TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): ____Maryland Department of Transportation____________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *TPF-5(285)*	**Transportation Pooled Fund Program - Report Period:** ■ Quarter 1 (January 1 – March 31) ☐ Quarter 2 (April 1 – June 30) ☐ Quarter 3 (July 1 – September 30) ☐ Quarter 4 (October 1 – December 31)

Project Title:
Standardizing Lightweight Deflectometer Measurements for QA and Modulus Determination in Unbound Bases and Subgrades

Name of Project Manager(s): Rodney Wynn	**Phone Number:** 443-572-5043	**E-Mail** RWynn@sha.state.md.us
Lead Agency Project ID: *TPF-5(285)*	**Other Project ID (i.e., contract #):**	**Project Start Date:** January/15/2014
Original Project End Date: December/15/2016	**Current Project End Date:** December/31/2015	**Number of Extensions:** 0

Project schedule status:

■ On schedule ☐ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	**Total Cost to Date for Project**	**Percentage of Work Completed to Date**
$371,984	$15,241.50	6.3%

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	**Total Amount of Funds Expended This Quarter**	**Total Percentage of Time Used to Date**
$15,241.50 4.1%	$15,241.50	6.3%

Project Description:

Currently, compaction control using lightweight deflectometers (LWD) is being evaluated in many states and fully implemented for pavement construction quality assurance (QA) in some states and countries. However, there currently is no widely recognized standard for interpreting the load and deflection data obtained during construction QA testing and then relating these measurements to the material properties used during pavement design.

The main goal of this research is to provide a straightforward and practical procedure for using LWD for compaction control that can be implemented by field inspection personnel. This procedure must (1) fully account for the influence of moisture on LWD measurements, (2) include the effects of stress state on measured modulus and the differences between the LWD induced stress state and the stress states induced by design traffic loads, (3) be applicable to LWD testing of half-space conditions (i.e., subgrade) and finite thickness layered conditions (i.e., granular base layers).

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

The project started on January 15th. So, this quarterly report refers to the work performed in 2.5 months instead of 3 months. The project is on schedule.
The progress with respect to each Task is as followed:

Task 1. Literature Review (3.3% of the total effort). Percent completion of Task 1: 90%

Over hundred papers and dozen comprehensive reports have been reviewed. A significant progress on the literature review has been made during this reporting period. A summary of the significant results is provided in Appendix A.

Moving away from nuclear gauges and proper implementation of LWD for quality assurance of earthworks require (1) a comprehensive knowledge of the material performance of material and how the modulus of soils is affected by (a) compaction dry density, moisture content, and achieved porosity and (b) testing moisture content and degree of saturation, total and effective stresses; (2) how the snapshots obtained from LWD on one/two layer structure can be used to predict the design stiffness of layers and assure the proper compaction.

Project personnel participating in these activities: Schwartz, Khosravifar, Afsharikia.

Task 2. Equipment Evaluation (2.4% of the total effort). Percent completion of Task 2: 73%

Available devices for in situ stiffness and moisture measurement are under evaluation in order to determine the most appropriate equipment for more in-depth laboratory and field evaluation. A draft list of the available devices is provided in Appendix B.

Project personnel participating in these activities: Schwartz, Khosravifar, Afsharikia.

Task 3. Model Refinement/Development (12.6% of the total effort). Percentage completion of Task 3: 7%

Existing material models are being assessed using the data in literature (Nazarian et al 2013, Khouri et al 2012). Hydrus 1D, a very powerful software is found for prediction of the surface evaporation and moisture variations in the soil due to the soil properties (SWCC and hydraulic conductivity) and environmental condition.

Project personnel participating in these activities: Schwartz, Khosravifar, Afsharikia.
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Task 4. Controlled Trials (18.8% of the total effort). Percentage completion of Task 4: 3%

The Universal Test Machine at University of Maryland should be altered to ascertain accurate testing on unbound materials.

The UMD personnel are in touch with Instrotek and IPC global for this necessary alteration to the device.

The methodologies that has been used by other researchers and manufacturers to assess the LWD accuracy, calibration, and the effect of different configurations is collected through contacting the experts in use of LWD and literature review. This makes a platform of choosing the best technique for evaluating the LWD measurements during Task 4. Potential options are rubber mat, box filled with non-cohesive sand, test pit filled with non-cohesive sand, spring box, spring box filled with sharp clean sand, etc.
(Appendix C describes the information obtained so far on this respect.

Project personnel participating in these activities: Schwartz, Khosravifar, Afsharikia.

Task 5. Field Validation (53.7% of the total effort). Percentage completion of Task 5: 0%

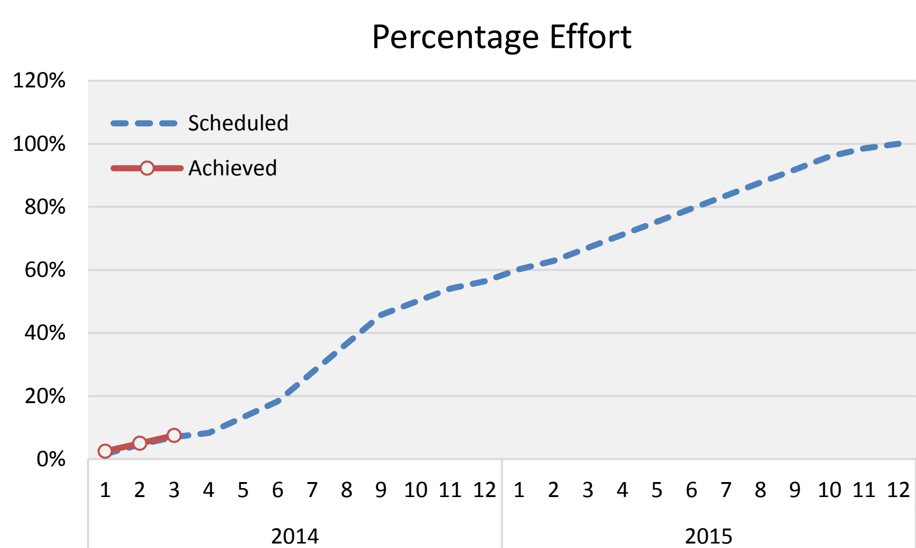
No progress was made on this task during the reporting period.

Task 6. Draft Test Specifications (3.3% of the total effort). Percentage completion of Task 6: 0%

No progress was made on this task during the reporting period.

Task 7. Workshop and Final Report (5.8% of the total effort). Percentage completion of Task 7: 0%

No progress was made on this task during the reporting period.



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Anticipated work next quarter:

- The documentation of the literature review will be completed during the next reporting period. The review will be documented in the form of an annotated bibliography.
- The appropriate moisture content and stiffness measurement devices will be selected, and will get rented or purchased for further evaluations.
- Project progress web meeting (P1) with TAC to review findings from literature review in Task 1 and to finalize the choice of equipment evaluated in Task 2 and the methodology to be carried on in Task 4 for controlled large-scale tests.
- Task 3 and Task 4 will be the main focus of the next quarter.

Significant Results:

Appendix A, B, and C

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

Not applicable

Potential Implementation:

LWDs should be implemented more widely and this should be done using standardized testing procedures and data interpretation methods. LWDs are a tool for performance based construction quality assurance testing, which not only results in a better product, but also provides the quantitative measures critical to better understanding the connection between pavement design and long term pavement performance. As the benefits of performance based quality assurance testing become increasingly apparent, more public agencies and private consultants are expected to acquire these tools and implement standardized procedures during their use. The product of this research will allow state DOT construction specifications to be modified to include this new light weight deflectometer (LWD) option during construction quality assurance.

Appendix A

Task I

The storyline of how to use LWD for mechanistic-based quality assurance of earthworks

The resilient modulus of geomaterials

The resilient modulus of geomaterials is influenced by several factors. Stress dependency and moisture dependency of geomaterials are widely accepted among researchers (e.g. Iekarp et al. 2000, Smith and Nair 1973, Vuong 1992, Haynes and Yoder 1963, Hicks and Monismith 1971, Barksdale and Itani 1989, Dawson et al. 1996, and Heydinger et al. 1996.) However, the effects of other factors including dry density is found relatively inconsistent. This in one hand makes it reasonable to move forward to modulus-based quality assurance of geomaterials but in the other hand challenging. In order to move away from conventional density measurement in the field, it is important to fully understand the compaction parameters (dry density, compaction moisture content, compaction energy, and porosity) on the long-term performance of the bases and subgrades.

In NCHRP 10-84, Nazarian et al. (2013) has tried to capture the effect of compaction MC, testing MC, and density on modulus. Free-free resonant column (FFRC) tests showed that the higher the difference between the MC at compaction and testing, the higher will be the seismic modulus which in turn is correlated with resilient modulus. They also found that the effects of density is negligible as compared to MC. They performed Mr testing on specimens compacted at 96% MDD, 98% MDD and 100% MDD and all to a similar OMC. However, they didn’t see an increasing response due to higher density. The reason could have been that they had tested Mr 24 hours after compaction which could have led to higher evaporation in less dense (more porous) specimens.

Cary and Zapata has developed models that predict changes in modulus from optimum condition (MDD-OMC) due to seasonal changes in degree of saturation of already compacted soils. However, the applicability of these models to the effect of MC at the time of compaction is questionable and Nazarian et al. could not find strong correlation between the measured and predicted Mr by the aforementioned model. Rafiei et al. (2012), contrary to Nazarian et al. found that compaction level had more effect on LWD modulus than MC. They considered this result as a consequence of small variations in the MCs.

Due to the importance of MC, Tan et al. (2014) proposes a discrete element modelling of the effect of moisture and fine particles on the LWD test. Their proposed model matched the trends in experimental LWD testing, showing a decrease in modulus due to an increase in fines and/or moisture content.

While several researches have focused on the effect of MC, Yideti et al. (2013) propose a packing theory-based framework for evaluating the resilient modulus of unbound granular materials. He found that lower porosity and higher packing has a significant effect on resilient modulus of materials.

Yan et al. (2013) proposed two gene expression programming (GEP) models to correlate resilient modulus with routine properties of subgrade soils and state of stress. When comparing GEP I and GEP II, it was interesting to see that GEP II which excluded compaction moisture content and deviator stress parameter yielded higher R^2 as compared to GEP I suggesting that these two parameters might have been intercorrelated with other parameters in GEP I model.

LWD measurements

LWD measurements not only are influenced by the modulus of material being test (as discussed earlier) but are also influenced by several factors in the LWD itself and how it functions, and the type of analysis and assumptions. The inherent variability of LWD and how it records the load and deflection, the contact stresses, LWD zone of influence, effect of finite layer, the stress states they apply, and the structural analysis method are some of the few items affecting the response and its interpretations. Examples of the studies looking at these important factors include:

- Benedetto et al. (2012) proposed an elliptic model for prediction of deflections induced by LWD. They suggested that a revised version of the Boussinesq equation be used to better represent stress distribution in soil, estimate the zone of influence of the LWD loadings, and back-calculate or estimate the mechanical characteristics of soil or pavement volume layers.
- Ruta & Szidlu (2004) proposed a method enabling the conversion of dynamic LWD response to a statical substitute (Boussinesq assumtions).
- Senseney & Mooney (2010) investigated the backcalculation of two layer system moduli from LWD response with radial sensors. They found that the radial distances of 300/600 mm are optimum for the high quality backcalculation on stiff over soft layered system. Backcalculated moduli closely matched laboratory resilient modulus test at a similar stress state as in the field and showed subgrade nonlinearity.
- Marradi et al. (2014) looked at the energy loss and maximum deflection due to successive LWD drops with variable weights as an indication of compaction quality and found reasonable correlations with the achieved field density.

Looking at the trend of maximum deflection (or energy loss) under successive drops at a point in conjunction to the composite modulus of the material and backcalculated layer moduli can ascertain the quality of road works. However, there needs to be a framework so that the modulus calculated during QA will be checked upon the target modulus at the same condition.

Finding the accurate target modulus at time of QA testing

Since the resilient modulus of the soils is usually available through laboratory measurements at OMC and MDD, it is vital for quality assurance to precisely (1) measure the moisture content at the time of testing, (2) predict the corresponding MC at the time of compaction to (a) assure it was placed and compacted within adequate limits of OMC and (b) predict the subsequent target modulus at the time of testing. This will prevent contractors to e.g. compact at “dry of optimum” to misleadingly provide higher apparent modulus at the time of QA testing which can potentially be within 24 hours after compaction.

The soil moisture models must be able to predict the variation of soil moisture content profile with time in covered and uncovered states, and for homogeneous and layered soils as a function of environmental factors (e.g. temperature, precipitation, radiation, wind speed) and soil properties (e.g. soil water characteristic curve (SWCC), gradation, plasticity, degree of compaction). For this purpose, Enhanced Integrated Climatic Model (EICM), SEEP/W, HUDRUS 1D, 2D, and 3D, and VADOSE/W will be assessed for their capability in prediction of the moisture changes in the soil from compaction to the time of QA testing.

In addition, the soil resilient modulus models (e.g. Cary & Zapata (2010) and Siekmeier (2011)) should be capable of relating the moisture content to suction head and the suction head to modulus, or directly relate the moisture content to modulus. NCHRP 10-84 has summarized several of the available models and has extensively evaluated the Cary & Zapata (2010) and Siekmeier (2011) Models. The results presented in their second phase of report was not promising.

Appendix B

TASK II

Equipment Evaluation

Available devices for in situ stiffness and moisture content measurement will be evaluated in order to determine the most appropriate equipment for more in-depth field evaluation.

A key outcome of the equipment evaluation will be a short list of devices to be evaluated further in the laboratory and the field. This will include recommendations as to whether the equipment can/should be rented or purchased for the project.

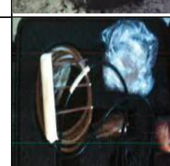
Table 1 shows the commercially available LWDs and their specificaitons.

Table 1. Comparison of Different LWD Devices (After Vennapusa and White 2009, Nazarian et. al 2009, Mooney and Miller 2009)

Device	Plate Style	Plate Diameter (mm)	Plate Thickness (mm)	Falling Height (cm)	Falling Weight (kg)	Plate Mass (kg)	Maximum Applied Force (kN)	Load Cell	Total Load Pulse (ms)	Type of Buffers	Deflection Transducer			Data Acquisition system	Additional/ external Deflectometer
											Type	Location	Measuring Range (mm)		
Zorn ZFG2000, Germany	Solid	100, 150, 200, 300	124, 45, 28, 20	72	10, 15	15	7	No	18±2	Steel Spring	Acceler-ometer	Plate	0.2-30 (±0.02)	SD card for data transfer to PC Deflection measuring (recording) printer Reading dynamic module on the display	-
Keros PFWD, Dynatest, Denmark	-	150, 200, 300	20		10, 15, 20	-	15	Yes	15-30	Rubber (Conical shape)	Velocity	Ground	0-2.2 (±0.002)	-	-
Dynatest 3031	Annulus	100, 150, 200, 300	20	Variable, Max 85	10, 15, 20	-	15	Yes	15-30	Rubber (Flat)	Velocity	Ground	0-2.2 (±0.002)	interfaced to a handheld PDA via a wireless Bluetooth connection. The data collection software, residing on the PDA, displays - in real time - the surface modulus and the time history graph from both the geophone(s) and the load cell.	2 additional radial geophones
Prima 100, Carl Bro Pavement Consultants, Denmark	Annulus	100, 200, 300	20	Variable, Max 85	10, 20	12	15	Yes	15-30	Rubber (Conical shape)	Velocity	Ground	0-2.2 (±0.002)	A portable PC or a PDA with a data collection program installed is required data can be seen on the display	2 additional radial geophones
Loadman, AL-Engineering Oy, Finland	Solid	110, 132, 200, 300	-	80	10	6	18	Yes	25-30	Rubber	Acceler-ometer	Plate	-	-	-
ELE	-	300	-	-	10	-	-	Yes	-	-	Velocity	Plate	-	-	-
CSM, Colorado School of Mines	Solid	200, 300	-	Variable	10	6.8, 8.3	8.8	Yes	15-20	Urethane	Velocity	Plate	-	-	-
Olson	Solid	100, 150, 200, 300	-	Variable, Max 60	9	-	9	Yes	20	Spring	Velocity	Plate	-	Interfaced the device via a cable connection with one of our handheld touch-screen acquisition systems for ease of use (Handheld, touch-screen data acquisition system [NDE 360™])	2 additional radial geophones
Humboldt	Solid	300	-	-	10, 15	-	-	-	-	-	Acceler-ometer	Plate	-	New, powerful, PC-software for evaluation, management and analysis of data USB transfer cable/ SD Card	-

The moisture content measurement techniques/devices are summarized in Table 1, from a study done by Christopher et al.

Table 2. Moisture measurement devices. From Christopher et al.

Device	**Description**	**Photo**
Oven (2)	Standard (ASTM D2216) forced air laboratory oven with one at 60°C and one at 110°C (tests samples were also sent to outside laboratories for support testing)	
Nuclear Gage	ASTM D6938 - The measurement of moisture Content is based on the thermalization (slowing down) of fast neutron radiation. It is a function of the hydrogen content of the materials and to a lesser degree, by other low atomic number elements e.g., carbon and oxygen.	
Lincoln Soil Moisture Meter	Push probe with measurement based on scale of 1 through 10	
General GLMM200 Moisture Meter	Push probe with measurement based on scale of 1 through 4	
Speedy® 2000 Moisture Device	Sample placed in vessel - measures pressure with calcium carbide	
DMM600 Duff Moisture Meter	Sample placed in vessel - measures pressure with calcium carbide	
Kelway Moisture Meter	Push probe in loosened materials with measurement based on % saturation	
Decagon Devices GS3 Moisture Probe	Push probe with readout box measurement based on conductivity	 

Hanna Instruments Soil Moisture Probe	Push probe with readout box measurement based on soil activity	

Nazarian et al. (2013) also evaluated several moisture content measurement devices. Their findings are as followed:

The calibrated moisture contents from the soil density gauge (SDG) tests carried out on the embankment are compared with the average oven-dried moisture contents. The raw SDG results were systematically and significantly lower than the oven-dried moisture contents by a factor of 2, indicating the need for a rigorous pre-testing calibration of the SDG before utilization in a project.

- The estimated dry densities with the SDG are systematically lower than expected indicating a need for a through calibration.
- correlations between the NDG and SDG measurements with the oven-dried moisture contents for the base and subgrade layers: Based on the limited available data, the uncertainties in moisture estimation are typically 15% or less of the measured values for both devices

- Sotelo et al (2014) compared three different moisture content measurement devices:
    - Soil Density Gauge (SDG)
    - Speedy Moisture Tester (SMT)
    - Time Domain Reflectometer (TDR)

They found that overall, the TDR and SMT were more accurate than the SDG in determining the moisture contents of the soils tested. However, the SDG results may be improved with a more rigorous calibration, since device performance seems to be material dependent.

The TDR and SMT demonstrated less uncertainty in moisture estimations over different soils as compared to the SDG.

The SMT had a tendency to underestimate the moisture content that may be refined through a calibration based on the oven-dry moisture measurements.

All devices exhibited acceptable level of repeatability.

The TDR was better in determining the dry density in the laboratory settings as compared to the SDG.

Partial field evaluation of moisture devices showed that the TDR and SMT presented less difference from the oven-dry moisture contents as compared to the SDG. Thorough calibration of the SDG may improve the device performance in quality control process

Table 3. From Nazarian et al. 2011 ***Table 5.8 – Advantages and Disadvantages of Moisture/Density Devices***

Device	Description	Advantages	Disadvantages
Electrical Density Gauge (EDG)	EDG is a portable, battery-powered instrument that uses a radio signal between four spikes to produce a current of a certain voltage and phase to measure capacitance, resistance, and impedance of the soil. These parameters are used to determine the density and water content of an unbound layer.	Does not require a licensed technician. Repeatable with a standard deviation in density measurements less than 1 pcf.	The necessity to run a series of lab and in situ tests for correlation purposes. Poor success rate in identifying areas with
Moisture + Density Indicator (M+DI)	*M+DI* utilizes time domain reflectometry (TDR) to measure the travel time of an electromagnetic step pulse produced by a pulse generator through four soil spikes in the ground. The voltage signal is analyzed to determine the water content and density of the material.	Requires no certified operators or safety training or instrument calibration.	Prior calibration of the device for each specific soil using laboratory compaction molds is required. May not be appropriate for aggregates or earth-rock mixtures that either interfere with penetration of the probes or have numerous and large void spaces. Time required to conduct a test
Soil Density Gauge (SDG)	The device is invented and manufactured by TransTech Systems, Inc. The SDG builds on the technology of the Pavement Quality Indicator (PQI). The SDG is a portable and non-destructive testing device for determining the in-place density, and moisture content of unbound pavement materials. The SDG produces an electromagnetic field using a transmitter and receiver. The operating frequency falls within radio frequency range. It uses advanced electrical impedance spectroscopy (EIS).	The SDG is designed to eliminate unit licensing and certification associated with nuclear materials usage. No special operator training/certification or radiation monitoring requirements are necessary. The unit is user friendly and cost effective for any crew member. Unit provides GPS logging for database management and offers fast, reliable and repeatable readings in real time.	This material is new and limited research has been performed using this device.

Speedy Moisture Tester	It is a portable system comprising a vessel with an integral pressure gauge. Soil samples and a reagent are introduced into the tester. Free moisture within the sample reacts with the reagent producing a gas and a pressure rise proportional to the amount of moisture.	Accurate and simple to use. Robust and reliable. Portable and requires no external power source. Can measure many materials over a wide moisture content range.	Some highly plastic clay soils or other soils not friable enough to break up may not produce representative results because some of the water may be trapped inside soil clods or clumps which cannot come in contact with the reagent. The calcium carbide reagent used with the Speedy tester is a hazardous product that must be handled with care by the user and with consideration for the environment.
Road-Bed Water Content Meter	The DOT600 is used to measure volumetric water content of samples of roadbed. The method used to estimate water content is based on measuring the dielectric permittivity of the material surrounding the probe rods. The DMM 600 calculation involves empirically derived calibration equation to provide volumetric water content.	This tool allows operators to monitor roadbed volumetric and gravimetric water content. Sample bulk density, compaction force, and Sample volume and weight can also be monitored. In Addition the system is completely portable.	The device is based on an empirically derived calibration equation to provide volumetric water content.
Vertek SMR	The Vertek SMR (Soil Moisture Resistivity) probe measures the moisture content of subgrade and base materials. It provides real-time, in-situ logs of soil moisture and resistivity without sampling. This probe uses the relationship between the soil dielectric constant and moisture.	Instantaneous measurements. Lightweight. Simple to operate. No licensing required. Faster than nuclear.	Research shows it provides reasonable correlation with core density measurements approximately 75 percent of the time. Must be calibrated to the mix, ideally with both a slope and linear offset. - Only performs a slope calibration

Appendix C

TASK IV

Evaluation of LWDs- calibration, check for accuracy, and comparison between different LWDs

Large scale laboratory testing

In order to verify the repeatability and accuracy of different LWD devices, it is important to compare the measurements on a reference known material. In an effort, this need was discussed with knowledgeable people in the community. Their recommendations and the practice they followed for calibrating their specific models of LWDs are as followed:

MnDOT- John Siekmeier recommendation

Zorn – Light Weight Deflectometer (LWD) Repeatability Test procedure

The results of this testing is currently being used to determine when devices require calibration and/or repair. The measurements and its variation on the stacks of the pads with different thicknesses are compared to the numbers in a reference charts. Table 1 provides the information on the material used in this test.

Table 4 Test pad requirements

Description	Plain Elastomeric Bearing (polychloroprene bearing pads) (without steel laminates)	
Dimensions	Diameter	Thickness
	18 in (460 mm)	13 mm (0.5 in) 25 mm (1 in) 50 mm (2 in) 65 mm (2.5 in) 120 mm (4.75 in)
Duro Hardness (ASTM D2240)	60 ± 5 shore point	
Minimum Tensile Strength (ASTM D412)	15.5 MPa (2250 psi)	
Minimum Ultimate Elongation (ASTM D412)	350%	
Vendor	DS Brown Company 300 East Cherry Street North Baltimore, OH 45872 419-257-3561 (phone) 419-257-0332 (Fax)	

These bearing pads are designed to withstand significant material property changes over time for bridge use.

According to MnDOT report, Zorn Company uses polyurethane – ACLACELL during calibration. There was an uncertainty about the quality of the material with respect to environmental degradation even though they were stored in closed boxes within the laboratory.

Paul Fleming UK

I used some shock absorbing mats I purchased from a specialist here in the UK, we used four on top of each other to get repeatable data

300m plate and 100kPa contact pressure gave a stiffness of approximately 30MPa.

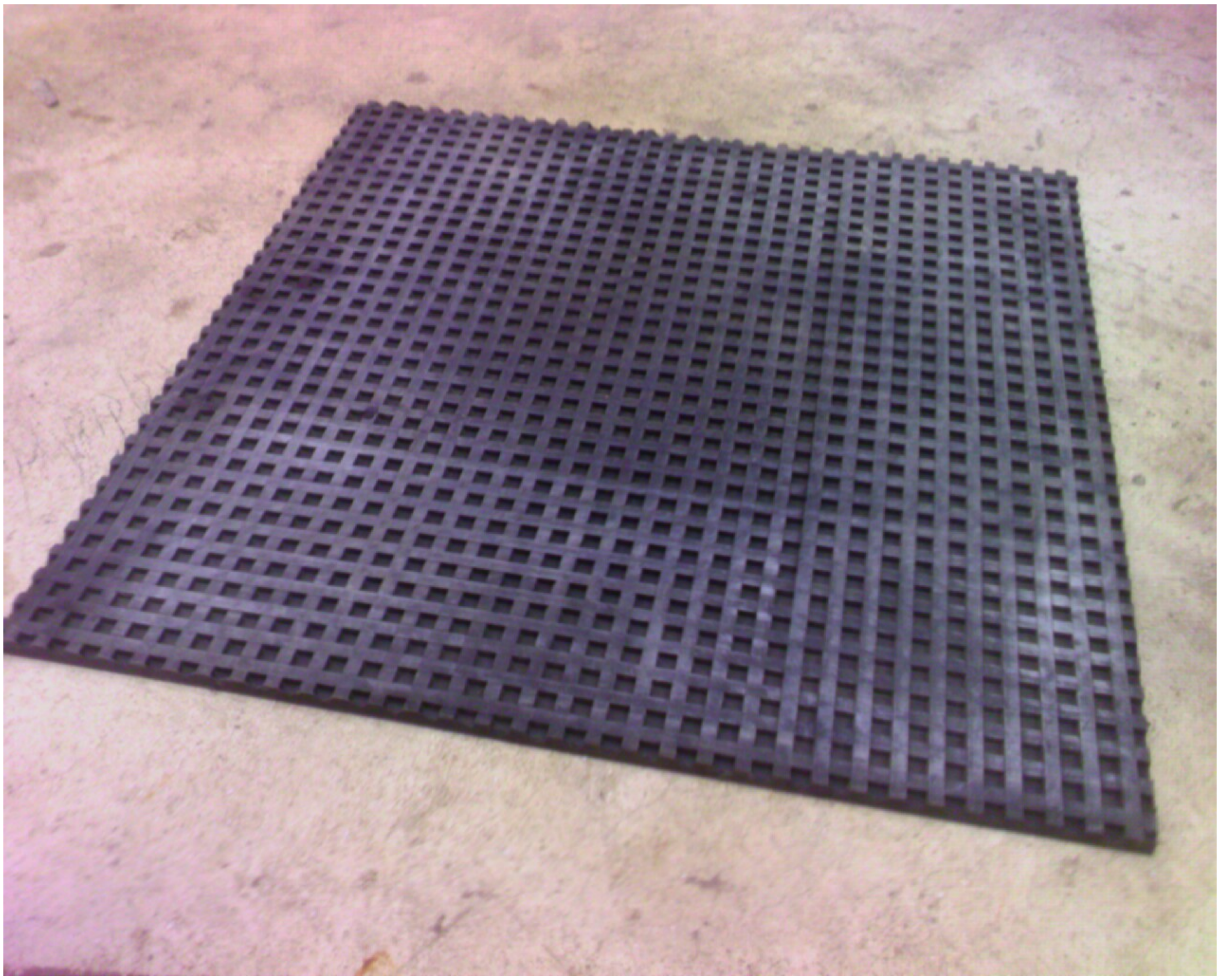


Figure 1. Shock absorbing mat- Four of these were stacked to evaluate the LWD response

Jens Preben Pedersen- Grontmij A/S

In my opinion you must build something like a “Spring Box” and fill it with a Sharp well graded sand.

Bilodeau and G. Dore (2013) used Ultra High Molecular Weight Polyethylene (UHMW) plastic plate. It has an elastic modulus of 550 MPa (80 ksi) which can be considered as having properties similar to stiff granular soils.

Garry Aicken Zorn- Kesslerdcp

Here are the details regarding limitations in the use of rubber mats for verifying LWD that are governed by ASTM E2835 (the ones that measure the plate deformation instead of the ground).
On a rubber plate there is no damping effect and no inertial mass like on real soil.
The falling mass, the plate springs, the load plate and the rubber work like a two mass oscillators.
Depending on masses and spring forces you get a chaos system where the resonance between the rubber mat and the LWD plate will affect the results.
You will see this effect in the deflection curves shown in the print outs.
You will see two, three or more peaks, an oscillating process. This leads to such big differences between single drops.
The reason of these deviations are not the LWD`s but the validation method. To demonstrate this effect make a test on well compacted soil with 10 or 20 tests (30….50 drops) at the same place. The deflection values will decrease something but the single deviation from drop to drop is smaller.
Zorn recommends that if a rubber mat is going to be used then, the device needs to be set up in calibration mode to measure the maximum deflection only and not the deflection curve. You will not get an Evd value in this mode.

This is what Zorn recommends for a verification program to avoid the problem with the rubber mat method.

Validation pits:
1. Size:
Minimum depth should be 60 cm (2 ft.), like the measuring depth and open with 1.5 m x 1.5 m because influence of wall, a compactor should work inside, vibrating plate or vibrating sheepsfoot.
2. Preparation of the validation pit
Fill in homogenous, well mixed material in three or four layers, single layer compacted and Evd tested. The final Evd should be in the range of 55 up to 65 MN/m².
3. Soil properties:
Take the same material like used in road construction, sub base, well to compact.
It should be a well graded soil with a wide range of particle sizes with a maximum of 1/2", but avoid small particle sizes like silt and clay, minimum should be 0.5 mm. Cohesive soils are very susceptible to moisture!
4. Lab tests:
To determine the soil condition it is recommended to run the Proctor test, sieve curve and other standard lab tests. From time to time, a moisture test on the surface is helpful, because of the near surface drying effect.
5. Procedure:
Take the validation test every time at the same place. The Evd will increase from test to test but will be constant at last.
Remarks:
The described validation pit will change over the time (earth works experience). You should make tests from week to week and monitor the changing properties.
It could be you have to compact again or to replace the evaporated water.

Dynatest:

Dynatest does not test the LWD moduli calculation on a reference material. Instead, they test the geophone and the load cell measurements to meet specifications. They use a PCC slab at the shop in DK to test all deflection devices. They have a range of values for LWD measurements on this slab and they use it mainly for testing the overall functionality of the device. The argument for not testing the moduli output value is that it is not part of the measuring device. It is in fact part of the calculations.

Regis Calvalho- recommendation

The best approach to compare all devices is to compare readings and not moduli in some sort of benchmarking approach with several devices, including FWD at very low load levels. Ideally these tests would be done in a controlled test pit inside the lab, where variations of moisture are not large. But that is difficult. So your best option is construction sites.

Alternatively you could have a really large dense rubber cube custom built and installed in a test pit. You would know what the elastic modulus of the cube is and you could use it to test all LWD devices. There are manufactures that can do it, e.g. http://www.rubbercal.com/index.html.

Grasmick 2013

Grasmick (2013) used soil box for his evaluations. Using this soil box even though reduces some of the uncertainties in the real projects, has its own issues. He explored the reflection of the seismic waves, induced by LWD testing, off the wood/soil box boundary and its effect on deflection measurements. In absence of energy absorbent in the boundary 30% of the incident wave amplitude will reflect back to the load source and interfere with deflection sensors measurements of the radial geophones. While past studies neglected this issue, he indicated that these reflections considerably affect the results.

He conducted two separate testing procedures:

- Zorn and Prima LWD drop mass for the impulse load at the center of the box, with the two-geophone system 30 cm and 60 cm radially offset from the plate.
- LWD testing using the two-geophone system by applying an impulse load using the rubber mallet to the Prima LWD plate. An accumulation of surface deflections were measured at radial offset distances of 20-80 cm.

He concluded that rubber mallet testing is able to produce measureable deflection bowls that are characteristic to the layered system and was validated by numerical results. The results show promise for an alternative and even more portable method for utilizing the LWD device to characterize layered systems.