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

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**Study Description:**

***Background***

Work by Prezzi et al. (2010), Senseney et al. (2009), Vennapusa and White (2009), and White et al. (2009) has shown the potential of lightweight deflectometers (LWDs) for determining the moduli of natural subgrades and compacted soil layers, including granular bases. A few of these studies, along with the recent NCHRP Synthesis 382 “Estimating Stiffness of Subgrade and Unbound Materials for Pavement Design” (Puppala, 2008), noted as an important research need the evaluation of the abilities of LWDs to determine in-place moduli that reflect moisture influences, stress/strain dependency, and layering effects. Several TRB committees have also identified the LWD as a technology ready for practical use but in need of some well-defined and focused research to fill the remaining gaps impeding widespread implementation.

Existing ASTM Standard Test Methods E 2583–07 and E 2835–11 only address measurement of deflections using LWD. These standards do not provide a standardized way to interpret deflection measurements for the calculation of stiffness or modulus.

Work currently underway in NCHRP Project 10-84 “Modulus Based Construction Specification for Compaction of Earthwork and Unbound Aggregate” addresses some of the issues described above. However, NCHRP 10-84 has a much broader scope that encompasses the entire range of possible *in situ* modulus measurement devices. The work proposed in the present solicitation is focused tightly on LWD devices that are already being evaluated on a trial basis by many states and used for production QA testing by a few.

Earthwork and unbound bases represent a significant portion of highway construction and are critical to the performance of highway infrastructures. For these materials, elastic modulus is the primary input to pavement structural design and a major factor governing pavement performance and service life. This is especially true for the new MEPDG as implemented in the DARWin-ME software. Nuclear gauges, which many agencies currently use for QA of earthwork and unbound bases, can only estimate density and moisture content, not modulus. Direct measurement of subgrade and base moduli during construction via LWD, in conjunction with in situ moisture measurement, can confirm whether construction meets the design intent. Equally important, LWD measurements can provide a database of realistic elastic modulus values for use in future MEPDG designs using DARWin-ME.

For those states that currently use nuclear gauges, another practical benefit from transitioning to LWD for construction QA is reduced costs. Although the initial cost of an LWD is roughly comparable to that of a nuclear gauge, nuclear gauges have much higher annual costs for maintenance, calibration, leak tests, film badges, Radiation Safety Officer training, and specialized on site storage. These recurring annual costs for nuclear gauges can be as much as 15% of the initial device cost. LWD devices require much less maintenance, less frequent calibration, and none of the radiation-related expenses and operational constraints.

As the benefits of performance related QA testing using LWDs become increasingly apparent, more public agencies and private consultants can be expected to acquire these tools and implement standardized procedures for their use. Performance related QA testing will result in increased compaction uniformity, improved documentation, and increased inspector safety and productivity. The standards developed in this research will provide a basis for state DOTs to modify their construction specifications to include the LWD option for construction QA. This will not only result in a better constructed highway system but it will also provide measured values of modulus that are vital to improving our understanding of the connection between pavement design and long term pavement performance.

***Objectives***

The primary objective of this study is to provide state DOT and local government engineers with a practical and theoretically sound methodology for the evaluation of in-place elastic modulus of unbound layers, subgrades, and other earthwork from LWD field test data. This will require the development of techniques to fully account for: (1) the influence of moisture suction pressures on LWD measurements, (2) the differences in the LWD induced stress states/strain levels and the stress states/strain levels induced by construction equipment and long term traffic loads, and (3) the effects of layering on LWD measurements when testing on finite-thickness layers (e.g., base or subbase over subgrade) vs. half-space conditions (e.g., subgrade). The test standards and analysis methodologies developed in this study will enable agencies to: (a) use LWDs with confidence for construction QA; (b) develop catalogs of appropriate design modulus values for use in pavement structural design, specifically in the MEPDG and its companion DARWin-ME software; and (c) reduce recurring annual costs associated with QA inspection of soils and unbound materials.

***Scope of Work***

The primary objective of this study is to provide state DOT and other highway and pavement engineers with a practical and theoretically sound methodology for interpreting LWD field measurements. There is currently no widely recognized standard for interpreting the load and deflection data obtained during construction QA testing and then relating these measurements to the elastic modulus values used in pavement design. This research will provide a straightforward procedure that can be employed by inspection personnel. The scope of the theoretical rigor will be tempered by an understanding of what can reasonably be done during construction QA testing.

Many issues must be evaluated in order to meet this objective. Although there is much good data available in many state DOT reports and other literature, it is expected that there will be gaps that will need to be filled by a focused, well-planned field and laboratory testing program. As a minimum, the following issues must be evaluated to determine how to best include the most significant and/or sensitive factors without making the final product impractical for widespread implementation. Any robust methodology for determining stiffness/modulus from LWD testing must consider:

* The operating characteristics, measurement performance, limitations, and reliability of all LWD devices currently on the market.
* The physical characteristics of the LWD including plate diameter, mass, rigidity, ground contact, and seating; hammer mass and drop height; load pulse amplitude and duration; and number/position of sensors.
* What is to be measured and how (where several technologies exist, the product of this research will justify the appropriate translation between LWD devices).
* The influence of moisture and the effect of soil type on the suction stress and thus the effective confining pressure and its influence on modulus. Measurement/estimation of in-place soil moisture will be required to evaluate properly the LWD deflection measurements and elastic modulus determination.
* The validity and limitations of the algorithms to estimate modulus (e.g., static Boussinesq elastic half space analysis vs. layered elastic analysis, load vs. unload moduli).
* The depth of the LWD zone of influence and the influence this has on measured modulus values.
* The influence of stress state and/or strain level, especially in comparison to actual stress states/strain levels beneath the finished pavement under traffic loading.
* The influence of pavement foundation layer thickness, number of layers, and moduli ratios.
* The effect of soil type on the stress distribution beneath the plate and resulting modulus.
* The spatial, temporal, and inherent variability of field modulus values.

The deliverables from this study will include proposed test standards and analysis methodologies. These will be drafted in standard AASHTO format. Recommendations for how LWD elastic modulus measurements can be used for pavement design using the MEDPG/DARWin-ME software will also be developed and forwarded to the appropriate AASHTO bodies (e.g., the Joint Technical Committee on Pavements, DARWin-ME Task Force).

An optional third year of funding is included for a pooled fund purchase of the test equipment recommended by the research. This funding will cover equipment purchase and training for sponsoring agencies, at their option.

**Duration Of Project:**

24 months

**Financial Commitment:**

Total cost of project/total financial commitment: $400,000

The total financial commitment includes all study costs, including travel expenses for participating agency personnel to attend three project meetings (one at the beginning of the project and the others at approximately the 50% and 75% points). In addition, there will be quarterly updates to all participating agencies via quarterly progress reports and follow-up conference calls and/or web meetings

Total financial commitment per state: $50,000 total (plus optional $25,000 for third year)

$25,000 per year for two years (with optional additional $25,000 for pooled fund equipment purchase and training in third year.)

Required number of participating agencies: 8

Start year for commitment: 2013 (calendar year)

End year for commitment: 2014

**Comments:**

100% SP&R Approval is requested.

The Maryland State Highway Administration (SHA) will serve as the lead agency for this pooled-fund project. The Maryland SHA will issue notice-to-proceed to the University of Maryland to conduct the study. Dr. Charles W. Schwartz, who will serve as Principal Investigator, has extensive experience in the topic. The project will require rental or purchase of various test equipment. The economic benefits of rental vs. purchase will be evaluated in each case.