# Maryland I-70 – Layered Granular Fill and Silty Subgrade – October 2007

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Intelligent Soil Compaction Systems (NCHRP 21-09)

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This demonstration project was conducted on Interstate 70 (I-70) in Frederick, Maryland. The machine configurations and roller-integrated compaction measurement (RICM) systems used on this project included (Figure 1): a Sakai SV610D smooth drum roller equipped with compaction control value (CCV) measurement system, a Dynapac CA362 smooth drum roller equipped with compaction meter value ($CMV_D$) measurement system along with automatic feedback control (AFC), and a Bomag BW213-DH smooth drum roller equipped with vibratory modulus ($E_{VIB}$) measurement system along with AFC. All three 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 test strips with two-layered granular subbase material placed over silty subgrade. The RICM systems were evaluated by conducting field testing in conjunction with a variety of in situ testing devices measuring: dry unit weight (γd) and moisture content (w) using a nuclear gauge device; California bearing ratio (CBR) from dynamic cone penetrometer; dynamic elastic modulus using a 300 mm plate light weight deflectometer ($E_{LWD-Z}$) and a 300 mm plate falling weight deflectometer ($E_{FWD}$) (Figure 2); and initial ($E_{V1}$) and re-load modulus ($E_{V2}$) using a static plate load test with 300 mm diameter plate (Figure 2). Only $E_{FWD}$, $E_{V1}$, and γd results are presented herein for brevity. All results from this project are available in NCHRP Report 676.

This tech brief presents correlations between the three RICM measurement systems and in situ point measurements, results showing influence of heterogeneous underlying layer conditions on compaction layer RICM and stiffness-based point measurements, and results from AFC mode in comparison with manual mode mapping operations.

## RICM Systems Overview

All three RICM systems used in this study (CCV, $CMV_D$, and $E_{VIB}$) are vibratory based technologies, which makes use of an accelerometer mounted to the roller drum to create a record of machine-ground interaction. CCV and CMV are index parameters calculated using drum acceleration data. CCV is calculated from first sub-harmonic, fundamental, and higher-order harmonics,


*Figure 1. (top to bottom) Sakai SV510D, Bomag BW213DH, and Dynapac CA362 smooth drum rollers*

while CMV is calculated from fundamental and second-order harmonics. $E_{VIB}$ values are derived by determining drum displacement, estimating the soil force, and using a dynamic model to extract stiffness. Soil stiffness is determined as the ratio of soil force to maximum drum displacement. To determine an elastic modulus of the soil, a continuum contact model of the drum/soil is required, and a relationship between a cylinder oscillating on an elastic half space is used.

The AFC system on the Dynapac roller uses bouncing value (BV), which gives a measurement of the degree of double jump that the vibratory drum is experiencing and automatically reduces the vibration amplitude if the BV exceeds a pre-determined target value. According to the manufacturer, the vibration amplitude on the machine was set to be reduced when BV approached 14. Further, the manufacturer indicated that $CMV_D$ was arbitrarily reported in the output as 250, for BV > 25. The AFC operations were performed using maximum amplitude (amax) setting on the roller.

The AFC system on the Bomag roller uses a concept of counter-rotating eccentric mass assembly that is directionally vectored to vary the vertical excitation force on the soil. If the counter-rotating masses are opposite each other in their rotation cycles, the eccentric force is zero. On the other hand, when the counter-rotating masses pass each other, the eccentric force is at maximum. The AFC system automatically adjusts the amplitude (by adjusting the vectors) depending on the pre-selected settings or the drum behavior. Two different AFC settings are available on the roller:


*Figure 2. Dynatest FWD (top) and static plate load test (bottom)*

(1) Pre-selected target $E_{VIB}$ and a maximum amplitude amax value: In this setting, the vibration amplitude is reduced below the amax value when $E_{VIB} \geq$ target $E_{VIB}$, and the amplitude is at the amax value when $E_{VIB} <$ target $E_{VIB}$.

(2) Pre-selected amax value: In this setting, the vibration amplitude is controlled based on the drum double jump behavior as measured by the jump value. When the jump value increases above 0, the amplitude is lowered to 0.6 mm.

More information about these measurement systems is provided in NCHRP Report 676.

## Materials and Test Strip Conditions

The subgrade material consisted of silt (SM, A-2-4), and the base material consisted of crushed limestone (SP-SM, A-1-a). The subgrade layer was divided into four roller lanes (see Figure 3). Lanes 3 and 4 were relatively stiff and heterogeneous with an isolated portion of a mixture of subgrade and fractured rock,


*Figure 3. Subgrade test strip layout (top) and base layer (bottom)*

while lanes 1 and 2 were relatively soft and homogenous. After compaction and mapping passes on subgrade, two layers of base materials (base layers 1 and 2) with nominal compacted thickness of about 150 mm were placed and compacted. The granular base layers were placed at relatively consistent moisture content (3.5% to 5.0%).Results from lanes 1, 3, and 4, after final compaction pass are presented in this tech brief.

## Comparison between In Situ Point Measurements and RICM Values

EV1, $E_{FWD}$, and γd point measurements and RICM values obtained from granular base layer 2 on lanes 1 and 4 are shown in Figures 4, 5, and 6, respectively. Both RICM values and stiffness-based point measurements (i.e., $E_{V1}$ and $E_{FWD}$) showed similar variation along the test strips with relatively soft and homogenous conditions on lane and relatively stiff and heterogeneous conditions on lanes 3 and 4. On the other hand, the dry unit weight measurements did not track well with the variations observed along the test strips.

Correlations between the point measurements and RICM values are shown in Figure 7. Results showed linear regression relationships between $E_{V1}$ and $E_{FWD}$ point measurements and RICM values with $R^2 > 0.70$. No statistically significant relationship was observed between γd and RICM values.

## Influence of Compaction Mode (AFC or Manual) and Amplitude on RICM

The influence of heterogeneous underlying layer conditions on RICM values obtained in AFC mode is evaluated herein in comparison with RICM values obtained in manual mode $CMV_D$ and $E_{VIB}$ measurement systems. These results are particularly interesting in that they demonstrate the influence of underlying layer conditions on AFC operations and the resulting RICM values.

$E_{VIB}$ measurements were obtained in manual mode at constant settings with nominal a = 0.70 mm and a = 1.90 mm, and in AFC mode with limit $E_{VIB}$ = 80 MPa and 120 MPa (frequency (f) = 30 Hz and speed (v) = 4km/h were constant) with $a_{max}$ = 2.50 mm. $CMV_D$ measurements were obtained in manual mode at constant settings with nominal a = 0.80 mm and a = 2.40 mm, and in AFC mode with maximum a = 2.50 mm (f = 28 Hz and v = 4km/h were constant).

Figure 8 presents $E_{VIB}$ measurements obtained in manual and AFC modes on Lanes 1, 2, and 3. $E_{FWD}$ point measurements are shown in comparison with $E_{VIB}$ measurements with manual a = 0.70 mm setting. Amplitude measurements (shown as grey lines) are also presented in comparison with $E_{VIB}$ measurements (shown as black lines) obtained in AFC mode. Similarly, Figure 9 presents $CMV_D$ measurements obtained in manual and AFC modes along with $E_{FWD}$ point measurements in comparison with $CMV_D$ measurements with manual a = 0.80 mm setting. The RICM values from underlying layers are shown on Figure 10, for reference.

$E_{VIB}$ measurements in manual mode with a = 1.90 mm showed roller jumping (jump values > 0) on lanes 3 and 4 generally at locations with $E_{FWD}$ > 120 MPa and $E_{VIB}$ > 100 MPa. During AFC mode compaction with maximum $E_{VIB}$ = 80 MPa, no roller jumping was observed across the test beds, and the amplitude was effectively reduced to a = 0.6 mm at locations where $E_{VIB}$ was > 80 MPa. For AFC setting with maximum $E_{VIB}$ = 120 MPa, the amplitude was reduced up to a = 0.6 mm where $E_{VIB}$ ≥ 120 MPa, but roller jumping was not prevented. Response distance for this test bed study was about 0.5 to 1 m.

$CMV_D$ measurements in manual mode with a = 2.40 mm showed roller jumping at several locations across lanes 3 and 4 where $E_{FWD}$ > 120 MPa. In AFC mode, the roller generally maintained a > 2.00 mm for the three test beds. No jumping was observed on lane 1. Jumping was noticed on lane 4 from about 0 to 15 m where the amplitude increased despite the increase in the BVs. Response distance for this test bed study was about 0.5 to 1.0 m.

The results from this study showed that the rollers were effective in decreasing vibration amplitude in areas with relatively high stiffness for some AFC settings. In some cases, the AFC mode did not necessarily prevent roller jumping—some roller operator judgment is still involved in selecting the proper limit values and maximum amplitude.

## Reference

Mooney, M., Rinehart, R., White, D.J., Vennapusa, P.*, Facas, N., Musimbi, O. (2010). *Intelligent Soil Compaction Systems*, NCHRP Report 676, National Cooperative Highway Research Program, Washington, D.C.

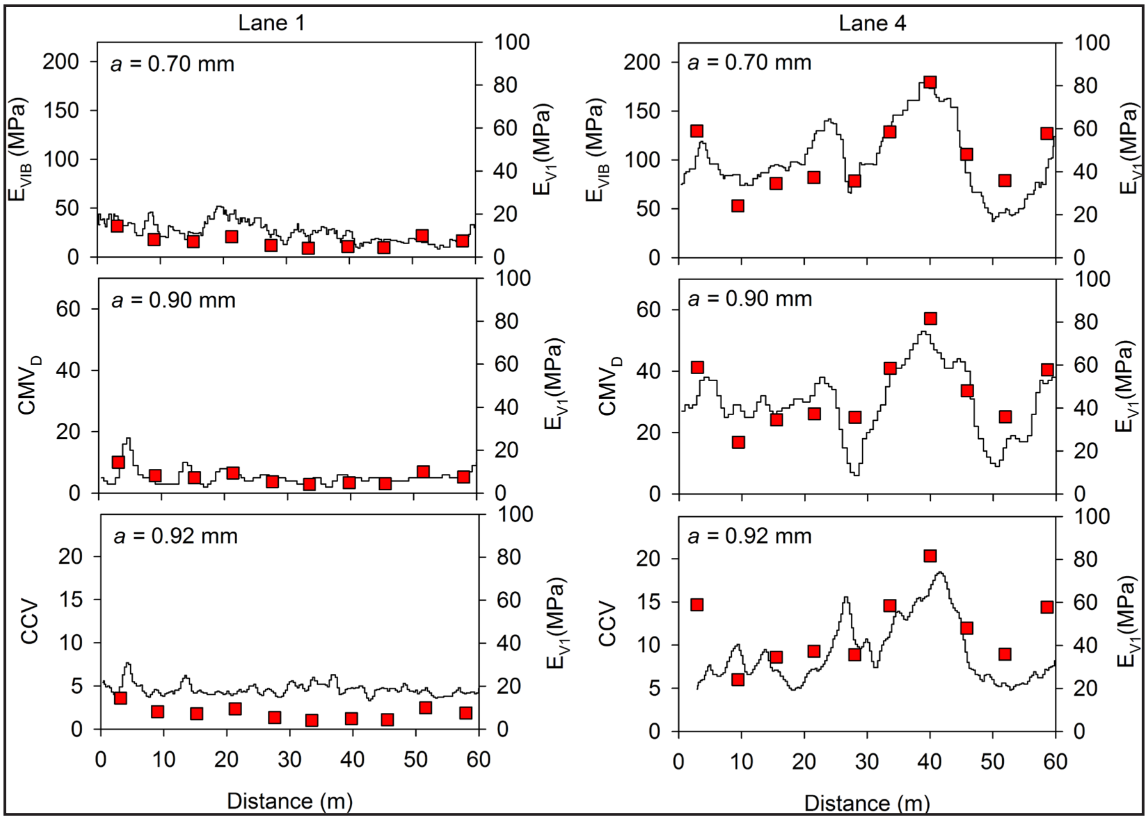


*Figure 4. Comparison between static plate load test modulus ($E_{V1}$), shown as points, and roller measurements ($E_{VIB}$, $CMV_D$, and CCV), shown as lines, on lanes 1 and 2*

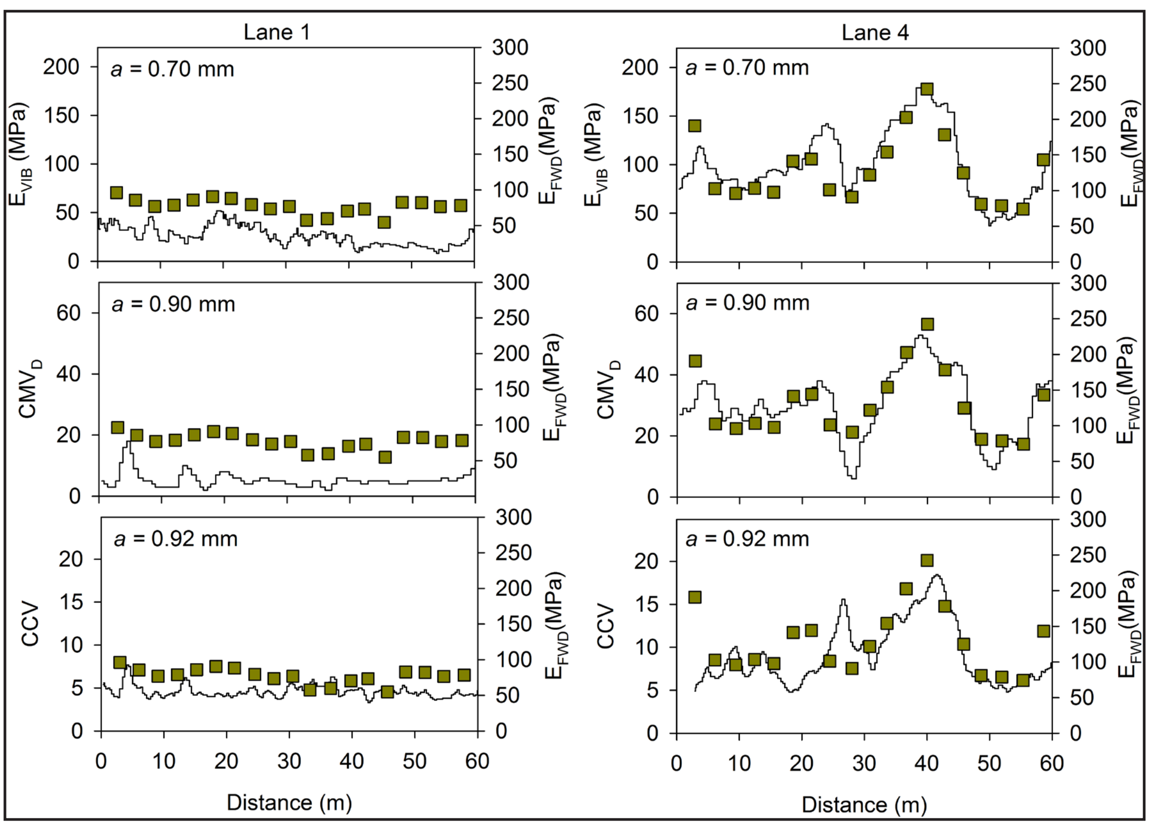


*Figure 5. Comparison between FWD dynamic modulus ($EFW_D$) shown as points and roller measurements ($E_{VIB}$, $CMV_D$, and CCV) shown as lines on lanes 1 and 2*

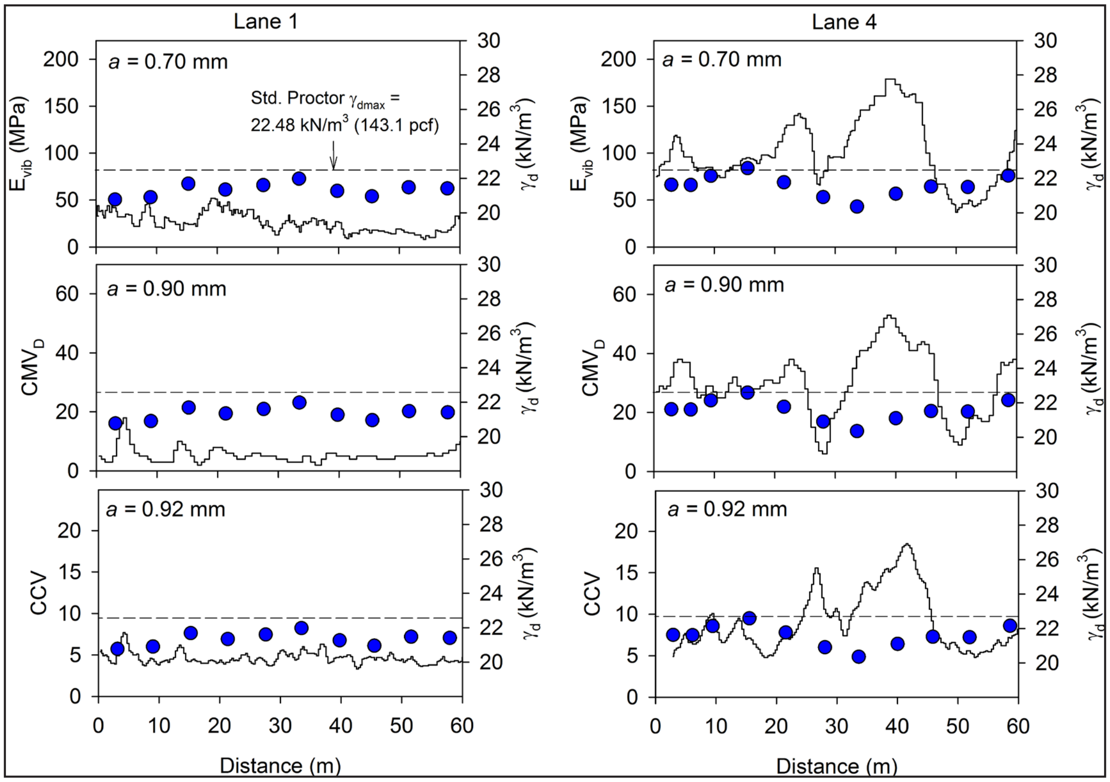


*Figure 6. Comparison between dry unit weight (γd) measurements shown as points and roller measurements ($E_{VIB}$, $CMV_D$, and CCV) shown as lines on lanes 1 and 2*

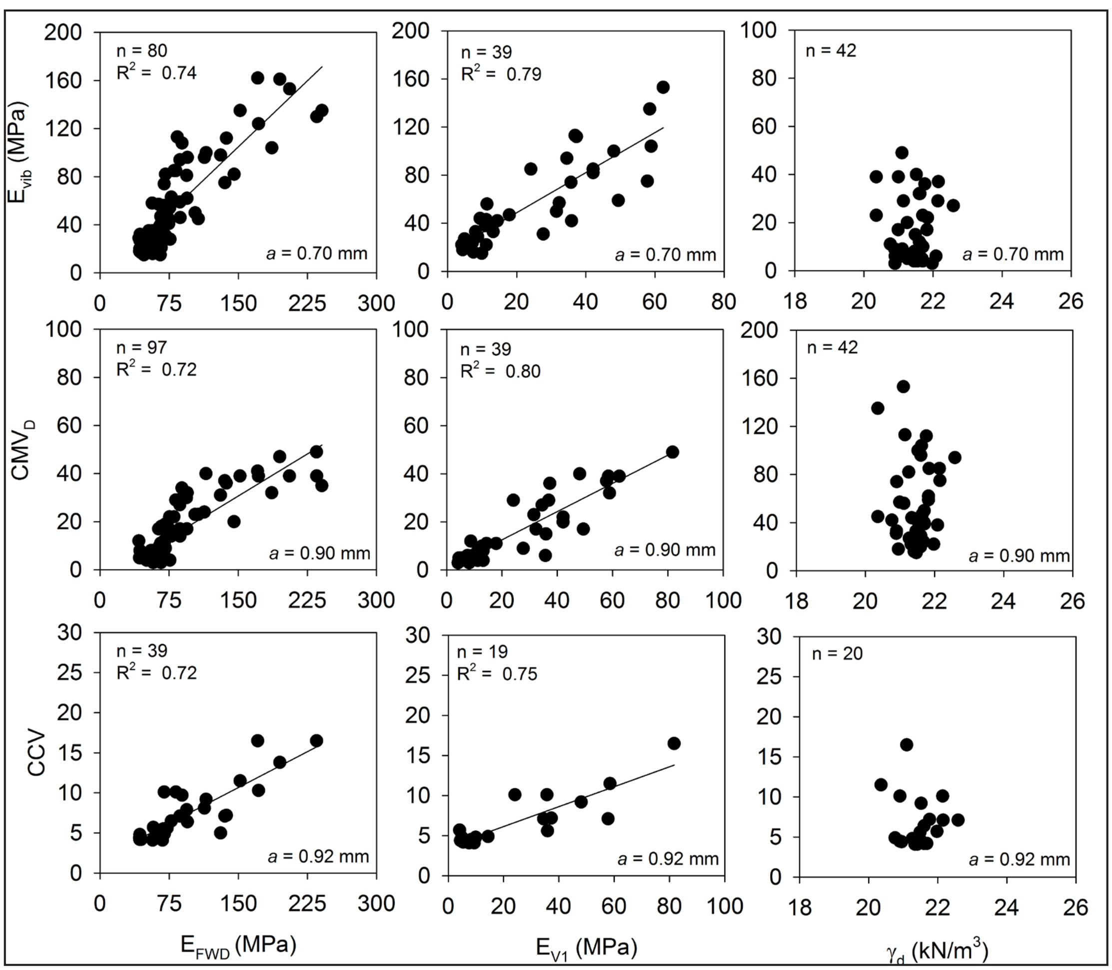


*Figure 7. Linear regressions between point measurements ($E_{FWD}$, $E_{V1}$, and d) and roller measurements ($E_{VIB}$, $CMV_D$, and CCV)*

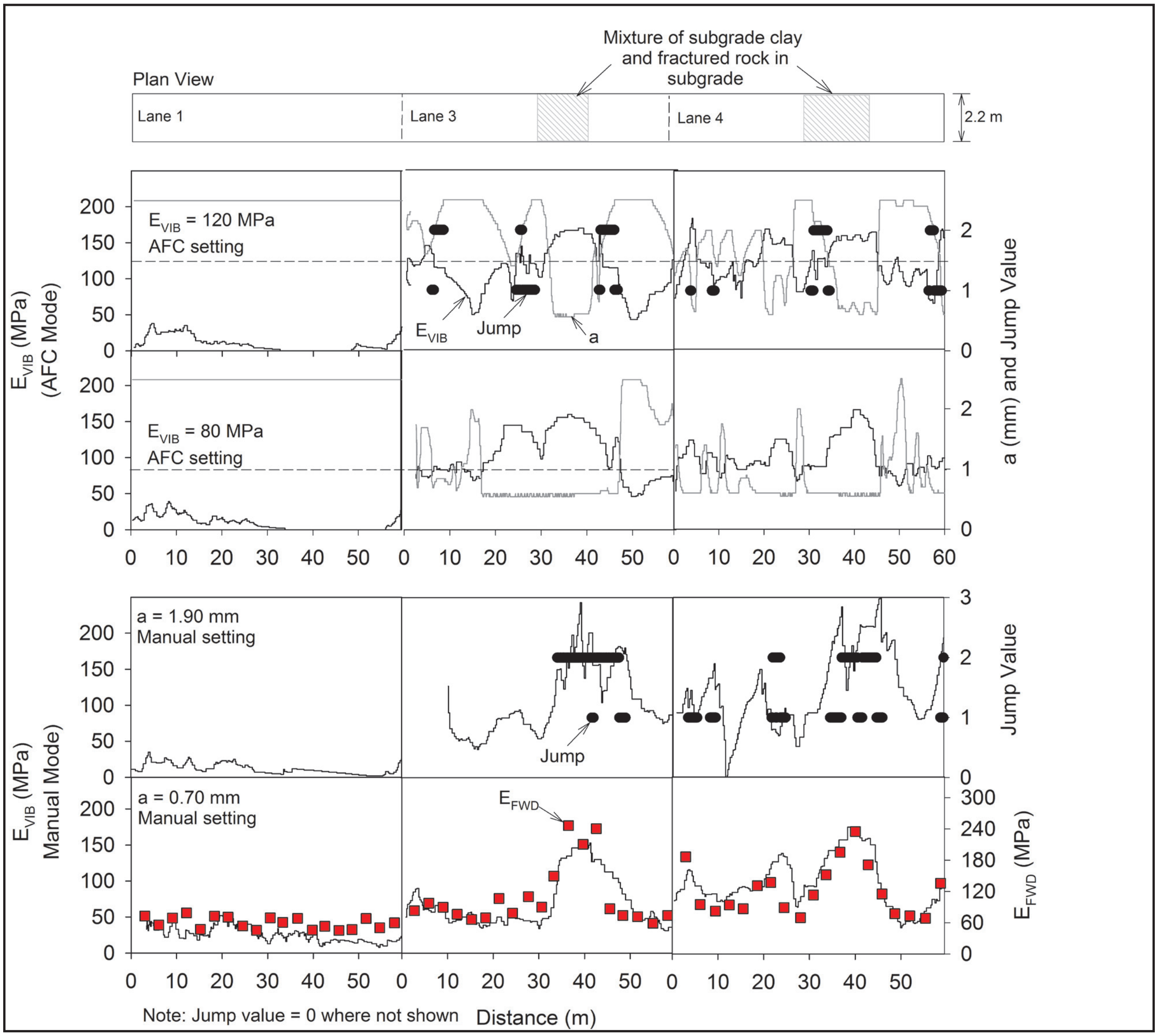


*Figure 8. Roller MV, amplitude, and jump measurements from AFC and manual high and low amplitude settings with comparison to $E_{FWD}$ measurements*

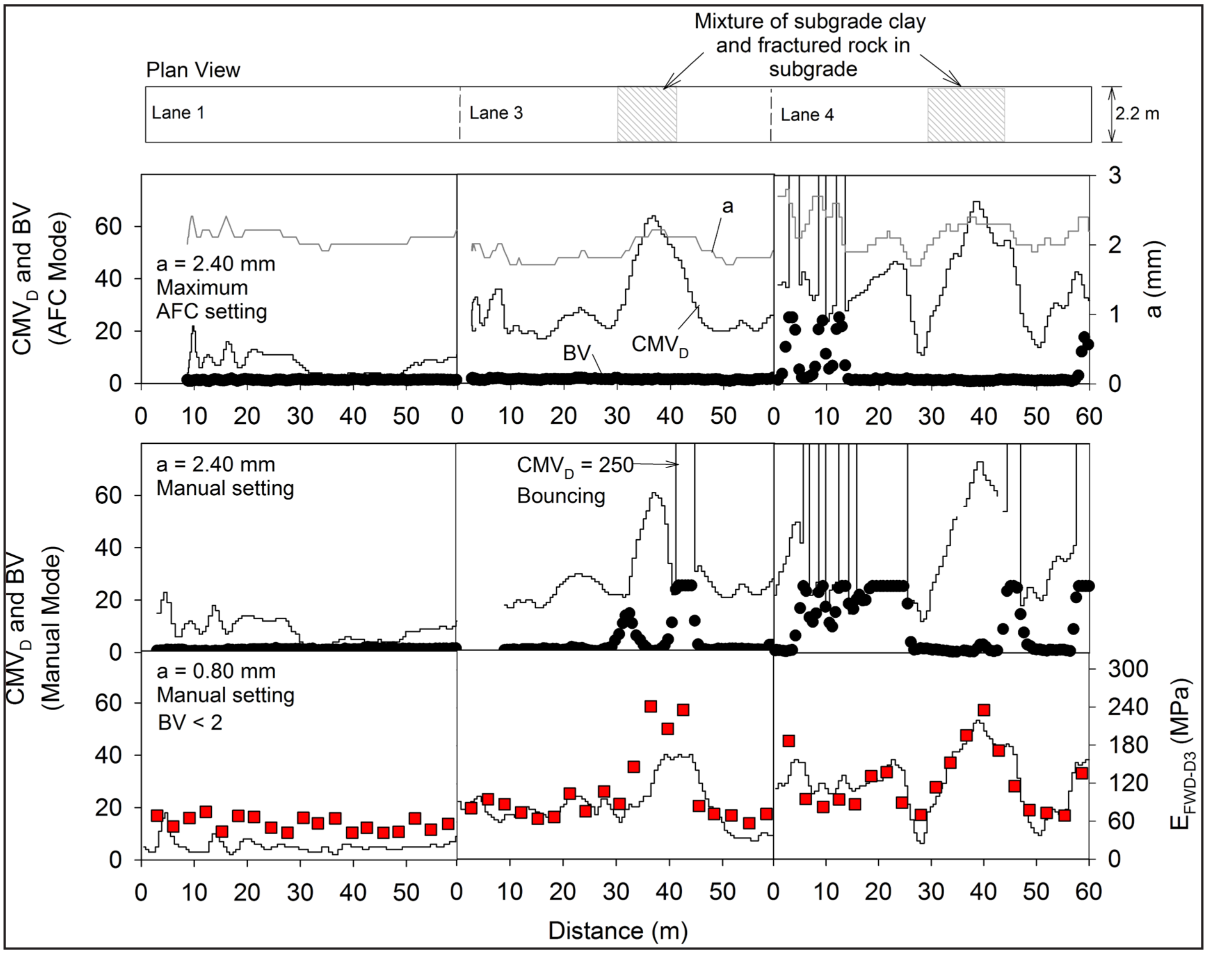


*Figure 9. CMV, amplitude, and bouncing measurements from AFC and manual high and low amplitude settings with comparison to $E_{FWD}$ measurements*

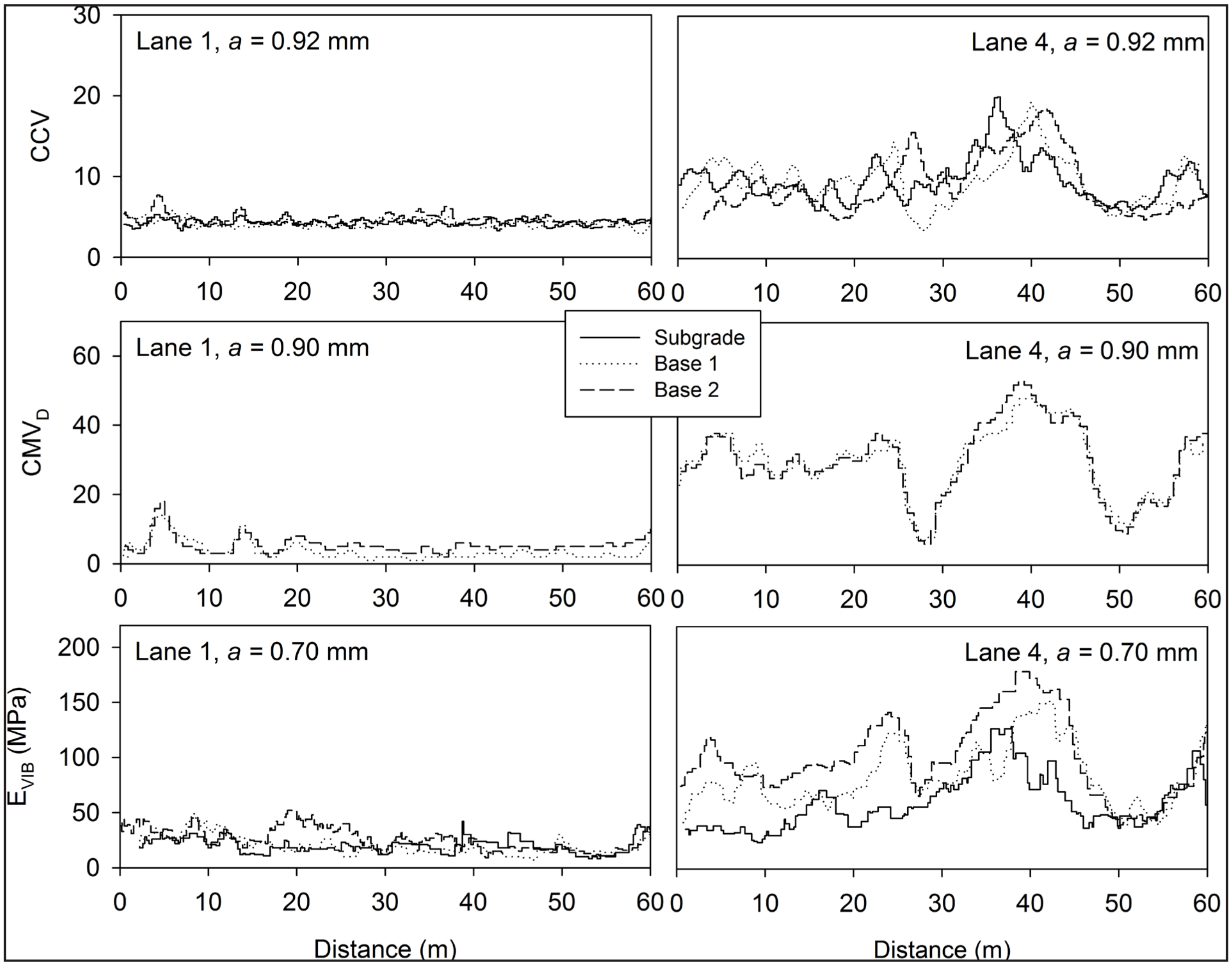


*Figure 10. Roller measurements ($E_{VIB}$, $CMV_D$, and CCV) on subgrade layer, base layer 1, and base layer 2 on lanes 1 and 4*