Joint Transportation Research Program

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Using the Light Weight Deflectometer for Performance-Based Quality Assurance Testing of Cement Modified Subgrades

Introduction

INDOT has been implementing light weight deflectometer (LWD) testing for compaction acceptance since the introduction of the 2016 standard specifications. LWD acceptance testing had been limited to the compaction of aggregates; however, INDOT has sought to expand its implementation because LWD is an easily operated, rapid in situ test that assesses soil stiffness. INDOT began specifying LWD testing for chemically modified soil acceptance with the introduction of the 2018 standard specifications. However, acceptance criteria for LWD testing of chemically modified soils were based on limited research. Indeed, acceptance criteria was not associated with performance-related engineering parameters. Resilient modulus (M_r) is the most critical performance-related engineering parameter for subgrades in pavement design, so chemically modified subgrade acceptance criteria should reflect M_r design values. In addition, INDOT requires that chemical modification increases soil unconfined compressive strength (UCS), so chemically modified subgrade acceptance criteria should reflect UCS increase. Therefore, the goal of this study is establishing LWD acceptance criteria that relate to subgrade M_r and UCS increase for chemically modified soil, particularly cement modified subgrade (CMS).

Successful outcomes for this study involve completing the following objectives:

- Develop laboratory-based relationships for predicting M_r and UCS increase from LWD measurements for CMS.
- Gather in situ LWD test measurements from field studies at INDOT's CMS construction projects to assess the laboratory-generated relationships predicting M_r and UCS increase from LWD.
- Revisit the INDOT construction project field studies after paving to conduct falling weight deflectometer (FWD) testing for additional assessment of CMS performance properties predicted from LWD testing.
- Compare LWD predicted M_r values with resilient moduli back-calculated from FWD testing for CMS using rigorous statistical analysis.
- Provide recommendations for CMS LWD acceptance criteria that adequately reflect design assumptions—M_r and UCS increase.
- Provide general recommendations for improving pavement design, construction, and performance as they pertain to CMS.

Findings

A rigorous field study consisting of LWD testing and falling weight deflectometer (FWD) testing at INDOT new pavement construction sites was conducted to verify the laboratory developed relationship. Recommendations for implementing results of this study into CMS construction acceptance is provided, as are recommendations for future research.

The key findings from this study are as follows:

- Unconfined laboratory LWD elastic moduli for cement modified soil increases with increasing applied axial stress following an exponential growth relationship. Using the generalized form of Hooke's law, the laboratory LWD elastic moduli can be used in three-dimensional applications (e.g., in situ LWD testing) for predicting in situ LWD deflections and elastic moduli (Section 3.3.1).
- At equivalent stress conditions and equal curing times, LWD elastic modulus is approximately equal to M_r for cement modified soil. Multiplying as-constructed (i.e., 1-day cured) LWD modulus by a curing coefficient allows for direct comparison with long-term M_r (Section 3.3.2).
- Using a probabilistic model with LWD deflection equaling 0.45 mm, there is a 90% probability that M_r meets or exceeds 9,000 psi (i.e., design M_r for clayey soil). Likewise, with LWD deflection equaling 0.43 mm,

there is a 90% probability that M_r meets or exceeds 9,500 psi (i.e., design M_r for sandy soil) (Section 3.3.2).

- If measured LWD deflection equals 0.27 mm, as specified in the INDOT standard specifications; then there is an 86% probability that ΔUCS will meet or exceed 70 psi (i.e., recommended UCS increase). For there to be a 90% probability that ΔUCS meets or exceeds 70 psi, measured LWD deflection should equal 0.21 mm (Section 3.3.3).
- Detailed case histories for new pavement construction projects incorporating CMS have been developed. Case histories consist of laboratory mix designs, LWD elastic moduli during construction, and FWD-derived resilient moduli after pavement placement have been generated (Section 4.2).
- LWD deflections from all field test sites combine into a skewed right distribution; however, logarithmic (base 10) transformation yields a nearly normal distribution with -0.586 average (0.259 mm) and 0.158 standard deviation (Section 5.1).
- Bland-Altman comparison between LWD and FWD measurements reveals that M_r predicted from 1-day cured LWD adequately agree with M_r back-calculated from FWD measured on the pavement surface (Section 5.1).
- A probabilistic model for LWD predicted M_r was generated using statistics from LWD field results combined with the standard error for predicting M_r from LWD elastic modulus. Predicted M_r equals 13,200 psi at p = 0.1 that corresponds to 90% of construction acceptance tests yielding passing results (Section 5.2).
- A probabilistic model for FWD back-calculated M_r was generated using statistics from FWD field tests. FWD back-calculated M_r equals 17,800 psi at p = 0.1 that corresponds to 90% of construction acceptance tests yielding passing results (Section 5.2).

Implementation

INDOT standard specifications require that LWD deflection measured on CMS equals no greater than 0.27 mm on average. Findings from the laboratory portion of this study suggests that 0.27 mm LWD deflection corresponds to 26,500 psi 28-day cure M_r that is much greater than the 9,000 psi to 9,500 psi M_r used in new pavement design. Therefore, the current maximum deflection criterion adequately assures pavement design assumptions.

Besides meeting design resilient moduli, CMSs must be able to function as construction working platforms. INDOT design procedures for chemical modification and stabilization of soils require that cement modification increase laboratory UCS by 100 psi (70 psi in the field, see Section 3.1.3). Findings from the laboratory study suggest that 0.27 mm LWD deflection corresponds to 89 psi UCS increase. Therefore, the current maximum deflection criterion adequately assures proper construction platform construction.

LWD field testing conducted at INDOT's new pavement construction projects showed that LWD deflection equals 0.26 mm on average. So, actual LWD deflections are consistent with the 0.27 mm required by INDOT standard specifications. Moreover, resilient moduli predicted from LWD measurements conducted during construction are in agreement with resilient moduli determined from FWD testing measured atop pavement layers.

A key finding from this study involved typical M_r values for CMS. Conservative estimates for CMS M_r equaled 13,200 psi based on LWD testing and 17,800 psi based on FWD testing, which are both significantly greater than the 9,000 psi to 9,500 psi resilient moduli used in new pavement design. However, neither the LWD- nor the FWD-based methods directly measure M_r. Therefore, there is no assurance that either method truly predicts M_r. Rather, it is recommended that additional testing be conducted to explore this finding further.

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