

**Laboratory Resilient Modulus Test Methods
For Subgrade Materials
Based on Presentations at October 19, 2007 Workshop and
Review of Related Materials**

**Prepared by CTC & Associates LLC
For Frozen Four Pooled Fund Study - TPF-5(119)
June 12, 2008**

Contents of This Report

Introduction

A. Workshop Presentations

B. National Test Methods

1. NCHRP & AASHTO Resilient Modulus Test Methods
2. NCHRP 1-28A versus AASHTO T 307
3. Variations in Protocol

C. Partner Laboratory Methods

1. Illinois Method
2. Michigan Method
3. Minnesota Method
4. Wisconsin Method

D. Summary and Research Suggestions

E. Attached Documents

Introduction

This report serves a dual purpose: to summarize the content presented at the October 19, 2007 Resilient Modulus Workshop of the North Central Pavement Research Coordination Partnership (Frozen Four) in Lansing, Michigan, and to further clarify differences in partner approaches to resilient modulus testing.

We review the national test methods for resilient modulus of subgrade materials and the variations on these methods used by each of the partner agencies in Illinois, Michigan, Minnesota and Wisconsin. We include all the resilient modulus presentations made at the workshop, as well as other relevant material provided by researchers in the partner states. Interviews and e-mail exchanges with various researchers and agency representatives expanded upon and clarified material since the October meeting, and include results of the April 3, 2008 Frozen Four quarterly meeting, held via teleconferencing and hosted in Madison, Wisconsin.

A. Workshop Presentations

The following presentations (attached) pertain to each partner state's method for laboratory testing of resilient modulus of soils for use in bases, subbases and subgrades. Some are official state procedures, others are protocols used by researchers to the state transportation agency.

Illinois

[Debakanta Mishra - University of Illinois, Urbana-Champaign](#). Debakanta Mishra, a graduate student studying with Erol Tutumluer at University of Illinois, Urbana-Champaign, reviewed uses of resilient modulus in design, protocols for testing, and the method used at the University of Illinois Advanced Transportation Research and Engineering Laboratory. The protocol is based on the AASHTO T 307 procedure.

Mishra described various aggregate conditions and how they might affect testing, the new calculation model from the MEPDG, and the ATREL method and its conditioning practices. Mishra also reviewed field measurement of stiffness and resilient modulus, including California Bearing Ratio, Dynamic Cone Penetrometer, Plate Bearing Test, and Dynamic Plate Bearing Test with a light-weight Falling Weight Deflectometer, determining that such field examination can be practical but requires calibration to lab testing and local conditions.

Michigan

[Gibert Baladi - Michigan State University](#). Gilbert Baladi of Michigan State University presented a review of uses for resilient modulus testing of soils in the MEPDG, and of various methods for testing. He discussed AASHTO standards and shortcomings.

Baladi described recent research efforts to compare lab and field testing to find correlations, quantify the impact of moisture content in both environments, and correlate resilient modulus values to common soil parameters.

[Ralph Hodek - Michigan Technological University](#). Ralph Hodek of Michigan Technological University presented the method he used in research for MDOT, as well as further research needs. Hodek's protocol is a variation on the T 307 method.

Hodek discussed testing in terms of reproducibility and the effects of conditioning, grain size distribution, material properties and saturation upon results. All are factors and are described; some have interactive impacts, such as saturation effects that vary with the ratio of fine aggregate to coarse aggregate in samples. Among Hodek's recommendations were evaluation and justification of eliminating dry density as a relevant materials classification for design and construction, development of alternative characterization categories, and development of a shared nomenclature for soils.

Minnesota

[Shongtao Dai - Minnesota Department of Transportation](#). Shongtao Dai of Mn/DOT presented the Mn/DOT procedure adopted most recently. The method, based on NCHRP Project 1-28A, includes certain Minnesota-specific variations in equipment configuration.

Dai described the advantages Mn/DOT sees in the newer method, including higher sensitivity in instrumentation and procedures that better simulate field conditions. He reviewed some of the Mn/DOT algorithms used for quality control of data, and a need for simplification of the procedure, for developing consistency in use of lab values, and for comparisons of field QA/QC values and design values.

[Joe Labuz - University of Minnesota](#). The University of Minnesota's Joe Labuz discussed in this presentation various technical issues with the testing protocol, equipment, calculations and interpretations of lab testing procedures.

[John Siekmeier - Minnesota Department of Transportation](#). Mn/DOT's John Siekmeier presented preliminary findings of an NCHRP synthesis report on state methods for lab testing the resilient modulus of

soils. The report will be released in the Spring of 2008, and includes a survey of state practices discussed by Siekmeier in this presentation.

The NCHRP project surveyed both the materials and geotechnical groups and pavement design groups at each state transportation agency and received greater than an 80% response for each group. Survey results indicate little satisfaction with standard lab tests, high variability, low reproducibility, and a frequent need to modify procedures. Field test methods were also reviewed, and the use of Light Weight Deflectometer drew particular interest. Conclusions included a need for standardization of lab and field methods, a greater emphasis on LWD and other non-intrusive field measuring methods, and a need for inter-agency efforts to build together databases of resilient modulus values and to focus on derivation of values from other common soil testing methods.

[Lev Khazanovich - University of Minnesota](#). The University of Minnesota's Lev Khazanovich reviewed in this presentation the use of resilient modulus with the new mechanistic-empirical design guide. The presentation describes the various input levels that can be used with MEPDG, and the effectiveness of different protocols at different input levels.

Khazanovich discussed refinement efforts for the procedure, a database of Mn/DOT resilient modulus values, and uses of the test method in Minnesota. He described various research results, including findings that Level 3 design inputs based on correlations with soil classification were reasonable, and that pavement stiffness impacts field-measured resilient modulus values

Wisconsin

[Hani Titi - University of Wisconsin-Milwaukee](#). Hani Titi of the University of Wisconsin-Milwaukee presented the method he employed in his research for the Wisconsin Highway Research Program and WisDOT. He reviewed procedures adopted from NCHRP Project 1-28A and findings from his research.

Titi described research that tested 19 samples of representative Wisconsin subgrade soils for various common soil characteristics as well as for resilient modulus. Titi discussed test results and models for predicting modulus from standard soil properties. Conclusions included that greater success was achieved with coarse-grained soils than with fine-grained, and that correlations developed in the study seemed reasonable.

B. National Test Methods

All four states used a test method based either on the 1997 AASHTO T 307 method updated in 1999, or the NCHRP Project 1-28A method of 2003. The AASHTO Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures recommends use of the latest NCHRP standards. The 1-28A method may essentially be considered an updated version of AASHTO T 307.

The test procedure is a way of developing one soil input, resilient modulus, for the MEPDG. Other inputs and state methods for categorizing materials are also employed. Some of these are discussed in Section C of this report.

Below we review the procedures developed through AASHTO and NCHRP, highlight some differences between the most recent AASHTO and NCHRP methods, and identify variations allowed by the protocols.

1. NCHRP & AASHTO Resilient Modulus Test Methods

The conventional method for testing the resilient modulus of subgrade material draws from NCHRP Projects 1-28 (in 1997) and 1-28A (in 2003). The 1997 NCHRP method drew from various AASHTO and ASTM methods, and additional methods were considered for the 2003 protocol. The 2003 method attempted to "harmonize" the previous NCHRP method with protocols used in FHWA's LTPP and with AASHTO TP46 (re-designated and revised as T 307 in 1999), T 292, and T 294.

The 2003 method was adopted by NCHRP Project 1-37A, Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, the MEPDG. The protocol can be reviewed in *Research Results Digest No. 285*, Jan. 2004 at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rrd_285.pdf; see *NCHRP 1-*

28A Review RRD Jan 2004, attached. The paper discusses methods for HMA and for unbound base materials; the latter begins on p. 12.

The heart of the method is the use of the triaxial test, which accounts for moisture content of base, subbase, and subgrade materials, and classifies materials for test purposes by grain size distribution and plasticity index. A sample is placed in a triaxial pressure chamber fitted with two vertical Linear Variable Differential Transformers (LVDTs, instruments that measure deformation), the sample's moisture content is limited to specified levels, and cycles of pressure and rest are applied at various levels over time. Stress response is measured at each cycle of stress, and a total resiliency in terms of (axial) deformation response is used in determining the material's resilient modulus, a measure of how the material will respond to various repeated loading stresses and various density and moisture conditions that it would be expected to face in the field.

Materials must also be prepared according to outlined procedures for sorting materials. For soils that are to be part of bases and subbases, the materials are sorted by grain size to fine-grained and coarse-grained samples. For subgrades, materials are either categorized and sorted according to grain size, or are simply undisturbed samples for subgrades. For bases and subbases, grains of large size – one inch or greater – are eliminated from testing. These variations in the process allow for further sensitivity to the specific locations under examination.

2. NCHRP 1-28A versus AASHTO T 307

AASHTO T 307, the 1999 re-designation and update of AASHTO TP 46 (1994), was relied upon in the NCHRP 1-28, but superseded in 1-28A. Some partners employ the T 307 method, others the 1-28A. An excellent article describes many of the technical differences between the T 307 and 1-28A methods, and identifies some of the differences we outline below. (See “Harmonized Resilient Modulus Test Method of Unbound Pavement Materials,” Dragos Andrei, Matthew W. Witczak, Charles W. Schwartz, Jacob Uzan, *Transportation Research Record No. 1874*, 2004: 29-37.)

One difference was revised predictive equations based on a greater number of inputs. Other differences we highlight here impact testing protocols rather than calculations. They include:

Sample Types and Compaction

In T 307, analysis broke samples into 2 types, based on gradation (over or under 12.5 mm (0.5 in.)), material type, cohesion characteristics, and field compaction conditions (impact versus static).

In 1-28A, samples sorted into 3 types based on gradation, plus type 4 for undisturbed subgrade materials placed in a thin-walled tube for testing. Compaction methods vary with type:

- Type 1, coarse-graded, maximum particle size over 9.5 mm (3/8 in.) – sample size of six inches, impact or vibratory compaction.
- Type 2, medium-graded, maximum particle size under 9.5 mm and less than 10 % passing No. 200 sieve – sample size of four inches, vibratory compaction.
- Type 3, fine-graded, maximum particle size under 9.5 mm and 10% or more passing No. 200 sieve – sample size of 2.8 inches, impact or kneading compaction.

Loading Time

In T 307, same time for all materials.

In 1-28A, increased loading time and shortened rest time for all subgrade materials.

Stress Sequences

In T 307, stress sequences jumped between high (failure level) stress and low stress.

In 1-28A, stress sequences begin with low stress and gradually increase. For coarse-grained subgrade materials, lower stress levels are used to reflect low quality of material. Overall, this method employs more stress-ratio families than T 307.

Placement of Load Cells and LVDTs

T 307 uses an external load cell, and the LVDTs are placed on the outside of the test cylinder.

In 1-28A uses an internal load cell, and the LVDTs are placed inside the test cylinder.

Conditioning

T307 requires 500 load repetitions and, if height still decreasing, up to 1000 total repetitions. Conditioning ceases at a vertical permanent strain of 5%.

In 1-28A 1000 load repetitions are required. Conditioning ceases at a vertical permanent strain of 5%.

3. Variations in Protocol

Essentially, all users of these procedures may adjust them as they see fit.

Sampling rates remain a variable agencies may determine. LVDT placement and use typically varies with each agency. The AASHTO and NCHRP protocols do not include quality control measures, and this informs varying approaches by each state in deviating stresses used, changes in calculation formulas, adjustments to the configuration of materials, and other tests and classification methods used outside or resilient modulus testing.

C. Partner Test Methods

Following is a review of the methods used by the four partner states. The table below presents the essential differences.

Comparison of Frozen Four Procedures for Testing Resilient Modulus of Soils				
	Illinois	Michigan	Minnesota	Wisconsin
Source Method	T 307	T 307	1-28A	T 307
LVDTs	2 external	2 external	3 internal	2 external
Conditioning	1000 loadings; use variations in deviating stress	500 loadings; 1000 if necessary	1000 loadings	500 loadings; 1000 if necessary
Quality Control			Apply variables to data for specimen non- uniformity; Use 2 external LVDTs to evaluate external performance	

1. Illinois Method

In addition to presentation materials, we discussed the Illinois methods with Erol Tutumluer at UI-UC, and reviewed the ATREL protocol. The ATREL methods have been used for all state testing needs for roughly 20 years, according to Tutumluer, and so its current protocol reflects, for our purposes, official Illinois DOT procedure. To review, see *Illinois ATREL Procedure*, attached.

The method used in Illinois is the AASHTO T 307 method. Though data acquisition rates may be adjusted, ATREL uses its instrument software's default sampling rate of 1000 points/second. Tutumluer notes that ATREL varies deviating stress levels to better simulate field conditioning.

Tutumluer's student, Debakanta Mishra, presented a method used with the MEPDG and based on T 307. It found the method to be effective. See [Debakanta Mishra - University of Illinois, Urbana-Champaign](#).

Contact: Erol Tutumluer, University of Illinois, Urbana-Champaign, (217) 333-8637, tutumlu@uiuc.edu.

2. Michigan Method

For Michigan, we draw on interviews and presentation materials.

Michigan DOT allows its transportation districts to employ soil-testing methods each district chooses, so no official state transportation documents were available.

A study by Ralph Hodek of Michigan Technological University – “Resilient Modulus at the Limits of Gradation and Varying Degrees of Saturation” (2003-0063) – followed a repeated load triaxial test method matching T 307 Hodek’s presentation at the October 2007 Frozen Four Resilient Modulus Workshop suggests the same. See [Ralph Hodek - Michigan Technological University](#) and *Ralph Hodek Proposal*, attached.

During an interview, Hodek explained that he uses the T 307 procedure but with the 2 LVDTs placed externally and a sampling rate of 500 points/second.

A study by Gilbert Baladi of Michigan State University – “Pavement Subgrade MR Design Values for Michigan’s Seasonal Changes” (2002-0532) – conducted repeated load triaxial tests “in accordance with the proper AASHTO standard test procedure,” according to its 2006 research proposal. Presumably, this refers to T 307. See *Gilbert Baladi Proposal*, attached.

Contact: Ralph Hodek, Michigan Technological University. (906) 487-2797, rjhodek@mtu.edu.

3. Minnesota Method

For Minnesota, we draw on interviews, Mn/DOT procedures, and presentation materials.

Mn/DOT follows the NCHRP Project 1-28A’s protocol for testing resilient modulus of samples in the lab with slight variation. See <http://www.mrrapps.dot.state.mn.us/mrrapps/mr/MnDOTMrTestingProtocol.asp>.

According to the Mn/DOT testing protocol, its differences are as follows.

1. Use three internal LVDTs rather than the two recommended in NCHRP 1-28a. Mn/DOT also uses two external LVDTs for quality control. For details on the LVDT configuration, see *Mn/DOT LVDT Paper*, attached.
2. Calculate baseline average load/deformation values from the last 60% of the sampling time history cycle.
3. Apply quality control based not on a 1.1 measurement ratio between the vertical LVDTs, but according to three variables that adjust for effect on deformation data of the non-uniformity of specimens.
 - a. Angle of Rotation (AR), a calculation that measure uniformity of deformation.
 - b. Signal-to-Noise Ration (SNR), a calculation that accounts for system noise.
 - c. Coefficient of Variation (COV), calculations that account for variation in the last five cycle data results.

Mn/DOT uses a sampling rate of 400 points/sec.

Apart from the M_R protocol changes, Mn/DOT also applies certain material index tests to specimens. These include indices for

1. Gradation
2. Procter compaction test for optimal moisture content and maximum density
3. Mn/DOT material classification
4. For fine-grained materials only:
 - a. Liquid limit
 - b. Plastic limit
 - c. Plasticity index
 - d. Percent silt
 - e. Percent clay
 - f. AASHTO group.

A 2007 TRB Annual Meeting paper – “Resilient Modulus of Base Course Containing Recycled Asphalt Pavement” – by Woosung Kim and Joseph Labuz of University of Minnesota, and Shongtao Dai of Mn/DOT, outlined a slightly different process. Kim, et al, employed a gyratory compactor rather than the NCHRP recommended vibratory hammer, because gyratory compacted specimens better match field density. Otherwise, Kim employed the Mn/DOT method with AR, SNR, and COV. See **Woosung Kim TRB 2007**, attached.

A 2002 TRB Annual Meeting paper – “Resilient Modulus of Mn/ROAD Subgrade Soil” – by Shongtao Dai and John Zollars of Mn/DOT was presented before NCHRP Project 1-28A was finished, and essentially matches the newer NCHRP practice by using thin-walled tube samples for undisturbed subgrade materials, as 1-28A would later recommend. Adjustments based on constitutive models (including the one used in 1-28A and MEPDG) and resistance R-value and plasticity index were also applied. See **Shongtao Dai TRB 2002**, attached.

A current research project on the equivalence, durability and environmental impacts of fly ash stabilized subgrades includes triaxial testing of samples in the Mn/DOT method. Among results expected will be a comparison of sample tested values, including differences between internal and external LVDT readings. A joint study with Paul Bloom at University of Minnesota and Tuncer Edil at University of Wisconsin-Madison, the LVDT comparison is not mentioned in the work plan. See **Mn/DOT Fly Ash Work Plan**, attached.

Contact: Shongtao Dai, Mn/DOT. (651) 366-5407, shongtao.dai@dot.state.mn.us.

4. Wisconsin Method

For Wisconsin, we draw on interviews, research documents, and presentation materials.

For the WisDOT process for testing resilient modulus of base, subbase, and subgrade materials, we look to WHRP study 0092-03-11, *Determination of Typical Resilient Modulus Values for Selected Soils in Wisconsin* (May 2006). This study drew upon the AASHTO T 307 method. The research sought to correlate material soil properties with resilient modulus model input parameters.

The study found that with fine-grained soils, T 307 protocol for measuring resilient modulus correlated with physical properties and allowed prediction based on those properties. Coarse-grained soils, however, did not correlate well. Researchers also determined that LTPP models for resilient modulus do not perform as well for prediction as do the T 307 models. See the final report for 0092-03-11 at http://www.whrp.org/Research/Geotechnics/geo_0092-03-11/.

A 2008 project, which is expected to conclude in April 2009, is focusing on expanding the number of specimens and M_R database to more soil samples, and is looking at improving predictive results for coarse-grained materials. The research will employ the same method used in 0092-03-11 for testing resilient modulus. See the proposed **Hani Titi Proposal** that was accepted and funded by WHRP, attached.

At the October 2007 Frozen Four Resilient Modulus Workshop, the WHRP investigator, Hani Titi of the University of Wisconsin-Milwaukee, presented his most current information on testing samples and comparing results to basic soil properties to develop correlations between properties and expected M_R values.

Titi’s WHRP work correlates M_R with physical and compaction properties that can be compared to the Mn/DOT material indices. For WisDOT and WHRP these were:

1. Particle size distribution from sieve and hydrometer analyses
2. Procter compaction test for optimal moisture content and maximum density
3. WisDOT soil classification, by
 - a. Unified Soil Classification System
 - b. AASHTO group
4. Liquid limit (Atterberg)

5. Plastic limit (Atterberg)
6. Organic content
7. Specific gravity

See [Hani Titi - University of Wisconsin-Milwaukee](#).

Contact: Hani Titi, University of Wisconsin-Milwaukee. (414) 229-6893, hanititi@uwm.edu.

D. Summary and Research Suggestions

The Frozen Four partners use recent methods developed through AASHTO and NCHRP for laboratory testing of resilient modulus of soils for pavement structural support. The most recent NCHRP work on the MEPDG and resilient modulus testing is the 1-28A method developed in 2006. The most up-to-date previous method 1-28A improves upon is the AASHTO T 307 method.

Researchers for three of the four partners use the T 307 protocol; Mn/DOT uses the 1-28A procedure. Of the T 307 users, Illinois supplements the procedure with conditioning methods pertaining to deviating stress. Wisconsin research has employed T 307 methods without variation.

Mn/DOT not only uses the most up-to-date of the testing protocols, but it also applies quality control equations to data to accommodate the irregularity of sample density within cylinders. It also adds a third LVDT internally to acquire more accurate data, and has been comparing these readings to those of two external LVDTs to examine the variation in results.

Agencies in Minnesota and Wisconsin have tracked various mechanical properties and descriptions of subgrade and base materials in their regions. The addition of resilient modulus data to previously tracked properties for materials available in each state constitutes a fairly robust data set for each state's respective foundation materials.

A newly approved FHWA pooled fund study, TPF-5(177) *Improving Resilient Modulus (MR) Test Procedures for Unbound Materials* intends to begin its work on test methods in Fall of 2008 (WisDOT is the only partner agency from this pooled fund involved in TPF-5(177)). The focus of the study is reducing variability in the test, but specific activities have not yet been identified. Contact FHWA's Mike Moravec for more information – Mike Moravec, (202) 366-3982 or mike.moravec@dot.gov. See the study's Web page at <http://www.pooledfund.org/projectdetails.asp?id=404&status=4>.

The following directions in resilient modulus research may suit Frozen Four partnership attention.

LVDT Placement. In interviews we learned that LVDT placement was internal for certain soil tests roughly 20 years ago, then was made external, then internal again. Though internal placement may offer greater accuracy, internal placement is a more delicate and time-consuming process. A simple study comparing readings from internal and external LVDTs in tests of a small number of comparable soil samples from each partner would identify how significant differences in readings from placements within and without are, and could yield recommendations for one method or another or, alternatively, appropriate calibration factors.

Data Compilation. The states may benefit from a consolidation of data on subgrade, base and subbase materials at each partner's disposal. The physical properties of a soil sample are a conventional way to classify materials; resilient modulus is a newer, mechanistic way to classify materials. Using a shared or uniform classification system for soils, various physical characteristics of soils and their resilient modulus results could be compared to identify trends in resilient modulus performance. Resilient modulus trends could be identified according to, say, soil type, cohesion, grain size, or any number of soil properties or classifications the partners choose.

Correlation to Conventionally Measured Properties. This research would incorporate or expand on simple data collation and comparison with testing of specimens. Equipment for conducting resilient modulus laboratory testing is expensive, and not all agencies may have the equipment at their disposal. The protocol is also time-consuming. Correlating resilient modulus to various soil properties can provide

predictive approaches to assigning resilient modulus values to materials for use as low-level MEPDG inputs. By conducting resilient modulus testing on materials for which each partner has or can identify common soil classifications and conventional soil testing data, resilient modulus expectations may correlate to more easily determined physical properties of materials.

Quality Control. Because neither T 307 nor 1-28A provide detail on quality control and leave full elimination of permanent or plastic deformation to “every effort” to achieve “acceptable vertical deformation ratios,” a uniform method for effectively conditioning samples to eliminate plastic or permanent deformation before resilient modulus testing may warrant collaborative attention. Various quality control methods or applications such as used by Mn/DOT may also be applied to specimens in each state to eliminate or reduce the impact of non-uniformity in soil samples during testing.

E. Attached Documents

The following documents provide further information on partner state research, as well as on work around the U.S. and Europe on testing of resilient modulus in the laboratory.

Illinois ATREL Procedure
Ralph Hodek Proposal
Gilbert Baladi Proposal
Shongtao Dai TRB 2002
Woosung Kim TRB 2007
NCHRP 1-28A Review RRD Jan 2004
Hani Titi Proposal
Mn/DOT Testing Granular Soils 2004
Mn/DOT LVDT Paper
Mn/DOT Fly Ash Work Plan
European Procedure