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Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials (FHWA DTFH61-07-C-R0032)

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http://www.ceer.iastate.edu/research/project/project.cfm?projectID=-373342403

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Introduction

This demonstration was conducted on US Highway 69 near Pleasanton, Kansas. The machine configurations and roller-integrated compaction measurement (RICM) systems used on this project included (as shown in Figure 1) a Sakai SV610 padfoot roller equipped with continuous compaction value (CCV) measurement and a Caterpillar CS56 padfoot roller equipped with machine drive power (MDP) measurement system. A smooth drum shell kit was installed on the Sakai padfoot roller near the end of the project. Both machines were equipped with real-time kinematic (RTK) global positioning system (GPS) and on-board display and documentation systems.

The project involved constructing and testing calibration and production test areas with cohesive subgrade materials. The RICM systems were evaluated by conducting field testing in conjunction with a variety of in situ testing devices measuring the following: dry unit weight (γd), moisture content (w), California bearing ratio (CBR) from dynamic cone penetrometer, dynamic elastic modulus using a 200 mm plate light weight deflectometer (E_{LWD-Z2}) and a 450 mm plate falling weight deflectometer ($E_{FWD-D4.5}$), and initial (E_{V1}) and re-load modulus (E_{V2}) using a static plate load test with a 300 mm diameter plate.

The goals of this field study were as follows:

- Evaluate the effectiveness of the padfoot roller measurement values—MDP and CCV—in assessing the compaction quality of fine grained cohesive subgrade materials
- Develop project-specific correlations between padfoot roller IC measurement values and various conventionally used in situ point measurements in earthwork quality control (QC) and quality assurance (QA) practice
- Evaluate the advantages of using the technology for production compaction operations

Figure 1. Sakai SV610 padfoot roller (left), Sakai SV610 padfoot roller setup with smooth drum shellkit (right), and Caterpillar CS56 padfoot roller (bottom)

RICM Systems Overview

CCV and MDP measurement technologies were evaluated in this study. CCV is a vibratory-based technology that makes use of an accelerometer mounted to the roller drum to create a record of machine-ground interaction. CCV is calculated using the acceleration data from first sub-harmonic, fundamental, and higher-order harmonics. CCV obtained from padfoot and smooth drum shell kit configurations are denoted as CCV_{PD} and CCV_{SD}, respectively. Additional information about CCV is provided in White et al. (2008).

MDP relates to the soil properties controlling drum sinkage and uses the concepts of rolling resistance and sinkage to determine the stresses acting on the drum and the energy necessary to overcome the resistance to motion. MDP values can be obtained in both vibratory and static compaction operation modes. The MDP values reported on this project are shown as either MDP_{80} or MDP_{40}, depending on the setting used. Detailed information about these settings are provided in White et al. (2008). In brief, MDP_{40} provides higher resolution between soft and stiff ground conditions than MDP_{80}.

Test Beds and Materials

A total of seven test beds (TBs) consisting of cohesive subgrade materials were constructed and tested in this field study. TBs 1, 2, 3 (lift 4), 4, and 5 involved construction of calibration test strips by obtaining in situ point measurements at multiple roller passes. TB3 involved obtaining roller measurements during production construction with seven lifts of weathered shale and lean clay fill materials placed over wet/soft foundation subgrade layer. In situ point measurements were obtained at select locations on the foundation subgrade and on each lift after final pass on TB3. TBs 6 and 7 involved mapping a production area consisting of stiff weathered shale and relatively soft lean clay subgrade materials, respectively.

TB 1, 2, and 4 subgrade materials were classified as CL or A-6(4). The TB3 foundation layer subgrade was classified as CH or A-7-6(36). The TB3 subgrade fill material was classified as CL or A-6(10) to A-6(12).

Calibration Test Strips

Calibration test strips were constructed on five test beds with multiple roller lanes compacted using different vibration settings (i.e., static, low amplitude, and high amplitude). In situ tests were obtained at multiple roller passes to develop compaction curves and compare with RICM value compaction curves. Correlation analysis was performed between in situ test measurements and RICM values on each test bed. Following is a summary of key findings from the calibration test strips.

- MDP_{80} values are repeatable provided the direction of travel along the test bed is constant. The values are not reproducible with change in direction of travel along the test bed.
- MDP_{80} values were influenced by the sloping grade in the direction of travel. Regression relationship between slope angle (α) and MDP_{80} values produced an R^2 value = 0.6. The relationship indicates a decrease in MDP_{80} values with increasing slope angle.
- The CCV_{PD} values are repeatable and the values generally increased with increasing passes similar to in situ point measurements.
- The MDP_{80} and CCV_{PD} values along the test strips generally track well with changes in in situ point measurements.
- TB2 subgrade material compacted using the CS56 padfoot roller in high amplitude mode resulted in higher dry unit weights (96% of standard Proctor maximum density (γdmax)) than in static mode (91% of standard Proctor (γdmax)). (Note that both lanes had average moisture content +0.4% of standard Proctor optimum moisture content.)
- TB3 subgrade material compacted using the SV610 padfoot roller in high and low amplitude settings resulted in similar average γd, E_{LWD-Z2}, and CBR values after pass 13.

Production Area Analysis

Seven lifts of a production area test bed (TB3) with weather shale and lean clay fill materials was constructed over a wet fat clay

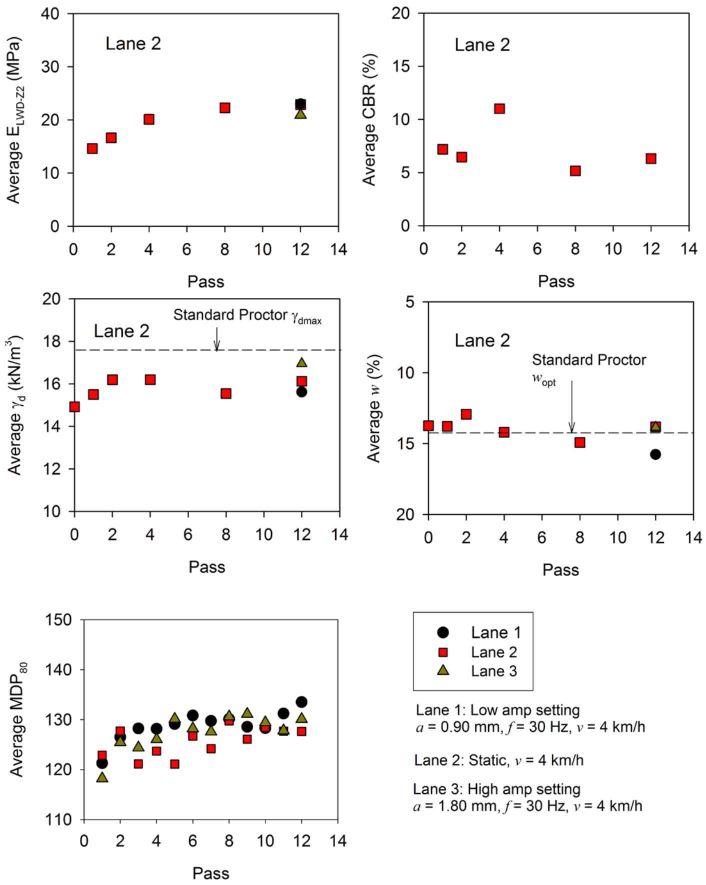

Figure 2. Comparison between average in situ point measurement and average MDP_{80} per pass compaction growth on TB2 subgrade clay material

foundation layer. Color-coded maps of RICM measurements, pass coverage information, and elevation data are presented in Figure 3 from lift 3. Similar figures were developed for various stages of embankment construction and are presented in White et al. (2008). Analyzing and visualizing data in terms of compaction growth on average and at a given point is demonstrated from the production data in Figure 3.

The color-coded maps with 100% coverage and the opportunity to visualize compaction curves can be effective if utilized by the roller operator to make informed decisions on the compaction process to promptly adjust process control measures. Results demonstrated that isolated soft/wet spots can be identified easily using RICM maps. Application of geostatistical analysis methods to analyze RICM measurements to quantify non-uniformity of compacted fill materials is demonstrated on this project and full details of this analysis is presented in White et al. (2008).

Comparison between Padfoot and Smooth Drum CCV

CCV_{PD} and CCV_{SD} measurements are compared by mapping lean clay subgrade (TB6) and weather shale subgrade (TB7) materials. TB7 was comparatively stiffer than TB6. Mapping passes were performed using low and high amplitude settings with each drum setup.

CCV_{PD} and CCV_{SD} maps from TBs 6 and 7 at high amplitude settings are presented in Figures 5 and 6, respectively. Also shown in Figures 5 and 6 are histogram plots of CCV measurements separately for TBs 6 and 7. On average, both CCV_{PD} and CCV_{SD} measurements were higher on TB7 compared to TB 6. Similarly, in situ point measurements were higher on TB7 compared to TB6. The average CCV_{PD} and CCV_{SD} values on TB6 lean clay subgrade material were higher with the low amplitude setting than with the high amplitude setting. In contrast, the CCV_{PD} and CCV_{SD} values on TB7 weathered shale material with the low amplitude setting were lower than with the high amplitude setting. This difference could be because of differences in the stress dependency of the materials; however, additional information would be required to clarify the behavior.

Figure 7 shows linear regression relationships between CCV_{PD} and CCV_{SD} measurement values for low and high amplitude settings. The relationships indicate that CCV_{SD} values at a = 0.63 mm show poor correlations with CCV_{PD} measurements. However, CCV_{SD} values at a = 1.48 mm show good correlations ($R^2 > 0.6$) with CCV_{PD} measurements.

Application of CCV measurements from the smooth drum are much more mature than from the padfoot drum. To the authors' knowledge, this is the first documented project with CCV_{PD} measurements. Although the regression relationships between CCV_{PD} and CCV_{SD} measurements show scatter, the trends are quite encouraging. The padfoot roller measurements demonstrate similar advantages as the smooth drum roller measurements.

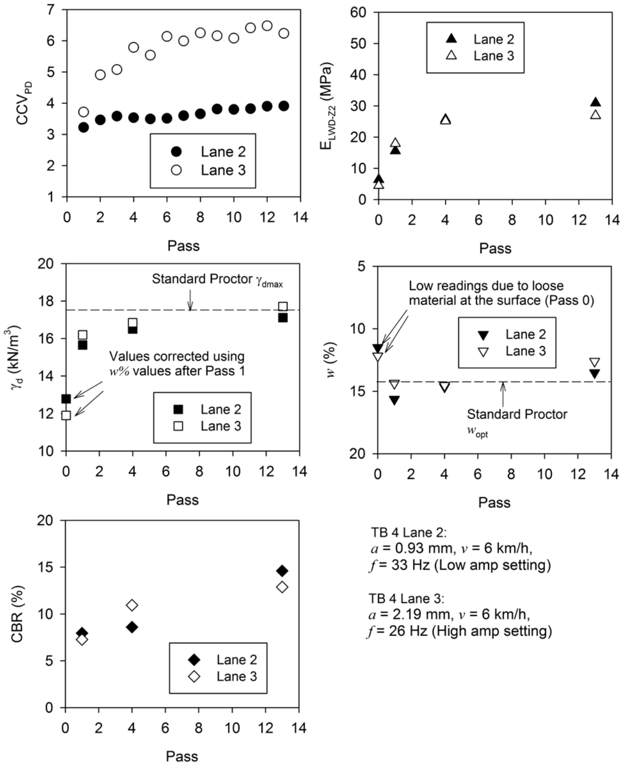

Figure 3. Comparison between average in situ point measurement and average CCV per pass compaction growth on TB4 subgrade clay material

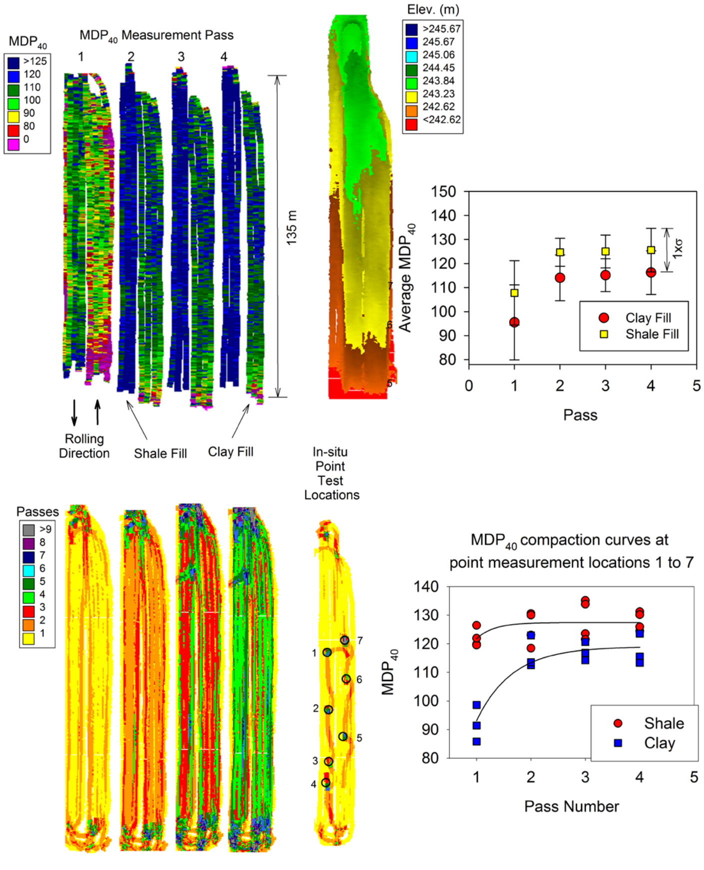

Figure 4. MDP_{40}, elevation, pass coverage, average MDP_{40} (low amplitude setting) per pass, and MDP_{40} at select point locations on TB3 lift 3 clay fill and shale fill material

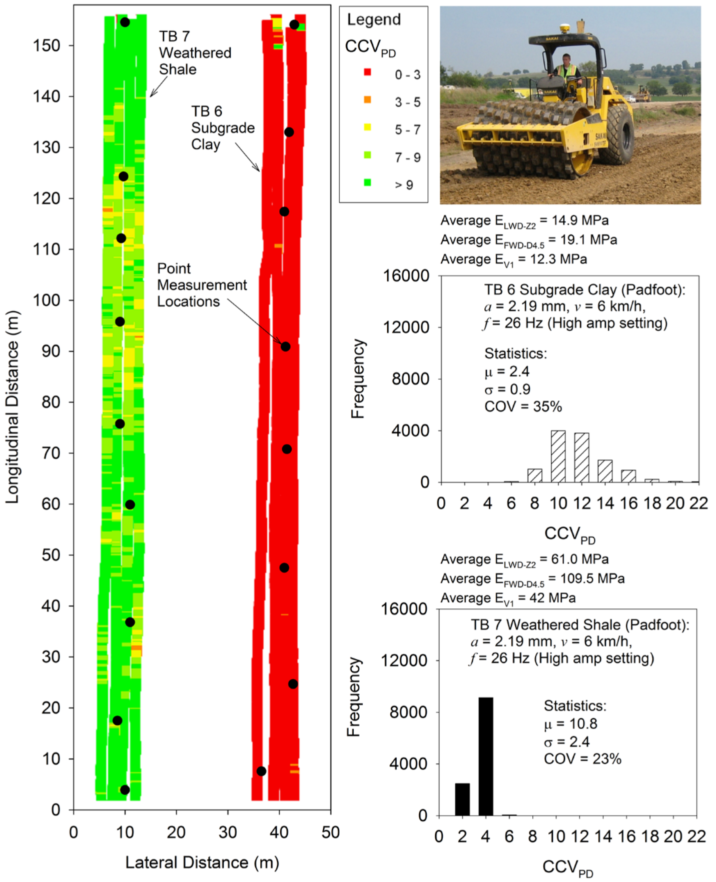

Figure 5. CCV_{PD} map and histogram plots for TBs 6 and 7 (high amplitude setting)

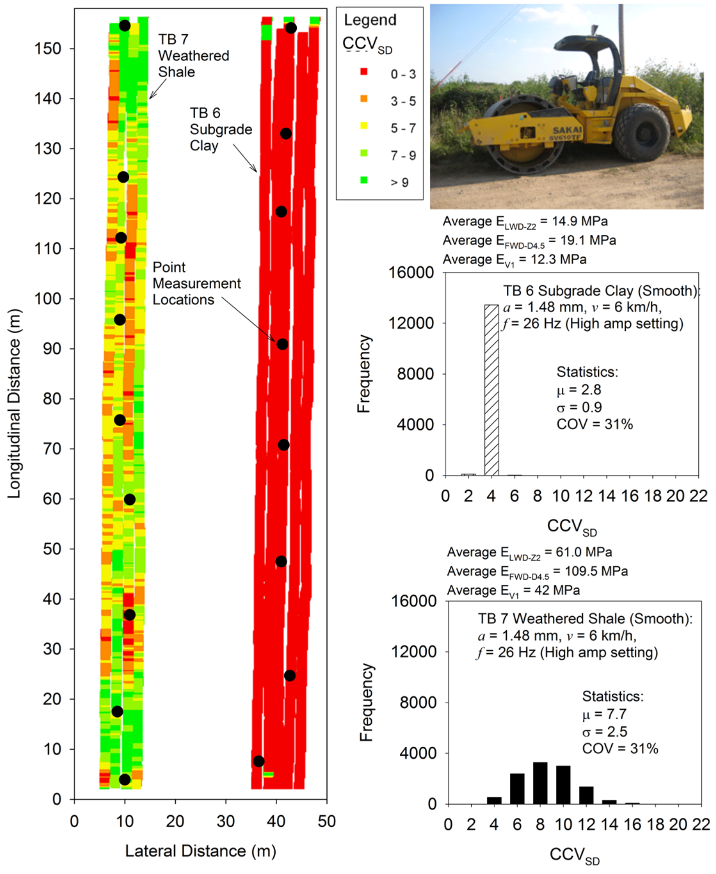

Figure 6. CCV_{SD} map and histogram plots for TBs 6 and 7 (high amplitude setting)

Summary of Regression Analysis

Simple regression analysis was performed combining data from multiple test beds to develop site wide correlations between RICM values and in situ point measurements. Examples of such correlations are presented in Figures 8 and 9. Additional correlation plots are presented in White et al. (2008).

Simple linear regression analysis between RICM values and point measurements produced R^2 values ranging from 0 to 0.9. Reasons for cases with poor correlations are attributed to the influence of underlying support conditions, variations in moisture content, and narrow range of correlated measurements. Point measurements obtained over a wide range of RICM values from calibration test strips helped produce better correlations.

Multiple regression analysis demonstrated that RICM values are influenced by change in amplitude in correlation with in situ point measurement values. Moisture content was also statistically significant for some cases. For some multiple regression models assessing the influence of amplitude, the intercept was not always statistically significant. This resulted in a lower R^2 value than obtained from separate simple linear regression analysis on different amplitudes. In such cases, it is appropriate to interpret the relationships separately for different amplitude settings, instead of combining the results through multiple regression analysis. Although influence of amplitude can be accounted for through multiple regression analysis, it is recommended that all measurements obtained from calibration areas and production areas be obtained at a constant amplitude setting to avoid complication in data analysis and interpretation.

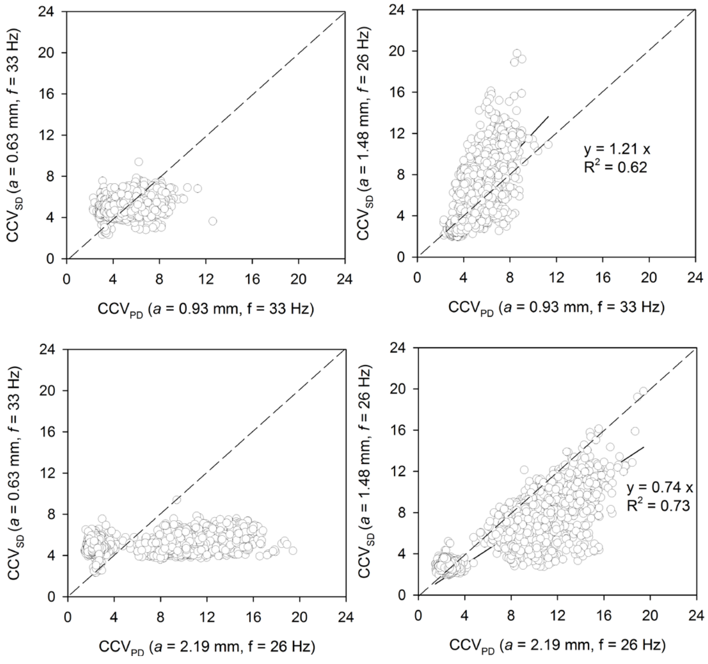

Figure 7. Regression relationships between CCV_{SD} and CCV_{PD} measurement values from TBs 6 and 7

Reference

White, D. J., P. Vennapusa, H. Gieselman, L. Johanson, and R. Goldsmith. 2008. *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials.* FHWA TPF-5(128) - Texas IC Demonstration Field Project. Report submitted to The Transtec Group.

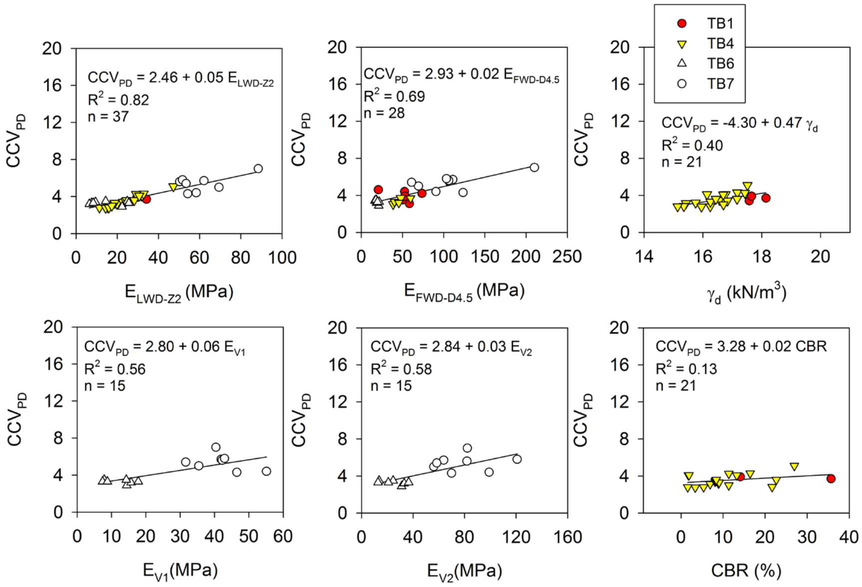

Figure 8. Regression relationships between CCV_{PD} and in situ point measurement values from TBs 1, 2, and 4 calibration test strips and TBs 6 and 7 (a = 0.93 mm, f = 33 Hz)

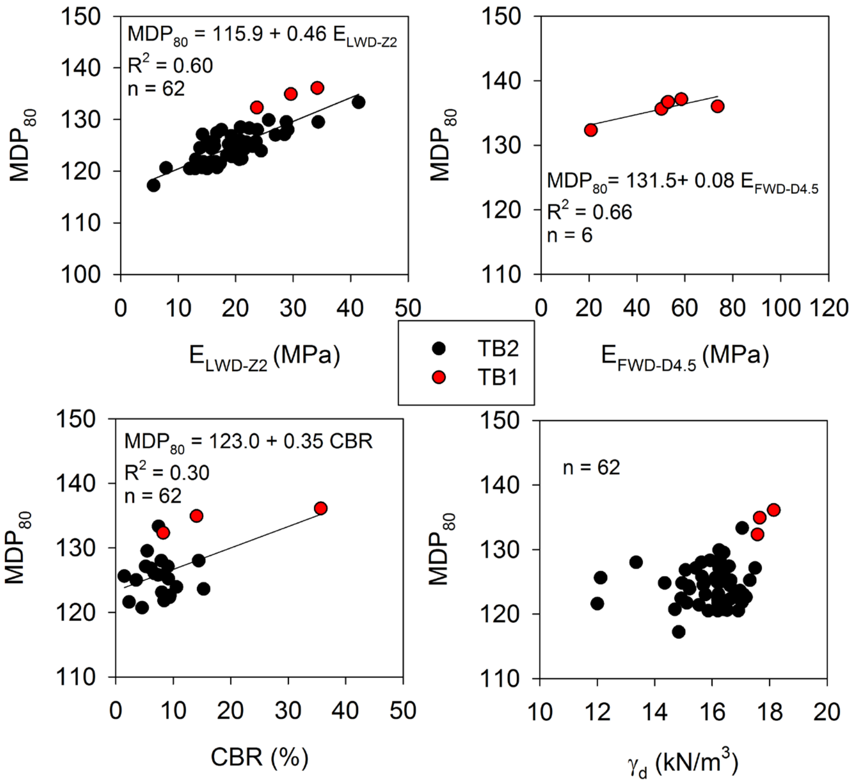

Figure 9. Regression relationships between MDP_{80} (static – driving uphill) and in situ point measurement values – TB 1 and 2 subgrade clay