Sensitivity of Subgrade Resilient Modulus to Moisture Variation

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Abstract

Subgrade soil is the foundation soil that supports the different pavement layers and the dynamic load of traffic. American Association of State Highway and Transportation Officials guide for the design of pavement structures recommends the use of soil resilient modulus to represent the dynamic strength of subgrade soil. Soil resilient modulus can be obtained from repeated load tests. The instrumentation and technical experience required for this test are not available in many soil testing laboratories. For certain types of soil, resilient modulus is sensitive to the variation of moisture content. Pavement design guide requires the use of an effective value for subgrade resilient modulus that reflects the seasonal variation of soil moisture content. The objective of this research is to evaluate the sensitivity of resilient modulus of typical Manitoba soils to the variation of moisture content. A repeated load triaxial test was conducted on three types of soils: sandy silt, sandy clay, and high plastic clay. Soil samples were prepared at four levels of moisture contents that cover the dry and wet sides of standard proctor compaction curve (below and above the optimum moisture content). Soil samples were subjected to loading combinations with different dynamic loads and confining pressures. Results showed that cohesive soils are more sensitive to moisture variation than cohesionless soils. The results of these tests will be used to develop effective values for subgrade resilient modulus which will be incorporated in the structural design of new pavements. The results of these tests will also be used as reference values for assessment of basic techniques to improve resilient modulus and reduce its sensitivity to moisture content variation.

Introduction

Resilient modulus (M_R) of subgrade soils is the primary material property for design and analysis of pavements. Moisture content of subgrade soils is one of the most important variables in M_R prediction [3]. Seasonal variation of subgrade moisture content can significantly affect subgrade M_R and subsequently pavement design [2]. Seasonal variations are critical for determining the design M_R for a particular project. American Association of State Highway and Transportation Officials (AASHTO) pavement design guide requires the use of an effective value for subgrade resilient modulus that reflects the seasonal variation of soil moisture content [1]. The same concept has been used in development of the 2002 Design Guide under National Cooperative Highway Research Program (NCHRP) Project 1-37A [4].

Effect of moisture variation on subgrade resilient modulus has been investigated in several studies. Nazzal et al. evaluated the resilient modulus of four groups of soil at four levels of moisture contents [5]. According to AASHTO soil classification, the four soil groups were classified as A-4, A-6, A-7-5, and A-7-6 soils. The four levels of moisture contents were chosen based on the stiffness behavior of each soil sample to cover both the dry and wet sides of the optimum moisture content (OMC). Results showed that resilient modulus deceased by 50% to 70%, depending on type of soil, due to the increase in moisture content from dry side of OMC to wet side of OMC.

Several prediction models have been proposed to evaluate subgrade M_R from physical properties of subgrade soils. K. P. George conducted sensitivity analysis for several prediction models and found that sample moisture content was the most significant variable in predicting soil M_R [3]. Yau and Von Quintus studied the effect of soil physical properties on the M_R test data collected for Long Term Pavement Performance (LTPP) program [6]. M_R test data was divided into four groups according to soil type: gravel, sand, silt, and clay. Statistical analysis was performed to investigate the significance of each soil property in predicting subgrade M_R. Results of statistical analysis showed that optimum moisture content was significant variable in predicting M_R for the four soil groups, while specimen moisture content was a significant variable in predicting M_R for sand and clay soils.

This paper studies the sensitivity of subgrade M_R to moisture variation for typical soils available in Manitoba. Results of this study will be incorporated in the 2002 Mechanistic-Empirical Pavement Design Guide (MEPDG) for design and analysis of pavements in Manitoba [4]. Using laboratory measured values for subgrade M_R increases the reliability of pavement design and reduces the uncertainty associated with using empirical and default values provided by MEPDG.

Laboratory Evaluation of Resilient Modulus

Six soil samples were collected from different areas in Manitoba to represent three types of soil:

- Silty sand/Sandy silt (from central & southern Manitoba),
- Sandy clay (from western Manitoba), and
- High plastic clay (from Red River Valley).

Grain size analysis, Atterberg limits, and standard Proctor tests were conducted for the collected samples. Four moisture contents were selected for each soil sample. The four moisture contents were selected according to the standard Proctor compaction curve of the sample to cover both dry and wet sides of the curve. Table 1 shows the AASHTO classification of the soil samples, the optimum moisture content, and the selected moisture contents for resilient modulus tests.

M_R tests were conducted according to the test protocol developed under NCHRP Project 1-28A [7]. The dimensions of the cylindrical specimens were 101.6 mm in diameter and 203.2 mm in height. Specimens were compacted in eight layers to reach the target moisture content. Two measuring systems were used to measure the axial deformation of the specimen. The first measuring system consisted of two Linear Variable Differential Transducers (LVDTs) mounted directly on the specimen to measure the axial deformation of the middle 101.6 mm "On sample LVDTs". The second measuring system consisted of two LVDTs mounted on the top loading plate to measure the total axial deformation of the specimen "End LVDTs". Figure 1 shows the test specimen and the two measuring systems. For each soil sample, three replicates were tested at each moisture content.

Table 1: Classification of Soil Samples and Moisture Contents for M_R Tests

Sample ID	Soil Type	AASHTO Classification	Optimum Moisture Content (%)	Moisture Contents for M_R Tests (%)
HC1	High Plastic Clay	A-7-6	28.2	26 28 30 32
HC2	High Plastic Clay	A-7-6	20.4	18 20 22 24
SC1	Sandy Clay	A-6	14.1	12 13.5 15.5 17
SC2	Sandy Clay	A-6	13.4	10 12 14 15.5
SS1	Sandy Silt	A-4	13	8 10.5 13 14.5
SS2	Silty Sand	A-2-4	10.8	7 9 12.5 15

Two values were calculated for soil M_R at each moisture content. The first M_R value was calculated from the recoverable strain measured by the on sample LVDTs. The second M_R value was calculated from the recoverable strain measured by the end LVDTs. The resilient strain measured with the end LVDTs showed good repeatability. The variation between the three replicates was less than 10% for most of the tested specimens. The repeatability of the resilient strain measured with the on sample LVDTs was dependant on the type of soil and moisture content. In general, the resilient strain measured with the on sample LVDTs showed higher variability between the three replicates than the strain measured with the end LVDTs [8].

According to recommendations of M_R test protocol, M_R values of the tested soils were reported for confining pressure of 14 KPa and cyclic stress of 41 KPa. The M_R values calculated from the on sample LVDTs were not considered in the analysis, where they showed higher variability and less reliability than M_R values calculated from the end LVDTs.

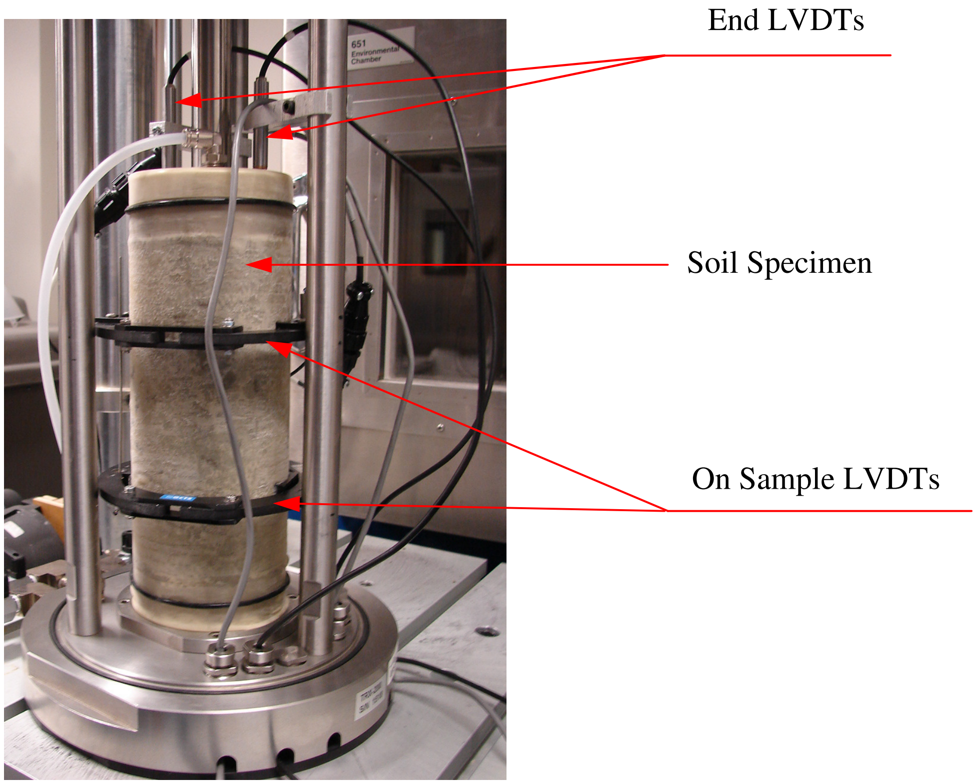

Figure 1: Soil Specimen for M_R Test after Mounting Instrumentation

Resilient Modulus for High Plastic Clay Soil Samples

The two high plastic clay soil samples, HC1 and HC2, were classified as A-7-6 soils according to AASHTO soil classification system. HC1 soil sample contained 83% clay, while HC2 soil sampled contained 51% clay. Figure 2 shows the calculated resilient modulus from the end LVDTs for HC1 soil sample. The resilient modulus of HC1 soil sample showed sensitivity to moisture content variation. The resilient modulus decreased from 63.9 MPa to 31.5 MPa (-50.7%) due to increasing the moisture content from 28.0% to 32.6%. Although it is known that the decline is likely not linear, a straight line trend is shown to illustrate the sensitivity.

Figure 3 shows the calculated resilient modulus from the end LVDTs for HC2 soil sample. The resilient modulus of HC2 soil sample showed sensitivity to moisture content variation. The resilient modulus decreased from 108.0 MPa to 34.8 MPa (-67.8%) due to increasing the moisture content from 18.8% to 23.8%. Although it is known that the decline is likely not linear, a straight line trend is shown to illustrate the sensitivity.

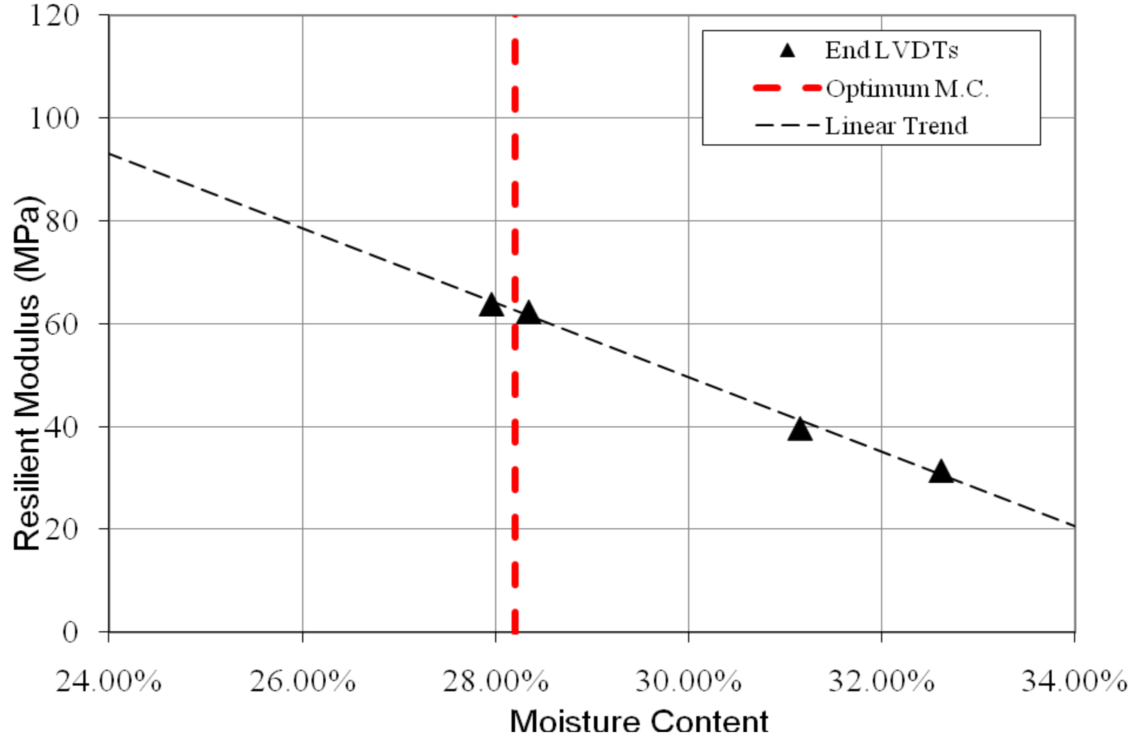

Figure 2: Resilient Modulus for HC1 Soil Sample

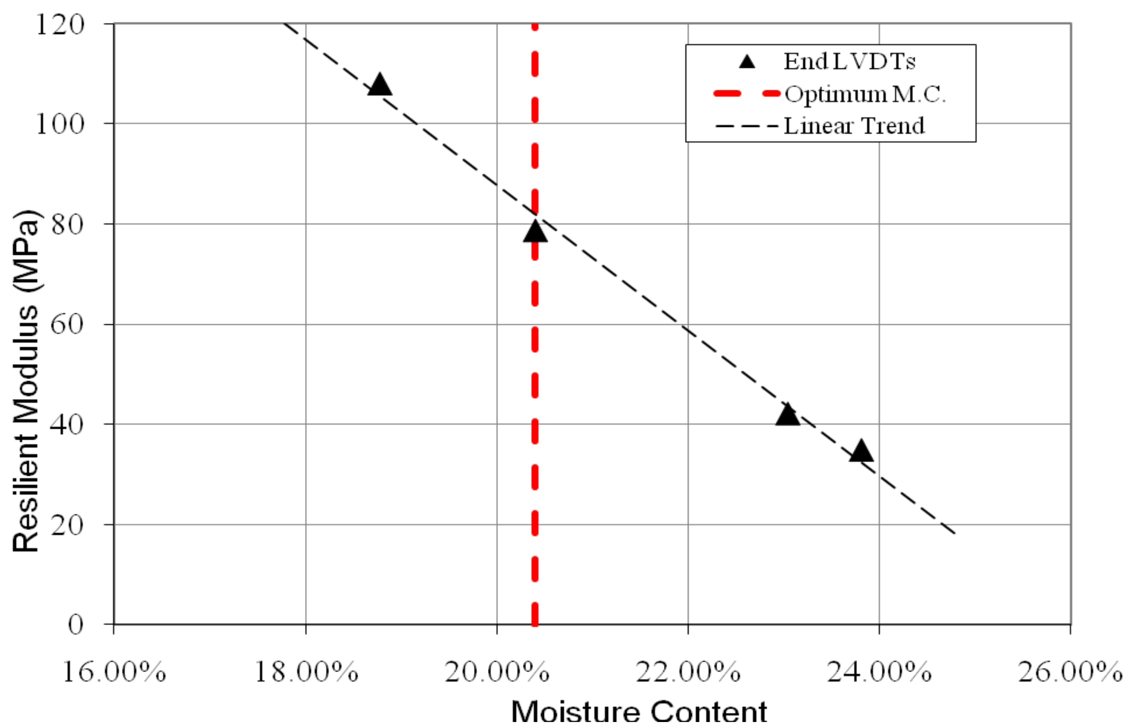

Figure 3: Resilient Modulus for HC2 Soil Sample

Resilient Modulus for Sandy Clay Soil Samples

The two sandy clay soil samples, SC1 and SC2, were classified as A-6 soils according to AASHTO soil classification system. SC1 soil sample contained 30% clay, while SC2 soil sampled contained 31% clay. Figure 4 shows the calculated resilient modulus from the end LVDTs for SC1 soil sample. The resilient modulus of SC1 soil sample showed high sensitivity to moisture content variation. The resilient modulus decreased from 101.9 MPa to 15.4 MPa (-84.9%) due to increasing the moisture content from 12.4% to 16.9%. Although it is known that the decline is likely not linear, a straight line trend is shown to illustrate the sensitivity. The permanent strain of the SC1 soil specimens exceeded 5% at moisture content 16.9% and the test was stopped before completing all the loading sequences.

Figure 5 shows the calculated resilient modulus from the end LVDTs for SC2 soil sample. The resilient modulus of SC2 soil sample showed high sensitivity to moisture content variation. The resilient modulus decreased from 105.4 MPa to 20.9 MPa (-80.2%) due to increasing the moisture content from 10.6% to 15.2%. Although it is known that the decline is likely not linear, a straight line trend is shown to illustrate the sensitivity. The permanent strain of the SC2 soil specimens exceeded 5% at moisture content 15.2% and the test was stopped before completing all the loading sequences.

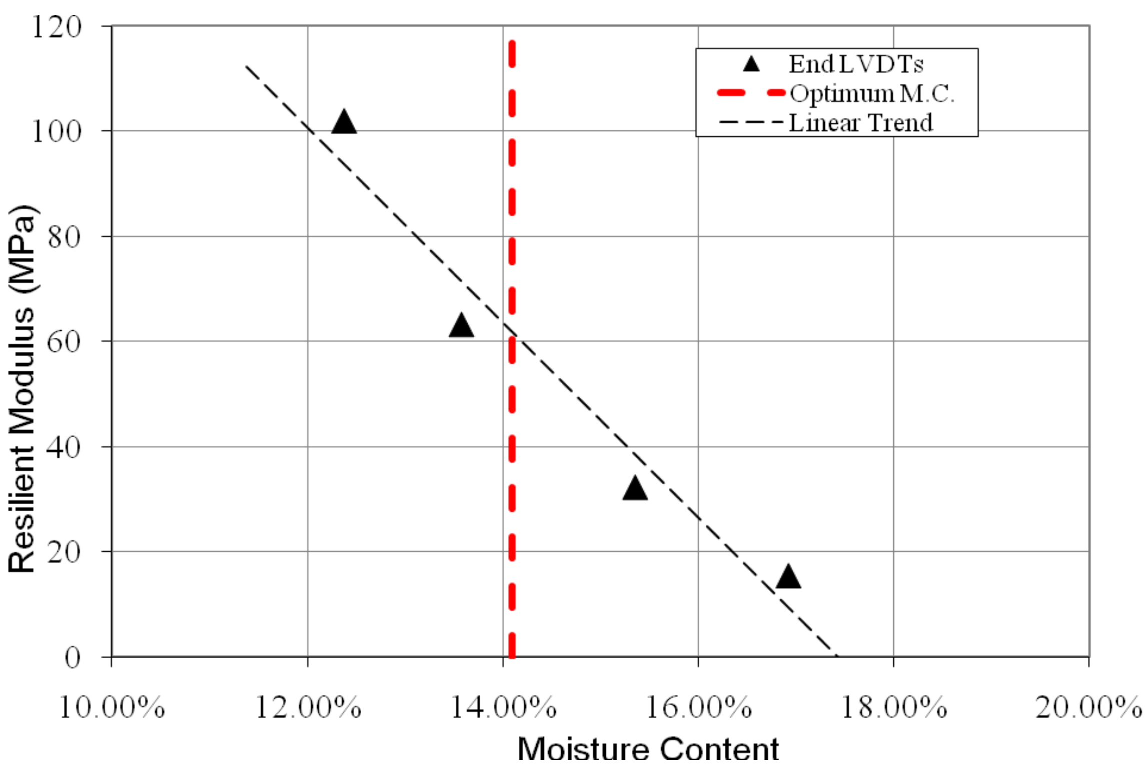

Figure 4: Resilient Modulus for SC1 Soil Sample

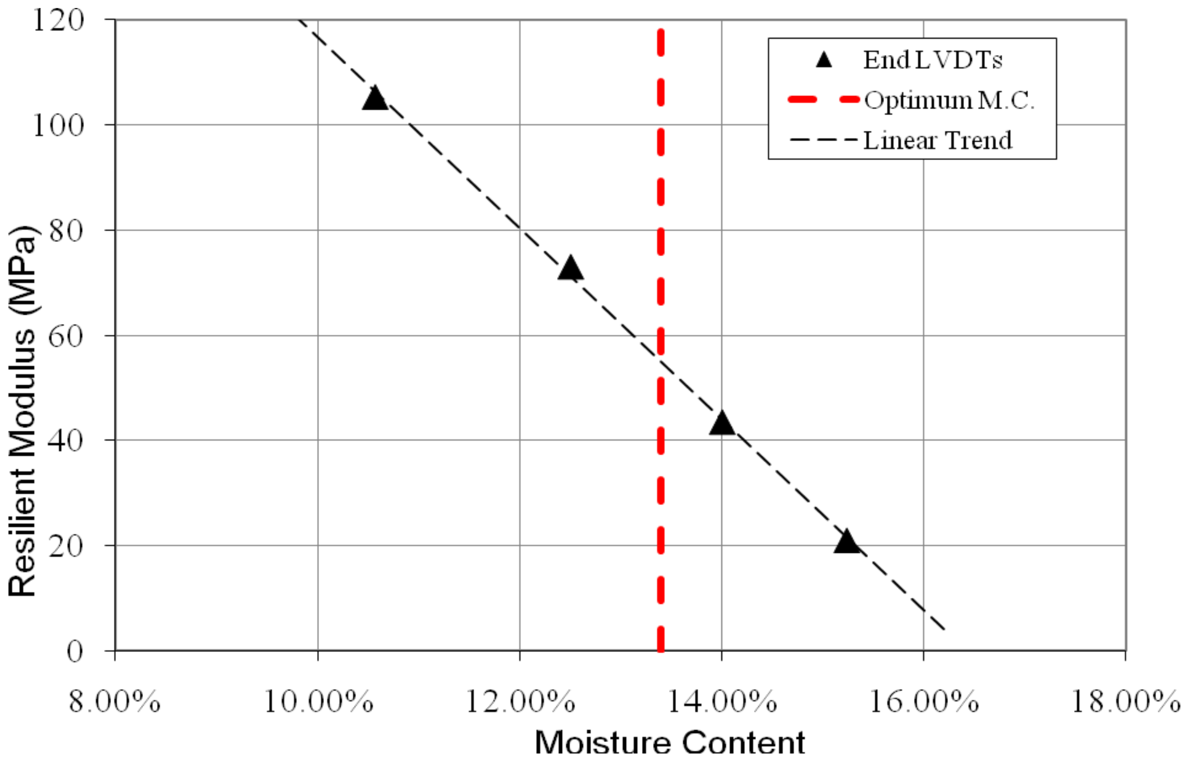

Figure 5: Resilient Modulus for SC2 Soil Sample

Resilient Modulus for Sandy Silt/Silty Sand Soil Samples

SS1 soil sample was classified as A-4 soil according to AASHTO soil classification system, while SS2 soil sample was classified as A-2-4 soil. SS1 soil sample contained 46% silt and 47% fine sand, while SS2 soil sample contained 23% silt and 66% fine sand. Figure 6 shows the calculated resilient modulus from the end LVDTs for SS1 soil sample. The resilient modulus of SS1 soil sample showed low sensitivity to moisture content variation. The resilient modulus decreased from 66.6 MPa to 56.9 MPa (-14.6%) due to increasing the moisture content from 8.5% to 14.9%. Although it is known that the decline is likely not linear, a straight line trend is shown to illustrate the sensitivity. The permanent strain of the SS1 soil specimens exceeded 5% at moisture content 14.9% and the test was stopped before completing all the loading sequences.

Figure 7 shows the calculated resilient modulus from the end LVDTs for SS2 soil sample. The resilient modulus of SS2 soil sample showed low sensitivity to moisture content variation. The resilient modulus decreased from 58.4 MPa to 39.5 MPa (-32.4%) due to increasing the moisture content from 7.7% to 14.0%. Although it is known that the decline is likely not linear, a straight line trend is shown to illustrate the sensitivity. The permanent strain of the SS2 soil specimens exceeded 5% at moisture content 14.0% and the test was stopped before completing all the loading sequences.

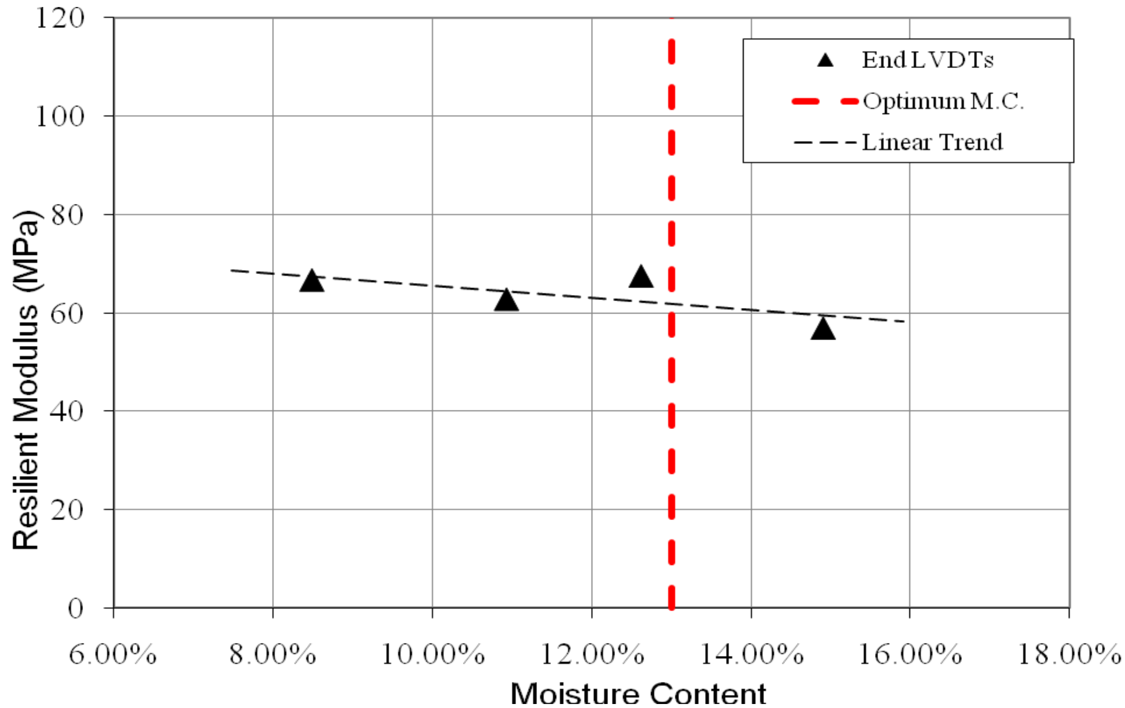

Figure 6: Resilient Modulus for SS1 Soil Sample

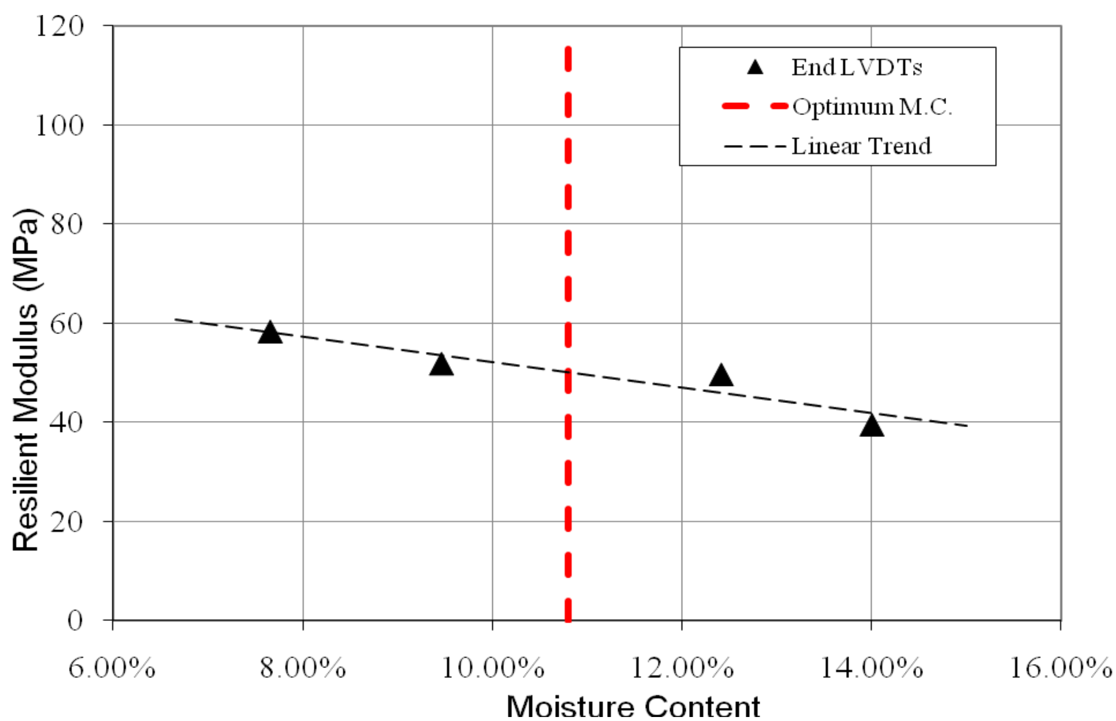

Figure 7: Resilient Modulus for SS2 Soil Sample

Summary and Conclusions

Resilient modulus of subgrade soils is the primary material property for design and analysis of pavements. Seasonal variation of subgrade moisture content can significantly affect subgrade M_R and subsequently pavement design. Seasonal variations are critical for determining the design M_R for a particular project. AASHTO pavement design guide requires the use of an effective value for subgrade resilient modulus that reflects the seasonal variation of soil moisture content. The same concept has been used in development of the 2002 Design Guide under NCHRP Project 1-37A.

The objective of this research was to investigate the sensitivity of subgrade M_R to moisture variation for typical soils available in Manitoba. Six soil samples were collected from different areas in the province to represent three types of soil available in Manitoba: silty sand/sandy silt (from central & southern Manitoba), sandy clay (from western Manitoba), and high plastic clay (from Red River Valley). M_R tests were conducted for each soil sample at four levels of moisture content. The four moisture contents were selected to cover both dry and wet sides of standard Proctor compaction curve. For each soil sample, three replicates were tested at each moisture content. M_R values were reported for confining pressure of 14 KPa and a cyclic stress of 41 KPa. According to M_R test protocol, this stress state represents the stress state that subgrade encounters under traffic loading.

For high plastic clay soils, M_R values ranged from 31.5 to 108.0 MPa at moisture contents ranging from 18.8% to 32.6%. M_R values showed high sensitivity to moisture content variation. For silty sand/sandy silt soils, M_R values ranged from 39.5 to 66.6 MPa at moisture contents ranging from 7.7% to 14.9%. For moisture contents at the high end of the wet side of the Proctor curve, the total permanent strain exceeded 5%. Excluding the moisture contents at the high end of the wet side of Proctor curve, M_R values for silty sand/sandy silt soils were not sensitive to moisture content variation.

For sandy clay soils, M_R values ranged from 15.4 to 105.4 MPa at moisture contents ranging from 10.6% to 16.9%. For moisture contents at the high end of the wet side of the proctor curve, the total permanent strain exceeded 5%. M_R values showed high sensitivity to moisture content variation. Increasing moisture content allowed sandy clay soil to compact easily. At moisture contents higher than the optimum moisture content, compaction of subgrade soil at higher density can improve M_R and reduce its sensitivity to moisture variation.

Acknowledgement

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