In Situ Testing for Mechanistic Empirical Pavement Design

OMRR Research Seminar

Unsaturated Soil Engineering – Applications in Pavements

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Maplewood, MN

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Mn/DOT

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Why Mechanistic Empirical Design?

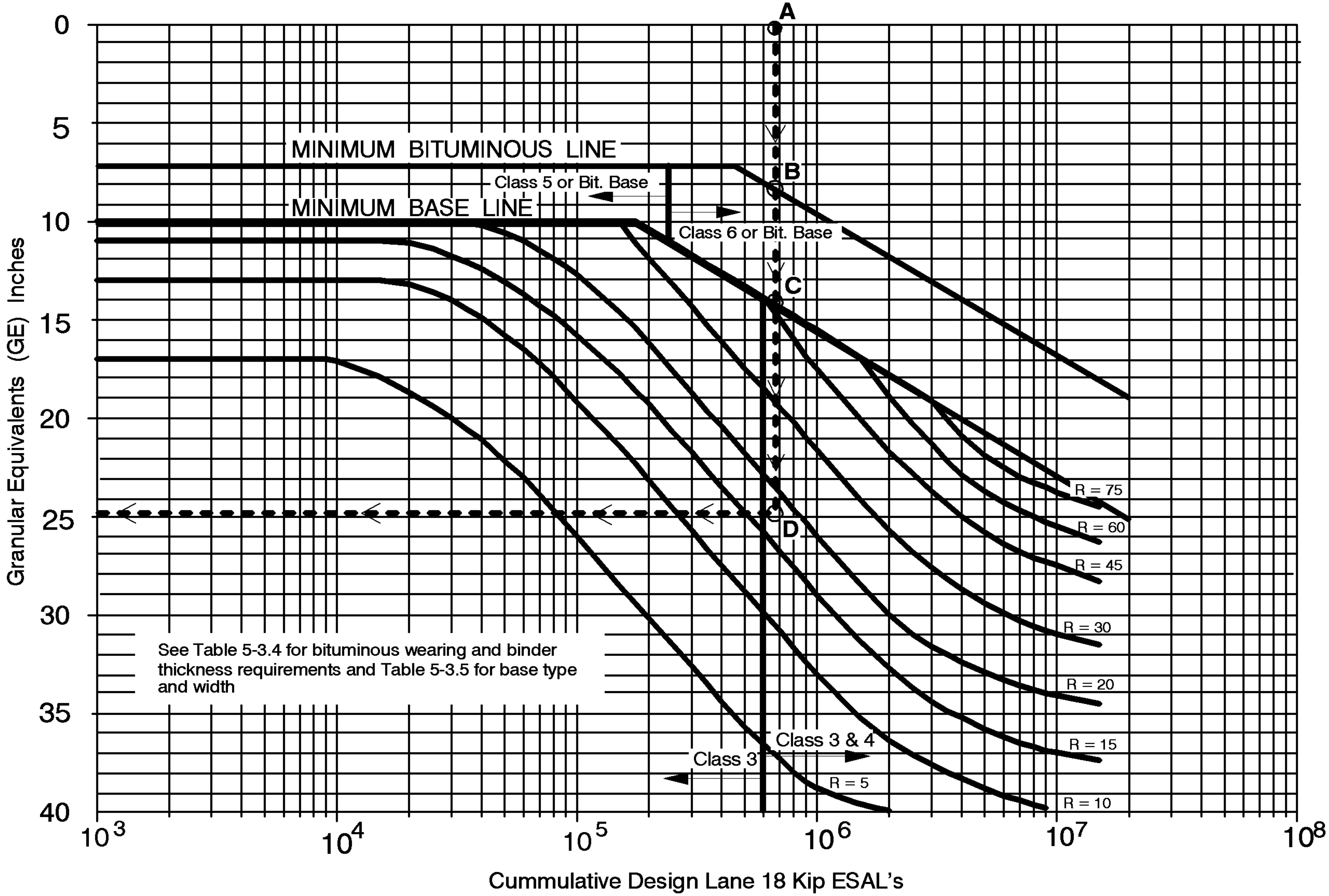
- **Our current procedures cannot adequately address issues facing us today**
  - Traffic Volume
  - Axle Loads
  - New Materials
  - Seasonal Optimization
  - Field Staff Reductions

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**



BITUMINOUS PAVEMENT DESIGN CHART (AGGREGATE BASE)

Figure 5-3.6 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.

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Index Tests and Method Specs

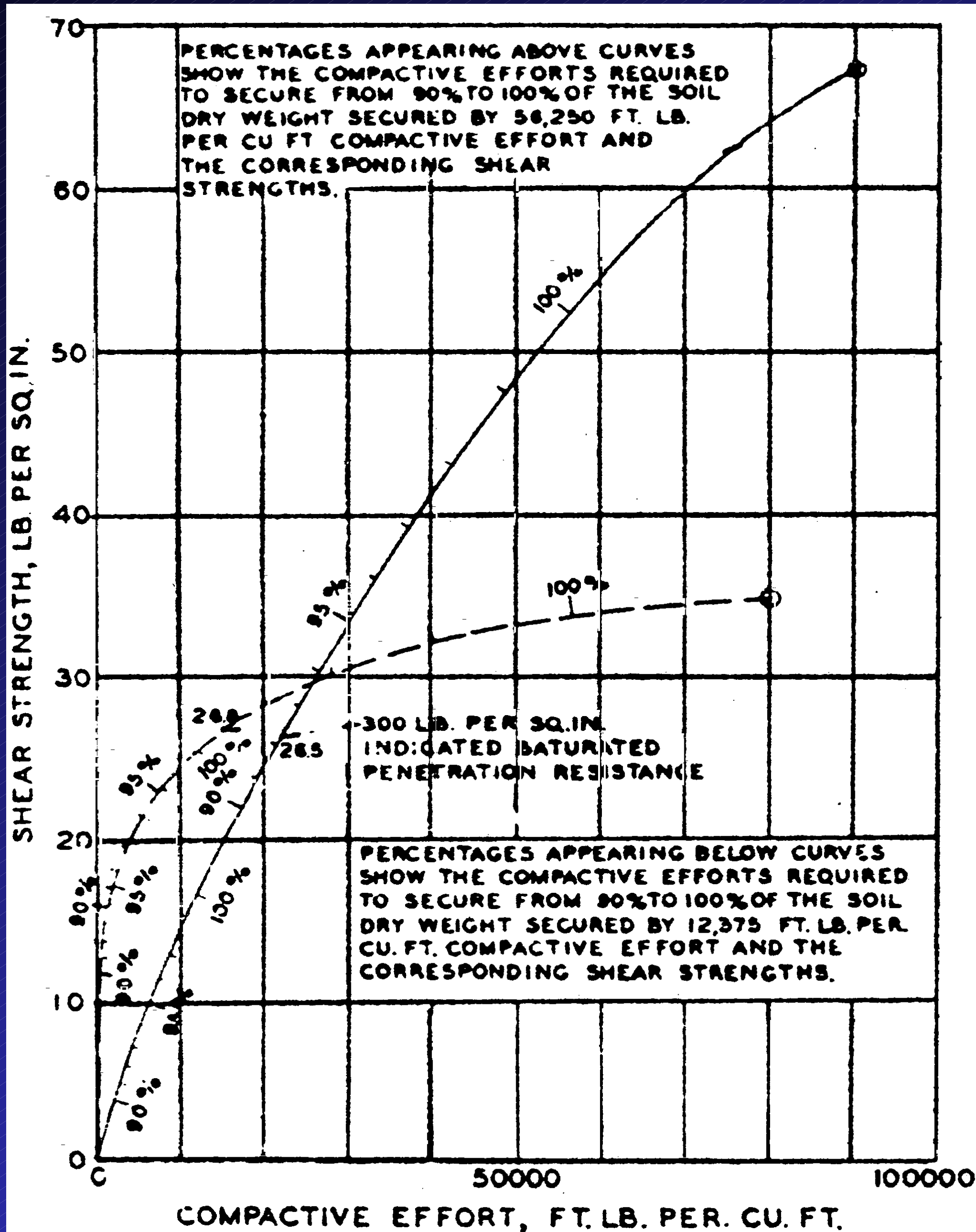
- **Soil Classification and Gradation**
- **Compaction Testing and Test Rolling**
- **Moisture and Lift Thickness Limits**
- **R-Value and Compaction Testing**
  - Not adequate for ME Design

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'."


PERCENTAGES APPEARING ABOVE CURVES SHOW THE COMPACTIVE EFFORTS REQUIRED TO SECURE FROM 90% TO 100% OF THE SOIL DRY WEIGHT SECURED BY 56,250 FT. LB. PER CU FT COMPACTIVE EFFORT AND THE CORRESPONDING SHEAR STRENGTHS.
PERCENTAGES APPEARING BELOW CURVES SHOW THE COMPACTIVE EFFORTS REQUIRED TO SECURE FROM 90% TO 100% OF THE SOIL DRY WEIGHT SECURED BY 12,375 FT. LB. PER CU. FT. COMPACTIVE EFFORT AND THE CORRESPONDING SHEAR STRENGTHS.
300 LB. PER SQ. IN. INDICATED SATURATED PENETRATION RESISTANCE
100%
95%
90%
26.5
SHEAR STRENGTH, LB. PER SQ. IN.
COMPACTIVE EFFORT, FT. LB. PER. CU. FT.
0
10
20
30
40
50
60
70
50000
100000

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

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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

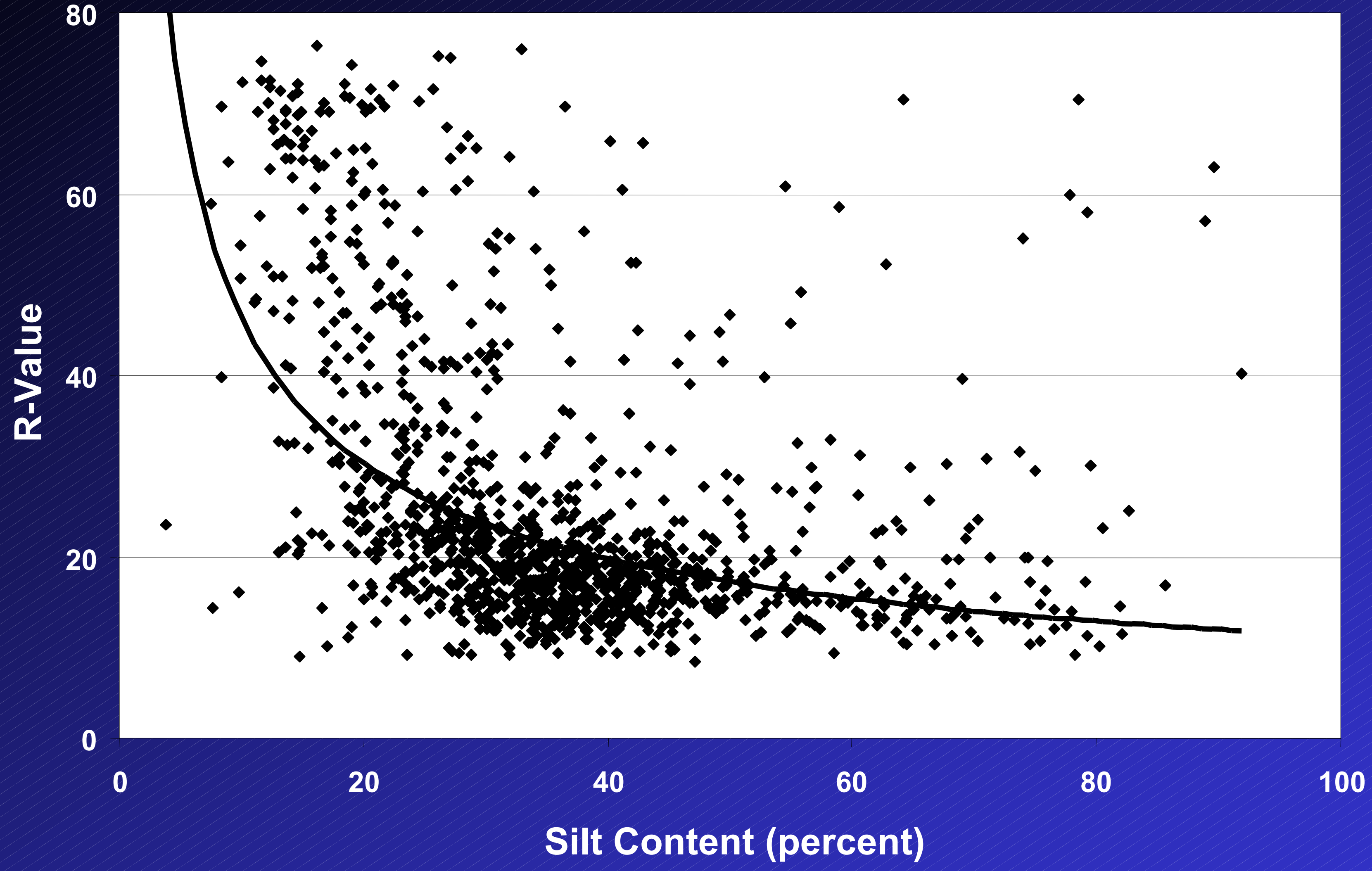
Soil Index Tests

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



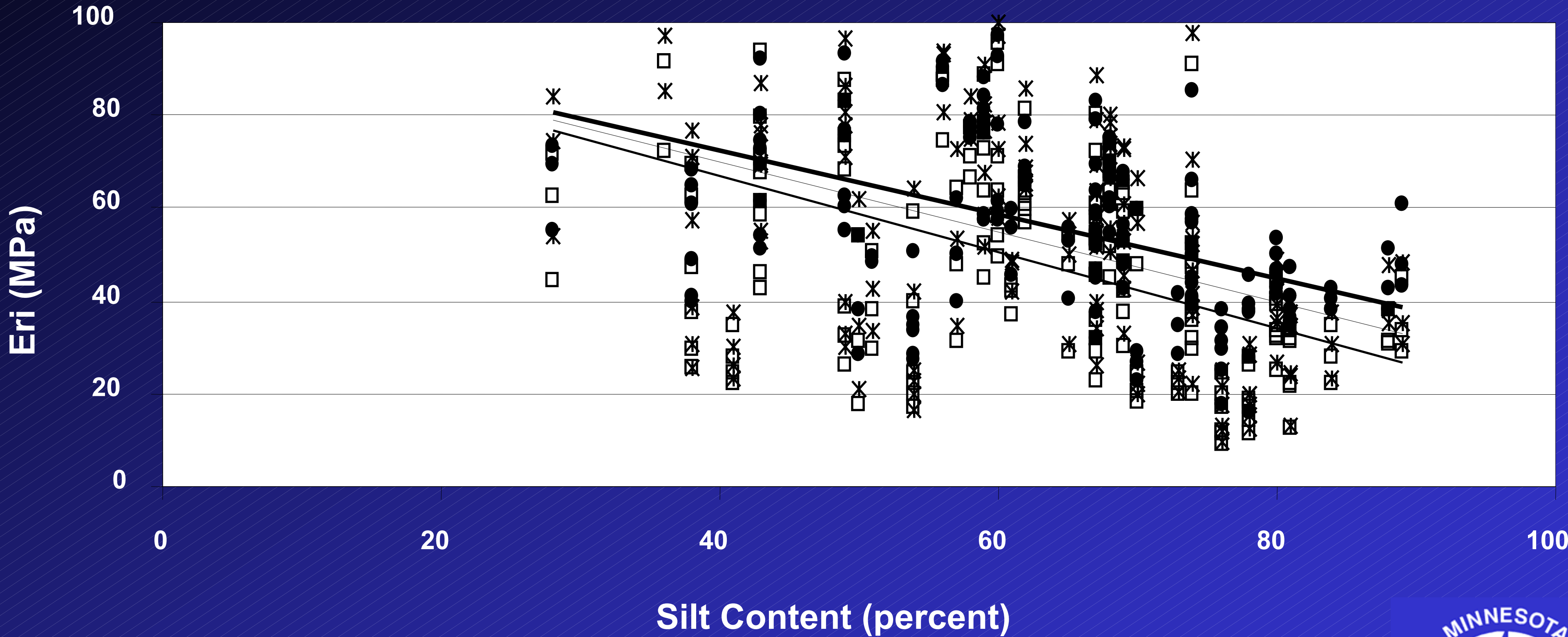
R-Value vs Silt Content

- 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			
	Estimated From		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

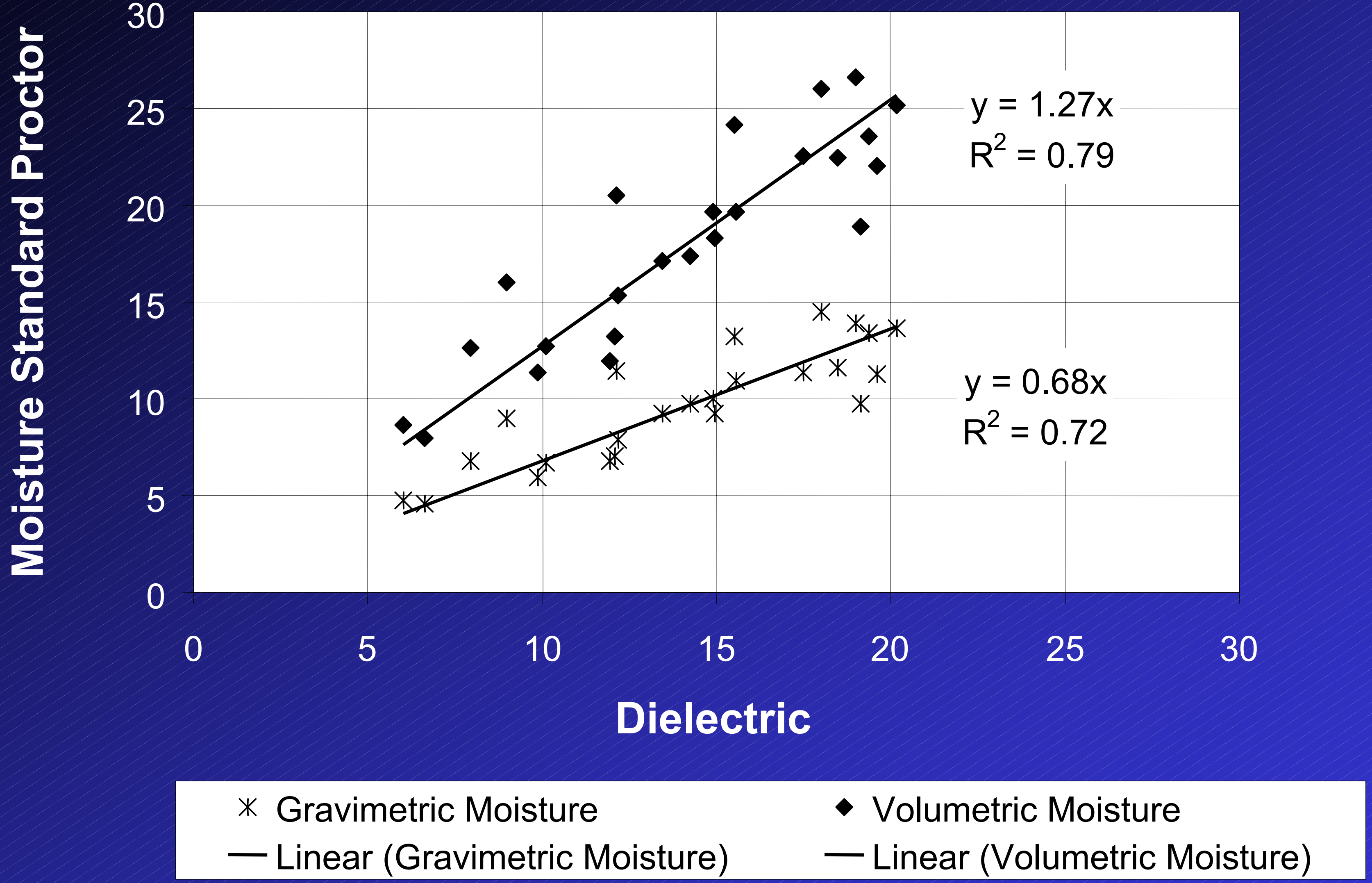
Resistance Factors

- **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

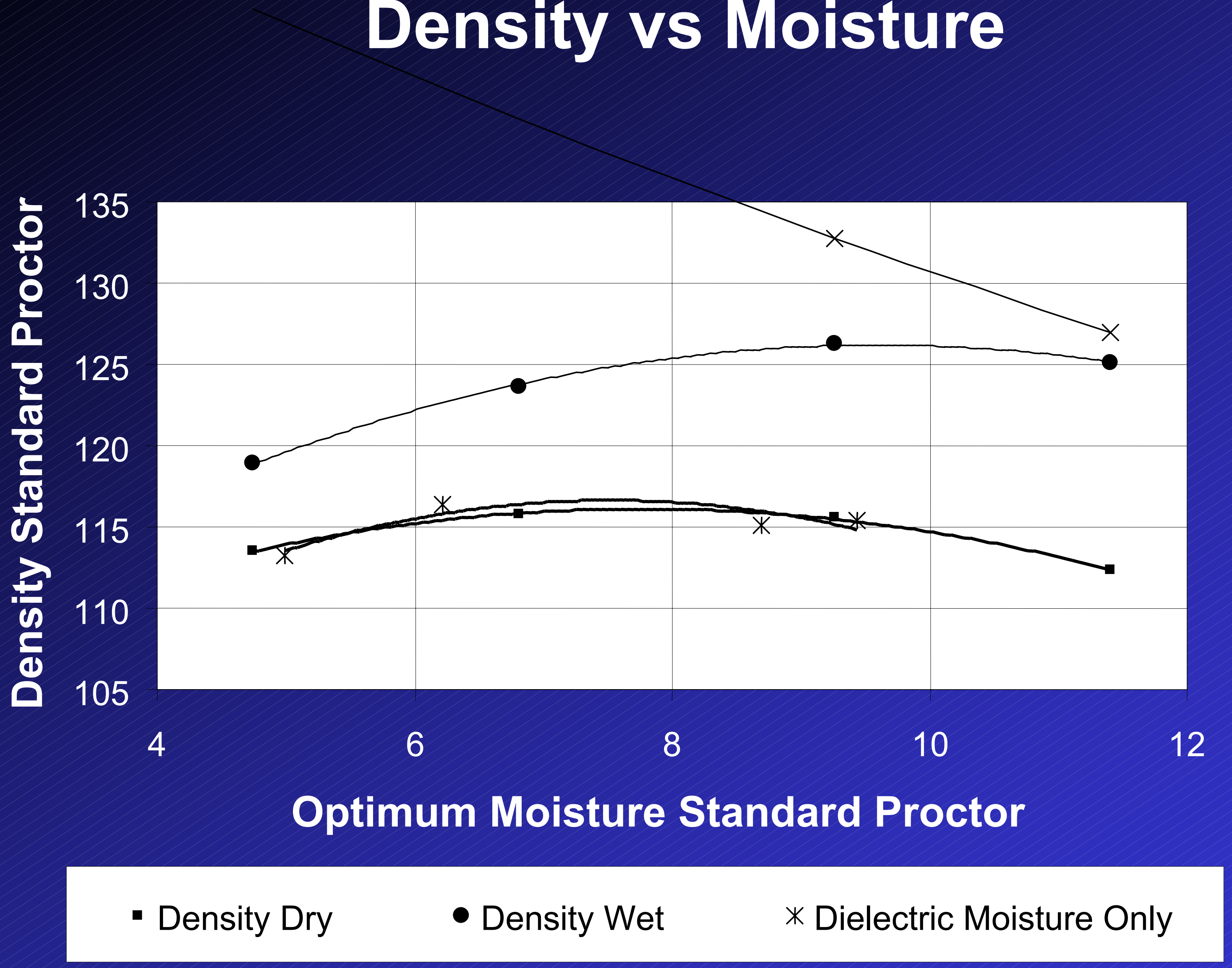
Unsaturated Moisture Conditions

- **Laboratory**
  - Proctor
  - Resilient Modulus
- **In Situ Construction**
  - Compaction Testing
  - DCP/PFWD/GeoGauge
- **In Situ Seasonal**
  - Manual and Automated Dielectric Measurement

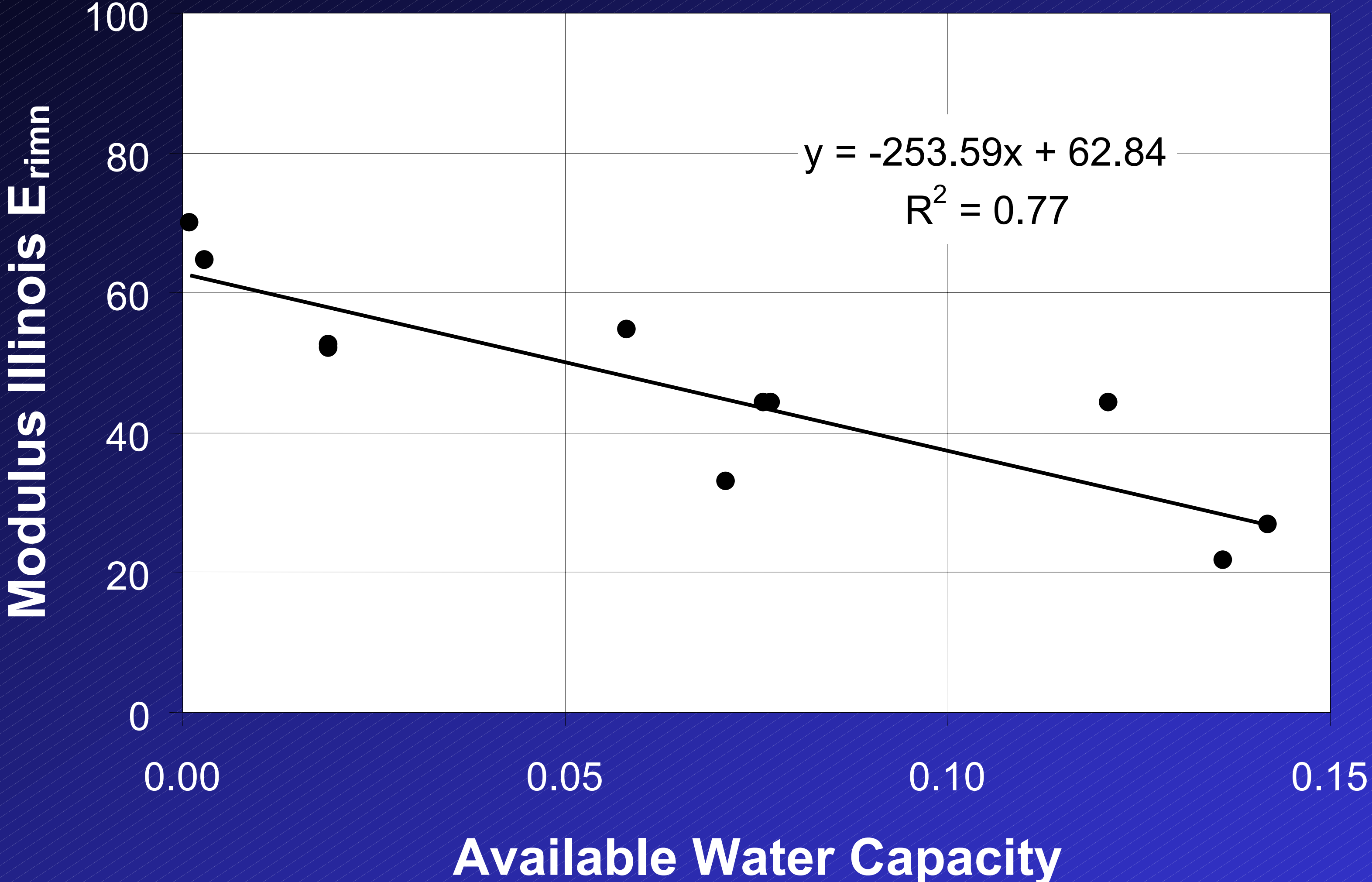
Moisture vs Dielectric



Density vs Moisture



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

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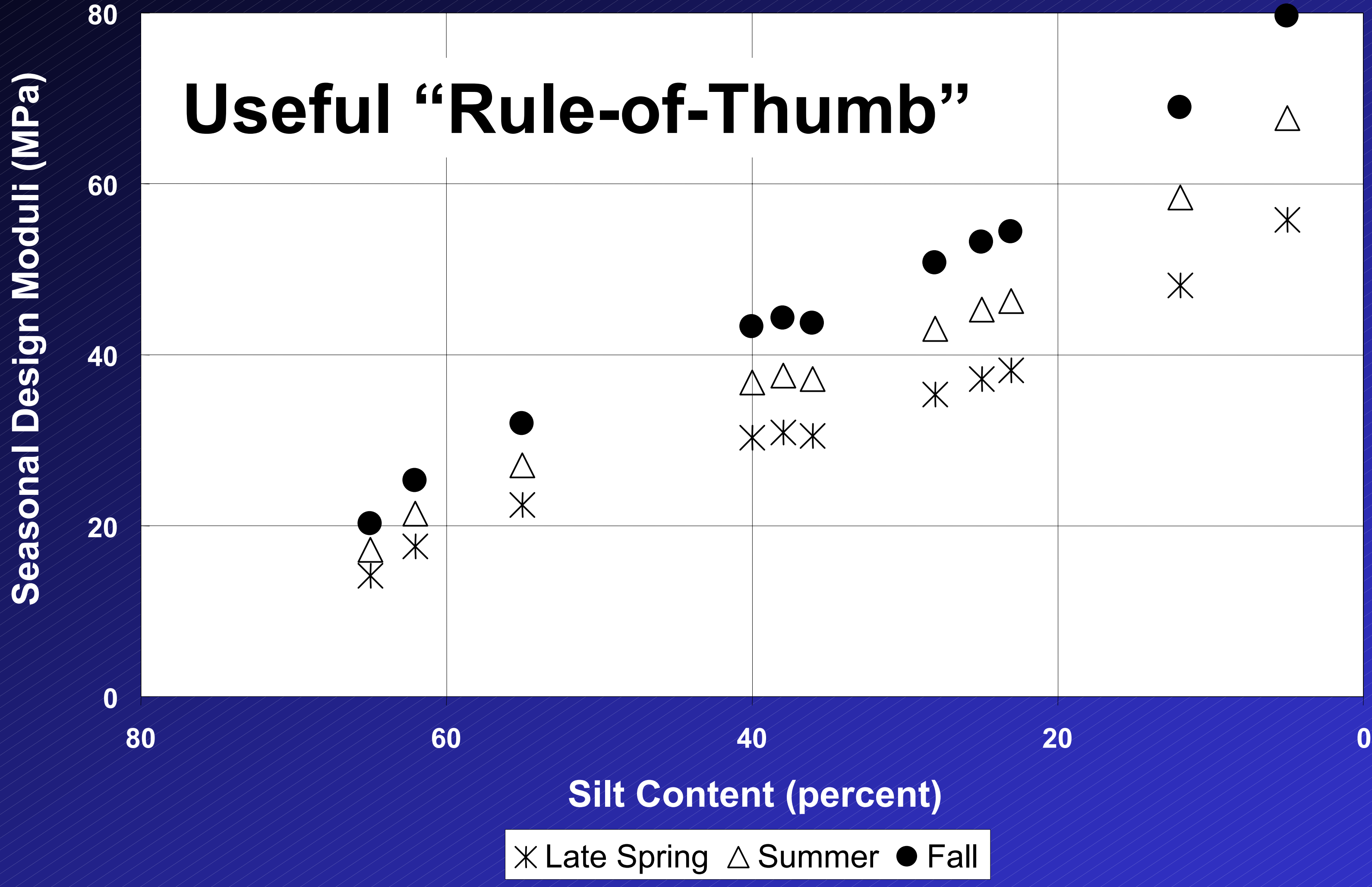
Seasonal Design Moduli vs Silt Content



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

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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).

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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

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