Intelligent Soil Compaction: Research Update

By

David J. White, Ph.D.
Mark Thompson, Pavana Vennapusa, Heath Gieselman, Mike Kruse, Amy Heurung, and Eddy Blahut

Intelligent Compaction Open House
Akeley, MN
July 20, 2006

PGA
PARTNERSHIP FOR GEOTECHNICAL ADVANCEMENT

ctre
Center for Transportation Research and Education
IOWA STATE UNIVERSITY

Acknowledgements - UPDATE

- FHWA Technology Deployment Program
- MnDOT
- Iowa Highway Research Board
- Caterpillar, Inc.
- Center for Transportation Research and Education (CTRE) at Iowa State University

Overview - UPDATE

- Introduction
- Field Project Results:
  - February 2005; Peoria, IL
  - August 2005; Peoria, IL
  - July and October/November 2005; TH 14, Janesville, MN
  - June 2006; Peoria, IL
  - June, July 2006; TH 64, Akeley, MN
  - July 2006; MnROAD, Albertville, MN
- Upcoming Work

February 2005

Edwards Arena at Peoria, IL

Caterpillar Prototype Padfoot Roller

Phase 2 Methodology

- Construct uniform test strips, varying soil type, moisture content, and lift thickness (23 strips)
- Compare power to engineering properties of compacted soil over entire compaction curve (e.g. 1, 2, 4, 8 passes)
  - Density
  - Clegg Impact Value
  - DCP index
  - GeoGauge modulus
  - PFWD modulus
  - Plate load test (PLT)

Nuclear Moisture-Density

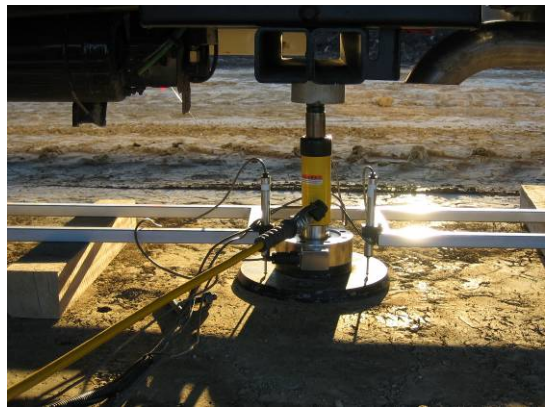
Drive Core

Dynamic Cone Penetrometer

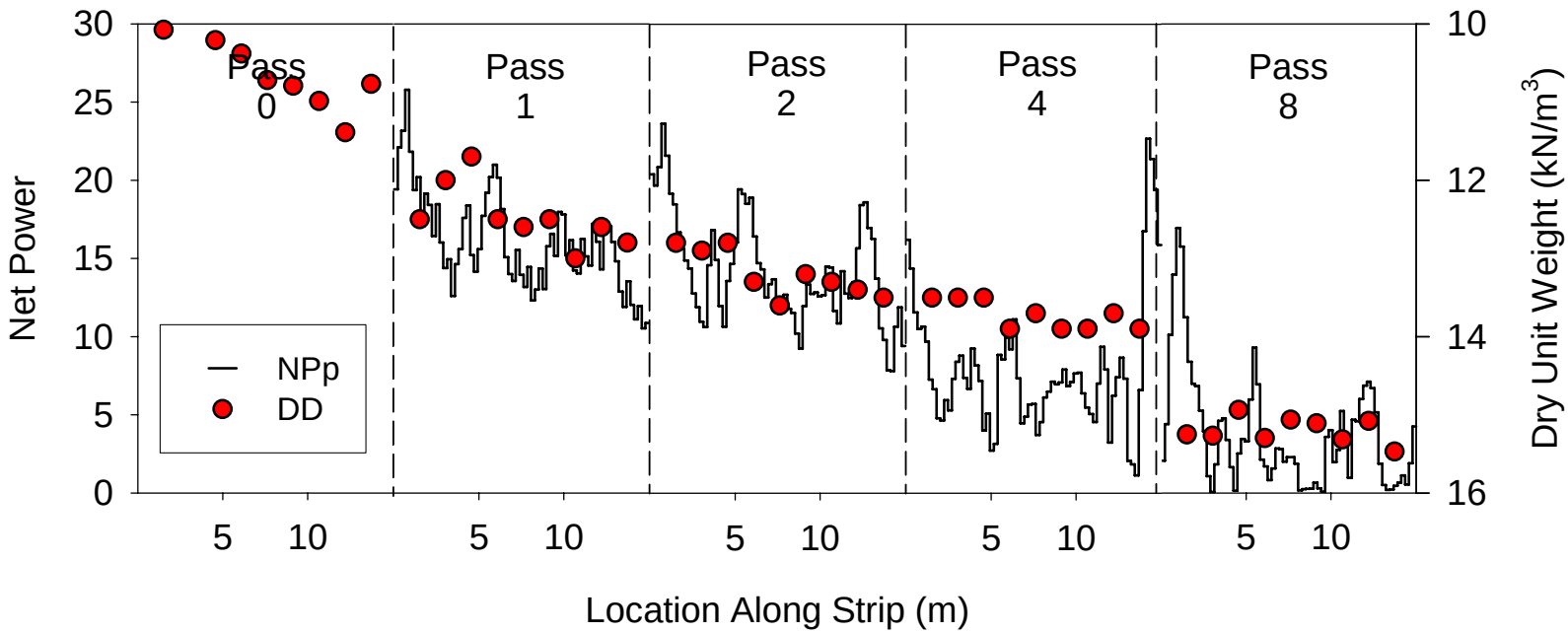
Clegg Impact & Portable FWD

GeoGauge

Plate Load Test

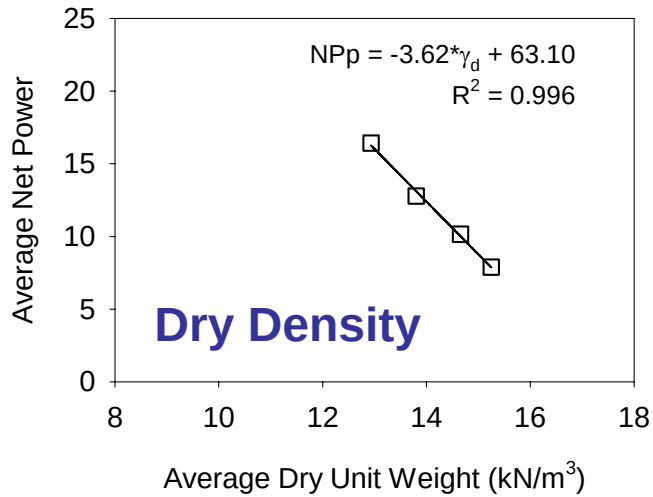


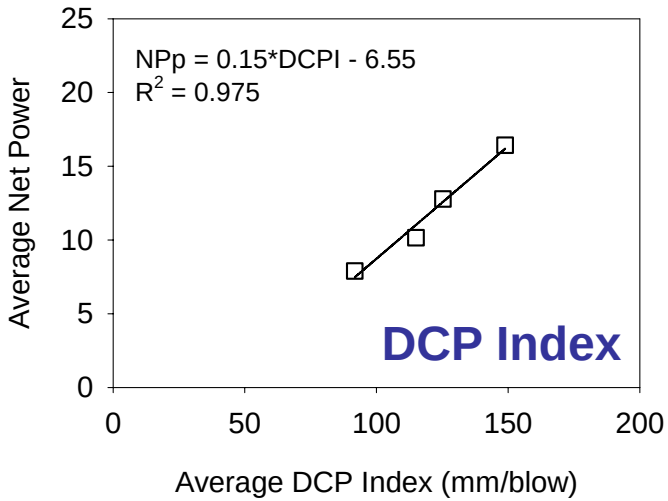
Raw Data Along Strip Length

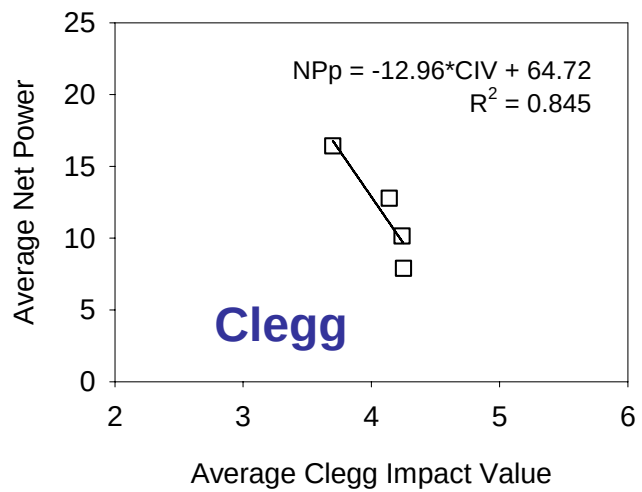


Kickapoo Silt (Strip 1)

- Relationships for single test strip using averaged data (1 point per roller pass)
- High R^2 values, but generally only 4 points and identical soil conditions



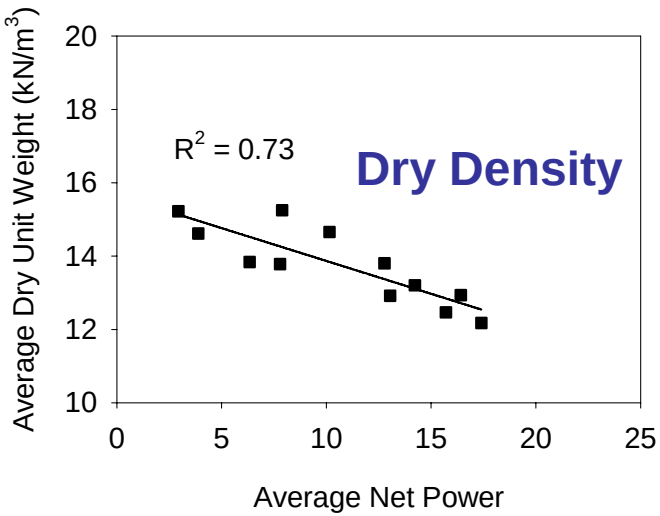


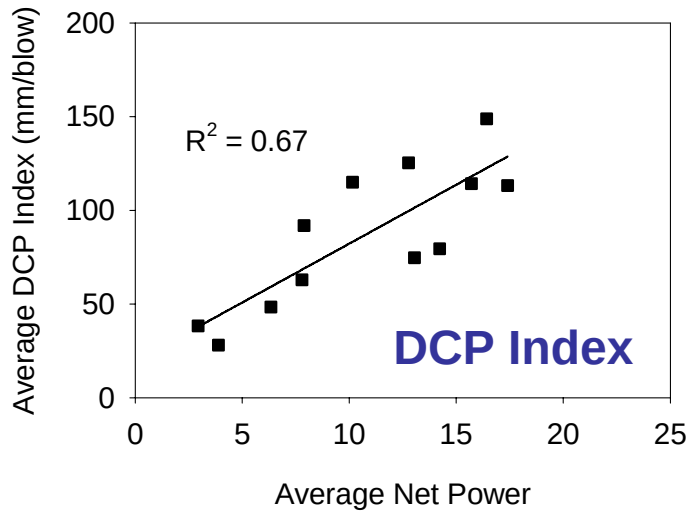


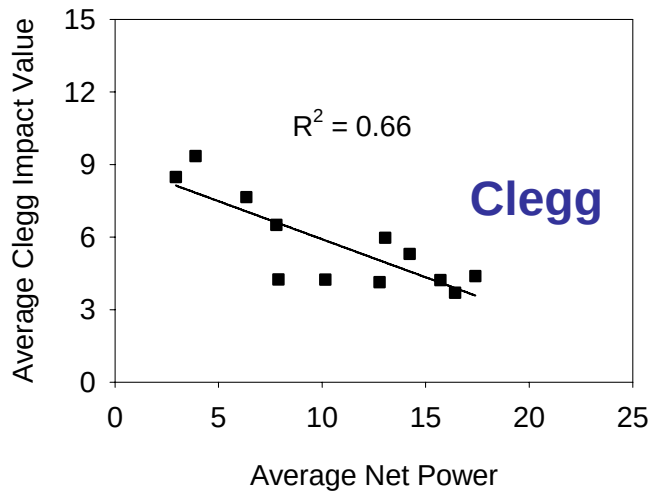
Kickapoo Silt (Strip 1)

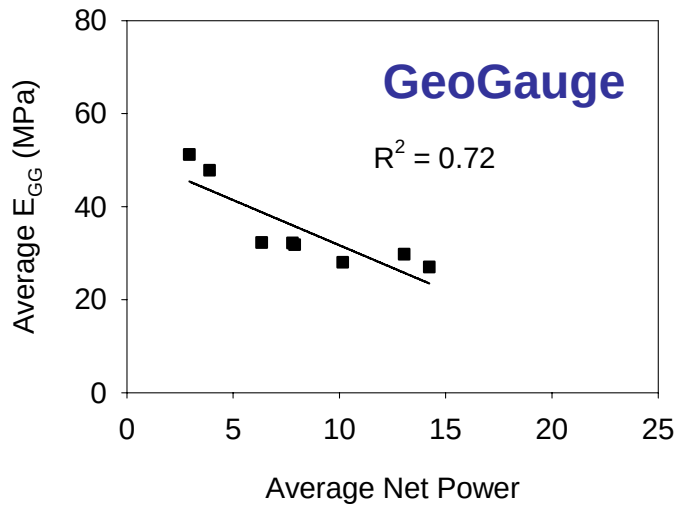
Linear Regression Analysis

- *So how about combining data from test strips of varying moisture content, lift thickness, and cohesive soil type?*









Kickapoo Silt (30-cm lift) – data from 3 strips

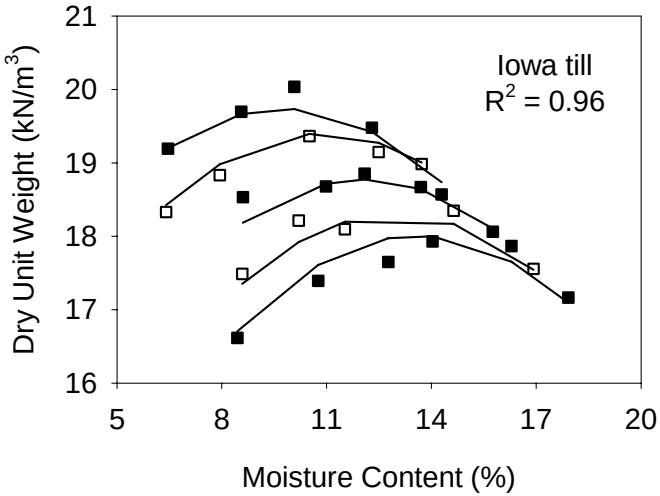
IOWA STATE UNIVERSITY

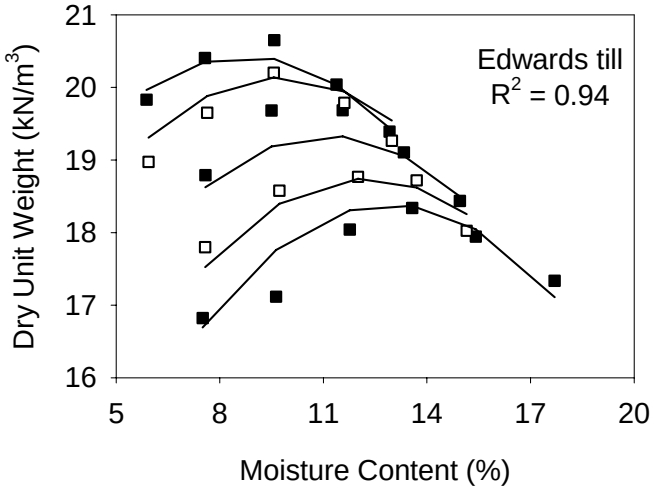
ctre Center for Transportation Research and Education

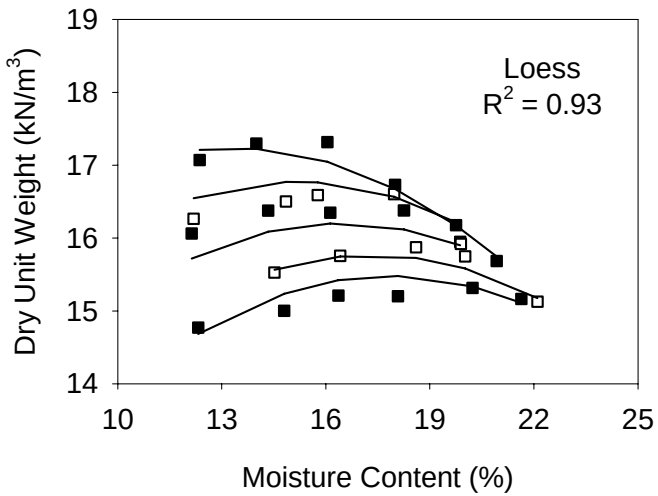
Multiple Linear Regression Analysis

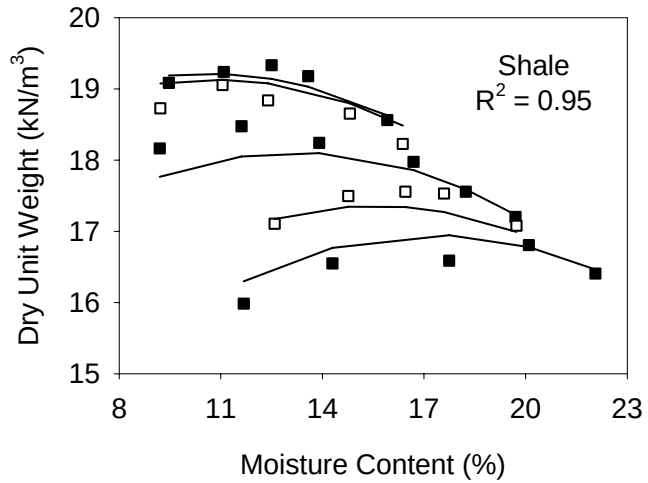
- Based on laboratory Proctor data, quadratic “compaction model” developed for relating net power to density, strength, and stiffness

$$\gamma_d = b_0 + b_1 \cdot E + b_2 \cdot E^2 + b_3 \cdot w + b_4 \cdot w^2 + b_5 \cdot E \cdot w + b_6 \cdot E^2 w$$





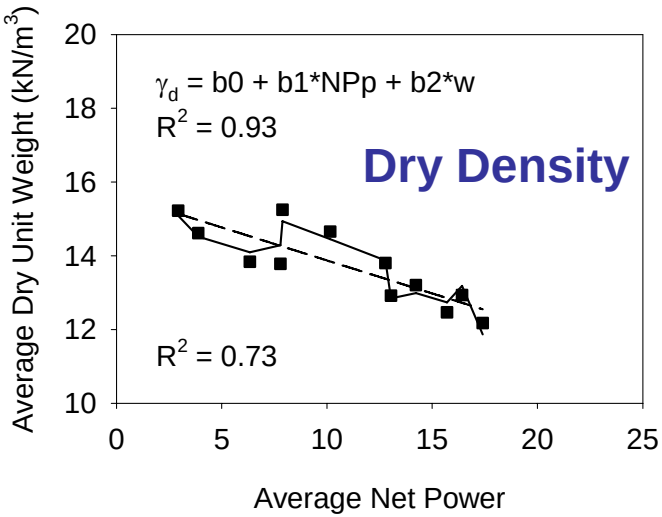


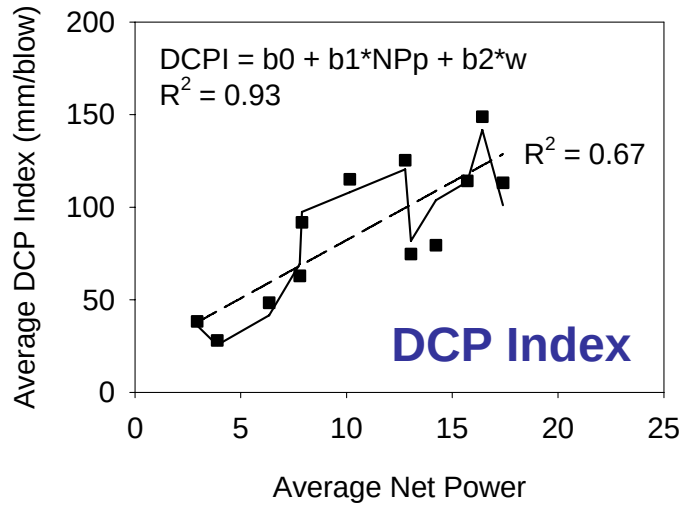


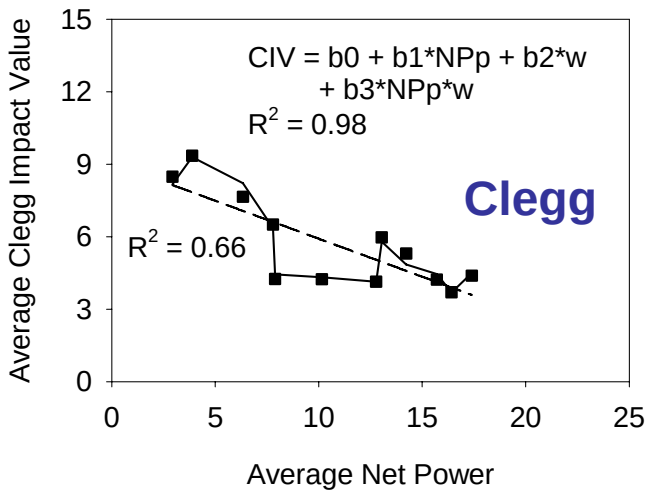
Model verification: laboratory data (points) and model predictions (lines)

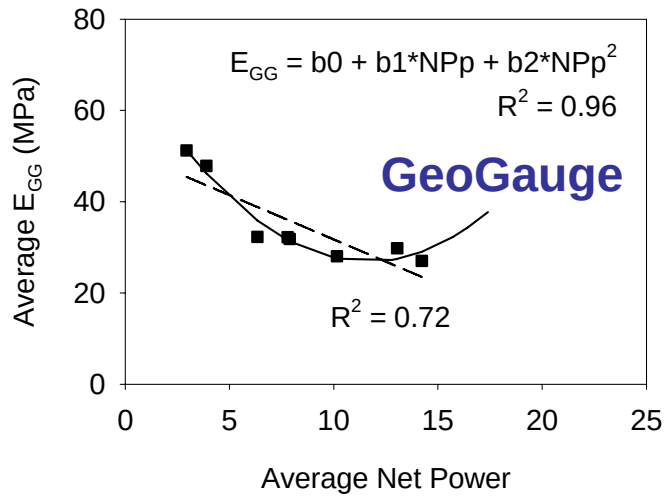
IOWA STATE UNIVERSITY

ctre Center for Transportation Research and Education







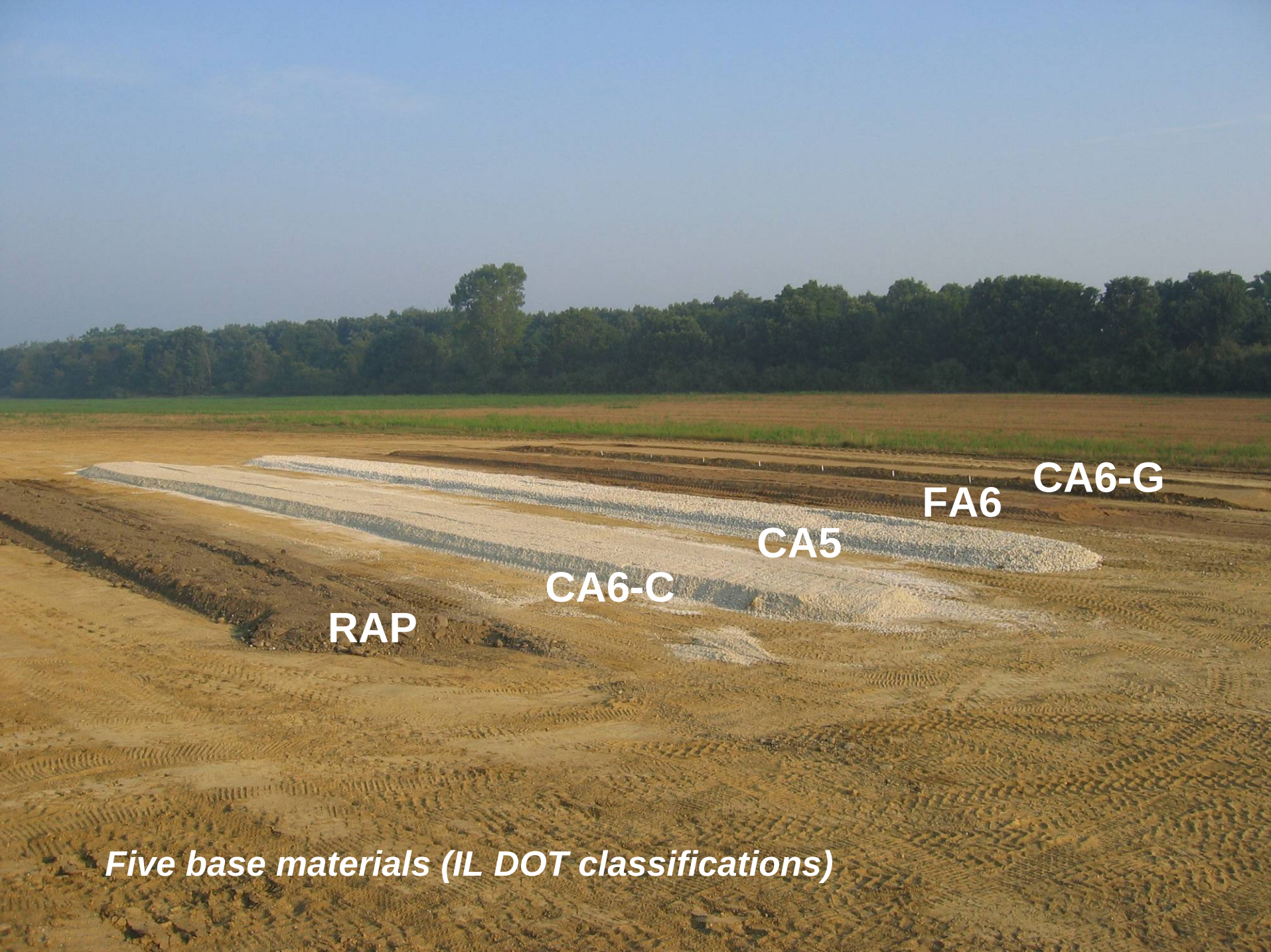


Kickapoo Silt (30-cm lift) – data from 3 strips

August 2005

Peoria, IL

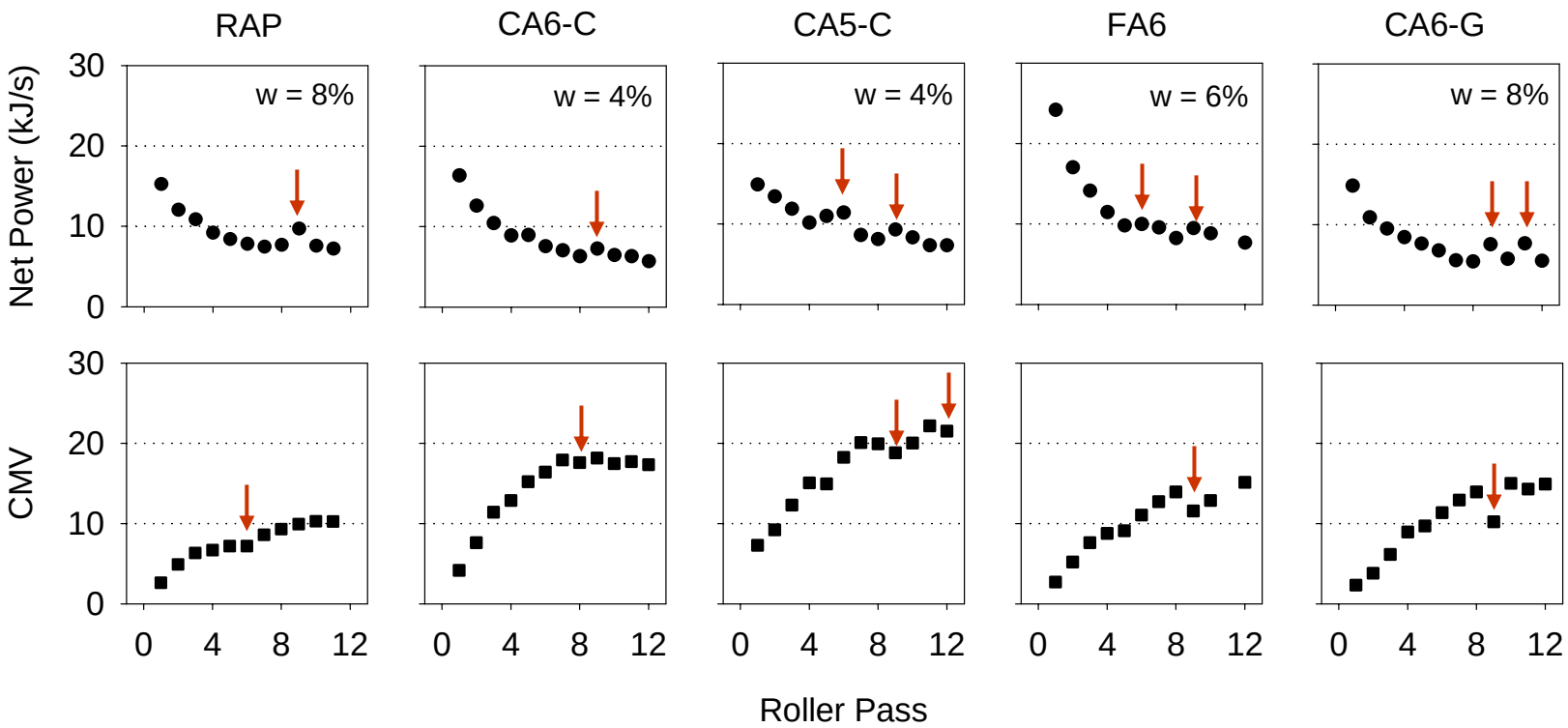
Caterpillar Prototype Smooth Drum Roller



Five base materials (IL DOT classifications)

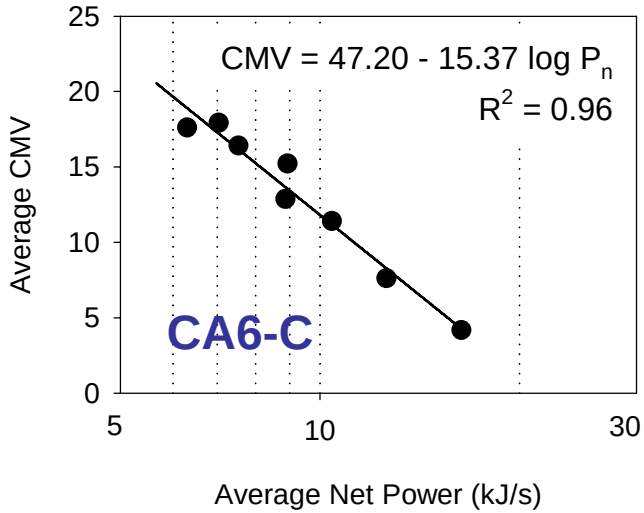

CATERPILLAR

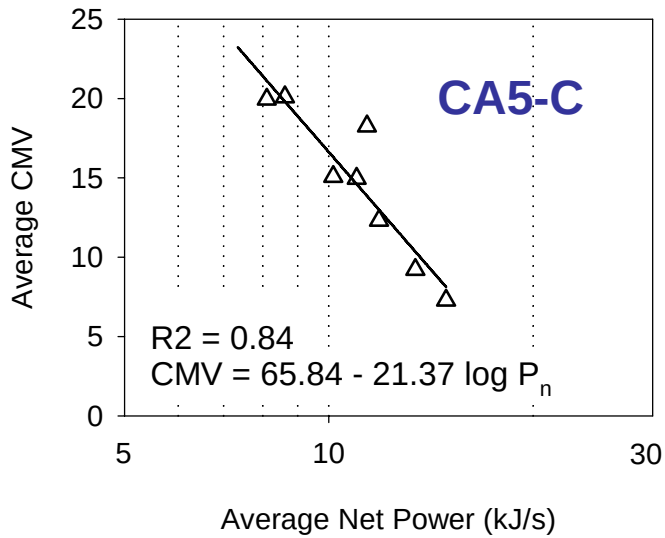
Roller-Generated Data on Base Materials

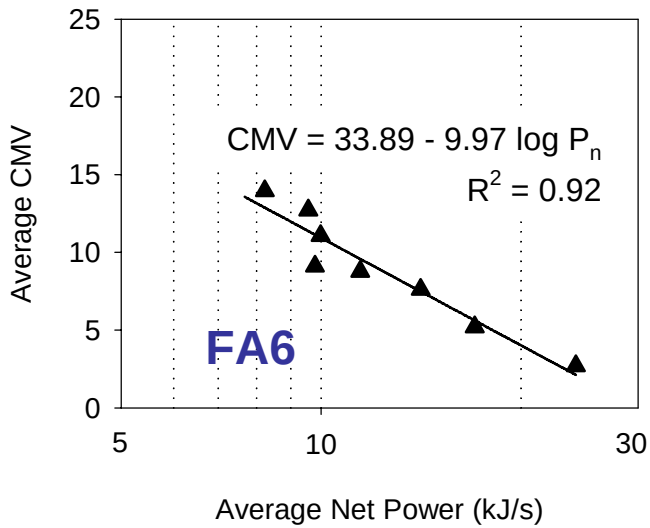


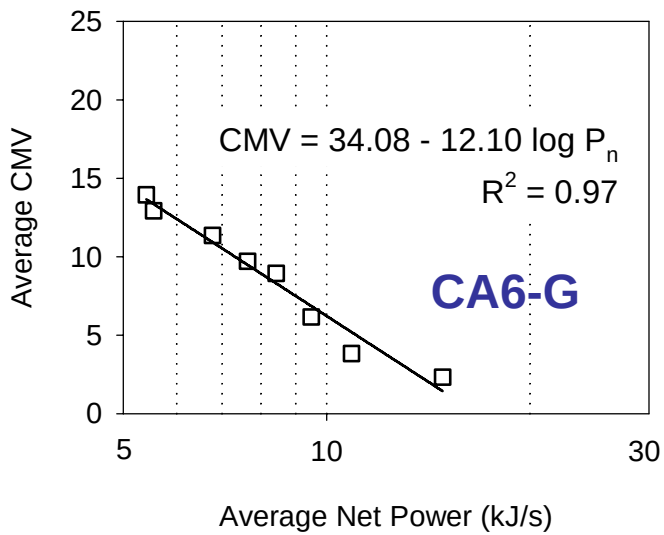
All passes @ amplitude = 2.0 mm

Power and CMV compaction curves for 5 strips

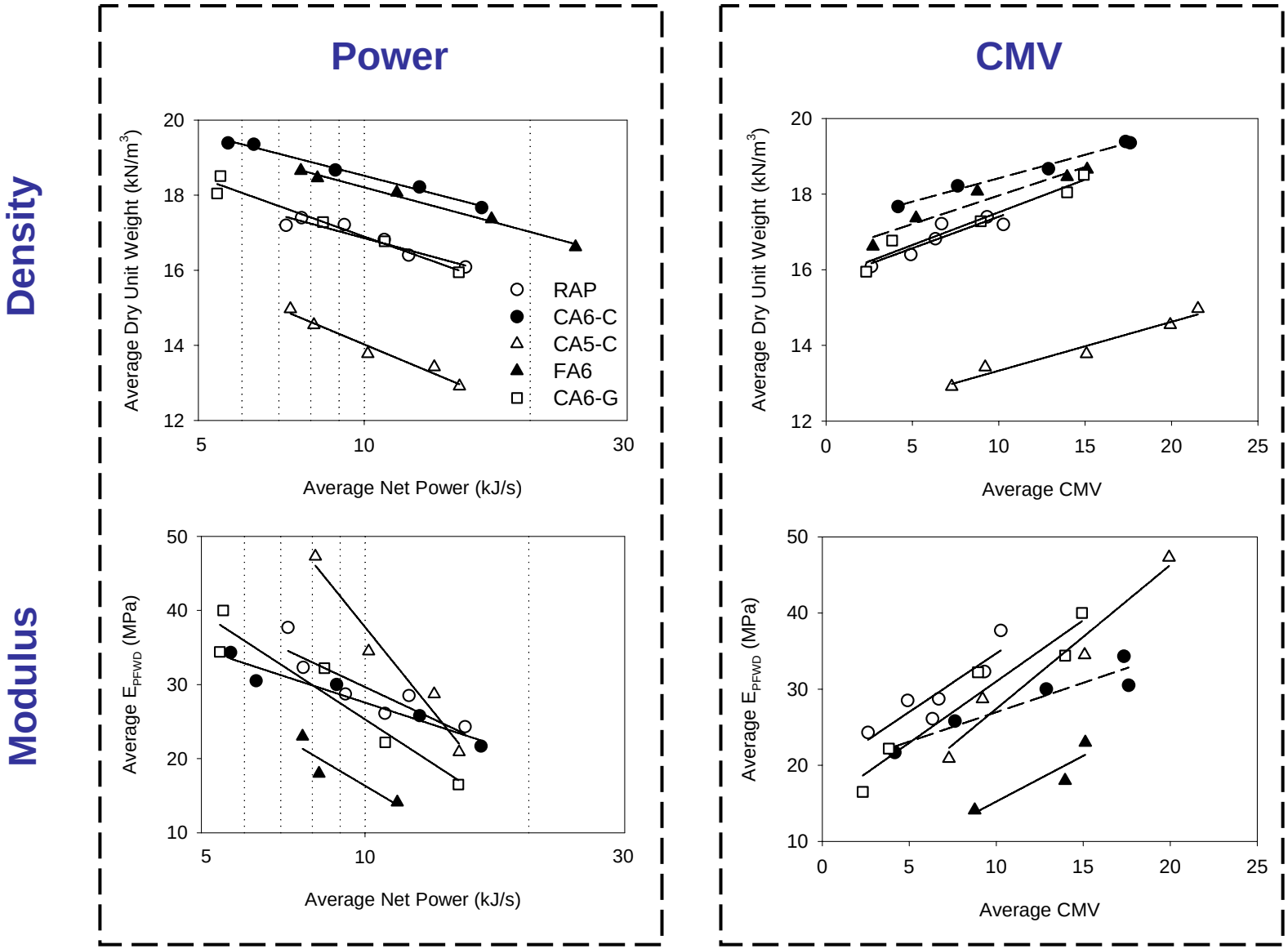








CMV and Machine Power for Base Materials



Density and Modulus from Power and CMV

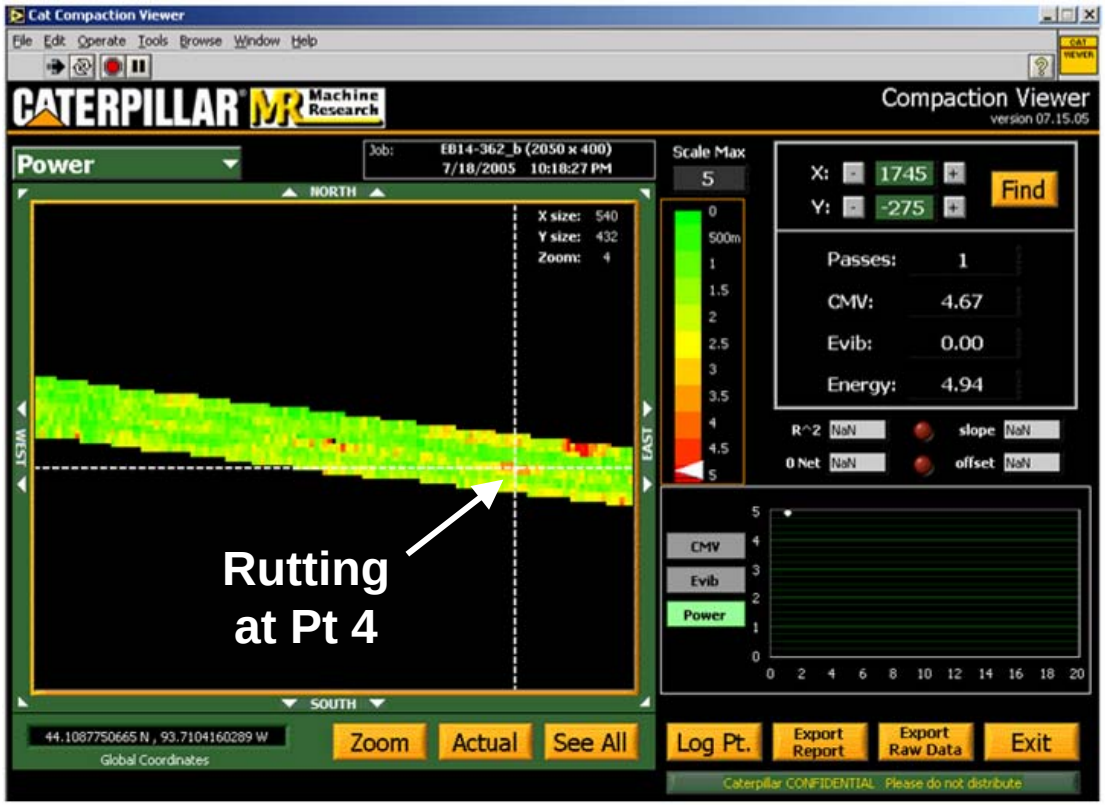
IOWA STATE UNIVERSITY

ctre Center for Transportation Research and Education

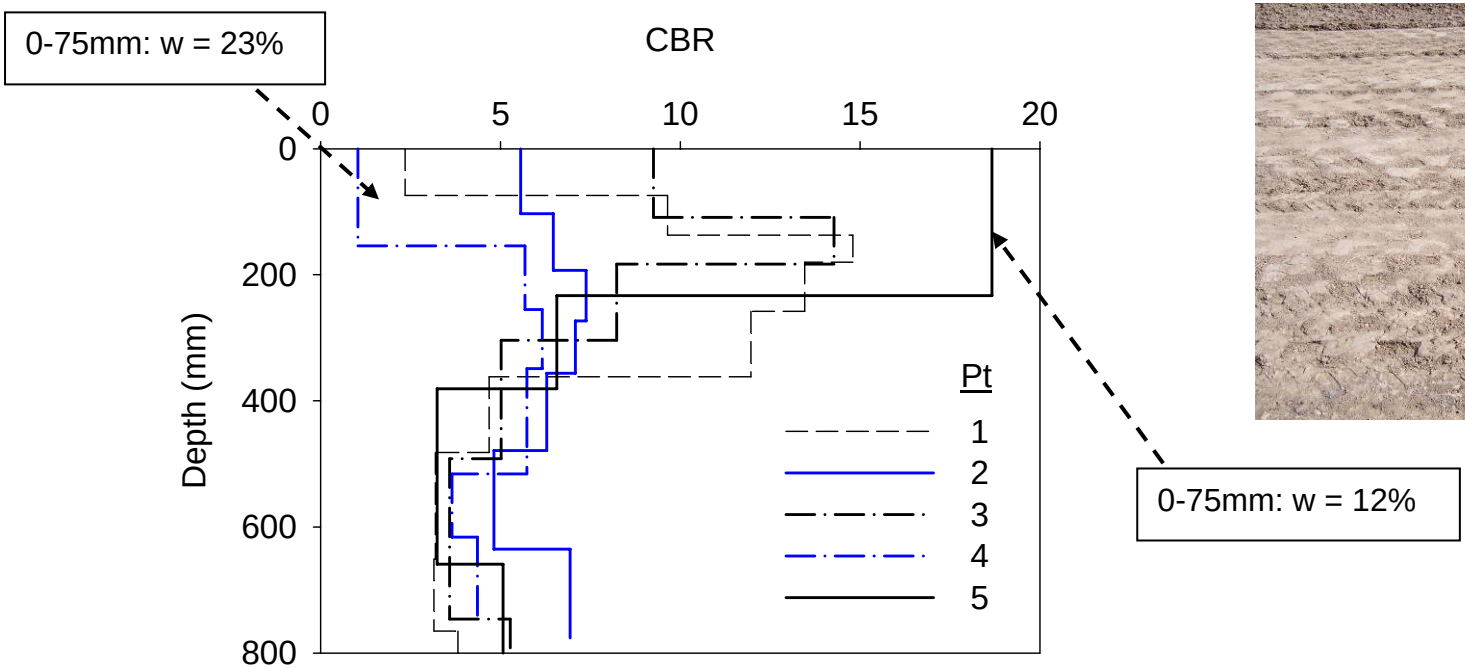
July and October 2005

TH 14 at Janesville, MN

Mapping Exercises with Caterpillar CS-563

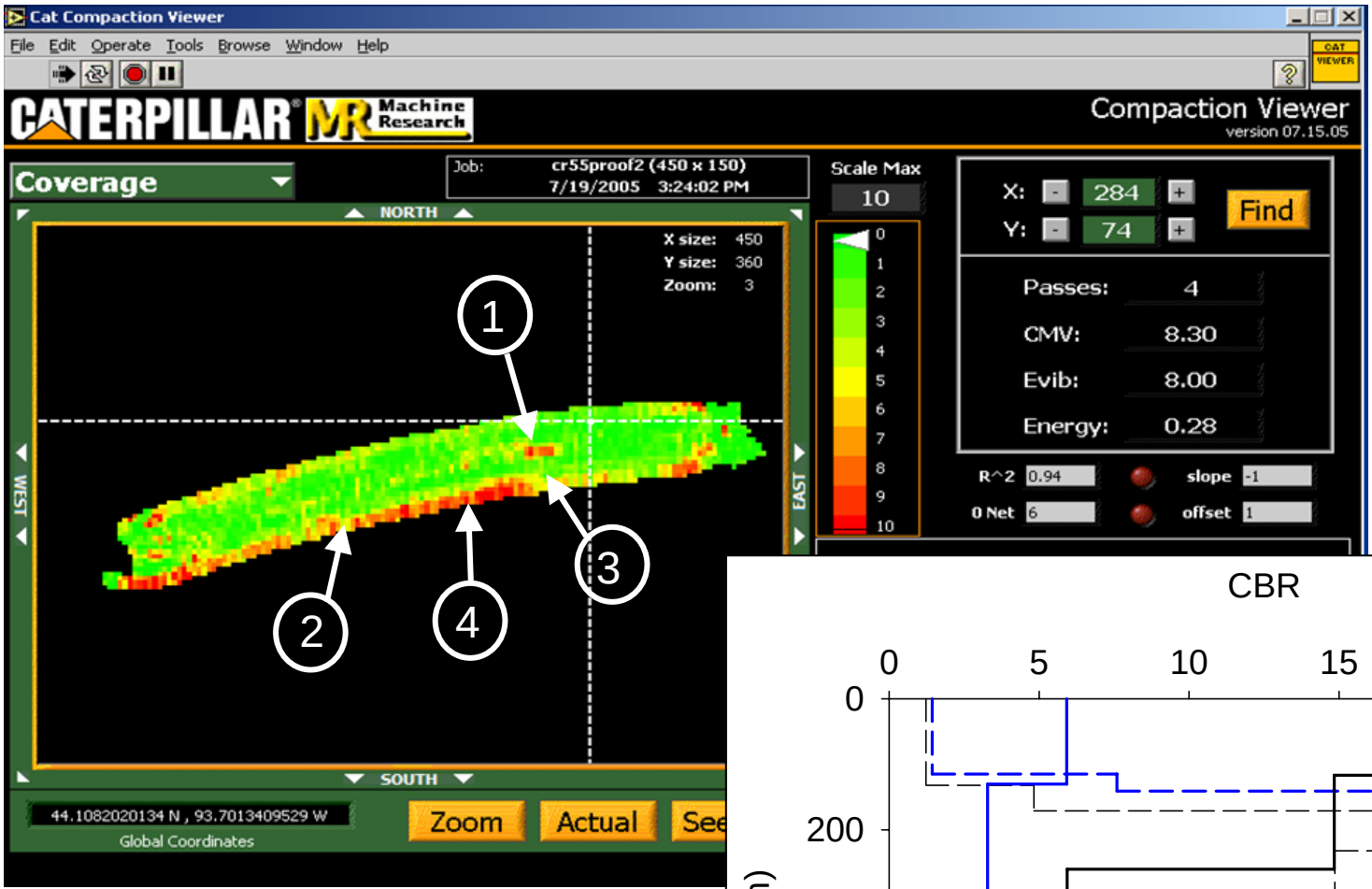


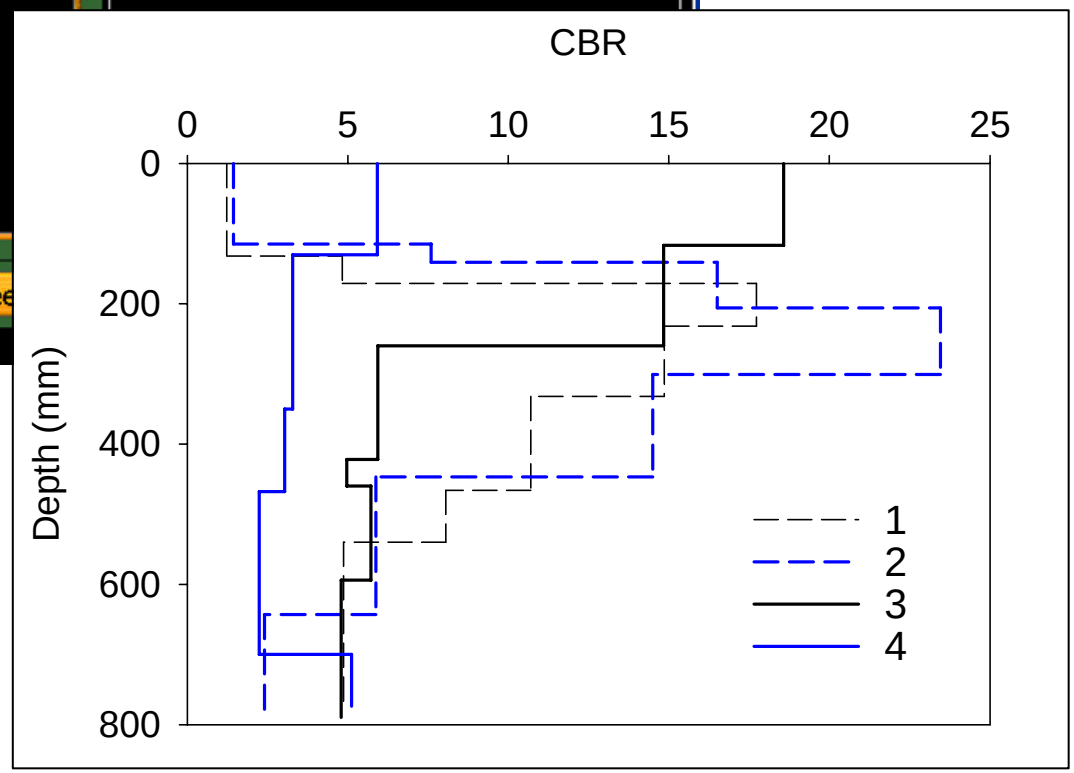
(Rutting at Pts 1 and 2)



IOWA STATE UNIVERSITY

ctre
Center for Transportation Research and Education

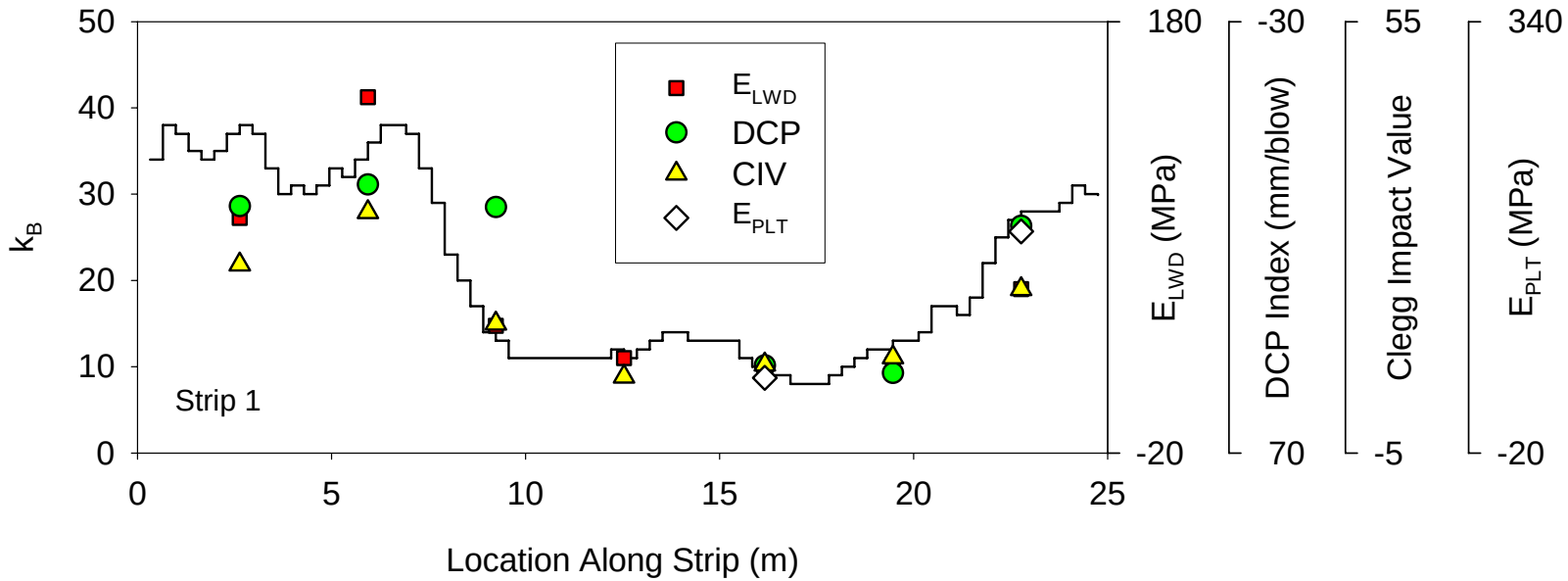


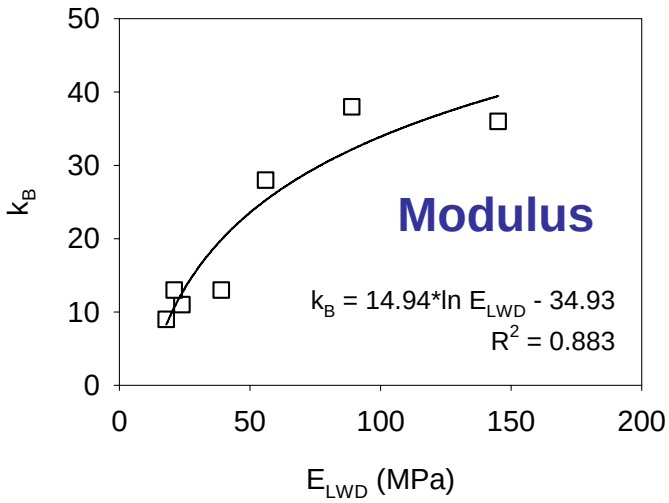


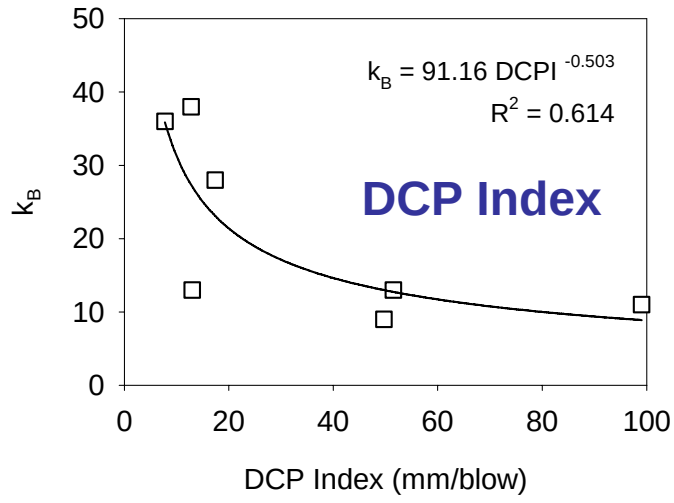
IOWA STATE UNIVERSITY

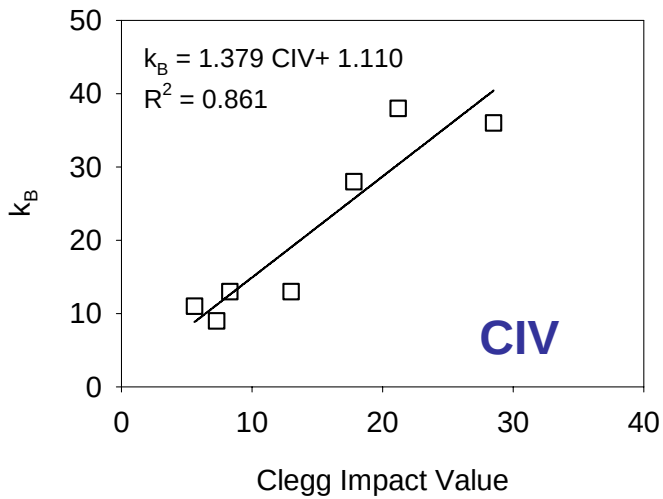
AMMANN Smooth Drum Roller

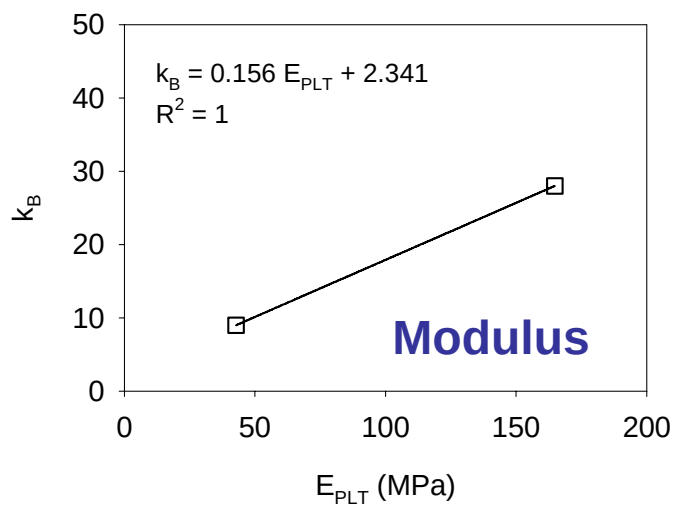
Strip 1 (subgrade and median)





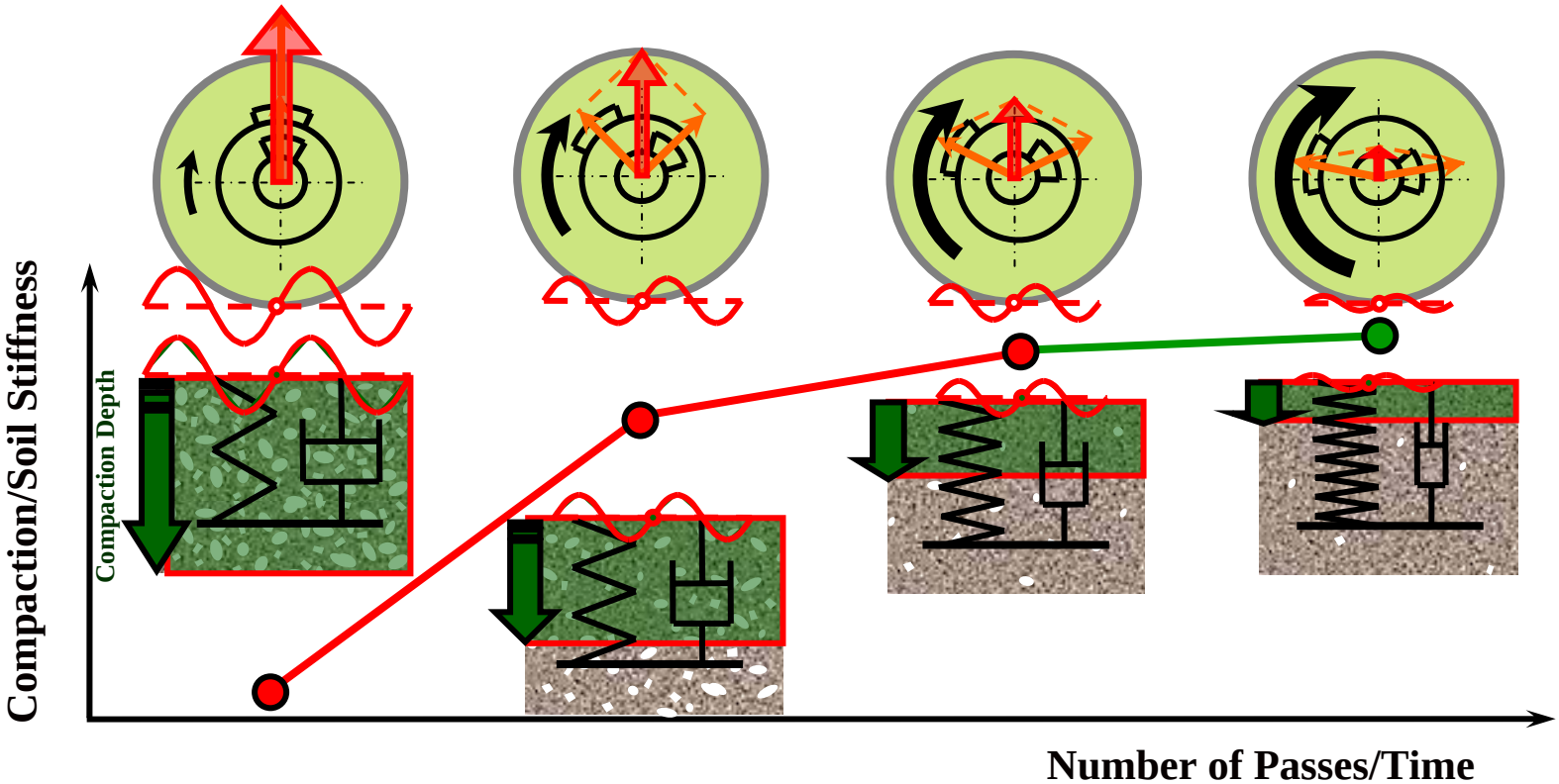






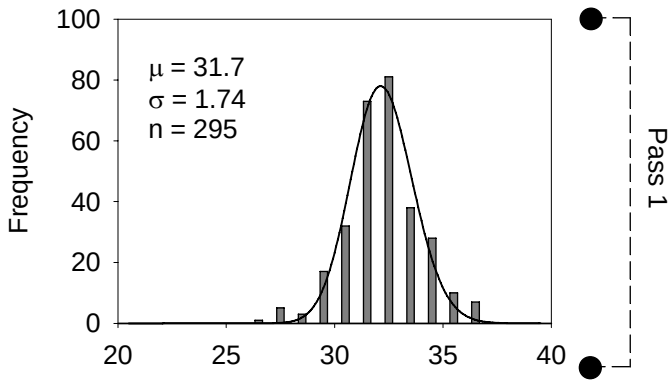
Regressions for field measurements and k_B

Variable Feedback Control for Uniformity

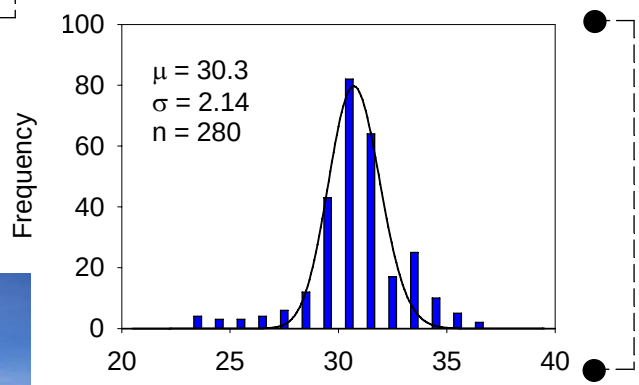


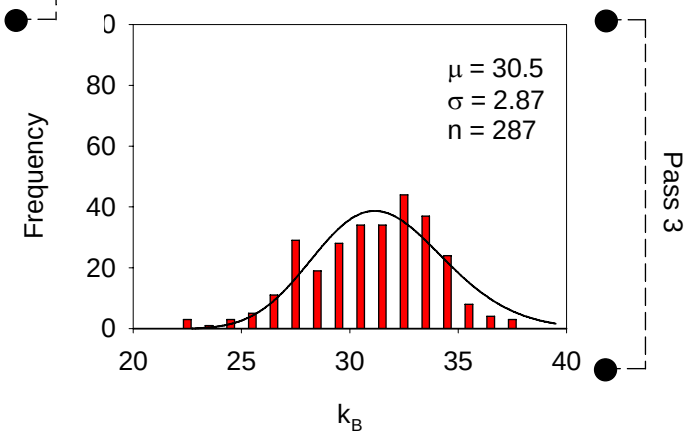
(Slide courtesy of AMMANN)

Evaluation of Variable Feedback Control

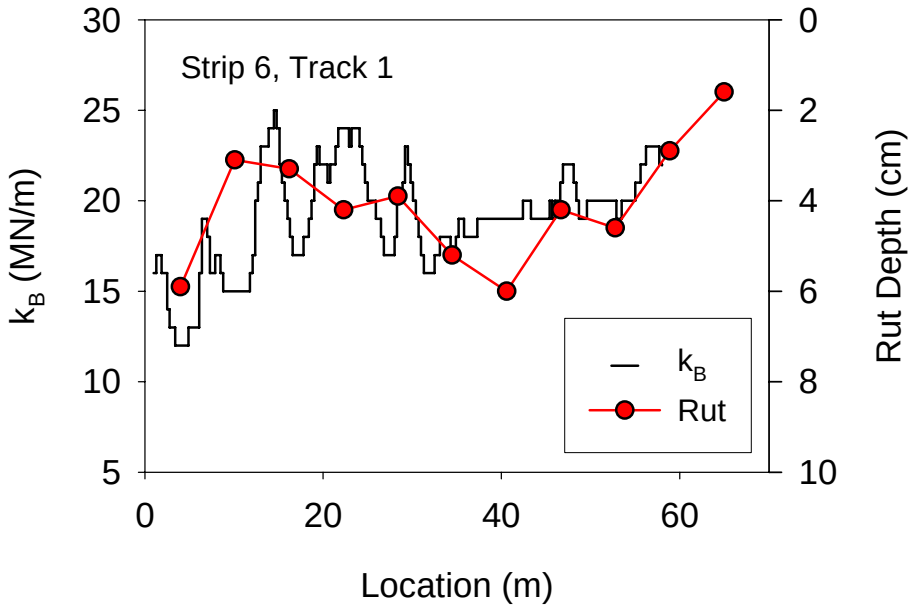


Strip 2 (relatively uniform Class 5)



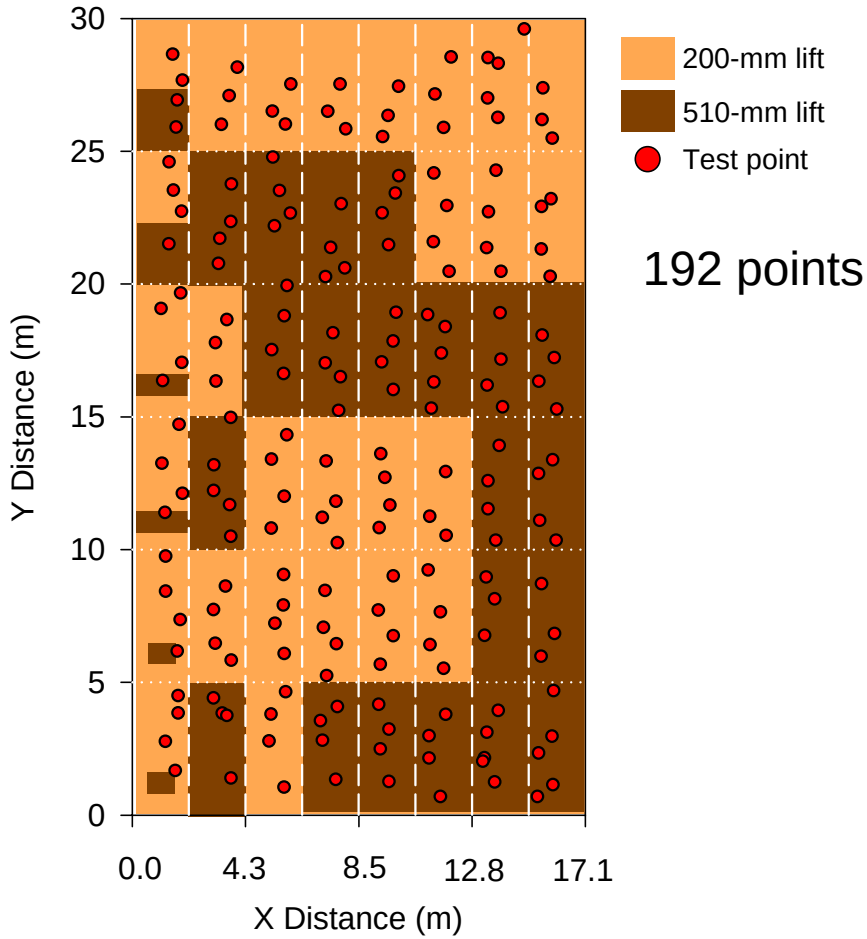


AMMANN k_B Comparison to Test Rolling



June 2006

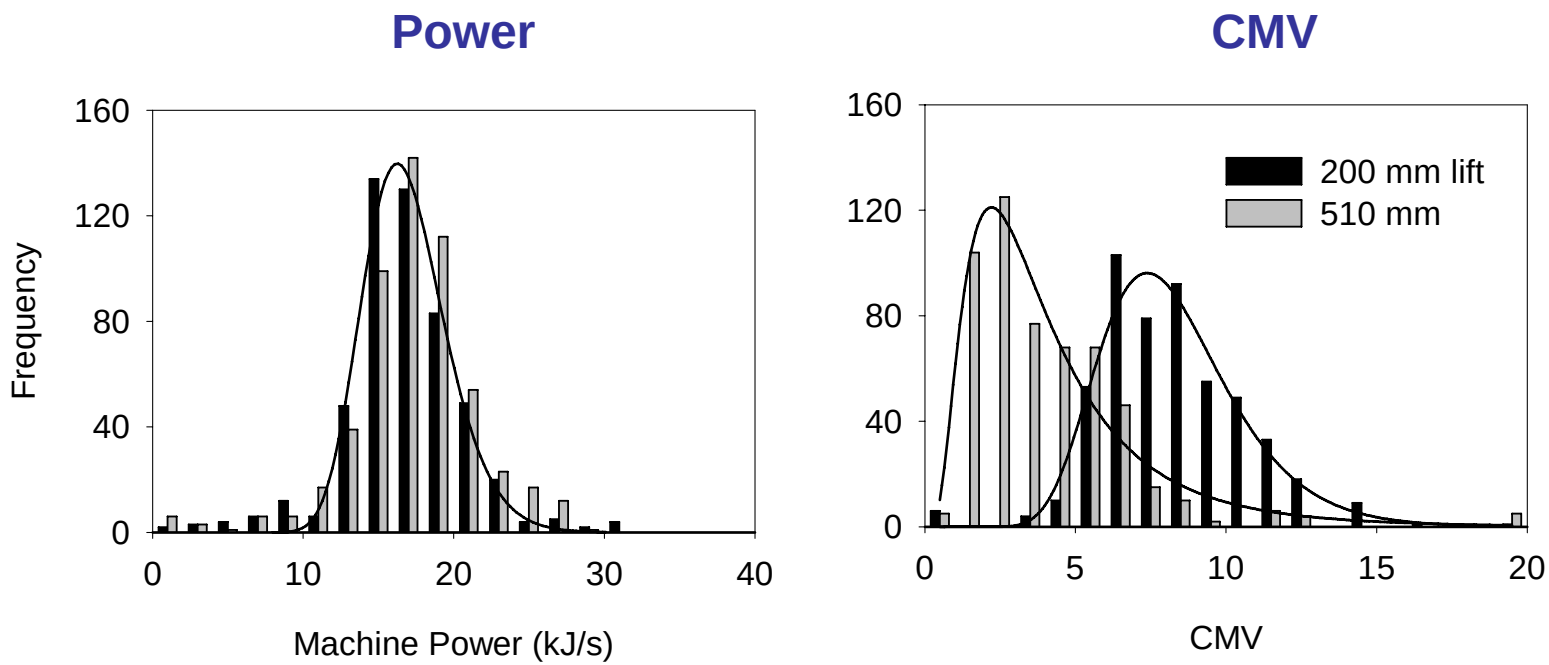
Peoria, IL



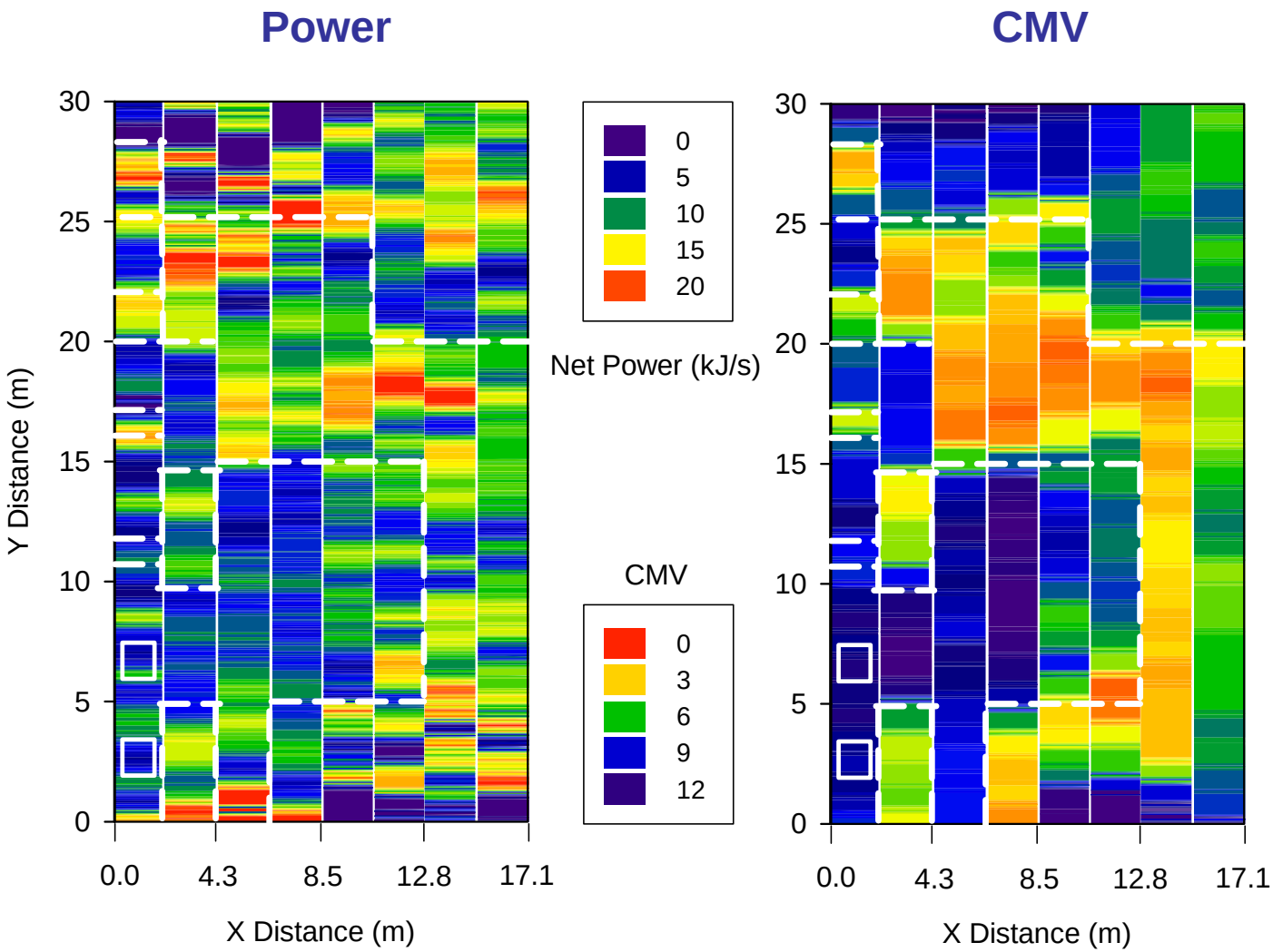
Design of spatial testing


Iowa State crew testing with nuke, Clegg, PFWD, DCP

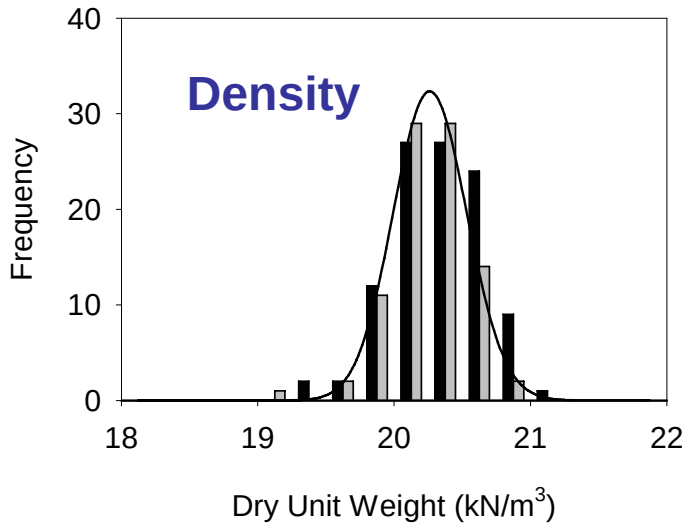
Effect of lift thickness on…

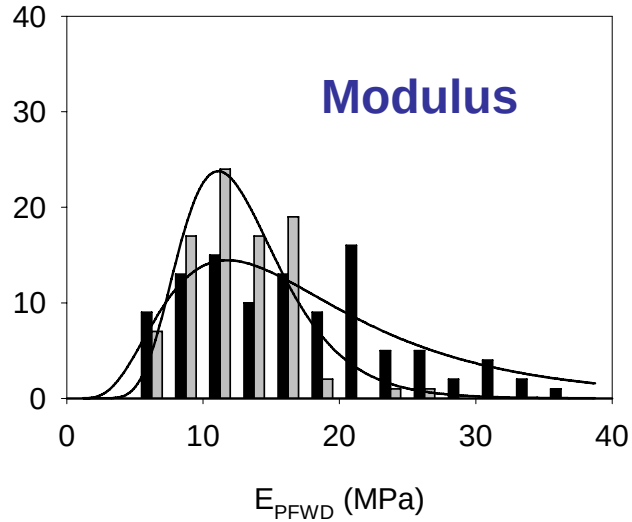


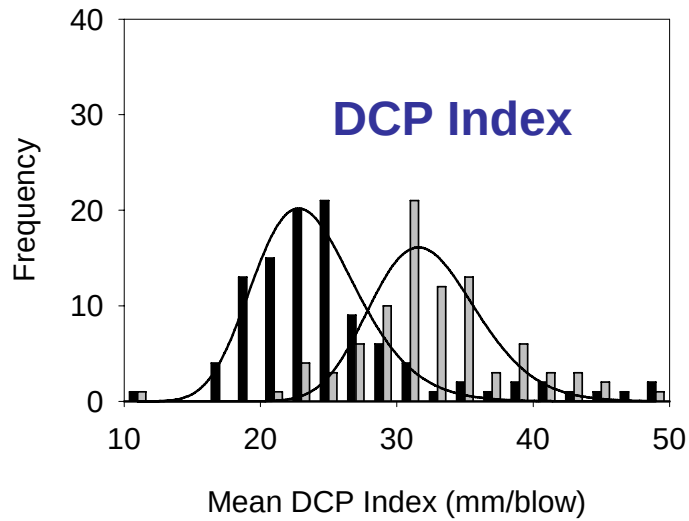
Machine power and CMV distribution plots

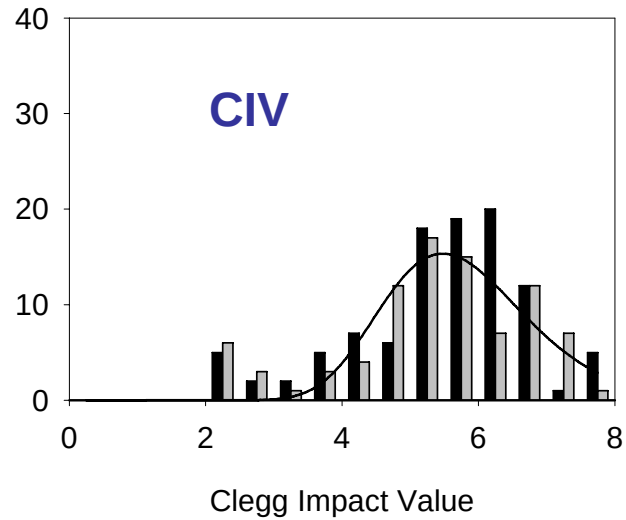


Machine power and CMV – raw data

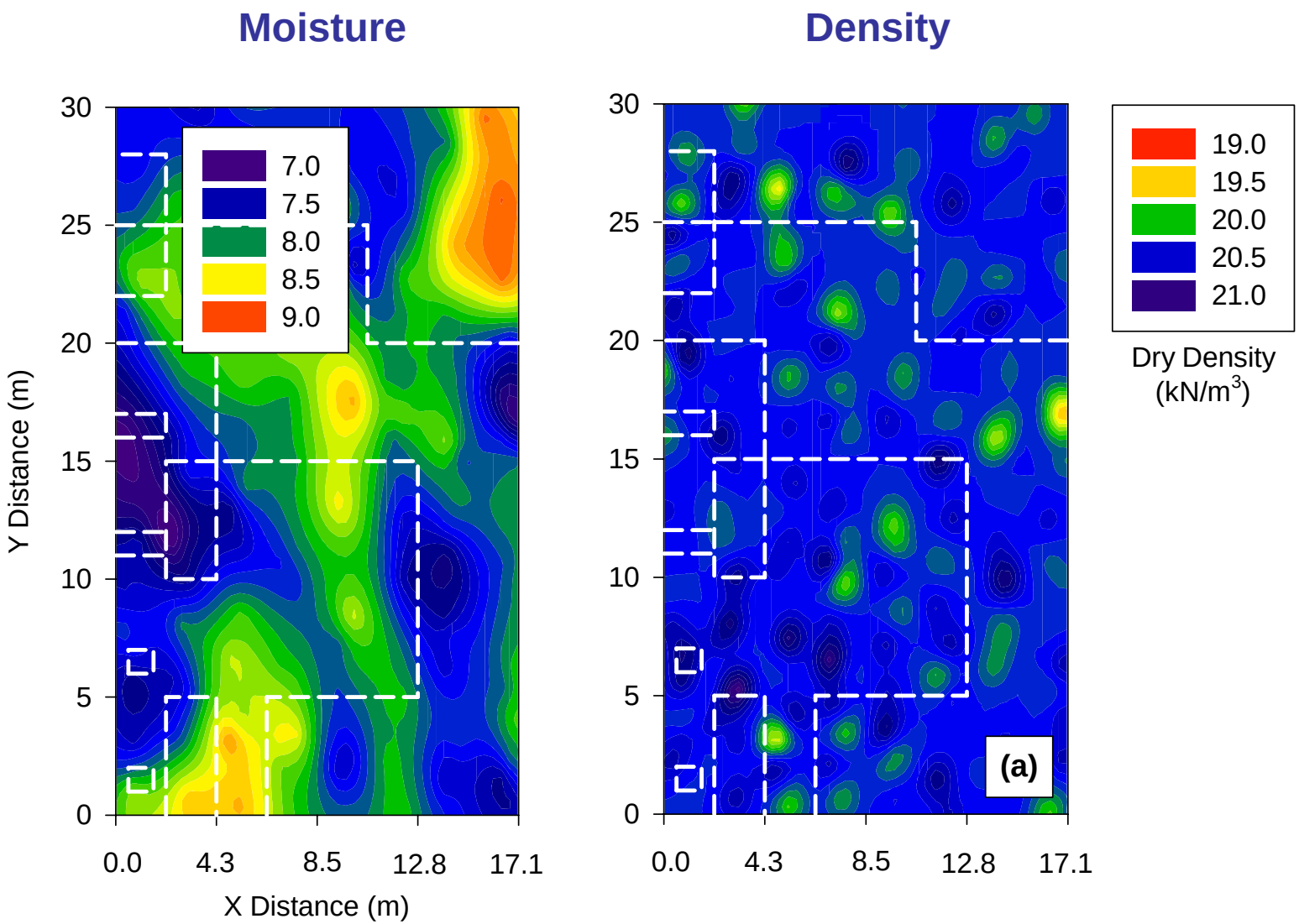




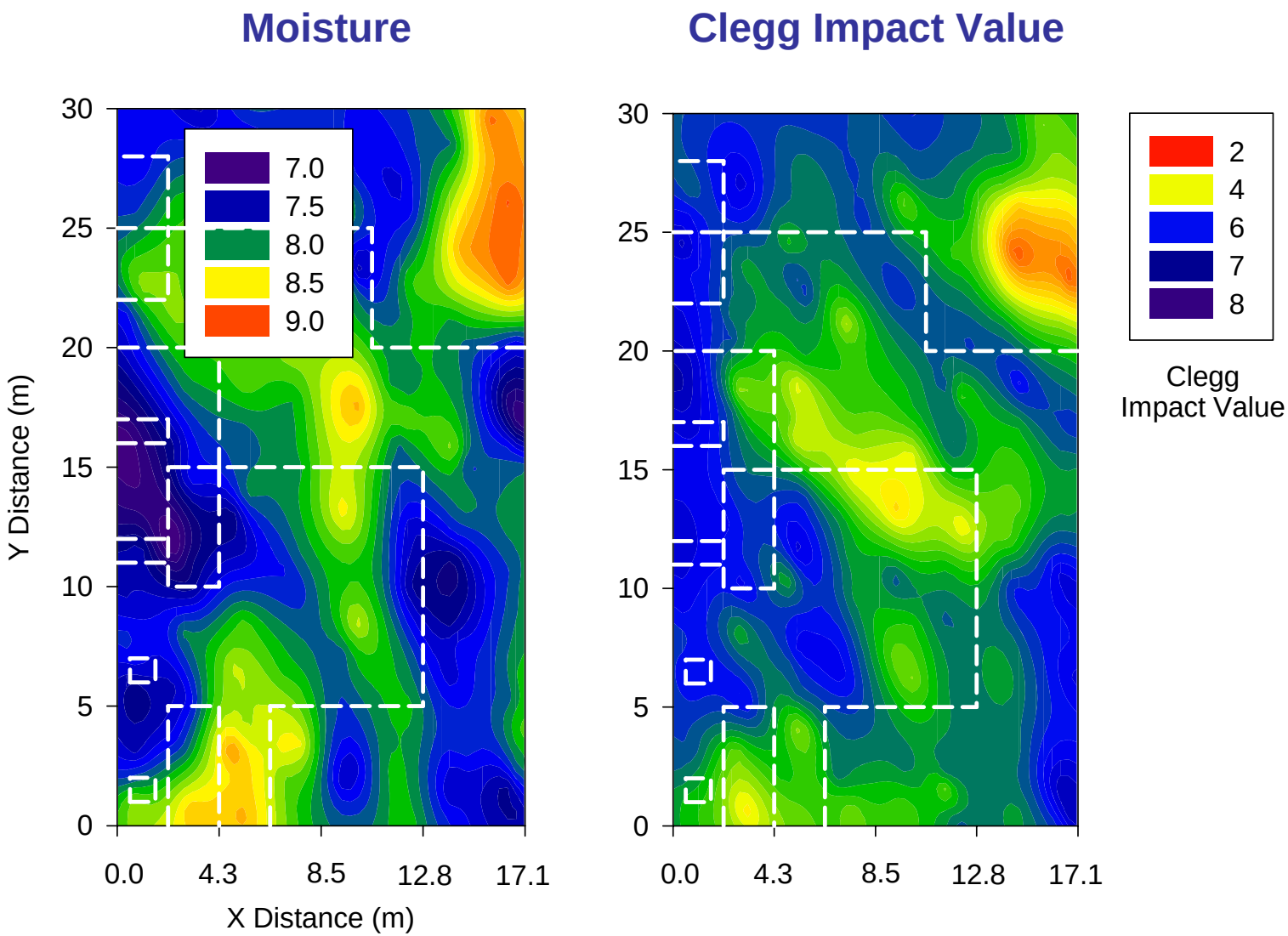




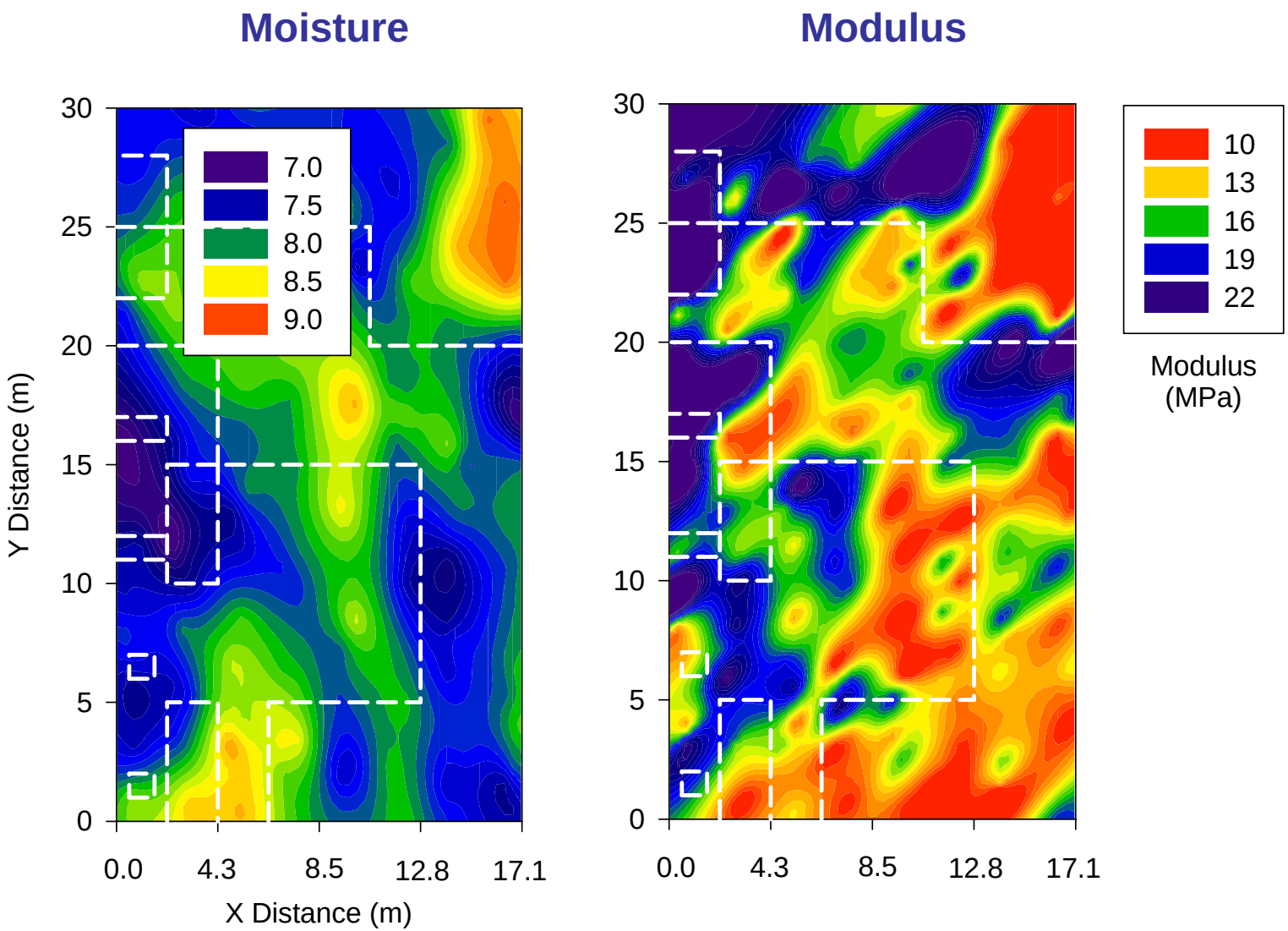
Distribution plots of field measurements



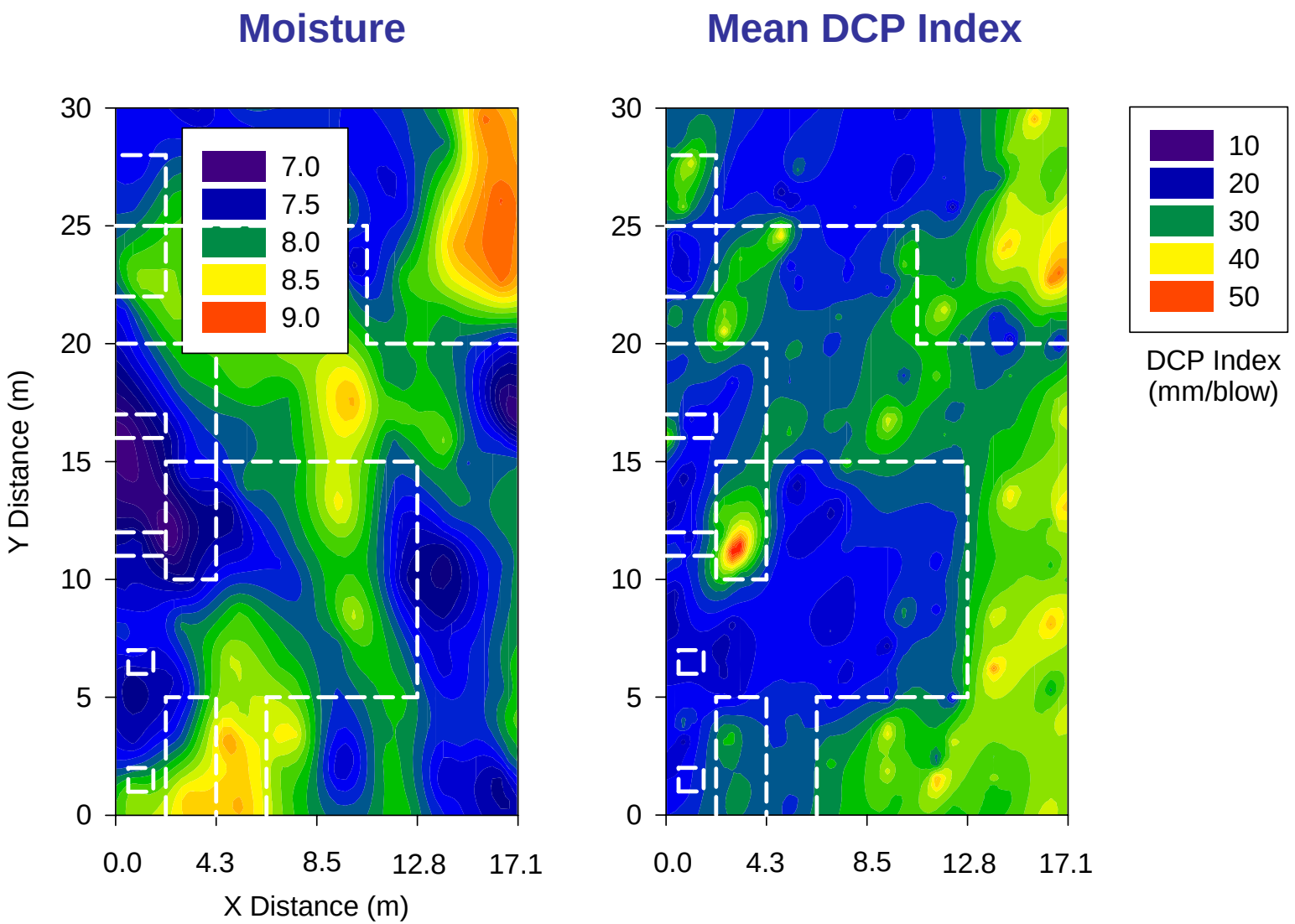
Moisture and density – kriged surfaces (192 points)



Moisture and CIV – kriged surfaces (192 points)



Moisture and modulus – kriged surfaces (192 points)



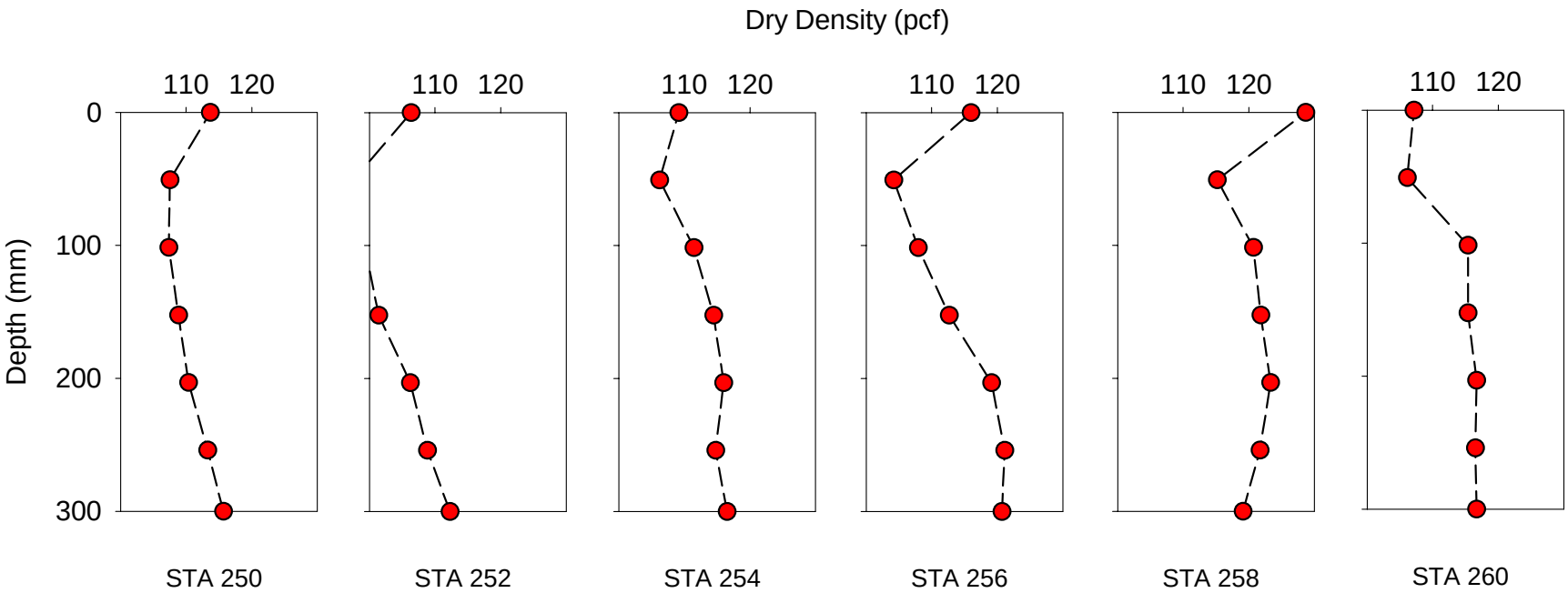
Moisture and DCP index – kriged surfaces (192 points)

June 2006

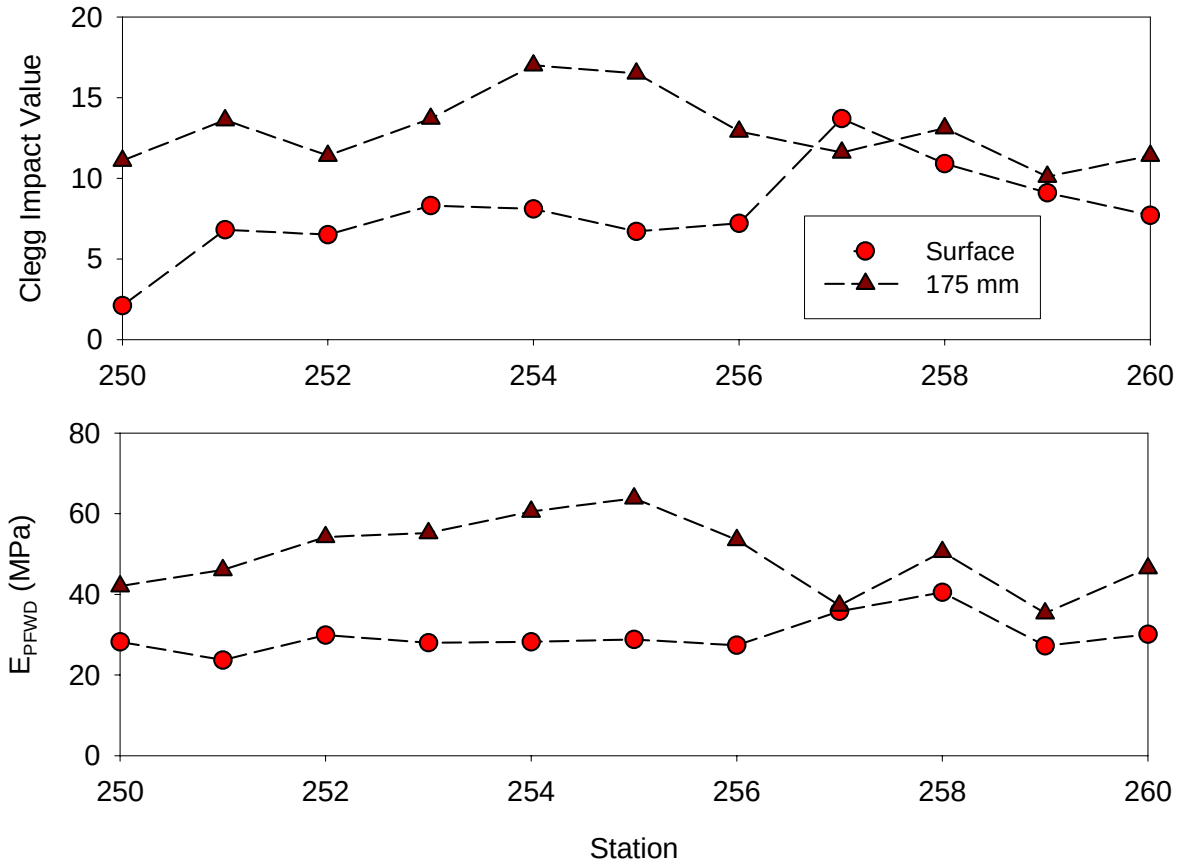
TH 64 at Akeley, MN

Caterpillar CS-563 Smooth Drum Roller

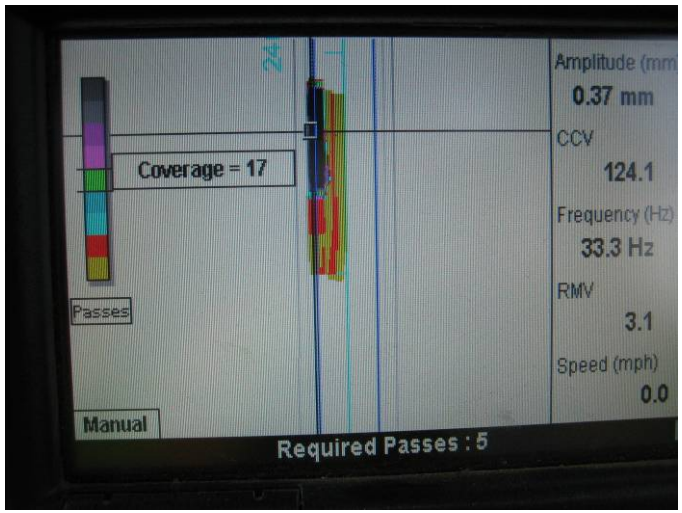
Effect of confining pressure on *sand density*

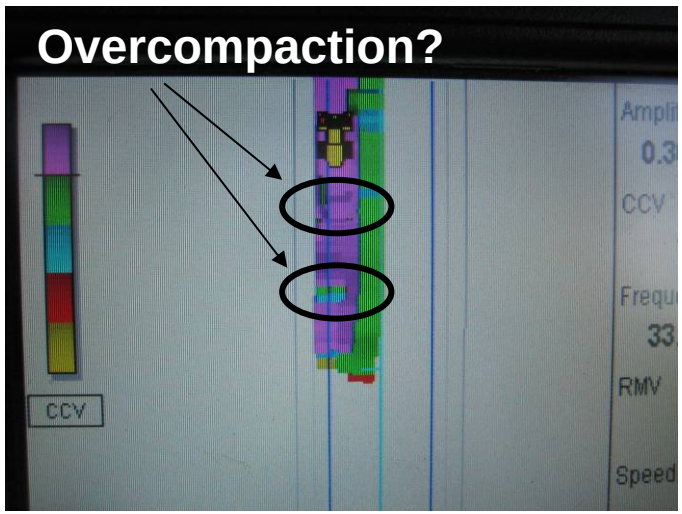


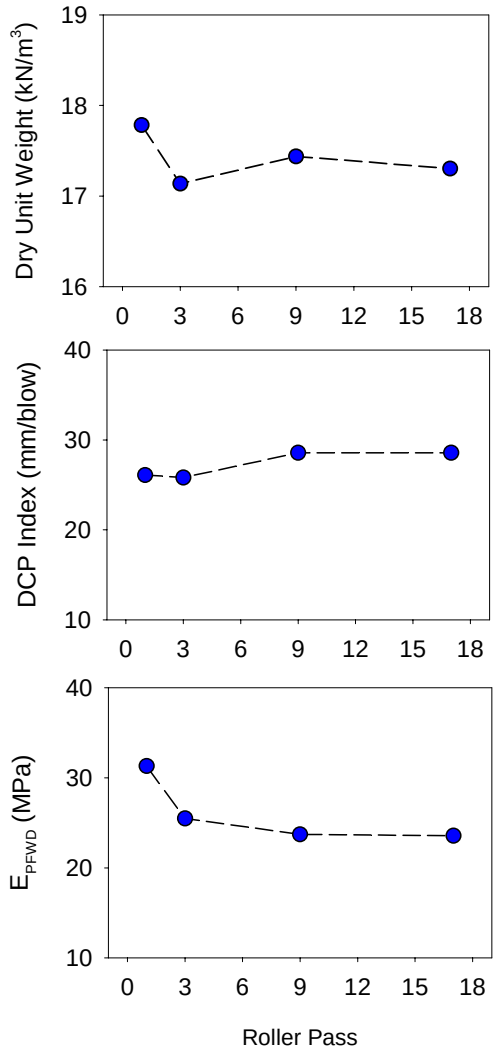
Effect of confining pressure on *sand stability*



Overcompaction?







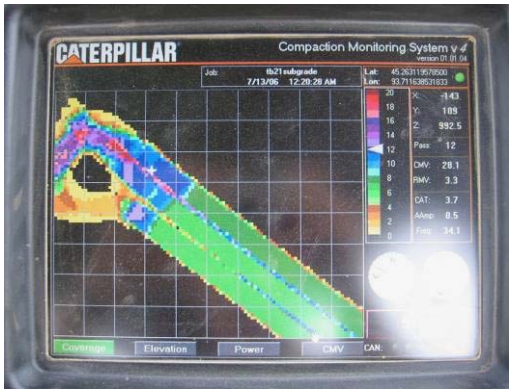
IOWA STATE UNIVERSITY

ctre Center for Transportation Research and Education


Who’s actually compacting the sand?

Upcoming Analysis with TH 64 Data

- Regressions using proof testing data
- Evaluation of IC machine use (e.g. calibration procedure)
- Spatial analysis
  - Spatial relation of various measurements
  - Multiple scales
- Implementation of *GIS for IC data management*

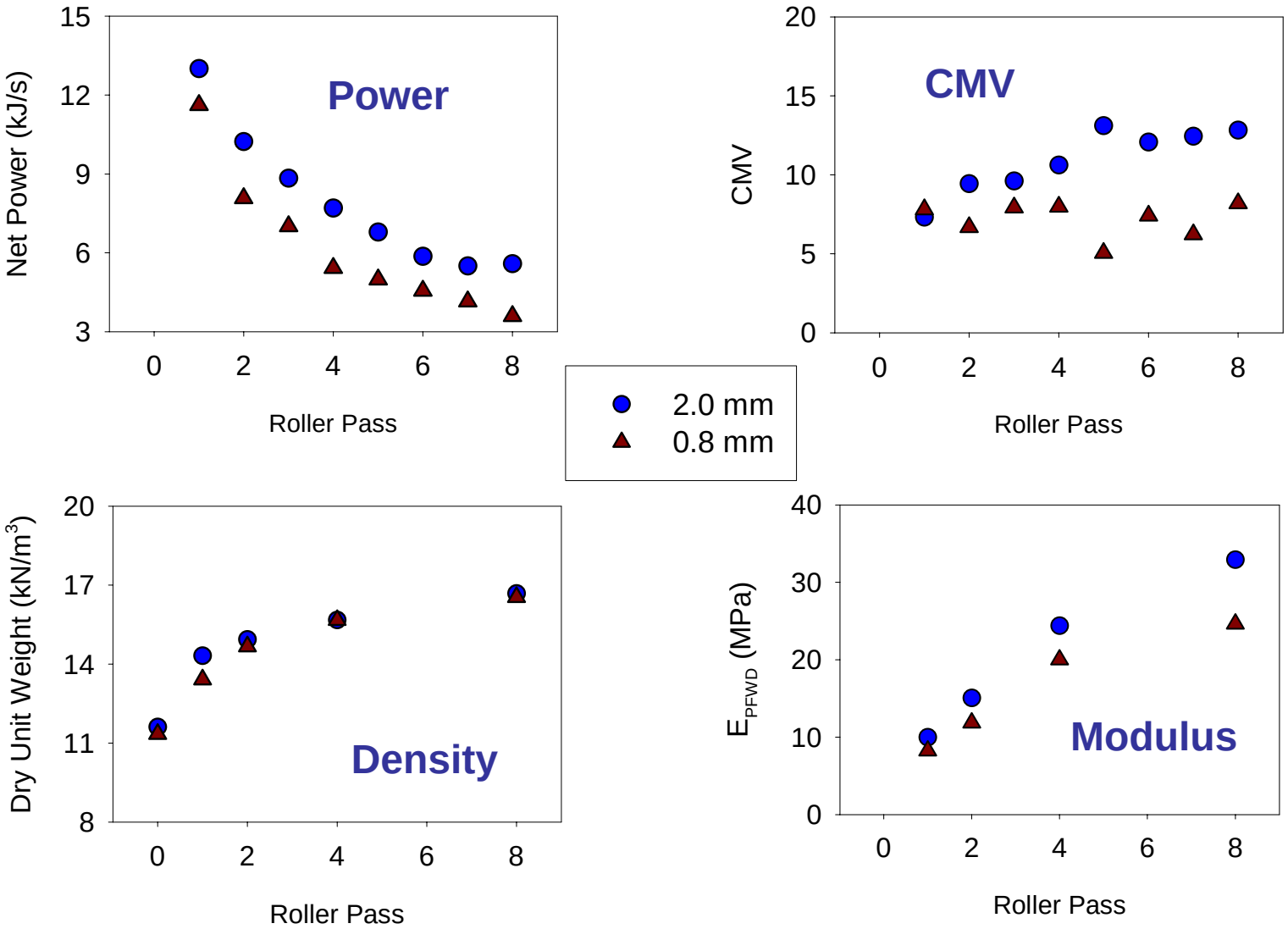


July 2006

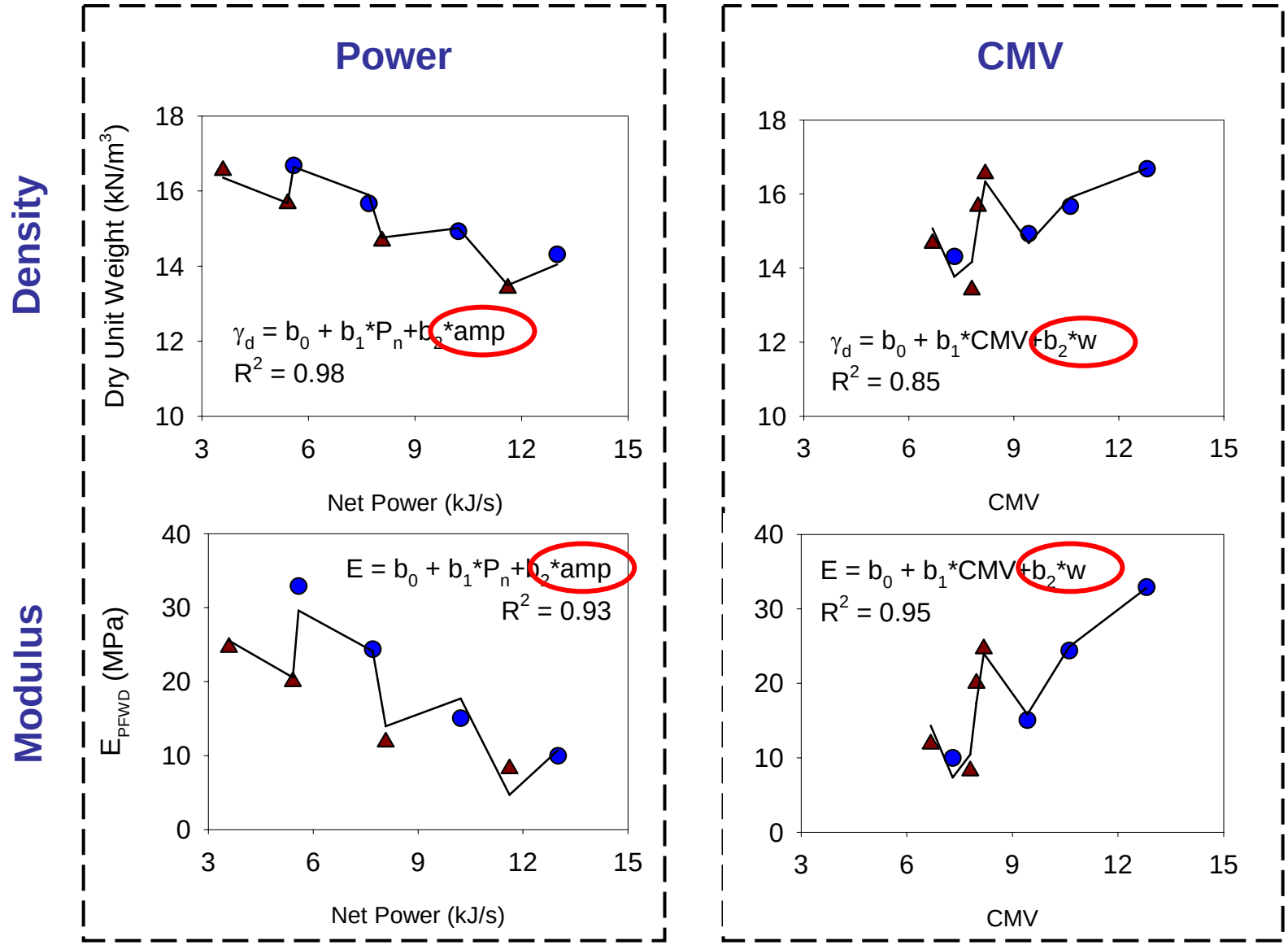
MnROAD at Albertville, MN

IOWA STATE UNIVERSITY

ctre
Center for Transportation Research and Education



Compaction curves for two strips at two amplitudes



Density and Modulus from Power and CMV

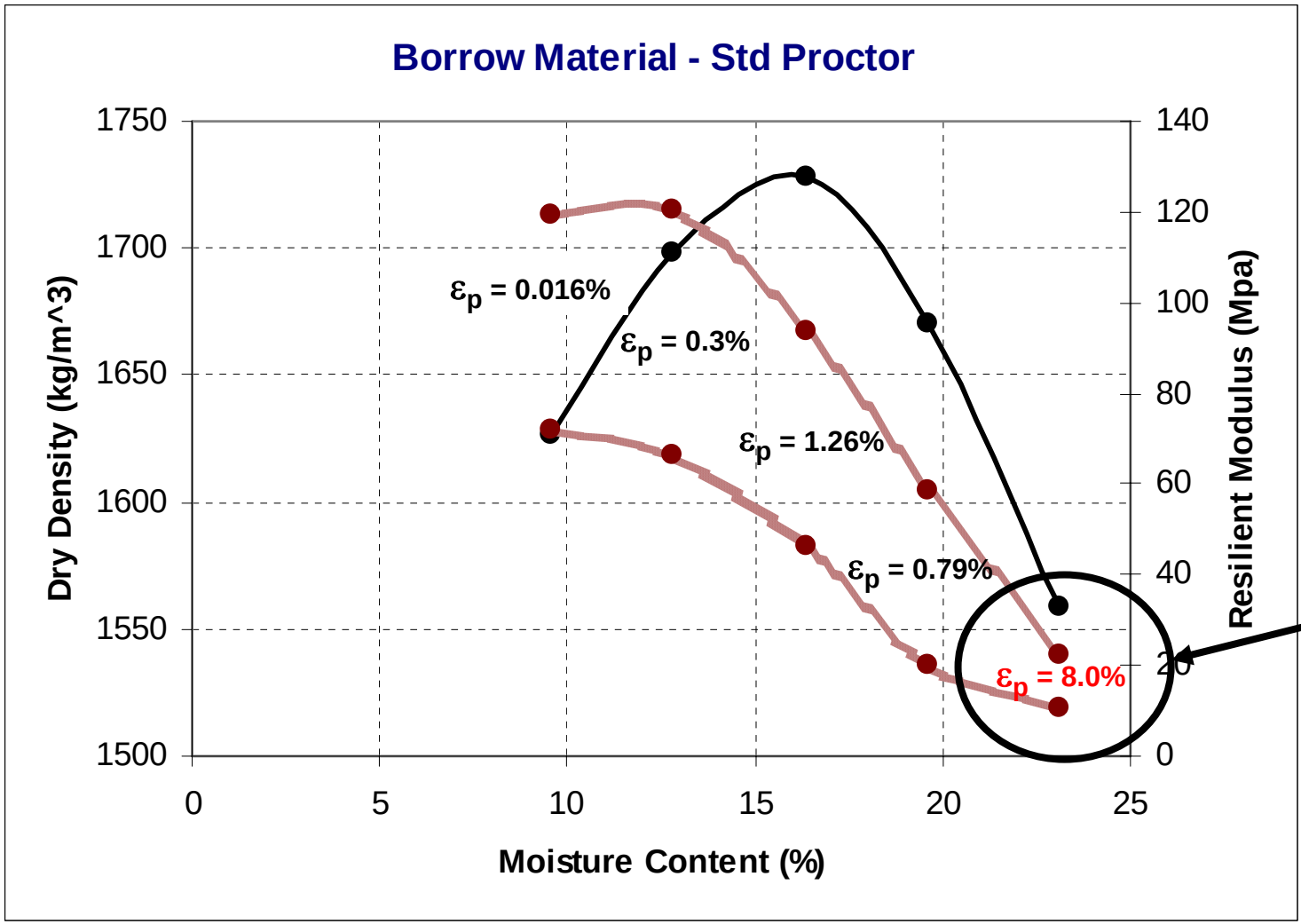
Upcoming Analysis with MnROAD Data

- Amplitude studies (mapping and test strips)
- Variable soil conditions
  - Lift thickness
  - Moisture content
  - Soil type (subgrade and base materials)
- Comparison of machines and IC output
  - Caterpillar
  - BOMAG
  - AMMANN

Resilient Modulus Testing

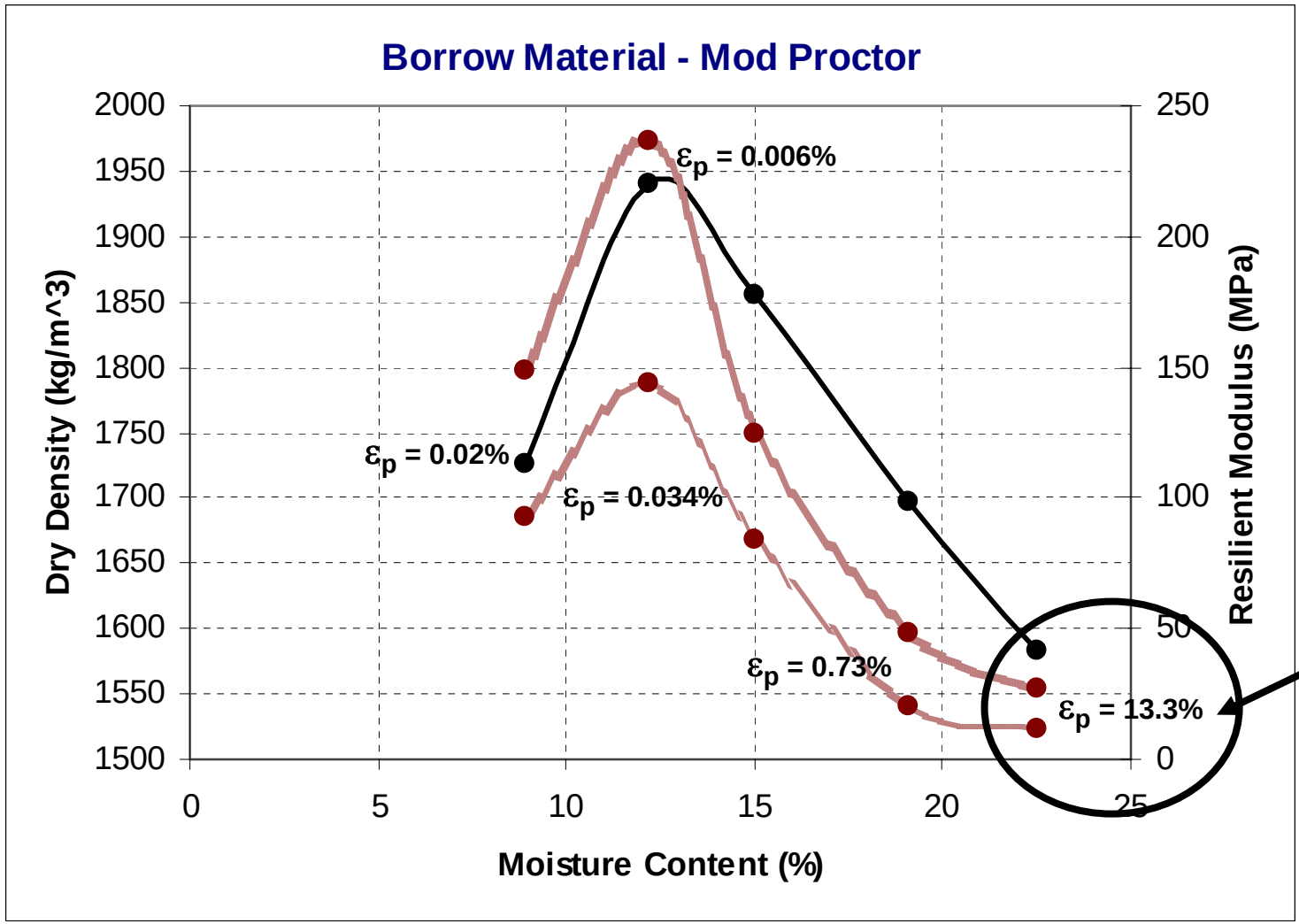
- TASK 1:
  - Relationship between Moisture-Density and Mr
- Task 2:
  - Relationship between In-situ Modulus (from LWD and Roller predicted values) and Mr
- Task 3:
  - Relationship between laboratory compaction methods and Mr

Task 1 – Test Results

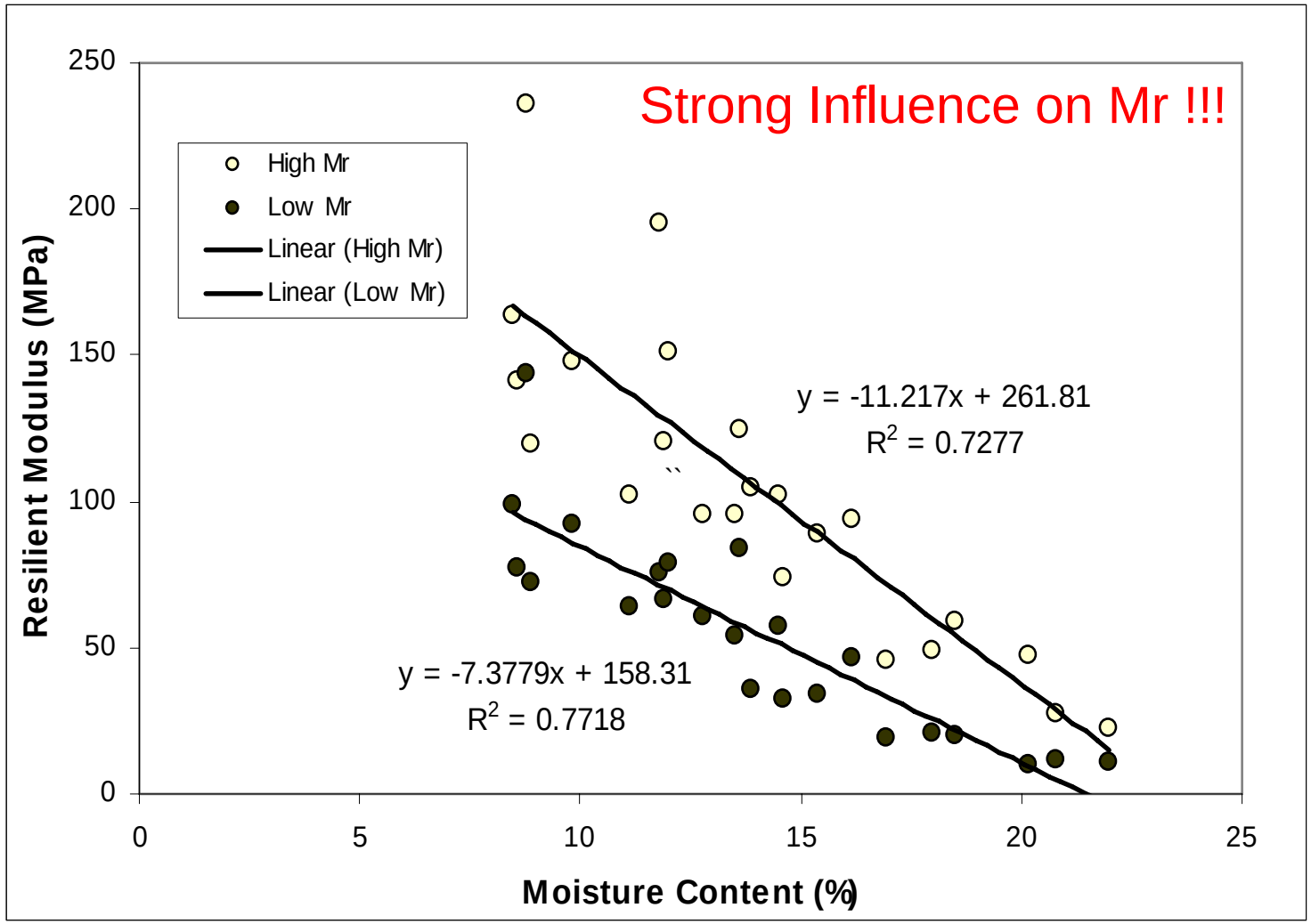


Task 1 – Test Results

contd..



Moisture Content Vs. Mr



Relationships

- Moisture Content - highest influence on Resilient Modulus

- Non-linear regression model between Moisture Content – Density – Soil Index Properties and Resilient Modulus for a range of Subgrade Soils and Base Materials.

Task 2

Prima/Zorno LWD In-situ Modulus and Roller Data
Vs
Laboratory Resilient Modulus

- Perform LWD tests on subgrade materials
- Obtain Shelby Tube samples at the location of LWD tests and perform Lab Mr.
- Prepare re-constituted samples at target In-situ Moisture and Density at the locations of LWD tests

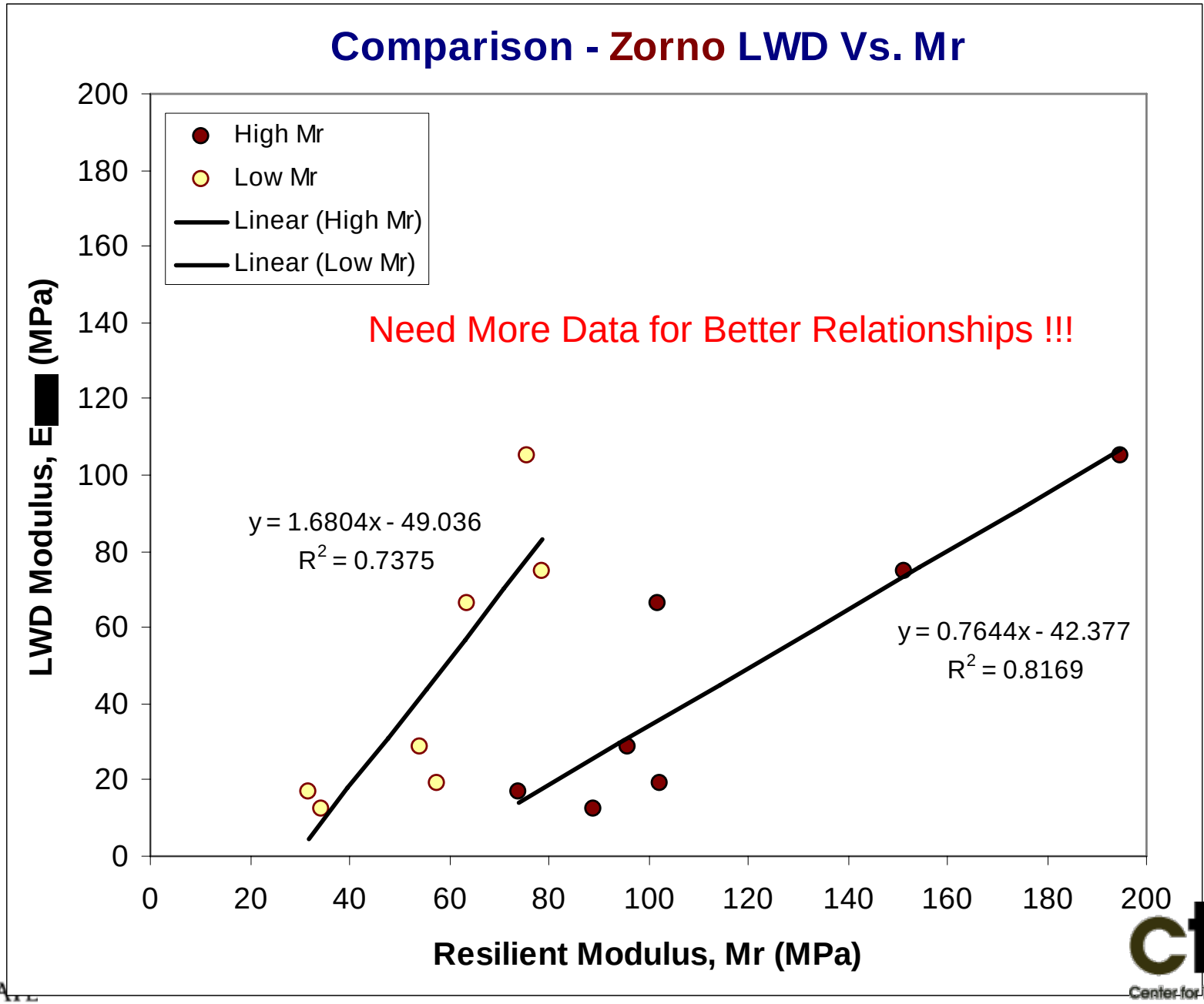
LWD Spot Tests

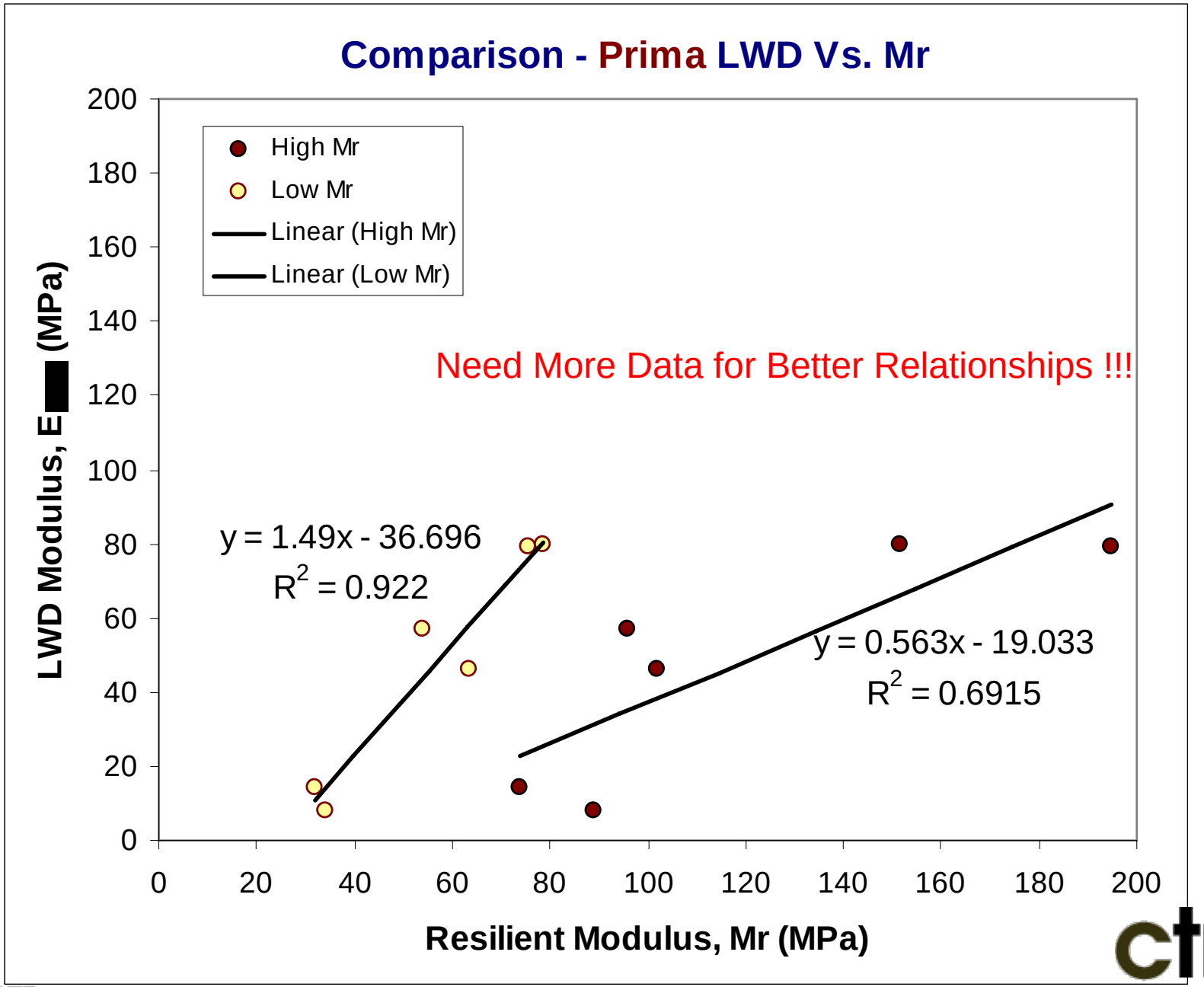
Mn DOT Drill Rig

DCP Test

Shelby Core

“Undisturbed” Samples


Comparison - Zorno LWD Vs. Mr
High Mr
Low Mr
Linear (High Mr)
Linear (Low Mr)
Need More Data for Better Relationships !!!
y = 1.6804x - 49.036
R2 = 0.7375
y = 0.7644x - 42.377
R2 = 0.8169
LWD Modulus, E (MPa)
Resilient Modulus, Mr (MPa)
0
20
40
60
80
100
120
140
160
180
200


Comparison - Prima LWD Vs. Mr
High Mr
Low Mr
Linear (High Mr)
Linear (Low Mr)
Need More Data for Better Relationships !!!
y = 1.49x - 36.696
R2 = 0.922
y = 0.563x - 19.033
R2 = 0.6915
LWD Modulus, E (MPa)
Resilient Modulus, Mr (MPa)
0
20
40
60
80
100
120
140
160
180
200

Task 3

Laboratory Compaction Methods.. And its Influence on:

- Roller Compaction Data
- Resilient Modulus

GIS Database

- Task 1:
  - Create spatial maps using Roller Data
- Task 2:
  - Results of all spot tests as a geographic database
- Task 3:
  - Spatial analysis of spot tests from TH 64 over Class 6 base layer – Comparison to Roller Spatial Data

IC Research Projects at Iowa State University

- FHWA/IHRB (Phase 1 completed, Phase 2 just completed)
  - http://www.ctre.iastate.edu/reports/tr495.pdf
- Caterpillar IC Evaluation (ending Fall 2006)
- Minnesota DOT IC Evaluation (ending Spring 2006)
- NCHRP 21-09 (just started, ending 2008)

Our plans for 2006 and 2007...

…on the road

Thank you

David J. White, Ph.D.

djwhite@iastate.edu