DEVELOPMENT OF SOIL RESILIENT MODULUS TESTING SYSTEM FOR GREEN HIGHWAY

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Abstract: Resilient Modulus (M_r or E) is a fundamental property to characterize subgrade soils, base and subbase of pavement structure. Since it becomes essential for teaching and research activates in civil engineering, a testing system was developed with an Instron machine at the University of Rhode Island (URI). Before preparing the specimens, moisture content, maximum dry density, grain size and specific gravity need to be determined in the laboratory. Using these results, resilient modulus specimens were prepared to duplicate field conditions sometimes with the help of mathematical models. To prepare specimen the base plate of the triaxial cell was attached with a split mold which was covered with membrane inside. A specimen was compacted in the split mold with six equal layers of 50mm (2in.) thickness so that total height of the specimen not greater than 340mm (13.5 in.). After compacting specimen the split mold was removed and assembled into the triaxial chamber. The second step of resilient modulus testing includes computer operation which utilizes two software, i.e., Instron Console (control software for load frame) and Instron Wavematrix (software to control testing sequences). Instron Wavematrix software consists of three phases, i.e. proportional-integral-derivative (PID) setting, conditioning and resilient modulus phase. Air confining pressure was provided throughout the test according to the testing sequence for specific material provided by AASHTO T307-99 procedure. Each testing sequences consists of fifteen cycles with increasing air confining pressure. Load or deviator stress was applied from the top of the triaxial chamber apparatus with increasing amplitude. Displacement was measured by Linear Variable Differential Transducers (LVDTs) attached to the top of triaxial chamber. Finally results obtained from software were used as an input for MATLAB software to arrange and calculate the resilient modulus in a simple Microsoft Excel sheet and to generate different graphs against resilient modulus.

Introduction: Design for pavement structures are mainly based upon the strength of subgrade soils and layer materials. The 1993 AASHTO Guide for Design of Pavement Structures (AASHTO Guide) recommended the use of effective soil resilient modulus and assigning appropriate layer coefficients based on resilient modulus value expected (AASHTO 1993). Resilient modulus is defined as deviator stress over recoverable strain measured during specific incremental loading sequences which attempt to recreate vehicular loading conditions on pavement structures. Resilient modulus testing equipment and procedures have undergone rapid changes over the last few years. Therefore, state department of transportation (DOT) and educational institutions requires an upgrading for the determination of resilient modulus values.

Rhode Island Transportation Research Center (RITRC) at the University of Rhode Island (URI) has done significant research in the area of materials used for pavement structures (Jin et al. 1994 and Lee et al. 1994). Therefore, the URI is in a good position to utilize the above equipment to train future transportation work forces. However, Transportation Research Board (TRB) revised the AASHTO Guide as Mechanistic-Empirical Pavement Design Guide (MEPDG) in 2002, and finally AASHTO provided new AASHTOWare Pavement ME Design recently (TRB 2002; AASHTO 2012). Fortunately, both Guides recommend the use of effective soil resilient modulus and assigning appropriate layer coefficients based on resilient modulus value expected. Thus, there is a need to develop and/or upgrade a testing system at educational institutions.

The states, especially Rhode Island (RI), are having a hard time keeping up with and paying for maintenance and rehabilitation (M&R). This means there will be more wear done to our highways than ever before, and the states will
have to do more M&R with less funding. To meet upcoming highway demand, RIDOT has been testing alternative subbase material strategies such as reclamations and has been expanding their use. Full-depth reclamation (FDR) is a recycling technique in which all of the existing pavement section and all or a predetermined portion of the underlying aggregate are uniformly blended to produce a base course. FDR has been proposed as a viable alternative in road construction, where asphalt and aggregate resources are conserved, and material and transportation costs are reduced because recycling eliminates the need for hauling new materials and disposing of old materials. The mixture of recycled asphalt pavement (RAP) and aggregate produced from full-depth reclamation (Fig. 1) has the potential to have engineering properties that exceed those of a 100% aggregate base material, although little data are available to substantiate the claim.

![Fig 1 Full Depth Reclamation and RAP](image)

Pavements are located on material layers called the base and sub-grade. It has been proven that the mechanical properties of the base layer greatly affect the pavement performance. Therefore, it is important to determine stiffness, strength, and permanent deformation characteristics of the base. By conducting cyclic triaxial or resilient modulus testing that simulates traffic load, the recoverable and permanent axial strain can be measured and used to estimate the performance of the pavement structure. The resilient modulus was found to be dependent on a number of factors: soil type, test method, specimen density, specimen moisture, specimen size, confining pressure, deviator stress, etc. One soil specimen may have many different resilient modulus values depending on the states of stresses. Conducting the resilient modulus test and selecting an appropriate resilient modulus value for pavement designs are very complex processes.

RITRC research team started developing resilient modulus testing set up from early 1990s, and was successful to develop one in accordance with the procedure of AASHTO T 307 for a research project sponsored by New England Transportation Consortium (NETC) in early 2000s (Lee et al. 2001). However, the data acquisition system was too old or did not follow the advanced software. Thus, the testing system needed new software to control servo-hydraulic equipment and data acquisition. This report presents initial effort to develop the testing system and recent updated system. Software updating efforts was carried out through a research project sponsored by RIDOT (Bradshaw et al. 2015).

**Current Status of Knowledge:** Most pavement materials, especially soils, are not pure elastic material, but exhibit elastic-plastic behavior. That means that they act partly elastic under a static load but experience some permanent deformation. However, under repeated loads, they express other important properties. At the beginning, they perform just like they would under a static load. But after certain repetitions, the permanent deformation under each load repetition is almost completely recoverable. By this point, it can be nearly considered elastic, if the repeat load is small enough compared to its strength, otherwise the soil structure would be damaged. Figure 2 illustrates the behavior of granular soils or unbounded material under a sequence of repeating loads. Resilient modulus (Mr) is a measurement of the elastic property of soil recognizing certain nonlinear characteristics. Resilient modulus is defined as the ratio of the axial deviator stress to the recoverable axial strain, and is presented in the following equation:

\[ M_r = \frac{\sigma_d}{\varepsilon_r} \]

Where \( \sigma_d \) = axial deviator stress

\( \varepsilon_r \) = axial recoverable strain

As exhibited in Figure 2, there are two components to the total deformation, a resilient or recoverable portion and a permanent portion.
Only the recoverable portion is included in the measurement of resilient modulus.

Figure 2 Concept of Resilient Modulus of Soils

The MR tests conducted in the laboratory generally follow the procedure of AASHTO T 307 procedure. Cyclic axial stress (Fig. 3), which simulates traffic loading, was applied to a cylindrical specimen at a given confining pressure within a conventional triaxial cell.

Figure 3: Example Cyclic Axial Stress

Experimental to Update the Testing System:

Sample Collection: Reclaimed materials were obtained from Bridge Town Road, Rhode Island (Fig. 4). An in-situ blend (the mixture of RAP and aggregate) was taken during FDR operation.

In addition, pure RAP and pure aggregate materials were sampled at three different locations namely Reclaimed Base (RB-1), (RB-2) and (RB-3) with various blended mixtures and different ratios of RAP and aggregates.

Moisture Content Determination: RAP material obtained from RIDOT of each location was sieved by using ¾ in sieve. Moisture contents were measured for both materials which retained and passed ¾ in sieve after the period of one week.

Gradation Test Procedure: Sieve tests for each material were conducted according to the procedure from the American Society for Testing and Materials (ASTM) Standards C136-01, “Standard Test Method for Sieve Analysis of Fine and Coarse Aggregate. About 65 lbs. of representative material of each sample (containing coarse and fine grained particles) were collected. Then, the representative material of each sample was put into the coarse grained soil sieve shaker (Fig. 5), and masses on each sieves were measured after 10 minute shaking. Sieves used for gradation 37.5mm, 10mm, 4.75mm, 2.38mm, 0.599mm, 0.075mm, and 0.01mm (pan)
Figure 5 Sieves for Course Grained Materials

Gradation curve from the sieve analysis for Reclaimed Base (RB-2) is shown in Fig. 6.

Figure 6 Grain Distribution Curve for RB-2 Material

Modified Proctor Compaction Test: Modified Proctor compaction tests were performed following the procedure of AASHTO T180, “The Moisture-Density Relations of Soils” Using a 4.53 kg (10 lbs.) Rammer and a 457.2 mm (18 in) Drop. Also, ASTM Standard D1557 was referenced which uses a 4-inch-diameter (100 mm) mold and holds 1/30 cubic foot of soil and 5 layers of 25 blows each (Fig. 7). Modified Proctor test was performed only on materials which passed ¾ in. sieve. 2% increment of water was added to the material until it achieves maximum density or optimum moisture content. Moisture content by air dried method of every trail was recorded by collecting sample from top, middle and bottom of the mold.

Figure 7 Modified Proctor

From the Proctor compaction tests, density at different moisture contents were measured, and the maximum dry density and optimum moisture content for each different mixture were estimated. Proctor curve for Reclaimed Base (RB-2) material is shown in Figure 8.

Figure 8 Proctor Curve for Reclaimed Base (RB-2) Material

Specific Gravity: Specific Gravity for coarse particles which retained ¾ in. sieve was performed by using AASHTO T 209 procedure. Apparatus used for this procedure consists of vacuum pump, agitating machine and a container with lid as shown in Figure 9.

Figure 9 Specific Gravity Apparatus
Formula used to calculate specific gravity is as follow

\[ G_s = \frac{A}{(A + D - E)} \]

A= mass of dried Material
D= mass of Container plus water
E= mass of container + water and sample after vacuum and agitate

Sample Calculations for resilient modulus testing: Optimum moisture content and maximum dry density measured from modified proctor test was converted into field conditions by applying following equations:

\[
\rho_{dmax(\text{field})} = \frac{\rho_{dmax(Mr)} P_{f(1\frac{3}{4}^-)}}{100 - \frac{\rho_{dmax(\text{field})} P_{c(1\frac{3}{4}^-)}}{k}}
\]

Where:
\( \rho_{dmax(Mr)} \) = maximum dry density for resilient modulus
\( \rho_{dmax(\text{field})} \) = maximum dry density in field conditions
\( P_{f(1\frac{3}{4}^-)} \) = Percent finer of 1 3/4"- material from grain size
\( P_{c(1\frac{3}{4}+)} \) = Percent finer of 1 3/4"+ material from grain size
\( k = \rho_{\text{water}} \times G_s \)

\[
w_{ct} = w_f P_f + W_c P_c
\]

\( w_{ct} \) = corrected water content to be used in resilient modulus sample
\( w_f \) = optimum water content of 3/4"

\[
w_c = w_{f2} - w_{c1}
\]

\( w_{f2} \) = \( w_f \) = optimum water content of 3/4" - in decimal (Step 11b)
\( w_{c1} \) = water content of coarse particles
\( w_{f1} \) = water content of fine particles
\( P_{f(3/4^-)} \) = Percent finer of 3/4"- material
\( P_{c(3/4+)} \) = Percent coarser of 3/4"+ material

Material which passed 1 1/2 in. sieve was used to prepare resilient modulus sample. After applying the above mentioned equations optimum moisture content (OMC) for Reclaimed Base (RB-2) material under field condition was found to be 6.08% and maximum dry density of 124.46 lbs/ft³. Total density of sample with moisture content was happened to be 132.02 lbs/ft³. Volume of split mold was 0.193 ft³ which gave the total weight of sample required to make specimen that was 25.81 lbs and weight of calculated water in sample was found to be 1.48 lbs. According to AASHTO T 307 procedure sample for resilient modulus has to compact into six equal 2 in. thick layers, so weight per lift became 4.31 lbs.

Sample Preparation for resilient modulus testing: Firstly membrane was attached to the base of triaxial cell using elastics. Split Mold was attached by tightening screws on opposite direction. It should be careful about membrane not caught in split mold while tightening. Membrane was stretched over the top of the split mold and was secured with elastics. Vacuum line was attached with swage lock fittings to perimeter of split mold. Portable vacuum was attached to the line so that membrane expands to the walls of the split mold. A filter paper was placed at the bottom of split mold. The first lift of soil was put into split mold according to calculations of OMC and weight per lift of specimen and was compacted using impact hammer as shown in Figure 10. When finished vacuum was released from split mold and small vacuum was applied to the base of the sample. Membrane should be carefully folded over the top and bottom of the sample. The second membrane was carefully placed on the top of first one.

![Figure 10 Impact Hammer with Split mold](image)
The height and diameter of the sample was measured and recorded. The triaxial apparatus was assembled as shown in Figure 11. Rods were tightened the same amount. Vacuum was removed from the base of the sample and transported to the Instron servo-hydraulic testing machine.

Figure 11 Triaxial cell with specimen

Resilient Modulus Testing Equipment: The resilient modulus (MR) test system consisted of all appropriate sensors and data acquisition system (Figure 12) necessary for conducting the test, generally following the procedure of AASHTO T 307. The specimen was located inside the chamber, which acts as a pressure vessel. The base contained a port for the air supply for confinement. Axial load is applied by a servo-hydraulic load frame which was 22.2 KN capacity and 102 mm stroke. The load frame system is operated by a controlling program named Instron Console. The load cell had a 22.2 KN capacity. Load and displacement data were collected by a Wavematrix Instron where all testing sequences were created.

Resilient Modulus Testing & Computer Operation Procedure: Resilient modulus testing and computer operation procedure consists of three phases as follows:

- Proportional Integral Derivative (PID) Settings
- Conditioning Phase
- Resilient Modulus Testing Phase

Figure 12 Triaxial cell with specimen

Triaxial chamber was placed into the Instron testing machine load frame. Piston of machine was adjusted just above the triaxial chamber but not in contact with the sample. Seating load of -0.050 KN, -0.10KN and -0.20 KN was applied from the load control frame. Confining pressure of 80.18 KN (11.63 psi) was applied on the sample. All drainage valves leading into the specimen to atmospheric pressure were opened. This was done to simulate drained conditions. New and old PID settings were recorded with date and time.

The test was began by applying a minimum of 500 repetitions of a load equivalent to a maximum axial stress of 103.4 kPa (15 psi) and corresponding cyclic stress of 93.1 kPa (13.50 psi) using a have sine shaped load pulse with durations. If the sample is still decreasing in height at the end of the conditioning period, stress cycling shall be continued up to 1000 repetitions prior to testing as outlined in Sequence No. 0, Table 1.
The above stress sequence constitutes sample conditioning, that is, the elimination of the effects of the interval between compaction and loading and the elimination of initial loading versus reloading. This conditioning also aids in minimizing the effects of initially imperfect contact between the sample cap and base plate and the test specimen.

The testing was performed following the loading sequences in Table 1 using a haver sine shaped load pulse as described above. The maximum axial stress was decreased to 21.0 kPa (3 psi) and set the confining pressure was set to 21.0 KPa (3.0 psi) (Sequence No. 1, Table 1). At this confining pressure three loading sequences were performed on the sample with 100 cycles of loading with same amplitude. After the completion of 300 cycles software allowed 1 min of break time to change confining pressure from 21.0 KPa (3 psi) to 34.47 kPa (5 psi) and similarly it completed 300 loading cycles under same confining pressure. After the completion of 15 sequences as shown in Table 1, wave matrix software saved the data file in the C drive of computer. Data obtained from the test was too large that it was impossible to handle on Microsoft Excel sheet. Matlab code was set up to get output from the data obtained from wave matrix. After running through the code we get resilient modulus values in a simple excel sheet as shown in Table 2. Deviator Stress and resilient strain relationship is showing in the Figure 13.

### Table 1: Testing Sequence for Base/Subbase Materials

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![Figure 13: Deviator Stress VS Resilient Strain Chart](image-url)
Resilient modulus value for each sequence is showing in the Table 2. Reported value of resilient modulus was calculated by taking the average for all values obtained under different sequences which happened to be 99.93 MPa which is showing the stiffness of the material.

**Conclusions and Summary:**

A resilient modulus testing system was gradually developed for educational purposes through conducting several research programs. This paper described testing equipment and procedures for preparing and testing untreated subgrade soils and untreated base/subbase materials for determination of resilient modulus ($M_r$) under conditions representing a simulating the physical conditions and stress states of materials beneath flexible pavements subjected to moving wheel loads. Reclaimed Base (RB-2) material provided by RIDOT was tested with the developed testing system at URI to determine resilient modulus value. The testing was conducted in accordance with the procedure of AASHTO T 307-99, and the resilient modulus was determined as 99.93 MPa.

**References:**


American Association of State Highway and Transportation Officials (AASHTO), (2012). AASHTOWare Pavement ME Design, Washington, D.C.


