for only one sample.

(3) Relationship 3: Soil vs. Sieve Analysis

This is a one to many relationship. One sample is required to have many sieve analysis data; one record of SieveAnalysis must correspond to only one sample.

(4) Relationship 4: Soil vs. UnifiedClassification or AASHTOClassification

This is a one to many relationship. Many samples may be classified in one single classification, whereas one soil sample ought to be defined as one only group classification or Group symbol.

(5) Relationship 5: MRCondition vs. MRResult

This is a one to many relationship. One test is required to produce more than one resilient modulus, but one single resilient modulus must be derived from just one test.

(6) Relationship 6: MRCondition vs. MRRegression

This is a one to many relationship. In this program, one test should produce two resilient modulus - full-length modulus and middle-modulus, but one single set of regression parameters must be derived from just one test.

(7) Relationship 7: CountyDistrict vs. Location

This is also a one to many relationship. There must be many sample sites in one county, but one sampled location is required to be located in just one county.

3.6 Implementation of the Database

The database was developed applying Microsoft Access 2000. Following the relational model, the database schema was transferred into a set of two-dimensional Access tables. The cascade and restricted relationships, and the integrity rules of the relational model were all integrated into the table system.

All relations (tables) including their attribute types, keys, primary keys, and foreign keys, as the outcomes of the logical model implementation, were screen-captured from the open view of the Microsoft Access 2000, and were displayed in Figures 3.4 through 3.11.

Table 3.1 Description of attributes of the soil entity
(continued on next page)

Attribute	Value Type	PK	FK	Table Related To	Description
SampleID	Text	Yes			unique identification of a soil sample
MaterialNo	Text				a number used to classify a material and its usage
LocationNo1	Num		Yes	Location	same with the PK of the Location entity
AASHTO Classification No	Num		Yes	AASHTO Classification	same with the PK of the AASHTO Classification entity
Unified Classification Symbol	Text		Yes	Unifeid Classification	unified soil classification, such as CH, CL
StdOMC	Num				standard optimum moisture Content (%)
StdDryUW	Num				Standard dry unit weight (KN / m3)
MdfOMC	Num				modified optimum moisture content (%)
MdfDryUW	Num				Modified dry unit weight(KN/ m3)
GroupIndex	Num				a numerical quantity based on the liquid limit, plastic index, and the percent <0.074 mm
Specific Gravity	Num				specific gravity of the soil sample
Plasticity Index	Num				range in water content over which soil material is plastic

Table 3.1 Description of attributes of the soil entity (continued)

Attributes	Value Type	PK	FK	Table Related To	Description
MR_FWD	Num				resilient modulus derived from FWD test
MR_Dyna-flect	Num				resilient modulus derived from dynaflect test
MR_PLT	Num				resilient modulus derived from PLT test
DateSampled	Time				date the sample was taken
IntendedUse	Text				intended usage of a soil
Remarks	Text				detail description

Table 3.2 Description of attributes of the MRCondition entity

Attribute	Value Type	PK	FK	Table Related To	Description
RecordNo	Num	yes			unique number used to represent a test
TestNo	Text				SampleID + Method + TestDate + Samplesize + CompactionType + LabNo
SampleID1			yes	Soil	same with the PK of the Soil entity
SampleSize	Num				diameter of a specimen (inch)
Method	Text				test procedure
TestDate	Time				date the sample was tested
MC	Num				test moistrure content (%)
DryUW	Num				test dry unit weight (KN / m3)
Compaction Type	Text				standard or modified Procter test
LabNo	Text				designated number of a laboratory

Table 3.3 Description of attributes of the MRResult entity

Attribute	Value Type	PK	FK	Table Related To	Description
MRRecordNo	Num	yes			unique no. used to indentify each row of the test results
Test RecordNo	Num		Yes	MRCondition	same with the PK of MRCondition entity
SequenceNo	Text				sequence no. of the stress condition based on a MR test procedure
Confining Pressure	Num				minor principal stress
AxialLoad	Num				the deviatoric load applied on a soil specimen
DevStress	Num				the principal stress difference(deviator stress)
Bulk Stress	Num				the sum of three principal stresses
Middle Strain	Num				the strain measured on the middle LVDT
Total Strain	Num				the strain measured on the full length LVDT
Middle Modulus	Num				the measured modulus based on the middle length LVDT
FullLength Modulus	Num				the measured modulus based on the full length LVDT

Table 3.4 Description of attributes of the MRRegression entity

Attribute	Value Type	PK	FK	Table Related To	Description
MRRegNo	Num	Yes			unique no. of the regression analysis results
Test RecordNo1	Num		Yes	MRCondition	same with the PK of MRCondition entity
k1	Num				regression constant
k2	Num				regression constant
r12 Square	Num				regression coefficient
k3	Num				regression constant
k4	Num				regression constant
r34 Square	Num				regression coefficient
k5	Num				regression constant
k6	Num				regression constant
k7	Num				regression constant
r567 Square	Num				regression coefficient

Table 3.5 Description of attributes of the Location entity (continued on next page)

Attribute	Value Type	PK	FK	Table Related To	Description
Location No	Num	yes			unique no. of locations where sampled
County	Text		yes	County District	name of the county
Project ID	Text				project no that the soils belonged to
Station From	Text				place where the sample was taken between two locations
StationTo	Text				used in conjunction with StationFrom
Offset Distance	num				distance between the sampling location and the reference line
Offset Direction	Text				direction of the sampling location in relation to the reference line used; enter R for right, L for left
Mainline	Y/N				to indicate if the sample is referenced to the mainline roadway
Reference Line	Text				line on the plans used as the reference for determining sample location

Table 3.5 Description of attributes of the Location entity (continued)

Attribute	Value Type	PK	FK	Table Related To	Description
Roadway ID	Text				a designated unique ID number to identify a roadway segment
Roadway side	Text				side of a divided highway; R for right side, L for left side
MP	Num				milepost where a sample was taken
Layer	Text				pavement layer where a sample was taken
Desc.	Text				detail information of a sample location

Table 3.6 Description of attributes of the CountyDistrict entity

Attribute	Value Type	PK	FK	Table Related To	Description
County1	Test	Yes			county name
District	Num				district number

Table 3.7 Description of attributes of the AASHTOClassification entity

Attribute	Value Type	PK	Description
ClassificationNo	Num	Yes	classification number
Classification	Text		classification of soil sample
GroupNo	Text		group number of classification
SoilType	Text		type of a soil,such as clay or sand
GroupIndex	Num		group index number of classification
Definition	Text		definition

Table 3.8 Description of attributes of the UnifiedClassification entity

Attribute	Value Type	PK	Description
GroupSymbols	Text	Yes	such as GW, GP, or ML, and so on
TypicalName	Text		typical name, such as granular soil,clay soil
MajorDivision	Text		groups of soil unified classification

Table 3.9 Description of attributes of the SieveAnalysis entity

Attribute	Value Type	PK	FK	Table Related To	Description
SieveRecordNo	Num	Yes			unique no. of the sieve analysis results
SampleID2	Text		Yes	Soil	same with the PK of soil entity
SieveNo	Text				number of sieve size
PassingPer	Num				percentage of soil passing a particular sieve size

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

FORM 675-050-04
MATERIALS - 06/98

PROJECT ID: 193891-1-52-01
PAY ITEM NO.
MATERIAL NO. 407F
SAMPLE NO. IA001
DATE SAMPLED ~~12 2099~~
STA FROM 51+60.00
STA TO 53+45.00
SAMP FROM 52+00
~~RDWAY SIDE~~ C
OFFSET DISTANCE 0.0
OFFSET DIRECTION C
MAINLINE Y
REFERENCE LINE C/L CONSTRUCTION
PLANT OR PIT NO. 01305
QUANT REP 1,600.00 M2
INTENDED USE OR PART OF STRUCTURE PLACED BASE ROCK RDWY

ROAD NO.
DISTRICT NO. 01
COUNTY 64
SECTION 010
CONTRACT
SAMPLED BY PING
MATERIAL DESC. BASE - SHELL ROCK MATERIAL
MANUFACTURER OR PRODUCER (NOT JOBBER) VF
SOURCE (PLACE FROM WHICH SHIPMENT WAS MADE) 01-305
GRADE
BATCH NO.
LOT NO.
LAB NO.
DESIGN MIX NO.
SLUMP
% AIR
PRODUCERS: CMT.
F.A.
C.A.
RETARDANT
FLY ASH
REMARKS:

SUBMITTED BY
PHONE
ADDRESS
RECYCLED PAPER

Figure 3.1 FDOT sample transmittal card
(Form 675-050-04)

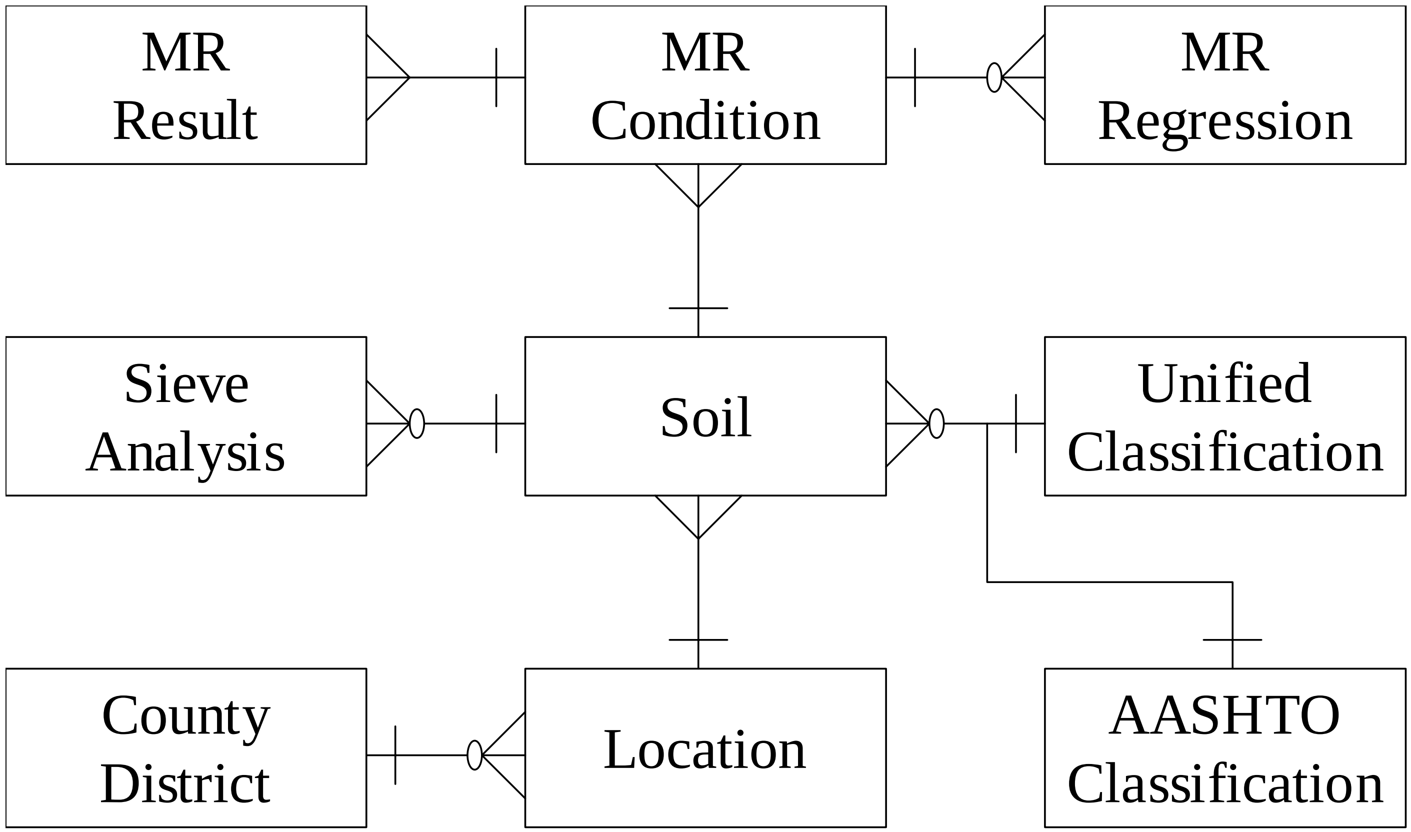


Figure 3.2 The Entity – Relation Schema of RMDB

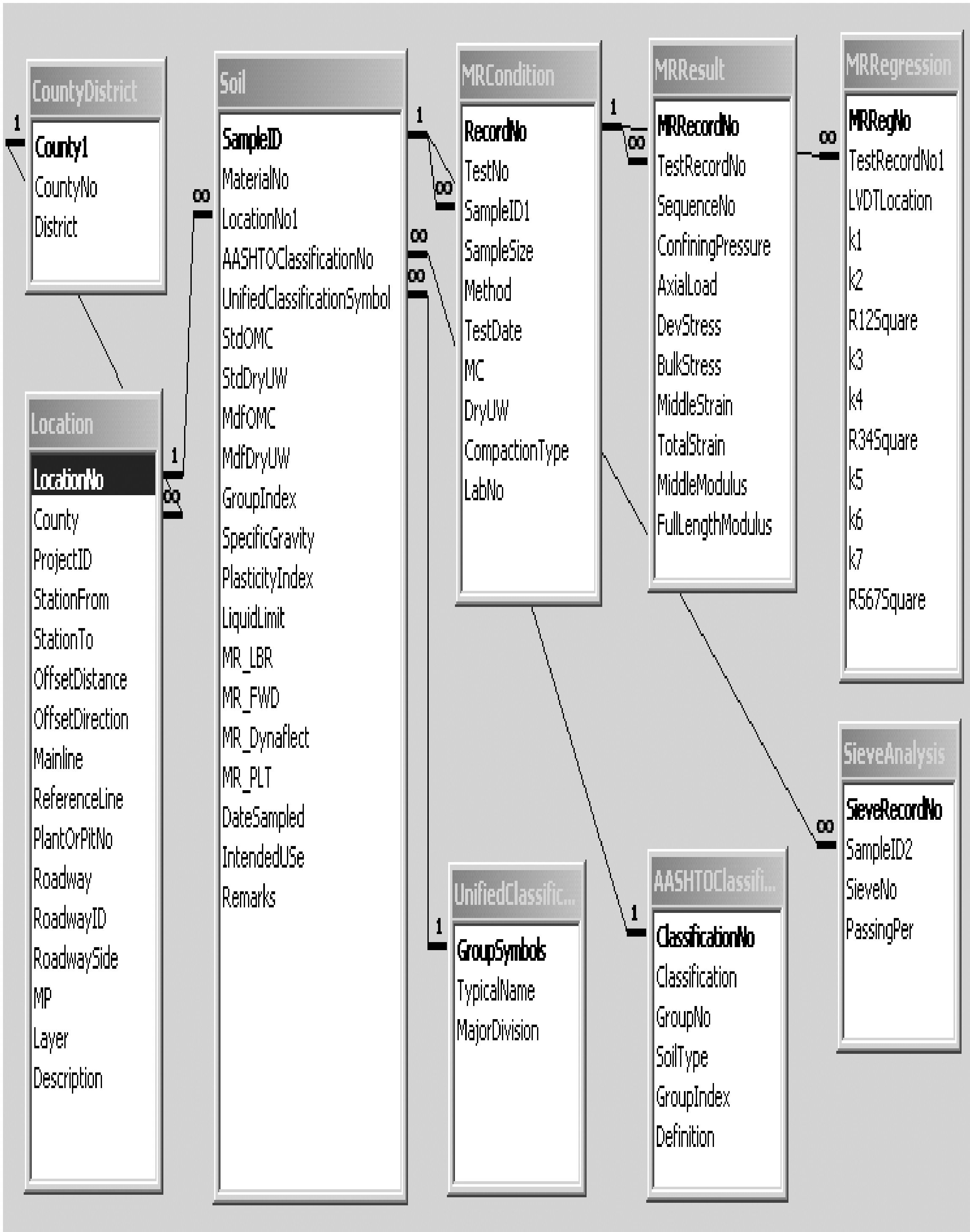


Figure 3.3 Entity relationships of the RMDB

MRCondition : Table

Record	TestNo	SampleNo1	Sample	Method	TestDate	WC(%)	Den(kg/cm3)	Standard	LabN
1	A1AEST292-91I4	A1AES	4	T292-91I	9/7/1995	12.4	17.04	Stadard	0123
2	A1ASST292-91I4	A1ASS	4	T292-91I	10/3/1995	10.1	18.32	Stadard	0123
3	A1BEST292-91I4	A1BES	4	T292-91I	8/29/1995	10.8	16.94	Stadard	0123
4	A1BSST292-91I4	A1BSS	4	T292-91I	9/26/1995	12	16.37	Stadard	0155
5	A2AEST292-91I4	A2AES	4	T292-91I	11/15/1995	10.8	17.38	Stadard	0155
6	A2ASST292-91I4	A2ASS	4	T292-91I	9/28/1995	10.6	18.51	Stadard	0167
7	A2BEST292-91I4	A2BES	4	T292-91I	8/25/1995	13.4	16.53	Stadard	0167
8	A2BSST292-91I4	A2BSS	4	T292-91I	9/27/1995	10.8	16.67	Stadard	0156
9	B3ASST292-91I4	B3ASS	4	T292-91I	11/15/1995	11.7	17.69	Stadard	0156
10	B4ASST292-91I4	B4ASS	4	T292-91I	10/3/1995	11.3	17.72	Stadard	0234
11	B5CEST292-91I4	B5CES	4	T292-91I	9/21/1995	12.8	16.4	Stadard	0232
12	B5CSST292-91I4	B5CSS	4	T292-91I	10/18/1995	13.5	15.76	Stadard	0233
13	B6CEST292-91I4	B6CES	4	T292-91I	9/22/1995	12.4	15.98	Stadard	0256
14	B6CSST292-91I4	B6CSS	4	T292-91I	10/19/1995	14.2	15.86	Stadard	0256
15	C2GEST292-91I4	C2GES	4	T292-91I	9/13/1995	9.7	18.13	Stadard	0987
16	C2GSST292-91I4	C2GSS	4	T292-91I	11/12/1995	6.9	20.25	Stadard	0987
17	C3GSST292-91I4	C3GSS	4	T292-91I	11/9/1995	8.9	19.94	Modified	1245
18	D3MEST292-91I4	D3MES	4	T292-91I	8/18/1995	9.6	16.64	Modified	1246
19	D3MSST292-91I4	D3MSS	4	T292-91I	10/5/1995	8.9	18.51	Modified	1245
20	D4MEST292-91I4	D4MES	4	T292-91I	8/23/1995	9.5	17.67	Modified	1246
21	D4MSST292-91I4	D4MSS	4	T292-91I	10/9/1995	9.5	18.54	Modified	1267
22	E1SEST292-91I4	E1SES	4	T292-91I	10/26/1995	8.5	17.13	Modified	1786

Record: 1 of 80

Figure 3.4 MRCondition table

Soil : Table

SampleNo	LocationNo1	ClassificationNo	GroupIndex	SpecificGravity	MR_LBR	FWD(MPa)	DYN(0.001
A1AES	1	A-2-4	0	0	0	0	
A1ASS	1	A-2-4	0	0	0	0	
A1BES	2	A-2-4	0	0	0	0	
A1BSS	2	A-2-4	0	0	0	0	
A2AES	3	A-2-4	0	0	0	0	
A2ASS	4	A-2-4	0	0	0	0	
A2BES	5	A-2-4	0	0	0	0	
A2BSS	5	A-2-4	0	0	0	0	
B3ASS	6	A-2-4	0	0	0	0	
B4ASS	7	A-2-4	0	0	0	0	
B5CES	8	A-2-4	0	0	0	0	
B5CSS	8	A-2-4	0	0	0	0	
B6CES	9	A-2-4	0	0	0	0	
B6CSS	9	A-2-4	0	0	0	0	
C2GES	10	A-2-4	0	0	0	0	
C2GSS	11	A-2-4	0	0	0	0	
C2JSC	20	A-2-4	0	0	0	0	
C3GSS	12	A-2-4	0	0	0	0	
D3MES	13	A-2-4	0	0	0	0	
D3MSS	13	A-2-4	0	0	0	0	
D4MES	14	A-2-4	0	0	0	0	
D4MSS	14	A-2-4	0	0	0	0	

Record: 1 of 30

Figure 3.5 Soil table

Location : Table

LocationNo	ReferenceLine	PlantOrPitNo	Roadway	RoadwaySide	MP	Layer	Description
1	C/L Constructio	01305	U.S.17	C	677	Embankment	
2	C/L Constructio	01305	S.R.884	C	-1	Embankment	
3	C/L Constructio	01305	U.S.17	C	78	Embankment	
4	C/L Constructio	01305	U.S.1	C	-1	Subgrade	
5	C/L Constructio	01305	S.R.884	C	887	Embankment	
6	C/L Constructio	01305	U.S.301	C	876	Subgrade	
7	C/L Constructio	01305	U.S.301	C	56	Subgrade	
8	C/L Constructio	01305	U.S.17	C	34	Embankment	
9	C/L Constructio	01305	U.S.17	C	23	Embankment	
10	C/L Constructio	01305	U.S.17	C	-1	Embankment	
11	C/L Constructio	01305	U.S.27	C	-1	Subgrade	
12	C/L Constructio	01305	U.S.27	C	3555	Subgrade	
13	C/L Constructio	01305	U.S.1	C	123	Embankment	
14	C/L Constructio	01305	U.S.1	C	878	Embankment	
15	C/L Constructio	01305	U.S.114	C	-1	Embankment	
16	C/L Constructio	01305	U.S.114	C	3556	Embankment	
17	C/L Constructio	01305	U.S.114	C	47	Embankment	
18	C/L Constructio	01305	U.S.114	C	5786	Embankment	
19	C/L Constructio	01305	U.R.17	C	6	Subgrade	
20	C/L Constructio	01305	U.S.27	C	768	Silty Clay	
0					-1		

Figure 3.6 Location table

MRResult : Table

RecordNum	TestRecordNo	SequenceNo	ConfiningPressure	AxialLoad	DevStress	BulkStress	MiddleStrain
1	1	1	103.42	0.376	46.328	356.588	0.00019
2	1	2	103.42	0.545	67.201	377.461	0.00028
3	1	3	103.42	0.825	101.742	412.002	0.00041
4	1	4	68.95	0.263	32.4	239.25	0.00016
5	1	5	68.95	0.377	46.444	253.294	0.00024
6	1	6	68.95	0.543	67.021	273.871	0.00034
7	1	7	68.95	0.825	101.778	308.628	0.00049
8	1	8	34.47	0.152	18.806	122.216	0.00013
9	1	9	34.47	0.263	32.466	135.876	0.00023
10	1	10	34.47	0.377	46.441	149.851	0.00032
11	1	11	34.47	0.545	67.264	170.674	0.00045
12	1	12	13.79	0.152	18.711	60.081	0.00019
13	1	13	13.79	0.264	32.579	73.949	0.00031
14	1	14	13.79	0.383	47.3	88.67	0.0005
15	2	1	103.42	0.377	46.558	356.818	0.00015
16	2	2	103.42	0.542	66.902	377.162	0.00022
17	2	3	103.42	0.824	101.676	411.936	0.00034
18	2	4	68.95	0.264	32.618	239.468	0.00013
19	2	5	68.95	0.376	46.432	253.282	0.00019
20	2	6	68.95	0.544	67.112	273.962	0.00028
21	2	7	68.95	0.824	101.697	308.547	0.00041
22	2	8	34.47	0.152	18.743	122.153	0.0001

Record: 1 of 1142

Figure 3.7 MRResult table

MRRegression : Table

RecordNo1	TestRecordNo1	LVDTLocation	k1	k2	R12Square
1	TableA-3T292-91I4	FullLen	3.02	0.819	1
9	TableA-3T292-91I4	Middle	5.029	0.747	0.918
10	A2424%o2T292-91I4	Middle	15.523	0.467	0.948
11	TableA-4T292-91I4	Middle	5.975	0.72	0.92
12	TableA-4T292-91I4	FullLen	3.573	0.792	1
16	A2412%S2T292-91I4	Middle	11.835	0.521	0.987
19	TableD-4T292-91I4	FullLen	4.778	0.697	1
24	A2420%O2T292-91I4	Middle	10.4	0.586	0.983
27	A2424%o2T292-91I4	FullLen	6.981	0.599	1
35	A2420%O2T292-91I4	FullLen	6.581	0.653	1
39	TableC-6T292-91I4	Middle	14.698	0.519	0.83
40	TableC-6T292-91I4	FullLen	8.973	0.589	0.9
41	TableC-7T292-91I4	Middle	8.917	0.612	0.875
42	TableC-7T292-91I4	FullLen	5.097	0.687	0.9
49	TableD-3T292-91I4	Middle	20.837	0.445	0.988
50	TableD-3T292-91I4	FullLen	14.11	0.491	1
51	SR44-1-ST-1T292-91I4Star	Middle	3.347	0.962	0.201
56	TableB-3T292-91I4	Middle	132.803	0.17	0.339
57	TableB-3T292-91I4	FullLen	42.355	0.333	0.8
58	TableB-4T292-91I4	Middle	65.131	0.277	0.624
59	TableB-4T292-91I4	FullLen	24.935	0.421	0.8
69	A2412%S1T292-91I4	FullLen	7.474	0.574	1

Record: 1 of 210

Figure 3.8 MRRgression table

Classification : Table

AASHTOClassification	GroupNo	SoilType	Symbol	GroupIndex	Definition
Unknown					
A-1-a	A-1	Sand	GW	0	Largely Gravel but can include sand and fines.
A-1-b	A-1	Sand	GP	0	Gravelly sand or graded sand;may include fines
A-2-4	A-2	Sand		0	Sands,gravels with low-plasticity silt fines.
A-2-5	A-2	Sand		0	Sands,gravels with elastic silt fines.
A-2-6	A-2	Sand		4max	Sands,gravels with clay fines.
A-2-7	A-2	Sand		4max	Sands.gravels with highly plastic clay fines.
A-3	A-3	Sand		0	Fine sands.
A-4	A-4	Sand		8max	Low-compressibility silts.
A-5	A-5	Sand		12max	High-compressibility silts.
A-6	A-6	Clay		16max	Low-to-medium-compressibility clays
A-7-5	A-7	Clay		20max	High-compressibility silty clays.
A-7-6	A-7	Clay		20max	High-compressibility,high-volume-change clays
A-8	A-8	Clay		20max	Peat,highly organic soils.
Limerock					

Record: 4 of 15

Figure 3.9 AASHTOClassification table

UnifiedClassification : Table

GroupSymbols	TypicalName	MajorDivision1	MajorDivision2	MajorDivision3
CH	Inorganic silts and very fine			
CL				
GC	Clayer gravels, hravel-sand-clay mixtures			
GM	Silty gravels, gravel-and-silt mixtures			
GP	Poorly graded gravels, gravel-sand mixtures			
GW	Well-graded gravels,gravel-sand mixtures			
MH				
ML				
OH				
OL				
PT				
SC	Clayer sands, sand-clay mixtures			
SM	Silty sands, sand-silt mixtures			
SP	Poorly graded sands,gravelly sands			
SW	Well-graded sands,gravelly sands			

Record: 1 of 15

Figure 3.10 UnifiedClassification table

CountyDistrict : Table

County	CountyNo	District
Alachua		2
Clay		2
Dade		6
Gadsden		3
Jefferson		3
Lee		9
Martin		4
Osceola		5
Polk		1
Seminole		5

Record: 1 of 10

Figure 3.11 CountyDistrict table

CHAPTER 4

DATABASE APPLICATION

4.1 Application Structure

The applications of the resilient modulus database (RMDB) include the basic data manipulations such as data entry, data query, and data report. In addition, some advanced features are also incorporated into the database, e.g., database access control, security management, communication with outside data resources, and data analysis.

4.1.1 Main menu

The database applications fall into five main menu items:

- System
- Data Entry
- Data Query
- Analysis
- Help

The main menu is shown in Figure 4.1. Each main menu item contains a certain number of submenu items, as discussed below.

4.1.2 Submenu

The submenu items of the System include:

- User Registration
- Database Sign In
- Data Backup/Data Restore
- Exit

These submenus are demonstrated in Figure 4.2. The main functions include database access control, data security management, and exit from the database.

The submenu items of the Data Entry include:

- Soil
- Test Data
- Classification
- CountyDistrict

The basic data manipulation and maintenance functions such as data entry/import, editing, and deletion are incorporated respectively into each data entity. The sub_ menu Classification also contains its second-step submenus: AASHTO and Unified, which are used to classify two major types of soil classification criteria, as shown in Figure 4.3.

The Data Query includes no submenu. The advanced query and report of the query results are the major functions (Figure 4.4).

The Analysis contains two categories of submenu. The first category contains submenus such as:

- MR vs. Bulk Stress
- MR vs. Confining Pressure
- MR VS. Confining Pressure plus Deviator Stress

The regression analyses between MR values and states of stress are presented under these submenus. The second category is the Comparative Analysis, in which two sub-menus are incorporated:

- Between T292-91I and T294-92
- Between Middle and Full Length LVDT

These submenus correspond to the two types of comparative analysis on MR values due to the effects of test procedure and LVDT position. The submenus are illustrated in Figure 4.5.

4.2 System Management

The system management includes two major functions: database access control and data security control. The database access control is to administer user authorization and management by controlling the menu activity with the help of user name and password method. The data security control refers to the data back-up/restore functions for dismissing an unexpected or erroneous data manipulation. In addition, the function of menu control is also presented.

4.2.1 Access control

The RMDB users are categorized into three different levels of database access: manager level, registered user level, and general user level. The operation restriction or function availability is controlled by the database menu activities for each user level. Being activated after access means the function of the menu is available to the user. The detailed function availability for different levels of users is described as follows.

<u>Manager level</u> All functions are available to the manager level users, especially the user registration application. No database user other than the manager level users can authorize other users to access the RMDB system. The manager level users will monopolize the username “manager”.

<u>Registered user level</u> Every function is opened to this level of users but user registration. The user

registration menu is inactive for non-manager registered users.

General user level The user registration, data backup/restoration, and data entry are prohibited to general users. Registration, Backup/Restore, and Data Entry menus will be inactive when this type of user accesses the RMDB. But all other database functions are available for them. The general users don’t need to execute the sign-in process while accessing the database.

User Registration can only be accessed under the supervision of the RMDB manager level users. The information needed for a new user registration includes the name of the user, work phone number, E-mail address, unique username and password, as demonstrated in Figure 4.6.

The RMDB will show a message, “Successfully registered. Welcome to the RMDB!” on the message board after a successful registration, as demonstrated in Figure 4.7. The sign-in form is also demonstrated in Figure 4.8.

4.2.2 Data security

The database access control discussed above is one type of data security countermeasure. The RMDB also provides the users a data backup/restore function, as another type of data security countermeasure.

The data backup function allows the RMDB to copy all the data information into the backup space. By activating the Data Backup menu, the RMDB will remind the user that all the data in the database will be backed up into temporary files, and let the user make a choice: to continue or not. By pressing the “Yes” button, all the data will be transferred into those temporary files so that the database will be empty and a successful backup message will be given, as shown in Figure 4.9. The data backup functions can be used all the time along the database operations for securing the data. But the backup data in the temporary files will be replaced by the next backup operation. Only the last backup data can be restored. In that case, all the current data inside the RMDB will be replaced by the last backup data. Because this operation will delete all the current data, a warning message, as demonstrated in Figure 4.10, will give the user a choice of “yes” or “no” to continue the data restoration operation.

4.3 Data Entry

Most of the basic data manipulation functions, such as data entry/import, edit, and deletion, are incorporated under the Data Entry menu for each RMDB data table or entity.

The execution of those functions is performed through various command buttons on different database forms.

4.3.1 Soil data

Five command buttons (VIEW, NEW, EDIT, DELETE, QUIT), four record tracking buttons, and twenty five text boxes or combo boxes are presented on the main form of the soil data (Figure 4.11). The basic data manipulation functions are described in the following sections.

Entry of soil data A new entry of the soil data record can be executed using the following procedures:

1. Activate the soil data entry form.

   The soil data entry form (Figure 4.12) can be activated simply by clicking the NEW button on the main form of the soil data. Only two command buttons are shown on the form: SAVE, and BACK. The SAVE button is for submitting the new data entry, whereas the BACK button can lead to the original main entry form without saving the data.

2. Input the soil data information.

   Fill out all the text boxes and combo boxes for the soil data items. The item of sample ID must be filled out since it is the identification of the soil sample.

3. Submit the soil data entry.

   Submit the data entry by clicking the “SAVE” button on the entry form of the soil data.

Before the database can be updated, a message box will be displayed, as shown in Figure 4.13, to provide a chance for confirmation. If the “Yes” button is selected, then the record will be saved to the end of the soil data table in the database. Otherwise, the data entry will be discarded. Another message will be shown as in Figure 4.14, while saving an existing soil data record into RMDB. The data entry will be denied.

<u>Edit of soil data</u> The following procedures are used to edit the soil data:

1. Find the targeted data record for editing.

   Track and find the data record that is intended for editing, and show it on the main entry form of the soil data.

2. Activate the edit form.

   Pressing the EDIT button will lead the RMDB to the data edit form, which contains the same format as the data entry form as shown in Figure 4.12. But, the SAVE button is for submitting the updated data of an existing soil data record instead of a new data record.

3. Modify the data record.

   Modify the data items as needed. Note that the sample ID is not editable since it is the identification of the soil data record.

4. Submit the edited data record.

Submit the edited data record by clicking the “SAVE” button on the data edit form. Before the database is updated, a message will be displayed, as shown in Figure 4.15, to confirm the editing operation. A second message during the editing operation will be displayed when trying to edit a soil data record that doesn’t exist in the database (Figure 4.16).

<u>Deletion of soil data</u> The deletion operation only takes the following two steps:

1. Find the targeted data record for deletion.

   This is the same step as in the <u>Edit</u> operation.

2. Submit the deletion.

   By clicking the “DELETE” button, as illustrated in Figure 4.11, the current soil data record displayed on the form will be deleted. A message (see Figure 4.17) will be displayed to warn the user that the operation will delete not only the soil data, but also all the resilient modulus test data of the particular sample. The message allows the user to confirm the deletion operation.

View and tracking of soil data By clicking the “VIEW” button on the main form of the soil data, the current data record can be viewed in a two-dimensional tabular format, as shown in Figure 4.18. For tracking a data record, use the scroll bar of the data table to find the data record, and double click on it, or single click on it and then press the “BACK” button. The RMDB will pick up the selected data record and show it on the main form of the soil data for further editing or deletion operations.

Two other methods are available to track a soil data record:

1. Use the four record tracking buttons, “FIRST”, “PREVIOUS”, ”NEXT”, and “LAST”, as demonstrated in Figure 4.11.
2. Input a sample ID into the Sample ID textbox on the main form of the soil data.

   When a sample ID in the textbox is being activated, the database will search for this particular sample ID, and display the data information. A message box will be shown if tracking a data record that doesn’t exist in the database (Figure 4.19).

4.3.2 Resilient modulus test data

The tabular form of the soil resilient modulus test data is demonstrated in Figure 4.20. Four types of control are shown on the form: command buttons, test identification items, test condition data items, and data grid.

The nine command buttons are exactly the same as those shown on the main form of the soil data in Figure 4.11. The red-labeled data items, such as Sample ID, Test Procedure, Sample Size, Compaction Type, and Lab No., are for the soil test identification. The data grid on the form can display the resilient modulus test data of the current soil data record in a two-dimensional tabular format. The grid will be replaced with a new set of test data when a new soil data record is selected.

<u>Entry of test data</u> Only the samples that have already been stored in the soil data table can be selected and entered as resilient modulus test data. The following procedures are required to enter a resilient modulus test data:

1. Activate the entry form.

   The main entry form of the soil resilient modulus test data (Figure 4.21) can be seen by clicking the "NEW" button on the tabular form of the resilient modulus test data.

2. Input the test condition data.

   Fill out the items of the test condition data on the main entry form of the test data. The red-labeled data items must be filled out since they are the components of the soil resilient modulus test identification.

3. Obtain the full-path name of the resilient modulus test data file.

   Obtain the full path name of the resilient modulus test data file in Microsoft (MS) Excel format with the help of a common dialogue box (Figure 4.22), and display it in the textbox as demonstrated in Figure 4.23. The RMDB can track an Excel test data file by its full path name, and import all the test data of the file to the database programmatically.

4. Submit the test data entry.

   By clicking the “SUBMIT” button on the main entry form, an intermediate entry form will display all the input data, as demonstrated in Figure 4.24.

5. Save the test data entry.

   By pressing the “SAVE” button on the intermediate entry form, the test data entry will be saved in the database, and the resilient modulus test data will be displayed in tabular format (Figure 4.20). A message will be shown to indicate that the test data entry has been successfully saved (Figure 4.25).

Edit of test data The following procedures are used to edit the test data:

1. Find the targeted data record for editing.

   Track and find the test data file that is intended for editing, and show it on a tabular format.

2. Activate the edit form.

   Pressing the “EDIT” button on the tabular form will switch the interface to the editing format, which is exactly the same as the main entry form of the resilient modulus test data, as demonstrated in Figure 4.21.

3. Modify the test data or the data source file.

   Modify the data items or the data source file as needed. Note that the red-labeled items cannot be edited. The test data can be replaced by following the same procedures as in the test data entry.

4. Submit the edited test data (file).

   Submit the edited test data (file) by pressing the “SAVE” button. The RMDB will show a message, “Do you want to continue?” If the answer is “Yes”, then the database will be updated by the edited test data. If not, the edited test data (file) will be discarded.

Deletion of test data The following steps are used to delete a record of resilient modulus test data:

1. Find the targeted data record for deletion.

   Track and find the test data that is intended for deletion, and show it on the tabular form.

2. Submit the data record for deletion.

   By clicking the “DELETE” button on the tabular form of the resilient modulus test data, the RMDB will show a message (Figure 4.26), and ask the user to confirm the deletion operation. The test data record will be deleted from the database if the selection is “Yes”, or the data will be kept if “No” is selected.

The test data record can be viewed and tracked in the same way as discussed previously for the soil data table. The view of the test data table is demonstrated in Figure 4.27.

4.4 Data Query

The data query and data report are incorporated into the Data Query menu. The query objects include the soil data/sample information and the resilient modulus test data.

As demonstrated in Figure 4.28, the main form of the data query contains nine query constraints, such as roadway, roadway ID, district, county, milepost, test date, sample size, soil classification, and test method.

Each constraint also includes a certain number of choices. The constraint items can be selected individually or jointly for the data query. The selected constraints will control the outcome of the data query. If no constraint is specified, the query outcomes will include all the data records in the RMDB.

The query results can be reported in units of either metric or customary system. The default is the metric units system.

4.4.1 Procedures of query operation

The following procedures are used to execute a data query:

1. Select query constraints

   Select the query constraint items to obtain the desired query results. Fill out the selected constraint items with proper input data information on the main form of the data query (Figure 4.28).

2. Process query request

   Execute the query request by clicking the "Search" button on the main form of the data query (Figure 4.28). The search will result in selecting a set of sample IDs in the combo box, and listing all the associated resilient modulus test data of those samples in a tabular grid form (Figure 4.29). A summary table can be printed in an MS Excel file format by clicking the

"Output" button. A sample summary table is presented in Table 4.1 for illustration.

4.4.2 Report of query results

If a report is needed for an individual resilient modulus test in the summary table from the query operation, then the following procedures are used to present a summary report of the test results:

1. Find the desired test number.

   By clicking on a sample ID in the combo box of the summary table (Figure 4.29), a list box will be activated to display the test numbers related to the sample. One sample may have more than one test number. The desired test number can also be obtained by entering a sample ID in the designated sample ID textbox on the form of the summary table (Figure 4.29). Then the corresponding test numbers will be shown according to the sample ID.

2. Retrieve the test result data.

   Choose one test number by clicking it on the list box. A summary table of the individual soil test results will be displayed, as demonstrated in Figure 4.30.

3. Report the query results.

   By clicking the "Output" button on the summary table of the individual test results (Figure 4.30), all the information concerning the individual test results will be transferred to an MS Excel workbook. The output report will include a summary table of the resilient modulus test results (illustrated in Table 4.2), and two plots of the graphic presentation of the test results: resilient modulus versus confining pressure (Figure 4.31), and resilient modulus versus bulk stress (Figure 4.32).

4.5 Data Analysis

The data analysis is organized into two parts: the regular analysis, which relates to the effect of the state of stresses on resilient modulus test results during a test, and the comparative analysis, which relates to the effect of different test procedures or LVDT positions on resilient modulus test results. The comparative analysis is presented in Chapter 5. The regular data analysis is presented in the following sections.

4.5.1 Regular analysis

The regular data analysis consists of the following three conditions:

(1) MR vs. Bulk Stress

(2) MR vs. Confining Pressure

(3) MR vs. Confining Pressure plus Deviator Stress

These submenus have been illustrated in Figure 4.5. Each resilient modulus test in the database may be analyzed to produce three different regression equations in terms of the bulk stress, confining pressure, and confining pressure plus deviator stress.

4.5.2 Analysis procedures

The following steps are used to carry out a regular data analysis:

1. Execute the analysis operation.

   By clicking the submenu of a regular analysis, the analysis operation will be executed. The regression parameters of the resilient modulus tests will be exhibited in a tabular format as demonstrated in Figure 4.33, Figure 4.34, and Figure 4.35, for the MR versus bulk stress, MR versus confining pressure, and MR versus confining pressure plus deviator stress, respectively.

2. Report the analyzed results.

   The analyzed results can be reported in the following format:

   a. Report the results of all the regression parameters in a single file.

      By clicking the “Report” button on the summary table of the analyzed results, the regression equation parameters of all the tests will be printed out in a single spreadsheet, as demonstrated in Table 4.5.

b. Print out the results of an individual test.

By clicking the “Search” button, the advanced search option will be activated to search for the desired sample ID and test number. The corresponding results will be reported graphically as displayed in Figure 4.31 and Figure 4.32, for the test.

Table 4.1 A sample summary table of test results from query operation

Test No	Conf. Pres. (KPa)	Axial Load (KN)	Dev. Stress (KPa)	Bulk Stress (KPa)	Middle strain	Total Strain	Mid MR (MPa)	Full MR (MPa)
2000DRZZT292-91I4	103.42	0.375	46.260	356.52	0.00015	0.00016	314.213	281.412
	103.42	0.543	66.950	377.20	0.00021	0.00024	316.557	281.457
	103.42	0.824	101.590	411.85	0.00031	0.00036	327.591	285.205
	68.95	0.264	32.590	239.44	0.00012	0.00014	264.275	226.761
	68.95	0.378	46.600	253.45	0.00018	0.00021	262.102	222.900
	68.95	0.544	67.070	273.92	0.00026	0.00030	263.526	223.940
	68.95	0.825	101.740	308.59	0.00036	0.00043	282.020	235.391
	34.47	0.153	18.830	122.24	0.00009	0.00012	200.672	158.432
	34.47	0.265	32.700	136.11	0.00017	0.00021	195.844	156.122
	34.47	0.377	46.560	149.97	0.00024	0.00030	196.665	156.612
	34.47	0.545	67.230	170.64	0.00033	0.00042	205.277	162.289
	13.79	0.152	18.760	60.13	0.00013	0.00018	141.981	106.055
	13.79	0.264	32.550	73.92	0.00023	0.00031	142.952	107.962
	13.79	0.376	46.360	87.73	0.00030	0.00041	154.298	114.313
2000PZZT292-91I4	103.42	0.374	46.190	356.45	0.00015	0.00017	309.947	268.139
	103.42	0.541	66.780	377.04	0.00022	0.00025	308.805	268.941
	103.42	0.821	101.290	411.55	0.00032	0.00037	314.284	271.289
	68.95	0.264	32.520	239.37	0.00013	0.00015	255.415	219.239
	68.95	0.375	46.280	253.13	0.00018	0.00022	251.025	214.628
	68.95	0.544	67.150	274.00	0.00027	0.00031	251.407	216.491
	68.95	0.823	101.520	308.36	0.00038	0.00045	264.618	225.861
	34.47	0.151	18.680	122.09	0.00010	0.00012	189.427	155.538
	34.47	0.264	32.600	136.01	0.00018	0.00021	186.080	153.758
	34.47	0.377	46.450	149.86	0.00025	0.00030	186.222	154.549
	34.47	0.544	67.120	170.53	0.00035	0.00042	194.536	161.034
	13.79	0.152	18.730	60.10	0.00014	0.00018	132.419	101.678
	13.79	0.264	32.550	73.92	0.00024	0.00031	135.074	105.416
	13.79	0.376	46.380	87.75	0.00032	0.00041	146.167	113.138

Table 4.2 Report of test results of an individual test

Material No:				Sample No:	2A-1ASS	Date Sampled:	
Sample By:		STA From:		STA To:		SAMP From:	
RDWay Side:						Mainline:	FALSE
Plant/Pit No:		Quant. Rep:		Lab No.		RDway No:	U.S.17
Reference Line:							
Intended Use:							
RDWay ID:		Dist. No:	1	County :	Polk	Layer:	Embankment
Material Desc.:							
Test No:	2A-1ASST292-91I4	Classification		Sample size	4.0	(Inch)	
Test Method:	T292-91I	AASHTO:	A-2-4	OMC (%)		DUW	
Test Date:	34975.000	Unified:		Test OMC (%)	10.10	Test DUW	18.32 (KN/m3)
Compaction Type:							

Confining Pressure (KPa)	Axial Load (KN)	Dev. Stress (KPa)	Bulk Stress (KPa)	Middle Strain	Full Strain	Mid MR (MPa)	Full MR (MPa)
103.42	0.377	46.560	356.818	0.00015	0.00017	308.798	271.785
103.42	0.542	66.900	377.162	0.00022	0.00025	302.897	272.069
103.42	0.824	101.680	411.936	0.00034	0.00037	302.602	271.468
68.95	0.264	32.620	239.468	0.00013	0.00015	246.129	213.282
68.95	0.376	46.430	253.282	0.00019	0.00022	240.610	207.797
68.95	0.544	67.110	273.962	0.00028	0.00032	241.595	209.707
68.95	0.824	101.700	308.547	0.00041	0.00047	248.970	217.833
34.47	0.152	18.740	122.153	0.00010	0.00013	186.037	149.002
34.47	0.264	32.530	135.936	0.00018	0.00022	176.177	145.466
34.47	0.376	46.420	149.827	0.00026	0.00032	175.362	146.169
34.47	0.545	67.200	170.606	0.00037	0.00044	183.070	152.133
13.79	0.152	18.750	60.118	0.00015	0.00019	125.627	99.090
13.79	0.265	32.630	73.996	0.00025	0.00032	128.109	102.106
13.79	0.376	46.390	87.763	0.00034	0.00043	135.334	107.902

Table 4.3 Summary report
of regression parameters from the data analysis

Test Record No.	k1	k2	r 2
200DRZZT292-91I4	20.242	0.462	0.98
200DRZZT292-91I4	9.982	0.559	1.00
200OPZZT292-91I4	17.763	0.478	0.98
200OPZZT292-91I4	10.422	0.545	1.00
200SAZZT292-91I4	19.318	0.469	0.99
200SAZZT292-91I4	9.257	0.569	1.00
30ADRZZT292-91I4	40.582	0.341	0.87
30ADRZZT292-91I4	18.438	0.455	0.90
30AOPZZT292-91I4	21.008	0.441	0.95
30AOPZZT292-91I4	13.537	0.496	1.00
30ASAZZT292-91I4	9.084	0.520	0.96
30ASAZZT292-91I4	7.667	0.537	1.00
369DRZZT292-91I4	17.505	0.483	0.95
369DRZZT292-91I4	6.324	0.607	1.00
369OPZZT292-91I4	13.421	0.518	0.99
369OPZZT292-91I4	4.721	0.633	1.00
50DRZZT292-91I4	22.312	0.451	0.97
50DRZZT292-91I4	8.091	0.601	1.00
50OPTZZT292-91I4	22.307	0.456	0.98
50OPTZZT292-91I4	9.480	0.567	1.00
I75DRZZT292-91I4	68.731	0.301	0.67
I75DRZZT292-91I4	16.105	0.503	0.90
I75OPZZT292-91I4	31.937	0.417	0.89
I75OPZZT292-91I4	15.909	0.502	0.90
I75SOZZT292-91I4	12.486	0.531	0.95
I75SOZZT292-91I4	6.158	0.627	1.00
A2412%D1T292-91I4	19.432	0.456	0.97
A2412%D1T292-91I4	7.042	0.607	1.00
A2412%D2T292-91I4	15.145	0.516	0.99

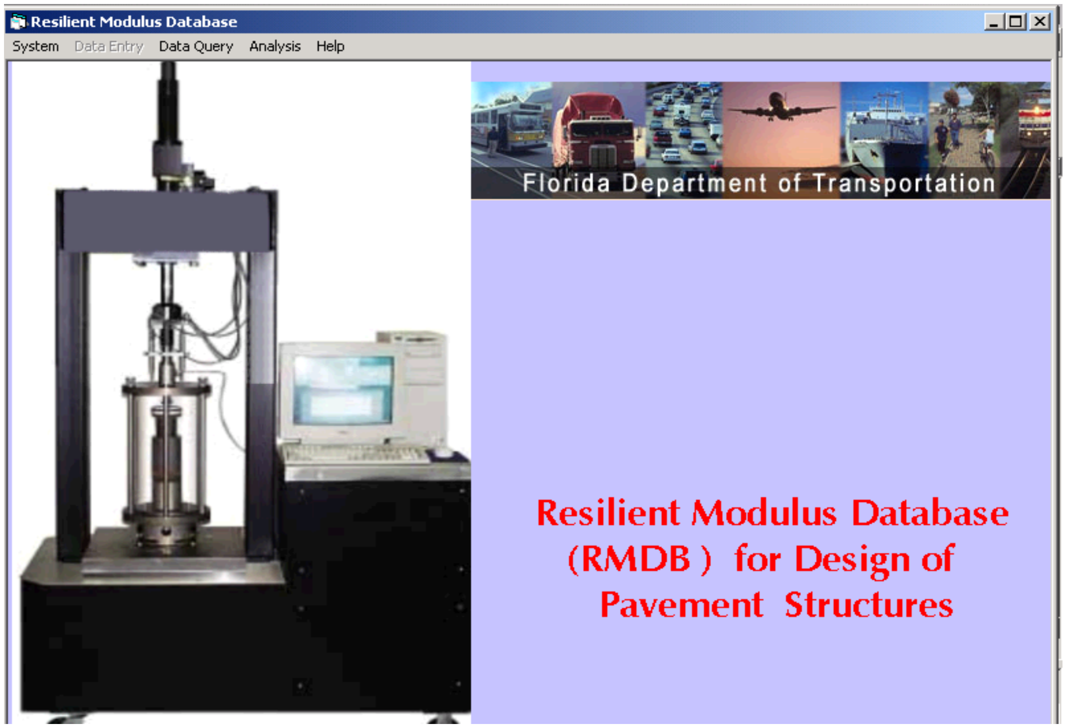


Figure 4.1 Main form of the resilient modulus database

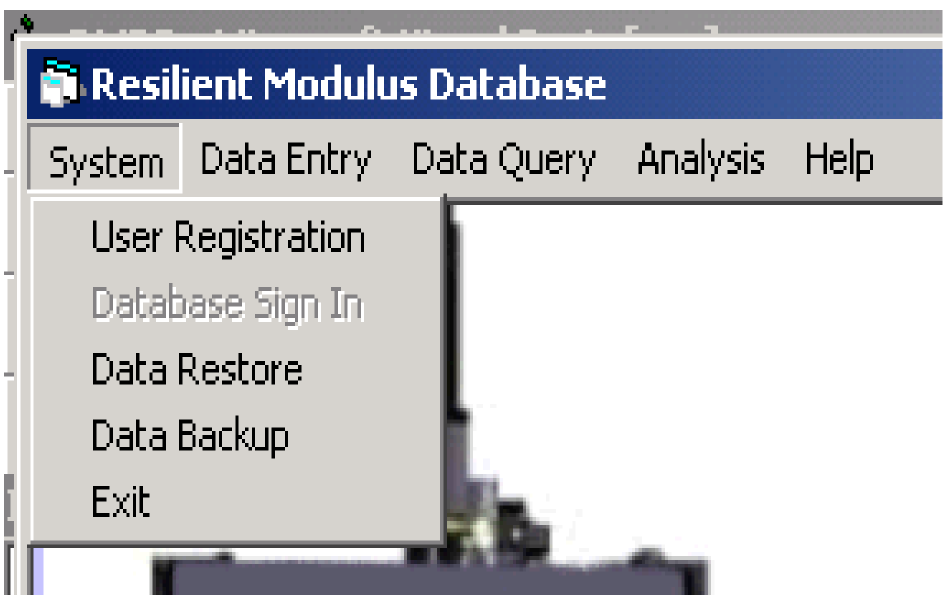


Figure 4.2 Main menu item: System

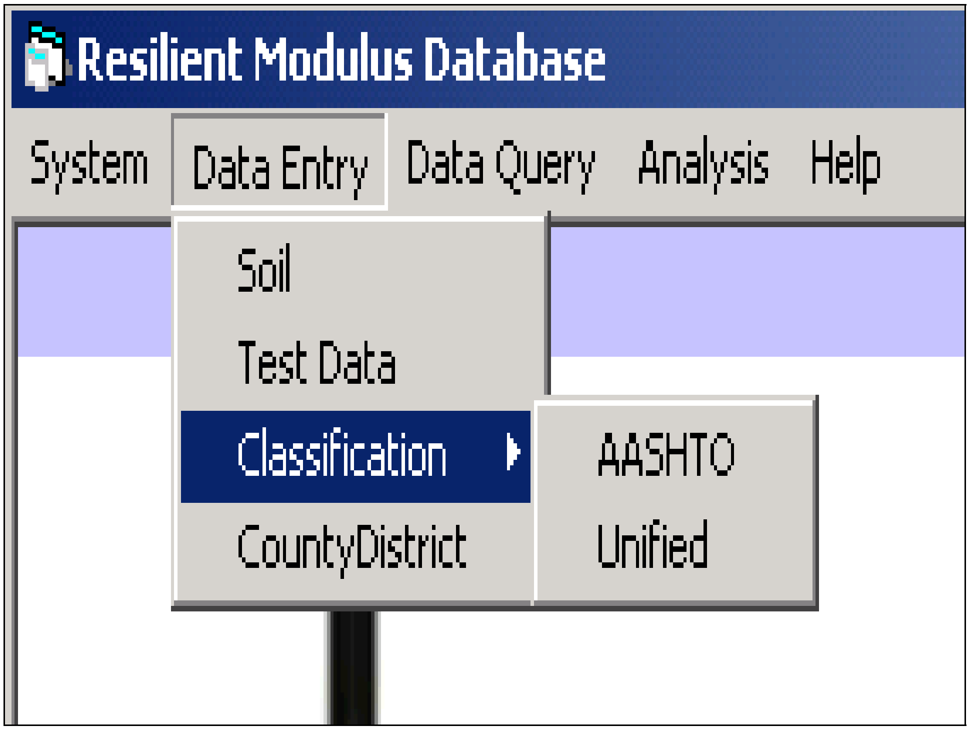


Figure 4.3 Main menu item: <u>Data Entry</u>

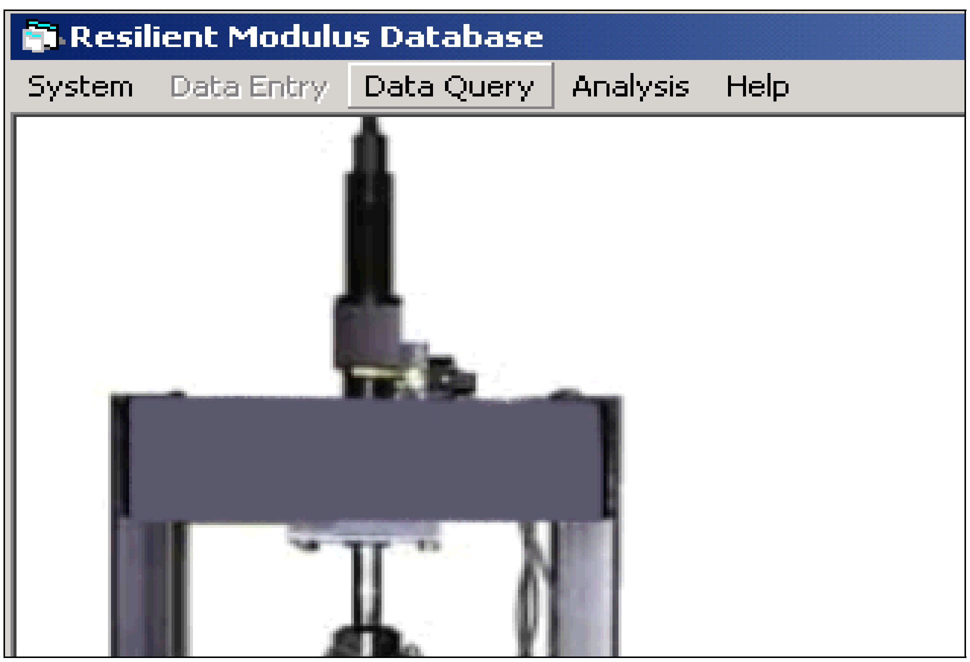


Figure 4.4 Main menu item: <u>Data Query</u>

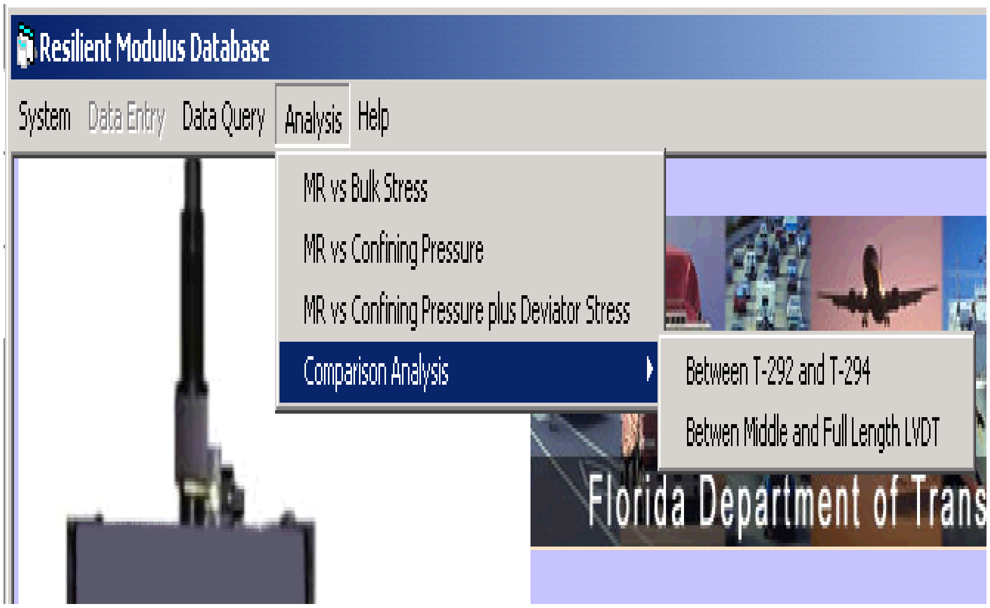


Figure 4.5 Main menu item: <u>Analysis</u>

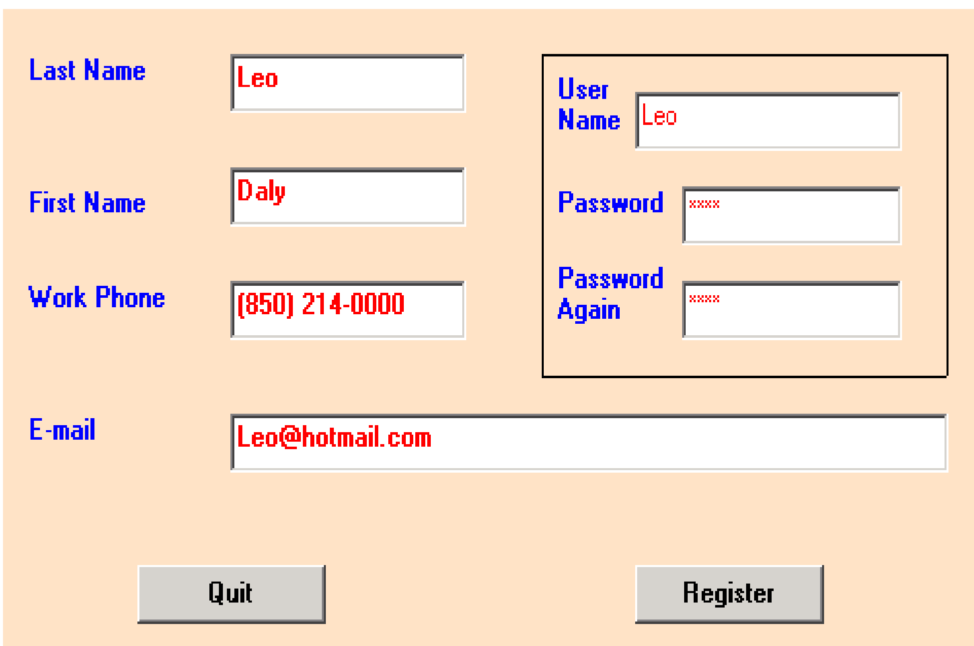


Figure 4.6 User registration form

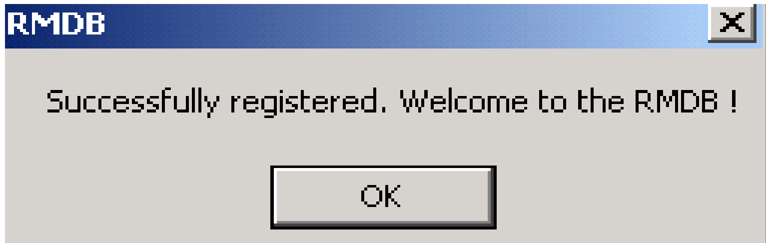


Figure 4.7 Message after a successful registration

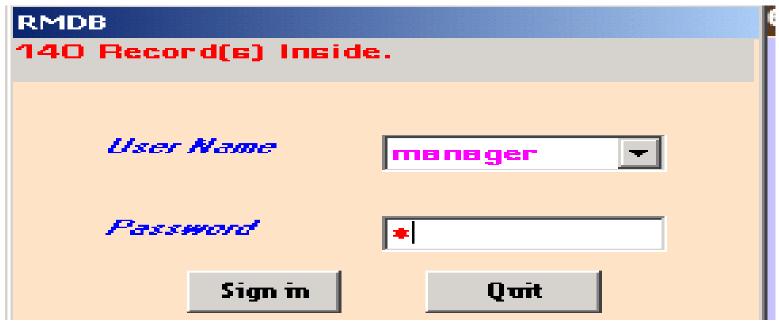
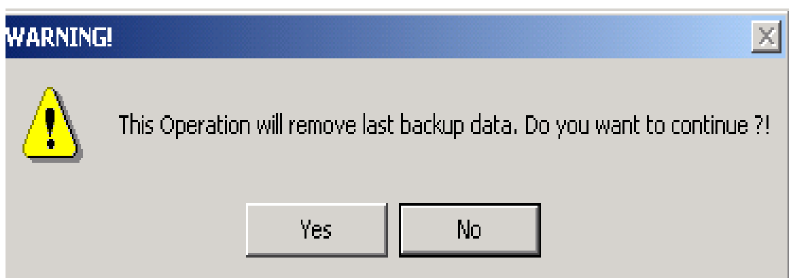


Figure 4.8 Sign-in form



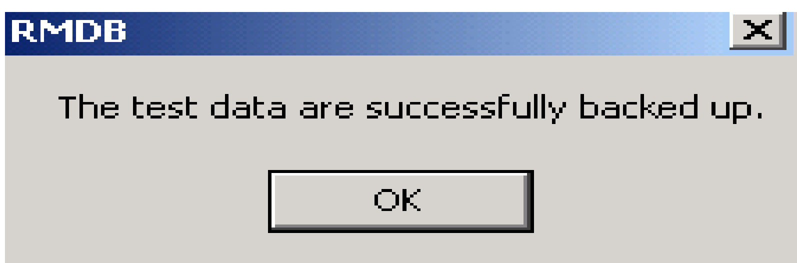


Figure 4.9 Messages in the Data Backup

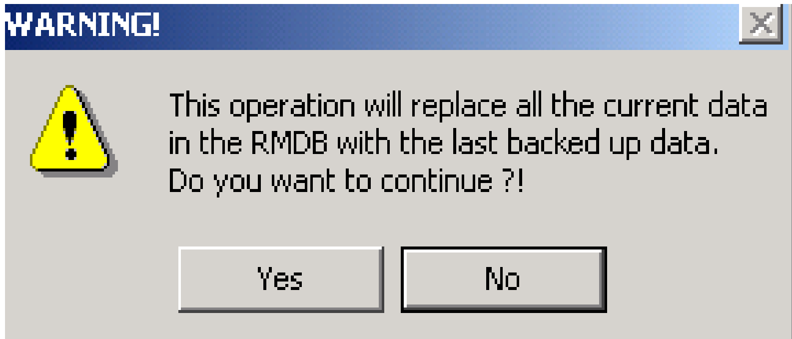


Figure 4.10 Messages in the Data Restoration

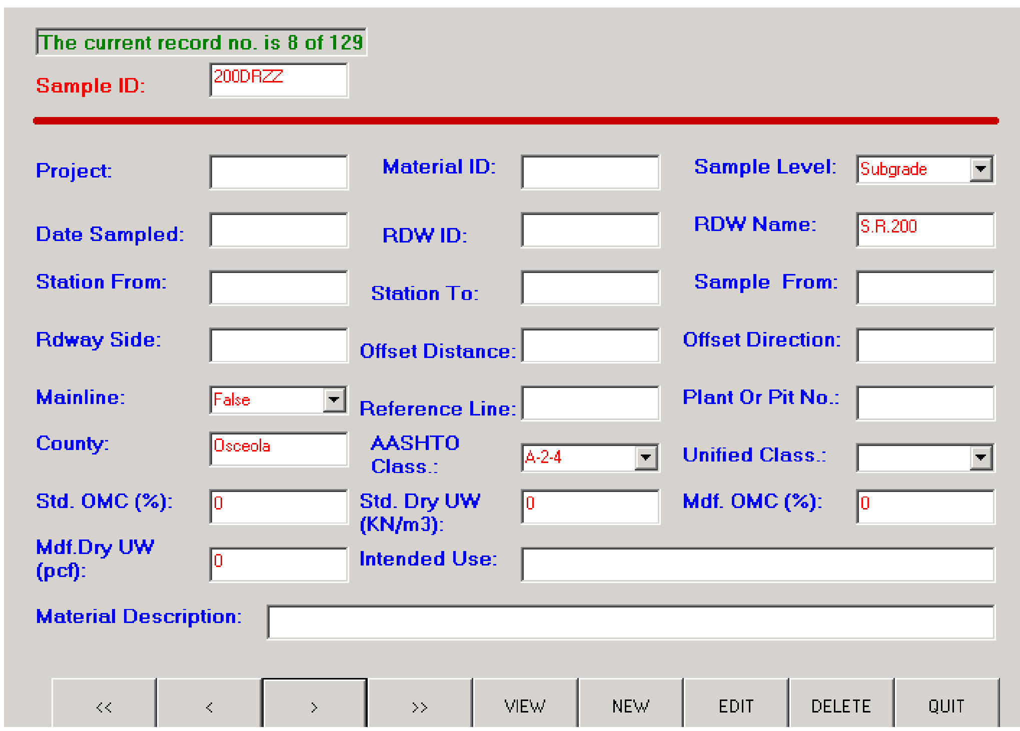


Figure 4.11 Main form of the soil data

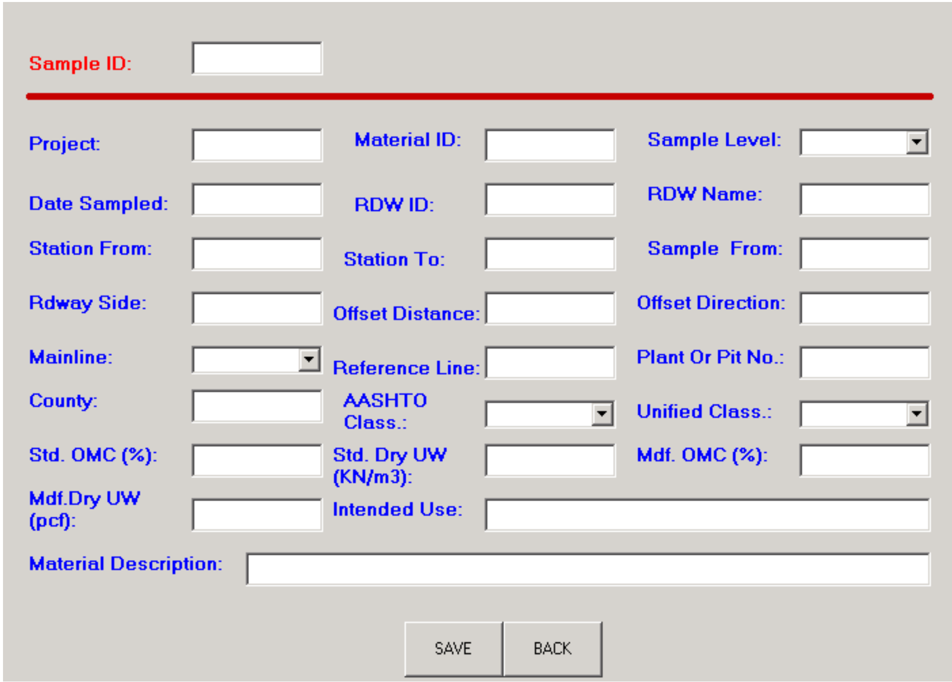


Figure 4.12 Entry form of the soil data

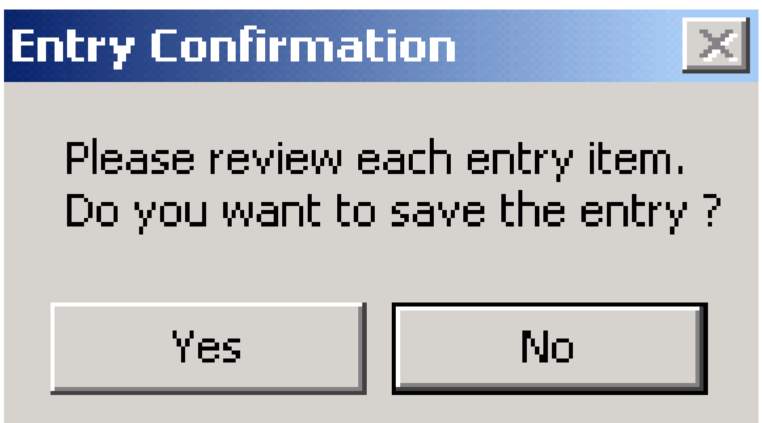


Figure 4.13 Message of confirmation
for the soil data entry

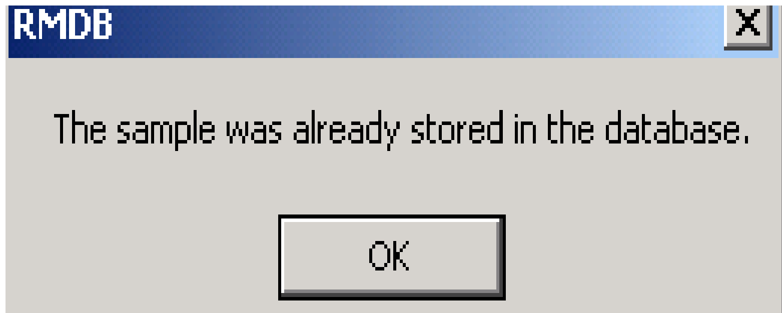


Figure 4.14 Message while saving an existing soil record

Figure 4.15 Message of confirmation for editing soil data

Figure 4.16 Message while editing a nonexisting soil record

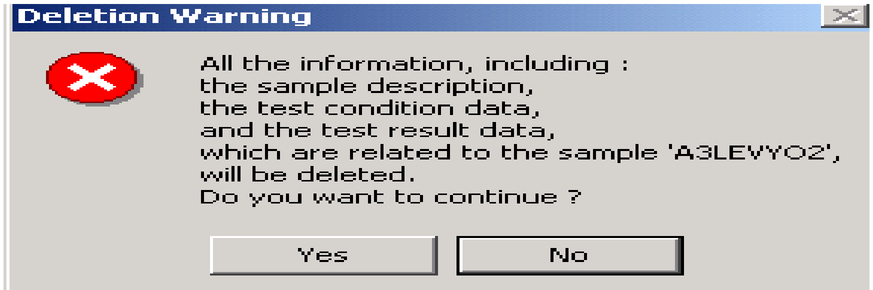
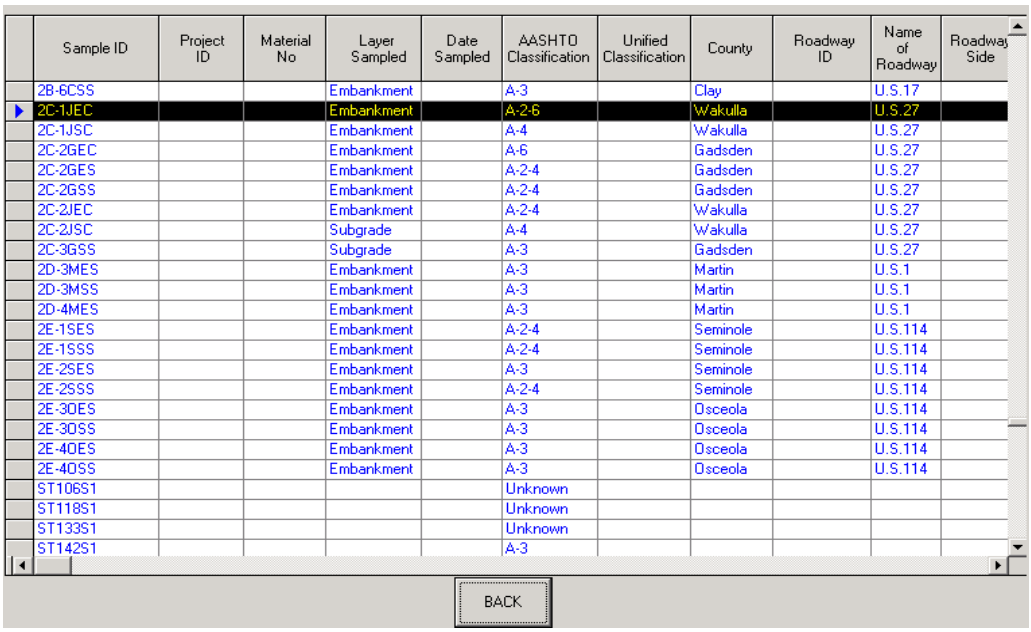


Figure 4.17 Message of confirmation
for deleting a soil data

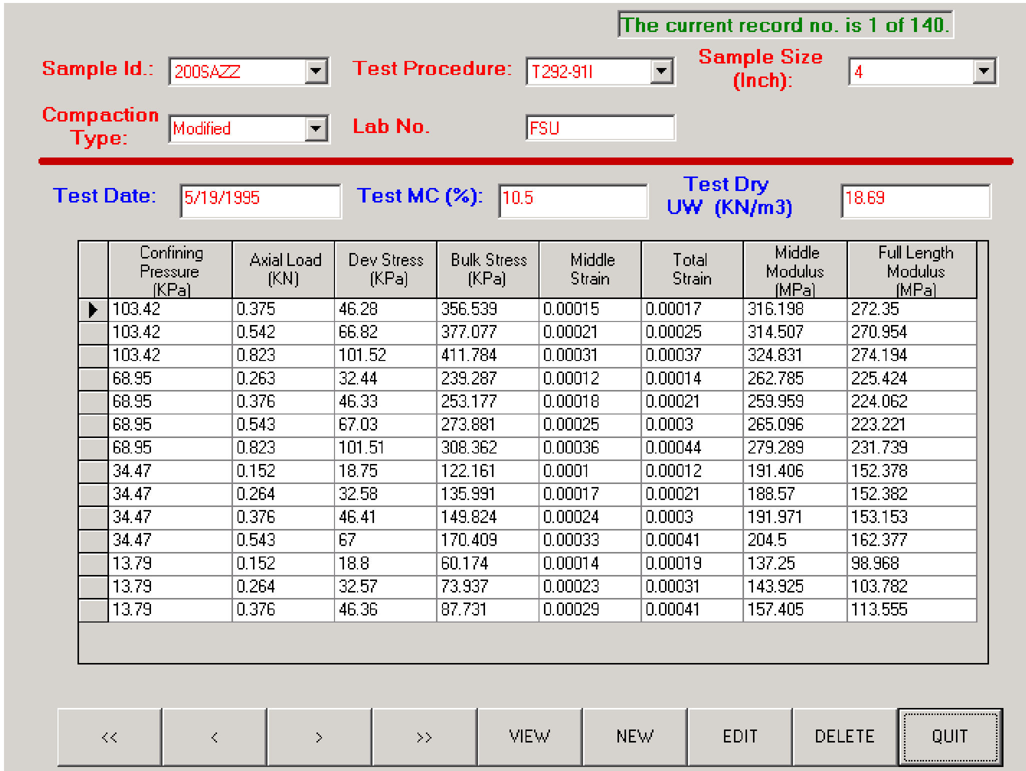


Sample ID	Project ID	Material No	Layer Sampled	Date Sampled	AASHTO Classification	Unified Classification	County	Roadway ID	Name of Roadway	Roadway Side
2B-6CSS			Embankment		A-3		Clay		U.S.17	
2C-1JEC			Embankment		A-2-6		Wakulla		U.S.27	
2C-1JSC			Embankment		A-4		Wakulla		U.S.27	
2C-2GEC			Embankment		A-6		Gadsden		U.S.27	
2C-2GES			Embankment		A-2-4		Gadsden		U.S.27	
2C-2GSS			Embankment		A-2-4		Gadsden		U.S.27	
2C-2JEC			Embankment		A-2-4		Wakulla		U.S.27	
2C-2JSC			Subgrade		A-4		Wakulla		U.S.27	
2C-3GSS			Subgrade		A-3		Gadsden		U.S.27	
2D-3MES			Embankment		A-3		Martin		U.S.1	
2D-3MSS			Embankment		A-3		Martin		U.S.1	
2D-4MES			Embankment		A-3		Martin		U.S.1	
2E-1SES			Embankment		A-2-4		Seminole		U.S.114	
2E-1SSS			Embankment		A-2-4		Seminole		U.S.114	
2E-2SES			Embankment		A-3		Seminole		U.S.114	
2E-2SSS			Embankment		A-2-4		Seminole		U.S.114	
2E-3OES			Embankment		A-3		Osceola		U.S.114	
2E-3OSS			Embankment		A-3		Osceola		U.S.114	
2E-4OES			Embankment		A-3		Osceola		U.S.114	
2E-4OSS			Embankment		A-3		Osceola		U.S.114	
ST106S1					Unknown					
ST118S1					Unknown					
ST133S1					Unknown					
ST142S1					A-3					

BACK

Figure 4.18 View the form of the soil data table

Figure 4.19 Message while tracking a nonexisting
soil record



Confining Pressure (KPa)	Axial Load (KN)	Dev Stress (KPa)	Bulk Stress (KPa)	Middle Strain	Total Strain	Middle Modulus (MPa)	Full Length Modulus (MPa)
103.42	0.375	46.28	356.539	0.00015	0.00017	316.198	272.35
103.42	0.542	66.82	377.077	0.00021	0.00025	314.507	270.954
103.42	0.823	101.52	411.784	0.00031	0.00037	324.831	274.194
68.95	0.263	32.44	239.287	0.00012	0.00014	262.785	225.424
68.95	0.376	46.33	253.177	0.00018	0.00021	259.959	224.062
68.95	0.543	67.03	273.881	0.00025	0.0003	265.096	223.221
68.95	0.823	101.51	308.362	0.00036	0.00044	279.289	231.739
34.47	0.152	18.75	122.161	0.0001	0.00012	191.406	152.378
34.47	0.264	32.58	135.991	0.00017	0.00021	188.57	152.382
34.47	0.376	46.41	149.824	0.00024	0.0003	191.971	153.153
34.47	0.543	67	170.409	0.00033	0.00041	204.5	162.377
13.79	0.152	18.8	60.174	0.00014	0.00019	137.25	98.968
13.79	0.264	32.57	73.937	0.00023	0.00031	143.925	103.782
13.79	0.376	46.36	87.731	0.00029	0.00041	157.405	113.555

Figure 4.20 Tabular form of resilient modulus test data

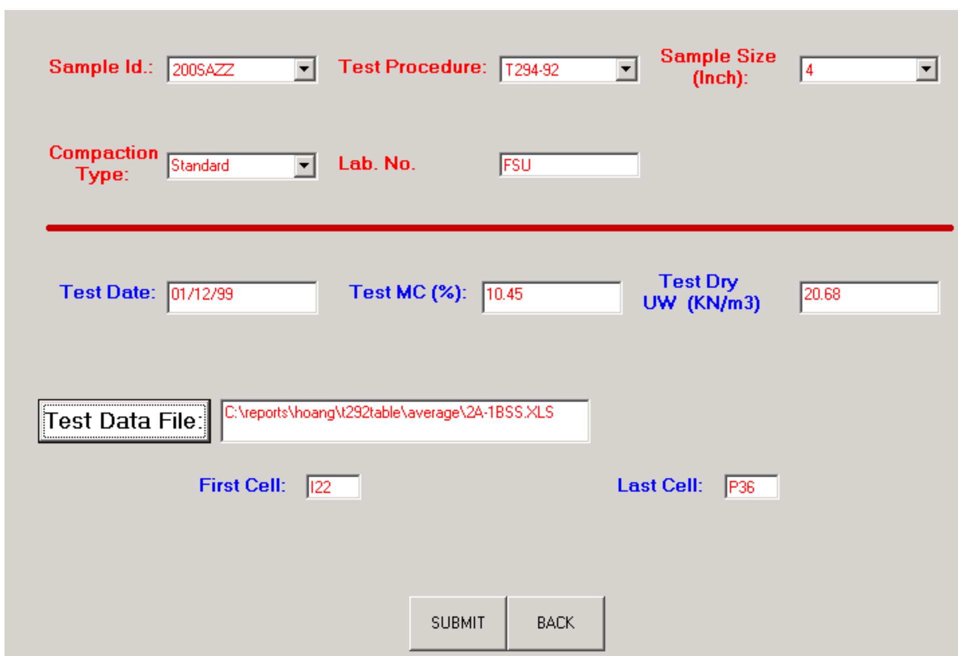


Figure 4.21 Main entry form of resilient modulus test data

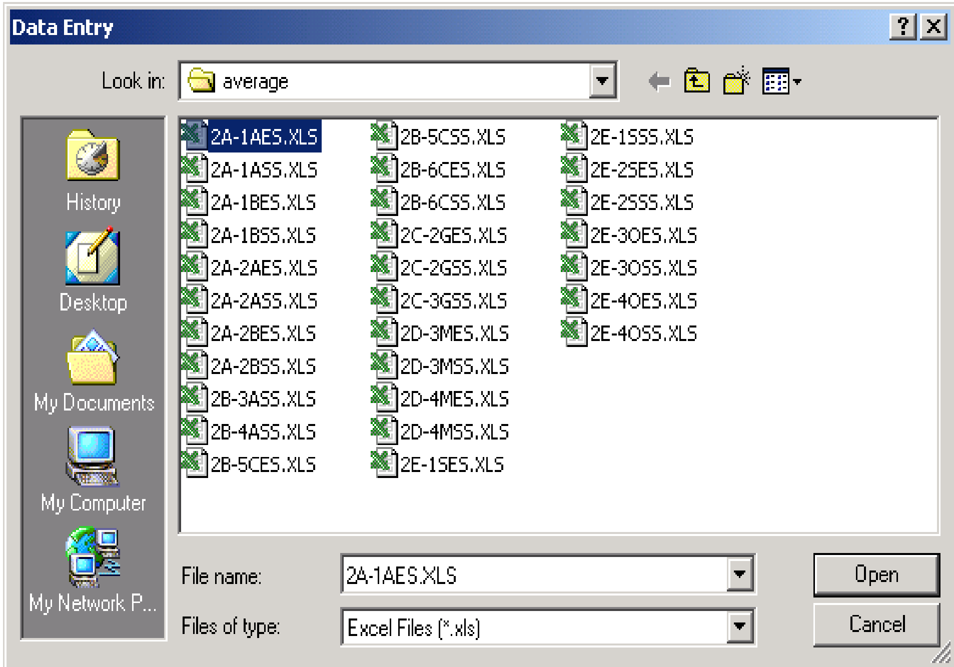


Figure 4.22 Common dialogue box for data file selection

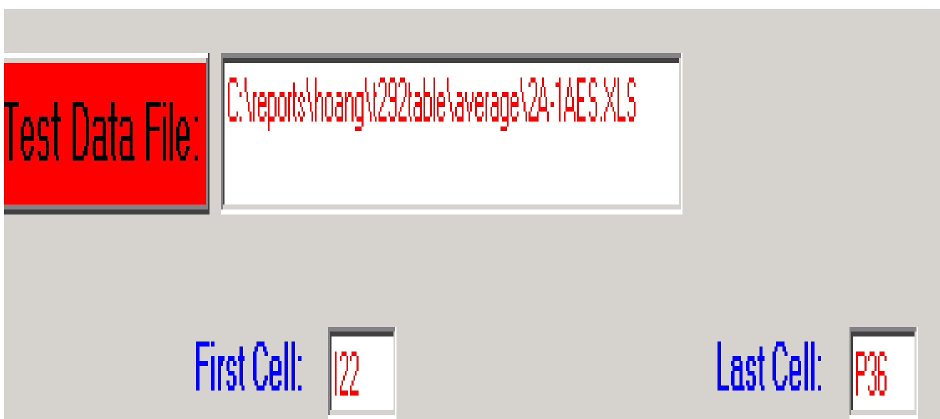
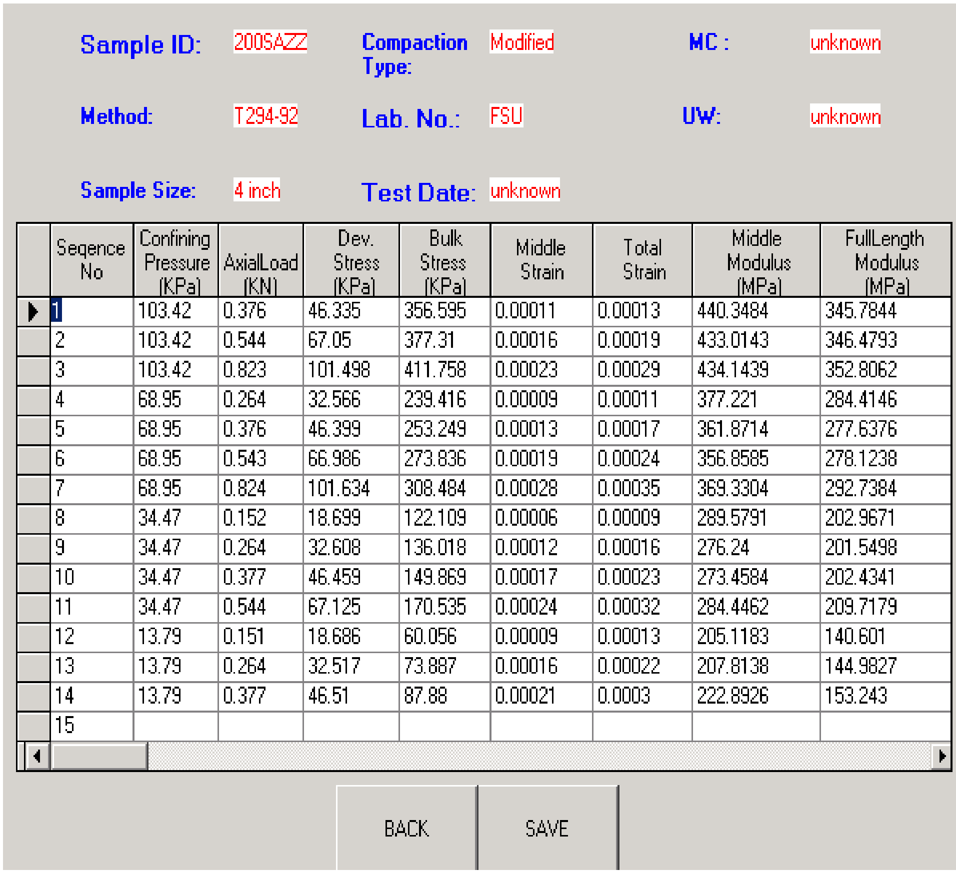


Figure 4.23 Full path name of a resilient modulus test data file in MS Excel format



Seqence No	Confining Pressure (KPa)	AxialLoad (KN)	Dev. Stress (KPa)	Bulk Stress (KPa)	Middle Strain	Total Strain	Middle Modulus (MPa)	FullLength Modulus (MPa)
1	103.42	0.376	46.335	356.595	0.00011	0.00013	440.3484	345.7844
2	103.42	0.544	67.05	377.31	0.00016	0.00019	433.0143	346.4793
3	103.42	0.823	101.498	411.758	0.00023	0.00029	434.1439	352.8062
4	68.95	0.264	32.566	239.416	0.00009	0.00011	377.221	284.4146
5	68.95	0.376	46.399	253.249	0.00013	0.00017	361.8714	277.6376
6	68.95	0.543	66.986	273.836	0.00019	0.00024	356.8585	278.1238
7	68.95	0.824	101.634	308.484	0.00028	0.00035	369.3304	292.7384
8	34.47	0.152	18.699	122.109	0.00006	0.00009	289.5791	202.9671
9	34.47	0.264	32.608	136.018	0.00012	0.00016	276.24	201.5498
10	34.47	0.377	46.459	149.869	0.00017	0.00023	273.4584	202.4341
11	34.47	0.544	67.125	170.535	0.00024	0.00032	284.4462	209.7179
12	13.79	0.151	18.686	60.056	0.00009	0.00013	205.1183	140.601
13	13.79	0.264	32.517	73.887	0.00016	0.00022	207.8138	144.9827
14	13.79	0.377	46.51	87.88	0.00021	0.0003	222.8926	153.243
15								

Figure 4.24 Intermediate entry form of resilient modulus test data

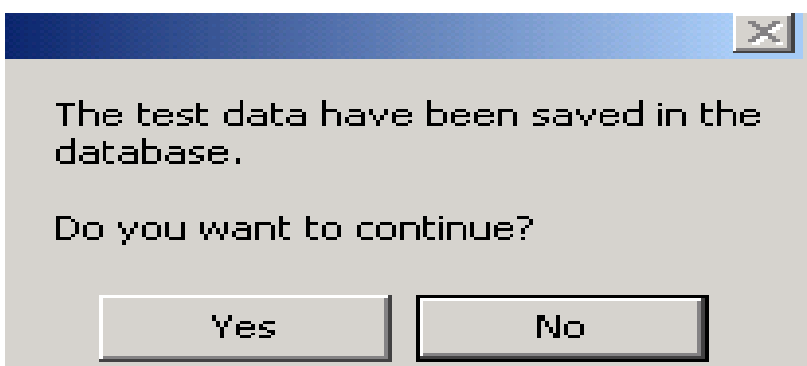


Figure 4.25 Message shown after an entry of test data

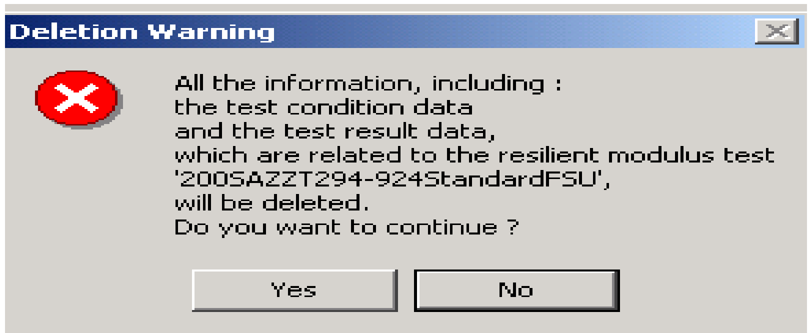
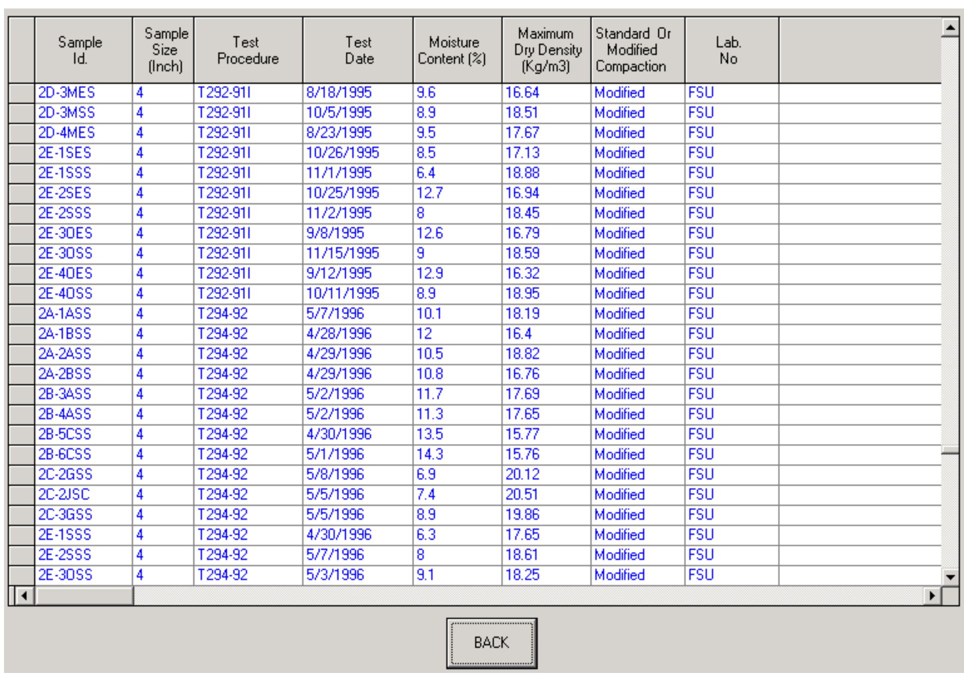


Figure 4.26 Message shown for test data deletion



Sample Id.	Sample Size (Inch)	Test Procedure	Test Date	Moisture Content (%)	Maximum Dry Density (Kg/m3)	Standard Or Modified Compaction	Lab. No
2D-3MES	4	T292-91I	8/18/1995	9.6	16.64	Modified	FSU
2D-3MSS	4	T292-91I	10/5/1995	8.9	18.51	Modified	FSU
2D-4MES	4	T292-91I	8/23/1995	9.5	17.67	Modified	FSU
2E-1SES	4	T292-91I	10/26/1995	8.5	17.13	Modified	FSU
2E-1SSS	4	T292-91I	11/1/1995	6.4	18.88	Modified	FSU
2E-2SES	4	T292-91I	10/25/1995	12.7	16.94	Modified	FSU
2E-2SSS	4	T292-91I	11/2/1995	8	18.45	Modified	FSU
2E-3OES	4	T292-91I	9/8/1995	12.6	16.79	Modified	FSU
2E-3OSS	4	T292-91I	11/15/1995	9	18.59	Modified	FSU
2E-4OES	4	T292-91I	9/12/1995	12.9	16.32	Modified	FSU
2E-4OSS	4	T292-91I	10/11/1995	8.9	18.95	Modified	FSU
2A-1ASS	4	T294-92	5/7/1996	10.1	18.19	Modified	FSU
2A-1BSS	4	T294-92	4/28/1996	12	16.4	Modified	FSU
2A-2ASS	4	T294-92	4/29/1996	10.5	18.82	Modified	FSU
2A-2BSS	4	T294-92	4/29/1996	10.8	16.76	Modified	FSU
2B-3ASS	4	T294-92	5/2/1996	11.7	17.69	Modified	FSU
2B-4ASS	4	T294-92	5/2/1996	11.3	17.65	Modified	FSU
2B-5CSS	4	T294-92	4/30/1996	13.5	15.77	Modified	FSU
2B-6CSS	4	T294-92	5/1/1996	14.3	15.76	Modified	FSU
2C-2GSS	4	T294-92	5/8/1996	6.9	20.12	Modified	FSU
2C-2JSC	4	T294-92	5/5/1996	7.4	20.51	Modified	FSU
2C-3GSS	4	T294-92	5/5/1996	8.9	19.86	Modified	FSU
2E-1SSS	4	T294-92	4/30/1996	6.3	17.65	Modified	FSU
2E-2SSS	4	T294-92	5/7/1996	8	18.61	Modified	FSU
2E-3OSS	4	T294-92	5/3/1996	9.1	18.25	Modified	FSU

Figure 4.27 View of the test data table

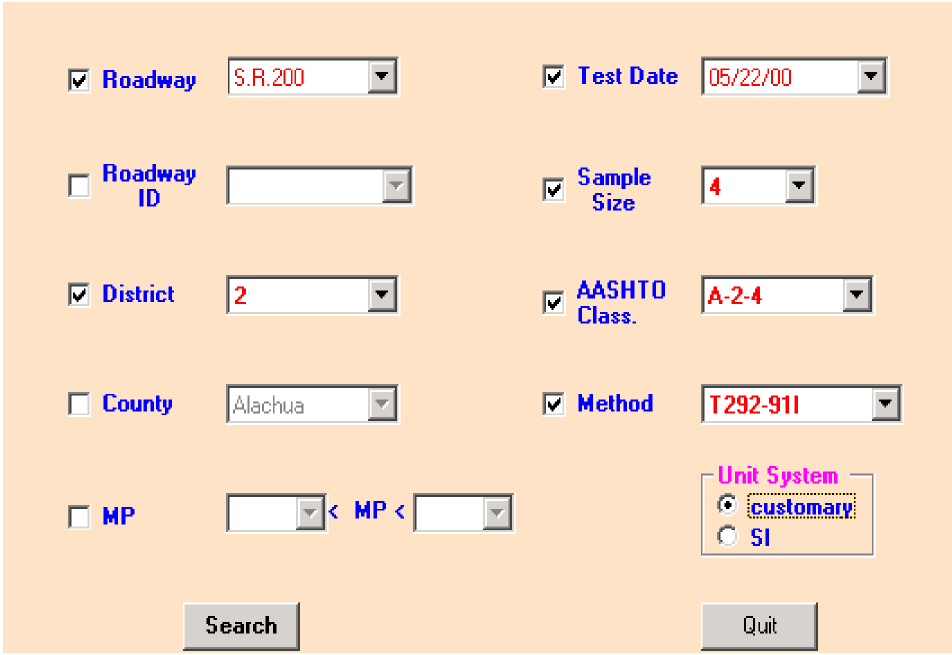
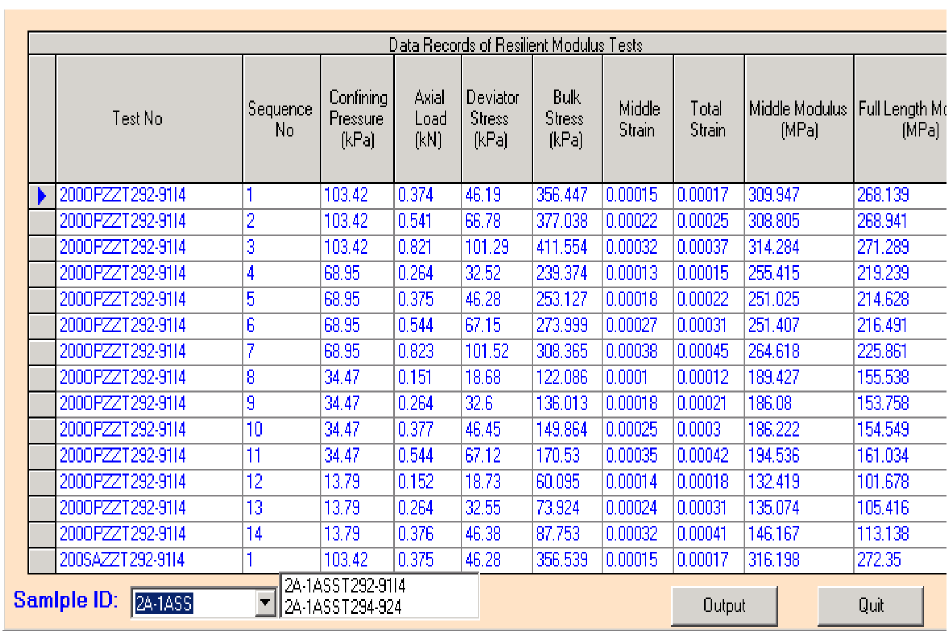


Figure 4.28 Main form of data query



Data Records of Resilient Modulus Tests

Test No	Sequence No	Confining Pressure (kPa)	Axial Load (kN)	Deviator Stress (kPa)	Bulk Stress (kPa)	Middle Strain	Total Strain	Middle Modulus (MPa)	Full Length Mo (MPa)
2000PZZT292-91I4	1	103.42	0.374	46.19	356.447	0.00015	0.00017	309.947	268.139
2000PZZT292-91I4	2	103.42	0.541	66.78	377.038	0.00022	0.00025	308.805	268.941
2000PZZT292-91I4	3	103.42	0.821	101.29	411.554	0.00032	0.00037	314.284	271.289
2000PZZT292-91I4	4	68.95	0.264	32.52	239.374	0.00013	0.00015	255.415	219.239
2000PZZT292-91I4	5	68.95	0.375	46.28	253.127	0.00018	0.00022	251.025	214.628
2000PZZT292-91I4	6	68.95	0.544	67.15	273.999	0.00027	0.00031	251.407	216.491
2000PZZT292-91I4	7	68.95	0.823	101.52	308.365	0.00038	0.00045	264.618	225.861
2000PZZT292-91I4	8	34.47	0.151	18.68	122.086	0.0001	0.00012	189.427	155.538
2000PZZT292-91I4	9	34.47	0.264	32.6	136.013	0.00018	0.00021	186.08	153.758
2000PZZT292-91I4	10	34.47	0.377	46.45	149.864	0.00025	0.0003	186.222	154.549
2000PZZT292-91I4	11	34.47	0.544	67.12	170.53	0.00035	0.00042	194.536	161.034
2000PZZT292-91I4	12	13.79	0.152	18.73	60.095	0.00014	0.00018	132.419	101.678
2000PZZT292-91I4	13	13.79	0.264	32.55	73.924	0.00024	0.00031	135.074	105.416
2000PZZT292-91I4	14	13.79	0.376	46.38	87.753	0.00032	0.00041	146.167	113.138
200SAZZT292-91I4	1	103.42	0.375	46.28	356.539	0.00015	0.00017	316.198	272.35

Samlple ID: 2A-1ASS
2A-1ASST292-91I4
2A-1ASST294-924
Output
Quit

Figure 4.29 Summary table of test results from query operation

Triaxial Test Results

Summary of Resilient Modulus Test Results

SampleID:2A-2AES County:Polk Sample Size:4 inch
Highway:U.S.17 Method:T292-91I MC:10.8 %
Test Date:11/15/1995 MP:unknown UW:17.38 KN/m3

Confining Pressure (kPa)	Axial Load (kN)	Deviator Stress (kPa)	Bulk Stress (kPa)	Middle Strain	Total Strain	Middle Modulus (MPa)	Full Length Modulu (MPa)
103.42	0.379	46.79	357.05	0.00013	0.00017	348.683	275.663
103.42	0.546	67.41	377.665	0.0002	0.00024	341.713	275.611
103.42	0.823	101.56	411.815	0.0003	0.00037	339.284	278.786
68.95	0.264	32.58	239.429	0.00011	0.00015	288.164	220.521
68.95	0.377	46.45	253.304	0.00017	0.00021	280.244	217.03
68.95	0.544	67.07	273.915	0.00024	0.0003	276.221	221.097
68.95	0.823	101.57	308.42	0.00036	0.00045	285.816	228.945
34.47	0.15	18.46	121.871	0.00009	0.00012	215.457	156.946
34.47	0.264	32.58	135.989	0.00016	0.00021	207.004	156.52
34.47	0.376	46.39	149.802	0.00022	0.00029	207.063	158.597
34.47	0.544	67.07	170.484	0.00032	0.00041	213.51	164.551
13.79	0.152	18.79	60.155	0.00013	0.00018	147.87	107.907
13.79	0.264	32.58	73.952	0.00022	0.00029	151.591	112.627
13.79	0.379	46.74	88.105	0.0003	0.0004	155.74	116.716

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Figure 4.30 Summary table of resilient modulus test results

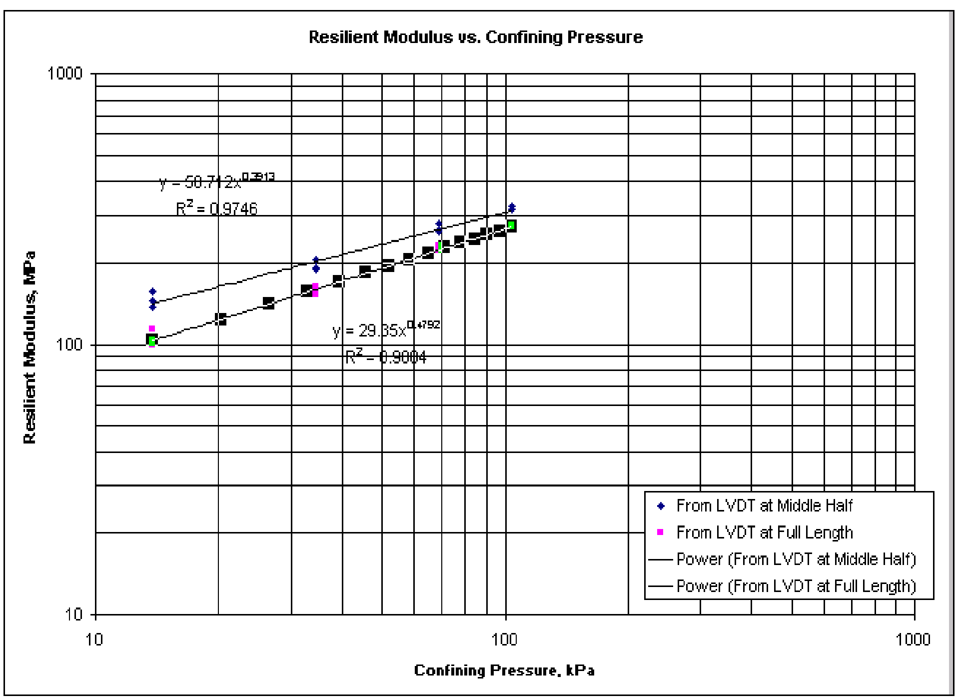


Figure 4.31 Resilient modulus versus confining pressure

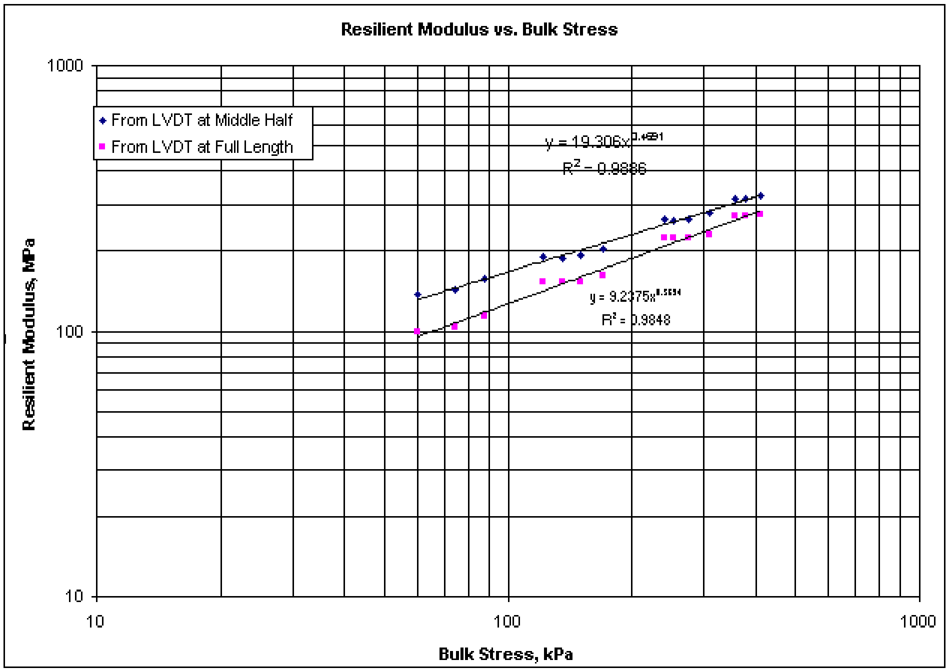
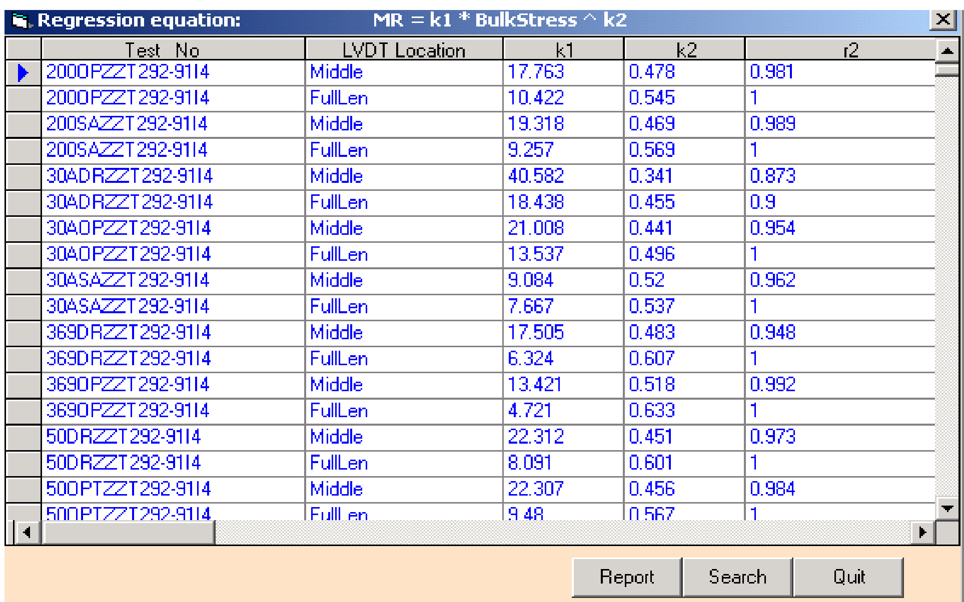


Figure 4.32 Resilient modulus versus bulk stress



Regression equation: MR = k1 * BulkStress ^ k2

Test No	LVDT Location	k1	k2	r2
200OPZZT292-9114	Middle	17.763	0.478	0.981
200OPZZT292-9114	FullLen	10.422	0.545	1
200SAZZT292-9114	Middle	19.318	0.469	0.989
200SAZZT292-9114	FullLen	9.257	0.569	1
30ADRZZT292-9114	Middle	40.582	0.341	0.873
30ADRZZT292-9114	FullLen	18.438	0.455	0.9
30AOPZZT292-9114	Middle	21.008	0.441	0.954
30AOPZZT292-9114	FullLen	13.537	0.496	1
30ASAZZT292-9114	Middle	9.084	0.52	0.962
30ASAZZT292-9114	FullLen	7.667	0.537	1
369DRZZT292-9114	Middle	17.505	0.483	0.948
369DRZZT292-9114	FullLen	6.324	0.607	1
369OPZZT292-9114	Middle	13.421	0.518	0.992
369OPZZT292-9114	FullLen	4.721	0.633	1
50DRZZT292-9114	Middle	22.312	0.451	0.973
50DRZZT292-9114	FullLen	8.091	0.601	1
50OPTZZT292-9114	Middle	22.307	0.456	0.984
50OPTZZT292-9114	FullLen	9.48	0.567	1

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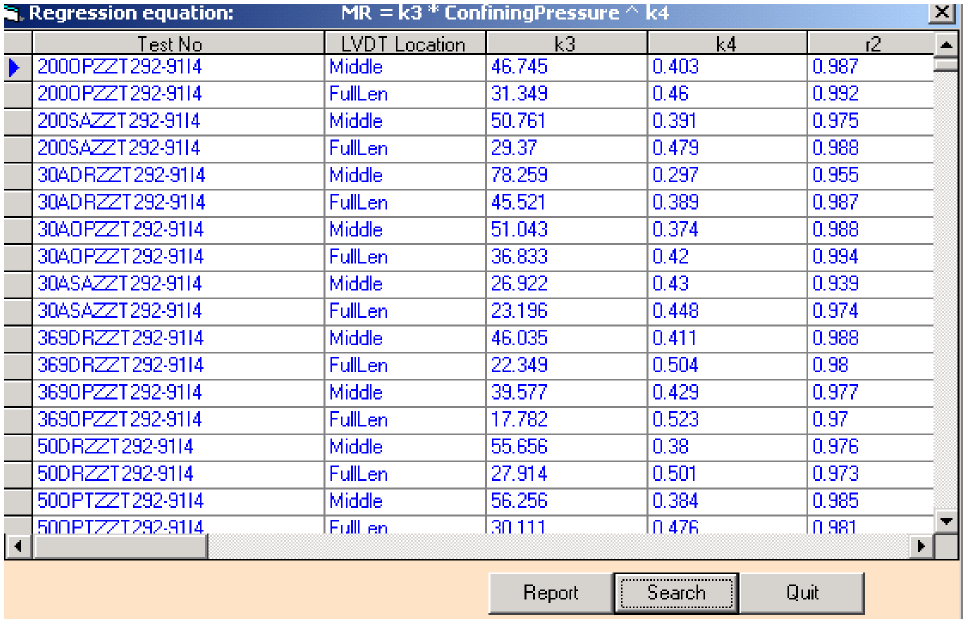
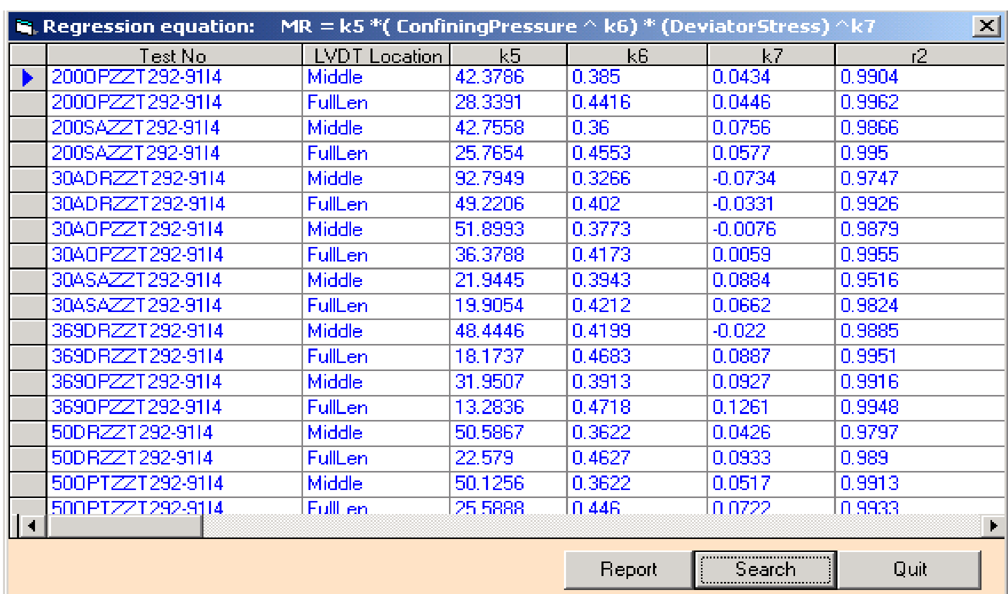
Figure 4.33 Results of regression analysis:
MR versus bulk stress



Test No	LVDT Location	k3	k4	r2
200OPZZT292-9114	Middle	46.745	0.403	0.987
200OPZZT292-9114	FullLen	31.349	0.46	0.992
200SAZZT292-9114	Middle	50.761	0.391	0.975
200SAZZT292-9114	FullLen	29.37	0.479	0.988
30ADRZZT292-9114	Middle	78.259	0.297	0.955
30ADRZZT292-9114	FullLen	45.521	0.389	0.987
30AOPZZT292-9114	Middle	51.043	0.374	0.988
30AOPZZT292-9114	FullLen	36.833	0.42	0.994
30ASAZZT292-9114	Middle	26.922	0.43	0.939
30ASAZZT292-9114	FullLen	23.196	0.448	0.974
369DRZZT292-9114	Middle	46.035	0.411	0.988
369DRZZT292-9114	FullLen	22.349	0.504	0.98
369OPZZT292-9114	Middle	39.577	0.429	0.977
369OPZZT292-9114	FullLen	17.782	0.523	0.97
50DRZZT292-9114	Middle	55.656	0.38	0.976
50DRZZT292-9114	FullLen	27.914	0.501	0.973
50OPTZZT292-9114	Middle	56.256	0.384	0.985
50OPTZZT292-9114	FullLen	30.111	0.476	0.981

Figure 4.34 Results of regression analysis:
MR versus confining pressure



Test No	LVDT Location	k5	k6	k7	r2
200OPZZT292-9114	Middle	42.3786	0.385	0.0434	0.9904
200OPZZT292-9114	FullLen	28.3391	0.4416	0.0446	0.9962
200SAZZT292-9114	Middle	42.7558	0.36	0.0756	0.9866
200SAZZT292-9114	FullLen	25.7654	0.4553	0.0577	0.995
30ADRZZT292-9114	Middle	92.7949	0.3266	-0.0734	0.9747
30ADRZZT292-9114	FullLen	49.2206	0.402	-0.0331	0.9926
30AOPZZT292-9114	Middle	51.8993	0.3773	-0.0076	0.9879
30AOPZZT292-9114	FullLen	36.3788	0.4173	0.0059	0.9955
30ASAZZT292-9114	Middle	21.9445	0.3943	0.0884	0.9516
30ASAZZT292-9114	FullLen	19.9054	0.4212	0.0662	0.9824
369DRZZT292-9114	Middle	48.4446	0.4199	-0.022	0.9885
369DRZZT292-9114	FullLen	18.1737	0.4683	0.0887	0.9951
369OPZZT292-9114	Middle	31.9507	0.3913	0.0927	0.9916
369OPZZT292-9114	FullLen	13.2836	0.4718	0.1261	0.9948
50DRZZT292-9114	Middle	50.5867	0.3622	0.0426	0.9797
50DRZZT292-9114	FullLen	22.579	0.4627	0.0933	0.989
50OPTZZT292-9114	Middle	50.1256	0.3622	0.0517	0.9913
50OPTZZT292-9114	FullLen	25.5888	0.446	0.0722	0.9933

Figure 4.35 Results of regression analysis:
MR versus confining pressure plus deviator stress

CHAPTER 5

COMPARATIVE ANALYSIS

5.1 Introduction

The comparative analysis of the resilient modulus data was conducted to study the effects of different test procedures and LVDT positions on the resilient modulus test results. The analysis was performed by means of the linear regression modeling. The T292-91I and T294-92 test procedures with various LVDT positions for A-2-4, A-3 soils were involved in the study.

5.1.1 LVDT positions

As demonstrated in Figure 5.1 (same as in Figure 2.3), four positions of LVDT placement are related to this study:

1. Position A

   The middle length LVDT of the T292-91I test procedure is Position A, which is placed on the clamps around the specimen to measure the deformation of the half length of specimen (10.2-cm/4.0-in.), as illustrated in Figure

5.1(a). Position A is the standard deformation measurement position for the T292-91I test procedure.

2. Position B

   The full length LVDT inside the chamber of the T292-91I test procedure is Position B, which measures the deformation of the full length of specimen (20.3-cm/8.0-in.), as demonstrated in Figure 5.1(a).

3. Position 1

   The middle length LVDT of the T294-92 test procedure is Position 1, as illustrated in Figure 5.1(b).

4. Position 3

   The full length LVDT outside the chamber of the T294-92 test procedure, as shown in Figure 5.1(b), is Position 3. Position 3 is the standard LVDT position to measure deformation for the T294-92 test procedure.

5.1.2 Purpose of comparative analysis

The purpose of the comparative analysis is to determine two types of adjustment factors:

1. The adjustment factors (AF) are those between the soil (A-2-4 or A-3) resilient modulus values measured from Position A and Position B (Figure 5.1(a)) under the confining pressure of 13.79 kPa (2 psi) or 34.47 kPa (5 psi) for the T292-91I test procedure, and between the soil resilient modulus values measured at Position 1 and

Position 3 (Figure 5.1(b)) under the confining pressure of 20.68 kPa (3 psi) or 34.47 kPa (5 psi) for the T294-92 test procedure.

$$AF(B,A) = \frac{MR(LVDTs \quad at \quad Position\ B)}{MR(LVDTs \quad at \quad Position\ A)} \tag{5.1}$$

$$AF(3,1) = \frac{MR(LVDTs \quad at \quad Position\ 3)}{MR(LVDTs \quad at \quad Position\ 1)} \tag{5.2}$$

2. The adjustment factors (AF) are those between the soil (A-2-4 or A-3) resilient modulus values measured from Position A (T292-91I) and Position 1 (T294-92), and between the soil resilient modulus values measured from Position A (T292-91I) and Position 3 (T294-92) under the confining pressure of 34.47 kPa (5 psi).

$$AF(A,1) = \frac{MR(LVDTs \quad at \quad Position\ A, T292-91I)}{MR(LVDTs \quad at \quad Position\ 1,\ T294-92)} \tag{5.3}$$

$$AF(A,3) = \frac{MR(LVDTs \quad at \quad Position\ A, T292-91I)}{MR(LVDTs \quad at \quad Position\ 3,\ T294-92)} \tag{5.4}$$

5.2 Regression Model

The linear regression models were used in the comparative study of the soil resilient modulus data. The linear regression model of MR_{T292} (resilient modulus from the T292-91I test procedure) versus MR_{T294} (resilient modulus from the T294-92 test procedure) is presented as the following, where the intercept of the linear regression model is forced to zero:

$$MR_{T292} = b \times MR_{T294} \tag{5.5}$$

$$b = \frac{\sum_{i=1}^{n} (MR_{T294i} \times MR_{T292i})}{\sum_{i=1}^{n} (MR_{T294i})^2} \tag{5.6}$$

Where,

MR_{T294} = full length (outside the chamber, Position 3) MR(MPa) from the T294-92 test procedure

MR_{T292} = middle length (Position A) MR (MPa) from the T292-91I test procedure

b = slope of the linear regression line

b = adjustment factor between the modulus obtained from the T294-92 and T292-91I test procedures

The linear regression model of MR_{mid} (resilient modulus measured at Position A or Position 1) versus MR_{ful} (resilient modulus measured at Position B or Position 3 is presented as the following, where the intercept is forced to zero:

$$MR_{full} = m \times MR_{mid} \tag{5.7}$$

$$m = \frac{\sum_{i=1}^{n} (MR_{midi} \times MR_{fuli})}{\sum_{i=1}^{n} (MR_{midi})^2} \tag{5.8}$$

Where,

MR_{ful} = full length MR (MPa), which was measured inside the chamber (Position B) when the T292-91I test procedure was applied, or was obtained from the outside chamber full length LVDT position (Position 3) when the T294-92 test procedure was used

MR_{mid} = middle length MR (MPa), measured at Position A in the T292-91I, or Position 1 in T294-92

m = slope of the linear regression line

m = adjustment factor between the full length modulus and the middle modulus

5.3 Procedures of Comparative Analysis

The comparative analysis function of the RMDB falls into two submenus (Figure 4.5):

(1) MRs between T292-91I and T294-92

(2) MRs between middle and full length LVDTs

The procedures to execute the comparative analysis are summarized as follows:

1. Define the range of analysis.

   Define the range of resilient modulus data for analysis by selecting the constraint factors, as demonstrated in Figures 5.2 and 5.3.

2. Execute the analysis.

   By clicking the “Analysis” menu, the linear regression parameters will be determined and subsequently displayed on the right hand side of the form. The “Output” menu will be activated simultaneously for reporting the results, as demonstrated in Figures 5.2 and 5.3.

3. Report the analysis results.

   The analysis results can be output into either a new or an existing MS Excel file.

   A new Excel file would be created as a tabular format, which is shown in Table 5.1. One data record of the regression parameters will be saved automatically. As for the existing file, a common dialog box will be shown for selecting the full path name of the existing Excel file. By clicking the “To Existing File” menu, the “Output” button will be activated. By pressing the “Open” button on the common dialog box (Figure 4.22), the full path name of the existing file will be displayed in a textbox. Subsequently, by clicking the “Output” button, the results will be appended to the end of the existing Excel file (see Table 5.2).

5.4 Adjustment Factors

The first type of adjustment factors is the slope of regression equations to compare the resilient modulus values obtained from the four LVDT Positions. The second type of adjustment factors is the slope of regression equations to compare the resilient modulus values obtained from the T292-91I and T294-92 test procedures.

The entire set of test data was categorized into eight groups, at confining pressure 13.79 kPa (2 psi) or 34.47 kPa (5 psi) for the T292-91I test procedure, and at 20.68 kPa (3 psi) or 34.47 kPa (5 psi) for the T294-92 test procedure, to compare and determine the first type of adjustment factors. One adjustment factor was produced based on each group of data. Consequently, eight adjustment factors were defined as shown in Table 5.3.

For the second type of adjustment factors, the entire set of test data was categorized into four groups, and four adjustment factors were defined based on each group of the test data, as summarized in Table 5.4.

5.4.1 Adjustment factors for the LVDT positions

Eight adjustment factors for the four LVDT positions were determined, and are presented as follows.

AF(B,A)-1 The adjustment factor used to adjust the resilient modulus values measured at the middle length LVDT to the values at the full length LVDT, under the confining pressure of 13.79 kPa (2 psi) of the T292-91I test procedure for the A-2-4 soil (see Table 5.3).

The test data on which the adjustment factor AF(B,A)-1 is based were searched from the RMDB, and are summarized in Table 5.5. The data are plotted in Figure 5.4 for illustration. The adjustment factor AF(B,A)-1 was determined to be 0.73.

AF(B,A)-2 The adjustment factor used to adjust the resilient modulus values measured at the middle length LVDT to the values at the full length LVDT, under the confining pressure of 34.47 kPa (5 psi) of the T292-91I test procedure for the A-2-4 soil (Table 5.3).

The test data on which the adjustment factor AF(B,A)-2 is based were extracted from the RMDB, and are summarized in Table 5.6. The data are presented in Figure 5.5. The adjustment factor AF(B,A)-2 was determined to be 0.79 from the linear regression analysis.

AF(B,A)-3 The adjustment factor used to adjust the resilient modulus values measured at the middle length LVDT to the values at the full length LVDT, under the confining pressure of 13.79 kPa (2 psi) of the T292-91I test procedure for the A-3 soil (refer to Table 5.3).

The test data on which the adjustment factor AF(B,A)-3 is based were obtained from the RMDB, and are summarized in Table 5.7. The data are presented in Figure 5.6. The adjustment factor AF(B,A)-3 was found to be 0.71 from the linear regression analysis.

AF(B,A)-4 The adjustment factor used to adjust the resilient modulus values measured at the middle length LVDT to the values at the full length LVDT, under the confining pressure of 34.47 kPa (5 psi) of the T292-91I test procedure for the A-3 soil (Table 5.3).

The test data are summarized in Table 5.8, and are shown in Figure 5.7. The adjustment factor AF(B,A)-4 was determined to be 0.76 from the linear regression analysis.

AF(3,1)-1 The adjustment factor used to adjust the resilient modulus values measured at the middle length LVDT to the values at the full length LVDT, under the confining pressure of 20.68 kPa (3 psi) of the T294-92 test procedure for the A-2-4 soil (Table 5.3).

The test data were extracted from the RMDB, and are summarized in Table 5.9. The data are presented in Figure 5.8. The adjustment factor AF(3,1)-1 was found to be 0.64 from the linear regression analysis.

AF(3,1)-2 The adjustment factor used to adjust the resilient modulus values measured at the middle length LVDT to the values at the full length LVDT, under the confining pressure of 34.47 kPa (5 psi) of the T294-92 test procedure for the A-2-4 soil (Table 5.3).

The test data were extracted from the RMDB, and are summarized in Table 5.10. The results are shown in Figure 5.9. The adjustment factor AF(3,1)-2 was found to be 0.66 from the linear regression analysis.

AF(3,1)-3 The adjustment factor used to adjust the resilient modulus values measured at the middle length LVDT to the values at the full length LVDT, under the confining pressure of 20.68 kPa (3 psi) of the T294-92 test procedure for the A-3 soil (Table 5.3).

The test data were extracted from the RMDB, and are summarized in Table 5.11. The test results are shown in Figure 5.10. The adjustment factor AF(3,1)-3 was determined to be 0.59 from the linear regression analysis.

AF(3,1)-4 The adjustment factor used to adjust the resilient modulus values measured at the middle length LVDT to the values at the full length LVDT, under the confining pressure of 34.47 kPa (5 psi) of the T294-92 test procedure for the A-3 soil (Table 5.3).

The test data were obtained from the RMDB, and are summarized in Table 5.12. The test results are shown in Figure 5.11. The adjustment factor AF(3,1)-4 was found to be 0.58 from the linear regression analysis.

5.4.2 Adjustment factors for the test procedures

Four adjustment factors were determined for correlation of resilient modulus values from the T292-91I and T294-92 test procedures. The adjustment factors are presented as follows.

<u>AF(A,1)-(A-2-4)</u> The adjustment factor used to adjust the resilient modulus values of the T294-92 measured at the middle length LVDT to the values of the T292-91I at the middle length LVDT (see Equation 5.3), under the confining pressure of 34.47 kPa (5 psi) for the A-2-4 soil.

The test data were obtained from the RMDB, and are summarized in Table 5.13. The results are shown in Figure 5.12. The adjustment factor AF(A,1)-(A-2-4) was found to be 1.07 from the regression analysis.

<u>AF(A,1)-(A-3)</u> The adjustment factor used to adjust the resilient modulus values of the T294-92 measured at the middle length LVDT to the values of the T292-91I at the middle length LVDT (see Equation 5.3), under the confining pressure of 34.47 kPa (5 psi), for the A-3 soil.

The test data were extracted from the RMDB, and are summarized in Table 5.14. The results are plotted in Figure 5.13. The adjustment factor AF(A,1)-(A-3) was determined to be 1.06 from the regression analysis.

AF(A,3)-(A-2-4) The adjustment factor used to adjust the resilient modulus values of the T294-92 measured at the full length LVDT to the values of the T292-91I at the middle length LVDT (see Equation 5.4), under the confining pressure of 34.47 kPa (5 psi) for the A-2-4 soil.

The test data were extracted from the RMDB, and are summarized in Table 5.15. The results are presented in Figure 5.14. The adjustment factor AF(A,3)-(A-2-4) was determined to be 1.42 from the regression analysis.

AF(A,3)-(A-3) The adjustment factor used to adjust the resilient modulus values of the T294-92 measured at the full length LVDT to the values of the T292-91I at the middle length LVDT (see Equation 5.4), under the confining pressure of 34.47 kPa (5 psi) for the A-3 soil.

The test data were obtained from the RMDB, and are summarized in Table 5.16. The results are shown in Figure 5.15. The adjustment factor AF(A,3)-(A-3) was found to be 1.60 from the regression analysis.

5.5 Summary

The adjustment factors were determined from the regression analysis. The adjustment factors between the soil resilient modulus values measured from Position A and Position B (Equation 5.1), and from Position 1 and Position 3 (Equation 5,2) are summarized in Table 5.17. The second type of adjustment factors are summarized in Table 5.18 for adjusting the soil resilient modulus values measured between the Position A (T292-91I) and Position 3 (T294-92) as presented in Equations 5.3 and 5.4.

As shown in Table 5.17, the range of adjustment factors AF(B,A) varies from 0.71 at 13.79 kPa (2 psi) to 0.79 at 34.47 kPa(5 psi) with an average value of 0.75. The range of adjustment factor AF(3,1) varies from 0.58 to 0.66 with an average value of 0.62. Therefore, the resilient modulus values measured from the full length LVDT are about 75% (from T292-91I) or 62% (for the T294-92) of the values measured from the middle length LVDT. The reduction in the resilient modulus value of 25 to 38% is considered due to the effect of LVDT positions.

From the adjustment factors shown in Table 5.18, the difference is negligible in the modulus values measured between the middle length LVDTs (Equation 5.3) from the

T292-91I and T294-92 test procedures. However, the difference is very significant (42 to 60% higher) in the modulus values measured from the middle LVDT of the T292-91I test procedure and from the full length LVDT of the T294-92 test procedure (refer to Equation 5.4).

In addition, most R-square values of the adjustment factors are close to 0.8, which means the correlations are strong. The good relationships show the quality of the comparative analysis, and add to the confidence in the test results.

Table 5.1 Report of comparative analysis results in a new MS Excel file

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Regression Parameters Between Resilinet Modulus Values from T292-91I and T292-92**												
2	Classification	Sample Size (inch)	Confining Pressure (KPa)	MC (%)		Dry UW (KN/m3)		Linear					
3				<=	<=	<=	<=	Middle			full		
4								a	b	r2	a	b	r2
5	A-2-4	4	68.95	6	14	15.8	20.5	342	1.021	1	196.9	1.73	0.9
6													
7													
8													
9													
10													
11													
12													

Table 5.2 Report of comparative analysis results in an existing MS Excel file

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Regression Parameters Between Resilinet Modulus Values from T292-91I and T292-92**												
2	Classification	Sample Size (inch)	Confining Pressure (KPa)	MC (%)		Dry UW (KN/m3)		Linear					
3				<=	<=	<=	<=	Middle			full		
4								a	b	r2	a	b	r2
5	A-2-4	4	68.95	6	14	15.8	20.5	342	1.021	1	196.9	1.73	0.9
6	A-2-4	4	103.42					413	1.401	1	228.3	1.95	0.8
7	A-2-4	6	103.42	7	15			356	0.966	0.9	211.2	1.55	0.9
8													
9													
10													
11													
12													
13													
14													
15													
16													

Table 5.3 Groups of adjustment factor for comparative analysis
(Middle vs Full LVDT)

Description	Adjustment Factor Group		
	Confining Pressures, Kpa (psi)		
	13.79 (2)	20.68 (3)	34.47 (5)
T292-91I A-2-4 Soil	AF(B,A)-1	-	AF(B,A)-2
T292-91I A-3 Soil	AF(B,A)-3	-	AF(B,A)-4
T294-92 A-2-4 Soil	-	AF(3,1)-1	AF(3,1)-2
T294-92 A-3 Soil	-	AF(3,1)-3	AF(3,1)-4

Table 5.4 Groups of adjustment factor for comparative analysis
(T292-91I vs T294-92 Test Procedure @ 34.47 KPa (5 psi))

Description	Soil Type	T294-92 Test Procedure	
		T294-92 Position 1	T294-92 Position 3
T292-91I Test Procedure Position A	A-2-4	AF(A,1)-(A-2-4)	AF(A,3)-(A-2-4)
	A-3	AF(A,1)-(A-3)	AF(A,3)-(A-3)

Table 5.5 Summary of resilient modulus test data for adjustment factor AF(B,A)-1

Sample ID	Confining Pressure (kPa)	Middle Modulus (MPa)	Full Modulus (MPa)
200OPZZ	13.79	137.887	106.744
200SAZZ	13.79	146.193	105.435
200SAZZ	13.79	131.941	111.109
2A-1ASS	13.79	129.690	103.033
2A-2ASS	13.79	145.818	111.389
2B-4ASS	13.79	151.307	120.651
2B-5CSS	13.79	95.520	78.733
2C-2GES	13.79	142.721	102.741
2C-2GSS	13.79	186.838	149.172
2E-1SES	13.79	146.255	116.796
2E-1SSS	13.79	181.917	137.135
2E-2SSS	13.79	171.684	127.003
30ADRZZ	13.79	173.684	129.163
30AOPZZ	13.79	138.632	112.612
30ASAZZ	13.79	89.056	78.524
A2412%D1	13.79	138.403	99.053
A2412%D2	13.79	140.202	94.849
A2412%O1	13.79	115.167	87.537
A2412%O2	13.79	114.664	92.791
A2412%S1	13.79	101.531	88.369
A2412%S2	13.79	112.075	90.471
A2420%O2	13.79	127.603	107.878
A2420%S2	13.79	111.961	97.221
A2424%o2	13.79	113.760	92.473
CLIU-A24-1	13.79	126.996	98.826
CLIU-A24-2	13.79	142.084	106.282
I75DRZZ	13.79	242.176	138.613
I75OPZZ	13.79	188.882	135.886
I75SOZZ	13.79	123.371	92.294
SR44-1-ST-1	13.79	153.183	84.848
SR44-1-ST-2	13.79	158.390	98.113
SR44-3-ST-2	13.79	103.980	73.088
SR44-5-ST-1	13.79	69.158	66.285
SR44-5-ST-2	13.79	78.961	72.200
SR44-7-ST-1	13.79	130.242	94.647
SR44-7-ST-2	13.79	149.241	85.560
SR44-9-ST-1	13.79	91.347	78.399
SR44-9-ST-2	13.79	83.257	65.831
TableB-3	13.79	276.306	173.029
TableB-4	13.79	208.585	148.405
TableC-6	13.79	135.907	114.141
TableC-7	13.79	117.044	92.535

Table 5.6 Summary of resilient modulus test data for adjustment factor AF(B,A)-2

Sample ID	Confining Pressure (kPa)	Middle Modulus (MPa)	Full Modulus (MPa)
200OPZZ	34.47	189.066	156.220
200SAZZ	34.47	194.112	155.073
200SAZZ	34.47	178.477	156.725
2A-1ASS	34.47	180.162	148.193
2A-2ASS	34.47	196.017	156.590
2B-4ASS	34.47	202.501	167.671
2B-5CSS	34.47	130.954	110.435
2C-2GES	34.47	189.759	142.855
2C-2GSS	34.47	238.325	201.582
2E-1SES	34.47	192.091	158.738
2E-1SSS	34.47	235.473	186.983
2E-2SSS	34.47	223.982	175.029
30ADRZZ	34.47	220.166	175.787
30AOPZZ	34.47	187.636	160.007
30ASAZZ	34.47	114.169	107.254
A2412%D1	34.47	182.517	138.738
A2412%D2	34.47	191.958	141.833
A2412%O1	34.47	170.707	145.948
A2412%O2	34.47	172.497	151.198
A2412%S1	34.47	142.916	127.546
A2412%S2	34.47	153.339	134.046
A2420%O2	34.47	188.786	165.860
A2420%S2	34.47	162.091	143.397
A2424%o2	34.47	156.940	132.622
CLIU-A24-1	34.47	195.926	158.391
CLIU-A24-2	34.47	219.440	171.598
I75DRZZ	34.47	309.180	192.278
I75OPZZ	34.47	249.673	189.569
I75SOZZ	34.47	169.510	133.353
SR44-1-ST-1	34.47	789.884	133.166
SR44-1-ST-2	34.47	195.014	138.175
SR44-3-ST-2	34.47	135.103	92.452
SR44-5-ST-1	34.47	107.093	104.223
SR44-5-ST-2	34.47	121.031	109.438
SR44-7-ST-1	34.47	189.802	137.085
SR44-7-ST-2	34.47	205.086	127.842
SR44-9-ST-1	34.47	126.336	110.846
SR44-9-ST-2	34.47	127.379	103.313
TableB-3	34.47	296.260	219.997
TableB-4	34.47	257.485	199.709
TableC-6	34.47	184.444	155.634
TableC-7	34.47	188.085	155.738

Table 5.7 Summary of resilient modulus test data for adjustment factor AF(B,A)-3

Sample ID	Confining Pressure (kPa)	Middle Modulus (MPa)	Full Modulus (MPa)
2A-1AES	13.79	99.192	73.082
2A-1BES	13.79	163.336	122.384
2A-1BSS	13.79	145.141	104.939
2A-2AES	13.79	151.734	112.417
2A-2BES	13.79	136.086	106.462
2A-2BSS	13.79	149.079	109.614
2B-3ASS	13.79	116.964	101.695
2B-5CES	13.79	116.708	93.974
2B-6CES	13.79	119.498	101.845
2B-6CSS	13.79	91.142	74.246
2C-3GSS	13.79	131.941	111.109
2D-3MES	13.79	154.126	109.374
2D-3MSS	13.79	211.942	146.276
2D-4MES	13.79	214.791	142.013
2E-2SES	13.79	170.824	125.177
2E-3OES	13.79	153.506	104.870
2E-3OSS	13.79	230.149	160.811
2E-4OES	13.79	100.697	81.409
2E-4OSS	13.79	204.404	132.565
369DRZZ	13.79	137.441	87.042
369OPZZ	13.79	125.815	73.736
50DRZZ	13.79	156.345	109.049
50OPTZZ	13.79	157.943	109.258
CLIU-A3-1	13.79	141.278	89.478
CLIU-A3-2	13.79	131.663	85.696
SR44-11-ST-1	13.79	126.365	84.848
SR44-11-ST-2	13.79	69.158	66.285
ST142S1	13.79	207.784	111.125
ST154S1	13.79	78.931	67.909
ST166S1	13.79	130.832	101.448
TableD-3	13.79	141.482	115.556
TableD-4	13.79	148.175	96.164
TableE-5	13.79	157.040	113.604
TableE-6	13.79	155.630	121.495

Table 5.8 Summary of resilient modulus test data for adjustment factor AF(B,A)-4

Model No.	Sample ID	Confining Pressure (kPa)	Middle Modulus (MPa)	Full Modulus (MPa)
Model 6	2A-1AES	34.47	145.799	112.222
	2A-1BES	34.47	218.100	170.119
	2A-1BSS	34.47	192.242	145.233
	2A-2AES	34.47	210.758	159.153
	2A-2BES	34.47	181.875	147.212
	2A-2BSS	34.47	197.504	149.761
	2B-3ASS	34.47	157.912	140.912
	2B-5CES	34.47	156.172	127.888
	2B-6CES	34.47	156.493	138.267
	2B-6CSS	34.47	125.275	104.164
	2C-3GSS	34.47	178.477	156.725
	2D-3MES	34.47	197.750	150.495
	2D-3MSS	34.47	280.931	204.167
	2D-4MES	34.47	291.838	204.979
	2E-2SES	34.47	222.365	174.251
	2E-3OES	34.47	205.365	151.776
	2E-3OSS	34.47	304.387	227.150
	2E-4OES	34.47	132.607	109.098
	2E-4OSS	34.47	276.893	186.353
	369DRZZ	34.47	193.778	127.427
	369OPZZ	34.47	174.128	106.635
	50DRZZ	34.47	204.867	154.920
	50OPTZZ	34.47	212.605	154.381
	CLIU-A3-1	34.47	192.111	127.138
	CLIU-A3-2	34.47	176.982	122.349
	SR44-11-ST-1	34.47	179.227	133.166
	SR44-11-ST-2	34.47	107.093	104.223
	ST142S1	34.47	210.102	170.846
	ST154S1	34.47	110.510	98.532
	ST166S1	34.47	180.246	156.483
	TableD-3	34.47	188.677	161.852
	TableD-4	34.47	196.900	149.862
	TableE-5	34.47	201.266	158.815
	TableE-6	34.47	208.068	168.324

Table 5.9 Summary of resilient modulus test data for adjustment factor AF(3,1)-1

Sample ID	Confining Pressure (kPa)	Middle Modulus (MPa)	Full Modulus (MPa)
2A-1ASS	20.68	135.772	95.380
2A-2ASS	20.68	155.352	100.730
2B-4ASS	20.68	150.343	100.282
2B-5CSS	20.68	123.459	81.906
2C-2GSS	20.68	213.916	128.675
2E-1SSS	20.68	196.537	118.717
2E-2SSS	20.68	182.042	122.060

Table 5.10 Summary of resilient modulus test data for adjustment factor AF(3,1)-2

Sample ID	Confining Pressure (kPa)	Middle Modulus (MPa)	Full Modulus (MPa)
200SAZZ	34.47	280.931	204.167
200SAZZ	34.47	181.875	147.212
2A-1ASS	34.47	192.276	128.218
2A-2ASS	34.47	221.323	136.280
2B-4ASS	34.47	211.918	134.597
2B-5CSS	34.47	162.769	107.508
2C-2GSS	34.47	256.077	156.594
2E-1SSS	34.47	265.801	155.234
2E-2SSS	34.47	229.109	149.256

Table 5.11 Summary of resilient modulus test data for adjustment factor AF(3,1)-3

Sample ID	Confining Pressure (KPa)	Middle Modulus (MPa)	Full Modulus (MPa)
2A-1BSS	20.68	159.973	96.688
2A-2BSS	20.68	171.584	100.965
2B-3ASS	20.68	113.835	81.702
2B-6CSS	20.68	102.263	73.693
2C-3GSS	20.68	105.571	79.233
2E-3OSS	20.68	230.973	128.431
2E-4OSS	20.68	225.922	121.702

Table 5.12 Summary of resilient modulus test data for adjustment factor AF(3,1)-4

Sample ID	Confining Pressure (KPa)	Middle Modulus (MPa)	Full Modulus (MPa)
2A-1BSS	34.47	212.393	127.408
2A-2BSS	34.47	227.817	133.370
2B-3ASS	34.47	160.267	110.757
2B-6CSS	34.47	135.250	96.880
2C-3GSS	34.47	177.207	119.110
2E-3OSS	34.47	308.545	166.774
2E-4OSS	34.47	295.040	157.721

Table 5.13 Summary of resilient modulus test data for adjustment factor AF(A,1)-(A-2-4)

Sample ID	Soil Class.	Confining Pressure (kPa)	T292-91I Modulus (MPa)	T294-92 Modulus (MPa)
200SAZZ	A-2-4	34.47	178.477	181.875
200SAZZ	A-2-4	34.47	194.112	181.875
2A-1ASS	A-2-4	34.47	180.162	192.276
2A-2ASS	A-2-4	34.47	196.017	221.323
2B-4ASS	A-2-4	34.47	202.501	211.918
2B-5CSS	A-2-4	34.47	130.954	162.769
2C-2GSS	A-2-4	34.47	238.325	256.077
2E-1SSS	A-2-4	34.47	235.473	265.801
2E-2SSS	A-2-4	34.47	223.982	229.109

Table 5.14 Summary of resilient modulus test data for adjustment factor AF(A,1)-(A-3)

Sample ID	Soil Class.	Confining Pressure (kPa)	T292-91I Modulus (MPa)	T294-92 Modulus (MPa)
2A-1BSS	A-3	34.47	192.242	212.393
2A-2BSS	A-3	34.47	197.504	227.817
2B-3ASS	A-3	34.47	157.912	160.267
2B-6CSS	A-3	34.47	125.275	135.250
2C-3GSS	A-3	34.47	178.477	177.207
2E-3OSS	A-3	34.47	304.387	308.545
2E-4OSS	A-3	34.47	276.893	295.040

Table 5.15 Summary of resilient modulus test data for adjustment factor AF(A,3)-(A-2-4)

Sample ID	Soil Class.	Confining Pressure (kPa)	T292-91I Modulus (MPa)	T294-92 Modulus (MPa)
200SAZZ	A-2-4	34.47	178.477	147.212
200SAZZ	A-2-4	34.47	194.112	147.212
2A-1ASS	A-2-4	34.47	180.162	128.218
2A-2ASS	A-2-4	34.47	196.017	136.280
2B-4ASS	A-2-4	34.47	202.501	134.597
2B-5CSS	A-2-4	34.47	130.954	107.508
2C-2GSS	A-2-4	34.47	238.325	156.594
2E-1SSS	A-2-4	34.47	235.473	155.234
2E-2SSS	A-2-4	34.47	223.982	149.256

Table 5.16 Summary of resilient modulus test data for adjustment factor AF(A,3)-(A-3)

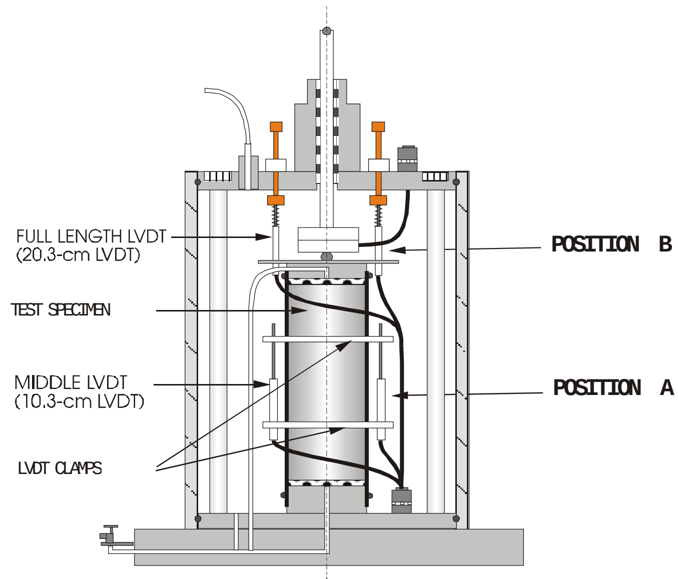
Sample ID	Soil Class.	Confining Pressure (kPa)	T292-91I Modulus (MPa)	T294-92 Modulus (MPa)
2A-1BSS	A-3	34.47	192.242	127.408
2A-2BSS	A-3	34.47	197.504	133.370
2B-3ASS	A-3	34.47	157.912	110.757
2B-6CSS	A-3	34.47	125.275	96.880
2C-3GSS	A-3	34.47	178.477	119.110
2E-3OSS	A-3	34.47	304.387	166.774
2E-4OSS	A-3	34.47	276.893	157.721

Table 5.17 Adjustment factors from comparative analysis
(Middle vs. Full Length LVDT)

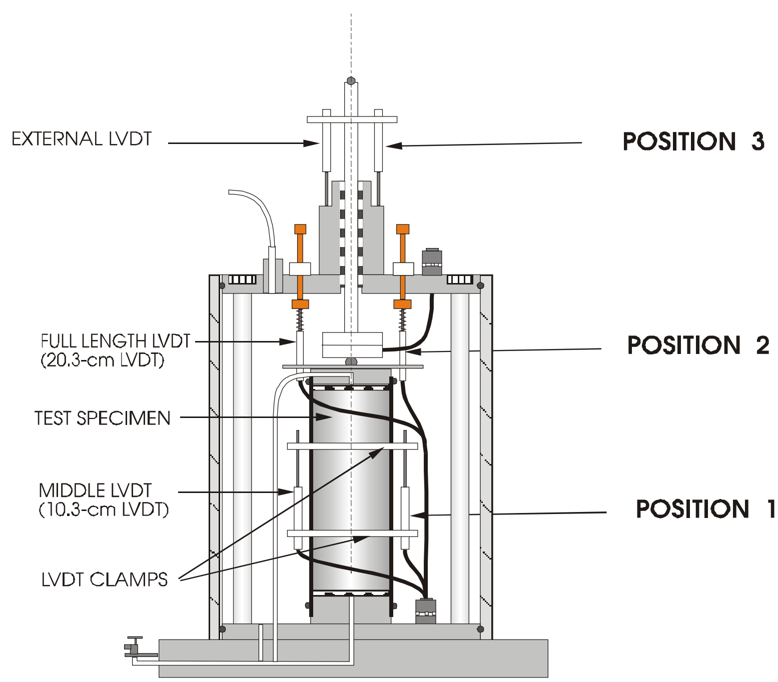
Group No.	AASHTO Class.	Test Procedure	Confining Pressure (kPa)	m (Slope)	R-Square	N (Number of Tests)
AF(B,A)-1	A-2-4	T292-91I	13.79	0.73	0.70	42
AF(B,A)-2			34.47	0.79	0.76	42
AF(B,A)-3	A-3		13.79	0.71	0.72	34
AF(B,A)-4			34.47	0.76	0.80	34
AF(3,1)-1	A-2-4	T294-92	20.68	0.64	0.85	7
AF(3,1)-2			34.47	0.66	0.68	7
AF(3,1)-3	A-3		20.68	0.59	0.68	7
AF(3,1)-4			34.47	0.58	0.66	7

Table 5.18 Adjustment factors from comparative analysis
(T292-91I vs. T294-92 Test Procedure @ 34.47kPa (5 psi))

Group No.	b (Slope)	R-Square	N (Number of Tests)	Description
AF(A,1)-(A-2-4)	1.07	0.83	9	Middle Length A-2-4
AF(A,1)-(A-3)	1.06	0.97	7	Middle Length A-3
AF(A,3)-(A-2-4)	1.42	0.73	9	Middle Length of T292-91I, full length of T294-92, A-2-4 soil
AF(A,3)-(A-3)	1.6	0.85	7	Middle Length of T292-91I, full length of T294-92, A-3 soil



(a) T 292-91I



(b) T294-92

Figure 5.1 Different positions of LVDTs, T 292-91I and T 294-92

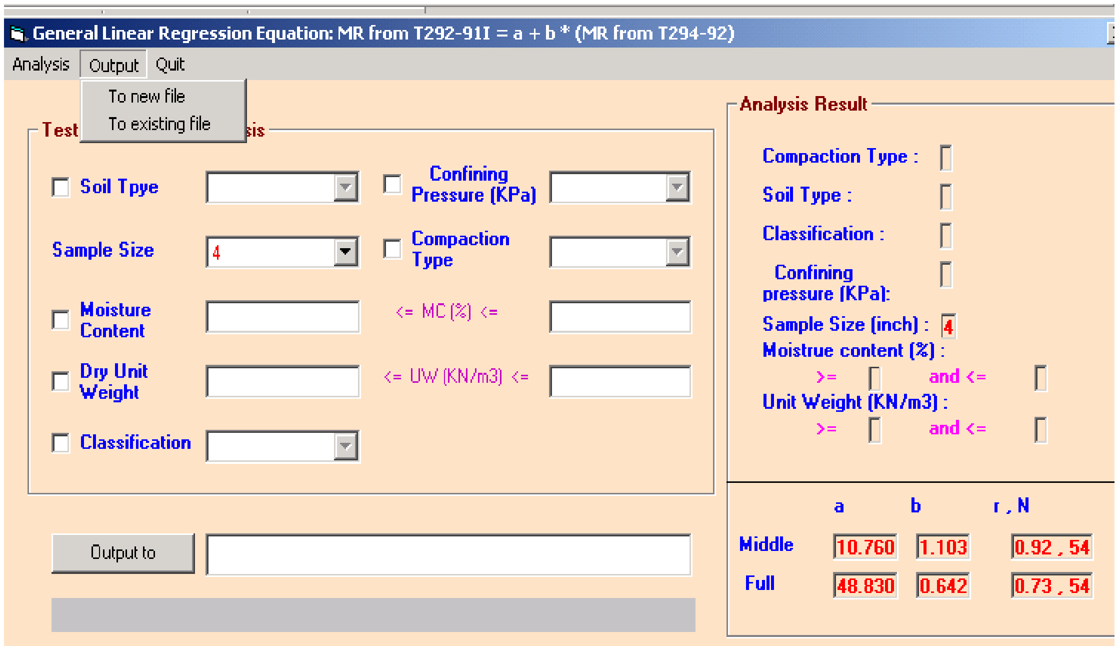


Figure 5.2 Comparative analysis between T292-91I and T294-92 test procedures

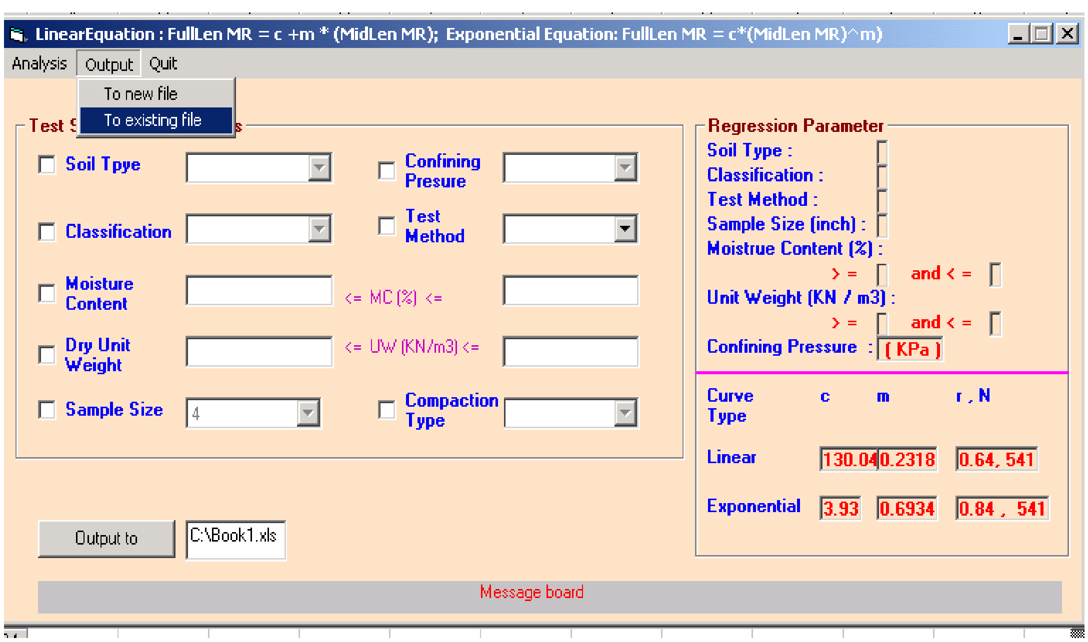


Figure 5.3 Comparative analysis between full-length LVDT and middle-length LVDT MR values

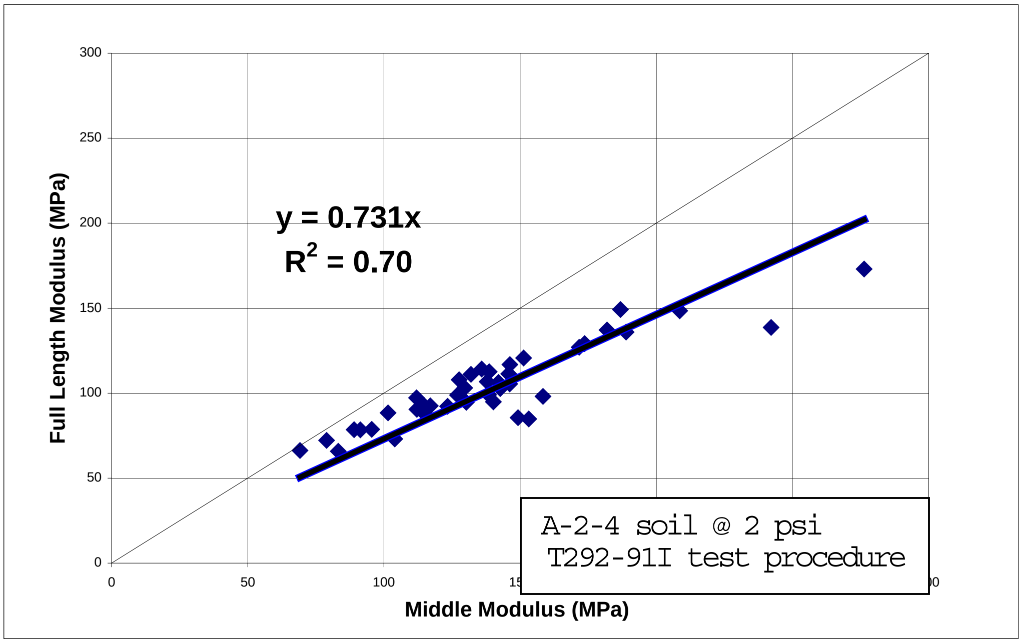


Figure 5.4 Full Length modulus versus middle length modulus for adjustment factor AF(B,A)-1

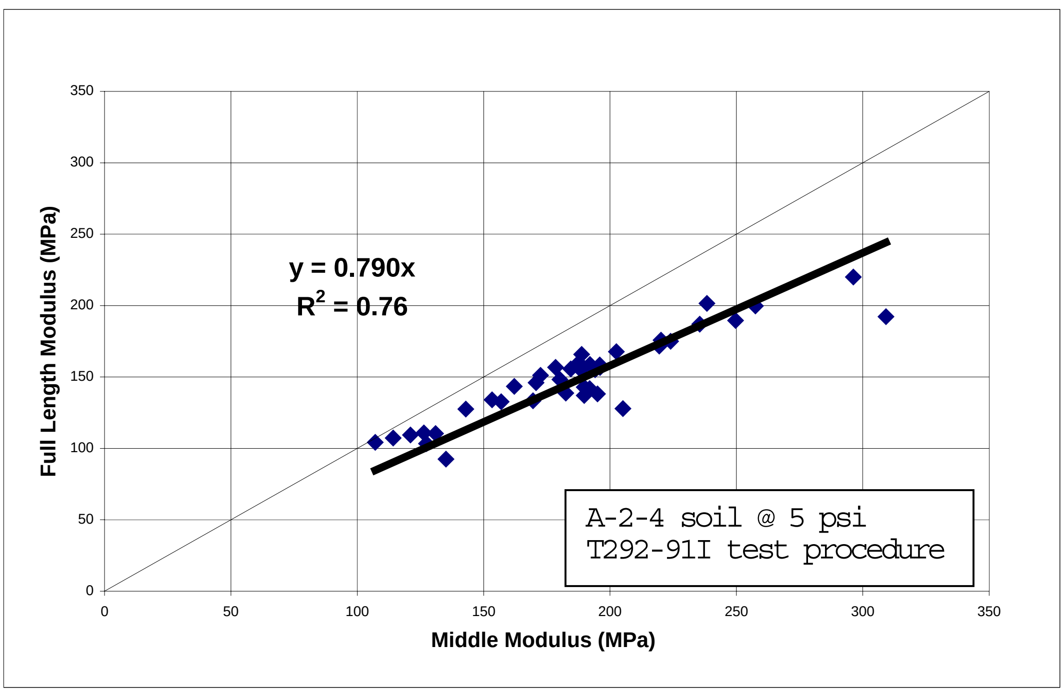


Figure 5.5 Full Length modulus versus middle length modulus for adjustment factor AF(B,A)-2

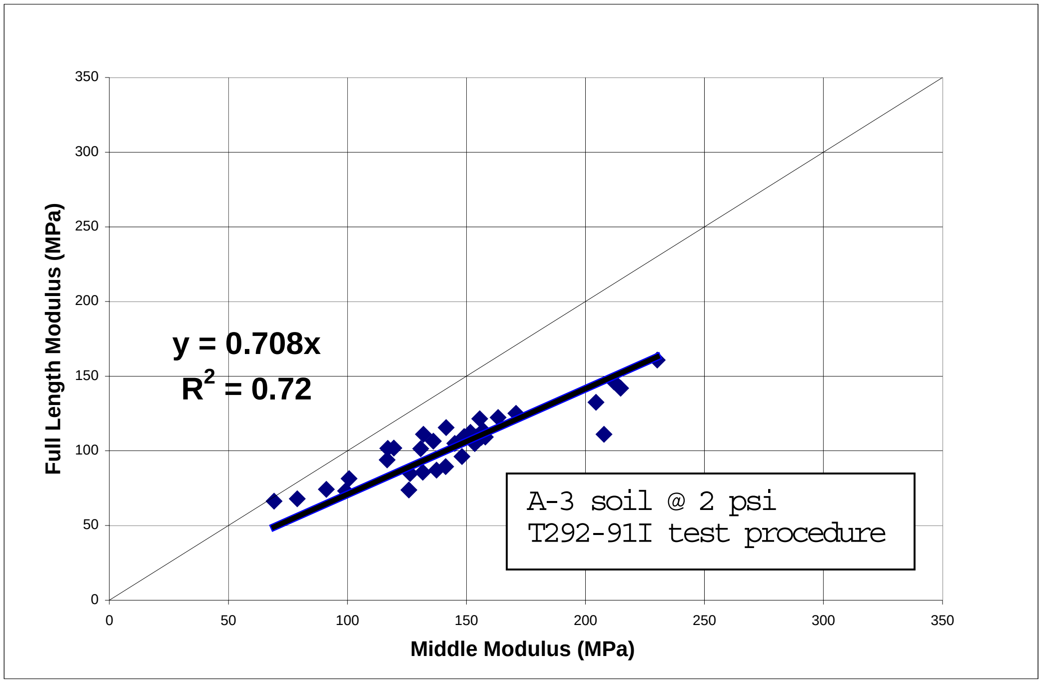


Figure 5.6 Full Length modulus versus middle length modulus for adjustment factor AF(B,A)-3

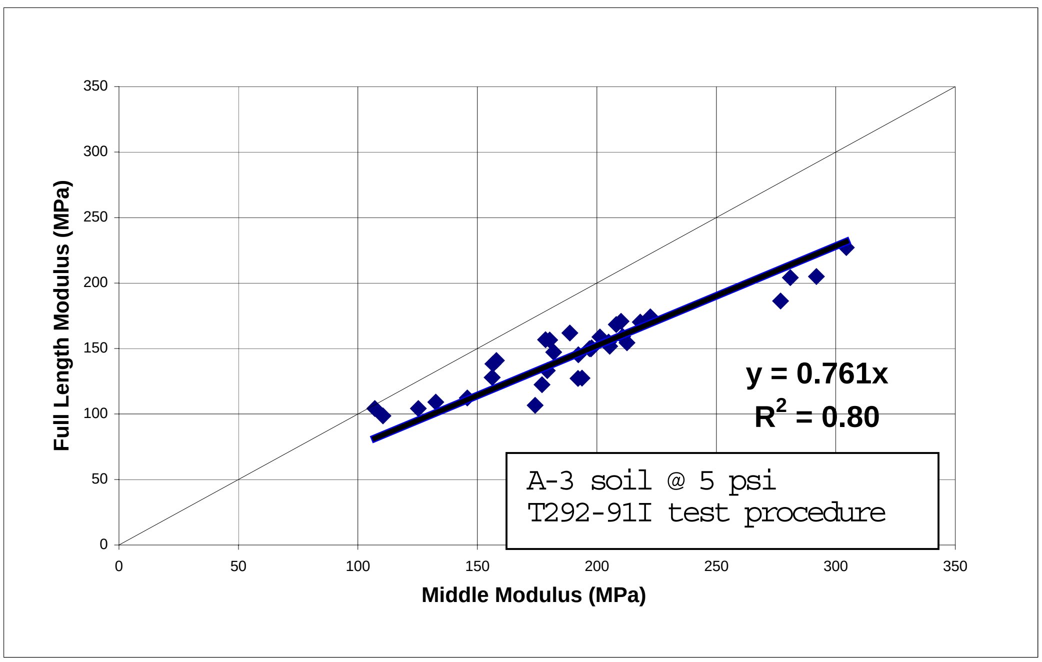


Figure 5.7 Full Length modulus versus middle length modulus for adjustment factor AF(B,A)-4

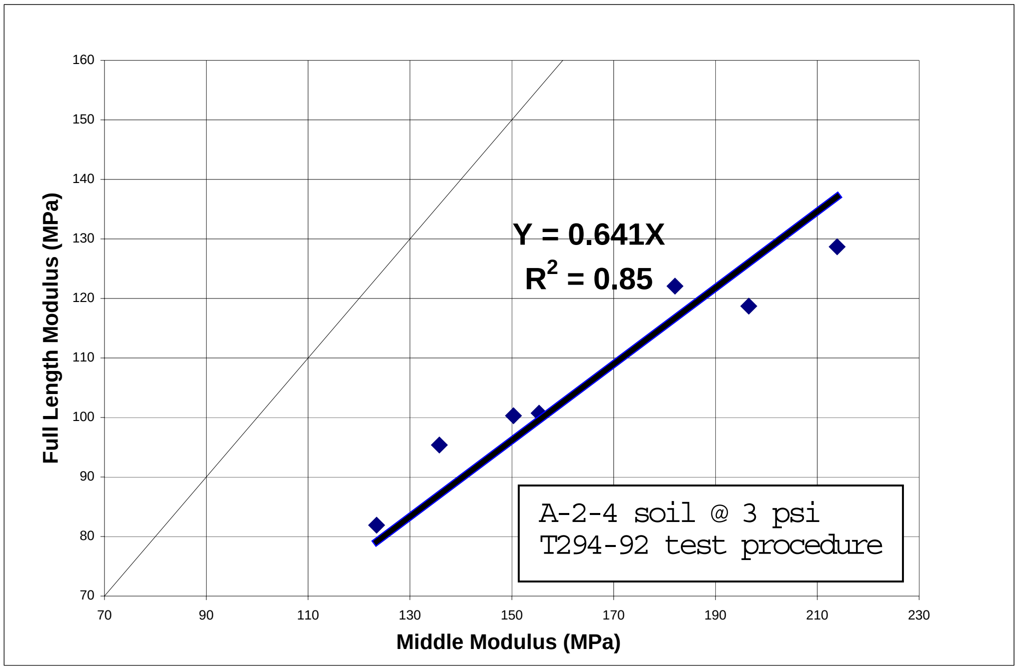


Figure 5.8 Full Length modulus versus middle length modulus for adjustment factor AF(3,1)-1

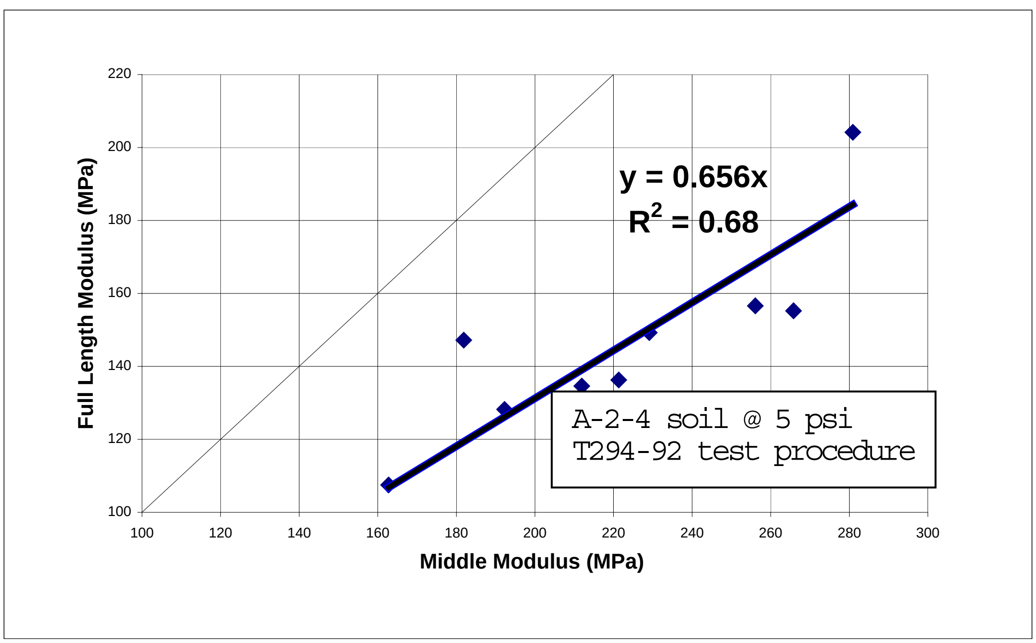


Figure 5.9 Full Length modulus versus middle length modulus for adjustment factor AF(3,1)-2

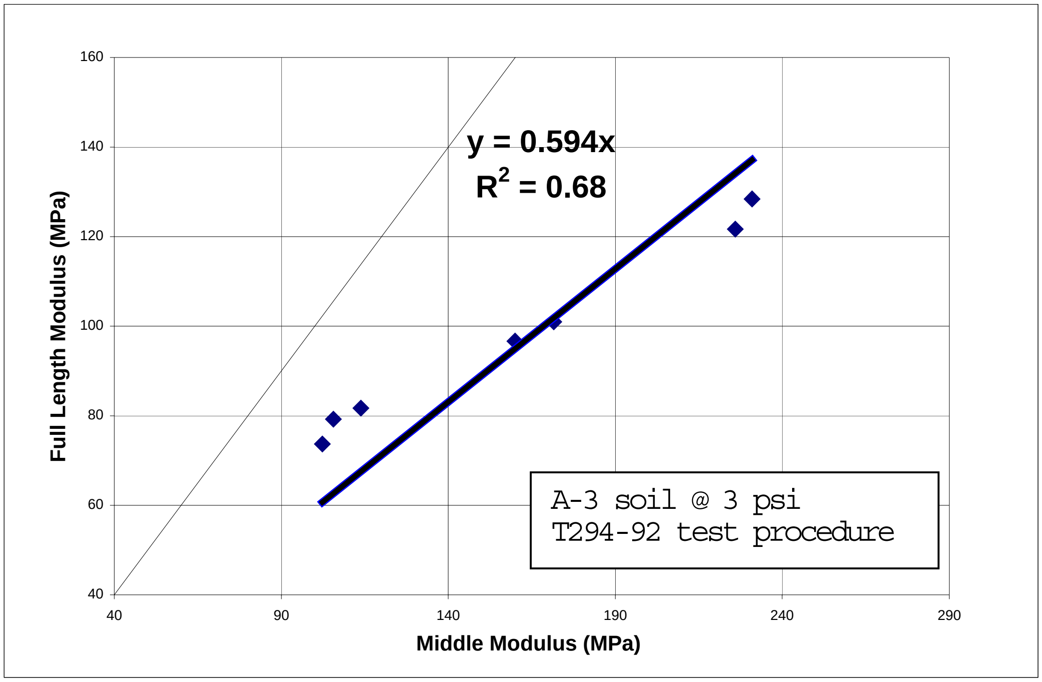


Figure 5.10 Full Length modulus versus middle length modulus for adjustment factor AF(3,1)-3

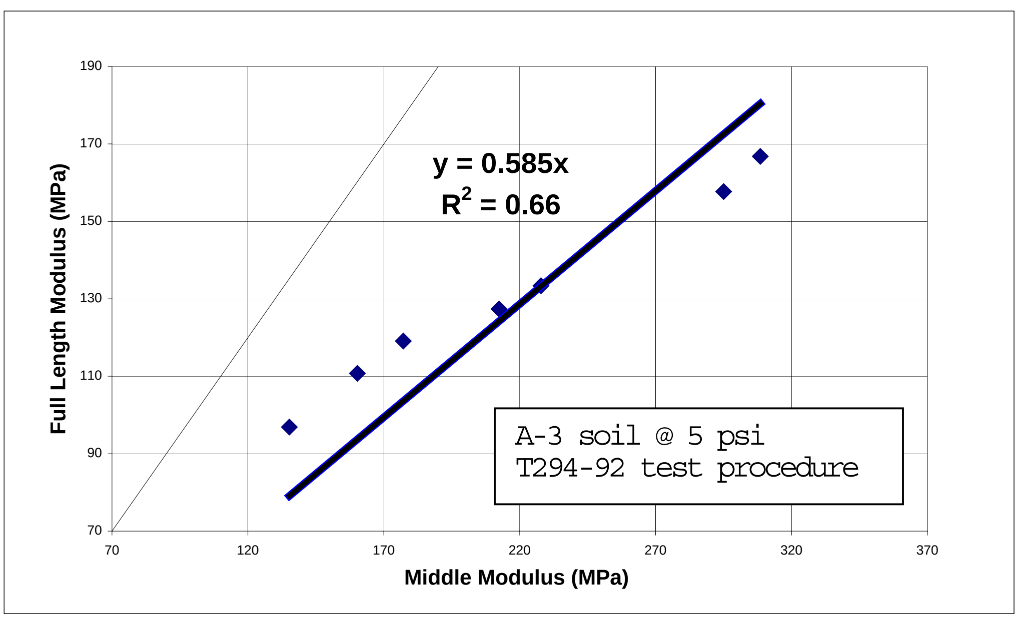


Figure 5.11 Full Length modulus versus middle length modulus for adjustment factor AF(3,1)-4

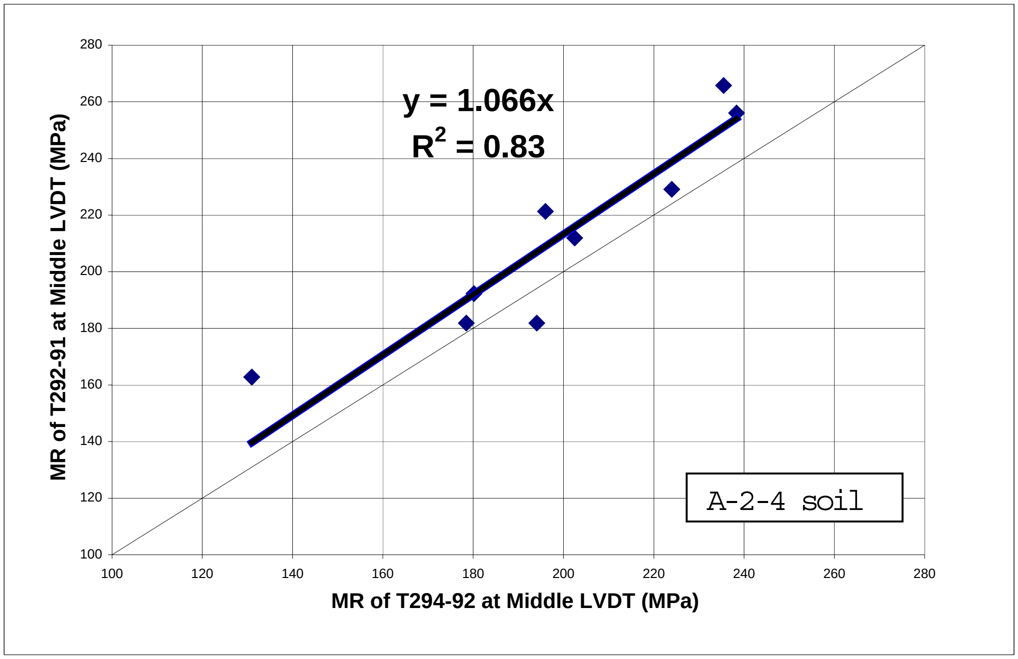


Figure 5.12 Comparison of modulus values for adjustment factor AF(A,1)-(A-2-4)

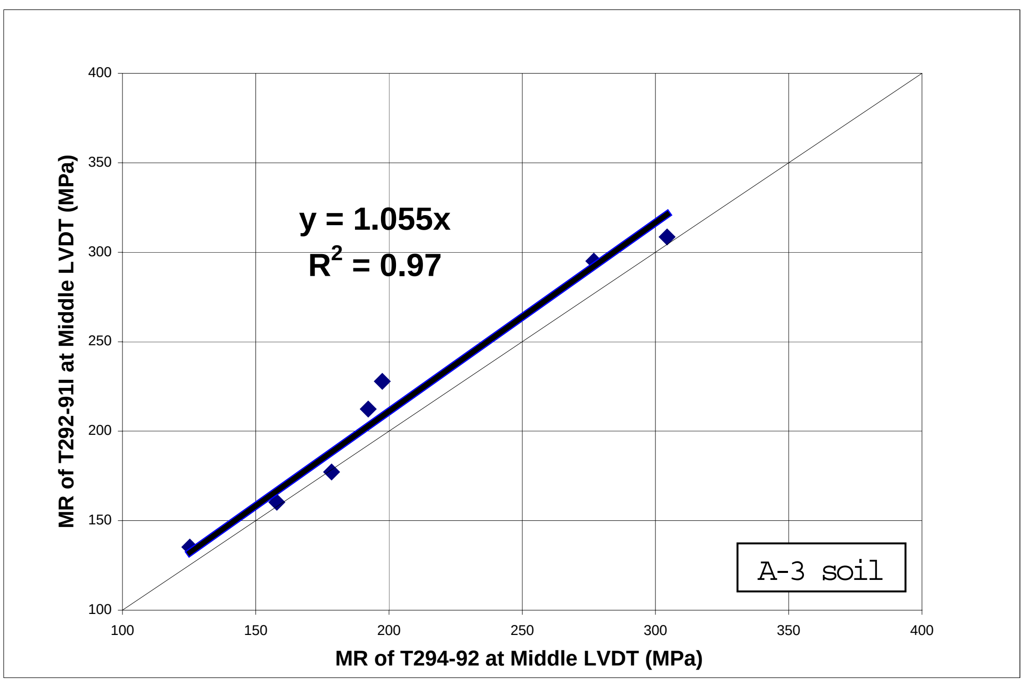


Figure 5.13 Comparison of modulus values for adjustment factor AF(A,1)-(A-3)

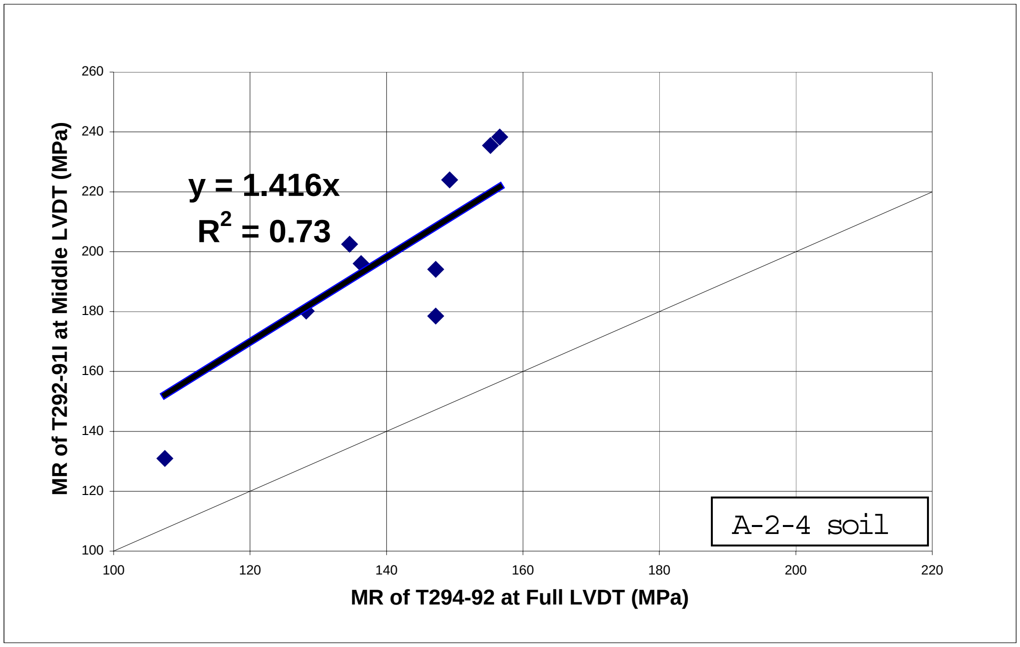


Figure 5.14 Comparison of modulus values for adjustment factor AF(A,3)-(A-2-4)

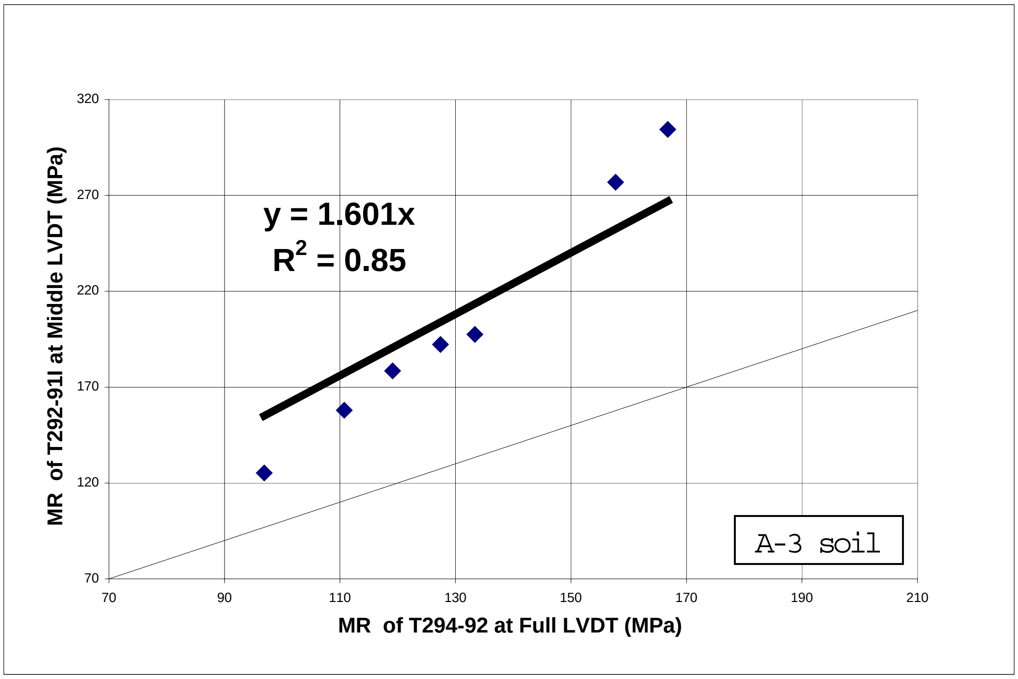


Figure 5.15 Comparison of modulus values for adjustment factor AF(A,3)-(A-3)

CHAPTER 6

SUMMARY, CONCLUSION, AND RECOMMENDATION

6.1 Summary

The primary objectives of this study were to develop a soil resilient modulus database system and to analyze the effects of different test procedures and LVDT positions on resilient modulus values through the database system. In order to achieve the objectives, a comprehensive literature review was conducted towards the basic database development concepts including the entities and relationships for the relational database model. The resilient modulus concept and the test procedures of T292-91I and T294-92 were also discussed, especially the resilient modulus measurement and different types of LVDT positions that were involved in the database analysis.

For the development of the database, user requirements were carefully collected and implemented into the database design process. Microsoft Visual Basic 6.0 plus Access 2000 were selected as the major development tools. The database was established with a full consideration of convenience, efficiency, data security, and functionality. In addition to the data entry/import, data query, and data edit functions, the RMDB was developed to include strong data communication functions with Microsoft Excel. The test data in Excel file format can be imported into the database, and the data from the database can also be printed out automatically into an Excel file format with graphical presentations. The data analysis function was another major feature of the database. The general data analysis and the comparative analysis of the RMDB included most common data analysis functions of the soil resilient modulus. The final product of the RMDB was a distributable software package.

The desired adjustment factors, which reflect the effects of different test procedures and LVDT positions on resilient modulus values, were determined by applying the functions of comparative analysis and the resilient modulus test data accommodated in the database. The linear regression models were used for the determination of each type of adjustment factors. Twelve adjustment factors were determined based on the resilient modulus test data from the database.

6.2 Conclusions

1. A resilient modulus database (RMDB) was developed using Visual Basic 6.0 and Microsoft Access. The database system was established according to the relational database model. The RMDB was applied to determine the resilient modulus adjustment factors.

2. The LVDT positions obviously affect the resilient modulus values. The resilient modulus values measured from the full length LVDT are about 75% (for the T292-91I) or 62% (for the T294-92) of the values measured from the middle length LVDT. The reduction in the resilient modulus value of 25 to 38 % is considered due to the effect of LVDT positions.
3. The difference is negligible in the modulus values measured between the middle length LVDTs from the T292-91I and T294-92 test procedures.
4. The difference is very significant (42 to 60% higher) in the modulus values measured from the middle LVDT of the T292-91I test procedure and from the full length LVDT of the T294-92 test procedure.
5. Strong correlations existed in the comparative analysis of the test data. The good correlations show the quality of the analysis, and add to the confidence in the test results.

6.3 Recommendations

1. The RMDB would become more useful if the database could be upgraded to fit server-client computer system in the future.

2. The soil resilient modulus test procedure should be formalized and standardized to establish a uniform tabular format of the resilient modulus test data for more efficient operation of the RMDB.
3. More resilient modulus tests should be performed to populate and enhance the RMDB. Automated pavement design procedures could be included in the future to further expand the capabilities of the RMDB.

APPENDIX

USER MANUAL OF THE RESILIENT MODULUS DATABASE

APPENDIX

TABLE OF CONTENTS

LIST OF FIGURES

A.1 APPLICATION STRUCTURE

A.1.1 Main Menu

The database applications fall into five main menu items (Figure A.1):

- System Database access control; data security management
- Data Entry Data entry/import; data edit and deletion
- Data Query Resilient modulus test data search; query result report
- Analysis General analysis and comparative analysis of the resilient modulus test data
- Help User manual of the resilient modulus database

Each main menu item contains a certain number of submenu items.

A.1.2 Submenu

The submenus of the System include (see Figure A.2):

- User Registration Registration of the new database users, edit of registration information of a registered user

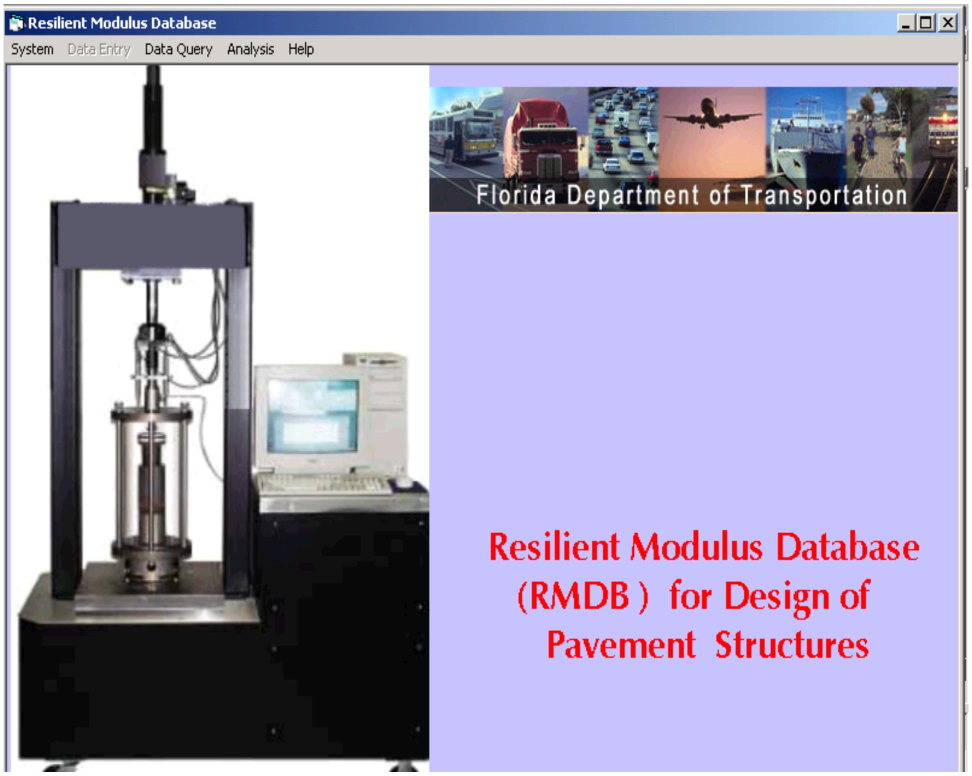


Figure A.1 Main form of the resilient modulus database

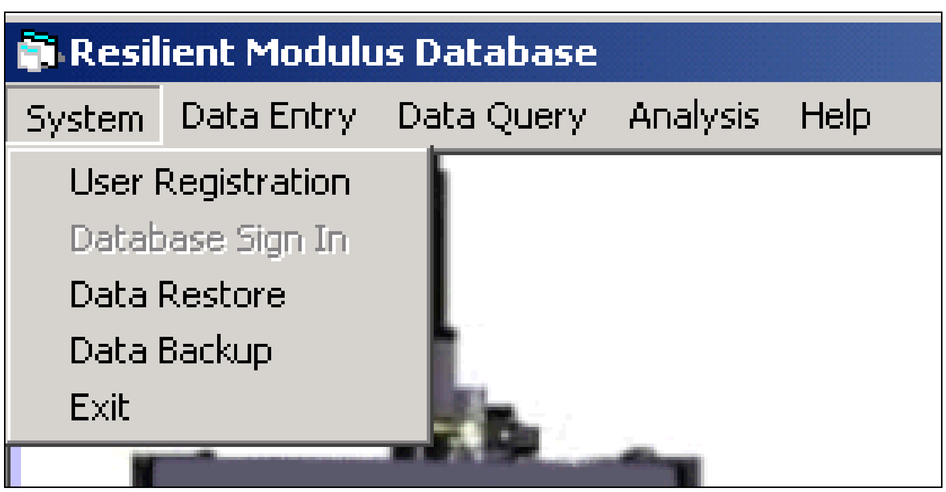


Figure A.2 Main menu item: System

- Database Sign In Database sign in for registered users or the database manager user
- Data Backup/Data Restore Backing up all the current data in the database; restoring the last backed up data
- Exit Exiting the database

The submenu of the Data Entry (Figure A.3):

- Soil Data entry, edit, or deletion of the soil samples for resilient modulus test
- Test Data Entry of the resilient modulus test condition data; import of the resilient modulus test result data; data edit or deletion
- Classification
  - AASHTO Display the criteria of the AASHTO soil classification.
  - Unified Display the criteria of the unified soil classification.
- CountyDistrict Display the name of counties, county number, and district number in Florida.

The Submenus of the Analysis (see Figure A.4):

- MR vs. Bulk Stress Conduct the regression analysis between the resilient modulus values and the bulk stress values

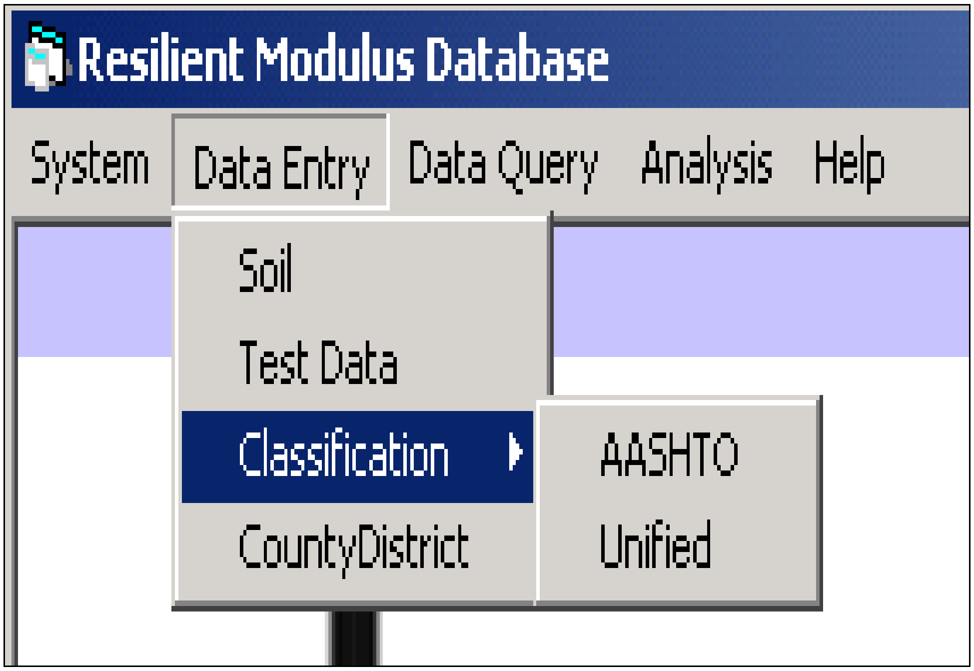


Figure A.3 Main menu item: Data Entry

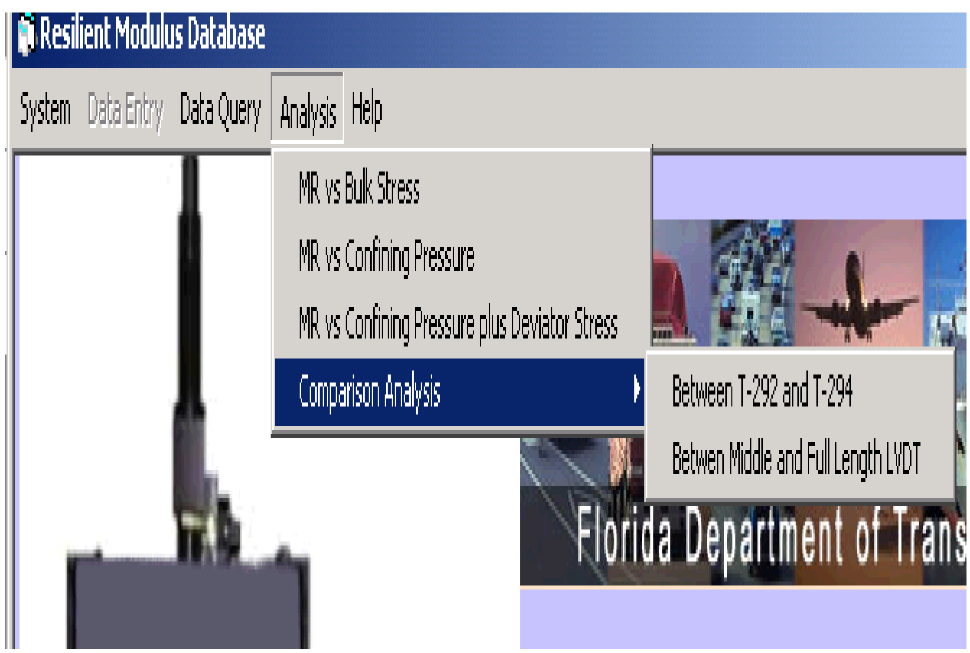


Figure A.4 Main menu item: Analysis

- MR vs. Confining Pressure Conduct the regression analysis between the resilient modulus values and the confining pressure values.
- MR VS. Confining Pressure plus Deviator Stress Conduct the regression analysis between the resilient modulus values and the test confining pressure values plus the deviator stress values.
- Comparative Analysis
    - Between T292-91I and T294-92 Conduct the regression analysis between the resilient modulus values measured at the middle LVDT of the T292-91I test procedure and that measured at the middle LVDT or the full length LVDT of the T294-92 test procedure.
    - Between Middle and Full Length LVDT Conduct the regression analysis between the resilient modulus values of the middle length LVDT and that of the full length LVDT of the T292-91I or the T294-92 test procedure.

A.2 SYSTEM MANAGEMENT

A.2.1 Access Control

The RMDB users are categorized into three different levels of database access: manager level, registered user level, and general user level. The operation restriction or function availability is controlled by the database menu activities for each user level. Being activated after access means the function of the menu is available to the user. The detailed function availability for different levels of users is described as follows.

Manager level All functions are available to the manager level users, especially the user registration application. No database user other than the manager level users can authorize other users to access the RMDB system. The manager level users will monopolize the username "manager".

Registered user level Every function is opened to this level of users but user registration. The user registration menu is inactive for non-manager registered users.

General user level The user registration, data backup/restoration, and data entry are prohibited to general users. Registration, Backup/Restore, and Data Entry menus will be inactive when this type of user accesses the RMDB. But all other database functions are available for them. The general users don’t need to execute the sign-in process while accessing the database.

User Registration can only be accessed under the supervision of the RMDB manager level users. The information needed for a new user registration includes the name of the user, work phone number, E-mail address, unique username and password, as demonstrated in Figure A.5.

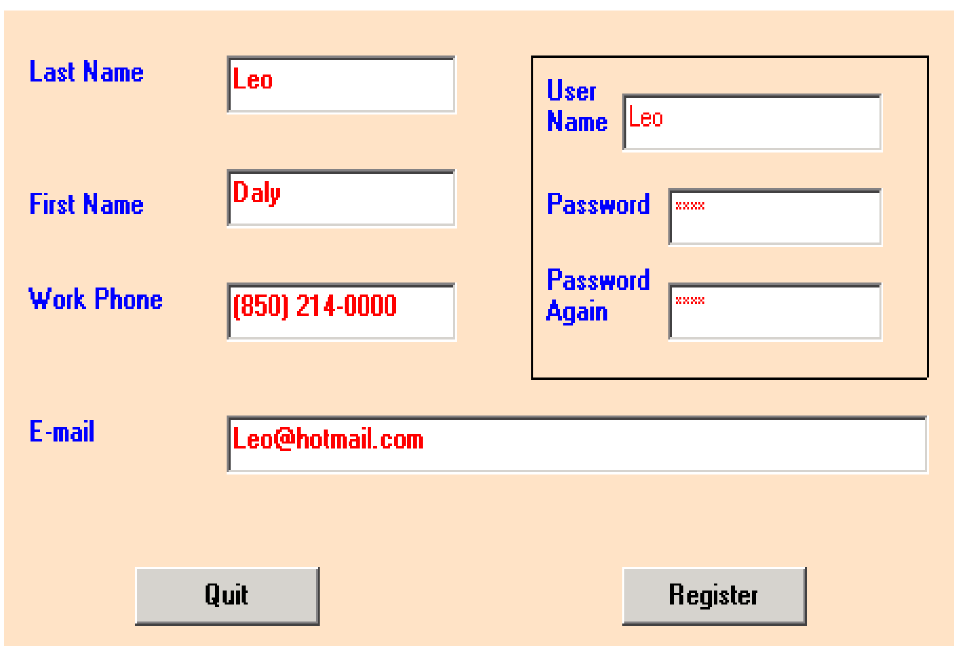


Figure A.5 User registration form

The RMDB will show a message, “Successfully registered. Welcome to the RMDB!” on the message board after a successful registration, as demonstrated in Figure A.6. The sign-in form is also demonstrated in Figure A.7.

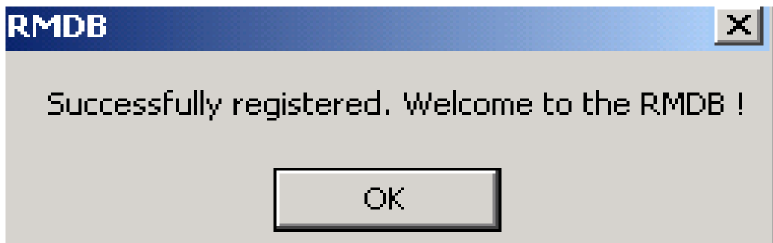


Figure A.6 Message after a successful registration

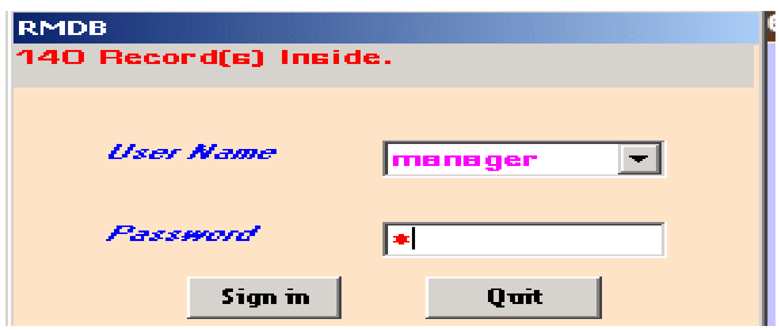


Figure A.7 Sign-in form

A.2.2 Data Security

The database access control discussed above is one type of data security countermeasure. The RMDB also provides the users a data backup/restore function, as another type of data security countermeasure.

The data backup function allows the RMDB to copy all the data information into the backup space. By activating the Data Backup menu, the RMDB will remind the user that all the data in the database will be backed up into temporary files, and let the user make a choice: to continue or not. By pressing the “Yes” button, all the data will be transferred into those temporary files so that the database will be empty and a successful backup message will be given, as shown in Figure A.8. The data backup functions can be used all the time along the database operations for securing the data. But the backup data in the temporary files will be replaced by the next backup operation. Only the last backup data can be restored. In that case, all the current data inside the RMDB will be replaced by the last backup data. Because this operation will delete all the current data, a warning message, as demonstrated in Figure A.9, will give the user a choice of “yes” or “no” to continue the data restoration operation.

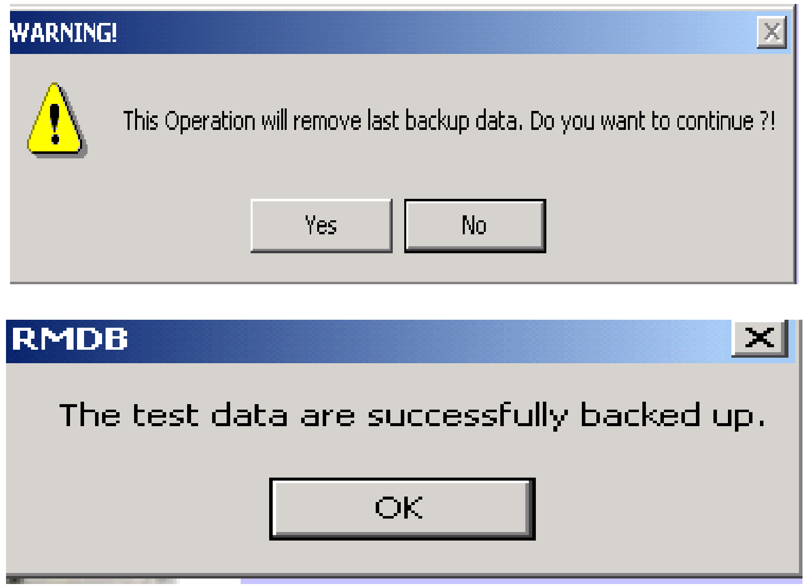


Figure A.8 Messages in the Data Backup

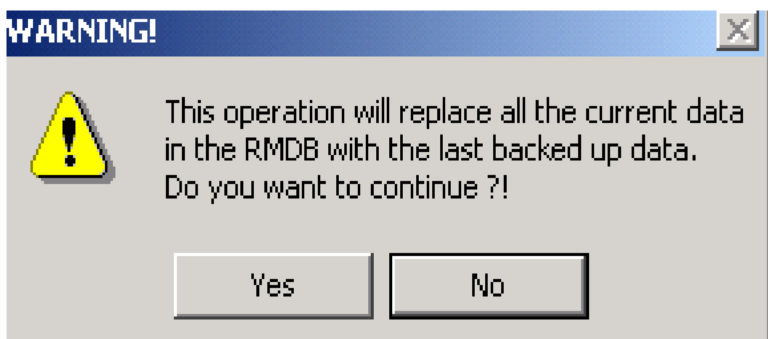


Figure A.9 Message in the Data Restoration

A.3 DATA ENTRY

A.3.1 Entry of Soil Data

The main form of soil data is shown in Figure A.10.

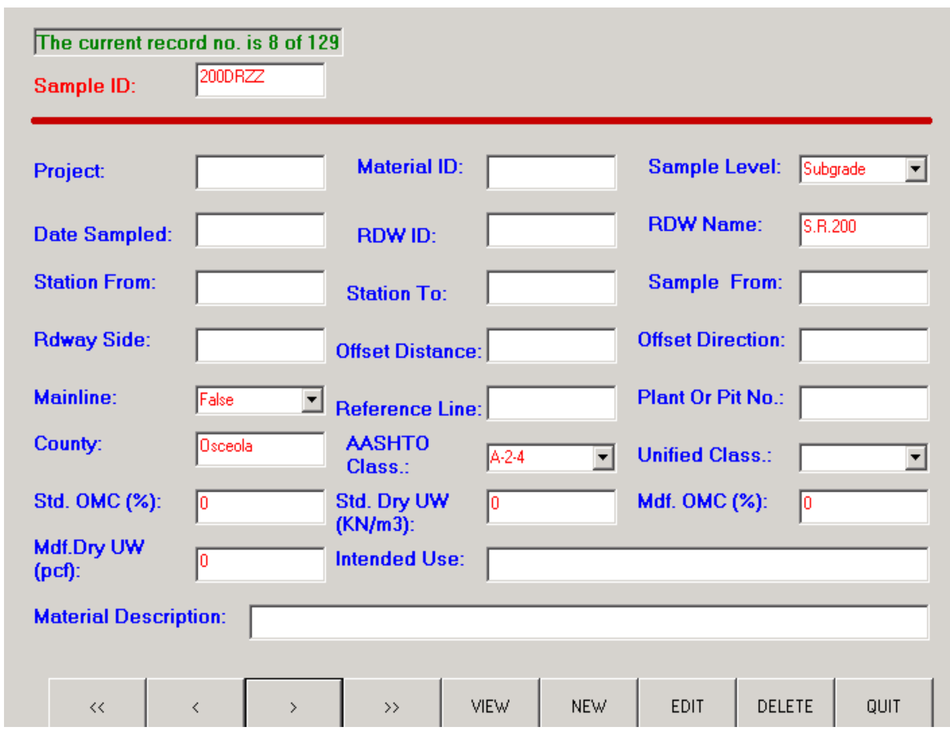


Figure A.10 Main form of the soil data entry

A new entry of the soil data record can be executed using the following procedures:

1. Activate the soil data entry form.

The soil data entry form (Figure A.11) can be activated simply by clicking the NEW button on the main form of the soil data. Only two command buttons are shown on the form: SAVE, and BACK. The SAVE button is for submitting the new data entry, whereas the BACK button can lead to the original main entry form without saving the data.

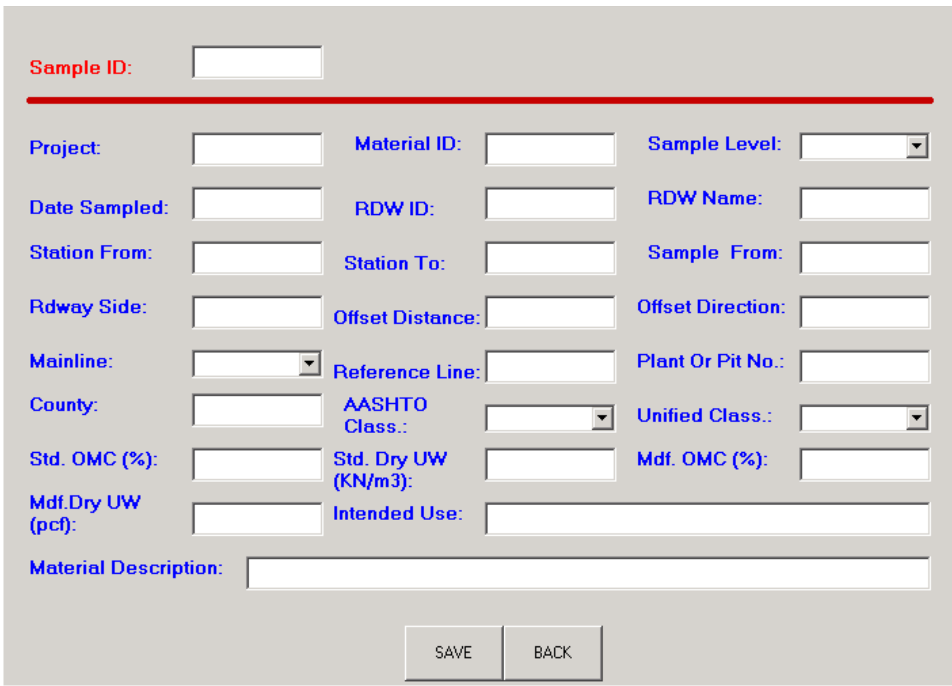


Figure A.11 Entry form of the soil data

2. Input the soil data information

Fill out all the text boxes and combo boxes for the soil data items. The sample ID must be filled out since it is the identification of the soil sample.

3. Submit the soil data entry.

Submit the data entry by clicking the “SAVE” button on the entry form of the soil data.

Before the database can be updated, a message box will be displayed, as shown in Figure A.12, to provide a chance for confirmation. If the “Yes” button is selected, then the record will be saved to the end of the soil data table in the database. Otherwise, the data entry will be discarded. Another message will be shown as in Figure A.13, while saving an existing soil data record into RMDB. The data entry will be denied.

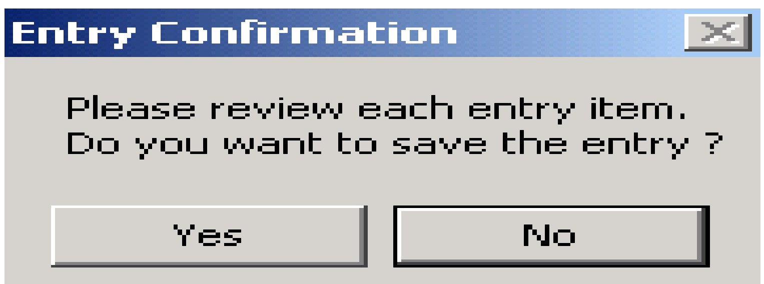


Figure A.12 Message of confirmation for the soil data entry

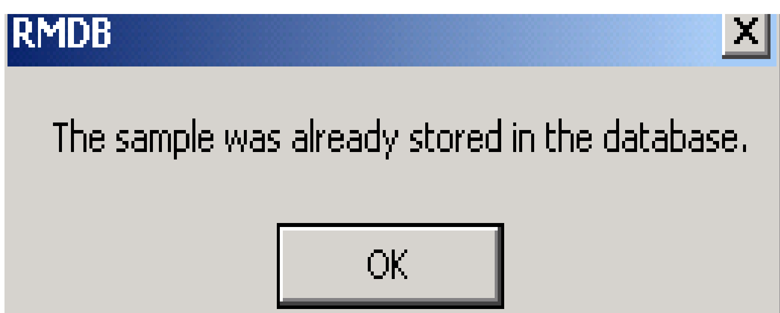


Figure A.13 Message while saving an existing soil record

Edit

The following procedures are used to edit the soil data:

1. Find the targeted data record for editing.

   Track and find the data record that is intended for editing, and show it on the main entry form of the soil data.

2. Activate the edit form.

   Pressing the EDIT button will lead the RMDB to the data edit form, which contains the same format as the data entry form as shown in Figure 12. But, the SAVE button is for submitting the updated data of an existing soil data record instead of a new data record.

3. Modify the data record.

   Modify the data items as needed. Note that the sample ID cannot be edited since it is the identification of the soil data record.

4. Submit the edited data record.

   Submit the edited data record by clicking the “SAVE” button on the data edit form. Before the database is updated, a message will be displayed, as shown in Figure A.14, to confirm the editing operation. A second message during the editing operation will be displayed when trying to edit a soil data record that doesn't exist in the database (Figure A.15).

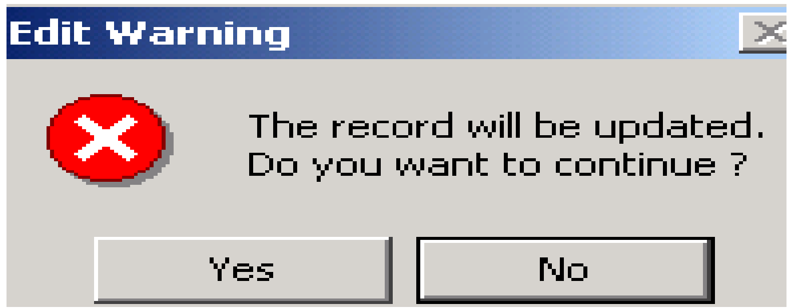


Figure A.14 Message of confirmation for editing soil data

Figure A.15 Message while editing a nonexisting soil record

Deletion

The deletion operation only takes the following two steps:

1. Find the targeted data record for deletion.

   This is the same step as in the Edit operation.

2. Submit the deletion.

   By clicking the "DELETE" button, as illustrated in Figure A.10, the current soil data record displayed on the form will be deleted. A message (see Figure A.16) will be displayed to warn the user that the operation will delete not only the soil data, but also all the resilient modulus test data of the particular sample. The message allows the user to confirm the deletion operation.

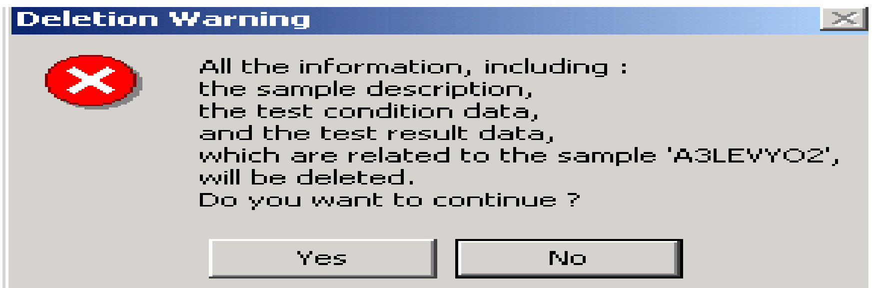


Figure A.16 Message of confirmation for deleting a soil data

View and tracking

By clicking the “VIEW” button on the main form of the soil data, the current data record can be viewed in a two-dimensional tabular format, as shown in Figure A.17. For tracking a data record, use the scroll bar of the data table to find the data record, and double click on it, or single click on it and then press the “BACK” button. The RMDB will pick up the selected data record and show it on the main form of the soil data for further editing or deletion operations.

Sample ID	Project ID	Material No	Layer Sampled	Date Sampled	AASHTO Classification	Unified Classification	County	Roadway ID	Name of Roadway	Roadway Side
2B-6CSS			Embankment		A-3		Clay		U.S.17	
2C-1JEC			Embankment		A-2-6		Wakulla		U.S.27	
2C-1JSC			Embankment		A-4		Wakulla		U.S.27	
2C-2GEC			Embankment		A-6		Gadsden		U.S.27	
2C-2GES			Embankment		A-2-4		Gadsden		U.S.27	
2C-2GSS			Embankment		A-2-4		Gadsden		U.S.27	
2C-2JEC			Embankment		A-2-4		Wakulla		U.S.27	
2C-2JSC			Subgrade		A-4		Wakulla		U.S.27	
2C-3GSS			Subgrade		A-3		Gadsden		U.S.27	
2D-3MES			Embankment		A-3		Martin		U.S.1	
2D-3MSS			Embankment		A-3		Martin		U.S.1	
2D-4MES			Embankment		A-3		Martin		U.S.1	
2E-1SES			Embankment		A-2-4		Seminole		U.S.114	
2E-1SSS			Embankment		A-2-4		Seminole		U.S.114	
2E-2SES			Embankment		A-3		Seminole		U.S.114	
2E-2SSS			Embankment		A-2-4		Seminole		U.S.114	
2E-3OES			Embankment		A-3		Osceola		U.S.114	
2E-3OSS			Embankment		A-3		Osceola		U.S.114	
2E-4OES			Embankment		A-3		Osceola		U.S.114	
2E-4OSS			Embankment		A-3		Osceola		U.S.114	
ST106S1					Unknown					
ST118S1					Unknown					
ST133S1					Unknown					
ST142S1					A-3					

BACK

Figure A.17 View the form of the soil data table

Two other methods are available to track a soil data record:

1. Use the four record tracking buttons, "FIRST", "PREVIOUS", "NEXT", and "LAST", as demonstrated in Figure A.10.
2. Input a sample ID into the Sample ID textbox on the main form of the soil data.

   When a sample ID in the textbox is being activated, the database will search for this particular sample ID, and display the data information. A message box will be shown if tracking a data record that doesn't exist in the database (Figure A.18).

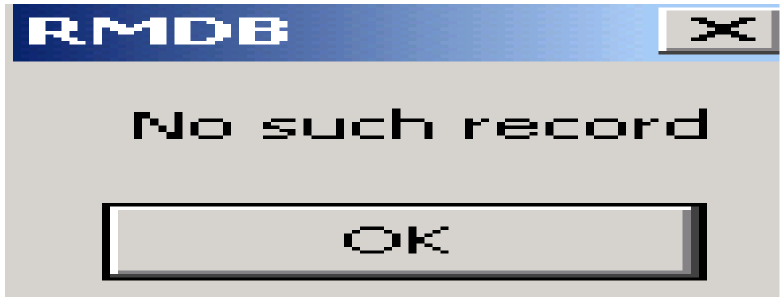


Figure A.18 Message while tracking a nonexisting soil record

A.3.2 Entry of Resilient Modulus Test Data

Only the samples that have already been stored in the soil data table can be entered resilient modulus test data. The following procedures are required to enter a resilient modulus test data:

1. Activate the entry form.

   The main entry form of the soil resilient modulus test data (Figure A.19) can be seen by clicking the "NEW" button on the tabular form of the resilient modulus test data.

2. Input the test condition data.

   Fill out the items of the test condition data on the main entry form of the test data. The red-labeled data items must be filled out since they are the components of the soil resilient modulus test identification.

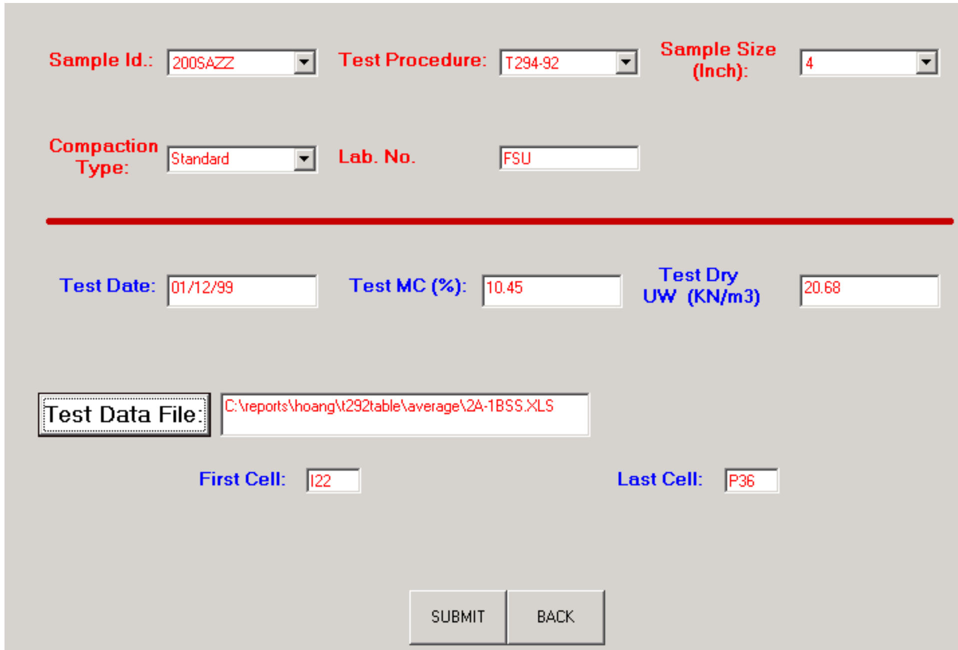


Figure A.19 Main entry form of resilient modulus test data

3. Obtain the full-path name of the resilient modulus test data file.

   Obtain the full path name of the resilient modulus test data file in Microsoft (MS) Excel format with the help of a common dialogue box (Figure A.20), and display it in the textbox as demonstrated in Figure A.21. The RMDB can track an Excel test data file by its full path name, and import all the test data of the file to the database programmatically.

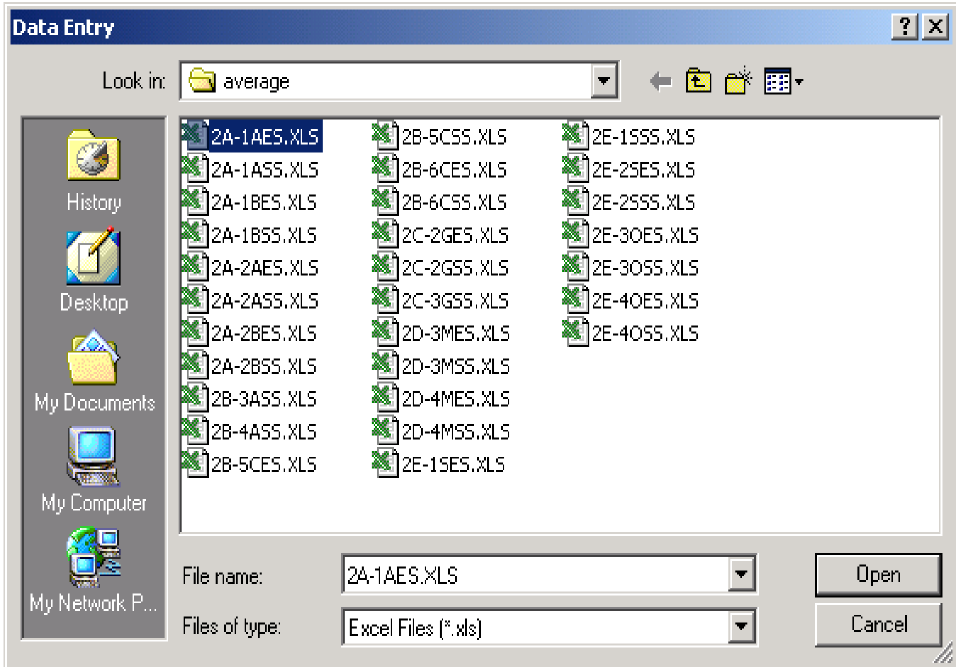


Figure A.20 Common dialogue box for data file selection

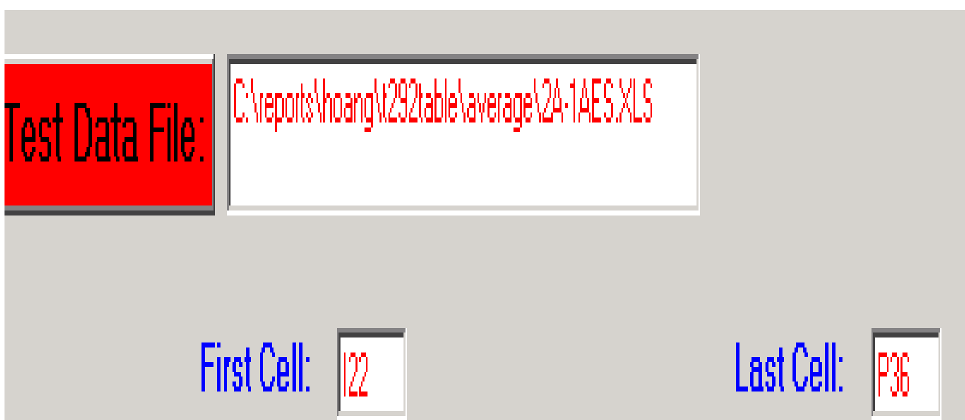
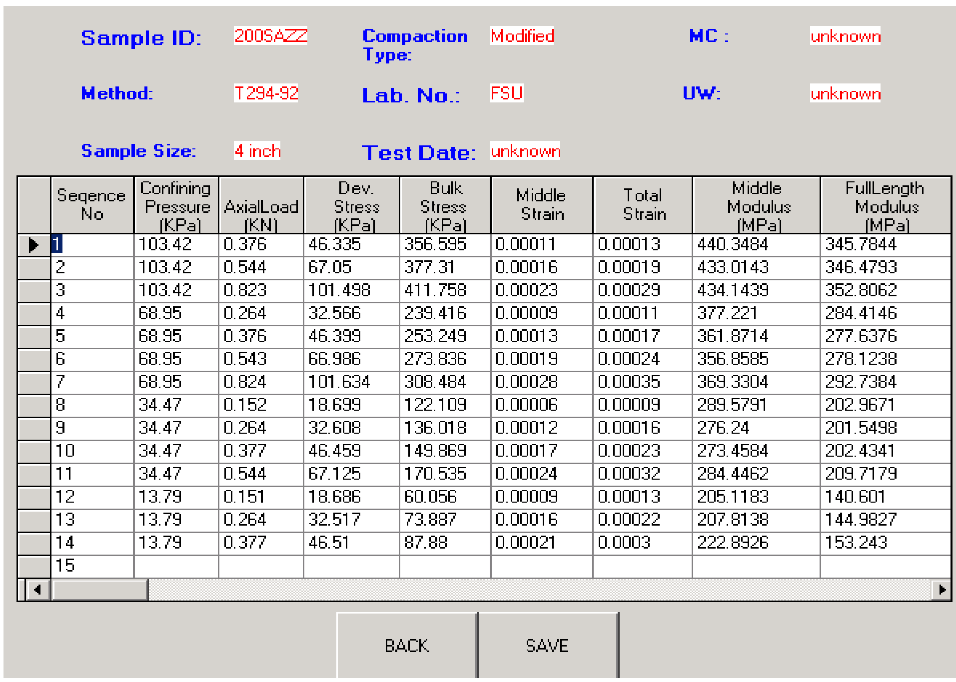


Figure A.21 Full path name of a resilient modulus test data file in MS Excel format

4. Submit the test data entry.

By clicking the “SUBMIT” button on the main entry form, an intermediate entry form will display all the input data, as demonstrated in Figure A.22.



Sample ID: 200SAZZ
Compaction Type: Modified
MC : unknown
Method: T294-92
Lab. No.: FSU
UW: unknown
Sample Size: 4 inch
Test Date: unknown

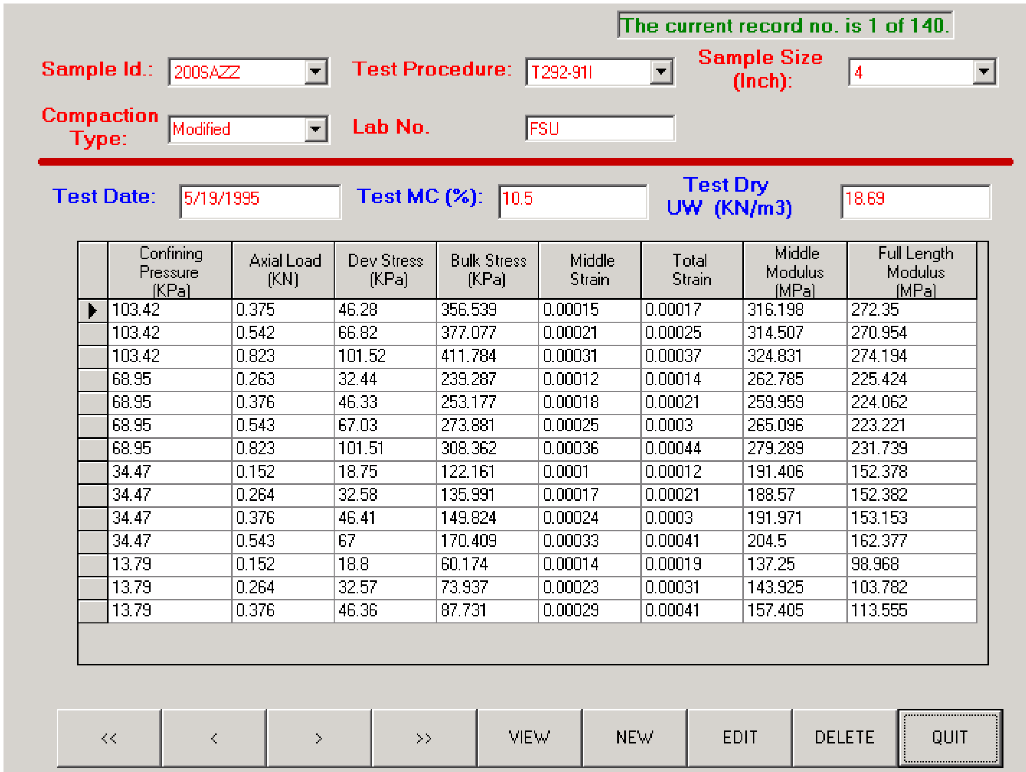
Seqence No	Confining Pressure (KPa)	AxialLoad (KN)	Dev. Stress (KPa)	Bulk Stress (KPa)	Middle Strain	Total Strain	Middle Modulus (MPa)	FullLength Modulus (MPa)
1	103.42	0.376	46.335	356.595	0.00011	0.00013	440.3484	345.7844
2	103.42	0.544	67.05	377.31	0.00016	0.00019	433.0143	346.4793
3	103.42	0.823	101.498	411.758	0.00023	0.00029	434.1439	352.8062
4	68.95	0.264	32.566	239.416	0.00009	0.00011	377.221	284.4146
5	68.95	0.376	46.399	253.249	0.00013	0.00017	361.8714	277.6376
6	68.95	0.543	66.986	273.836	0.00019	0.00024	356.8585	278.1238
7	68.95	0.824	101.634	308.484	0.00028	0.00035	369.3304	292.7384
8	34.47	0.152	18.699	122.109	0.00006	0.00009	289.5791	202.9671
9	34.47	0.264	32.608	136.018	0.00012	0.00016	276.24	201.5498
10	34.47	0.377	46.459	149.869	0.00017	0.00023	273.4584	202.4341
11	34.47	0.544	67.125	170.535	0.00024	0.00032	284.4462	209.7179
12	13.79	0.151	18.686	60.056	0.00009	0.00013	205.1183	140.601
13	13.79	0.264	32.517	73.887	0.00016	0.00022	207.8138	144.9827
14	13.79	0.377	46.51	87.88	0.00021	0.0003	222.8926	153.243
15								

BACK SAVE

Figure A.22 Intermediate entry form of resilient modulus test data

5. Save the test data entry

By pressing the “SAVE” button on the intermediate entry form, the test data entry will be saved in the database, and the resilient modulus test data will be displayed in tabular format (Figure A.23). A message will be shown to indicate that the test data entry has been successfully saved (Figure A.24).



The current record no. is 1 of 140.

Sample Id.: 200SAZZ | Test Procedure: T292-91I | Sample Size (Inch): 4

Compaction Type: Modified | Lab No. FSU

Test Date: 5/19/1995 | Test MC (%): 10.5 | Test Dry UW (KN/m3) 18.69

Confining Pressure (KPa)	Axial Load (KN)	Dev Stress (KPa)	Bulk Stress (KPa)	Middle Strain	Total Strain	Middle Modulus (MPa)	Full Length Modulus (MPa)
103.42	0.375	46.28	356.539	0.00015	0.00017	316.198	272.35
103.42	0.542	66.82	377.077	0.00021	0.00025	314.507	270.954
103.42	0.823	101.52	411.784	0.00031	0.00037	324.831	274.194
68.95	0.263	32.44	239.287	0.00012	0.00014	262.785	225.424
68.95	0.376	46.33	253.177	0.00018	0.00021	259.959	224.062
68.95	0.543	67.03	273.881	0.00025	0.0003	265.096	223.221
68.95	0.823	101.51	308.362	0.00036	0.00044	279.289	231.739
34.47	0.152	18.75	122.161	0.0001	0.00012	191.406	152.378
34.47	0.264	32.58	135.991	0.00017	0.00021	188.57	152.382
34.47	0.376	46.41	149.824	0.00024	0.0003	191.971	153.153
34.47	0.543	67	170.409	0.00033	0.00041	204.5	162.377
13.79	0.152	18.8	60.174	0.00014	0.00019	137.25	98.968
13.79	0.264	32.57	73.937	0.00023	0.00031	143.925	103.782
13.79	0.376	46.36	87.731	0.00029	0.00041	157.405	113.555

<< | < | > | >> | VIEW | NEW | EDIT | DELETE | QUIT

Figure A.23 Tabular form of resilient modulus test data

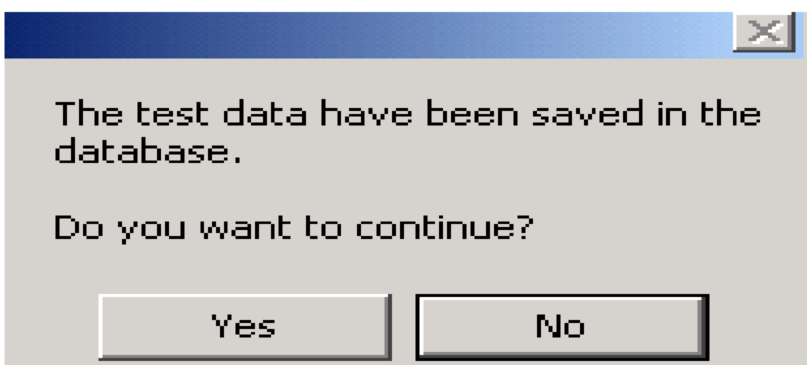


Figure A.24 Message shown after an entry of test data

Edit

The following procedures are used to edit the test data:

1. Find the targeted data record for editing.

   Track and find the test data file that is intended for editing, and show it on a tabular format.

2. Activate the edit form.

   Pressing the “EDIT” button on the tabular form will switch the interface to the editing format, which is exactly the same as the main entry form of the resilient modulus test data, as demonstrated in Figure A.19.

3. Modify the test data or the data source file.

   Modify the data items or the data source file as needed. Note that the red-labeled items can not be edited. The test data can be replaced by following the same procedures as in the test data entry.

4. Submit the edited test data (file).

   Submit the edited test data (file) by pressing the “SAVE” button. The RMDB will show a message, “Do you want to continue?” If the answer is “Yes”, then the database will be updated by the edited test data. If not, the edited test data (file) will be discarded.

Deletion

The following steps are used to delete a record of resilient modulus test data:

1. Find the targeted data record for deletion.

   Track and find the test data that is intended for deletion, and show it on the tabular form.

2. Submit the data record for deletion.

   By clicking the “DELETE” button on the tabular form of the resilient modulus test data, the RMDB will show a message (Figure A.25), and ask the user to confirm the deletion operation. The test data record will be deleted from the database if the selection is “Yes”, or the data will be kept if “No” is selected.

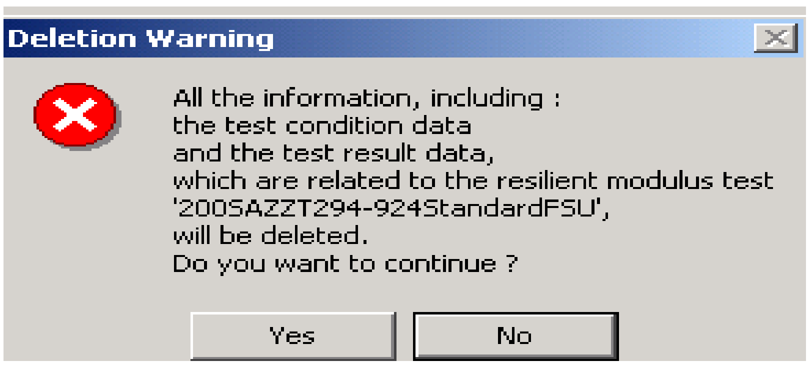


Figure A.25 Message shown for test data deletion

The test data record can be viewed and tracked in the same way as discussed previously for the soil data table. The view of the test data table is demonstrated in Figure A.26.

Sample Id.	Sample Size (Inch)	Test Procedure	Test Date	Moisture Content (%)	Maximum Dry Density (Kg/m3)	Standard Or Modified Compaction	Lab. No
2D-3MES	4	T292-91I	8/18/1995	9.6	16.64	Modified	FSU
2D-3MSS	4	T292-91I	10/5/1995	8.9	18.51	Modified	FSU
2D-4MES	4	T292-91I	8/23/1995	9.5	17.67	Modified	FSU
2E-1SES	4	T292-91I	10/26/1995	8.5	17.13	Modified	FSU
2E-1SSS	4	T292-91I	11/1/1995	6.4	18.88	Modified	FSU
2E-2SES	4	T292-91I	10/25/1995	12.7	16.94	Modified	FSU
2E-2SSS	4	T292-91I	11/2/1995	8	18.45	Modified	FSU
2E-3OES	4	T292-91I	9/8/1995	12.6	16.79	Modified	FSU
2E-3OSS	4	T292-91I	11/15/1995	9	18.59	Modified	FSU
2E-4OES	4	T292-91I	9/12/1995	12.9	16.32	Modified	FSU
2E-4OSS	4	T292-91I	10/11/1995	8.9	18.95	Modified	FSU
2A-1ASS	4	T294-92	5/7/1996	10.1	18.19	Modified	FSU
2A-1BSS	4	T294-92	4/28/1996	12	16.4	Modified	FSU
2A-2ASS	4	T294-92	4/29/1996	10.5	18.82	Modified	FSU
2A-2BSS	4	T294-92	4/29/1996	10.8	16.76	Modified	FSU
2B-3ASS	4	T294-92	5/2/1996	11.7	17.69	Modified	FSU
2B-4ASS	4	T294-92	5/2/1996	11.3	17.65	Modified	FSU
2B-5CSS	4	T294-92	4/30/1996	13.5	15.77	Modified	FSU
2B-6CSS	4	T294-92	5/1/1996	14.3	15.76	Modified	FSU
2C-2GSS	4	T294-92	5/8/1996	6.9	20.12	Modified	FSU
2C-2JSC	4	T294-92	5/5/1996	7.4	20.51	Modified	FSU
2C-3GSS	4	T294-92	5/5/1996	8.9	19.86	Modified	FSU
2E-1SSS	4	T294-92	4/30/1996	6.3	17.65	Modified	FSU
2E-2SSS	4	T294-92	5/7/1996	8	18.61	Modified	FSU
2E-3OSS	4	T294-92	5/3/1996	9.1	18.25	Modified	FSU

BACK

Figure A.26 View of the test data table

A.4 DATA QUERY

A.4.1 Procedures of Query Operation

The following procedures are used to execute a data query:

1. Select query constraints.

Select the query constraint items to obtain the desired query results. Fill out the selected constraint items with proper input data information on the main form of the data query (Figure A.27).

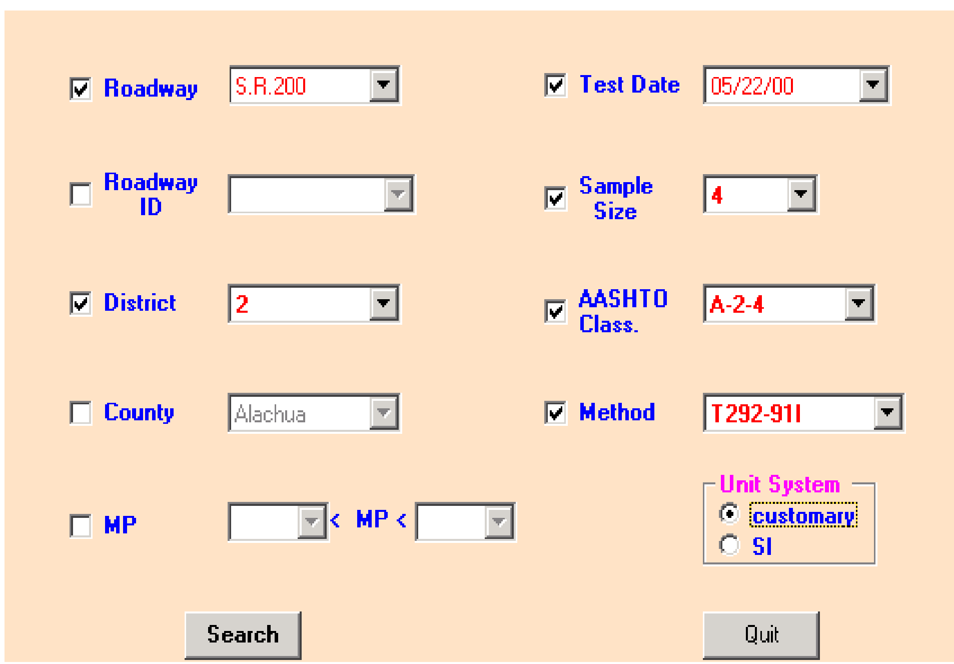
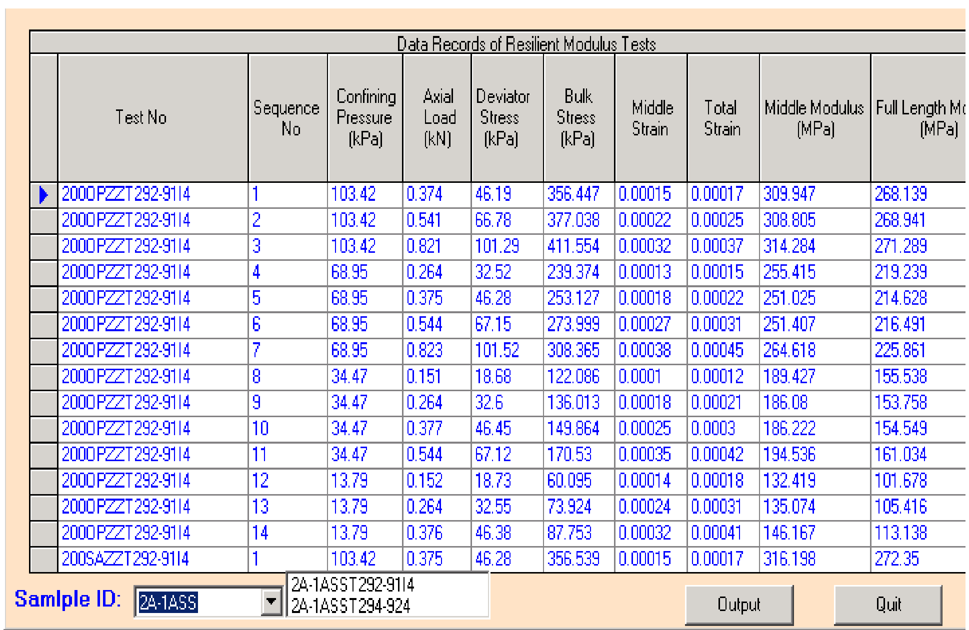


Figure A.27 Main form of data query

2. Process query request

Execute the query request by clicking the “Search” button on the main form of the data query (Figure A.27). The search will result in selecting a set of sample IDs in the combo box, and listing all the associated resilient modulus test data of those samples in a tabular grid form (Figure A.28). A summary table can be printed in an MS Excel file format by clicking the “Output” button.



Data Records of Resilient Modulus Tests

Test No	Sequence No	Confining Pressure (kPa)	Axial Load (kN)	Deviator Stress (kPa)	Bulk Stress (kPa)	Middle Strain	Total Strain	Middle Modulus (MPa)	Full Length Mo (MPa)
2000PZZT292-9114	1	103.42	0.374	46.19	356.447	0.00015	0.00017	309.947	268.139
2000PZZT292-9114	2	103.42	0.541	66.78	377.038	0.00022	0.00025	308.805	268.941
2000PZZT292-9114	3	103.42	0.821	101.29	411.554	0.00032	0.00037	314.284	271.289
2000PZZT292-9114	4	68.95	0.264	32.52	239.374	0.00013	0.00015	255.415	219.239
2000PZZT292-9114	5	68.95	0.375	46.28	253.127	0.00018	0.00022	251.025	214.628
2000PZZT292-9114	6	68.95	0.544	67.15	273.999	0.00027	0.00031	251.407	216.491
2000PZZT292-9114	7	68.95	0.823	101.52	308.365	0.00038	0.00045	264.618	225.861
2000PZZT292-9114	8	34.47	0.151	18.68	122.086	0.0001	0.00012	189.427	155.538
2000PZZT292-9114	9	34.47	0.264	32.6	136.013	0.00018	0.00021	186.08	153.758
2000PZZT292-9114	10	34.47	0.377	46.45	149.864	0.00025	0.0003	186.222	154.549
2000PZZT292-9114	11	34.47	0.544	67.12	170.53	0.00035	0.00042	194.536	161.034
2000PZZT292-9114	12	13.79	0.152	18.73	60.095	0.00014	0.00018	132.419	101.678
2000PZZT292-9114	13	13.79	0.264	32.55	73.924	0.00024	0.00031	135.074	105.416
2000PZZT292-9114	14	13.79	0.376	46.38	87.753	0.00032	0.00041	146.167	113.138
200SAZZT292-9114	1	103.42	0.375	46.28	356.539	0.00015	0.00017	316.198	272.35

Figure A.28 Summary table of test results from query operation

A.4.2 Report of Query Results

If a report is needed for an individual resilient modulus test in the summary table from the query operation, then the following procedures are used to present a summary report of the test results:

1. Find the desired test number.

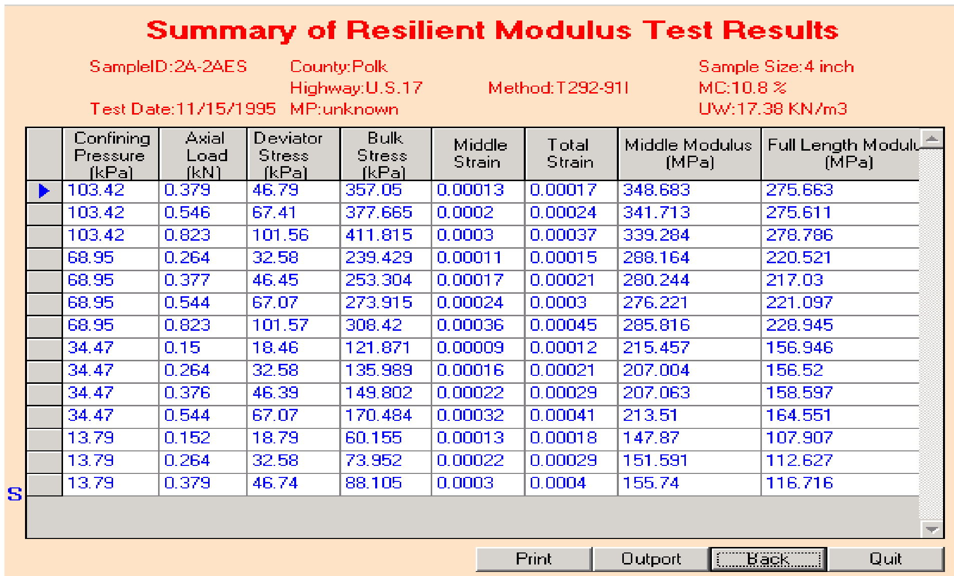
   By clicking on a sample ID in the combo box of the summary table (Figure A.28), a list box will be activated to display the test numbers related to the sample. One sample may have more than one test number. The desired test number can also be obtained by entering a sample ID in the designated sample ID textbox on the form of the summary table (Figure A.28). Then the corresponding test numbers will be shown according to the sample ID.

2. Retrieve the test result data.

   Choose one test number by clicking it on the list box. A summary table of the individual soil test results will be displayed, as demonstrated in Figure A.29.

3. Report the query results.

   By clicking the “Output” button on the summary table of the individual test results (Figure A.29), all the information concerning the individual test results will be transferred to an MS Excel workbook. The output report will include a summary table of the resilient modulus test results, and two plots of the graphic presentation of the test results: resilient modulus versus confining pressure (Figure A.30), and resilient modulus versus bulk stress (Figure A.31).


Summary of Resilient Modulus Test Results

SampleID:2A-2AES County:Polk Sample Size:4 inch
Highway:U.S.17 Method:T292-91I MC:10.8 %
Test Date:11/15/1995 MP:unknown UW:17.38 KN/m3

Confining Pressure (kPa)	Axial Load (kN)	Deviator Stress (kPa)	Bulk Stress (kPa)	Middle Strain	Total Strain	Middle Modulus (MPa)	Full Length Modulu (MPa)
103.42	0.379	46.79	357.05	0.00013	0.00017	348.683	275.663
103.42	0.546	67.41	377.665	0.0002	0.00024	341.713	275.611
103.42	0.823	101.56	411.815	0.0003	0.00037	339.284	278.786
68.95	0.264	32.58	239.429	0.00011	0.00015	288.164	220.521
68.95	0.377	46.45	253.304	0.00017	0.00021	280.244	217.03
68.95	0.544	67.07	273.915	0.00024	0.0003	276.221	221.097
68.95	0.823	101.57	308.42	0.00036	0.00045	285.816	228.945
34.47	0.15	18.46	121.871	0.00009	0.00012	215.457	156.946
34.47	0.264	32.58	135.989	0.00016	0.00021	207.004	156.52
34.47	0.376	46.39	149.802	0.00022	0.00029	207.063	158.597
34.47	0.544	67.07	170.484	0.00032	0.00041	213.51	164.551
13.79	0.152	18.79	60.155	0.00013	0.00018	147.87	107.907
13.79	0.264	32.58	73.952	0.00022	0.00029	151.591	112.627
13.79	0.379	46.74	88.105	0.0003	0.0004	155.74	116.716

Print Outport Back Quit

Figure A.29 Summary table of resilient modulus test results

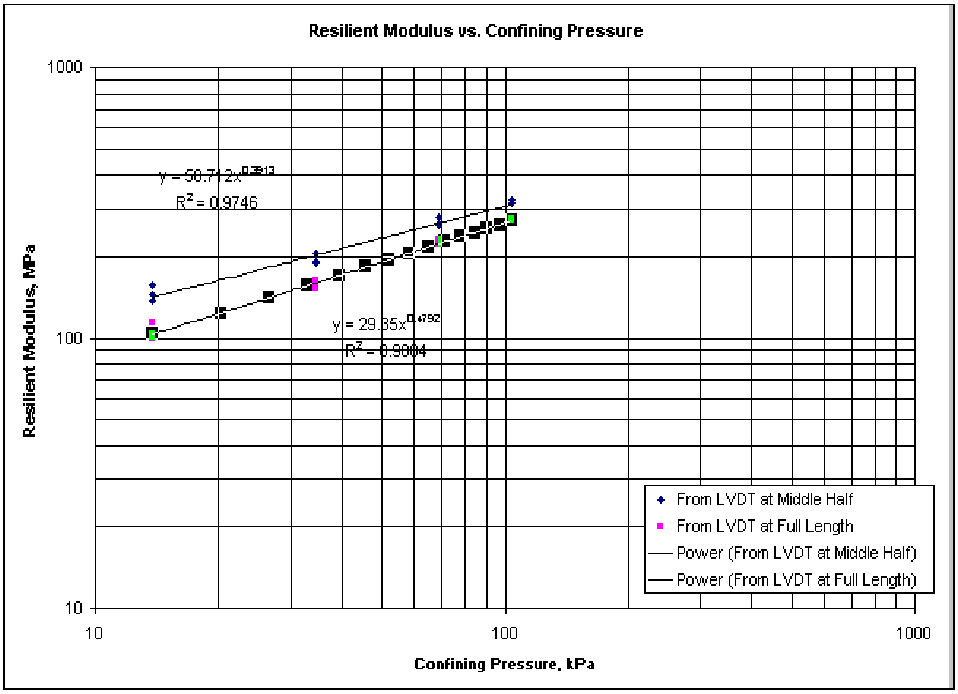


Figure A.30 Resilient modulus versus confining pressure

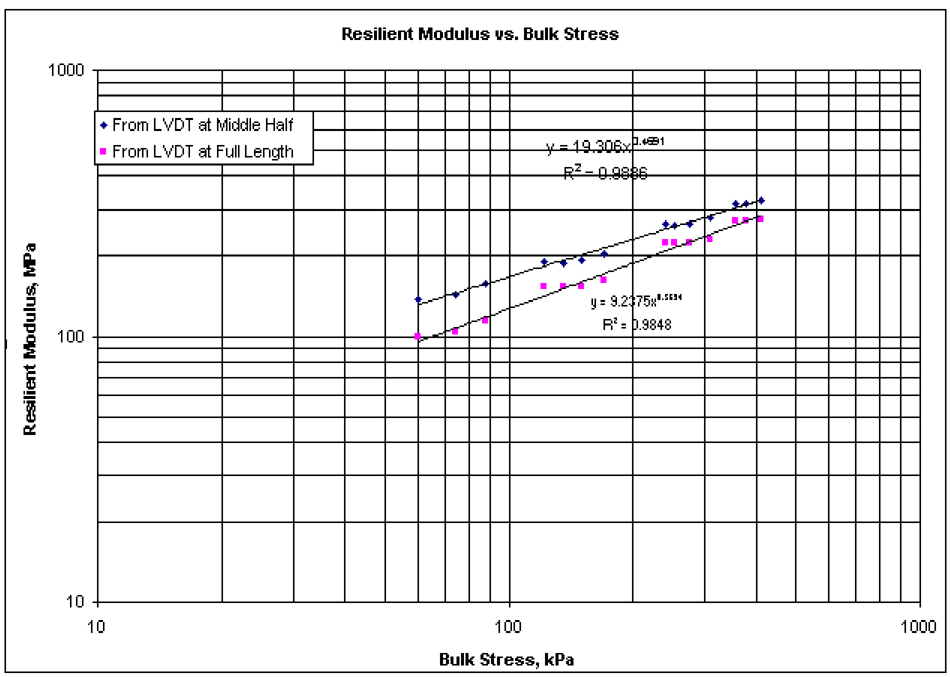


Figure A.31 Resilient modulus versus bulk stress

A.5 DATA ANALYSIS

The data analysis is organized into two parts: the regular analysis, which relates to the effect of the state of stresses on resilient modulus test results during a test, and the comparative analysis, which relates to the effect of different test procedures or LVDT positions on resilient modulus test results. The analysis is presented in the following sections.

A.5.1 Regular Analysis

The regular data analysis consists of the following three conditions:

(1) MR vs. Bulk Stress

(2) MR vs. Confining Pressure

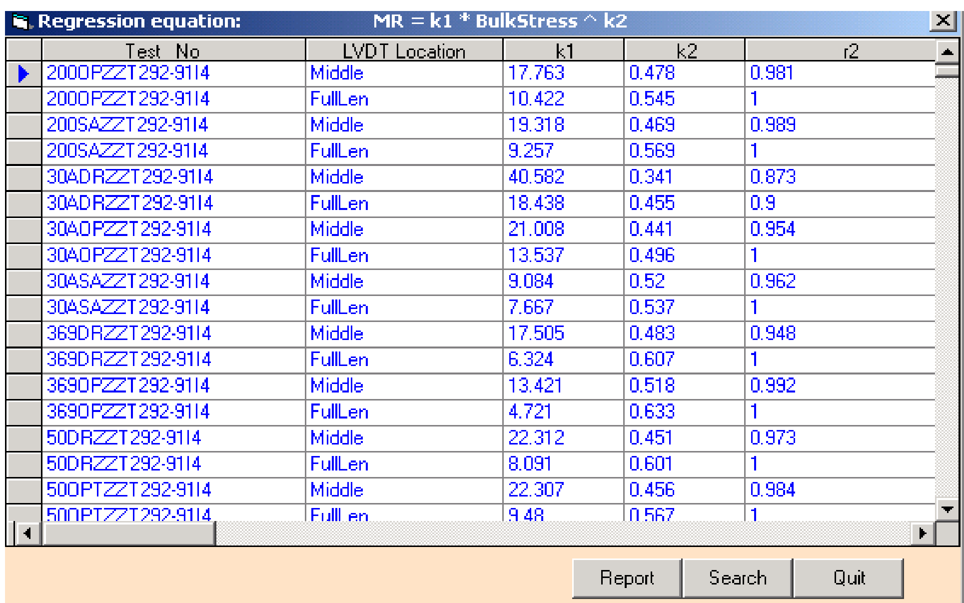
(3) MR vs. Confining Pressure plus Deviator Stress

These submenus have been illustrated in Figure A.4. Each resilient modulus test in the database may be analyzed to produce three different regression equations in terms of the bulk stress, confining pressure, and confining pressure plus deviator stress.

The following steps are used to carry out a regular data analysis:

1. Execute the analysis operation.

   By clicking the submenu of a regular analysis, the analysis operation will be executed. The regression parameters of the resilient modulus tests will be exhibited in a tabular format as demonstrated in Figure A.32, Figure A.33, and Figure A.34, for the MR versus bulk stress, MR versus confining pressure, and MR versus confining pressure plus deviator stress, respectively.



Test No	LVDT Location	k1	k2	r2
2000PZZT292-9114	Middle	17.763	0.478	0.981
2000PZZT292-9114	FullLen	10.422	0.545	1
200SAZZT292-9114	Middle	19.318	0.469	0.989
200SAZZT292-9114	FullLen	9.257	0.569	1
30ADRZZT292-9114	Middle	40.582	0.341	0.873
30ADRZZT292-9114	FullLen	18.438	0.455	0.9
30AOPZZT292-9114	Middle	21.008	0.441	0.954
30AOPZZT292-9114	FullLen	13.537	0.496	1
30ASAZZT292-9114	Middle	9.084	0.52	0.962
30ASAZZT292-9114	FullLen	7.667	0.537	1
369DRZZT292-9114	Middle	17.505	0.483	0.948
369DRZZT292-9114	FullLen	6.324	0.607	1
3690PZZT292-9114	Middle	13.421	0.518	0.992
3690PZZT292-9114	FullLen	4.721	0.633	1
50DRZZT292-9114	Middle	22.312	0.451	0.973
50DRZZT292-9114	FullLen	8.091	0.601	1
500PTZZT292-9114	Middle	22.307	0.456	0.984
500PTZZT292-9114	FullLen	9.48	0.567	1

Figure A.32 Results of regression analysis: MR versus bulk stress

Regression equation: MR = k3 * ConfiningPressure ^ k4

Test No	LVDT Location	k3	k4	r2
2000PZZT292-9114	Middle	46.745	0.403	0.987
2000PZZT292-9114	FullLen	31.349	0.46	0.992
200SAZZT292-9114	Middle	50.761	0.391	0.975
200SAZZT292-9114	FullLen	29.37	0.479	0.988
30ADRZZT292-9114	Middle	78.259	0.297	0.955
30ADRZZT292-9114	FullLen	45.521	0.389	0.987
30AOPZZT292-9114	Middle	51.043	0.374	0.988
30AOPZZT292-9114	FullLen	36.833	0.42	0.994
30ASAZZT292-9114	Middle	26.922	0.43	0.939
30ASAZZT292-9114	FullLen	23.196	0.448	0.974
369DRZZT292-9114	Middle	46.035	0.411	0.988
369DRZZT292-9114	FullLen	22.349	0.504	0.98
369OPZZT292-9114	Middle	39.577	0.429	0.977
369OPZZT292-9114	FullLen	17.782	0.523	0.97
50DRZZT292-9114	Middle	55.656	0.38	0.976
50DRZZT292-9114	FullLen	27.914	0.501	0.973
500PTZZT292-9114	Middle	56.256	0.384	0.985
500PTZZT292-9114	FullLen	30.111	0.476	0.981

Report Search Quit

Figure A.33 Results of regression analysis:
MR versus confining pressure

Regression equation: MR = k5 *(ConfiningPressure ^ k6) * (DeviatorStress) ^k7

Test No	LVDT Location	k5	k6	k7	r2
2000PZZT292-9114	Middle	42.3786	0.385	0.0434	0.9904
2000PZZT292-9114	FullLen	28.3391	0.4416	0.0446	0.9962
200SAZZT292-9114	Middle	42.7558	0.36	0.0756	0.9866
200SAZZT292-9114	FullLen	25.7654	0.4553	0.0577	0.995
30ADRZZT292-9114	Middle	92.7949	0.3266	-0.0734	0.9747
30ADRZZT292-9114	FullLen	49.2206	0.402	-0.0331	0.9926
30AOPZZT292-9114	Middle	51.8993	0.3773	-0.0076	0.9879
30AOPZZT292-9114	FullLen	36.3788	0.4173	0.0059	0.9955
30ASAZZT292-9114	Middle	21.9445	0.3943	0.0884	0.9516
30ASAZZT292-9114	FullLen	19.9054	0.4212	0.0662	0.9824
369DRZZT292-9114	Middle	48.4446	0.4199	-0.022	0.9885
369DRZZT292-9114	FullLen	18.1737	0.4683	0.0887	0.9951
369OPZZT292-9114	Middle	31.9507	0.3913	0.0927	0.9916
369OPZZT292-9114	FullLen	13.2836	0.4718	0.1261	0.9948
50DRZZT292-9114	Middle	50.5867	0.3622	0.0426	0.9797
50DRZZT292-9114	FullLen	22.579	0.4627	0.0933	0.989
500PTZZT292-9114	Middle	50.1256	0.3622	0.0517	0.9913
500PTZZT292-9114	FullLen	25.5888	0.446	0.0722	0.9933

Report Search Quit

Figure A.34 Results of regression analysis:
MR versus confining pressure plus deviator stress

2. Report the analyzed results.

The analyzed results can be reported in the following format:

a. Report the results of all the regression parameters in a single file.

By clicking the “Report” button on the summary table of the analyzed results, the regression equation parameters of all the tests will be printed out in a single spreadsheet.

b. Print out the results of an individual test.

By clicking the “Search” button, the advanced search option will be activated to search for the desired sample ID and test number. The corresponding results will be reported graphically as displayed in Figure A.30 and Figure A.31, for the test.

A.5.2 Comparative Analysis

The comparative analysis function of the RMDB falls into two submenus (Figure A.4):

(1) MRs between T292-91I and T294-92

(2) MRs between middle and full length LVDTs

The procedures to execute the comparative analysis are summarized as follows:

1. Define the range of analysis.

Define the range of resilient modulus data for analysis by selecting the constraint factors, as demonstrated in Figures A.35 and A.36.

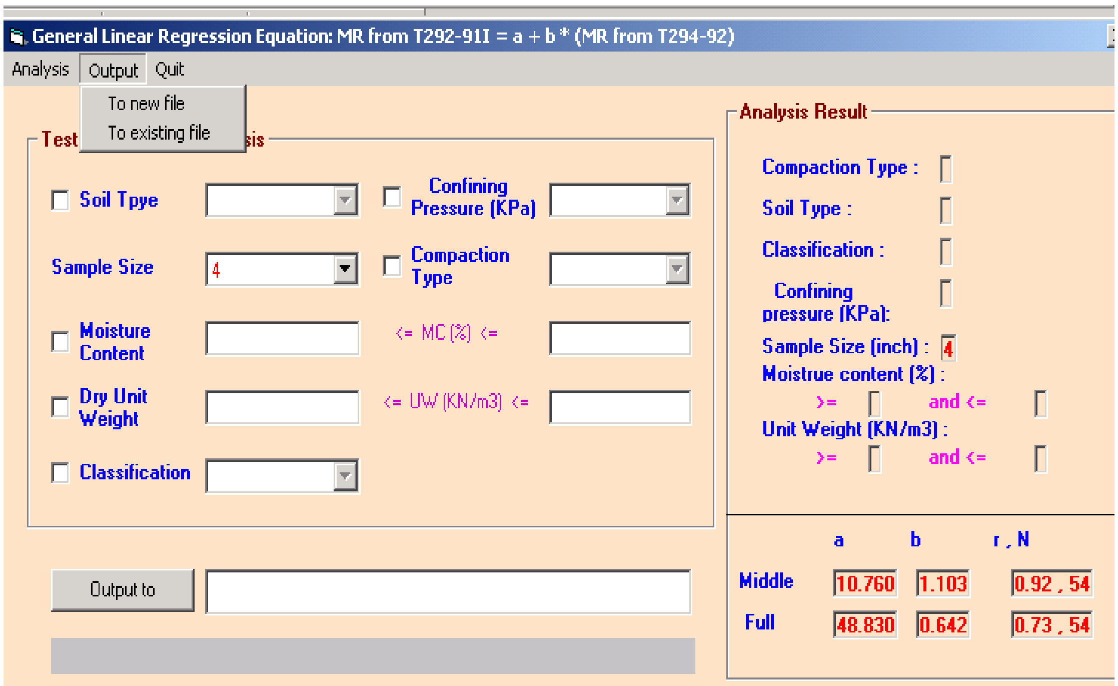


Figure A.35 Comparative analysis between T292-91I and T294-92 test procedures

2. Execute the analysis.

By clicking the “Analysis” menu, the linear regression parameters will be determined and subsequently displayed on the right hand side of the form. The “Output” menu will be activated simultaneously for reporting the results, as demonstrated in Figures A.35 and A.36.

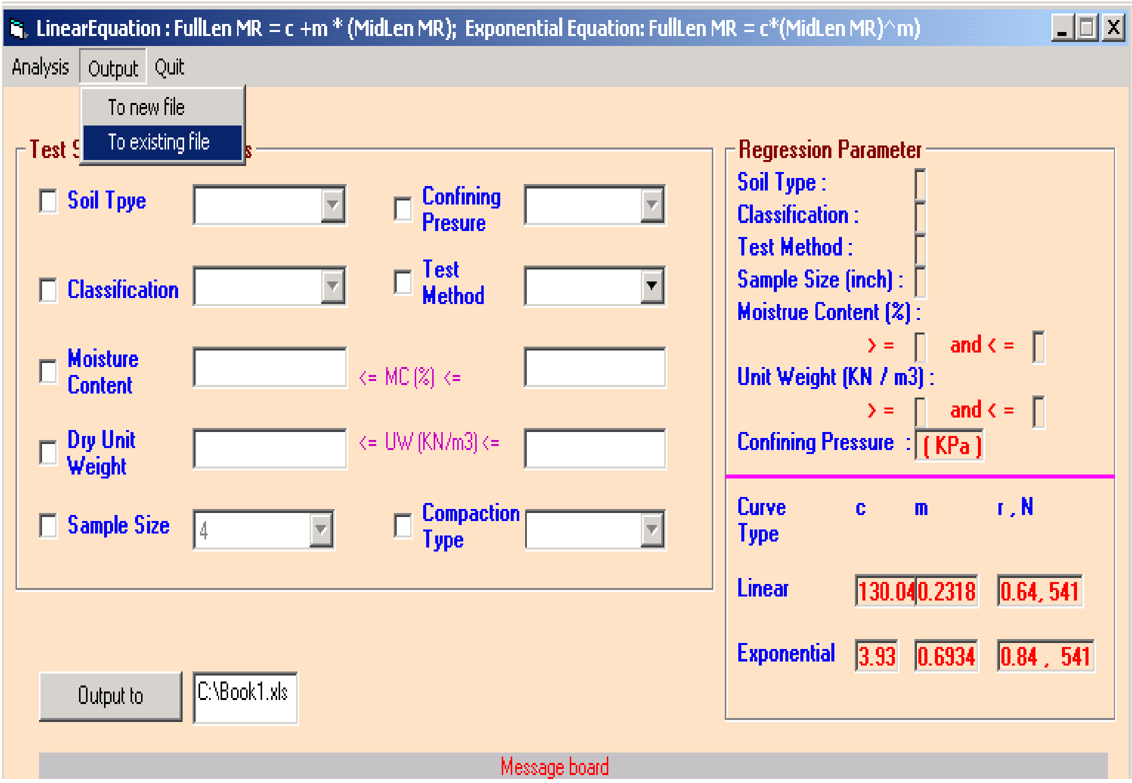


Figure 36 Comparative analysis between full-length LVDT and middle-length LVDT MR values

3. Report the analysis results

The analysis results can be printed out into either a new or an existing MS Excel file.

A new Excel file would be created. One data record of the regression parameters will be saved automatically. As for the existing file, a common dialog box will be shown for selecting the full path name of the existing Excel file. By clicking the "To Existing File" menu, the "Output" button will be activated. By pressing the "Open" button on the common dialog box, the full path name of the existing file will be displayed in a textbox. Subsequently, by clicking the “Output” button, the results will be appended to the end of the existing Excel file.

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