

In Situ Testing for Mechanistic Empirical Pavement Design

OMRR Research Seminar

Unsaturated Soil Engineering – Applications in Pavements

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Office of Materials and Road Research



Mn/DOT

Office of Materials and Road Research



Why Mechanistic Empirical Design?

- **Our current procedures cannot adequately address issues facing us today**
 - ◆ Traffic Volume
 - ◆ Axle Loads
 - ◆ New Materials
 - ◆ Seasonal Optimization
 - ◆ Field Staff Reductions



Outline of Presentation

- **Current Design Procedure**
- **Empirical Design and Index Tests**
- **Mechanistic Design**
- **In Situ Testing Devices**
- **Mechanistic Properties Table**

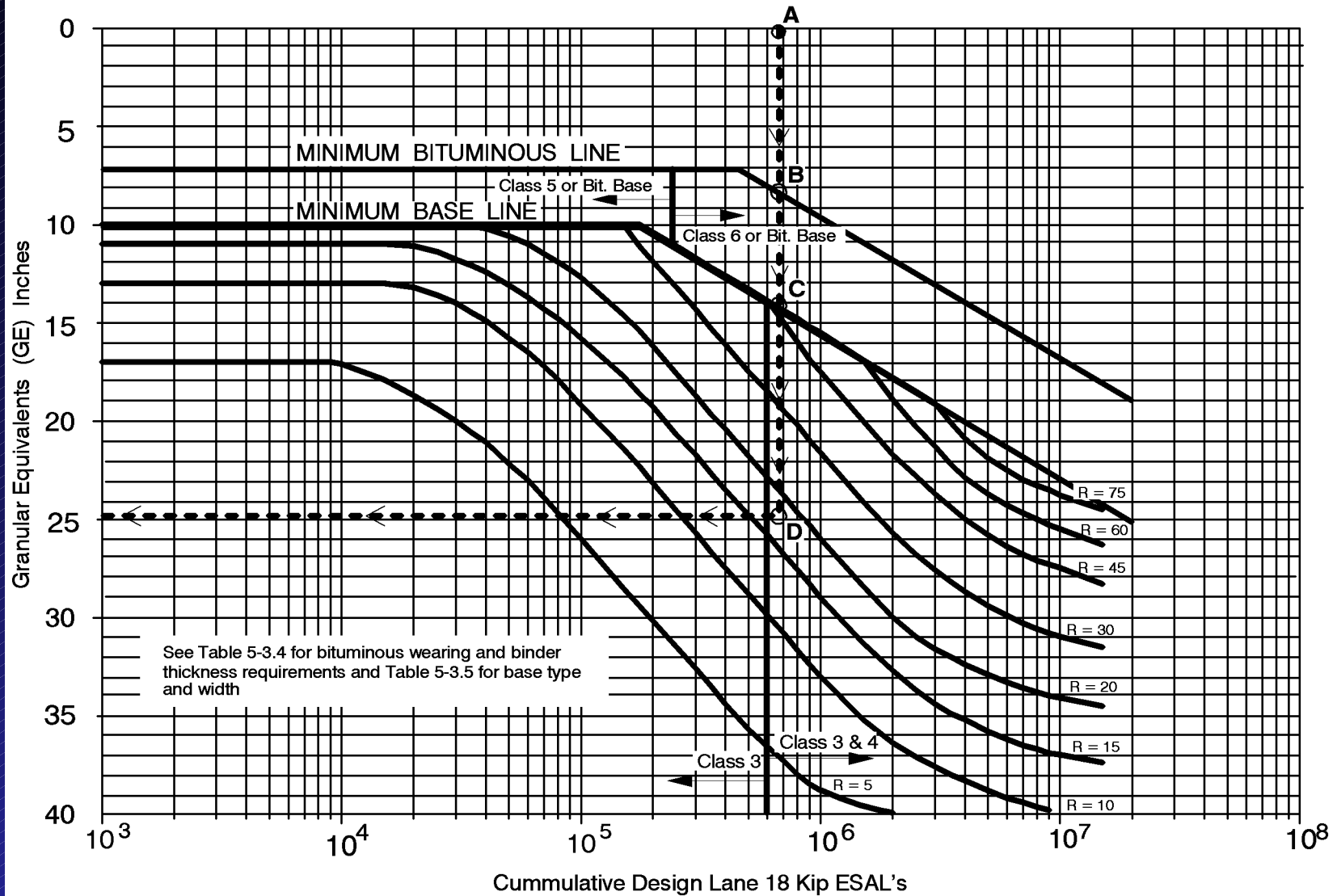


Current Design Procedure

- **Predominantly Empirical**
 - ◆ AASHO Road Test
 - ◆ Mn/DOT Investigation 183
- **Depends on Conditions Remaining the Same**
 - ◆ Traffic and Materials
- **Limited Failure Modes**
- **Worst Case or Simplified Time Periods**



Figure 5-3.6 Bituminous Pavement Design Chart (Aggregate Base)



BITUMINOUS PAVEMENT DESIGN CHART (AGGREGATE BASE)

AASHO Road Test

“80% of the flexible test sections failed during the spring. The increased failure during the spring period did not allow ‘smooth’ development of axle load repetitions and damage to the subgrade.” (Peattie, 1965)

Therefore seasonal strains caused by temperature and moisture changes should be considered.



Index Tests and Method Specs

- **Soil Classification and Gradation**
- **Compaction Testing and Test Rolling**
- **Moisture and Lift Thickness Limits**
- **R-Value and Compaction Testing**
 - ◆ Not adequate for ME Design



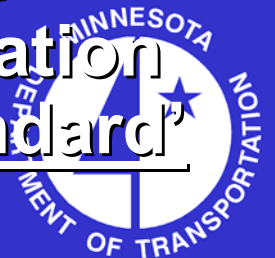
Mn/DOT 1961 Investigation 176

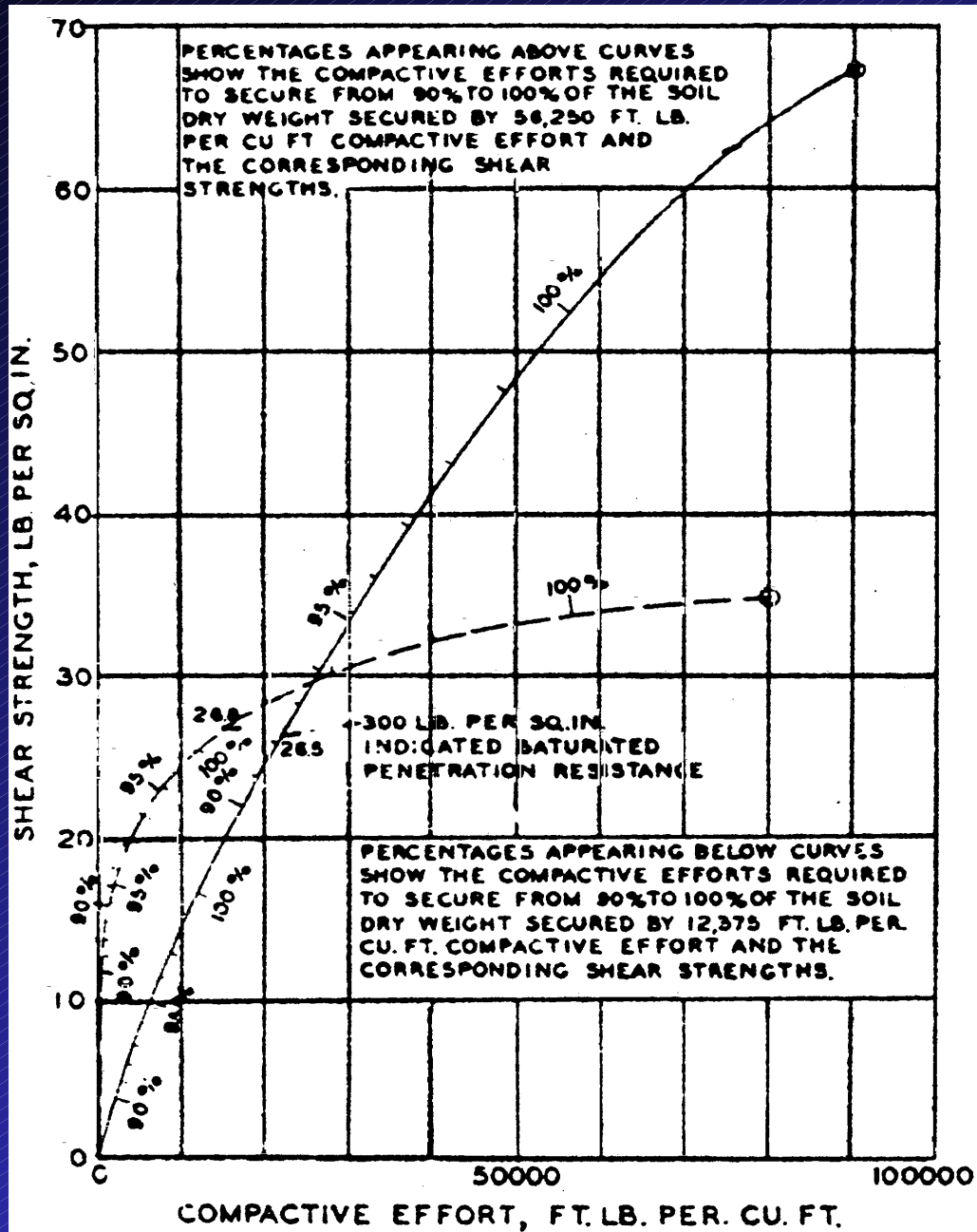
- R-Value compaction pressures vary considerably depending on the soil.
- Relative moisture and density of R-Value specimens vary considerably within a soil group and between groups.
- R-Value test does not conform to the usual concepts of controlling moisture and density in test specimens.



Proctor 1948

- “Originally published objective of compaction in earth fills was a saturated penetration resistance of 300 lb per sq in.”
- “Soil would then have twice the penetration resistance required to permit loaded truck travel when fully saturated.”
- “The 12 inch blow was required principally to assure accurate determination of this penetration resistance and was never intended as a ‘standard’ or ‘optimum’.”





Mechanistic Tests Are Needed

- Achieve agreement between construction quality assurance and seasonal pavement design.
- Quantify alternative materials and construction practices. Show economic benefit of improved materials. Reward good construction.
- This requires new specifications and new tools. Tools must be quantitative, portable, and accurate in the field.



In-Situ Testing of Mechanical Properties



Prima Portable FWD

- **Impulse Device**
 - ◆ Load measured
 - ◆ Velocity measured
Deflection calculated
 - ◆ Variable falling mass



Test Type and Equipment

■ Shear Strength

- ◆ Dynamic Cone Penetrometer (DCP)
- ◆ Rapid Compaction Control Device (RCCD)

■ Elastic Modulus

- ◆ Dynatest Falling Weight Deflectometer (FWD)
- ◆ Loadman Portable FWD (PFWD)
- ◆ PRIMA PFWD
- ◆ Humboldt GeoGauge

■ Density

- ◆ Sand Cone, Nuclear Gauge



Soil Properties Table

- Provide Standardized Input Values
- Left to Right
- Classification and Index Properties
- Strength Tests and Moisture Conditions
- MnPAVE Design Moduli
- Basic to Intermediate to Advanced



Soil Classification

Mn/DOT Standard Textural Classification	Field Identification	Ribbon Length (inches)	Rating	Possible Equivalent Classes		
				Soil Factor	AASHTO	ASTM Unified
Sand (Sa)	Will form a cast when wet. Crumbles easily. 100% passes 2	0	Good to Excellent	50-75	A-1, A-3	SP-SM
Loamy Sand (LSa)	Grains clearly seen. Will form a cast. Will stand light jarring.	0	Good to Excellent	50-75	A-2	SM, SC
Sandy Loam (SaL) plastic (10 to 20 % clay)	Slightly plastic to plastic. Sand grains seen and felt. Gritty.	0.75 - 1.5	Fair	100-130	A-4	SM, SC
Clay Loam (CL)	Smooth, shiny, moderate resistance to ribboning.	1.5 - 2.5	Fair to Good	100	A-6	CL
Silty Clay Loam (SiCL)	Dull appearance, slippery. Less resistance to ribboning than CL.	1.5 - 2.5	Poor	120-130	A-6	ML/CL, MH/CH



Soil Index Tests

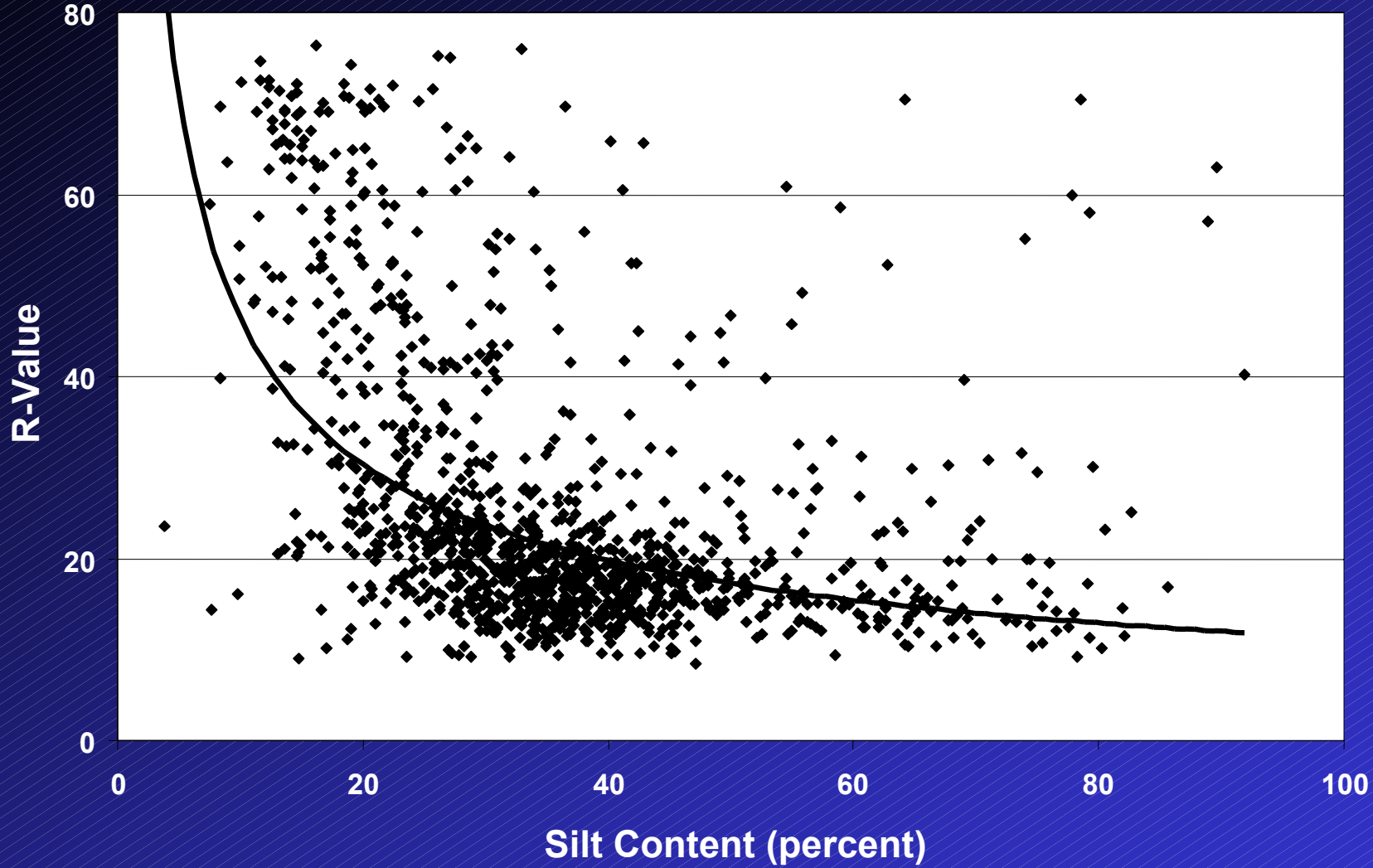
Mn/DOT Standard Textural Classification	Sieve Analysis				Atterberg Limits				Standard Proctor		
	Passing #200		Silt Content		Plastic Limit		Liquid Limit		Density	Optimum Moisture	Saturation
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev			
	%	%	%	%	%	%	%	%	lb /ft ³	%	%
Sand (Sa)	7	3	5	2	NA	NA	NA	NA	112 - 134	7 - 12	60 - 86
Loamy Sand (LSa)	15	3	12	3	NA	NA	NA	NA	116 - 133	8 - 11	62 - 92
Sandy Loam (SaL) plastic (10 to 20 % clay)	42	5	28	5	17	3	27	6	113 - 125	10 - 14	79 - 89
Clay Loam (CL)	62	6	38	6	19	3	37	5	103 - 115	14 - 20	81 - 91
Silty Clay Loam (SiCL)	85	7	62	7	23	9	37	6	99 - 112	15 - 21	80 - 86

Soil Strength Tests in Minnesota

Mn/DOT Standard Textural Classification	R-Value (240 psi Exudation Pressure)					Plate Load	
	Estimated From			Measured		Estimated From	
	#200	Silt Content	Plastic Limit	Mean	Std Dev	R-Value	
	%	%	%	%	%	MPa	ksi
Sand (Sa)	61	51	NA	ND	ND	50	7.2
Loamy Sand (LSa)	39	30	NA	60	14	41	6.0
Sandy Loam (SaL) plastic (10 to 20 % clay)	18	17	16	22	6	29	4.2
Clay Loam (CL)	14	14	14	17	4	27	4.0
Silty Clay Loam (SiCL)	11	10	8	16	5	22	3.1



R-Value vs Silt Content



R-Value vs Silt Content

- Silt causes more problems than clay
- Simple one variable relationship
- Should do resilient modulus test
- Need to develop Minnesota database

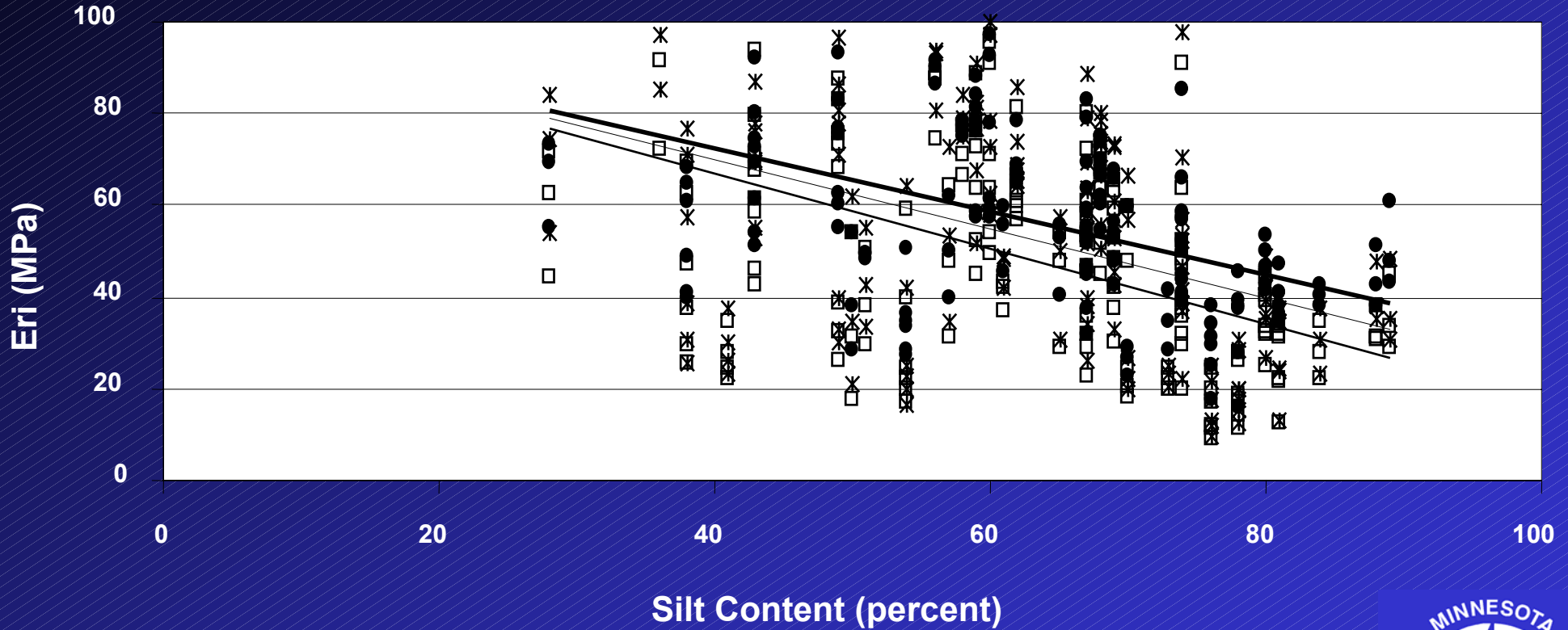


Soil Strength Tests in Illinois

Mn/DOT Standard Textural Classification	ERIMN				CBR	DCP	
	Estimated From				Estimated From		
	Silt Content		R-Value Silt Content		R-Value	CBR	ERIMN
	MPa	ksi	MPa	ksi	%	mm/blow	mm/blow
Sand (Sa)	70	10.2	83	12.0	14.1	15	14
Loamy Sand (LSa)	65	9.4	68	9.9	7.2	22	15
Sandy Loam (SaL) plastic (10 to 20 % clay)	52	7.5	54	7.8	3.9	30	18
Clay Loam (CL)	44	6.4	46	6.7	3.4	32	21
Silty Clay Loam (SiCL)	27	3.9	34	5.0	3.1	33	34



Laboratory Eri vs Silt Content



Laboratory Modulus E_{ri}

- Laboratory conditions
- standard Proctor 95% maximum density
- standard Proctor optimum moisture
- 10 psi deviator stress



In Situ Soil Moisture

Mn/DOT Standard Textural Classification	Lab Optimum	In Situ Equilibrium (water depth greater than 5 feet)		
	Saturation		Pore Suction Resistance Factor	Susceptibility Resistance Factor
	Clay Content	Plastic Limit		
	%	%		
Sand (Sa)	80	70	1.13	1.59
Loamy Sand (LSa)	81	75	1.07	1.46
Sandy Loam (SaL) plastic (10 to 20 % clay)	83	85	0.98	1.17
Clay Loam (CL)	85	85	1.00	1.00
Silty Clay Loam (SiCL)	85	90	0.95	0.60



Resistance Factors

■ Saturation Resistance Factor

- ◆ Adjustment from lab to in situ conditions
- ◆ Resistance to taking on water

■ Available Water Resistance Factor

- ◆ Resistance to moisture influence
- ◆ Dependent on soil type
- ◆ Normalized to clay loam

■ Seasonal Moisture Resistance Factor

- ◆ Based on Mn/ROAD clay loam



Unsaturated Moisture Conditions

■ Laboratory

- ◆ Proctor
- ◆ Resilient Modulus

■ In Situ Construction

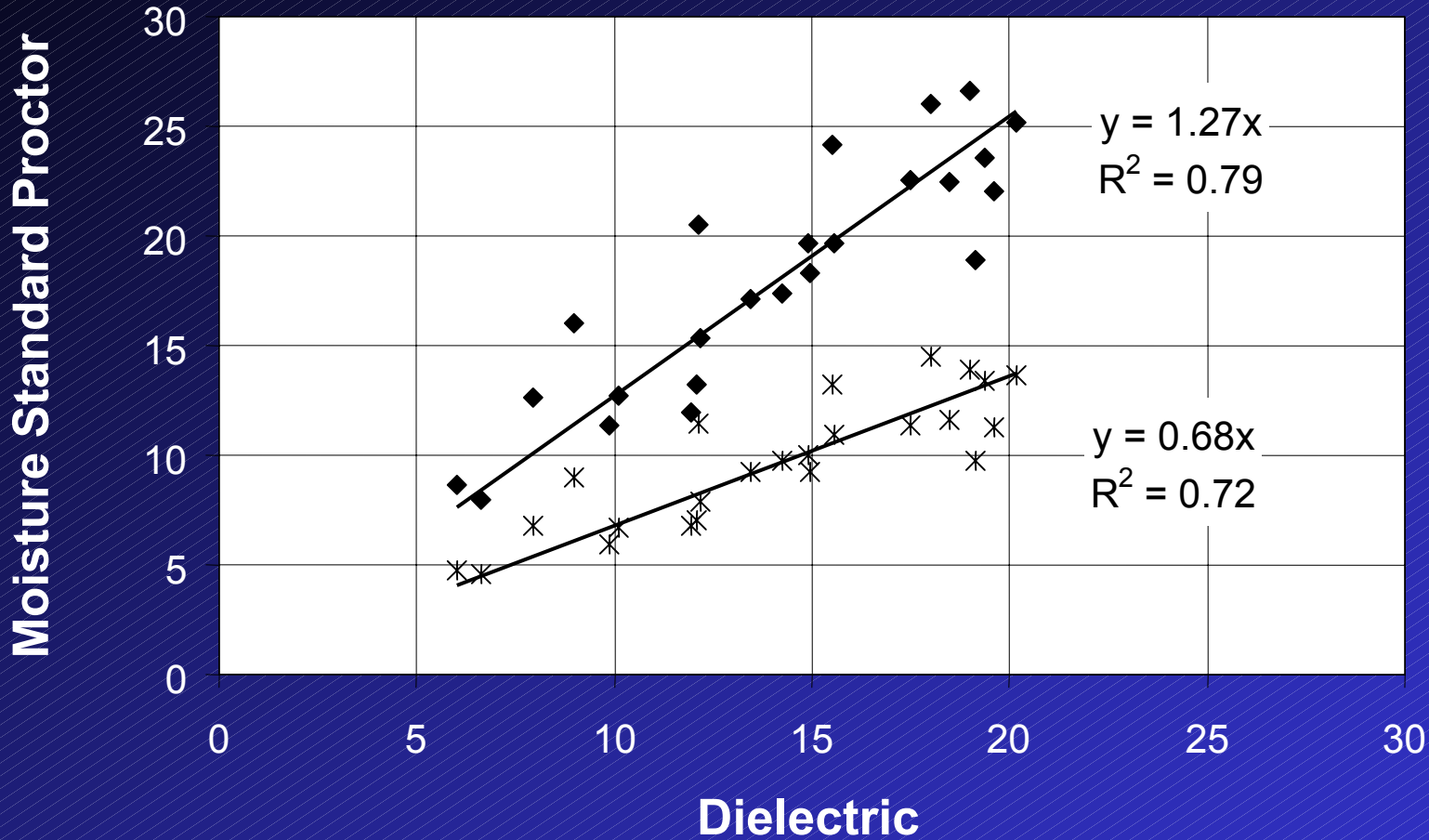
- ◆ Compaction Testing
- ◆ DCP/PFWD/GeoGauge

■ In Situ Seasonal

- ◆ Manual and Automated Dielectric Measurement



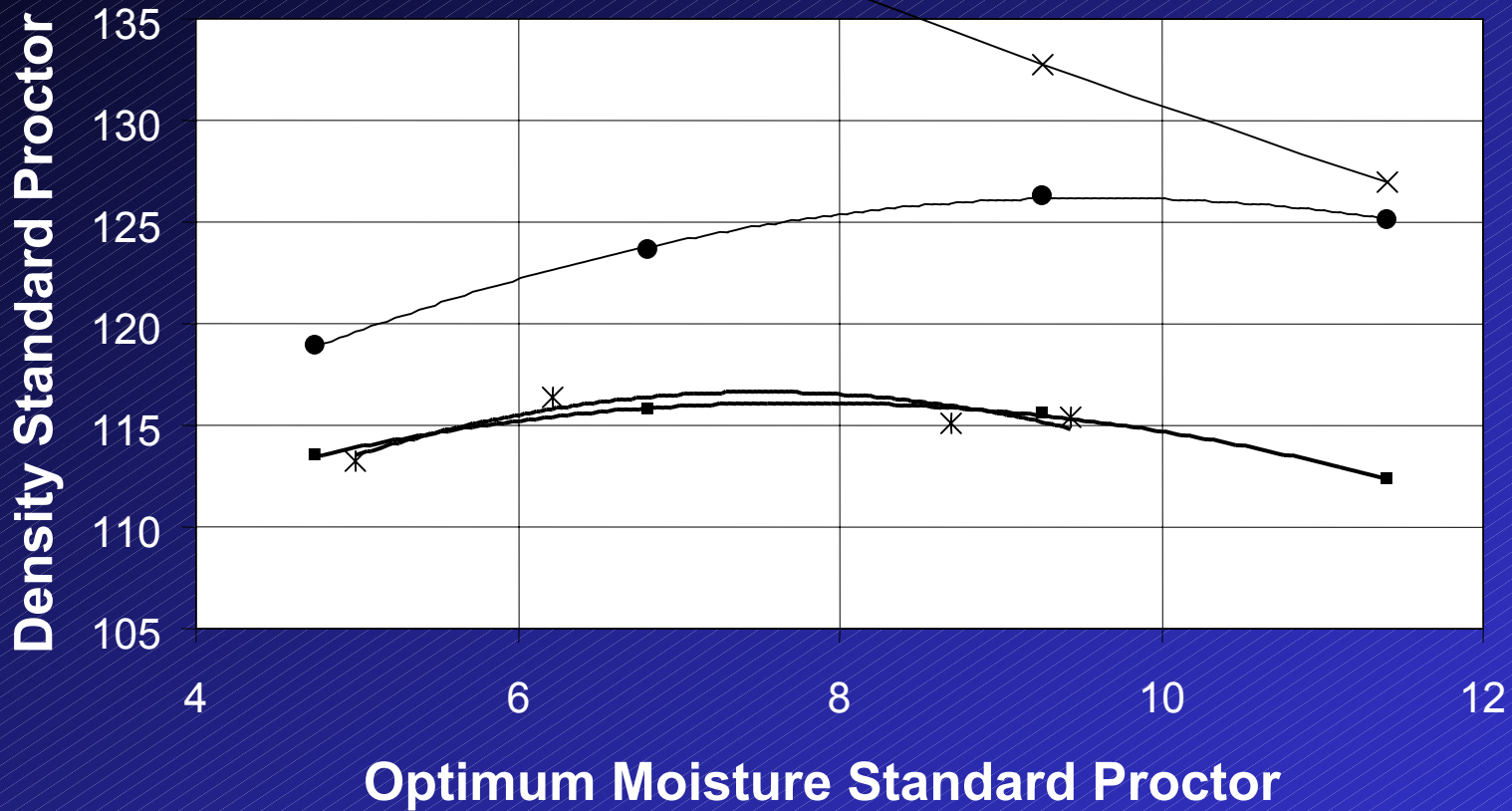
Moisture vs Dielectric



* Gravimetric Moisture ◆ Volumetric Moisture
— Linear (Gravimetric Moisture) — Linear (Volumetric Moisture)



Density vs Moisture



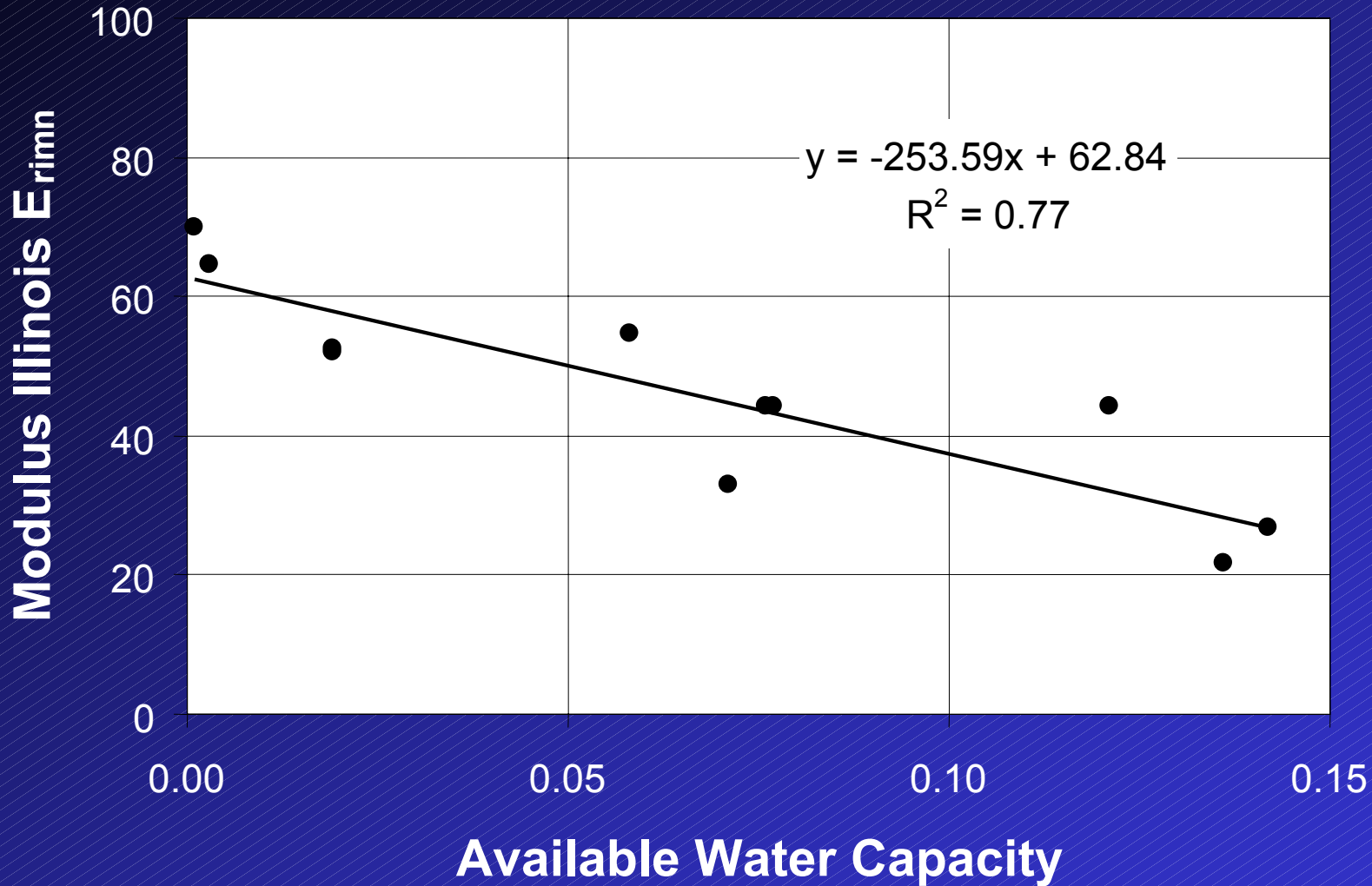
■ Density Dry

● Density Wet

* Dielectric Moisture Only



Modulus vs Available Water

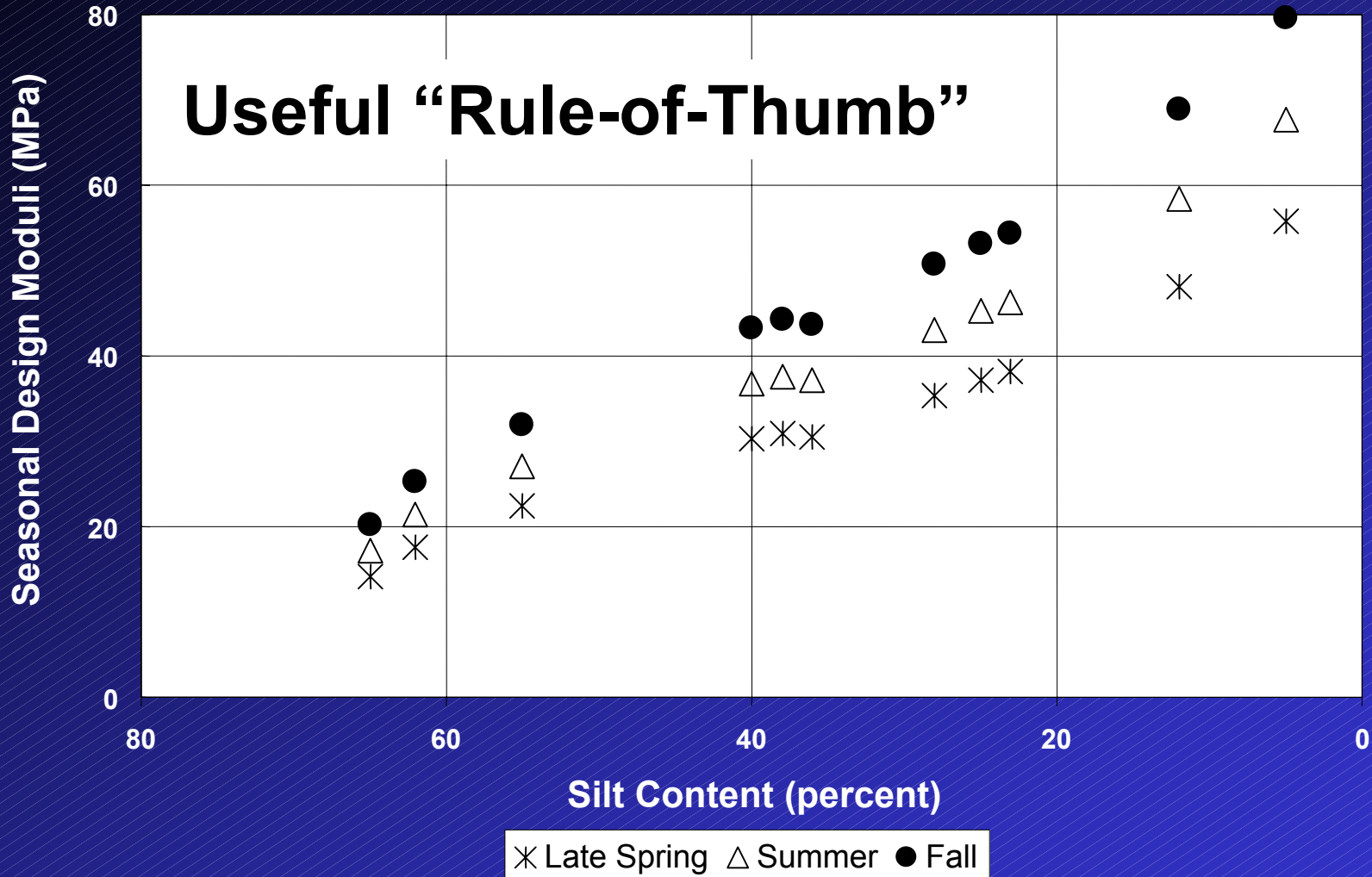


Soil Moduli for Design

Mn/DOT Standard Textural Classification	Early Spring		Late Spring		Summer		Fall		Winter	
	2 weeks		Various Lengths Based on Location							
	Seasonal Moisture Resistance Factor									
	Frozen		0.7		0.85		1.0		Frozen	
	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
Sand (Sa)	350	50	56	8.1	68	9.8	80	11.5	350	50
Loamy Sand (LSa)	350	50	48	7.0	58	8.5	69	10.0	350	50
Sandy Loam (SaL) plastic (10 to 20 % clay)	350	50	35	5.1	43	6.2	51	7.3	350	50
Clay Loam (CL)	350	50	31	4.5	38	5.4	44	6.4	350	50
Silty Clay Loam (SiCL)	350	50	18	2.6	21	3.1	25	3.7	350	50



Seasonal Design Moduli vs Silt Content



Conclusions

- Sand cone testing has been useful, but is not time efficient, does not verify design properties, and should be replaced.
- Field tests are now available that can measure the mechanistic properties used to design pavements.



Conclusions (continued)

- Useful correlations exist between the strength, measured using the DCP, and the elastic deformation modulus, measured using the PFWDs and GeoGauge.
- Need to define which modulus: static or dynamic loading, stress level, boundary conditions, relative density, and moisture.



Recommendations

- Continue transition to mechanistic design. Conduct additional testing during the 2002 construction season.
- Implement quality control and quality assurance tests that measure the mechanical properties of constructed pavement system.
- Verify relationships between the properties measured during construction and the seasonal material properties.



Recommendations (cont)

- Standardize laboratory modulus testing to provide the designer with the best-case and worst-case material properties.
- Develop other quantitative in situ testing techniques that better define moisture sensitivity and drainage characteristics.
- Provide incentives for producing pavement structures that are stronger, stiffer, and more uniform than minimum specified.



University of Minnesota ME Projects

- Mechanistic Design 1999
- Seasonal Properties 2000
- Dynamic Analysis of FWD 2001
- PFWD Calibration 2002
- Modulus of Select Granular 2002
- MnROAD TDR Data Analysis 2002
- Moisture Retention Characteristics 2003
- Moisture Effects on DCP/PFWD 2003



Thank you.

- Questions?

- <http://mnroad.dot.state.mn.us>



Appendix

- The following slides may be of interest, but were not included in the seminar presentation.



New DCP Specification 2211

- Defines Minimum Shear Strength of Aggregate Base.
- "The full thickness of each layer of Classes 5 and 6 shall be compacted to achieve a penetration index value less than or equal to 10 mm per blow."



Specification (continued)

- "...must be tested and approved within 24 hours of placement and final compaction. Beyond the 24 hour limit, the same aggregate can only be accepted by the Specified Density Method" (sandcone and standard Proctor).



State DOTs Using DCP

California

Colorado

Florida

Illinois

Iowa

Kansas

Kentucky

Maryland

Michigan

Minnesota

Mississippi

Missouri

Montana

New Jersey

North Carolina

North Dakota

Ohio

Oklahoma

Pennsylvania

South Carolina

Texas

Utah

Wisconsin



Current/Future Standards

- Mn/DOT DCP Specification Aggregate Base
- ASTM DCP Test Method
- ASTM GeoGauge Test Method
- FHWA GeoGauge Pooled Funds Study
- FHWA Subgrade Performance Study
- AASHTO Test Procedures
- AASHTO 2002 Pavement Design
- United Kingdom Performance Specs.



In Situ Mechanistic Test Equipment

■ Stiffness Measurement

- ◆ GeoGauge Humboldt <http://www.hmc-hsi.com>
- ◆ PFWD Loadman <http://www.al-engineering.fi>
- ◆ PFWD PRIMA <http://www.pavement-consultants.com>
- ◆ PFWD LWDT <http://www.controls.it>

■ Strength Measurement

- ◆ DCP Kessler <http://www.kesslerdcp.com>
- ◆ DCP CSIR Nick Coetzee nfcoetzee@dynatest.com
- ◆ DCP TMC Tool Tom Clark (763) 559-2896
- ◆ DCP Vertek ARA <http://www.vertek.ara.com>

