Department of Civil & Environmental Engineering

An Introduction to Continuous Compaction Control Systems

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Primary Project Sponsor: Delaware DOT

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Outline of Presentation

- Some background & operating principles of continuous compaction control systems
- Compactometer Value (CMV) & Machine Drive Power (MDP) theory
- Delaware-based soil compaction field study
- In-situ test results
- Roller-measured test results
- Comparisons between roller data & in-situ test results

CCC versus IC

- Continuous Compaction Control (CCC) technology continuously and instantaneously measures machine parameters that are related to the effectiveness of soil compaction, and uses these parameters to control the compaction process.

- Intelligent Compaction (IC) uses CCC data to adjust the operational behavior of the compactor in real-time, effectively optimizing the compaction process.

Equipment Used in a CCC System









A CCC Compactor in Action



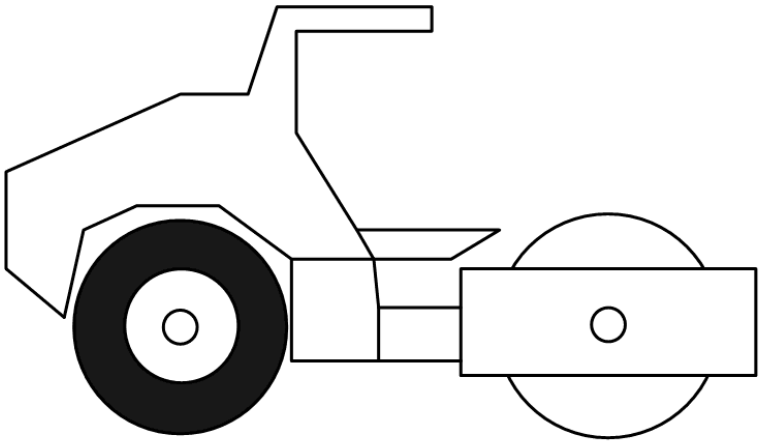
Stakeless Grading - A Tangential Benefit of GPS

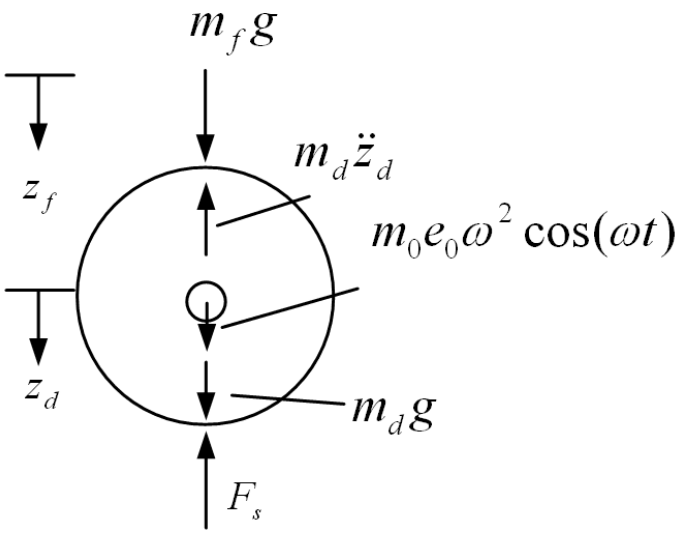


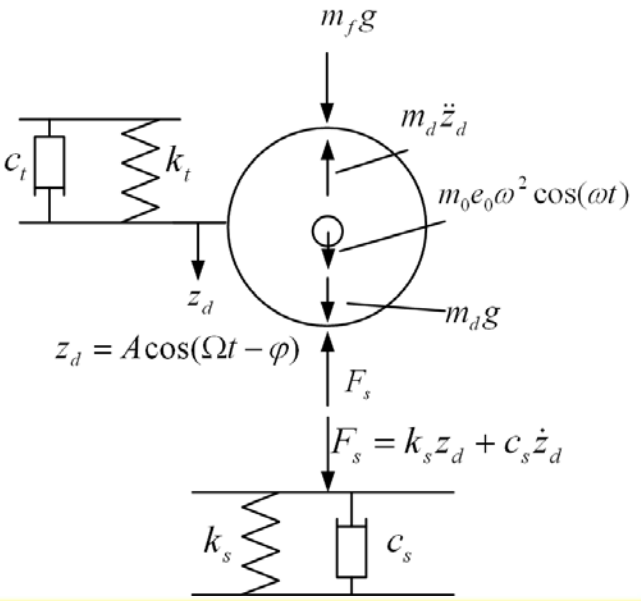
IC/CCC Manufacturers

Manufacturer	Measurement Value
AMMANN	K_s
BOMAG	E_{vib}
Caterpillar	*CMV and MDP*
Geodynamik	*CMV*
DYNAPAC	*CMV*
Ingersoll	*CMV*
Sakai	*CCV*

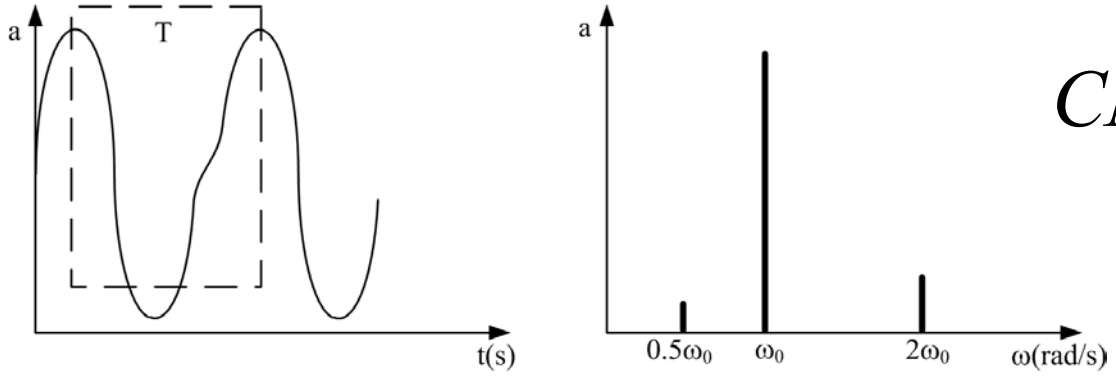
Vibration-Based Compaction Monitoring







Compactometer Value (CMV)



$$CMV = C\frac{\hat{a}(2\omega_0)}{\hat{a}(\omega_0)}$$

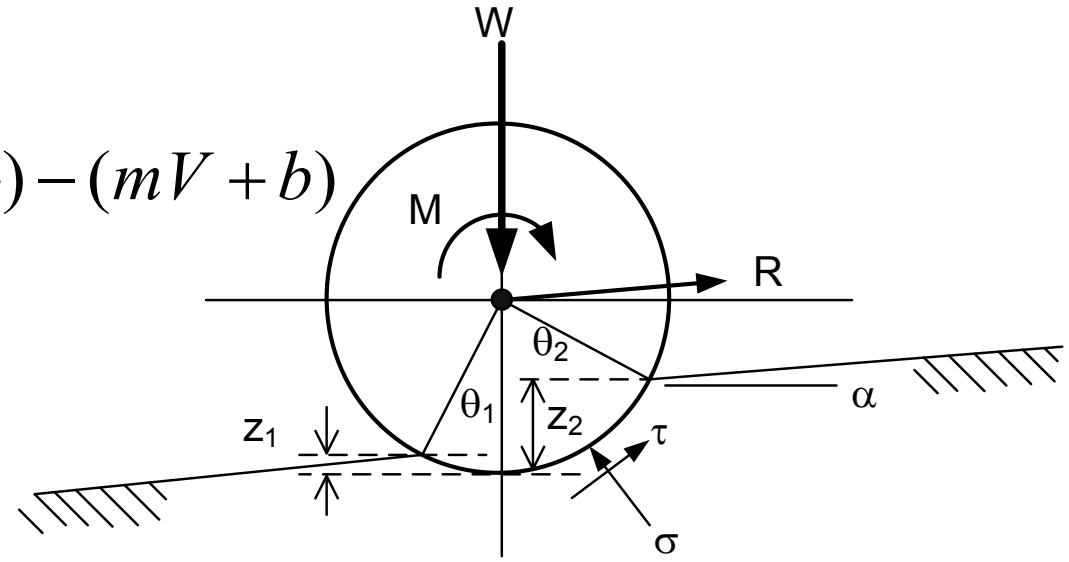
$\hat{a}(2\omega_0)$= amplitude of the first harmonic of the acceleration response signal

$\hat{a}(\omega_0)$ = amplitude of the exciting frequency

C = a constant value chosen to empirically scale the output CMV values to an easier-to-interpret range.

Machine Drive Power System (MDP)

$$MDP = P_g - WV(\sin\alpha + \frac{a}{g}) - (mV + b)$$



P_g = gross power needed to move the machine;
W = roller weight;
V = roller velocity;
α = slope angle;
a = acceleration of the machine;
g = acceleration of gravity;
m and b = machine internal loss coefficients specific to a particular machine

CCC Field Study in the State of Delaware

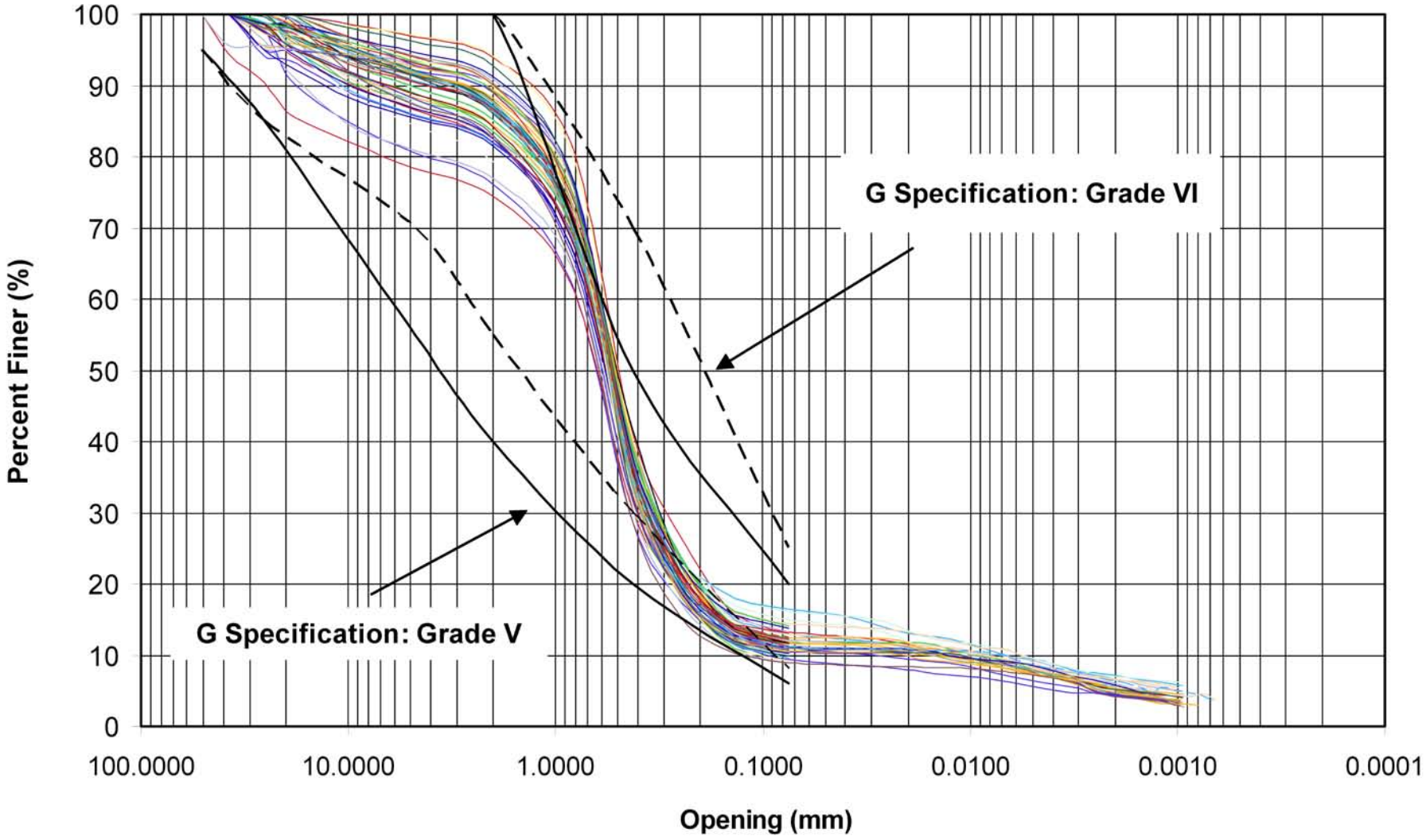
- Location: Burrice Borrow Pit, Odessa, Delaware
- Time: July 21, 2008 to July 25, 2008



General Descriptions

- Embankment:
  - 61 m (200 ft) by 6 m (20 ft) embankment
  - Five 20 cm (8 in.) loose lift layers
  - Final height after compaction: 0.9 m (3.0 ft)
- Material:
  - Poorly-graded sand with silt (SP-SM) which conforms to DelDOT “Select Fill” borrow specifications (Class G, Grades 5 & 6) .

Sieve Analysis Results



Equipment Utilized

Construction Equipment:

- Caterpillar 980H bucket loader
- Caterpillar D6K dozer
- Water Truck
- Caterpillar CS56 compactor



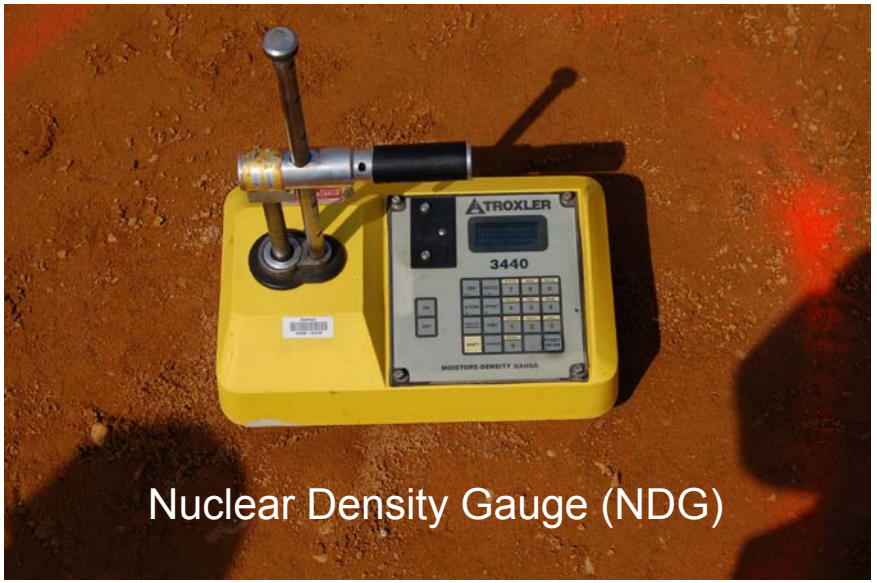


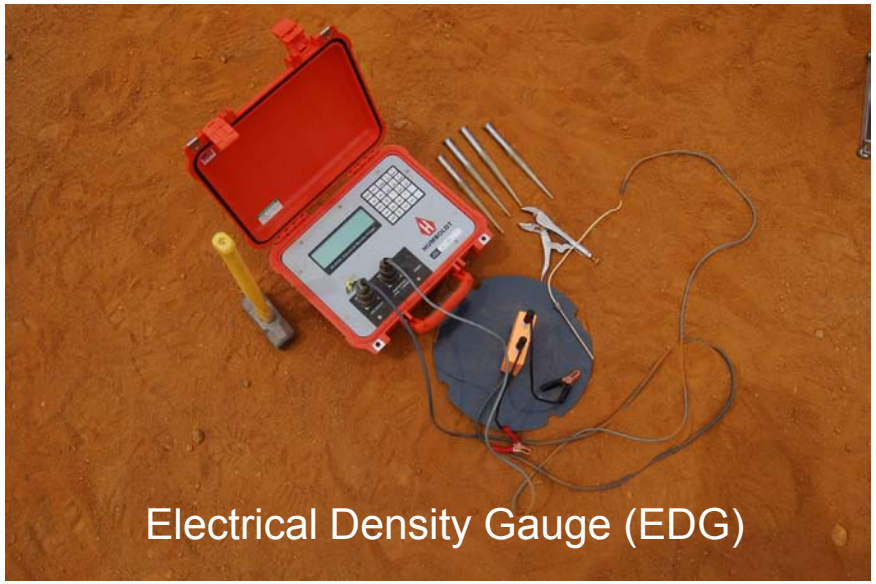




In Situ Tests Performed: Density Based Tests







In Situ Tests Performed: Modulus Based Tests











The Results of Nuclear Density Gauge Tests

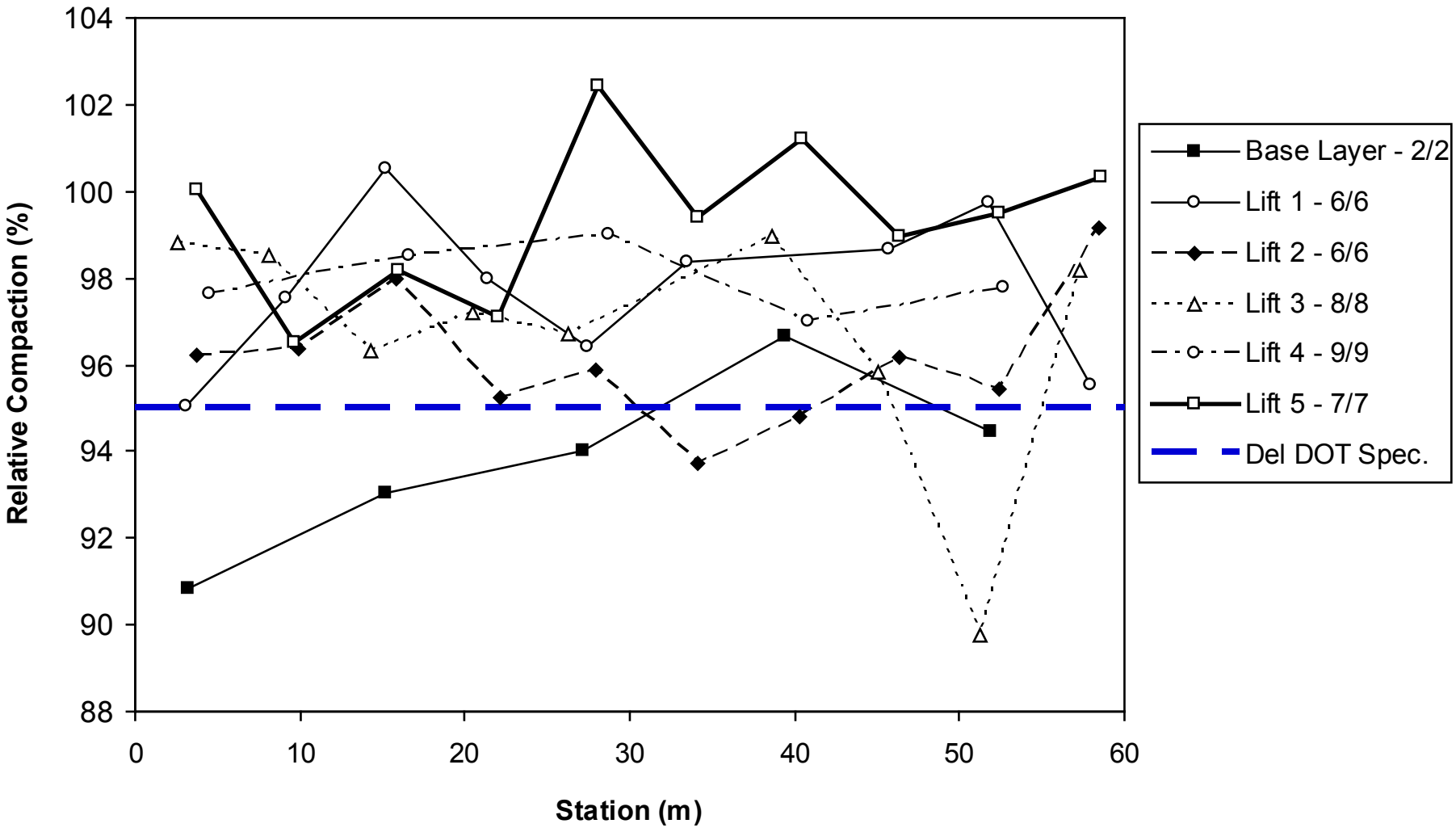
Measuring:
Dry Unit Weight
Moisture Content

The Results of 1-Pt Proctor Tests

For a Standard Energy, Measuring*:
Maximum Dry Unit Weight
Optimum Moisture Content

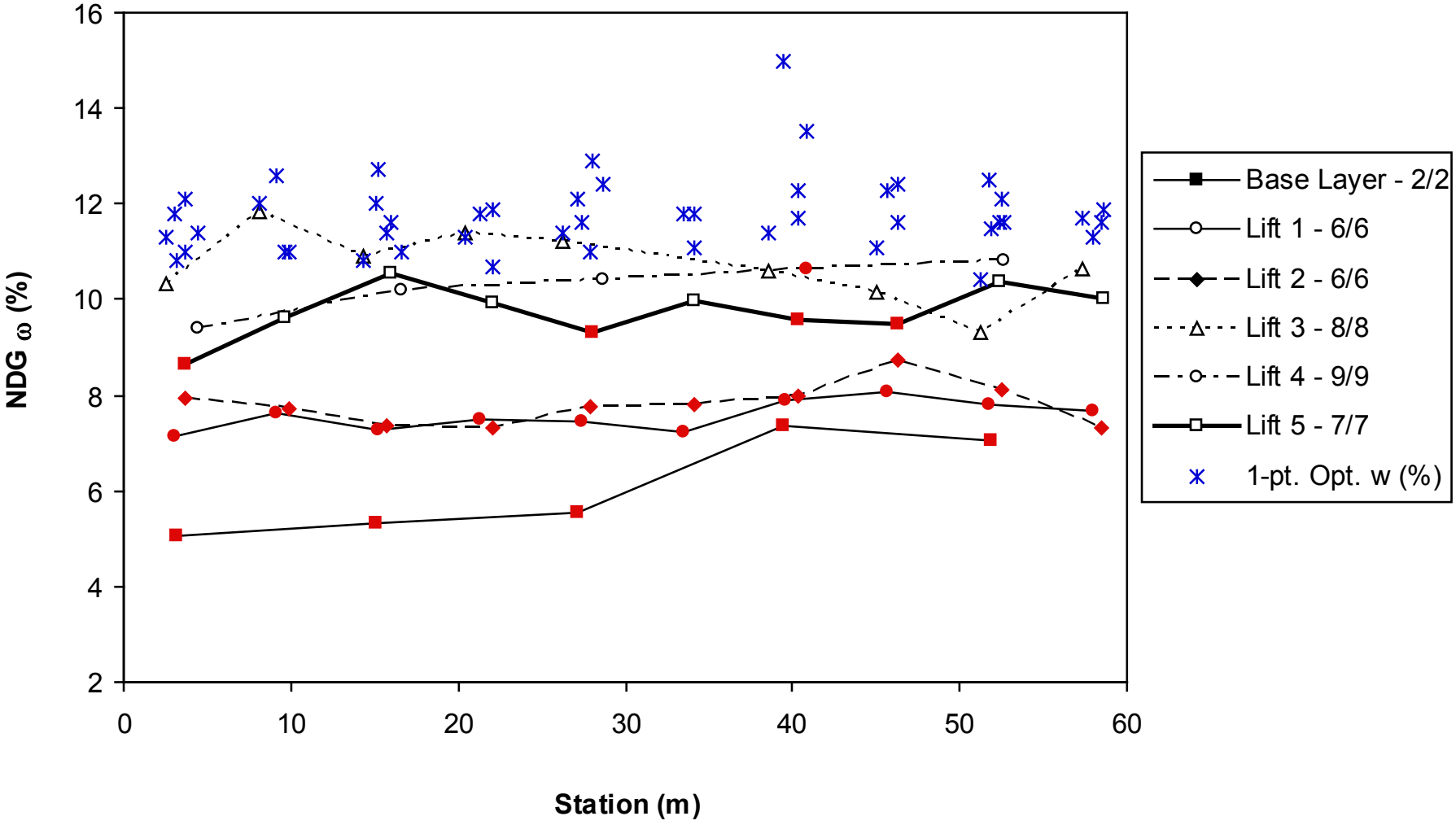
***(Determined using a family of curves approach)**

NDG Degree of Compaction (All Final Passes)

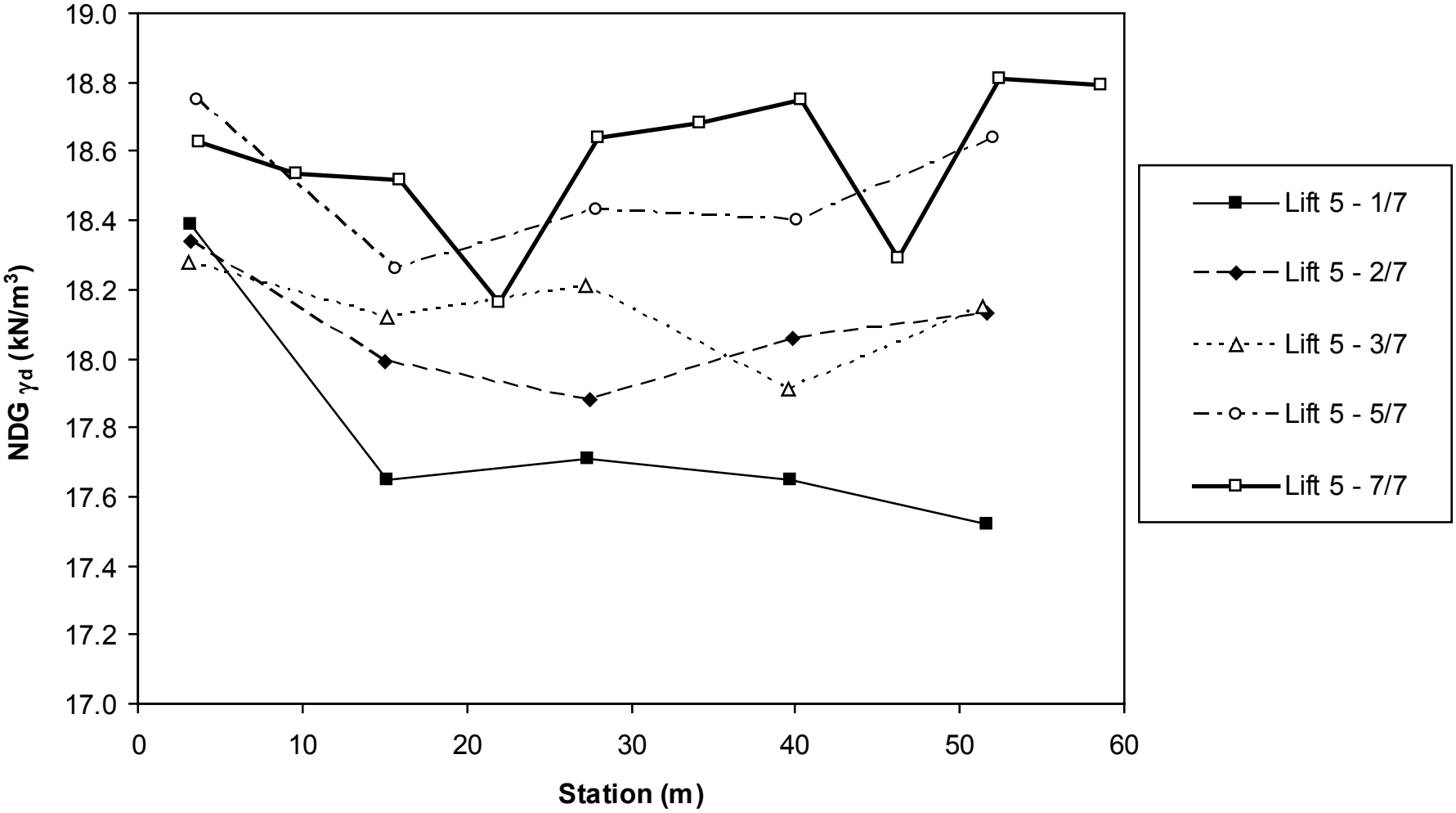


*Note: Relative Compaction determined using Standard Proctor test, 1-pt method, family of curves

NDG Moisture Content (All Final Passes)



NDG Dry Unit Weight (Lift 5)

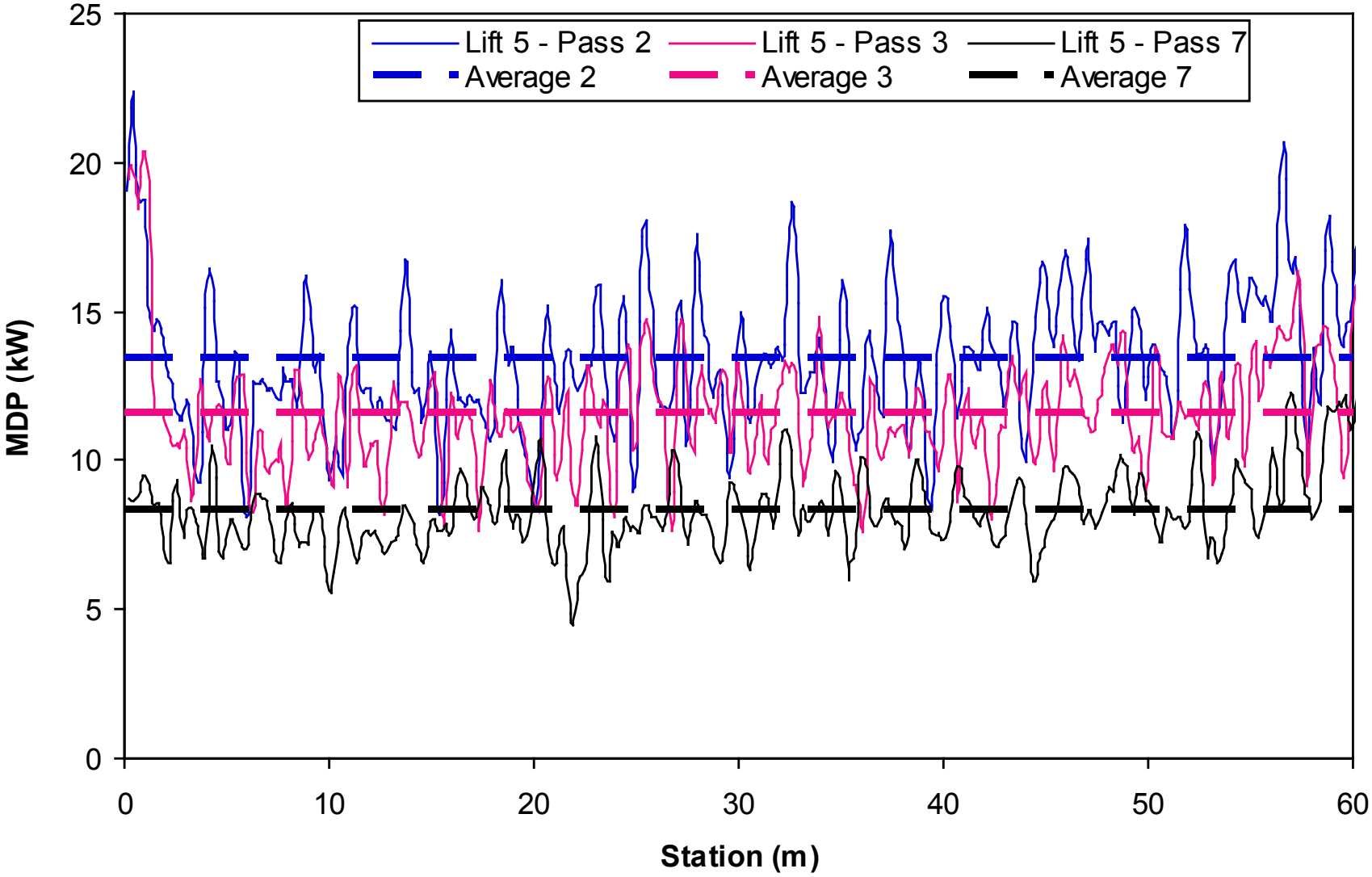


Continuous Compaction Control

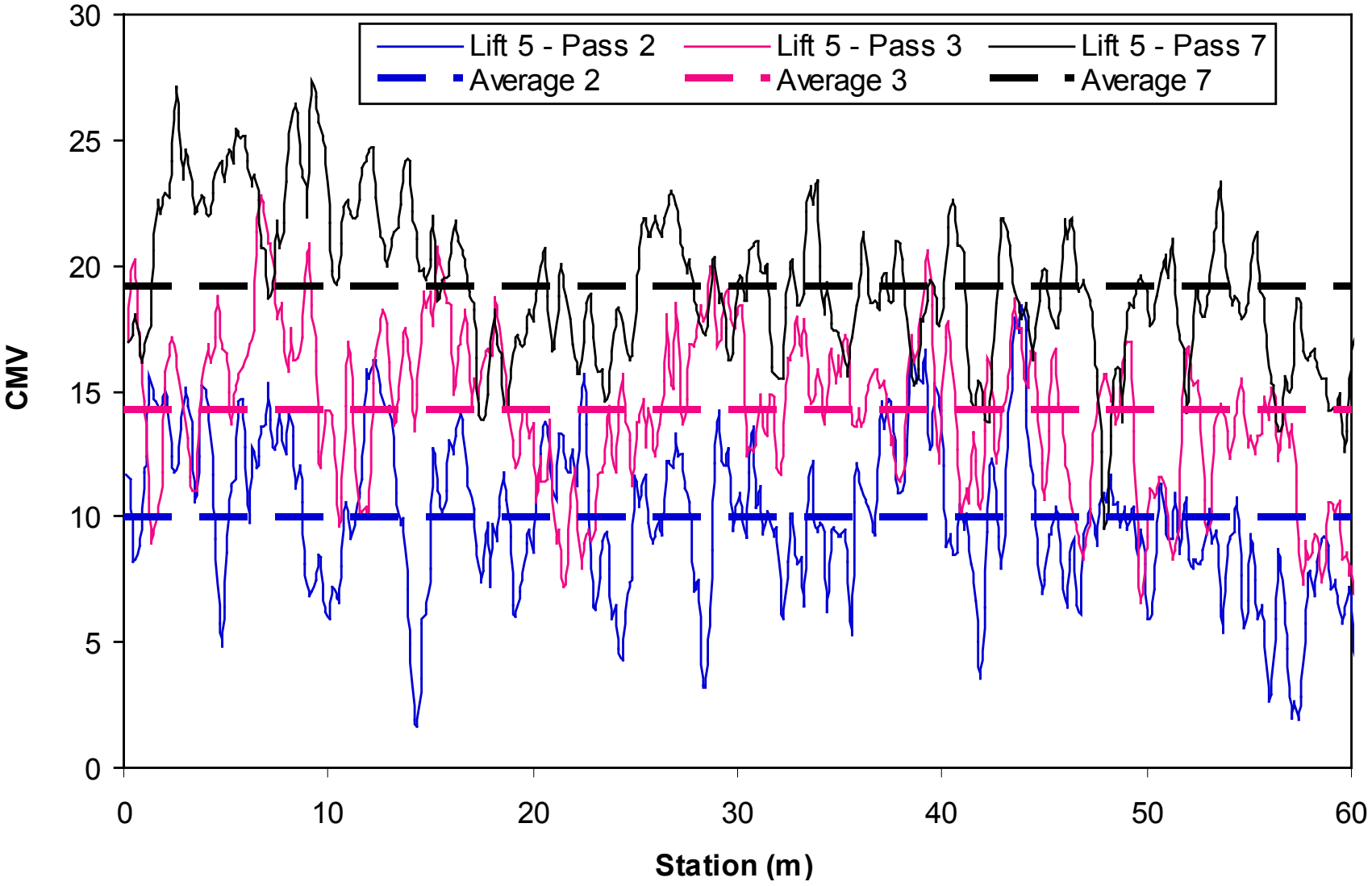
Roller-Recorded Measurements of:

Location (x,y,z)
Roller Speed
Machine Drive Power (MDP)
Compactometer Value (CMV)
Roller Measured Value (RMV)

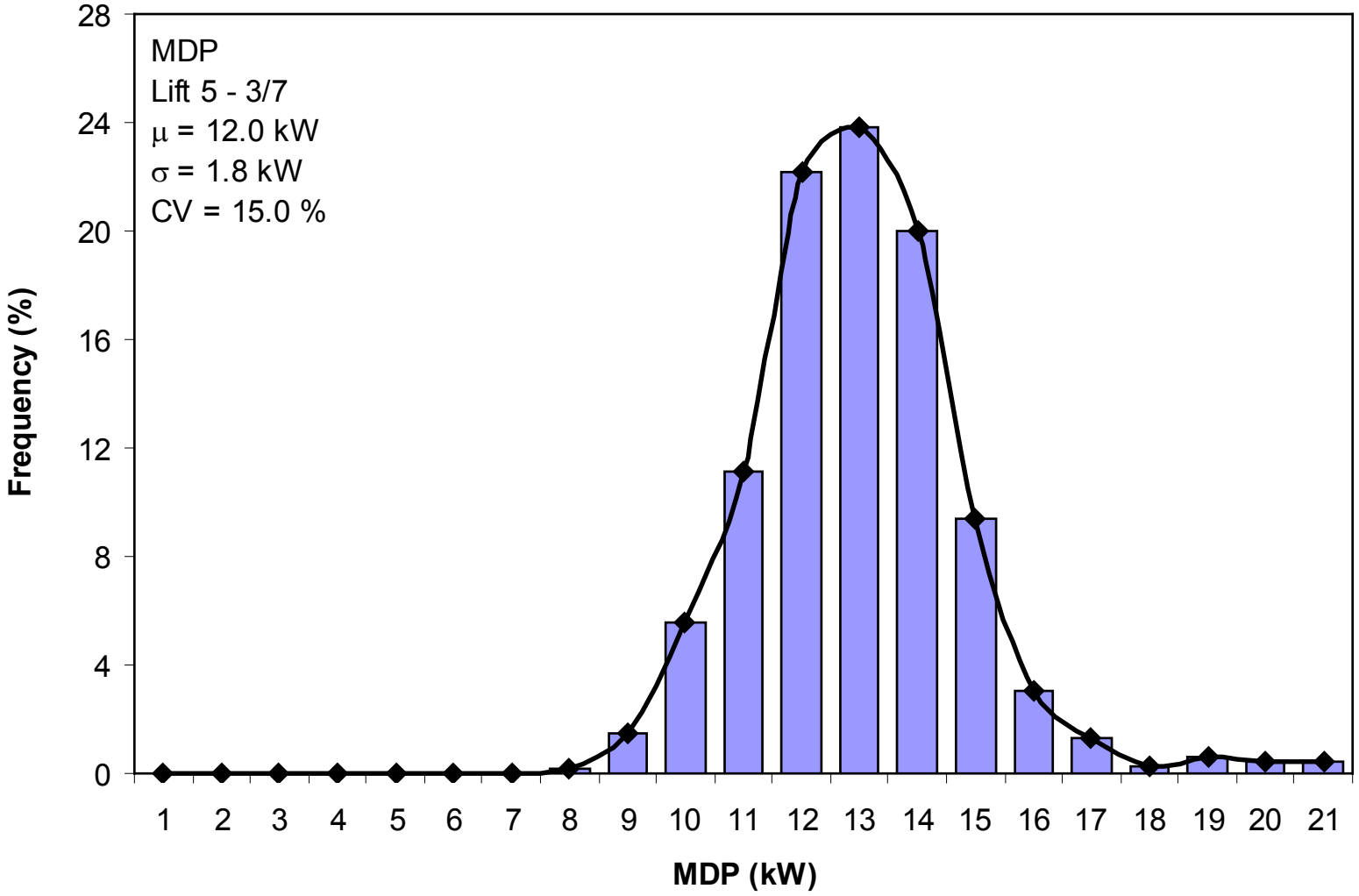
Variation of MDP Values along the Centerline



Variation of CMV Values along the Centerline



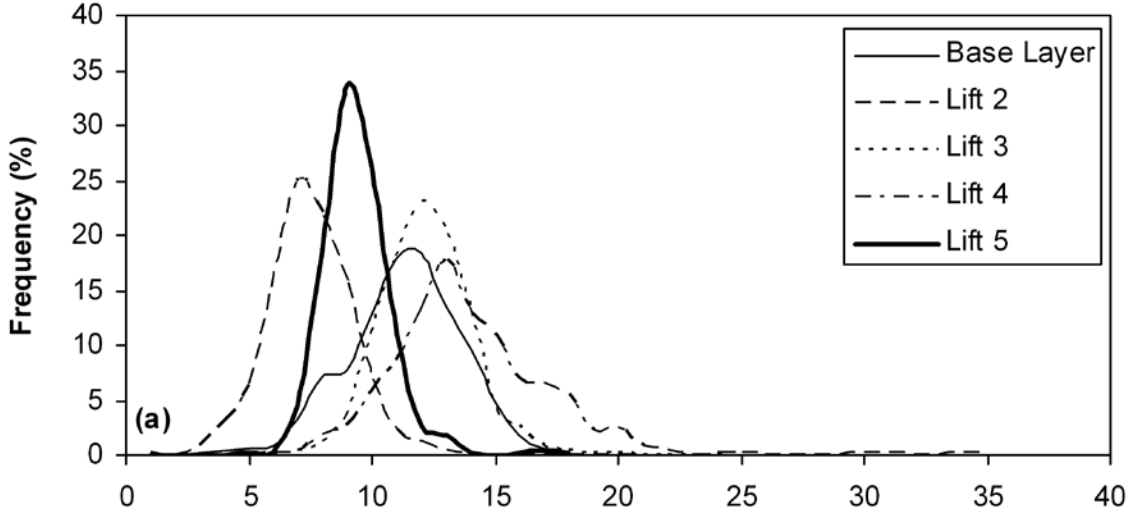
Histogram of Recorded Data for Lift 5, Pass 3/7



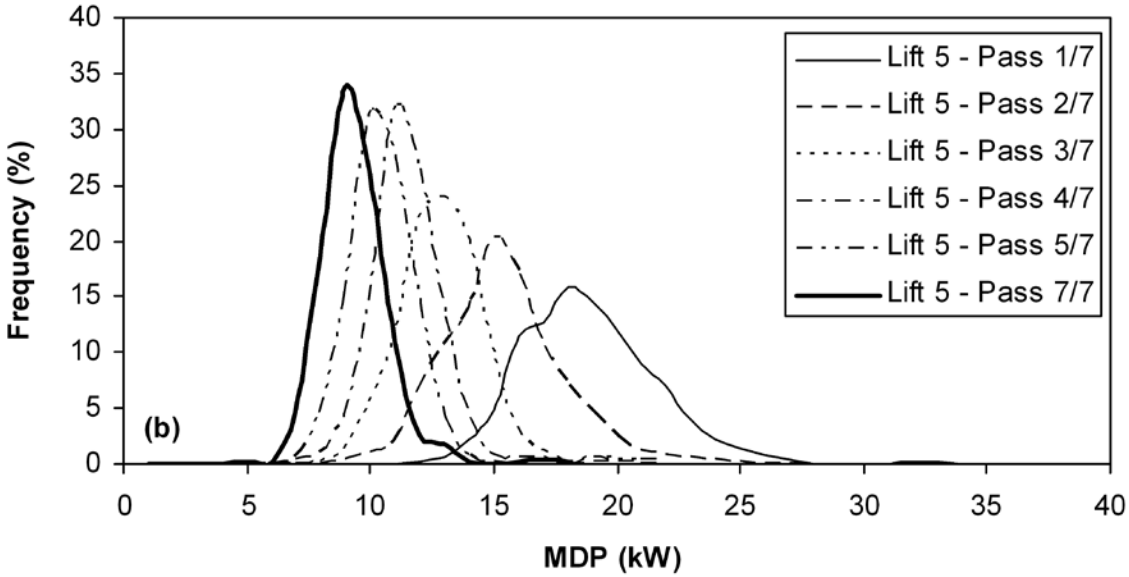
*Note: Data included in the histogram includes all values recorded from three side-by-side roller transects

Comparison of Histograms: MDP Values

Final Passes



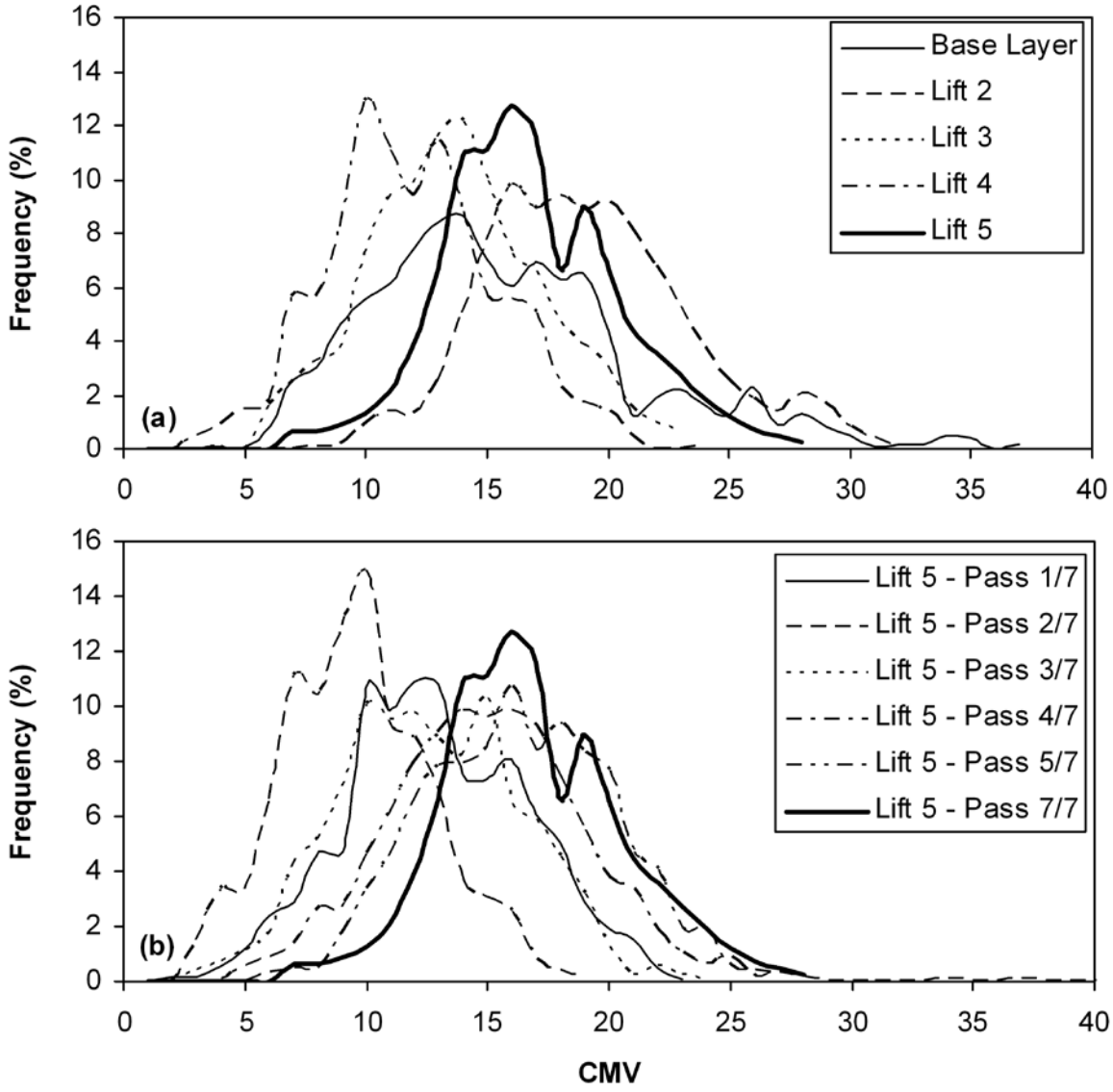
Lift 5, Pass 1-7



Comparison of Histograms: CMV Values

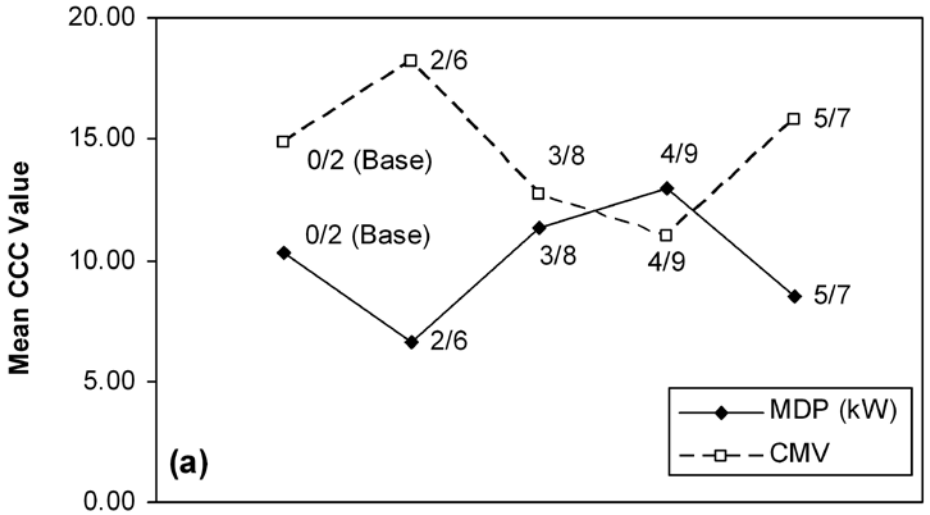
Final Passes

Lift 5, Pass 1-7

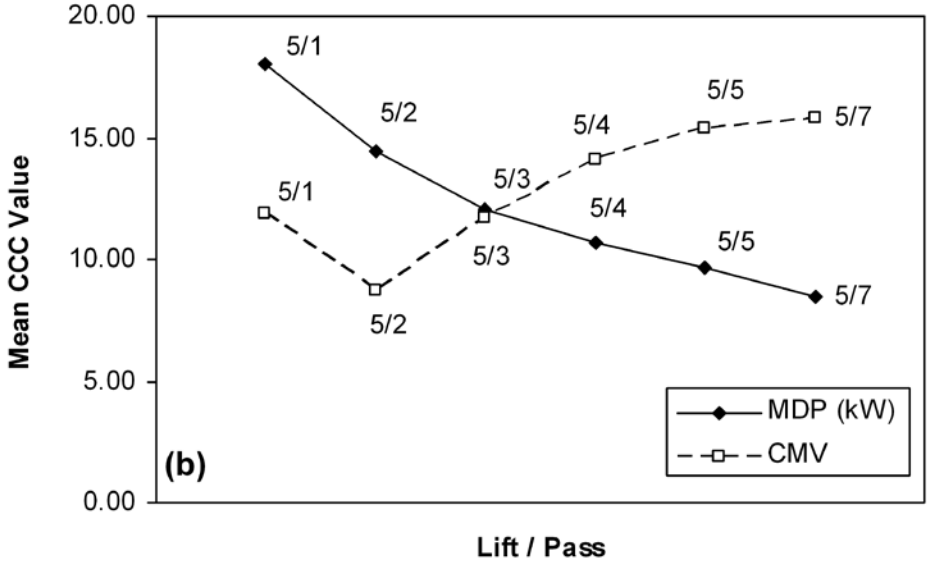


Average of CCC Values for Each Lift & Pass

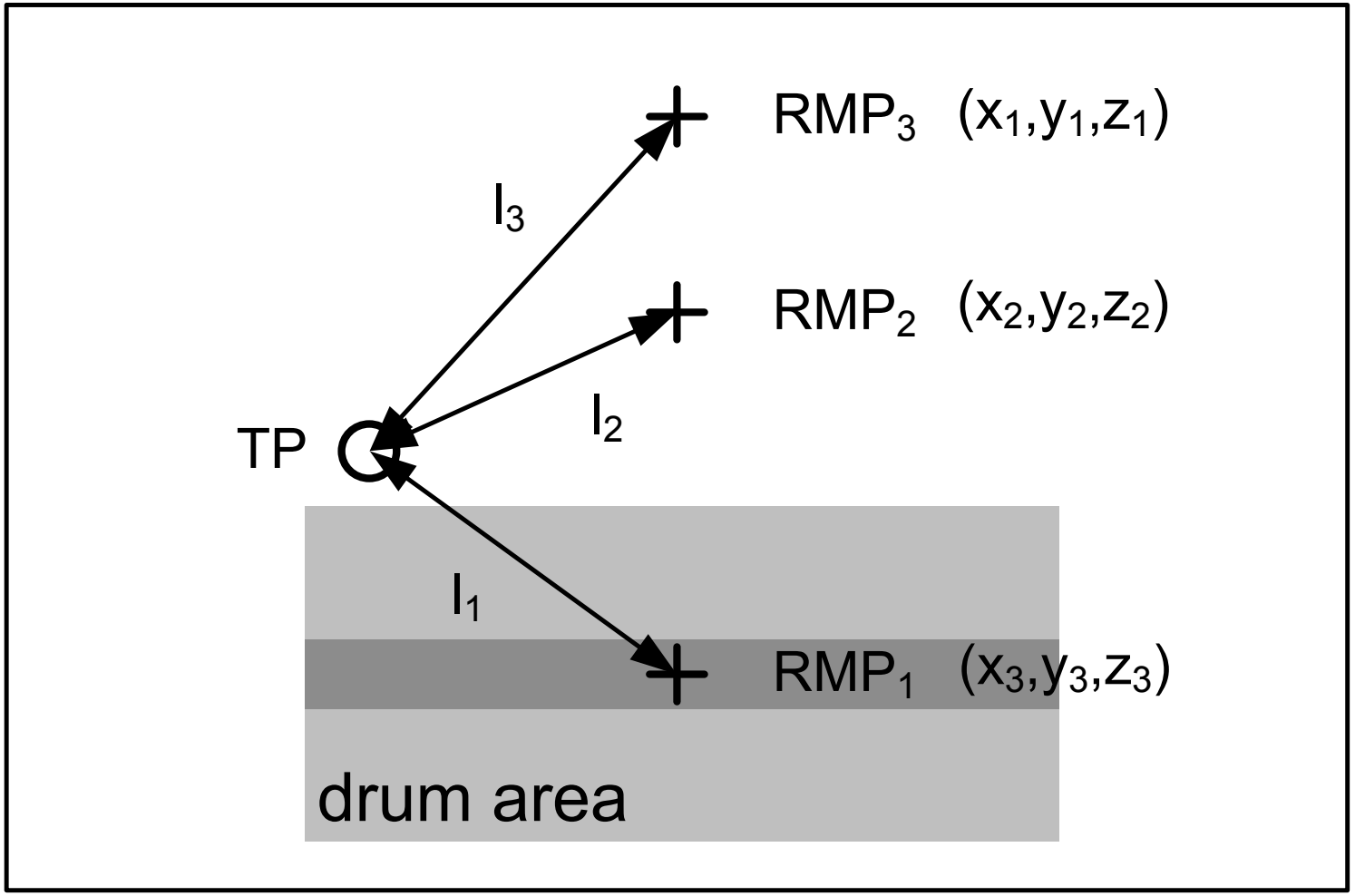
Final Passes



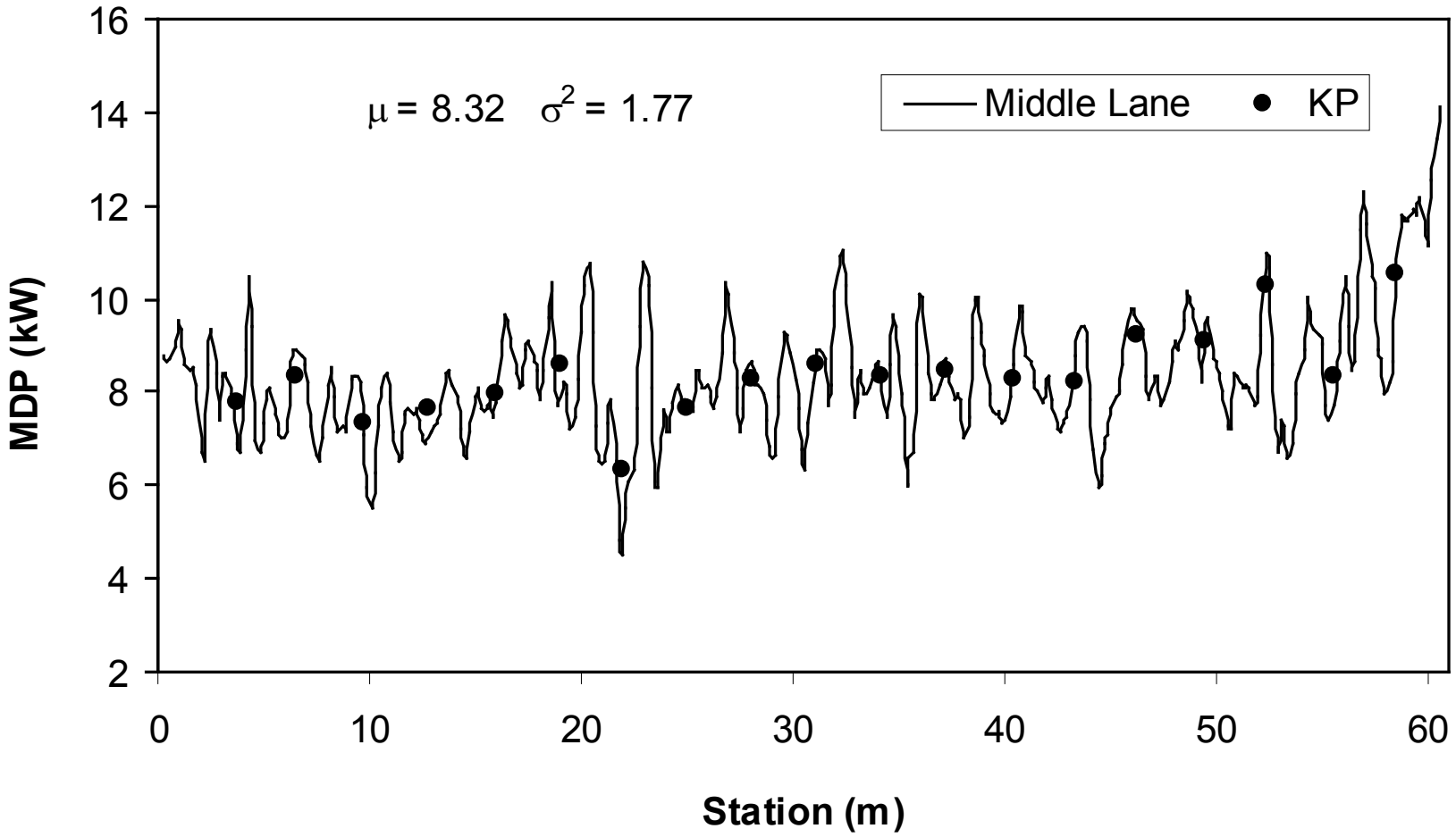
Lift 5, Pass 1-7



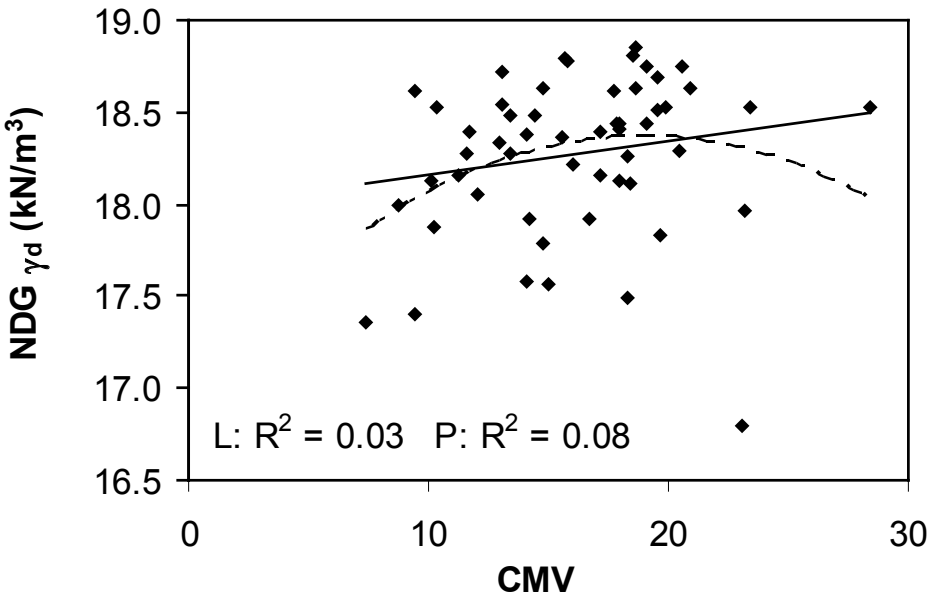
Spatial Averaging of the CCC Data: Kriging Method

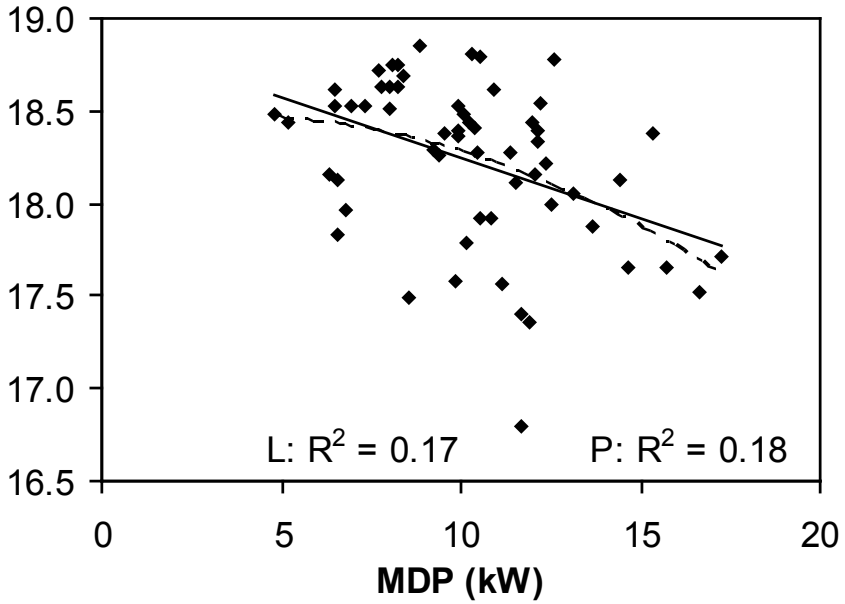


Comparison Between Kriged Data Points and MDP Data Trace Along the Centerline for Lift 5, Pass 7

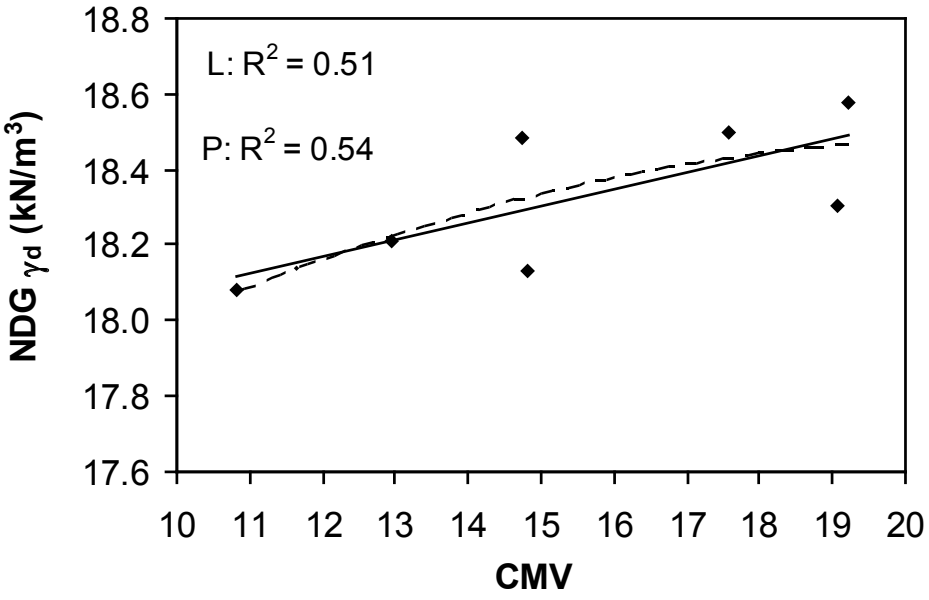


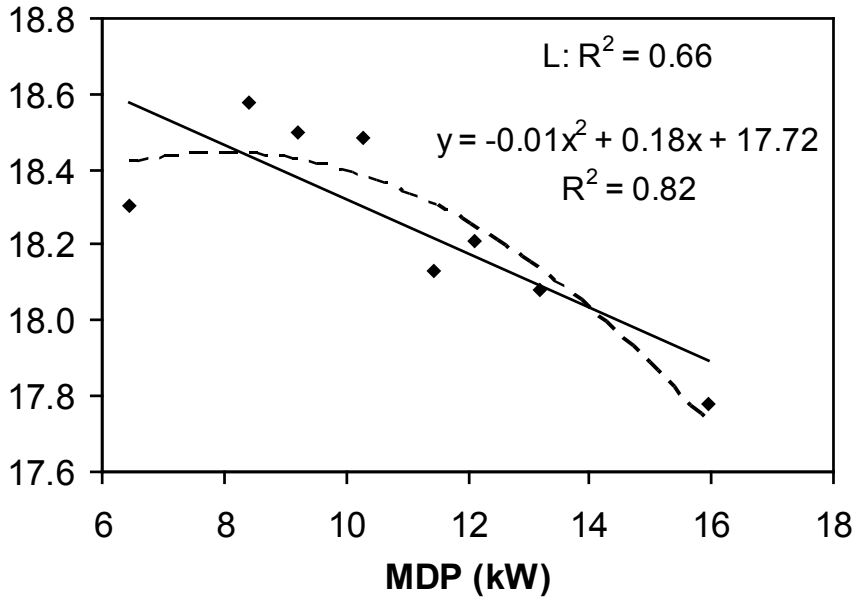
Univariate Regression Analysis Results: NDG vs. CCC Data – All In-Situ Test Points





Univariate Regression Analysis Results: NDG vs. CCC Data – Avg Values for Each Lift





Conclusions

- For the soil that was studied, both MDP & CMV technologies showed reasonable & consistent behavior with increasing compaction
- Effect of compaction amplitude should be taken into account for interpretation of the CMV values.
- CMV values are affected by underlying layers
- Point-by-point comparisons or calibrations with in-situ test results do not work well
- Average values for a given lift correlate much more strongly with average in-situ test results than do point-by-point comparisons
- MDP showed slightly better correlation with in-situ testing measurements than did CMV.

Thank You !



Questions?

