Characterizing the Soil Resilient Modulus for Typical Manitoba Soils

Haithem Soliman, M.Sc.
Graduate Student
Department of Civil Engineering
University of Manitoba
Email: umsolimh@cc.umanitoba.ca

Ahmed Shalaby, P.Eng.
Associate Professor and Associate Dean
Faculty of Engineering
University of Manitoba
E-mail: shalabya@cc.umanitoba.ca

Said Kass, P.Eng.
Director of Materials Engineering Branch
Manitoba Infrastructure and Transportation
E-mail: Said.Kass@gov.mb.ca

and

Tony N. Ng, P.Eng.
Geotechnical Engineer
Manitoba Infrastructure and Transportation
E-mail: Tony.Ng@gov.mb.ca

Paper prepared for presentation

at the "**Soil Stabilization for Changing Environments**" Session

of the 2009 Annual Conference of the
Transportation Association of Canada
Vancouver, British Columbia.

Abstract

Resilient modulus of unbound materials is a fundamental property that is required for pavement design and estimation of its remaining service life. This paper highlights efforts to quantify the resilient modulus of subgrade soils in Manitoba. The research has two main objectives. The first objective is to model the relationship between the resilient modulus and cyclic stress, confining pressure, moisture content and dry density for typical Manitoba subgrade soils. The second objective is to evaluate the effect of basic soil improvement techniques. The resilient modulus test is performed on three types of soils: silty sand (from central & southern Manitoba), sandy clay (from western Manitoba), and high plastic clay (from Red River Valley). Soil samples are prepared at four moisture contents and dry densities. The moisture contents were selected such that two moisture contents are on the dry side (below the optimum moisture content) and the other two are on the wet side (above the optimum moisture content), according to the Standard Proctor Compaction Curve. Each sample is subjected to sixteen loading combinations that constitute a range of cyclic loads and confining pressures. The values of resilient modulus obtained from these tests will be incorporated in the structural design of new pavements. These values will also be used as base values to evaluate the adequacy of basic soil improvement techniques.

Introduction

The resilient modulus of subgrade soils is an essential material property in any mechanistically-based design/analysis procedure for pavements. The resilient modulus (M_R) is one of the required material properties for the 1993 American Association of State Highway and Transportation Officials (AASHTO) Design Guide which is an empirically-based design procedure [1]. Resilient modulus is also the primary material input parameter for the 2002 AASHTO Design Guide. The 2002 Design Guide was developed under National Cooperative Highway Research Program (NCHRP) Project 1-37A based on mechanistic principles [2]. The M_R of subgrade soil is a measure of the elastic modulus of the material from a given stress state. M_R is mathematically defined as the ratio of the applied cyclic stress to the "recoverable" strain measured during the unloading phase of the loading cycle.

$$M_R = \frac{\sigma_c}{\varepsilon_r} \quad \textbf{(1)}$$

Where:

σ_c = applied cyclic stress, and

ε_r = recoverable (resilient) strain.

Previous studies have shown that the resilient modulus test results can be affected by sampling technique, testing procedure, and other errors that can occur during the testing program [6]. Some of these errors include incorrect conditioning/stress sequence, leaks in the membrane, incorrect stress levels, instability of the Linear Variable Differential Transducer (LVDT) clamps attached to the specimen, exceeding the LVDT linear range limits, and specimen disturbance at high stress levels. The location of the LVDTs has also an influence on the value of M_R, where it can be attached directly to the specimen or mounted on the top of the end plates. This influence is addressed extensively in the literature [3, 4].

The value of M_R depends on the stress state and the physical properties of subgrade soil. Several relationships have been proposed for determining M_R for subgrade soil as a function of its physical properties [6]. These physical properties can be: dry density, moisture content, Atterberg limits, and gradation. A potential benefit of estimating M_R for subgrade soil from its physical properties is that the seasonal variations in resilient modulus can be estimated from the seasonal changes in the physical properties of subgrade soil. Seasonal variations are critical for determining value of M_R for the design of a particular project. The seasonal variations in resilient modulus are also primary input in the 2002 AASHTO Design Guide.

The available relationships in the literature for estimating the resilient modulus of subgrade soil either fit a wide range of soil types or fit a specific soil type. Therefore, transportation agencies should calibrate their own relationships based on the available soil types in their region.

Experimental Program

The objective of this research is to evaluate the sensitivity of the resilient modulus to the variation in the physical properties of the soil. For this purpose, six soil samples were collected to represent three types of soil: sandy silt, sandy clay, and high plastic clay. Grain size analysis, Atterberg limits, and standard Proctor tests were conducted for the collected samples. For each soil sample, four moisture contents were selected to evaluate the sensitivity of resilient modulus to the variation in moisture content and dry density. The four moisture contents were selected to cover both the dry and wet sides of the standard proctor compaction curve. Table 1 shows the maximum dry density, the optimum moisture content, and the selected moisture contents for the six soil samples.

This project also investigates the effect of using two different methods for measuring soil deformation on the value of the resilient modulus. The first method consists of two LVDTs mounted directly to the middle third of the specimen, thus eliminating the effect of end zones. The gauge length of these LVDTs is 101.6 mm (4 inches). The second method consists of two LVDTs mounted on the top loading plate with a gauge length of 203.2 mm (8 inches).

Table 1: Properties of Soil Samples and the Proposed Moisture contents for M_R Tests

Soil Type	Optimum Moisture Content (%)	Max. Dry Density (Kg/m^3)	Properties of M_R Soil Sample		
			Moisture content (%)	Dry density (Kg/m^3)	Relative density (%)
High Plastic Clay (Red River Valley)	20.4	1631	18	1600	98.1
			20	1620	99.3
			22	1620	99.3
			24	1585	97.2
	28.2	1473	26	1418	96.3
			28	1471	99.9
			30	1449	98.4
			32	1408	95.6
Sandy Clay (Western Manitoba)	14.1	1856	12	1785	96.2
			13.5	1840	99.1
			15.5	1835	98.9
			17	1780	95.9
	13.4	1877	10	1800	95.9
			12	1865	99.4
			14	1875	99.9
			15.5	1840	98
Sandy Silt (Central & Southern Manitoba)	13	1865	8	1764	94.6
			10.5	1835	98.4
			13	1865	100.0
			14.5	1835	98.4
	10.8	1859	7	1780	95.8
			9	1840	99
			12.5	1845	99.2
			15	1780	95.8

Test Procedures

The M_R tests in this project are conducted according to the test protocol developed under NCHRP Project 1-28A [5]. The test protocol provides the required procedures for specimen preparation and testing. The test specimen measures 101.6 mm in diameter and 203.2 mm in height. The test specimen is compacted in eight layers, one inch each, to reach the target moisture content/dry density level according to standard proctor compaction curve.

According to the test protocol, subgrade soils are classified into two groups based on the percent passing 75 µm (No.200) sieve. Each group has a different testing procedure. The first group is coarse-grained subgrade soils for which the percent passing 75 µm sieve is less than 35%. The second group is cohesive subgrade soils for which the percent passing 75 μm sieve is greater than 35%. The results of grain size analysis showed that the six soil samples belong to the second group (cohesive subgrade soils).

After applying 1000 conditioning cycles, the test specimen is subjected to 16 loading sequences. According to MR test protocol, the load pulse is Haversine shaped load form. The load pulse is of the form $\frac{1-COS(\theta)}{2}$, where θ changes from 2 to 2π, with load duration of 0.2 sec and frequency 1 Hz. Table 2 shows the values of the confining pressure and cyclic stress for each loading sequence. Pressurized air and computer-controlled regulator are used to apply the confining pressure. The air pressure inside the triaxial cell is monitored with pressure transducer.

Four LVDTs are used for measuring the vertical deformation of the specimen. Two LVDTs are mounted directly on the specimen using two circular clamps (On sample LVDTs) to measure the vertical deformation of the middle 101.6 mm of the specimen. The other two LVDTs are mounted on the top loading plate (End LVDTs) to measure the total vertical deformation of the specimen. Figure 1 shows the setup for M_R test.

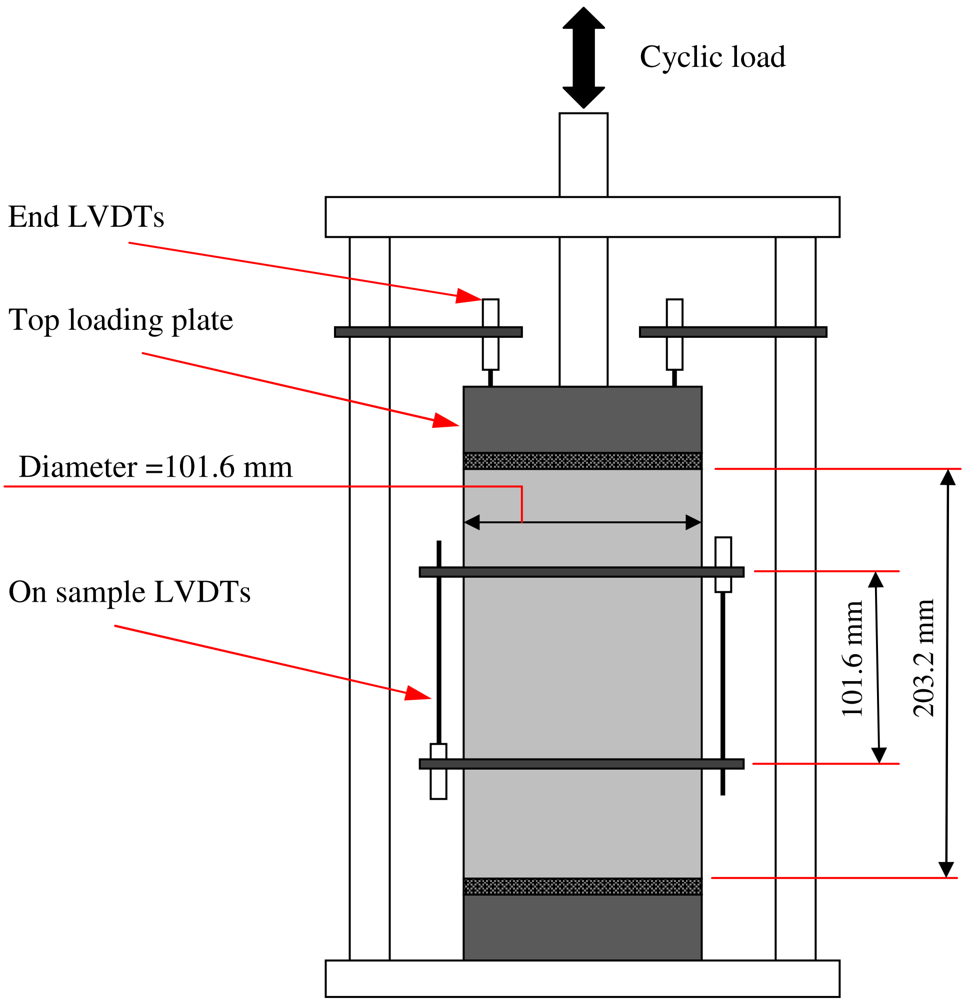


Figure 1: Setup for Soil Resilient Modulus Test

Table 2: Loading Sequence for Fine-Grained Subgrade Soils

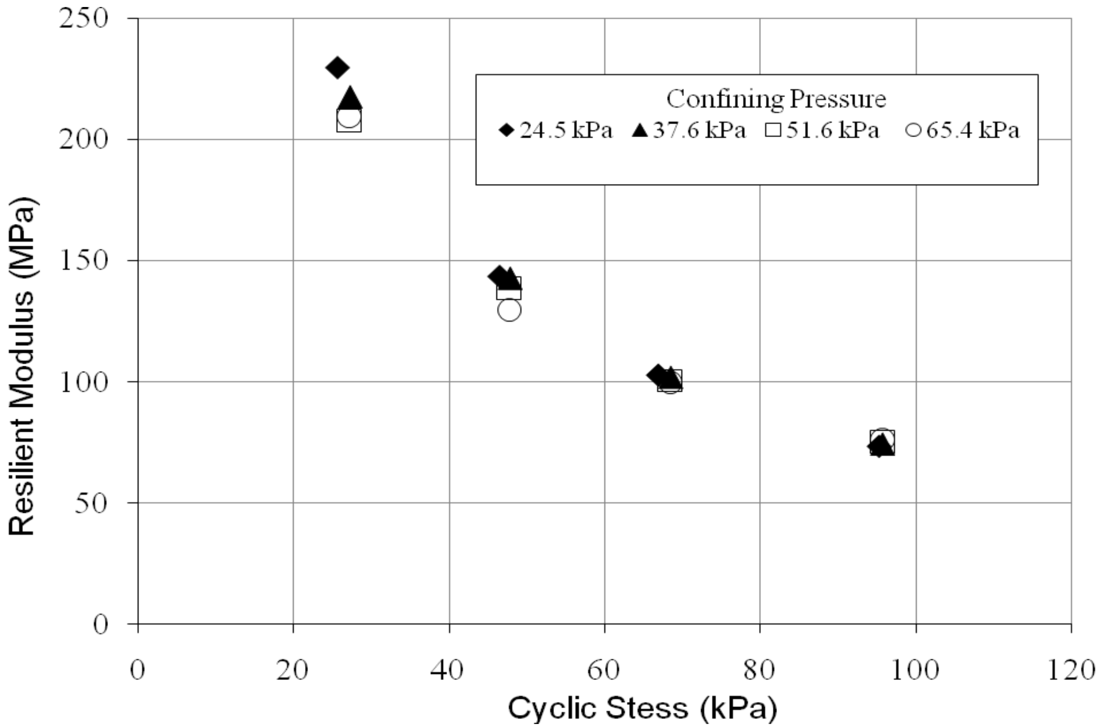
Sequence	Confining Pressure (kPa)	Contact Stress (kPa)	Cyclic Stress (kPa)	Total Stress (kPa)	No. of Cycles
Conditioning	27.6	5.5	48.3	53.8	1000
1	55.2	11.0	27.6	38.6	100
2	41.4	8.3	27.6	35.9	100
3	27.6	5.5	27.6	33.1	100
4	13.8	2.8	27.6	30.4	100
5	55.2	11.0	48.3	59.3	100
6	41.4	8.3	48.3	56.6	100
7	27.6	5.5	48.3	53.8	100
8	13.8	2.8	48.3	51.1	100
9	55.2	11.0	69.0	80.0	100
10	41.4	8.3	69.0	77.3	100
11	27.6	5.5	69.0	74.5	100
12	13.8	2.8	69.0	71.8	100
13	55.2	11.0	96.6	107.6	100
14	41.4	8.3	96.6	104.9	100
15	27.6	5.5	96.6	102.1	100
16	13.8	2.8	96.6	99.4	100

Test Results

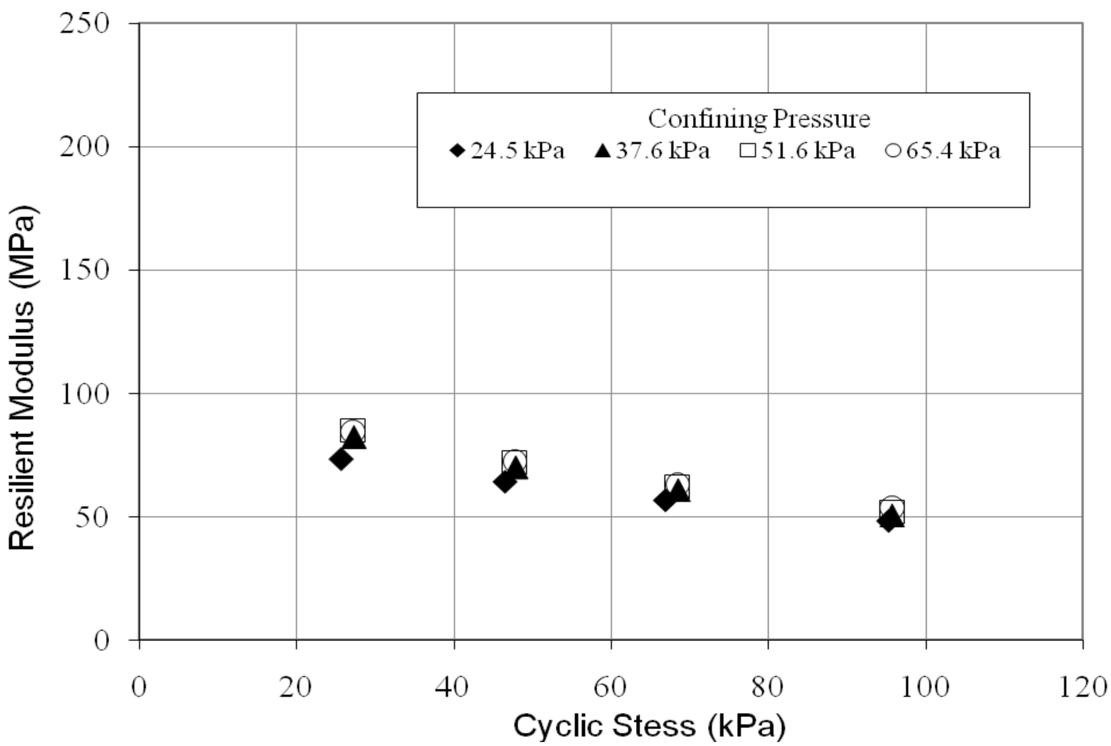
During each loading sequence, vertical deformations, cyclic load, and confining pressure are recorded for the last 5 cycles. The recorded data is processed to minimize the effect of any noise in the measured signals.

Two values are calculated for the soil resilient modulus. The first M_R value is calculated from the recoverable strain measured by the on sample LVDTs. The second M_R value is calculated from the recoverable strain measured by the end LVDTs. The M_R values for the last 5 cycles are averaged.

Figure 2 shows M_R values for soil sample number 2 (high plastic clay with PI = 56) tested at moisture content 26%. The M_R values in Figure 2 (a) are calculated from the recoverable strain of the end LVDTs, while the M_R values in Figure 2 (b) are calculated from the recoverable strain of the on sample LVDTs. The M_R values calculated from measurements of the on sample LVDTs are higher than the M_R values calculated from measurements of the end LVDTs by 50% to 150%. The effect of using different measuring systems (on sample LVDTs or end LVDTs) on M_R values decreases with the increase of the cyclic stress for this type of soil. The dependency of the difference between M_R values calculated from the two measuring system on the cyclic stress can be due to the slippage of the on sample LVDTs during the test.



a) M_R calculated from on sample LVDTs



b) M_R calculated from end LVDTs

Figure 2: Resilient Modulus for High Plastic Clay at Moisture Content 26%

Figure 3 shows M_R values for soil sample number 1 (high plastic clay with PI = 27) tested at moisture content 18%. The M_R values in Figure 3 (a) are calculated from the recoverable strain of the end LVDTs, while the M_R values in Figure 3 (b) are calculated from the recoverable strain of the on sample LVDTs. The M_R values calculated from measurements of the on sample LVDTs are higher than the M_R values calculated from measurements of the end LVDTs by 100%. The effect of using different measuring systems (on sample LVDTs or end LVDTs) on M_R values is not dependant on the value of the cyclic stress for this type of soil.

Figure 4 shows M_R values for soil sample number 4 (sandy clay with PI = 17) tested at moisture content 10%. The M_R values in Figure 4 (a) are calculated from the recoverable strain of the end LVDTs, while the M_R values in Figure 4 (b) are calculated from the recoverable strain of the on sample LVDTs. The M_R values calculated from measurements of the on sample LVDTs are higher than the M_R values calculated from measurements of the end LVDTs by 30% to 40%. The effect of using different measuring systems (on sample LVDTs or end LVDTs) on M_R values is not dependant on the value of the cyclic stress for this type of soil.

Summary

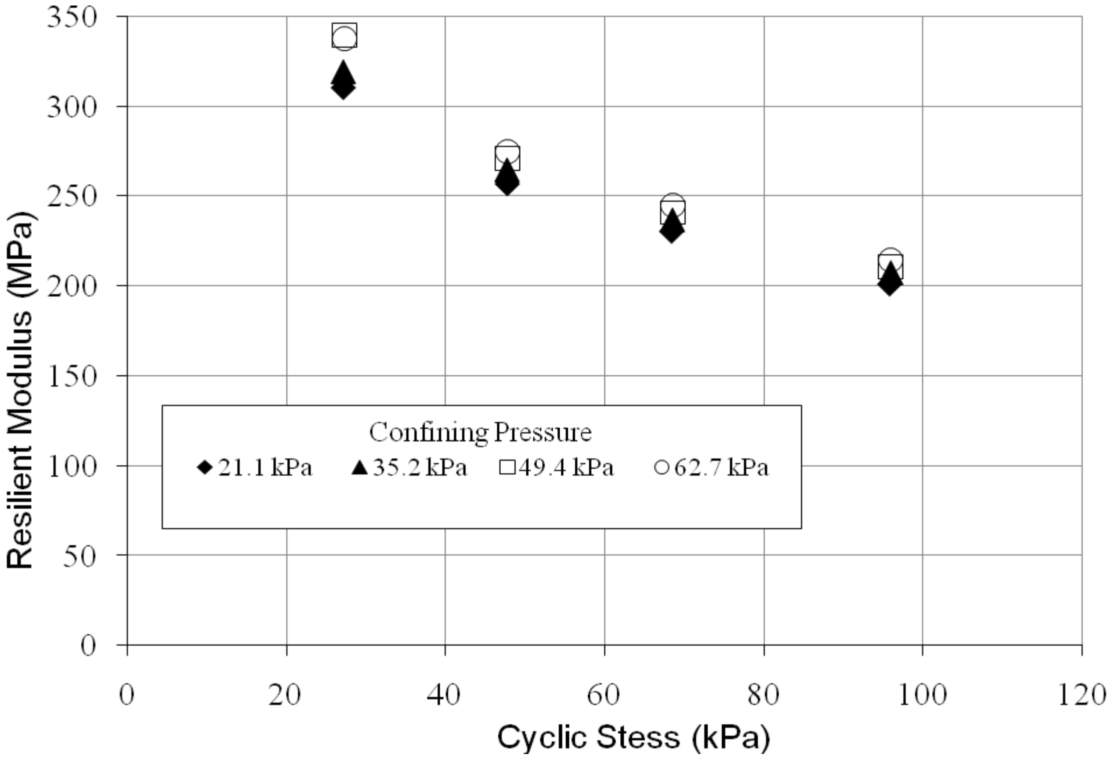
The resilient modulus of subgrade soil is the primary input parameter for soil strength in the 2002 AASHTO Design Guide. The seasonal variation in soil resilient modulus is also a required input in the design guide. The seasonal variation in resilient modulus can be estimated from the variation in the physical properties of subgrade soil. Where, the relationship between resilient modulus and the physical properties of soil can be easily estimated.

The objective of this research it evaluate the sensitivity of subgrade resilient modulus to the variation in the physical properties of the soil. For this purpose, six soil samples were collected to represent three types of soil: sandy silt, sandy clay, and high plastic clay. The basic properties of these soil samples (grain size analysis, Atterberg limits, maximum dry density, and optimum moisture content) were evaluated.

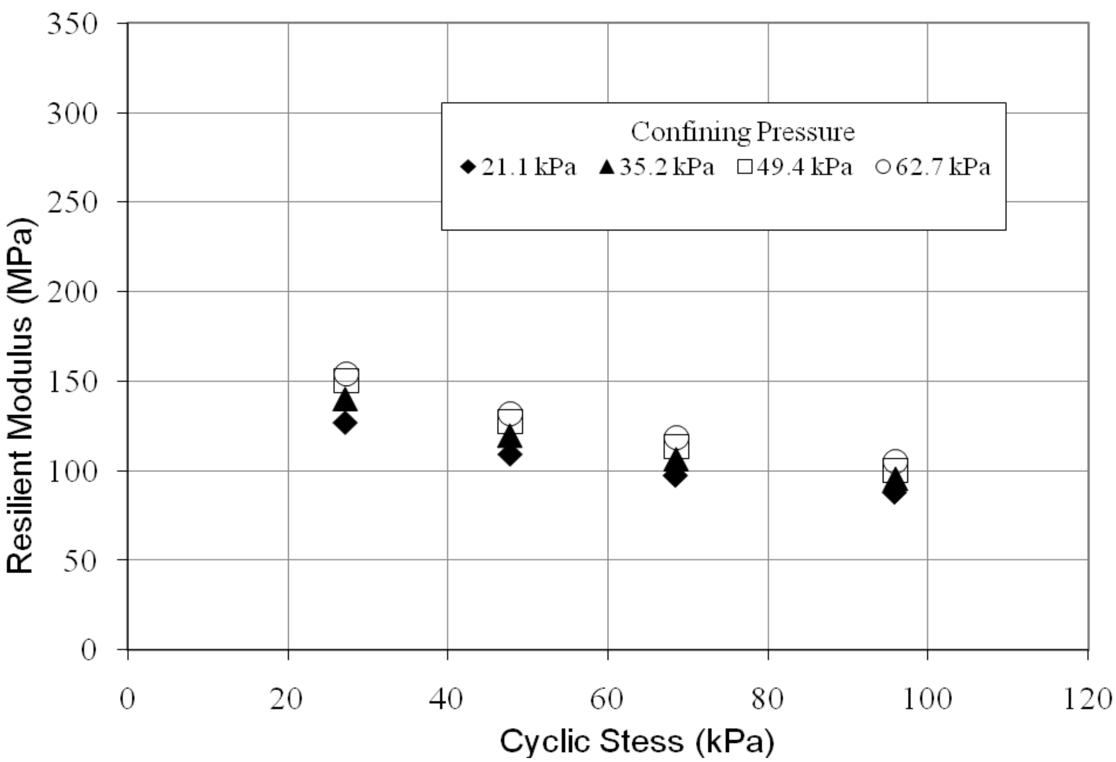
For each soil sample, four moisture contents were selected for the resilient modulus test. Two moisture contents are at the dry side of the standard Proctor compaction curve and the other two moisture contents are at the wet side.

The effect of using two different systems to measure the soil deformation is also investigated in this research: on sample LVDTs and end LVDTs. The on sample LVDTs measures the deformation of the middle 101.6 mm of specimen. The end LVDTs measures the total deformation of the specimen.

Using the end LVDTs measurements, the calculated M_R values are in the range of: 90 MPa to 150 MPa for sample number 1 (high plastic clay with PI = 27), 50 MPa to 90 MPa for sample number 2 (high plastic clay with PI = 56), and 100 MPa to 175 MPa for sample number 4 (sandy clay with PI = 17).

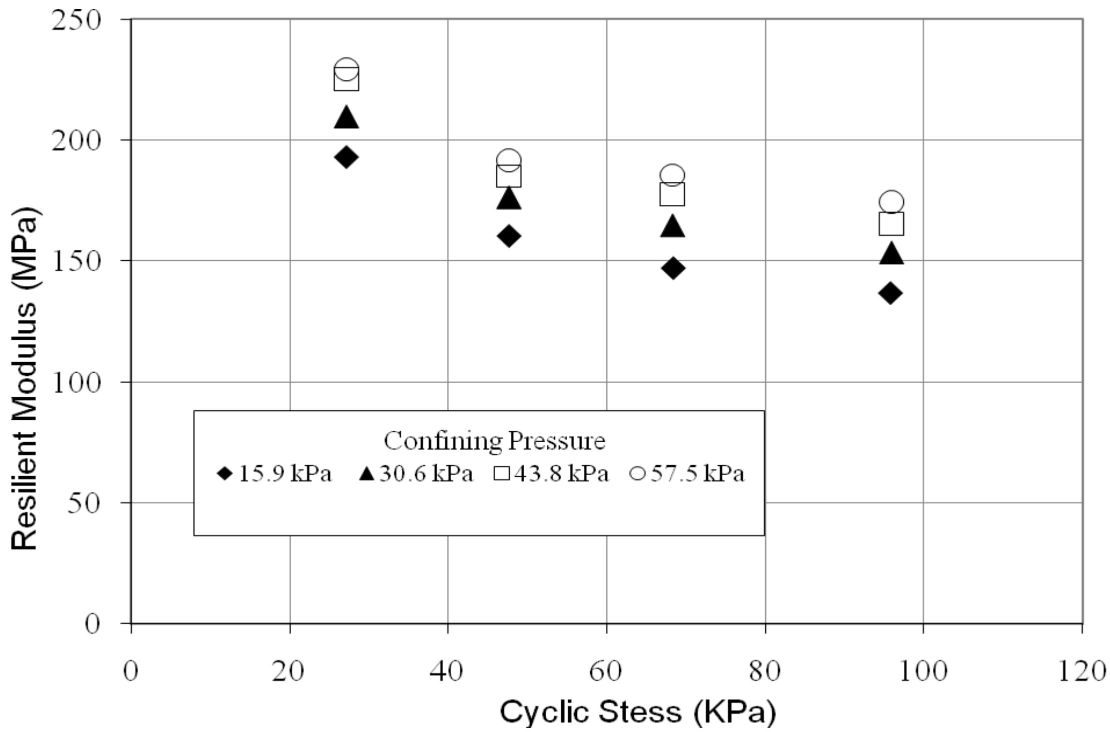


a) M_R calculated from on sample LVDTs

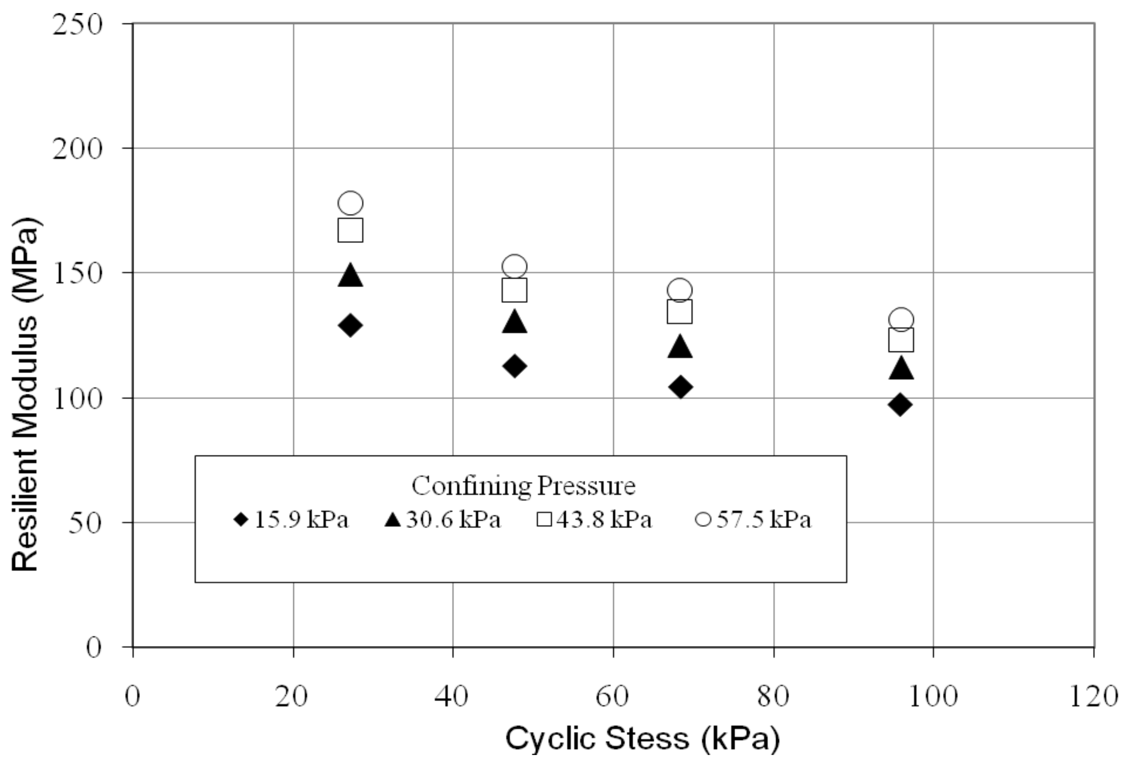


b) M_R calculated from end LVDTs

Figure 3: Resilient Modulus for High Plastic Clay at Moisture Content 18%



a) M_R calculated from on sample LVDTs



b) M_R calculated from end LVDTs

Figure 4: Resilient Modulus for Sandy Clay at Moisture Content 10%

Using the on sample LVDTs measurements, the calculated M_R values are in the range of: 200 MPa to 340 MPa for sample number 1 (high plastic clay with PI = 27), 75 MPa to 225 MPa for sample number 2 (high plastic clay with PI = 56), and 140 MPa to 230 MPa for sample number 4 (sandy clay with PI = 17).

Results demonstrated that the resilient modulus values calculated from the measurements of the on sample LVDTs are higher than the resilient modulus values calculated from the measurements of the end LVDTs. For soft soils, the different between the M_R values calculated from the two measuring methods varies with change of the cyclic stress. This variation can be due to slippage of the on sample LVDTs during the test. The end LVDTs system provides more reliable measurements for soft soils and the calculated M_R values are in the range of the typical values used by transportation agencies.

References

1. American Association of State Highway and Transportation Officials (1993) *"AASHTO Guide for Design of Pavement Structures"*, Washington, D.C.

2. National Cooperative Highway Research Program (NCHRP) (2004) *"Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures"*, Project 1-37A final report.

3. Mohammed, L. N.; Puppala, A. J.; and Alavilli, P. (1994) *"Influence of Testing Procedures and LVDT Location on Resilient Modulus of Soils"*, Transportation Research Record, Volume 1462, p 91- 101.

4. Burczyk , J. M.; Ksaibati, K.; Andeson-Specher, R.; and Farrar, M. J. (1994) *"Factors Influencing Determination of a Subgrade Resilient Modulus Value"*, Transportation Research Record, Volume 1462, p 72-78.

5. Harrigan, E. T. (2004) *"Laboratory Determination of Resilient Modulus for Flexible Pavement Design"*, National Cooperative Highway Research Program (NCHRP), Research Results Digest Number 285.

6. Long Term Pavement Performance (LTPP) Program (2001) *"Study of LTPP Laboratory Resilient Modulus Test Data and Response Characteristics – Final Report"*, Federal Highway Administration, U.S. Department of Transportation.