TRANS NOW
TRANSPORTATION NORTHWEST

Final Report

TNW2011-15

Evaluation of High Percentage Recycled Asphalt Pavement as Base Materials

FINAL REPORT

By

Haifang Wen, PhD, PE
Assistant Professor
Dept. of Civil & Environmental Engineering
Washington State University
PO Box 642910
Email: haifang_wen@wsu.edu

Mengqi Wu
Research Assistant
Dept. of Civil & Environmental Engineering
Washington State University
Email: Mengqi.wu@email.wsu.edu

Department of Civil and Environmental Engineering
University of Washington
Seattle, WA 98195

A report prepared for

Transportation Northwest (TransNow)
University of Washington
112 More Hall, Box 352700
Seattle, Washington 98195-2700

and
Washington State Department of Transportation

June 2011

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. TNW2011-15	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE Evaluate High Percentage Recycled Asphalt Pavement as Base Materials		5.REPORT DATE 6/11 6. PERFORMING ORGANIZATION CODE 65-0345	
7. AUTHOR(S) Haifang Wen, Mengqi Wu		8. PERFORMING ORGANIZATION REPORT NO. TNW2011-15	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Transportation Northwest Regional Center X (TransNow) Box 352700, 112 More Hall University of Washington Seattle, WA 98195-2700		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. DTRT07-G-0010	
12. SPONSORING AGENCY NAME AND ADDRESS United States Department of Transportation Office of the Secretary of Transportation 1200 New Jersey Ave, SE Washington, D.C. 20590		13. TYPE OF REPORT AND PERIOD COVERED Final Technical Report 14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES			

ABSTRACT

This proposed research would evaluate the structural and drainage performance of RAP in regards to long-term flexible and rigid pavement structural performance which are the primary concerns for WSDOT. This study will evaluate high percentage RAP as base materials. The percentage of RAP to be evaluated will range from 20% to 100%, at an increment of 20%. The engineering performance of high percentage RAP will be evaluated, in terms of modulus, rutting potential, drainage, and stripping by which WSDOT is concerned. In addition, the field performance of pavements with high percentage RAP will be assessed. Another critical issue of RAP is the field quality acceptance criteria, especially the implication of asphalt to the nuclear densometer readings. The study will study and develop an appropriate specification for quality control by WSDOT, including, but not limited to, laboratory/field compaction methods to determine maximum density, acceptance criteria, and the method to determine field density. Using RAP as base course materials will contribute to sustainability by saving cost and energy and reducing greenhouse gas emission. The study will quantify the impact of using RAP on cost, energy, and greenhouse gas emission and compare to that of crushed aggregate. A life cycle analysis of RAP will be conducted.

17. KEY WORDS Recycled Asphalt Pavement, Sustainability, Compaction, Density, Performance, RAP, Base course material, M_r test, Hydraulic conductivity test		18. DISTRIBUTION STATEMENT No restrictions.	
19. SECURITY CLASSIF. (of this report) None	20. SECURITY CLASSIF. (of this page) None	21. NO. OF PAGES 142	22. PRICE

DISCLAIMER

This research was funded through Transportation Northwest (TransNOW) and the Federal Highway Administration. The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of TransNOW or the Federal Highway Administration at the time of publication.

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. This report does not constitute a standard, specification, or regulation.

The United States Government does not endorse products or manufacturers. Trade and manufacturers' names appear in this report only because they are considered essential to the object of the document.

ACKNOWLEDGEMENTS

The research team wishes to thank TransNOW for their support. The research team also wishes to thank Mr. Jeff Uhlmeyer, Ms. Kim Willoughby, Mr. Kevin Littleton, and Mr. Randy Mawdsley of the Washington Department of Transportation for their support and input. Thanks also go to Mr. Sam Nasralla of the City of Pullman for his help in identifying field construction for this project and assistance in field sampling. The lab assistance from undergraduate students Mr. Kelvin Daratha and Mr. Vincent Wen, is appreciated.

Table of Contents

CHAPTER 1 INTRODUCTION

1.1 PROBLEM STATEMENT

A large amount of construction waste is produced each year and it is becoming more difficult to find appropriate locations for disposal of this waste. Material recycling offers a viable solution and is beneficial to both the environment and the economy. The Federal Highway Administration (FHWA) estimated that 100.1 million tons of hot mixed asphalt (HMA) is scrapped each year [Cosentino 2001]. Recycled asphalt pavement (RAP) is one of the most commonly used recycled materials. RAP is the term given to removed and/or reprocessed asphaltic materials. RAP is generated when asphalt pavements are removed for reconstruction or rehabilitation. RAP consists of high-quality, well-graded aggregates coated by asphalt [RMRC 2010]. Many State Departments of Transportation allow the use of recycled asphalt pavement (RAP) to be blended with mineral aggregates to produce a composite base course material. McGarrah [2007] conducted a survey among the State Department of Transportation regarding the use of RAP as base course material. The results indicated that the percentage of RAP allowed by highway agencies to use as base course material varied from 2 percent to 60 percent [McGarrah 2007] Currently, the Washington Department of Transportation (WSDOT) allows up to 1.2 percent of bitumen (about 20 percent RAP) in base materials [WSDOT 2008]. An increased percentage of RAP in base course materials could offer potential economical and environmental benefits. However, as more RAP material is incorporated into the base course material, concerns are being raised by the agencies, such as the impact of a high percentage RAP on pavement, appropriate compaction requirements, and drainage characteristics, all of which may affect the overall long-term performance of both flexible and rigid pavement structures [Uhlmeyer 2008]. Research is needed to evaluate the potential use of high percentage recycled asphalt pavement as base course material, without compromising pavement performance. A successful application of high percentage RAP could contribute to sustainability, in terms of costs, energy, and greenhouse gas emission.

1.2 BACKGROUND

Some studies have been conducted on recycled materials, primarily focusing on laboratory evaluation of physical properties. Kim et al. [2007] found that RAP as base materials had higher resilient modulus, but higher rutting potential, than virgin aggregates in Minnesota. Wen et al. [2008] studied the recycled asphalt pavement with and without fly ash as base course materials in Wisconsin and compared them to crushed aggregates. Experimental roads were also built at MnROAD in Minnesota. In that study, it was also found that RAP had higher modulus and higher permanent deformation, when compared to crushed aggregate. Adding cementitious materials improved the resistance to permanent deformation. Jeon et al. [2009] reported that both the static shear strength and the resilient modulus of RAP were generally higher than virgin aggregate materials. However, the resistance of RAP to permanent deformation at low stress levels was lower than that of the typical aggregate base material in California. The opposite was true at higher stress levels [Jeon et al. 2009]. The sources of RAP could lead to large variations of the engineering properties of RAP. In addition, due to the existence of asphalt, unlike crushed aggregates, properties of RAP are affected by temperature fluctuation [Consentino 2001]. The permeability of RAP is another concern. The moisture trapped in RAP base could cause further moisture damage to RAP. Stripping due to moisture damage can generate fines, which can affect the permeability [Saeed 2008].

The above studies have shown that RAP has the potential to be a good base course material, but there are also some concerns about its use. The issues related to RAP must be addressed before high percentage RAP can be used for routine highway construction.

1.2 OBJECTIVES

The objective of this proposed research consisted of evaluating the engineering performance of RAP in terms of stiffness (modulus), rutting potential, and permeability under different climatic conditions.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

According to the National Asphalt Pavement Association (NAPA), more than 90 percent of U.S. roads and highways are paved with HMA. About 500 million tons (454 million metric tons) of HMA are produced each year. During rehabilitation or reconstruction, the existing HMA layers are removed either partial-depth or full-depth. In response to the shrinking supply of raw materials and the rising costs of virgin aggregates and binders, RAP is considered to be an alternative to virgin materials and a valuable component in HMA. In addition, RAP can be used in-situ as a base course material, which eliminates the transportation of RAP to HMA plant and reduces the need for virgin aggregates

2.2 CURRENT USE OF RAP AS BASE COURSE

The use of RAP as a base course material offers economical and environmental benefits. The WSDOT currently allows up to approximately 20 percent RAP to be blended with virgin crushed aggregates to form the base course materials. McGarrah conducted a survey of current practices of state DOTs regarding the use of RAP as a base course material and contacted seven states including Colorado, Florida, Illinois, Minnesota, Montana, New Jersey and Utah [McGarrah 2007]. The results of the survey are listed in Table 1.

Table 1 State DOT Survey Results [McGarrah 2007]

State	Rap Allowed[1]	Max %[2]	Processed[3]	Testing[4]
Florida	No	---	---	---
Illinois	No	---	---	---
Montana	Yes	50-60%	No	Corrected Nuclear Gauge
New Jersey	Yes	50%[5]	Yes – Gradation	Corrected Nuclear Gauge + Sample
Minnesota	Yes	3%[6]	Yes – Gradation	Dynamic Cone Penetrometer
Colorado	Yes	50%[5]	Yes – Max Agg. Size	Roller Compaction Strip
Utah	Yes	2%[6]	Yes – Gradation	Nuclear Gauge or Breakdown Curve
Texas[7]	Yes	20%	Unknown	Various (including Nuclear Gauge)
California[7]	Yes	50%	Unknown	No special testing procedure listed
New Mexico[7]	Yes	Unknown	Unknown	Corrected Nuclear Gauge
Rhode Island[7]	Yes	Unknown	Yes – Gradation	Unknown
South Dakota[7]	No	---	---	---

1 Describes whether state allows RAP as a base course material.
2 Maximum percentage of RAP (by weight) allowed.
3 Describes whether the listed state requires the RAP blend to be processed prior to placement and what requirements must be met.
4 Describes the type of QA testing required.
5 These are modified values. The current values are 100%, but the materials department is in the process of modifying current values.
6 These values are the maximum AC content allowed in the RAP blend.
7 These states were not contacted and the information listed in the table is from the state's current standard specification.

As shown in the table, the maximum percentage of RAP as a base course material allowed by state DOTs varies from 0 percent to 60 percent. For the State of

Montana, whether RAP may be used as base course material is decided on a project-by-project basis, and the maximum percentage of RAP used as base course material is 60 percent. The maximum percentage of RAP used as base course was selected on the basis of the research conducted by Mokwa et al. [2005], which proved that the blending of RAP with virgin aggregate only caused minor changes to the engineering properties of the blended base course material.

In Florida, RAP was allowed to be used in embankment for roadways or as backfill for pipes and culverts. RAP is also allowed to be used in roadway subbase and base if it meets specifications, such as the Limerock Bearing Ratio. A study conducted by Cosentino et al. [2001] indicated that the deformation potential of RAP significantly increased with the increase of temperature.

2.3 PAST STUDIES ON RESILIENT MODULUS OF RAP

The stiffness of the base layer greatly affects the performance of a pavement. High stiffness is desired to prolong the pavement life. Resilient modulus ($\mathrm{M_r}$) is a property that represents the stiffness of base course material. A resilient modulus test is commonly conducted in the laboratory to determine $\mathrm{M_r}$, in accordance with the NCHRP 1-28A or the AASHTO T307 test protocol. Resilient modulus tests is conducted by by applying repeated compressive loading (Figure 1) on test specimens of the unbound material under a confined condition. Resilient modulus is defined as the ratio of the peak-to-peak repeated deviator stress to the peak-to-peak recoverable strain of the specimen, as shown in Equation 1 [Witczak 2004].

$$\mathrm{M_r} = \mathrm{S_{cyclic}}/\varepsilon_\mathrm{r} \qquad (1)$$

where, $\mathrm{M_r}$ is the resilient modulus,

S_{cyclic}=$(P_{max} - P_{contact})/A$, and A is the initial cross-sectional area of the sample, $\varepsilon_r = \frac{e_r}{L}$, and e_r is the recoverable axial deformation due to S_{cyclic} , L is the distance between measurement points for resilient axial deformation, e_r.

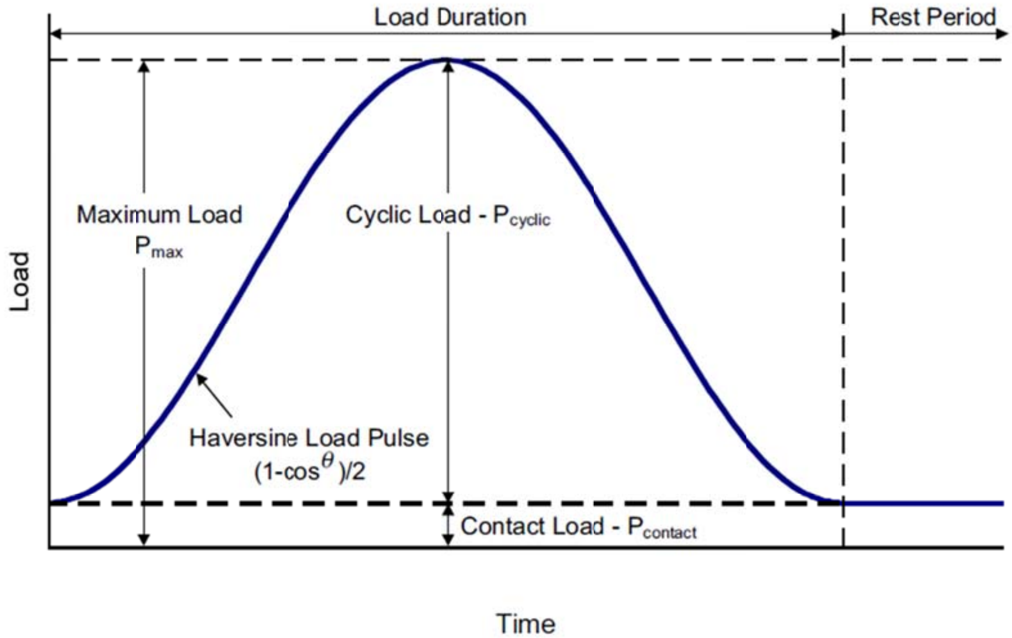


Figure 1 Witczak (2004) Definition of Resilient Modulus Terms

Temperature and moisture content are primary factors affecting the in situ modulus of unbound pavement materials on a seasonal basis [Richter 2006]. In a pavement design, such as that of the American Association of State Highway and Transportation Officials (AASHTO) 1993 design method [AASHTO 1993] or the Mechanistic Empirical Pavement Design Guide (MEPDG) [ARA 2004], resilient modulus is the primary design property for unbound materials. In the MEPDG, the effects of fluctuation of moisture content on resilient modulus are modeled with a soil-water characteristic curve (SWCC). Moisture content also affects the permanent deformation of unbound materials. MEPDG only considers traditional unbound materials, such as virgin aggregates. Recycled materials, such as RAP, may present unique properties that are not accounted for in the MEPDG. For instance, the asphalt in RAP is sensitive to temperature, which is not considered for traditional unbound materials. Characterization of resilient modulus of base materials with RAP must include the effects of climatic effects, such as temperature and moisture contents, in the MEPDG.

Wen et al. [2008] studied the resilient modulus of base materials with RAP. It was found that base materials containing RAP had a higher resilient modulus, which is in agreement with other findings [Mohamed 1997]. Kim et al. [2007] conducted resilient modulus tests on specimens containing different contents of RAP and two moisture contents, 65 percent and 100 percent of optimum moisture content (OMC), respectively. It was reported that specimens with 100 percent OMC had lower M_r values than those of specimens with 65 percent OMC. Attia et al. [2009] also found that samples containing RAP had higher M_r values than those of crushed aggregates. In addition, the sensitivity of the resilient modulus of RAP to moisture content was higher than that of granular material [Mohamed 2008]. Sargious et al. [1991] studied the effects of low temperature on the behaviors of RAP. It was concluded that resilient modulus increased with the decrease of temperature from 20℃ to -40°C. However, the effects of high temperature on resilient modulus and permanent deformation were not considered.

2.4 PAST STUDIES ON OTHER ENGINEERING PROPERTIES OF RAP

2.4.1 Moisture-density relationship

Cooley [2005] determined the optimum moisture content (OMC) and the maximum dry unit weight (MDUW) for samples containing different percentages of RAP using modified proctor compaction method. Their results indicated that increasing the percentage of RAP caused a decrease of OMC and MDUW. Attia et al. [2009] found that RAP had a lower MDUW compared to aggregate samples, based on both impact compaction method and gyratory compaction. For the gyratory compaction, increasing RAP decreased OMC, whereas for standard proctor compaction, OMC increased with the increase of RAP percentage. Gupta et al. [2009] conducted tests to determine the OMC and MDUW for samples containing different percentages of RAP using a gyratory compactor at a compaction angle of 1.25 degrees, compaction pressure of 600 kPa (87.02 psi), and 50 gyrations. It was concluded that increasing RAP increased MDUW and OMC. MacGregor et al. [1999] evaluated the relationship between OMC, MDUW and RAP content. The results indicated that no correlation was found between the RAP content and OMC or MDUW.

2.4.2 Permanent deformation

Permanent deformation in base course greatly affects the pavement performance, such as rutting. A series of repeated triaxial compression tests were conducted by Mohammad et al. [2006] to determine the permanent deformation of base course materials. Two vertical linear variable differential transducers (LVDT) were used to detect the displacements. A haversine load pulse of 0.1-second loading and 0.9-second rest period was applied to samples for 10,000 cycles. The permanent deformation of RAP exhibited an initial acceleration and then reached a steady state. It was reported that M_r was not sufficient in characterizing base course material of pavement structure, and thus permanent deformation should be incorporated in the pavement design procedure [Mohammad et al. 2006].

Kim et al. [2007] conducted 20 M_r tests for samples with different percentages of RAP to investigate the effects of RAP on resilient modulus. Specimens were prepared using a gyratory compactor and the NCHRP 1-28A test protocol was followed. The test results showed that the RAP specimens were stiffer at high confining pressure when compared to virgin aggregate samples. However, the permanent deformation of specimens containing RAP was greater than that of virgin aggregates. Wen et al. [2008] also reported similar findings.

2.4.3 Permeability

Hydraulic conductivity is recognized as an important parameter for base course material. If the subgrade material is saturated, the pavement may deteriorate rapidly under dynamic traffic loading [Attia 2009, ARA 2004]. The moisture trapped between the particles in the base layer may lead to the destruction of the pavement structure due to loss of support. For asphalt pavement, moisture can infiltrate into the base layer through surface cracking or shoulder over time.

Compaction efforts during sample preparation reduce the volume of large pores and increase the volume of small pores [Gupta 2009]. Trzebiatowski et al. [2005] conducted a study to determine the hydraulic conductivity of RAP as a base course material. It was concluded that the hydraulic conductivity of RAP ranged from 4.5×10^{-8} to 1.7×10^{-6} m/s when compacted with modified proctor efforts, and ranged from 2.4×10^{-5} to 9.0×10^{-5} m/s when compacted with standard proctor efforts. For the hydraulic conductivity testing conducted in a study by Trzebiatowski et al. [2005], a rigid-wall, compaction-mold permeameter was selected for sample preparation and the ASTM D5856 test protocol was followed. By comparing the testing result of RAP and crushed stone, it was reported that the permeability of RAP is comparable to that of traditional base course material. Another study by Gupta [2009] found that samples containing RAP had higher hydraulic conductivity when compared to aggregates. However, no correlation was detected between RAP percentage and hydraulic conductivity. Bouchedid et al. [2001] tested the coefficients of permeability of base course materials in a triaxial permeameter and a rigid wall permeameter, respectively. It was found that the difference in the coefficient of permeability between the two methods was caused by different boundary conditions and sample preparation methods. Based on the results of field permeability measurements, triaxial permeameter was recommended to be used for lab testing since the average field permeability was close to that of the triaxial permeability. Macgregor et al. [1999] conducted 12 hydraulic conductivity tests on samples containing RAP, crushed-stone base materials and gravel-borrow subbase materials. It was found that hydraulic conductivity was not significantly affected by the RAP percentage in the RAP/crushed stone mixtures, while the hydraulic conductivity of RAP/gravel-borrow mixtures increased by nearly one order of magnitude when the RAP percentage increased from 0% to 50%. The uniform gradation of RAP used in the study was believed to be the reason for the increased hydraulic conductivity. Since factors such as compaction efforts, type of soil and gradation affect hydraulic conductivity, it is difficult to determine, based on the literature, to determine whether the RAP percentage affects the hydraulic conductivity of mixtures.

2.4.4 Moisture damage

The base materials in the field are subjected to moisture damage and/or freezing-thawing cycles. When RAP is used in the base course, asphalt may strip off the aggregates and affect the permeability. In the laboratory, pavement materials are subjected to freezing-thawing conditioning to determine stripping. For hot mix asphalt, WSDOT Test Method T718 is commonly followed, which specifies a minimum of 16-hour freezing at -18±3°C (0±5°F) followed by 60±1°C (140±2°F) for 24 hours. For aggregates, the AASHTO T102 introduces procedures for freezing and thawing, in which samples should be cooled until the center of the samples reaches -23°±3°C (-9°±5°F) and the temperature shall be held for a minimum of 2 hours prior to the thawing cycle, which lasts a minimum of 30 minutes at 21°±3°C (70°±5°F). According to the AASHTO T102, the procedure of alternate freezing and thawing should be repeated for 25 cycles.

Base course exhibits seasonal variations of modulus due to fluctuation of moisture content and/or temperature. The stresses and strains induced in the pavement by traffic loads also vary with the change of the modulus of the base materials [Mohammad et al. 2006]. Attia et al. subjected a set of samples to two freezing-thawing cycles to evaluate the effects of freezing-thawing on the resilient modulus of RAP as compared to that of virgin aggregates [Attia et al. 2009]. One cycle of freezing-thawing consisted of 24-hour freezing at -12°F followed by 24-hour thawing at room temperature. Based on test results, samples containing RAP compacted at OMC did not show loss of strength due to freezing-thawing cycles. It was reported that the moisture content decreased, which indicated loss of moisture during conditioning and/or testing. The decreased moisture content could be a reason for higher modulus after freezing-thawing conditioning.

CHAPTER 3 MATERIALS AND EXPERIMENTS

In order to study the effects of high percentage of RAP on the performance of base course, laboratory tests were conducted, in terms of resilient modulus, rutting potential and hydraulic conductivity.

3.1 CHARACTERIZATION OF BASE COURSE MATERIAL CONTAINING RAP

3.1.1 Sampling

Materials used in this study included crushed aggregates and RAP. Crushed aggregates were sampled from POE Asphalt Paving Inc. in Pullman, WA. RAP was collected from two sources: POE Asphalt Paving Inc. in Pullman, WA and Fairmount Road construction site in Pullman, WA. The RAP samples from the Fairmount Road project was collected in-situ after the milling of the existing pavement section. The RAP collected from the POE Asphalt Paving Inc. was referred to as RAP1 and the RAP from the Fairmount Road project was referred to as RAP2.

3.1.2 Gradation

As some fine particles adhere to large RAP particles, more accurate results can be obtained by performing wet sieving, instead of using the dry sieving method. Particle gradation for RAP was conducted in accordance with the AASHTO T 11-05 Procedure A was chosen.

Since the objective of this study was to evaluate the effects of RAP, in order to eliminate the effects of gradation on the material properties, one single gradation was selected which meets the WSDOT specification 9-03.9(3) for crushed surfacing base course material. Crushed aggregate particles were added to RAP to obtain the target gradation of the mixture. Figure 2 and Table 2 show the typical gradations for mixtures containing RAP1 and RAP2, the original gradations of RAP1 and RAP2, and the WSDOT specification on the gradation for base course materials. RAP 1 has a maximum size of 12.5 mm (0.5 in), which is intended for use in HMA, while the RAP2 has a maximum size of 31.5mm (1.25 in).

Table 2. Gradations of RAP

Sieve size,"(mm)	**Passing percentage**				
	Blended RAP/Aggregates				
	RAP1 mixtures	RAP2 mixtures	**RAP1**	**RAP2**	**WSDOT specification**
1-1/4"(31.5)	100	100		100.00	100
1"(25.0)	99	94		93.56	80-100
3/4(19.0)	86	84		82.26	
5/8(16.0)	76	75		71.23	50-80
1/2(12.5)	72	66	100.00	61.31	
3/8(9.5)					
1/4(6.3)					
No.4(4.75)	39	31	47.10	22.20	25-45
No.6(3.35)					
No.8(2.36)	22	18	21.79	11.07	
No.10(2.00)					
No.16(1.18)	15	12	10.62	5.70	
No.20(0.850)					
No.30(0.600)					
No.40(0.425)	10	7	5.14	2.52	3-18
No.50(0.300)					
No.80(0.180)					
No.100(0.150)	7	4	3.13	1.44	
No.200(0.075)	3	2	2.47	1.08	7.5max

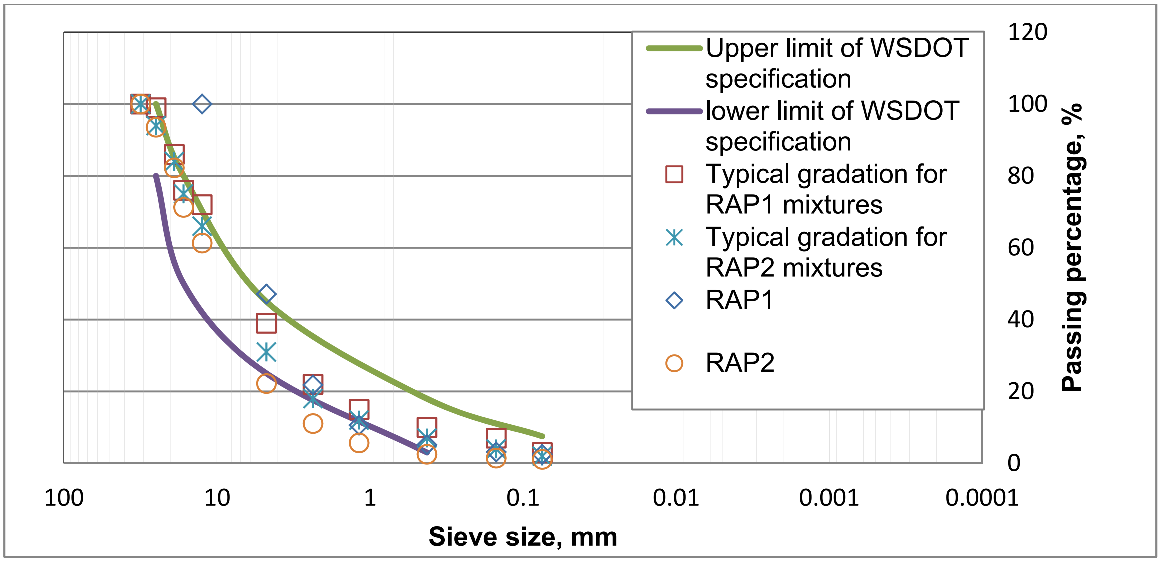


Figure 2 Gradation for evaluated samples and required gradation in WSDOT specifications

3.1.3 Asphalt content determination

The Ignition Oven Method was used to determine the asphalt content in RAP1 and RAP2 [AASHTO T308]. The ignition oven was preheated to 538°C (1000°F) and the weight of the assembly with lid was recorded. Mixtures were placed on the tray and spread evenly with a hot spatula. The tray containing the sample was placed into the ignition oven and the ignition was started until the weight loss become constant. The calibrated asphalt content was calculated as follows:

$$AC\% = [[(WS - WA) / WS] \times 100] - CF \quad (2)$$

where,

AC% = measured (corrected) asphalt content percent by weight of the HMA sample;

WA = total weight of aggregate remaining after ignition;

WS = total weight of the HMA sample prior to ignition; and

CF= calibration factor, percent by weight of HMA sample, which depends on oven setup and efficiency.

3.1.4 Specific gravity

The bulk specific gravity of coarse aggregates was determined in accordance with the AASHTO T 85. Aggregate retained on the No. 4 sieve was soaked in water for 15 hours before testing. Based on the testing data, bulk specific gravity can be calculated according to the equation presented as follows:

$$G_{sb} = A/(B-C) \quad (3)$$

where,

G_{sb} = bulk specific gravity;

A = mass of oven-dry test sample in air;

B = mass of saturated-surface-dry test sample in air;

C = mass of test sample in water.

3.1.5 Moisture-density relationship

The modified proctor compaction test was conducted to determine the optimum moisture content (OMC) and maximum dry unit weight (MDUW) in accordance with the D method of the AASHTO T 180, because less than 30 percent by mass of the material is retained on the 19 mm (3/4 in) sieve. This procedure uses a 48 N (10 lb) hammer and a 45.72 cm (18 in) drop height. Particles retained on the 19-mm (0.75 in) sieve were removed prior to compaction, and samples were compacted in 5 lifts in a 152-mm (6 in) mold using 56 blows per layer. The wet density was calculated as shown in Equation 4. Based on the wet density and the average moisture content, dry density was calculated based on Equation 5.

$$W1 = (A-B)/V \tag{4}$$

where,

W1 is wet density;

A is the mass of compacted specimen and mold;

B is the mass of mold;

V is the volume of mold.

$$W=\frac{W1}{w+100}\times 100 \tag{5}$$

where,

W is the dry density;

w is the moisture content of the specimen by percentage.

3.1.5.1 Correction for OMC and MDUW

As specified by the AASHTO T-224, corrections to OMC and MDUW values were needed if more than 5% particles are retained on 19-mm (3/4 in) sieve. Based on the typical gradations chosen in this study, 14% particles were retained on 19.00 mm (3/4 in) sieve for testing samples containing different percentages of RAP1 and 16% were retained on 19.00 mm (3/4 in) sieve for samples containing RAP2. The OMC and MDUW values from the compaction tests were corrected in accordance with the adjustment equations expressed as follows:

$$MC_T = (MC_f \cdot P_f + MC_C \cdot P_C)/100 \tag{6}$$

where,

MC_T is the corrected moisture content of the testing sample, expressed as a decimal;

MC_f is the moisture content of the fine particles, which are passing 19.00 mm mm (3/4 inch) sieve, expressed as a decimal;

MC_C is the moisture content of the oversized particles, which are retained on 19.00 mm mm (3/4 inch) sieve, expressed as a decimal; can be assumed to be 0.02 for most construction applications.

P_f is the percentage of fine particles, by weight;

P_C is the percentage of coarse particles, by weight.

$$D_d = 100\ D_f\ k / (D_f \cdot P_C + k \cdot P_f) \qquad (7)$$

where,

D_d is the corrected total dry density, kg/m^3;

D_f is the dry density of the fine particles, kg/m^3;

K equals to 1000× Bulk Specific Gravity of coarse particles, kg/m^3.

$$P_f = 100\ M_{DF} / (M_{DF} + M_{DC}) \qquad (8)$$

$$P_C = 100\ M_{DC} / (M_{DF} + M_{DC}) \qquad (9)$$

where,

M_{DF} = mass of fine particles;

M_{DC} = mass of coarse particles

3.1.6 Stiffness

3.1.6.1 Introduction

The fatigue life of the hot mix asphalt surface layer is greatly affected by the stiffness of the base course. High stiffness of the base course reduces the tensile strain at the bottom of the HMA layer and prolongs the fatigue life of pavement. Resilient modulus, adopted in the MEPDG, is an effective measure of engineering performance of granular materials.

3.1.6.2 Resilient modulus test

3.1.6.2.1 Sample preparation and conditioning

Resilient modulus tests were conducted on mixtures containing different percentages of RAP and crushed aggregates in accordance with the NCHRP 1-28A test protocol. Samples for resilient modulus testing were prepared in accordance with the manual compaction procedure in the NCHRP 1-28A. Sample particles retained on 25.0 mm (1 in) sieve were removed before sample preparation. After the materials were well mixed, the resulting mixture was compacted in a split mold with a diameter of 152 mm (6 in) for 6 layers, with each layer of 50.8 mm (2 in) height to make a target height of 304.8 mm (12 in). The mass of each layer was determined based on the corrected OMC and 95% MDUW. For testing samples containing moisture contents other than the OMC, the dry density of samples was kept constant. Latex membrane was placed between the sample and the split mold, and vacuum was applied during the compaction.

Table 3 shows the testing schedule. For testing samples containing RAP1 or RAP2 with OMC, temperatures were varied from -20 to 60°C (-4 to 140°F) in order to determine the effects of temperature on resilient modulus. For tests on specimens with varied moisture contents, the moisture contents varied from OMC-4% to OMC+2% to evaluate the effects on stiffness of base course material, while controlling other factors, such as the temperature and the percentage of RAP. Tests designed to evaluate the effects of moisture content were conducted immediately after sample preparation to avoid moisture loss. Samples used to determine the effect of temperature on M_r were put in the environmental chamber of a Geotechnical Consulting and Testing Systems (GCTS) overnight at the target temperature.

Table 3. Test variables of RAP percentage, temperature and moisture content

RAP	RAP Percentage, %	Temperature, °C					
		-20	20				60
RAP1	0	OMC	OMC-4%	OMC-2%	OMC	OMC+2%	OMC
	20	OMC	OMC-4%	OMC-2%	OMC	OMC+2%	OMC
	40	OMC	OMC-4%	OMC-2%	OMC	OMC+2%	OMC
	60	OMC	OMC-4%	OMC-2%	OMC	OMC+2%	OMC
RAP2	0	OMC	OMC-4%	OMC-2%	OMC	OMC+2%	OMC
	20	OMC	OMC-4%	OMC-2%	OMC	OMC+2%	OMC
	40	OMC	OMC-4%	OMC-2%	OMC	OMC+2%	OMC
	60	OMC	OMC-4%	OMC-2%	OMC	OMC+2%	OMC
	80	OMC	OMC-4%	OMC-2%	OMC	OMC+2%	OMC

3.1.6.2.2 Resilient modulus test procedures

Samples were placed in a triaxial cell of the GCTS, as presented in Figure 3, for testing, following the NCHRP 1-28A protocol for base and subbase materials. Two linear variable differential transducers (LVDTs) were used to measure the axial deformation. The resilient modulus was calculated based on the average value of the two LVDTs' readings. A triaxial chamber was used to provide an air-tight environment so that the target confining pressure could be reached during the test. The water valves for drainage were kept open [Witczak 2004]. According to the NCHRP1-28A protocol, the test sequence for base and subbase material consisted of 1 pre-conditioning sequence and 30 load sequences. For each confining pressure, cyclic stress increased from 0.5 to 7 times of confining pressure. For each sequence, the axial loading was applied using a haversine-shaped loading, and 0.1-second load pulse followed by a 0.9-

second rest period. The test sequences for base and subbase materials are listed in Table 4.

Figure 3 Resilient modulus sample

3.1.7 Permanent deformation

In the field, base materials are subjected to stresses such as the weight of surface layer and repeated traffic loading. Compressive deformation in base course occurs due to the repeated dynamical traffic loading. Tthe permanent deformation of base layer contributes to the rutting of asphalt pavement. When RAP is added to the base course material, permanent deformation should be evaluated to determine the rutting potential. In this study, permanent deformation was evaluated after resilient modulus testing following NCHRP 1-28A protocol because no test procedures for permanent deformation have been introduced. As shown in Figure 4, two clamps were used to fix the LVDTs so that the accurate deformation could be detected.

Table 4. Test Sequence for Base/Subbase Materials (Witczak 2004)

Sequence	Confining pressure		Contact stress		Cyclic stress		Maximum stress		Number of load
	Kpa	Psi	Kpa	Psi	Kpa	Psi	Kpa	Psi	
0	103.5	15	20.7	3	207	30	227.7	33	1000
1	20.7	3	4.1	0.6	10.4	1.5	14.5	2.1	100
2	41.4	6	8.3	1.2	20.7	3	29	4.2	100
3	69	10	13.8	2	34.5	5	48.3	7	100
4	103.5	15	20.7	3	51.8	7.5	72.5	10.5	100
5	138	20	27.6	4	69	10	96.6	14	100
6	20.7	3	4.1	0.6	20.7	3	24.8	3.6	100
7	41.4	6	8.3	1.2	41.4	6	49.7	7.2	100
8	69	10	13.8	2	69	10	82.8	12	100
9	103.5	15	20.7	3	103.5	15	124.2	18	100
10	138	20	27.6	4	138	20	165.6	24	100
11	20.7	3	4.1	0.6	41.4	6	45.5	6.6	100
12	41.4	6	8.3	1.2	82.8	12	91.1	13.2	100
13	69	10	13.8	2	138	20	151.8	22	100
14	103.5	15	20.7	3	207	30	227.7	33	100
15	138	20	27.6	4	276	40	303.6	44	100
16	20.7	3	4.1	0.6	62.1	9	66.2	9.6	100
17	41.4	6	8.3	1.2	124.2	18	132.5	19.2	100
18	69	10	13.8	2	207	30	220.8	32	100
19	103.5	15	20.7	3	310.5	45	331.2	48	100
20	138	20	27.6	4	414	60	441.6	64	100
21	20.7	3	4.1	0.6	103.5	15	107.6	15.6	100
22	41.4	6	8.3	1.2	207	30	215.3	31.2	100
23	69	10	13.8	2	345	50	358.8	52	100
24	103.5	15	20.7	3	517.5	75	538.2	78	100
25	138	20	27.6	4	690	100	717.6	104	100
26	20.7	3	4.1	0.6	144.9	21	149	21.6	100
27	41.4	6	8.3	1.2	289.8	42	298.1	43.2	100
28	69	10	13.8	2	483	70	496.8	72	100
29	103.5	15	20.7	3	724.5	105	745.2	108	100
30	138	20	27.6	4	966	140	993.6	144	100

Figure 4 LVDTs used for measuring the permanent deformation

3.1.8 Permeability

Based on the typical gradations for both RAP1 and RAP2, less than 10% particles passed 75-μm sieve. Therefore, the constant head method was chosen for determining the permeability, in accordance with the AASHTO T-215 specification. As shown in Figure 5, a constant-head permeameter with a diameter of 152 mm (6 in) was used to conduct the hydraulic conductivity test. Only RAP2 mixtures were tested due to time limitations. Particles larger than 19 mm (3/4 in) were removed and the percentage of oversize particles was recorded. Water was added to the dry samples containing different percentages of RAP such that OMC could be reached. Samples were compacted in the permeability cylinder in thin layers to a height about 2.03 cm (0.8 in) above the upper manometer outlet. As shown in Figure 5, the distance between the bottom of the permeameter and the upper manometer outlet is about 20.32 cm (8 in); thus, the total sample height of 22.35 cm (8.8 in) would allow the top surface of the sample to reach 2.03 cm (0.8 in) above the upper manometer outlet. Since the compaction was conducted inside the permeameter mold which was made of transparent acrylic, only 90% MDUW could be achieved by using the hammer of 22.2 N (5 pounds) with standard proctor compaction efforts. This density level simulates the worst compaction scenario possible in the field. The weight of samples added to each layer was calculated on the basis of 90% MDUW. Hydraulic conductivity tests were conducted in accordance with AASHTO T125 test protocol to evaluate the permeability of base course material containing different percentages of RAP. After the sample was saturated, test runs were repeated at increments of 0.5 cm (0.2 inch) head so that the range for laminar flow could be established. When the relationship between velocity and hydraulic gradient starts to deviate from the linear relationship, it indicates the start of turbulent flow. The test was run within the range of laminar flow. Coefficient of permeability was calculated as follows:

$$K = QL/Ath \tag{10}$$

where,

K is coefficient of permeability;

Q is quantity of water discharged;

L is the distance between manometers, which is 15.24cm (6 inches) in this study;

A is the cross-sectional area of specimen, which equals 182.3cm^2 (28.26in^2) in this study;

t is total time of discharge;

and h is difference in head on manometers.

Figure 5 Constant-head Permeability Test Equipment

3.1.9 Moisture damage

In order to evaluate the engineering performance of RAP in terms of stiffness (modulus), rutting potential and permeability due to moisture damage, testing samples after freezing-thawing were tested for resilient modulus, rutting potential and permeability.

3.1.9.1 Freezing-thawing test samples

Samples containing different percentages of RAP1 and RAP2 were prepared based on the selected gradation and water was added to achieve OMC. Well-mixed samples were compacted into the split mold by 50.8 mm (2 in) height per layer, totaling 304.8 mm (12 in). The membrane used for compaction was cut off and replaced with a new membrane using a membrane stretcher so that a minimum amount of moisture would be lost during conditioning and testing. Samples with the new membrane were placed in the triaxial cell for freezing and thawing to eliminate external disturbance due to handling. The freezing-thawing consisted of the following steps:

- Freezing for 24 hours at -20°C (-4°F) after sample preparation
- Thawing for 24 hours at 60°C (140°F) after freezing

Samples after the thawing were removed from the triaxial cell and kept inside the membrane for 12 hours at room temperature. Resilient modulus tests were not conducted on the samples until the temperature of the samples decreased to room temperature.

3.1.9.2 Freezing-thawing of permeability test samples

Samples containing different percentages of RAP2 were prepared and mixed thoroughly at OMC and were kept inside sealed plastic bags to prevent moisture from evaporation during freezing-thawing. The steps were listed as follows:

- Put the well-mixed samples containing OMC in the freezer for 24 hours at a temperature below -18°C (-0.4°F).
- Leave the sample in the oven for 24 hours with the temperature set as 60°C(140°F)

Samples after the thawing conditioning were removed from the oven and kept inside the plastic bags for 12 hours at room temperature. Samples were compacted in the permeameter. Permeability tests were conducted in accordance with the AASHTO T-215 specification. Permeability tests were not conducted on the samples until the temperature of the samples decreased to room temperature.

CHAPTER 4: ANALYSIS AND RESULTS

After completion of laboratory tests, test results were analyzed to determine resilient modulus, rutting potential and hydraulic conductivity. The effects of temperature, moisture content and freezing-thawing on resilient modulus, rutting, and hydraulic conductivity were also evaluated.

4.1 ASPHALT CONTENT DETERMINATION

Asphalt content in RAP1 and RAP2 were 4.86% and 6.11%, respectively. The asphalt contents for samples containing different percentages of RAP are listed in Table 5.

Table 5. Asphalt content

	RAP1 percentage, %			
	20	40	60	
Asphalt Content, %	0.97	1.94	2.92	
	RAP2 percentage, %			
	20	40	60	80
Asphalt Content, %	1.22	2.44	3.67	4.89

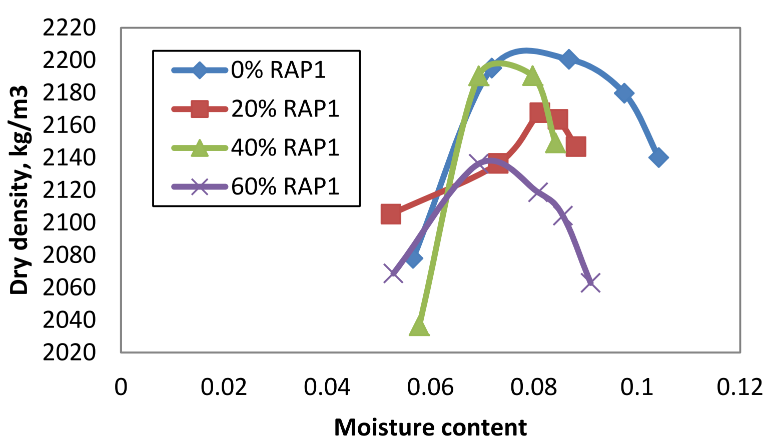
4.2 BULK SPECIFIC GRAVITY AND MOISTURE-DENSITY RELATIONSHIP

The relationships between moisture content and dry density for samples containing different percentages of RAP1 and RAP2 were established based on the modified proctor tests. As recommended by the AASHTO T-224, corrections to OMC and MDUW were made, since more than 5% oversize particles were retained on a 19.00 mm (3/4 inch) sieve for both RAP1 and RAP2 mixtures. Bulk specific gravity tests were conducted since bulk specific gravity is needed for corrections to OMC and MDUW. Table 6 shows the OMC and MDUW values from the modified proctor tests.

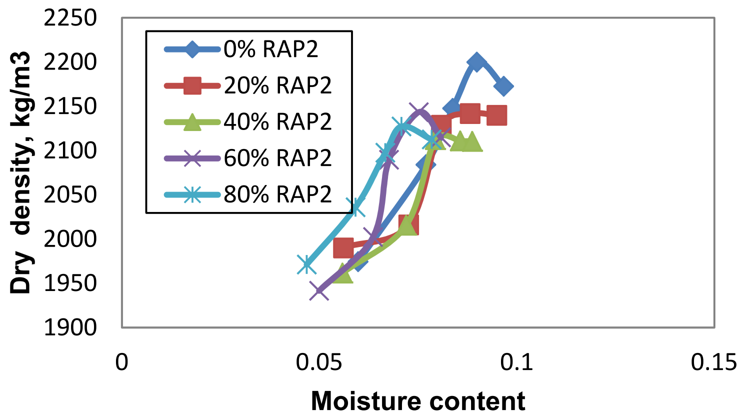
The corrected values of OMC and MDUW for samples containing different percentages of RAP were calculated based on bulk specific gravity values as listed in Table 6. The moisture-density relationship curves are shown in Figure 6. As shown in Figure 7, OMC value and bulk specific gravities of mixtures decreased with the increase of RAP percentage.

Table 6. Compaction characteristics before and after correction

Material	Proctor compaction result		Bulk specific gravity	After correction	
	Optimum moisture content,%	Maximum dry unit weight, kg/m^3		OMC,%	MDUW, kg/m^3
0% RAP1	8.9	2199	2.603	7.9	2247
20% RAP1	8.2	2169	2.581	7.3	2218
40% RAP1	7.5	2207	2.559	6.7	2250
60% RAP1	7.2	2138	2.537	6.5	2186
0% RAP2	9.0	2200	2.590	7.9	2254
20% RAP2	8.8	2142	2.510	7.7	2193
40% RAP2	7.9	2113	2.510	7.0	2167
60% RAP2	7.5	2143	2.460	6.6	2189
80% RAP2	7.1	2127	2.440	6.3	2172



(a)



(b)

Figure 6 (a) Moisture-density relationship for RAP1 mixtures; (b) Moisture-density relationship for RAP2 mixtures

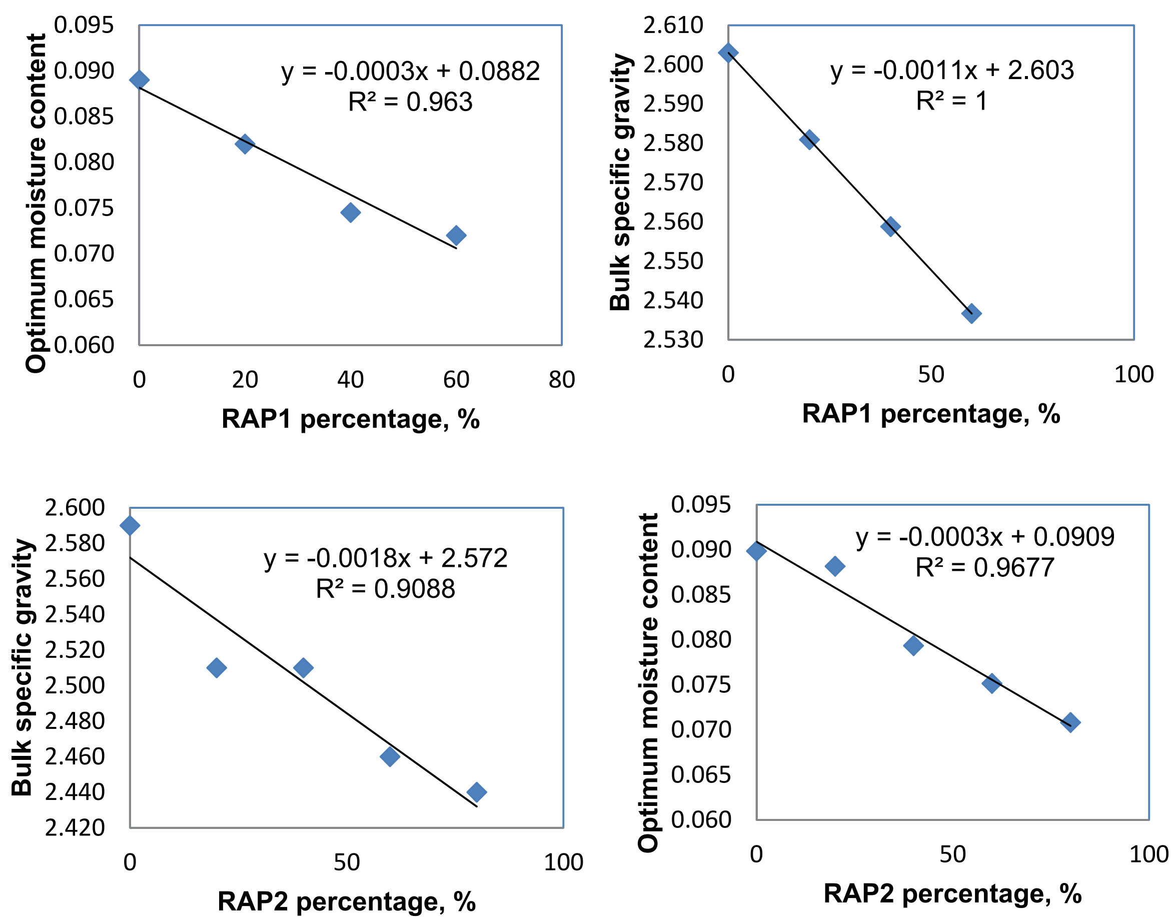


Figure 7 Relation of OMC, Bulk Specific Gravity and RAP Percentage

4.3 STIFFNESS

4.3.1 Modeling of resilient modulus

Resilient modulus is dependent on the stress states, such as deviator and confining stresses. Similar to the MEPDG, the resilient modulus can be modeled as shown in Equation 11 [Witczak 2004].

$$M_r = k_1 p_a \left(\frac{\sigma_b - 3k_6}{p_a}\right)^{k_2} \left(\frac{\tau_{oct}}{p_a} + k_7\right)^{k_3} \qquad (11)$$

where, M_r is resilient modulus, k_1, k_2, k_3, k_6, k_7 are empirical constants, P_a is the atmospheric pressure, τ_{oct} is the octahedral shear stress, and σ_b is the bulk stress. Bulk stress is calculated by:

$$\sigma_b = \sigma_1 + \sigma_2 + \sigma_3 \qquad (12)$$

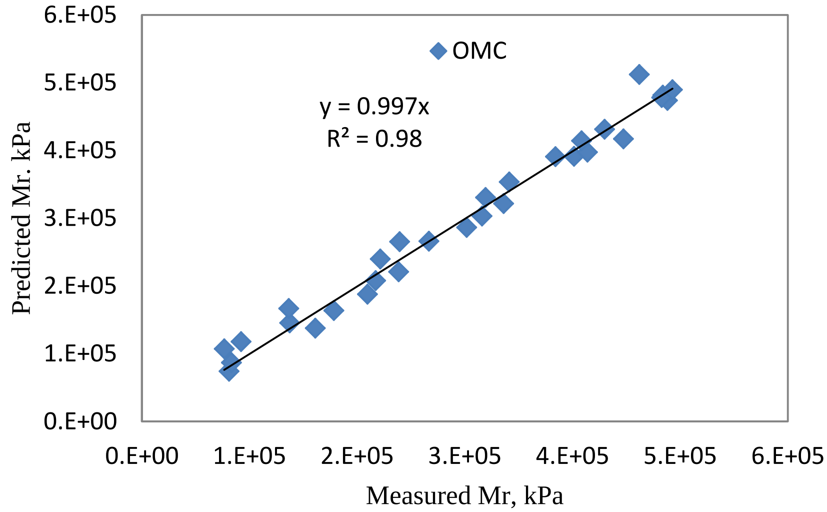
where σ_b is the bulk stress and σ_1, σ_2, σ_3 are the principal stresses acting on the specimen. Octahedral shear stress is calculated as:

$$\tau_{oct} = \frac{1}{3} \cdot \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2} \qquad (13)$$

Based on M_r test data, model coefficients were determined using the Excel Solver and the results are shown in Table 7. As an illustration, Figure 8 shows the relationship between measured and predicted M_r for 0% RAP1 sample based on the NCHRP 1-28A model. It can be seen that the model is effective in characterizing the resilient modulus.

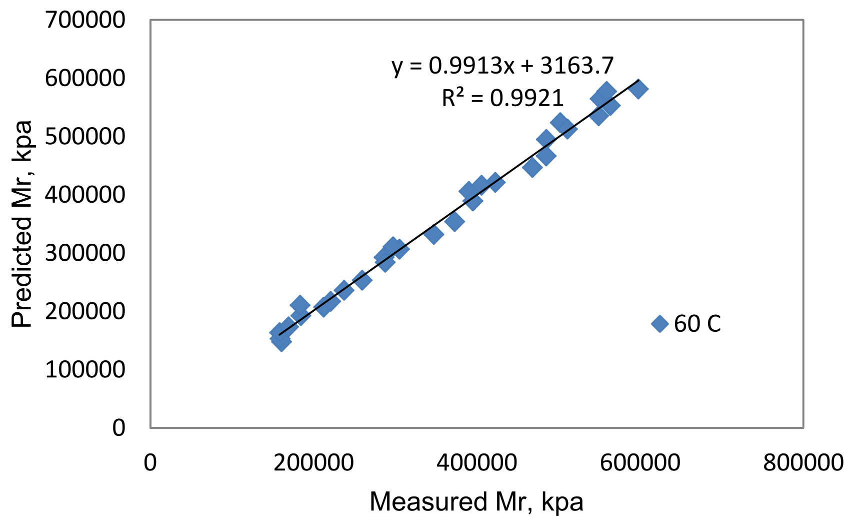
Table 7. Coefficients and R^2 for different samples based on NCHRP 1-28A model

RAP1 percentage	**Condition**	**Model coefficients**					**Coefficient of determination**
		k1	k2	k3	k6	k7	R^2
0	OMC-4%	3045.17	1.95	-2.19	-107.40	4.29	0.98
	OMC-2%	4878.25	2.12	-2.66	-107.29	4.57	0.99
	OMC	1913.71	1.19	-1.17	-8.01	2.10	0.99
	OMC+2%	315556.61	1.49	-3.23	-46.24	7.91	0.99
	20C	1913.71	1.19	-1.17	-8.01	2.10	0.99
	60C	4136.65	1.51	-1.77	-67.82	4.23	0.99
20	OMC-4%	8.64E+09	1.20	-5.77	-40.86	17.08	0.95
	OMC-2%	2013.37	1.40	-1.41	-38.77	2.72	0.98
	OMC	614.02	1.49	-1.05	-35.75	1.29	0.99
	OMC+2%	765.04	1.27	-0.80	-25.13	1.20	0.99
	20C	614.02	1.49	-1.05	-35.75	1.29	0.99
	60C	332.97	1.38	-0.58	-52.25	1.00	0.91
40	OMC-4%	1348.81	1.25	-0.83	-44.01	1.00	0.97
	OMC-2%	1274.34	1.35	-1.14	-35.24	1.80	0.99
	OMC	74.96	2.40	-1.43	-114.53	1.00	0.94
	OMC+2%	1306.94	1.27	-1.08	-22.86	1.66	0.99
	20C	74.96	2.40	-1.43	-114.53	1.00	0.94
	60C	733.63	1.25	-0.70	-44.00	1.00	0.91
60	OMC-4%	28.60	3.02	-1.90	-168.03	1.00	0.77
	OMC-2%	1080.94	1.32	-1.02	-30.32	1.34	0.99
	OMC	2006.57	1.02	-0.82	-13.56	1.00	0.98
	OMC+2%	1083.87	1.26	-0.86	-42.14	1.40	0.99
	20C	218.77	1.82	-0.90	-84.85	1.00	0.97
	60C	1310.75	1.33	-1.24	-43.66	2.15	0.99



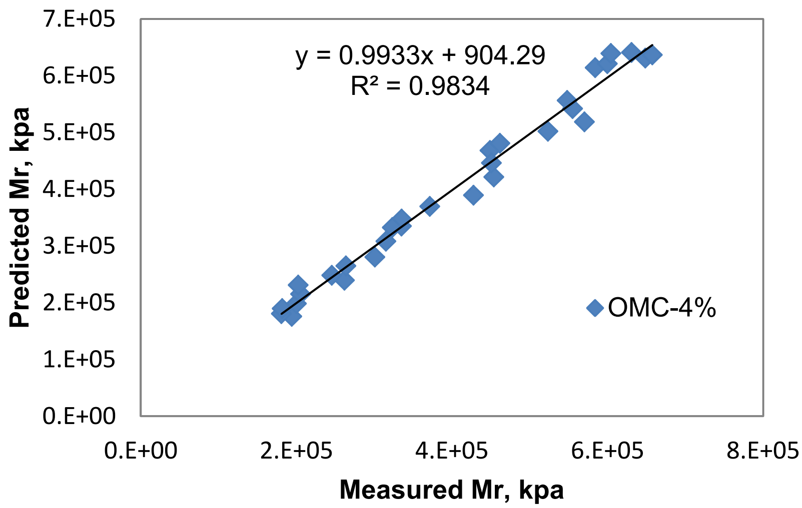
OMC
y = 0.997x
R² = 0.98
Predicted Mr. kPa
Measured Mr, kPa
6.E+05
5.E+05
4.E+05
3.E+05
2.E+05
1.E+05
0.E+00
0.E+00
1.E+05
2.E+05
3.E+05
4.E+05
5.E+05
6.E+05

(a)



y = 0.9913x + 3163.7
R² = 0.9921
60 C
Predicted Mr, kpa
Measured Mr, kpa
700000
600000
500000
400000
300000
200000
100000
0
0
200000
400000
600000
800000

(b)

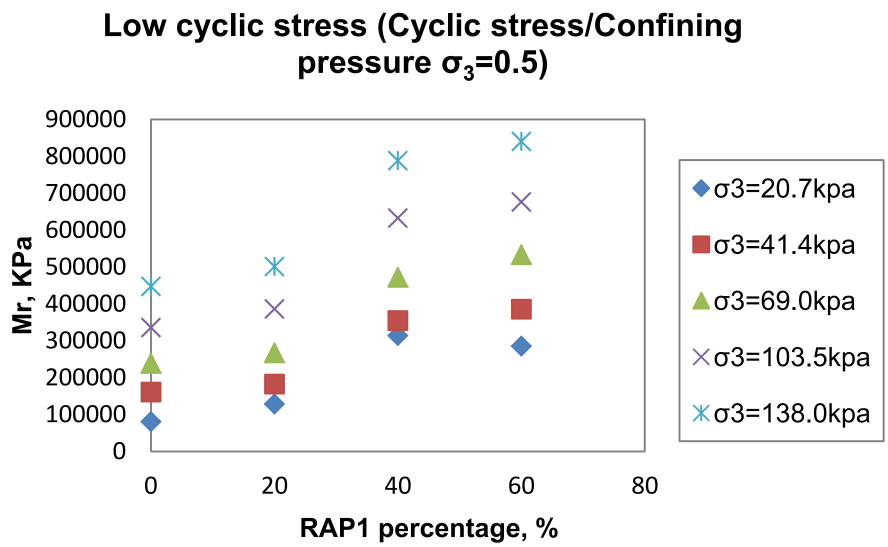


(c)

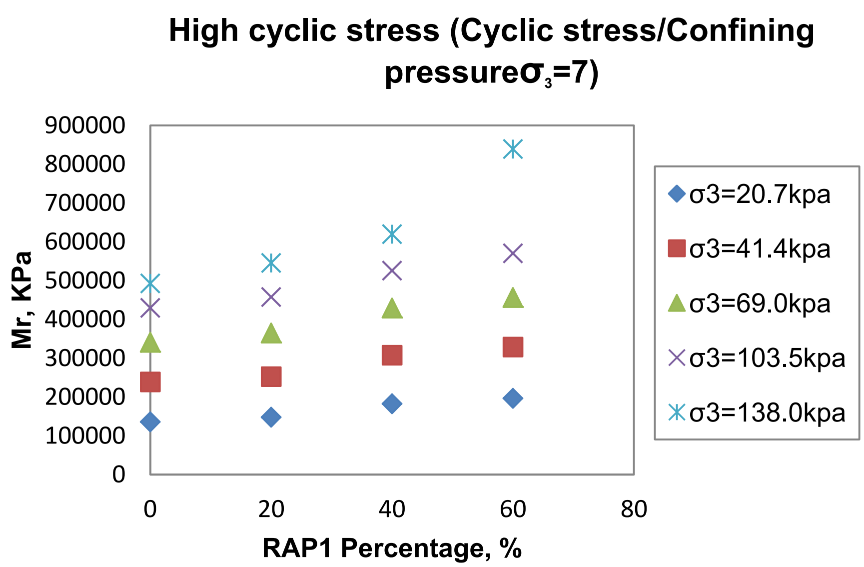
Figure 8 (a) Relation between predicted M_r and measured M_r for 0% RAP1 with OMC tested at 20°C; (b) Relation between predicted M_r and measured M_r for 0% RAP1 with OMC tested at 60°C; (c) Relation between predicted M_r and measured M_r for 0% RAP1 with OMC-4% tested at 20°C

4.3.2 Effect of RAP percentage on resilient modulus

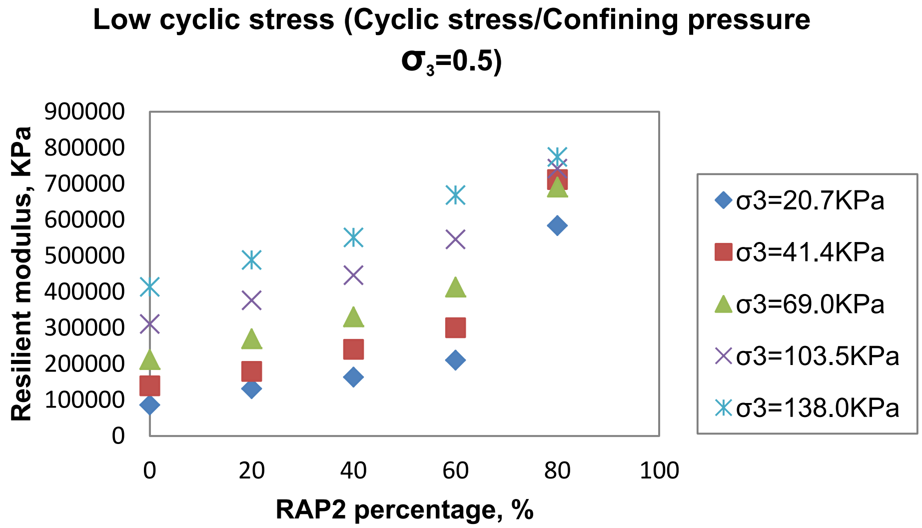
Figure 9 shows the relationship between resilient modulus and RAP percentage at OMC and room temperature. The results indicated that increasing RAP percentage increased M_r for both RAP1 and RAP2 at low cyclic stress and high cyclic stress. Detailed resilient modulus testing results for all samples are presented in Appendix A.


Low cyclic stress (Cyclic stress/Confining pressure σ3=0.5)
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
Mr, KPa
0
20
40
60
80
RAP1 percentage, %
σ3=20.7kpa
σ3=41.4kpa
σ3=69.0kpa
σ3=103.5kpa
σ3=138.0kpa

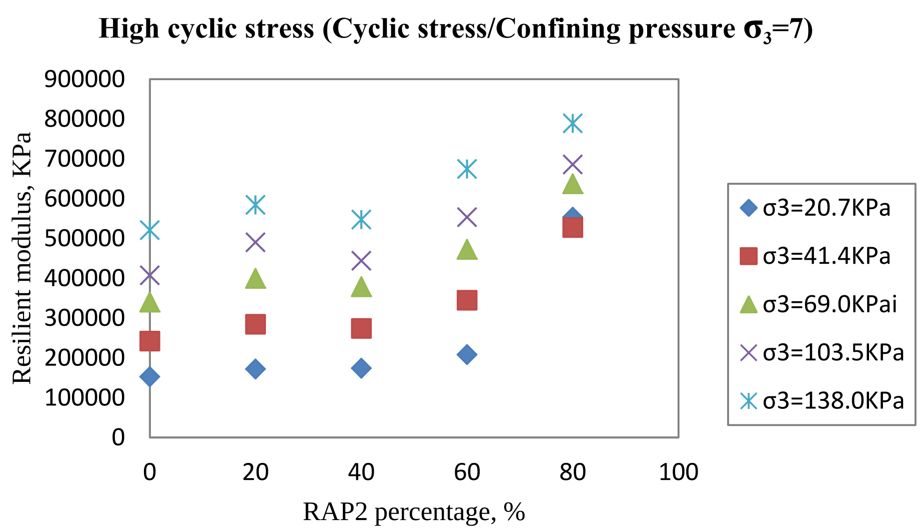
(a)


High cyclic stress (Cyclic stress/Confining pressureσ3=7)
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
Mr, KPa
0
20
40
60
80
RAP1 Percentage, %
σ3=20.7kpa
σ3=41.4kpa
σ3=69.0kpa
σ3=103.5kpa
σ3=138.0kpa

(b)



(c)



(d)

Figure 9(a) Effect of RAP1 percentage on M_r at low cyclic stress ; (b) Effect of RAP1 percentage on M_R at high cyclic stress; (c) Effect of RAP2 percentage on M_R at low cyclic stress; (d) Effect of RAP2 percentage on M_R at high cyclic stress

4.3.3 Modeling the effect of moisture content on M_r

In a pavement structure, moisture content in unbound base layers may change over time due to environmental conditions, which would affect the resilient modulus [ARA 2004]. In the MEPDG, the change of modulus in response to the change of moisture content is included.

Both the dry density and moisture content affect the resilient modulus. In this study, modulus was determined at different moisture contents while keeping the density constant, which simulates the field conditions. The moisture contents in this study varied from OMC-4% to OMC+2%. In the MEPDG, models were proposed to account for the effects of moisture content on resilient modulus of unbound materials [ARA 2004], as shown in Equation 14. The model is referred to as K_w model for the rest of the paper.

$$\text{Log}\frac{M_r}{M_{ropt}} = K_w(W - W_{opt}) \qquad (14)$$

where,

M_r = resilient modulus at moisture content w (%);

M_{ropt}= resilient modulus at optimum moisture content W_{opt}(%) and maximum dry density;

K_W= gradient of log resilient modulus ratio (log (M_r/M_{ropt})) with respect to variation in percent moisture content (W- W_{opt}); K_W is material constant.

Witczak et al. [2000] developed a sigmoid model predicting the changes of resilient modulus as a function of degree of saturation in MEPDG. The model was developed based on the degree of saturation ranging from 30% to -30%. The same model was introduced, as presented in Equation 15. This model is referred to as the sigmoid model for the rest of the paper.

$$\text{Log}\frac{M_r}{M_{ropt}} = a + \frac{b-a}{1+\text{Exp}[\beta+K_s*(W-W_{opt})]} \tag{15}$$

where a = minimum of $\log(M_r/M_{ropt})$

b= maximum of $\log(M_r/M_{ropt})$; for coarse grained soil, b is assumed to be 0.30

β = location parameter – obtained as a function of a and b by imposing the condition of a zero intercept: β=Ln(-b/a)

K_S= regression parameter

M_r= resilient modulus at moisture content W

M_{ropt}= resilient modulus at OMC and maximum dry density.

Both the K_W model and the Sigmoid model were selected to evaluate the effect of moisture content on M_r of RAP. Table 8 shows the model parameters and R^2 for all the testing samples. The relationship between measured and predicted M_r is shown in Figure 10 for the sample containing 20% RAP1, as an illustration. The main factor to determine the reliability of a model is the goodness of fit statistics and the mathematical stability [Mohamed 2009]. Models are considered to have good fit with R^2>0.7. Based on the same set of testing data, random numbers were selected as the original value for each parameter. Five trial tests were conducted for each model, and regression results showed that the two models under evaluation were stable, as the coefficients kept constant. In addition, statistical analysis for comparing the means of measured data and predicted data was done using the t-method. Measured data and predicted data were assumed as two groups, and the 30 loading sequences were subjects randomly assigned to each group. The hypotheses for the comparison of means for the two groups were:

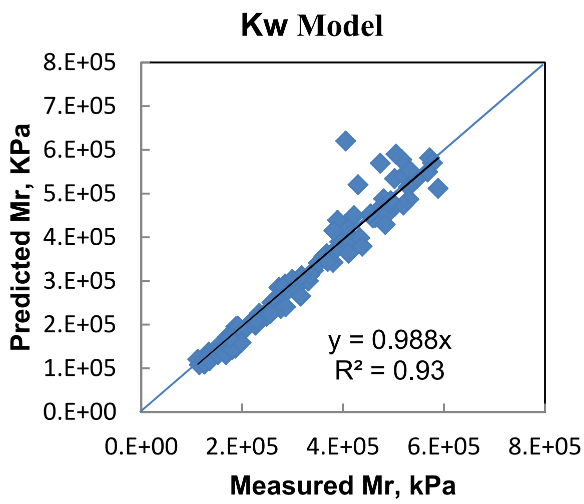
Ho: measured data = predicted data (means of the two groups are equal)

Ha: measured data≠ predicted data (means are not equal)

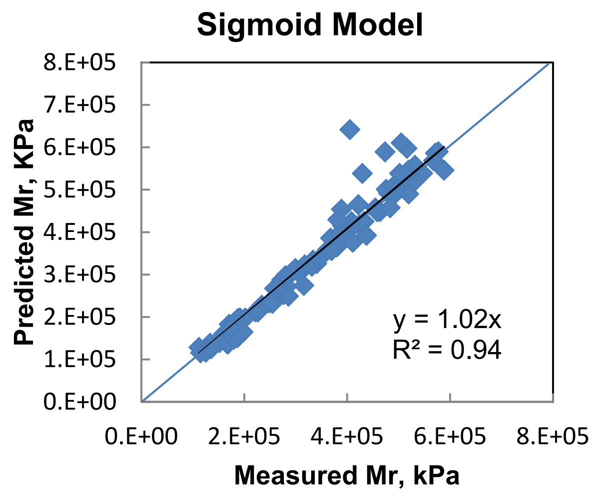
By using the data analysis function in Excel, an F-test was first conducted to determine whether the variances were equal in both groups. Based on the result from the F-test, a T-test was conducted to find whether equal or unequal variances case and probability p-value could be obtained. Generally, the null hypotheses Ho of equal means is rejected if p value is less than 0.05, which indicates that significant difference exists between the two groups under comparison. The results for the F-test and T-test are included in Table 8. Based on available testing data in this study, both of the two models are effectivie constitutive models to determine the effects of moisture content on M_r.

Table 8. Model coefficients P-value and R^2 for determining the effect of moisture content on M_r

Material	Model											
	Kw model			**Sigmoid model(b=log(2))**				**Sigmoid model**				
	Kw	R^2	P	a	Ks	R^2	P	a	b	Ks	R^2	P
0% RAP1	-0.028	0.929	0.074	-0.001	57.770	0.748	0.0003	-1E-08	0.130	57.770	0.923	0.862
20%RAP1	-0.014	0.937	0.749	-0.010	0.590	0.935	0.968	-5E-05	0.070	3.480	0.941	0.833
40%RAP1	-0.04	0.78	0.698	-1E-05	2.450	0.745	0.409	-1E-06	0.260	3.500	0.884	0.286
60%RAP1	-0.024	0.806	0.204	-0.006	2.000	0.765	0.060	-1E-05	0.500	3.000	0.763	0.060
0% RAP2	-0.045	0.932	0.569	-0.003	1.362	0.978	0.854	-2E-04	0.229	3.104	0.972	0.149
20%RAP2	-0.009	0.975	0.926	-8E-07	2.453	0.957	0.875	-0.046	0.027	11.593	0.987	0.764
40%RAP2	-0.034	0.939	0.34	-2E-05	2.453	0.971	0.494	-1E-05	0.500	2.453	0.970	0.536
60%RAP2	-0.07	0.852	0.494	-0.1526	60.000	0.713	0.688	-3E-05	0.300	2.453	0.851	0.504
80%RAP2	0.0147	0.537	0.347	-0.0001	2.658	0.702	0.433	-1E-04	0.309	2.658	0.56	0.347



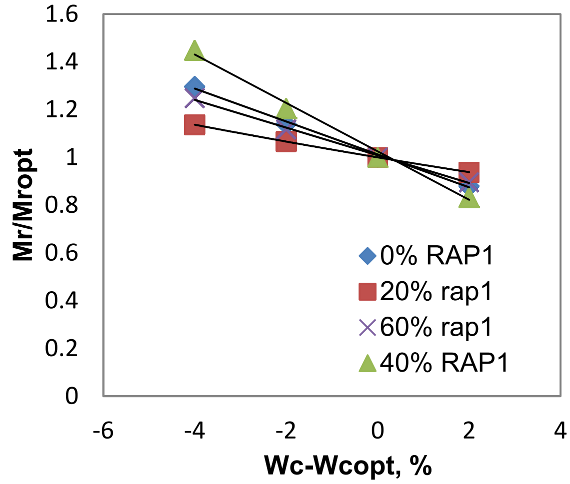
(a)



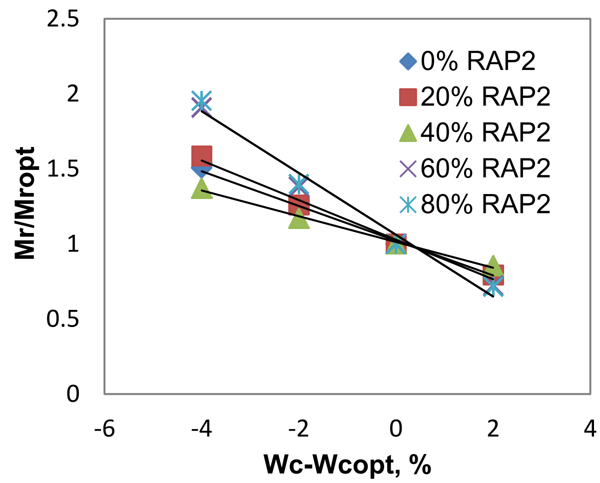
(b)

Figure 10(a) Relationship between predicted and measured Mr for 20% RAP1 based on Kw Model; (b) Relationship between predicted and measured Mr for 20% RAP1 based on sigmoid model

Based on the K_w model, the relationship between the M_r and the moisture content of samples is plotted in Figure 11. For all the samples, M_r values decreased with the increase of moisture content from OMC-4% to OMC+2%. However, the effects of RAP percentage on the sensitivity of resilient modulus to moisture content were not pronounced.



(a)

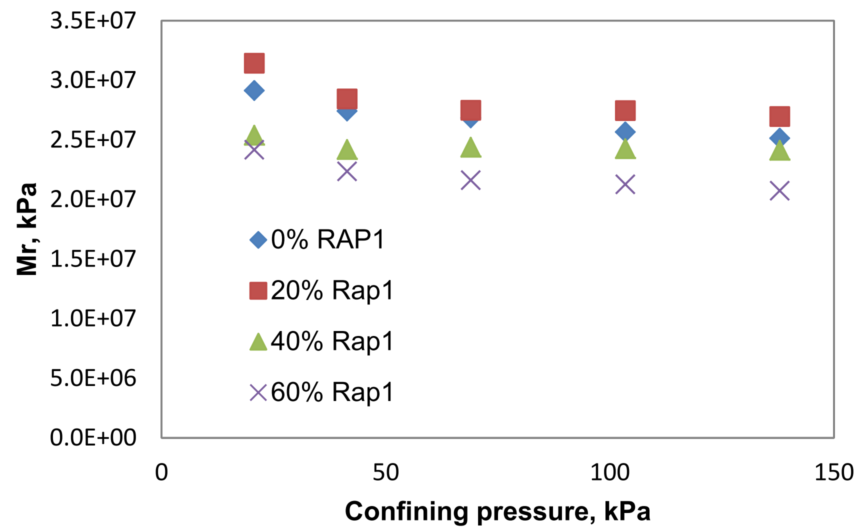


(b)

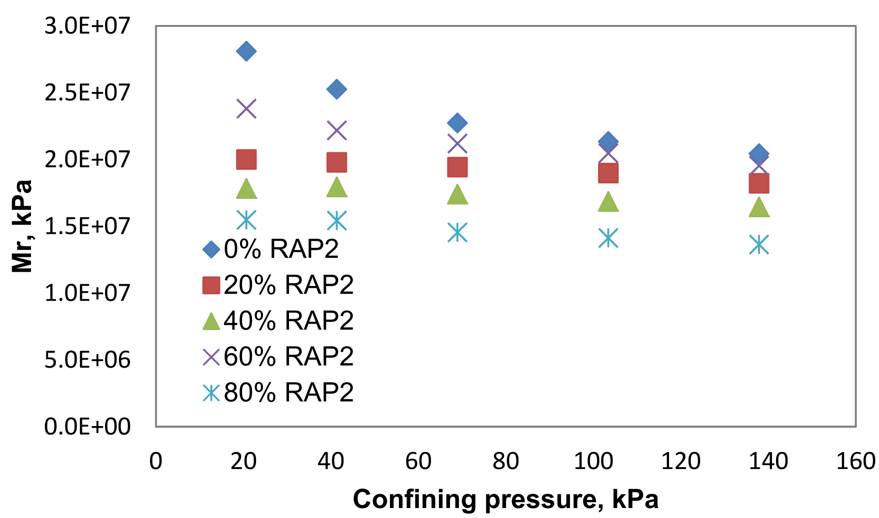
Figure 11(a) Effect of moisture content on resilient modulus of RAP1 mixtures; (b) Effect of moisture content on resilient modulus of RAP2 mixtures

4.3.4 Effect of temperature on resilient modulus

The temperature was varied from -20°C (-4°F) to 60°C (140°F) to evaluate the effects of temperature on M_r. The M_r value for frozen coarse-grained material recommended by the MEPDG varies from 10,342 MPa (1500 ksi) to 34,473 MPa (5000 ksi) [ARA 2004]. Figure 12 shows the relationship between M_r at high cyclic stresses (Cyclic stress/Confining pressure=7) and confining pressure for different samples tested at -20°C. The $M_r$values range from 12,800 MPa (1856 ksi) to 33,607 MPa (4874 ksi), which is consistent with values recommended by the MEPDG for granular materials. When the RAP1 percentage increased from 0% to 20%, no significant change of $M_r$was observed and the values remained about 27,000 MPa (3916 ksi). However, M_r of the 60% RAP1 sample decreased by up to 30%. The M_r values of samples decreased with the increase of RAP1 percentage at -20°C (-4°F). For the tests at 60°C (140°F), Figure 13 shows the effects of high temperature on resilient modulus. Except for the 0% RAP sample, the resilient moduli at 60°C (140°F) were lower than those at 20°C (-4°F), as expected. This is due to the fact that asphalt stiffness reduces as temperature increases.



(a)



(b)

Figure 12(a) Effect of RAP1 percentages on M_r at -20°C (-4°F); (b) Effect of RAP2 percentages on M_r at -20°C (-4°F)

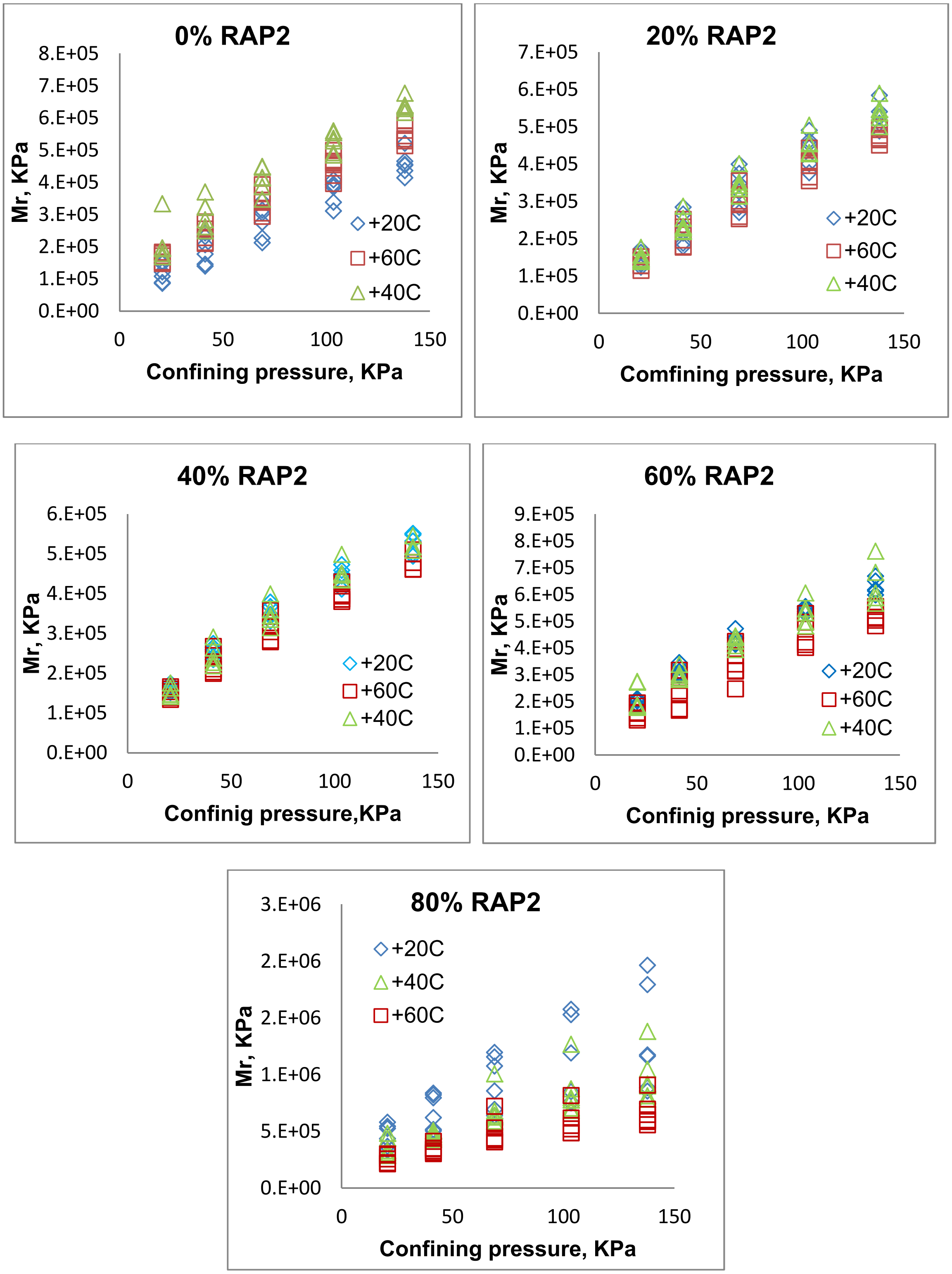


Figure 13 Effect of temperature on M_R for different samples

Models are needed to account for the effects of temperature on resilient modulus. Based on the observation of the test data, similar to the models for moisture, both the K_T model and Sigmoidal model were proposed. The K_T model is expressed as Equation 16.

$$\mathrm{Log}\frac{M_r}{M_{ropt}} = K_T(T - T_{opt}) \tag{16}$$

where,

M_r = resilient modulus at temperature T(℃);

M_{ropt}= resilient modulus at 20℃;

K_T= gradient of log resilient modulus ratio (log (M_r/M_{ropt})) with respect to variation in temperature; K_T is material constant;

Sigmoid model is presented in Equation 17:

$$\mathrm{Log}\frac{M_r}{M_{r\_ref}} = a + \frac{b-a}{1+\mathrm{Exp}[\beta+K_s*(T-T_{ref})]} \tag{17}$$

where

a = minimum of log(M_r/M_{ropt});

b= maximum of log(M_r/M_{ropt}); both a and b are obtained by regression;

β = location parameter – obtained as a function of *a* and *b* by imposing the condition of a zero intercept: β=Ln(-b/a);

K_S= regression parameter;

M_r=resilient modulus at temperature T (℃);

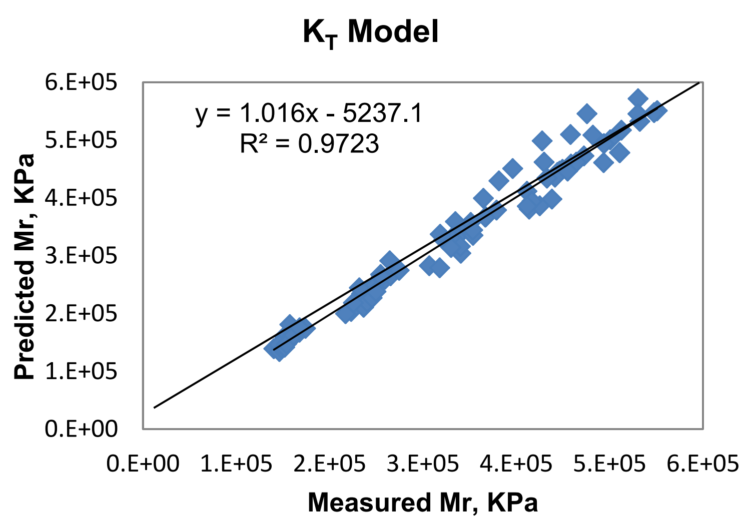
M_{r_ref}=resilient modulus at reference temperature, 20℃ (68°F).

Based on the M_r testing data for RAP1 samples tested at 20℃ (68°F) and 60℃ (140°F), as well as for RAP2 samples tested at 20°C (68°F), 40°C (104°F) and 60°C

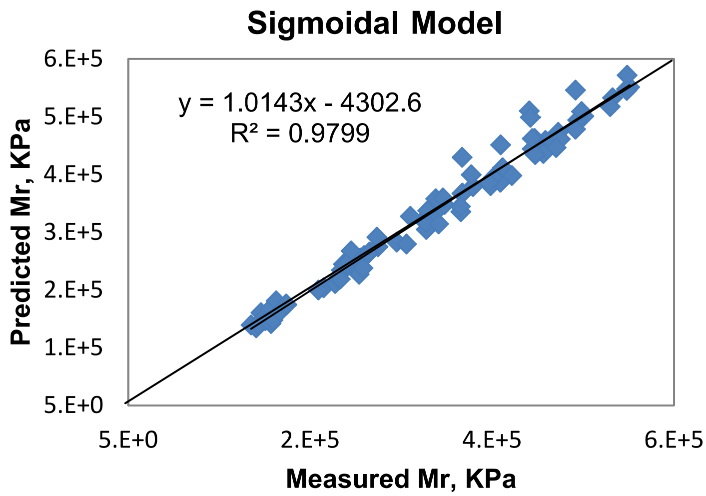
(140°F), models in Equations 16 and 17 were evaluated for fitness and reliability. Model coefficients were obtained using the Excel Solver. The same statistic methods used for models evaluating the effect of moisture content on M_r, including F-test and T-test, were conducted for comparing the measured data and the predicted data. Table 9 lists model coefficients and coefficients of determination. The relationship between tested and predicted M_r was plotted in Figure 14 for 40% RAP2, as an example, based on the two models. For test samples containing different percentages of RAP, M_r decreased with the increase of temperature, as shown in Figure 15.

Table 9. Model efficient and R^2 for evaluating the effects of temperature on M_R

Material	Model					
	Equation (16)		Equation (17)			
	KT	R^2	a	b	Ks	R^2
0% RAP1	0.00266	0.982	-5.3E-07	2.006	1.00	0.912
20%RAP1	-0.00190	0.952	-0.07585	2.014	1.00	0.952
40%RAP1	-0.00036	0.943	-0.01444	3.000	1.00	0.943
60%RAP1	-0.00609	0.997	-0.24353	1.793	1.00	0.997
0% RAP2	0.00305	0.980	-0.00001	2.006	1.00	0.920
20%RAP2	-0.00054	0.975	-1.36330	1.0E-05	0.20	0.980
40%RAP2	-0.00082	0.972	-1.12997	1.0E-04	0.16	0.980
60%RAP2	-0.00166	0.906	-0.16598	0.175	0.06	0.902
80%RAP2	-0.00674	0.932	-0.17388	0.301	1.00	0.854

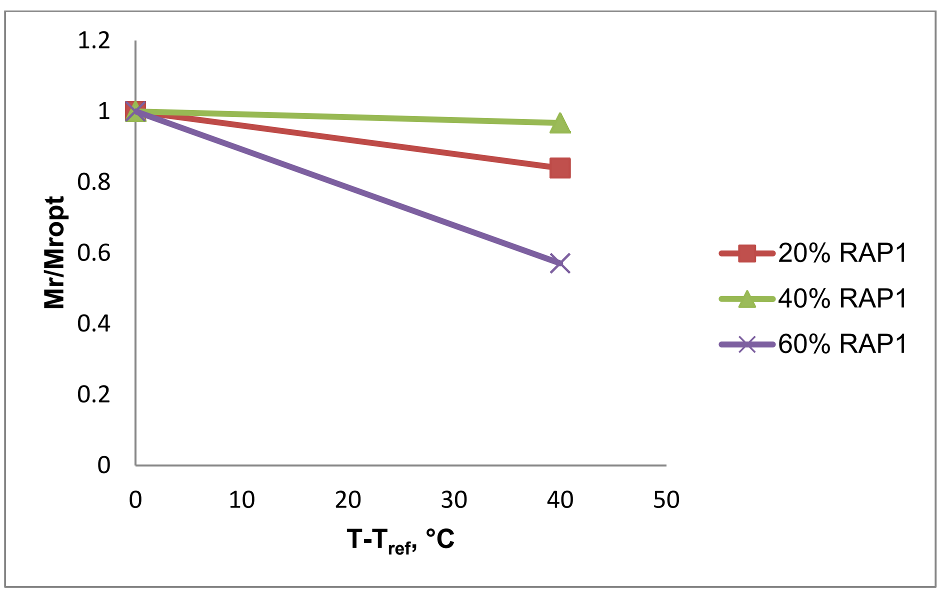


(a)

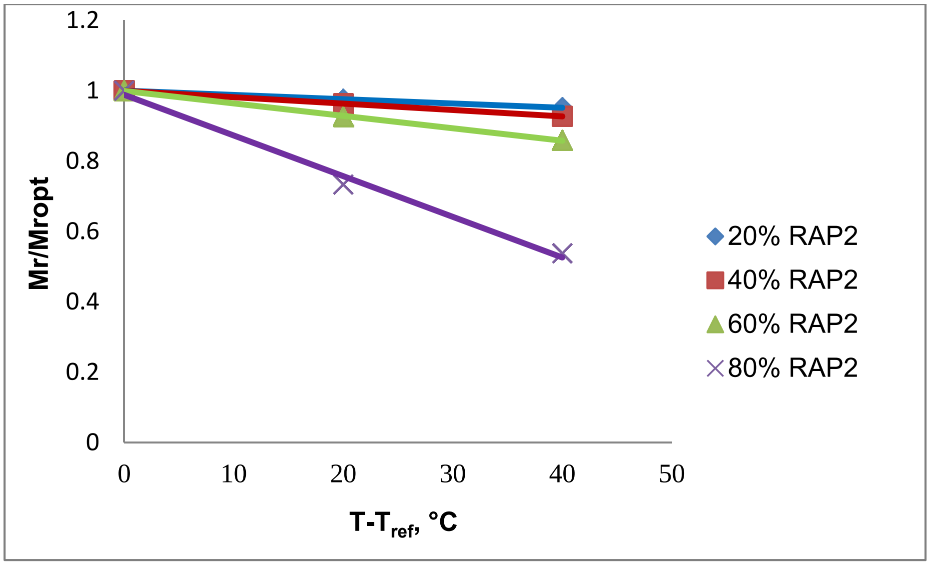


(b)

Figure 14(a) Relation between predicted and measured M_r for 40% RAP2 based on K_T Model; (b) Relation between predicted and measured M_r for 40% RAP2 based on Sigmoidal Model



(a)



(b)

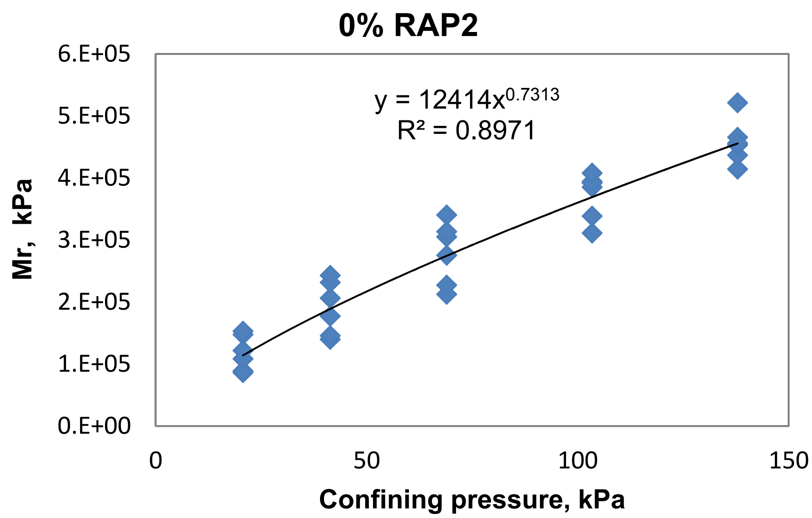
Figure 15(a) Effect of temperature on M_r for RAP1 mixtures based on K_T Model; (b) Effect of temperature on M_r for RAP2 mixtures based on K_T Model

Based on the K_T model, M_r decreased with the increase of temperature from 20°C (68°F) to 60°C (140°F) for samples containing different percentages of RAP2 varying from 20% to 80%. The samples with higher RAP percentage were more sensitive to the temperature. As shown in Figure 15, M_r values of samples containing higher RAP percentages decreased more rapidly with increasing temperature when compared to samples with lower RAP percentages, which indicated that the asphalt in RAP was more sensitive to temperature compared to virgin aggregate.

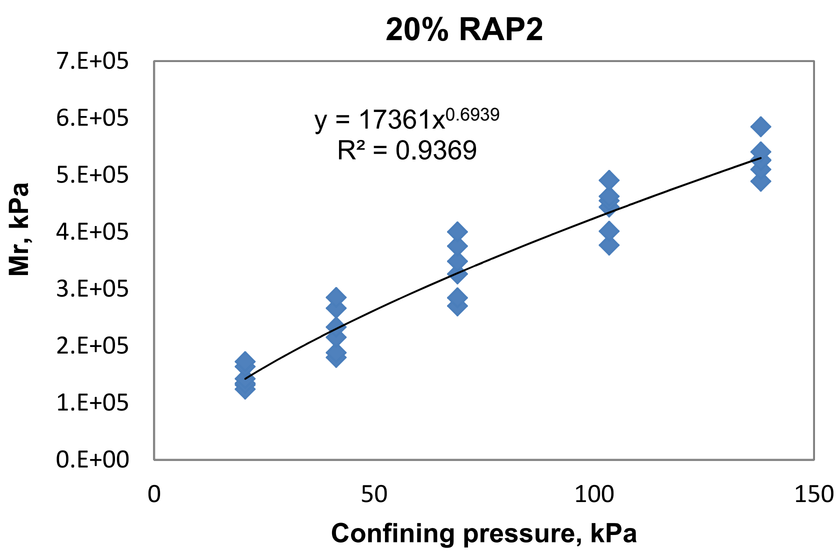
4.3.5 Effect of state of stress on resilient modulus

4.3.5.1 Effect of Confining Pressure on Resilient Modulus

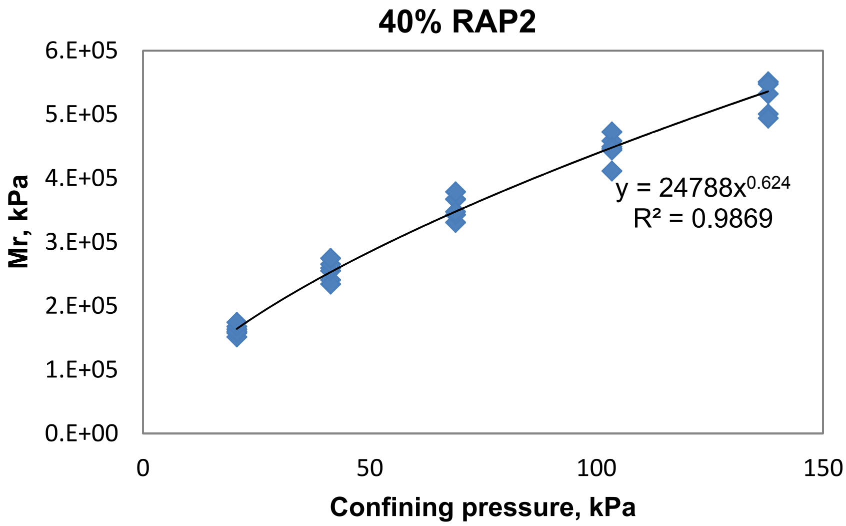
The test results indicated that M_r increased with the increase of confining pressure. Figure 16 presents the effects of confining pressure on M_r measured at OMC and room temperature.


0% RAP2
y = 12414x^0.7313
R² = 0.8971
Mr, kPa
Confining pressure, kPa
6.E+05
5.E+05
4.E+05
3.E+05
2.E+05
1.E+05
0.E+00
0
50
100
150

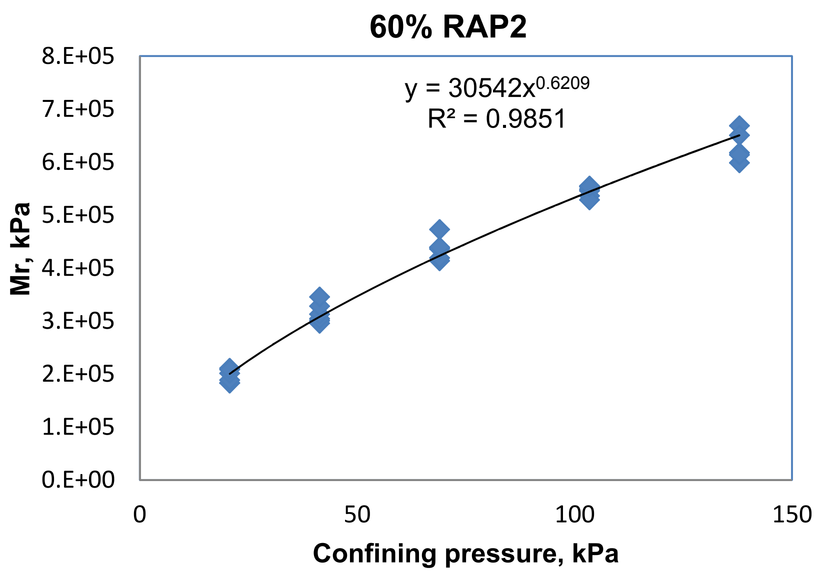
(a)


20% RAP2
y = 17361x^0.6939
R² = 0.9369
Mr, kPa
Confining pressure, kPa
7.E+05
6.E+05
5.E+05
4.E+05
3.E+05
2.E+05
1.E+05
0.E+00
0
50
100
150

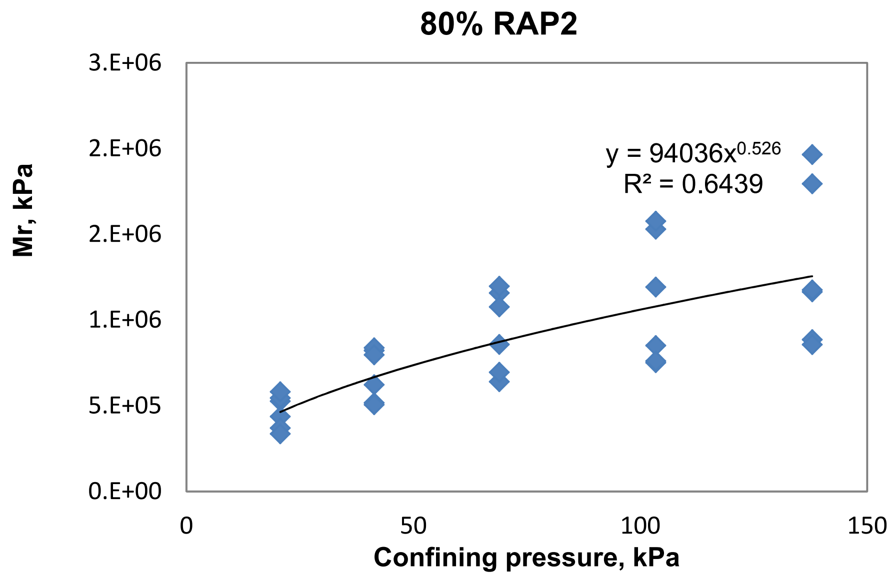
(b)


40% RAP2
6.E+05
5.E+05
4.E+05
3.E+05
2.E+05
1.E+05
0.E+00
Mr, kPa
y = 24788x0.624
R² = 0.9869
0
50
100
150
Confining pressure, kPa

(c)


60% RAP2
8.E+05
7.E+05
6.E+05
5.E+05
4.E+05
3.E+05
2.E+05
1.E+05
0.E+00
Mr, kPa
y = 30542x0.6209
R² = 0.9851
0
50
100
150
Confining pressure, kPa

(d)

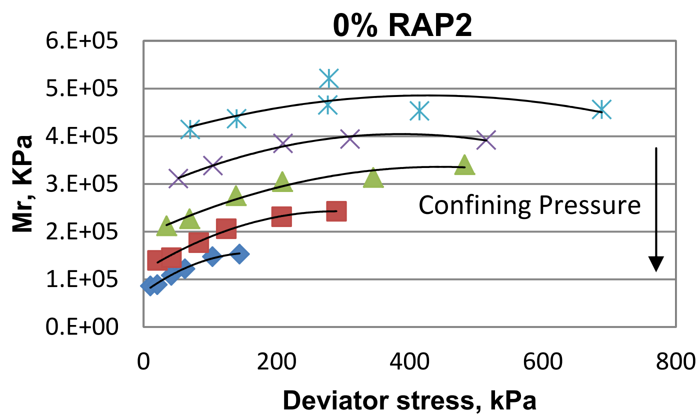


(e)

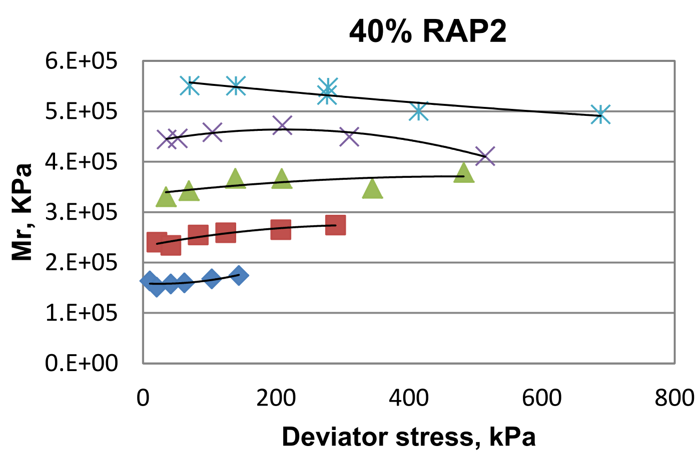
Figure 16(a) Effect of confining pressure on Mr for 0%RAP2; (b) Effect of confining pressure on Mr for 20%RAP2; (c) Effect of confining pressure on Mr for 40%RAP2; (d) Effect of confining pressure on Mr for 60%RAP2 (e) Effect of confining pressure on Mr for 80%RAP2

4.3.5.2 Effect of Deviator Stress on Resilient Modulus

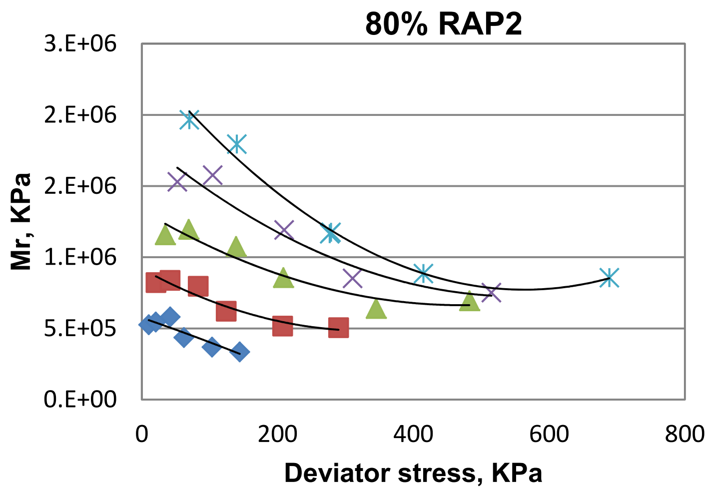
As shown in Table 4, the loading sequence for base course material specified in NCHRP 1-28A consisted of 30 sequences with varied confining pressures and deviator stresses. Figure 17 presents the effect of deviator stress on M_r of samples containing 0, 40 and 80% RAP2. For 0% of RAP2 samples, increase of deviator stress led to an increase of M_r, especially at low confining pressures. However, increasing deviator stress led to a decrease of Mr for the sample containing 80% RAP2, for which the M_r value reduced more rapidly at high confining pressure. For the 40% RAP2 sample, the effect of deviator stress on M_r was dependent on the confining pressure. At low confining pressure, increasing deviator stress resulted in increased M_r. However, the opposite was true at high confining pressure. It can be concluded that the effects of deviator stress on Mr containing RAP are dependent on RAP percentage as well as confining pressure.



(a)



(b)



(c)

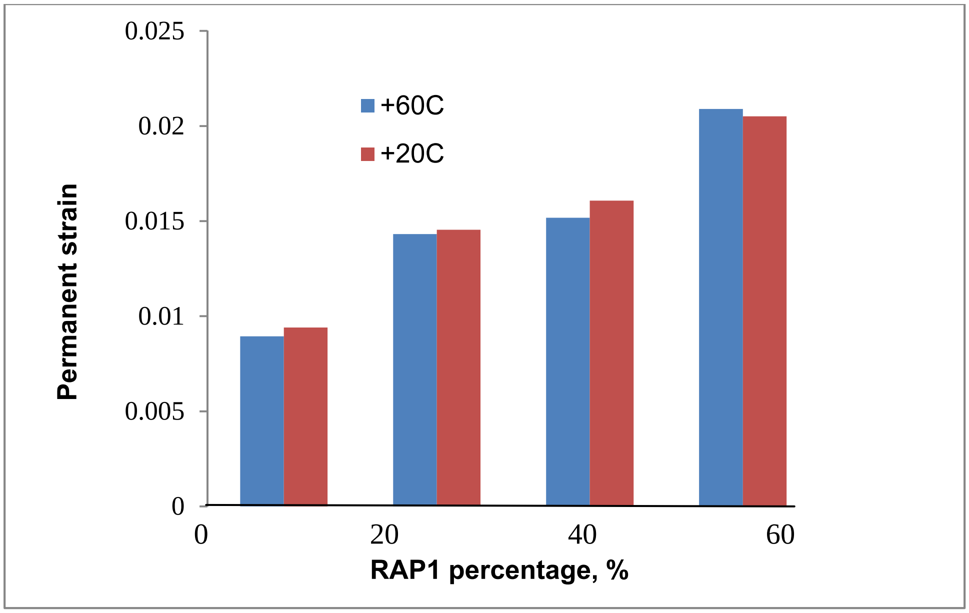
Figure 17(a) Effect of deviator stress on Mr for samples containing 0% RAP2; (b) Effect of deviator stress on Mr for samples containing 40% RAP2; (c) Effect of deviator stress on Mr for samples containing 80% RAP2

4.4 PERMANENT DEFORMATION

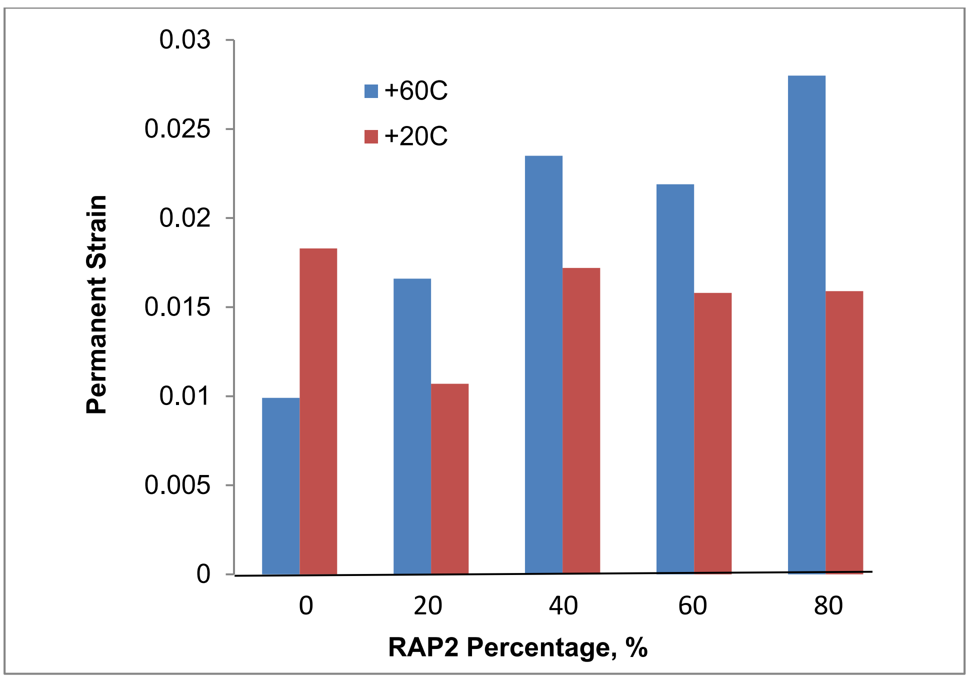
Permanent deformation was determined after resilient modulus tests. In accordance with the NCHRP 1-28A protocol, 30 loading sequences were applied to the specimen, in addition to the pre-conditioning. In this study, only the permanent deformation generated during the 30 sequences was considered, since the deformation generated during pre-conditioning may differ considerably due to compaction during the sample preparation. Figure 18 shows the permanent strain of RAP1 mixtures tested at room temperature, around 20℃ (68°F) and 60°C (140°F). For RAP 1, the difference in permanent strain between 20℃ (68°F) and 60°C (140°F) was insignificant, whereas the opposite was true for RAP2. This might be due to the fact that the maximum size of RAP1 is only 12.5 mm (0.5 in), while the maximum size of RAP2 is 31.5 mm (0.75 in). Large particles might play a significant role in resisting permanent deformation. When RAP percentage increased, permanent strain also increased under certain conditions, such as 60°C (140°F), OMC-4 or OMC-2; and OMC at 20°C for RAP1, as shown in Figure 19. At high temperature, high asphalt content in mixtures led to higher permanent deformation. In addition, at OMC-4 and OMC-2, the high permanent deformation at high RAP percentage could be due to the fact that it was more difficult to compact RAP than aggregate when materials were dry. However, at OMC+2 or after freeze-thaw conditioning, the permanent deformation was not sensitive to RAP percentage, as shown in Figure 20. With regard to moisture content, as shown in Figure 21, increasing moisture content increased the permanent deformation, as expected.

Table 10. Permanent Strain for RAP1 and RAP2 mixtures

RAP percentage	Temperature, °C		After Freeze-thaw	Moisture content,%			
	60	20	Conditioning	OMC-4	OMC-2	OMC	OMC+2
0% RAP1	8.95E-03	9.40E-03	9.29E-03	3.93E-03	7.85E-03	9.40E-03	1.37E-02
20% RAP1	1.43E-02	1.45E-02	9.01E-03	1.22E-02	1.18E-02	1.45E-02	1.54E-02
40% RAP1	1.52E-02	1.61E-02	9.74E-03	2.14E-03	9.62E-03	1.61E-02	1.63E-02
60% RAP1	2.09E-02	2.10E-02	1.02E-02	9.65E-03	1.66E-02	2.10E-02	1.63E-02
0% RAP2	9.91E-03	1.83E-02	6.85E-03	1.43E-03	9.79E-03	1.83E-02	1.27E-02
20% RAP2	1.66E-02	1.07E-02	4.93E-03	4.28E-03	8.89E-03	1.07E-02	1.36E-02
40% RAP2	2.35E-02	1.72E-02	1.18E-02	4.28E-03	1.01E-02	1.72E-02	1.33E-02
60% RAP2	2.19E-02	1.58E-02	9.56E-03	7.24E-03	1.06E-02	1.58E-02	1.21E-02
80% RAP2	2.80E-02	1.59E-02	7.20E-03	9.35E-03	1.44E-02	1.59E-02	1.36E-02

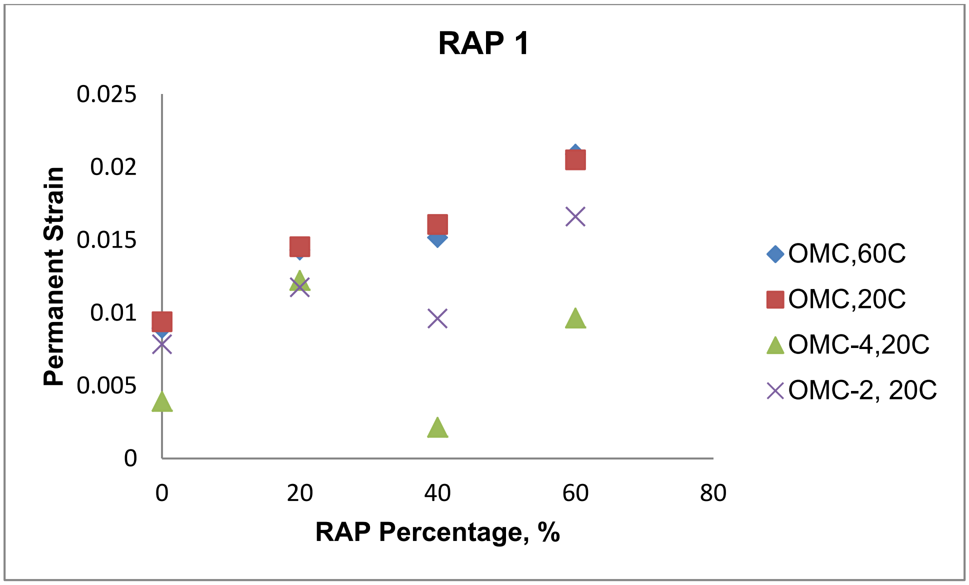


(a)

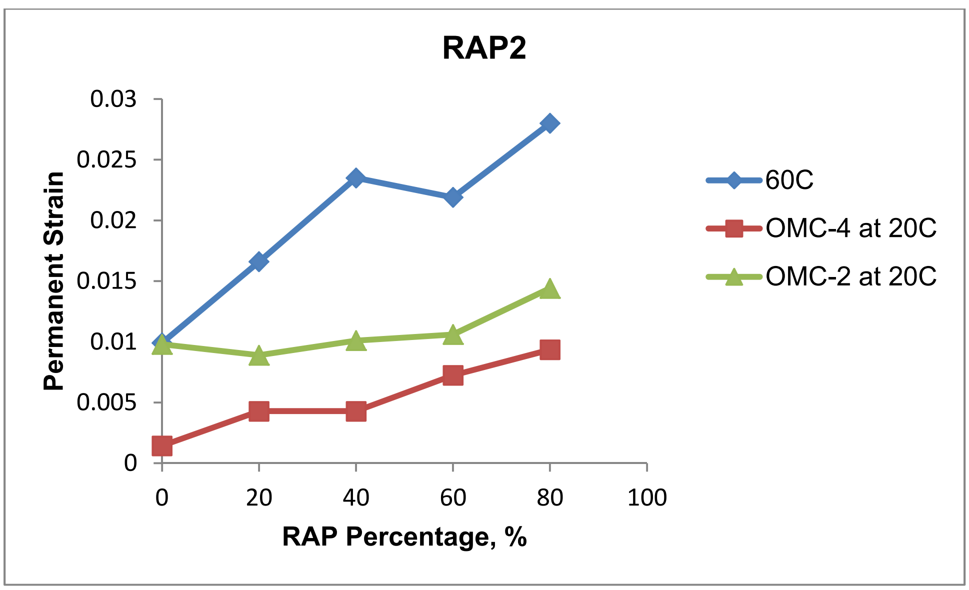


(b)

Figure 18 (a) Relationship between permanent Strain and RAP1 percentage for specimens tested at 20°C and 60°C; (b) Relationship between permanent strain and RAP2 percentage for specimens tested at 20°C and 60°C

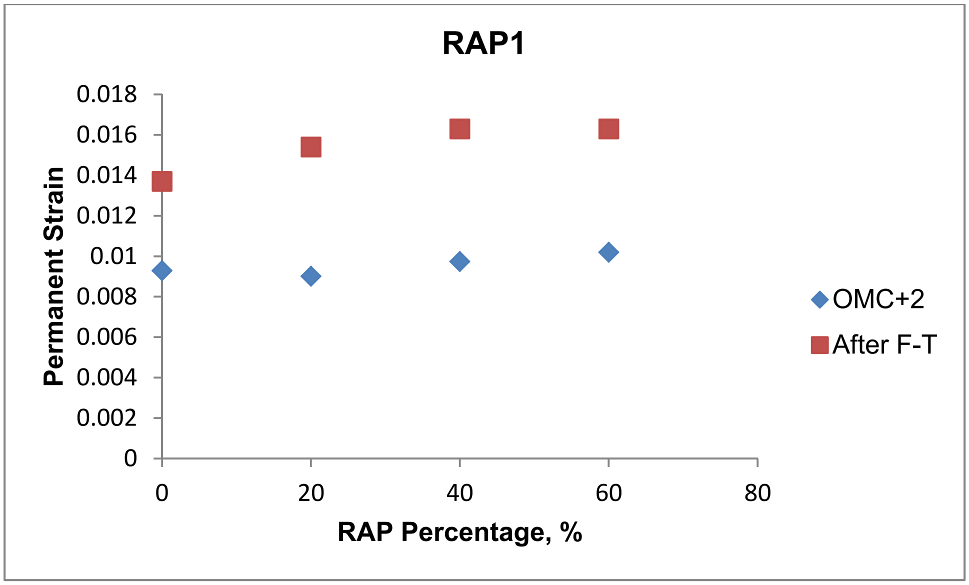


(a)

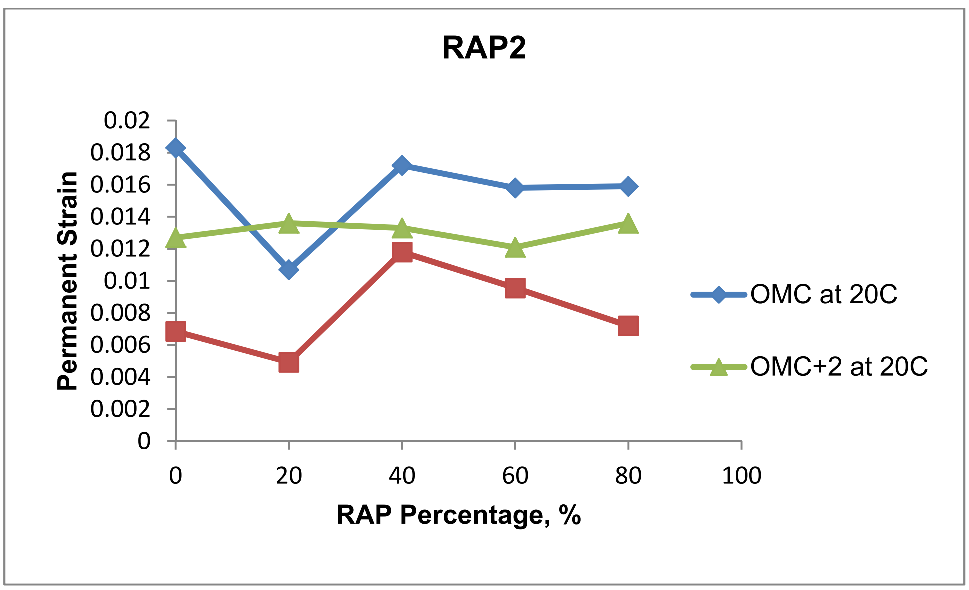


(b)

Figure 19 Relationship between Permanent Strain and RAP Percentage for (a) RAP 1; and (b) RAP 2

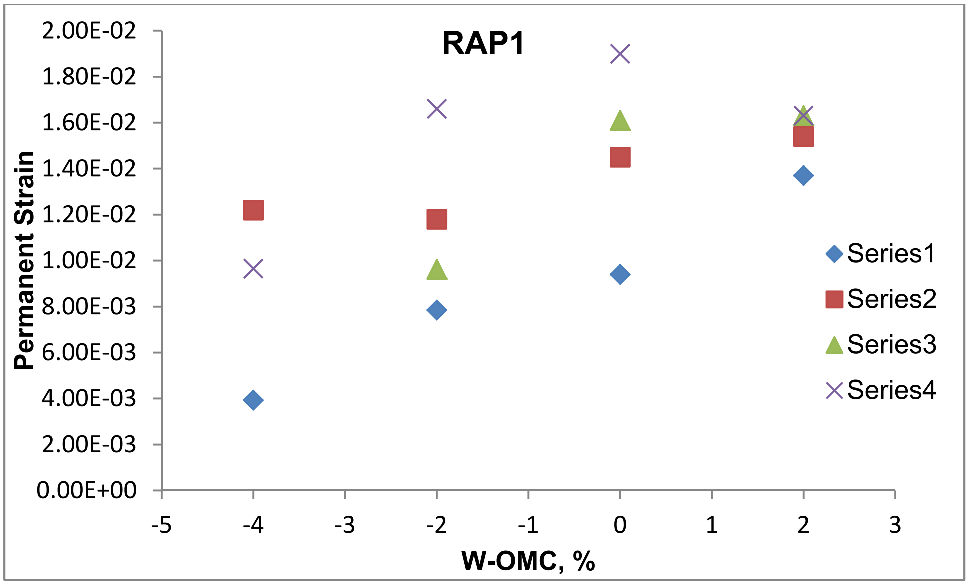


(a)

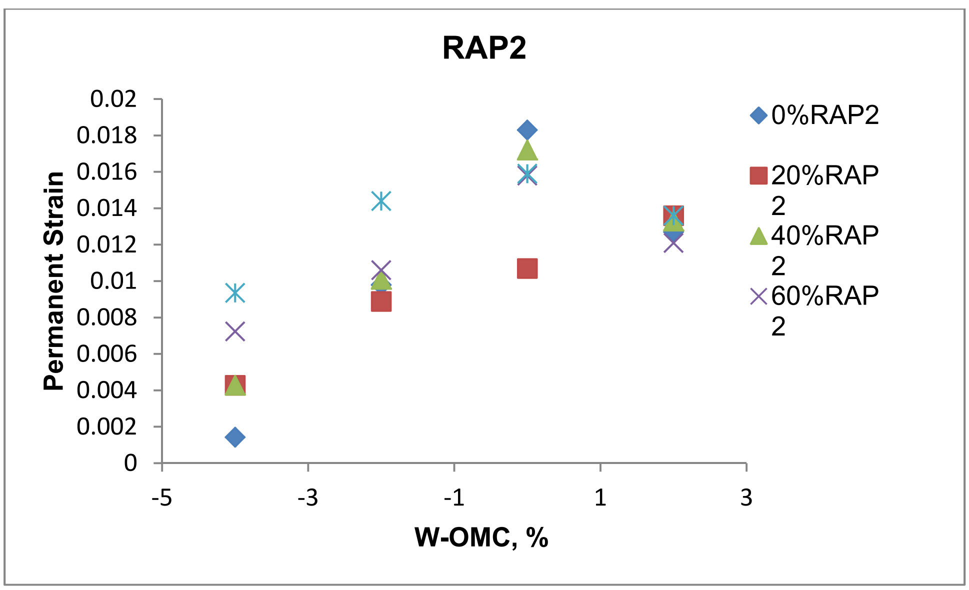


(b)

Figure 20 Relationship between permanent strain and RAP percentage for (a) RAP 1; and (b) RAP 2



(a)



(b)

Figure 21 Relationship between permanent strain and moisture content for (a) RAP 1; and (b) RAP 2

4.5 PERMEABILITY

Hydraulic conductivity tests were conducted following the AASHTO T 215 for samples containing different percentages of RAP2 only at room temperature. Coefficient of permeability was calculated based on Equation 10. The results are presented in Table 11 and Figure 22. The capacity of compacted samples to drain decreased with the increase of RAP percentage. Considering the same gradation used for all the mixtures, the reduction of permeability might be due to the aggregation of RAP particles as a result of compaction.

Table 11. Coefficient of permeability for RAP2 mixtures

RAP2 Percentage, %	k, cm/s
0	0.16170
20	0.08574
40	0.07511
60	0.03828
80	0.01059

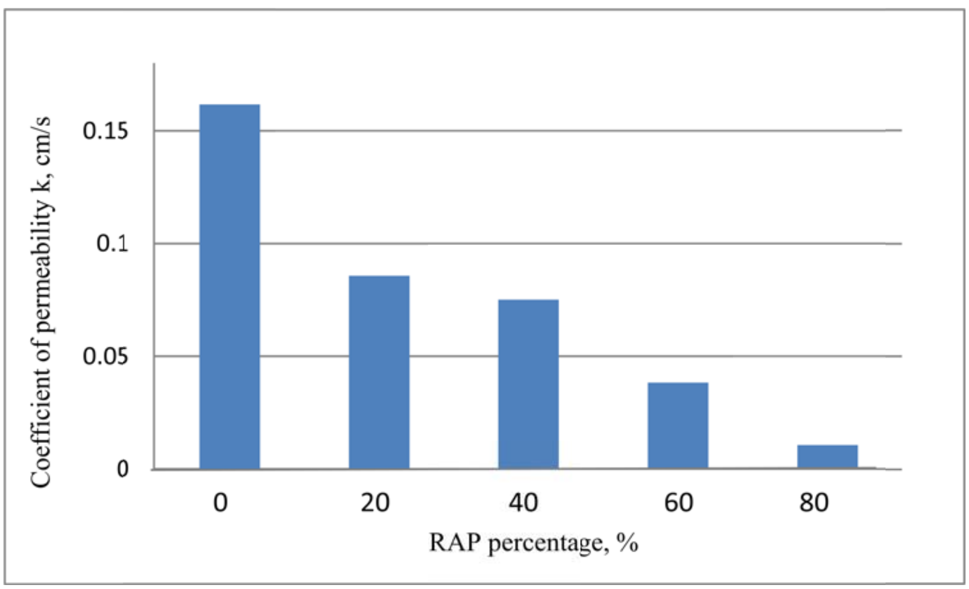


Figure 22 Trend of hydraulic conductivity with the increase of RAP2 percentage

4.6 MOISTURE DAMAGE

4.6.1 Effect of freeze-thaw on resilient modulus

Two sets of samples containing different percentages of RAP1 and RAP2 were tested to study the effects of freezing-thawing on resilient moduli. One set was tested immediately after compaction, while the other set was placed in the triaxial cell to determine freezing and thawing conditions prior to the testing. For RAP mixtures and virgin aggregates, M_r values increased after freezing-thawing, as shown in Figure 23. However, moisture content in the conditioned samples was reduced, indicating loss of moisture, as indicated in Table 12. During 24-hour thawing, moisture in the samples was drained to the bottom of the sample and was lost through the water drain line at the bottom of the triaxial chamber.

Table 12. Moisture Content of Specimens before and after Mr Test

Sample	Condition	MC before test, %	MC after test, %
0% RAP2	no freeze-thaw cycle	7.87	7.24
20% RAP2	no freeze-thaw cycle	7.73	7.53
40% RAP2	no freeze-thaw cycle	6.99	6.67
60% RAP2	no freeze-thaw cycle	6.63	6.33
80% RAP2	no freeze-thaw cycle	6.27	6.17
0% RAP2	with freeze-thaw cycle	7.87	5.85
20% RAP2	with freeze-thaw cycle	7.73	5.37
40% RAP2	with freeze-thaw cycle	6.99	4.60
60% RAP2	with freeze-thaw cycle	6.63	4.46
80% RAP2	with freeze-thaw cycle	6.27	4.20

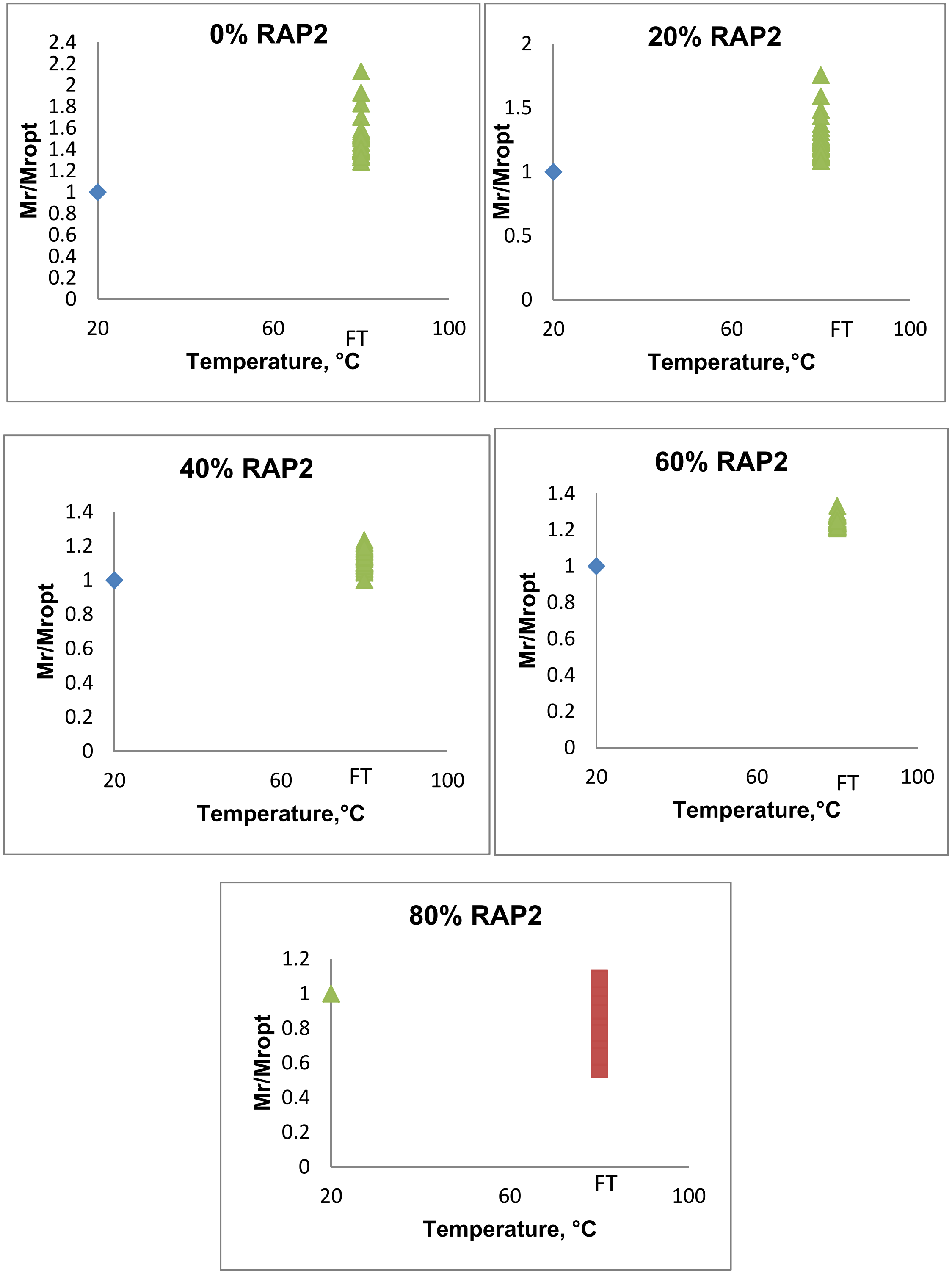


Figure 23 Effect of Freeze-thaw conditioning on Mr of specimens containing different percentages of RAP2

4.6.2 Effect of freeze-thaw on permeability

As introduced in Chapter 3, the well-mixed loose samples were conditioned with freezing-thawing, followed by the permeability tests. Figure 24 shows the relationship between the coefficient of permeability and RAP percentage. The results indicated that permeability increased after freezing-thawing, which could be due to the change of gradation of RAP particles during conditioning. During the freezing and thawing, RAP particles could disintegrate which could change the gradation of RAP and thus lead to an increase in permeability.

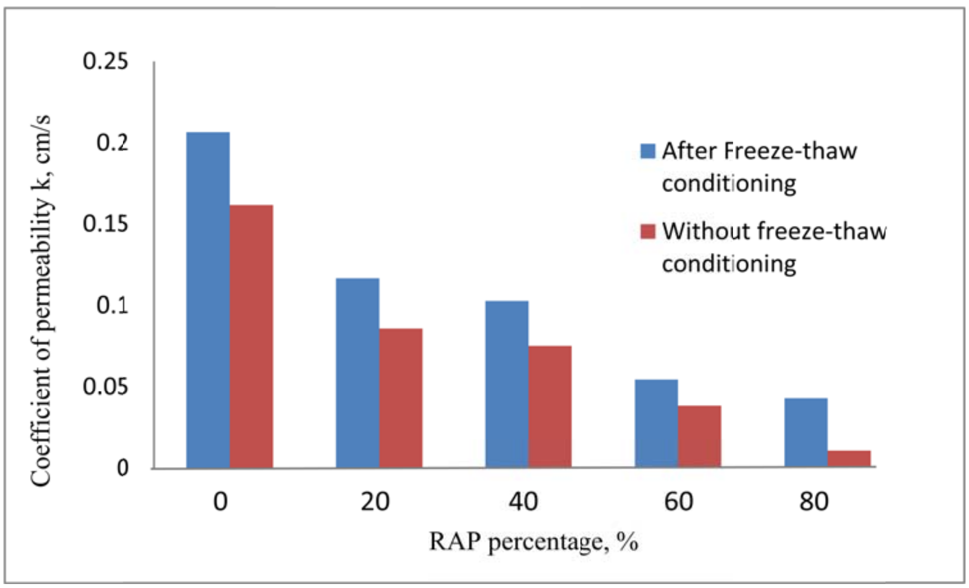


Figure 24 Effect of Freeze-thaw conditioning on permeability of specimens containing different percentages of RAP2

4.7 SUMMARY

Based on laboratory experiments, the resilient moduli of mixtures containing RAP were higher than those without RAP, and they increased with the increase of RAP percentage. Based on the NCHRP 1-28A report, the resilient modulus shall be reported at confining pressure of 35kPa (5.07psi) and deviator stress of 103kPa (14.94psi).

Stress states that are close to these criteria were used to interpolate the resilient modulus values at the confining pressure of 41kPa (5.95psi) and deviator stress of 103kPa (14.94psi), as shown in Table 13.

Table 13. Resilient Modulus at Confining Pressure of 41kPa (5.95psi) and Deviator Stress of 103kPa (14.94psi)

RAP, %	RAP 1			RAP2		
	Deviator Stress					
	82kpa (11.89psi)	122kPa (17.69psi)	Average	82kpa (11.89psi)	122kPa (17.69psi)	Average
0	209.53 MPa (30.39 ksi)	217 MPa (31.48 ksi)	213.2 MPa (30.94 ksi)	176.99 MPa (25.67 ksi)	206.22 MPa (29.91 ksi)	191.61 MPa (27.79 ksi)
20	197 MPa (28.65 ksi)	212 MPa (30.75 ksi)	204.77 MPa (29.70 ksi)	214.91 MPa (31.17 ksi)	232.84 MPa (33.77 ksi)	223.87 MPa (32.47 ksi)
40	246.21 MPa (35.71 ksi)	263 MPa (38.25 ksi)	254.97 MPa (36.98 ksi)	255.66 MPa (37.08 ksi)	259.31 MPa (37.61 ksi)	257.45 MPa (37.34 ksi)
60	368.46 MPa (53.44 ksi)	364.8 MPa (52.91 ksi)	366.67 Mpa (53.18 ksi)	304.54 MPa (44.17 ksi)	313.02 MPa (45.40 ksi)	308.82 MPa (44.79 ksi)
80				527.86 MPa (76.56 ksi)	482.15 MPa (69.93 ksi)	505.4 MPa (73.25 ksi)

The higher M_r values of mixtures containing RAP are beneficial to pavement performance, because RAP strengthens the support to the surface layer from the base and reduces the tensile strain at the bottom of HMA. However, the rutting potential in the base is also increased, especially at high temperature and excessive moisture content.

Therefore, RAP as a base course material has its advantages and disadvantages when compared to virgin aggregates. Current pavement design methods, such as the AASHTO 1993, are not capable of capturing the performance of base materials containing RAP. For instance, only resilient modulus is used in a pavement design. The MEPDG includes prediction models for fatigue, rutting, and other performance distresses, and can be used to predict the performance of a pavement containing RAP base material. Thus, a life cycle cost analysis is possible to evaluate the cost-effectiveness of using RAP. However, it is noted that the characteristics of RAP are different from those of traditional materials. For instance, the rutting potential of virgin aggregates is negatively correlated with the stiffness of those aggregates. That is, high stiffness materials are more resistant to rutting. This is, apparently, not the case for RAP. Therefore, the rutting prediction model for granular materials in the MEPDG is not applicable to base materials containing RAP. A rutting prediction model specific to RAP has to be developed and included in the MEPDG before the cost-effectiveness of using RAP as a base material can be assessed.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Currently, WSDOT allows up to 1.2 bitumen content (about 20% RAP to be blended with crushed aggregates) in the base materials [WSDOT 2008]. The use of high percentage RAP could contribute to the effort to promote sustainability, in terms of costs, energy, and greenhouse gas emissions. This study investigated the potential of using a high percentage of RAP as a base course material. Based on laboratory experiments, the following conclusions and recommendations can be made.

5.1 CONCLUSIONS

(1) Modified proctor compaction method was used in this study to evaluate the relationship between moisture content and dry density. OMC decreased with the increase of RAP percentage. In addition, increase of RAP percentage led to the reduction of bulk specific gravity.

(2) M_r test was conducted following NCHRP 1-28A protocol. Overall, M_r increased with the increase of RAP percentage.

(3) M_r of base materials containing RAP decreased with the increase of moisture content. Two models, Kw model and sigmoidal model, can be used as constitutive models to determine the effects of moisture content on M_r.

(4) M_r of mixtures containing RAP reduced with elevated temperature. Two temperature models, the K_T model and the Sigmoidal model, were used to account for the effects of temperature on M_r of base materials containing RAP. In addition, specimens containing a higher percentage of RAP were more sensitive to the increase

of temperature. For samples tested at -20°C, the range for $M_r$values was consistent with values recommended by the MEPDG.

(5) M_r increased with the increase of confining pressure. However, the effects of deviator stress on M_r of samples containing RAP were dependent on RAP percentage as well as confining pressure.

(6) For specimens containing different percentages of RAP1 and RAP2, permanent strain increased with the increase of RAP percentage.

(7) Constant-head permeameter was selected for conducting permeability test for specimens containing RAP as base course material. The result indicated that hydraulic conductivity was reduced by the addition of RAP.

(8) Freezing-thawing did not significantly affect the modulus of specimens containing RAP, but increased the coefficient of permeability.

5.2 RECOMMENDATIONS

(1) More sources of RAP should be studied to draw a general conclusion on the use of RAP in base course.

(2) Current pavement design method, such as AASHTO 1993, could not capture the rutting potential of RAP in a base course. The cost-effectiveness of the use of RAP as a base material should be determined by the MEPDG.

(3) The rutting model for granular materials in the MEPDG is not applicable to RAP as a base material. A rutting model for RAP is needed in MEPDG.

CHAPTER 6 REFERENCES

Wijeratne A. and Sargious M., Prediction of Rutting in Virgin and Recycled Asphalt Mixtures for Pavements Using Tiaxial Tests, *Journal of Asphalt Paving Technologists.* Vol. 56, 1987, pp. 111-129.

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

Applied Research Associates (ARA) (2004). Guide for Mechanistic-Empirical Design on New and Rehabilitated Pavement Structures. NCHRP Project 1-37A. Prepared for National Cooperative Highway Research Program, Washington, D.C

Attia M., Abdelrahman M., and Alam T. (2009), Investigation of Stripping in Minnesota Class 7 (RAP) and Full-Depth Reclamation Base Materials, Minnesota Department of Transportation, Techinique Report, MN/RC 2009-05.

Attia A. and Abdelrahman M. (2009), Modeling the effect of moisture on resilient modulus of untreated reclaimed asphalt pavement, submitted for 89th Transportation Research Board Meeting and Publication in the Transportation Research Record, Washington DC, 2009.

Bouchedid M.B. and Humphrey D.N. (2005), Permeability of Base Material for Maine Roads, *Transportation Research Record: Journal of the Transportation Research Board,* Transportation Research Board of the National Academies, Washington D.C., pp 142-149.

Cooley D.A. (2005), Effects of Reclaimed Asphalt Pavement on Mechanical Properties of Base Materials, A thesis submitted to the faculty of Brigham Young University in partial fulfillment of the requirements for the degree of Master of Science, Brigham Young University, Provo, Utah.

Cosentino P.J. and Kalajian E.H. (2001), Developing Specifications for Using Recycled Asphalt Pavement as Base, Subbase or General Fill. (accessed online at www.dot.state.fl.us/research-center/Completed_Proj/Summary_SMO/FDOT_BB892_rpt.pdf on July 12, 2007)

Gupta S., Kang D.H. and Ranaivoson A. (2009), Hydraulic and Mechanical Properties of Recycled Materials, Report to Minnesota department of Transportation, St. Paul, MN.

Guthrie W. S, Cooley D., and Eggett D. L. (2005), Effects of Reclaimed Asphalt Pavement on Mechanical Properties of Base Materials, *Transportation Research*

Records, No. 2005, Transportation Research Board of the National Academies, Washington DC, pp. 44-52

Jeon E., Steven B., and Harvey J. (2009), The Performance Evaluation of Recycled Pulverized Asphalt Concrete Material Based on Comprehensive Laboratory Testing, *Transportation Research Record: Journal of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington DC, pp 42-52.

Kim W., Labuz J.F., and Dai S. (2007), Resilient Modulus of Base Course Containing Recycled Asphalt Pavement, *Transportation Research Record: Journal of the Transportation Research Board*, No. 2005, Transportation Research Board of the National Academies, Washington DC, pp. pp 27-35.

MacGregor J.A.C, Highter W.H., and DeGroot D.J. (1999), Structural Numbers for Reclaimed Asphalt Pavement Base and Subbase Course Mixes, *Transportation Research Record: Journal of the Transportation Research Board*, No. 1687, Transportation Research Board of the National Academies, pp. 22-28.

McGarrah E.J. (2007), Evaluation of Current Practices of Reclaimed Asphalt Pavement/Virgin Aggregate as Base Course Material, A thesis submitted to the faculty of University of Washington in partial fulfillment of the requirements for the degree of Master of Science, Seattle, WA.

Mohamed H. M., Nenad G. and Walter J.P. (1997), Recycled Asphalt Pavement as a base and subbase material. *Testing soil mixed with waste or recycled materials*. ASTM Publication 04-012750-38, Fredericksburg, VA, pp 42-53.

Mohammad L.N., Herath A., Rasoulian M., and Zhang Z. (2006), Laboratory Evaluation of Untreated and Treated Pavement Base Materials From a Repeated Load Permanent Deformation Test, In *Transportation Research Record: Journal of the Transportation Research Board*, *No. 1967,* Transportation Research Board of the National Academies, Washington D.C., pp 78-88.

Mokwa R.L., and Peebles C.S. (2005), Evaluation of the Engineering characteristics of RAP/Aggregate Blends. (accessed online at www.mdt.mt.gov/research/docs/research_proj/rap_aggregate/final_report.pdf on July 12, 2007).

Recycled Materials Resource Center (RMRC), User Guidelines for Byproducts ans Secondary Use Materials in Pavement Construction (Accessed at http://www.rmrc.unh.edu/tools/uguidelines/rap131.asp on Nov 15, 2010)

Richter C.A. (2006), Seasonal Variations in the Moduli of Unbound Pavement Layers, Publication FHWA-HRT-04-079, FHWA, U.S. Department of Transportation, McLean, VA.

Saeed A. (2008), "Performance-Related Tests of Recycled Aggregates for Use in Unbound Pavement Layers," NCHRP Report 598, National Cooperative Highway Research Program, Washington DC.

Sargious M.N. (1991), Mushule Behavior of recycled asphalt pavement at low temperature, *Canadian Journal of Civil Engineering,* Vol. 18, Issue 3, pp. 428-435.

Seed H.B, Mitchell J.K., and Chan C.K. (1962), Studies of swell and swell pressure characteristics of compacted clays, *Highway Research Board Bulletin,* Washington DC.

Trzebiatowski B.D and Benson C.H. (2005), Saturated hydraulic conductivity of compacted recycled asphalt pavement, ASTM International, ISSN: 1945-7545.

Uhlmeyer J., Construction and Performance of Reclaimed Asphalt Pavement (RAP) in Untreated Aggregate Base, Research Need Statement, Washington Department of Transportation, Olympia, WA.

Viyanant C., Rathje E.M, Rauch A.F (2004), Compaction Control of Crushed Concrete and Recycled Asphalt Pavement Using Nuclear Gauge*. Geotechnical Engineering for Transportation Projects*, pp. 958-966.

Washington Department of Transportation (2008), *Standard specifications for Road, Bridge, and Municipal Construction,* Olympia, WA, 2008.

Wen H., Warner J., and Edil T., "Laboratory Comparison of Crushed Aggregate, Recycled Pavement Materials with and without High Carbon Fly Ash," Compendium of Paper CD-ROM for 87th Transportation Research Board meeting, Washington DC, 2008

Wen H, Warner.J, Edil T, WangG. (2010), Laboratory comparison of crushes aggregate and recycled pavement material with and without high carbon fly ash, *Geotechnical and Geological Engineering*, *V*ol. 28, Number 4*,* pp.405-411.

Witczak M.W. (2004), Laboratory determination of resilient modulus for flexible pavement design. Research Result Digest number 285, National Cooperative Highway Research Program, Washington DC.

(http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rrd_285.pdf. Accessed on July 28th, 2010)

Witczak M.W., Andrei D., and Houston W.N. (2000), Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. Appendix DD-1: Resilient modulus as Function of Soil Moisture-Summary of Predictive Models.

Appendix A Detailed Testing Result

Table B.1 Resilient modulus test result for 0% RAP1 sample containing OMC tested at 20°C

0% RAP1 Sample containing OMC tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.27	80958.24
2	41.37	21.14	161102.89
3	68.95	35.44	238468.96
4	103.42	53.22	336029.77
5	137.90	70.43	447345.62
6	20.68	20.94	83171.45
7	41.37	41.76	178319.10
8	68.95	70.53	266585.78
9	103.42	105.92	384168.97
10	137.90	140.47	462024.56
11	20.68	45.76	76469.75
12	41.37	83.50	209510.98
13	68.95	140.09	301618.04
14	103.42	208.07	401392.07
15	137.90	276.14	483915.41
16	20.68	60.14	92176.01
17	41.37	124.84	217074.53
18	68.95	208.30	315945.34
19	103.42	310.79	413844.00
20	137.90	415.48	488100.53
21	20.68	103.04	137302.19
22	41.37	207.08	221404.44
23	68.95	344.43	319144.51
24	103.42	519.40	408431.62
25	137.90	699.83	482812.25
26	20.68	142.06	136350.71
27	41.37	289.55	239406.65
28	68.95	482.75	341166.37
29	103.42	726.28	429729.52
30	137.90	966.03	492788.97

Table B.2 Resilient modulus test result for 20% RAP1 sample containing OMC tested at 20°C

20% RAP1 Sample containing OMC tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.54	128628.59
2	41.37	21.19	182931.69
3	68.95	35.03	267323.52
4	103.42	52.72	386202.92
5	137.90	70.02	501069.57
6	20.68	20.99	115590.60
7	41.37	41.71	184345.12
8	68.95	69.45	274721.59
9	103.42	104.65	395386.73
10	137.90	139.85	508384.91
11	20.68	44.37	117093.66
12	41.37	83.23	197541.68
13	68.95	139.68	303383.10
14	103.42	208.54	417491.33
15	137.90	275.76	501483.26
16	20.68	63.56	125663.84
17	41.37	124.82	212020.67
18	68.95	208.84	319847.78
19	103.42	309.40	416822.53
20	137.90	414.44	483384.52
21	20.68	106.56	139929.09
22	41.37	206.53	233359.95
23	68.95	343.77	333864.82
24	103.42	518.89	425344.45
25	137.90	693.61	519195.89
26	20.68	147.23	148154.54
27	41.37	288.98	252803.16
28	68.95	484.01	365291.12
29	103.42	732.71	457853.23
30	137.90	970.51	545871.70

Table B.3 Resilient modulus test result for 40% RAP1 sample containing OMC tested at 20°C

40% RAP1 Sample containing OMC tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.32	313994.13
2	41.37	21.05	354817.98
3	68.95	34.71	471980.59
4	103.42	52.50	632538.80
5	137.90	70.08	788560.25
6	20.68	20.62	164570.95
7	41.37	41.75	244384.66
8	68.95	69.64	354549.09
9	103.42	104.92	499228.67
10	137.90	139.28	614529.69
11	20.68	41.62	150353.97
12	41.37	83.47	246204.88
13	68.95	138.94	377791.32
14	103.42	207.91	496587.98
15	137.90	274.88	570610.09
16	20.68	62.19	158606.99
17	41.37	125.00	263738.24
18	68.95	208.18	384699.86
19	103.42	308.49	473421.59
20	137.90	412.95	555000.36
21	20.68	103.62	173596.19
22	41.37	207.68	286511.63
23	68.95	342.63	386037.44
24	103.42	516.71	480833.46
25	137.90	692.70	580373.07
26	20.68	144.47	182814.48
27	41.37	288.15	308119.80
28	68.95	484.24	429329.62
29	103.42	731.06	525911.38
30	137.90	972.23	619900.71

Table B.4 Resilient modulus test result for 60% RAP1 sample containing OMC tested at 20°C

60% RAP1 Sample containing OMC tested at 20°C			
Sequence	Confining pressure (psi)	Cyclic stress (Kpa)	Resilient Modulus (kPa)
1	20.68	9.78	285367.10
2	41.37	20.57	385899.55
3	68.95	34.43	533385.30
4	103.42	51.77	676623.87
5	137.90	69.47	840512.25
6	20.68	19.97	241013.13
7	41.37	41.00	364939.49
8	68.95	68.09	500021.57
9	103.42	103.14	667233.21
10	137.90	138.43	835237.76
11	20.68	40.59	241923.23
12	41.37	82.01	368462.71
13	68.95	137.91	526394.01
14	103.42	208.57	673914.23
15	137.90	274.75	756616.84
16	20.68	61.57	235042.27
17	41.37	123.45	364822.28
18	68.95	207.77	521664.21
19	103.42	309.00	647976.16
20	137.90	411.49	740152.16
21	20.68	102.89	249955.63
22	41.37	204.61	395331.58
23	68.95	342.24	534584.98
24	103.42	514.86	641267.56
25	137.90	686.91	743185.86
26	20.68	143.96	261331.97
27	41.37	285.66	408514.35
28	68.95	480.85	556889.52
29	103.42	25.88	673017.92
30	137.90	264.40	765697.24

Table B.5 Resilient modulus test result for 0% RAP1 sample containing OMC+2% tested at 20°C

0% RAP1 Sample containing OMC+2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.97	123423.05
2	41.37	21.17	178484.57
3	68.95	35.11	272632.48
4	103.42	52.86	389271.09
5	137.90	70.12	512963.03
6	20.68	20.20	121526.99
7	41.37	41.91	191453.61
8	68.95	69.57	295454.13
9	103.42	104.88	424558.45
10	137.90	139.43	544203.17
11	20.68	41.29	136585.14
12	41.37	83.45	225658.50
13	68.95	139.94	339408.20
14	103.42	208.26	473545.70
15	137.90	277.26	576994.63
16	20.68	62.16	152153.50
17	41.37	125.25	250617.52
18	68.95	208.06	370255.35
19	103.42	311.95	486866.37
20	137.90	412.88	561819.27
21	20.68	103.41	188764.66
22	41.37	206.57	274383.75
23	68.95	344.76	379266.79
24	103.42	519.66	471249.75
25	137.90	698.93	547974.60
26	20.68	149.33	164626.11
27	41.37	290.65	280478.71
28	68.95	485.72	399661.48
29	103.42	734.60	488941.69
30	137.90	977.06	530696.34

Table B.6 Resilient modulus test result for 20% RAP1 sample containing OMC+2% tested at 20°C

20% RAP1 Sample containing OMC+2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.54	111963.96
2	41.37	21.20	170679.71
3	68.95	34.85	258884.34
4	103.42	52.57	367580.18
5	137.90	70.32	475793.39
6	20.68	19.86	115032.13
7	41.37	41.68	178050.20
8	68.95	69.45	267199.41
9	103.42	104.92	384286.18
10	137.90	140.18	489900.06
11	20.68	40.73	125312.21
12	41.37	83.12	201809.54
13	68.95	139.50	306837.37
14	103.42	208.17	423289.82
15	137.90	277.02	502317.52
16	20.68	61.63	135681.92
17	41.37	124.87	226320.40
18	68.95	208.20	331244.81
19	103.42	311.50	413568.21
20	137.90	412.80	486997.37
21	20.68	102.90	151670.86
22	41.37	208.12	248273.30
23	68.95	343.63	333906.19
24	103.42	519.46	433032.11
25	137.90	697.20	530441.24
26	20.68	143.99	161944.05
27	41.37	290.42	276472.86
28	68.95	483.47	380114.85
29	103.42	732.89	483667.20
30	137.90	974.90	588191.72

Table B.7 Resilient modulus test result for 40% RAP1 sample containing OMC+2% tested at 20°C

40% RAP1 Sample containing OMC+2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.51	124671.00
2	41.37	20.82	198196.68
3	68.95	34.76	294157.91
4	103.42	52.37	410762.04
5	137.90	70.11	529427.71
6	20.68	19.37	120065.30
7	41.37	41.58	203347.07
8	68.95	69.56	313228.81
9	103.42	104.70	429295.15
10	137.90	139.39	540748.90
11	20.68	40.58	131214.12
12	41.37	83.43	227016.77
13	68.95	138.99	343110.69
14	103.42	208.30	460066.45
15	137.90	277.02	544051.49
16	20.68	61.40	143417.84
17	41.37	124.06	243309.08
18	68.95	208.17	359113.42
19	103.42	311.33	454867.80
20	137.90	412.12	528386.60
21	20.68	102.84	160799.52
22	41.37	207.10	269495.37
23	68.95	345.08	367256.13
24	103.42	518.38	453868.06
25	137.90	695.49	544113.54
26	20.68	143.89	172644.72
27	41.37	290.40	289690.11
28	68.95	483.45	393876.78
29	103.42	732.72	479626.88
30	137.90	971.77	561688.27

Table B.8 Resilient modulus test result for 60% RAP1 sample containing OMC+2% tested at 20°C

60% RAP1 Sample containing OMC+2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	7.69	235842.06
2	41.37	19.96	298529.19
3	68.95	33.80	392808.10
4	103.42	52.96	510074.12
5	137.90	70.96	644342.62
6	20.68	16.46	197286.58
7	41.37	40.78	278113.81
8	68.95	70.00	392670.20
9	103.42	105.28	527814.33
10	137.90	139.66	649851.53
11	20.68	37.98	189991.92
12	41.37	85.12	302300.62
13	68.95	139.66	428488.46
14	103.42	208.37	556027.68
15	137.90	277.58	651292.54
16	20.68	61.36	197914.00
17	41.37	125.86	317944.82
18	68.95	208.31	453047.59
19	103.42	309.71	564673.70
20	137.90	416.60	646348.99
21	20.68	102.21	216150.63
22	41.37	207.70	348192.12
23	68.95	341.44	471677.22
24	103.42	519.25	581820.96
25	137.90	695.47	692881.71
26	20.68	143.33	231656.94
27	41.37	290.99	382141.91
28	68.95	481.24	519568.20
29	103.42	728.33	623092.98
30	137.90	966.29	711628.55

Table B.9 Resilient modulus test result for 0% RAP1 sample containing OMC-4% tested at 20°C

0% RAP1 Sample containing OMC-4% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.47	194101.20
2	41.37	21.19	261835.29
3	68.95	35.35	335140.35
4	103.42	53.45	448945.21
5	137.90	70.96	584041.08
6	20.68	19.45	180801.21
7	41.37	41.91	245542.98
8	68.95	70.60	335367.88
9	103.42	105.94	461638.45
10	137.90	139.92	599733.54
11	20.68	40.54	181869.90
12	41.37	84.12	263696.88
13	68.95	139.57	371579.14
14	103.42	207.98	523443.06
15	137.90	276.53	648438.11
16	20.68	62.03	200058.27
17	41.37	125.32	300956.14
18	68.95	207.03	427647.30
19	103.42	311.81	570368.77
20	137.90	412.98	657539.19
21	20.68	103.95	205408.60
22	41.37	207.02	315049.03
23	68.95	346.06	453930.12
24	103.42	522.19	555165.83
25	137.90	687.72	630842.69
26	20.68	144.99	202388.70
27	41.37	290.93	323405.47
28	68.95	485.98	450751.63
29	103.42	728.98	547995.29
30	137.90	957.79	604270.29

Table B.10 Resilient modulus test result for 20% RAP1 sample containing OMC-4% tested at 20°C

20% RAP1 Sample containing OMC-4% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	8.80	186496.28
2	41.37	20.62	227692.46
3	68.95	34.75	299384.14
4	103.42	52.33	388947.03
5	137.90	69.89	473780.12
6	20.68	18.86	167983.86
7	41.37	41.55	227520.09
8	68.95	69.27	317731.09
9	103.42	105.41	421724.71
10	137.90	139.61	516182.88
11	20.68	39.86	166439.43
12	41.37	83.05	255064.64
13	68.95	140.09	369531.40
14	103.42	207.49	493133.70
15	137.90	276.67	577070.48
16	20.68	60.95	179953.16
17	41.37	125.42	286022.10
18	68.95	207.89	410996.46
19	103.42	310.82	519519.94
20	137.90	413.68	567741.87
21	20.68	102.15	197872.63
22	41.37	207.06	315793.66
23	68.95	343.41	437755.02
24	103.42	521.20	494319.60
25	137.90	695.91	504923.74
26	20.68	143.30	174844.14
27	41.37	289.59	280506.29
28	68.95	485.35	381548.96
29	103.42	735.77	429639.89
30	137.90	972.65	405204.87

Table B.11 Resilient modulus test result for 40% RAP1 sample containing OMC-4% tested at 20°C

40% RAP1 Sample containing OMC-4% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.18	338504.99
2	41.37	20.91	476903.45
3	68.95	34.65	627050.57
4	103.42	52.34	808796.36
5	137.90	69.78	980448.23
6	20.68	20.84	324425.90
7	41.37	41.62	475386.60
8	68.95	69.24	622279.40
9	103.42	104.61	806645.20
10	137.90	140.36	977731.70
11	20.68	41.58	345523.85
12	41.37	83.16	486976.69
13	68.95	139.68	655712.07
14	103.42	209.49	843683.84
15	137.90	276.86	975380.59
16	20.68	62.36	344724.06
17	41.37	124.42	497394.66
18	68.95	209.51	672769.70
19	103.42	311.53	844269.89
20	137.90	415.50	944492.08
21	20.68	103.68	363277.85
22	41.37	208.29	523167.27
23	68.95	344.95	697873.51
24	103.42	518.69	818497.29
25	137.90	3.81	901489.48
26	20.68	144.60	319330.67
27	41.37	290.79	484735.89
28	68.95	484.27	657773.61
29	103.42	726.56	804190.67
30	137.90	971.06	851157.75

Table B.12 Resilient modulus test result for 60% RAP1 sample containing OMC-4% tested at 20°C

60% RAP1 Sample containing OMC-4% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.74	1004635.04
2	41.37	20.89	948690.98
3	68.95	34.96	1025774.37
4	103.42	51.78	1136883.38
5	137.90	69.98	1378220.56
6	20.68	20.61	571244.41
7	41.37	40.97	643198.09
8	68.95	68.98	758843.85
9	103.42	103.68	964300.71
10	137.90	138.91	1102037.27
11	20.68	42.06	399337.43
12	41.37	82.37	527931.54
13	68.95	136.94	710697.76
14	103.42	206.74	852647.02
15	137.90	275.19	955771.90
16	20.68	61.27	332796.13
17	41.37	122.76	537529.05
18	68.95	206.59	697266.78
19	103.42	311.24	809354.84
20	137.90	412.60	876047.82
21	20.68	102.99	338139.57
22	41.37	204.04	483674.10
23	68.95	342.75	635758.65
24	103.42	514.07	727465.81
25	137.90	687.40	823406.35
26	20.68	143.26	315979.82
27	41.37	287.66	468547.00
28	68.95	481.05	628781.15
29	103.42	719.95	745316.34
30	137.90	946.42	846448.63

Table B.13 Resilient modulus test result for 0% RAP1 sample containing OMC-2% tested at 20°C

0% RAP1 Sample containing OMC-2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.35	166232.59
2	41.37	21.12	223886.55
3	68.95	35.00	303907.10
4	103.42	52.68	424565.35
5	137.90	70.26	565721.71
6	20.68	19.51	152291.39
7	41.37	41.95	222231.81
8	68.95	69.55	310808.75
9	103.42	105.21	439864.81
10	137.90	139.65	559964.58
11	20.68	40.56	154470.14
12	41.37	83.52	238227.64
13	68.95	139.16	343310.64
14	103.42	209.52	481281.62
15	137.90	277.48	585378.66
16	20.68	61.83	162033.68
17	41.37	125.07	256050.59
18	68.95	209.39	369896.82
19	103.42	312.01	486170.00
20	137.90	412.46	570030.93
21	20.68	103.17	171189.92
22	41.37	207.66	275266.28
23	68.95	345.61	378949.63
24	103.42	518.73	472449.43
25	137.90	699.67	552552.72
26	20.68	141.48	149650.70
27	41.37	291.17	258339.65
28	68.95	486.02	373399.35
29	103.42	732.29	471925.43
30	137.90	975.78	549436.29

Table B.14 Resilient modulus test result for 20% RAP1 sample containing OMC-2% tested at 20°C

20% RAP1 Sample containing OMC-2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.61	133772.08
2	41.37	20.86	187475.34
3	68.95	34.92	272604.90
4	103.42	52.75	391043.04
5	137.90	70.14	501821.10
6	20.68	19.80	130042.01
7	41.37	41.86	191488.09
8	68.95	69.42	284856.89
9	103.42	104.91	408500.56
10	137.90	139.71	519257.94
11	20.68	41.07	127773.64
12	41.37	83.15	221728.49
13	68.95	138.28	341076.73
14	103.42	209.26	463975.78
15	137.90	277.38	546733.55
16	20.68	62.94	143190.31
17	41.37	124.62	234097.68
18	68.95	208.59	350956.92
19	103.42	311.86	458659.92
20	137.90	411.53	529999.97
21	20.68	107.00	162219.84
22	41.37	207.46	262462.71
23	68.95	344.17	361836.85
24	103.42	518.82	454688.54
25	137.90	697.35	531813.29
26	20.68	143.87	159179.25
27	41.37	291.77	282919.46
28	68.95	485.71	393263.15
29	103.42	731.82	480281.88
30	137.90	972.74	571451.25

Table B.15 Resilient modulus test result for 40% RAP1 sample containing OMC-2% tested at 20°C

40% RAP1 Sample containing OMC-2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.26	150036.81
2	41.37	20.59	222528.28
3	68.95	34.69	320571.73
4	103.42	52.42	444291.25
5	137.90	70.09	562357.07
6	20.68	19.17	146134.37
7	41.37	41.71	230939.89
8	68.95	69.48	335947.03
9	103.42	104.64	463555.20
10	137.90	139.45	581041.86
11	20.68	40.29	152973.97
12	41.37	82.94	252161.95
13	68.95	138.49	372447.88
14	103.42	208.51	499952.62
15	137.90	277.89	575657.05
16	20.68	61.91	164888.11
17	41.37	124.62	269212.68
18	68.95	208.21	390739.67
19	103.42	311.66	499194.20
20	137.90	411.86	577084.27
21	20.68	102.75	181573.43
22	41.37	207.21	293785.60
23	68.95	345.81	403177.81
24	103.42	517.26	487528.27
25	137.90	695.97	570086.09
26	20.68	143.98	179932.47
27	41.37	289.84	300873.41
28	68.95	483.00	414030.16
29	103.42	726.40	515769.19
30	137.90	970.44	612364.74

Table B.16 Resilient modulus test result for 60% RAP1 sample containing OMC-2% tested at 20°C

60% RAP1 Sample containing OMC-2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.56	163192.00
2	41.37	20.92	246901.25
3	68.95	34.92	353314.93
4	103.42	52.31	484660.05
5	137.90	69.70	604194.45
6	20.68	19.62	151333.02
7	41.37	41.68	248080.25
8	68.95	69.13	370648.35
9	103.42	104.83	502882.89
10	137.90	139.01	615494.96
11	20.68	41.56	162047.47
12	41.37	83.14	274218.28
13	68.95	138.53	400619.86
14	103.42	209.00	521698.68
15	137.90	278.10	598878.59
16	20.68	61.40	169714.44
17	41.37	124.40	284787.94
18	68.95	208.30	407114.72
19	103.42	310.79	511556.50
20	137.90	411.30	610503.15
21	20.68	102.62	189757.50
22	41.37	206.86	309553.91
23	68.95	344.07	415064.37
24	103.42	515.10	507626.48
25	137.90	689.54	602477.66
26	20.68	143.31	193142.83
27	41.37	289.35	317296.72
28	68.95	479.51	433714.69
29	103.42	730.38	524711.69
30	137.90	969.95	632814.59

Table B.17 Resilient modulus test result for 0% RAP1 sample containing OMC tested at 60°C

0% RAP1 Sample containing OMC tested at 60°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.20	160751.26
2	41.37	20.75	212351.62
3	68.95	35.25	286346.15
4	103.42	52.86	390153.61
5	137.90	69.71	502076.20
6	20.68	20.86	158979.31
7	41.37	41.98	220832.17
8	68.95	69.58	305127.47
9	103.42	104.89	422634.81
10	137.90	140.23	549243.24
11	20.68	41.80	158269.15
12	41.37	83.54	237427.85
13	68.95	139.84	347288.91
14	103.42	211.00	468016.11
15	137.90	278.13	563605.02
16	20.68	62.73	169238.71
17	41.37	125.04	259477.28
18	68.95	211.02	372799.51
19	103.42	312.46	484915.15
20	137.90	413.30	550904.87
21	20.68	104.57	184455.43
22	41.37	209.15	287642.37
23	68.95	347.03	395152.31
24	103.42	519.06	485142.68
25	137.90	691.74	559054.48
26	20.68	146.12	183490.17
27	41.37	292.06	297322.61
28	68.95	485.36	405666.82
29	103.42	729.40	511032.49
30	137.90	973.07	597899.54

Table B.18 Resilient modulus test result for 20% RAP1 sample containing OMC tested at 60°C

20% RAP1 Sample containing OMC tested at 60°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.44	114384.02
2	41.37	20.97	147816.70
3	68.95	34.78	200665.01
4	103.42	52.45	258001.81
5	137.90	71.86	364353.43
6	20.68	20.93	109530.11
7	41.37	41.70	146251.59
8	68.95	69.65	210145.30
9	103.42	106.22	297239.87
10	137.90	139.96	393483.78
11	20.68	41.71	115025.23
12	41.37	83.30	168735.39
13	68.95	139.21	254368.27
14	103.42	210.79	351039.66
15	137.90	277.82	419215.02
16	20.68	62.31	122506.04
17	41.37	124.53	190440.08
18	68.95	210.88	279665.13
19	103.42	310.04	347619.86
20	137.90	412.08	409203.83
21	20.68	104.40	130490.17
22	41.37	208.84	211606.99
23	68.95	344.01	271487.95
24	103.42	520.11	330562.23
25	137.90	696.15	405439.29
26	20.68	147.13	117893.45
27	41.37	288.79	206573.81
28	68.95	484.12	290483.01
29	103.42	730.47	571699.46
30	137.90	965.27	396180.92

Table B.19 Resilient modulus test result for 40% RAP1 sample containing OMC tested at 60°C

40% RAP1 Sample containing OMC tested at 60°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.19	185303.49
2	41.37	20.70	270963.95
3	68.95	34.49	374847.25
4	103.42	52.28	479164.93
5	137.90	69.89	581579.65
6	20.68	20.86	183331.59
7	41.37	41.44	263627.93
8	68.95	69.13	368835.03
9	103.42	104.50	485197.84
10	137.90	139.13	579132.01
11	20.68	41.47	176147.25
12	41.37	82.63	277824.23
13	68.95	138.61	379839.06
14	103.42	208.69	488707.27
15	137.90	276.93	562777.65
16	20.68	61.69	176050.73
17	41.37	124.15	267847.52
18	68.95	208.50	380611.27
19	103.42	309.88	478771.93
20	137.90	413.96	550043.03
21	20.68	103.21	181973.32
22	41.37	207.88	289979.69
23	68.95	344.54	387788.71
24	103.42	515.64	472883.80
25	137.90	689.08	567576.40
26	20.68	144.56	190984.77
27	41.37	289.48	306051.37
28	68.95	479.88	422779.60
29	103.42	721.80	508295.28
30	137.90	965.89	683828.89

Table B.20 Resilient modulus test result for 60% RAP1 sample containing OMC tested at 60°C

60% RAP1 Sample containing OMC tested at 60°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.21	301549.09
2	41.37	20.57	436934.54
3	68.95	34.60	629994.63
4	103.42	51.91	896787.25
5	137.90	69.78	1123149.02
6	20.68	20.75	271646.53
7	41.37	41.39	373737.20
8	68.95	68.58	489644.96
9	103.42	103.58	693653.92
10	137.90	138.85	886086.59
11	20.68	40.81	222652.39
12	41.37	81.71	335478.19
13	68.95	137.40	500145.67
14	103.42	207.62	625961.20
15	137.90	276.82	711525.13
16	20.68	61.03	211282.93
17	41.37	123.43	324356.95
18	68.95	206.54	463934.41
19	103.42	310.73	540514.48
20	137.90	412.22	598223.59
21	20.68	103.58	224748.39
22	41.37	206.04	320819.94
23	68.95	343.94	444842.83
24	103.42	501.65	522519.16
25	137.90	673.40	672038.86
26	20.68	142.29	229464.41
27	41.37	288.64	378329.11
28	68.95	477.07	500538.67
29	103.42	714.90	583517.07
30	137.90	945.99	700010.89

Table B.21 Resilient modulus test result for 0% RAP1 sample containing OMC tested at -20°C

0% RAP1 Sample containing OMC tested at -20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.30	13644469.00
2	41.37	21.65	29482222.25
3	68.95	35.81	21089386.24
4	103.42	53.06	25501906.61
5	137.90	69.82	25784012.49
6	20.68	21.45	22895185.15
7	41.37	42.11	24337340.79
8	68.95	69.60	24685270.91
9	103.42	105.34	27160399.04
10	137.90	140.20	26243589.41
11	20.68	42.25	29039523.69
12	41.37	83.07	26880740.80
13	68.95	141.63	27354789.82
14	103.42	209.66	26864379.54
15	137.90	275.78	26986644.27
16	20.68	62.36	29404435.60
17	41.37	125.13	27383237.59
18	68.95	209.32	27410520.14
19	103.42	310.59	26389978.89
20	137.90	412.38	26314915.67
21	20.68	103.73	30034313.02
22	41.37	207.46	27752189.82
23	68.95	344.11	26736985.12
24	103.42	517.60	26152095.99
25	137.90	701.20	26078977.09
26	20.68	146.03	29143696.57
27	41.37	290.37	27426736.61
28	68.95	482.60	26839868.68
29	103.42	728.86	25665912.20
30	137.90	950.57	25141359.08

Table B.22 Resilient modulus test result for 20% RAP1 sample containing OMC tested at -20°C

20% RAP1 Sample containing OMC tested at -20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.00	12134937.79
2	41.37	22.04	31479460.98
3	68.95	35.43	30013318.49
4	103.42	51.61	29427926.04
5	137.90	68.80	32013652.97
6	20.68	29.24	31923917.70
7	41.37	41.65	28317670.21
8	68.95	70.09	30327002.35
9	103.42	109.76	31871476.18
10	137.90	142.07	31171258.45
11	20.68	41.80	33309481.17
12	41.37	85.01	31482667.04
13	68.95	142.44	31262393.35
14	103.42	208.09	30216155.34
15	137.90	276.34	29021204.32
16	20.68	62.07	30870964.20
17	41.37	128.45	30937291.77
18	68.95	207.46	30310441.14
19	103.42	310.98	28701901.23
20	137.90	410.12	29421148.49
21	20.68	106.46	33606714.15
22	41.37	207.50	28687656.66
23	68.95	344.12	28195502.01
24	103.42	515.59	28072547.81
25	137.90	691.88	27434224.31
26	20.68	149.72	31439981.60
27	41.37	290.55	28436956.40
28	68.95	480.59	27490561.37
29	103.42	726.14	27463340.87
30	137.90	967.05	26970607.06

Table B.23 Resilient modulus test result for 40% RAP1 sample containing OMC tested at -20°C

40% RAP1 Sample containing OMC tested at -20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.21	10777629.04
2	41.37	21.97	22933326.94
3	68.95	35.89	18595118.26
4	103.42	51.96	26657047.30
5	137.90	67.36	21846230.61
6	20.68	22.06	16679085.97
7	41.37	42.15	21413074.39
8	68.95	69.46	24969658.95
9	103.42	110.43	26094848.82
10	137.90	143.18	25748704.44
11	20.68	42.38	25600936.01
12	41.37	84.81	24031592.79
13	68.95	142.72	25087359.35
14	103.42	208.15	24426152.15
15	137.90	274.97	24622645.83
16	20.68	61.28	23984480.91
17	41.37	131.66	25170710.06
18	68.95	207.44	25095012.53
19	103.42	309.40	24809038.69
20	137.90	411.60	24817753.66
21	20.68	108.63	25132340.74
22	41.37	206.66	23866966.67
23	68.95	342.76	24279624.77
24	103.42	517.30	24126657.70
25	137.90	693.43	24607373.94
26	20.68	153.32	25398071.57
27	41.37	288.95	24202113.92
28	68.95	483.87	24382756.55
29	103.42	727.65	24270813.28
30	137.90	968.27	24129098.44

Table B.24 Resilient modulus test result for 60% RAP1 sample containing OMC tested at -20°C

60% RAP1 Sample containing OMC tested at -20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	11.16	13755398.74
2	41.37	21.99	17295346.25
3	68.95	36.17	23559715.62
4	103.42	53.10	24744614.08
5	137.90	69.44	24504807.54
6	20.68	21.84	17969453.54
7	41.37	42.71	27518064.56
8	68.95	72.57	24612124.43
9	103.42	108.08	24099526.83
10	137.90	146.35	24157787.52
11	20.68	43.53	24042941.56
12	41.37	83.94	25585546.91
13	68.95	144.78	23901288.77
14	103.42	209.06	23543430.20
15	137.90	274.69	23797495.10
16	20.68	63.74	25516426.97
17	41.37	128.91	23481632.49
18	68.95	207.66	22823748.57
19	103.42	311.08	22817825.97
20	137.90	410.23	22381346.49
21	20.68	104.64	24323599.53
22	41.37	205.13	22511464.34
23	68.95	346.14	22374251.78
24	103.42	514.31	21824712.07
25	137.90	689.82	21233645.24
26	20.68	148.24	24167481.55
27	41.37	287.22	22357807.79
28	68.95	480.06	21629128.50
29	103.42	726.34	21277426.94
30	137.90	965.71	20734699.25

Table B.25 Resilient modulus test result for 0% RAP1 sample containing OMC tested after FT conditioning

0% RAP1 Sample containing OMC tested after freeze-thaw conditioning			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.34	149057.75
2	41.37	20.93	205353.44
3	68.95	35.10	286249.63
4	103.42	53.34	410293.20
5	137.90	71.03	546188.86
6	20.68	20.48	126112.00
7	41.37	42.06	193370.35
8	68.95	69.84	283146.99
9	103.42	105.36	422648.60
10	137.90	139.03	547340.28
11	20.68	40.32	134337.45
12	41.37	82.45	219991.01
13	68.95	138.02	332520.34
14	103.42	207.70	468305.68
15	137.90	277.53	564411.70
16	20.68	62.50	153401.45
17	41.37	124.11	246859.88
18	68.95	208.79	357348.36
19	103.42	312.43	468995.16
20	137.90	414.42	556400.00
21	20.68	101.91	168776.76
22	41.37	206.37	280837.24
23	68.95	345.85	376846.73
24	103.42	517.40	474193.81
25	137.90	689.10	551828.77
26	20.68	144.58	172299.98
27	41.37	289.28	279968.50
28	68.95	482.32	388698.82
29	103.42	722.54	490879.12
30	137.90	959.83	576546.48

Table B.26 Resilient modulus test result for 20% RAP1 sample containing OMC tested after FT conditioning

20% RAP1 Sample containing OMC tested after freeze-thaw conditioning			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.37	186365.28
2	41.37	21.11	266434.09
3	68.95	35.24	365098.07
4	103.42	52.52	501083.36
5	137.90	69.86	642122.51
6	20.68	20.95	182345.64
7	41.37	42.38	264600.09
8	68.95	69.56	376826.05
9	103.42	103.85	533468.03
10	137.90	138.16	664054.73
11	20.68	42.11	187034.07
12	41.37	82.88	293578.75
13	68.95	137.37	422552.08
14	103.42	206.39	570561.83
15	137.90	275.99	677265.09
16	20.68	62.61	203491.86
17	41.37	123.80	306561.58
18	68.95	205.94	435989.96
19	103.42	310.96	571713.25
20	137.90	413.73	646824.73
21	20.68	103.65	210834.77
22	41.37	205.48	328045.64
23	68.95	345.18	451165.32
24	103.42	515.47	552132.14
25	137.90	0.26	651692.43
26	20.68	144.74	206187.71
27	41.37	287.75	331941.18
28	68.95	481.85	467967.84
29	103.42	726.02	588260.67
30	137.90	962.29	682746.42

Table B.27 Resilient modulus test result for 40% RAP1 sample containing OMC tested after FT conditioning

40% RAP1 Sample containing OMC tested after freeze-thaw conditioning			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	8.74	638151.13
2	41.37	20.45	572051.09
3	68.95	34.75	706236.85
4	103.42	52.01	982006.45
5	137.90	69.89	1214752.76
6	20.68	20.19	322950.42
7	41.37	41.42	433659.53
8	68.95	68.83	586916.19
9	103.42	103.54	845138.63
10	137.90	137.48	1057841.88
11	20.68	41.38	282485.09
12	41.37	82.72	415864.16
13	68.95	137.27	597058.38
14	103.42	207.44	775611.90
15	137.90	275.25	859500.41
16	20.68	62.09	252520.48
17	41.37	124.01	382224.64
18	68.95	206.47	557999.58
19	103.42	309.05	671218.38
20	137.90	412.48	758430.16
21	20.68	102.75	247370.09
22	41.37	206.73	384761.91
23	68.95	344.17	501641.84
24	103.42	514.83	598575.22
25	137.90	661.37	698756.04
26	20.68	143.20	231477.68
27	41.37	285.22	368586.81
28	68.95	455.00	512887.18
29	103.42	693.88	627029.89
30	137.90	930.51	729913.45

Table B.28 Resilient modulus test result for 60% RAP1 sample containing OMC tested after FT conditioning

60% RAP1 Sample containing OMC tested after freeze-thaw conditioning			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.29	558558.05
2	41.37	20.78	701424.31
3	68.95	34.47	899979.53
4	103.42	51.83	1246441.07
5	137.90	69.35	1542674.30
6	20.68	20.50	399020.27
7	41.37	41.62	545547.65
8	68.95	68.75	750053.04
9	103.42	103.24	971629.84
10	137.90	137.79	1151362.37
11	20.68	40.49	334154.40
12	41.37	81.87	503730.95
13	68.95	135.93	692861.03
14	103.42	206.69	860803.52
15	137.90	274.03	944816.13
16	20.68	61.76	320502.78
17	41.37	122.79	459025.34
18	68.95	204.91	646431.73
19	103.42	306.98	783154.76
20	137.90	410.52	846414.16
21	20.68	102.03	300170.14
22	41.37	201.43	448048.89
23	68.95	339.42	599037.17
24	103.42	505.88	723370.33
25	137.90	680.31	827474.26
26	20.68	142.35	285808.36
27	41.37	284.70	446207.99
28	68.95	477.89	617060.07
29	103.42	714.05	730127.19
30	137.90	953.90	837313.08

Table B.29 Resilient modulus test result for 0% RAP2 sample containing OMC tested at 20°C

0% RAP2 Sample containing OMC tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.29	86170.67
2	41.37	21.04	139791.20
3	68.95	35.01	212392.99
4	103.42	52.58	311036.28
5	137.90	70.11	414181.84
6	20.68	20.91	88659.68
7	41.37	41.60	145582.79
8	68.95	69.47	227023.66
9	103.42	104.74	338387.78
10	137.90	139.58	436617.38
11	20.68	41.98	108268.37
12	41.37	83.47	177009.10
13	68.95	139.88	275369.70
14	103.42	210.19	384982.55
15	137.90	277.18	465630.52
16	20.68	62.27	121830.36
17	41.37	124.82	206256.66
18	68.95	209.45	304941.31
19	103.42	311.99	394200.84
20	137.90	416.42	453130.32
21	20.68	103.55	147540.91
22	41.37	207.81	231422.52
23	68.95	347.08	313490.81
24	103.42	518.39	392111.73
25	137.90	1.63	455943.39
26	20.68	145.06	152849.87
27	41.37	289.47	242819.55
28	68.95	483.57	340311.42
29	103.42	727.35	407728.35
30	137.90	942.86	521154.00

Table B.30 Resilient modulus test result for 20% RAP2 sample containing OMC tested at 20°C

20% RAP2 Sample containing OMC tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.25	131503.70
2	41.37	20.85	179691.16
3	68.95	34.44	270136.58
4	103.42	52.36	376770.89
5	137.90	70.12	488714.17
6	20.68	20.58	123809.15
7	41.37	41.69	188095.87
8	68.95	69.11	284222.57
9	103.42	104.36	401185.23
10	137.90	139.94	509667.33
11	20.68	41.71	134034.08
12	41.37	82.98	214882.00
13	68.95	138.81	326280.59
14	103.42	209.71	443670.72
15	137.90	276.89	526435.38
16	20.68	62.18	142149.21
17	41.37	124.32	232870.42
18	68.95	208.66	348343.81
19	103.42	310.45	454854.01
20	137.90	414.78	525270.17
21	20.68	103.55	163529.85
22	41.37	207.36	266220.36
23	68.95	345.17	375019.62
24	103.42	515.01	462576.14
25	137.90	688.72	540576.53
26	20.68	144.29	172196.56
27	41.37	289.81	284856.89
28	68.95	482.56	400047.59
29	103.42	724.95	490513.70
30	137.90	968.20	584571.97

Table B.31 Resilient modulus test result for 40% RAP2 sample containing OMC tested at 20°C

40% RAP2 Sample containing OMC tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.21	163516.06
2	41.37	20.82	240758.02
3	68.95	34.70	330872.49
4	103.42	52.39	446463.09
5	137.90	69.91	551042.77
6	20.68	20.67	151401.97
7	41.37	41.35	234283.84
8	68.95	68.92	342952.11
9	103.42	104.43	458590.97
10	137.90	138.01	550808.35
11	20.68	41.47	157752.04
12	41.37	82.96	255064.64
13	68.95	137.75	367366.44
14	103.42	208.97	472628.70
15	137.90	275.70	532420.03
16	20.68	61.83	159868.73
17	41.37	123.63	259284.23
18	68.95	208.35	366897.60
19	103.42	308.97	449593.31
20	137.90	411.08	500738.62
21	20.68	102.71	167694.28
22	41.37	206.14	265330.93
23	68.95	341.77	347675.02
24	103.42	512.63	411451.52
25	137.90	650.23	494078.29
26	20.68	143.11	174340.83
27	41.37	252.78	274625.07
28	68.95	447.01	378866.90
29	103.42	680.07	444201.61
30	137.90	918.01	547740.18

Table B.32 Resilient modulus test result for 60% RAP2 sample containing OMC tested at 20°C

60% RAP2 Sample containing OMC tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.30	210855.46
2	41.37	20.80	300859.62
3	68.95	34.59	413657.84
4	103.42	52.04	546044.07
5	137.90	70.09	668853.48
6	20.68	20.91	183138.54
7	41.37	41.50	295633.39
8	68.95	68.95	419242.59
9	103.42	103.87	555027.94
10	137.90	137.45	650672.01
11	20.68	41.40	183028.22
12	41.37	82.12	304562.10
13	68.95	135.92	436017.54
14	103.42	206.10	548843.34
15	137.90	274.17	617873.65
16	20.68	61.49	188778.45
17	41.37	122.42	313035.76
18	68.95	206.23	438347.97
19	103.42	303.51	536205.25
20	137.90	408.21	598816.54
21	20.68	102.26	201354.48
22	41.37	202.82	328059.43
23	68.95	340.85	439382.18
24	103.42	477.72	528614.12
25	137.90	645.97	613791.95
26	20.68	140.78	208614.66
27	41.37	285.84	345427.33
28	68.95	443.25	472828.65
29	103.42	677.35	553738.62
30	137.90	907.89	1555298.60

Table B.33 Resilient modulus test result for 80% RAP2 sample containing OMC tested at 20°C

80% RAP2 Sample containing OMC tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.06	584241.02
2	41.37	20.77	925786.60
3	68.95	34.58	1295056.00
4	103.42	51.83	1726743.63
5	137.90	69.84	2025286.61
6	20.68	20.74	553614.51
7	41.37	41.29	712076.71
8	68.95	68.74	809830.58
9	103.42	104.07	1001160.08
10	137.90	139.68	1097631.52
11	20.68	41.09	371972.14
12	41.37	82.33	527869.49
13	68.95	138.48	691240.76
14	103.42	208.28	811140.58
15	137.90	277.15	873717.40
16	20.68	61.67	340442.42
17	41.37	123.11	482171.04
18	68.95	206.50	637730.55
19	103.42	310.08	742006.85
20	137.90	411.95	813484.80
21	20.68	102.24	304796.52
22	41.37	205.68	470732.64
23	68.95	344.61	614205.64
24	103.42	513.47	685876.64
25	137.90	684.20	774563.90
26	20.68	143.61	293723.54
27	41.37	289.05	455577.96
28	68.95	480.69	602263.92
29	103.42	722.58	690123.81
30	137.90	953.14	789463.47

Table B.34 Resilient modulus test result for 0% RAP2 sample containing OMC+2% tested at 20°C

0% RAP2 Sample containing OMC+2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.01	107751.26
2	41.37	20.74	126608.42
3	68.95	34.65	190964.08
4	103.42	52.30	293840.75
5	137.90	69.91	418311.80
6	20.68	20.73	101235.72
7	41.37	41.52	143907.37
8	68.95	69.01	220101.33
9	103.42	104.75	333478.71
10	137.90	139.61	451227.37
11	20.68	41.09	117976.19
12	41.37	82.51	179001.68
13	68.95	138.78	273204.75
14	103.42	210.03	393938.84
15	137.90	277.17	482860.52
16	20.68	62.04	136433.45
17	41.37	123.34	209407.56
18	68.95	207.69	297701.82
19	103.42	310.07	383734.60
20	137.90	411.89	461762.56
21	20.68	103.09	141728.62
22	41.37	206.70	213116.94
23	68.95	343.33	275121.49
24	103.42	512.52	361547.27
25	137.90	665.13	456494.97
26	20.68	142.96	143148.94
27	41.37	289.43	229884.99
28	68.95	453.49	311263.80
29	103.42	723.95	382085.78
30	137.90	965.27	408382.24

Table B.35 Resilient modulus test result for 20% RAP2 sample containing OMC+2% tested at 20°C

20% RAP2 Sample containing OMC+2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.18	129090.54
2	41.37	20.85	185641.33
3	68.95	35.01	261918.03
4	103.42	52.81	357548.31
5	137.90	70.15	440499.13
6	20.68	20.58	120154.93
7	41.37	41.62	184745.01
8	68.95	69.35	266909.83
9	103.42	104.63	369214.24
10	137.90	139.41	456074.39
11	20.68	41.74	129497.33
12	41.37	82.93	201547.54
13	68.95	138.40	299859.88
14	103.42	208.45	410403.52
15	137.90	275.65	477579.13
16	20.68	62.49	139742.93
17	41.37	123.87	228099.25
18	68.95	207.98	333078.82
19	103.42	309.93	420387.12
20	137.90	413.23	473035.49
21	20.68	103.30	150760.76
22	41.37	205.97	244577.72
23	68.95	344.21	336057.35
24	103.42	515.08	398317.01
25	137.90	687.19	463141.51
26	20.68	143.47	146789.38
27	41.37	288.71	245736.03
28	68.95	481.25	342193.68
29	103.42	710.83	401212.80
30	137.90	956.71	507785.06

Table B.36 Resilient modulus test result for 40% RAP2 sample containing OMC+2% tested at 20°C

40% RAP2 Sample containing OMC+2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.27	141039.15
2	41.37	20.90	231677.62
3	68.95	34.90	332361.76
4	103.42	52.54	443388.03
5	137.90	70.24	538390.89
6	20.68	20.90	143438.52
7	41.37	41.64	237503.69
8	68.95	68.94	340849.21
9	103.42	104.67	460225.03
10	137.90	138.54	550698.03
11	20.68	41.27	149595.54
12	41.37	82.77	253534.00
13	68.95	137.90	369862.34
14	103.42	204.86	475159.07
15	137.90	275.52	549043.29
16	20.68	61.62	162647.32
17	41.37	123.64	268019.89
18	68.95	207.48	383086.49
19	103.42	309.02	474593.70
20	137.90	409.89	535060.72
21	20.68	102.57	197121.10
22	41.37	205.79	303645.10
23	68.95	342.17	396813.95
24	103.42	513.97	475317.65
25	137.90	682.11	558509.79
26	20.68	143.62	195397.41
27	41.37	288.46	316951.98
28	68.95	478.78	427957.57
29	103.42	682.74	521643.53
30	137.90	911.58	594907.21

Table B.37 Resilient modulus test result for 60% RAP2 sample containing OMC+2% tested at 20°C

60% RAP2 Sample containing OMC+2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.26	179863.53
2	41.37	20.48	284670.73
3	68.95	34.63	398323.90
4	103.42	52.51	539349.26
5	137.90	69.75	656732.50
6	20.68	20.70	166577.33
7	41.37	41.73	280306.35
8	68.95	68.85	411092.99
9	103.42	103.98	550318.82
10	137.90	137.69	661014.14
11	20.68	41.41	178691.42
12	41.37	82.32	299432.40
13	68.95	134.81	436072.70
14	103.42	205.84	556427.57
15	137.90	272.78	633448.90
16	20.68	61.26	189957.45
17	41.37	122.70	313828.65
18	68.95	204.55	445518.51
19	103.42	308.43	553897.20
20	137.90	408.12	622162.19
21	20.68	102.47	204732.91
22	41.37	202.10	330989.70
23	68.95	342.34	453219.96
24	103.42	511.44	533840.35
25	137.90	683.53	606249.09
26	20.68	143.80	209352.40
27	41.37	287.47	342214.37
28	68.95	478.51	465396.10
29	103.42	716.95	549567.29
30	137.90	933.58	635089.86

Table B.38 Resilient modulus test result for 80% RAP2 sample containing OMC+2% tested at 20°C

80% RAP2 Sample containing OMC+2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.31	260166.76
2	41.37	20.80	411913.47
3	68.95	34.80	538921.79
4	103.42	52.23	678906.04
5	137.90	69.73	796089.33
6	20.68	20.67	252003.37
7	41.37	41.03	396669.16
8	68.95	68.32	540500.69
9	103.42	104.13	675065.66
10	137.90	135.41	766200.56
11	20.68	41.13	254513.06
12	41.37	82.22	402743.44
13	68.95	136.03	539438.89
14	103.42	205.65	648451.90
15	137.90	272.74	717116.78
16	20.68	61.50	262111.08
17	41.37	122.59	400302.70
18	68.95	204.77	531282.40
19	103.42	304.53	631690.74
20	137.90	409.40	695563.77
21	20.68	101.98	274680.22
22	41.37	201.89	410899.94
23	68.95	340.07	528483.12
24	103.42	509.17	597934.01
25	137.90	679.06	677989.03
26	20.68	143.20	266027.30
27	41.37	284.15	410189.78
28	68.95	474.78	539687.10
29	103.42	679.50	624816.67
30	137.90	906.84	756444.47

Table B.39 Resilient modulus test result for 0% RAP2 sample containing OMC-4% tested at 20°C

0% RAP2 Sample containing OMC-4% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.33	198824.11
2	41.37	20.97	282140.35
3	68.95	34.83	373495.88
4	103.42	53.15	499931.94
5	137.90	70.46	628946.63
6	20.68	20.78	199051.63
7	41.37	41.79	278899.82
8	68.95	70.42	386947.55
9	103.42	105.37	518954.57
10	137.90	139.56	658332.08
11	20.68	41.76	205429.28
12	41.37	83.94	310091.70
13	68.95	139.15	443036.40
14	103.42	209.25	597072.17
15	137.90	277.22	723715.06
16	20.68	63.10	215730.05
17	41.37	124.41	334312.98
18	68.95	207.92	483763.73
19	103.42	312.08	634510.70
20	137.90	415.86	744654.44
21	20.68	104.81	245977.35
22	41.37	206.83	382541.80
23	68.95	345.58	541383.21
24	103.42	516.33	669474.01
25	137.90	686.32	758423.27
26	20.68	144.53	242467.92
27	41.37	291.00	384024.18
28	68.95	483.06	541976.16
29	103.42	717.69	675796.50
30	137.90	936.72	752976.41

Table B.40 Resilient modulus test result for 20% RAP2 sample containing OMC-4% tested at 20°C

20% RAP2 Sample containing OMC-4% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.36	515114.19
2	41.37	20.72	509150.23
3	68.95	34.76	632221.64
4	103.42	52.70	801867.13
5	137.90	70.16	974194.69
6	20.68	20.89	336905.41
7	41.37	41.68	442236.61
8	68.95	69.21	586212.92
9	103.42	104.01	778914.49
10	137.90	138.28	949504.57
11	20.68	41.10	301783.51
12	41.37	82.60	430791.31
13	68.95	138.05	596741.22
14	103.42	207.87	776011.80
15	137.90	276.67	896807.94
16	20.68	62.51	288242.21
17	41.37	123.65	416429.53
18	68.95	206.53	579104.43
19	103.42	308.78	735525.78
20	137.90	411.12	833534.75
21	20.68	103.35	270391.69
22	41.37	205.60	412561.57
23	68.95	340.96	568810.56
24	103.42	492.40	686062.80
25	137.90	685.86	749529.03
26	20.68	143.52	256953.80
27	41.37	289.28	389608.93
28	68.95	481.30	533771.40
29	103.42	722.22	653195.49
30	137.90	956.90	737159.84

Table B.41 Resilient modulus test result for 40% RAP2 sample containing OMC-4% tested at 20°C

40% RAP2 Sample containing OMC-4% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.34	297239.87
2	41.37	20.62	387078.55
3	68.95	34.75	496408.71
4	103.42	52.66	654022.86
5	137.90	70.24	820510.56
6	20.68	20.66	253775.32
7	41.37	41.47	358699.73
8	68.95	69.51	490065.54
9	103.42	104.61	649548.16
10	137.90	139.25	810106.37
11	20.68	41.51	241819.81
12	41.37	82.95	360126.95
13	68.95	138.41	519085.57
14	103.42	206.66	679126.67
15	137.90	275.76	786519.40
16	20.68	62.14	247059.83
17	41.37	123.77	374985.15
18	68.95	207.03	522512.26
19	103.42	310.64	655905.13
20	137.90	409.29	736966.79
21	20.68	103.25	244488.08
22	41.37	205.77	382645.22
23	68.95	344.15	522298.53
24	103.42	513.66	632793.90
25	137.90	684.24	715427.57
26	20.68	144.16	241957.71
27	41.37	288.27	378025.74
28	68.95	479.98	531709.87
29	103.42	717.46	636241.28
30	137.90	959.18	705319.85

Table B.42 Resilient modulus test result for 60% RAP2 sample containing OMC-4% tested at 20°C

60% RAP2 Sample containing OMC-4% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.10	566087.13
2	41.37	20.93	696522.14
3	68.95	35.31	1233520.29
4	103.42	52.68	1687409.04
5	137.90	71.08	1609401.76
6	20.68	20.96	469946.64
7	41.37	42.05	801639.61
8	68.95	69.98	985343.51
9	103.42	104.31	1163435.09
10	137.90	137.67	1253970.14
11	20.68	41.42	445470.25
12	41.37	83.43	708381.12
13	68.95	136.73	929385.66
14	103.42	207.49	1017879.87
15	137.90	276.23	1108097.77
16	20.68	62.36	543086.22
17	41.37	123.49	711132.13
18	68.95	206.91	869208.23
19	103.42	310.82	975615.01
20	137.90	415.13	1064247.11
21	20.68	104.41	547257.55
22	41.37	205.79	769123.93
23	68.95	345.96	863395.95
24	103.42	515.74	882542.69
25	137.90	688.69	916078.78
26	20.68	142.71	422055.65
27	41.37	287.17	554565.99
28	68.95	479.43	715868.83
29	103.42	688.74	824171.67
30	137.90	916.64	876509.77

Table B.43 Resilient modulus test result for 80% RAP2 sample containing OMC-4% tested at 20°C

80% RAP2 Sample containing OMC-4% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.31	1380075.25
2	41.37	20.74	3729856.69
3	68.95	34.36	5751737.29
4	103.42	52.08	906129.65
5	137.90	69.62	5225798.33
6	20.68	20.67	1328716.20
7	41.37	41.35	2245318.99
8	68.95	68.72	2823906.31
9	103.42	103.77	3402169.58
10	137.90	138.64	3003163.10
11	20.68	40.73	1070266.23
12	41.37	81.14	1195592.23
13	68.95	136.14	1245634.38
14	103.42	206.75	1320732.07
15	137.90	274.42	1353744.17
16	20.68	61.47	687572.75
17	41.37	122.72	801798.19
18	68.95	205.08	927041.45
19	103.42	307.11	1069349.23
20	137.90	408.92	1050981.60
21	20.68	102.31	488307.38
22	41.37	204.62	623127.45
23	68.95	339.78	792621.26
24	103.42	507.76	873558.82
25	137.90	684.67	898959.10
26	20.68	142.32	402536.60
27	41.37	289.12	556262.10
28	68.95	479.46	722529.17
29	103.42	715.99	819972.77
30	137.90	953.32	876082.30

Table B.44 Resilient modulus test result for 0% RAP2 sample containing OMC-2% tested at 20°C

0% RAP2 Sample containing OMC-2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.07	138026.14
2	41.37	20.08	188123.44
3	68.95	34.51	267357.99
4	103.42	52.57	361519.69
5	137.90	69.94	405322.08
6	20.68	20.20	145762.06
7	41.37	41.27	220618.43
8	68.95	69.40	314331.97
9	103.42	104.62	412678.79
10	137.90	139.07	436403.64
11	20.68	40.56	142162.99
12	41.37	82.70	228009.61
13	68.95	138.03	329638.33
14	103.42	207.65	438685.81
15	137.90	278.00	464775.57
16	20.68	61.20	143817.74
17	41.37	123.81	226734.08
18	68.95	205.58	335147.24
19	103.42	309.84	449765.68
20	137.90	410.09	460618.03
21	20.68	97.66	143293.73
22	41.37	185.33	227657.98
23	68.95	344.59	377026.00
24	103.42	513.55	424186.13
25	137.90	649.00	481495.36
26	20.68	140.14	152477.55
27	41.37	241.12	233932.21
28	68.95	441.20	382121.22
29	103.42	683.08	477903.19
30	137.90	908.14	471194.59

Table B.45 Resilient modulus test result for 20% RAP2 sample containing OMC-2% tested at 20°C

20% RAP2 Sample containing OMC-2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.88	172568.87
2	41.37	20.82	237469.22
3	68.95	34.78	332892.66
4	103.42	52.58	445428.88
5	137.90	69.15	568114.19
6	20.68	20.51	157462.46
7	41.37	41.45	234642.37
8	68.95	68.98	337953.41
9	103.42	104.57	473221.65
10	137.90	137.89	581814.07
11	20.68	41.71	164591.64
12	41.37	82.77	248555.99
13	68.95	135.60	369538.29
14	103.42	206.24	491161.80
15	137.90	276.91	567638.45
16	20.68	62.18	175623.25
17	41.37	123.35	269012.73
18	68.95	207.03	384355.12
19	103.42	311.49	483212.15
20	137.90	411.47	546181.97
21	20.68	100.19	183607.38
22	41.37	204.25	287607.89
23	68.95	344.14	397337.95
24	103.42	510.91	485149.58
25	137.90	684.22	573133.57
26	20.68	143.92	192618.83
27	41.37	288.83	316883.03
28	68.95	478.15	421917.76
29	103.42	720.74	519244.15
30	137.90	949.81	601981.23

Table B.46 Resilient modulus test result for 40% RAP2 sample containing OMC-2% tested at 20°C

40% RAP2 Sample containing OMC-2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	8.96	161482.10
2	41.37	19.57	230450.36
3	68.95	34.56	340221.78
4	103.42	52.68	464037.83
5	137.90	70.14	589225.93
6	20.68	19.75	140811.62
7	41.37	41.30	241992.18
8	68.95	69.29	355514.36
9	103.42	103.46	491223.86
10	137.90	137.92	607779.72
11	20.68	41.22	179118.89
12	41.37	82.87	276100.54
13	68.95	136.16	411906.57
14	103.42	207.04	523925.69
15	137.90	274.47	599119.91
16	20.68	61.85	167239.23
17	41.37	123.08	275879.91
18	68.95	207.29	406308.03
19	103.42	308.09	511832.29
20	137.90	411.31	586550.77
21	20.68	102.69	186641.07
22	41.37	203.30	302617.78
23	68.95	341.65	420690.49
24	103.42	512.80	507902.27
25	137.90	669.91	599423.28
26	20.68	142.54	202767.91
27	41.37	287.06	324584.48
28	68.95	479.87	445173.78
29	103.42	709.61	541162.58
30	137.90	913.13	639426.66

Table B.47 Resilient modulus test result for 60% RAP2 sample containing OMC-2% tested at 20°C

60% RAP2 Sample containing OMC-2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.08	299618.56
2	41.37	20.92	396634.69
3	68.95	34.96	537142.94
4	103.42	51.71	75063.22
5	137.90	69.73	829060.06
6	20.68	20.63	249259.26
7	41.37	41.93	372261.72
8	68.95	69.21	518051.36
9	103.42	104.49	659531.77
10	137.90	138.48	777321.80
11	20.68	42.46	248618.04
12	41.37	83.01	378522.16
13	68.95	137.82	521850.37
14	103.42	208.68	647907.21
15	137.90	275.75	734201.99
16	20.68	62.83	234442.42
17	41.37	123.25	369655.50
18	68.95	207.91	506088.95
19	103.42	308.51	620872.87
20	137.90	412.18	704044.32
21	20.68	103.08	276810.70
22	41.37	205.06	395193.68
23	68.95	342.60	522698.42
24	103.42	513.84	609820.57
25	137.90	687.30	692743.81
26	20.68	142.14	225313.76
27	41.37	288.33	371937.67
28	68.95	481.68	520154.26
29	103.42	718.20	613171.42
30	137.90	944.02	694881.19

Table B.48 Resilient modulus test result for 80% RAP2 sample containing OMC-2% tested at 20°C

80% RAP2 Sample containing OMC-2% tested at 20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.19	367980.08
2	41.37	20.60	476179.50
3	68.95	34.25	654919.18
4	103.42	51.81	916533.84
5	137.90	69.50	1091750.30
6	20.68	20.49	323281.37
7	41.37	41.20	544823.70
8	68.95	68.54	710125.50
9	103.42	103.44	853501.97
10	137.90	139.08	987791.15
11	20.68	40.86	340421.73
12	41.37	82.12	508178.06
13	68.95	137.46	662758.52
14	103.42	206.87	767351.98
15	137.90	275.80	839112.61
16	20.68	61.54	316641.72
17	41.37	123.29	480792.09
18	68.95	205.91	613185.21
19	103.42	307.82	724680.33
20	137.90	412.06	792352.37
21	20.68	102.48	332265.23
22	41.37	203.68	469981.11
23	68.95	342.86	590377.36
24	103.42	512.59	670825.38
25	137.90	685.28	761243.23
26	20.68	142.67	298411.98
27	41.37	287.17	443856.88
28	68.95	479.37	591101.31
29	103.42	715.26	683615.16
30	137.90	943.93	770082.30

Table B.49 Resilient modulus test result for 0% RAP2 sample containing OMC tested at 40°C

0% RAP2 Sample containing OMC tested at 40°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.34	333837.24
2	41.37	20.68	370145.03
3	68.95	34.47	413733.68
4	103.42	51.71	492423.54
5	137.90	68.95	677216.82
6	20.68	20.68	194073.62
7	41.37	41.37	249376.47
8	68.95	68.95	347619.86
9	103.42	103.42	485073.73
10	137.90	137.90	634910.59
11	20.68	41.37	169052.55
12	41.37	82.74	262228.29
13	68.95	137.90	386864.82
14	103.42	206.84	528717.55
15	137.90	275.79	639805.87
16	20.68	62.05	178925.84
17	41.37	124.11	284112.25
18	68.95	206.84	415671.11
19	103.42	310.26	537053.31
20	137.90	413.69	638578.60
21	20.68	103.42	196045.52
22	41.37	206.84	323177.94
23	68.95	344.74	447000.89
24	103.42	517.11	554186.78
25	137.90	689.48	629746.42
26	20.68	144.79	196328.21
27	41.37	289.58	323646.79
28	68.95	482.63	449710.53
29	103.42	723.95	560316.22
30	137.90	965.27	617232.44

Table B.50 Resilient modulus test result for 0% RAP2 sample containing OMC tested at 40°C

20% RAP2 Sample containing OMC tested at 40°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.96	145996.48
2	41.37	20.89	228354.35
3	68.95	34.83	314656.03
4	103.42	52.80	427895.51
5	137.90	70.22	546354.33
6	20.68	20.35	141576.94
7	41.37	41.87	219570.43
8	68.95	69.46	314531.92
9	103.42	104.33	429122.78
10	137.90	139.04	547064.49
11	20.68	40.89	139260.30
12	41.37	83.15	221459.59
13	68.95	137.12	335092.08
14	103.42	208.86	454998.80
15	137.90	275.60	524732.38
16	20.68	63.29	146423.95
17	41.37	123.93	233063.47
18	68.95	209.17	343289.95
19	103.42	308.90	431094.68
20	137.90	413.37	500642.10
21	20.68	105.77	156214.51
22	41.37	209.01	254664.74
23	68.95	343.88	352170.40
24	103.42	514.18	456915.55
25	137.90	688.61	537122.25
26	20.68	145.20	176974.62
27	41.37	290.49	287118.37
28	68.95	482.10	401481.70
29	103.42	33.50	504330.79
30	137.90	244.05	589729.25

Table B.51 Resilient modulus test result for 40% RAP2 sample containing OMC tested at 40°C

40% RAP2 Sample containing OMC tested at 40°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.50	222569.65
2	41.37	20.77	315600.61
3	68.95	34.45	419435.65
4	103.42	51.79	494119.66
5	137.90	69.53	567638.45
6	20.68	20.66	221845.70
7	41.37	41.75	284753.46
8	68.95	69.12	404129.29
9	103.42	103.09	570292.93
10	137.90	137.54	752776.46
11	20.68	41.72	172224.14
12	41.37	82.82	269247.16
13	68.95	136.15	425130.72
14	103.42	207.79	553090.51
15	137.90	274.09	639840.34
16	20.68	62.00	169204.23
17	41.37	123.70	278672.29
18	68.95	207.59	424268.87
19	103.42	308.46	518285.78
20	137.90	411.40	594907.21
21	20.68	102.91	186537.65
22	41.37	206.54	311525.81
23	68.95	341.36	411410.15
24	103.42	515.08	510053.44
25	137.90	688.66	609234.52
26	20.68	144.46	207649.40
27	41.37	286.06	323364.10
28	68.95	478.77	448510.84
29	103.42	33.79	543065.54
30	137.90	270.07	633442.01

Table B.52 Resilient modulus test result for 60% RAP2 sample containing OMC tested at 40°C

60% RAP2 Sample containing OMC tested at 40°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.29	302624.67
2	41.37	20.66	503572.37
3	68.95	34.52	738718.05
4	103.42	52.20	1011123.01
5	137.90	69.71	1247137.44
6	20.68	20.47	272149.85
7	41.37	41.52	338477.41
8	68.95	68.98	445159.99
9	103.42	103.99	606042.25
10	137.90	137.93	762608.39
11	20.68	41.00	187199.55
12	41.37	82.45	288421.47
13	68.95	137.58	425585.77
14	103.42	208.43	546416.39
15	137.90	274.66	605456.19
16	20.68	61.59	177898.52
17	41.37	123.24	282154.14
18	68.95	206.55	408576.41
19	103.42	307.74	498546.09
20	137.90	410.20	567472.97
21	20.68	102.66	182966.17
22	41.37	206.64	297674.24
23	68.95	341.90	393849.20
24	103.42	513.36	482308.94
25	137.90	683.70	588543.35
26	20.68	143.78	275107.70
27	41.37	285.35	304975.79
28	68.95	477.94	439127.07
29	103.42	33.22	531833.98
30	137.90	269.83	683380.73

Table B.53 Resilient modulus test result for 80% RAP2 sample containing OMC tested at 40°C

80% RAP2 Sample containing OMC tested at 40°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.36	4014437.79
2	41.37	20.20	2970447.47
3	68.95	34.52	1905669.47
4	103.42	51.73	2400561.33
5	137.90	69.40	2646414.58
6	20.68	20.79	839953.77
7	41.37	41.35	955909.79
8	68.95	68.49	1287244.24
9	103.42	103.49	1661774.33
10	137.90	139.20	1912447.01
11	20.68	41.20	483722.36
12	41.37	82.29	500393.88
13	68.95	138.35	642984.35
14	103.42	207.43	797640.65
15	137.90	275.96	918450.58
16	20.68	61.24	330831.13
17	41.37	123.31	431267.05
18	68.95	206.44	626450.73
19	103.42	308.78	776701.27
20	137.90	411.80	902082.43
21	20.68	102.81	311684.38
22	41.37	204.80	473001.01
23	68.95	343.07	584427.18
24	103.42	515.75	684876.90
25	137.90	684.22	783568.45
26	20.68	143.61	286904.63
27	41.37	288.46	449386.47
28	68.95	478.99	591080.62
29	103.42	33.08	706360.96
30	137.90	269.76	814484.54

Table B.54 Resilient modulus test result for 0% RAP2 sample containing OMC tested at 60°C

0% RAP2 Sample containing OMC tested at 60°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.49	171962.13
2	41.37	21.22	213144.52
3	68.95	35.18	294785.34
4	103.42	52.97	396517.48
5	137.90	70.44	513997.24
6	20.68	21.06	147830.48
7	41.37	42.19	210290.09
8	68.95	69.64	304941.31
9	103.42	104.92	422214.23
10	137.90	140.39	544906.44
11	20.68	42.34	151381.28
12	41.37	83.82	228699.09
13	68.95	139.09	338394.67
14	103.42	210.13	454888.49
15	137.90	277.06	535495.09
16	20.68	62.88	152643.03
17	41.37	125.08	255423.17
18	68.95	210.39	364856.75
19	103.42	312.12	466120.05
20	137.90	415.93	529455.28
21	20.68	104.15	183207.48
22	41.37	209.24	273976.96
23	68.95	346.39	367924.92
24	103.42	519.41	460831.77
25	137.90	0.41	535150.35
26	20.68	145.67	178608.68
27	41.37	290.72	277403.65
28	68.95	483.96	392794.31
29	103.42	716.19	499249.35
30	137.90	926.35	591942.47

Table B.55 Resilient modulus test result for 0% RAP2 sample containing OMC tested at 60°C

20% RAP2 Sample containing OMC tested at 60°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.16	128166.64
2	41.37	20.97	177808.89
3	68.95	34.98	253864.95
4	103.42	52.72	355797.04
5	137.90	70.13	451461.79
6	20.68	20.84	115432.02
7	41.37	41.94	179898.00
8	68.95	69.18	260077.13
9	103.42	104.35	365966.81
10	137.90	139.03	470187.95
11	20.68	42.40	128525.17
12	41.37	83.12	197093.52
13	68.95	138.03	291551.69
14	103.42	208.29	396221.00
15	137.90	275.18	477268.87
16	20.68	63.71	141356.31
17	41.37	123.60	220921.80
18	68.95	208.25	316938.19
19	103.42	309.24	404391.29
20	137.90	412.71	465430.57
21	20.68	104.21	143266.16
22	41.37	206.99	231643.15
23	68.95	343.28	318916.99
24	103.42	513.06	409169.35
25	137.90	684.93	497794.56
26	20.68	144.68	152125.92
27	41.37	287.50	252106.79
28	68.95	479.91	355204.09
29	103.42	720.87	443181.19
30	137.90	918.56	667543.48

Table B.56 Resilient modulus test result for 20% RAP2 sample containing OMC tested at 60°C

40% RAP2 Sample containing OMC tested at 60°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.06	160434.10
2	41.37	20.32	203622.86
3	68.95	34.32	282760.88
4	103.42	51.92	380514.74
5	137.90	69.66	478110.03
6	20.68	20.21	139129.30
7	41.37	41.22	199672.16
8	68.95	68.58	279203.18
9	103.42	104.14	386306.34
10	137.90	138.28	478606.45
11	20.68	40.96	134130.60
12	41.37	82.64	210958.88
13	68.95	136.82	304410.42
14	103.42	206.94	398013.64
15	137.90	274.65	461031.72
16	20.68	61.56	140370.36
17	41.37	123.40	219956.54
18	68.95	207.22	316186.66
19	103.42	307.94	394097.42
20	137.90	405.67	462031.46
21	20.68	102.24	153911.66
22	41.37	205.03	244501.87
23	68.95	342.21	327273.43
24	103.42	511.71	429570.94
25	137.90	684.90	509846.60
26	20.68	143.56	166136.06
27	41.37	288.18	267426.94
28	68.95	478.46	357727.57
29	103.42	672.40	385706.50
30	137.90	965.27	546637.02

Table B.57 Resilient modulus test result for 60% RAP2 sample containing OMC tested at 60°C

60% RAP2 Sample containing OMC tested at 60°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	9.98	130641.86
2	41.37	20.31	173079.08
3	68.95	34.12	247432.14
4	103.42	51.37	422379.71
5	137.90	69.33	504075.68
6	20.68	20.35	138791.46
7	41.37	40.44	167328.86
8	68.95	67.09	313863.13
9	103.42	103.13	402267.70
10	137.90	137.70	483549.99
11	20.68	40.34	155800.82
12	41.37	81.53	231539.73
13	68.95	137.69	316510.71
14	103.42	206.28	413133.84
15	137.90	274.19	511756.44
16	20.68	60.88	159310.26
17	41.37	122.43	240109.91
18	68.95	206.60	340297.63
19	103.42	308.02	496925.82
20	137.90	410.85	515396.88
21	20.68	102.39	182924.80
22	41.37	206.22	279327.29
23	68.95	341.69	371999.72
24	103.42	515.34	529703.50
25	137.90	0.78	555682.94
26	20.68	142.96	195080.25
27	41.37	287.88	317489.77
28	68.95	480.87	425268.61
29	103.42	721.38	719095.58
30	137.90	949.88	710787.39

Table B.58 Resilient modulus test result for 80% RAP2 sample containing OMC tested at 60°C

80% RAP2 Sample containing OMC tested at 60°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.11	293061.65
2	41.37	20.32	352618.56
3	68.95	34.63	722411.95
4	103.42	51.52	817070.07
5	137.90	69.45	908522.13
6	20.68	20.57	301369.83
7	41.37	41.22	412851.15
8	68.95	68.50	530758.39
9	103.42	103.66	618811.34
10	137.90	138.31	696901.35
11	20.68	41.19	258539.60
12	41.37	82.04	348578.23
13	68.95	137.15	427164.67
14	103.42	207.65	523298.27
15	137.90	274.43	601719.23
16	20.68	61.52	219984.12
17	41.37	122.59	304920.63
18	68.95	206.31	408279.93
19	103.42	307.59	488438.38
20	137.90	410.33	558613.21
21	20.68	101.84	214957.84
22	41.37	203.48	314456.08
23	68.95	340.22	409403.78
24	103.42	512.03	489410.54
25	137.90	649.95	587957.30
26	20.68	139.29	224644.97
27	41.37	255.85	329086.75
28	68.95	447.21	441691.92
29	103.42	682.26	553573.14
30	137.90	912.79	650396.22

Table B.59 Resilient modulus test result for 0% RAP2 sample containing OMC tested after FT conditioning

0% RAP2 Sample containing OMC tested after freeze-thaw conditioning			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.37	183428.12
2	41.37	20.75	255602.43
3	68.95	40.95	325832.43
4	103.42	52.63	481674.62
5	137.90	70.33	635427.70
6	20.68	20.46	170934.82
7	41.37	41.22	247714.83
8	68.95	69.28	355493.67
9	103.42	104.17	494471.29
10	137.90	138.50	638082.18
11	20.68	41.07	171644.98
12	41.37	82.73	268364.63
13	68.95	137.45	392104.83
14	103.42	207.03	541162.58
15	137.90	276.65	646011.15
16	20.68	62.02	182738.64
17	41.37	123.89	289538.43
18	68.95	206.30	420166.49
19	103.42	310.97	544927.12
20	137.90	412.22	635248.44
21	20.68	103.09	189516.19
22	41.37	205.95	307478.58
23	68.95	344.58	432928.69
24	103.42	517.18	545913.07
25	137.90	685.14	636427.44
26	20.68	144.98	196507.47
27	41.37	287.74	321647.31
28	68.95	483.26	457825.65
29	103.42	725.18	574712.47
30	137.90	933.19	690985.65

Table B.60 Resilient modulus test result for 20% RAP2 sample containing OMC tested after FT conditioning

20% RAP2 Sample containing OMC tested after freeze-thaw conditioning			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.40	230691.67
2	41.37	20.86	285525.68
3	68.95	34.76	370724.19
4	103.42	52.37	505116.79
5	137.90	70.70	656311.92
6	20.68	21.02	183517.75
7	41.37	41.78	251989.58
8	68.95	69.46	340056.31
9	103.42	104.55	493905.92
10	137.90	139.87	646086.99
11	20.68	42.17	192115.51
12	41.37	83.47	281147.51
13	68.95	138.91	412561.57
14	103.42	209.37	567059.29
15	137.90	277.70	691164.92
16	20.68	63.11	181401.06
17	41.37	124.72	291172.48
18	68.95	208.86	426330.40
19	103.42	312.45	563777.39
20	137.90	415.03	665171.68
21	20.68	104.41	193301.41
22	41.37	205.88	315931.56
23	68.95	344.01	450965.37
24	103.42	518.31	566831.76
25	137.90	686.85	645376.83
26	20.68	146.84	191205.40
27	41.37	288.57	319378.93
28	68.95	483.52	454826.44
29	103.42	723.18	564956.39
30	137.90	963.63	633793.64

Table B.61 Resilient modulus test result for 40% RAP2 sample containing OMC tested after FT conditioning

40% RAP2 Sample containing OMC tested after freeze-thaw conditioning			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.44	201657.85
2	41.37	21.08	273521.90
3	68.95	34.94	364036.27
4	103.42	52.34	491010.12
5	137.90	70.22	628105.47
6	20.68	20.66	158117.46
7	41.37	41.80	249948.73
8	68.95	68.98	360154.53
9	103.42	103.32	489817.33
10	137.90	138.35	602477.66
11	20.68	42.09	157683.09
12	41.37	82.52	279361.76
13	68.95	138.12	399247.80
14	103.42	206.93	513100.92
15	137.90	274.81	597823.70
16	20.68	62.31	176319.62
17	41.37	123.96	280664.87
18	68.95	205.97	404287.87
19	103.42	309.23	508288.38
20	137.90	412.40	574229.84
21	20.68	103.17	190902.03
22	41.37	204.91	301121.62
23	68.95	344.23	416753.59
24	103.42	514.76	500883.41
25	137.90	680.28	583916.97
26	20.68	143.38	206635.87
27	41.37	286.13	320744.10
28	68.95	483.09	441947.03
29	103.42	722.16	539949.10
30	137.90	934.33	653512.65

Table B.62 Resilient modulus test result for 60% RAP2 sample containing OMC tested after FT conditioning

60% RAP2 Sample containing OMC tested after freeze-thaw conditioning			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.17	268605.94
2	41.37	20.51	385368.65
3	68.95	34.43	515024.56
4	103.42	52.49	661379.57
5	137.90	70.53	815380.86
6	20.68	20.38	237800.17
7	41.37	41.20	365560.02
8	68.95	69.85	511397.92
9	103.42	104.86	675527.61
10	137.90	138.79	807086.46
11	20.68	40.97	235986.85
12	41.37	83.28	375922.84
13	68.95	138.38	529220.86
14	103.42	206.90	678492.35
15	137.90	275.43	779162.70
16	20.68	61.06	251258.73
17	41.37	124.88	386726.92
18	68.95	207.70	534109.25
19	103.42	309.91	664027.15
20	137.90	412.63	753845.15
21	20.68	103.27	257464.02
22	41.37	207.05	404701.55
23	68.95	343.32	549718.98
24	103.42	515.60	658021.82
25	137.90	684.26	757416.64
26	20.68	144.96	267564.83
27	41.37	287.39	417077.64
28	68.95	481.21	574912.42
29	103.42	718.69	691799.23
30	137.90	929.74	791883.53

Table B.63 Resilient modulus test result for 80% RAP2 sample containing OMC tested after FT conditioning

80% RAP2 Sample containing OMC tested after freeze-thaw conditioning			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.26	436617.38
2	41.37	20.82	587881.46
3	68.95	34.54	742372.28
4	103.42	52.03	979248.55
5	137.90	69.80	1248543.97
6	20.68	20.68	351522.29
7	41.37	41.51	569968.88
8	68.95	69.03	707995.02
9	103.42	104.21	927875.71
10	137.90	138.85	1140420.39
11	20.68	40.53	326880.43
12	41.37	81.81	505558.06
13	68.95	137.23	687165.96
14	103.42	206.24	930054.46
15	137.90	275.40	990011.26
16	20.68	61.74	319227.25
17	41.37	123.09	507357.59
18	68.95	196.52	694281.35
19	103.42	309.55	871786.86
20	137.90	411.09	948173.88
21	20.68	100.50	333485.61
22	41.37	204.83	523725.74
23	68.95	344.40	697432.25
24	103.42	513.32	815732.49
25	137.90	684.37	883397.64
26	20.68	140.87	329362.54
27	41.37	286.95	524222.16
28	68.95	476.81	717413.26
29	103.42	711.80	822806.51
30	137.90	950.60	909714.92

Table B.64 Resilient modulus test result for 0% RAP2 sample containing OMC tested at -20°C

0% RAP2 Sample containing OMC tested at -20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.38	19821654.16
2	41.37	20.44	20008446.92
3	68.95	34.30	29041247.38
4	103.42	53.06	28618329.88
5	137.90	70.35	30186411.36
6	20.68	20.34	21427932.60
7	41.37	41.09	26747920.20
8	68.95	70.14	30108107.60
9	103.42	104.75	30769638.85
10	137.90	137.90	31735552.94
11	20.68	40.89	25945453.22
12	41.37	82.44	30157170.70
13	68.95	138.27	28409556.64
14	103.42	201.58	27038196.37
15	137.90	263.26	25281301.97
16	20.68	61.98	28245054.63
17	41.37	123.10	30040559.67
18	68.95	199.35	26995724.66
19	103.42	296.52	25414184.62
20	137.90	397.39	23916912.29
21	20.68	103.13	28835211.36
22	41.37	197.62	26560830.97
23	68.95	329.33	24792484.38
24	103.42	501.59	22927714.61
25	137.90	672.83	21678081.27
26	20.68	144.08	28106856.12
27	41.37	272.63	25257060.00
28	68.95	465.67	22728966.35
29	103.42	706.73	21342720.29
30	137.90	940.49	20437149.12

Table B.65 Resilient modulus test result for 20% RAP2 sample containing OMC tested at -20°C

20% RAP2 Sample containing OMC tested at -20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.43	12659663.28
2	41.37	21.30	14637879.38
3	68.95	35.96	19098925.05
4	103.42	53.13	17958173.71
5	137.90	69.77	19748431.84
6	20.68	20.34	16209897.76
7	41.37	42.49	18000424.78
8	68.95	69.25	20512543.29
9	103.42	104.57	20820263.19
10	137.90	138.21	20258030.23
11	20.68	42.26	17708480.09
12	41.37	82.50	19292757.35
13	68.95	136.50	19829783.08
14	103.42	202.49	20946464.82
15	137.90	267.07	20711195.03
16	20.68	63.06	19917601.60
17	41.37	122.80	20191875.03
18	68.95	200.42	20030551.51
19	103.42	300.59	20486839.63
20	137.90	403.12	19799639.20
21	20.68	103.19	19436623.35
22	41.37	197.57	20190702.93
23	68.95	333.37	19759029.08
24	103.42	505.46	19568202.89
25	137.90	679.19	19038795.87
26	20.68	142.89	20003806.75
27	41.37	273.77	19788180.12
28	68.95	469.82	19432376.18
29	103.42	713.41	18989029.52
30	137.90	951.04	18219553.95

Table B.66 Resilient modulus test result for 40% RAP2 sample containing OMC tested at -20°C

40% RAP2 Sample containing OMC tested at -20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	12.86	13507525.33
2	41.37	20.51	13709259.03
3	68.95	35.67	15959431.92
4	103.42	53.23	18995289.96
5	137.90	71.00	18571793.30
6	20.68	20.73	13714664.52
7	41.37	41.40	18375168.62
8	68.95	69.46	18113891.80
9	103.42	105.32	19345191.98
10	137.90	139.85	19288523.97
11	20.68	41.35	15967395.37
12	41.37	83.05	18808262.78
13	68.95	138.27	18539456.89
14	103.42	206.06	18625186.30
15	137.90	266.77	18288453.26
16	20.68	62.29	17843679.38
17	41.37	124.21	18036539.52
18	68.95	202.57	18651103.69
19	103.42	299.57	18029169.03
20	137.90	401.15	18033257.62
21	20.68	102.48	17690105.56
22	41.37	198.85	17992295.87
23	68.95	332.48	18062946.44
24	103.42	505.48	17725110.24
25	137.90	678.00	17026154.25
26	20.68	144.19	17822946.85
27	41.37	273.76	17941102.30
28	68.95	469.73	17413281.07
29	103.42	711.65	16862438.25
30	137.90	946.60	16447759.98

Table B.67 Resilient modulus test result for 60% RAP2 sample containing OMC tested at -20°C

60% RAP2 Sample containing OMC tested at -20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.60	22332117.92
2	41.37	21.49	19017608.29
3	68.95	35.74	20484750.52
4	103.42	53.08	25764065.96
5	137.90	70.04	23973042.51
6	20.68	20.97	22736350.63
7	41.37	42.08	21328372.30
8	68.95	69.80	27422248.12
9	103.42	104.59	24734671.84
10	137.90	139.18	24375710.11
11	20.68	41.61	23653332.63
12	41.37	82.83	24533110.52
13	68.95	138.75	23700699.61
14	103.42	207.95	23043787.85
15	137.90	276.82	22276980.55
16	20.68	62.30	23598346.94
17	41.37	124.13	24203747.97
18	68.95	207.44	22254351.96
19	103.42	301.27	22185507.81
20	137.90	402.54	21533050.06
21	20.68	103.17	23725265.63
22	41.37	200.09	22118083.98
23	68.95	345.72	21569702.59
24	103.42	517.31	20970886.05
25	137.90	678.49	20561854.59
26	20.68	143.98	23811615.56
27	41.37	290.27	22186018.02
28	68.95	482.81	21204763.10
29	103.42	711.13	20474787.60
30	137.90	950.59	19542519.93

Table B.68 Resilient modulus test result for 80% RAP2 sample containing OMC tested at -20°C

80% RAP2 Sample containing OMC tested at -20°C			
Sequence	Confining pressure (KPa)	Cyclic stress (KPa)	Resilient Modulus (KPa)
1	20.68	10.50	12800212.90
2	41.37	21.14	13136090.98
3	68.95	35.00	15323838.75
4	103.42	52.10	14621690.49
5	137.90	70.11	15398026.33
6	20.68	21.31	13451932.91
7	41.37	41.95	14888407.27
8	68.95	68.99	15568837.04
9	103.42	105.30	15804361.94
10	137.90	138.42	15361759.91
11	20.68	42.00	15107398.54
12	41.37	82.16	15350686.93
13	68.95	138.10	15188887.67
14	103.42	208.23	16061364.01
15	137.90	266.57	15474075.50
16	20.68	62.33	16102698.08
17	41.37	124.17	15554523.53
18	68.95	207.02	15324362.75
19	103.42	298.78	15136639.20
20	137.90	412.81	14792763.20
21	20.68	103.07	15390910.95
22	41.37	199.26	15229222.00
23	68.95	347.10	14978501.06
24	103.42	515.16	14546654.85
25	137.90	675.30	14351429.80
26	20.68	143.05	15482852.53
27	41.37	290.72	15437085.13
28	68.95	481.82	14548571.59
29	103.42	716.39	14132700.53
30	137.90	949.75	13640504.51