UNSATURATED SOIL MECHANICS IMPLEMENTATION DURING PAVEMENT CONSTRUCTION QUALITY ASSURANCE

April 27, 2010

CTS Annual Conference, Saint Paul, MN

John Siekmeier, PE

Mn/DOT

Office of Materials and Road Research

MINNESOTA DEPARTMENT OF TRANSPORTATION

Acknowledgements

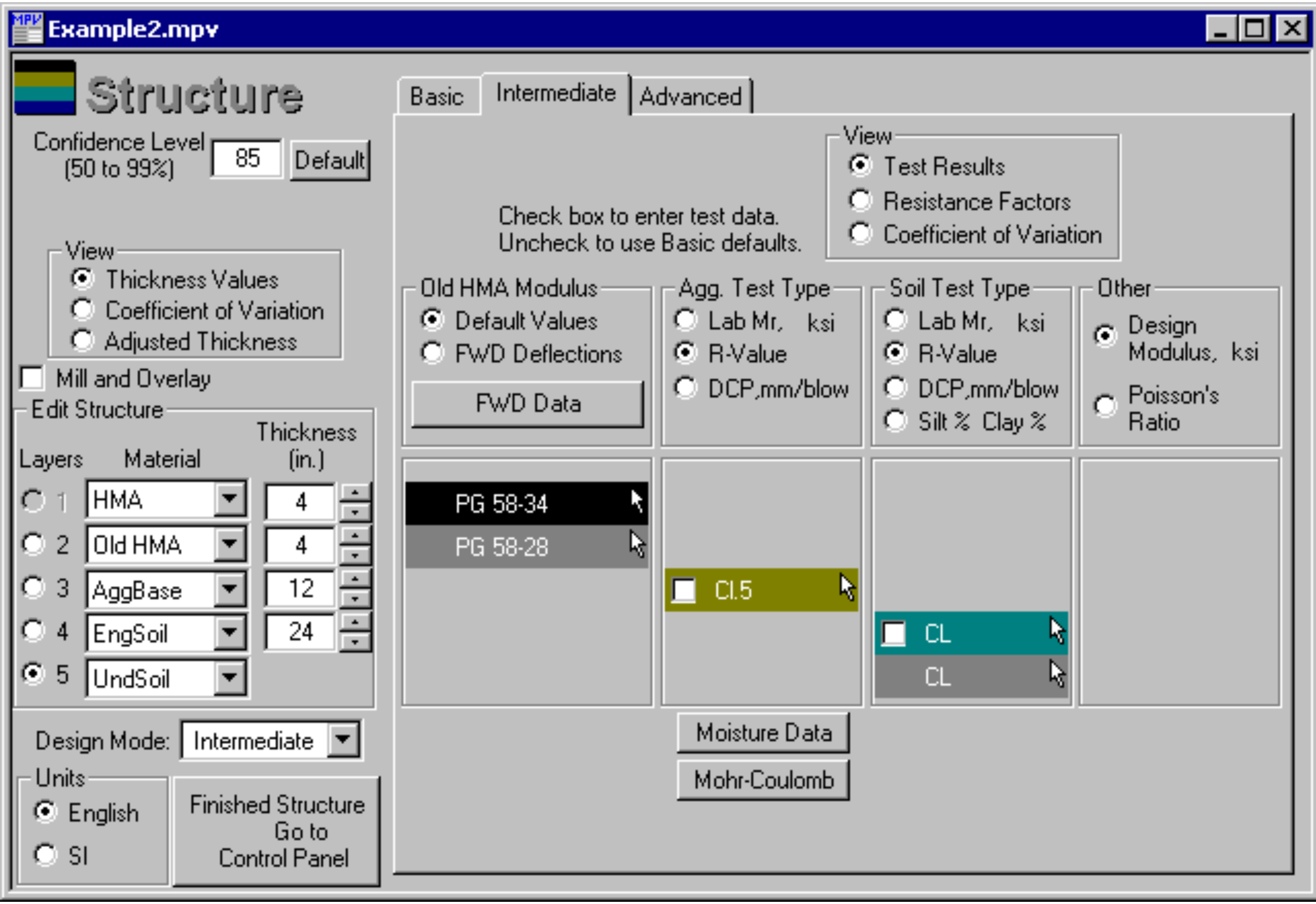
- Arizona State University
- Colorado School of Mines
- Federal Highway Administration
- Iowa State University
- Loughborough University
- Minnesota Department of Transportation
- Minnesota Local Road Research Board
- National Cooperative Highway Research Board
- University of Illinois
- University of Minnesota
- University of Missouri
- University of Wisconsin

Topics

- M-E Pavement Design Framework
- Performance Based Construction QA
- Unsaturated Soil Mechanics
- What We've Learned
- Next Steps

Mechanistic Empirical Design

- Provides the Framework for Performance Based Material Property Inputs
- Sponsor: MN Local Road Research Board
- Contact: Bruce.Tanquist@state.mn.us


Example2.mpv
Structure
Confidence Level (50 to 99%)
85
Default
View
Thickness Values
Coefficient of Variation
Adjusted Thickness
Mill and Overlay
Edit Structure
Layers
Material
Thickness (in.)
1 HMA 4
2 Old HMA 4
3 AggBase 12
4 EngSoil 24
5 UndSoil
Design Mode: Intermediate
Units
English
SI
Finished Structure Go to Control Panel
Basic
Intermediate
Advanced
Check box to enter test data.
Uncheck to use Basic defaults.
View
Test Results
Resistance Factors
Coefficient of Variation
Old HMA Modulus
Default Values
FWD Deflections
FWD Data
Agg. Test Type
Lab Mr, ksi
R-Value
DCP,mm/blow
Soil Test Type
Lab Mr, ksi
R-Value
DCP,mm/blow
Silt % Clay %
Other
Design Modulus, ksi
Poisson's Ratio
PG 58-34
PG 58-28
Cl.5
CL
CL
Moisture Data
Mohr-Coulomb

Performance Based Testing

- Achieve agreement between construction quality assurance, pavement design and performance
- Quantify the performance of alternative materials and construction practices
- Show the economic benefit of improved materials and construction practices
- Reward good construction and greater uniformity
- Implement tools that will strengthen the decisions made by construction inspection personnel

MINNESOTA DEPARTMENT OF TRANSPORTATION

General QC/QA Procedure

- **Quality Control by the Contractor**
  - Prepares Quality Control Plan
  - Includes moisture testing
  - Includes roller compaction value
  - Includes corrective actions to be taken
- **Quality Assurance by Agency Owner**
  - Review and approval of the Contractor’s QC plan
  - QA testing using the light weight deflectometer (LWD) dynamic cone penetrometer (DCP) and moisture tests
  - Approval of the Contractor’s QC report
  - Archive of electronic QC and QA data

MINNESOTA DEPARTMENT OF TRANSPORTATION

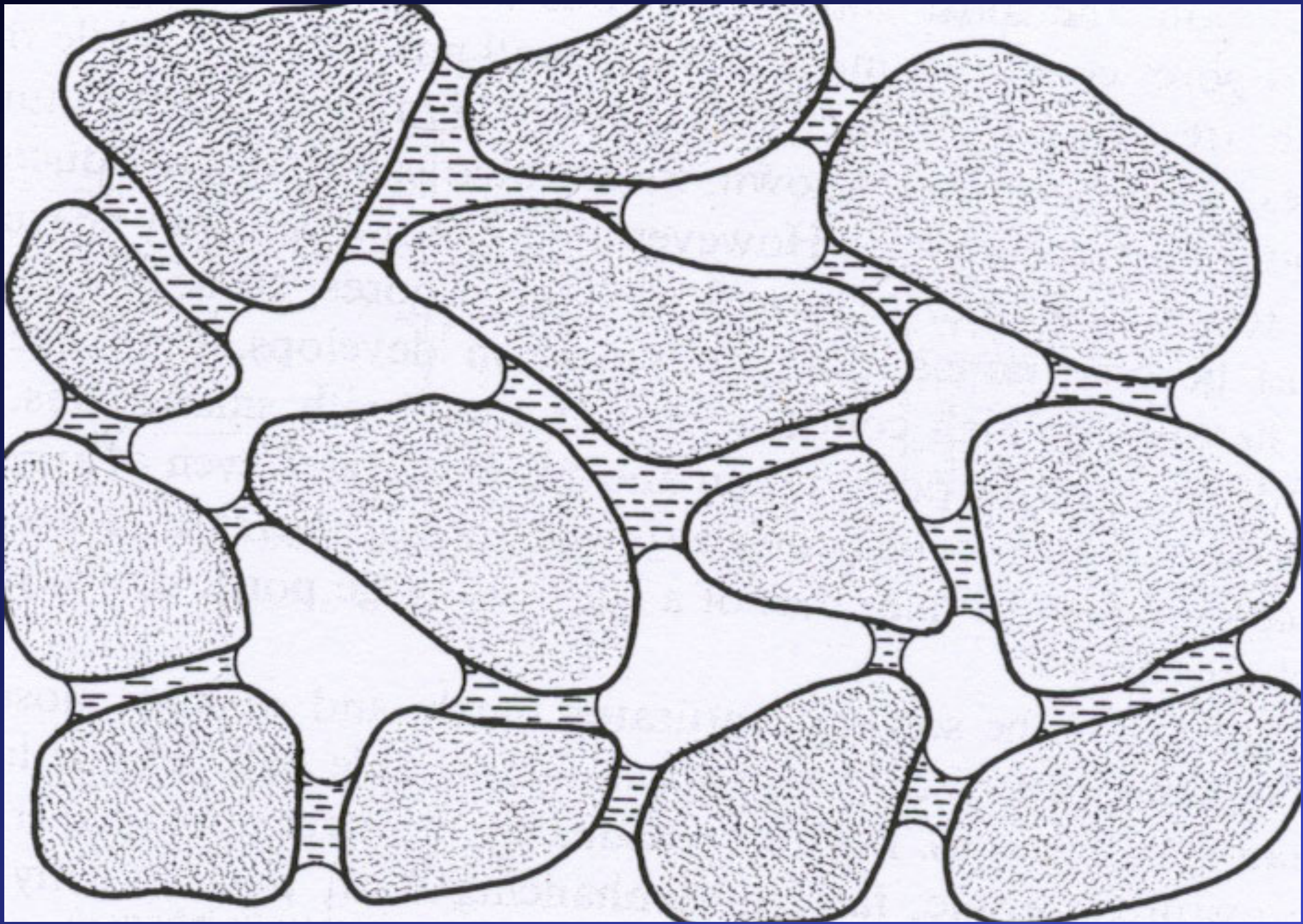
DCP and LWD Granular Target Values

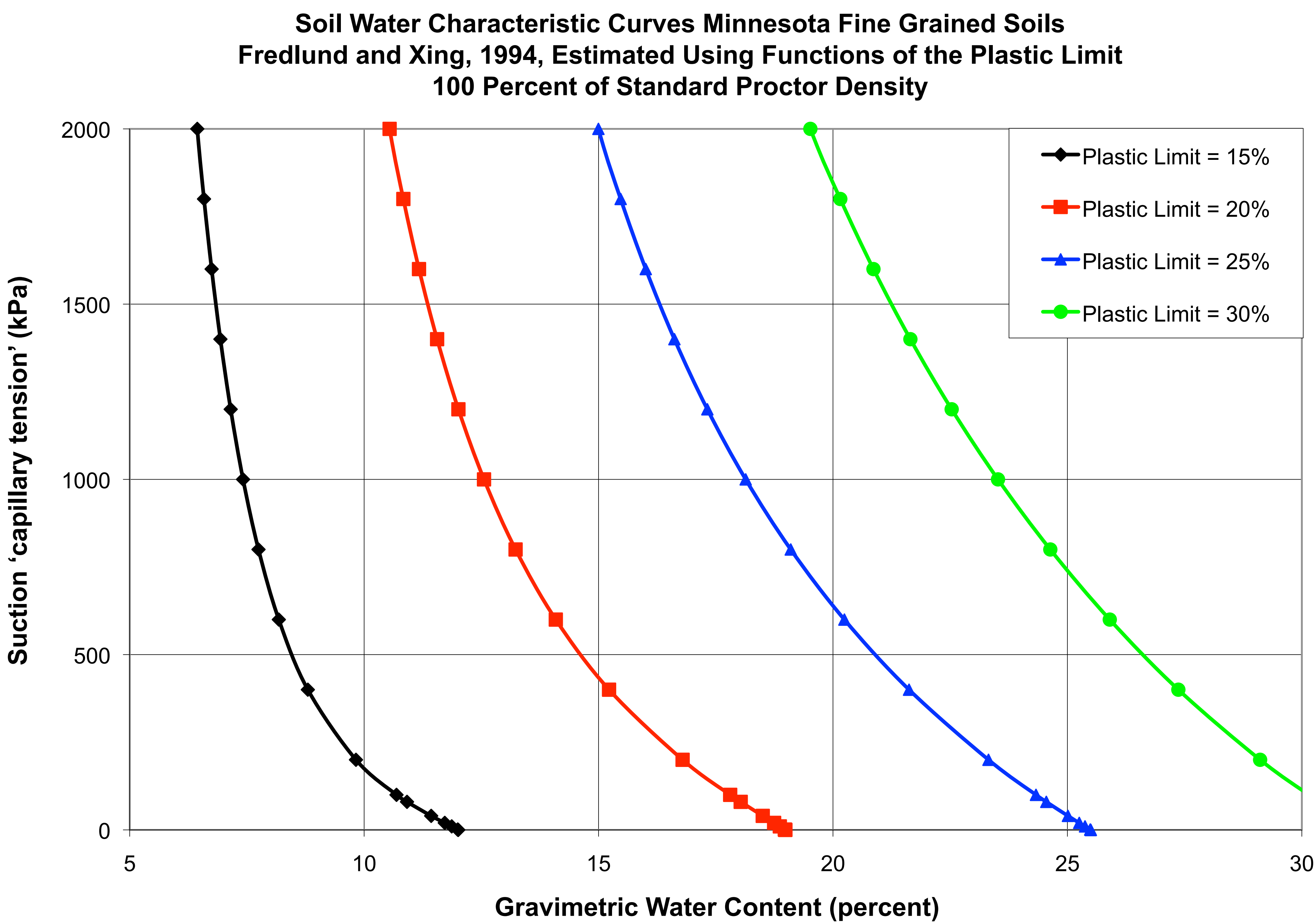
Grading Number	Moisture Content	Target DPI	Target LWD Deflection Zorn	Inverse DPI
GN	%	mm/drop	mm	drops/10cm
3.1-3.5	5 - 7	10	0.4	10
	7 - 9	12	0.5	8
	9 - 11	16	0.7	6
3.6-4.0	5 - 7	10	0.4	10
	7 - 9	15	0.7	7
	9 - 11	19	0.8	5
4.1-4.5	5 - 7	13	0.6	8
	7 - 9	17	0.7	6
	9 - 11	21	0.9	5
4.6-5.0	5 - 7	15	0.7	7
	7 - 9	19	0.8	5
	9 - 11	23	1.0	4
5.1-5.5	5 - 7	17	0.7	6
	7 - 9	21	0.9	5
	9 - 11	25	1.1	4
5.6-6.0	5 - 7	19	0.8	5
	7 - 9	24	1.1	4
	9 - 11	28	1.2	4

Unsaturated Soil Mechanics

- **Strength and Modulus Greatly Affected by Suction**
- **Suction Depends on Solids, Voids and Water**
  - Quantity of Gravel, Sand, Silt, and Clay Particles
  - Distribution of Particles and Voids
  - Particle Shape and Void Shape
  - Packing Density (measure of void space)
  - Moisture Content (measure of water in voids)

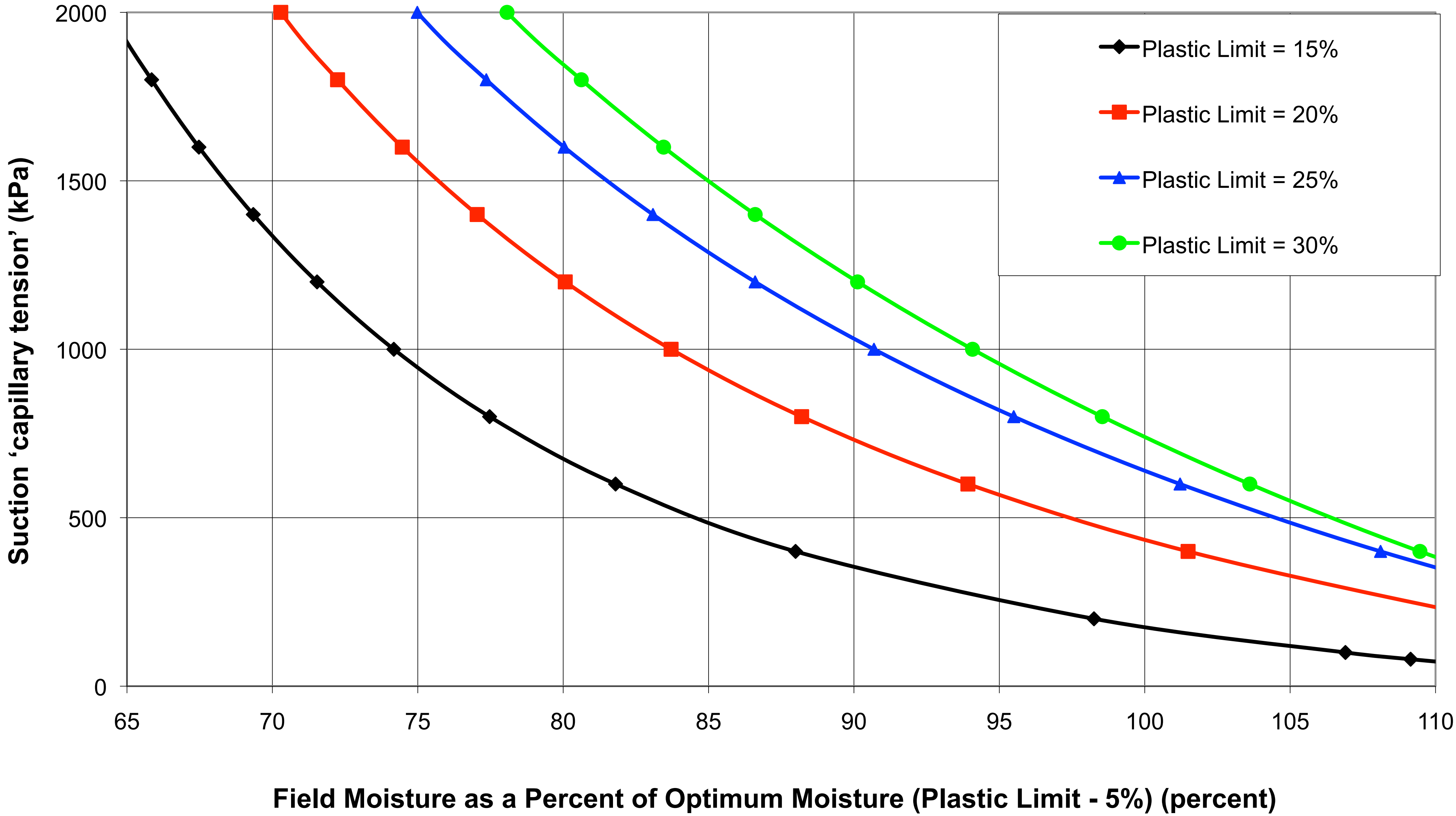
Fundamentals of Soil Physics, Hillel 1980

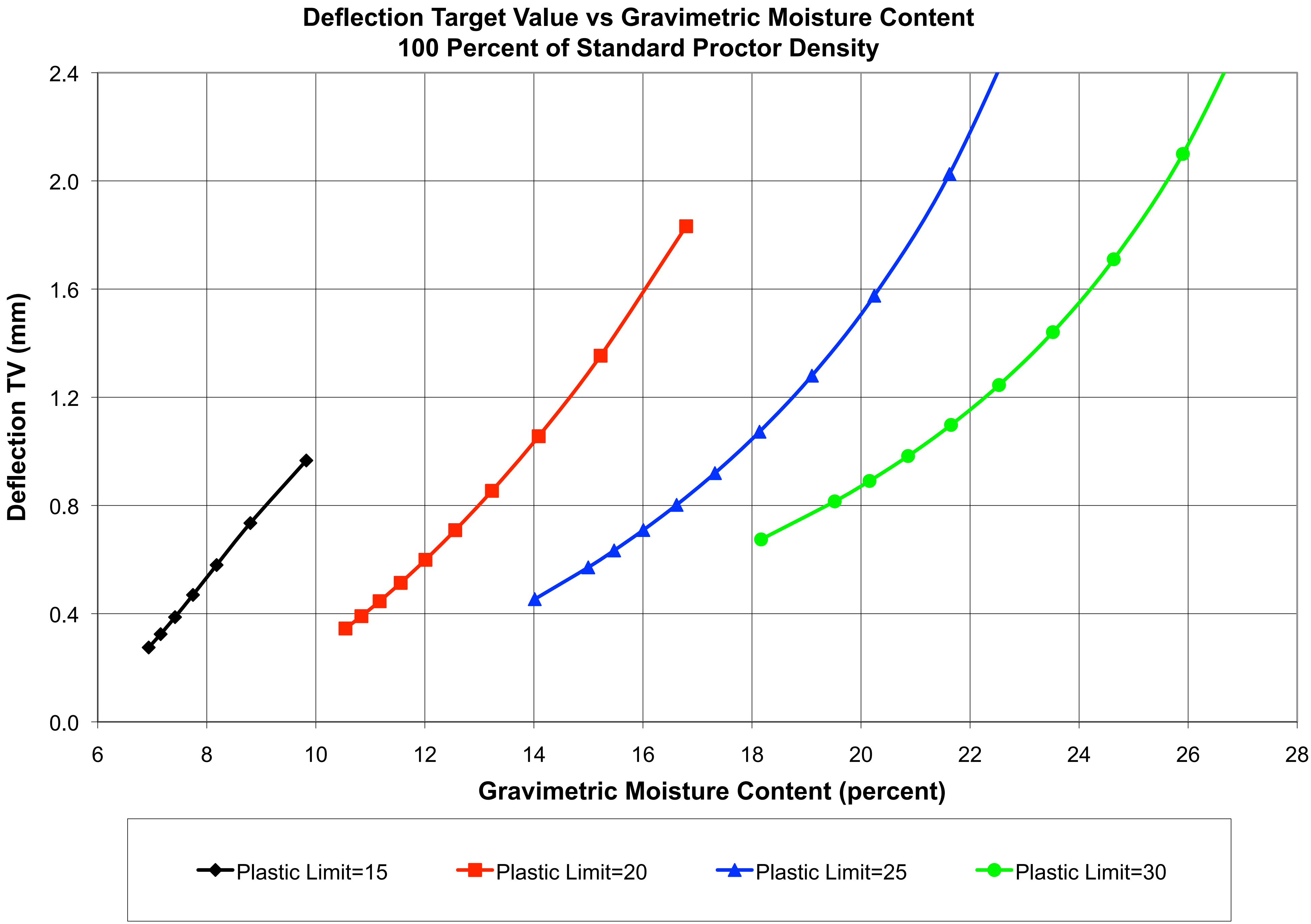


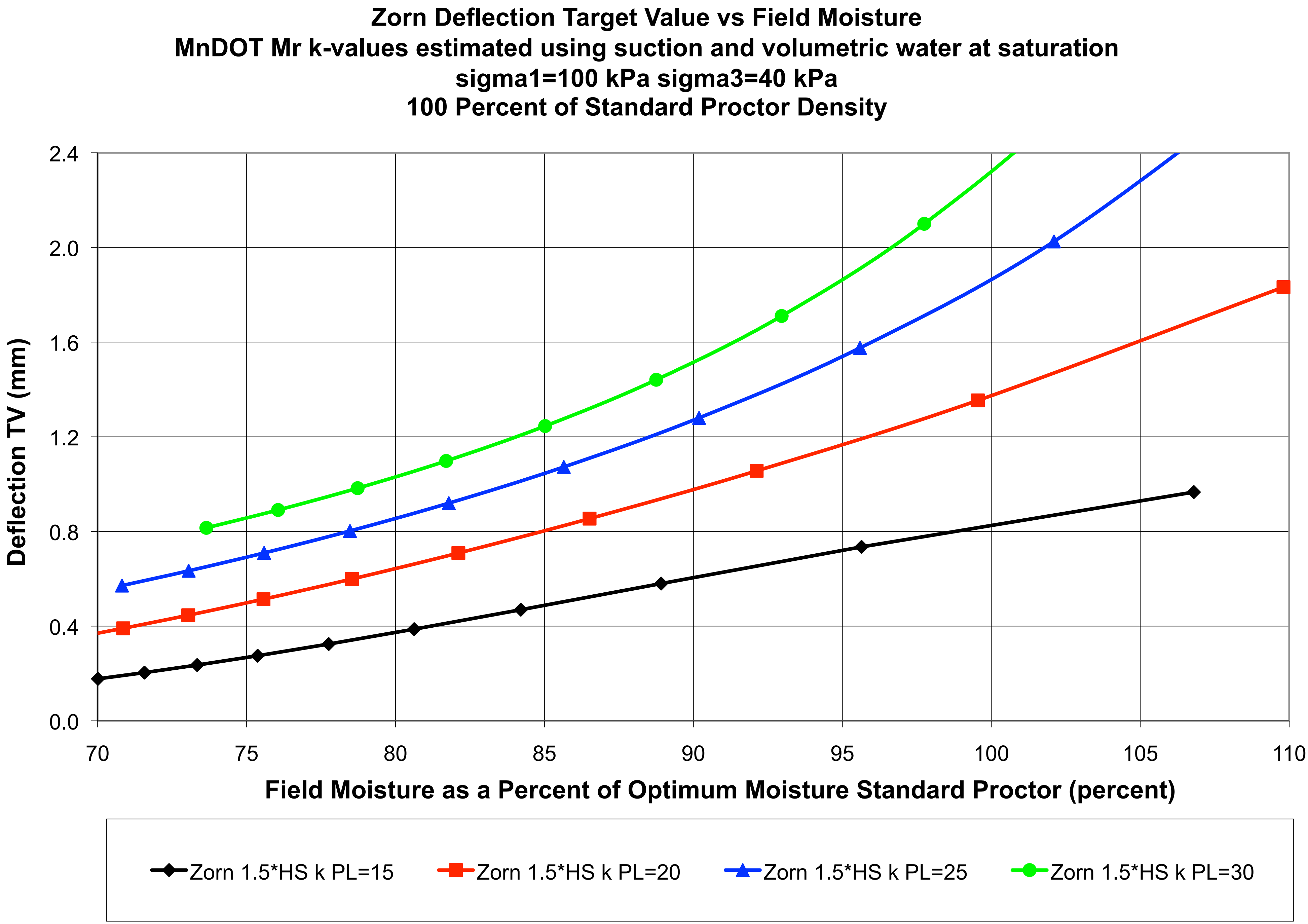


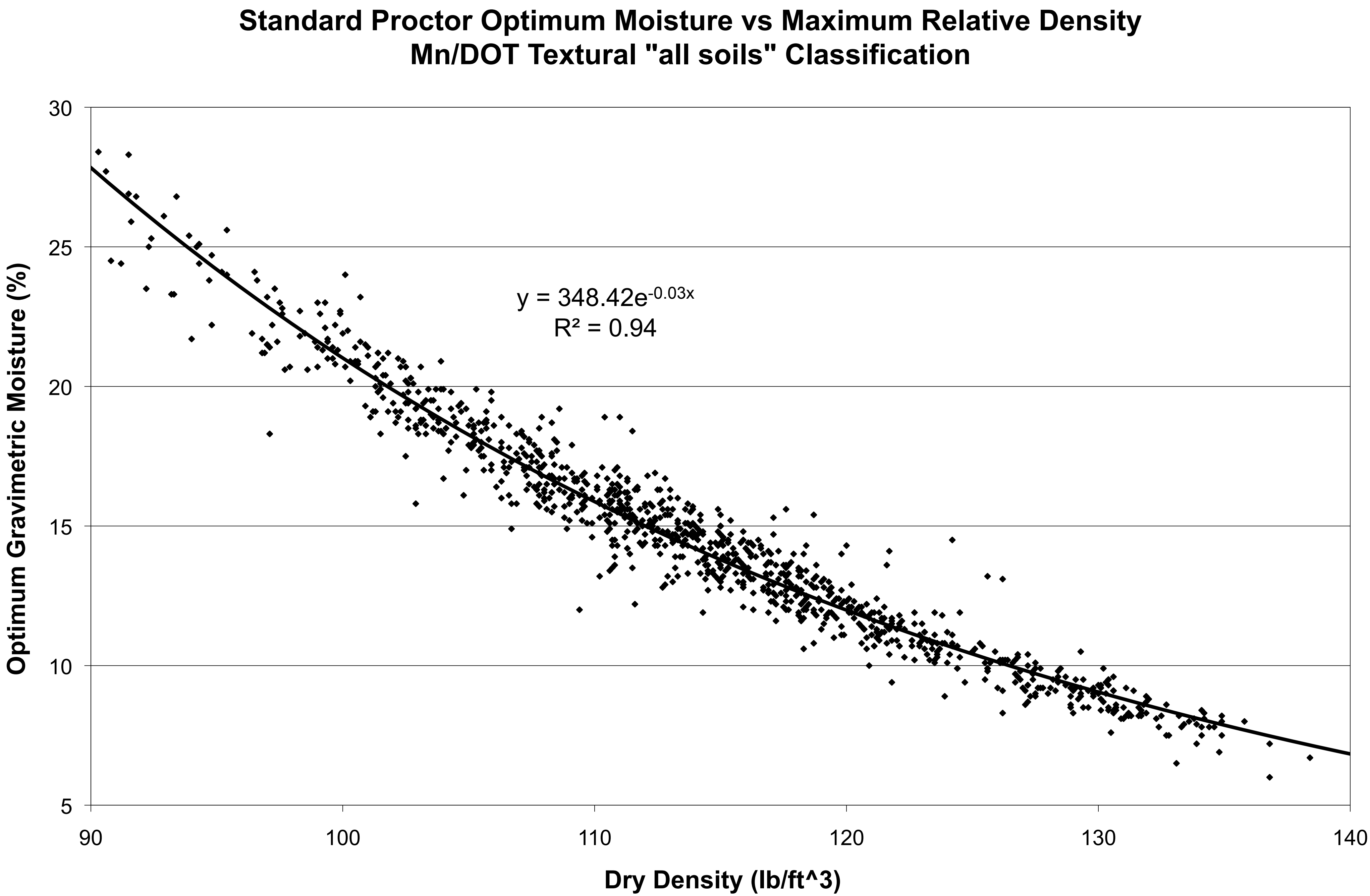
Soil Water Characteristic Curves Minnesota Fine Grained Soils
Fredlund and Xing, 1994, Estimated Using Functions of the Plastic Limit
100 Percent of Standard Proctor Density
Suction 'capillary tension' (kPa)
Gravimetric Water Content (percent)
Plastic Limit = 15%
Plastic Limit = 20%
Plastic Limit = 25%
Plastic Limit = 30%
0
500
1000
1500
2000
5
10
15
20
25
30

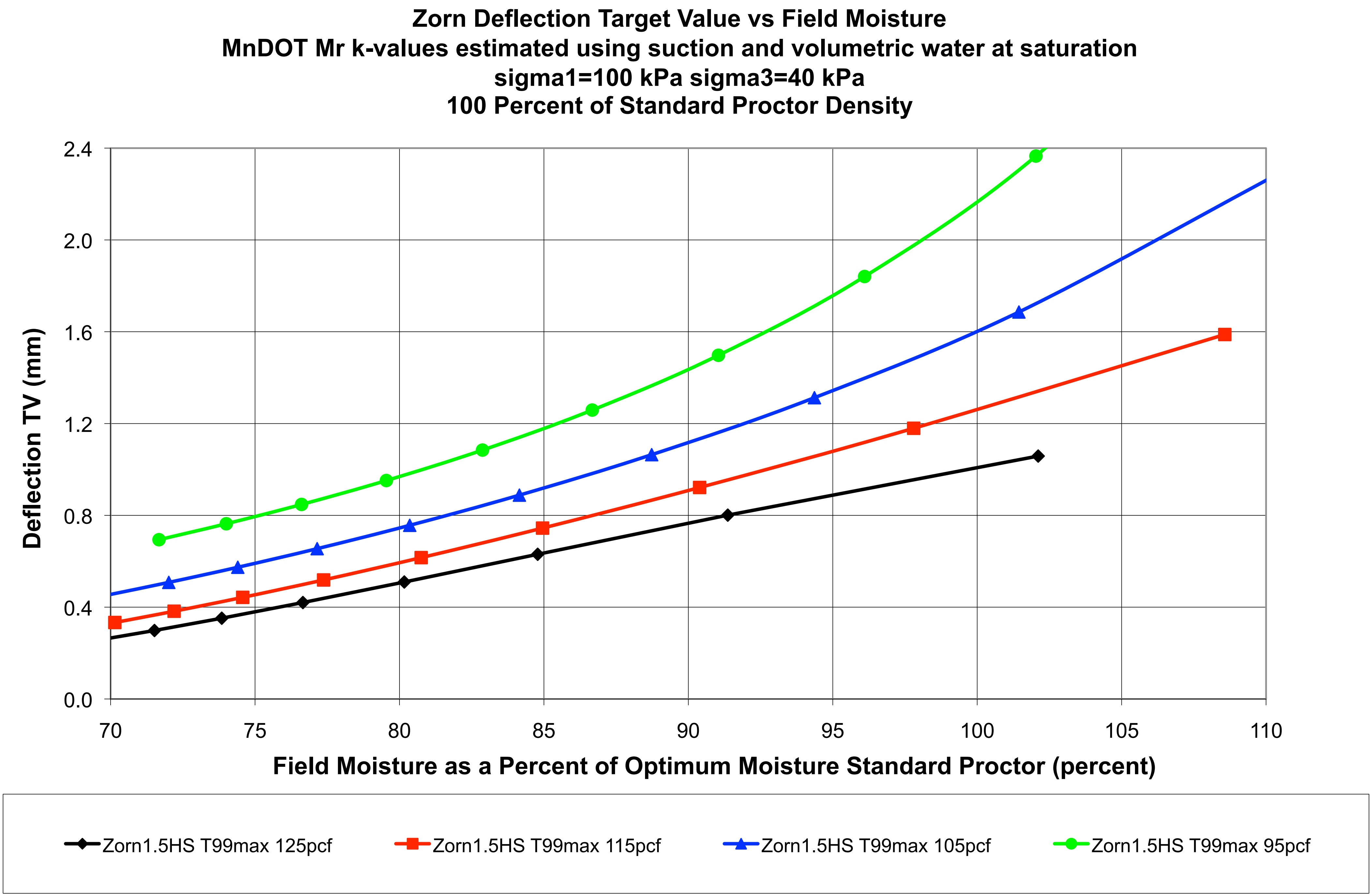
Soil Water Characteristic Curves Minnesota Fine Grained Soils
Fredlund and Xing, 1994, Estimated Using Functions of the Plastic Limit
100 Percent of Standard Proctor Density




Deflection Target Value vs Gravimetric Moisture Content
100 Percent of Standard Proctor Density
Deflection TV (mm)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
6
8
10
12
14
16
18
20
22
24
26
28
Gravimetric Moisture Content (percent)
Plastic Limit=15
Plastic Limit=20
Plastic Limit=25
Plastic Limit=30

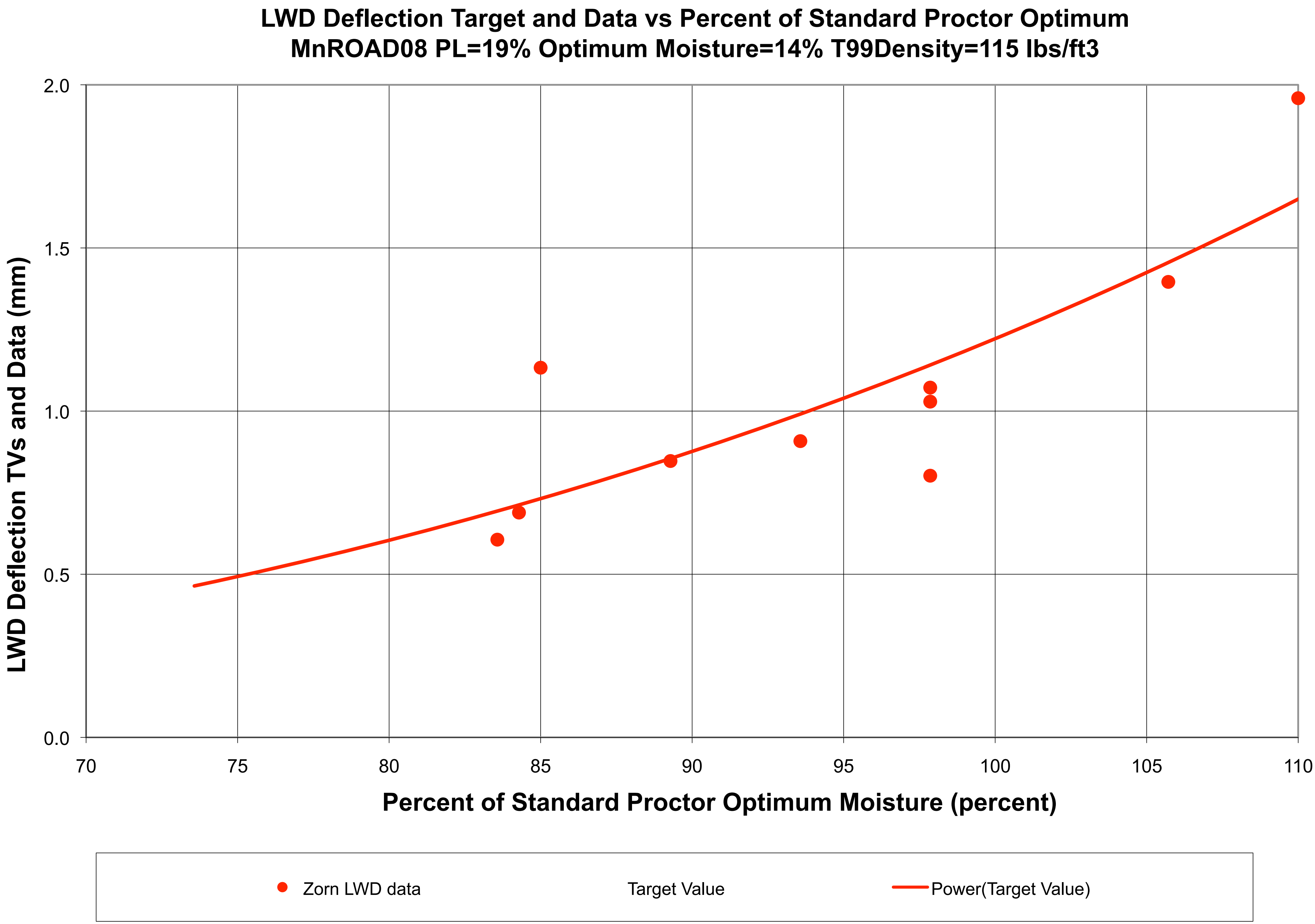

Zorn Deflection Target Value vs Field Moisture
MnDOT Mr k-values estimated using suction and volumetric water at saturation
sigma1=100 kPa sigma3=40 kPa
100 Percent of Standard Proctor Density
Deflection TV (mm)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
70
75
80
85
90
95
100
105
110
Field Moisture as a Percent of Optimum Moisture Standard Proctor (percent)
Zorn 1.5*HS k PL=15
Zorn 1.5*HS k PL=20
Zorn 1.5*HS k PL=25
Zorn 1.5*HS k PL=30

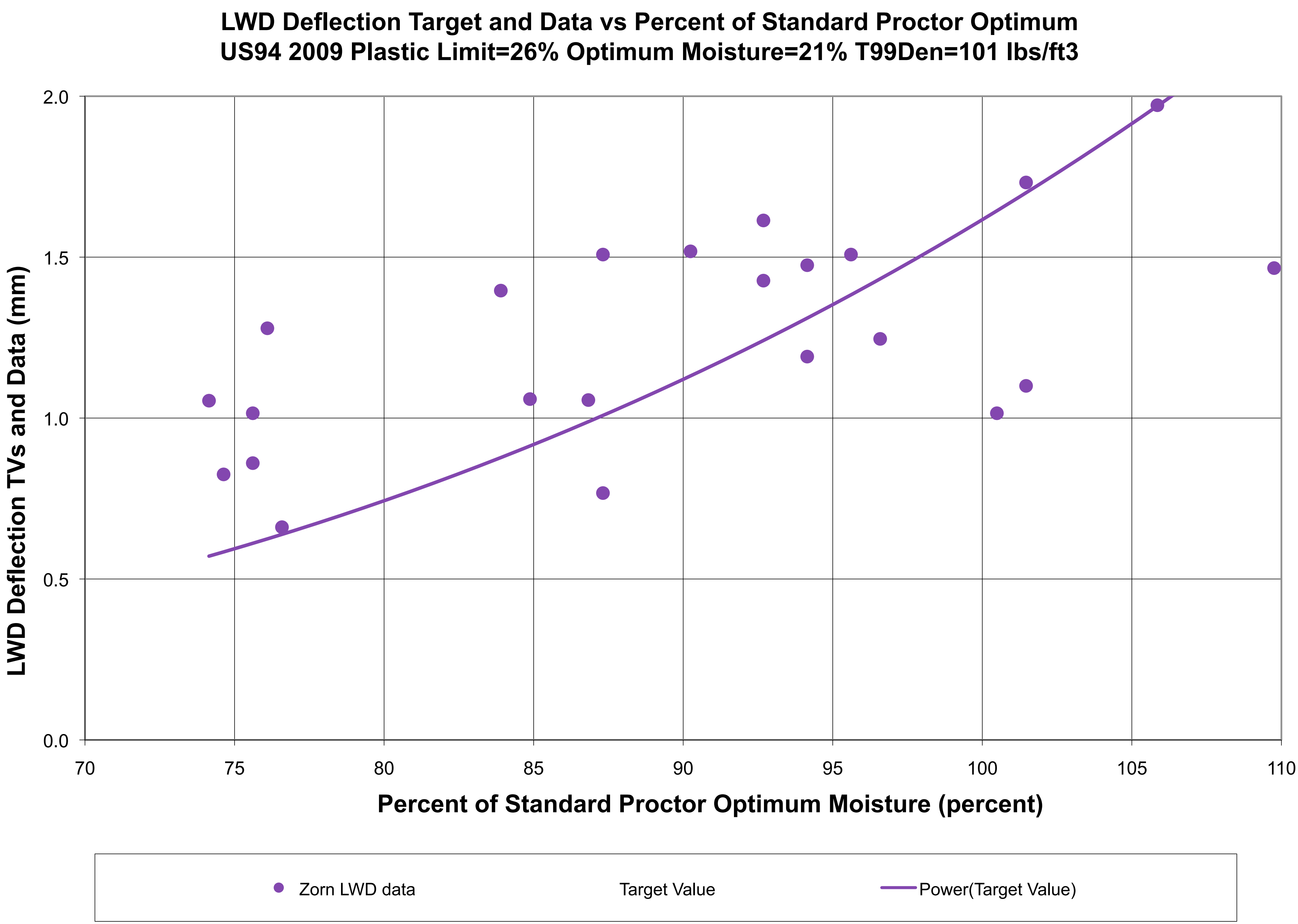

Standard Proctor Optimum Moisture vs Maximum Relative Density
Mn/DOT Textural "all soils" Classification
y = 348.42e^-0.03x
R² = 0.94
Optimum Gravimetric Moisture (%)
Dry Density (lb/ft^3)
30
25
20
15
10
5
90
100
110
120
130
140

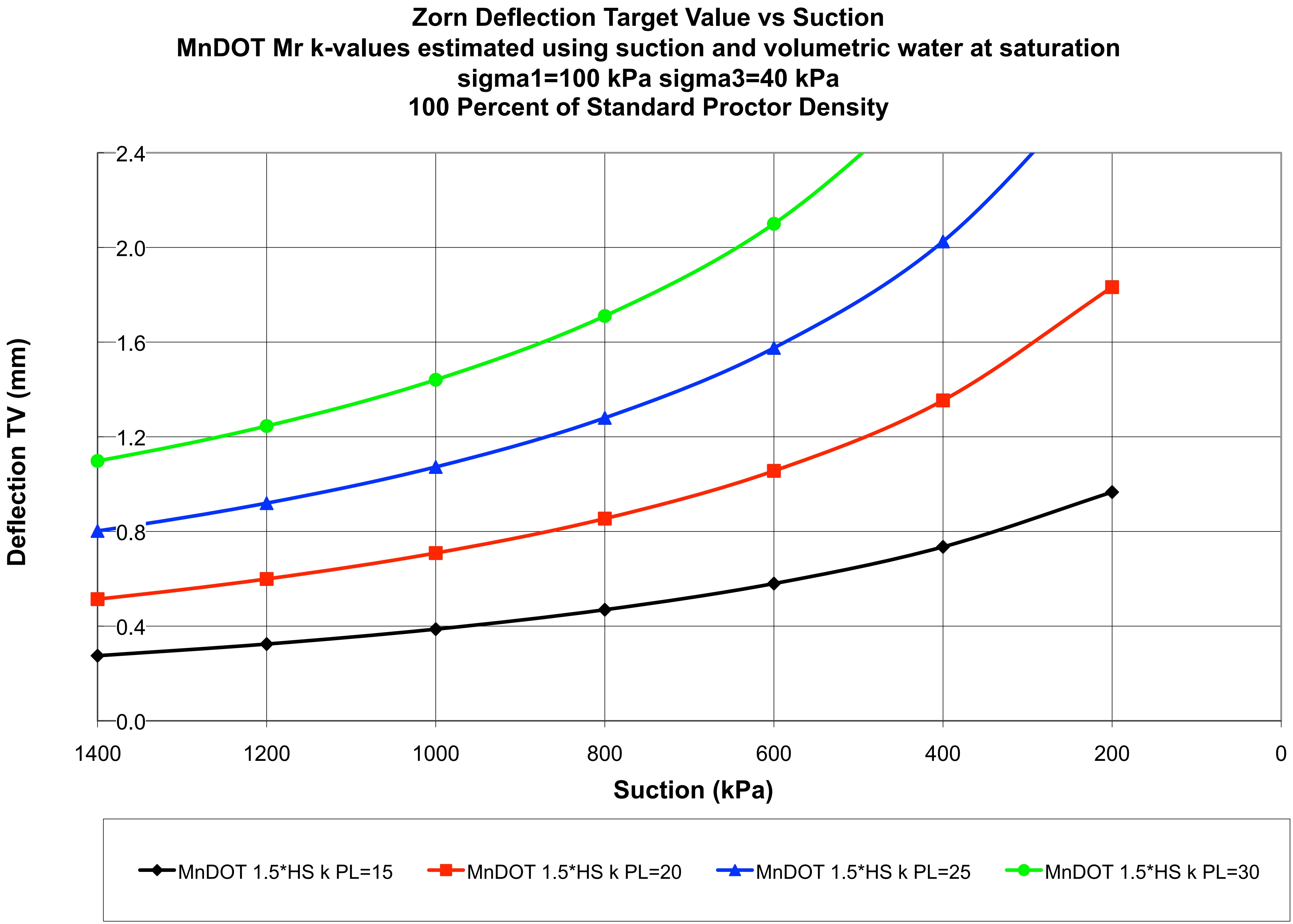

Zorn Deflection Target Value vs Field Moisture
MnDOT Mr k-values estimated using suction and volumetric water at saturation
sigma1=100 kPa sigma3=40 kPa
100 Percent of Standard Proctor Density
Deflection TV (mm)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
70
75
80
85
90
95
100
105
110
Field Moisture as a Percent of Optimum Moisture Standard Proctor (percent)
Zorn1.5HS T99max 125pcf
Zorn1.5HS T99max 115pcf
Zorn1.5HS T99max 105pcf
Zorn1.5HS T99max 95pcf

Why Deflection Target Values?

- Design engineer can determine allowable deflection for each layer of the pavement foundation using pavement design software. This includes the moisture content range allowed during construction and the expected deflections.
- Construction engineer and inspection personnel measure deflection and moisture to verify that the design parameters have been achieved.


LWD Deflection Target and Data vs Percent of Standard Proctor Optimum
MnROAD08 PL=19% Optimum Moisture=14% T99Density=115 lbs/ft3
LWD Deflection TVs and Data (mm)
2.0
1.5
1.0
0.5
0.0
70
75
80
85
90
95
100
105
110
Percent of Standard Proctor Optimum Moisture (percent)
Zorn LWD data
Target Value
Power(Target Value)


LWD Deflection Target and Data vs Percent of Standard Proctor Optimum
US94 2009 Plastic Limit=26% Optimum Moisture=21% T99Den=101 lbs/ft3
LWD Deflection TVs and Data (mm)
2.0
1.5
1.0
0.5
0.0
70
75
80
85
90
95
100
105
110
Percent of Standard Proctor Optimum Moisture (percent)
Zorn LWD data
Target Value
Power(Target Value)



Zorn Deflection Target Value vs Suction
MnDOT Mr k-values estimated using suction and volumetric water at saturation
sigma1=100 kPa sigma3=40 kPa
100 Percent of Standard Proctor Density
Deflection TV (mm)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
1400
1200
1000
800
600
400
200
0
Suction (kPa)
MnDOT 1.5*HS k PL=15
MnDOT 1.5*HS k PL=20
MnDOT 1.5*HS k PL=25
MnDOT 1.5*HS k PL=30

Conclusions

- Compaction equipment and field tests are now available that can measure the properties used to design pavements and predict performance.
- LWDs and DCPs can be used during construction quality assurance to efficiently verify design target values.
- Several options exist to quantify moisture and more field measurement devices are coming.
- The time is now to accelerate implementation of performance based quality assurance so that our investments are well spent.

Roadmap: What's Next

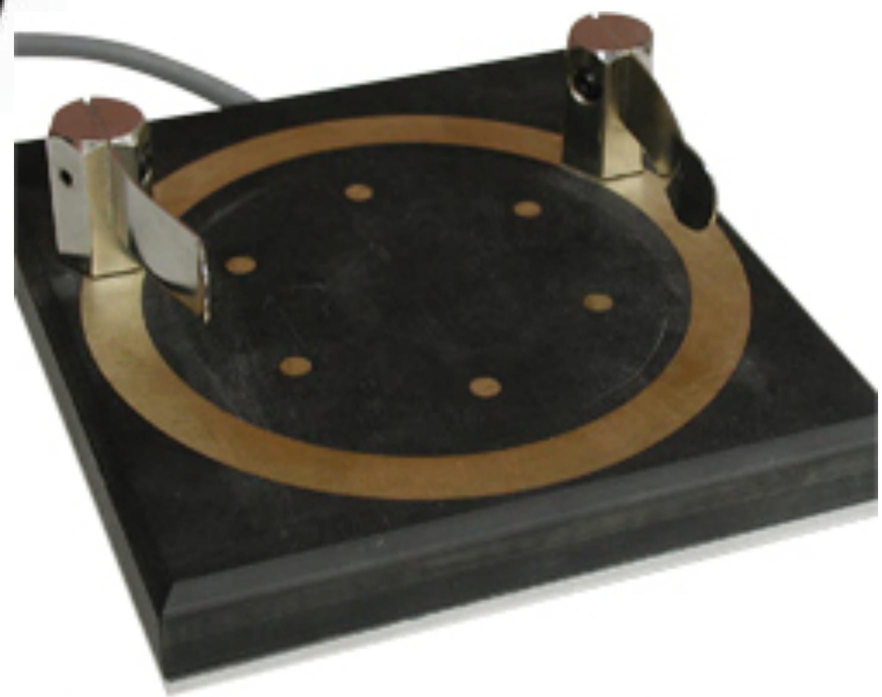
- Purchase more LWDs for performance based QA testing
- Specification to include design-based minimum targets
- Specification to include design-based uniformity targets
- Industry/Agency inspector certification training
- Educate designers, opportunity to refine/validate design
- MnPAVE enhancements to predict construction QA targets
- MnPAVE enhancements to include unsaturated mechanics
- Continued participation with national projects
- Implementation of new moisture/suction QA test

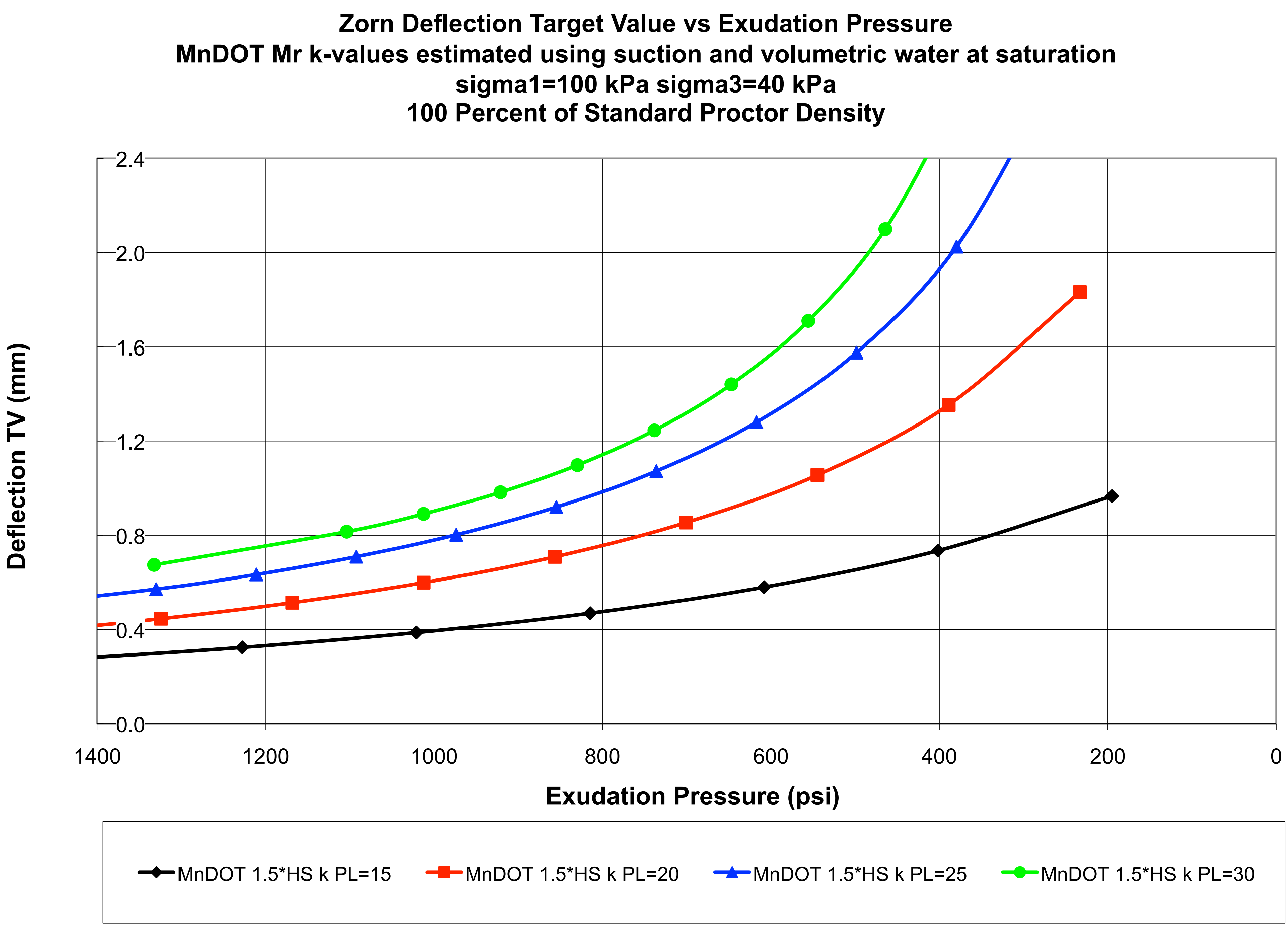
Thank You.

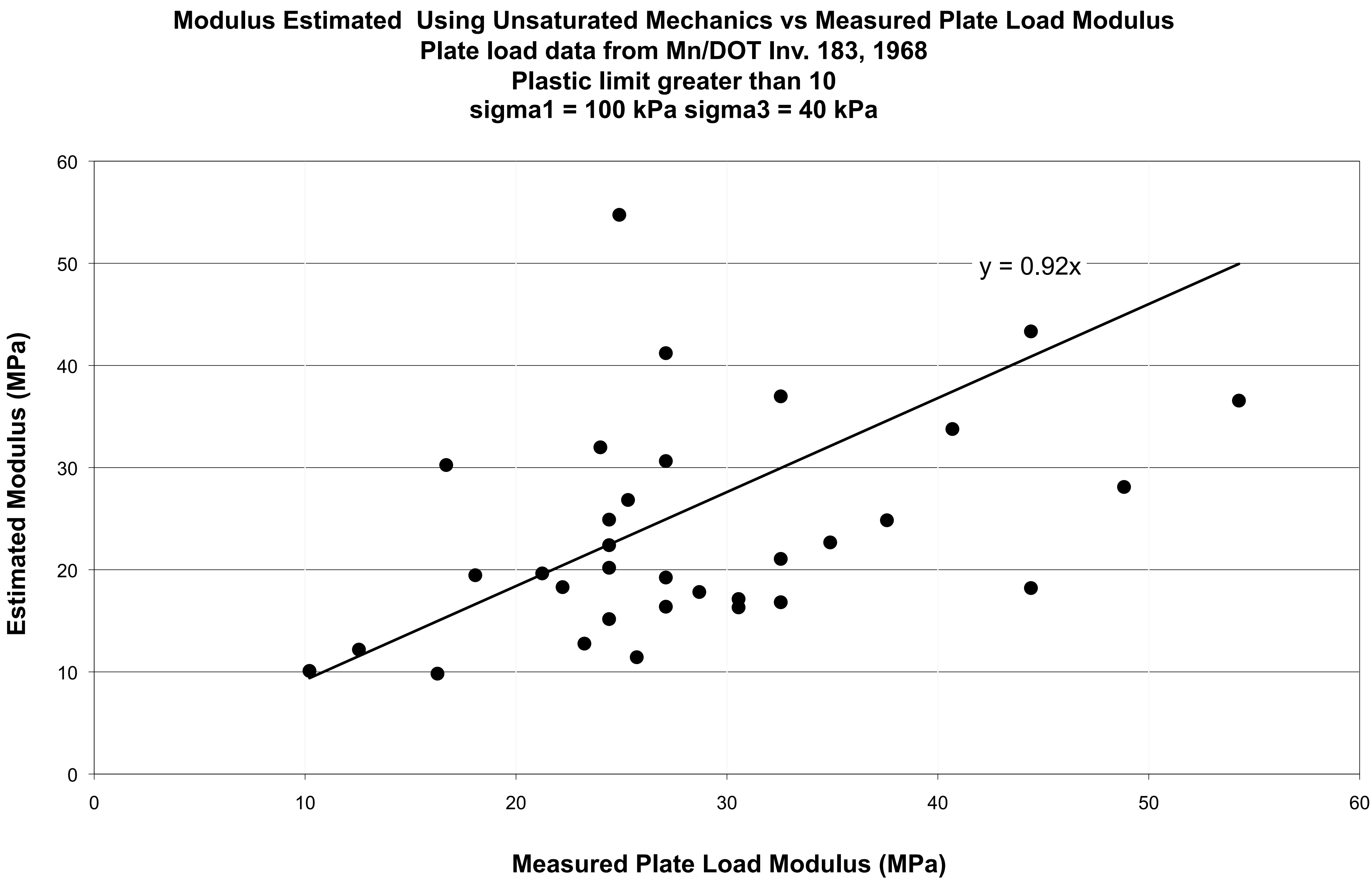
Questions?

http://www.dot.state.mn.us/materials/research_lwd.html


INSTRON
300 DX




Zorn Deflection Target Value vs Exudation Pressure
MnDOT Mr k-values estimated using suction and volumetric water at saturation
sigma1=100 kPa sigma3=40 kPa
100 Percent of Standard Proctor Density
Deflection TV (mm)
2.4
2.0
1.6
1.2
0.8
0.4
0.0
1400
1200
1000
800
600
400
200
0
Exudation Pressure (psi)
MnDOT 1.5*HS k PL=15
MnDOT 1.5*HS k PL=20
MnDOT 1.5*HS k PL=25
MnDOT 1.5*HS k PL=30


Modulus Estimated Using Unsaturated Mechanics vs Measured Plate Load Modulus
Plate load data from Mn/DOT Inv. 183, 1968
Plastic limit greater than 10
sigma1 = 100 kPa sigma3 = 40 kPa
y = 0.92x
Estimated Modulus (MPa)
Measured Plate Load Modulus (MPa)
0
10
20
30
40
50
60