# Standardizing Lightweight Deflectometer Modulus Measurements for Compaction Quality Assurance

## Introduction

Elastic modulus is the fundamental material input required for the structural design of pavements. Modulus-based compaction quality assurance (QA) of unbound materials is gaining popularity as conventional nuclear density gauge (NDG) testing becomes less desirable due to safety, regulatory, and cost concerns. The Lightweight Deflectometer (LWD) is a portable device that can be used to measure the surface modulus of unbound layers directly in the field. The principal objective of this research was to provide a straightforward procedure for using LWDs for modulus-based compaction QA that is suitable for practical implementation by field inspection personnel and that does not increase workload significantly.

The Zorn ZFG 3000, Dynatest 3031, and Olson LWD-1 devices were selected as representing the range of commercially available device configurations. In addition, two non-nuclear water content devices were evaluated: a Decagon GS-1 volumetric and an Ohaus MB45 gravimetric moisture analyzer.

Three test pits were designed and constructed at the Federal Highway Administration's Turner Fairbank Highway Research Center to simulate under controlled conditions scenarios of acceptable and failing construction quality. The pits were carefully constructed using two different cohesive and non-cohesive subgrade soils and one type of granular aggregate base. LWD deflections on the final layer at each pit were initially used to assess the spatial variability for the three LWD types. Additional material was collected for further routine and advanced tests in the laboratory, including compaction moisture-density relations and resilient modulus tests on samples prepared at optimum and field conditions. Lastly, the concept of LWD testing directly on the compacted Proctor mold was developed to derive the target modulus values for the field.

## Results Summary

**Evaluation of MC Measurement Devices.** MC as a critical factor affecting the modulus of geomaterials in the field. The MC should be measured and compared to the acceptable MC range derived from Proctor testing in the lab. It was found that the Decagon sensor is difficult to insert when the soil us compacted to a high density and impractical for base materials having large aggregate sizes. Therefore, only the Ohaus moisture analyzer was evaluated versus NDG and oven drying during the field validation phase.

A good correlation was observed between the water content measured by the Ohaus MB45 and the nuclear moisture-density gauge for the large-scale test pit soils after applying a 1.11 correction factor determined from laboratory calibration. The MC data from the Ohaus device also correlated well versus oven dried samples in the field validation sites after applying the correction factor. Newer Ohaus device models with higher soil capacity appropriate for testing larger aggregates in the field are now commercially available.

**Evaluation of LWD Devices.** Different LWDs with different configurations (drop height, deflection sensor type, plate size and type, etc.) measure different modulus values in the field and in the lab. To minimize the effect of these discrepancies, it is recommended that the same type of LWD be used for target modulus determination in the lab and the as-placed modulus in the field. The plate size and applied pressure should also be reported with the target modulus value.

**Laboratory Testing Program.** Routine laboratory tests including moisture-density relations plus the LWD testing on the Proctor mold were performed on all soils. The LWD on mold test provides essential insights into the moisture, density and stress dependency of the soil that can be used to tailor the compaction criteria in the field. The LWD on mold moduli were interpolated at the appropriate applied stress level and compaction MC of the test pits and field validation sites to establish the target LWD modulus.

**Field Testing Program.** A total of eight projects in six states were visited during the field validation phase. MC in the field was measured using the Ohaus MB45 analyzer and compared to the acceptable MC range from Proctor moisture-density relations testing. The LWD on mold tests were performed on the soil samples collected from each test site. Then the target moduli ($E_{LWD\_Target}$) were estimated at the corresponding field water content and plate pressure and compared to measured moduli in the field ($E_{LWD\_Field}$) by calculating the field to target modulus ratio (Figure 1). LWD on mold target moduli were also corrected for the effect of finite layer thickness for aggregate base layers.

For the sites at which NDG measurements were available, percent compaction (PC) was used as a reference for the quality of compaction and compared to the field to target modulus ratios. For the well-compacted material, both the PC and $E_{LWD\_Field}/E_{LWD\_Target}$ criteria were satisfied. Sites with inadequate compaction failed to meet both criteria. This confirmed the applicability of the proposed LWD testing methodology for field QA evaluation.

**Specification Development.** Draft test method specifications were developed for LWD testing in the field and for target modulus determination in the lab. The specifications are written in AASHTO format and provide the additional steps required to establish the target modulus using the Proctor method of moisture-density relationship determination (AASHTO T-99 and T-180) and to adjust the target field modulus for finite layer thickness. The specifications are written generally so that agencies can make appropriate adjustments for their local material and equipment conditions.

The steps for calculating the acceptance criteria and the minimum required sampling frequency were illustrated using the data collected from the field validation sites. However, the results must be used with caution because of the limited number of materials evaluated in this study.

## Conclusions

Overall, the LWD on mold method of target modulus determination provides a smooth transition from density-based methods to modulus-based compaction QA. It is applicable to a variety of geomaterials, including chemically stabilized and non-stabilized subgrades and bases. It is cost efficient and does not increase work in the field significantly. To effectively implement this QA plan, agencies should calibrate the specifications using test projects in conjunction with conventional density-based NDG QA.

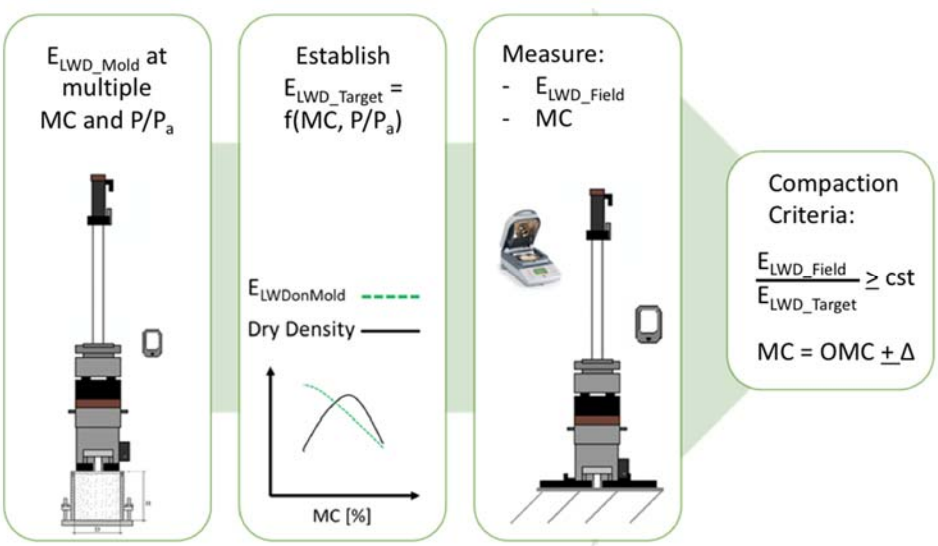


**Figure 1. Flowchart for the LWD on mold method of compaction QA.**