Seasonal Instrumentation of SHRP Pavements

FINAL REPORT

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The Ohio State University

June 2004

Prepared in Cooperation with the Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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16. Abstract

Test pavements constructed by the Ohio Department of Transportation (ODOT) on U.S. 23 in Delaware, OH Ohio were studied. Environmental data collected from 1997 to 2003 at five test locations are presented. Also, porewater pressures in the near surface soils beneath select pavement sections were measured. These measurements showed that pore pressures in the soil under the pavement have continued to increase over time strongly suggesting that the subsurface soils quickly became saturated as water was drawn up into the profile.

Models used to predict the resilient modulus of cohesive subgrade soils typical of those found in Ohio were evaluated. The current study consisted of performing a series of static laboratory tests to determine the soil's engineering properties. These tests were followed by the direct measurement of the resilient modulus. Tests were performed on both unsaturated and saturated soil samples. The moduli as predicted by these existing methods were compared with the measured values. An improved and more accurate resilient modulus prediction model has been developed and validated in this study.

Results obtained from M_r laboratory testing show that for cohesive soils, the water content, the applied deviator stress, the confining stress and the unconfined compressive strength all affected the resilient modulus of the sample. The resilient modulus values of the saturated soil samples were, in most cases, less than half that of the modulus at optimum moisture content.

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The work presented in this report was part of a project to install and monitor seasonal instrumentation at five SHRP pavement sections. That effort was in turn part of a larger effort to install and monitor seasonal and structural performance instrumentation at 33 pavement test sections on US 23 in Delaware, Ohio. Many individuals participated in this research. Professor S. Sargand and his students and staff from Ohio University led the project team and contributed countless times to the success of this work. Help with instrumentation installation, scheduling and sample collection were provided by R. Green and B. Young of ODOT. B. Young directed the collection of the soil samples used in the modulus testing. Direction and insight into modulus testing and usage from R. Green and A. Morse of ODOT are greatly appreciated. The efforts of several students in collecting and presenting field data and performing laboratory tests should be acknowledged. Of particular note were the efforts of H-G Kim, S-H Lee, B. Zand, W. Tu and M. Amin.

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1. INTRODUCTION

1.1 Background

The Ohio Department of Transportation (ODOT) constructed a series of 34 instrumented pavement test sections in 1995 on U.S.23 in Delaware County, Ohio. An Ohio State University (OSU) team calibrated, installed and monitored Strategic Highway Research Program (SHRP) environmental instrumentation on five sections. The measurements made consisted of soil moisture and temperature and frost depth profiles from the pavement surface down to a depth of about two meters. Descriptions of the installation procedures along with the first two years of data were presented in the final report titled "Seasonal Instrumentation of SHRP Pavements – The Ohio State University State Job No. 14586(0); Contract No. 8011," dated September, 1998. In addition to the SHRP instrumentation, OSU developed and constructed tensiometers to directly measure the porewater pressures in the subsurface soils and installed the devices at four locations. Additional tensiometers were constructed and installed at three more test sections at the US 23 site in 2002. All the environmental instruments continued to be monitored throughout the term of the project. The data from all the readings are presented and discussed in subsequent sections.

In conjunction with this program to measure in the field the insitu properties of the subsurface materials over an extended time period, a laboratory program to evaluate the elastic properties of a representative sampling of soils typically encountered in pavement construction in the state was begun. Specifically, testing was performed with the intent to identify relationships between static soil properties routinely measured in the laboratory and the resilient modulus of cohesive subgrade soils.

1.2 Site Details

As previously described in the 1998 final report, the location selected for the SPS experiments is on U.S. 23 north of Delaware, in Delaware County, Ohio. The project consists of two southbound lanes for SPS-1 (flexible pavement) tests, two northbound lanes for SPS-2 (rigid pavement), an SPS-8 (flexible and rigid light traffic) section and an SPS-9 section (asphalt program field verification studies) at the southern end of the site in the southbound lanes. Ohio State University was given charge of sections 390904, 390108, 390201, 390211 and 390263. A figure showing the relative positions of the OSU sections presented in the 1998 final report is reproduced here as Figure 1.1. The tensiometer locations added during the current project (390160, 390106, 390109 and 390212) have been appended to the figure for reference.

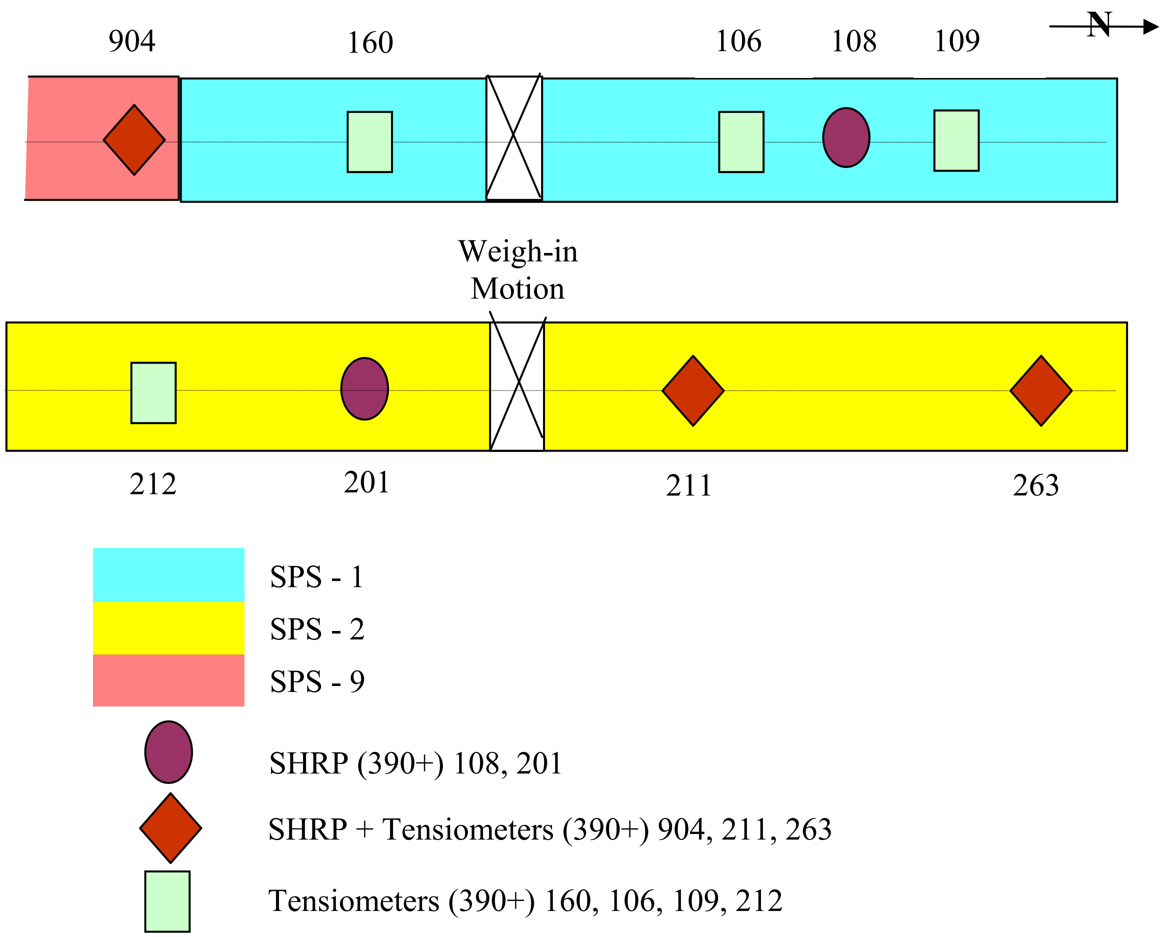

Fig 1.1 Location of OSU Field Instrumentation

2. RESEARCH OBJECTIVES

The present program continued the field study begun with the 1995-1997 study. The intent was to provide a direct measure of the performance of the test sections and to document the changing state of stress in the subgrade materials from construction through the intermediate term. Moisture content, resistivity and frost depth were monitored monthly and the data added to the project data base. The porewater pressure response and therefore the soil effective stresses in the upper two feet of the subgrade were documented throughout the time period. These additional experimental test results complement the data from the SHRP instrumentation protocol.

In many pavement system designs, an essential design input is the elastic stiffness of the supporting soil. In this project, we sought to develop a rational method to predict the elastic response of the supporting soil based on the use of the resilient modulus. By determining the basic properties of representative Ohio soils and also performing cyclic resilient modulus tests on them, relationships that would allow the correlation of actual stiffness for a particular subgrade soil with conventionally obtained material data (e.g. Atterberg limits, grain size distribution, compaction density and moisture content) could be developed by employing routine laboratory testing methods.

3. DESCRIPTION OF THE RESEARCH

3.1 Literature Review

A review of the literature on the behavior of the saturated and unsaturated soil was presented in the 1998 report of the pavement monitoring project. The reader is referred to that report for a discussion of the methodologies behind the uses of the tensiometers. A review of the development of resilient modulus testing and currently used models for predicting modulus values is presented in the following paragraphs.

3.1.1 Resilient Modulus Defined

When subjected to repeated loads, such as moving wheel loads, the soils below a pavement experience repeated elastic deformations. These repeated soil deformations can result in a fatigue failure of the pavement surface. Seed, et al. (1962) suggested the definition of resilient modulus by measuring the relationship between the applied stress, referred to as the deviator stress (σ_d) and the recoverable or elastic strain (ε_r). In the AASHTO Guide for Design of Pavement Structures (1993), resilient modulus was defined as a "measure of the elastic property of soil recognizing certain nonlinear characteristics". Resilient modulus can be more simply described as the unloading portion of the stress-strain curve resulting from the load that occurs as vehicles pass over the pavement. The resilient modulus can be used directly for the design of flexible pavements, and can be converted to a modulus of subgrade reaction (k-value) for the design of rigid pavements. An example of a typical compacted fine-grained subgrade soil response to a single load cycle as obtained in a dynamic laboratory triaxial test is depicted in Figure 3.1.

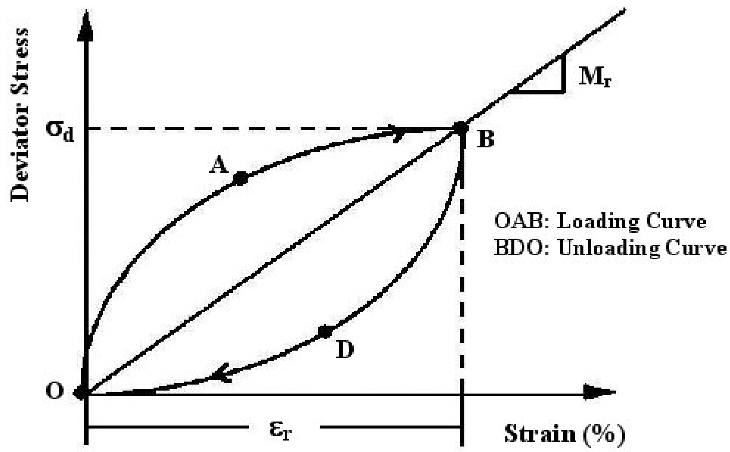

Figure 3.1 Representation of M_r (Kim and Drabkin (1994))

$$M_r = \frac{\sigma_1 - \sigma_3}{\varepsilon_r} = \frac{\sigma_d}{\varepsilon_r} \tag{3.1}$$

where:

M_r = resilient modulus,
σ_1 = major principal stress,
σ_3 = minor principal stress,
σ_d = repeated axial deviator stress,
ε_r = recoverable (resilient) axial strain.

Seed proposed testing the soil in the laboratory to measure the resilient modulus. The test was designed to reproduce the state of stress in the soil generated by a moving vehicle so that, even though the load would not be sufficient to cause the supporting soil to yield, the deflections would result in deformations and therefore stresses in the pavement. Because pavement surfaces are stiffer than the underlying soil, the induced pavement stresses would ultimately define pavement performance.

Following Seed's suggestion, the resilient modulus for a particular soil is typically determined in the laboratory by subjecting a prepared sample to repeated loading cycles of sufficient magnitude to induce measurable but not permanent strain. The test typically takes from 2 to 8 hours to complete on specialized equipment, usually by a specially trained technician. Because neither the equipment nor the trained personnel are always present in government or commercial laboratories, researchers have studied the characteristics of the resilient modulus and attempted to relate M_r to static soil properties and stress states, with the goal of reducing costs and time associated with laboratory testing.

3.1.2 Past Laboratory Programs to Measure Resilient Modulus

Seed and others have shown the M_r of cohesive soils decreases nonlinearly with increasing deviator stress at constant confining stress (Seed, et al. (1962), Fredlund, et al. (1977), Woolstrum (1990), Drumm, et al. (1990), Sargand, et al. (1991), Li and Selig (1994), Pezo and Hudson (1994), Lee et al. (1995), Mohammad, et al. (1999), Kim (1999), Huang (2001), and Masada and Sargand (2002)). Fredlund, et al. demonstrated that the resilient modulus is a function of three stress variables, the net confining stress, the deviator stress and the matric suction. They found that M_r is more strongly affected by deviator stress and suction than confining stress.

Woolstrum collected soil samples at 14 locations to represent the major soil types in Nebraska. Sample response at different cell pressures and water contents was measured. A good correlation between the Nebraska Group Index, a term expressed as a function several indirect measures of stiffness, and the resilient modulus was reported.

Carmichael identified correlations between resilient modulus and Plasticity Index, water content and percentage of material passing the #200 sieve. Separate relationships for coarse and fine grained soils were developed. Santha presented relationships for granular materials with M_r given as an explicit function of the bulk and deviator stress. The model for granular soils was given in terms of three constants which were, in turn, functions of the moisture content, percent compaction, density, silt and clay, swelling and shrinkage potential, and other parameters. The expression for cohesive materials was a function of moisture content, density, compaction and Atterberg Limits. Santha found good correlation between predicted and measured Resilient Moduli when the data base was extensive.

M_r has been found to decrease rapidly with increasing amplitude of the cyclic load up to 'breakpoint' stress (Thomson and Robnett (1976)). As the deviator stress is increased past the breakpoint stress, the modulus may gradually increase, decrease, or remain constant. In some research programs, the modulus was found to increase with increases in the confining stress at a constant deviator stress, (Pezo and Hudson (1994), Lee et al. (1994), Mohammad, et al. (1999), and Kim (1999)). However, other researchers have suggested that the confining stress has no significant effect on the M_r of cohesive soils (Fredlund, et al. (1977), Muhanna, et al. (1999), and Masada and Sargand (2002)). Increasing moisture content has been shown to decrease the value of M_r (Seed, et al. (1962), Chu, et al. (1977), Fredlund, et al. (1977), Woolstrum (1990), Sargand, et al. (1991), Burczyk, et al.(1994), Li and Selig (1994), Pezo and Hudson (1994), Mohammad, et al. (1995), Lee, et al. (1995), Thadkamalla and George (1995), Drumm, et al. (1997), Kim (1999), Muhanna, et al. (1999), Huang (2001), Masada and Sargand (2002), Butalia, et al. (2003), and Li and Qubain (2003)). Mohammad, et al. (1995) explained that the reduction of M_r was caused by higher positive pore pressure with an increase in moisture content. Drumm, et al. (1997) showed that the reduction in M_r of A-7 soils was greater than that of A-4 and A-6 soils as moisture content was increased above optimum. Huang (2001) and Butalia, et al. (2003) showed that M_r of saturated samples was significantly lower than that of unsaturated samples, and suggested that the reduction could be explained by a buildup in pore water pressure. Li and Qubain (2003) made similar observations and found that, for cohesive soils, M_r of fully saturated samples was approximately half of M_r at optimum moisture content for cohesive soils at constant dry unit weight.

Burczyk, et al. conducted resilient modulus tests and found that on samples tested and grouped according to R-value, liquid limit, plasticity index, soil classification, group index and water content, water content and $\log_{10}M_r$ could be related. Brown and Pappin found that when the experimental parameters were presented as functions of effective stresses a more reasonable estimate of the modulus could be made. Cosentino and Chen developed correlations between the resilient moduli and the material parameters obtained in pressuremeter and CBR tests.

Drumm, et al. (1996) suggested dropping a weight on a standard Proctor specimen as an alternative testing method for resilient modulus. The results of cone penetration tests (CPT) have been shown to correlate well with M_r in some cohesive soils (Mohammad, et al. (1998), Mohammad, et al. (1999) and Rahim and George (2002)).

Several researchers have proposed the use of nondestructive methods to determine in-situ the resilient modulus of subgrade soils. Wang and Anani (1981) evaluated the modulus of pavement layers from road-rater deflection basins. FWD tests have been correlated with resilient modulus by Andrew, et al. (1998), Dai and Van Deusen (1998), Mikhail, et al. (1999), and Rahim and George (2003).

Guan, et al. (1998) suggested a pavement design weight factor that can be calculated on the basis of seasonal changes in M_r as obtained in the laboratory or by in situ tests. Andrew, et al. (1998) conducted monthly FWD tests and measurement of soil moisture content for different climatic regions of Tennessee. They showed that M_r from results of FWD tests decreased with an increasing in situ soil moisture content.

Lee, et al. (1995, 1997) proposed that the unconfined compressive stress at 1% axial strain was a good predictor of M_r for cohesive soils. M_r for some cohesive soils was reported to increase with increasing soil plasticity index (Woolstrum (1990), Pezo and Hudson (1994), and Kim (1999)). The number of repeated stresses (Seed, et al. (1962) and Raad and Zeid (1990)) appeared to have little effect on M_r.

3.1.3 Existing Models for Resilient Modulus of Cohesive Soils

Many models have been developed for estimating M_r of cohesive soils using the results of simple laboratory tests and/or stress state in soils. Six of the more widely cited models currently used by federal and state highway agencies for estimating M_r of cohesive soils are summarized below.

3.1.3.1 USDA Model

Carmichael and Stuart (1986) proposed a model which in this report is referred to as the USDA (United States Department of Agriculture) model. A regression analysis using data from more than 250 different soils was conducted. The resulting USDA model for cohesive soils, along with its coefficients of determination, was found to be a function of plasticity index, water content, particle grain size, moisture content, density, confining stress and deviator stress. The value for resilient modulus is:

$$M_r = 37.431 - 0.4566(PI) - 0.6179(\%W) - 0.1424(S200) + 0.1791(CS) - 0.3248(DS) + 36.422(CH) + 17.097(MH) \quad (3.2)$$

where: M_r = resilient modulus (ksi),
PI = plasticity index,
%W = percent water (%),
S200 = percent passing No. 200 sieve (%),
CS = confining stress (psi), and
DS = deviator stress (psi),
CH = 1 for CH soil,
= 0 otherwise (for MH, ML, or CL soil),
MH = 1 for MH soil,
= 0 otherwise (for CH, ML, or CL soil).

The laboratory tests required for the USDA model are the Atterberg Limits, sieve analysis, and moisture content measurement. In this model, soil type is the most important factor affecting M_r.

3.1.3.2 Hyperbolic Model

Drumm, et al. (1990) assumed the resilient modulus could be obtained by adopting a hyperbolic relationship between stress and strain. The model is based on the results of static tests on eleven Tennessee soils. The procedure proposed for estimating M_r is as follows:

$$M_r = \frac{a' + b'\sigma_d}{\sigma_d} \quad \text{for } \sigma_d > 0 \tag{3.3}$$

where: M_r = resilient modulus in ksi,
a' = 318.2+0.337(q_u)+0.73(% *clay*)+2.26(PI)–0.915(γ)–2.19(S)–0.304(% < #200)
b' = 2.1+0.00039(1/*a*)+0.104(q_u)+0.09(LL)–0.1(% *finer* #200)
σ_d = deviator stress (psi),
q_u = unconfined compressive strength (psi),
% *clay* = percent soil particles finer than 0.002mm (%),
PI = plasticity index,
γ = dry unit weight (pcf),
S = degree of saturation (%),
%< #200 = percent soil particles finer than 0.075mm (%),
a = material parameter for hyperbolic representation of stress-strain response,
LL = liquid limit.

The material parameter *a* is obtained from the unconfined compression test as the intercept of the linear relation by plotting the stress-strain data in the transformed coordinates ε/σ and ε as shown in Figure 3.2.The model requires unconfined compression test, liquid and plastic limit tests, sieve analysis, hydrometer test, specific gravity test for determining '% clay', degree of saturation, and the measurement of moisture content and dry density for the specimen.

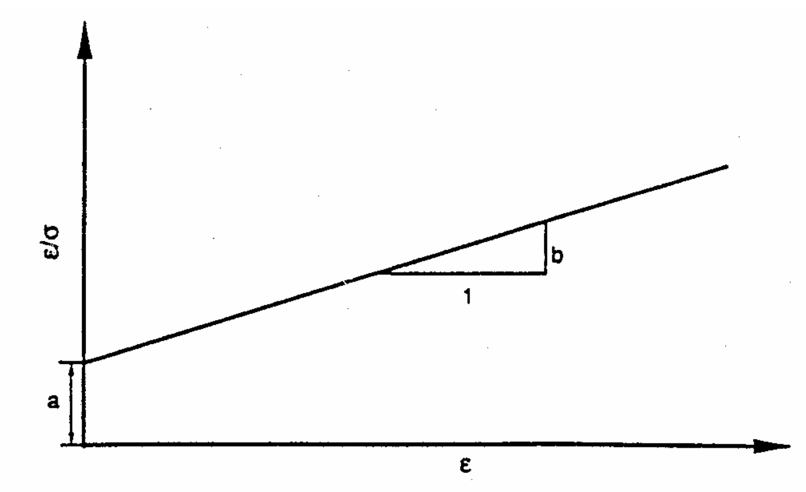

Figure 3.2 Hyperbolic Model Parameter *a* (Drumm, et al. (1990))

3.1.3.3 GDOT Model

The GDOT (Georgia Department of Transportation) model was proposed by Santha (1994), using data from 14 cohesive Georgia soils. The GDOT model was derived from the modified bulk stress model proposed by Uzan (1988):

$$\mathrm{Log}(\mathrm{M_r}) = \mathrm{Log}(k_1 P_a) + k_3 \mathrm{Log}\left[\frac{\sigma_\mathrm{d}}{P_a}\right] \tag{3.4}$$

where: $\mathrm{M_r}$ = the resilient modulus in psi,
P_a = atmospheric pressure (14.7 psi),
σ_d = deviator stress (psi),

$\log(k_1)$ = 19.813-0.045*MOIST-0.131*MC-.171*COMP+0.037*SLT+ 0.015*LL-0.016*PI-0.021*SW-0.052*DEN+0.00001*(S40*SATU)

k_3 = 10.274-0.097*MOIST-1.06*MCR-3.471*COMP+0.0088*S40-0.0087*PI + 0.014*SH - 0.046*DEN
MOIST = optimum moisture content (%),
MC = moisture content (%),
COMP = compaction ratio (γ_d to $\gamma_{d\ max}$)
SLT = percentage of silt (%),
LL = liquid limit,

PI	= plasticity index,
CLY	= percentage of clay (%),
SW	= percent swell (%),
DEN	= maximum dry unit weight (pcf),
MCR	= ratio of MC and MOIST,
S40	= percent passing #40 sieve (%),
SATU	= percent saturation (%), and
SH	= percent shrinkage (%).

The liquid and plastic limit tests, shrinkage test, swell test, sieve analysis, hydrometer test, specific gravity test, proctor compaction test and the measurement of moisture content and dry density for the specimen are all required to properly use this model. This model requires more laboratory tests than the other two discussed above.

3.1.3.4 TxDOT Model

Pezo and Hudson (1994) presented a model referred to as the TxDOT (Texas Department of Transportation) model. The TxDOT model consists of seven correction factors as shown in Equation (3.5). These factors can be determined from Table 3.1.

$$M_r = F_0 * F_1 * F_2 * F_3 * F_4 * F_5 * F_6 \qquad (3.5)$$

where:

F_0 = 9.80 (for units in ksi)
= 67.60 (for units in MPa)
F_1 = moisture content factor,
F_2 = percent of dry density with respect to the maximum density,
F_3 = function for the plasticity index,
F_4 = function for the sample age,
F_5 = function of the confining pressure,
F_6 = correction factor for the deviator stress.

The TxDOT model requires Atterberg limits, Proctor density, moisture content and sample dry density.

Moisture Content, %	F_1	$(\gamma_d / \gamma_{d,max})$*100, %	F_2
10	4.00	100	1.00
15	2.00	95	0.90
20	1.00	90	0.80
25	0.50	85	0.70
PI	F_3	Sample Age, days	F_4
10	1.00	2	1.00
20	1.50	10	1.10
30	2.00	20	1.15
≥ 40	2.50	≥ 30	1.20
Confining Pressure (σ_c), kPa (psi)	F_5	σ_d, kPa (psi)	F_6
13.8 (2)	1.00	13.8 (2)	1.00
27.6 (4)	1.05	27.6 (4)	0.98
41.4 (6)	1.10	41.4 (6)	0.96
		55.2 (8)	0.94
		69.0 (10)	0.92

Table 3.1 Correction Factors for TxDOT Model (Pezo and Hudson (1994))

3.1.3.5 UCS Model

The UCS (Unconfined Compressive Strength) model (Lee, et al. (1995)) is based on the results of unconfined compressive strength tests on samples obtained from five in-service subgrades in the state of Indiana. The model uses the axial stress at 1% strain in unconfined compression and a regression constant to estimate the resilient modulus.

$$M_r = a \cdot S_{u\,1.0\%} \tag{3.6}$$

where: a = a regression constant shown in Figure 3.3.

$S_{u1.0\%}$ = axial stress at 1% strain in unconfined compression

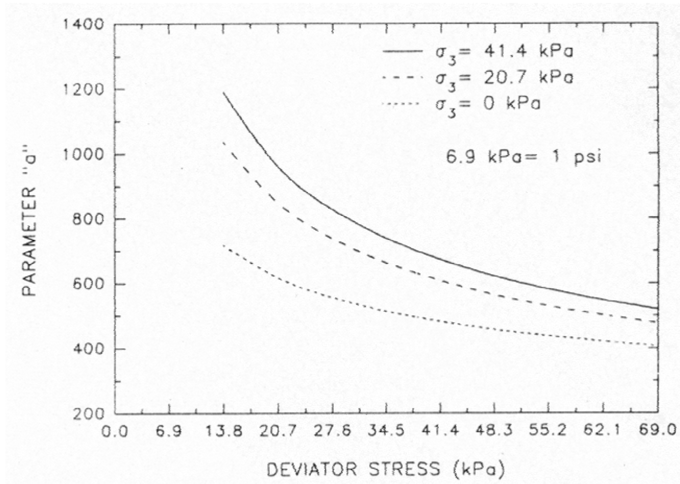

Figure 3.3 Chart for Estimation of Parameter *a* (Lee, et al. (1995))

3.1.3.6 ODOT Model

The Ohio Department of Transportation (ODOT, 1999) employs a standard relationship between M_r and the California Bearing Ratio (CBR)

$$M_r = 1200 * CBR \tag{3.7}$$

The CBR can be measured directly in a laboratory test or determined from a relationship between CBR and Group Index as shown in Figure 3.4. The appropriate Group Index value can be calculated using Figure 3.5.

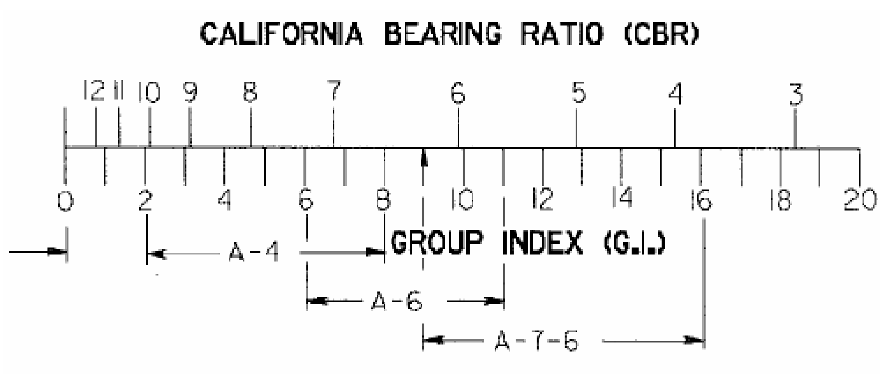

Figure 3.4 Relationship between California Bearing Ratio and Group Index (ODOT (1999))

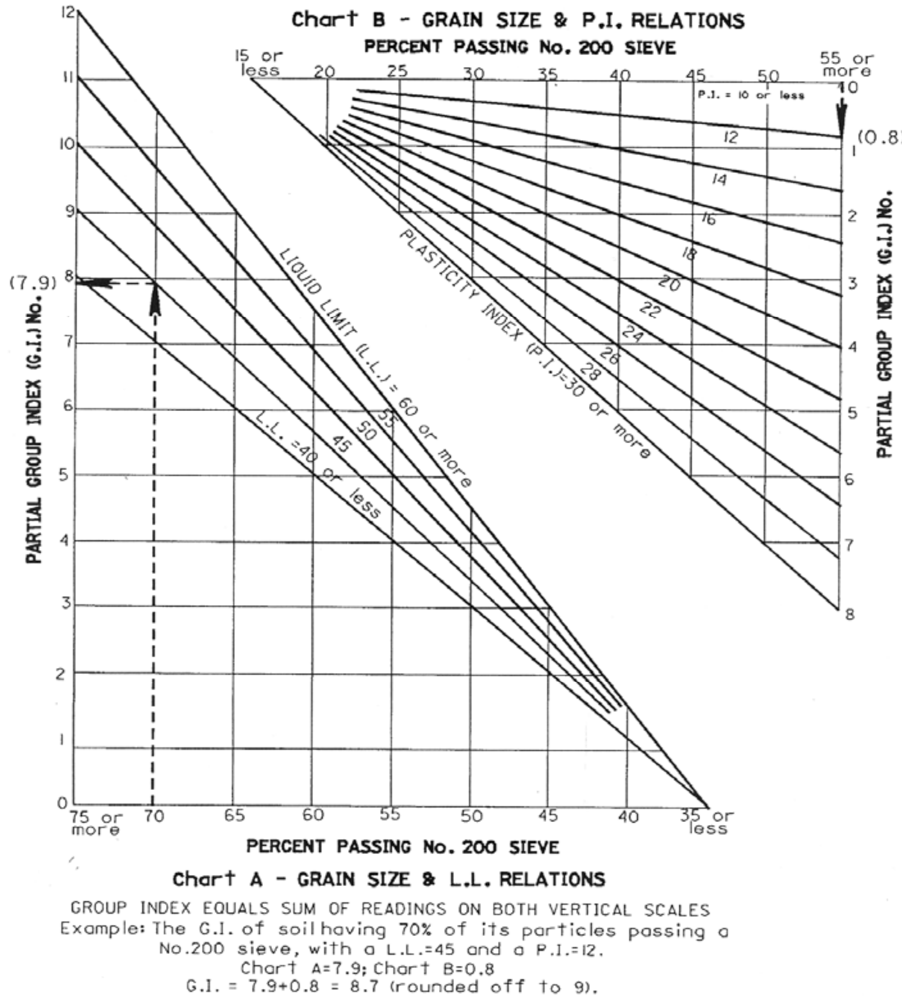

Figure 3.5 Calculation of Group Index (ODOT (1999))

3.1.4 Summary of Resilient Modulus Review

One of objectives of this study was to evaluate the suitability of existing regression models commonly in use by pavement engineers. Table 3.2 summarizes the input parameters, advantages, and limitations of the six models mentioned in the previous section.

In general, the modulus for cohesive soils is nonlinear with respect to deviator stress (σ_d). The Hyperbolic, GDOT, and UCS models allow for non-linearity while the USDA, TxDOT, and ODOT models predict linear behavior. Although confining stress (σ_3) affects M_r it not considered in the Hyperbolic, GDOT or ODOT models. The ODOT model does not consider the effect of deviator stress (σ_d). In the USDA model, the M_r of soil classified as CH or MH is greater than for soils classified as other types.

Existing Regression Model	Input Parameters	Advantages	Limitations
USDA Model (Carmichael & Stuart, 1986)	USCS soil type, PI, *w*, % passing No. 200 sieve, σ_3, σ_d		- Linear model - Soil type
Hyperbolic Model (Drumm, et al., 1990)	q_u, % of *clay*, PI, γ, S, % passing No. 200 sieve, Hyperbolic parameter *a*, LL, σ_d	- Nonlinear model	- σ_3
GDOT Model (Santha, 1994)	w, w_{opt}, γ_d, $\gamma_{d,max}$, % of silt, % of clay,% swell, % passing #40 sieve, S, % shrinkage, LL, PI, σ_d, P_a	- Nonlinear model	- σ_3 - Complex model - Many tests required
TxDOT Model (Pezo & Hudson, 1994)	W, γ_d, $\gamma_{d,max}$, PI, Sample age, σ_3, σ_d		- Linear model - Input parameters have narrow range as shown in Table2.3
UCS Model (Lee, et al., 1995)	$S_{u \text{ at } 1.0\% \text{ of axial strain}}$, σ_3, σ_d	- Nonlinear model - Simplicity of Model	- σ_3 at 0, 20.7, 41.4 kPa - 13 kPa < σ_d < 60 kPa
ODOT Model (ODOT, 1999)	GI (% passing No. 200 sieve, LL, PI), CBR	- Simplicity of model	- Linear model - σ_3, σ_d

Table 3.2 Summary of Reviewed M_r Estimation Models

4. LABORATORY AND FIELD TESTING PROCEDURES

4.1 Laboratory Resilient Modulus Test Program

The AASHTO test procedure for obtaining the resilient modulus has been modified in 1991, 1994, and 1999. The primary differences in the methods are in the specification of the applied waveform and sequence, sample conditioning before testing, number of loading cycles, and procedure for measuring the axial displacements. The 1994 AASHTO procedure T294-94 (Tables 4.1 and 4.2) was used in this study to test unsaturated samples. A modified T294-94 test procedure developed by Huang (2001) was used to test saturated samples.

Test Procedure	T294-94
Waveform	Haversine
Load duration (sec)	0.1
Cycle duration (sec)	1.0

Table 4.1 Waveform and Frequency of Load

Test Procedure	Deviator Stress (kPa)	Confining stress (kPa)	Number of Cycles
T294-94	14, 28, 41, 55, 69	41	100
	14, 28, 41, 55, 69	21	100
	14, 28, 41, 55, 69	0	100

Table 4.2 Applied Stress and Number of Load Cycles for Fine-grained Soils

4.2 Resilient Modulus Sample Collection and Laboratory Work

Thirteen soil samples were collected from road construction sites across Ohio by ODOT engineers. Laboratory tests were performed to determine the basic engineering properties. M_r tests were conducted on compacted unsaturated samples at three water contents (dry of optimum, optimum, and wet of optimum). In addition to the tests performed on all samples, examples from each soil type were compacted and tested under saturated conditions to measure static unconfined compressive strength as well as the resilient modulus including transient pore pressure.

4.2.1 Sample Collection

The soils tested were collected from construction sites selected by ODOT. Sample, name, location, date collected, and soil type are described in Table 4.3.

4.2.2 Basic Engineering Properties Testing and Results

All soil samples were oven dried at 60 °C, for 24 hours, air dried in the laboratory over a two-week period then thoroughly pulverized. The data sheets and complete test results for all thirteen samples are in Appendix A.

Soil Type	Sample Name	Description	Location	Date Collected
A-4	MUS-60-21	Mile post 21 State route 60, Muskingum County	E	7/29/98
	GRE-35-21.13. 302, 400	Mile post 21.13, Project station 302+00, and 400+00, U.S. highway 35, Greene County	SW	7/22/98
	WAS-7-Mari	Marietta City State route 7, Washington County	SE	7/29/98
	SHE-SR47	State Route 47 Shelby County	W	6/25/99
A-6	WAR-741-3	Mile post 3 State route 741, Warren County	SW	7/22/98
	WAS-821-113, 116	Project station 113+75 and 116+00 State route 821, Washington County	SE	7/29/98
	BEL-SR147, 265	Near the split Belmont County	E	7/21/99
	ATH-50-Cool	Coolville City, Mile post 34 U. S. highway 50, Athens County	SE	7/29/98
	ATH-50-222, 228, 413	Project station 222+00, 228+00, and 413+50 U. S. highway 50, Athens County	SE	7/29/98
A-7-6	ATH-SR7	7 miles west Athens County	SE	7/21/99
	FAI-I70	New off ramp Fairfield County	Central	7/21/99
	CRA-Beal	Beal Ave near Bucyrus Crawford County	N	6/25/99
	HEN-SR6, 24	State Route 6/24 Henry County	NW	6/25/99

Table 4.3 Cohesive Samples Tested in Laboratory M_r Program

4.2.2.1 Classification Tests

Atterberg limits (AASHTO T89-96, and T90-96), sieve analyses and hydrometer tests (AASHTO T88-97) were conducted. Results are summarized in Table 4.4.

Soil Type		Sample Name	LL	PI	% gravel	% sand	% <#200
AASHTO	USCS						
A-4	SC-SM	MUS-60-21	29	6	29	29	42
	CL	GRE-35-21.13, 320, 400	24	8	14	22	64
	CL	WAS-7-Mari	29	10	34	3	63
	CL	SHE-SR47	26	9	3	17	80
A-6	CL	WAR-741-3	28	11	26	23	61
	CL	WAS-821-113, 116	32	11	11	13	76
	CL	BEL-SR147, 265	35	11	5	4	91
	CL	ATH-50-Cool	33	13	8	8	84
	CL	ATH-50-222, 228, 413	31	12	26	18	56
A-7-6	CH	ATH-SR7	59	32	0	0	100
	CH	FAI-I70	55	36	1	7	92
	CL	CRA-Beal	41	21	0	7	93
	CL	HEN-SR6, 24	41	20	0	5	95

Table 4.4 Classification and Engineering Properties of Laboratory Samples

Standard Proctor compaction tests were conducted on each soil sample (Procedure A, AASHTO T99-97). The samples tested for compressive strength followed ODOT minimum compaction requirements (Table 4.5). Table 4.6 lists results for each sample.

4.2.2.2 Unsaturated Strength

Unconfined compression tests (AASHTO T208-96), on samples compacted 2% dry of optimum (DRY), at optimum moisture content (OMC), and at 2% wet of optimum (WET) were performed. Triplicate specimens for each soil sample were prepared at the desired moisture content and dry density and tested.

Maximum Laboratory Dry Weight kN/m^3 (pcf)	Minimum Compaction Requirements Percent Laboratory Maximum (%)
14.12 – 16.47 (90 – 104.9)	102
16.48 –18.83 (105 – 119.9)	100
>18.84 (>120)	98

Table 4.5 Embankment Soil Compaction Requirements (ODOT, 1997)

As shown in Table 4.6, the unconfined compressive strengths for the A-4 samples ranged from 200 to 360 kPa when tested dry of optimum, 150 to 325 kPa at optimum, and from 80 to 200 kPa for the samples compacted above optimum moisture content. Unconfined compressive strengths for the A-6 group ranged from 345 to 700 kPa dry of optimum, 190 to 560 kPa at optimum, and 90 to 335 kPa at wet of optimum. For the A-7-6 group, the unconfined compressive strength ranged from 320 to 550 kPa dry of optimum, 260 to 450 kPa at optimum, and 200 to 365 kPa wet of optimum.

4.2.2.3 Saturated strength

Saturated soil samples tested for unconfined compressive strength were first compacted at the optimum moisture content and maximum dry density. Each sample was saturated in a triaxial chamber through a combination of flushing with deaired water and application of elevated backpressure. Degree of saturation was monitored by periodically checking the B-value. Saturation was deemed complete when the B-value was 0.95 or greater. Tests were conducted on six saturated (SAT) samples, two from each of the principal soil groups. Unconfined compressive strengths are listed in Table 4.6. Table 4.7 shows the reduction of unconfined compressive strength due to an increase in the moisture content from the optimum condition to saturation. The two A-4 samples show reductions of 52 and 38%, the strengths of two A-6 samples decreased 67 and 82%, and the two A-7-6 samples strength reductions were 59 and 82%. Clearly, the adverse affects of saturation on the strength of compacted soil are significant.

Soil Type	Sample	Optimum Moisture Content (%)	Maximum Dry Density (kN/m^3)	Sample Moisture Content (%)	Sample Dry Density (kN/m^3)	q_u (kPa)
A-4	MUS-60-21	14.4	18.24	DRY: 11.4	17.94	256.1
				OMC: 14.4	18.24	151.3
				WET: 16.4	17.94	103.7
	GRE-35-21.13, 302, 400	12.3	19.81	DRY: 10.3	18.98	209.1
				OMC: 12.3	19.42	168.6
				WET: 14.3	18.74	80.3
	WAS-7-Mari	14	19.38	DRY: 11.0	18.69	266.8
				OMC: 14.0	18.99	202.4
				WET: 16.0	18.59	153.0
				SAT: 16.5	18.99	97.6
	SHE-SR47	14.5	18.28	DRY: 12.5	17.79	360.4
				OMC: 14.5	18.28	325.7
				WET: 16.0	17.93	197.3
				SAT: 17.2	18.28	200.7
A-6	WAR-741-3	14	18.79	DRY: 12.0	18.53	347.6
				OMC: 14.0	18.79	192.0
				WET: 16.0	18.48	92.1
	WAS-821-113, 116	14.8	18.60	DRY: 10.8	18.24	399.1
				OMC: 14.8	18.60	215.2
				WET: 17.8	18.04	108.0
	BEL-SR147, 265	13.8	18.29	DRY: 11.3	18.22	364.1
				OMC: 13.8	18.29	316.3
				WET: 15.8	18.14	259.1
	ATH-50-Cool	16	18.43	DRY: 14.0	18.04	688.8
				OMC: 16.0	18.43	409.7
				WET: 18.0	18.04	223.6
				SAT: 19.0	18.43	135.7
	ATH-50-222, 228, 413	13.4	18.73	DRY: 11.4	18.24	696.1
				OMC: 13.4	18.73	555.0
				WET: 15.4	18.43	331.1
				SAT: 15.8	18.73	97.6
A-7-6	ATH-SR7	24.2	14.82	DRY: 21.2	14.84	320.6
				OMC: 24.2	15.11	264.5
				WET: 27.2	14.79	200.4
	FAI-I70	18.6	15.61	DRY: 17.1	15.80	340.4
				OMC: 18.6	15.92	304.3
				WET: 20.1	15.87	282.8
				SAT: 24.8	15.92	54.3
	CRA-Beal	17.7	16.88	DRY: 15.7	16.51	348.1
				OMC: 17.7	16.88	329.3
				WET: 19.7	16.53	218.7
				SAT: 21.5	16.88	134.6
	HEN-SR6, 24	19.6	16.53	DRY: 17.6	16.02	549.3
				OMC: 19.6	16.53	450.4
				WET: 21.6	16.16	365.0

Table 4.6 Compaction and Unconfined Compressive Strength Test Results

Soil Type	Soil Sample	Reduction compared with w_{opt}, kPa	% of reduction compared with w_{opt}
A-4	WAS-7-Mari	-104.8	-51.7
	SHE-SR47	-125.0	-38.4
A-6	ATH-50-Cool	-274.0	-66.9
	ATH-50-222, 228, 413	-457.4	-82.4
A-7-6	FAI-I70	-250.0	-82.2
	CRA-Beal	-194.7	-59.1

Table 4.7 Reduction in Unconfined Compressive Strength due to Increase in Moisture Content from w_{opt} to w_{sat}

4.2.3 Resilient Modulus Testing and Results

The major components of M_r testing system in the Soil Mechanics Laboratory at The Ohio State University are shown in Figure 4.1. The specified load was applied by a loading system manufactured by MTS Systems Corporation. A conventional triaxial pressure chamber (see Figure 4.2) was modified to include an internal load cell to measure axial load, an LVDT to measure axial displacement, and a pore water pressure transducer. The load cell was mounted inside the triaxial pressure chamber between the steel piston and the top platen on the soil specimen. The LVDT was mounted on the external steel rod in the top cover of the triaxial pressure chamber. The pore water pressure transducer was mounted on the bottom drainage valve.

The soil specimens for the M_r tests were 72.8 mm in diameter and 152.2 mm in height. They were compacted according to the compaction requirements listed in Table 4.6. The testing protocol in AASHTO T294-94 (Table 4.8), was followed for the samples tested at their as compacted water contents. During these tests, the bottom drainage valves were open and no pore pressures were measured. For fully saturated samples a modified procedure (Huang (2001)) and listed in Table 4.9, was followed.

Figures 4.3, 4.4 and 4.5 show results of M_r tests on A-4, A-6 and A-7-6 samples respectively. These results illustrate the effect of varying the deviator and confining stresses, and the moisture content. Results from the complete M_r test program are given in Appendix B. As shown in Figures 4.3, 4.4, and 4.5, the modulus at constant confining stress decreased with increase in deviator stress. In many cases, this rate was more pronounced at low deviator stress than that at high deviator stress. As mentioned earlier, this nonlinear trend in M_r with respect to deviator stress has been observed by other researchers (Seed, et al. (1962), Fredlund, et al. (1977), Woolstrum (1990), Drumm, et al. (1990), Li and Selig (1994), Pezo and Hudson (1994), Lee et al. (1995), Mohammad, et al. (1999), Kim (1999), Huang (2001), and Masada and Sargand (2002)). The modulus increased with an increase in confining stress but, as found in other studies, was strongly dependent on moisture content with significant decreases in modulus associated with relatively small percentage increases in moisture content.

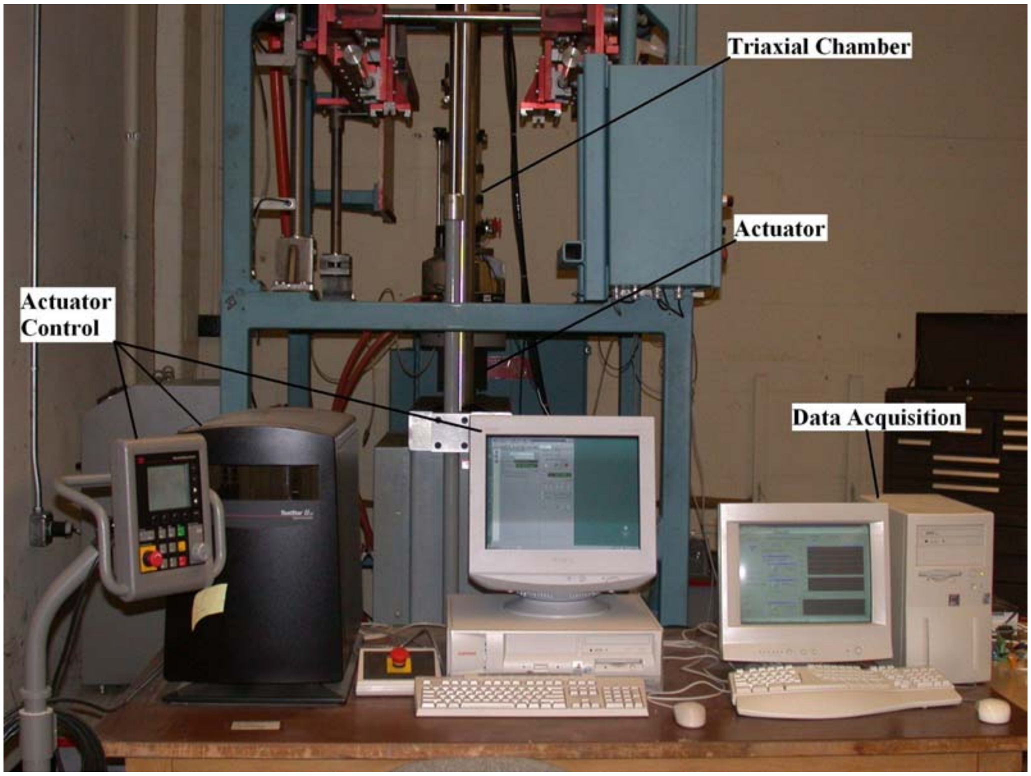

Figure 4.1 M_r Testing System

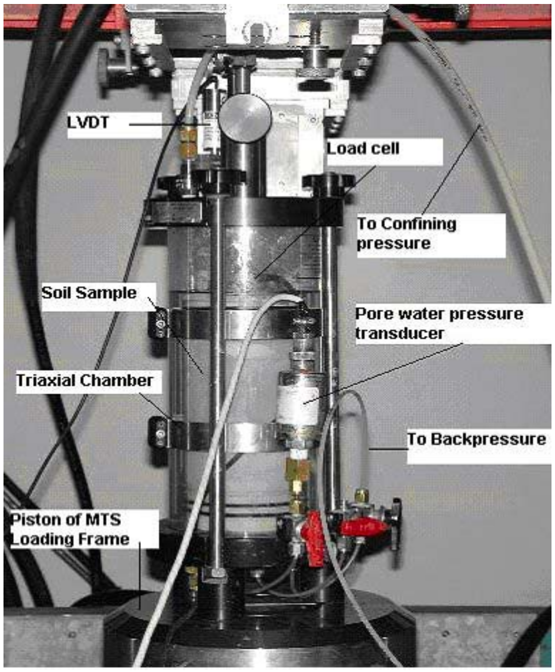

Figure 4.2 Modified Triaxial Cell for M_r Tests

Sequence No.	Confining Pressure (kPa)	Deviator Stress (kPa)	Number of load applications
0	41	28	1000
1	41	14	100
2	41	28	100
3	41	41	100
4	41	55	100
5	41	69	100
6	21	14	100
7	21	28	100
8	21	41	100
9	21	55	100
10	21	69	100
11	0	14	100
12	0	28	100
13	0	41	100
14	0	55	100
15	0	69	100

Table 4.8 M_r Testing Sequences for Unsaturated Samples

Testing Procedure	Sequence	Confining Pressure, kPa	Deviator Stress, kPa	Number of Loading Cycles
Modified Testing, Saturated Soil	1	21	14	1000
	2	21	14	100
	3	21	28	100
	4	21	41	100
	5	21	55	100
	6	21	69	100

Table 4.9 Modified M_r Testing Sequences for Saturated Samples (Huang, 2001)

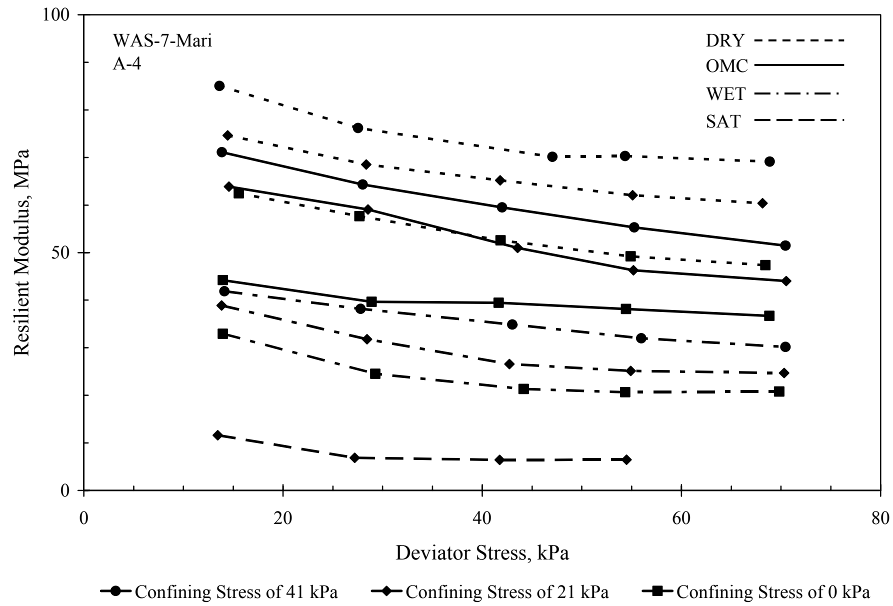

Figure 4.3 M_r Test Results for A-4 Soil (WAS-7-Mari)

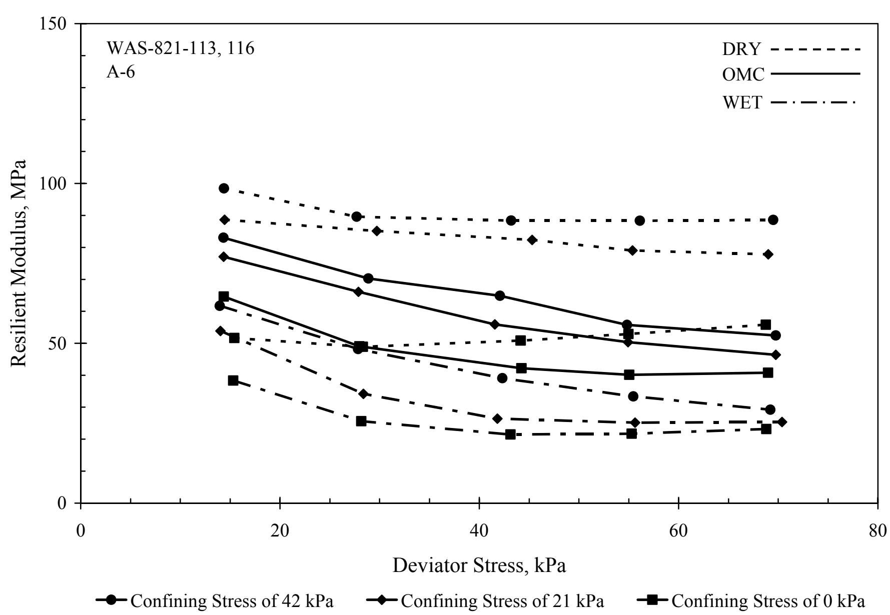

Figure 4.4 M_r Test Results for A-6 Soil (WAS-821-113,116)

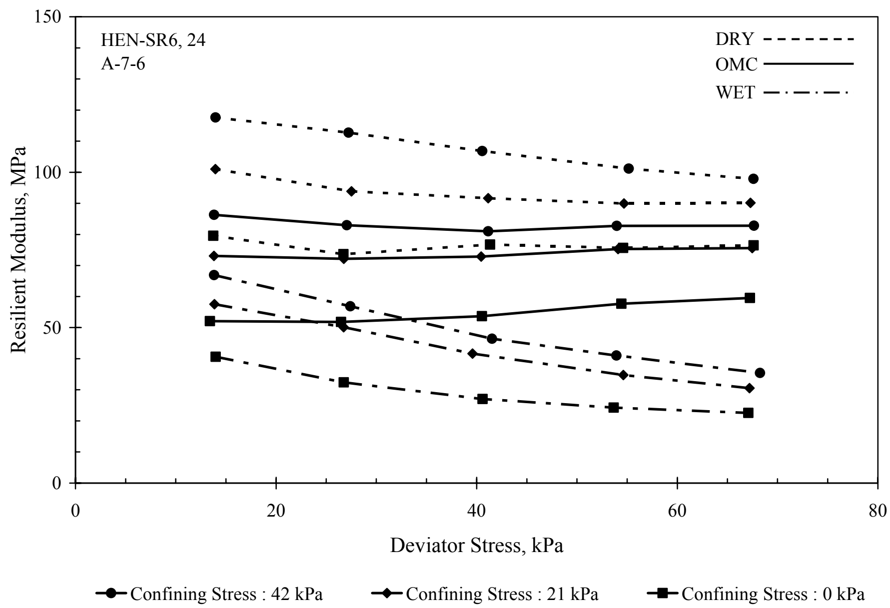

Figure 4.5 M_r Test Results for A-7-6 Soil (HEN-SR6, 24)

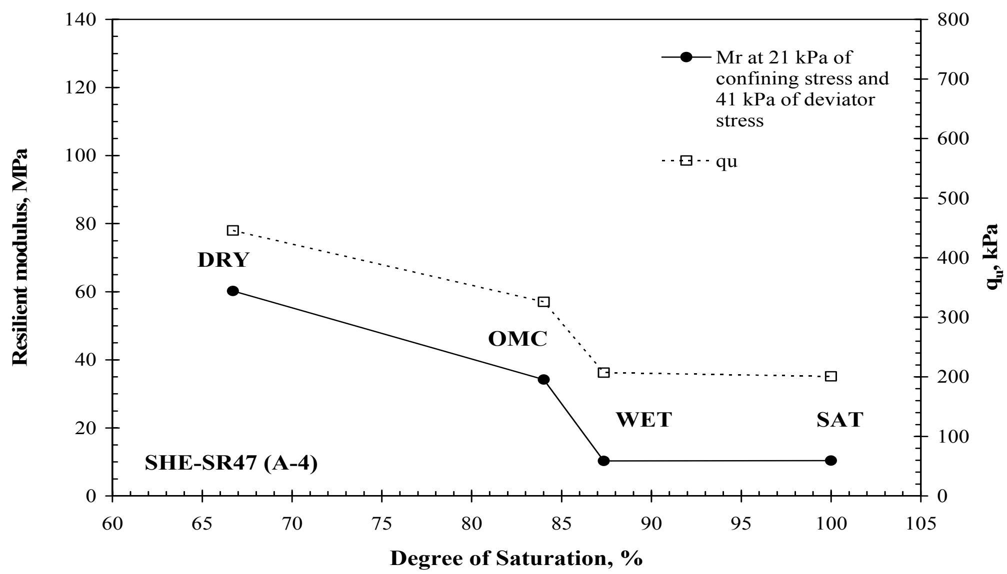

Figure 4.6 M_r and q_u v. Degree of Saturation for A-4 soil

Figures 4.6, 4.7 and 4.8 show M_r for a deviator stress of 41 kPa and a confining stress of 21 kPa for an A-4, A-6 and A-7-6 soils. M_r clearly decreased with increasing degree of saturation. It is obvious the degree of saturation has a significant effect on the modulus. Also as unconfined compressive strength decreases, modulus decreases.

Soil Type	Sample	DRY			OMC			WET		
		k_1	k_2	R^2	k_1	k_2	R^2	k_1	k_2	R^2
A-4	MUS-60-21	51.6	-0.041	0.03	30.2	-0.027	0.004	4.1	0.305	0.85
	GRE-35-21.13, 320,400	116.1	-0.142	0.13	89.8	-0.15	0.18	20.0	-0.022	0.005
	WAS-7-Mari	111.1	-0.153	0.29	96.3	-0.183	0.25	76.5	-0.27	0.46
	SHE-SR47	79.0	-0.08	0.05	90.2	-0.256	0.43	13.4	-0.044	0.01
A-6	WAR-741-3	97.6	-0.069	0.07	108.6	-0.232	0.29	14.7	-0.021	0.02
	WAS-821-113, 116	84.6	-0.04	0.01	171.8	-0.312	0.61	160.7	-0.448	0.59
	BEL-SR147, 265	49.3	0.064	0.005	98.9	-0.153	0.29	114.5	-0.355	0.42
	ATH-50-Cool	104.4	-0.033	0.03	102.4	-0.068	0.1	271.7	-0.515	0.66
	ATH-50-222, 228, 413	149.5	-0.113	0.13	122.8	-0.225	0.11	119.2	-0.225	0.31
A-7-6	ATH-SR7	109.4	-0.064	0.04	79.2	-0.01	0.002	129.4	-0.222	0.51
	FAI-I70	68.8	0.0004	0.0	153.5	-0.179	0.19	82.3	-0.049	0.03
	CRA-Beal	111.4	-0.087	0.05	122.5	-0.213	0.16	108.9	-0.341	0.46
	HEN-SR6, 24	116.9	-0.069	0.07	62.4	0.031	0.009	155.6	-0.391	0.49

Table 4.10 Model Regression Constants

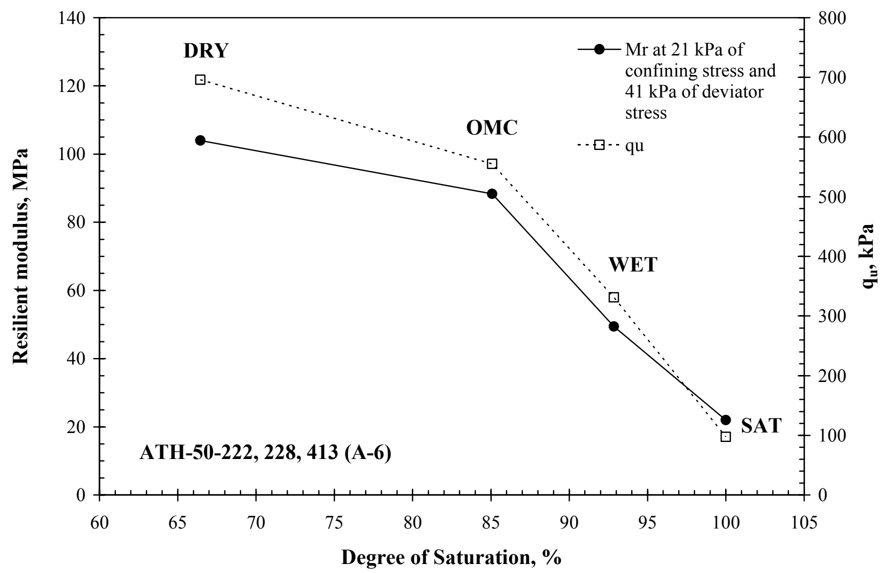

Figure 4.7 M_r and q_u v. Degree of Saturation for A-6 soil

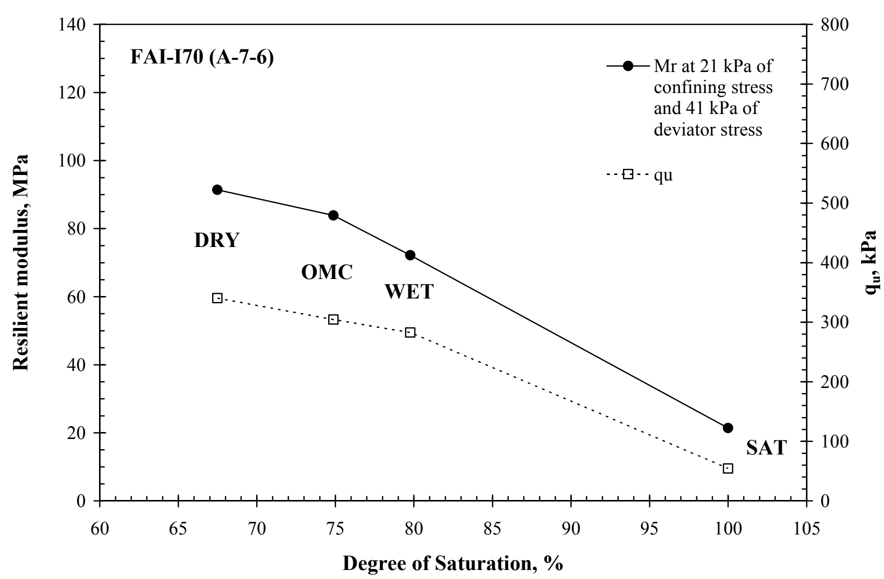

Figure 4.8 M_r and q_u v. Degree of Saturation for A-7-6 soil

Table 4.11 shows the range of reduction of M_r for seven soil samples at saturated condition as compared at optimum moisture content samples. In the case of A-4 group, the reduction in M_r ranged from 8 to 88%. The reduction in M_r for the A-6 soils ranged from 50 to 87%. The A-7-6 soils modulus drop ranged from 44 to 82%.

Soil Type	Soil Sample	Reduction in M_r, MPa	% M_r Reduction
A-4	WAS-7-Mari	-39.8 to -52.3	-81.8 to -88.4
	SHE-SR47	-3.4 to -23.8	-7.7 to -73.9
A-6	ATH-50-Cool	-51.4 to -70.0	-58.2 to 85.0
	ATH-50-222, 228, 413	-63.4 to -72.0	-67.3 to -86.7
	DEL-23 (Huang(2001))	-39.6 to -41.1	-49.6 to -77.4
A-7-6	FAI-I70	-59.9 to -80.0	-70.9 to -81.7
	CRA-Beal	-29.1 to -31.9	-43.5 to -63.6

Table 4.11 Reduction in M_r due to Increase in Moisture Content from w_{opt} to w_{sat}

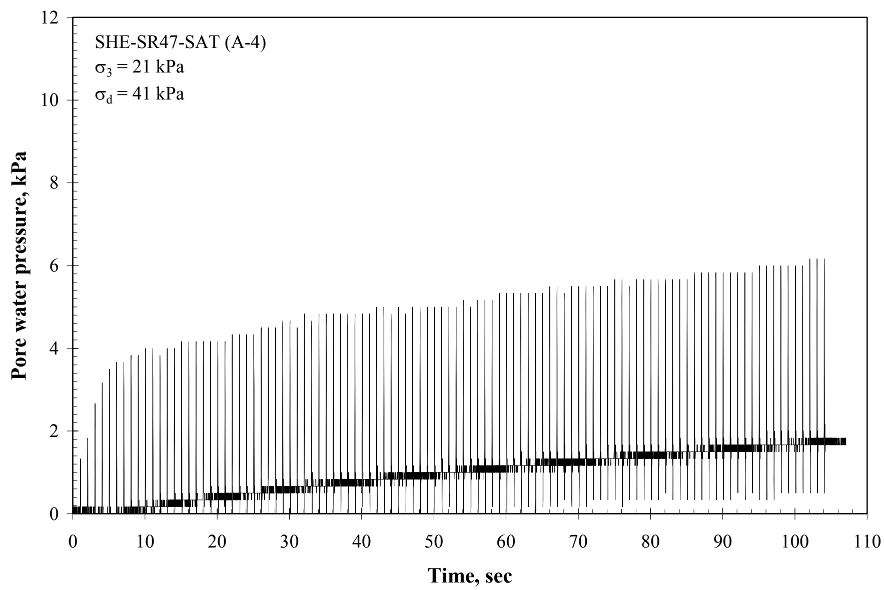

Figure 4.9 Pore Water Pressure Buildup A-4 Soil

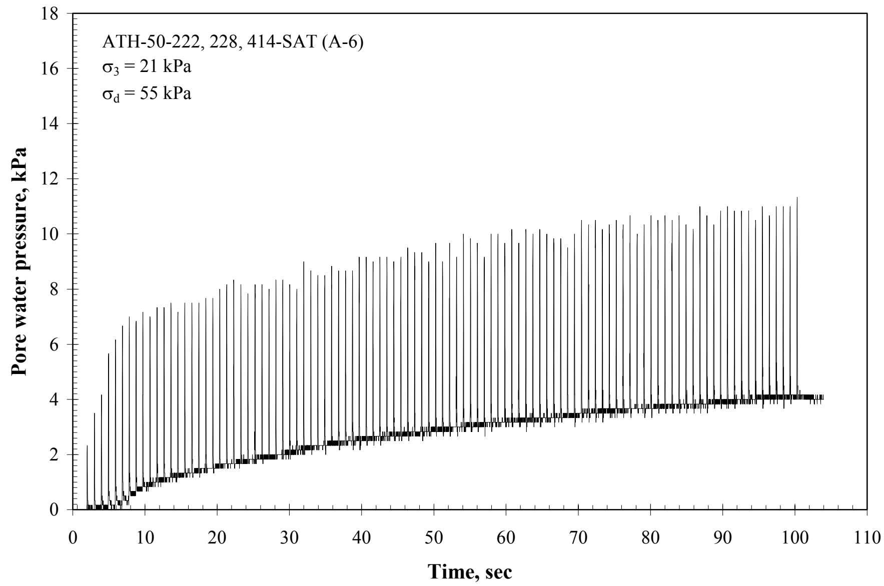

Figure 4.10 Pore Water Pressure Buildup for A-6 Soil

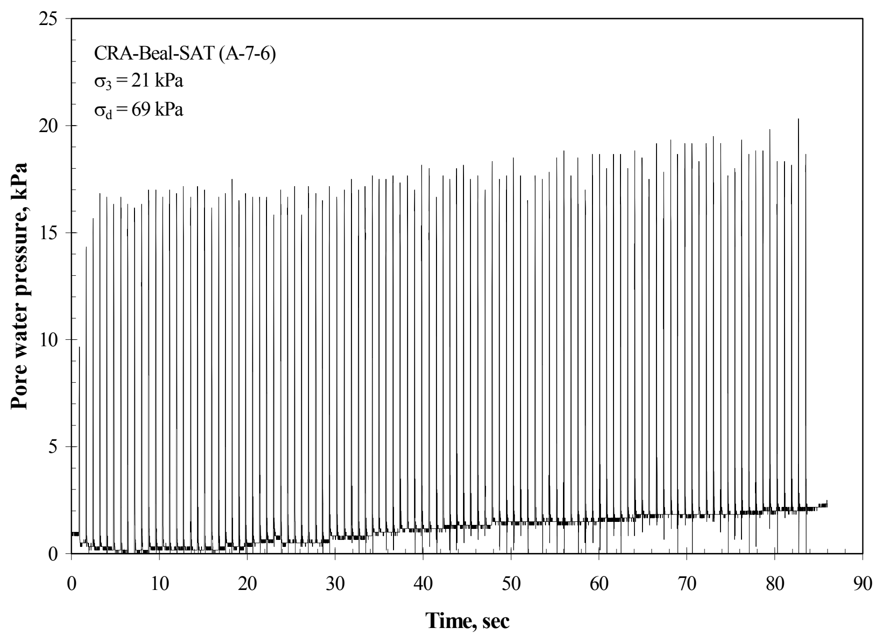

Figure 4.11 Pore Water Pressure Buildup for A-7-6 Soil

4.3 Field Data Collection at the US 23 SHRP Site

4.3.1 SHRP Instrumentation

The OSU test sections were shown schematically in Figure 1.1. The characteristics of each section are listed in Table 4.12. Figure 4.12 depicts a typical SHRP configuration of the instrumentation as installed at test section 390263. At five locations the subsurface temperatures, moisture content and resistivity are recorded monthly. The installation and initial calibration procedures of the SHRP instruments were presented in the 1998 report. A complete listing of the data collected at each location over the period of the project is maintained by ODOT and the reader seeking the data for a specific location or transducer type is referred the project website. A review of the general data trends will be presented below.

4.3.1.1 Moisture content

The TDR data plotted in Figure 4.13 (section 390263) clearly show seasonal fluctuations in the moisture. However, it is clear from the data plotted in Figure 4.14 that the average annual moisture content in the subgrade has continued to increase since construction and installation. After seven years, the average moisture content is approximately 25% indicating full saturation is likely. This observation is supported by the pore pressure data presented below.

4.3.1.2 Soil Temperature

The temperature profile for 2003 (390263) is shown in Figure 4.15. Figure 4.16 is the temperature time history since 1996 at each transducer depth (390263).

4.3.1.3 Resistivity

The soil resistivity profile for test section 390263 is shown in Figure 4.17. The readings in the spring of 2003 are questionable due to electrical problems with the collection system that have since been corrected. A seasonally averaged plot of the data since the summer of 1996 is presented in Figure 4.18. The data suggest that with the exception of the readings that can be associated with equipment problems, there has been little variation in soil resistivity since the devices were installed.

4.3.2 Tensiometers

Tensiometers have been installed at seven SPS sections plus the weather station. The devices were constructed with pressure gages capable of recording negative (referenced to the atmosphere) pressures because the on-site soils were known to be partially saturated at the time of placement. As discussed in the 1998 report, the pore water in partially saturated fine grained soils exists at pressures below atmospheric.

The tensiometers at sections 390211, 390263 and 390904 and the weather station were installed in 1996 during the same time period that the SHRP instrumentation was placed. The tensiometers at sections 390160, 390106 and 390121 were installed in 2002 and a final set of tensiometers was placed at section 390109 in 2003. The pore pressure values were recorded at three depths (0, 30.5 and 61 cm (0, 12, and 24 inches)) below the base into the subbase.

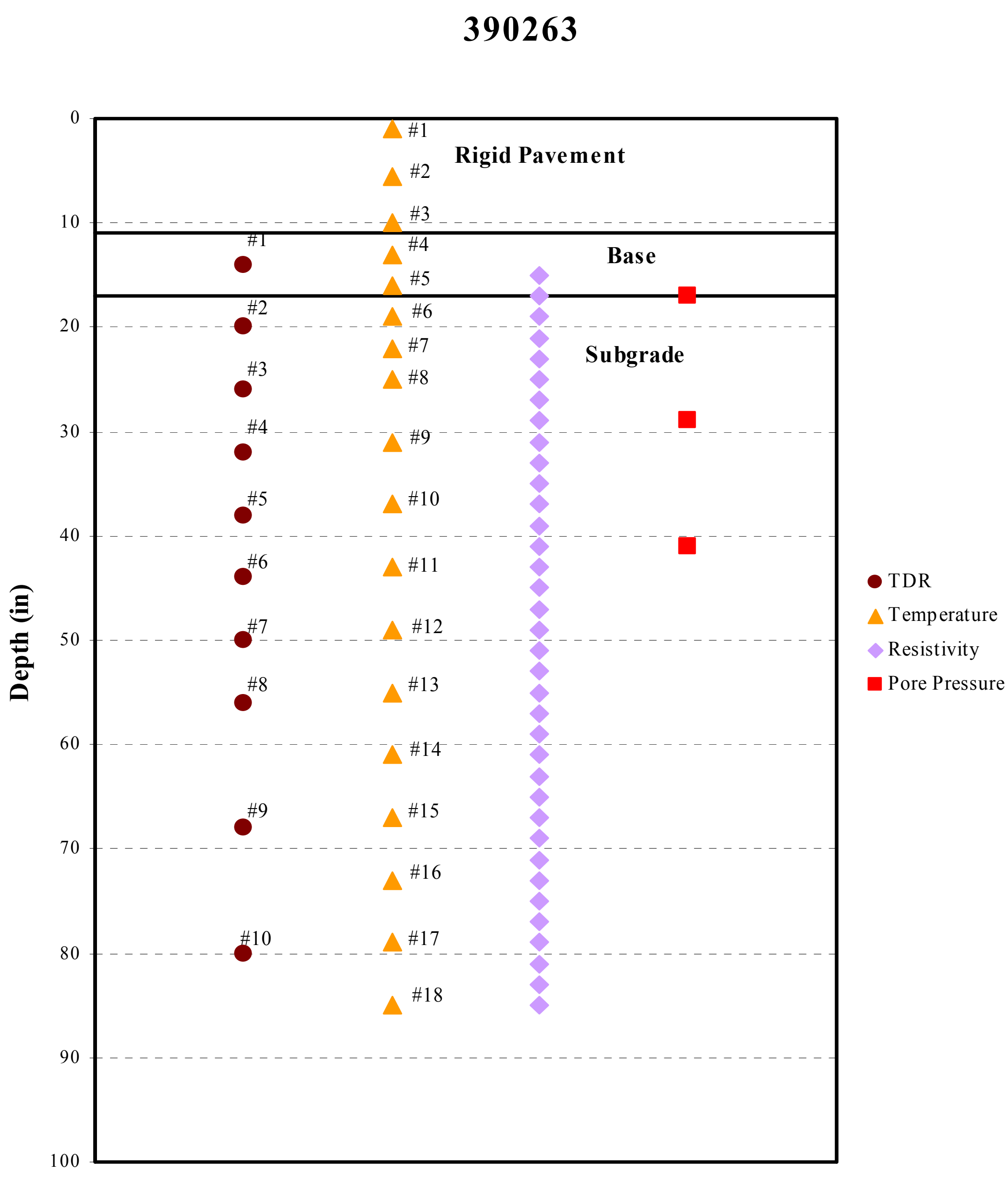

Figure 4.12 Instrumentation Configuration (390263)

	Section	Designation	Thickness (in)			Base	Drain	Environmental Instrument
			AC	PCC	Base	Type		
390109	J9	SPS-1	3.25		35.25	9.25" ATB/ 4" NJ / 6" DGAB 16" Cement Soil	Yes	Soil Suction
390108	J8	SPS-1	7		12	4" PATB/ 8" DGAB	Yes	Temperature Moisture Frost Depth
390160	S7	SPS-1	4		15	11" ATB/ 4" DGAB	Yes	Soil Suction
390106	J6	SPS-1	7		12	8" ATB/ 4" DGAB	No	Soil Suction
390904	SHRP	Experimental SHRP Mix SPS-9	4		22	12" ATB/ 4" PATB/ 6" DGAB	Yes	Temperature Moisture Frost Depth Soil Suction
390212	J12	SPS-2		11	8	4" PATB/ 4" DGAB	Yes	Soil Suction
390201	J1	SPS-2		8	6	DGAB	No	Temperature Moisture Frost Depth
390211	J11	SPS-2		11	8	4" PATB/ 4" DGAB	Yes	Temperature Moisture Frost Depth Soil Suction
390263	S4	SPS-2		11	6	DGAB	Yes	Temperature Moisture Frost Depth Soil Suction

SPS-1: Strategic study of structural factors for flexible pavement AC: Asphalt Concrete
SPS-2: Strategic study of structural factors for rigid pavement PCC: Portland Cement Concrete
SPS-9: Asphalt program field verification studies
DGAB: Dense Graded Aggregate Base ATB: Asphalt Treated Base ATB: Permeable Asphalt Treated Base

Table 4.12 Ohio State University Test Sections

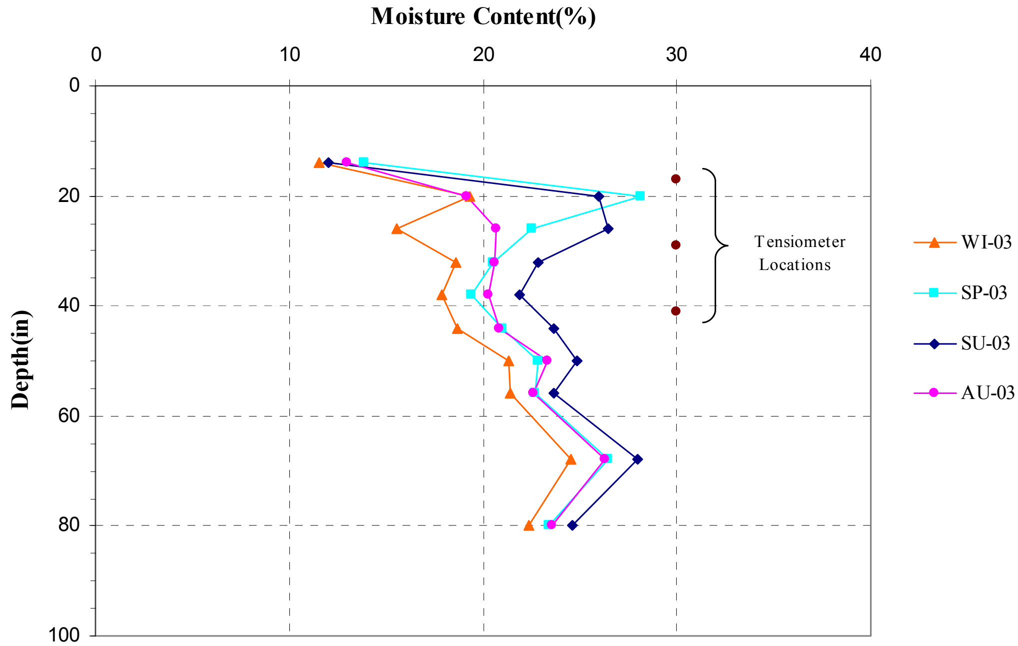

Figure 4.13 Seasonal Moisture Content in 2003 (390263)

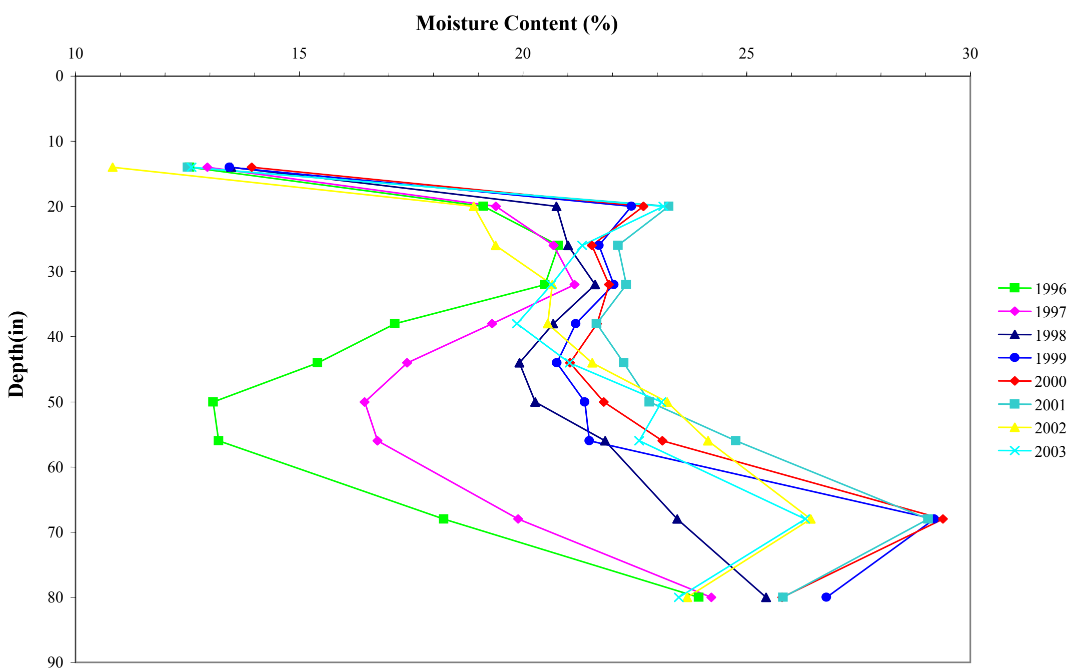

Figure 4.14 Annual Average Moisture Content, 1996-2003 (390263)

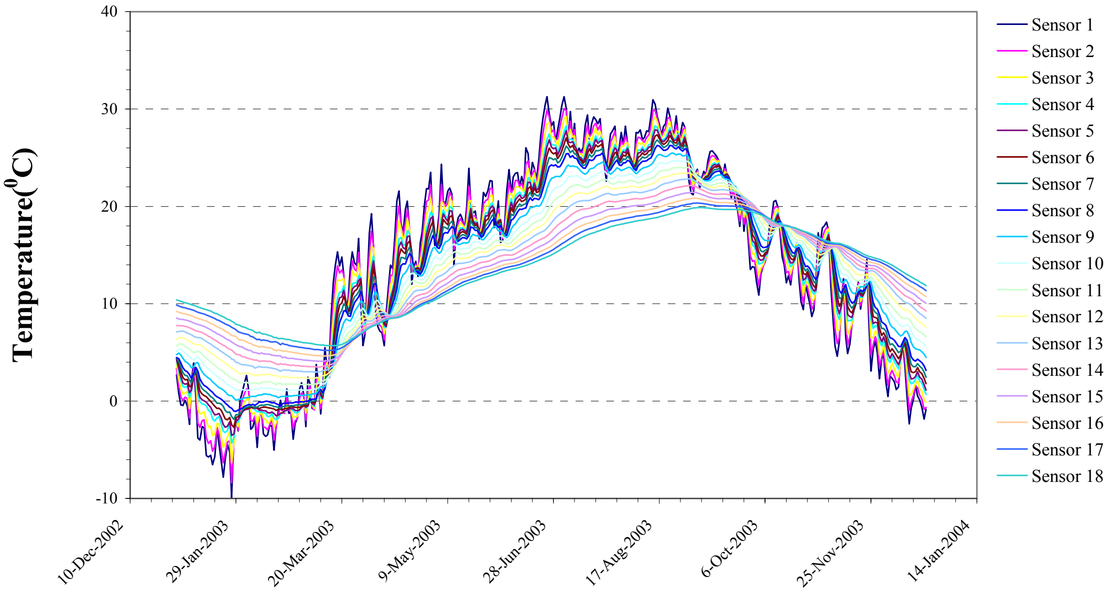

Figure 4.15 Seasonal Soil Temperatures, 2003 (390263)

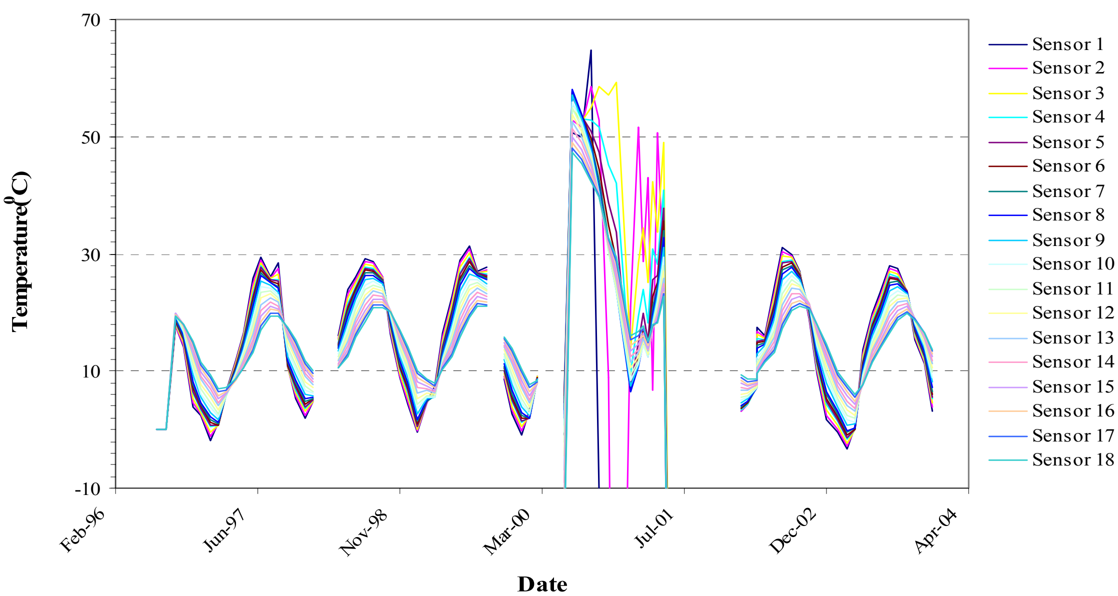

Figure 4.16 Soil Temperature Variations, 1996-2003 (390263)

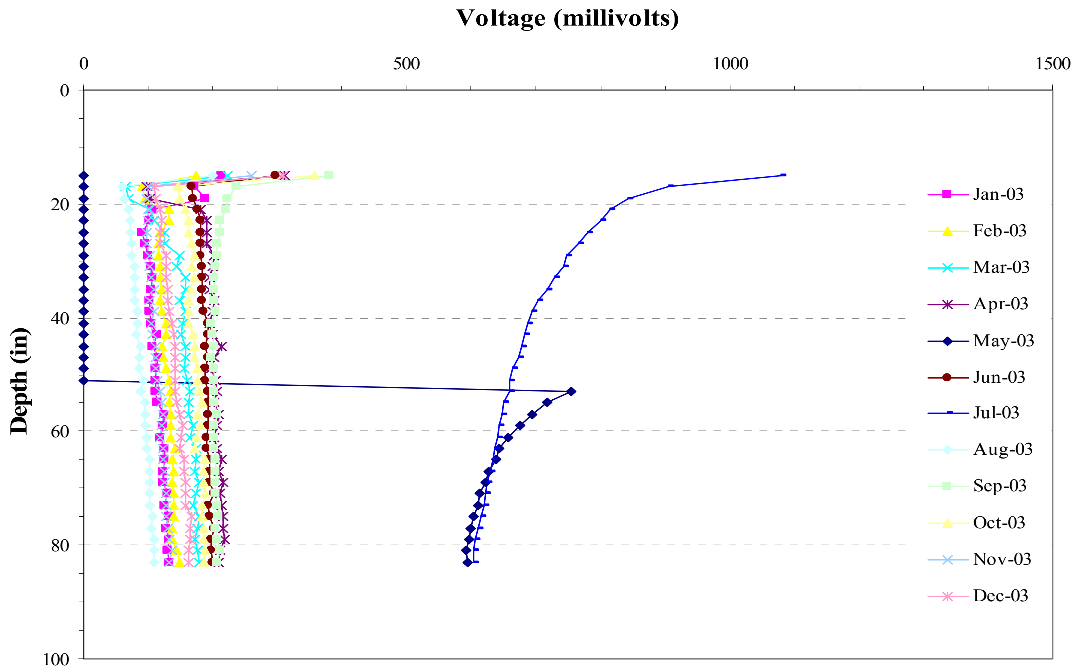

Figure 4.17 Soil Resistivity, 2003 (390263)

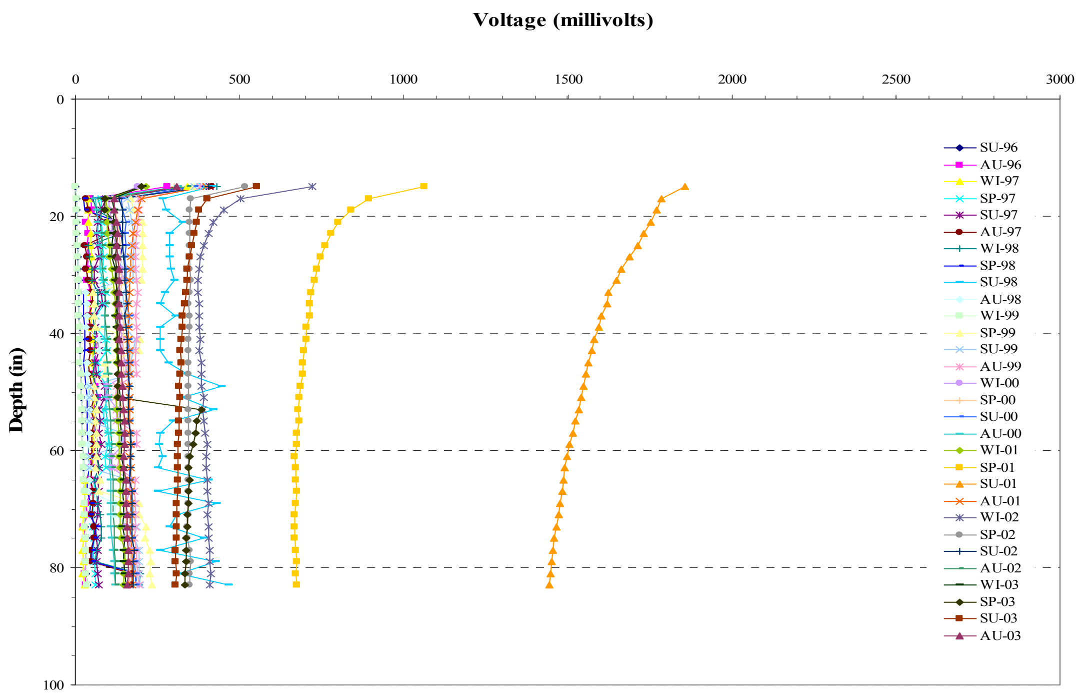

Figure 4.18 Seasonal Resistivity Variation, 1996-2003 (390263)

5. RESULTS

5.1 Tensiometer Data

The readings for the seven highway sites plus the weather station are presented in Figures 5.1 through 5.8. In 2003 all the tensiometers placed during construction in 1996 recorded positive pore pressures throughout the year at all locations except at 12" into the subbase in section 390263 at the end of the summer. The moisture contents as determined by the TDRs were still comparatively high at that time so there appears to be some need to continue to refine the correlation between indirect measure of moisture content provided by the TDRs and the indication of the water table and saturation as given by the tensiometers. The initial pore pressure values recorded by the tensiometers installed in 2002 and 2003 were all less than atmospheric at the surface of the subbase but at 12" and 24" into the subbase positive pore pressures existed by the time the first reading was taken. The pore pressures continued to increase through the following month. They are now typically greater than atmospheric and therefore have a negative effect of subgrade performance. Pore pressure measurements at the weather station show a wider fluctuation at a depth of 12 inches than at any location under pavement, indicative of increased effect of changes in surface moisture conditions. At a depth of 24 inches the pore pressures remained negative throughout the year. A review of the pore pressures recorded at the weather station from the time the tensiometers were installed (Figure 5.9) demonstrates a distinct difference in response at this location when compared with the pressure readings recorded under paved sections (Figure 5.10).

With the exception noted above for the water content and pore pressure data collected late summer 2003 at test section 390263, increases in water content correspond to increases in pore pressures. Although seasonal changes are apparent, the trend has been since installation to increasing water content until apparent saturation at about 25% is reached. These data, particularly when contrasted with the weather station data, strongly suggest that water is being drawn up into the profile from depth. Only one of the more recently installed tensiometers is in a section (390106) without edge drains. However, the similarity between the pore pressure data collected at this location and the data from the other sections that were designed with drains is a strong indication that the base and subbase should not be considered to be free draining.

5.2 Laboratory Resilient Modulus Tests - Comparison and Analysis of Existing Models

The six models presented earlier have been used by a number of agencies to estimate the value of resilient modulus appropriate for use in design. In this section the predicted M_r using these six models is compared with the results from of the resilient modulus tests conducted on the thirteen Ohio soil samples.

The models were used to predict M_r for the soil samples at optimum moisture content at confining stresses of 0, 21 and 41 kPa. Figures 5.11, 5.12, and 5.13

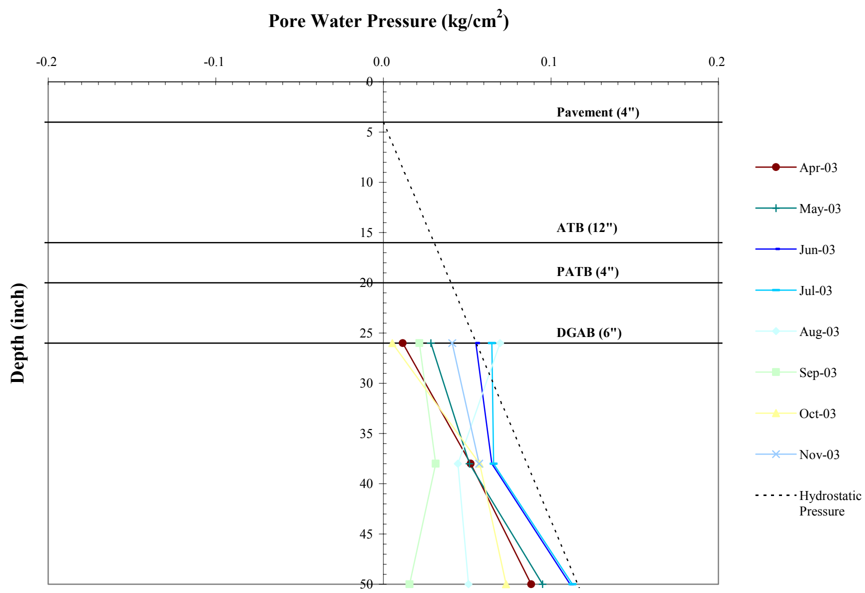

Figure 5.1 Pore Water Pressure, 2003 (390904)

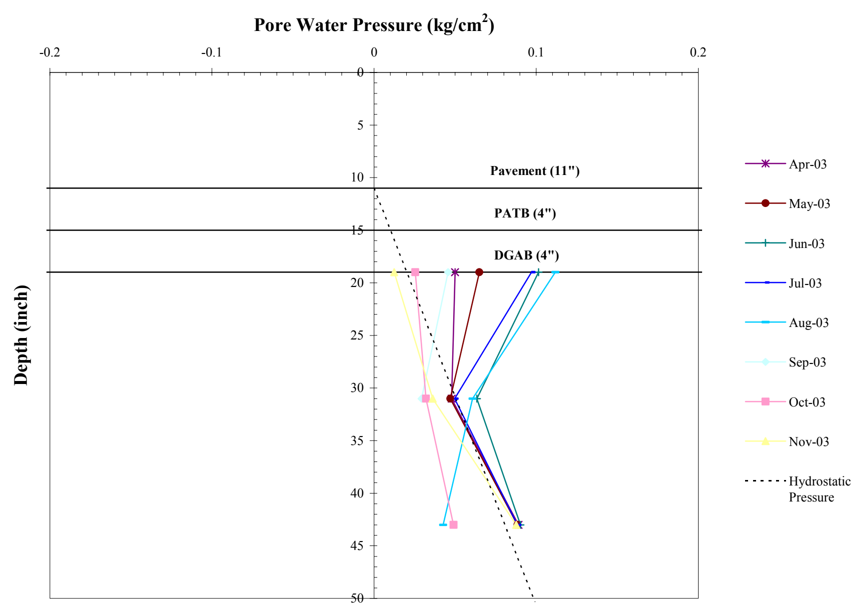

Figure 5.2 Pore Water Pressure, 2003 (390211)

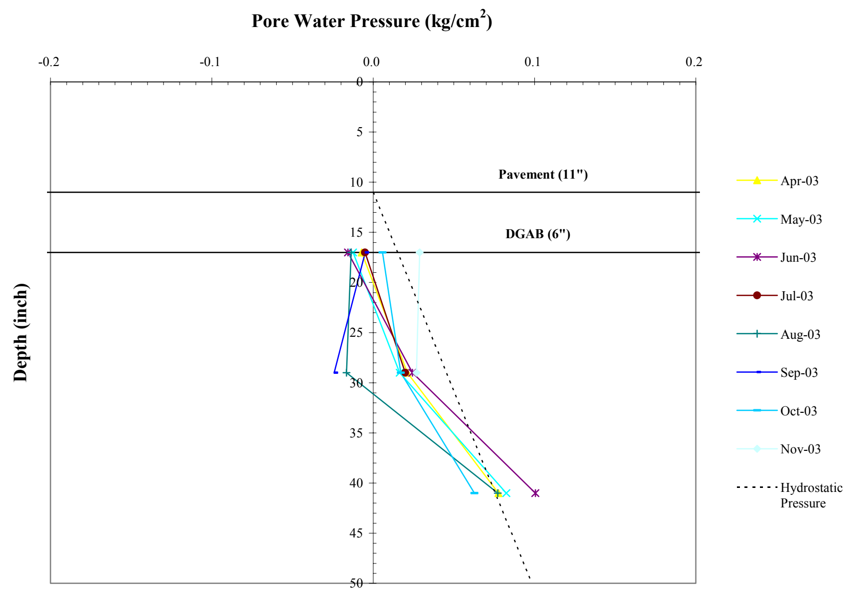

Figure 5.3 Pore Water Pressure, 2003 (390263)

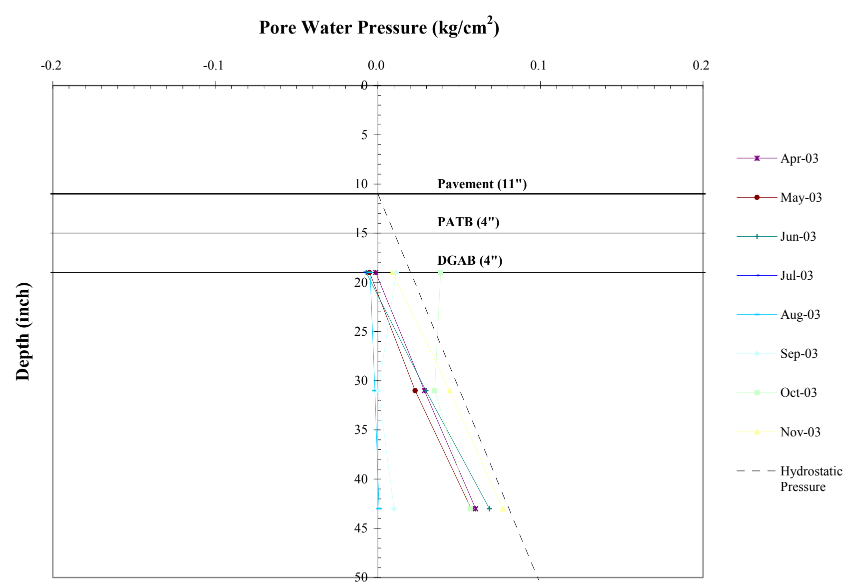

Figure 5.4 Pore Water Pressure, 2003 (390212)

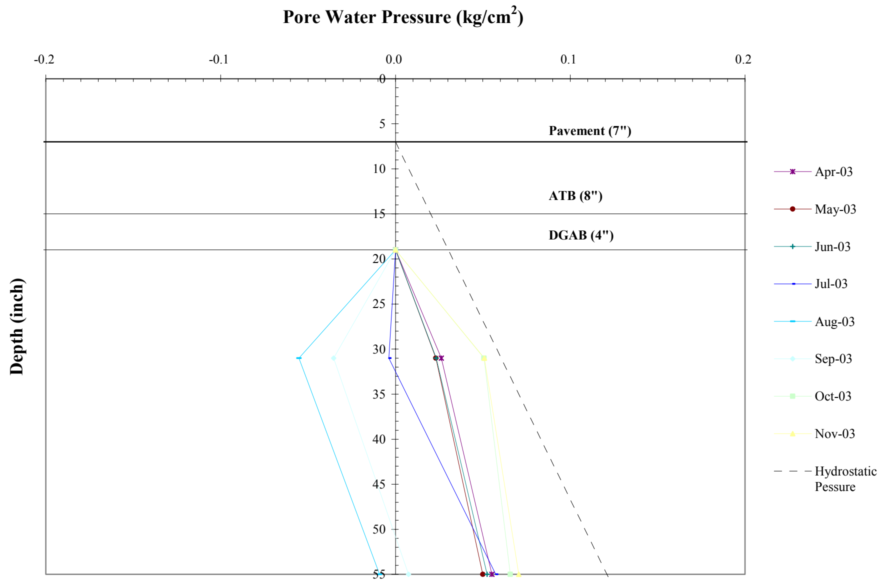

Figure 5.5 Pore Water Pressure, 2003 (390106)

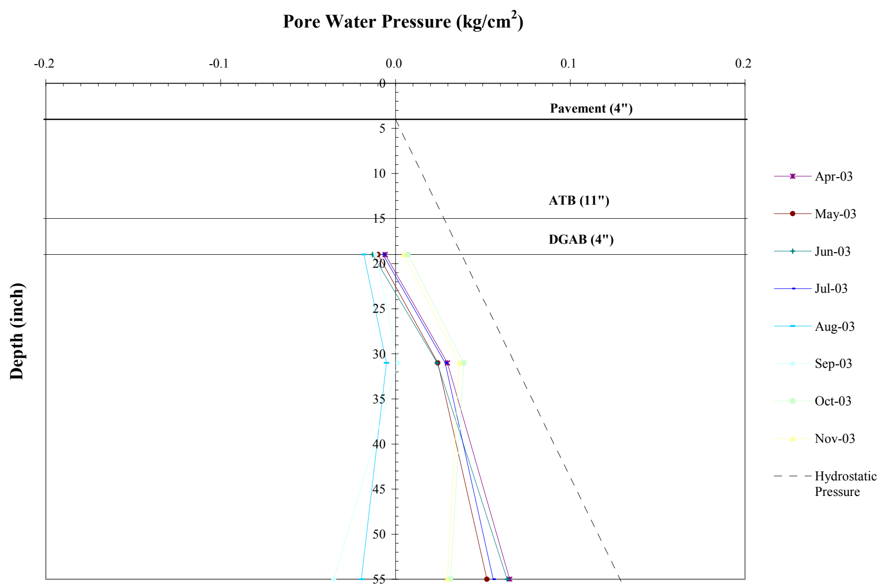

Figure 5.6 Pore Water Pressure, 2003 (390160)

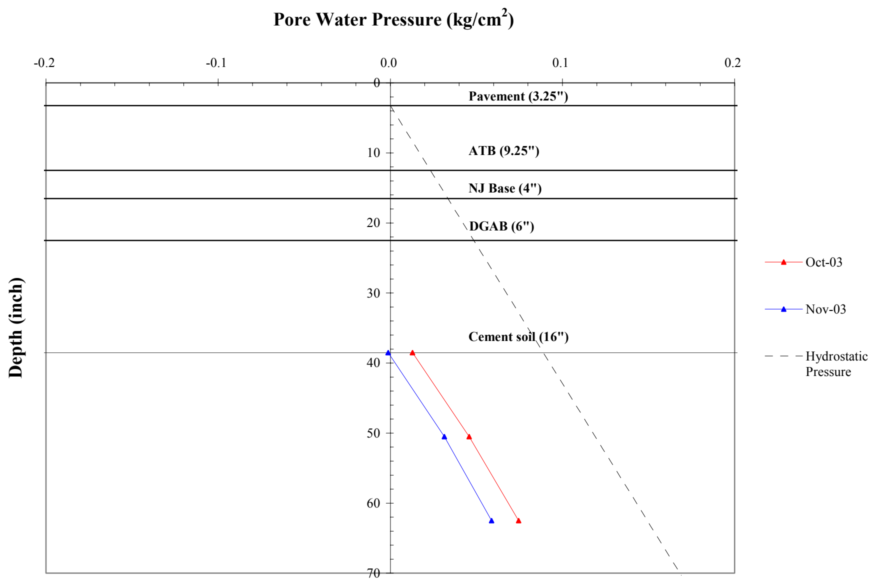

Figure 5.7 Pore Water Pressure, 2003 (390109)

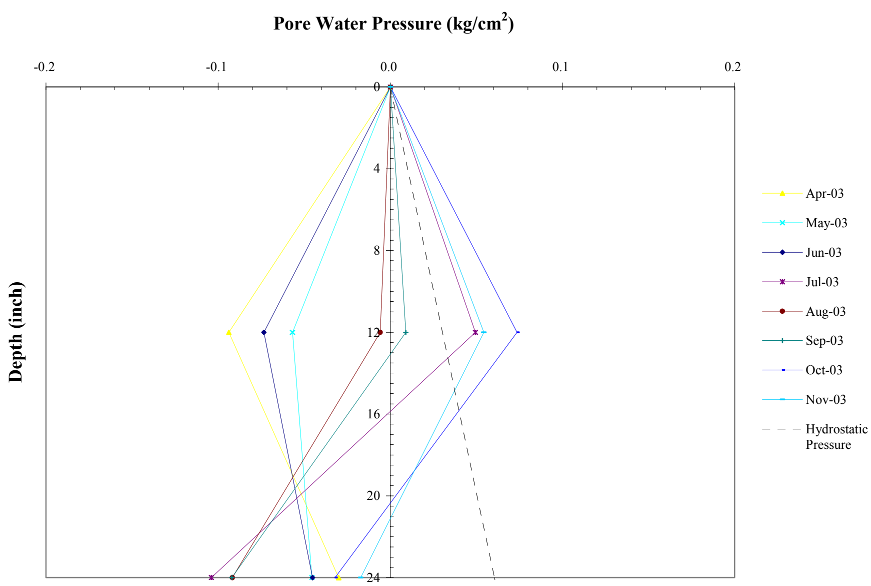

Figure 5.8 Pore Water Pressure, 2003 (Weather Station)

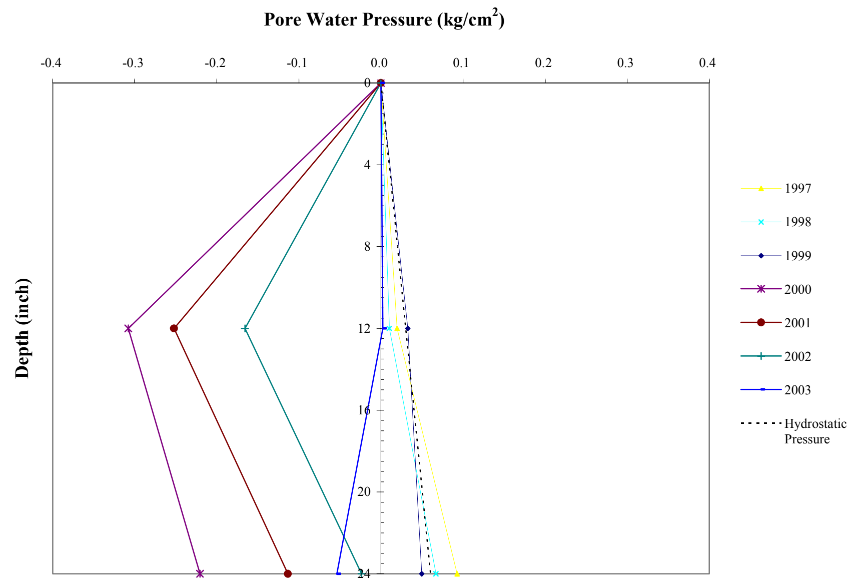

Figure 5.9 Pore Water Pressure Histories, Weather Station

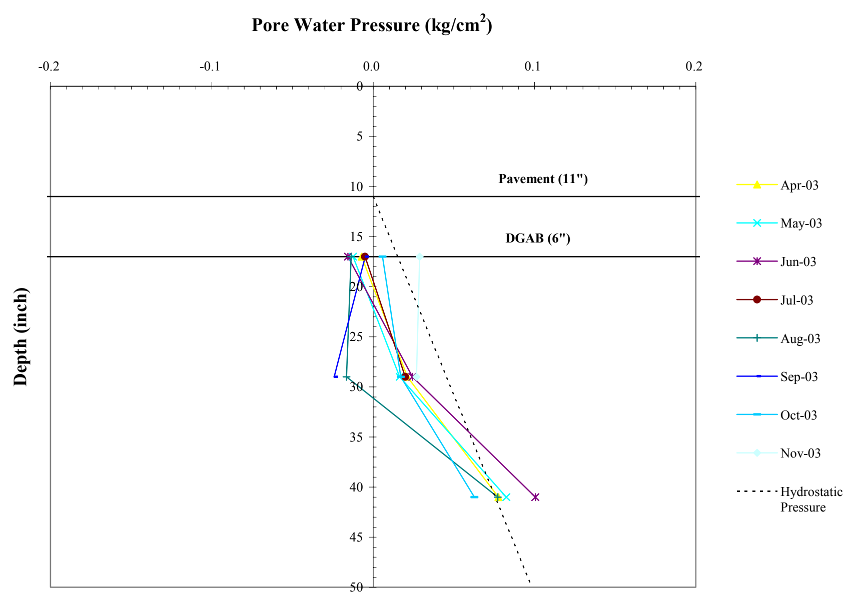

Figure 5.10 Pore Water Pressure Histories, 390263

present the comparisons of the predicted and measured values of M_r for representative A-4, A-6 and A-7-6 soils respectively. It is apparent that the predicted values of M_r from the six models are very different from the measured M_r values.

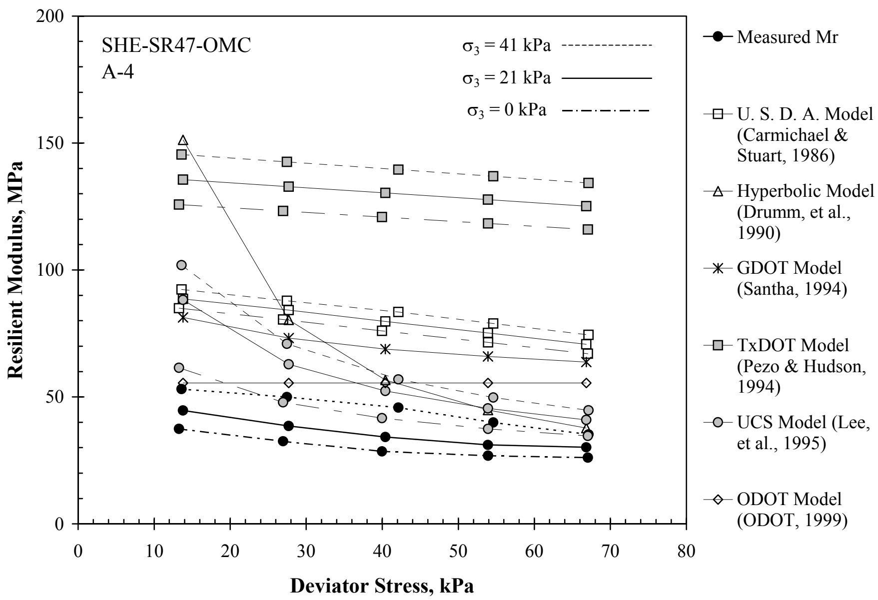

Figure 5.11 Estimated v. Measured M_r for an A-4 Soil

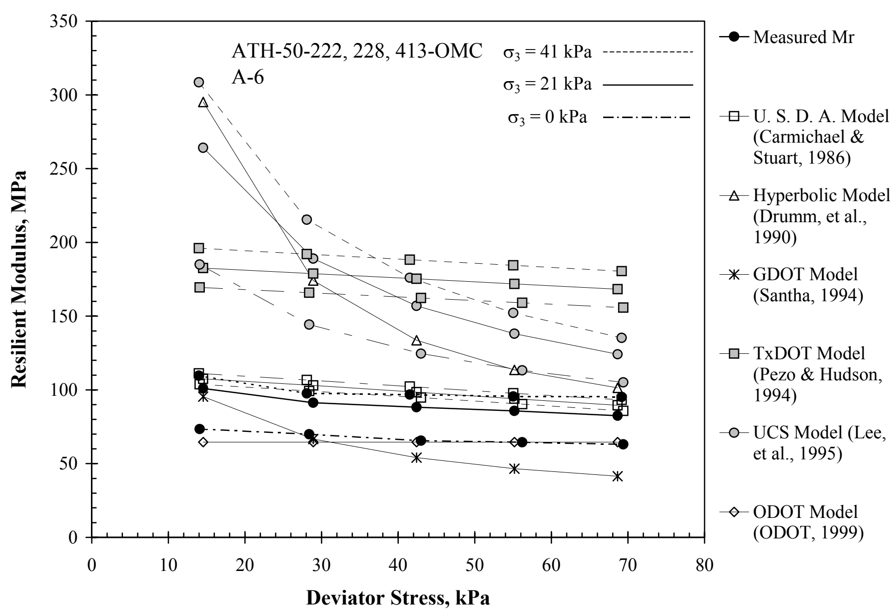

Figure 5.12 Estimated v. Measured M_r for an A-6 soil

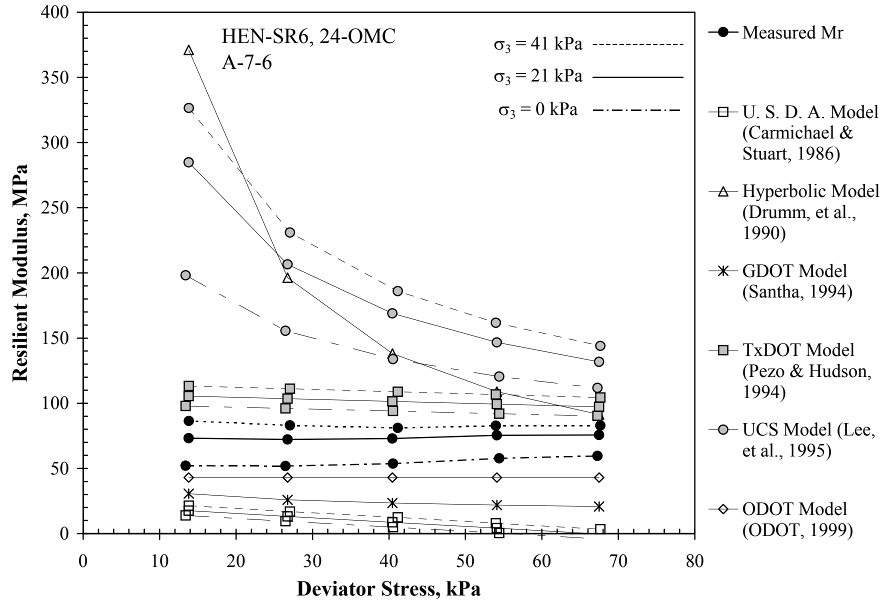

Figure 5.13 Estimated v. Measured M_r for an A-7-6 soil

Tables 5.1 and 5.2 show the error range in the estimated M_r compared with the measured value for each soil sample at optimum moisture content. A negative value means the model underestimates M_r while a positive number indicates the model overestimates the measured M_r of the soil sample.

The range using the USDA model was -110 to +275%, with an average error of +53%. The error in Hyperbolic model ranged between -65 and +705%, with an average error of +103%. The GDOT model had average error of only -1% but the range of predictions to measurements was between -85 and +280%. The TxDOT model had an error range of -10% to +450%, with an average of +156%. The UCS model's range was -80% to +290%. The average was +23%. The ODOT model while as good as any of the other five, misestimated the measured modulus by between -83 and +330%. The average error for the ODOT model was +5%.

The M_r predicted from the six models shows large variations with the laboratory results measured from M_r tests on all the soil samples. It is apparent that these existing models are not capable of consistently predicting reasonable M_r values that would be accurate when compared with those actually measured using the accepted AASHTO T294-94 procedure.

Soil Type	Sample	USDA Model (Carmichael & Stuart, 1986)	Hyperbolic Model (Drumm, et al., 1990)	GDOT Model (Santha, 1994)	TxDOT Model (Pezo & Hudson, 1994)	UCS Model (Lee, et al. 1995)	ODOT Model (ODOT, 1999)
A-4 Group	MUS-60-21	-30 to 100	35 to 580	25 to 280	190 to 450	-35 to 60	94 to 330
	GRE-35-21.13, 302, 400	70 to 175	-65 to 90	-25 to 80	150 to 280	-80 to -55	-15 to 57
	WAS-7-Mari	50 to 145	-25 to 250	-35 to 130	120 to 245	-35 to 15	-14 to 67
	SHE-SR47	70 to 170	5 to 305	45 to 150	170 to 345	25 to 100	4 to 113
A-6 Group	WAR-741-3	35 to 170	-25 to 195	-40 to 35	120 to 325	-70 to -45	-21 to 81
	WAS-821-113, 116	0 to 65	-35 to 145	-45 to -10	85 to 215	-20 to 20	-37 to 30
	BEL-SR147, 265	-15 to 20	-10 to 355	45 to 110	125 to 215	65 to 190	-30 to 16
	ATH-50-Cool	-40 to -15	-35 to 210	-80 to -40	45 to 75	-40 to 25	-46 to -20
	ATH-50-222, 228, 413	-5 to 45	5 to 305	-60 to 30	80 to 150	40 to 185	-41 to 2
A-7-6 Group	ATH-SR7	120 to 245	10 to 600	-85 to -65	-10 to 25	-45 to 20	-83 to -72
	FAI-I70	100 to 275	40 to 705	-65 to -25	80 to 200	0 to 85	-80 to -61
	CRA-Beal	-95 to -55	15 to 555	-50 to 10	55 to 235	15 to 110	-58 to 10
	HEN-SR6,24	-110 to -70	10 to 615	-75 to -45	25 to 90	70 to 290	-50 to -17

Table 5.1 Range of Percent Error of Predicted M_r Compared with Measured M_r for Samples at w_{opt}

Regression Model	Average of Percent Error	Standard Deviation of Percent Error
USDA Model (Carmichael & Stuart, 1986)	53	87
Hyperbolic Model (Drumm, et. Al., 1990)	103	135
GDOT Model (Santha, 1994)	-1	67
TxDOT Model (Pezo & Hudson, 1994)	156	94
UCS Model (Lee, et al., 1995)	23	71
ODOT Model (ODOT, 1999)	5	75

Table 5.2 Average and Standard Deviation of Error in Predicted M_r for Existing Regression Models at w_{opt}

5.3 Need for an Improved Model

It is clear that existing models in common use do not provide the precision necessary to be used confidently in the prediction of M_r values for cohesive soils. A more accurate regression model, based on basic soil properties and stress state of the soil needed to be developed and verified to make useful predictions of M_r for cohesive soils.

A model that recognized resilient modulus as a function of the stress state in the subgrade soil and the basic engineering properties of the soil was developed. The stress state parameters used in the model are the deviator and confining stresses. The major soil properties explicitly included are moisture content and unconfined compressive strength. Classification parameters are also used to distinguish among otherwise similar materials.

The new model for predicting the resilient modulus of cohesive soils is given as:

$$\frac{M_r}{P_a} = k_1 \left[\frac{\dfrac{\sigma_{oct}}{P_a}}{\left(\dfrac{\tau_{oct}}{P_a} \right)^2} \right]^{k_2} \tag{5.1}$$

$$= k_1 \left[\frac{P_a \cdot \sigma_{oct}}{\tau_{oct}^{\ 2}} \right]^{k_2} \tag{5.2}$$

$$= k_1 \left[\frac{9P_a}{2} \left(\frac{1}{3\sigma_d} + \frac{\sigma_3}{\sigma_d^2} \right) \right]^{k_2} \tag{5.3}$$

where:

M_r	= Resilient Modulus (kPa)
P_a	= Atmosphere Pressure (101 kPa)
σ_{oct}	= Octahedral Normal Stress ($[\sigma_1+2\sigma_3]/3$)
τ_{oct}	= Octahedral Shear Stress($\{2^{0.5}[\sigma_1-\sigma_3]\}/3$)
σ_1	= Major Principal Stress ($\sigma_d + \sigma_3$)
σ_d	= Deviator Stress (kPa)
σ_3	= Minor Principal Stress or Confining Stress (kPa)
k_1, k_2	= Model Constants

In the development of the two model constants, k_1 and k_2, the measured values for stresses were substituted into equation 5.1 and a regression analysis was performed to identify values for k_1 and k_2 that would best predict the measured M_r. The best fit values for k_1 and k_2 as determined in this procedure are listed in Table 5.3. Multiple correlation coefficient values, R^2, in Table 5.3 show the relation between the calculated resilient modulus and the measured resilient modulus values.

Soil Type	*Soil Name*		41 kPa of σ_3		21 kPa of σ_3		0 kPa of σ_3		R^2
			k_1	k_2	k_1	k_2	k_1	k_2	
A-4	MUS-60-21	DRY	422.2	0.0568	398.7	0.0561	388.1	-0.0236	**0.977**
		OMC	276.1	0.0907	244.3	0.0268	281.8	-0.2324	**0.918**
		WET	197.4	-0.1826	193.8	-0.1744	225.6	-0.4338	**0.941**
	GRE-35-21.13, 302 ,400	DRY	653.8	0.0791	589.2	0.1088	414.1	0.1661	**0.990**
		OMC	535.9	0.0635	412.0	0.0850	310.2	0.2237	**0.992**
		WET	140.8	0.1397	175.6	-0.0026	180.9	-0.0410	**0.805**
	WAS-7-Mari	DRY	588.5	0.0758	531.6	0.0820	404.5	0.1867	**0.995**
		OMC	439.6	0.1005	356.8	0.1431	337.8	0.1087	**0.979**
		WET	250.4	0.1083	178.5	0.1875	143.7	0.3434	**0.983**
		SAT			33.0	-0.4318			**0.854**
	SHE-SR47	DRY	539.0	0.1012	475.4	0.1012	401.1	0.1012	**0.949**
		OMC	306.2	0.1152	237.1	0.1559	207.4	0.2467	**0.963**
		WET	70.7	0.2332	153.2	-0.1530	144.9	-0.3586	**0.750**
		SAT			833.1	-1.118			**0.915**
A-6	WAR-741-3	DRY	767.7	0.0422	742.5	0.0258	566.8	0.0575	**0.994**
		OMC	409.7	0.1338	327.9	0.1240	260.6	0.2817	**0.975**
		WET	122.4	0.0301	133.1	0.0215	164.5	-0.1767	**0.848**
	WAS-821-113,116	DRY	795.6	0.0440	717.2	0.0503	533.2	-0.0182	**0.989**
		OMC	387.4	0.1627	356.7	0.1889	277.4	0.3545	**0.977**
		WET	193.3	0.2461	140.5	0.3275	167.9	0.2450	**0.950**
	BEL-SR147,265	DRY	783.0	0.0625	677.8	0.0604	577.1	-0.4268	**0.999**
		OMC	504.0	0.0832	453.8	0.1120	407.4	0.1077	**0.992**
		WET	207.9	0.2236	178.2	0.2568	166.1	0.2463	**0.994**
	AHT-50-Cool	DRY	993.7	0.0107	911.9	0.0275	753.8	0.0284	**0.981**
		OMC	783.6	0.0434	773.0	0.0305	622.4	0.0600	**0.994**
		WET	236.3	0.2699	189.1	0.3254	168.4	0.4546	**0.979**
		SAT			325.6	-0.777			**0.916**
	ATH-50-222, 228, 413	DRY	949.5	0.0663	843.8	0.0948	681.8	0.0979	**0.992**
		OMC	838.2	0.0552	746.1	0.0730	579.4	0.0955	**0.992**
		WET	464.8	0.0552	388.7	0.1090	314.5	0.2054	**0.981**
		SAT			200.5	-0.6412			**0.888**
A-7-6	ATH-SR7	DRY	897.3	0.0447	812.5	0.0462	614.4	0.0782	**0.991**
		OMC	757.6	0.0473	763.2	0.0166	665.2	-0.0216	**0.959**
		WET	430.9	0.1454	458.8	0.1040	394.2	0.1627	**0.980**
	FAI-I70	DRY	781.3	0.1110	710.8	0.1197	542.5	-0.4169	**0.998**
		OMC	775.2	0.0788	589.6	0.1454	506.2	0.1409	**0.986**
		WET	692.7	0.0467	640.5	0.0516	553.1	0.0021	**0.994**
		SAT			101.4	-0.4559			**0.765**
	CRA-Beal	DRY	705.0	0.1128	683.0	0.1042	707.3	-0.0984	**0.998**
		OMC	480.0	0.1567	413.3	0.1345	318.5	0.1582	**0.983**
		WET	253.7	0.1467	208.8	0.1780	139.9	0.3770	**0.961**
		SAT			159.2	-0.486			**0.92**
	HEN-SR6,24	DRY	877.1	0.0606	814.9	0.0501	728.3	0.0329	**0.987**
		OMC	788.6	0.0171	762.3	-0.0126	615.1	-0.0729	**0.989**
		WET	261.1	0.1983	233.6	0.2177	162.1	0.3812	**0.974**

Table 5.3 Model Constants for Each Soil Sample

Figure 5.14 shows the comparison of all measured resilient modulus values with the corresponding values calculated for all moisture contents using the new empirical model. The correlation coefficient (R^2) from the multiple regression analyses was 0.996. Clearly the new model characterizes very well the basic relationship between the modulus and the soil properties and boundary conditions. Developing the model constants, k_1 and k_2, as functions that can be derived from the static soil properties will enable the engineer to reliably predict resilient behavior from basic soil properties.

5.4 Evaluation of Model Constants and Regression Coefficients

The model constants, k_1 and k_2, were assumed to be functions of the confining stress, degree of saturation, unconfined compressive strength, liquid limit, plasticity index, moisture content, and optimum moisture content.

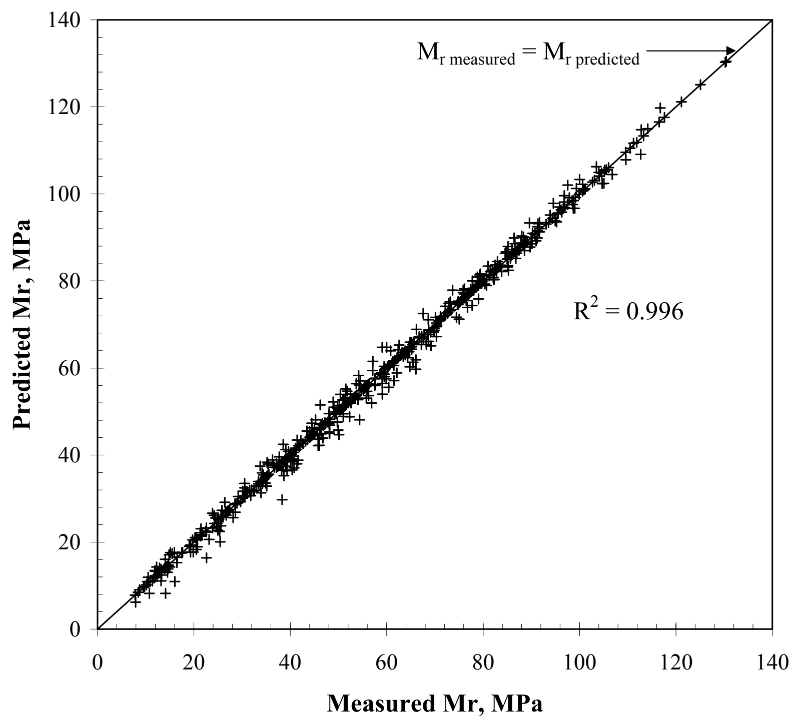

Figure 5.14 Predicted v. Measured M_r, All Moisture Contents

$$k_1 = a_1\sigma_3^{\ a_2} + a_3\left(\frac{S}{100}\right)^{a_4} + a_5 q_u + a_6 PI + a_7(LL - w) + a_8(w_{opt} - w)$$
$$+ a_9\,(\%passing\ \#200 - a_{10}) \tag{5.4}$$

$$k_2 = b_1\sigma_3^{\ b_2} + b_3\left(\frac{S}{100}\right)^{b_4} + b_5 q_u^{\ b_6} + b_7 PI + b_8 LL \tag{5.5}$$

where: $a_1 = a_{11} + a_{12}\left(\frac{w_{opt} - w}{w_{opt}}\right)$

$b_1 = b_{11} + b_{12}\left(w - w_{opt}\right)$

w_{opt}	= Optimum Moisture Content (%)
w	= Sample Moisture Content (%)
σ_3	= Confining Stress (kPa)
S	= Degree of Saturation (%)
q_u	= Unconfined Compressive Strength (kPa)
PI	= Plasticity Index
LL	= Liquid limit
%passing #200	= percent soil particles finer than 0.075mm

Equations 5.4 and 5.5 consist of input parameters (stress state and basic engineering properties) and regression coefficients, a_n and b_n. The regression coefficients (Table 5.4) were evaluated separately for the three specific soil types considered in this study.

5.5 Model Verification

Measured modulus values were compared with the predicted values using static strength and classification properties for the proposed and the existing models as reviewed earlier. The applicability of the proposed model is extended by calculating the modulus for a stabilized soil subgrade. Results for the stabilized soil material are also presented.

Comparisons between predicted and observed M_r were evaluated using percent error and multiple correlation coefficients. Table 5.5 shows the range of percent error, average percent error, standard deviation of percent error, and correlation coefficient, R^2, for the A-4, A-6, and A-7-6 soil types. Figures 5.15 to 5.18 illustrate the comparison of measured resilient modulus with predicted resilient modulus values for all sample moisture contents.

k_1				k_2			
Coefficient	A-4	A-6	A-7-6	Coefficient	A-4	A-6	A-7-6
a_{11}	6.46	8.32	9.28	b_{11}	0.0024	0.00753	0.01
a_{12}	44.41	71.96	39.98	b_{12}	0.0039	0.0027	0.00
a_2	0.73	0.7	0.64	b_2	0.351	0.523	0.46
a_3	-120.4	-29.8	-193.39	b_3	0.043	0.205	0.08
a_4	19.24	6.5	2.02	b_4	24	13.4	15.30
a_5	0.11	0.886	0.73	b_5	3.17	1.13	2.58
a_6	28.6	5.3	2.57	b_6	-0.638	-0.612	-0.60
a_7	0	4.8	10.43	b_7	-0.00016	-0.00021	0.00
a_8	57.27	30.07	23.28	b_8	-0.00028	-0.00016	0.00
a_9	2.66	0	0				
a_{10}	54.27	0	0				

Table 5.4 Regression Coefficients for Specific Cohesive Soil Types

Soil Type	Error % range	Error % average	Standard Deviation of Error %	Multiple Correlation R^2
A-4	-85.1 to 78.8	-2.45	29.3	0.85
A-6	-43.6 to 110.3	1.65	19.3	0.93
A-7-6	-54.2 to 52.3	-0.03	15.3	0.92
All Soil Types	**-85.1 to 110.3**	**-0.09**	**21.8**	**0.92**

Table 5.5 Predicted v. Measured M_r for All Moisture Contents

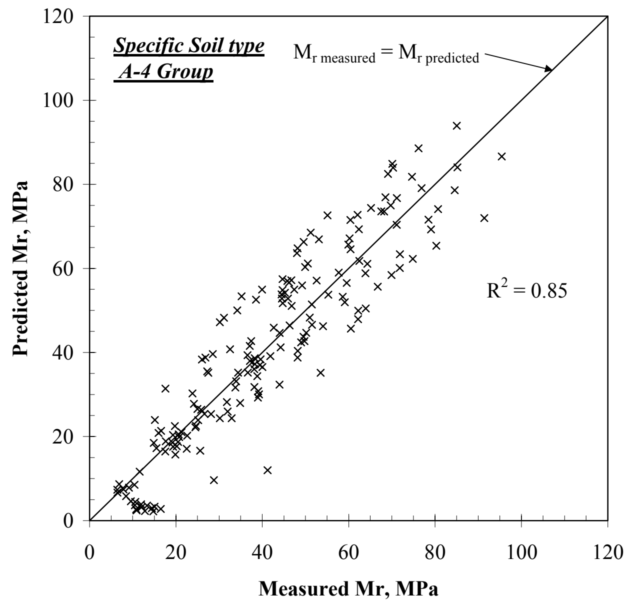

Figure 5.15 Predicted v. Measured M_r A-4 Soils, All Moisture Contents

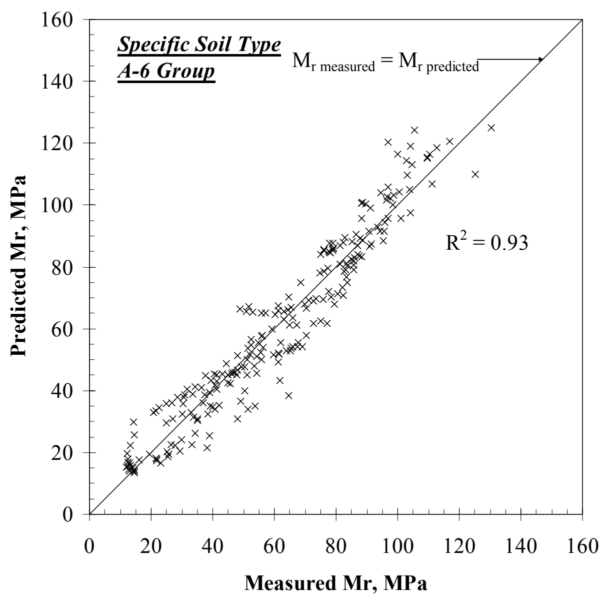

Figure 5.16 Predicted v. Measured M_r A-6 Soils, All Moisture Contents

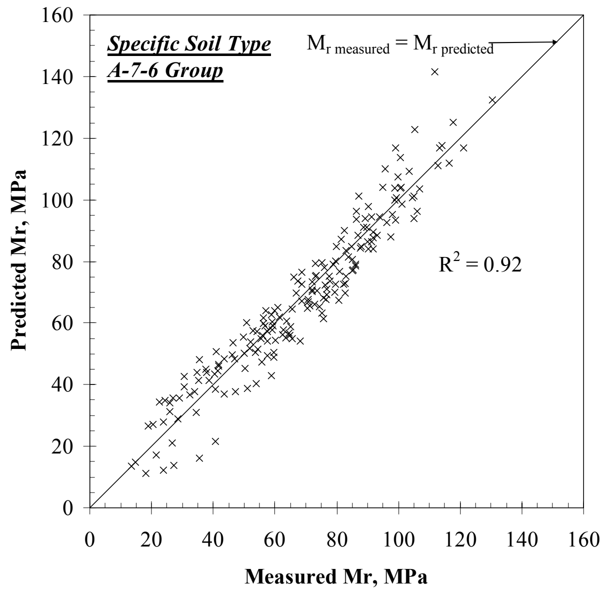

Figure 5.17 Predicted v. Measured M_r A-7-6 Soils, All Moisture Contents

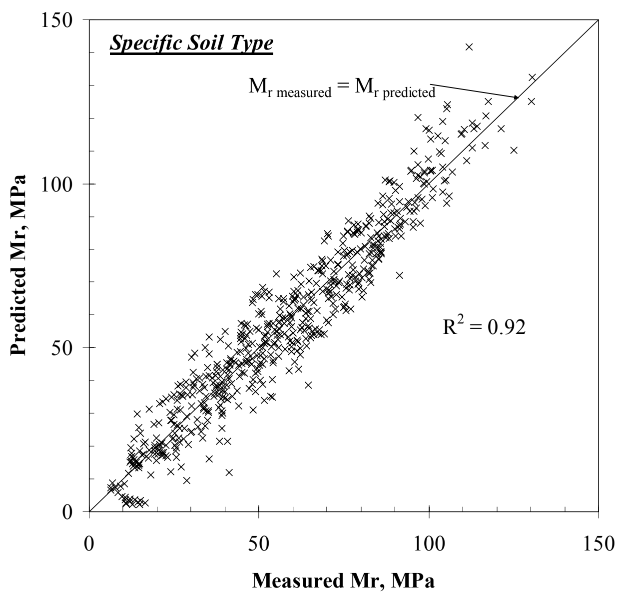

Figure 5.18 Predicted v. Measured M_r All Soils, All Moisture Contents

5.6 Effect of Moisture Content on Model Accuracy

The effect of moisture on modulus was quantified in the model by comparing the predicted and measured M_r at various moisture contents (dry of optimum, optimum, wet of optimum, and saturated). Figures 5.19, 5.20, and 5.21 present those comparisons for an A-4, an A-6, and an A-7-6 soil, respectively. As moisture content increases, the predicted M_r is reduced significantly and remains close to the experimentally obtained value for all tested moisture contents.

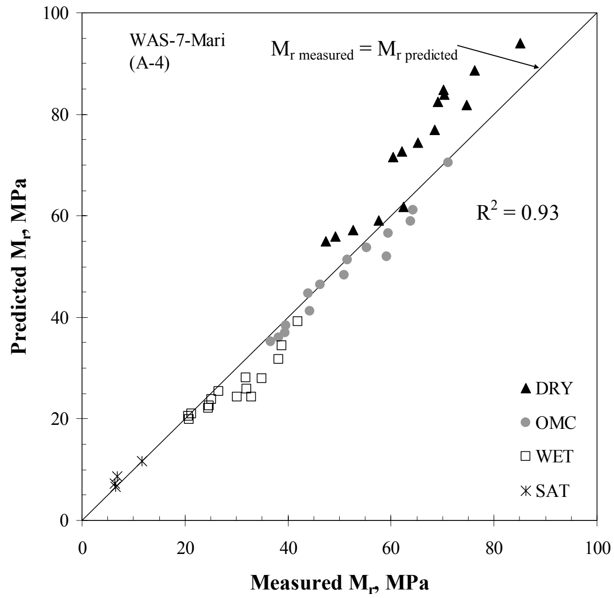

Figure 5.19 Predicted v. Measured M_r A-4 soil

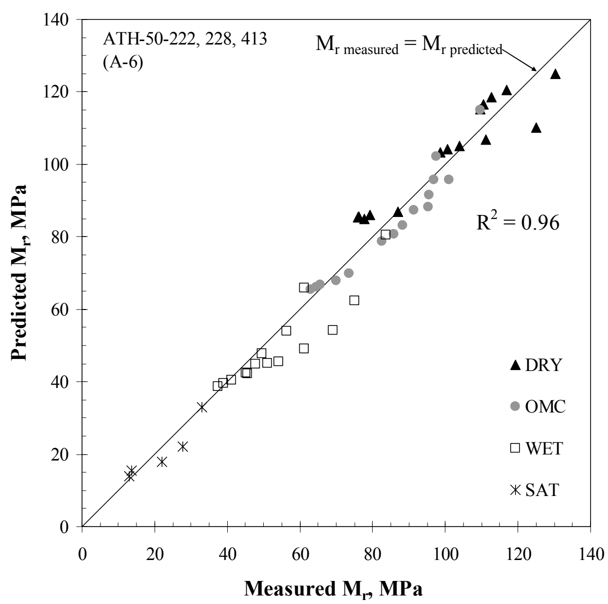

Figure 5.20 Predicted v. Measured M_r A-6 soil

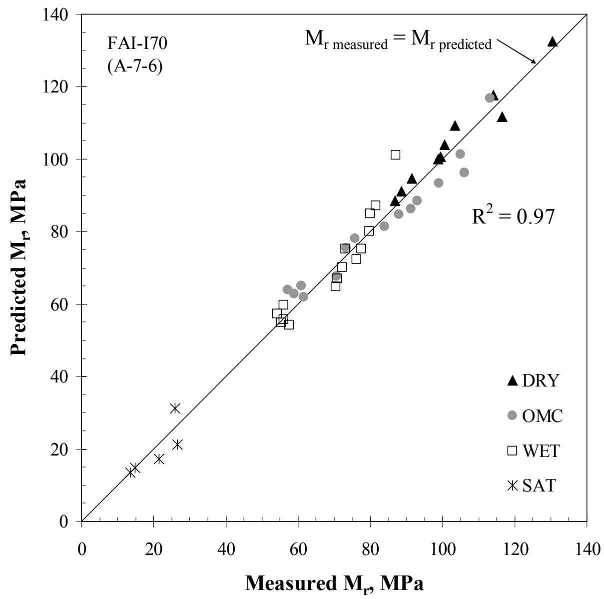

Figure 5.21 Predicted v. Measured M_r A-7-6 soil

5.7 Comparison of Proposed and Existing Models with Experimental Observations

Figures 5.22 through 5.66 show the comparison of the measured resilient modulus with the resilient modulus estimated by the existing models and the proposed model. Figures 5.22 to 5.25, 5.26 to 5.30, and 5.31 to 5.34 are for the A-4, A-6, and A-7-6 soil types, respectively, at dry of optimum moisture. Figures 5.35 to 5.38, 5.39 to 5.43, and 5.44 to 5.47 and 5.48 to 5.51, 5.52 to 5.56, and 5.57 to 5.60 are for the three soil types at optimum and wet of optimum, respectively. Finally, Figures 5.61 and 5.62, 5.63 and 5.64, 5.65 and 5.66 present the comparisons for the three soil types at saturation. It is quite evident from the results shown in these figures that the six existing models don't predict actual behavior consistently or well. On the other hand, M_r predicted by the model developed in this study is generally close to the measured value even as the moisture conditions change. Table 5.6 summarizes the data depicted in Figures 5.22 to 5.66. For each soil type, the average error and standard deviation of error are shown. While most existing models investigated significantly overestimate M_r, the quantities predicted by the proposed model are generally slightly conservative.

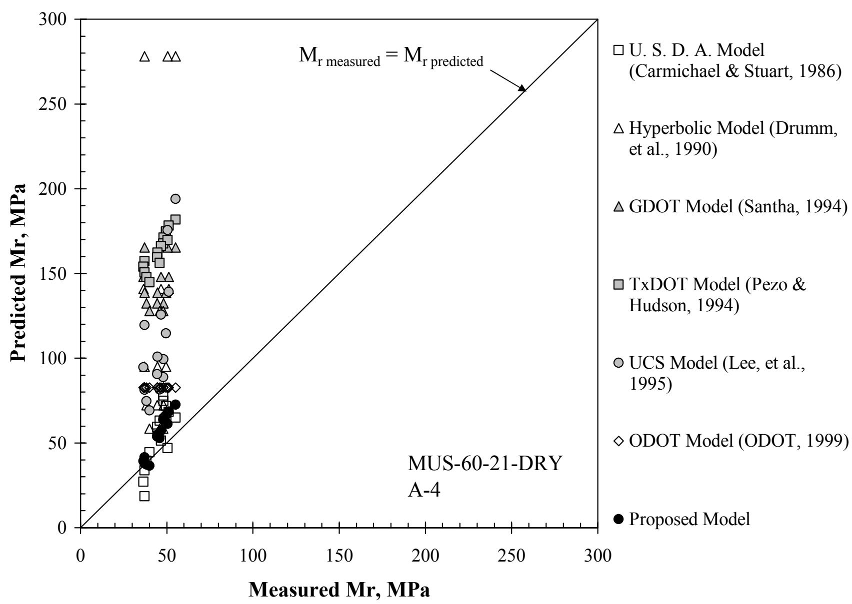

Figure 5.22 Predicted v. Measured M_r A-4 Soil Dry of w_{opt}

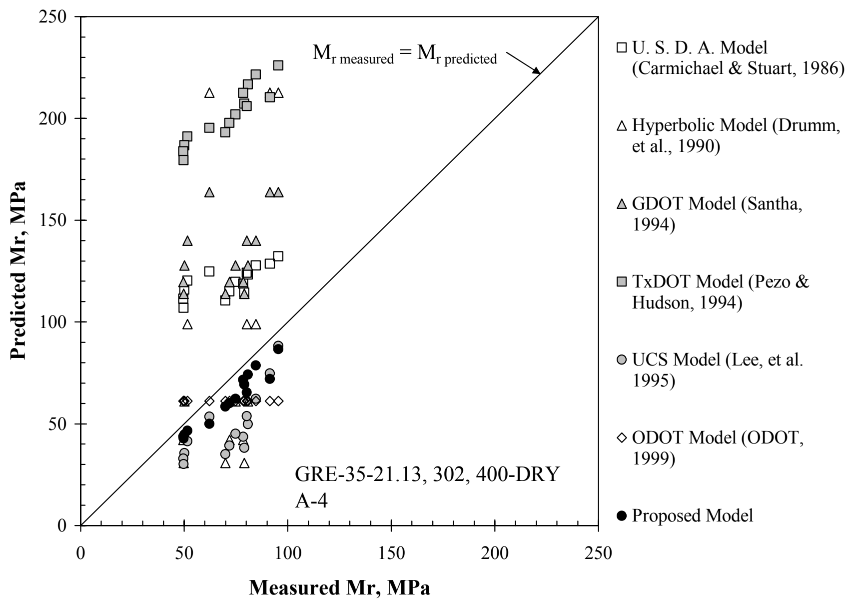

Figure 5.23 Predicted v. Measured M_r A-4 Soil Dry of w_{opt}

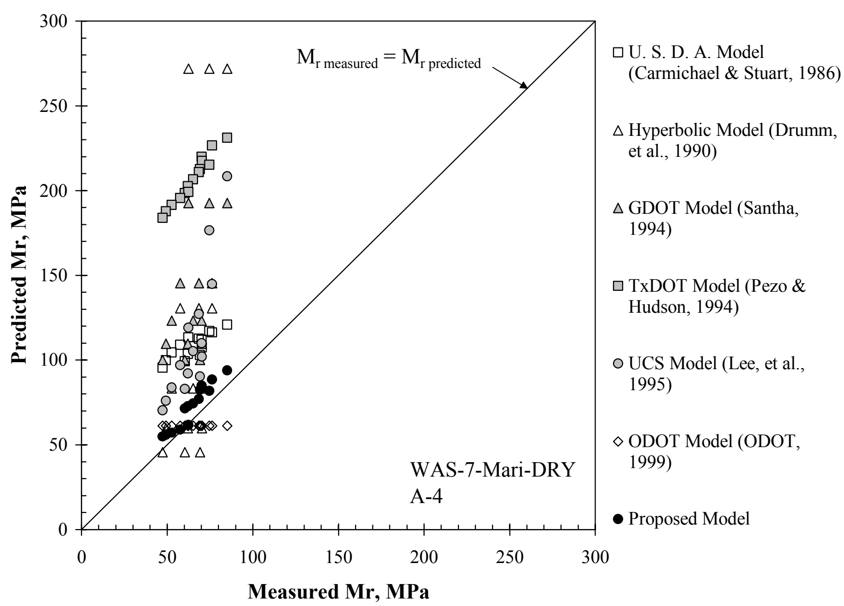

Figure 5.24 Predicted v. Measured M_r A-4 Soil Dry of w_{opt}

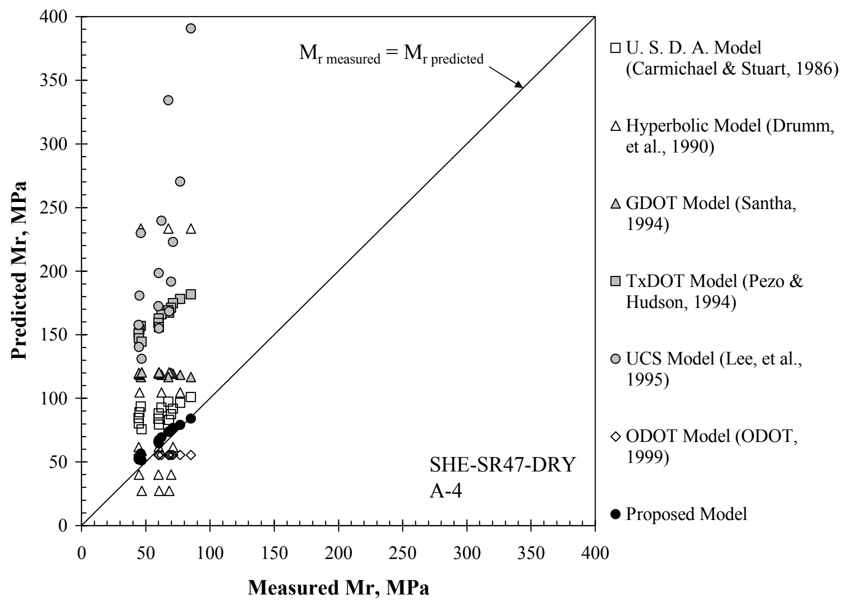

Figure 5.25 Predicted v. Measured M_r A-4 Soil Dry of w_{opt}

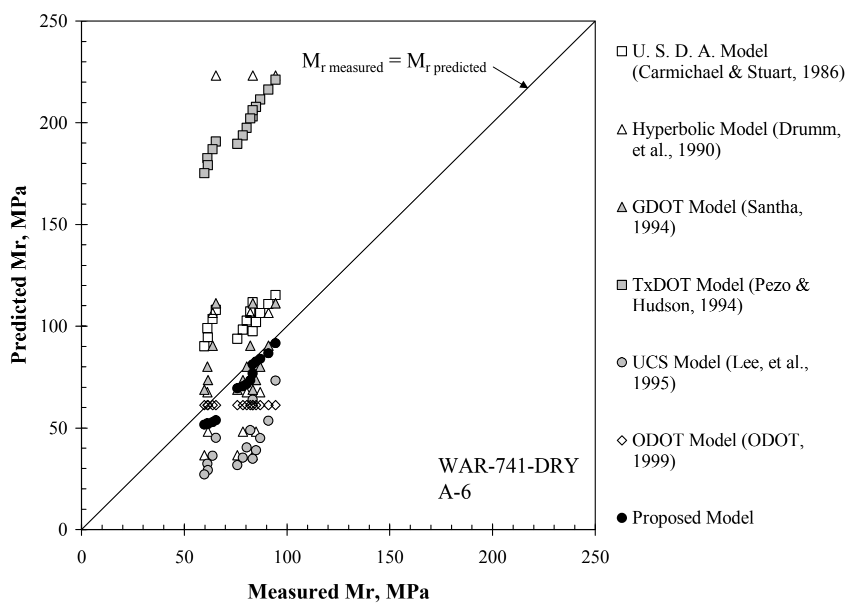

Figure 5.26 Predicted v. Measured M_r A-6 Dry of w_{opt}

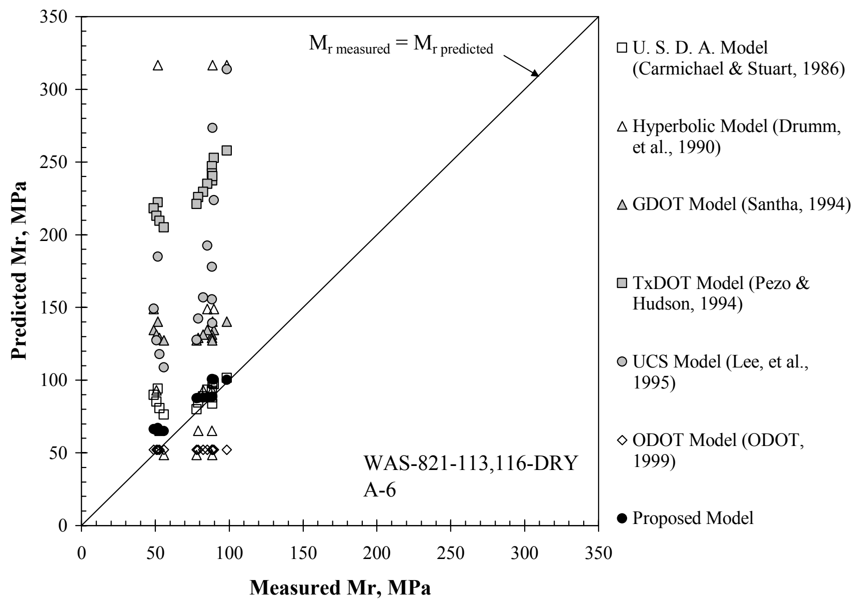

Figure 5.27 Predicted v. Measured M_r A-6 Soil Dry of w_{opt}

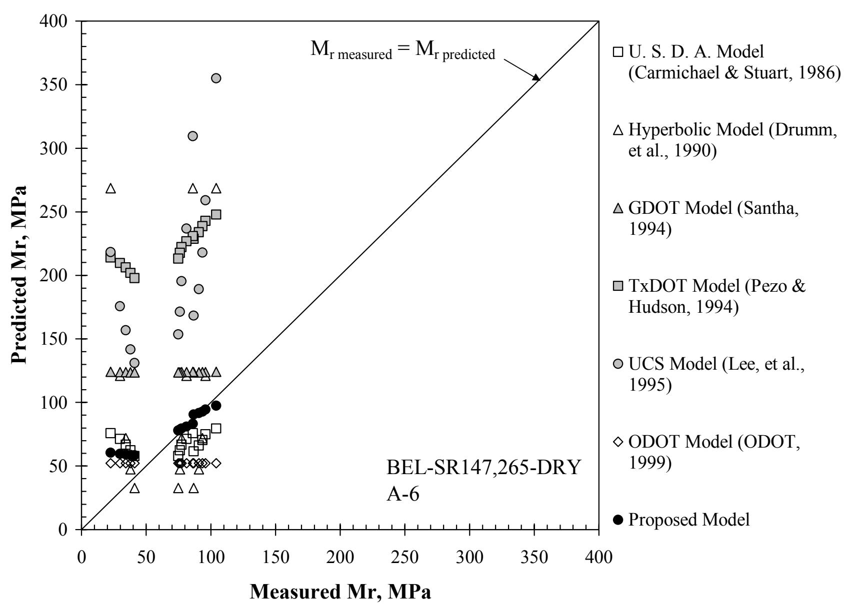

Figure 5.28 Predicted v. Measured M_r A-6 Soil Dry w_{opt}

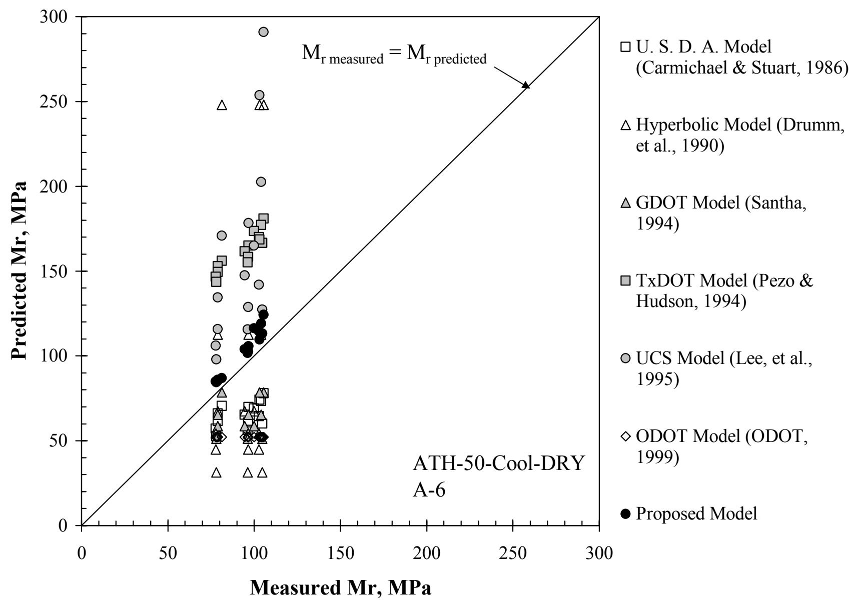

Figure 5.29 Predicted v. Measured M_r A-6 Soil at Dry of w_{opt}

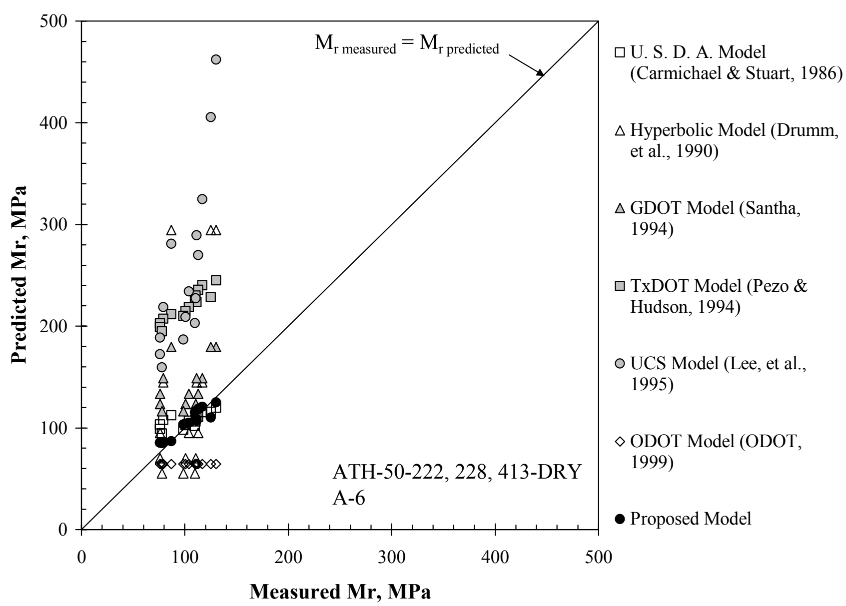

Figure 5.30 Predicted v. Measured M_r A-6 Soil Dry of w_{opt}

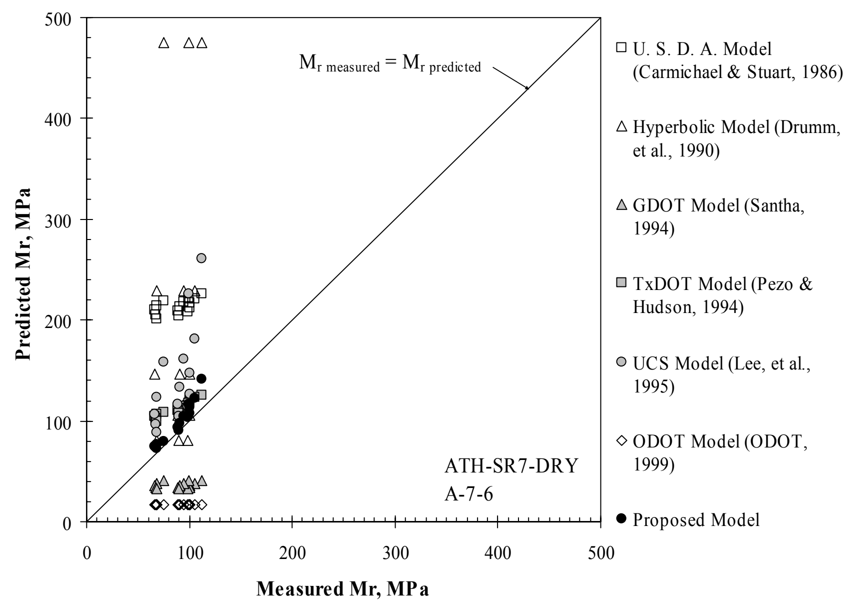

Figure 5.31 Predicted v. Measured M_r A-7-6 Soil at Dry of w_{opt}

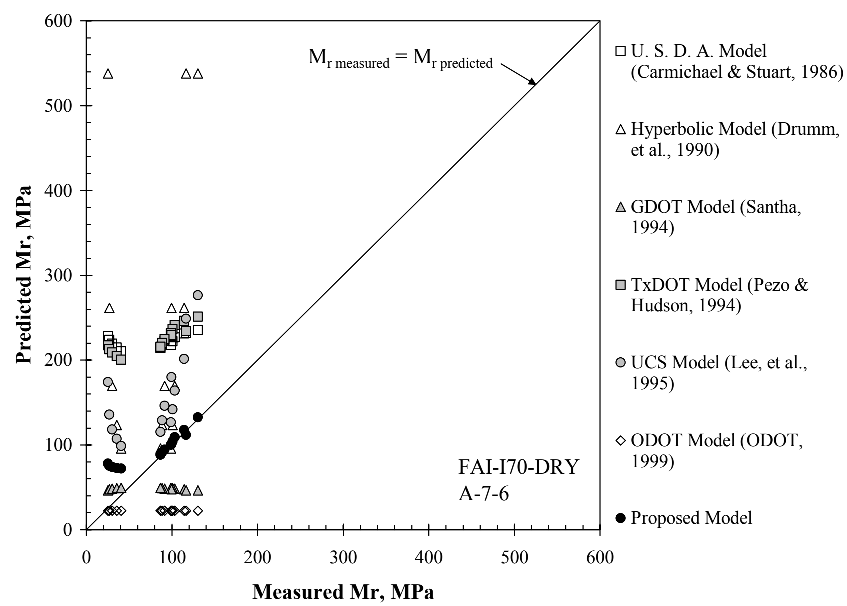

Figure 5.32 Predicted v. Measured M_r A-7-6 Soil at Dry of w_{opt}

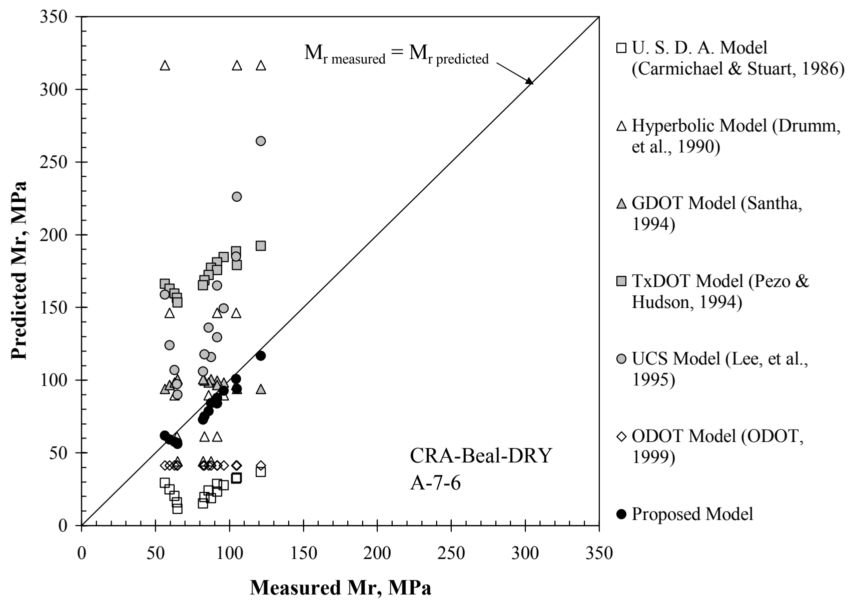

Figure 5.33 Predicted v. Measured M_r A-7-6 Soil at Dry of w_{opt}

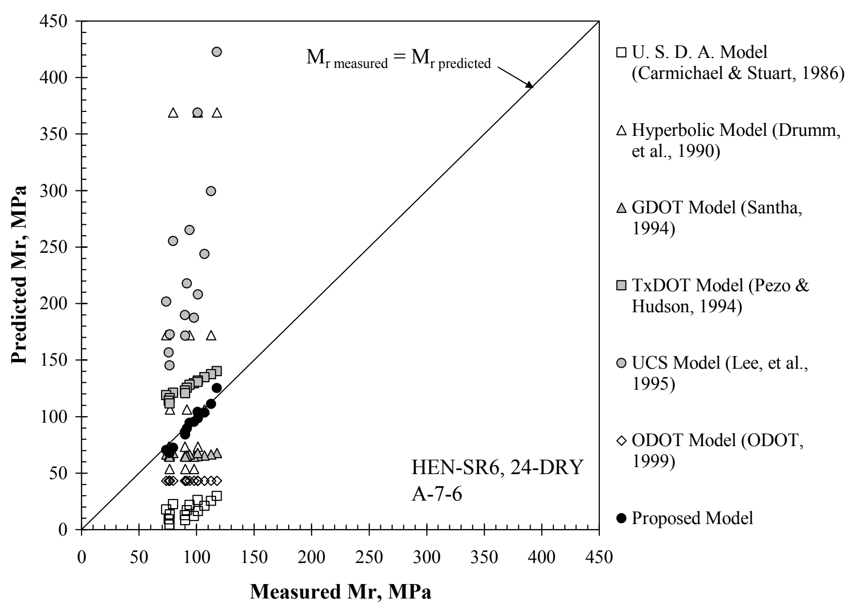

Figure 5.34 Predicted v. Measured M_r A-7-6 Soil at Dry of w_{opt}

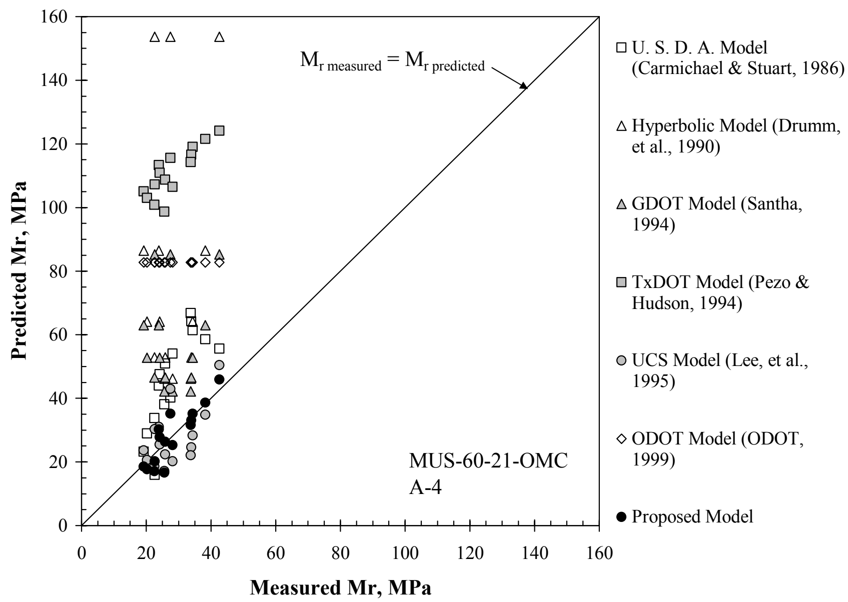

Figure 5.35 Predicted v. Measured M_r A-4 Soil at w_{opt}

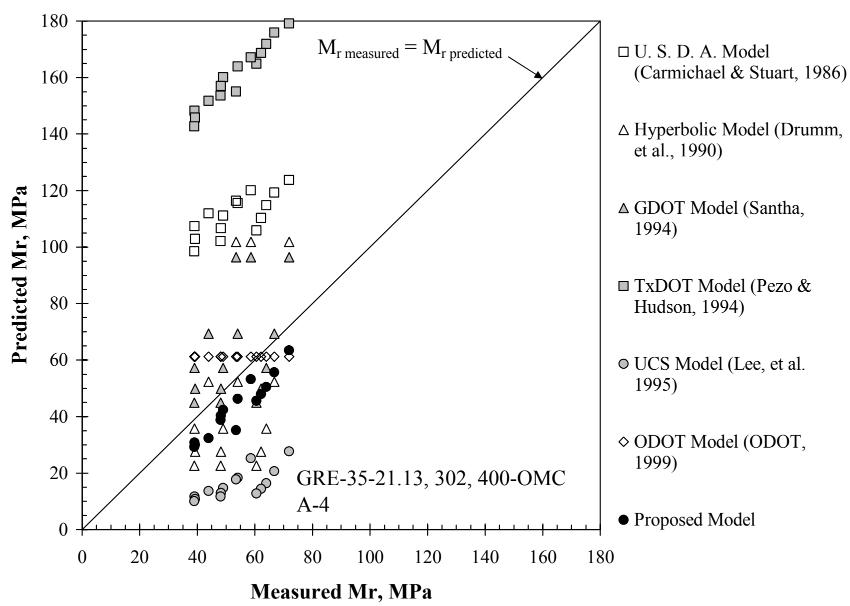

Figure 5.36 Predicted v. Measured M_r A-4 Soil at w_{opt}

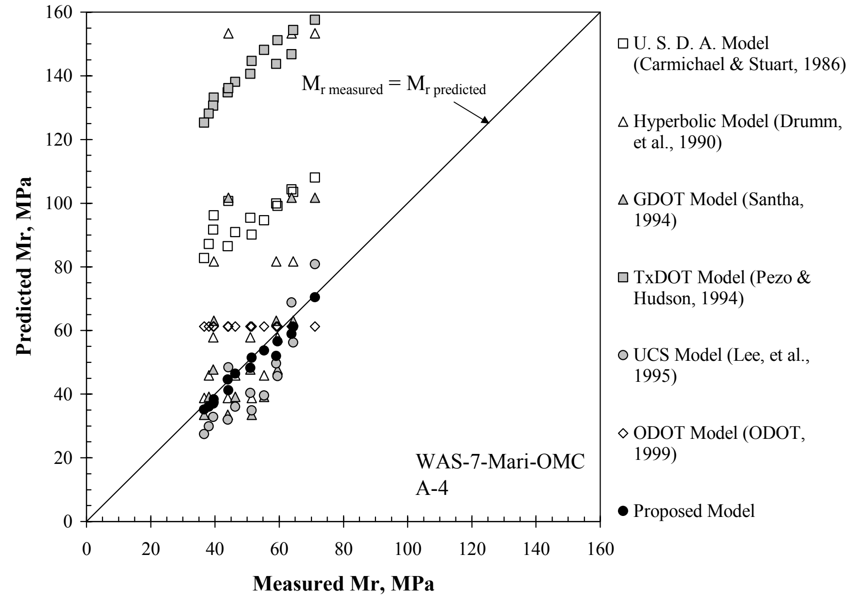

Figure 5.37 Predicted v. Measured M_r A-4 Soil at w_{opt}

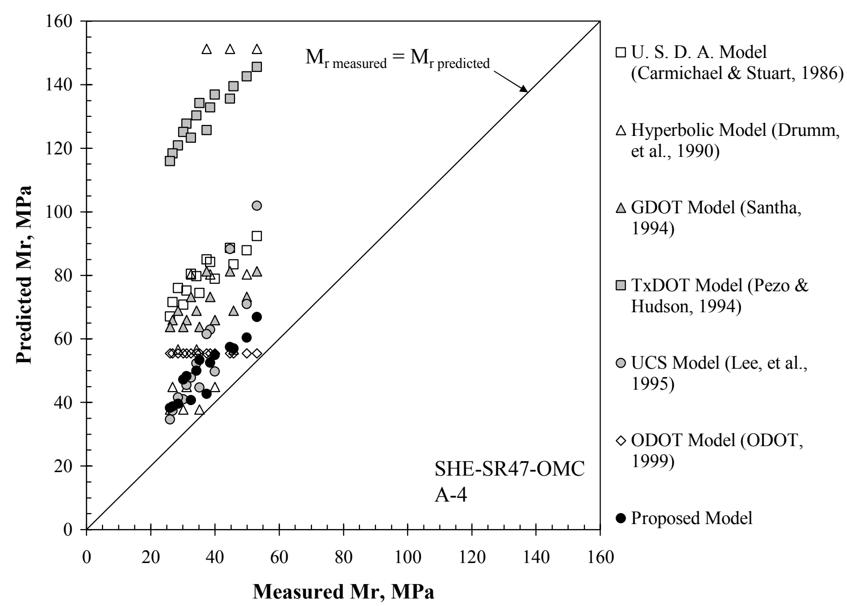

Figure 5.38 Predicted v. Measured M_r A-4 Soil at w_{opt}

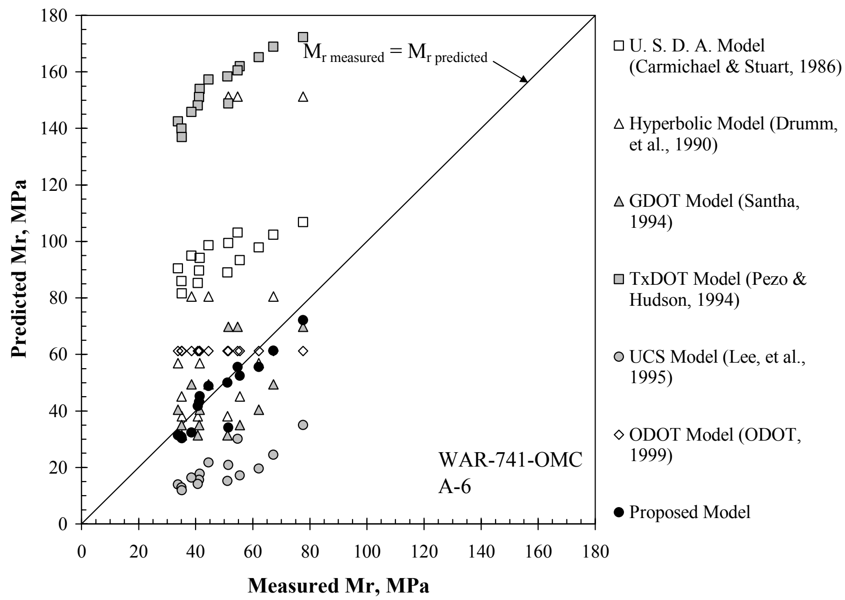

Figure 5.39 Predicted v. Measured M_r A-6 Soil at w_{opt}

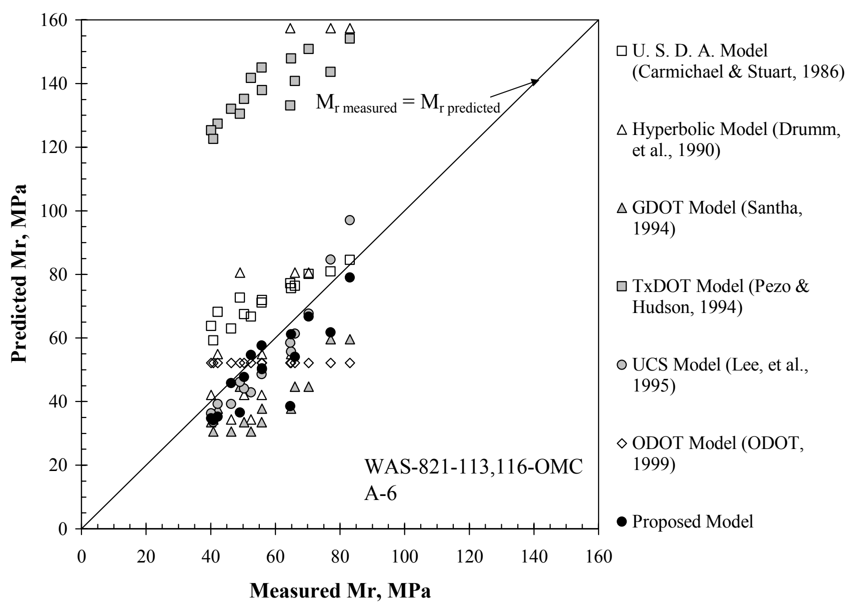

Figure 5.40 Predicted v. Measured M_r A-6 Soil at w_{opt}

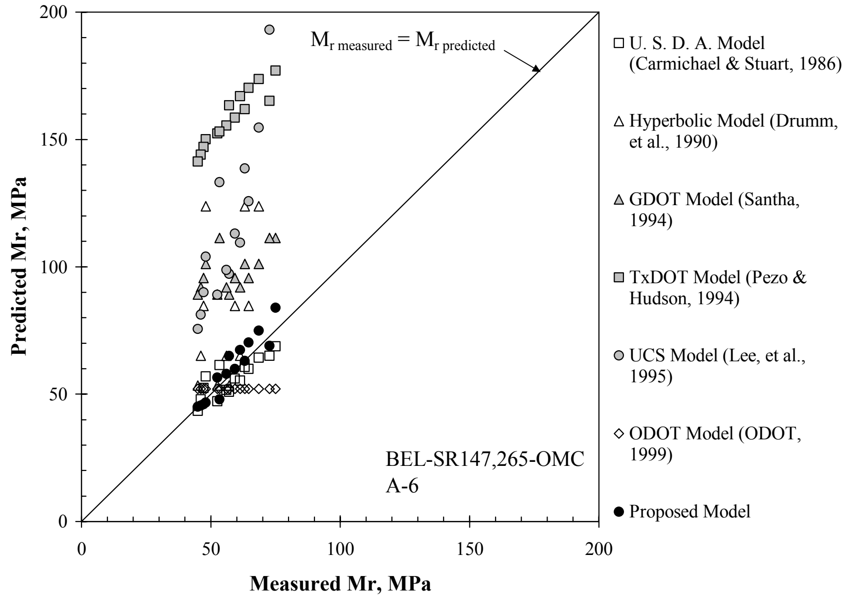

Figure 5.41 Predicted v. Measured M_r A-6 Soil at w_{opt}

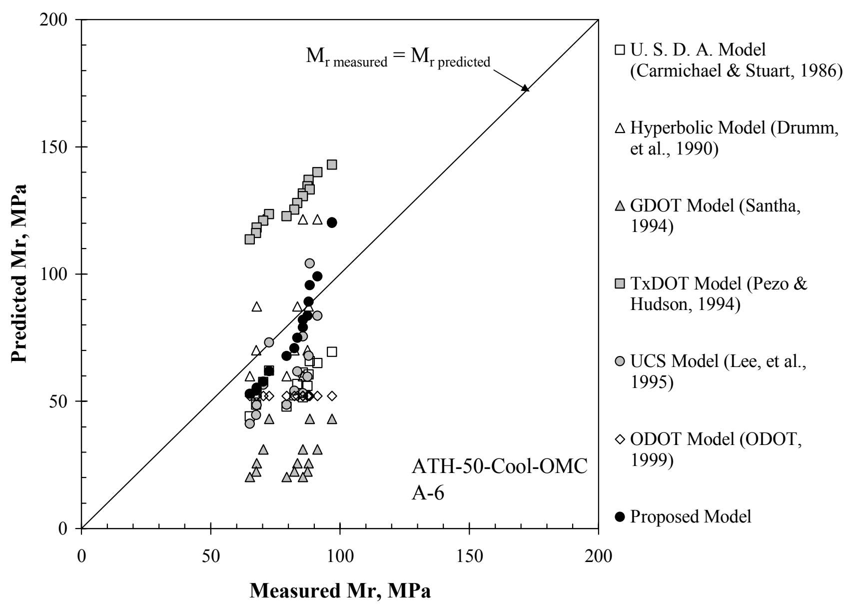

Figure 5.42 Predicted v. Measured M_r A-6 Soil at w_{opt}

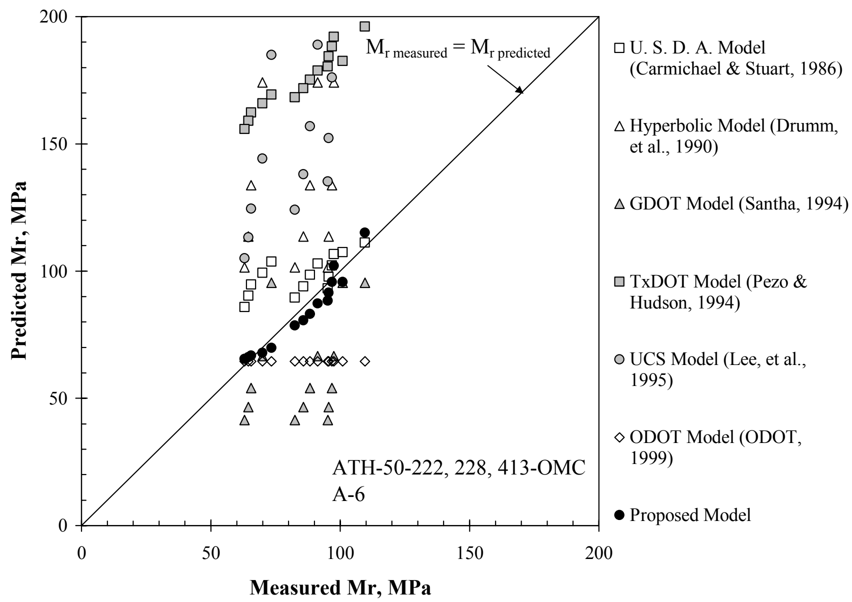

Figure 5.43 Predicted v. Measured M_r A-6 Soil at w_{opt}

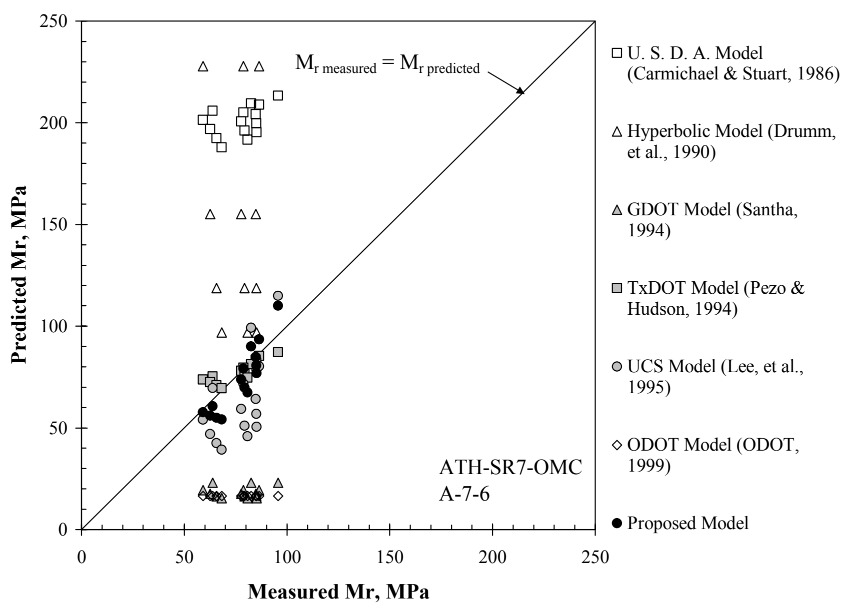

Figure 5.44 Predicted v. Measured M_r A-7-6 Soil at w_{opt}

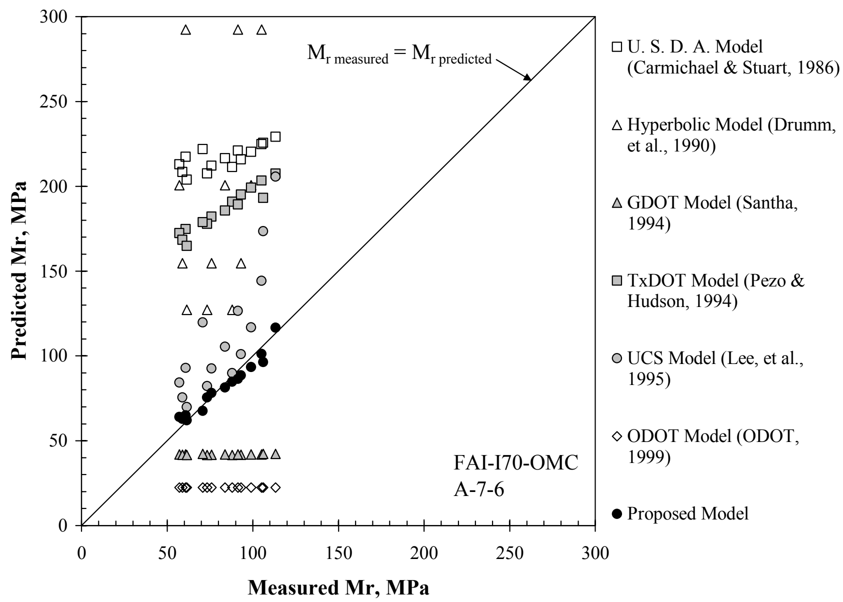

Figure 5.45 Predicted v. Measured M_r A-7-6 Soil at w_{opt}

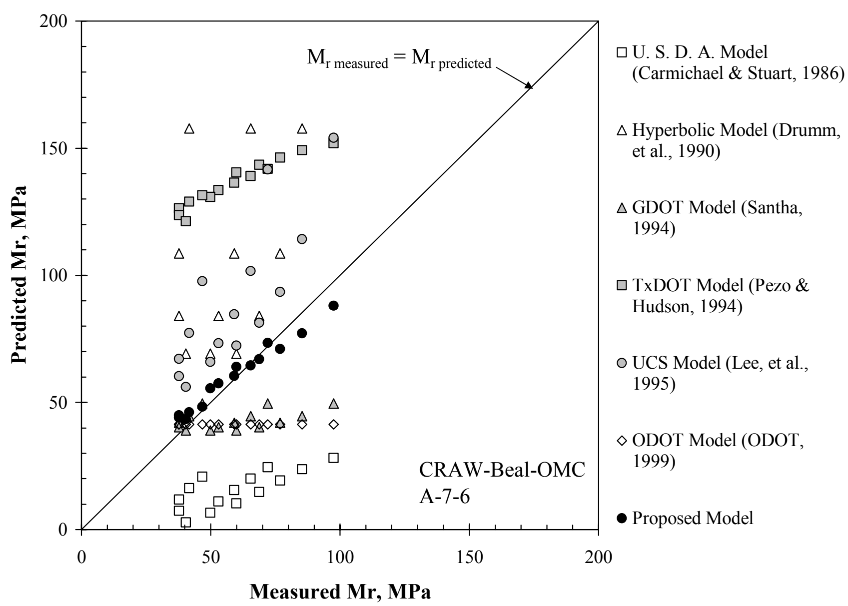

Figure 5.46 Predicted v. Measured M_r A-7-6 Soil at w_{opt}

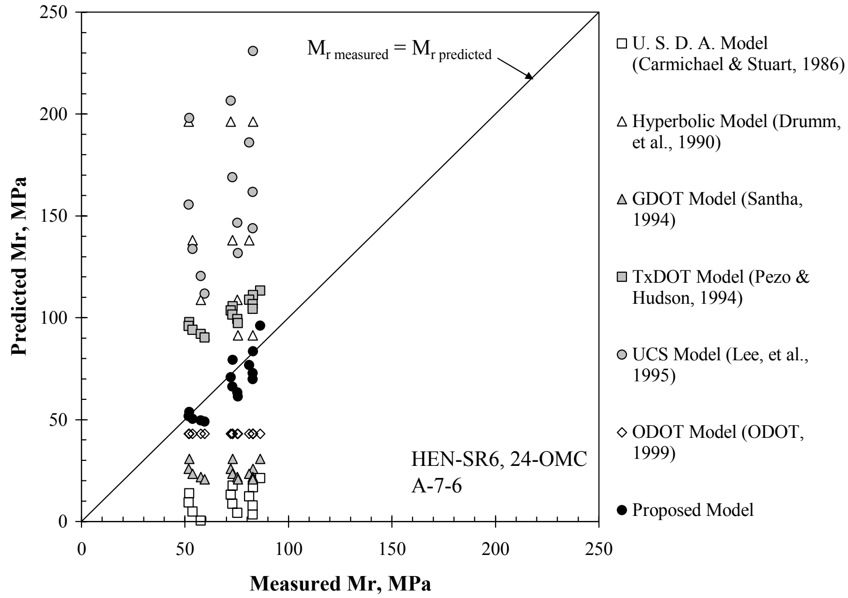

Figure 5.47 Predicted v. Measured M_r A-7-6 Soil at w_{opt}

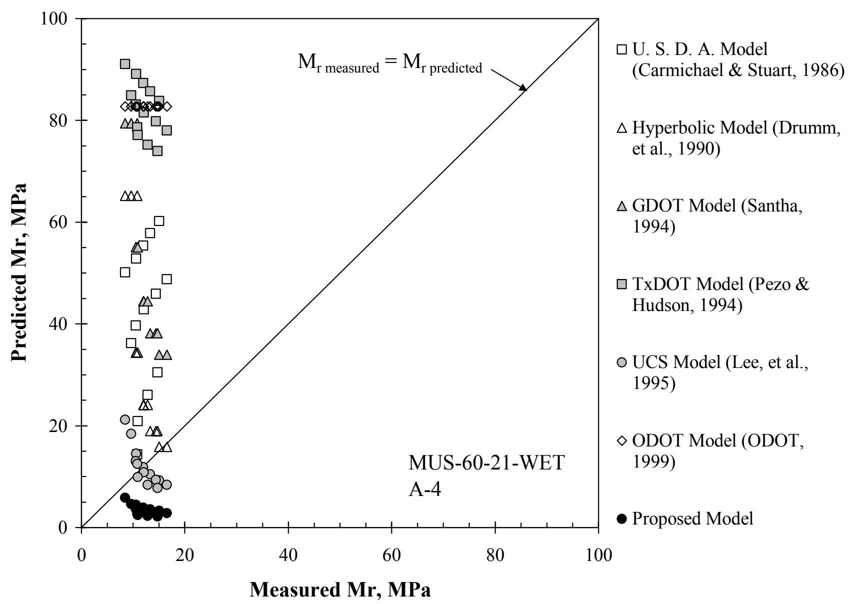

Figure 5.48 Predicted v. Measured M_r A-4 Soil Wet of w_{opt}

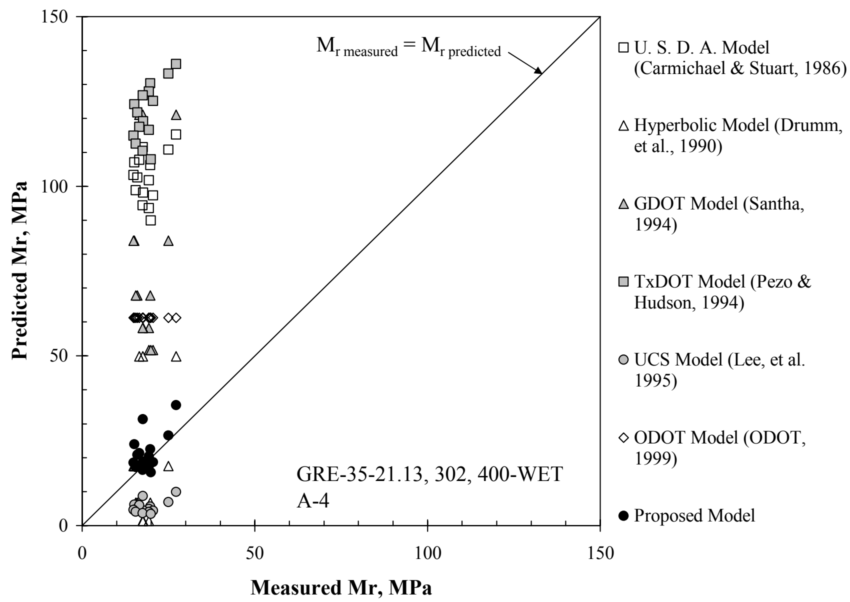

Figure 5.49 Predicted v. Measured M_r A-4 Soil Wet of w_{opt}

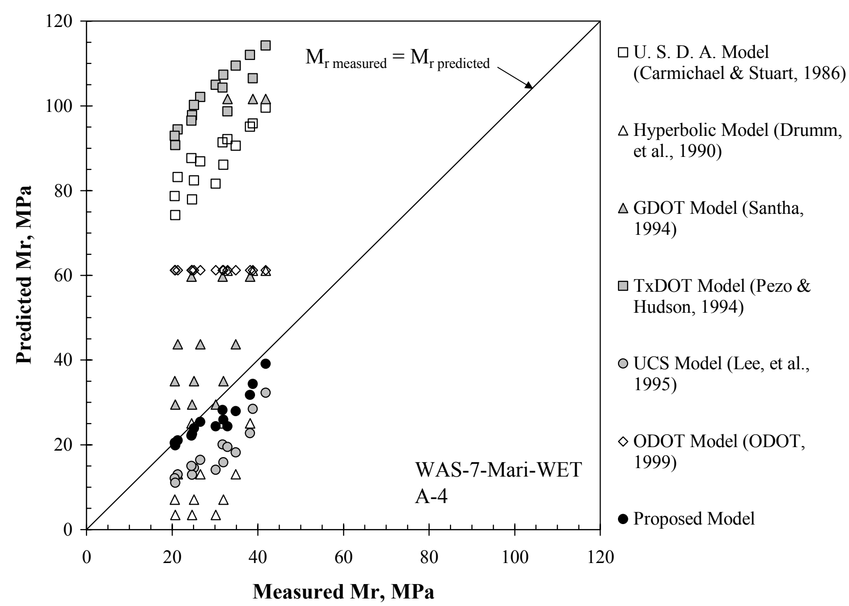

Figure 5.50 Predicted v. Measured M_r A-4 Soil Wet of w_{opt}

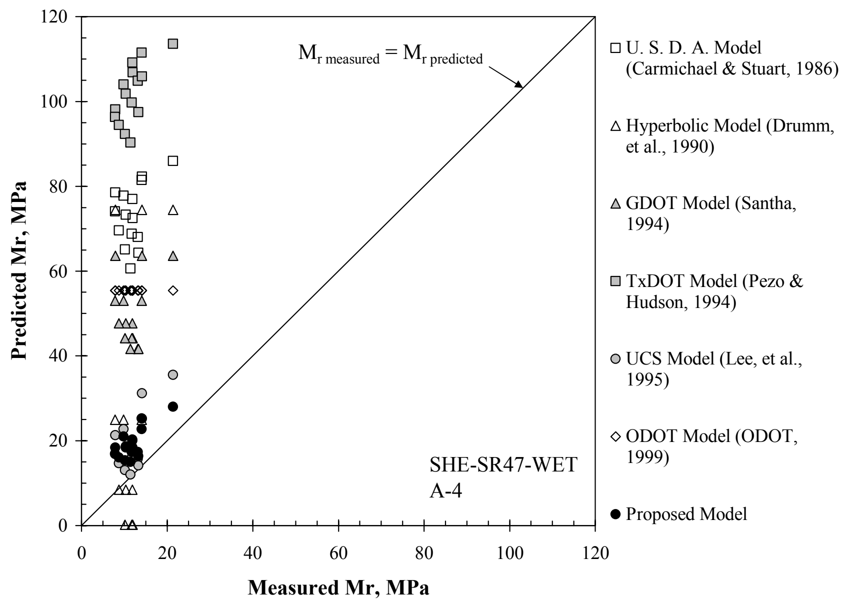

Figure 5.51 Predicted v. Measured M_r A-4 Soil Wet of w_{opt}

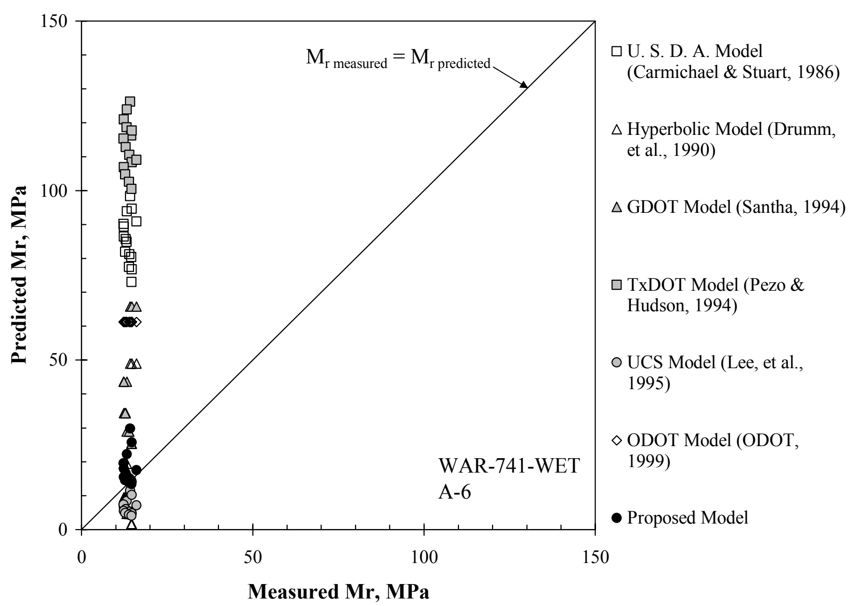

Figure 5.52 Predicted v. Measured M_r A-6 Soil Wet of w_{opt}

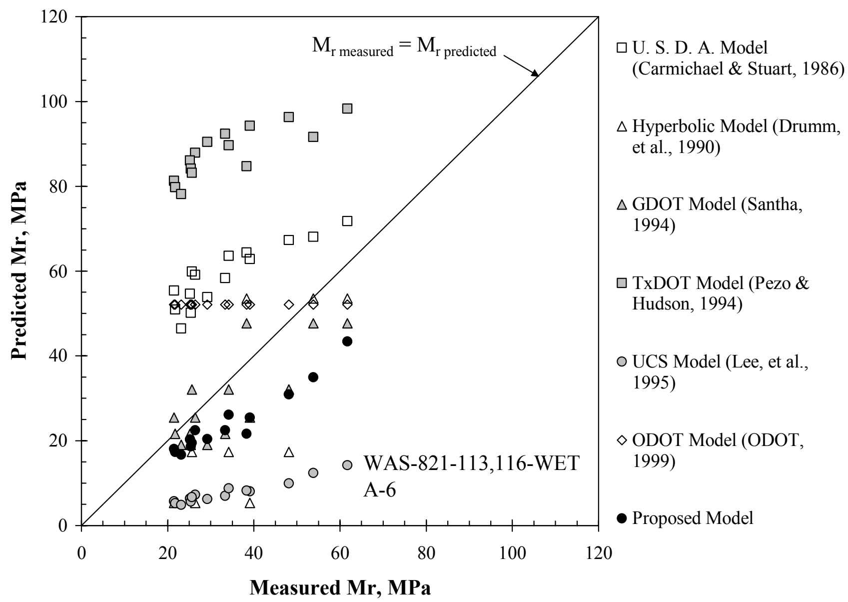

Figure 5.53 Predicted v. Measured M_r A-6 Soil Wet of w_{opt}

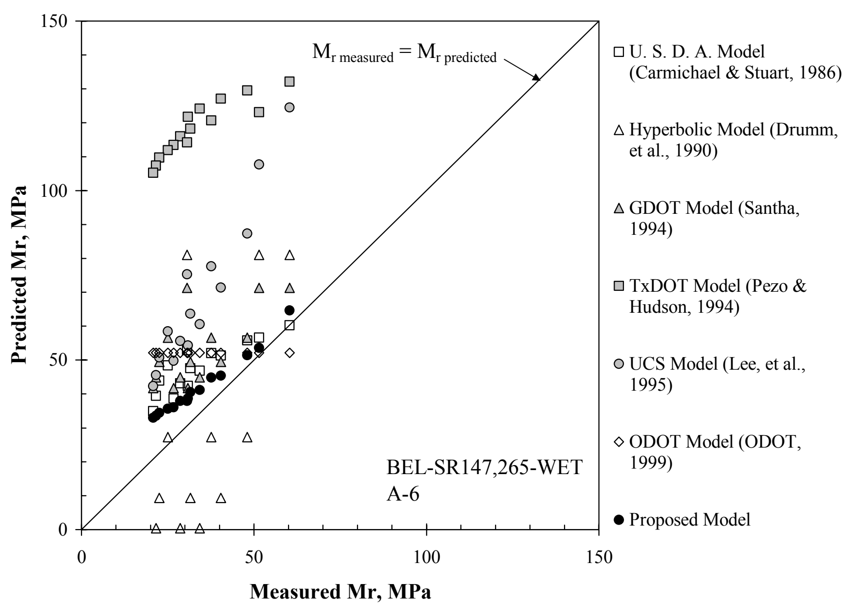

Figure 5.54 Predicted v. Measured M_r A-6 Soil Wet of w_{opt}

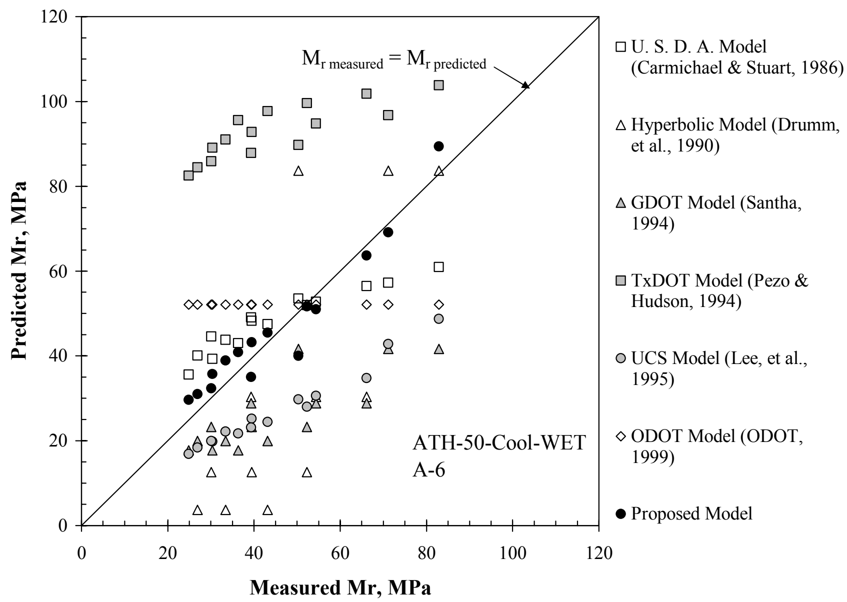

Figure 5.55 Predicted v. Measured M_r A-6 Soil Wet of w_{opt}

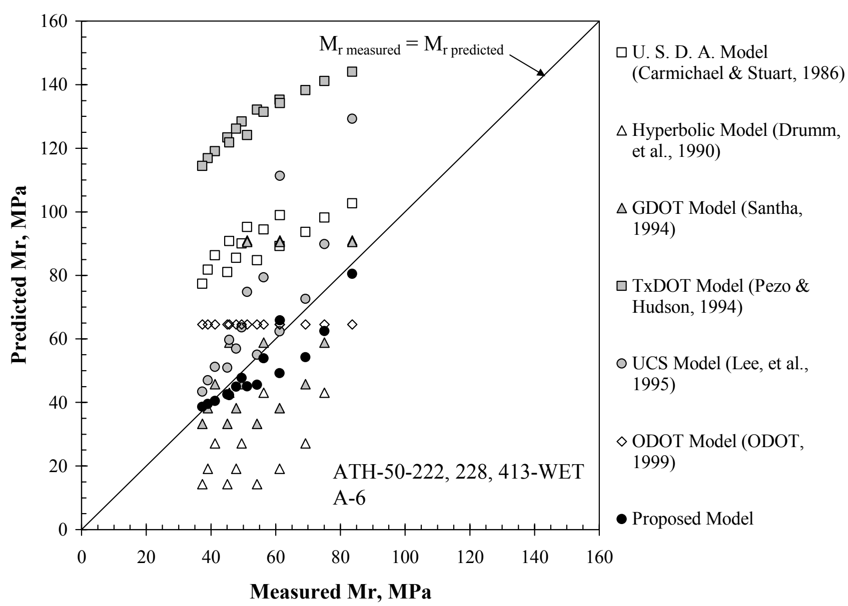

Figure 5.56 Predicted v. Measured M_r A-6 Soil Wet of w_{opt}

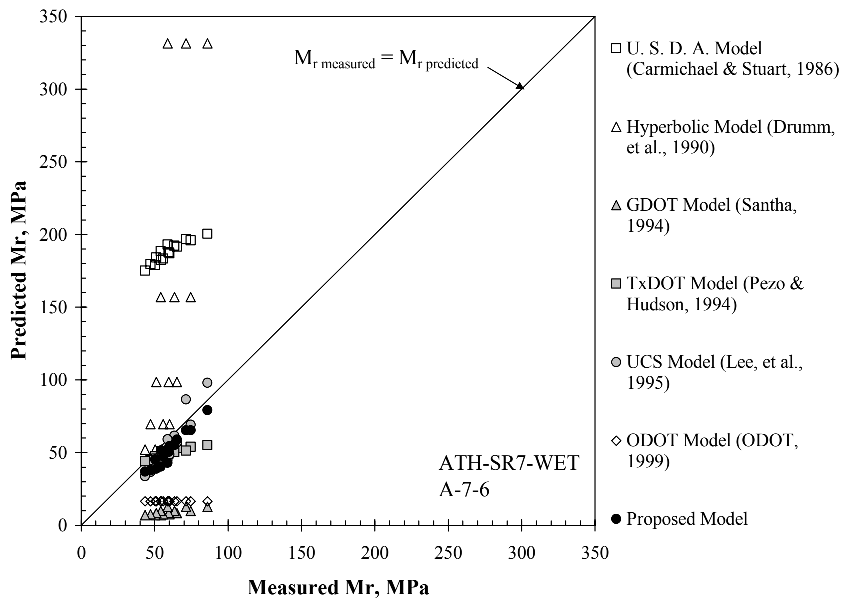

Figure 5.57 Predicted v. Measured M_r A-7-6 Soil Wet of w_{opt}

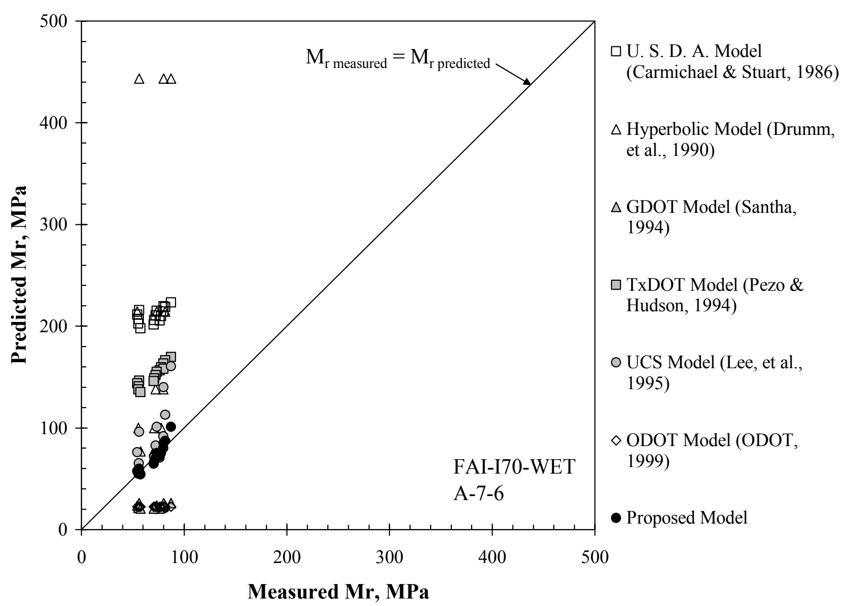

Figure 5.58 Predicted v. Measured M_r A-7-6 Soil Wet of w_{opt}

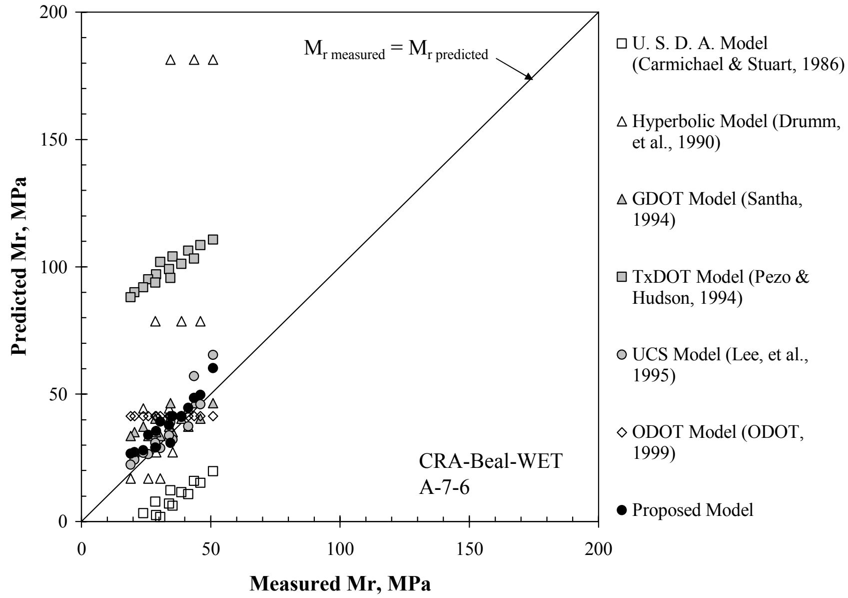

Figure 5.59 Predicted v. Measured M_r A-7-6 Soil Wet of w_{opt}

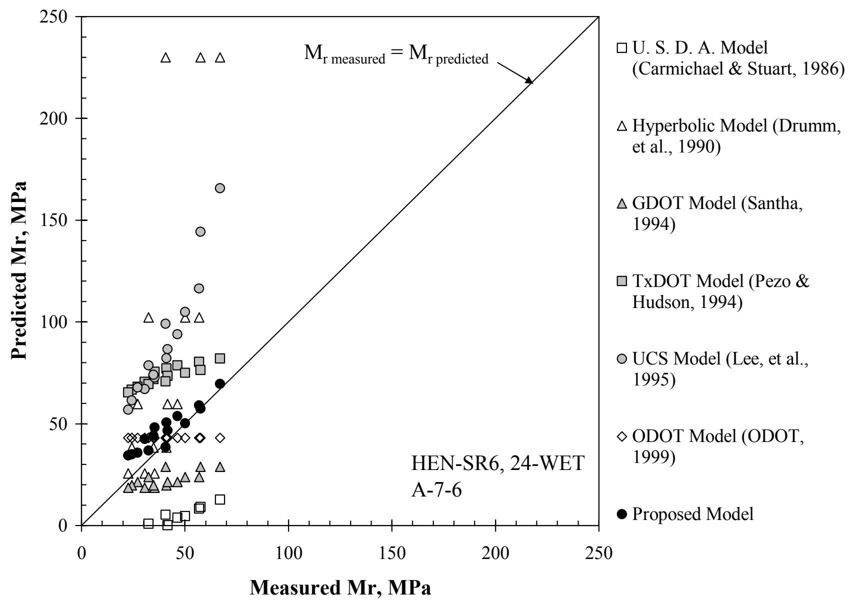

Figure 5.60 Predicted v. Measured M_r A-7-6 Soil Wet of w_{opt}

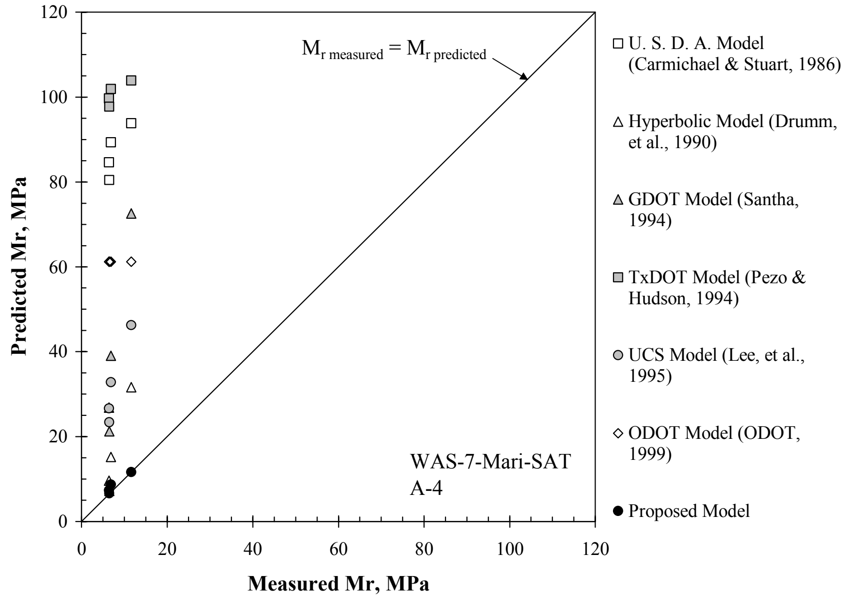

Figure 5.61 Predicted v. Measured M_r A-4 Soil at w_{sat}

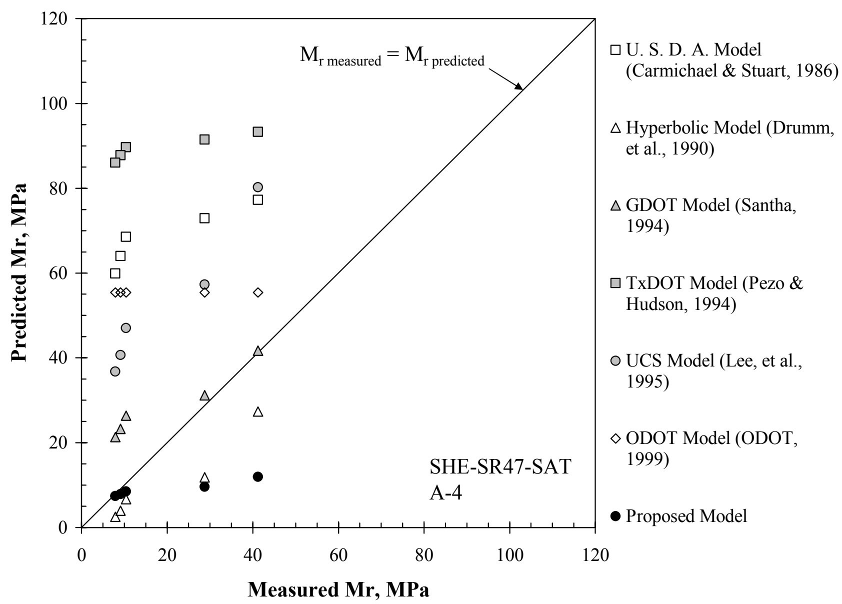

Figure 5.62 Predicted v. Measured M_r A-4 Soil at w_{sat}

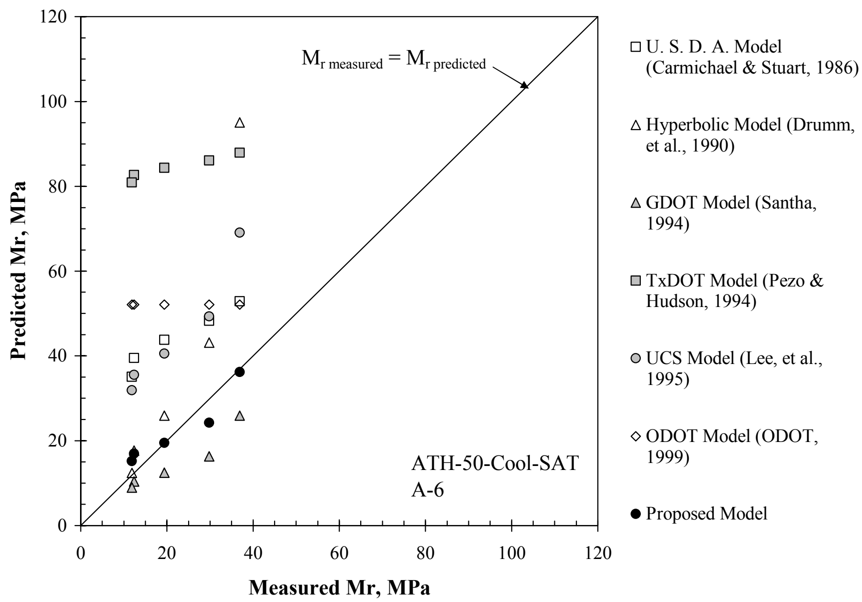

Figure 5.63 Predicted v. Measured M_r A-6 Soil at w_{sat}

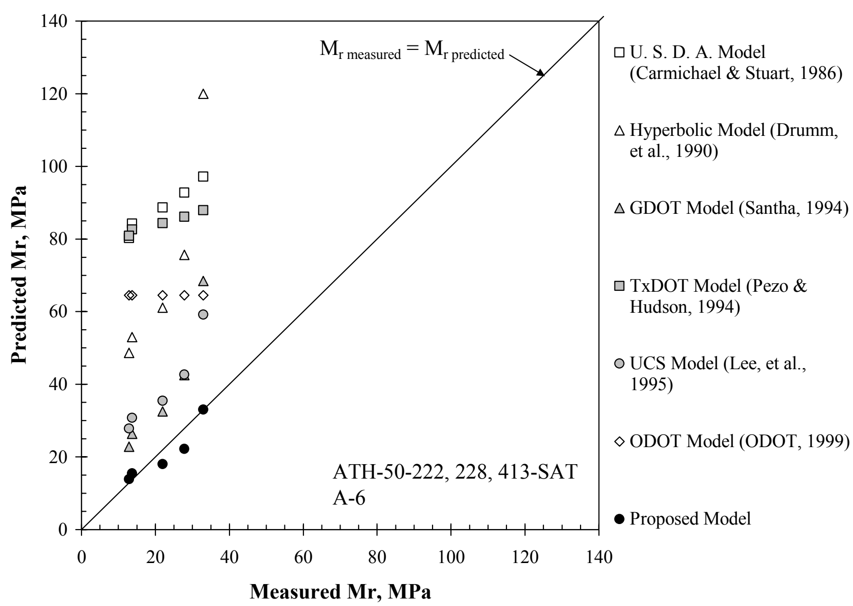

Figure 5.64 Predicted v. Measured M_r A-6 Soil at w_{sat}

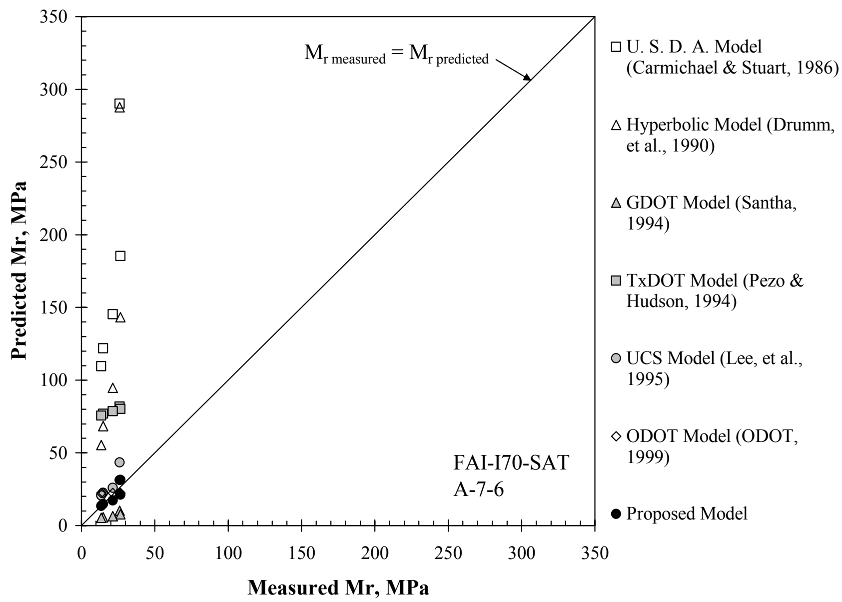

Figure 5.65 Predicted v. Measured M_r A-7-6 Soil at w_{sat}

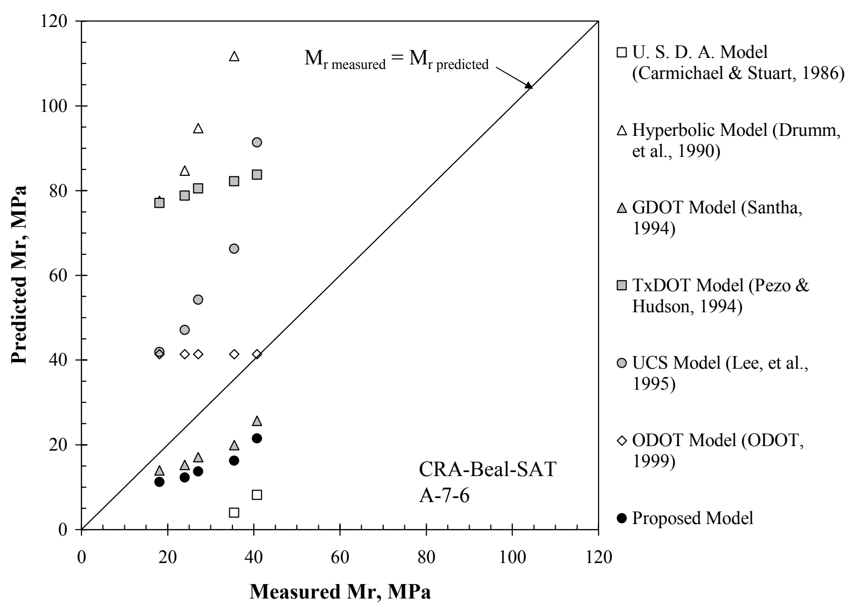

Figure 5.66 Predicted v. Measured M_r A-7-6 Soil at w_{sat}

Regression Model	A-4 group		A-6 group		A-7-6 group	
	Ave % Error	Std Dev % Error	Ave % Error	Std Dev % Error	Ave % Error	Std Dev % Error
USDA Model (Carmichael & Stuart, 1986)	171.8	178.0	62.3	134.6	58.3	165.4
Hyperbolic Model (Drumm, et. Al., 1990)	74.6	159.7	25.7	121.4	151.1	217.5
GDOT Model (Santha, 1994)	155.3	151.2	25.5	83.3	-38.1	40.0
TxDOT Model (Pezo & Hudson, 1994)	336.0	211.9	204.2	171.4	100.2	111.8
UCS Model (Lee, et al., 1995)	29.8	97.9	42.2	109.8	67.6	84.0
ODOT Model (ODOT, 1999)	141.6	187.8	25.4	98.2	-45.1	40.3
Proposed Model	**-2.4**	**29.3**	**1.6**	**19.3**	**0.0**	**15.3**

Table 5.6 Model Predictions All Samples and Moisture Contents

5.8 Applicability of Model to Stabilized Subgrade Soils

The motivation for the model developed in this study was to improve predictions of M_r for natural cohesive soils. It was demonstrated in the previous section that for a range of natural soils, the proposed model more accurately predicts the modulus than do the models commonly in current usage.

It is well known that in many cases unsuitable soils can be improved by chemical stabilization. Combinations of lime, cement, lime-fly ash, and/or other additives have been incorporated into the soil and compacted onsite to increase strength and stiffness. In this effort, a lime-fly ash mix was added to A-4, A-6, and A-7-6 natural soils and the resulting increases in the strength and M_r were documented. The suitability of the proposed model for predicting the resilient modulus of stabilized soils was evaluated for the lime-fly ash stabilized mixes. The basic soil properties of lime-fly ash stabilized A-4, A-6, and A-7-6 soils were measured after 7 days of curing and input into the proposed constitutive model to evaluate M_r. The predicted M_r was then compared with laboratory measured values recorded after 7 days of curing. Table 5.7 is a comparison of the predicted M_r and the laboratory measured M_r. Lime-fly ash stabilization of cohesive soils resulted in significant gains in M_r over the unmodified sample. Because the model requires as input directly measured static soil properties, these increases in modulus were correctly predicted by the proposed model. In general, the calculated M_r was within 30 % of the measured value. By incorporating the stabilized soil properties the proposed model, although developed for natural soils, can also be used for modified soils. The applicability of the model to allow estimations of any stabilized soil modulus is being investigated in a follow up project by constructing both cement and lime stabilized lab specimens and subjecting them to static strength and classification tests and direct M_r tests as was done with the lime-fly ash samples described above. The data from these tests will be incorporated into the model as they are obtained.

5.9 Advantages and Limitations of Proposed Model

The proposed constitutive model for estimating the resilient modulus of cohesive soils has been shown to be applicable for both natural and stabilized soils over a range of stress states typical of highway applications and for soil properties consistent with the A-4, A-6, or A-7-6 classification for cohesive soils. The input parameters for the model are confining stress, deviator stress, degree of saturation, sample moisture content, optimum moisture content, unconfined compressive strength, plasticity index, liquid limit, and % passing #200 sieve. These input values can all be obtained from four static laboratory tests (Standard Proctor Compaction, Unconfined Compressive Strength, Atterberg Limits, and Sieve Analysis).

Because the data set was limited to thirteen samples in three soil types, the applicability of the proposed model over the full range of cohesive soils potentially considered for use as subgrade soils has not been thoroughly tested. As more soils become available for evaluation, the utility of the model will be evaluated and extended. Further, the model has not yet been tested on cohesionless soils.

The resilient moduli for some very weak soils at high water contents and low dry unit weights (almost always unsuitable as highway subgrades), were over-predicted when compared with experimental observations. These limitations can be overcome by including more experimental testing for cohesionless soils and for very weak and wet soils in the model.

Soil Name (Orginal Soil Classification)	Mix Name	Mixture Content	Modified Mixture Classification	Measured M_r (MPa)	Predicted M_r (MPa)	Percent Error (%)
FAI-33-537 (A-4)	Control	100% Soil	A-4	61	76	25
	MIX I	5% Lime 10% Fly ash	A-4	84	110	31
	MIX II	5% Lime 15% Fly ash	A-4	101	97	-3
DEL-23 (A-6)	Control	100% Soil	A-6	49	49	0
	MIX I	15 % Fly ash	A-4	77	66	-14
	MIX II	5% Lime 15% Fly ash	A-4	103	105	2
FAI-33-541 (A-7-6)	Control	100% Soil	A-7-6	19	47	145
	MIX I	15 % Fly ash	A-4	64	63	-1
	MIX II	5% Lime 15% Fly ash	A-4	100	117	17

Table 5.7 Predicted v. Measured M_r for Untreated Natural and Lime-Fly Ash Stabilized A-4, A-6, and A-7-6 Soils (Lee (2003))

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Environmental instrumentation to measure temperature, soil moisture, frost depth and soil suction, has been in place and functioning for seven years. The tensiometers, which measured pore water pressures, have documented relatively rapid increases in pore water pressure leading to the conclusion that, for the subsurface conditions at US 23, subgrade soils are likely to become saturated within months of the placement of pavement. Further, it appears that free draining bases and edge drains had little to no effect on the measured subgrade moisture conditions. The increase in pore pressures has been generally accompanied by an increase in water content as measured by TDRs embedded near the tensiometers. Because only three sites had both TDRs and tensiometers installed, the correlations are not precise enough to be able to use TDRs to predict pore pressure (and thereby effective stresses) without further studies.

Laboratory resilient modulus tests have shown that knowledge of the water content and pore water pressure of the subgrade are critical to the design of a pavement section.

Subgrade soils compacted at the optimum moisture content and then allowed to saturate have resilient moduli only about one third the value measured if the water content remained constant at the optimum value. Being able to predict the modulus at different stages in the design life of a pavement system is crucial to an appropriate design. However conducting the laboratory tests necessary to measure directly the resilient modulus is costly and time consuming even without considering the added time required preparing and testing saturated samples. A predictive tool was developed to help engineers select a design value for resilient modulus for the subgrade soil by conducting just a few conventional laboratory tests.

6.2 Recommendations

The structural properties of subbases and subgrades are strongly dependent on moisture. Laboratory tests on clays typical of those found in Ohio subgrades have documented significant losses in stiffness and strength with increasing water content. The empirical model developed during this research was shown to make significant improvements in predictions of resilient modulus over existing models. However the size of the study that led to the model was quite small. Additional test data will allow a widening of the range of static properties and the incorporation of additional materials into the model. Because of the strong tendency of the base and subgrade materials to support negative pore pressures, initially unsaturated soils fairly quickly become saturated, and thereby experience reductions in strength and stiffness. Additional monitoring of the pavement profiles is necessary since the data collected to date indicate the drains have not prevented the base from becoming saturated and only through continued monitoring will the effects these moisture changes have on pavement performance as the sections age be documented. In future work it is recommended that ground water monitoring wells be installed at SPS sections containing tensiometers to allow for better interpretation of the readings. Further, new techniques for ensuring that the porous ceramic tips of the tensiometers installed are saturated for reliable long-term readings should be investigated.

In addition it is suggested that the subgrade materials at other locations be instrumented with tensiometers to determine the conditions that lead to subgrade and/or subbase saturation and whether other conditions do result in those materials being able to drain freely. Since at high values of negative pore pressure such as those that exist when compacted, soil strength is greater and compressibility is lower than when the pore pressures are zero or positive, considerable error would be introduced into roadway design if the soil properties are evaluated when the material is unsaturated unless the material is prevented from becoming saturated over time.

7. IMPLEMENTATION

We have shown that tensiometers can be used in conjunction with other instrumentation to establish the appropriate material properties required to analyze the performance of pavement sections. Installation of tensiometers and a study of the water pressures recorded will improve our understanding of how and if drains work.

A tool to provide reliable predictions of resilient modulus that can be used to design pavement systems over a range of subsurface moisture conditions has been developed. The proposed model requires only static properties as inputs. Because the model can reliably predict the value of the modulus from static soil properties readily obtained in a conventional geotechnical/materials laboratory, the need to conduct laboratory resilient modulus tests, or make overly coarse or conservative estimates based on current predictive tools is minimized. The method proposed should replace the current procedure for most A-4, A-6 and A-7-6 soils. The method can be updated and/or expanded as new test data are generated.

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9. APPENDICES

9.1 APPENDIX A

ENGINEERING PROPERTIES

Liquid Limit, Plastic Limit, and Plasticity Index

Location: MP 21 SR-60 Muskingum Co.

Depth: Surface

Description: Uncompacted, Disturbed, Air-dried

Sample No.: MUSK-60-21

Date: 8/6/98

Tested by: D.G. kim

Liquid Limit

Number of blows	12	18	27	31
Mass of can (g)	24.85	15.55	15.70	17.10
Mass wet soil + can (g)	35.80	25.30	27.65	28.25
Mass wet soil (g)	10.95	9.75	11.95	11.15
Mass dry soil + can (g)	33.15	23.05	24.95	25.75
Mass dry soil (g)	8.30	7.50	9.25	8.65
Mass water (g)	2.65	2.25	2.70	2.50
Moisture content (%)	**32%**	**30%**	**29%**	**29%**

Plastic Limit

Mass of can (g)	16.55	15.25
Mass wet soil + can (g)	35.75	25.90
Mass wet soil (g)	19.20	10.65
Mass dry soil + can (g)	32.30	23.90
Mass dry soil (g)	15.75	8.65
Mass water (g)	3.45	2.00
Moisture content (%)	**22%**	**23%**

Liquid Limit: 29%

Plastic Limit: 23%

Plasticity Index: 6%

Table A.1 Atterberg Limits MUS-60-21

Liquid Limit, Plastic Limit, and Plasticity Index

Location: MP 21.13 US-35 Greene Co.
Date: 8/4/98
Depth: Surface
Tested by: D.G. kim
Description: Uncompacted, Disturbed, Air-dried
Sample No.: GREEN-35-21.13

Liquid Limit

Number of blows	8	13	62	25
Mass of can (g)	24.90	15.55	15.70	17.10
Mass wet soil + can (g)	39.35	31.45	30.35	31.40
Mass wet soil (g)	14.45	15.90	14.65	14.30
Mass dry soil + can (g)	36.30	28.40	27.85	28.85
Mass dry soil (g)	11.40	12.85	12.15	11.75
Mass water (g)	3.05	3.05	2.50	2.55
Moisture content (%)	**27%**	**24%**	**21%**	**22%**

Plastic Limit

Mass of can (g)	16.50	15.20
Mass wet soil + can (g)	28.85	37.50
Mass wet soil (g)	12.35	22.30
Mass dry soil + can (g)	27.10	34.25
Mass dry soil (g)	10.60	19.05
Mass water (g)	1.75	3.25
Moisture content (%)	**17%**	**17%**

Liquid Limit: 23%

Plastic Limit: 17%

Plasticity Index: 6%

Table A.2 Atterberg Limits GRE-35-21.13

Liquid Limit, Plastic Limit, and Plasticity Index

Location: PS 302+00 US-35 Greene Co. Date: 8/5/98

Depth: Surface Tested by: D.G. kim

Description: Compacted, Disturbed, Air-dried

Sample No.: GREEN-35-302

Liquid Limit

Number of blows	33	18	27	25
Mass of can (g)	15.60	15.55	15.70	17.10
Mass wet soil + can (g)	28.40	28.00	26.70	28.50
Mass wet soil (g)	12.80	12.45	11.00	11.40
Mass dry soil + can (g)	26.05	25.55	24.60	26.30
Mass dry soil (g)	10.45	10.00	8.90	9.20
Mass water (g)	2.35	2.45	2.10	2.20
Moisture content (%)	**22%**	**25%**	**24%**	**24%**

Plastic Limit

Mass of can (g)	16.55	15.25
Mass wet soil + can (g)	32.10	28.20
Mass wet soil (g)	15.55	12.95
Mass dry soil + can (g)	30.00	26.45
Mass dry soil (g)	13.45	11.20
Mass water (g)	2.10	1.75
Moisture content (%)	**16%**	**16%**

Liquid Limit: 24%

Plastic Limit: 16%

Plasticity Index: 8%

Table A.3 Atterberg Limits GRE-35-302

Liquid Limit, Plastic Limit, and Plasticity Index

Location:	PS 400+00 US-35 Greene Co.	Date:	8/4/98
Depth:	Surface	Tested by:	D.G. kim
Description:	Compacted, Disturbed, Air-dried		
Sample No.:	GREEN-35-400		

Liquid Limit

Number of blows	10	15	31	28
Mass of can (g)	16.90	15.30	24.85	17.00
Mass wet soil + can (g)	30.25	26.20	37.35	29.40
Mass wet soil (g)	13.35	10.90	12.50	12.40
Mass dry soil + can (g)	27.40	24.00	34.90	26.95
Mass dry soil (g)	10.50	8.70	10.05	9.95
Mass water (g)	2.85	2.20	2.45	2.45
Moisture content (%)	**27%**	**25%**	**24%**	**25%**

Plastic Limit

Mass of can (g)	15.60	17.65
Mass wet soil + can (g)	37.25	35.60
Mass wet soil (g)	21.65	17.95
Mass dry soil + can (g)	34.15	32.95
Mass dry soil (g)	18.55	15.30
Mass water (g)	3.10	2.65
Moisture content (%)	**17%**	**17%**

Liquid Limit: 25%

Plastic Limit: 17%

Plasticity Index: 8%

Table A.4 Atterberg Limits GRE-35-400

Liquid Limit, Plastic Limit, and Plasticity Index

Location: Marietta SR-7 WashingtonCo.

Depth: 1m below the surface

Description: Compacted, Disturbed, Air-dried

Sample No.: WAS-7-Mari

Date: 8/10/98

Tested by: D.G. Kim

Liquid Limit

Number of blows	9	15	23	41
Mass of can (g)	24.85	15.50	15.70	17.05
Mass wet soil + can (g)	33.45	23.45	24.55	24.05
Mass wet soil (g)	8.60	7.95	8.85	7.00
Mass dry soil + can (g)	31.40	21.60	22.55	22.50
Mass dry soil (g)	6.55	6.10	6.85	5.45
Mass water (g)	2.05	1.85	2.00	1.55
Moisture content (%)	**31%**	**30%**	**29%**	**28%**

Plastic Limit

Mass of can (g)	16.50	16.90
Mass wet soil + can (g)	29.50	23.20
Mass wet soil (g)	13.00	6.30
Mass dry soil + can (g)	27.35	22.20
Mass dry soil (g)	10.85	5.30
Mass water (g)	2.15	1.00
Moisture content (%)	**20%**	**19%**

Liquid Limit: 29%

Plastic Limit: 19%

Plasticity Index: 10%

Table A.5 Atterberg Limits WAS-7-Mari

Liquid Limit, Plastic Limit, and Plasticity Index

Location: SR-47 Shelby County

Date: 7/27/1999

Depth: roadbed

Tested by: D.G. Kim

Description: Disturbed, Air-dried

Sample No.: SHE-47

Liquid Limit

Number of blows	22	45	26	16
Mass of can (g)	14.88	17.78	13.95	14.46
Mass wet soil + can (g)	29.86	30.96	29.56	27.76
Mass wet soil (g)	14.98	13.18	15.61	13.30
Mass dry soil + can (g)	26.80	28.34	26.40	24.98
Mass dry soil (g)	11.92	10.56	12.45	10.52
Mass water (g)	3.06	2.62	3.16	2.78
Moisture content (%)	**26%**	**25%**	**25%**	**26%**

Plastic Limit

Mass of can (g)	15.89	15.90
Mass wet soil + can (g)	28.35	38.00
Mass wet soil (g)	12.46	22.10
Mass dry soil + can (g)	26.59	34.84
Mass dry soil (g)	10.70	18.94
Mass water (g)	1.76	3.16
Moisture content (%)	**16%**	**17%**

Liquid Limit: 26%

Plastic Limit: 17%

Plasticity Index: 9%

Table A.6 Atterberg Limits SHE-SR 47

<u>Liquid Limit, Plastic Limit, and Plasticity Index</u>

Location: MP 3 SR-741 Warren Co.
Date: 8/5/98

Depth: Surface
Tested by: D.G. kim

Description: Uncompacted, Disturbed, Air-dried

Sample No.: WAR-741-3

Liquid Limit

Number of blows	30	26	16	27
Mass of can (g)	16.90	15.30	24.85	17.00
Mass wet soil + can (g)	27.10	28.10	36.95	25.50
Mass wet soil (g)	10.20	12.80	12.10	8.50
Mass dry soil + can (g)	24.90	25.30	34.10	23.65
Mass dry soil (g)	8.00	10.00	9.25	6.65
Mass water (g)	2.20	2.80	2.85	1.85
Moisture content (%)	**28%**	**28%**	**31%**	**28%**

Plastic Limit

Mass of can (g)	24.85	17.60
Mass wet soil + can (g)	39.35	34.00
Mass wet soil (g)	14.50	16.40
Mass dry soil + can (g)	37.25	31.50
Mass dry soil (g)	12.40	13.90
Mass water (g)	2.10	2.50
Moisture content (%)	**17%**	**18%**

Liquid Limit: 28%

Plastic Limit: 17%

Plasticity Index: 11%

Table A.7 Atterberg Limits WAR-741-3

Liquid Limit, Plastic Limit, and Plasticity Index

Location: PS 113+75 SR-821 WashingtonCo.
Date: 8/8/98
Depth: Surface
Tested by: D.G. Kim
Description: Compacted, Disturbed, Air-dried
Sample No.: WAS-821-113

Liquid Limit

Number of blows	14	20	29	44
Mass of can (g)	16.90	15.30	24.85	17.00
Mass wet soil + can (g)	27.30	25.65	35.60	25.65
Mass wet soil (g)	10.40	10.35	10.75	8.65
Mass dry soil + can (g)	24.60	23.10	33.00	23.60
Mass dry soil (g)	7.70	7.80	8.15	6.60
Mass water (g)	2.70	2.55	2.60	2.05
Moisture content (%)	**35%**	**33%**	**32%**	**31%**

Plastic Limit

Mass of can (g)	15.70	17.05
Mass wet soil + can (g)	20.85	22.15
Mass wet soil (g)	5.15	5.10
Mass dry soil + can (g)	20.00	21.25
Mass dry soil (g)	4.30	4.20
Mass water (g)	0.85	0.90
Moisture content (%)	**20%**	**21%**

Liquid Limit: 33%

Plastic Limit: 21%

Plasticity Index: 12%

Table A.8 Atterberg Limits WAS-821-113

Liquid Limit, Plastic Limit, and Plasticity Index

Location: PS 116+00 SR-821 WashingtonCo.

Date: 8/8/98

Depth: Surface

Tested by: D.G. Kim

Description: Uncompacted, Disturbed, Air-dried

Sample No.: WAS-821-116

Liquid Limit

Number of blows	19	23	25	43
Mass of can (g)	24.85	15.55	15.70	17.10
Mass wet soil + can (g)	33.90	24.30	24.30	26.15
Mass wet soil (g)	9.05	8.75	8.60	9.05
Mass dry soil + can (g)	31.70	22.20	22.30	24.10
Mass dry soil (g)	6.85	6.65	6.60	7.00
Mass water (g)	2.20	2.10	2.00	2.05
Moisture content (%)	**32%**	**32%**	**30%**	**29%**

Plastic Limit

Mass of can (g)	16.55	15.25
Mass wet soil + can (g)	25.75	21.95
Mass wet soil (g)	9.20	6.70
Mass dry soil + can (g)	24.20	20.80
Mass dry soil (g)	7.65	5.55
Mass water (g)	1.55	1.15
Moisture content (%)	**20%**	**21%**

Liquid Limit: 31%

Plastic Limit: 20%

Plasticity Index: 11%

Table A.9 Atterberg Limits WAS-821-116

Liquid Limit, Plastic Limit, and Plasticity Index

Location: Near the split of SR147+SR265 Date: 1/17/2000

Depth: Tested by: lsh

Description: BEL-SR147,265

Sample No.:

Liquid Limit

Number of blows	18	40	29	
Mass of can (g)	6.26	6.18	7.68	
Mass wet soil + can (g)	20.49	19.03	21.10	
Mass wet soil (g)	14.23	12.85	13.42	0.00
Mass dry soil + can (g)	16.80	15.77	17.68	
Mass dry soil (g)	10.54	9.59	10.00	0.00
Mass water (g)	3.69	3.26	3.42	0.00
Moisture content (%)	35%	34%	34%	#DIV/0!

Plastic Limit

Mass of can (g)	30.73	30.29
Mass wet soil + can (g)	49.99	46.65
Mass wet soil (g)	19.26	16.36
Mass dry soil + can (g)	46.26	43.50
Mass dry soil (g)	15.53	13.21
Mass water (g)	3.73	3.15
Moisture content (%)	24%	24%

Liquid Limit: 35%

Plastic Limit: 24%

Plasticity Index: 11%

Table A.10 Atterberg Limits BEL-SR147, 265

Liquid Limit, Plastic Limit, and Plasticity Index

Location: MP 34 US-50 Athens County

Date: 8/10/98

Depth: Surface

Tested by: D.G. Kim

Description: Compacted, Disturbed, Air-dried

Sample No.: ATH-50-Cool

Liquid Limit

Number of blows	11	22	23	35
Mass of can (g)	16.90	15.25	24.85	17.00
Mass wet soil + can (g)	25.20	22.10	34.25	25.35
Mass wet soil (g)	8.30	6.85	9.40	8.35
Mass dry soil + can (g)	23.00	20.40	31.90	23.35
Mass dry soil (g)	6.10	5.15	7.05	6.35
Mass water (g)	2.20	1.70	2.35	2.00
Moisture content (%)	**36%**	**33%**	**33%**	**31%**

Plastic Limit

Mass of can (g)	17.60	15.60
Mass wet soil + can (g)	31.50	27.50
Mass wet soil (g)	13.90	11.90
Mass dry soil + can (g)	29.20	25.50
Mass dry soil (g)	11.60	9.90
Mass water (g)	2.30	2.00
Moisture content (%)	**20%**	**20%**

Liquid Limit: 33%

Plastic Limit: 20%

Plasticity Index: 13%

Table A.11 Atterberg Limits ATH-50-Cool

Liquid Limit, Plastic Limit, and Plasticity Index

Location: PS 222+00 US-50 Athens Co.

Date: 8/11/98

Depth: Surface

Tested by: D.G. Kim

Description: Disturbed, Air-dried, Compacted

Sample No.: ATH-50-222

Liquid Limit

Number of blows	9	17	23	27
Mass of can (g)	16.90	15.30	24.85	17.00
Mass wet soil + can (g)	24.95	24.60	33.40	27.40
Mass wet soil (g)	8.05	9.30	8.55	10.40
Mass dry soil + can (g)	22.80	22.20	31.25	24.80
Mass dry soil (g)	5.90	6.90	6.40	7.80
Mass water (g)	2.15	2.40	2.15	2.60
Moisture content (%)	**36%**	**35%**	**34%**	**33%**

Plastic Limit

Mass of can (g)	15.60	17.60
Mass wet soil + can (g)	26.85	26.20
Mass wet soil (g)	11.25	8.60
Mass dry soil + can (g)	25.00	24.80
Mass dry soil (g)	9.40	7.20
Mass water (g)	1.85	1.40
Moisture content (%)	**20%**	**19%**

Liquid Limit: 33%

Plastic Limit: 20%

Plasticity Index: 13%

Table A.12 Atterberg Limits ATH-50-222

Liquid Limit, Plastic Limit, and Plasticity Index

Location: PS 228+00 US-50 Athens Co.

Depth: Surface

Description: Compacted, Disturbed, Air-dried

Sample No.: ATH-50-228

Date: 8/11/98

Tested by: D.G. Kim

Liquid Limit

Number of blows	9	17	22	35
Mass of can (g)	24.85	15.50	15.70	17.05
Mass wet soil + can (g)	34.25	25.80	25.50	26.15
Mass wet soil (g)	9.40	10.30	9.80	9.10
Mass dry soil + can (g)	31.90	23.35	23.20	24.10
Mass dry soil (g)	7.05	7.85	7.50	7.05
Mass water (g)	2.35	2.45	2.30	2.05
Moisture content (%)	**33%**	**31%**	**31%**	**29%**

Plastic Limit

Mass of can (g)	16.55	15.25
Mass wet soil + can (g)	29.35	30.85
Mass wet soil (g)	12.80	15.60
Mass dry soil + can (g)	27.30	28.35
Mass dry soil (g)	10.75	13.10
Mass water (g)	2.05	2.50
Moisture content (%)	**19%**	**19%**

Liquid Limit: 30%

Plastic Limit: 19%

Plasticity Index: 11%

Table A.13 Atterberg Limits ATH-50-228

Liquid Limit, Plastic Limit, and Plasticity Index

Location: PS 413+50 US-50 Athens Co.
Date: 8/11/98
Depth: Surface
Tested by: D.G. Kim
Description: Disturbed, Air-dried, Compacted
Sample No.: ATH-50-413

Liquid Limit

Number of blows	12	18	31	26
Mass of can (g)	7.60	7.80	6.25	7.60
Mass wet soil + can (g)	17.55	17.25	12.70	15.05
Mass wet soil (g)	9.95	9.45	6.45	7.45
Mass dry soil + can (g)	15.20	15.05	11.25	13.35
Mass dry soil (g)	7.60	7.25	5.00	5.75
Mass water (g)	2.35	2.20	1.45	1.70
Moisture content (%)	**31%**	**30%**	**29%**	**30%**

Plastic Limit

Mass of can (g)	16.85	16.95
Mass wet soil + can (g)	28.75	21.90
Mass wet soil (g)	11.90	4.95
Mass dry soil + can (g)	26.80	21.10
Mass dry soil (g)	9.95	4.15
Mass water (g)	1.95	0.80
Moisture content (%)	**20%**	**19%**

Liquid Limit: 30%

Plastic Limit: 19%

Plasticity Index: 11%

Table A.14 Atterberg Limits ATH-50-413

Liquid Limit, Plastic Limit, and Plasticity Index

Location:	7 miles west of SR7 on US-50	Date:	1/18/2000
Depth:		Tested by:	lsh
Description:	ATH-SR7		
Sample No.:			

Liquid Limit

Number of blows	48	36	30	25
Mass of can (g)	7.73	7.58	7.77	7.52
Mass wet soil + can (g)	18.75	18.02	18.32	18.64
Mass wet soil (g)	11.02	10.44	10.55	11.12
Mass dry soil + can (g)	14.92	14.31	14.49	14.52
Mass dry soil (g)	7.19	6.73	6.72	7.00
Mass water (g)	3.83	3.71	3.83	4.12
Moisture content (%)	53%	55%	57%	59%

Plastic Limit

Mass of can (g)	30.75	30.68
Mass wet soil + can (g)	43.76	42.86
Mass wet soil (g)	13.01	12.18
Mass dry soil + can (g)	41.02	40.30
Mass dry soil (g)	10.27	9.62
Mass water (g)	2.74	2.56
Moisture content (%)	27%	27%

Liquid Limit: 59%

Plastic Limit: 27%

Plasticity Index: 32%

Table A.15 Atterberg Limits ATH-SR7

Liquid Limit, Plastic Limit, and Plasticity Index

Location:	New off ramp from I-70 East	Date:	1/16/2000
Depth:		Tested by:	lsh
Description:	FAI-I70		
Sample No.:			

Liquid Limit

Number of blows	41	36	23	22
Mass of can (g)	6.19	7.81	7.60	7.53
Mass wet soil + can (g)	16.63	15.54	18.57	22.21
Mass wet soil (g)	10.44	7.73	10.97	14.68
Mass dry soil + can (g)	13.13	12.90	14.58	16.94
Mass dry soil (g)	6.94	5.09	6.98	9.41
Mass water (g)	3.50	2.64	3.99	5.27
Moisture content (%)	50%	52%	57%	56%

Plastic Limit

Mass of can (g)	7.78	7.73
Mass wet soil + can (g)	10.81	10.76
Mass wet soil (g)	3.03	3.03
Mass dry soil + can (g)	10.31	10.28
Mass dry soil (g)	2.53	2.55
Mass water (g)	0.50	0.48
Moisture content (%)	20%	19%

Liquid Limit: 55%

Plastic Limit: 19%

Plasticity Index: 36%

Table A.16 Atterberg Limits FAI-I70

Liquid Limit, Plastic Limit, and Plasticity Index

Location:	Crawford Co.	Date:	7/22/1999
Depth:		Tested by:	D.G. Kim
Description:	Disturbed, Air-dried		
Sample No.:	CRA-Beal		

Liquid Limit

Number of blows	12	21	44	31
Mass of can (g)	23.50	13.87	17.82	15.96
Mass wet soil + can (g)	36.80	24.10	29.50	27.42
Mass wet soil (g)	13.30	10.23	11.68	11.46
Mass dry soil + can (g)	32.83	21.10	26.13	24.10
Mass dry soil (g)	9.33	7.23	8.31	8.14
Mass water (g)	3.97	3.00	3.37	3.32
Moisture content (%)	**43%**	**41%**	**41%**	**41%**

Plastic Limit

Mass of can (g)	13.99	15.80
Mass wet soil + can (g)	27.30	34.86
Mass wet soil (g)	13.31	19.06
Mass dry soil + can (g)	25.10	31.72
Mass dry soil (g)	11.11	15.92
Mass water (g)	2.20	3.14
Moisture content (%)	**20%**	**20%**

Liquid Limit: 41%

Plastic Limit: 20%

Plasticity Index: 21%

Table A.17 Atterberg Limits CRA-Beal

Liquid Limit, Plastic Limit, and Plasticity Index

Location:	SR-6 & 24 Henry County	Date:	7/23/1999
Depth:	borrow pit	Tested by:	D.G. Kim
Description:	Disturbed, Air-dried		
Sample No.:	HEN-6, 24		

Liquid Limit

Number of blows	20	45	28	11
Mass of can (g)	18.70	13.89	14.90	18.51
Mass wet soil + can (g)	31.90	25.30	28.31	30.40
Mass wet soil (g)	13.20	11.41	13.41	11.89
Mass dry soil + can (g)	27.98	22.18	24.43	26.63
Mass dry soil (g)	9.28	8.29	9.53	8.12
Mass water (g)	3.92	3.12	3.88	3.77
Moisture content (%)	**42%**	**38%**	**41%**	**46%**

Plastic Limit

Mass of can (g)	15.90	25.50
Mass wet soil + can (g)	26.50	35.41
Mass wet soil (g)	10.60	9.91
Mass dry soil + can (g)	24.70	33.70
Mass dry soil (g)	8.80	8.20
Mass water (g)	1.80	1.71
Moisture content (%)	**20%**	**21%**

Liquid Limit: 41%

Plastic Limit: 21%

Plasticity Index: 20%

Table A.18 Atterberg Limits HEN-SR6, 24

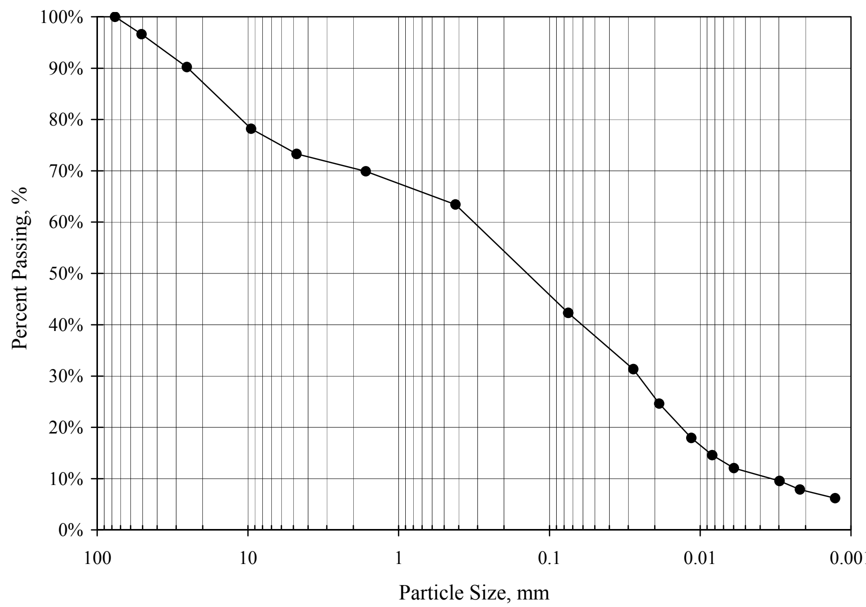

Figure A.1 Particle Size Distribution MUS-60-21

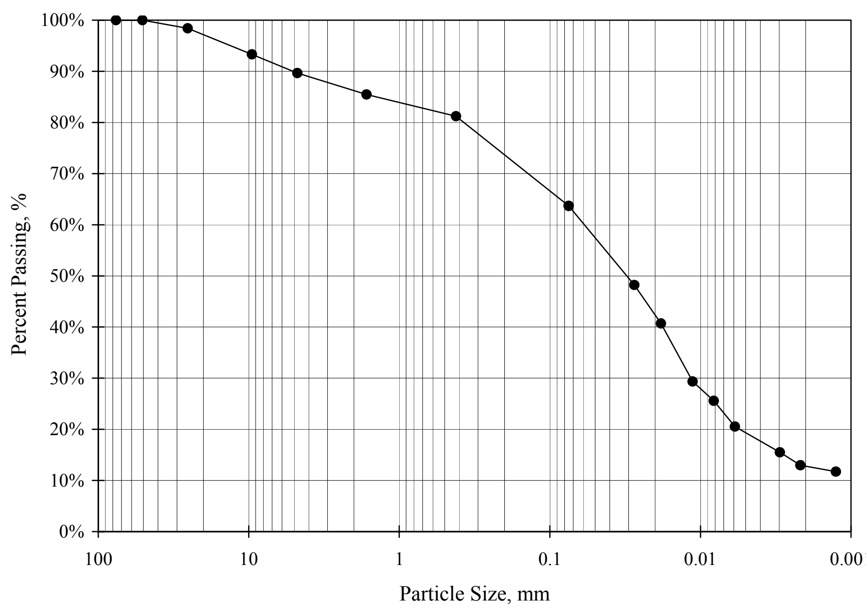

Figure A.2 Particle Size Distribution GRE-35-21.13, 320, 400

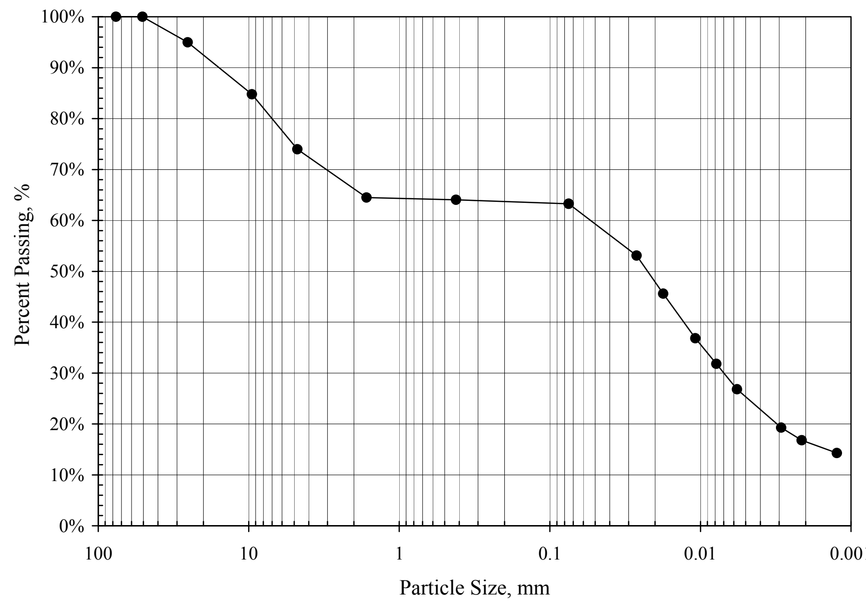

Figure A.3 Particle Size Distribution WAS-7-Mari

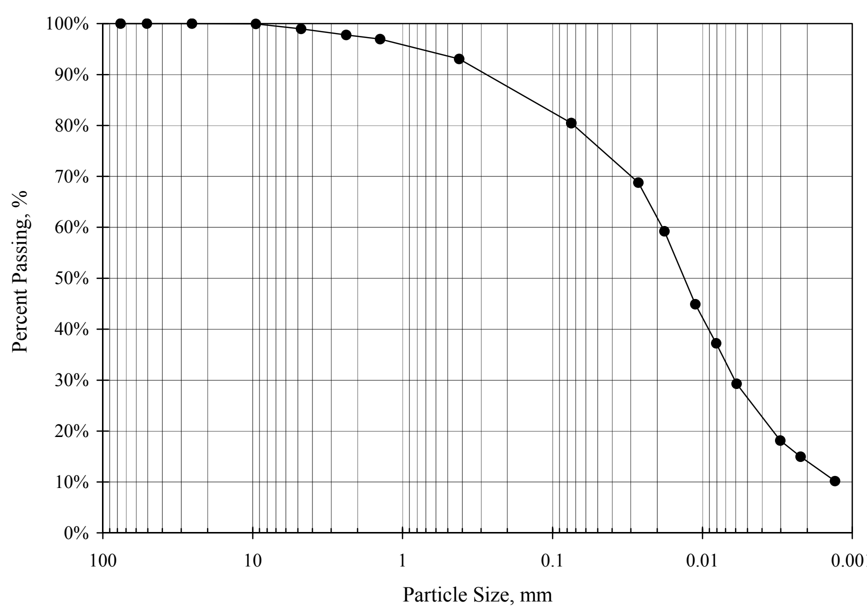

Figure A.4 Particle Size Distribution SHE-SR 47

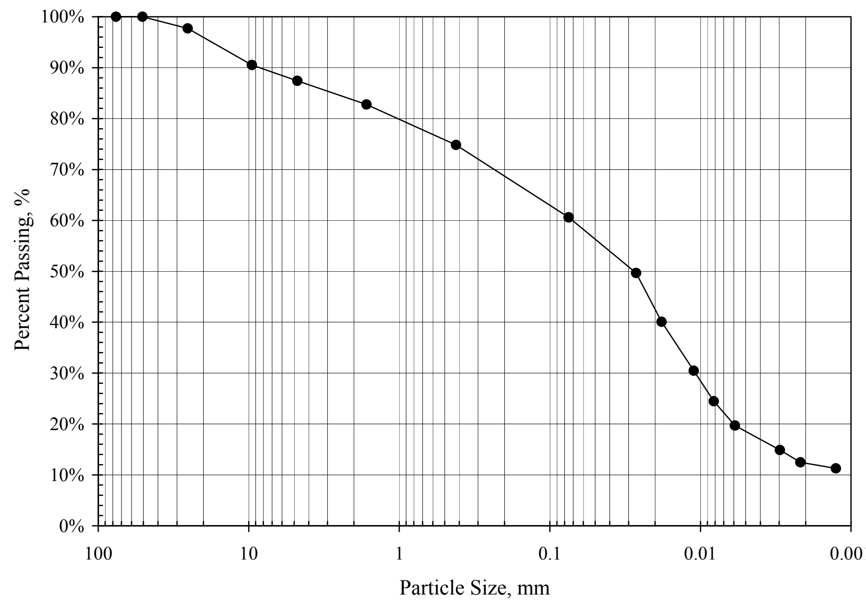

Figure A.5 Particle Size Distribution WAR-741-3

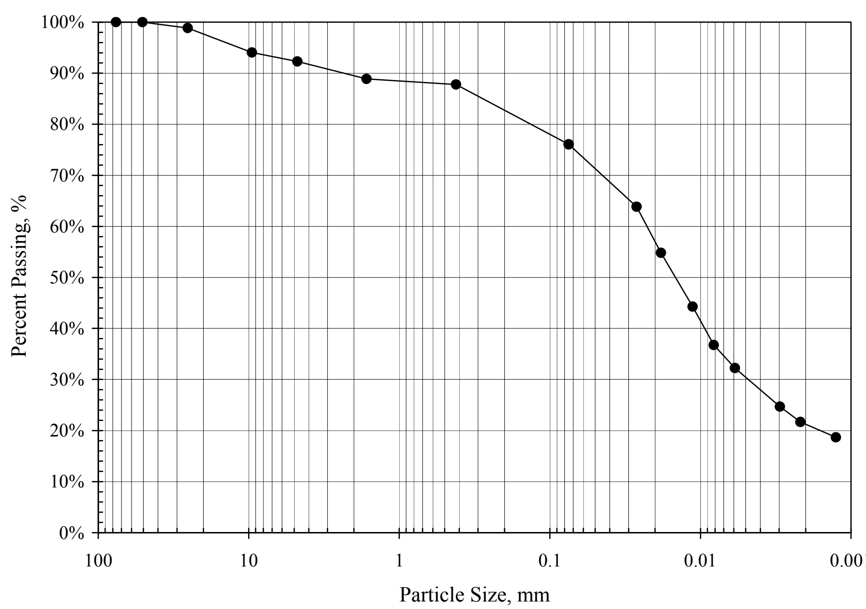

Figure A.6 Particle Size Distribution WAS-821-113, 116

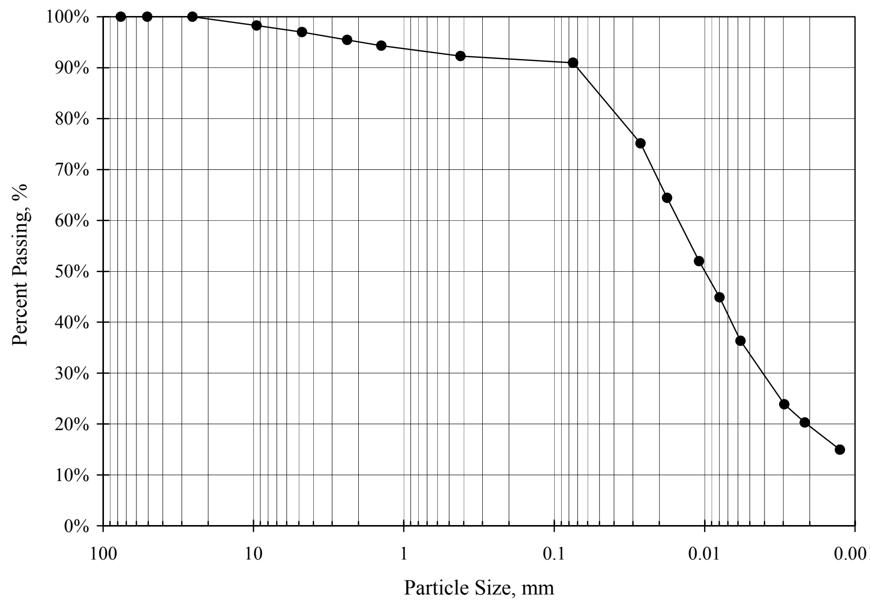

Figure A.7 Particle Size Distribution BEL-SR147, 265

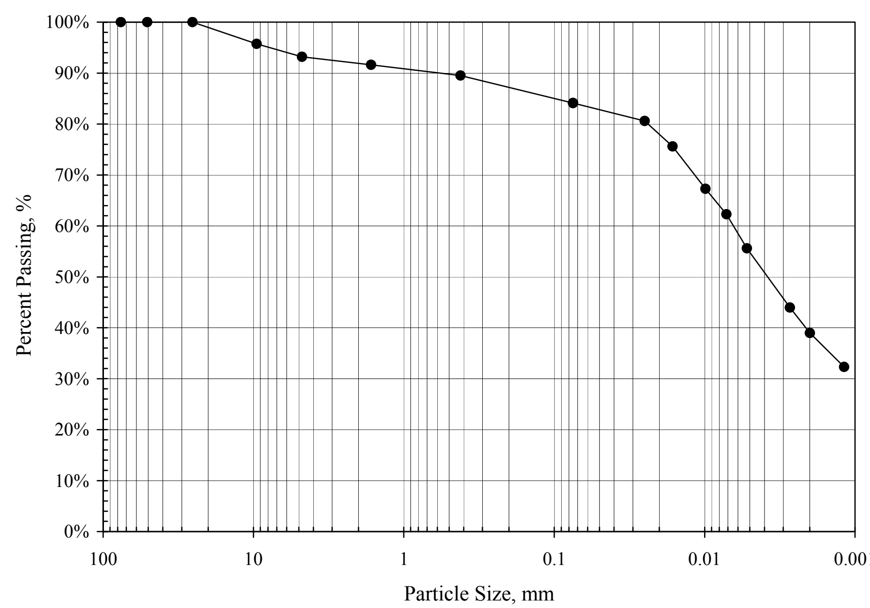

Figure A.8 Particle Size Distribution ATH-50-Cool

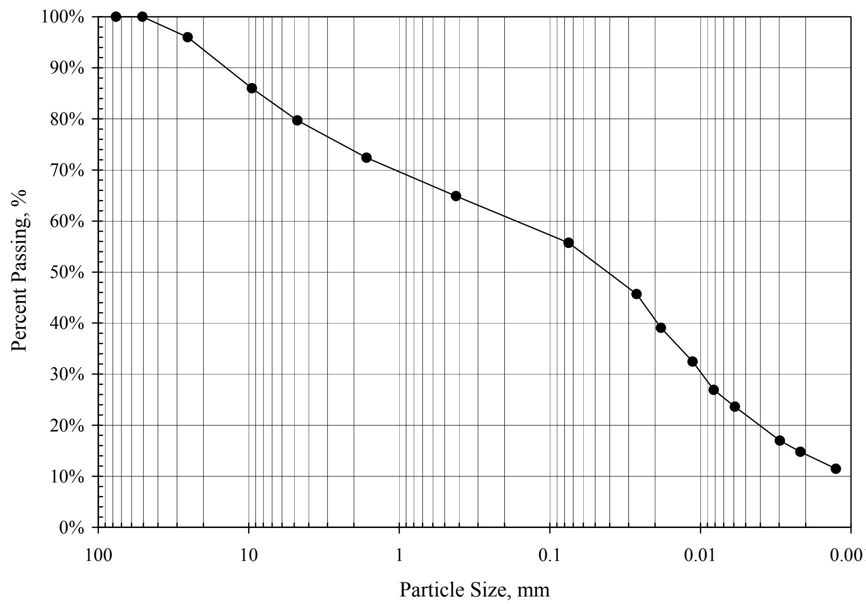

Figure A.9 Particle Size Distribution ATH-50-222, 228, 413

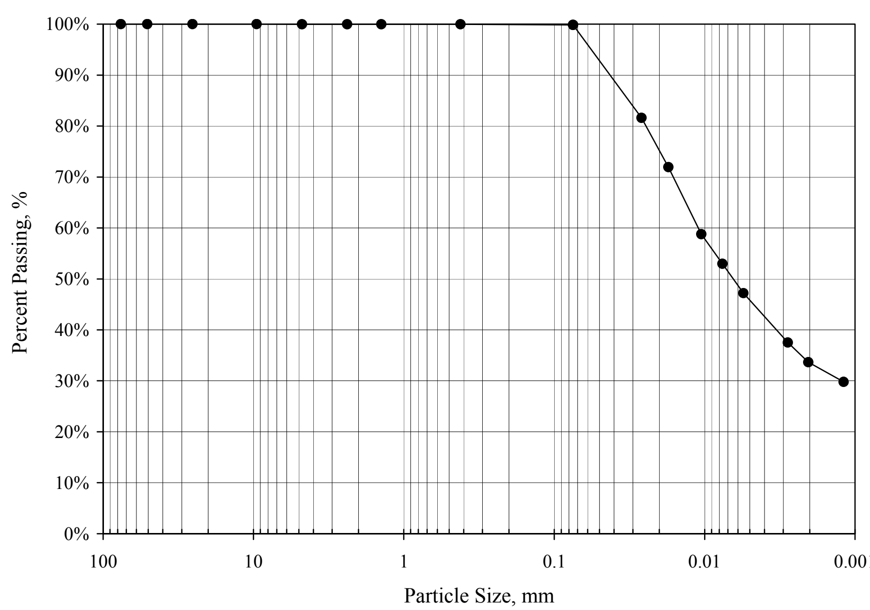

Figure A.10 Particle Size Distribution ATH-SR7

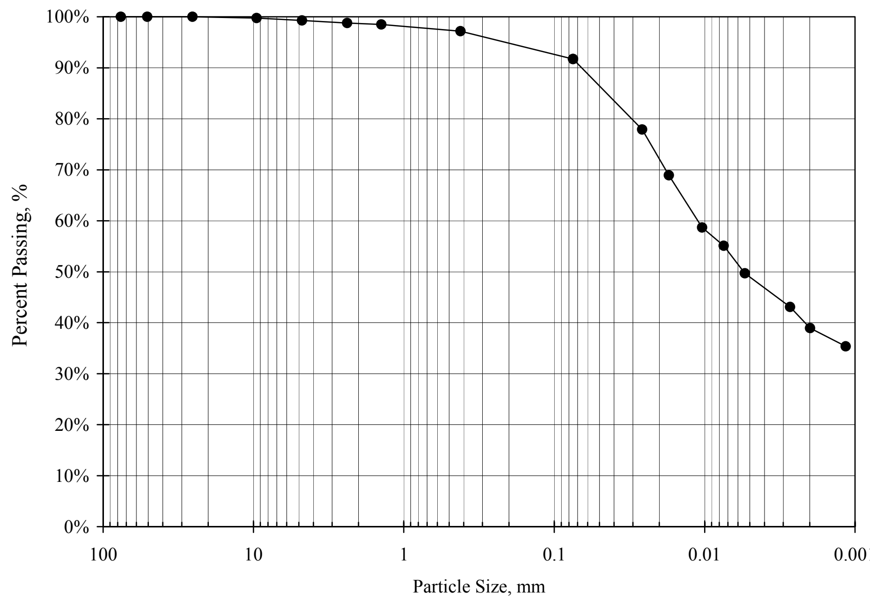

Figure A.11 Particle Size Distribution FAI-I70

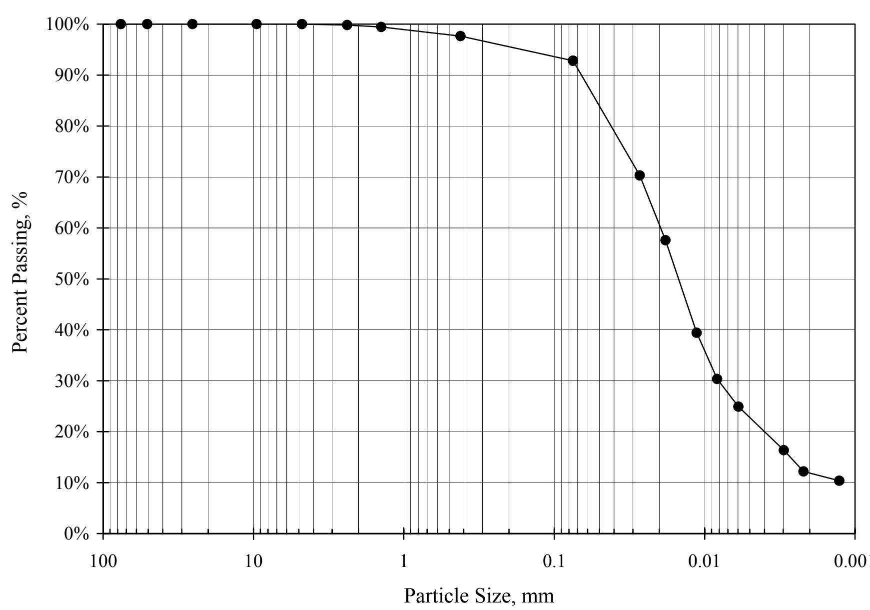

Figure A.12 Particle Size Distribution CRA-Beal

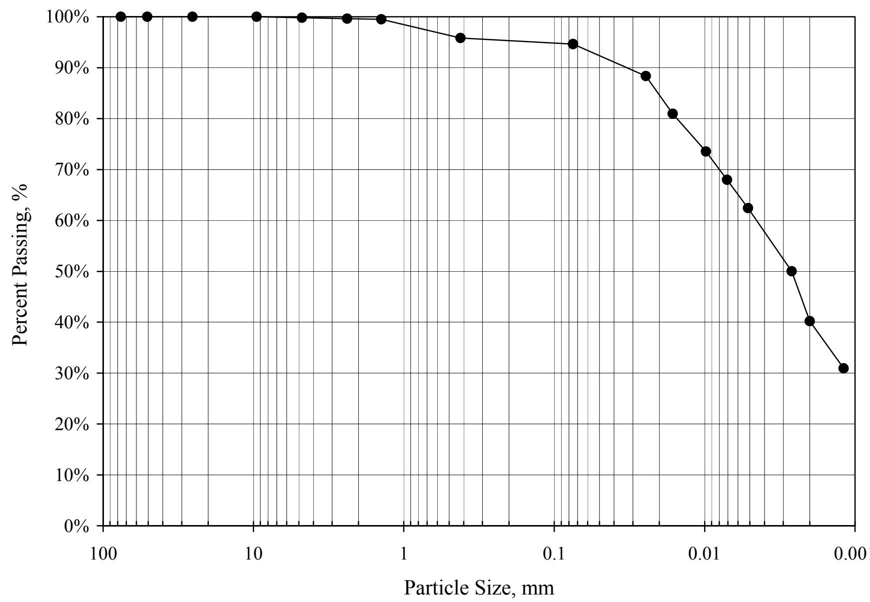

Figure A.13 Particle Size Distribution HEN-SR6, 24

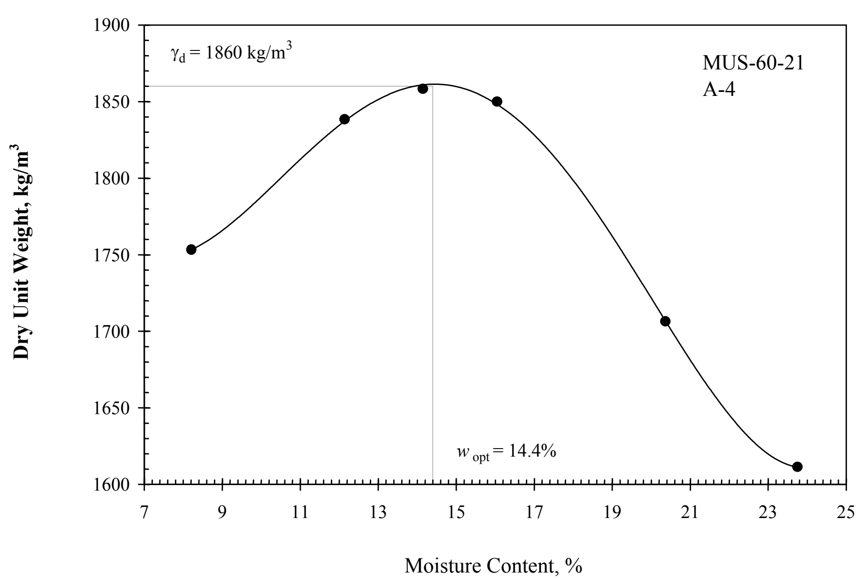

Figure A.14 Moisture Content v. Dry Unit Weight MUS-60-21

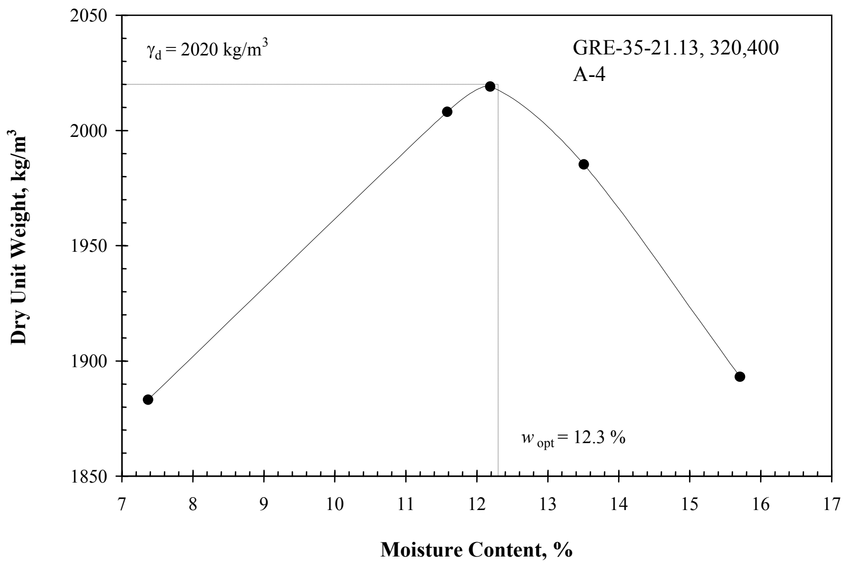

Figure A.15 Moisture Content v. Dry Unit Weight GRE-35-21.13, 320,400

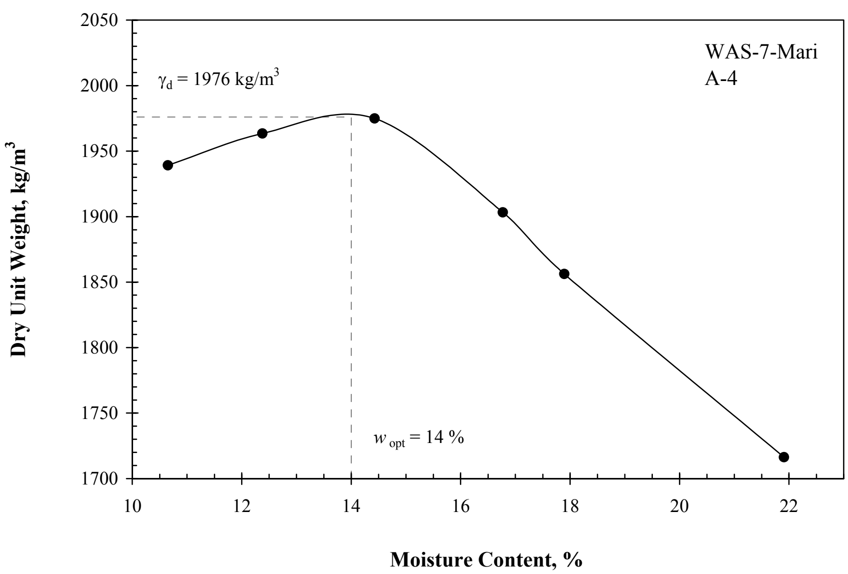

Figure A.16 Moisture Content v. Dry Unit Weight WAS-7-Mari

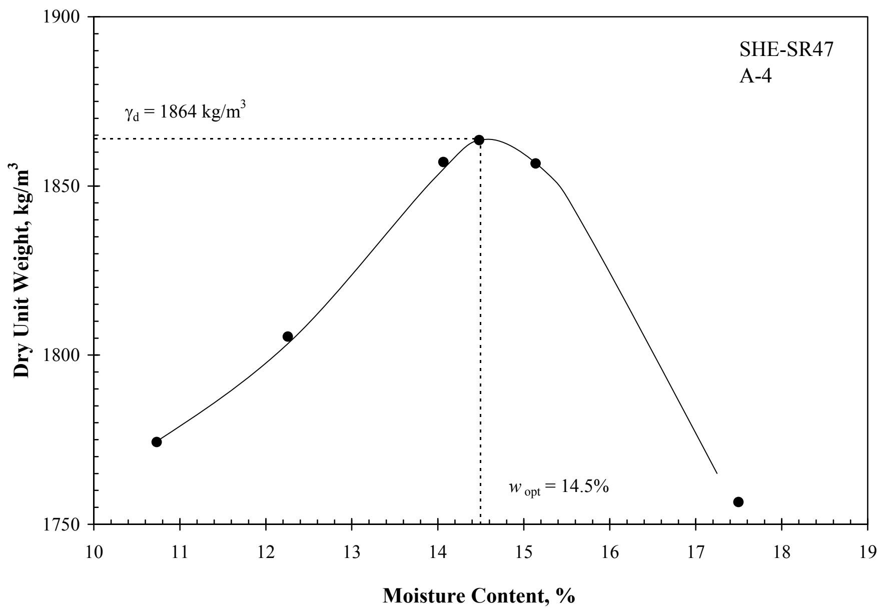

Figure A.17 Moisture Content v. Dry Unit Weight SHE-SR47

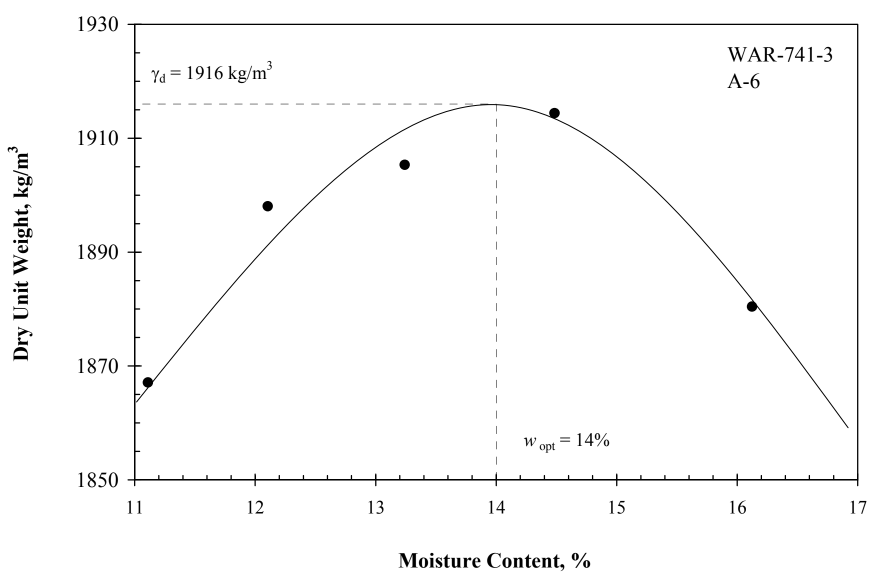

Figure A.18 Moisture Content v. Dry Unit Weight WAR-741-3

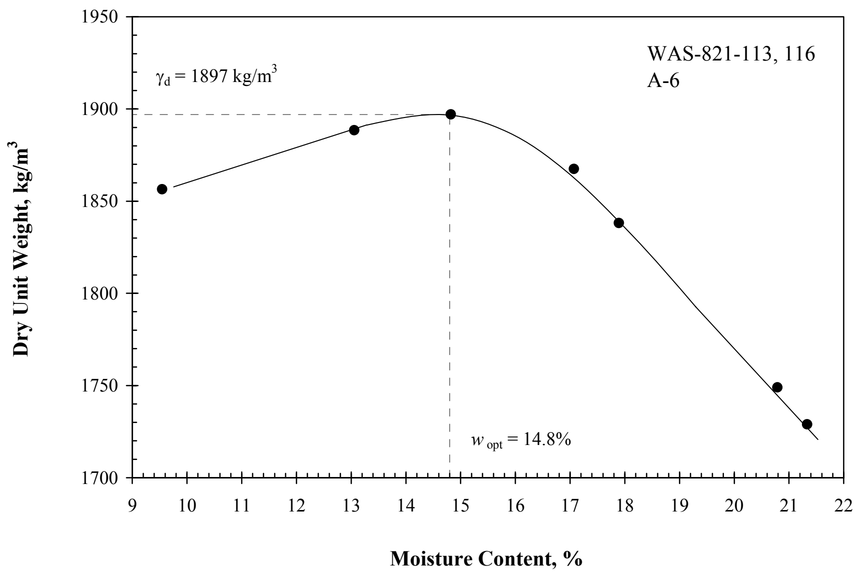

Figure A.19 Moisture Content v. Dry Unit Weight WAS-821-113, 116

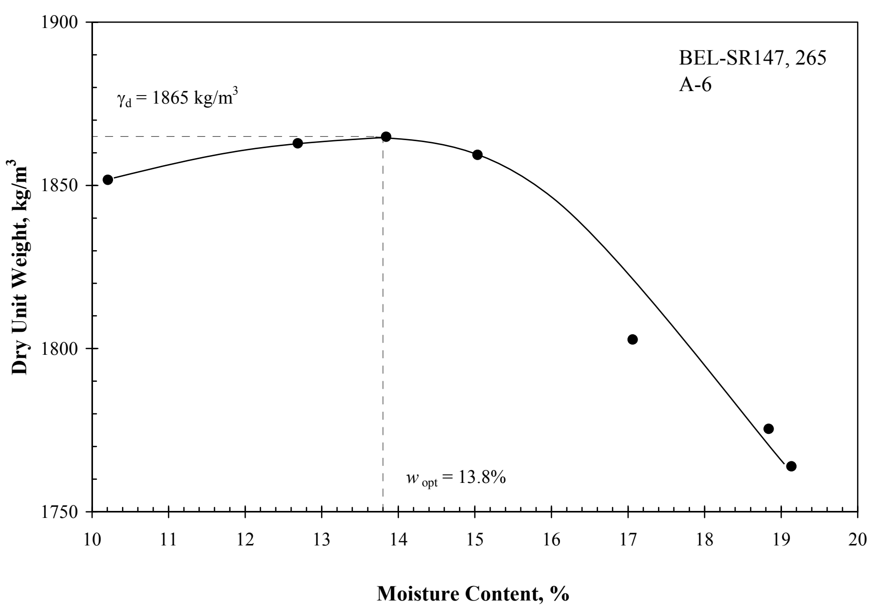

Figure A.20 Moisture contents v dry unit weight BEL-SR147, 265

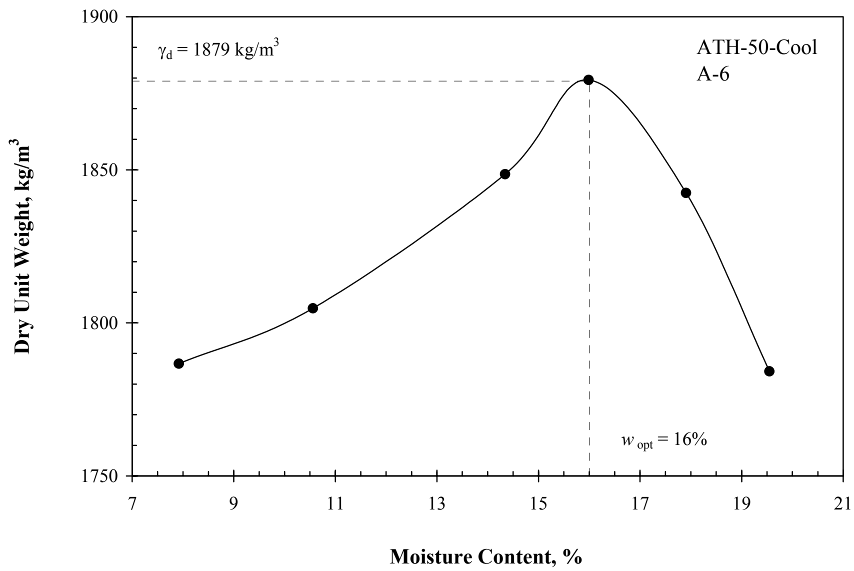

Figure A.21 Moisture Content v. Dry Unit Weight ATH-50-Cool

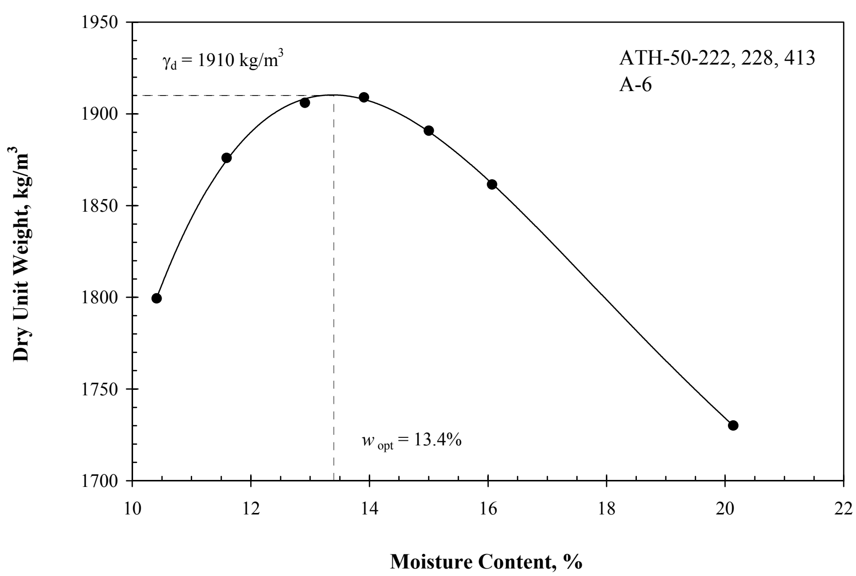

Figure A.22 Moisture Content v. Dry Unit Weight ATH-50-222, 228, 413

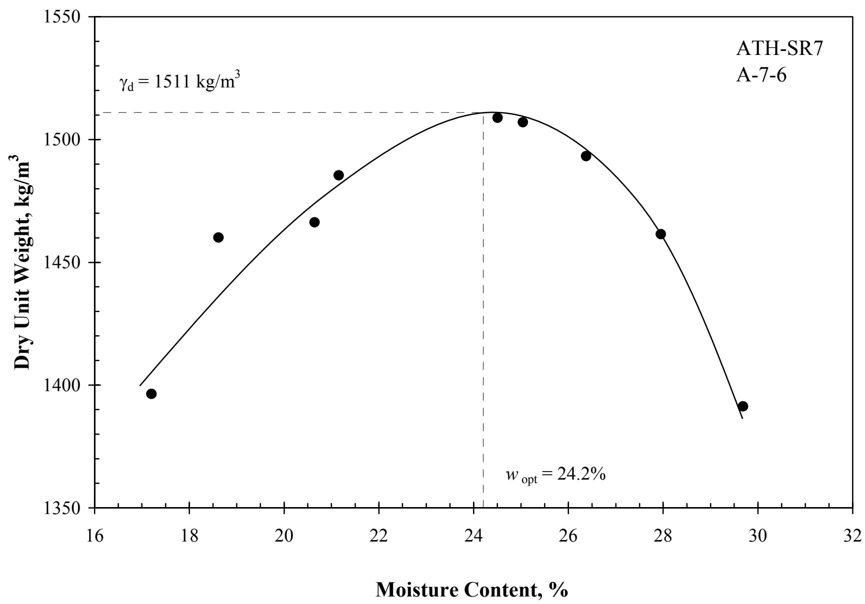

Figure A.23 Moisture Content v. Dry Unit Weight ATH-SR7

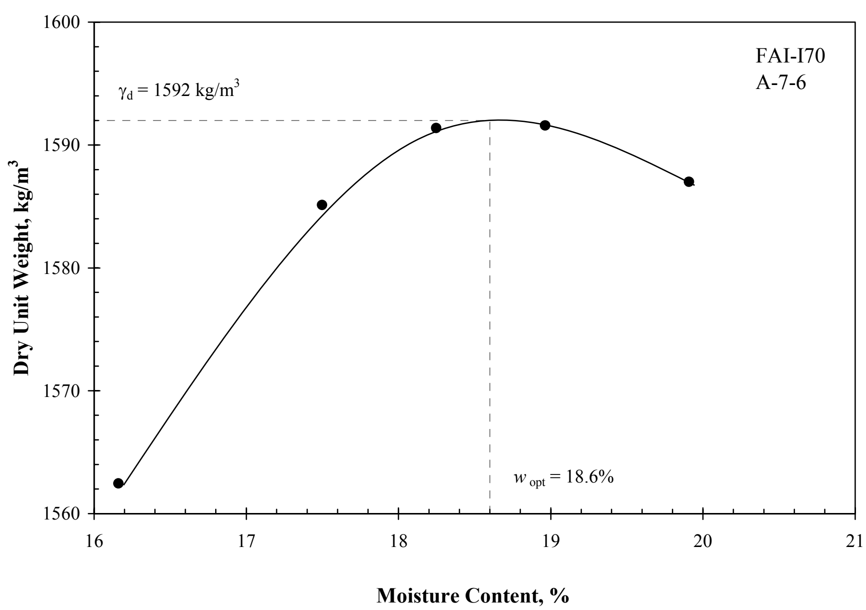

Figure A.24 Moisture Content v. Dry Unit Weight FAI-I70

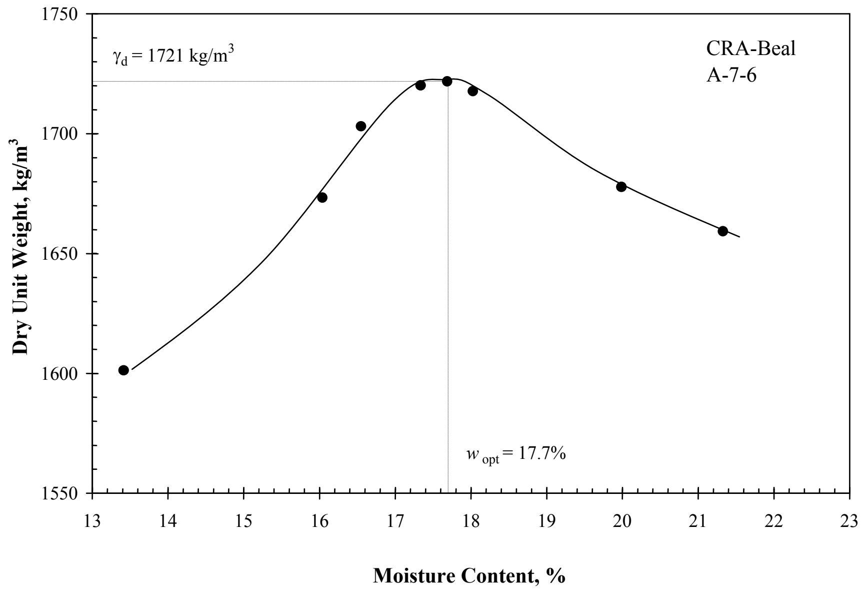

Figure A.25 Moisture Content v. Dry Unit Weight CRA-Beal

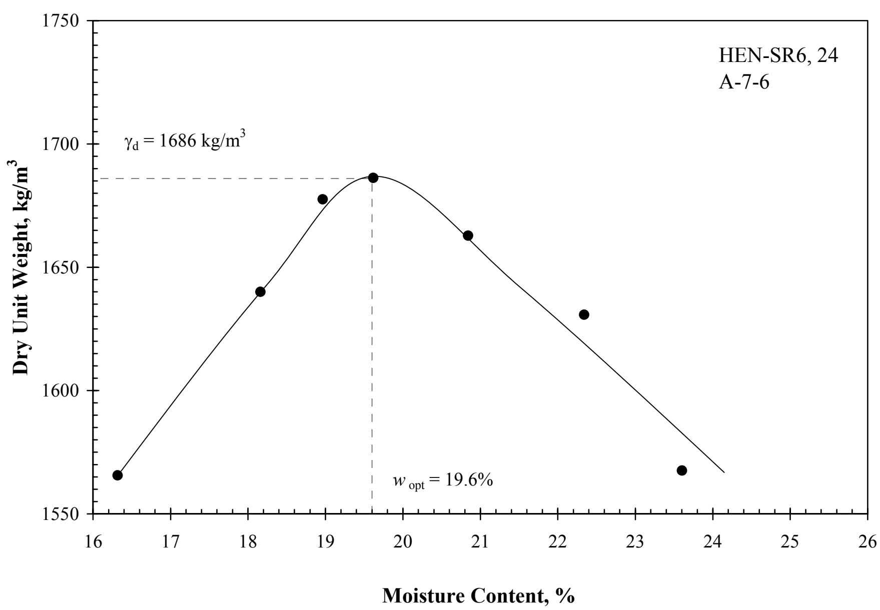

Figure A.26 Moisture Content v. Dry Unit Weight HEN-SR6, 24

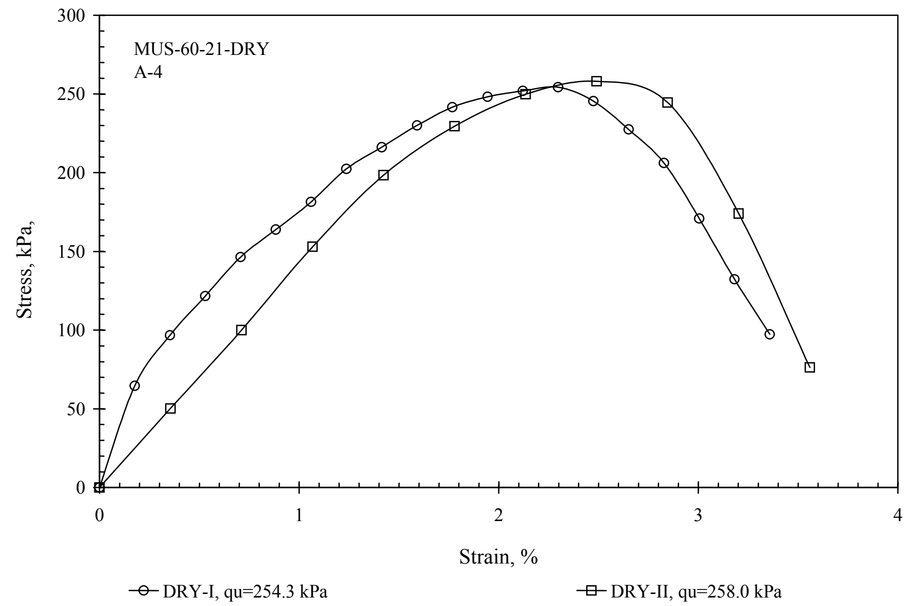

Figure A.27 Unconfined Compressive Strength MUS-60-21-DRY

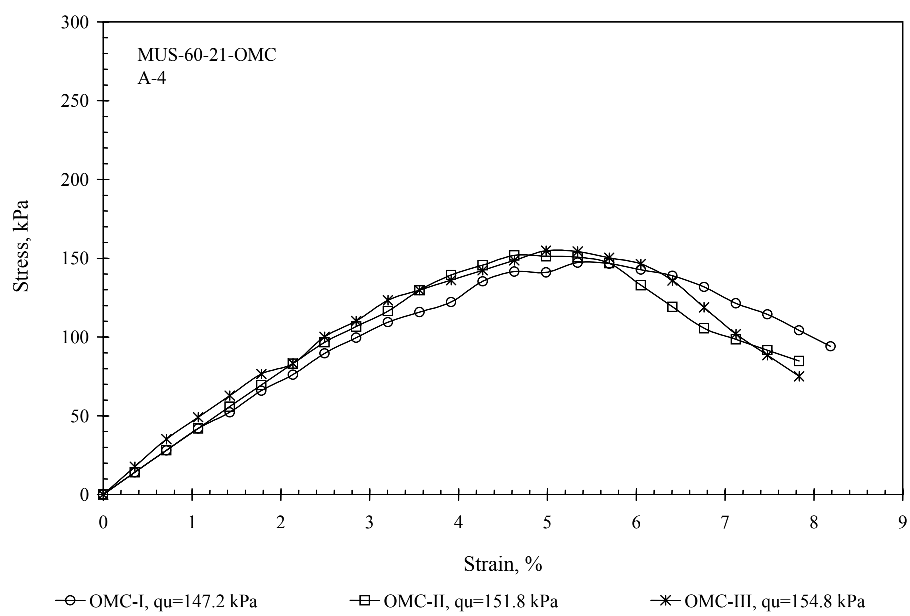

Figure A.28 Unconfined Compressive Strength MUS-60-21-OMC

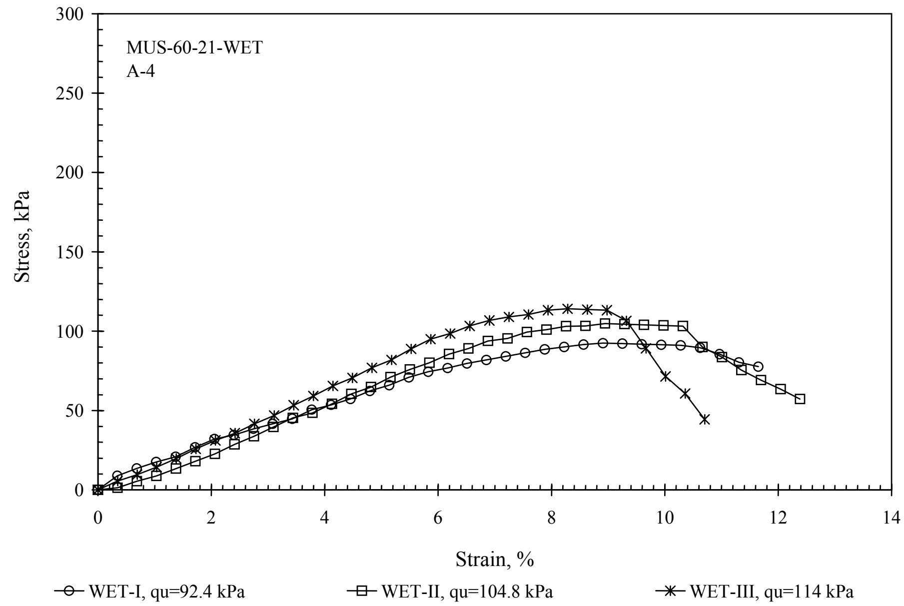

Figure A.29 Unconfined Compressive Strength MUS-60-21-WET

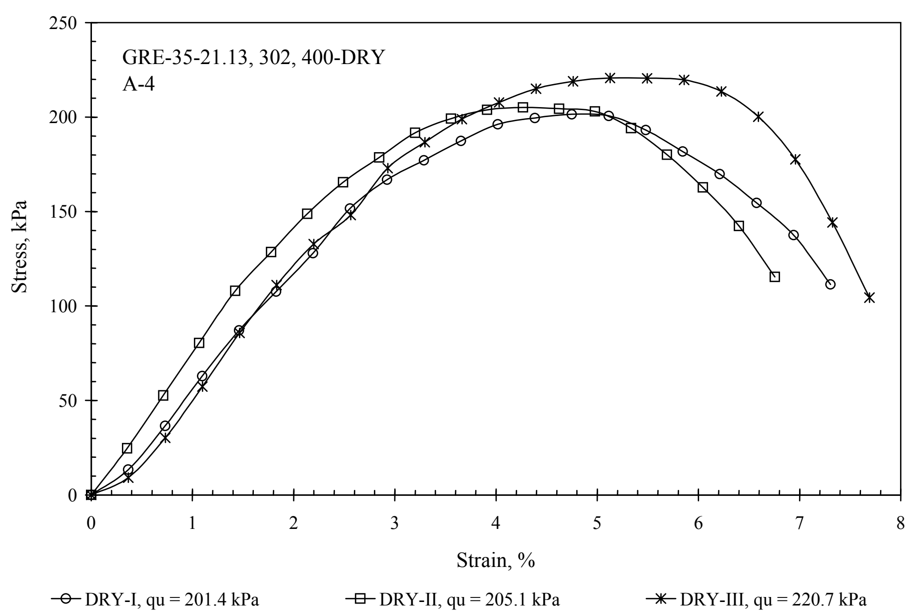

Figure A.30 Unconfined Compressive Strength GRE-35-21.13, 302, 400-DRY

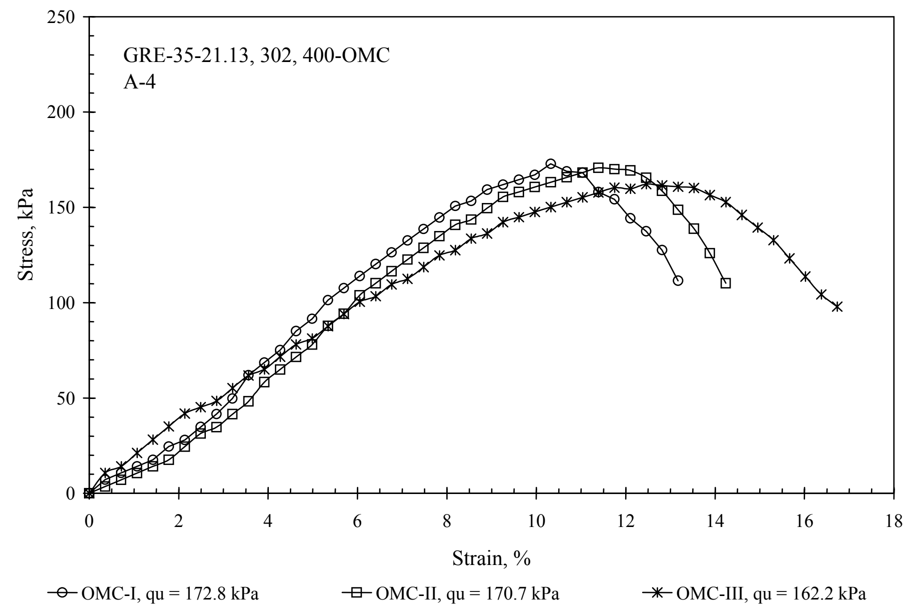

Figure A.31 Unconfined Compressive Strength GRE-35-21.13, 302, 400-OMC

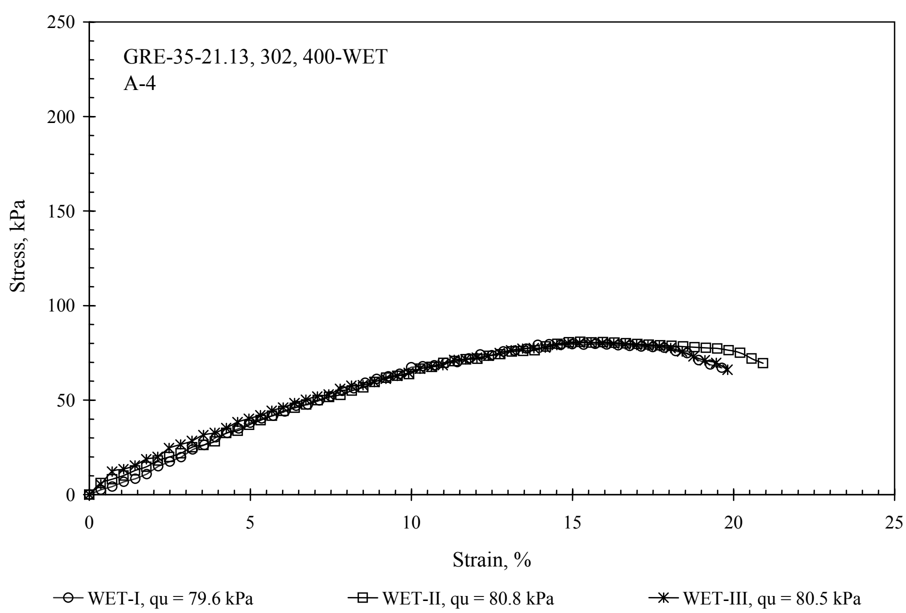

Figure A.32 Unconfined Compressive Strength GRE-35-21.13, 302, 400-WET

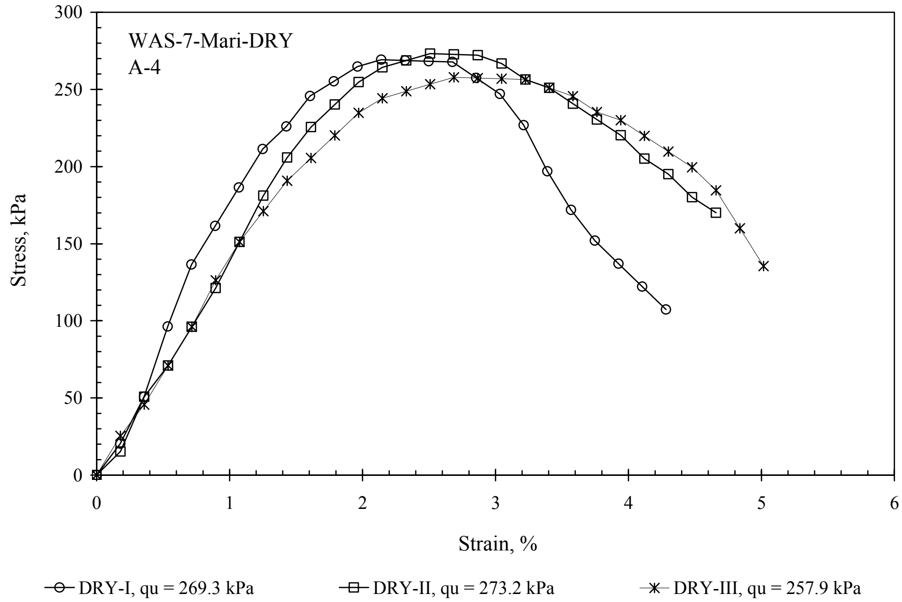

Figure A.33 Unconfined Compressive Strength WAS-7-Mari-DRY

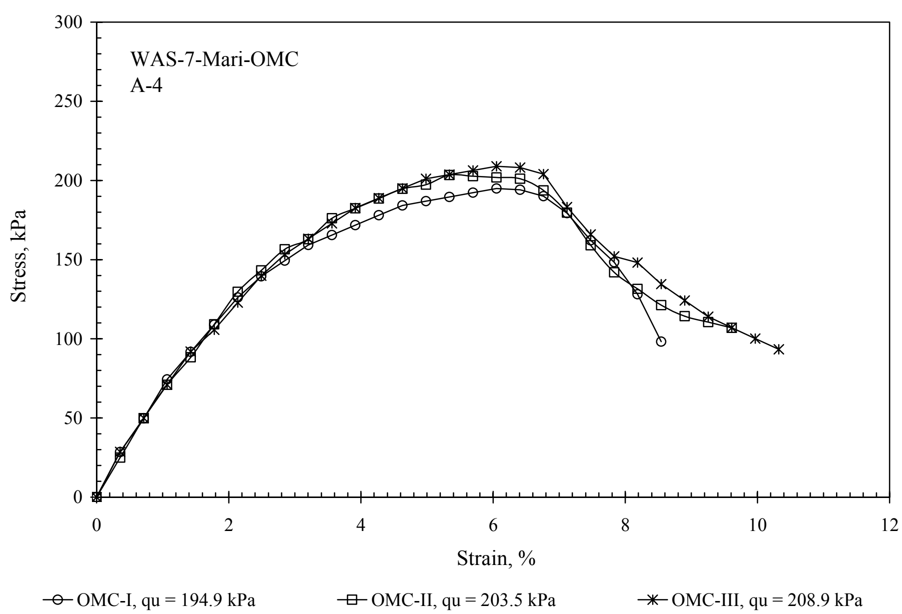

Figure A.34 Unconfined Compressive Strength WAS-7-Mari-OMC

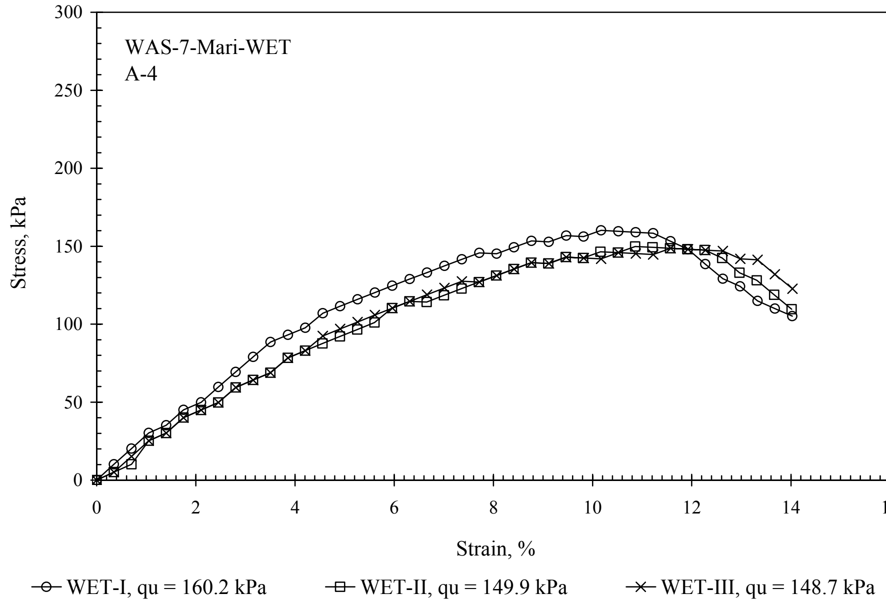

Figure A.35 Unconfined Compressive Strength WAS-7-Mari-WET

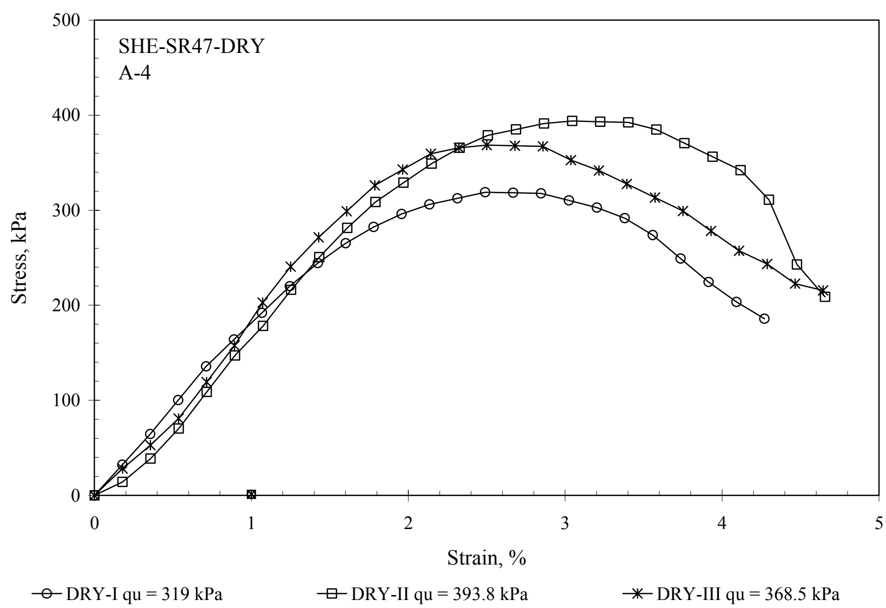

Figure A.36 Unconfined Compressive Strength SHE -SR47-DRY

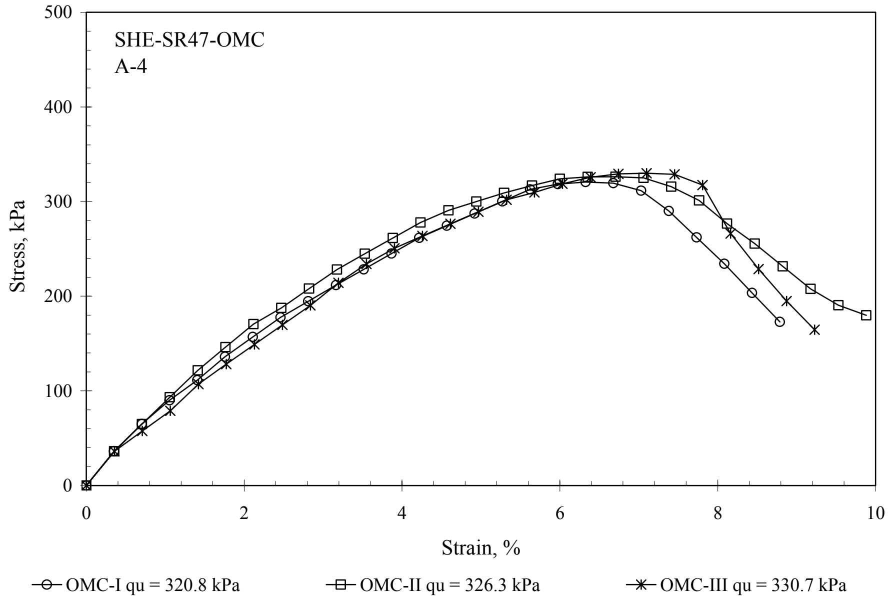

Figure A.37 Unconfined Compressive Strength SHE-SR47-OMC

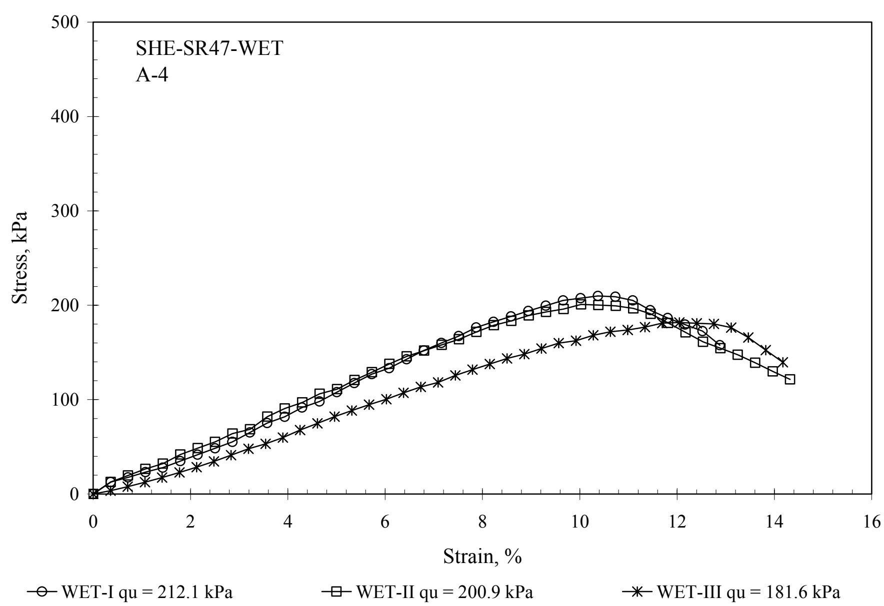

Figure A.38 Unconfined Compressive Strength SHE-SR47-WET

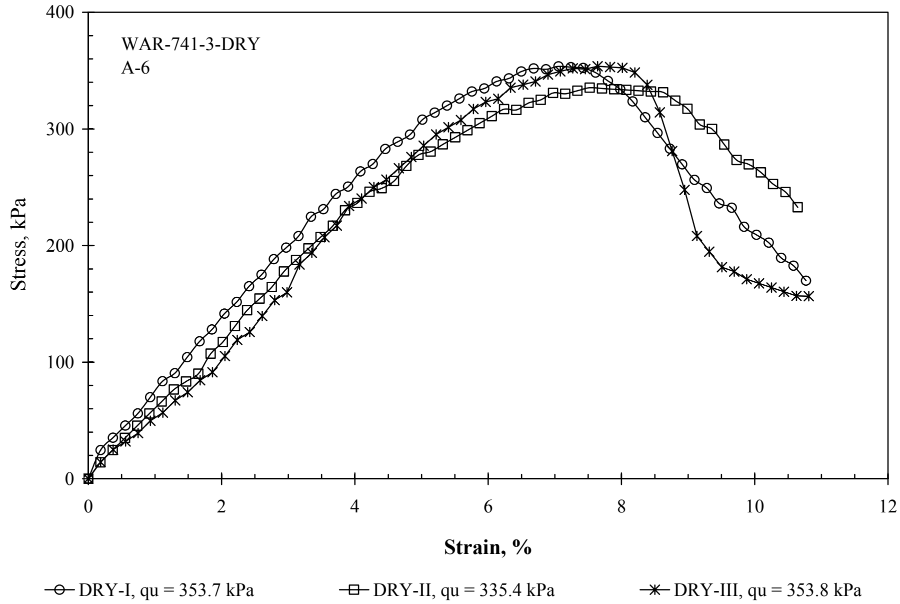

Figure A.39 Unconfined Compressive Strength WAR-741-3-DRY

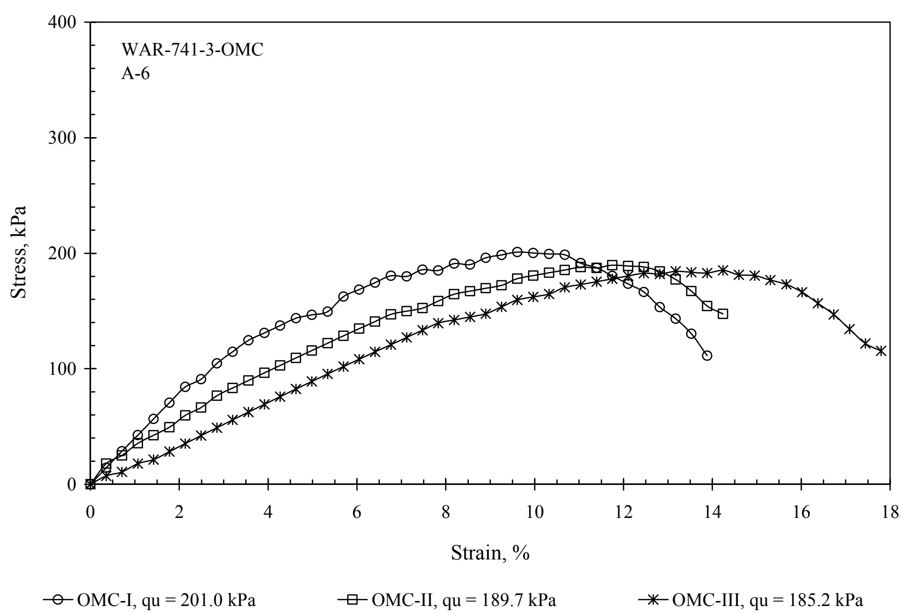

Figure A.40 Unconfined Compressive Strength WAR-741-3-OMC

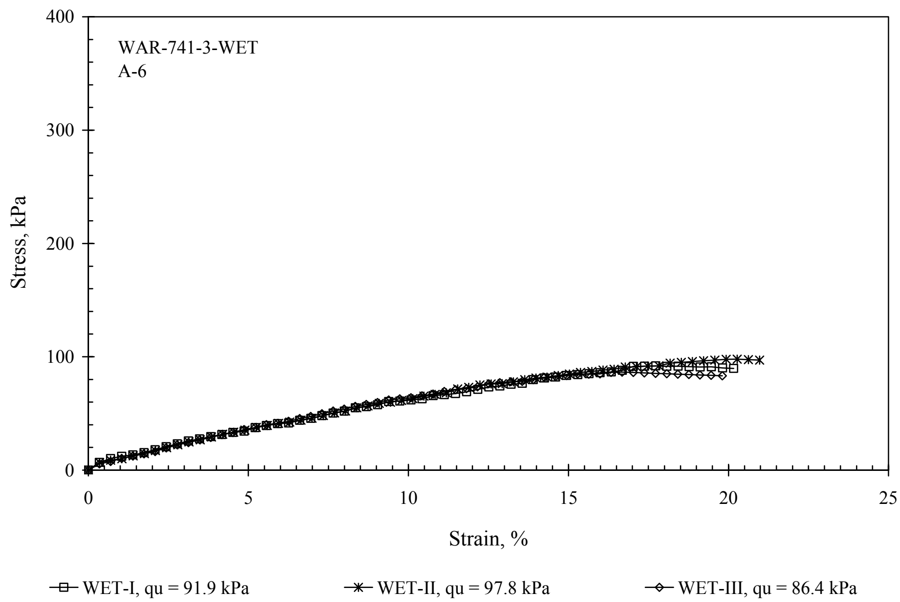

Figure A.41 Unconfined Compressive Strength WAR-741-3-WET

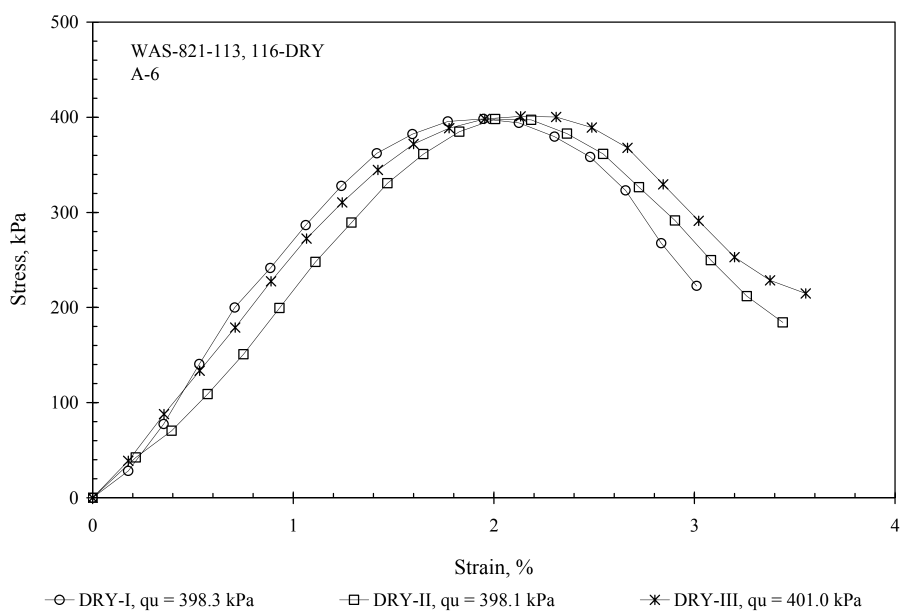

Figure A.42 Unconfined Compressive Strength test WAS-821-113, 116-DRY

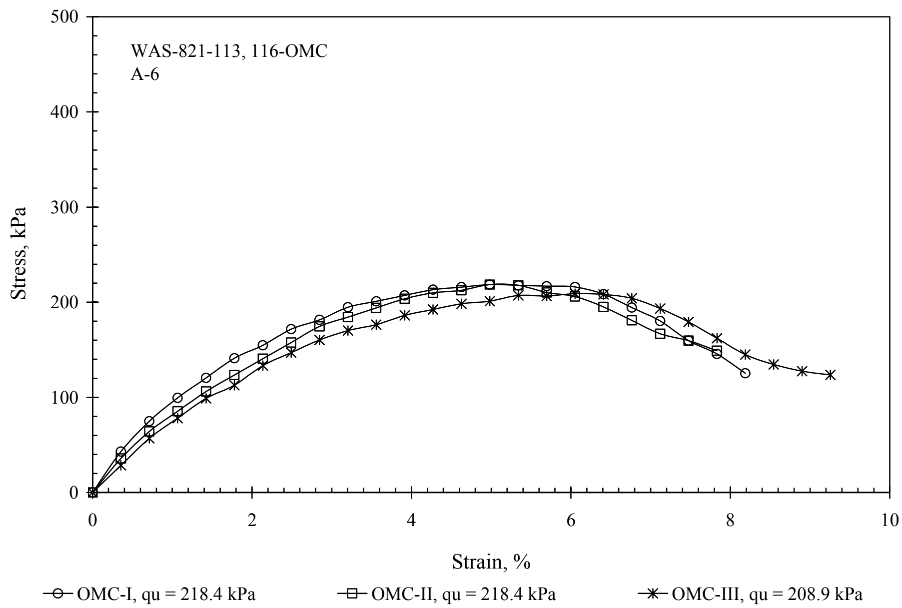

Figure A.43 Unconfined Compressive Strength WAS-821-113, 116-OMC

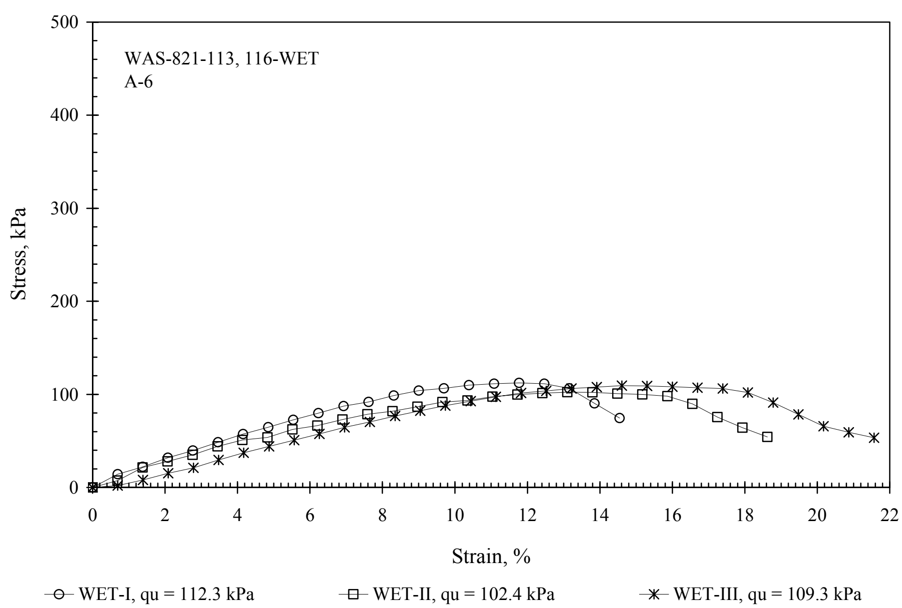

Figure A.44 Unconfined Compressive Strength WAS-821-113, 116-WET

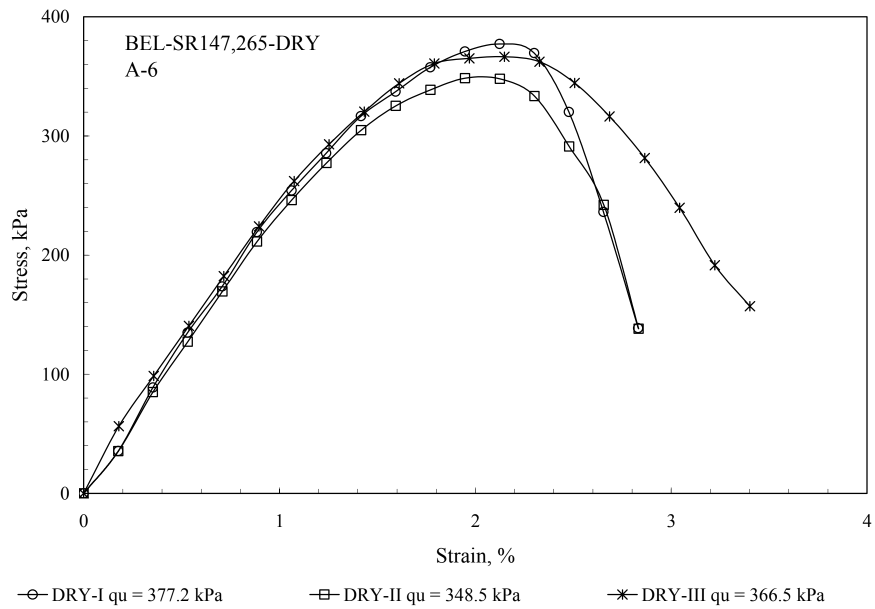

Figure A.45 Unconfined Compressive Strength BEL-SR147, 265-DRY

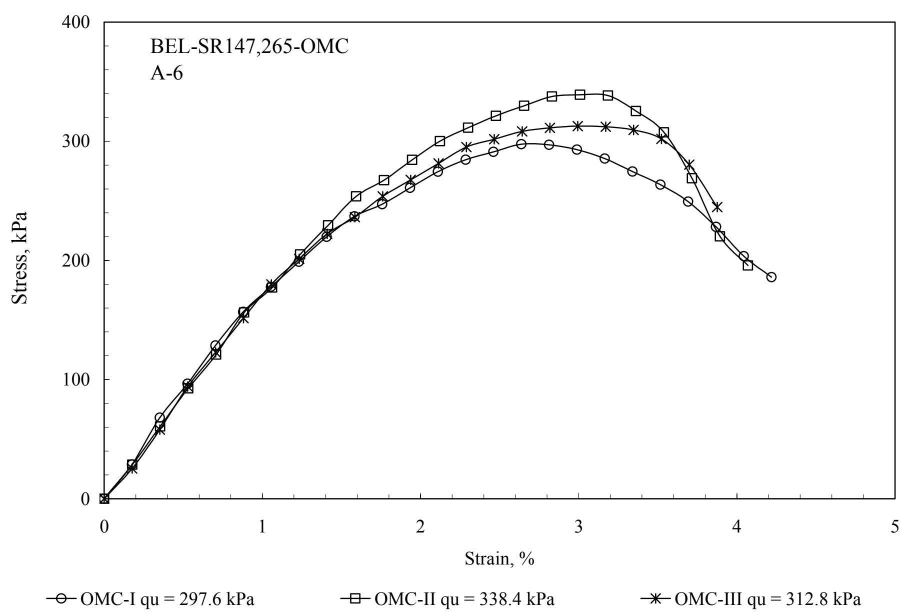

Figure A.46 Unconfined Compressive Strength BEL-SR147, 265-OMC

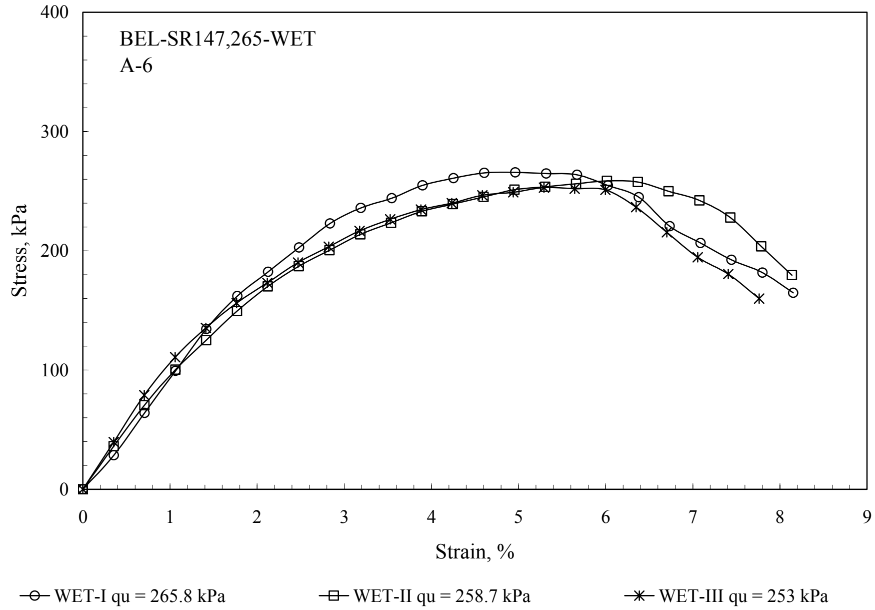

Figure A.47 Unconfined Compressive Strength BEL-SR147, 265-WET

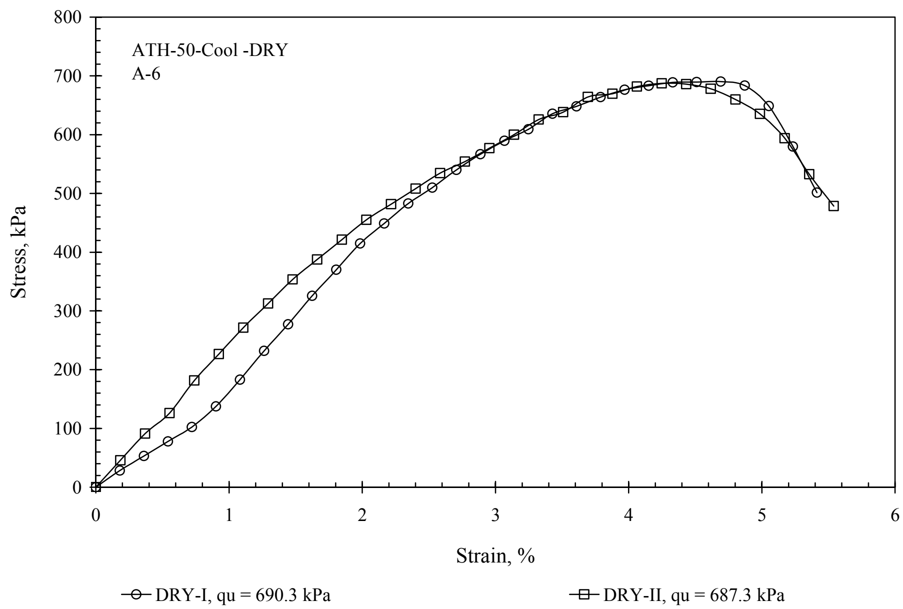

Figure A.48 Unconfined Compressive Strength ATH-50-Cool -DRY

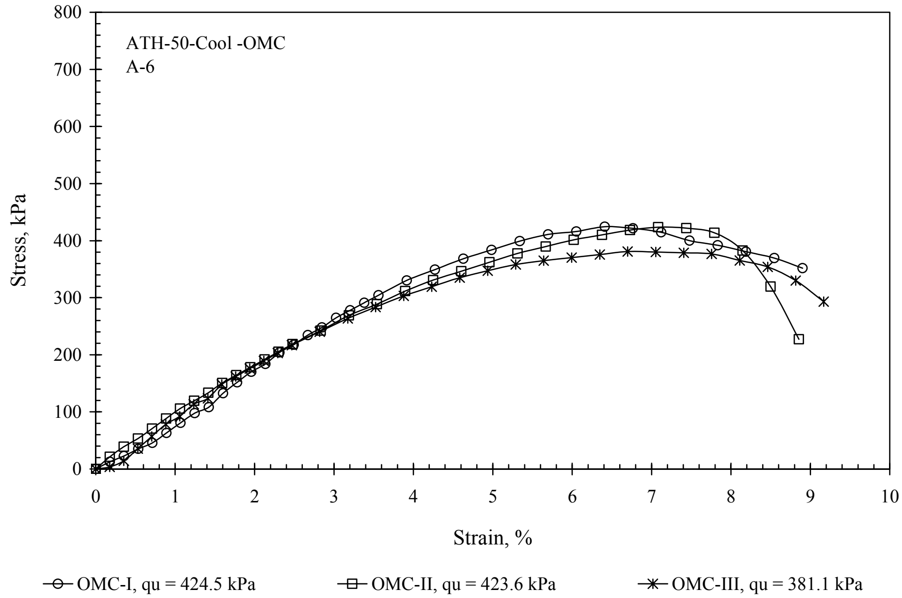

Figure A.49 Unconfined Compressive Strength ATH-50-Cool-OMC

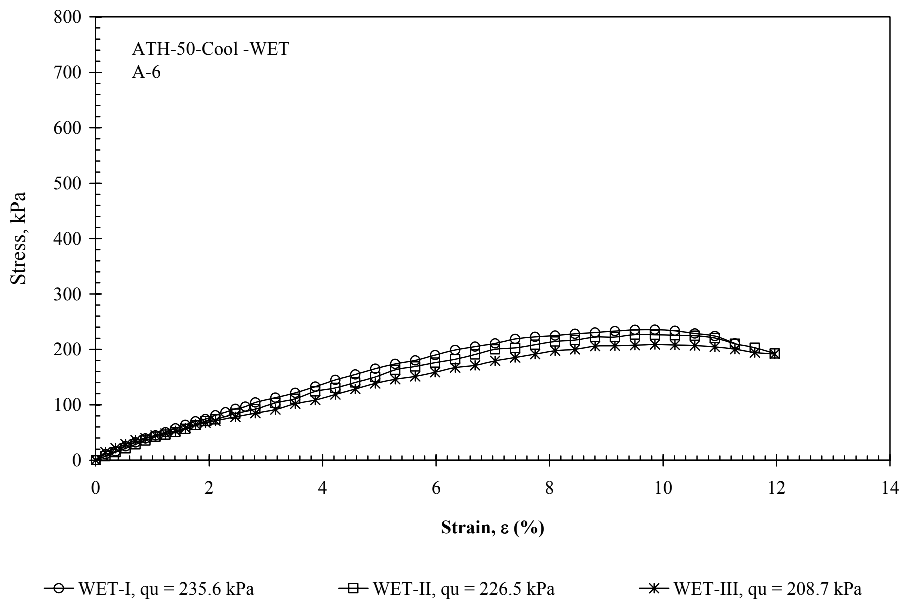

Figure A.50 Unconfined Compressive Strength ATH-50-Cool-WET

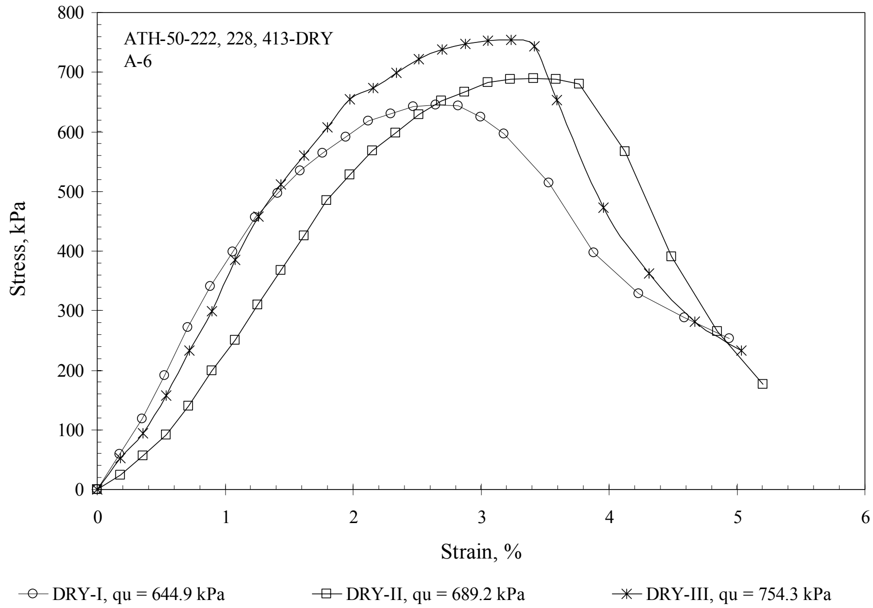

Figure A.51 Unconfined Compressive Strength ATH-50-222, 228, 413-DRY

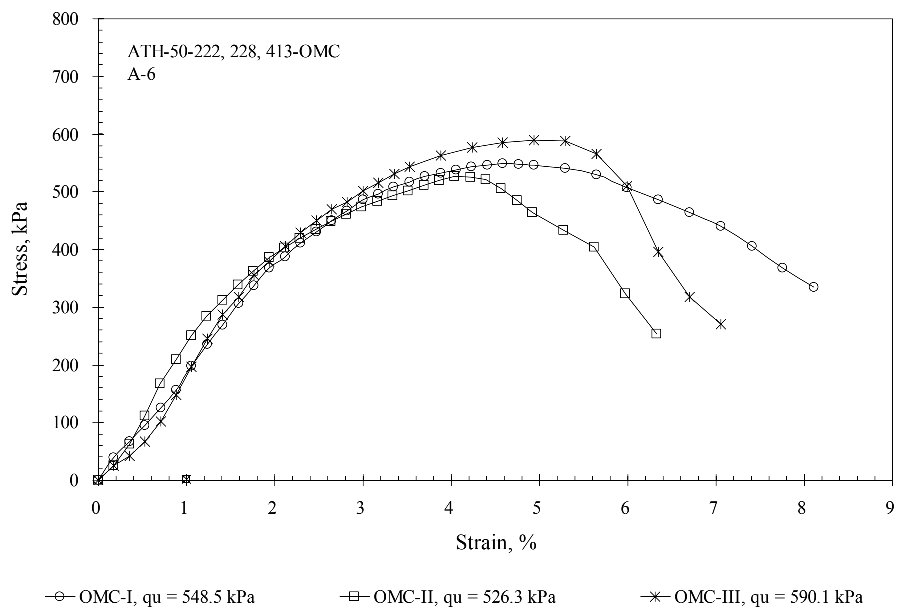

Figure A.52 Unconfined Compressive Strength ATH-50-222, 228, 413-OMC

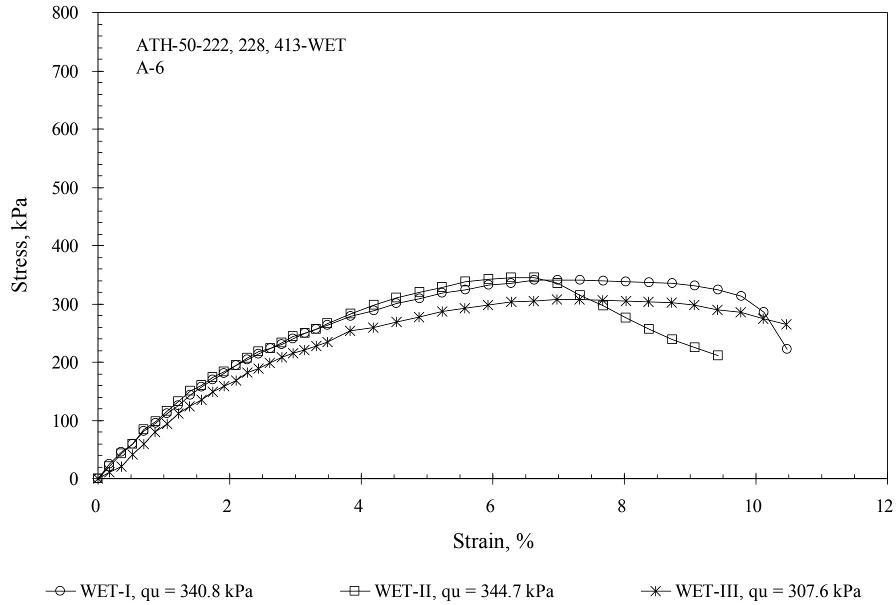

Figure A.53 Unconfined Compressive Strength ATH-50-222, 228, 413-WET

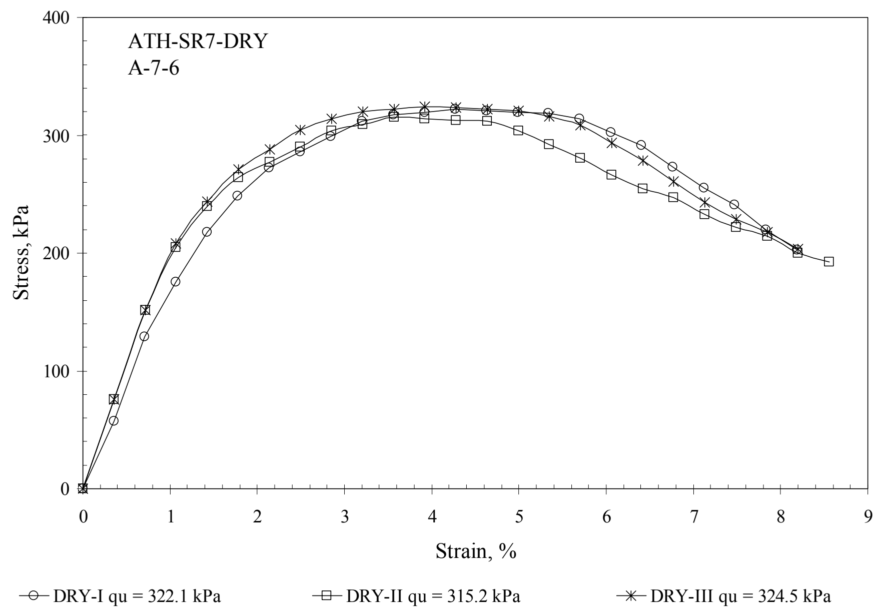

Figure A.54 Unconfined Compressive Strength ATH-SR7-DRY

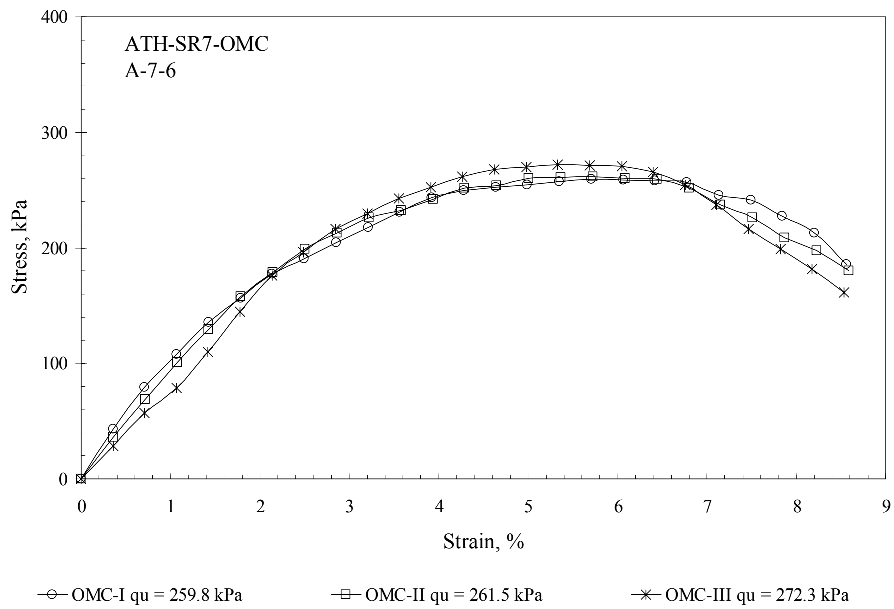

Figure A.55 Unconfined Compressive Strength ATH-SR7-OMC

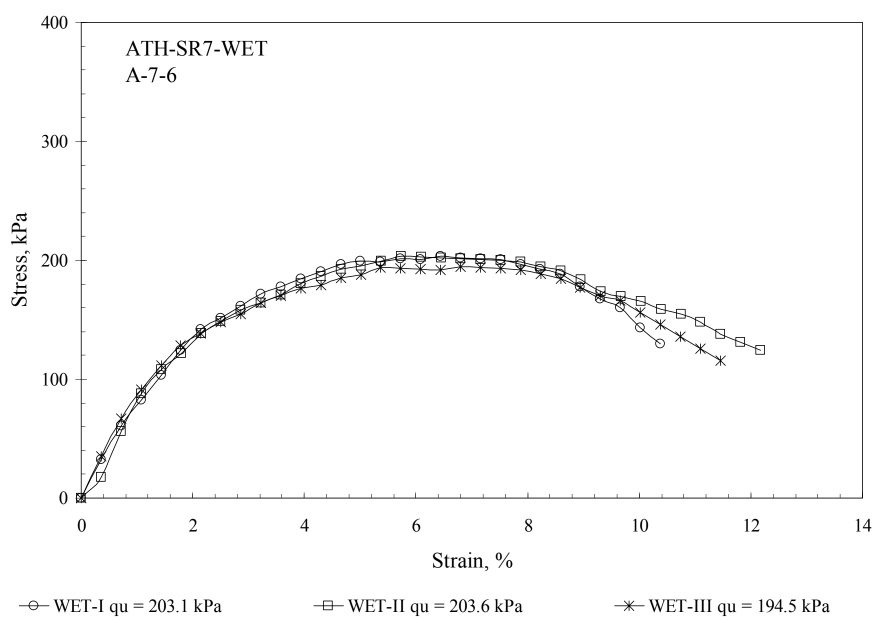

Figure A.56 Unconfined Compressive Strength ATH-SR7-WET

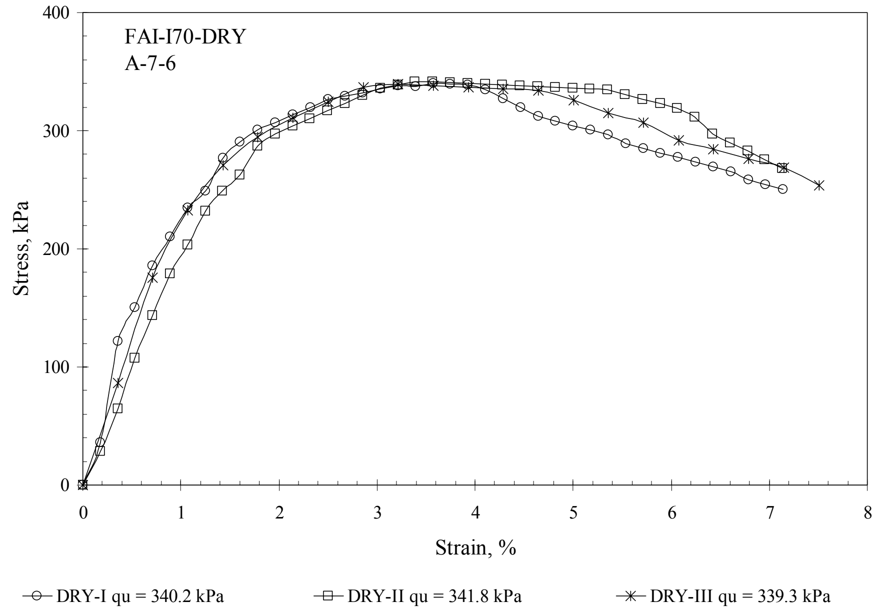

Figure A.57 Unconfined Compressive Strength FAI-I70-DRY

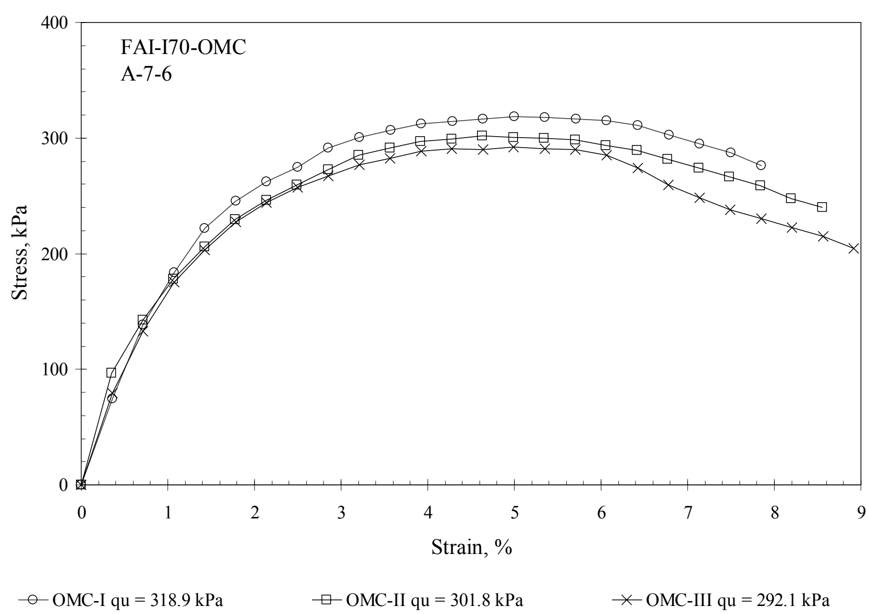

Figure A.58 Unconfined Compressive Strength FAI-I70-OMC

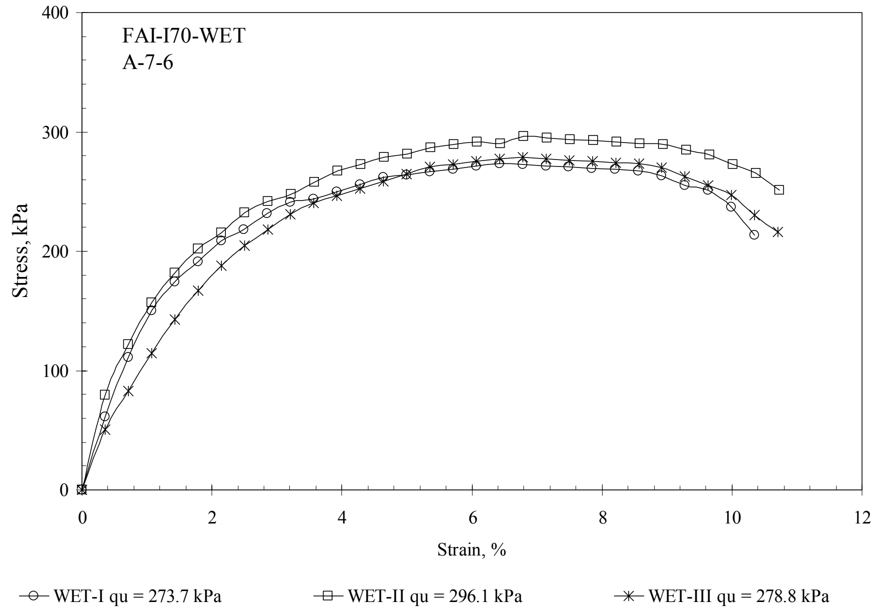

Figure A.59 Unconfined Compressive Strength FAI-I70-WET

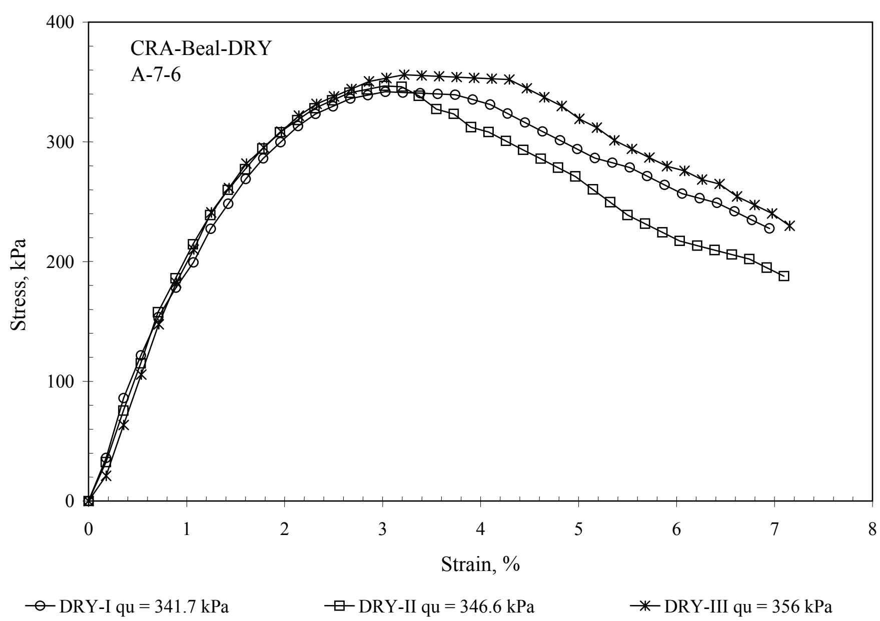

Figure A.60 Unconfined Compressive Strength CRA-Beal-DRY

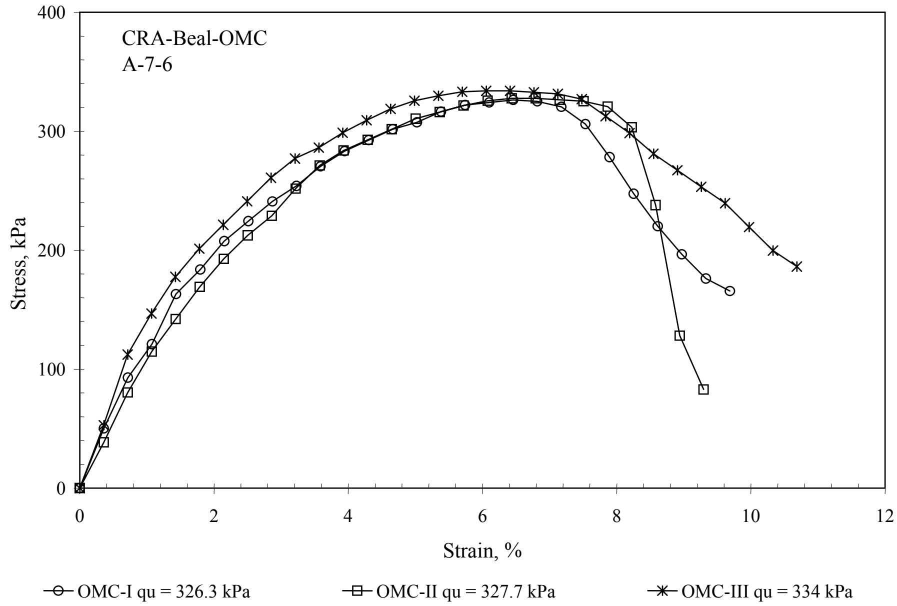

Figure A.61 Unconfined Compressive Strength CRA-Beal-OMC

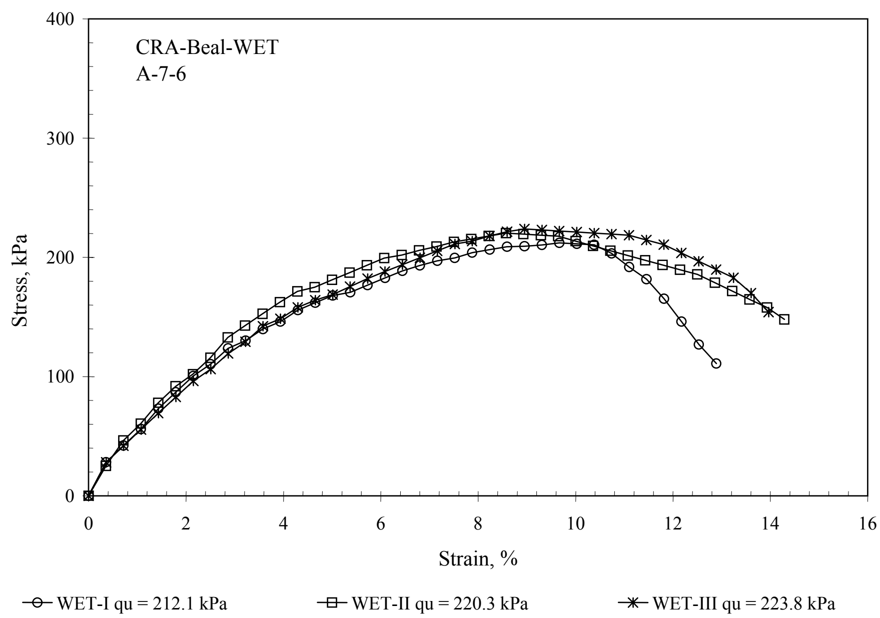

Figure A.62 Unconfined Compressive Strength CRA-Beal-WET

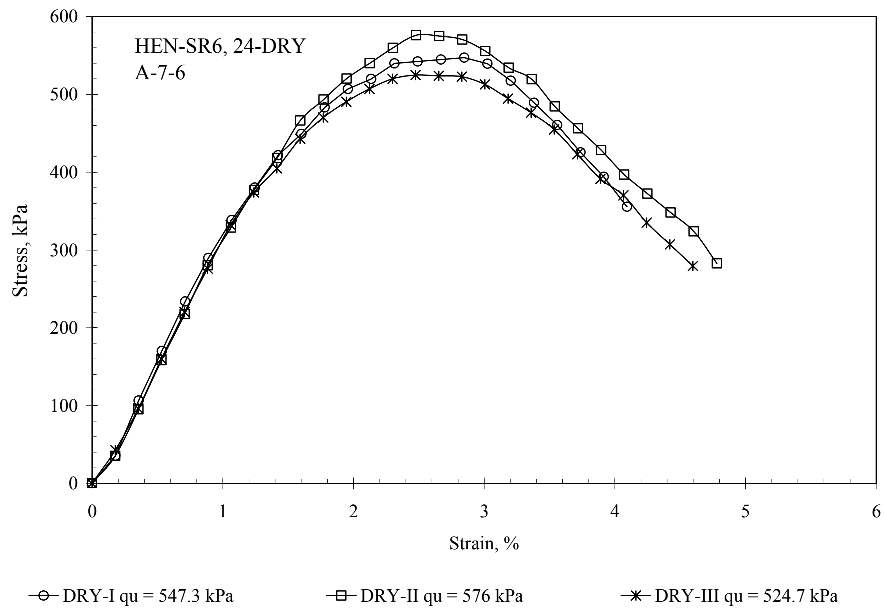

Figure A.63 Unconfined Compressive Strength HEN-SR6, 24-DRY

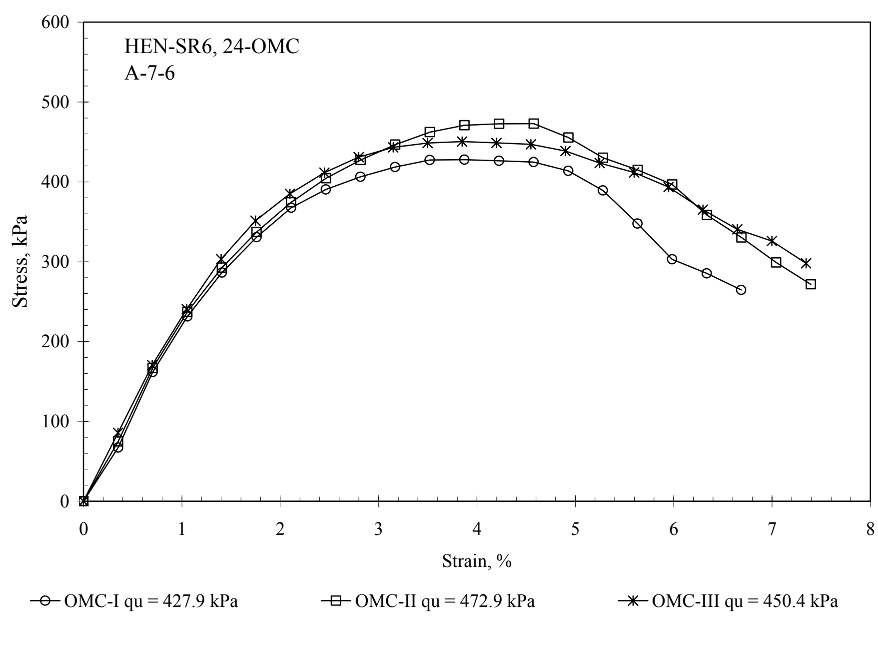

Figure A.64 Unconfined Compressive Strength HEN-SR6, 24-OMC

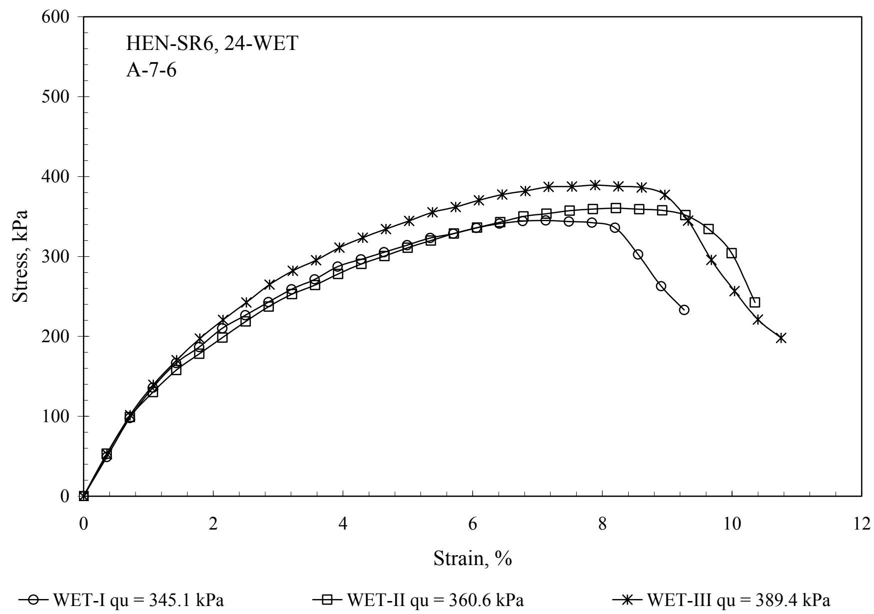

Figure A.65 Unconfined Compressive Strength HEN-SR6, 24-WET

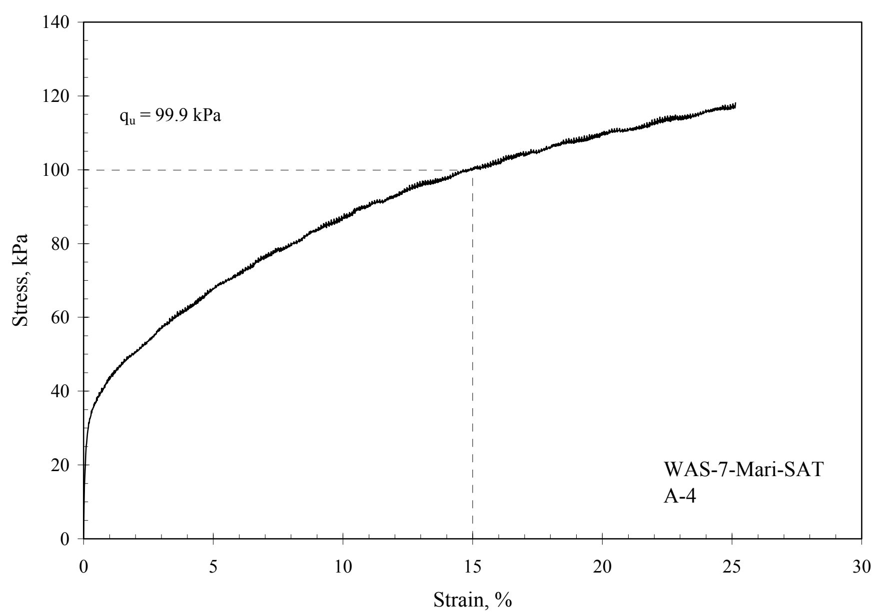

Figure A.66 Unconsolidated Undrained Strength WAS-7-Mari-SAT

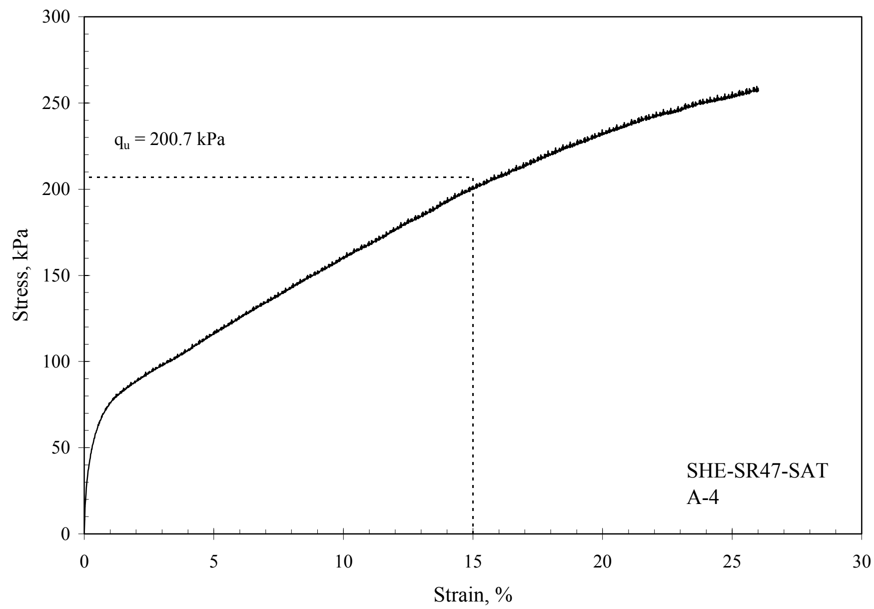

Figure A.67 Unconsolidated Undrained Strength SHE- SR47-SAT

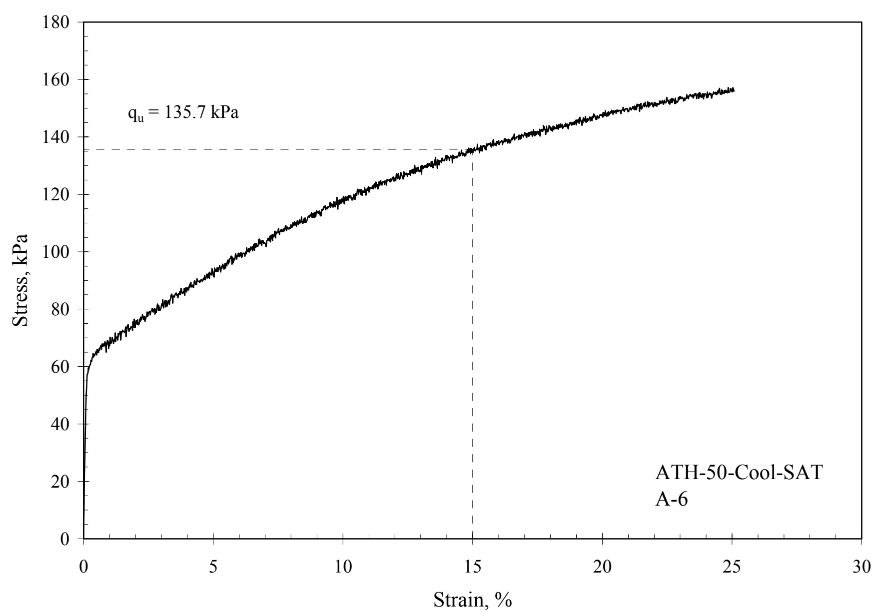

Figure A.68 Unconsolidated Undrained Strength ATH-50-Cool-SAT

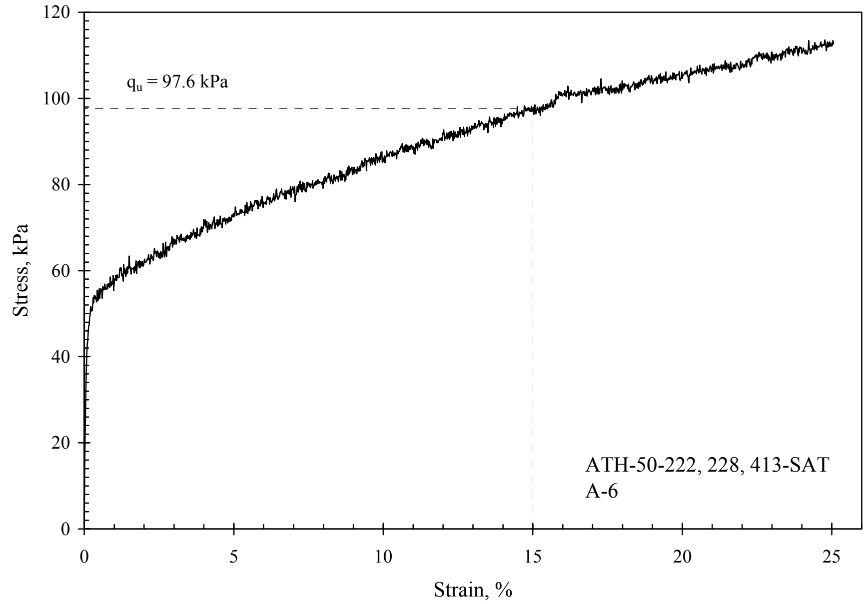

Figure A.69 Unconsolidated Undrained Strength ATH-50-222, 228, 413-SAT

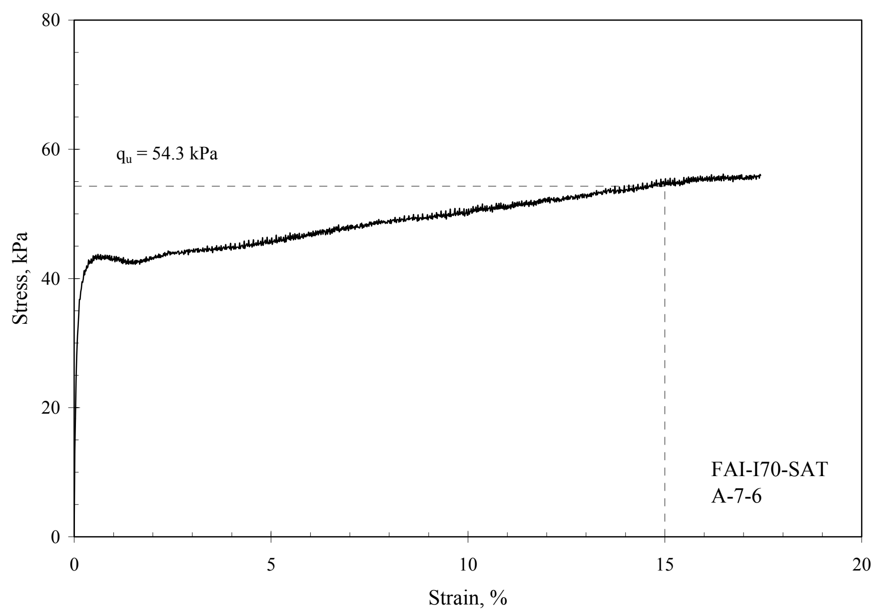

Figure A.70 Unconsolidated Undrained Strength FAI-I70-SAT

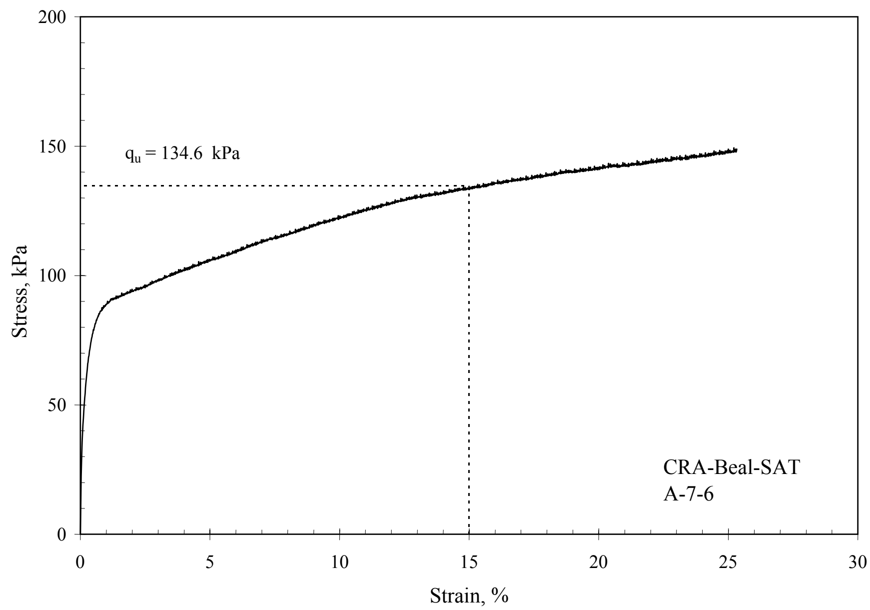

Figure A.71 Unconsolidated Undrained Strength CRA-Beal-SAT

9.2 APPENDIX B

RESILIENT MODULUS

Resilient Modulus Test for material type 2

Soil Sample: MUSK-60-21 Location: MP 21, SR-60 Tested by: D. G. Kim
Sample No.: MUSK-60-DRY Muskingum county Test Date: 5/17/1999

SPECIMEN INFORMATION
Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.98 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.27 cm
After Test Length: 15.23 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME
Initial Area: 41.62 cm^2
Initial Volume: 635.54 cm^3

SOIL PROPERTIES
Wet Density: 2038.62 kg/cm^3
Compaction Moisture Content: 11.40 %
Saturation: %
Dry Density: 1830.00 kg/cm^3
Moisture Content After Mr Testing: 11.22 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.46	0.21	15.214	0.042179	0.002477	0.000277	**55.108**	2.32
41	28	12.29	0.17	28.951	0.086261	0.001654	0.000566	**51.199**	1.04
41	41	17.89	0.17	42.151	0.129685	0.002357	0.000850	**49.578**	0.60
41	55	23.61	0.28	55.625	0.176124	0.003520	0.001155	**48.171**	0.39
41	69	29.37	0.22	69.206	0.219766	0.002831	0.001441	**48.035**	0.85
21	14	6.02	0.11	14.172	0.042780	0.001141	0.000281	**50.546**	1.28
21	28	11.97	0.12	28.207	0.092126	0.001718	0.000604	**46.705**	0.73
21	41	18.81	0.14	44.316	0.151311	0.001430	0.000992	**44.670**	0.46
21	55	23.44	0.17	55.216	0.189443	0.001275	0.001242	**44.455**	0.58
21	69	29.18	0.12	68.742	0.228194	0.001760	0.001496	**45.945**	0.29
0	14	6.25	0.10	14.720	0.060531	0.001730	0.000397	**37.109**	0.98
0	28	12.06	0.08	28.417	0.118522	0.001098	0.000777	**36.569**	0.34
0	41	18.48	0.10	43.549	0.178914	0.002066	0.001173	**37.126**	0.41
0	55	23.49	0.19	55.337	0.220756	0.001651	0.001447	**38.284**	0.20
0	69	29.30	0.14	69.041	0.262928	0.003508	0.001724	**40.051**	0.41

Table B.1 M_r Data Sheet for MUS-60-21-DRY

Resilient Modulus Test for material type 2

Soil Sample: MUSK-60-21 Location: MP 21, SR-60 Tested by: D. G. Kim
Sample No.: MUSK-60-OMC Muskingum county Test Date: 5/18/1999

SPECIMEN INFORMATION
Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.96 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.25 cm
After Test Length: 15.05 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME
Initial Area: 41.62 cm^2
Initial Volume: 634.57 cm^3

SOIL PROPERTIES
Wet Density: 2127.84 kg/cm^3
Compaction Moisture Content: 14.40 %
Saturation: %
Dry Density: 1860.00 kg/cm^3
Moisture Content After Mr Testing: 13.55 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.92	0.12	13.954	0.049610	0.001430	0.000328	**42.623**	0.98
41	28	12.10	0.10	28.503	0.112852	0.002115	0.000745	**38.268**	0.70
41	41	18.11	0.13	42.679	0.188018	0.001569	0.001241	**34.385**	0.33
41	55	23.75	0.14	55.948	0.249712	0.001282	0.001649	**33.938**	0.10
41	69	29.29	0.19	69.020	0.309565	0.003237	0.002044	**33.776**	0.47
21	14	6.21	0.09	14.641	0.080744	0.001299	0.000533	**27.468**	0.31
21	28	12.12	0.11	28.544	0.181313	0.001831	0.001197	**23.848**	0.26
21	41	18.19	0.19	42.853	0.268450	0.001654	0.001772	**24.182**	0.35
21	55	23.70	0.15	55.844	0.327108	0.002066	0.002159	**25.860**	0.13
21	69	29.23	0.18	68.872	0.370840	0.002070	0.002448	**28.132**	0.16
0	14	5.91	0.05	13.933	0.093264	0.001285	0.000616	**22.632**	0.31
0	28	11.84	0.13	27.892	0.220015	0.001192	0.001452	**19.203**	0.20
0	41	17.58	0.13	41.428	0.310322	0.001831	0.002049	**20.222**	0.13
0	55	23.43	0.23	55.211	0.371582	0.002074	0.002453	**22.506**	0.13
0	69	29.34	0.17	69.133	0.408661	0.004239	0.002698	**25.626**	0.18

Table B.2 M_r Data Sheet for MUS-60-21-OMC

Resilient Modulus Test for material type 2

Soil Sample: MUSK-60-21 | Location: MP 21, SR-60 | Tested by: D. G. Kim
Sample No.: MUSK-60-WET | Muskingum county | Test Date: 5/18/1999

SPECIMEN INFORMATION

Specific Gravity:

Diameter Top: 7.28 cm

Middle: 7.28 cm

Bottom: 7.28 cm

Average: 7.28 cm

Membrane Thickness: cm

Net Diameter : 7.11 cm

Ht of Spec.+Cap+Base: 24.69 cm

Ht of Cap+Base: 9.71 cm

Initial Length: 14.97 cm

After Test Length: 13.45 cm

Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.62 cm^2

Initial Volume: 623.26 cm^3

SOIL PROPERTIES

Wet Density: 2118.48 kg/cm^3

Compaction Moisture Content: 16.40 %

Saturation: %

Dry Density: 1820.00 kg/cm^3

Moisture Content After Mr Testing: 15.31 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.85	0.14	13.792	0.231914	0.004079	0.001632	**8.451**	0.12
41	28	12.20	0.16	28.753	0.386135	0.002024	0.002717	**10.582**	0.09
41	41	17.91	0.10	42.194	0.502304	0.006574	0.003535	**11.939**	0.12
41	55	23.09	0.10	54.410	0.581000	0.007403	0.004088	**13.310**	0.12
41	69	29.18	0.42	68.757	0.650377	0.009677	0.004577	**15.025**	0.15
21	14	5.89	0.10	13.876	0.205593	0.001491	0.001447	**9.592**	0.17
21	28	11.95	0.12	28.157	0.381165	0.005125	0.002682	**10.498**	0.04
21	41	17.45	0.16	41.116	0.484396	0.004462	0.003409	**12.063**	0.12
21	55	23.45	0.33	55.255	0.545486	0.011226	0.003838	**14.397**	0.16
21	69	29.46	0.51	69.400	0.597789	0.007837	0.004206	**16.499**	0.28
0	14	6.12	0.07	14.410	0.189764	0.001312	0.001335	**10.792**	0.11
0	28	11.74	0.09	27.659	0.360727	0.001950	0.002538	**10.896**	0.06
0	41	18.74	0.21	44.143	0.489636	0.005142	0.003445	**12.812**	0.07
0	55	23.51	0.13	55.395	0.534537	0.003204	0.003761	**14.728**	0.17
0	69								

Table B.3 M_r Data Sheet for MUS-60-21-WET

Resilient Modulus Test for material type 2

Soil Sample: GREEN-35-21.13, 302, ,400 | Location: MP 21.13, PS 400+00, and PS 302+00, US-35, | Tested by: D. G. Kim
Sample No.: GREEN-35-DRY | Greene county | Test Date: 5/13/1999

SPECIMEN INFORMATION

Specific Gravity:

Diameter Top: 7.28 cm

Middle: 7.28 cm

Bottom: 7.28 cm

Average: 7.28 cm

Membrane Thickness: cm

Net Diameter : 7.11 cm

Ht of Spec.+Cap+Base: 24.84 cm

Ht of Cap+Base: 9.71 cm

Initial Length: 15.12 cm

After Test Length: 15.08 cm

Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.62 cm^2

Initial Volume: 629.44 cm^3

SOIL PROPERTIES

Wet Density: 2134.86 kg/cm^3

Compaction Moisture Content: 10.30 %

Saturation: %

Dry Density: 1935.50 kg/cm^3

Moisture Content After Mr Testing: 10.30 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.99	0.05	14.113	0.022327	0.000000	0.000148	**95.442**	0.82
41	28	11.79	0.13	27.786	0.049606	0.000000	0.000329	**84.571**	0.94
41	41	18.11	0.19	42.674	0.079873	0.002083	0.000529	**80.716**	2.46
41	55	23.53	0.27	55.430	0.106667	0.002032	0.000706	**78.470**	0.83
41	69	30.43	0.13	71.691	0.136921	0.001113	0.000907	**79.058**	0.43
21	14	6.38	0.08	15.026	0.024816	0.000000	0.000164	**91.420**	1.08
21	28	12.54	0.09	29.545	0.055580	0.001363	0.000368	**80.290**	1.51
21	41	18.05	0.12	42.535	0.085832	0.001349	0.000568	**74.835**	1.04
21	55	23.94	0.13	56.396	0.118562	0.002070	0.000785	**71.835**	1.17
21	69	30.23	0.21	71.218	0.153797	0.002489	0.001019	**69.936**	1.51
0	14	5.89	0.08	13.880	0.033726	0.001363	0.000223	**62.203**	2.06
0	28	12.13	0.08	28.571	0.083731	0.001245	0.000555	**51.529**	0.89
0	41	18.60	0.04	43.831	0.131968	0.002083	0.000874	**50.158**	0.90
0	55	23.15	0.19	54.542	0.166192	0.001760	0.001101	**49.558**	0.77
0	69	29.57	0.17	69.679	0.211328	0.001108	0.001400	**49.785**	0.47

Table B.4 M_r Data Sheet for GRE-35-21.13, 302, 400-DRY

Resilient Modulus Test for material type 2

Soil Sample: GREEN-35-21.13, 302, ,400 Location: MP 21.13, PS 400+00, and PS 302+00, US-35, Greene county Tested by: D. G. Kim
Sample No.: GREEN-35-OMC Test Date: 5/14/1999

SPECIMEN INFORMATION			SOIL SPECIMEN VOLUME		
Specific Gravity:			Initial Area:	41.62	cm^2
Diameter Top:	7.28	cm	Initial Volume:	633.60	cm^3
Middle:	7.28	cm			
Bottom:	7.28	cm	SOIL PROPERTIES		
Average:	7.28	cm	Wet Density:	2223.09	kg/cm^3
Membrane Thickness:		cm	Compaction Moisture Content:	12.30	%
Net Diameter :	7.11	cm	Saturation:		%
Ht of Spec.+Cap+Base:	24.94	cm	Dry Density:	1979.60	kg/cm^3
Ht of Cap+Base:	9.71	cm	Moisture Content After Mr Testing:	11.66	%
Initial Length:	15.22	cm			
After Test Length:	15.14	cm			
Inside Diameter of Mold:	7.28	cm	COMMENTS:		

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.62	0.14	15.604	0.032978	0.001466	0.000217	**71.879**	1.73
41	28	11.75	0.12	27.690	0.062997	0.001363	0.000415	**66.741**	0.92
41	41	18.37	0.15	43.270	0.102946	0.001363	0.000678	**63.965**	0.36
41	55	23.50	0.19	55.364	0.135179	0.001437	0.000890	**62.181**	0.93
41	69	29.78	0.22	70.173	0.176111	0.002022	0.001160	**60.494**	0.74
21	14	6.10	0.12	14.364	0.037211	0.000000	0.000245	**58.600**	1.18
21	28	11.85	0.07	27.909	0.078379	0.001363	0.000516	**54.067**	0.90
21	41	18.41	0.08	43.383	0.134452	0.001102	0.000886	**48.984**	0.36
21	55	23.88	0.12	56.259	0.177119	0.001363	0.001167	**48.222**	0.50
21	69	29.80	0.24	70.220	0.221386	0.001236	0.001458	**48.152**	0.53
0	14	5.88	0.04	13.843	0.039285	0.001016	0.000259	**53.517**	1.09
0	28	12.20	0.07	28.736	0.099212	0.000000	0.000654	**43.969**	0.26
0	41	18.81	0.13	44.312	0.172131	0.002826	0.001134	**39.086**	0.53
0	55	23.43	0.13	55.192	0.213330	0.001566	0.001405	**39.276**	0.14
0	69	29.26	0.22	68.948	0.268392	0.002083	0.001768	**39.000**	0.41

Table B.5 M_r Data Sheet for GRE-35-21.13, 302, 400-OMC

Resilient Modulus Test for material type 2

Soil Sample: GREEN-35-21.13, 302, ,400 Location: MP 21.13, PS 400+00, and PS 302+00, US-35, Greene county Tested by: D. G. Kim
Sample No.: GREEN-35-WET Test Date: 5/14/1999

SPECIMEN INFORMATION			SOIL SPECIMEN VOLUME		
Specific Gravity:			Initial Area:	41.62	cm^2
Diameter Top:	7.28	cm	Initial Volume:	627.08	cm^3
Middle:	7.28	cm			
Bottom:	7.28	cm	SOIL PROPERTIES		
Average:	7.28	cm	Wet Density:	2184.27	kg/cm^3
Membrane Thickness:		cm	Compaction Moisture Content:	14.30	%
Net Diameter :	7.11	cm	Saturation:		%
Ht of Spec.+Cap+Base:	24.78	cm	Dry Density:	1911.00	kg/cm^3
Ht of Cap+Base:	9.71	cm	Moisture Content After Mr Testing:	14.03	%
Initial Length:	15.07	cm			
After Test Length:	14.48	cm			
Inside Diameter of Mold:	7.28	cm	COMMENTS:		

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.01	0.06	14.165	0.076911	0.000000	0.000521	**27.211**	0.25
41	28	12.01	0.12	28.288	0.167173	0.002214	0.001132	**25.002**	0.26
41	41	18.15	0.12	42.758	0.319972	0.002477	0.002166	**19.744**	0.27
41	55	23.42	0.24	55.169	0.422307	0.001249	0.002858	**19.300**	0.17
41	69	29.33	0.03	69.103	0.498074	0.006180	0.003371	**20.500**	0.24
21	14	5.90	0.02	13.897	0.116980	0.001014	0.000792	**17.552**	0.11
21	28	11.99	0.09	28.255	0.276306	0.001363	0.001870	**15.108**	0.13
21	41	17.58	0.11	41.425	0.383474	0.004830	0.002596	**15.961**	0.18
21	55	23.63	0.22	55.674	0.465831	0.003243	0.003153	**17.657**	0.06
21	69	29.31	0.16	69.059	0.527717	0.005110	0.003572	**19.336**	0.24
0	14	5.83	0.03	13.735	0.122602	0.001950	0.000830	**16.555**	0.29
0	28	12.45	0.08	29.335	0.291880	0.001285	0.001976	**14.849**	0.10
0	41	18.18	0.19	42.843	0.408673	0.005111	0.002766	**15.489**	0.09
0	55	23.43	0.06	55.200	0.465333	0.003329	0.003150	**17.527**	0.15
0	69	29.74	0.13	70.064	0.520903	0.000000	0.003526	**19.872**	0.09

Table B.6 M_r Data Sheet for GRE-35-21.13, 302, 400-WET

Resilient Modulus Test for material type 2

Soil Sample: WAS-7-Mari
Sample No.: WAS-7-DRY

Location: Marietta City SR-7
Washington County

Tested by: D. G. Kim
Test Date: 5/11/1999

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.28	cm
Middle:	7.28	cm
Bottom:	7.28	cm
Average:	7.28	cm
Membrane Thickness:		cm
Net Diameter :	7.11	cm
Ht of Spec.+Cap+Base:	24.81	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	15.09	cm
After Test Length:	15.06	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.62	cm^2
Initial Volume:	628.26	cm^3

SOIL PROPERTIES

Wet Density:	2115.77	kg/cm^3
Compaction Moisture Content:	11.00	%
Saturation:		%
Dry Density:	1906.10	kg/cm^3
Moisture Content After Mr Testing:	10.89	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.78	0.08	13.619	0.024262	0.002074	0.000161	**85.039**	6.11
41	28	11.69	0.04	27.543	0.054508	0.000000	0.000362	**76.178**	0.26
41	41	19.97	0.21	47.057	0.101153	0.001113	0.000671	**70.135**	0.50
41	55	23.07	0.10	54.348	0.116535	0.000000	0.000773	**70.308**	0.31
41	69	29.24	0.13	68.880	0.150246	0.001349	0.000997	**69.119**	0.56
21	14	6.13	0.14	14.448	0.029200	0.001102	0.000194	**74.653**	2.43
21	28	12.04	0.02	28.359	0.062448	0.002083	0.000414	**68.522**	2.20
21	41	17.74	0.06	41.802	0.096677	0.001566	0.000641	**65.199**	0.94
21	55	23.39	0.08	55.107	0.133878	0.001751	0.000888	**62.064**	0.78
21	69	28.92	0.12	68.146	0.170109	0.001349	0.001128	**60.395**	0.28
0	14	6.61	0.04	15.566	0.037575	0.001016	0.000249	**62.483**	1.40
0	28	11.75	0.07	27.682	0.072380	0.001113	0.000480	**57.666**	0.72
0	41	17.76	0.06	41.854	0.119995	0.002226	0.000796	**52.597**	0.90
0	55	23.31	0.06	54.912	0.168203	0.001010	0.001116	**49.218**	0.24
0	69	29.05	0.09	68.434	0.217719	0.001102	0.001444	**47.388**	0.24

Table B.7 M_r Data Sheet for WAS-7-Mari-DRY

Resilient Modulus Test for material type 2

Soil Sample: WAS-7-Mari
Sample No.: WAS-7-OMC

Location: Marietta City SR-7
Washington County

Tested by: D. G. Kim
Test Date: 5/20/1999

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.28	cm
Middle:	7.28	cm
Bottom:	7.28	cm
Average:	7.28	cm
Membrane Thickness:		cm
Net Diameter :	7.11	cm
Ht of Spec.+Cap+Base:	24.99	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	15.28	cm
After Test Length:	15.24	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.62	cm^2
Initial Volume:	636.03	cm^3

SOIL PROPERTIES

Wet Density:	2207.61	kg/cm^3
Compaction Moisture Content:	14.00	%
Saturation:		%
Dry Density:	1936.50	kg/cm^3
Moisture Content After Mr Testing:	13.89	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.89	0.11	13.871	0.029769	0.000000	0.000195	**71.116**	1.35
41	28	11.89	0.11	28.010	0.066482	0.001964	0.000436	**64.340**	1.49
41	41	17.83	0.17	42.001	0.107721	0.001331	0.000706	**59.518**	1.13
41	55	23.46	0.14	55.272	0.152546	0.001430	0.001000	**55.302**	0.54
41	69	29.90	0.13	70.449	0.208771	0.001016	0.001368	**51.481**	0.16
21	14	6.18	0.13	14.568	0.034798	0.000000	0.000228	**63.893**	1.38
21	28	12.11	0.16	28.537	0.073711	0.001215	0.000483	**59.089**	0.36
21	41	18.49	0.16	43.562	0.130407	0.002422	0.000854	**50.993**	0.80
21	55	23.42	0.19	55.177	0.181898	0.002559	0.001192	**46.301**	0.57
21	69	29.93	0.15	70.520	0.244637	0.003226	0.001603	**44.002**	0.65
0	14	5.93	0.08	13.963	0.048226	0.001309	0.000316	**44.216**	1.28
0	28	12.27	0.14	28.905	0.111316	0.002068	0.000729	**39.637**	0.58
0	41	17.68	0.18	41.652	0.161214	0.000000	0.001056	**39.432**	0.40
0	55	23.11	0.15	54.442	0.217873	0.001016	0.001428	**38.137**	0.20
0	69	29.22	0.07	68.833	0.286487	0.002489	0.001877	**36.672**	0.37

Table B.8 M_r Data Sheet for WAS-7-Mari-OMC

Resilient Modulus Test for material type 2

Soil Sample: WAS-7-Mari
Sample No.: WAS-7-WET

Location: Marietta City SR-7
Washington County

Tested by: D. G. Kim
Test Date: 5/22/1999

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.90 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.19 cm
After Test Length: 15.09 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.62 cm^2
Initial Volume: 632.21 cm^3

SOIL PROPERTIES

Wet Density: 2199.71 kg/cm^3
Compaction Moisture Content: 16.00 %
Saturation: %
Dry Density: 1896.30 kg/cm^3
Moisture Content After Mr Testing: 15.76 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.99	0.14	14.123	0.051100	0.001285	0.000338	**41.865**	1.49
41	28	11.80	0.12	27.797	0.110253	0.001802	0.000728	**38.177**	0.84
41	41	18.27	0.16	43.034	0.186769	0.001663	0.001234	**34.882**	0.39
41	55	23.76	0.13	55.976	0.265045	0.002657	0.001751	**31.973**	0.33
41	69	29.90	0.13	70.449	0.353705	0.004502	0.002337	**30.155**	0.40
21	14	5.87	0.13	13.831	0.053950	0.002370	0.000356	**38.867**	1.93
21	28	12.07	0.10	28.439	0.135428	0.001285	0.000895	**31.790**	0.29
21	41	18.14	0.14	42.735	0.243389	0.000880	0.001608	**26.580**	0.27
21	55	23.30	0.11	54.907	0.330725	0.001285	0.002185	**25.133**	0.18
21	69	29.84	0.15	70.311	0.431289	0.000881	0.002849	**24.679**	0.14
0	14	5.93	0.12	13.963	0.064231	0.001489	0.000424	**32.918**	0.75
0	28	12.43	0.16	29.274	0.180800	0.000830	0.001194	**24.511**	0.35
0	41	18.75	0.15	44.178	0.313776	0.002653	0.002073	**21.315**	0.28
0	55	23.07	0.18	54.364	0.398726	0.001749	0.002634	**20.639**	0.11
0	69	29.63	0.16	69.816	0.508906	0.002435	0.003362	**20.768**	0.15

Table B.9 M_r Data Sheet for WAS-7-Mari-WET

Resilient Modulus Test for material type 2

Soil Sample: WAS-7-Mari
Sample No.: WAS-7-SAT

Location: Marietta City SR-7
Washington County

Tested by: D. G. Kim
Test Date: 5/22/1999

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.90 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.19 cm
After Test Length: 15.09 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.62 cm^2
Initial Volume: 632.21 cm^3

SOIL PROPERTIES

Wet Density: kg/cm^3
Compaction Moisture Content: %
Saturation: %
Dry Density: 1896.30 kg/cm^3
Moisture Content After Mr Testing: %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14								
41	28								
41	41								
41	55								
41	69								
21	14	5.71	0.10	13.443	0.175417	0.001697	0.001159	**11.601**	0.17
21	28	11.54	0.16	27.192	0.598970	0.011968	0.003957	**6.876**	0.23
21	41	17.72	0.55	41.751	0.985613	0.027029	0.006511	**6.413**	0.16
21	55	23.13	0.51	54.486	1.278133	0.006811	0.008443	**6.453**	0.13
21	69								
0	14								
0	28								
0	41								
0	55								
0	69								

Table B.10 M_r Data Sheet for WAS-7-Mari-SAT

Resilient Modulus Test for material type 2

Soil Sample: SHE-SR47
Sample No.: SHE-SR47-DRY

Location: State route 47 Shelby County

Tested by: LSH
Test Date: 8/22/2000

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.30	cm
Middle:	7.30	cm
Bottom:	7.30	cm
Average:	7.30	cm
Membrane Thickness:	0.04	cm
Net Diameter :	7.11	cm
Ht of Spec.+Cap+Base:	24.54	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	14.82	cm
After Test Length:	14.82	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.82	cm^2
Initial Volume:	619.85	cm^3

SOIL PROPERTIES

Wet Density:	2056.50	kg/cm^3
Compaction Moisture Content:	12.50	%
Saturation:		%
Dry Density:	1828.00	kg/cm^3
Moisture Content After Mr Testing:	12.70	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.75	0.16	13.486	0.023468	0.000000	0.000158	**85.185**	2.36
41	28	11.75	0.10	27.562	0.053168	0.001428	0.000359	**76.872**	1.40
41	41	17.07	0.18	40.029	0.083389	0.001844	0.000563	**71.175**	1.14
41	55	22.87	0.11	53.632	0.114002	0.001304	0.000769	**69.742**	0.84
41	69	29.46	0.13	69.091	0.150117	0.001428	0.001013	**68.229**	0.67
21	14	5.97	0.12	14.004	0.030743	0.001166	0.000207	**67.576**	1.99
21	28	11.84	0.14	27.761	0.066032	0.002129	0.000445	**62.359**	1.48
21	41	17.45	0.30	40.920	0.100773	0.001346	0.000680	**60.192**	0.76
21	55	23.27	0.30	54.569	0.134993	0.001166	0.000911	**59.920**	0.34
21	69	29.08	0.25	68.198	0.167301	0.002856	0.001129	**60.433**	0.58
0	14	6.02	0.04	14.111	0.045345	0.002332	0.000306	**46.215**	2.09
0	28	11.87	0.16	27.835	0.091212	0.002332	0.000615	**45.248**	0.55
0	41	17.43	0.11	40.869	0.136036	0.001166	0.000918	**44.535**	0.29
0	55	24.20	0.25	56.749	0.188161	0.002181	0.001269	**44.713**	0.78
0	69	29.28	0.26	68.681	0.217600	0.001428	0.001468	**46.787**	0.43

Table B.11 M_r Data Sheet for SHE-SR47-DRY

Resilient Modulus Test for material type 2

Soil Sample: SHE-SR47
Sample No.: SHE-SR47-OMC

Location: State route 47 Shelby County

Tested by:
Test Date:

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.30	cm
Middle:	7.30	cm
Bottom:	7.30	cm
Average:	7.30	cm
Membrane Thickness:	0.04	cm
Net Diameter :	7.11	cm
Ht of Spec.+Cap+Base:	24.99	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	15.28	cm
After Test Length:	14.78	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.85	cm^2
Initial Volume:	639.53	cm^3

SOIL PROPERTIES

Wet Density:	2134.28	kg/cm^3
Compaction Moisture Content:	14.50	%
Saturation:		%
Dry Density:	1864.00	kg/cm^3
Moisture Content After Mr Testing:	14.50	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41.4	13.8	5.90	0.07	13.831	0.039155	0.000000	0.000260	**53.096**	0.64
41.4	27.6	11.82	0.09	27.697	0.083389	0.000000	0.000555	**49.926**	0.37
41.4	41.4	17.62	0.13	41.278	0.135514	0.000000	0.000902	**45.787**	0.35
41.4	55.2	23.01	0.10	53.925	0.202824	0.001963	0.001349	**39.967**	0.31
41.4	69.0	28.66	0.03	67.160	0.286674	0.002332	0.001907	**35.217**	0.27
20.7	13.8	6.23	0.18	14.589	0.049083	0.001065	0.000327	**44.676**	0.63
20.7	27.6	11.98	0.05	28.072	0.109439	0.000000	0.000728	**38.557**	0.16
20.7	41.4	17.64	0.12	41.328	0.181555	0.001347	0.001208	**34.219**	0.30
20.7	55.2	23.58	0.06	55.251	0.266857	0.002332	0.001775	**31.124**	0.29
20.7	69.0	28.49	0.13	66.766	0.332906	0.001304	0.002215	**30.147**	0.10
0.0	13.8	6.15	0.07	14.402	0.057862	0.001166	0.000385	**37.424**	0.78
0.0	27.6	11.75	0.05	27.536	0.127176	0.001155	0.000846	**32.550**	0.44
0.0	41.4	17.62	0.07	41.284	0.217600	0.001428	0.001448	**28.520**	0.24
0.0	55.2	23.77	0.04	55.694	0.312289	0.001963	0.002078	**26.809**	0.15
0.0	69.0	28.05	0.05	65.718	0.379190	0.003366	0.002523	**26.053**	0.24

Table B.12 M_r Data Sheet for SHE-SR47-OMC

Resilient Modulus Test for material type 2

Soil Sample: SHE-SR47
Sample No.: SHE-SR47-WET

Location: State route 47 Shelby County

Tested by: LSH
Test Date: 8/22/2000

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.30 cm
Middle: 7.30 cm
Bottom: 7.30 cm
Average: 7.30 cm
Membrane Thickness: 0.04 cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.88 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.17 cm
After Test Length: 14.29 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.85 cm^2
Initial Volume: 634.71 cm^3

SOIL PROPERTIES

Wet Density: 2091.71 kg/cm^3
Compaction Moisture Content: 15.50 %
Saturation: %
Dry Density: 1811.00 kg/cm^3
Moisture Content After Mr Testing: 15.90 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41.4	13.8	5.86	0.03	13.740	0.094594	0.001068	0.000642	**21.396**	0.26
41.4	27.6	11.36	0.07	26.623	0.278811	0.002983	0.001893	**14.066**	0.17
41.4	41.4	17.40	0.31	40.771	0.505272	0.006772	0.003430	**11.885**	0.10
41.4	55.2	23.28	0.18	54.557	0.672673	0.009141	0.004567	**11.947**	0.15
41.4	69.0	28.43	0.24	66.623	0.743809	0.006556	0.005050	**13.193**	0.13
20.7	13.8	5.78	0.00	13.539	0.141224	0.000000	0.000959	**14.121**	0.00
20.7	27.6	11.06	0.04	25.912	0.389687	0.000000	0.002646	**9.794**	0.03
20.7	41.4	17.18	0.13	40.256	0.574340	0.002340	0.003899	**10.324**	0.07
20.7	55.2	22.91	0.13	53.678	0.673705	0.002983	0.004574	**11.736**	0.07
20.7	69.0	29.28	0.83	68.598	0.762630	0.029168	0.005178	**13.275**	0.89
0.0	13.8	5.84	0.02	13.678	0.254349	0.001211	0.001727	**7.921**	0.05
0.0	27.6	11.23	0.04	26.324	0.496377	0.002866	0.003370	**7.811**	0.06
0.0	41.4	16.81	0.12	39.391	0.663265	0.002340	0.004503	**8.748**	0.07
0.0	55.2	23.30	0.09	54.590	0.792455	0.005232	0.005380	**10.147**	0.04
0.0	69.0	29.31	0.52	68.683	0.887120	0.007247	0.006023	**11.403**	0.15

Table B.13 M_r Data Sheet for SHE-SR47-WET

Resilient Modulus Test for material type 2

Soil Sample: SHE-SR47
Sample No.: SHE-SR47-SAT

Location: State route 47 Shelby County

Tested by: DGK
Test Date: 5/8/2002

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.30 cm
Middle: 7.30 cm
Bottom: 7.30 cm
Average: 7.30 cm
Membrane Thickness: 0.04 cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.86 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.14 cm
After Test Length: 15.14 cm
Inside Diameter of Mold: 7.30 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.85 cm^2
Initial Volume: 633.81 cm^3

SOIL PROPERTIES

Wet Density: 0.00 kg/cm^3
Compaction Moisture Content: %
Saturation: %
Dry Density: kg/cm^3
Moisture Content After Mr Testing: %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41.4	13.8								
41.4	27.6								
41.4	41.4								
41.4	55.2								
41.4	69.0								
20.7	13.8	5.75	0.08	13.470	0.049342	0.000000	0.000326	**41.340**	0.60
20.7	27.6	11.59	0.07	27.160	0.142501	0.001379	0.000941	**28.864**	0.29
20.7	41.4	17.14	0.05	40.173	0.586038	0.002181	0.003870	**10.381**	0.04
20.7	55.2	23.20	0.12	54.370	0.901282	0.003385	0.005952	**9.135**	0.03
20.7	69.0	29.16	0.40	68.330	1.301645	0.009511	0.008595	**7.949**	0.07
0.0	13.8								
0.0	27.6								
0.0	41.4								
0.0	55.2								
0.0	69.0								

Table B.14 M_r Data Sheet for SHE-SR47-SAT

Resilient Modulus Test for material type 2

Soil Sample: WAR-741-3
Sample No.: WAR-741-DRY

Location: MP 3, SR-741, Warren County

Tested by: D. G. Kim
Test Date: 5/14/1999

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.72 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.00 cm
After Test Length: 14.99 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.62 cm^2
Initial Volume: 624.51 cm^3

SOIL PROPERTIES

Wet Density: 2116.80 pcf
Compaction Moisture Content: 12.00 %
Saturation: %
Dry Density: 1890.00 pcf
Moisture Content After Mr Testing: 11.71 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.97	0.16	14.055	0.022327	0.000000	0.000149	**94.398**	2.57
41	28	12.26	0.06	28.876	0.047615	0.001113	0.000318	**90.979**	2.29
41	41	18.73	0.21	44.118	0.076065	0.001422	0.000507	**87.005**	2.64
41	55	23.63	0.15	55.667	0.098227	0.001349	0.000655	**84.987**	0.83
41	69	29.86	0.14	70.342	0.126492	0.000000	0.000844	**83.387**	0.40
21	14	5.83	0.12	13.739	0.024809	0.002022	0.000165	**83.393**	5.98
21	28	11.64	0.07	27.427	0.050104	0.001113	0.000334	**82.114**	1.80
21	41	18.14	2.00	42.728	0.079985	0.011352	0.000533	**80.393**	2.94
21	55	23.47	0.15	55.298	0.105659	0.001363	0.000705	**78.484**	0.64
21	69	29.20	0.12	68.796	0.135951	0.001113	0.000907	**75.884**	0.75
0	14	6.43	0.08	15.140	0.034732	0.000014	0.000232	**65.365**	0.83
0	28	12.19	0.14	28.715	0.067478	0.002083	0.000450	**63.843**	1.30
0	41	18.83	0.22	44.361	0.108522	0.001245	0.000724	**61.296**	0.07
0	55	24.26	0.18	57.160	0.139327	0.001016	0.000929	**61.519**	0.30
0	69	30.23	0.08	71.213	0.178587	0.000000	0.001191	**59.794**	0.17

Table B.15 M_r Data Sheet for WAR-741-3-DRY

Resilient Modulus Test for material type 2

Soil Sample: WAR-741-3
Sample No.: WAR-741-OMC

Location: MP 3, SR-741, Warren County

Tested by: D. G. Kim
Test Date: 5/17/1999

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 25.05 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.33 cm
After Test Length: 15.26 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.62 cm^2
Initial Volume: 638.18 cm^3

SOIL PROPERTIES

Wet Density: 2184.24 pcf
Compaction Moisture Content: 14.00 %
Saturation: %
Dry Density: 1916.00 pcf
Moisture Content After Mr Testing: 13.31 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.86	0.06	13.808	0.027229	0.000000	0.000178	**77.577**	0.84
41	28	11.66	0.14	27.470	0.062525	0.001113	0.000409	**67.216**	0.44
41	41	18.05	0.05	42.516	0.104684	0.001102	0.000684	**62.133**	0.50
41	55	23.37	0.11	55.060	0.151806	0.002083	0.000992	**55.490**	0.50
41	69	29.48	0.15	69.467	0.207853	0.002074	0.001359	**51.129**	0.45
21	14	6.02	0.03	14.185	0.039649	0.000000	0.000259	**54.730**	0.29
21	28	11.75	0.08	27.678	0.095255	0.001363	0.000623	**44.458**	0.72
21	41	17.84	0.23	42.042	0.155280	0.001354	0.001015	**41.418**	0.44
21	55	23.28	0.10	54.858	0.203398	0.001751	0.001330	**41.261**	0.41
21	69	28.54	0.11	67.250	0.252512	0.002083	0.001651	**40.743**	0.31
0	14	5.95	0.13	14.016	0.041666	0.001113	0.000272	**51.468**	0.58
0	28	11.77	0.14	27.739	0.110134	0.002215	0.000720	**38.548**	1.13
0	41	18.36	0.16	43.258	0.195953	0.004297	0.001281	**33.777**	0.44
0	55	23.29	0.13	54.876	0.239608	0.002828	0.001566	**35.038**	0.30
0	69	29.29	0.11	69.009	0.300634	0.002072	0.001965	**35.116**	0.21

Table B.16 M_r Data Sheet for WAR-741-3-OMC

Resilient Modulus Test for material type 2

Soil Sample: WAR-741-3 | Location: MP 3, SR-741, Warren County | Tested by: D. G. Kim
Sample No.: WAR-741-WET | Test Date: 5/17/1999

SPECIMEN INFORMATION			SOIL SPECIMEN VOLUME		
Specific Gravity:			Initial Area:	41.62	cm^2
Diameter Top:	7.28	cm	Initial Volume:	639.98	cm^3
Middle:	7.28	cm			
Bottom:	7.28	cm	SOIL PROPERTIES		
Average:	7.28	cm	Wet Density:	2186.60	pcf
Membrane Thickness:		cm	Compaction Moisture Content:	16.00	%
Net Diameter :	7.11	cm	Saturation:		%
Ht of Spec.+Cap+Base:	25.09	cm	Dry Density:	1885.00	pcf
Ht of Cap+Base:	9.71	cm	Moisture Content		
Initial Length:	15.38	cm	After Mr Testing:	15.67	%
After Test Length:	14.18	cm			
Inside Diameter of Mold:	7.28	cm	COMMENTS:		

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.28	0.08	14.798	0.154208	0.001006	0.001044	**14.181**	0.19
41	28	11.44	0.26	26.961	0.301390	0.007134	0.002040	**13.219**	0.04
41	41	18.22	0.06	42.924	0.512958	0.006416	0.003471	**12.366**	0.13
41	55	23.75	0.22	55.965	0.626942	0.009365	0.004243	**13.192**	0.12
41	69	29.29	0.36	69.018	0.702971	0.003764	0.004757	**14.508**	0.20
21	14	6.12	0.05	14.416	0.145359	0.001364	0.000984	**14.656**	0.20
21	28	11.91	0.12	28.056	0.337835	0.002727	0.002286	**12.272**	0.09
21	41	18.12	0.15	42.692	0.489143	0.002727	0.003310	**12.898**	0.16
21	55	23.83	0.20	56.136	0.594491	0.002024	0.004023	**13.953**	0.11
21	69	29.21	0.15	68.816	0.693537	0.006470	0.004693	**14.663**	0.14
0	14	5.97	0.05	14.062	0.129396	0.001016	0.000876	**16.059**	0.11
0	28	12.03	0.20	28.337	0.338831	0.001363	0.002293	**12.358**	0.19
0	41	17.70	0.16	41.692	0.483070	0.003734	0.003269	**12.753**	0.10
0	55	23.41	0.11	55.148	0.586219	0.001279	0.003967	**13.901**	0.05
0	69	29.17	0.82	68.719	0.695030	0.013960	0.004704	**14.609**	0.24

Table B.17 M_r Data Sheet for WAR-741-3-WET

Resilient Modulus Test for material type 2

Soil Sample: WAS-821-113, 116 | Location: PS 113+75 and PS116+00 SR-821 Washington County | Tested by: D. G. Kim
Sample No.: WAS-821-DRY | Test Date: 5/18/1999

SPECIMEN INFORMATION			SOIL SPECIMEN VOLUME		
Specific Gravity:			Initial Area:	41.62	cm^2
Diameter Top:	7.28	cm	Initial Volume:	634.43	cm^3
Middle:	7.28	cm			
Bottom:	7.28	cm	SOIL PROPERTIES		
Average:	7.28	cm	Wet Density:	2060.88	kg/cm^3
Membrane Thickness:		cm	Compaction Moisture Content:	10.80	%
Net Diameter :	7.11	cm	Saturation:		%
Ht of Spec.+Cap+Base:	24.96	cm	Dry Density:	1860.00	kg/cm^3
Ht of Cap+Base:	9.71	cm	Moisture Content		
Initial Length:	15.24	cm	After Mr Testing:	10.23	%
After Test Length:	15.22	cm			
Inside Diameter of Mold:	7.28	cm	COMMENTS:		

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.11	0.12	14.386	0.022250	0.000000	0.000146	**98.462**	1.93
41	28	11.76	0.11	27.701	0.047066	0.000000	0.000309	**89.631**	0.83
41	41	18.34	0.05	43.207	0.074422	0.000000	0.000489	**88.414**	0.25
41	55	23.82	0.11	56.126	0.096733	0.000014	0.000635	**88.362**	0.40
41	69	29.50	0.08	69.502	0.119465	0.001016	0.000784	**88.605**	0.83
21	14	6.13	0.14	14.448	0.024816	0.000000	0.000163	**88.666**	2.00
21	28	12.61	0.16	29.720	0.053184	0.001358	0.000349	**85.132**	1.57
21	41	19.23	0.14	45.301	0.083797	0.001654	0.000550	**82.350**	1.27
21	55	23.50	0.16	55.371	0.106655	0.000000	0.000700	**79.063**	0.55
21	69	29.29	0.16	69.006	0.135052	0.002512	0.000887	**77.834**	1.28
0	14	6.55	0.09	15.421	0.045483	0.001245	0.000299	**51.657**	1.17
0	28	12.02	0.13	28.318	0.088200	0.001312	0.000579	**48.904**	0.88
0	41	18.74	0.14	44.152	0.132289	0.001234	0.000869	**50.829**	0.26
0	55	23.34	0.12	54.983	0.158394	0.000941	0.001040	**52.865**	0.38
0	69	29.18	0.16	68.754	0.187689	0.001285	0.001232	**55.788**	0.28

Table B.18 M_r Data Sheet for WAS-821-113, 116-DRY

Resilient Modulus Test for material type 2

Soil Sample: WAS-821-113, 116
Sample No.: WAS-821-OMC

Location: PS 113+75 and PS116+00 SR-821
Washington County

Tested by: D. G. Kim
Test Date: 5/19/1999

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 25.03 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.32 cm
After Test Length: 15.25 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.62 cm^2
Initial Volume: 637.62 cm^3

SOIL PROPERTIES

Wet Density: 2177.76 kg/cm^3
Compaction Moisture Content: 14.80 %
Saturation: %
Dry Density: 1897.00 kg/cm^3
Moisture Content After Mr Testing: 14.03 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.09	0.18	14.337	0.026410	0.001141	0.000173	**83.060**	2.67
41	28	12.25	0.18	28.865	0.062772	0.001272	0.000411	**70.304**	0.87
41	41	17.86	0.16	42.074	0.099212	0.000000	0.000649	**64.827**	0.57
41	55	23.27	0.07	54.827	0.150312	0.001363	0.000983	**55.761**	0.42
41	69	29.61	0.18	69.758	0.203403	0.000000	0.001331	**52.425**	0.31
21	14	6.09	0.13	14.351	0.028512	0.001349	0.000187	**77.110**	4.51
21	28	11.83	0.17	27.868	0.064491	0.001574	0.000422	**66.073**	0.99
21	41	17.64	0.14	41.566	0.113686	0.001006	0.000744	**55.893**	0.48
21	55	23.31	0.08	54.920	0.166808	0.002196	0.001091	**50.338**	0.77
21	69	29.61	0.17	69.752	0.229968	0.001874	0.001504	**46.368**	0.39
0	14	6.10	0.12	14.364	0.034018	0.001202	0.000223	**64.584**	1.30
0	28	11.87	0.05	27.965	0.087173	0.000941	0.000570	**49.044**	0.55
0	41	18.78	0.13	44.242	0.143151	0.045643	0.000936	**42.166**	0.42
0	55	23.37	0.16	55.063	0.209850	0.001363	0.001373	**40.111**	0.10
0	69	29.28	0.32	68.987	0.258585	0.002383	0.001692	**40.782**	0.23

Table B.19 M_r Data Sheet for WAS-821-113, 116-OMC

Resilient Modulus Test for material type 2

Soil Sample: WAS-821-113, 116
Sample No.: WAS-821-WET

Location: PS 113+75 and PS116+00 SR-821
Washington County

Tested by: D. G. Kim
Test Date: 5/19/1999

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.85 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.13 cm
After Test Length: 14.90 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.62 cm^2
Initial Volume: 629.85 cm^3

SOIL PROPERTIES

Wet Density: 2149.12 kg/cm^3
Compaction Moisture Content: 16.80 %
Saturation: %
Dry Density: 1840.00 kg/cm^3
Moisture Content After Mr Testing: 15.96 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41.4	13.8	5.93	0.12	13.961	0.034018	0.001202	0.000227	**61.691**	2.63
41.4	27.6	11.82	0.21	27.843	0.086813	0.001566	0.000578	**48.165**	0.88
41.4	41.4	17.96	0.06	42.314	0.162643	0.001322	0.001083	**39.066**	0.26
41.4	55.2	23.54	0.31	55.467	0.250279	0.002468	0.001667	**33.376**	0.21
41.4	69.0	29.37	0.19	69.205	0.355528	0.002561	0.002368	**29.229**	0.31
20.7	13.8	5.95	0.09	14.028	0.039264	0.002438	0.000261	**53.815**	3.38
20.7	27.6	12.04	0.12	28.369	0.124651	0.001760	0.000830	**34.180**	0.72
20.7	41.4	17.75	0.16	41.820	0.237710	0.001016	0.001583	**26.416**	0.23
20.7	55.2	23.62	0.09	55.641	0.331892	0.002061	0.002210	**25.173**	0.14
20.7	69.0	29.87	0.21	70.375	0.416719	0.003514	0.002775	**25.358**	0.16
0.0	13.8	6.50	0.03	15.308	0.060015	0.001110	0.000400	**38.308**	0.67
0.0	27.6	11.95	0.11	28.161	0.165089	0.001309	0.001099	**25.614**	0.28
0.0	41.4	18.31	0.09	43.132	0.301552	0.002817	0.002008	**21.478**	0.19
0.0	55.2	23.47	0.10	55.295	0.382405	0.002897	0.002547	**21.713**	0.20
0.0	69.0	29.20	0.12	68.800	0.445983	0.005373	0.002970	**23.167**	0.34

Table B.20 M_r Data Sheet for WAS-821-113, 116-WET

Resilient Modulus Test for material type 2

Soil Sample: BEL-SR147, 265
Sample No.: BEL-SR147, 265-DRY
Location: Near the split Belmont County
Tested by: LSH
Test Date: 8/4/2000

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.30 cm
Middle: 7.30 cm
Bottom: 7.30 cm
Average: 7.30 cm
Membrane Thickness: 0.04 cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.84 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.12 cm
After Test Length: 15.05 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.85 cm^2
Initial Volume: 632.91 cm^3

SOIL PROPERTIES

Wet Density: 2067.95 kg/cm^3
Compaction Moisture Content: 11.30 %
Saturation: %
Dry Density: 1858.00 kg/cm^3
Moisture Content After Mr Testing: 11.70 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.93	0.04	16.243	0.023546	0.000000	0.000156	**104.074**	0.55
41	28	12.77	0.08	29.920	0.047092	0.000000	0.000312	**95.854**	0.63
41	41	17.86	0.12	41.844	0.067473	0.001170	0.000447	**93.579**	1.22
41	55	23.49	0.08	55.041	0.091542	0.000000	0.000607	**90.712**	0.31
41	69	29.47	0.02	69.058	0.120294	0.000000	0.000797	**86.610**	0.05
21	14	7.00	0.05	16.400	0.028753	0.000000	0.000191	**86.050**	0.59
21	28	12.14	0.08	28.451	0.052822	0.001170	0.000350	**81.290**	1.71
21	41	18.04	0.07	42.271	0.082385	0.001433	0.000546	**77.425**	1.08
21	55	23.65	0.02	55.413	0.109830	0.000000	0.000728	**76.118**	0.07
21	69	29.60	0.07	69.363	0.139916	0.002616	0.000927	**74.812**	1.33
0	14	6.96	0.04	16.315	0.109332	0.001170	0.000725	**22.516**	0.23
0	28	12.85	0.06	30.107	0.152997	0.001510	0.001014	**29.690**	0.25
0	41	17.65	0.07	41.368	0.182211	0.001351	0.001208	**34.253**	0.23
0	55	23.53	0.02	55.133	0.219685	0.000000	0.001456	**37.863**	0.04
0	69	29.33	0.13	68.729	0.252387	0.001510	0.001673	**41.084**	0.16

Table B.21 M_r Data Sheet for BEL-SR147, 265-DRY

Resilient Modulus Test for material type 2

Soil Sample: BEL-SR147, 265
Sample No.: BEL-SR147, 265-OMC
Location: Near the split Belmont County
Tested by: LSH
Test Date: 8/28/2000

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.30 cm
Middle: 7.30 cm
Bottom: 7.30 cm
Average: 7.30 cm
Membrane Thickness: 0.04 cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 25.02 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.31 cm
After Test Length: 15.30 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.85 cm^2
Initial Volume: 640.78 cm^3

SOIL PROPERTIES

Wet Density: 2122.37 kg/cm^3
Compaction Moisture Content: 13.80 %
Saturation: %
Dry Density: 1865.00 kg/cm^3
Moisture Content After Mr Testing: 14.50 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.02	0.05	14.104	0.028778	0.000000	0.000188	**74.999**	0.66
41	28	11.69	0.10	27.400	0.061219	0.001433	0.000400	**68.515**	1.13
41	41	17.45	0.04	40.879	0.096774	0.001850	0.000632	**64.662**	1.13
41	55	22.82	0.07	53.464	0.133375	0.000000	0.000872	**61.344**	0.19
41	69	28.75	0.07	67.356	0.180205	0.000827	0.001178	**57.117**	0.14
21	14	5.82	0.03	13.639	0.028702	0.000000	0.000188	**72.722**	0.43
21	28	11.52	0.05	26.984	0.065380	0.000000	0.000427	**63.160**	0.27
21	41	17.50	0.04	41.013	0.105931	0.001510	0.000692	**59.258**	0.72
21	55	23.09	0.09	54.102	0.147765	0.001433	0.000966	**56.034**	0.42
21	69	28.61	0.07	67.040	0.195485	0.001308	0.001277	**52.483**	0.30
0	14	5.76	0.07	13.488	0.038694	0.001170	0.000253	**53.388**	1.97
0	28	11.57	0.10	27.100	0.086309	0.000000	0.000564	**48.051**	0.41
0	41	17.37	0.04	40.708	0.132067	0.001433	0.000863	**47.175**	0.44
0	55	23.22	0.07	54.402	0.180448	0.002126	0.001179	**46.142**	0.65
0	69	28.46	0.08	66.694	0.227097	0.001969	0.001484	**44.945**	0.40

Table B.22 M_r Data Sheet for BEL-SR147, 265-OMC

Resilient Modulus Test for material type 2

Soil Sample: BEL-SR147, 265
Sample No.: BEL-SR147, 265-WET
Location: Near the split Belmont County
Tested by: LSH
Test Date: 8/28/2000

SPECIMEN INFORMATION
Specific Gravity:
Diameter Top: 7.30 cm
Middle: 7.30 cm
Bottom: 7.30 cm
Average: 7.30 cm
Membrane Thickness: 0.04 cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 25.00 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.29 cm
After Test Length: 15.28 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME
Initial Area: 41.85 cm^2
Initial Volume: 639.88 cm^3

SOIL PROPERTIES
Wet Density: 2142.30 kg/cm^3
Compaction Moisture Content: 15.80 %
Saturation: %
Dry Density: 1850.00 kg/cm^3
Moisture Content After Mr Testing: 16.90 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.82	0.06	13.628	0.034534	0.001170	0.000226	**60.354**	1.79
41	28	11.59	0.06	27.153	0.086309	0.000000	0.000565	**48.077**	0.23
41	41	17.12	0.02	40.110	0.151697	0.000013	0.000993	**40.406**	0.04
41	55	23.52	0.08	55.122	0.245847	0.001850	0.001609	**34.265**	0.29
41	69	29.05	0.10	68.058	0.337388	0.002136	0.002208	**30.827**	0.13
21	14	5.91	0.07	13.848	0.041112	0.001277	0.000269	**51.502**	1.14
21	28	11.59	0.03	27.162	0.110291	0.001969	0.000722	**37.644**	0.63
21	41	17.43	0.04	40.847	0.197729	0.001428	0.001294	**31.570**	0.22
21	55	22.97	0.01	53.816	0.287680	0.000000	0.001883	**28.587**	0.01
21	69	28.91	0.04	67.744	0.387502	0.001950	0.002536	**26.716**	0.11
0	14	5.65	0.03	13.249	0.066252	0.001351	0.000434	**30.569**	0.61
0	28	11.55	0.03	27.061	0.165293	0.001170	0.001082	**25.019**	0.16
0	41	17.23	0.06	40.380	0.273130	0.001398	0.001787	**22.593**	0.14
0	55	23.28	0.05	54.547	0.386417	0.002505	0.002529	**21.572**	0.12
0	69	28.66	0.05	67.165	0.494304	0.004129	0.003235	**20.765**	0.14

Table B.23 M_r Data Sheet for BEL-SR147, 265-WET

Resilient Modulus Test for material type 2

Soil Sample: ATH-50-Cool
Sample No.: ATH-50-DRY
Location: Coolville City US-50
Athens County
Tested by: D. G. Kim
Test Date: 5/12/1999

SPECIMEN INFORMATION
Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.94 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.23 cm
After Test Length: 15.22 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME
Initial Area: 41.62 cm^2
Initial Volume: 633.77 cm^3

SOIL PROPERTIES
Wet Density: 2097.60 kg/cm^3
Compaction Moisture Content: 14.00 %
Saturation: %
Dry Density: 1840.00 kg/cm^3
Moisture Content After Mr Testing: 13.39 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.84	0.19	13.76	0.019837	0.000000	0.000130	**105.544**	3.48
41	28	11.79	0.30	27.77	0.040620	0.001363	0.000267	**104.115**	2.33
41	41	17.54	1.39	41.32	0.062972	0.006021	0.000414	**100.005**	2.10
41	55	23.45	0.18	55.26	0.081864	0.000000	0.000538	**102.739**	0.79
41	69	28.97	0.18	68.27	0.099212	0.000000	0.000652	**104.730**	0.64
21	14	5.84	0.07	13.75	0.020335	0.001113	0.000134	**103.136**	4.22
21	28	12.05	0.12	28.40	0.044653	0.000000	0.000293	**96.811**	0.95
21	41	17.79	0.23	41.92	0.067452	0.001113	0.000443	**94.598**	1.52
21	55	23.53	0.49	55.43	0.087300	0.002713	0.000574	**96.672**	1.11
21	69	29.32	0.26	69.08	0.109144	0.000000	0.000717	**96.330**	0.85
0	14	6.19	0.17	14.58	0.027280	0.000000	0.000179	**81.368**	2.25
0	28	12.14	0.09	28.61	0.055182	0.001245	0.000363	**78.935**	1.32
0	41	18.55	0.09	43.71	0.084353	0.000000	0.000554	**78.871**	0.39
0	55	23.77	0.12	56.01	0.109559	0.002447	0.000720	**77.846**	1.87
0	69	29.70	0.25	69.97	0.136423	0.000000	0.000896	**78.064**	0.65

Table B.24 M_r Data Sheet for ATH-50-Cool-DRY

Resilient Modulus Test for material type 2

Soil Sample: ATH-50-Cool
Sample No.: ATH-50-OMC

Location: Coolville City US-50
Athens County

Tested by: D. G. Kim
Test Date: 5/22/1999

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 25.03 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.32 cm
After Test Length: 15.29 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.62 cm^2
Initial Volume: 637.62 cm^3

SOIL PROPERTIES

Wet Density: 2179.64 kg/cm^3
Compaction Moisture Content: 16.00 %
Saturation: %
Dry Density: 1879.00 kg/cm^3
Moisture Content After Mr Testing: 15.29 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.00	0.10	14.134	0.022327	0.000000	0.000146	**96.877**	1.65
41	28	12.12	0.16	28.552	0.047913	0.001312	0.000313	**91.253**	2.82
41	41	18.13	0.24	42.714	0.074422	0.000000	0.000486	**87.833**	1.15
41	55	23.30	0.35	54.884	0.096019	0.001202	0.000627	**87.474**	0.81
41	69	29.14	1.42	68.665	0.122784	0.008263	0.000802	**85.672**	1.68
21	14	6.07	0.03	14.304	0.024790	0.000000	0.000162	**88.297**	0.41
21	28	11.79	0.08	27.773	0.049606	0.000000	0.000324	**85.677**	0.55
21	41	17.81	0.39	41.968	0.076886	0.000000	0.000502	**83.534**	1.81
21	55	23.35	0.15	55.025	0.102199	0.001113	0.000668	**82.401**	1.02
21	69	29.04	0.35	68.418	0.131881	0.001006	0.000862	**79.400**	1.47
0	14	5.82	0.13	13.721	0.028948	0.001272	0.000189	**72.606**	2.12
0	28	12.01	0.15	28.304	0.061603	0.002435	0.000403	**70.384**	2.31
0	41	18.45	0.26	43.474	0.098217	0.001363	0.000642	**67.754**	1.75
0	55	23.44	0.06	55.220	0.125014	0.001349	0.000817	**67.602**	0.58
0	69	29.39	0.28	69.239	0.162712	0.001356	0.001063	**65.125**	0.94

Table B.25 M_r Data Sheet for ATH-50-Cool-OMC

Resilient Modulus Test for material type 2

Soil Sample: ATH-50-Cool
Sample No.: ATH-50-WET

Location: Coolville City US-50
Athens County

Tested by: D. G. Kim
Test Date: 5/22/1999

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.28 cm
Middle: 7.28 cm
Bottom: 7.28 cm
Average: 7.28 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 25.04 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.33 cm
After Test Length: 15.24 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.62 cm^2
Initial Volume: 637.97 cm^3

SOIL PROPERTIES

Wet Density: 2171.20 kg/cm^3
Compaction Moisture Content: 18.00 %
Saturation: %
Dry Density: 1840.00 kg/cm^3
Moisture Content After Mr Testing: 17.58 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.12	0.18	14.429	0.026626	0.001117	0.000174	**82.906**	2.64
41	28	11.77	0.25	27.729	0.064153	0.002229	0.000420	**66.096**	1.11
41	41	17.91	0.76	42.191	0.123556	0.009481	0.000808	**52.307**	1.86
41	55	23.31	0.19	54.929	0.194478	0.002397	0.001272	**43.178**	0.67
41	69	29.38	0.44	69.229	0.291273	0.002424	0.001906	**36.332**	0.68
21	14	6.04	0.16	14.238	0.030599	0.001285	0.000200	**71.181**	2.10
21	28	12.03	0.20	28.344	0.079652	0.001496	0.000521	**54.400**	0.95
21	41	17.99	0.10	42.382	0.164259	0.001654	0.001075	**39.442**	0.47
21	55	23.41	0.16	55.156	0.252519	0.002277	0.001652	**33.389**	0.41
21	69	29.36	0.22	69.179	0.348372	0.002519	0.002279	**30.354**	0.28
0	14	5.93	0.12	13.961	0.042497	0.002069	0.000278	**50.285**	1.79
0	28	12.06	0.08	28.409	0.110384	0.001359	0.000722	**39.342**	0.47
0	41	18.35	0.04	43.244	0.219756	0.001363	0.001438	**30.079**	0.15
0	55	23.07	0.15	54.352	0.308971	0.001800	0.002021	**26.889**	0.22
0	69	29.33	0.21	69.111	0.424578	0.003984	0.002778	**24.883**	0.36

Table B.26 M_r Data Sheet for ATH-50-Cool-WET

Resilient Modulus Test for material type 2

Soil Sample: ATH-50-Cool	Location: Coolville City US-50	Tested by:	D. G. Kim
Sample No.: ATH-50-SAT	Athens County	Test Date:	5/22/1999

SPECIMEN INFORMATION			SOIL SPECIMEN VOLUME		
Specific Gravity:			Initial Area:	41.62	cm^2
Diameter Top:	7.28	cm	Initial Volume:	637.97	cm^3
Middle:	7.28	cm			
Bottom:	7.28	cm	SOIL PROPERTIES		
Average:	7.28	cm	Wet Density:	2171.20	kg/cm^3
Membrane Thickness:		cm	Compaction Moisture Content:	18.00	%
Net Diameter :	7.11	cm	Saturation:		%
Ht of Spec.+Cap+Base:	25.04	cm	Dry Density:	1840.00	kg/cm^3
Ht of Cap+Base:	9.71	cm	Moisture Content		
Initial Length:	15.33	cm	After Mr Testing:	17.58	%
After Test Length:	15.24	cm			
Inside Diameter of Mold:	7.28	cm	COMMENTS:		

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14								
41	28								
41	41								
41	55								
41	69								
21	14	6.04	0.16	14.099	0.030599	0.001285	0.000382	**36.900**	2.10
21	28	12.03	0.20	28.173	0.079652	0.001496	0.000945	**29.800**	0.95
21	41	17.99	0.10	42.089	0.164259	0.001654	0.002170	**19.400**	0.47
21	55	23.41	0.16	55.204	0.252519	0.002277	0.004452	**12.400**	0.41
21	69	29.36	0.22	68.891	0.348372	0.002519	0.005789	**11.900**	0.28
0	14								
0	28								
0	41								
0	55								
0	69								

Table B.27 M_r Data Sheet for ATH-50-Cool-SAT

Resilient Modulus Test for material type 2

Soil Sample: ATH-50-222, 228, 413	Location: PS 228+00, PS 222+00, and PS 413+50 US-50	Tested by:	D. G. Kim
Sample No.: ATH-50-224-DRY	Athens County	Test Date:	5/13/1999

SPECIMEN INFORMATION			SOIL SPECIMEN VOLUME			
Specific Gravity:			Initial Area:	41.62	cm^2	
Diameter Top:	7.28	cm	Initial Volume:	635.85	cm^3	2.86614173
Middle:	7.28	cm				
Bottom:	7.28	cm	SOIL PROPERTIES			
Average:	7.28	cm	Wet Density:	2072.04	kg/cm^3	
Membrane Thickness:		cm	Compaction Moisture Content:	11.40	%	
Net Diameter :	7.11	cm	Saturation:		%	
Ht of Spec.+Cap+Base:	24.99	cm	Dry Density:	1860.00	kg/cm^3	
Ht of Cap+Base:	9.71	cm	Moisture Content			
Initial Length:	15.28	cm	After Mr Testing:	11.38	%	
After Test Length:	15.28	cm				
Inside Diameter of Mold:	7.28	cm	COMMENTS:			

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.10	0.39	14.365	0.016850	0.001113	0.000110	**130.27**	3.04
41	28	12.07	0.09	28.447	0.037211	0.000000	0.000244	**116.78**	0.88
41	41	17.30	0.32	40.756	0.055194	0.001236	0.000361	**112.81**	1.09
41	55	24.11	0.14	56.811	0.078545	0.001437	0.000514	**110.51**	1.48
41	69	30.07	0.33	70.847	0.098715	0.001113	0.000646	**109.63**	0.41
21	14	6.03	0.41	14.207	0.017348	0.000000	0.000114	**125.09**	8.42
21	28	12.07	0.27	28.429	0.039059	0.001232	0.000256	**111.21**	1.69
21	41	18.64	0.16	43.906	0.064491	0.000000	0.000422	**104.00**	0.89
21	55	23.58	0.33	55.557	0.084328	0.000000	0.000552	**100.64**	1.39
21	69	29.73	0.20	70.038	0.108528	0.001232	0.000710	**98.59**	1.58
0	14	5.98	0.10	14.101	0.024790	0.000000	0.000162	**86.89**	1.42
0	28	12.13	0.10	28.568	0.055057	0.001113	0.000360	**79.29**	1.97
0	41	18.35	0.09	43.245	0.086817	0.000000	0.000568	**76.09**	0.39
0	55	23.68	0.06	55.797	0.112126	0.001102	0.000734	**76.02**	0.66
0	69	29.46	0.20	69.419	0.136418	0.001751	0.000893	**77.74**	1.19

Table B.28 M_r Data Sheet for ATH-50-222, 228, 413-DRY

Resilient Modulus Test for material type 2

Soil Sample: ATH-50-222, 228, 413 | Location: PS 228+00, PS 222+00, and PS 413+50 US-50 | Tested by:
Sample No.: ATH-50-224-OMC | Athens County | Test Date:

SPECIMEN INFORMATION			SOIL SPECIMEN VOLUME		
Specific Gravity:			Initial Area:	41.62	cm^2
Diameter Top:	7.28	cm	Initial Volume:	645.29	cm^3
Middle:	7.28	cm			
Bottom:	7.28	cm	SOIL PROPERTIES		
Average:	7.28	cm	Wet Density:	2162.12	kg/cm^3
Membrane Thickness:		cm	Compaction Moisture Content:	13.20	%
Net Diameter :	7.11	cm	Saturation:		%
Ht of Spec.+Cap+Base:	25.22	cm	Dry Density:	1910.00	kg/cm^3
Ht of Cap+Base:	9.71	cm	Moisture Content		
Initial Length:	15.50	cm	After Mr Testing:	12.36	%
After Test Length:	15.50	cm			
Inside Diameter of Mold:	7.28	cm	COMMENTS:		

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.94	0.12	13.986	0.019787	0.000000	0.000128	**109.582**	2.18
41	28	11.92	0.06	28.088	0.044628	0.000000	0.000288	**97.572**	0.46
41	41	17.62	0.20	41.520	0.066482	0.001113	0.000429	**96.837**	1.79
41	55	23.35	0.11	55.016	0.089296	0.002483	0.000576	**95.563**	2.28
41	69	29.36	0.28	69.182	0.112608	0.002216	0.000726	**95.264**	1.66
21	14	6.17	0.17	14.538	0.022327	0.000000	0.000144	**100.942**	2.84
21	28	12.28	0.11	28.925	0.049134	0.001113	0.000317	**91.307**	2.54
21	41	17.99	0.05	42.386	0.074397	0.000000	0.000480	**88.323**	0.26
21	55	23.41	0.10	55.159	0.099710	0.001113	0.000643	**85.769**	1.21
21	69	29.14	0.26	68.646	0.129002	0.001751	0.000832	**82.500**	0.69
0	14	5.98	0.16	14.092	0.029756	0.000073	0.000192	**73.422**	2.09
0	28	12.05	0.27	28.399	0.062992	0.002222	0.000406	**69.918**	0.95
0	41	18.24	0.18	42.980	0.101702	0.000000	0.000656	**65.516**	0.65
0	55	23.85	0.16	56.198	0.135097	0.002074	0.000871	**64.502**	1.10
0	69	29.46	0.16	69.404	0.170647	0.001113	0.001101	**63.052**	0.33

Table B.29 M_r Data Sheet for ATH-50-222, 228, 413-OMC

Resilient Modulus Test for material type 2

Soil Sample: ATH-50-222, 228, 413 | Location: PS 228+00, PS 222+00, and PS 413+50 US-50 | Tested by: D. G. Kim
Sample No.: ATH-50-224-WET | Athens County | Test Date: 5/20/1999

SPECIMEN INFORMATION			SOIL SPECIMEN VOLUME		
Specific Gravity:			Initial Area:	41.62	cm^2
Diameter Top:	7.28	cm	Initial Volume:	638.66	cm^3
Middle:	7.28	cm			
Bottom:	7.28	cm	SOIL PROPERTIES		
Average:	7.28	cm	Wet Density:	2169.52	kg/cm^3
Membrane Thickness:		cm	Compaction Moisture Content:	15.40	%
Net Diameter :	7.11	cm	Saturation:		%
Ht of Spec.+Cap+Base:	25.06	cm	Dry Density:	1880.00	kg/cm^3
Ht of Cap+Base:	9.71	cm	Moisture Content		
Initial Length:	15.34	cm	After Mr Testing:	14.69	%
After Test Length:	15.29	cm			
Inside Diameter of Mold:	7.28	cm	COMMENTS:		

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.75	0.04	13.545	0.024801	0.000014	0.000162	**83.643**	0.58
41	28	11.65	0.13	27.459	0.056063	0.001349	0.000366	**75.032**	1.37
41	41	17.60	0.08	41.460	0.091770	0.000000	0.000599	**69.187**	0.31
41	55	23.64	0.07	55.707	0.139410	0.001113	0.000910	**61.197**	0.47
41	69	30.12	0.05	70.970	0.200499	0.001016	0.001309	**54.209**	0.31
21	14	5.90	0.17	13.896	0.034722	0.000000	0.000227	**61.291**	1.82
21	28	11.83	0.08	27.877	0.075916	0.001363	0.000496	**56.245**	0.71
21	41	18.62	0.10	43.865	0.135801	0.001245	0.000887	**49.470**	0.52
21	55	23.38	0.07	55.087	0.176616	0.001102	0.001153	**47.767**	0.41
21	69	29.41	0.13	69.284	0.235636	0.000000	0.001539	**45.029**	0.19
0	14	6.33	0.04	14.912	0.044653	0.000000	0.000292	**51.141**	0.34
0	28	11.92	0.11	28.074	0.094264	0.001751	0.000616	**45.623**	0.96
0	41	18.42	0.06	43.392	0.161214	0.000000	0.001053	**41.219**	0.14
0	55	23.47	0.12	55.293	0.216784	0.001349	0.001416	**39.061**	0.19
0	69	29.23	0.13	68.866	0.282363	0.001874	0.001844	**37.351**	0.24

Table B.30 M_r Data Sheet for ATH-50-222, 228, 413-WET

Resilient Modulus Test for material type 2

Soil Sample: ATH-50-222, 228, 413
Sample No.: ATH-50-224-SAT

Location: PS 228+00, PS 222+00, and PS 413+50 US-50
Athens County

Tested by: D. G. Kim
Test Date: 5/31/2002

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.30 cm
Middle: 7.30 cm
Bottom: 7.30 cm
Average: 7.30 cm
Membrane Thickness: cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.96 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.24 cm
After Test Length: 15.24 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.82 cm^2
Initial Volume: 637.44 cm^3

SOIL PROPERTIES

Wet Density: 0.00 kg/cm^3
Compaction Moisture Content: %
Saturation: %
Dry Density: kg/cm^3
Moisture Content After Mr Testing: 14.69 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14								
41	28								
41	41								
41	55								
41	69								
21	14	5.96	0.12	13.973	0.064918	0.003786	0.000426	**32.922**	2.46
21	28	11.68	0.18	27.404	0.150264	0.004148	0.000986	**27.812**	0.56
21	41	17.07	0.20	40.041	0.278296	0.003786	0.001826	**21.936**	0.35
21	55	22.94	0.44	53.811	0.598608	0.005173	0.003927	**13.704**	0.24
21	69	28.19	0.70	66.109	0.781509	0.004031	0.005127	**12.895**	0.32
0	14								
0	28								
0	41								
0	55								
0	69								

Table B.31 M_r Data Sheet for ATH-50-222, 228, 413-SAT

Resilient Modulus Test for material type 2

Soil Sample: ATH-SR7
Sample No.: ATH-SR7-DRY

Location: 7 miles West Athens County

Tested by: LSH
Test Date: 8/23/2000

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.30 cm
Middle: 7.30 cm
Bottom: 7.30 cm
Average: 7.30 cm
Membrane Thickness: 0.04 cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.78 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.07 cm
After Test Length: 14.85 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.85 cm^2
Initial Volume: 630.60 cm^3

SOIL PROPERTIES

Wet Density: 1833.76 kg/cm^3
Compaction Moisture Content: 21.20 %
Saturation: %
Dry Density: 1513.00 kg/cm^3
Moisture Content After Mr Testing: 21.80 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.84	0.15	13.677	0.018288	0.000000	0.000122	**111.876**	2.85
41	28	11.78	0.17	27.604	0.039243	0.000000	0.000262	**105.223**	1.49
41	41	17.57	0.06	41.171	0.061219	0.001433	0.000409	**100.641**	2.08
41	55	23.60	0.10	55.309	0.082821	0.001351	0.000554	**99.919**	1.51
41	69	28.73	0.14	67.309	0.102006	0.002616	0.000682	**98.754**	2.32
21	14	5.89	0.14	13.809	0.020828	0.000000	0.000139	**99.180**	2.35
21	28	11.74	0.16	27.515	0.043404	0.002340	0.000290	**94.990**	3.72
21	41	17.51	0.13	41.032	0.067996	0.000000	0.000455	**90.271**	0.67
21	55	23.27	0.15	54.514	0.091516	0.000000	0.000612	**89.108**	0.56
21	69	28.79	0.11	67.470	0.112456	0.000014	0.000752	**89.750**	0.34
0	14	5.61	0.06	13.140	0.026162	0.000000	0.000175	**75.134**	0.81
0	28	11.38	0.12	26.668	0.058112	0.001154	0.000388	**68.663**	1.02
0	41	16.99	0.14	39.821	0.090047	0.001398	0.000602	**66.161**	0.69
0	55	22.89	0.18	53.639	0.119248	0.002340	0.000797	**67.304**	1.06
0	69	28.80	0.09	67.473	0.146980	0.001170	0.000983	**68.676**	0.59

Table B.32 M_r Data Sheet for ATH-SR7-DRY

Resilient Modulus Test for material type 2

Soil Sample: ATH-SR7 | Location: 7 miles West Athens County | Tested by: LSH
Sample No.: ATH-SR7-OMC | Test Date: 8/23/2000

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.30	cm
Middle:	7.30	cm
Bottom:	7.30	cm
Average:	7.30	cm
Membrane Thickness:	0.04	cm
Net Diameter :	2.80	cm
Ht of Spec.+Cap+Base:	24.86	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	15.15	cm
After Test Length:	15.09	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.85	cm^2
Initial Volume:	633.88	cm^3

SOIL PROPERTIES

Wet Density:	1913.92	kg/cm^3
Compaction Moisture Content:	24.20	%
Saturation:		%
Dry Density:	1541.00	kg/cm^3
Moisture Content After Mr Testing:	24.30	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.87	0.07	13.748	0.021802	0.001351	0.000144	**95.575**	5.04
41	28	11.74	0.12	27.501	0.048113	0.001433	0.000318	**86.445**	1.80
41	41	18.15	0.10	42.533	0.075844	0.000000	0.000502	**84.769**	0.48
41	55	22.97	0.14	53.825	0.095702	0.001433	0.000633	**85.026**	1.01
41	69	28.94	0.15	67.805	0.120320	0.000000	0.000796	**85.184**	0.43
21	14	5.98	0.09	14.006	0.025701	0.001068	0.000170	**82.479**	3.20
21	28	11.64	0.09	27.277	0.052299	0.000000	0.000346	**78.838**	0.61
21	41	17.23	0.15	40.365	0.078461	0.000000	0.000519	**77.765**	0.69
21	55	23.43	0.12	54.892	0.104521	0.000000	0.000691	**79.385**	0.40
21	69	29.21	0.09	68.437	0.128143	0.000000	0.000848	**80.729**	0.24
0	14	5.71	0.11	13.382	0.031743	0.000989	0.000210	**63.756**	1.57
0	28	11.63	0.10	27.247	0.069740	0.001351	0.000461	**59.068**	0.79
0	41	17.19	0.12	40.267	0.097272	0.001170	0.000644	**62.579**	0.49
0	55	22.80	0.08	53.415	0.122911	0.000000	0.000813	**65.692**	0.22
0	69	28.72	0.13	67.285	0.149098	0.000000	0.000986	**68.214**	0.32

Table B.33 M_r Data Sheet for ATH-SR7-OMC

Resilient Modulus Test for material type 2

Soil Sample: ATH-SR7 | Location: 7 miles West Athens County | Tested by: LSH
Sample No.: ATH-SR7-WET | Test Date: 8/24/2000

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.30	cm
Middle:	7.30	cm
Bottom:	7.30	cm
Average:	7.30	cm
Membrane Thickness:	0.04	cm
Net Diameter :	7.11	cm
Ht of Spec.+Cap+Base:	24.91	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	15.20	cm
After Test Length:	15.18	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.85	cm^2
Initial Volume:	636.18	cm^3

SOIL PROPERTIES

Wet Density:	1918.18	kg/cm^3
Compaction Moisture Content:	27.20	%
Saturation:		%
Dry Density:	1508.00	kg/cm^3
Moisture Content After Mr Testing:	28.70	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.93	0.08	13.891	0.024592	0.001433	0.000162	**85.995**	4.60
41	28	11.63	0.13	27.241	0.055569	0.001308	0.000366	**74.467**	0.89
41	41	17.05	0.08	39.941	0.093111	0.001433	0.000613	**65.158**	0.79
41	55	23.06	0.11	54.043	0.136515	0.001170	0.000899	**60.129**	0.70
41	69	28.69	0.09	67.223	0.187269	0.002983	0.001233	**54.529**	0.91
21	14	5.76	0.02	13.496	0.028753	0.000000	0.000189	**71.289**	0.25
21	28	11.66	0.08	27.316	0.065380	0.000000	0.000430	**63.455**	0.42
21	41	17.40	0.17	40.778	0.104013	0.001136	0.000685	**59.545**	0.53
21	55	23.35	0.04	54.715	0.149073	0.000000	0.000982	**55.744**	0.09
21	69	28.79	0.02	67.464	0.203333	0.001308	0.001339	**50.392**	0.34
0	14	5.87	0.03	13.753	0.035555	0.001433	0.000234	**58.826**	2.42
0	28	11.52	0.04	26.983	0.075844	0.000000	0.000499	**54.031**	0.18
0	41	17.00	0.03	39.842	0.118550	0.001351	0.000781	**51.047**	0.58
0	55	22.81	0.08	53.441	0.172070	0.001170	0.001133	**47.170**	0.27
0	69	28.43	0.02	66.618	0.232766	0.000000	0.001533	**43.467**	0.03

Table B.34 M_r Data Sheet for ATH-SR7-WET

Resilient Modulus Test for material type 2

Soil Sample: FAI-I 70
Sample No.: FAI-I 70-DRY

Location: New off ramp Fairfield County

Tested by: LSH
Test Date: 9/2/2000

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.30	cm
Middle:	7.30	cm
Bottom:	7.30	cm
Average:	7.30	cm
Membrane Thickness:	0.04	cm
Net Diameter :	7.11	cm
Ht of Spec.+Cap+Base:	24.74	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	15.03	cm
After Test Length:	15.02	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.85	cm^2
Initial Volume:	628.85	cm^3

SOIL PROPERTIES

Wet Density:	1886.48	kg/cm^3
Compaction Moisture Content:	17.10	%
Saturation:		%
Dry Density:	1611.00	kg/cm^3
Moisture Content After Mr Testing:	16.90	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.43	0.02	15.068	0.017441	0.001351	0.000116	**130.468**	10.59
41	28	11.87	0.12	27.821	0.036601	0.000000	0.000244	**114.186**	1.15
41	41	17.69	0.20	41.441	0.060147	0.000000	0.000400	**103.504**	1.16
41	55	23.48	0.20	55.006	0.082103	0.001428	0.000547	**100.659**	1.02
41	69	29.20	0.27	68.422	0.104099	0.001170	0.000693	**98.746**	1.15
21	14	6.06	0.07	14.205	0.018313	0.000000	0.000122	**116.529**	1.34
21	28	11.81	0.08	27.677	0.041834	0.000000	0.000278	**99.387**	0.66
21	41	18.06	0.17	42.312	0.069566	0.001433	0.000463	**91.394**	1.51
21	55	23.46	0.07	54.978	0.093111	0.001433	0.000620	**88.718**	1.32
21	69	29.41	0.11	68.901	0.119248	0.001433	0.000794	**86.810**	1.11
0	14	5.83	0.04	13.654	0.080554	0.001170	0.000536	**25.466**	0.27
0	28	11.75	0.19	27.526	0.153651	0.001308	0.001023	**26.912**	0.40
0	41	17.35	0.25	40.660	0.202679	0.001510	0.001349	**30.136**	0.21
0	55	22.94	0.14	53.755	0.227010	0.002189	0.001511	**35.575**	0.36
0	69	28.79	0.22	67.460	0.248986	0.002189	0.001657	**40.703**	0.39

Table B.35 M_r Data Sheet for FAI-I70-DRY

Resilient Modulus Test for material type 2

Soil Sample: FAI-I 70
Sample No.: FAI-I 70-OMC

Location: New off ramp Fairfield County

Tested by: LSH
Test Date: 8/17/2000

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.30	cm
Middle:	7.30	cm
Bottom:	7.30	cm
Average:	7.30	cm
Membrane Thickness:	0.04	cm
Net Diameter :	7.11	cm
Ht of Spec.+Cap+Base:	24.67	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	14.95	cm
After Test Length:	14.96	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.85	cm^2
Initial Volume:	625.85	cm^3

SOIL PROPERTIES

Wet Density:	1926.06	kg/cm^3
Compaction Moisture Content:	18.60	%
Saturation:		%
Dry Density:	1624.00	kg/cm^3
Moisture Content After Mr Testing:	19.80	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.91	0.06	13.857	0.018288	0.000000	0.000122	**113.306**	1.08
41	28	11.76	0.06	27.553	0.039218	0.000000	0.000262	**105.062**	0.57
41	41	17.73	0.09	41.550	0.062763	0.000000	0.000420	**98.998**	0.50
41	55	23.48	0.10	55.011	0.088402	0.001170	0.000591	**93.070**	1.37
41	69	29.45	0.10	69.007	0.117251	0.001965	0.000784	**88.032**	1.50
21	14	6.33	0.07	14.840	0.020930	0.000000	0.000140	**106.034**	1.23
21	28	12.13	0.21	28.414	0.046568	0.001170	0.000311	**91.261**	1.17
21	41	17.65	0.10	41.347	0.073751	0.001170	0.000493	**83.850**	1.11
21	55	23.07	0.19	54.061	0.106585	0.001308	0.000713	**75.855**	0.80
21	69	29.41	0.17	68.903	0.140570	0.002505	0.000940	**73.315**	1.18
0	14	6.46	0.03	15.130	0.032023	0.001308	0.000214	**70.735**	2.65
0	28	13.17	0.00	30.855	0.075844	0.000000	0.000507	**60.836**	0.00
0	41	17.32	0.18	40.584	0.106192	0.002340	0.000710	**57.166**	0.94
0	55	23.65	0.13	55.410	0.140706	0.002855	0.000941	**58.911**	1.30
0	69	29.49	0.12	69.101	0.168040	0.004468	0.001124	**61.522**	1.40

Table B.36 M_r Data Sheet for FAI-I70-OMC

Resilient Modulus Test for material type 2

Soil Sample: FAI-I 70
Sample No.: FAI-I 70-WET
Location: New off ramp Fairfield County
Tested by: LSH
Test Date: 9/1/2000

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.30 cm
Middle: 7.30 cm
Bottom: 7.30 cm
Average: 7.30 cm
Membrane Thickness: 0.04 cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.68 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 14.97 cm
After Test Length: 14.93 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.85 cm^2
Initial Volume: 626.41 cm^3

SOIL PROPERTIES

Wet Density: 1941.60 kg/cm^3
Compaction Moisture Content: 20.00 %
Saturation: %
Dry Density: 1618.00 kg/cm^3
Moisture Content After Mr Testing: 20.40 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.86	0.10	13.727	0.023546	0.000000	0.000157	**87.157**	1.50
41	28	11.56	0.10	27.095	0.049708	0.000000	0.000332	**81.491**	0.68
41	41	17.26	0.18	40.447	0.075844	0.000000	0.000507	**79.727**	0.83
41	55	23.49	0.08	55.029	0.106177	0.001419	0.000710	**77.492**	0.88
41	69	28.80	0.11	67.493	0.132329	0.002983	0.000885	**76.278**	1.51
21	14	5.85	0.08	13.697	0.025639	0.001170	0.000171	**79.976**	3.10
21	28	11.47	0.07	26.882	0.054915	0.000000	0.000367	**73.184**	0.44
21	41	17.35	0.07	40.659	0.084216	0.001170	0.000563	**72.190**	1.09
21	55	23.37	0.24	54.762	0.115498	0.001969	0.000773	**70.893**	0.73
21	69	28.50	0.12	66.791	0.141747	0.002189	0.000948	**70.455**	0.83
0	14	5.87	0.04	13.755	0.036627	0.000000	0.000245	**56.144**	0.37
0	28	11.35	0.08	26.594	0.073254	0.000000	0.000490	**54.275**	0.38
0	41	17.57	0.06	41.162	0.109855	0.000000	0.000735	**56.017**	0.19
0	55	23.24	0.10	54.455	0.147005	0.001170	0.000983	**55.381**	0.32
0	69	28.76	0.15	67.391	0.175235	0.002340	0.001172	**57.502**	0.82

Table B.37 M_r Data Sheet for FAI-I70-WET

Resilient Modulus Test for material type 2

Soil Sample: FAI-I 70
Sample No.: FAI-I 70-SAT
Location: New off ramp Fairfield County
Tested by: DGK
Test Date: 3/31/2003

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.29 cm
Middle: 7.27 cm
Bottom: 7.27 cm
Average: 7.28 cm
Membrane Thickness: 0.04 cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.57 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 14.86 cm
After Test Length: cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.57 cm^2
Initial Volume: 617.56 cm^3

SOIL PROPERTIES

Wet Density: 2026.75 kg/cm^3
Compaction Moisture Content: 24.80 %
Saturation: %
Dry Density: 1624.00 kg/cm^3
Moisture Content After Mr Testing: %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14								
41	28								
41	41								
41	55								
41	69								
21	14	6.17	0.05	14.567	0.083290	0.000000	0.000561	**25.984**	0.20
21	28	12.02	0.12	28.368	0.158537	0.001689	0.001067	**26.588**	0.50
21	41	17.64	0.21	41.625	0.288702	0.002758	0.001943	**21.421**	0.26
21	55	23.64	0.60	55.784	0.559522	0.021102	0.003766	**14.834**	0.80
21	69	28.44	0.54	67.101	0.742750	0.025468	0.004999	**13.428**	0.27
0	14								
0	28								
0	41								
0	55								
0	69								

Table B.38 M_r Data Sheet for FAI-I70-SAT

Resilient Modulus Test for material type 2

Soil Sample: CRA-Beal
Sample No.: CRA-Beal-DRY

Location: Beal Ave near Bucyrus Crawford County

Tested by: LSH
Test Date: 8/30/2000

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.30	cm
Middle:	7.30	cm
Bottom:	7.30	cm
Average:	7.30	cm
Membrane Thickness:	0.04	cm
Net Diameter :	7.11	cm
Ht of Spec.+Cap+Base:	24.72	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	15.01	cm
After Test Length:	15.02	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.85	cm^2
Initial Volume:	628.23	cm^3

SOIL PROPERTIES

Wet Density:	1948.39	kg/cm^3
Compaction Moisture Content:	15.70	%
Saturation:		%
Dry Density:	1684.00	kg/cm^3
Moisture Content After Mr Testing:	16.20	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.83	0.17	13.672	0.017005	0.001398	0.000113	**121.180**	6.68
41	28	11.66	0.08	27.318	0.039218	0.000000	0.000261	**104.586**	0.76
41	41	17.68	0.17	41.415	0.064649	0.001308	0.000431	**96.199**	1.21
41	55	23.34	0.04	54.689	0.089554	0.001308	0.000596	**91.703**	1.41
41	69	28.94	0.07	67.802	0.116134	0.001433	0.000774	**87.666**	1.00
21	14	6.08	0.10	14.235	0.020381	0.001170	0.000136	**105.151**	6.41
21	28	11.59	0.05	27.155	0.044450	0.000000	0.000296	**91.724**	0.38
21	41	17.26	0.05	40.443	0.070612	0.000000	0.000470	**85.993**	0.23
21	55	23.21	0.09	54.378	0.098318	0.002983	0.000655	**83.100**	2.51
21	69	28.89	0.14	67.703	0.123565	0.001308	0.000823	**82.270**	0.80
0	14	5.79	0.04	13.573	0.036191	0.001068	0.000241	**56.346**	1.56
0	28	11.67	0.08	27.334	0.069042	0.001433	0.000460	**59.460**	1.25
0	41	17.66	0.14	41.369	0.098867	0.003411	0.000658	**62.876**	1.98
0	55	23.05	0.07	53.998	0.125552	0.000000	0.000836	**64.573**	0.19
0	69	28.72	0.16	67.288	0.155875	0.002983	0.001038	**64.832**	1.36

Table B.39 M_r Data Sheet for CRA-Beal-DRY

Resilient Modulus Test for material type 2

Soil Sample: CRA-Beal
Sample No.: CRA-Beal-OMC

Location: Beal Ave near Bucyrus Crawford County

Tested by: LSH
Test Date: 8/23/2000

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.30	cm
Middle:	7.30	cm
Bottom:	7.30	cm
Average:	7.30	cm
Membrane Thickness:	0.04	cm
Net Diameter :	7.11	cm
Ht of Spec.+Cap+Base:	24.93	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	15.22	cm
After Test Length:	15.20	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.85	cm^2
Initial Volume:	636.81	cm^3

SOIL PROPERTIES

Wet Density:	2024.44	kg/cm^3
Compaction Moisture Content:	17.70	%
Saturation:		%
Dry Density:	1720.00	kg/cm^3
Moisture Content After Mr Testing:	17.00	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	6.67	0.06	15.625	0.024418	0.001351	0.000161	**97.563**	5.68
41	28	11.90	0.05	27.882	0.049708	0.000000	0.000327	**85.294**	0.36
41	41	17.56	0.03	41.155	0.081513	0.001068	0.000536	**76.783**	0.96
41	55	23.03	0.37	53.953	0.119422	0.003168	0.000785	**68.718**	1.11
41	69	28.88	0.14	67.678	0.171572	0.001433	0.001128	**59.985**	0.69
21	14	6.02	0.09	14.114	0.029825	0.001433	0.000196	**72.056**	2.59
21	28	11.92	0.09	27.929	0.064856	0.001170	0.000427	**65.494**	1.05
21	41	17.34	0.08	40.631	0.104099	0.001655	0.000685	**59.066**	0.95
21	55	23.34	0.07	54.697	0.156921	0.001850	0.001032	**53.009**	0.75
21	69	29.03	0.12	68.030	0.207675	0.002340	0.001366	**49.814**	0.43
0	14	6.04	0.06	14.158	0.046020	0.001433	0.000303	**46.809**	1.09
0	28	11.68	0.02	27.360	0.099913	0.001170	0.000657	**41.645**	0.53
0	41	17.38	0.13	40.733	0.164247	0.001170	0.001080	**37.711**	0.30
0	55	23.45	0.08	54.951	0.221264	0.002987	0.001455	**37.770**	0.61
0	69	28.81	0.34	67.517	0.254218	0.003411	0.001672	**40.387**	0.41

Table B.40 M_r Data Sheet for CRA-Beal-OMC

Resilient Modulus Test for material type 2

Soil Sample: CRA-Beal
Sample No.: CRA-Beal-WET

Location: Beal Ave near Bucyrus Crawford County

Tested by: LSH
Test Date: 8/24/2000

SPECIMEN INFORMATION

	Specific Gravity:		
Diameter	Top:	7.30	cm
	Middle:	7.30	cm
	Bottom:	7.30	cm
	Average:	7.30	cm
	Membrane Thickness:	0.04	cm
	Net Diameter :	7.11	cm
	Ht of Spec.+Cap+Base:	25.00	cm
	Ht of Cap+Base:	9.71	cm
	Initial Length:	15.29	cm
	After Test Length:	15.25	cm
	Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.85	cm^2
Initial Volume:	639.95	cm^3

SOIL PROPERTIES

Wet Density:	2018.14	kg/cm^3
Compaction Moisture Content:	19.70	%
Saturation:		%
Dry Density:	1686.00	kg/cm^3
Moisture Content After Mr Testing:	20.60	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.95	0.10	13.951	0.041859	0.000000	0.000274	**50.889**	0.87
41	28	11.78	0.09	27.592	0.091542	0.001850	0.000600	**46.041**	1.15
41	41	17.67	0.08	41.395	0.152751	0.001419	0.001000	**41.381**	0.23
41	55	23.55	0.10	55.176	0.238521	0.002189	0.001562	**35.323**	0.25
41	69	29.25	0.10	68.540	0.342614	0.003028	0.002244	**30.547**	0.22
21	14	5.96	0.20	13.972	0.049028	0.002505	0.000321	**43.575**	2.06
21	28	11.73	0.09	27.495	0.108522	0.001510	0.000711	**38.689**	0.27
21	41	17.56	0.08	41.147	0.185151	0.001170	0.001213	**33.935**	0.28
21	55	23.32	0.04	54.649	0.288360	0.002505	0.001889	**28.939**	0.27
21	69	29.00	0.07	67.953	0.401696	0.001433	0.002631	**25.830**	0.09
0	14	6.09	0.08	14.264	0.063287	0.002189	0.000414	**34.437**	0.81
0	28	11.76	0.05	27.545	0.146980	0.001170	0.000963	**28.616**	0.21
0	41	17.24	0.09	40.391	0.257856	0.001433	0.001689	**23.918**	0.14
0	55	23.40	0.13	54.819	0.408000	0.002136	0.002672	**20.516**	0.09
0	69	29.36	0.13	68.783	0.551825	0.001850	0.003614	**19.033**	0.06

Table B.41 M_r Data Sheet for CRA-Beal-WET

Resilient Modulus Test for material type 2

Soil Sample: CRA-Beal
Sample No.: CRA-Beal-WET

Location: Beal Ave near Bucyrus Crawford County

Tested by: DGK
Test Date: 7/15/2002

SPECIMEN INFORMATION

	Specific Gravity:		
Diameter	Top:	7.29	cm
	Middle:	7.29	cm
	Bottom:	7.29	cm
	Average:	7.29	cm
	Membrane Thickness:	0.04	cm
	Net Diameter :	7.11	cm
	Ht of Spec.+Cap+Base:	24.92	cm
	Ht of Cap+Base:	9.71	cm
	Initial Length:	15.21	cm
	After Test Length:	15.21	cm
	Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.74	cm^2
Initial Volume:	634.82	cm^3

SOIL PROPERTIES

Wet Density:	2018.14	kg/cm^3
Compaction Moisture Content:	19.70	%
Saturation:		%
Dry Density:	1686.00	kg/cm^3
Moisture Content After Mr Testing:	20.60	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14								
41	28								
41	41								
41	55								
41	69								
21	14	5.97	0.17	14.033	0.052451	0.002181	0.000345	**40.717**	0.96
21	28	11.55	0.24	27.134	0.116596	0.002580	0.000767	**35.422**	1.45
21	41	17.41	0.04	40.913	0.229491	0.002758	0.001509	**27.119**	0.29
21	55	23.32	0.26	54.793	0.347938	0.005516	0.002288	**23.956**	0.36
21	69	29.60	0.50	69.555	0.583571	0.017499	0.003837	**18.136**	0.38
0	14								
0	28								
0	41								
0	55								
0	69								

Table B.42 M_r Data Sheet for CRA-Beal-SAT

Resilient Modulus Test for material type 2

Soil Sample: HEN-SR6/24
Sample No.: HEN-SR6/24-DRY

Location: State route 6/24 Henry County

Tested by: LSH
Test Date: 8/30/2000

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.30 cm
Middle: 7.30 cm
Bottom: 7.30 cm
Average: 7.30 cm
Membrane Thickness: 0.04 cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.86 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.15 cm
After Test Length: 15.15 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.85 cm^2
Initial Volume: 634.02 cm^3

SOIL PROPERTIES

Wet Density: 1921.58 kg/cm^3
Compaction Moisture Content: 17.60 %
Saturation: %
Dry Density: 1634.00 kg/cm^3
Moisture Content After Mr Testing: 17.80 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41	14	5.96	0.09	13.960	0.017983	0.000000	0.000119	**117.604**	1.68
41	28	11.62	0.13	27.231	0.036601	0.000000	0.000242	**112.707**	1.30
41	41	17.31	0.07	40.559	0.057531	0.000000	0.000380	**106.799**	0.46
41	55	23.55	0.17	55.172	0.082647	0.001433	0.000546	**101.150**	1.53
41	69	28.85	0.15	67.593	0.104597	0.000000	0.000690	**97.897**	0.49
21	14	5.95	0.04	13.953	0.020930	0.000000	0.000138	**100.995**	0.74
21	28	11.74	0.08	27.511	0.044389	0.000034	0.000293	**93.890**	0.59
21	41	17.56	0.18	41.146	0.067996	0.000000	0.000449	**91.672**	0.95
21	55	23.34	0.27	54.683	0.092065	0.001170	0.000608	**89.981**	0.27
21	69	28.72	0.16	67.293	0.113100	0.001308	0.000747	**90.143**	1.01
0	14	5.87	0.13	13.746	0.026162	0.000000	0.000173	**79.595**	1.71
0	28	11.40	0.04	26.720	0.054940	0.000000	0.000363	**73.677**	0.24
0	41	17.64	0.08	41.343	0.081600	0.001170	0.000539	**76.765**	0.99
0	55	23.31	0.16	54.613	0.109332	0.001170	0.000722	**75.679**	0.96
0	69	28.86	0.25	67.621	0.133899	0.001170	0.000884	**76.508**	0.61

Table B.43 M_r Data Sheet for HEN-SR6, 24-DRY

Resilient Modulus Test for material type 2

Soil Sample: HEN-SR6/24
Sample No.: HEN-SR6/24-OMC

Location: State route 6/24 Henry County

Tested by: LSH
Test Date: 8/26/2000

SPECIMEN INFORMATION

Specific Gravity:
Diameter Top: 7.30 cm
Middle: 7.30 cm
Bottom: 7.30 cm
Average: 7.30 cm
Membrane Thickness: 0.04 cm
Net Diameter : 7.11 cm
Ht of Spec.+Cap+Base: 24.96 cm
Ht of Cap+Base: 9.71 cm
Initial Length: 15.25 cm
After Test Length: 15.23 cm
Inside Diameter of Mold: 7.28 cm

SOIL SPECIMEN VOLUME

Initial Area: 41.85 cm^2
Initial Volume: 638.20 cm^3

SOIL PROPERTIES

Wet Density: 2016.46 kg/cm^3
Compaction Moisture Content: 19.60 %
Saturation: %
Dry Density: 1686.00 kg/cm^3
Moisture Content After Mr Testing: 19.80 %

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41.4	13.8	5.90	0.09	13.819	0.024443	0.001390	0.000160	**86.317**	3.74
41.4	27.6	11.55	0.16	27.062	0.049708	0.000000	0.000326	**82.956**	1.14
41.4	41.4	17.56	0.09	41.149	0.077414	0.001433	0.000508	**81.011**	1.13
41.4	55.2	23.03	0.10	53.971	0.099390	0.000000	0.000652	**82.743**	0.35
41.4	69.0	28.87	0.10	67.643	0.124480	0.001433	0.000817	**82.808**	0.71
20.7	13.8	5.89	0.09	13.810	0.028778	0.000000	0.000189	**73.121**	1.12
20.7	27.6	11.42	0.11	26.755	0.056510	0.001433	0.000371	**72.167**	1.28
20.7	41.4	17.26	0.20	40.444	0.084565	0.001351	0.000555	**72.879**	0.50
20.7	55.2	23.09	0.15	54.097	0.109481	0.000989	0.000718	**75.296**	0.65
20.7	69.0	28.79	0.21	67.469	0.136017	0.002136	0.000893	**75.592**	0.83
0.0	13.8	5.72	0.07	13.407	0.039243	0.000000	0.000258	**52.058**	0.62
0.0	27.6	11.30	0.04	26.486	0.077937	0.001170	0.000511	**51.792**	0.78
0.0	41.4	17.30	0.05	40.530	0.115087	0.000000	0.000755	**53.662**	0.17
0.0	55.2	23.23	0.07	54.429	0.143840	0.000000	0.000944	**57.659**	0.17
0.0	69.0	28.70	0.08	67.255	0.172095	0.001170	0.001129	**59.551**	0.46

Table B.44 M_r Data Sheet for HEN-SR6, 24-OMC

Resilient Modulus Test for material type 2

Soil Sample: HEN-SR6/24
Sample No.: HEN-SR6/24-WET

Location: State route 6/24 Henry County

Tested by: LSH
Test Date: 8/21/2000

SPECIMEN INFORMATION

Specific Gravity:		
Diameter Top:	7.30	cm
Middle:	7.30	cm
Bottom:	7.30	cm
Average:	7.30	cm
Membrane Thickness:	0.04	cm
Net Diameter :	7.11	cm
Ht of Spec.+Cap+Base:	24.93	cm
Ht of Cap+Base:	9.71	cm
Initial Length:	15.22	cm
After Test Length:	15.17	cm
Inside Diameter of Mold:	7.28	cm

SOIL SPECIMEN VOLUME

Initial Area:	41.85	cm^2
Initial Volume:	636.95	cm^3

SOIL PROPERTIES

Wet Density:	2003.97	kg/cm^3
Compaction Moisture Content:	21.60	%
Saturation:		%
Dry Density:	1648.00	kg/cm^3
Moisture Content After Mr Testing:	21.80	%

COMMENTS:

Chamber Confining Pressure (kPa)	Nominal Deviaator Stress (kPa)	Mean Deviator Load (kg)	Standard Deviation of Load (kg)	Mean Applied Deviator Stress (kPa)	Mean Recoverable Deformation (mm)	Standard Deviation of Recoverable Deformation (mm)	Mean of Resilient Strain (mm/mm)	Mean of Mr (MPa)	Standard Deviation of Mr (MPa)
41.4	13.8	5.90	0.06	13.824	0.031394	0.000000	0.000207	**66.906**	0.70
41.4	27.6	11.70	0.06	27.413	0.073228	0.000000	0.000482	**56.879**	0.31
41.4	41.4	17.73	0.08	41.533	0.135992	0.000000	0.000895	**46.405**	0.20
41.4	55.2	23.02	0.23	53.939	0.199827	0.002983	0.001315	**41.016**	0.32
41.4	69.0	29.13	0.13	68.246	0.292926	0.001679	0.001928	**35.400**	0.09
20.7	13.8	5.92	0.07	13.861	0.036627	0.000000	0.000241	**57.500**	0.69
20.7	27.6	11.41	0.04	26.733	0.081077	0.000000	0.000534	**50.098**	0.15
20.7	41.4	16.90	0.02	39.588	0.144520	0.001308	0.000951	**41.623**	0.32
20.7	55.2	23.31	0.13	54.630	0.238870	0.001351	0.001572	**34.750**	0.26
20.7	69.0	28.68	0.04	67.194	0.334249	0.002189	0.002200	**30.546**	0.21
0.0	13.8	5.97	0.04	13.980	0.052324	0.000000	0.000344	**40.596**	0.26
0.0	27.6	11.42	0.07	26.752	0.125552	0.001850	0.000826	**32.380**	0.47
0.0	41.4	17.32	0.06	40.587	0.228056	0.001170	0.001501	**27.041**	0.16
0.0	55.2	22.90	0.10	53.670	0.335818	0.002340	0.002210	**24.284**	0.21
0.0	69.0	28.63	0.09	67.093	0.451404	0.003968	0.002971	**22.584**	0.14

Table B.45 M_r Data Sheet for HEN-SR6, 24-WET

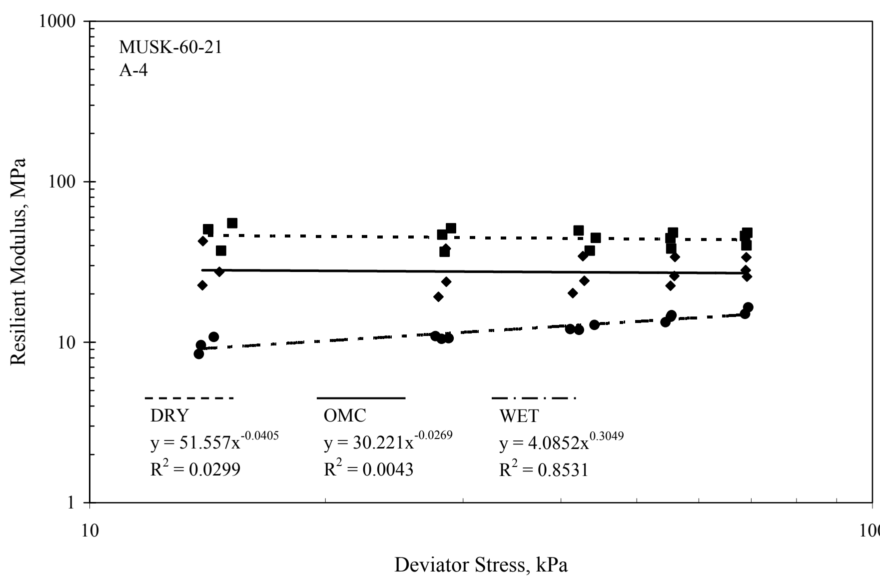

Figure B.1 M_r Test Data MUS-60-21

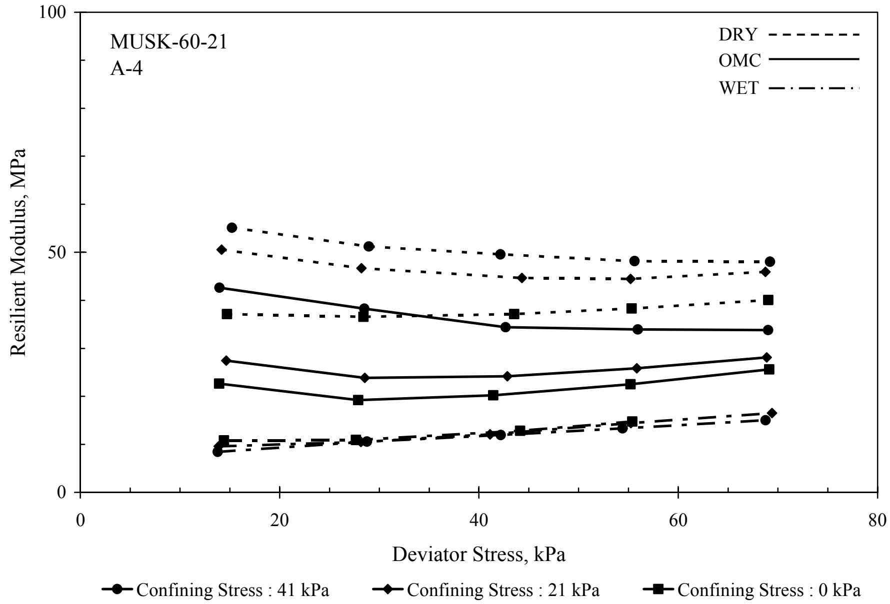

Figure B.2 M_r Test Data MUS-60-21

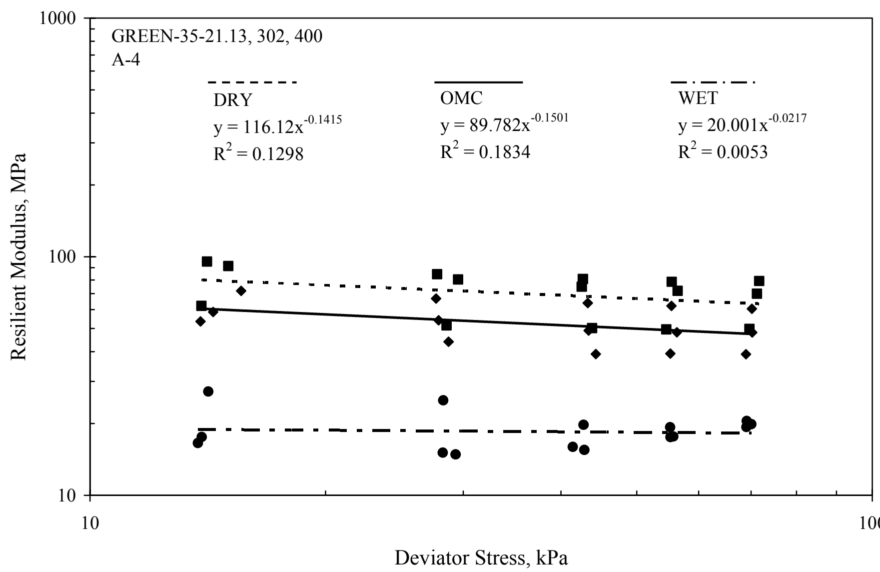

Figure B.3 M_r Test Data GRE-35-21.13, 302, 400

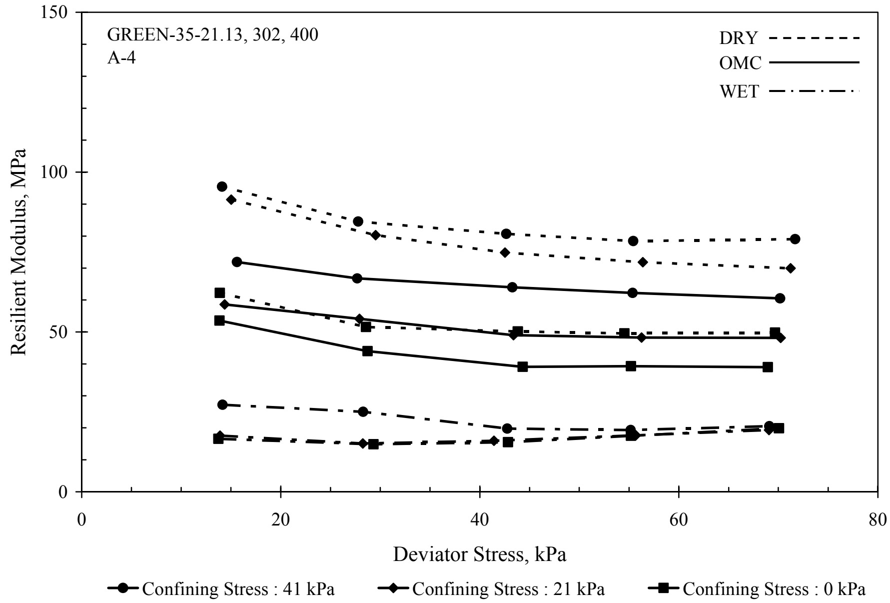

Figure B.4 M_r Test Data GRE-35-21.13, 302, 400

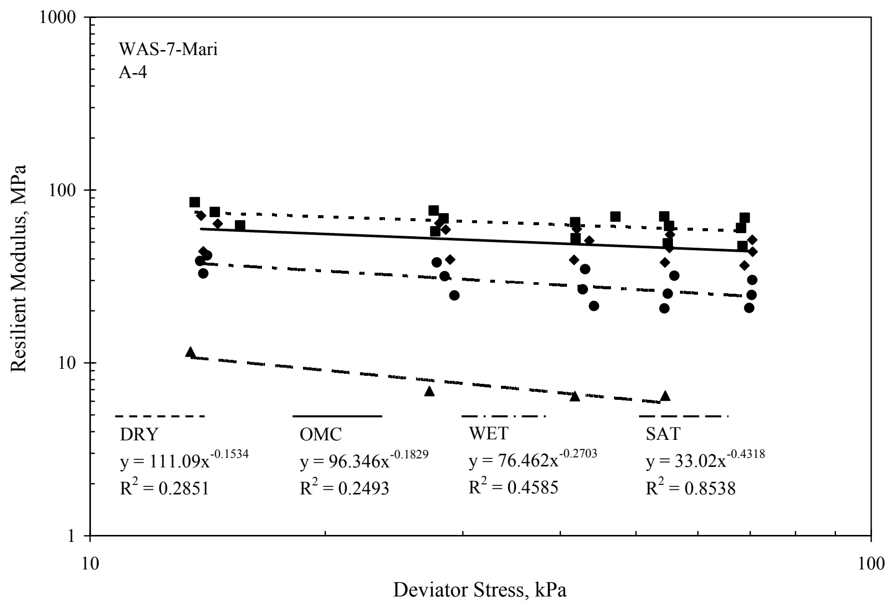

Figure B.5 M_r Test Data WAS-7-Mari

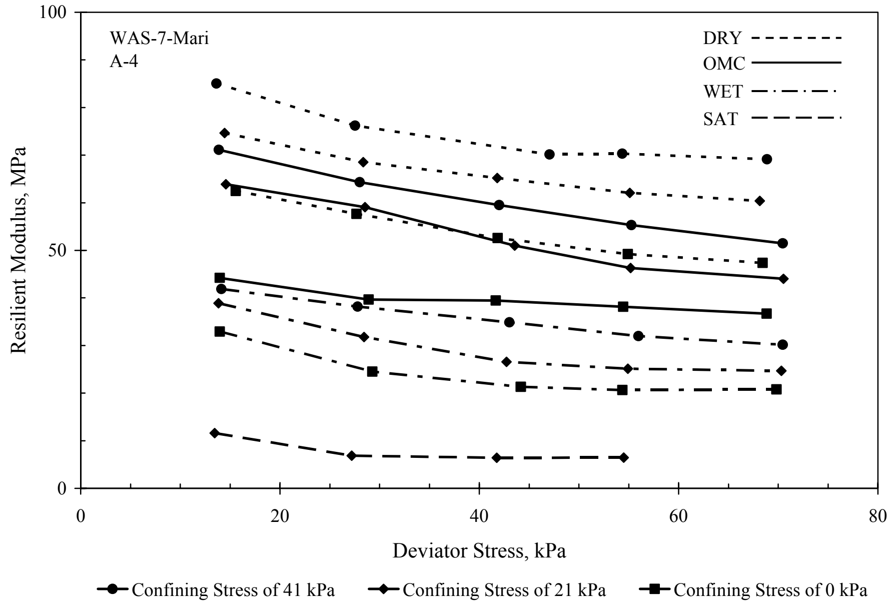

Figure B.6 M_r Test Data WAS-7-Mari

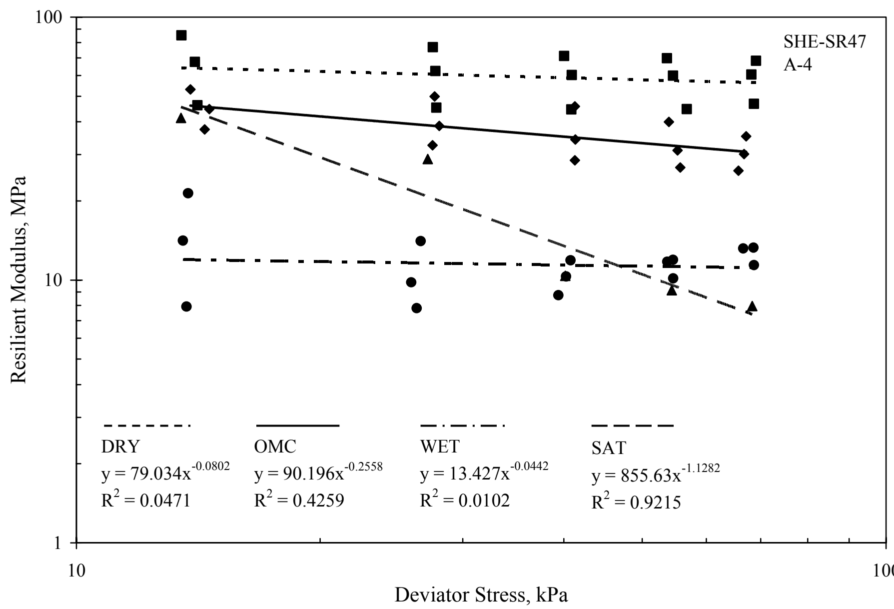

Figure B.7 M_r Test Data SHE-SR47

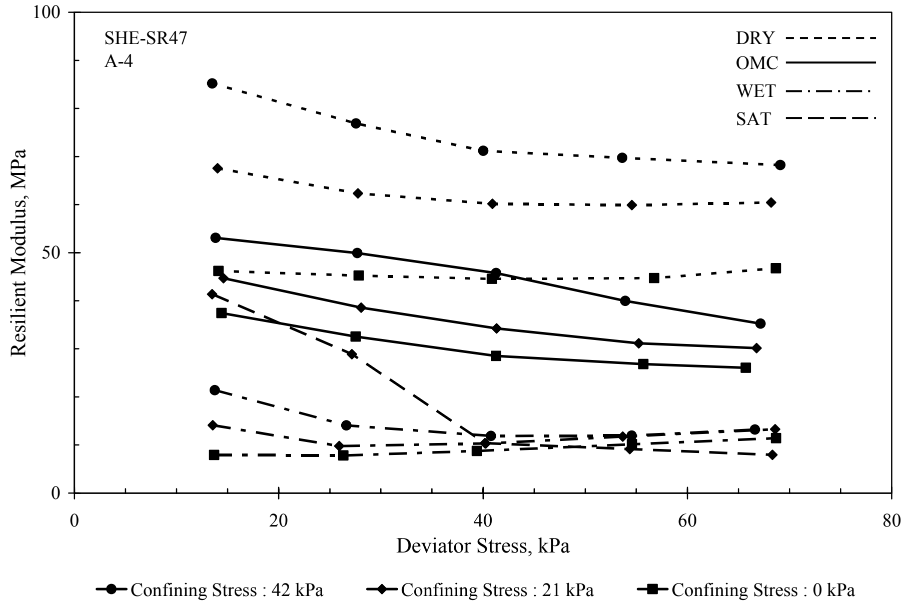

Figure B.8 M_r Test Data SHE-SR47

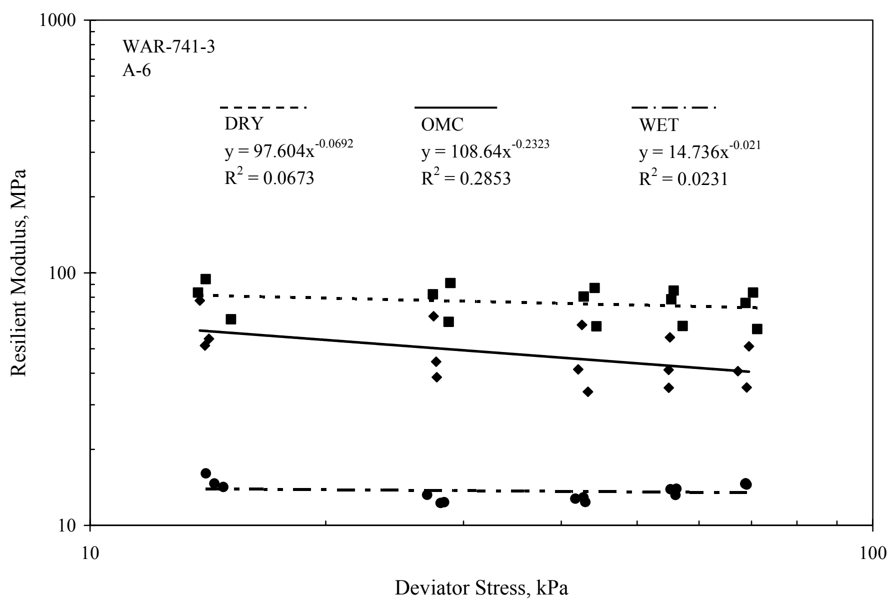

Figure B.9 M_r Test Data WAR-741-3

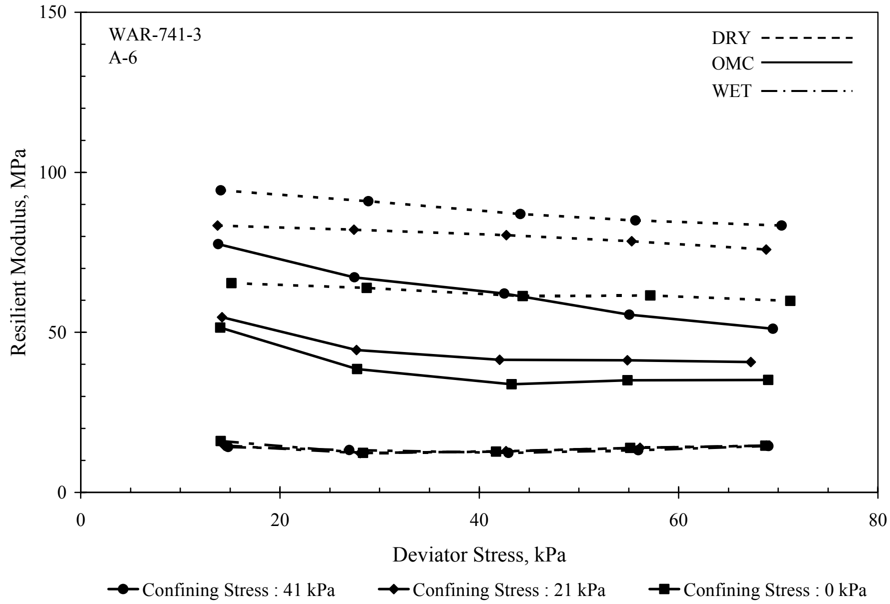

Figure B.10 M_r Test Data WAR-741-3

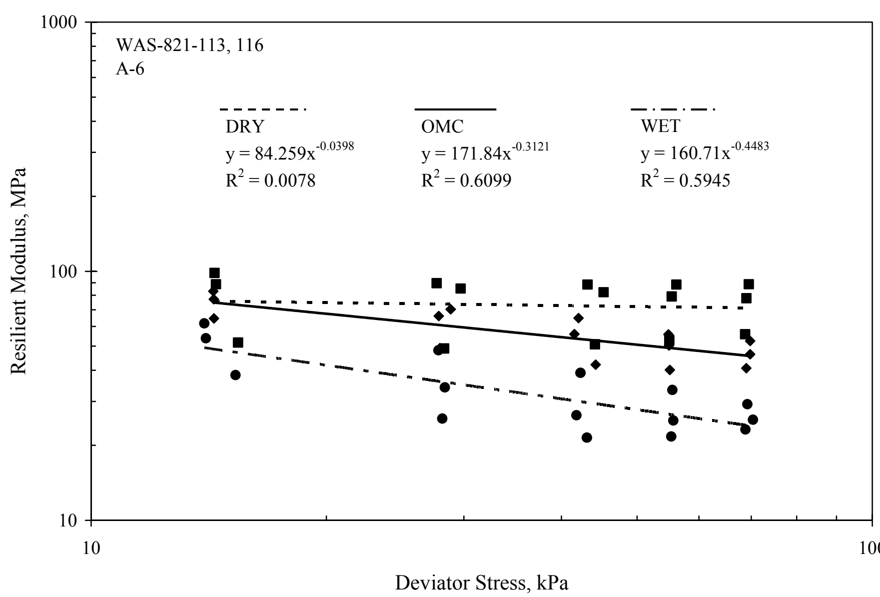

Figure B.11 M_r Test Data WAS-821-113, 116

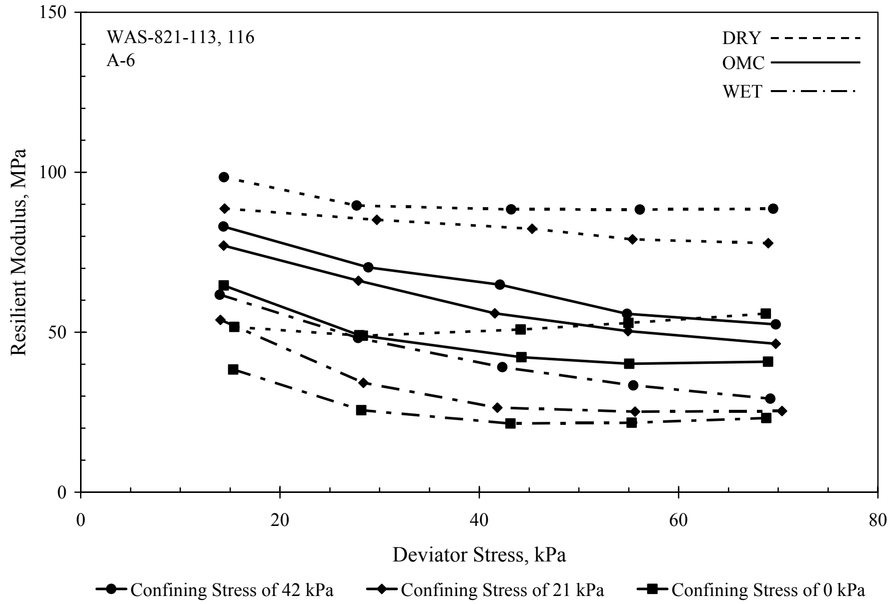

Figure B.12 M_r Test Data WAS-821-113, 116

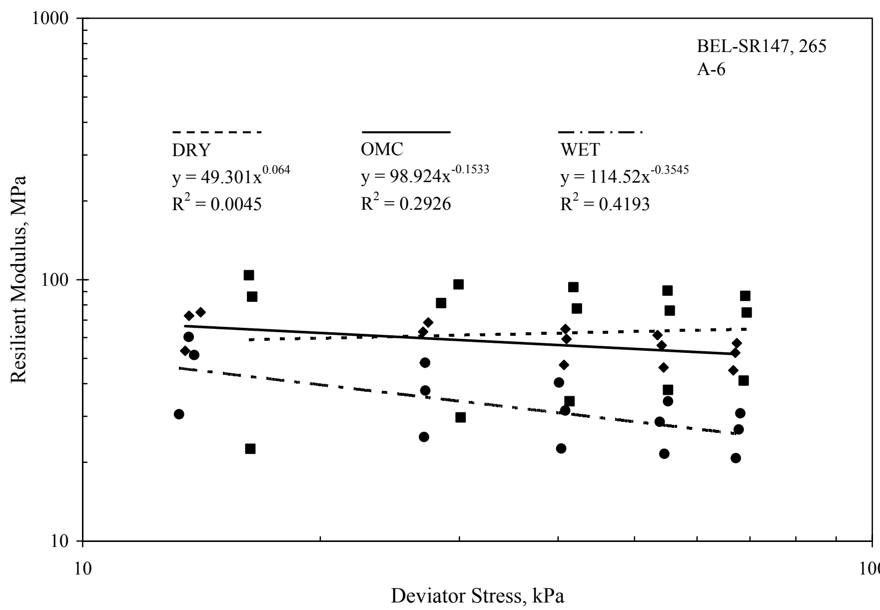

Figure B.13 M_r Test Data BEL-SR147, 265

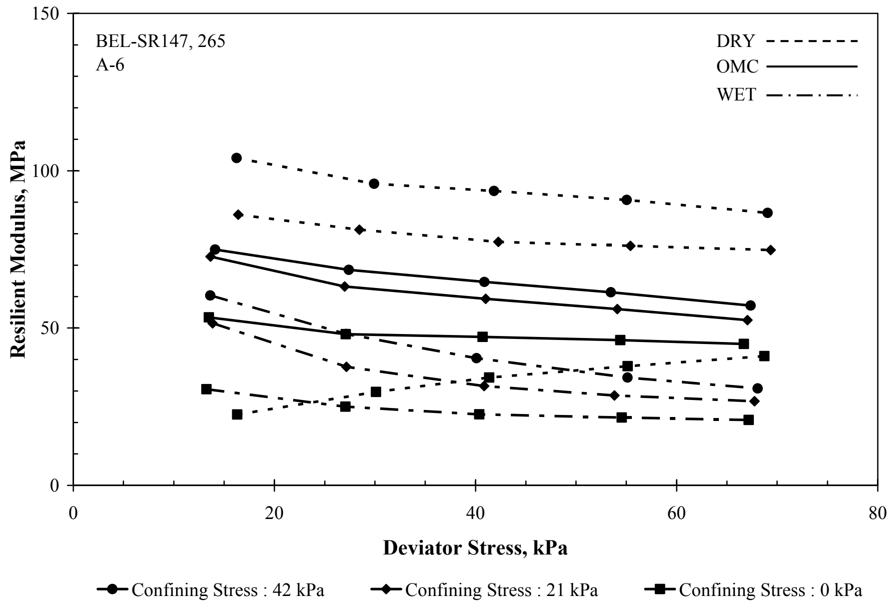

Figure B.14 M_r Test Data BEL-SR147, 265

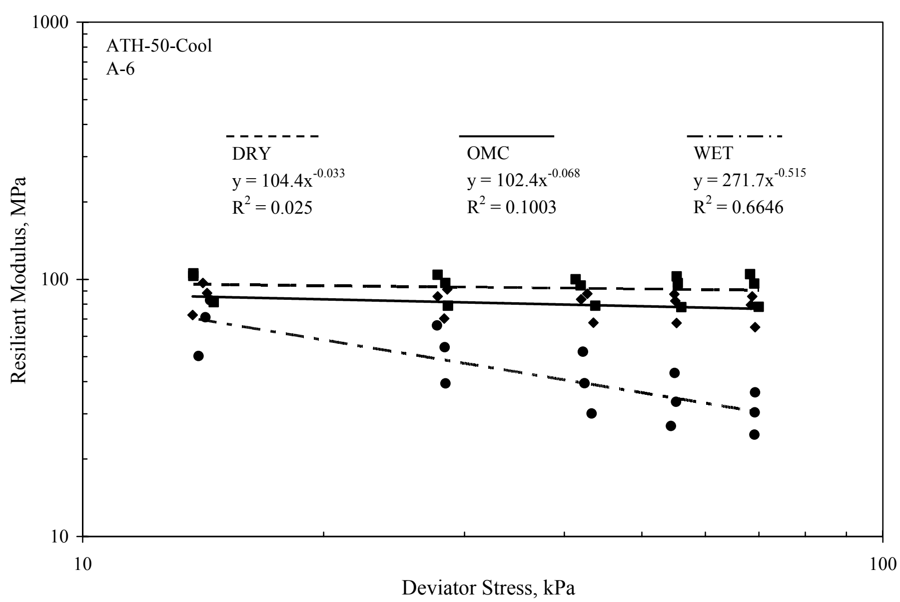

Figure B.15 M_r Test Data ATH-50-Cool

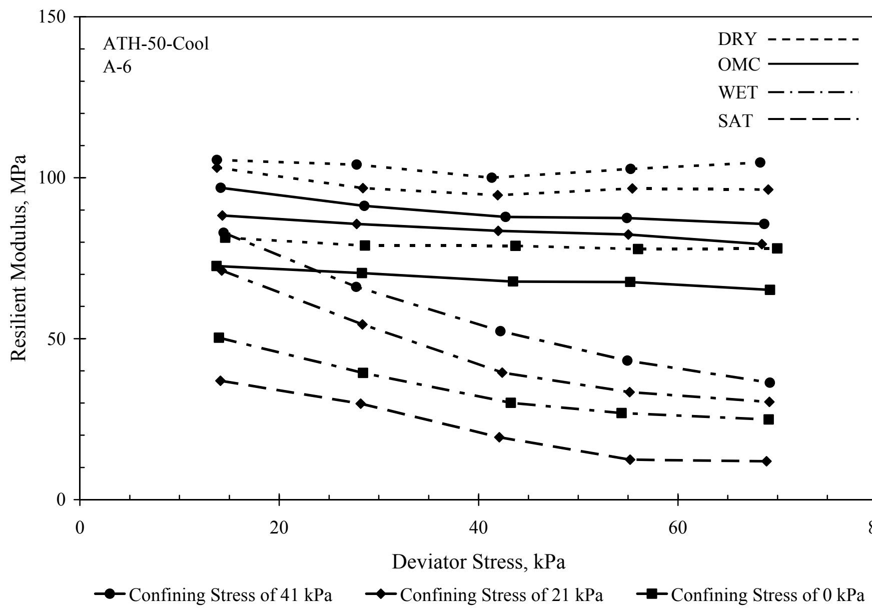

Figure B.16 M_r Test Data ATH-50-Cool

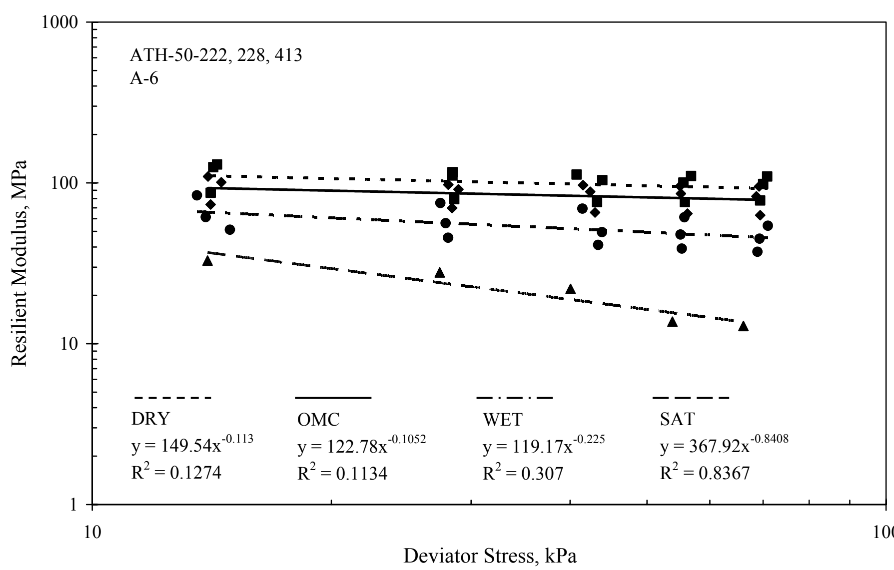

Figure B.17 M_r Test Data ATH-50-222, 228, 413

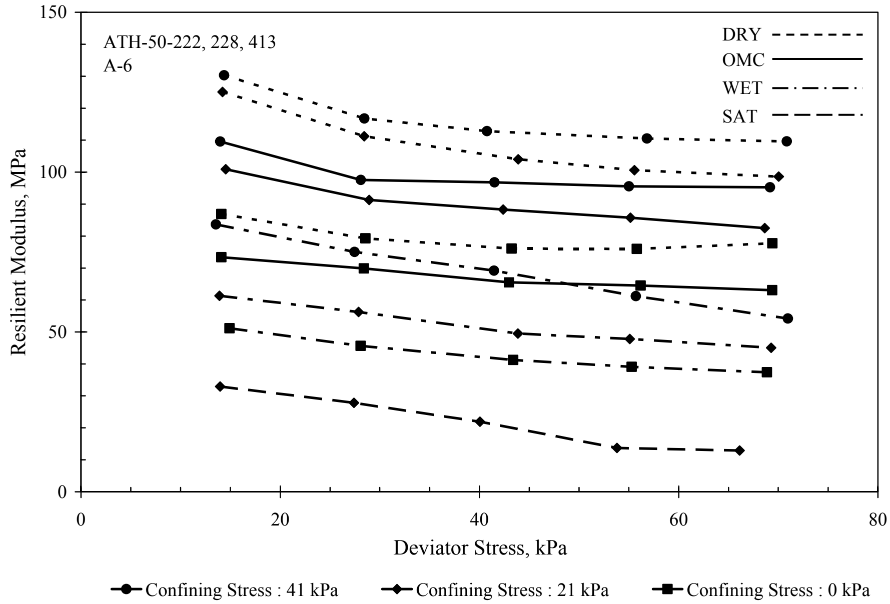

Figure B.18 M_r Test Data ATH-50-222, 228, 413

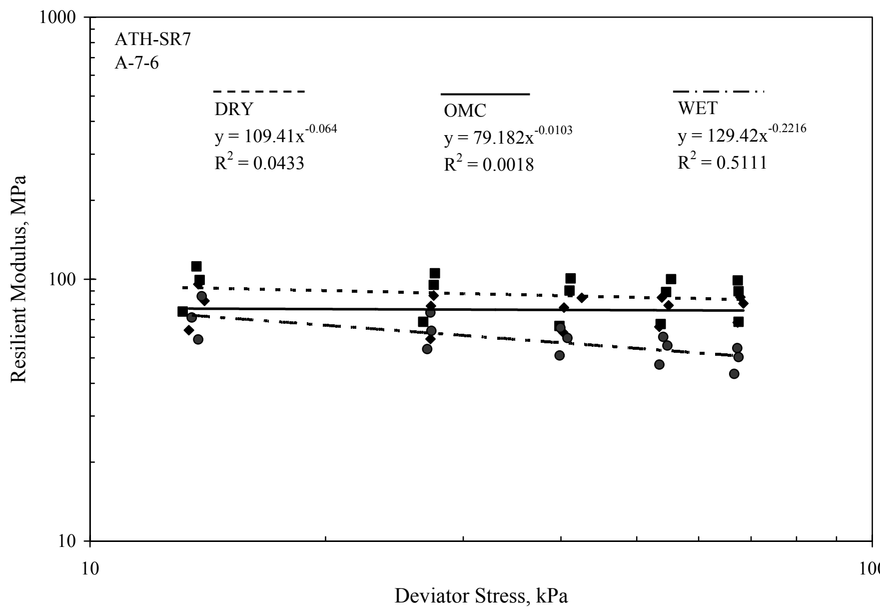

Figure B.19 M_r Test Data ATH-SR7

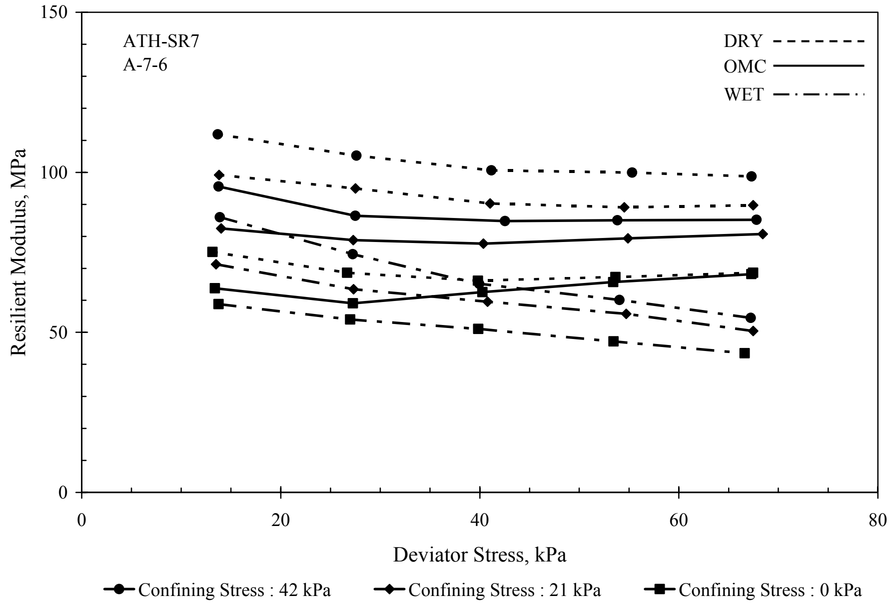

Figure B.20 M_r Test Data ATH-SR7

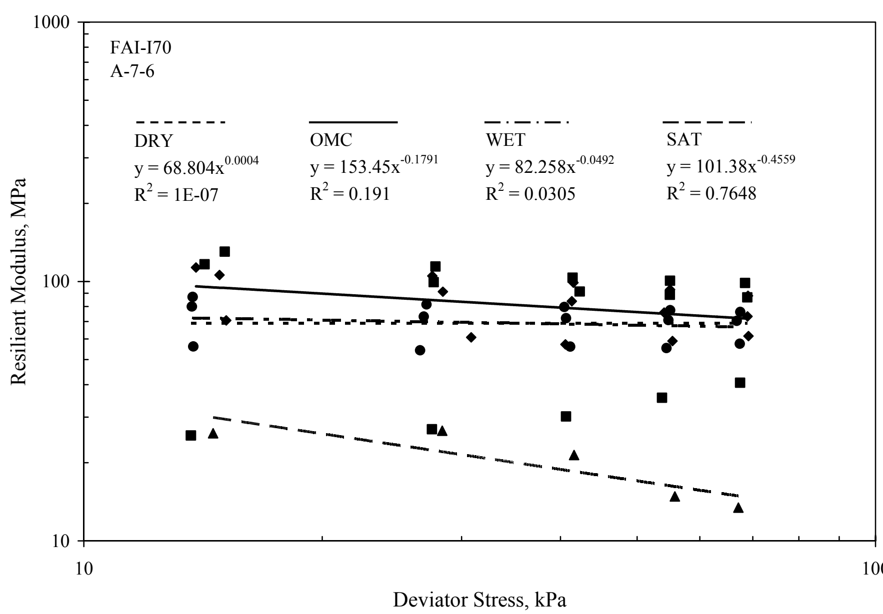

Figure B.21 M_r Test Data FAI-I70

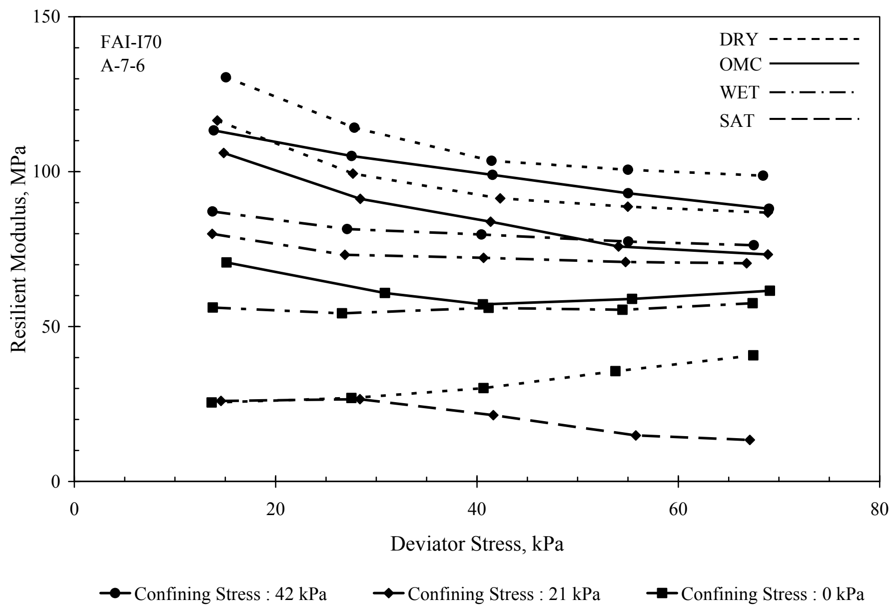

Figure B.22 M_r Test Data FAI-I70

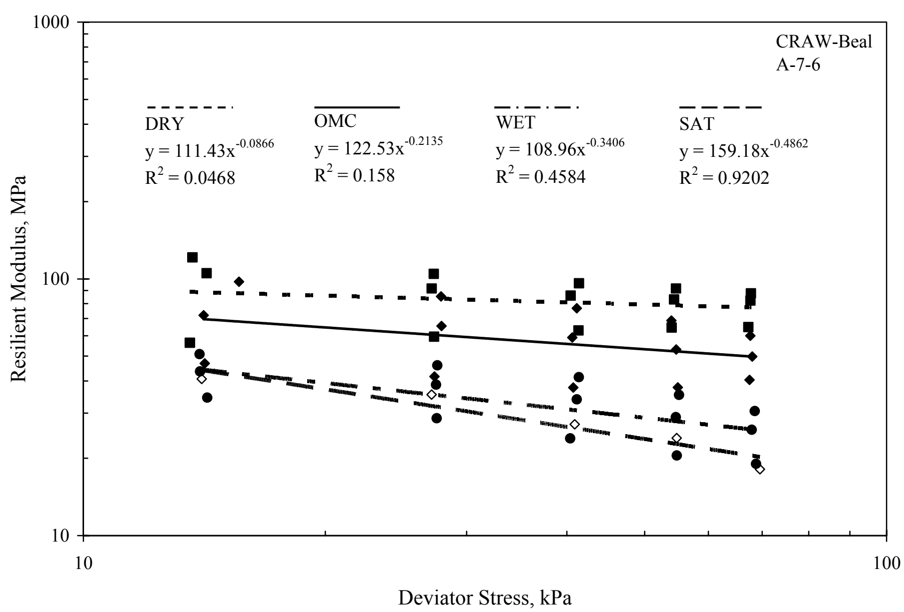

Figure B.23 M_r Test Data CRA-Beal

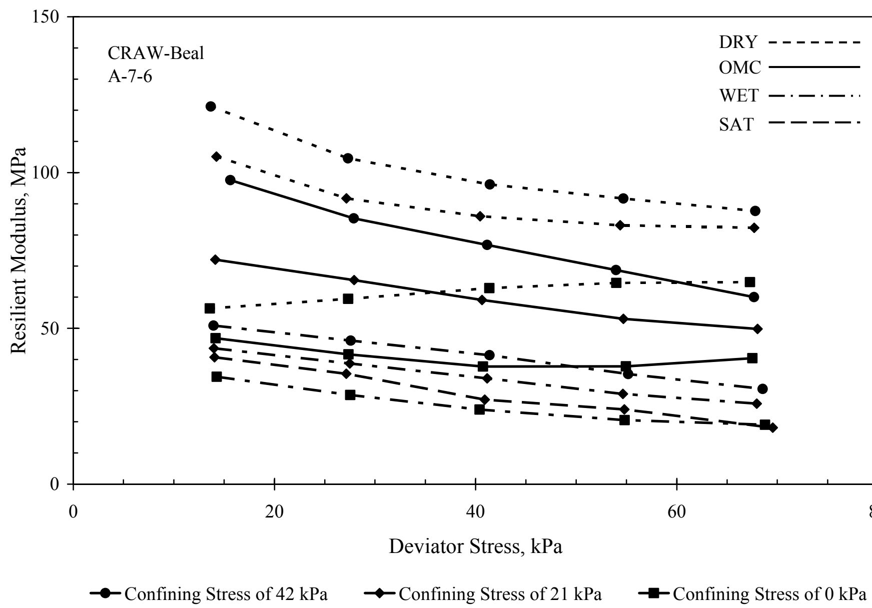

Figure B.24 M_r Test Data CRA-Beal

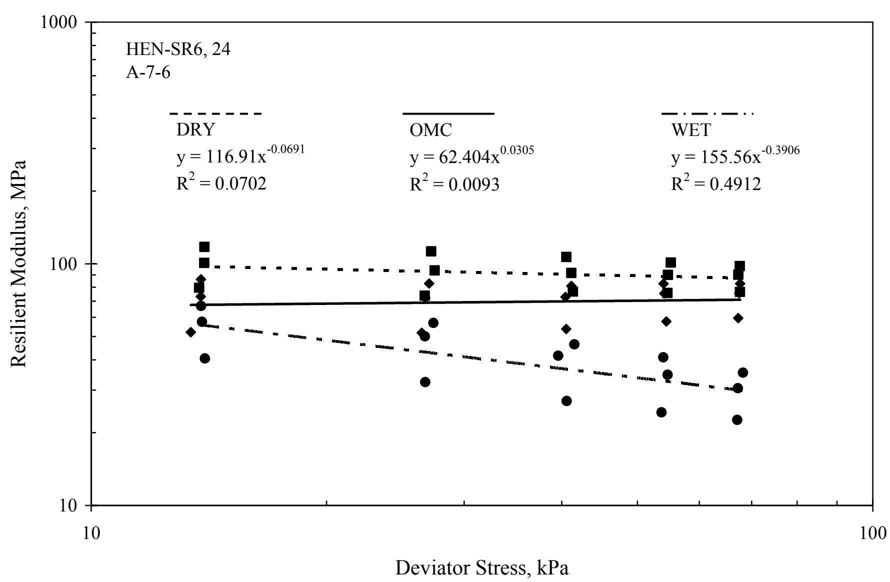

Figure B.25 M_r Test Data HEN-SR6, 24

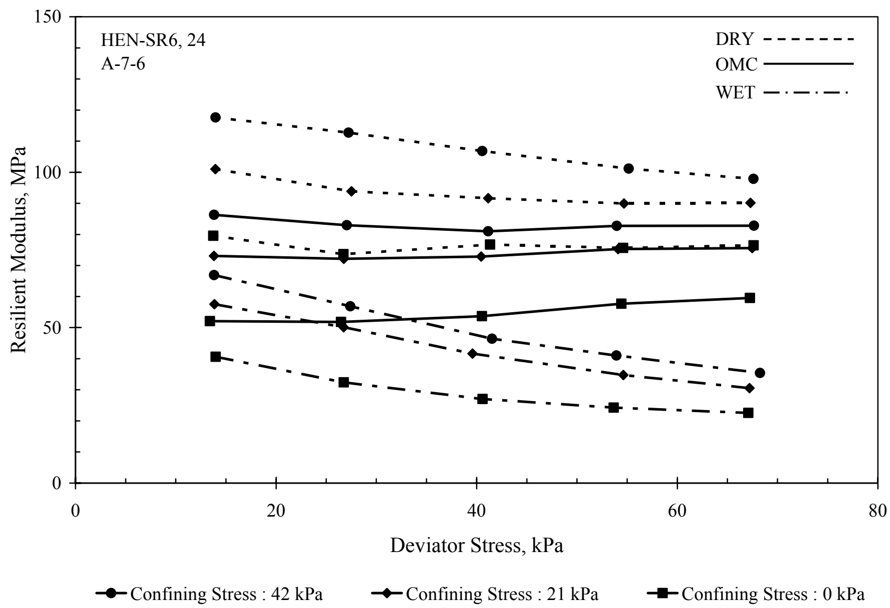

Figure B.26 M_r Test Data HEN-SR6, 24

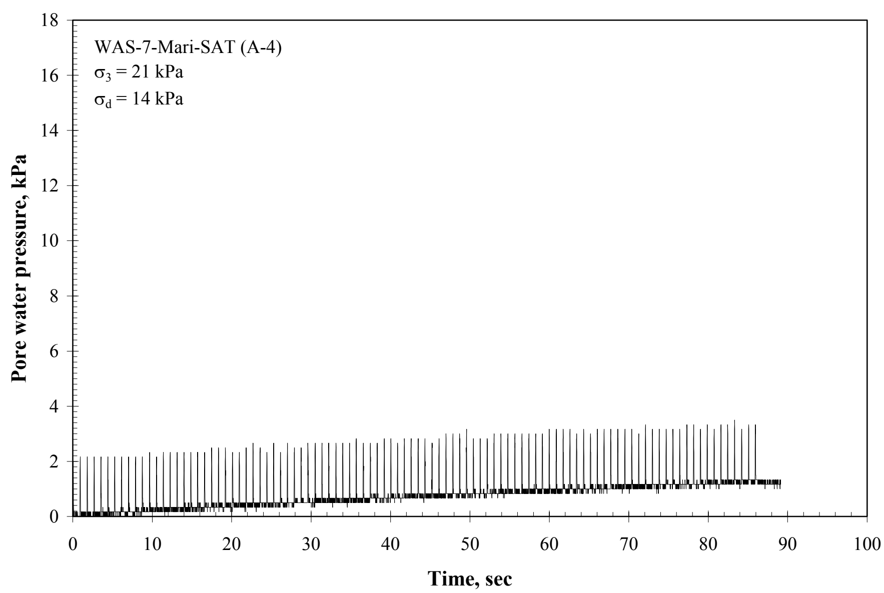

Figure B.27 Cyclic Pore Water Pressure WAS-7-Mari-SAT

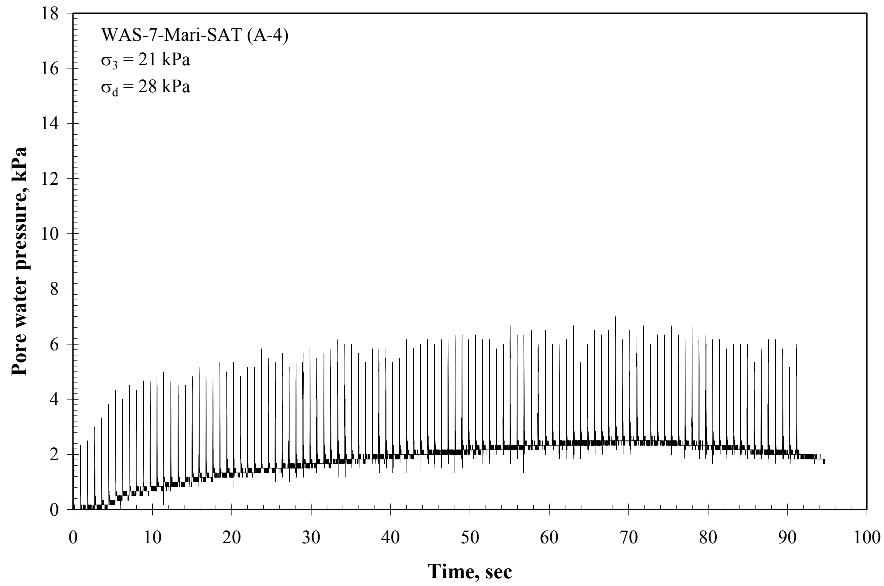

Figure B.28 Cyclic Pore Water Pressure WAS-7-Mari-SAT

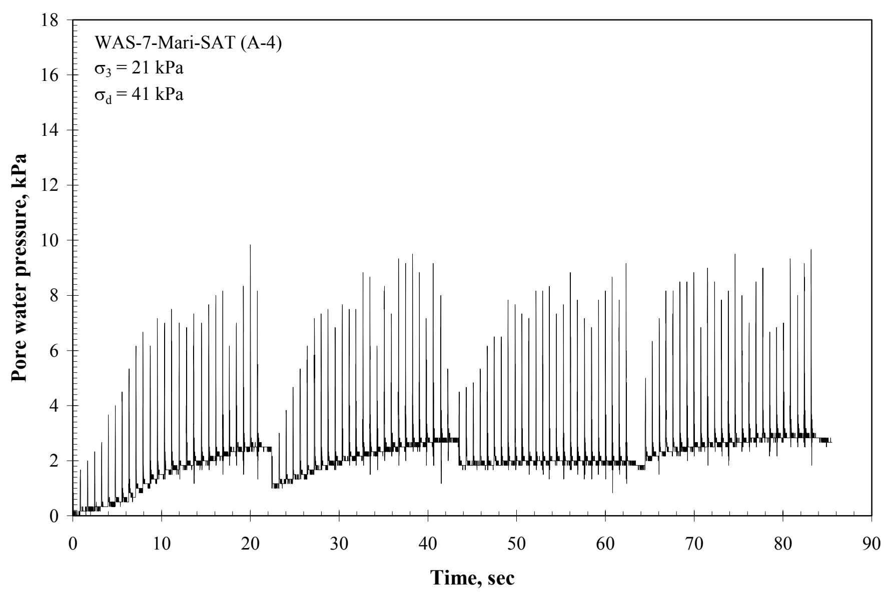

Figure B.29 Cyclic Pore Water Pressure WAS-7-Mari-SAT

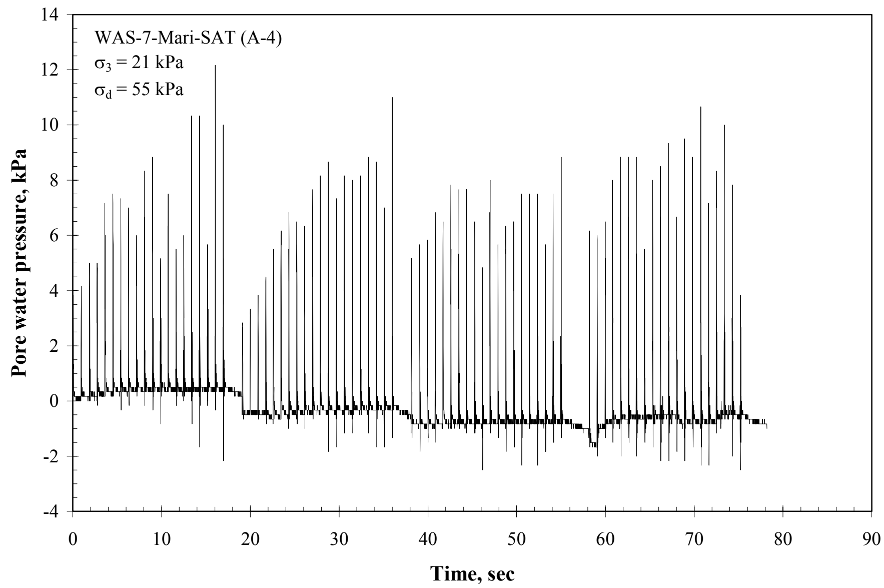

Figure B.30 Cyclic Pore Water Pressure WAS-7-Mari-SAT

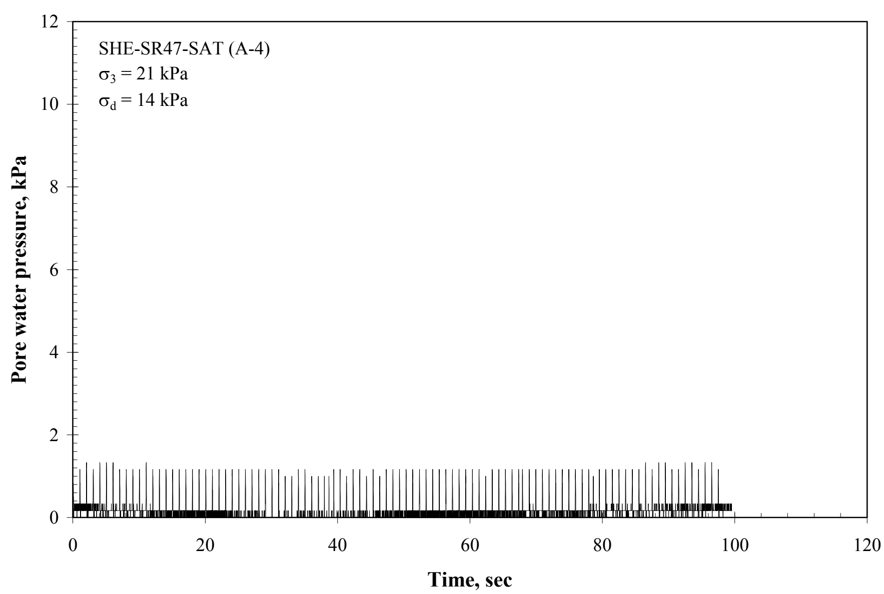

Figure B.31 Cyclic Pore Water Pressure SHE-SR47-SAT

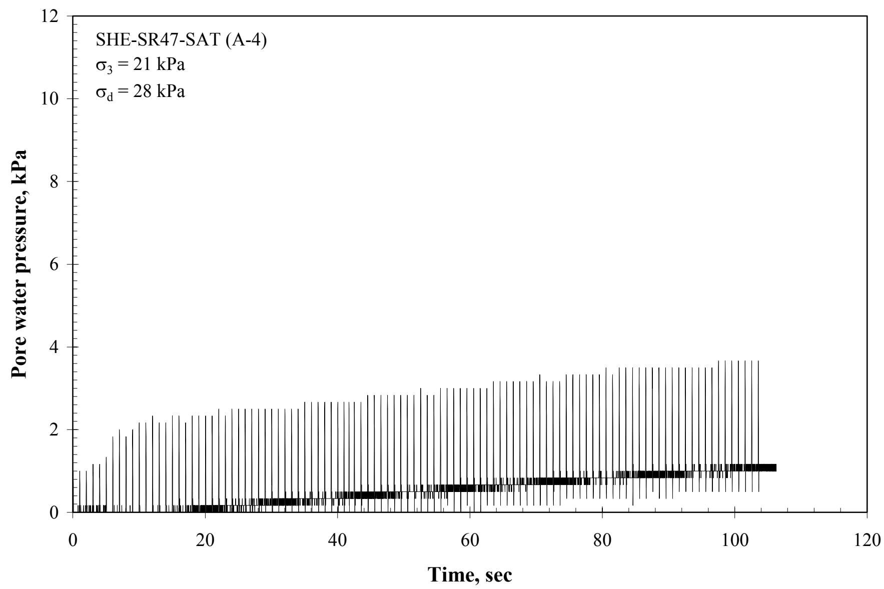

Figure B.32 Cyclic Pore Water Pressure SHE-SR47-SAT

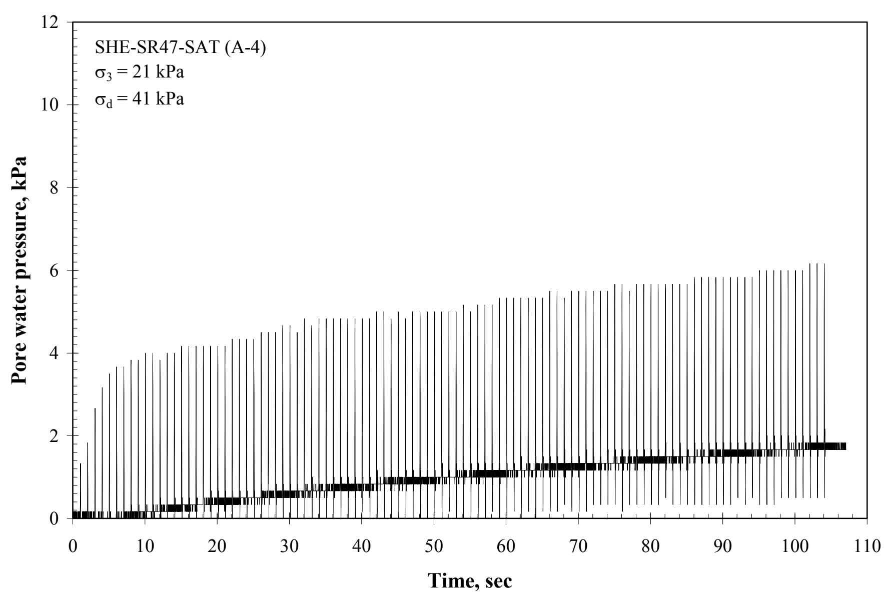

Figure B.33 Cyclic Pore Water Pressure SHE-SR47-SAT

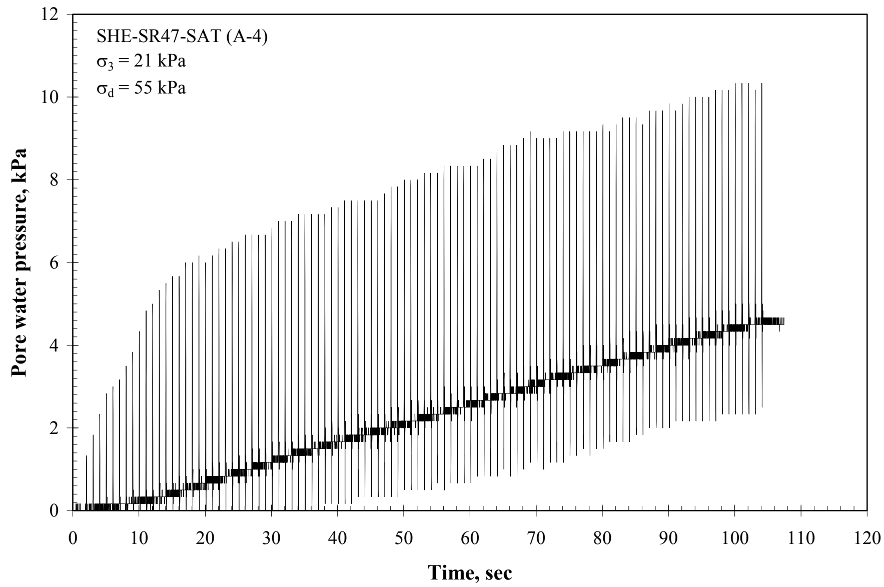

Figure B.34 Cyclic Pore Water Pressure SHE-SR47-SAT

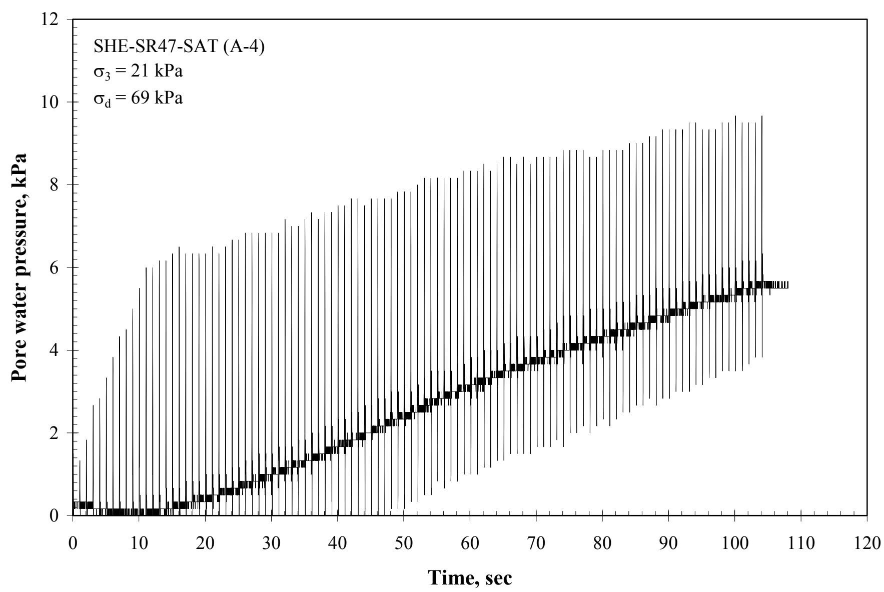

Figure B.35 Cyclic Pore Water Pressure SHE-SR47-SAT

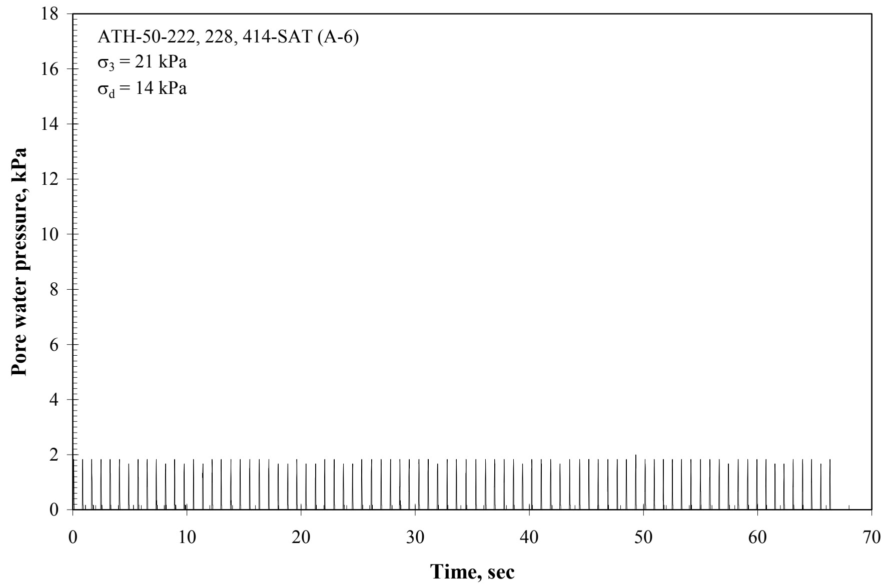

Figure B.36 Cyclic Pore Water Pressure ATH-50-222, 228, 414-SAT

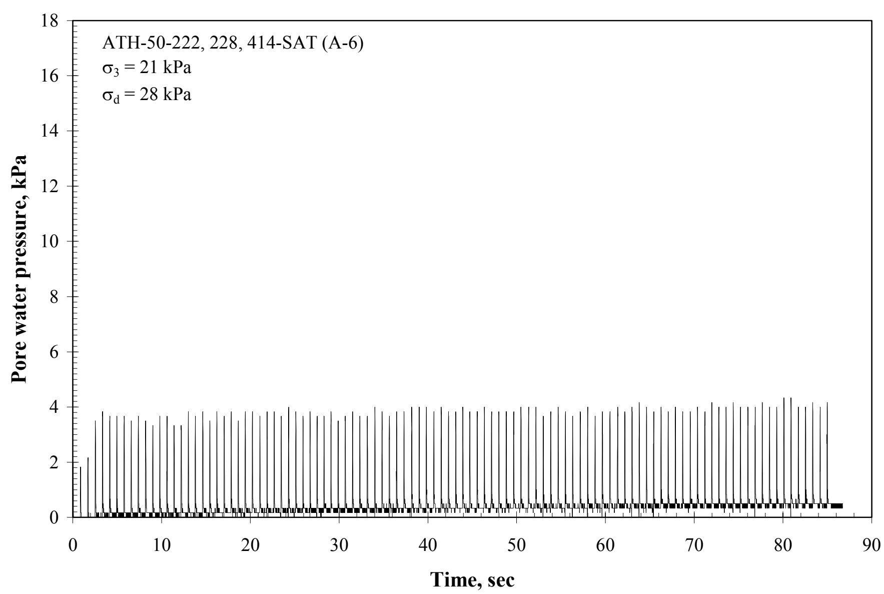

Figure B.37 Cyclic Pore Water Pressure ATH-50-222, 228, 414-SAT

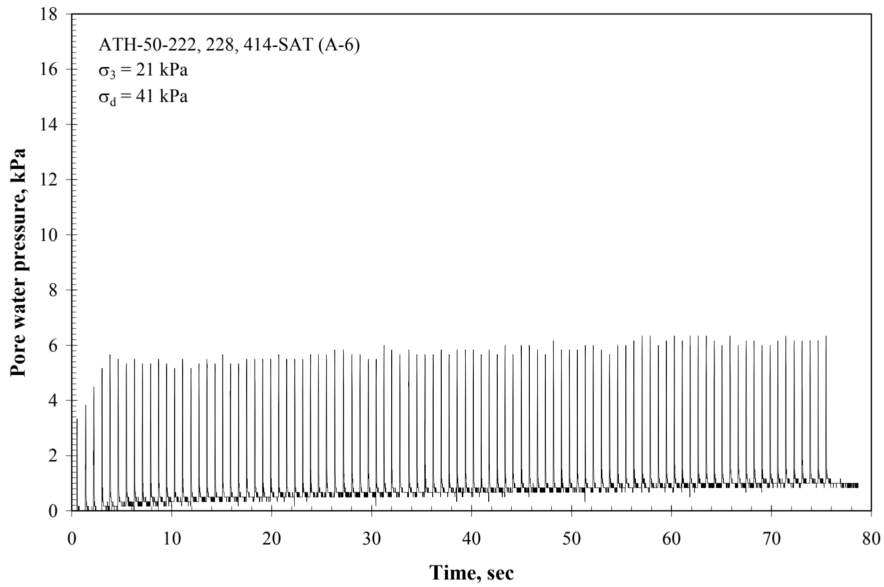

Figure B.38 Cyclic Pore Water Pressure ATH-50-222, 228, 414-SAT

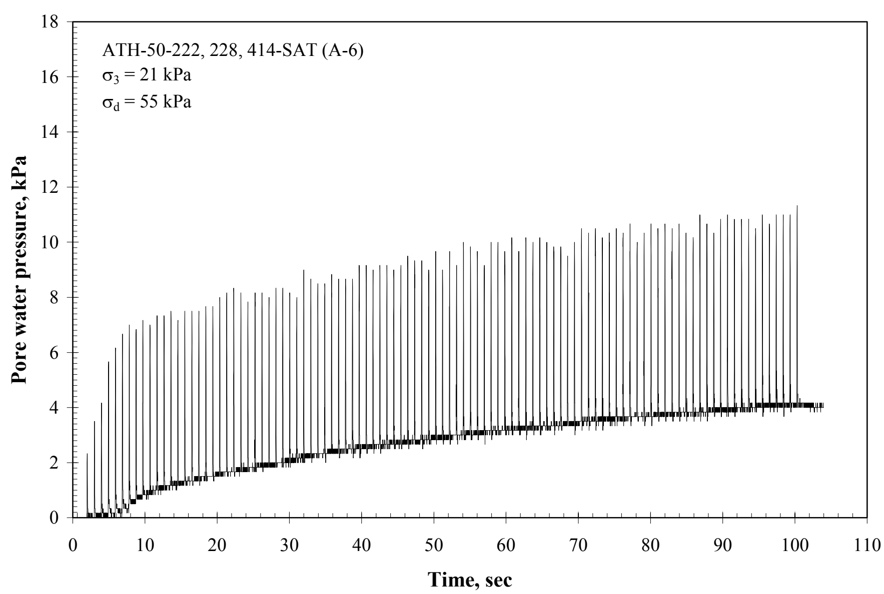

Figure B.39 Cyclic Pore Water Pressure ATH-50-222, 228, 414-SAT

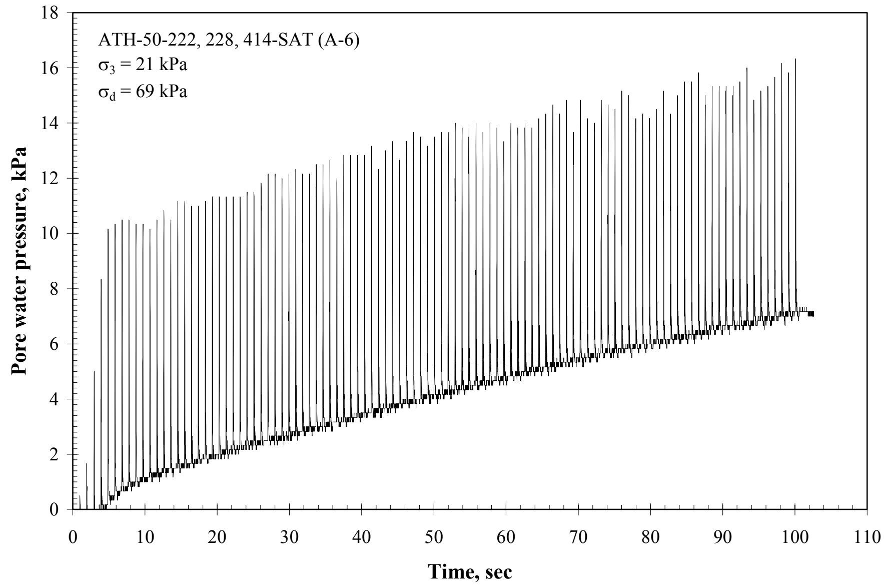

Figure B.40 Cyclic Pore Water Pressure ATH-50-222, 228, 414-SAT

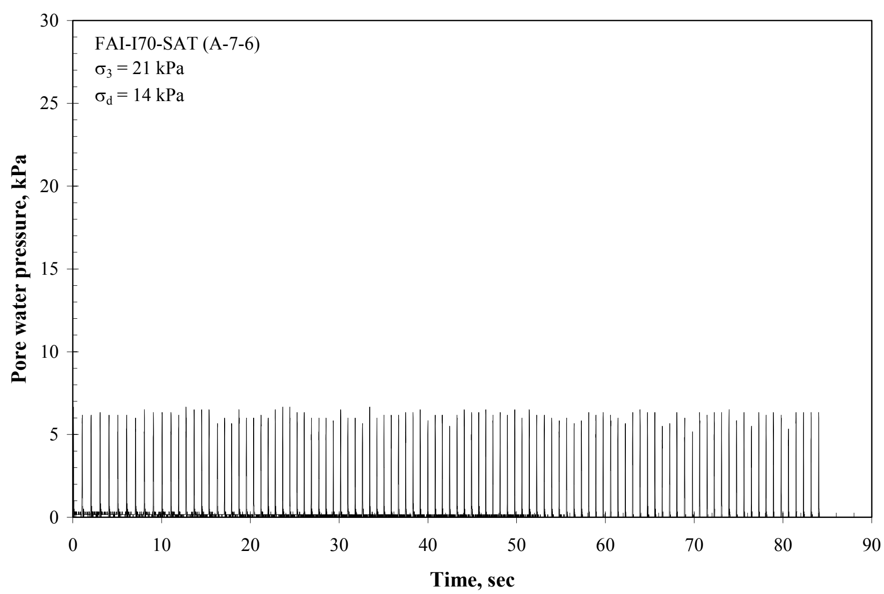

Figure B.41 Cyclic Pore Water Pressure FAI-I70-SAT

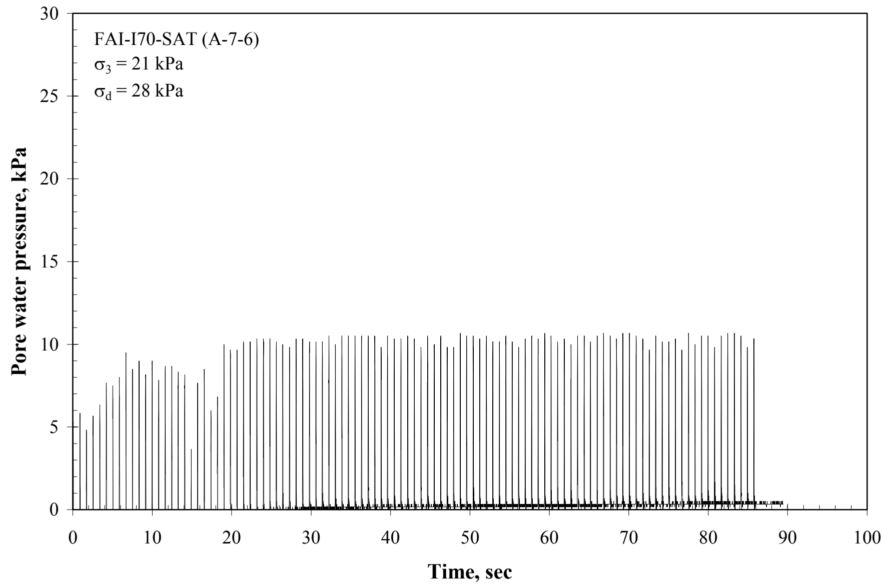

Figure B.42 Cyclic Pore Water Pressure FAI-I70-SAT

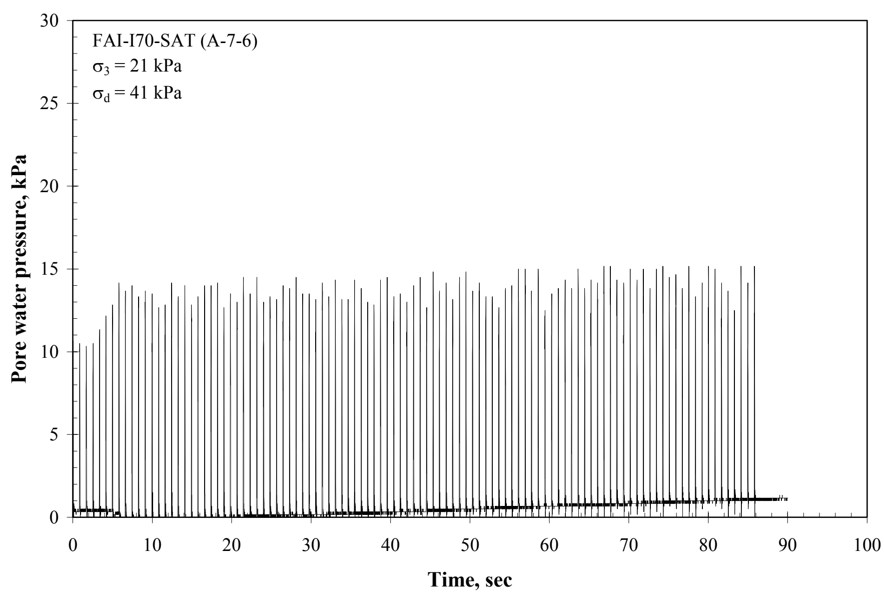

Figure B.43 Cyclic Pore Water Pressure FAI-I70-SAT

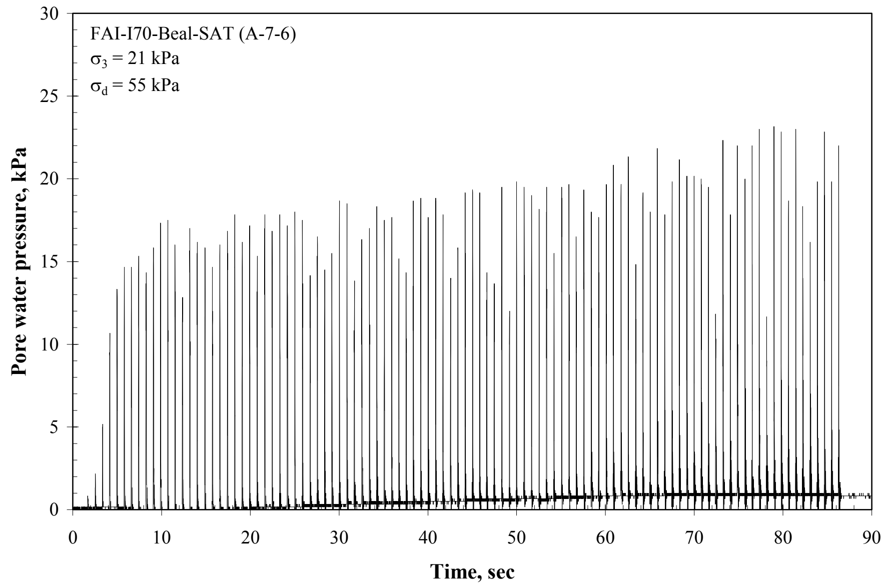

Figure B.44 Cyclic Pore Water Pressure FAI-I70-SAT

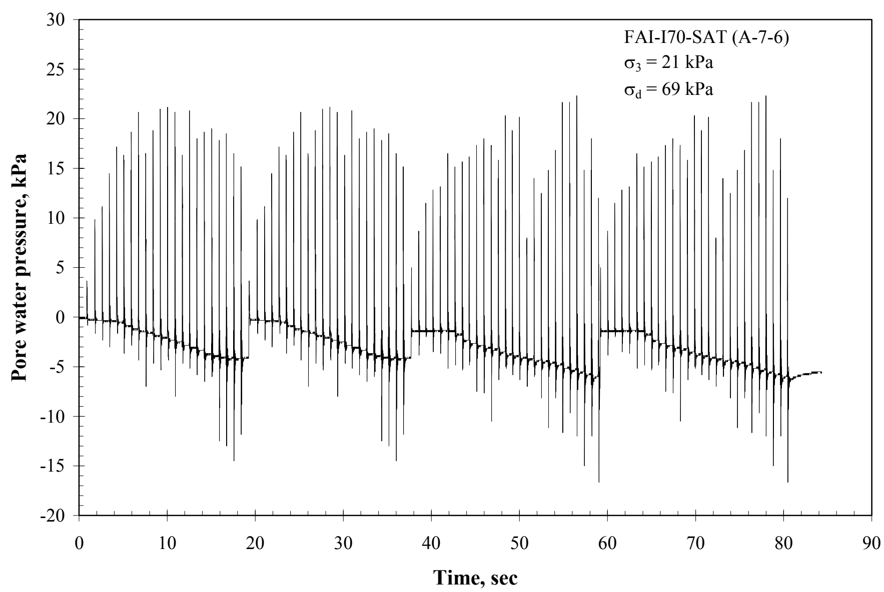

Figure B.45 Cyclic Pore Water Pressure FAI-I70-SAT

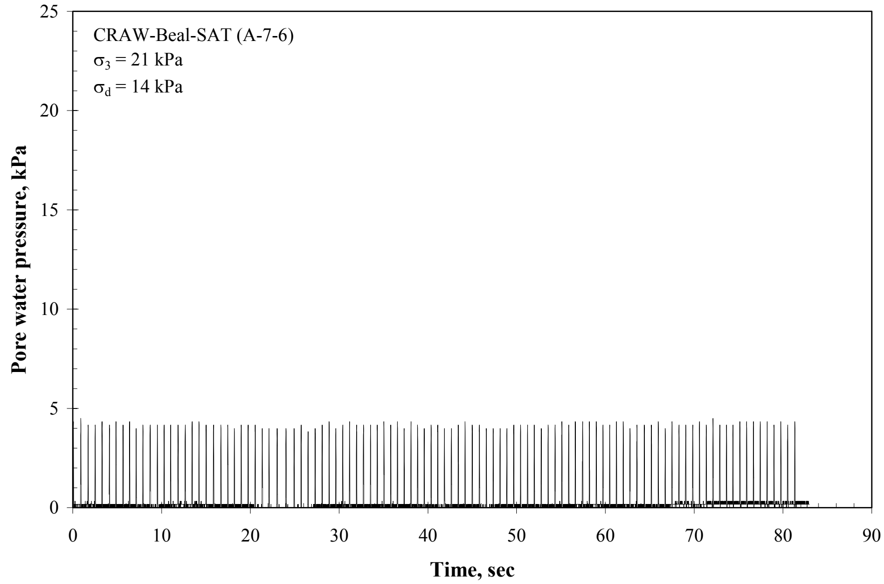

Figure B.46 Cyclic Pore Water Pressure CRA-Beal-SAT

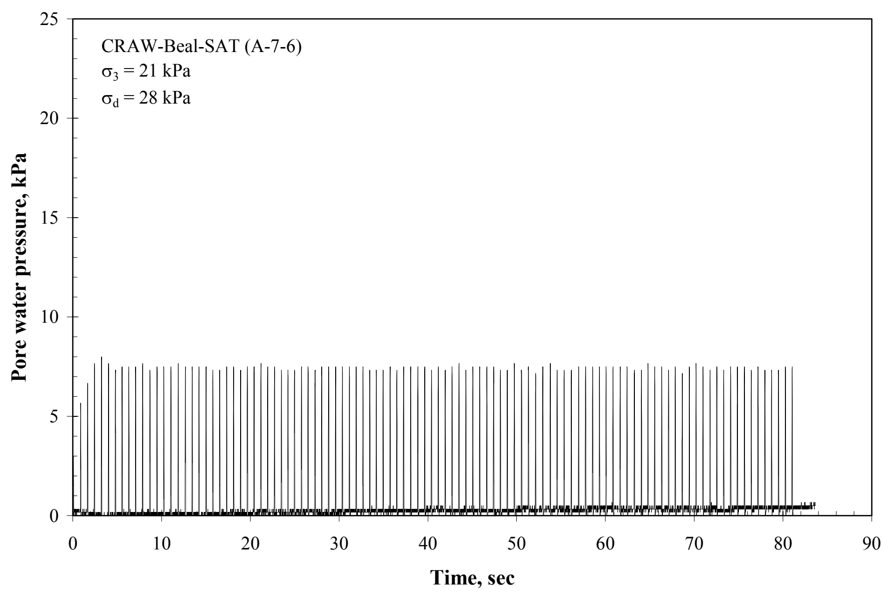

Figure B.47 Cyclic Pore Water Pressure CRA-Beal-SAT

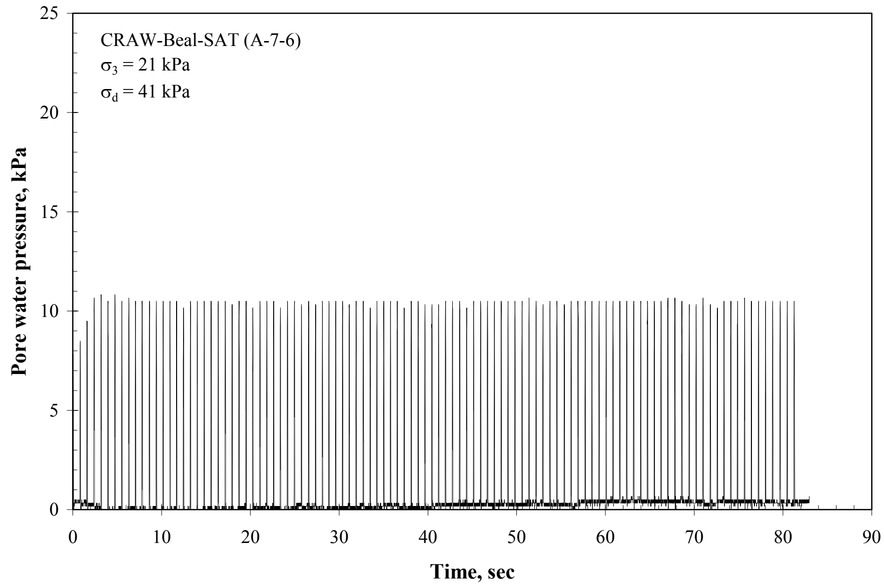

Figure B.48 Cyclic Pore Water Pressure CRA-Beal-SAT

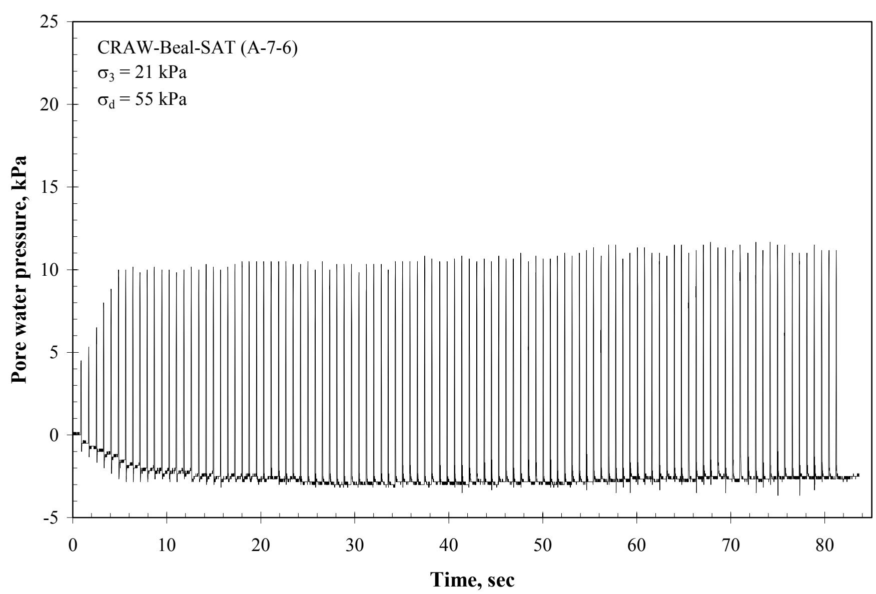

Figure B.49 Cyclic Pore Water Pressure CRA-Beal-SAT

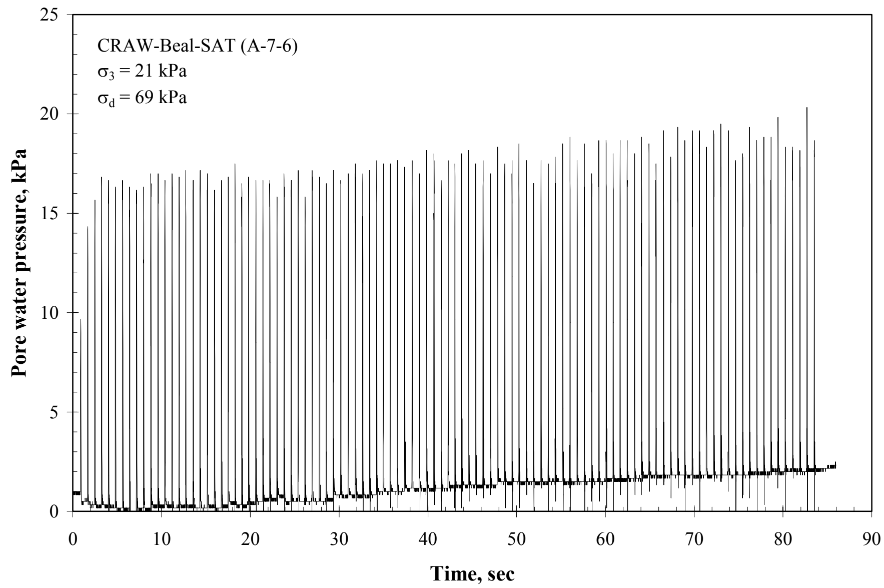

Figure B.50 Cyclic Pore Water Pressure CRA-Beal-SAT

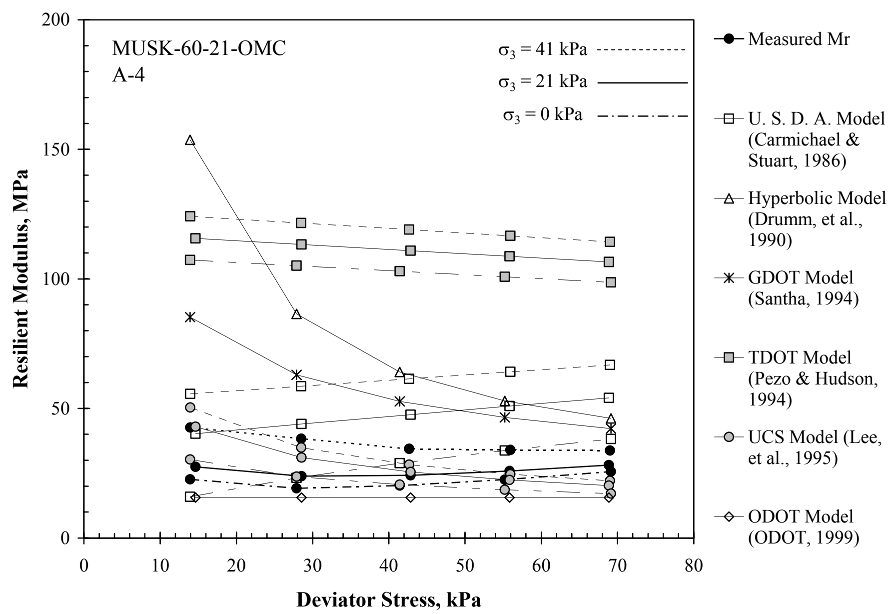

Figure B.51 Predicted v. Measured M_r MUS-60-OMC

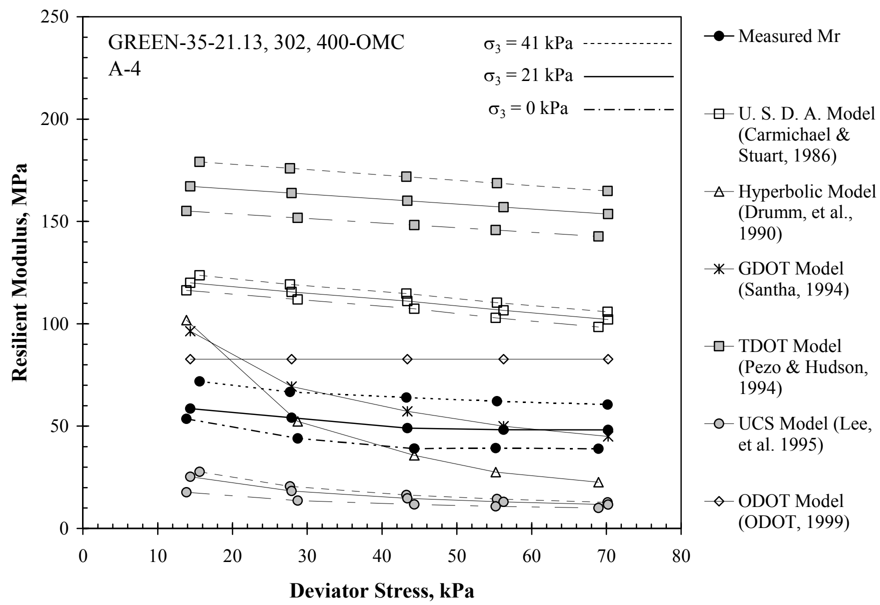

Figure B.52 Predicted v. Measured M_r GRE-50-21.13, 320, 400-OMC

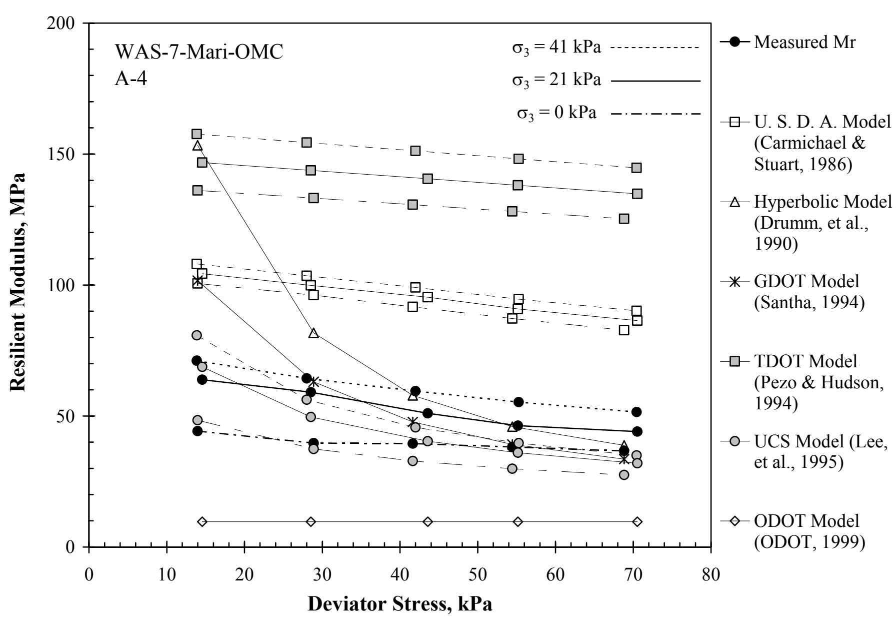

Figure B.53 Predicted v. Measured M_r WAS-7-Mari-OMC

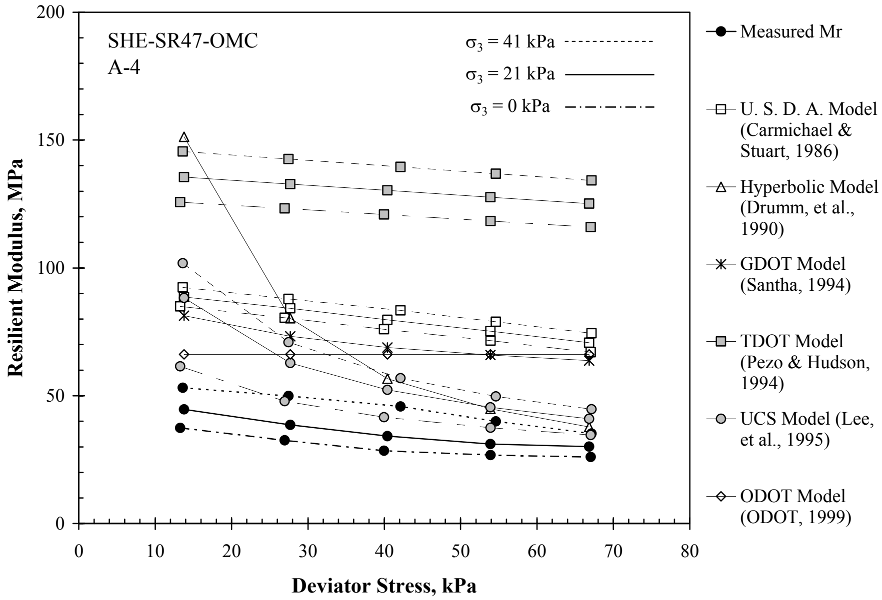

Figure B.54 Predicted v. Measured M_r SHE-SR47-OMC

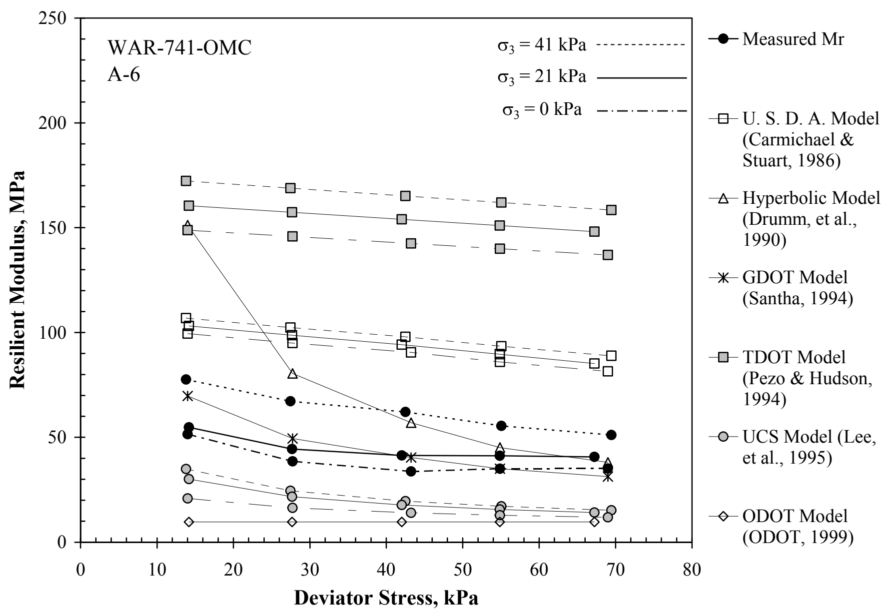

Figure B.55 Predicted v. Measured M_r WAR-741-OMC

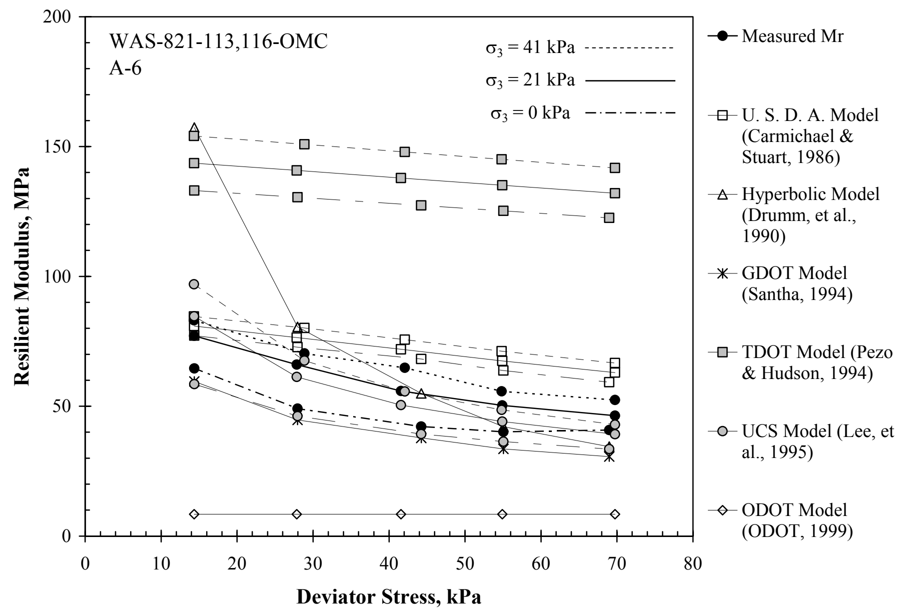

Figure B.56 Predicted v. Measured M_r WAS-821-113,116-OMC

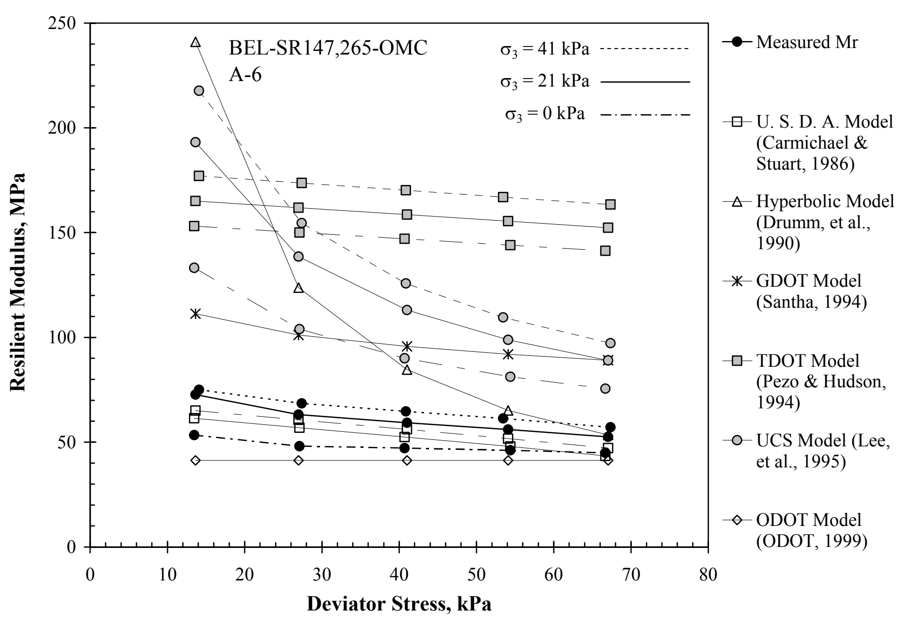

Figure B.57 Predicted v. Measured M_r BEL-SR147, 265-OMC

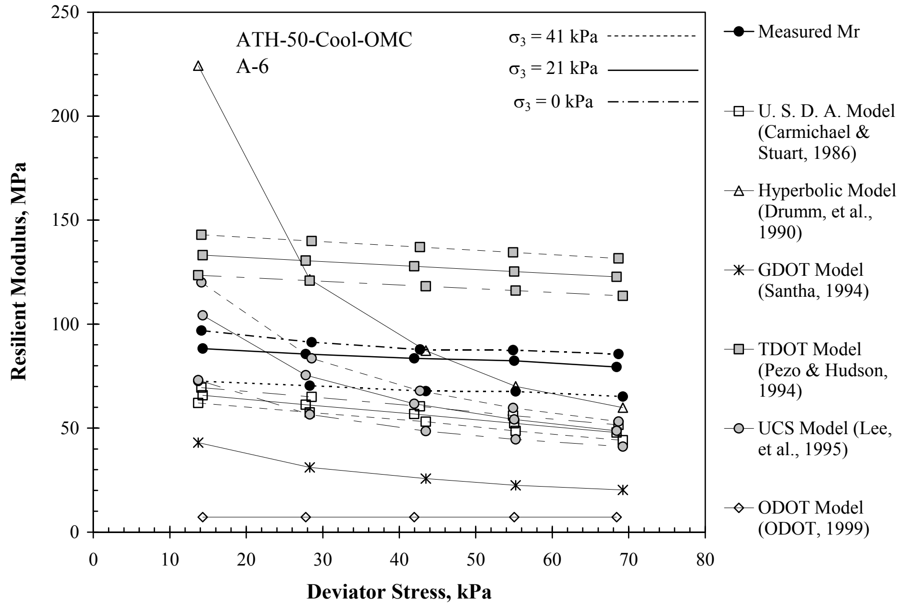

Figure B.58 Predicted v. Measured M_r ATH-50-Cool-OMC

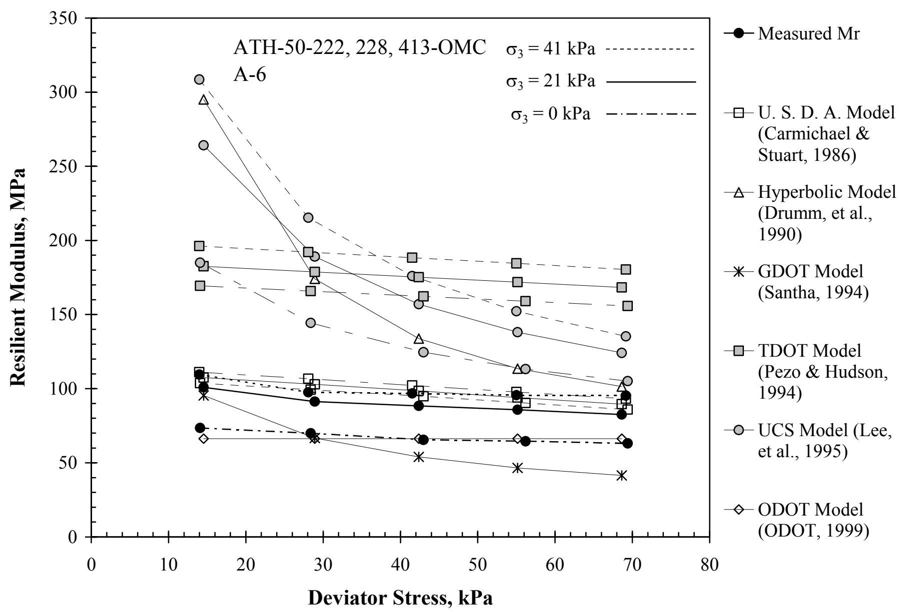

Figure B.59 Predicted v. Measured M_r ATH-50-222, 228, 413-OMC

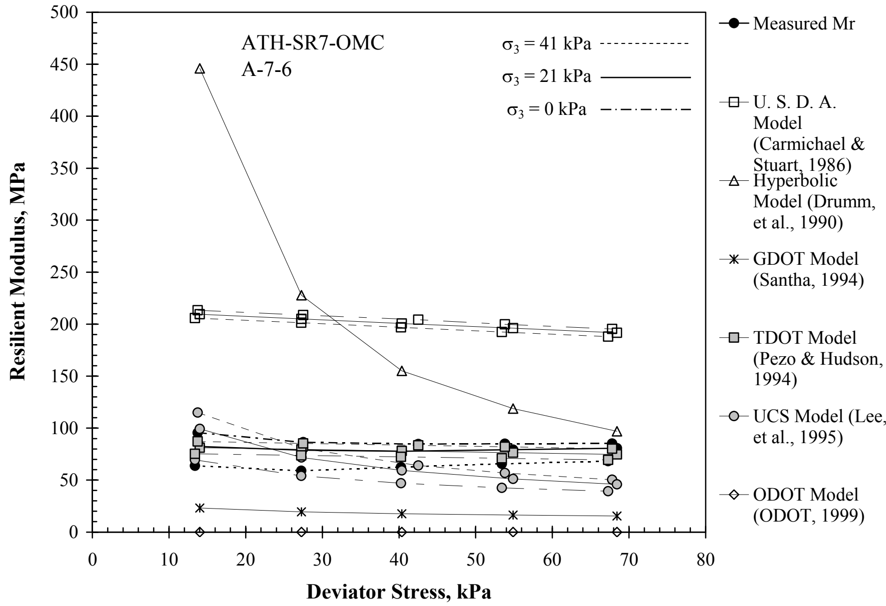

Figure B.60 Predicted v. Measured M_r ATH-SR7-OMC

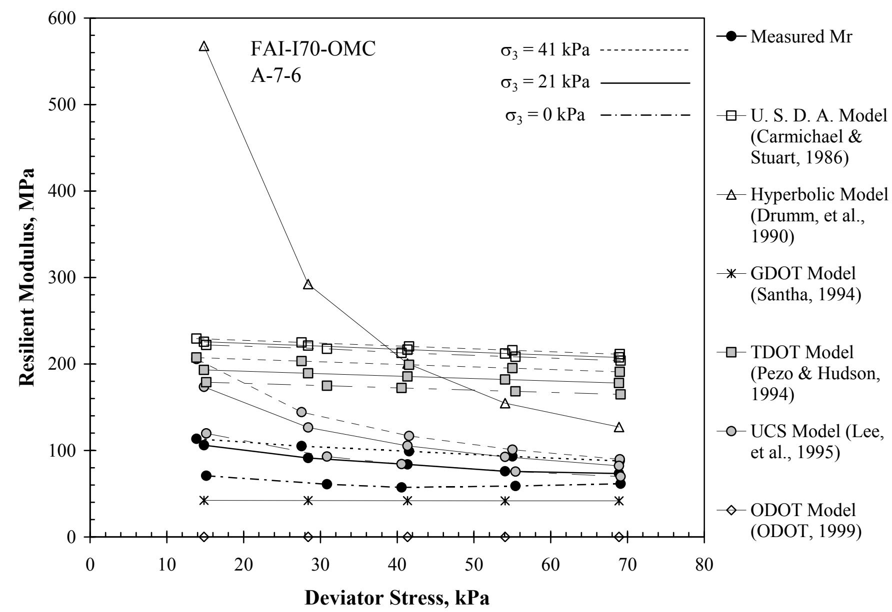

Figure B.61 Predicted v. Measured M_r FAI-I70-OMC

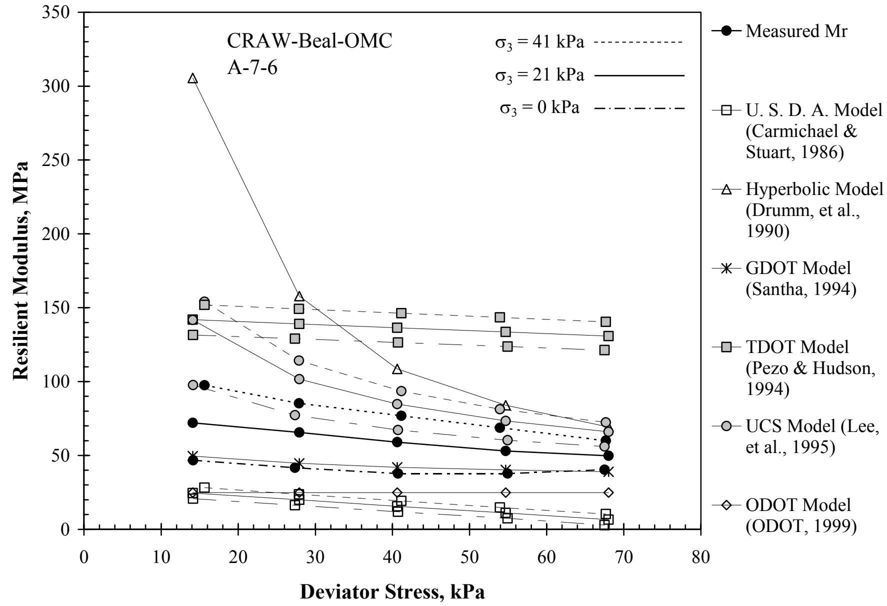

Figure B.62 Predicted v. Measured M_r CRA-Beal-OMC

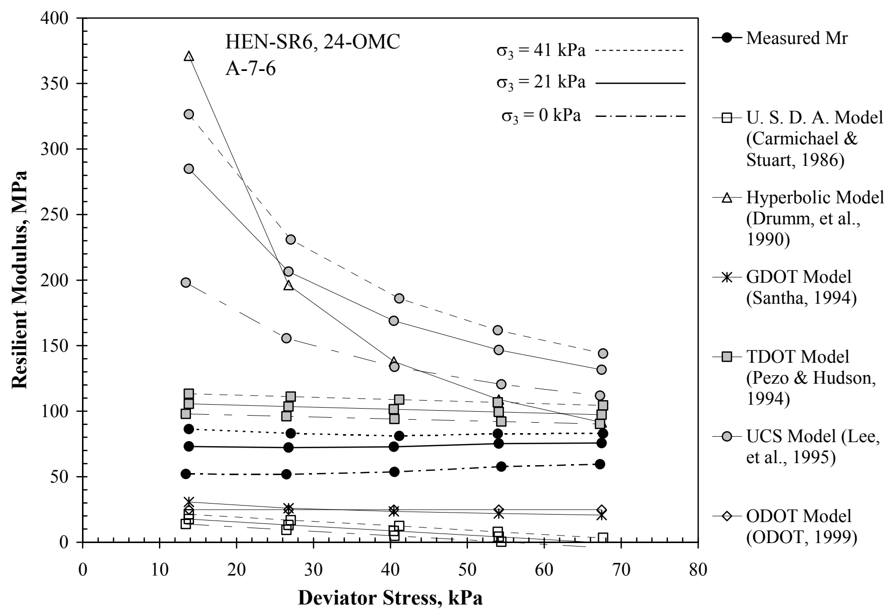

Figure B.63 Predicted v. Measured M_r HEN-SR6, 24-OMC