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Mississippi US 84—Untreated and Cement Treated Granular Materials—July 2009

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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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MORE INFORMATION
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Introduction

This demonstration project was conducted on US84 highway in Waynesboro, Mississippi. The machine configurations and roller-integrated compaction measurement (RICM) systems used on this project included (Figure 1): a Caterpillar CP56 padfoot roller equipped with machine drive power (MDP) and compaction meter value (CMV) measurement systems, a Sakai SW880 dual vibratory smooth drum roller equipped with compaction control value (CCV) measurement system, and a Case/Ammann SV212 smooth drum vibratory roller equipped with roller-integrated stiffness (k_s) measurement system with automatic feedback control (AFC). All the 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 nine test beds with untreated and cement treated granular base and granular subgrade materials. The RICM values were evaluated by conducting field testing in conjunction with a variety of in-situ testing devices measuring density (γ_d) or relative compaction (RC), moisture content (w), California bearing ratio (CBR), dynamic elastic modulus using a 300 mm diameter plate light weight deflectometer (E_{LWD}) and a 300 mm diameter plate falling weight deflectometer (E_{FWD}), and static initial and reload modulus (E_{V1} and E_{V2}) using a 300 mm diameter static plate load test. The goals of this field investigation were to:

- develop correlations between RICM values and traditional in-situ point measurement values (point-MVs),
- evaluate usefulness of using RICM maps for selection of QC/QA test locations,
- explore geostatistical methods to quantify and characterize spatial non-uniformity of embankment materials,
- evaluate AFC mode operations in comparison with manual mode operations,
- compare RICM values on untreated and treated subgrade and base layers (shortly after compaction and after 2 days of curing).

Figure 1 – Caterpillar CP56 (top left) padfoot roller equipped with MDP technology, Case SV212 (above) smooth drum roller equipped with k_s technology, and Sakai SW880 (bottom left) dual smooth drum roller equipped with CCV technology (from White et al. 2010)

Materials

Two granular subgrade materials and one granular base material were evaluated on the project. The subgarde materials consisted of light red silty sand classified as A-4 to white poorly graded to silty sand classified as A-3. The granular base material consisted of light red silty sand classified as A-2-4. All the materials were non-plastic.

Test Results

A total of nine test beds were constructed and tested as part of this project. A few highlights are presented in this document for brevity. Additional information is provided in White et al. (2010).

CCV map on a test bed consisting 5-day cured 150 mm thick cement treated granular base layer is presented in Figure 2. Following the mapping pass, in-situ point MVs (E_{LWD}, E_{FWD}, RC, E_{V1}, E_{V2}, and DCP-CBR profiles) were obtained from 20 test locations. Results from three selected locations with low, medium, and high CCVs are presented in Figure 2. The average CCV on this test bed was about 2 times higher than on an untreated base layer test bed (TB1) located adjacent to this test bed. Similarly, the average point-MVs (E_{LWD}, E_{FWD}, RC, E_{V1}, E_{V2}, and DCP-CBR) on this test bed were about 1.3 to 2.6 times higher than on TB1. The RC was however greater on TB1 (93%) than on TB2 (89%). Geostatistical analysis on CCV revealed that this test bed was comparatively more non-uniform (sill = 28, standard deviation = 6) than the untreated base layer (sill = 6, standard deviation = 13).

Results from TB7 consisting an untreated subgrade layer are presented in Figure 3. The subgrade material was variable across the test bed with portions of it containing white and red subgrade sand. White sand contained 8% fines (A-3) while the red sand contained about 37% fines passing the # 200 sieve (A-4). The portion of the test bed with white sand was unstable under construction traffic due to lack of confinement at the surface. The area was mapped in three roller lanes with Case/Ammann smooth drum roller for one pass each in manual mode and in AFC mode settings, and Caterpillar padfoot roller for one roller pass. In-situ point-MVs (E_{LWD}, E_{FWD}, RC, E_{V1}, E_{V2}, and DCP-CBR) were obtained at 10 test locations along one roller lane. The color-coded spatial RICM maps and linear plots along one lane are presented in Figure 3. DCP-CBR profiles at 6 selected locations (i.e., with high, low, and medium RICM values) are also presented in Figure 3. These results indicate that both point-MVs and RICM values tracked well together with relatively soft conditions in the area with white subgrade sand compared to the area with red subgrade sand.

Figure 4 compares k_s and measured amplitude (a^*) measurements obtained in manual and AFC modes in all three roller lanes. During AFC mode operation, the k_s measurements varied from 15 to 50 MN/m and the a^* measurements varied from 0.4 to 1.8 mm. The frequency (f) measurements remained relatively constant at about 30 Hz. Analysis of k_s and a^* measurements indicated that the a^* is reduced with increase in k_s. Comparison between k_s and a^* for different response distances (i.e., 0, 1, 2, and 3 m) indicated that the response distance for altering the amplitude and frequency was

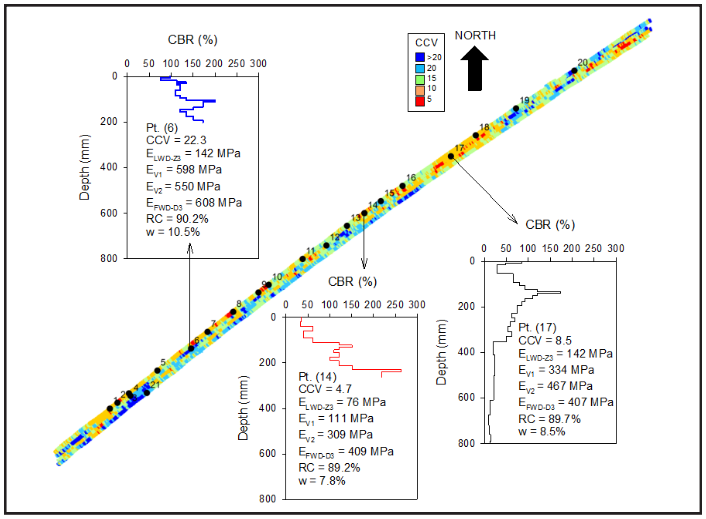

Figure 2. CCV map and point-MVs at three select locations with low, medium, and high CCV values – TB2 treated base material (amplitude (a) = 0.30 mm, frequency (f) = 55 Hz, speed (v) = 4 km/h nominal settings) (from White et al. 2010)

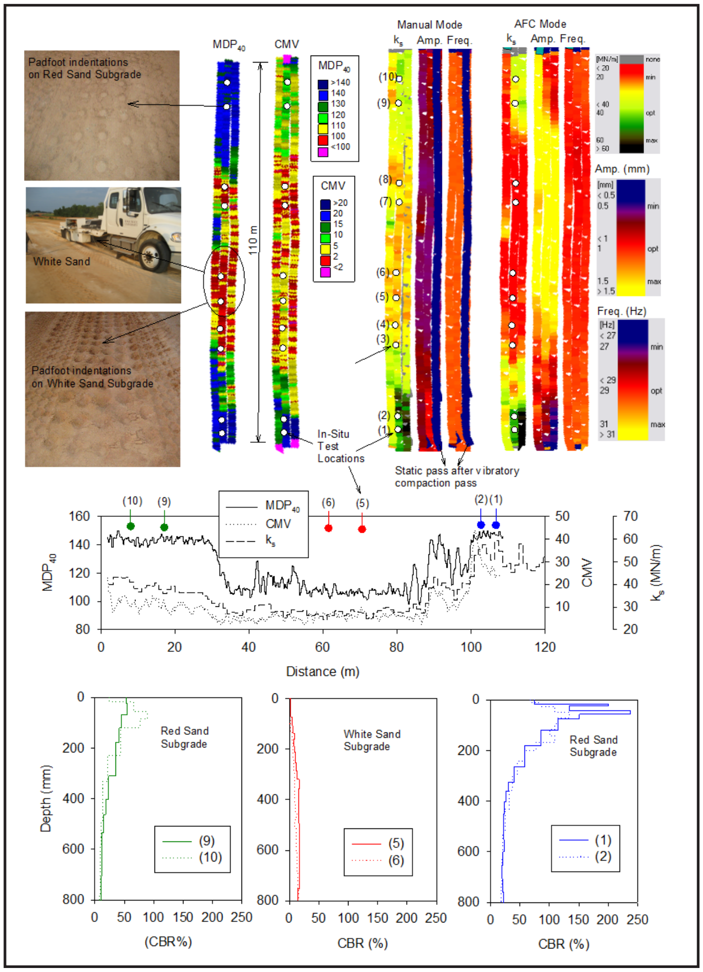

Figure 3. RICM spatial maps, MDP_{40}, CMV, and k_s measurements along the middle lane, and DCP-CBR profiles at selected locations—TB7 granular subgrade material (from White et al. 2010)

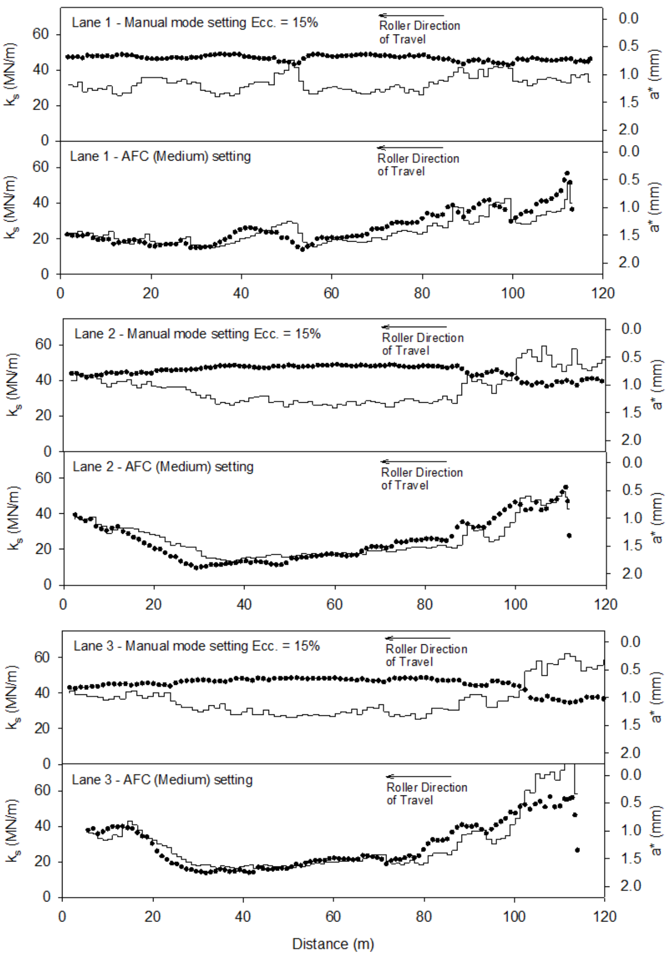

Figure 4. k_s (solid line) and a (black circles) measurements in manual and AFC mode settings—TB7 granular subgrade (from White et al. 2010)*

in the range of 1 to 2 m (for variation in travel speed = 3.8 to 4.2 km/h) (note that the roller data was reported approximately every 1 m).

Regression Analysis

The data obtained from multiple test beds are combined to develop site wide correlation results as some of the test bed results represented only a narrow range of measurement values. Combining results provided a perspective of more general trends and associated variability.

Relationships between CCV and point-MVs based on the data obtained from TB1 (granular base), TB2 (treated granular base after 5-day cure), and TB4 (granular subgrade) are presented in Figure 5. Correlation with E_{FWD} showed the best relationship with $R^2 = 0.50$ compared to other point-MVs. Correlations with E_{V1} and E_{LWD} yielded $R^2 = 0.40$ and 0.31, respectively. Relationships with E_{V2} and CBR were relatively weak with $R^2 < 0.30$. No trend was observed in relationship with Υ_d.

Relationships between MDP_{40} and point-MVs based on the data obtained from TBs 4 and 7 (granular subgrade) are presented in Figure 6. Non-linear exponential relationships were observed in correlations between MDP_{40} and all point-MVs. R^2 values for relationships with E_{LWD}, E_{V1}, E_{V2}, and CBR_{300} point-MVs varied from 0.49 to 0.76. R^2 values for relationships with Υ_d and w varied from 0.49 and 0.69, respectively. MDP_{40} values tend to reach an asymptotic value of 150, which is the maximum value programmed in the machine. This observed non-linearity has practical implications, for example, the MDP_{40} values are relatively insensitive (from about 140 and 150) to a change in E_{V1} from about 70 to 200 MPa while the MDP_{40} values are very sensitive (from about 100 to 140) to change in E_{V1} from about 10 to 70 MPa. The MDP settings on future projects could be adjusted for the measurement range of plate load test modulus values to provide the desired sensitivity for very stiff materials.

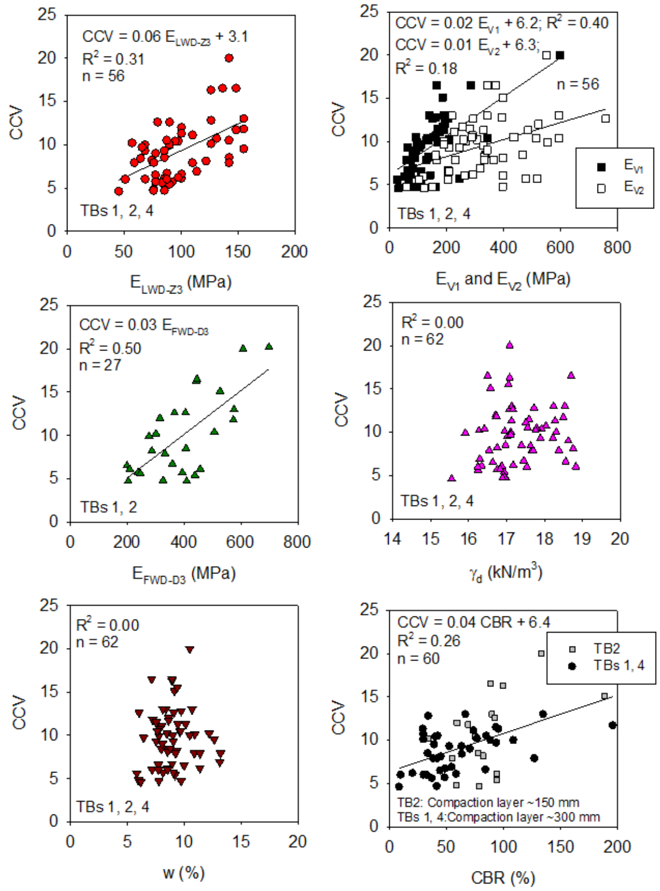

Figure 5. Regression analyses between CCV and point-MVs (from White et al. 2010)

Relationships between k_s and point-MVs based on data obtained from TB3 (treated granular base-no cure), TB4 (granular subgrade), TB5 (treated granular subgrade-no cure), TB7 (granular subgrade), and TB8 (treated granular base-2 day cure) are presented in Figure 7. Correlation with E_{FWD} showed the best relationship with $R^2 = 0.74$ compared to other point-MVs. Correlations with E_{V1}, E_{V2}, and E_{LWD} yielded $R^2 = 0.68$, 0.52, and 0.49, respectively. Relationship with Υ_d was relatively weak with $R^2 = 0.30$. Some influence of w was noted with $R^2 = 0.22$.

The effect of compaction time delay on cement stabilized red sand subgrade and base materials (5.5% of cement by dry weight) were studied in the laboratory, with standard Proctor test specimens compacted at 0, 30, 60, 120, and 240 minutes after mixing.

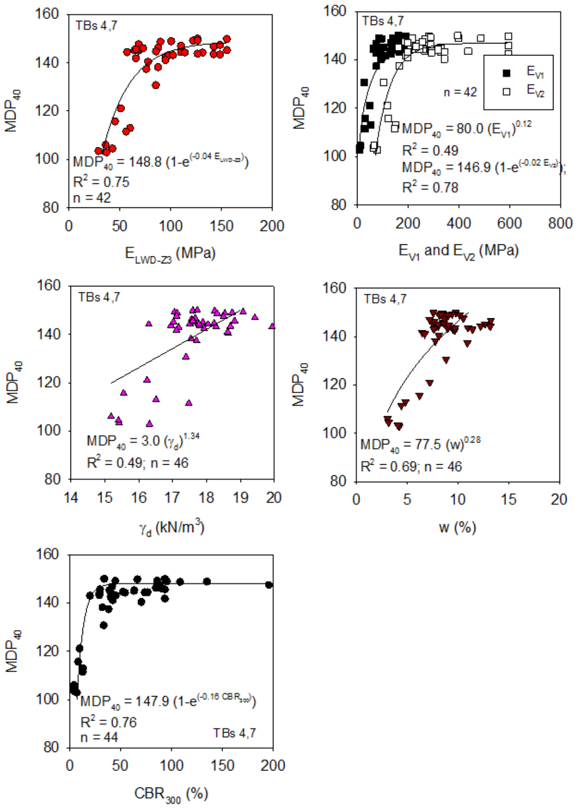

Figure 6. Regression analyses between MDP_{40} and point-MVs (from White et al. 2010)

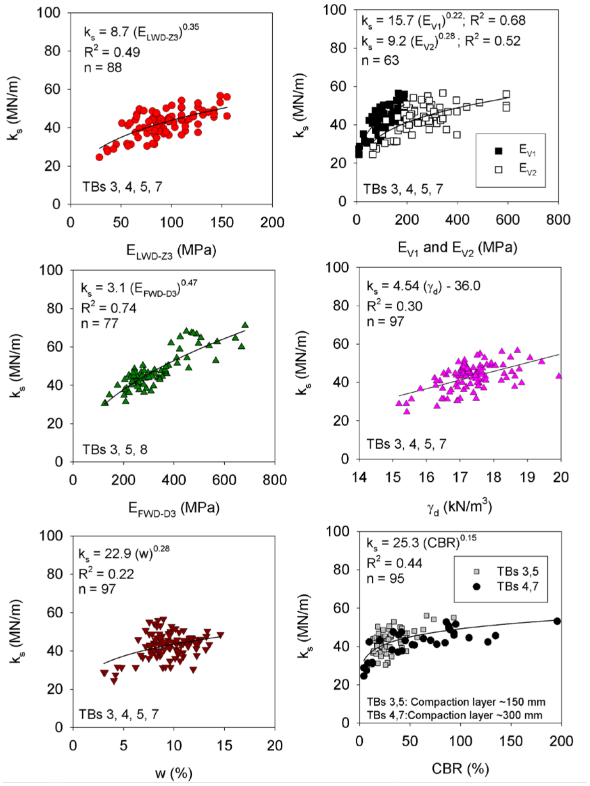

Figure 7. Regression analyses between k_s and point-MVs (from White et al. 2010)

Effect of Compaction Delay Time on Cement Treated Soils

Results obtained from this study indicated that the dry density of the treated materials decreased with increasing compaction delay time after mixing. Similar results have been demonstrated by Arman and Saifan (1967) and indicated that a delay of two or more hours in compaction after mixing results in reduced durability, compressive strength, and density of the soil-cement mixture. Project specifications indicated that the soil-cement mixture should be compacted within two hours after mixing.

Summary of Key Findings

- Empirical correlations between RICM values and different point-MVs sometimes showed weak correlations when evaluated independently for each test bed, because of the narrow measurement range. The correlations improved when data are combined for site-wide correlations with a wide measurement range.
- RICM values generally correlated better with modulus based point-MVs (E_{LWD}, E_{FWD}, E_{V1}, and E_{V2}) and CBR point MVs than with dry density point-MVs. Correlations with E_{FWD} and E_{V1} showed the strongest correlation coefficients (R^2 values).
- AFC mode operations using different performance settings were evaluated in this study. In high performance setting, the amplitude was decreased and the frequency was increased with increase in k_s. In low and medium performance settings, the amplitude was decreased with increase in k_s while the frequency remained constant. The response distance for altering the amplitude and/or frequency was about 1 to 2 m at a travel speed of about 4 km/h.
- Geostatistical analysis indicated that the spatial non-uniformity is higher on the treated subgrade/base layers after curing compared to shortly after compaction and untreated layers. Many factors contribute to this increased non-uniformity including non-uniform application of cement, water content, compaction delay time, and compaction energy over a given area. This is an important finding and has not been well documented. This finding is in contrary to the common presumption that stabilization creates a more "uniform" working platform. More research is warranted to further investigate this topic.

References

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Arman, A., and Saifan, F. (1967). "The effect of delayed compaction on stabilized soil-cement," *Highway Research Board* No. 198, Washington, D.C., 30-38.