GeoGauge™ Lecture

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GeoGauge™

- Directly measures the in-situ or in-place stiffness.
- Manufactured by Humboldt Mfg. Co. in Norridge, Illinois U.S.A.
- U.S.A. and World Patent Pending
- GeoGauge is trademark of Humboldt Mfg. Co.

Why The GeoGauge?

- **To Meet A Need**
  - **Relentless Pursuit of Lower Cost & Higher Quality**
- **By Achieving A Goal**
  - **Increased Precision of Design & Construction**
    - **Mechanistic Designs**
    - **Performance Specifications**
    - **Process Control**
  - **Increased Continuity Between Design & Construction**
    - **Design Parameters Used to Evaluate Construction**
    - **Contractor Warranties**
- **Through A Historically Successful Path**
  - **Structural Stiffness & Material Modulus**
    - **Engineering / Mechanistic Values**

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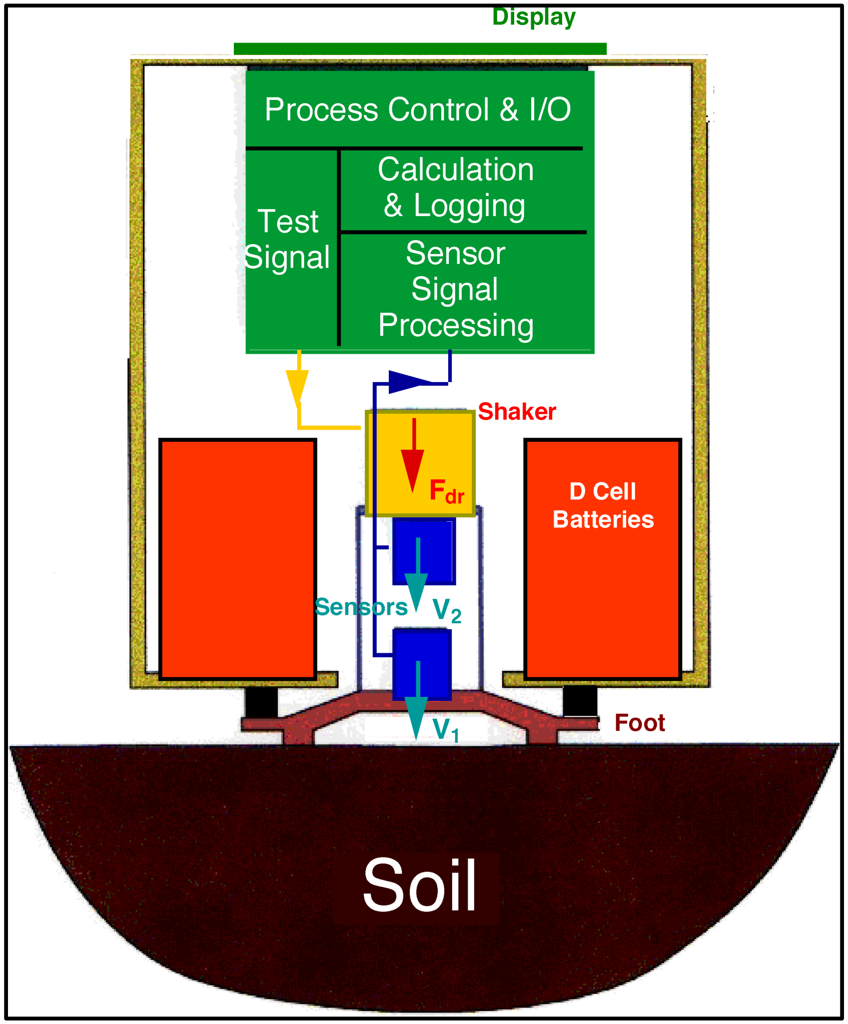
Physical Attributes

- **Size: 280mm diameter x 255mm tall**
- **114mm OD x 89mm ID Ring Foot**
- **Weight: 10 kg**
- **Powered by 6 D-Cell Batteries**
- **IR Data Downloading (Optional)**
- **Keypad User Interface**



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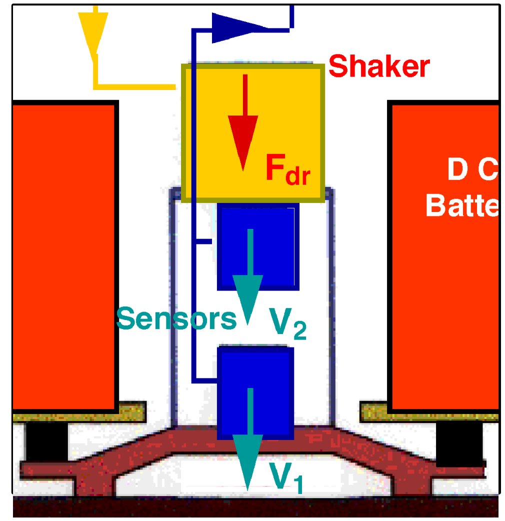
Operating Principle

Stiffness = *Resistance of a Layer or Structure to Deformation*

+ Foot Radius & Poisson's Ratio

Modulus = *Resistance of a Material to Deformation*



- **At GeoGauge Frequencies & Stress, Impedance is Predominately Stiffness**
- **No Need for a Non-Moving Displacement Reference**
- **Permits the Accurate Measurement of Small Displacements**

$$F_{dr} = K_{flex}\,(X_2 - X_1)$$

$$F_{dr} = K_{flex}(X_2 - X_1) + \text{ù}^2 m_{int} X_1$$

$$K_{gr} = \frac{F_{dr}}{X_1}$$

$$\overline{K_{gr}} = K_{flex} \frac{\sum_1^n \frac{(X_2 - X_1)}{X_1}}{n} = K_{flex} \frac{\sum_1^n \frac{(V_2 - V_1)}{V_1}}{n}$$

Measurement Procedure

- Inspect GeoGauge
- Power On
- Select Mode & Poisson's Ratio
- Seat the Foot
  - ≥ 60% Direct Contact
  - Moist Sand Assisted (3 to 6 mm thick)
    - Rough & Irregular Surfaces
    - Smooth Hard Surfaces
- Take the Measurement:
  - 75 Seconds (15 sec. Noise + 60 sec. Signal)
  - Results Displayed
    - Signal/Noise: ≥ 3/1 (10 db)
    - Standard Deviation: a Measure of Foot Contact
    - Average Stiffness or Modulus (English or SI)
- Examine the Foot Print
- Save Data

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Specification

- **Stiffness: 3 to >70 MN/m (17 to >399 klbf/in)**
- **Young's Modulus: 26 to >607 MPa (4 to >88 kpsi)**
- **Poisson's Ratio: 0.20 to 0.70 in 0.05 Increments**
- **Precision: Typically 3.9% Coefficient of Variation**
- **Bias: < 1% Coefficient of Variation**
- **Depth of Measurement: 220 to 310 mm**
- **Battery Life: > 1,500 measurements**
- **Operating Temperature: 0 to 38°C**

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Precision

Single Gauge

Date	Site	Material	Typical Stiffness, MN/m		Coeff. Of Var., %		
			Mean	1σ	Mean	65% Confidence	95% Confidence
8/16/96	Salisbury ByPass	Silty Sand	6.28	0.28	4.08	6.01	7.94
9/19/96	NM 44	Sandy Clay Subgrade*	11.33	0.37	3.31	-	-
10/12/96	16 Vegas Dr.	Sility Clay**	8.86	0.47	5.35	7.17	9.00
10/13/96	16 Vegas Dr.	Full Depth Pavement*	51.37	2.17	4.25	5.66	7.07
10/19/96	I70/I270	Graded GAB*	40.20	1.57	3.84	5.21	6.58
10/28/96	Rutters	Fat Clay*	12.74	0.35	2.67	3.13	3.59

* Assisted Seating (moist sand)
** Unprepared ground

- **Typical Coefficient Of Variation: 3.9%**
- **Basis: 3 Gauges, 3 Operators & 470 Measurements**

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Precision

Multiple Gauges

Date	Site	Material	No. of Measurements	Stiffness, MN/m		Coeff. of Var.
				Mean	1σ	%
11/6/96	16 Vegas Dr.	Sility Clay**	12	8.50	0.33	3.89
11/6/96	16 Vegas Dr.	Sility Clay**	30	9.94	0.39	3.91
11/7/96	16 Vegas Dr.	Full Depth Pavement*	16	44.83	1.72	3.83
11/23/96	16 Vegas Dr.	Sility Clay**	10	10.06	0.59	5.84

* Assisted Seating (moist sand)
** Unprepared ground

- **Statistics Based on Combined Measurements From Both Gauges**
- **Basis: 2 Gauges, 1 Operator & 68 Measurements**

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Bias

- **Reference: Moving Mass**
  - **Known Mass: 10 kg**
  - **25 Known Frequencies: 100 to 196 Hz**
  - **Stiffness = $-j\omega^2 M$**
- **Coefficient of variation: < 1%**

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Calibration Platen

- **Reference: Moving Mass, Platen of Certain Geometry**
  - **Known Mass: 10 kg**
  - **25 Known Frequencies: 100 to 196 Hz**
  - **Stiffness = $-j\omega^2 M$**
- **Coefficient of variation: < 1%**

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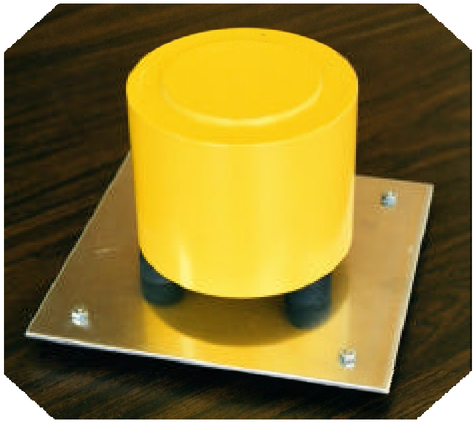
Verifier Mass



- Used whenever a check of GeoGauge operation is desired

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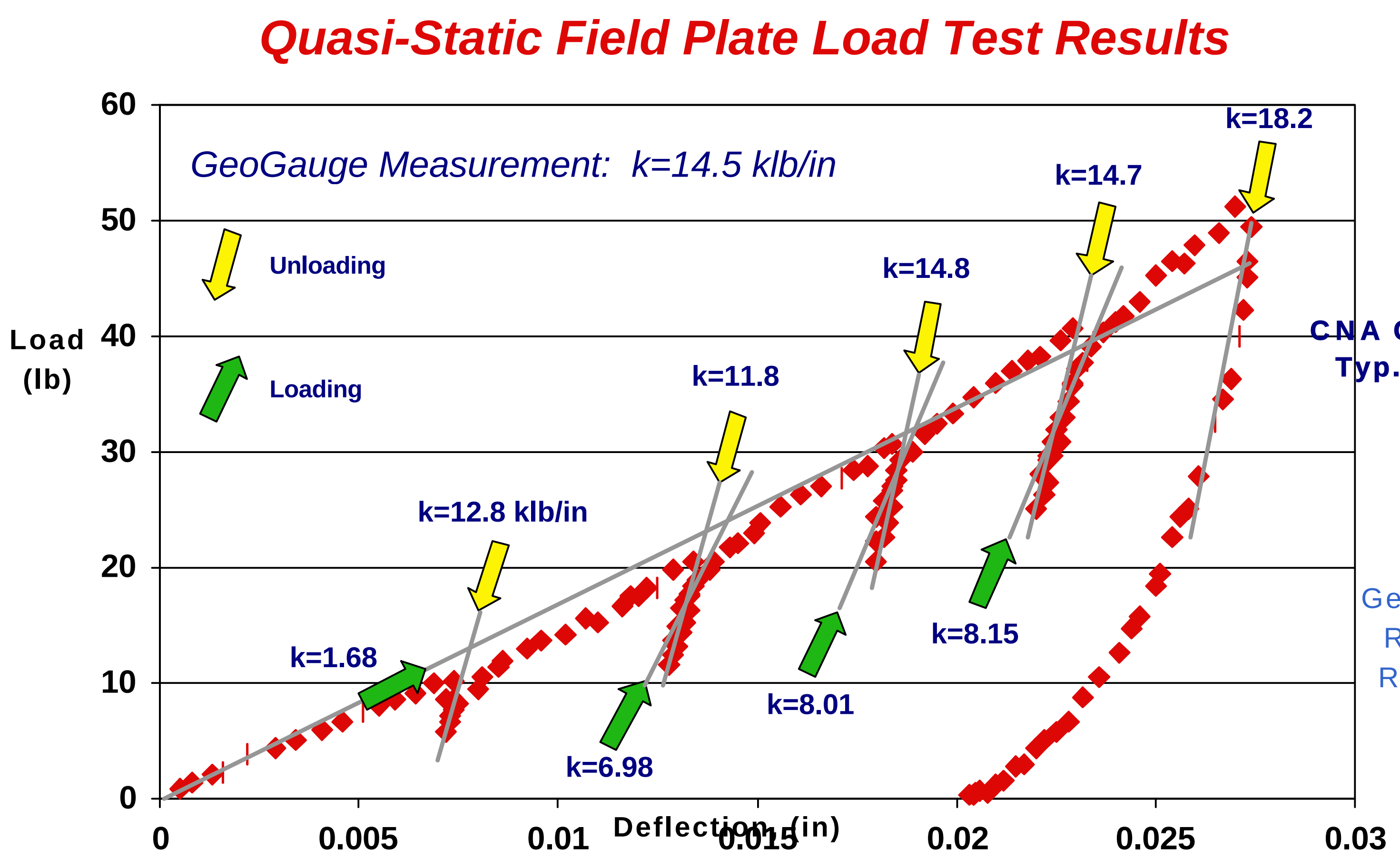
What is GeoGauge Stiffness ?



Performed by CNA Consulting Engineers Typ. of a Granular Base September, '99

GeoGauge Measures the Reaction of the Soil to Removing the Working Load

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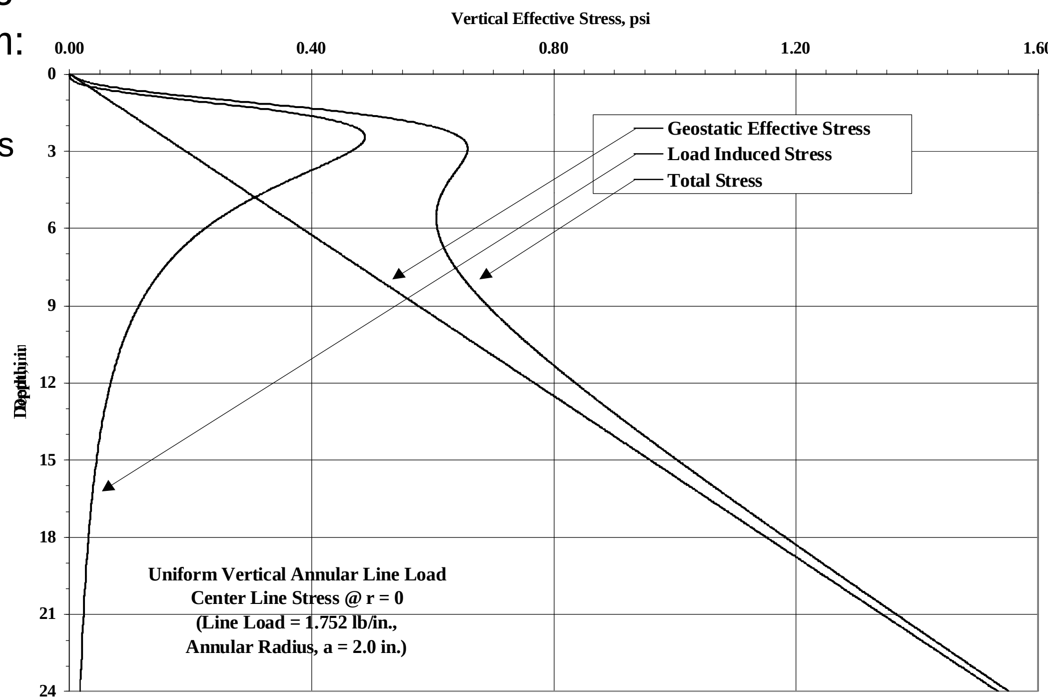
GeoGauge Stiffness: How To Confirm It?

University of New Mexico, ATR Institute

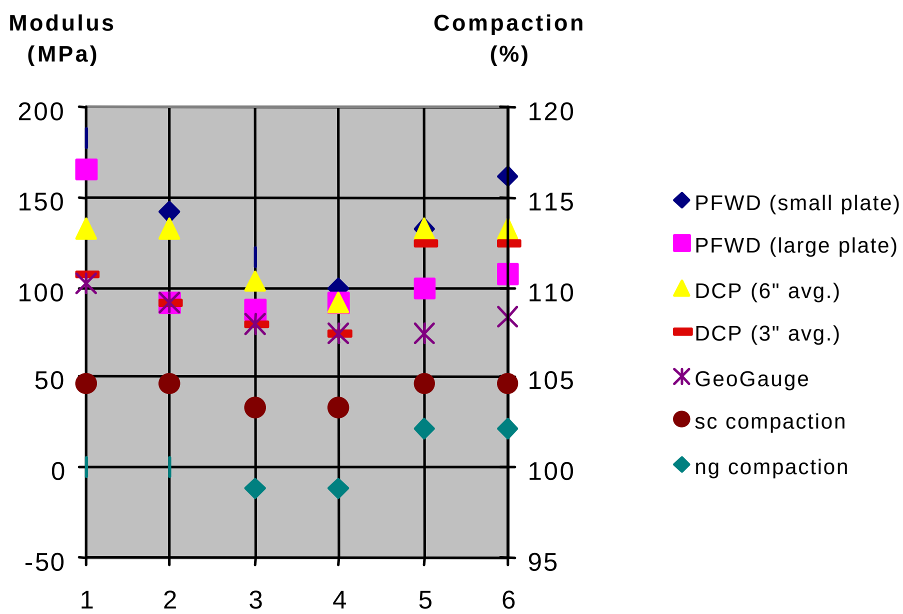
- Model Footing Precisely Constructed of Cohesionless Sand
- Measure Stiffness With GeoGauge
- Calculate 9' Layer Stiffness From:
  - Measured Void Ratio
  - Estimated Mean Effective Stress Under GeoGauge Foot
  - Estimated Poisson's Ratio
- Measured Stiffness Within 5% of Calculated Value
- GeoGauge Can Sense Boundaries Up to 12" From Its Foot
- To be Repeated on Silt, Clay & Layered Media

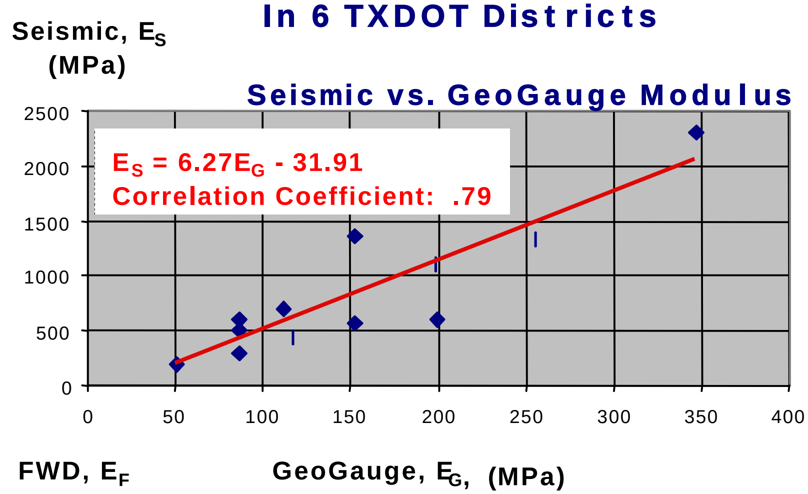


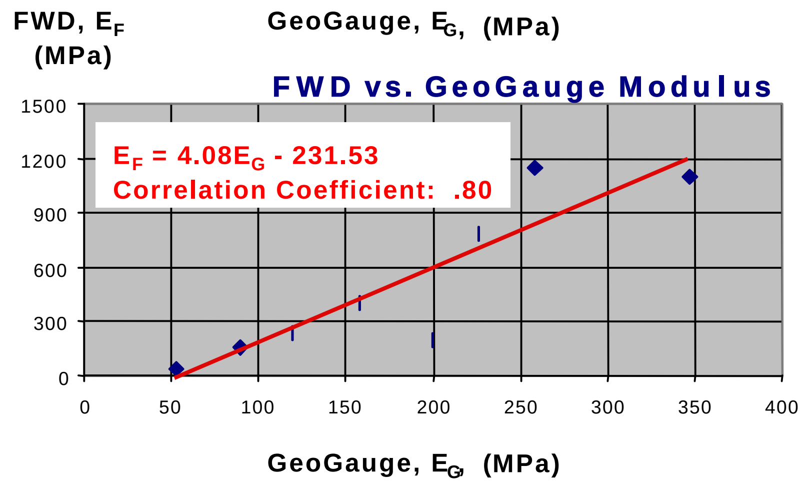
Correlation to Other Moduli

Subgrade & Base Materials
In 6 TXDOT Districts

Section 17, Mn / ROAD







13 Pavement Sections
at 5 MnDOT Sites

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Correlation to Dry Density

1

2

Calculate C From Regional Companion Measurements of Stiffness, Moisture Content & Dry Density

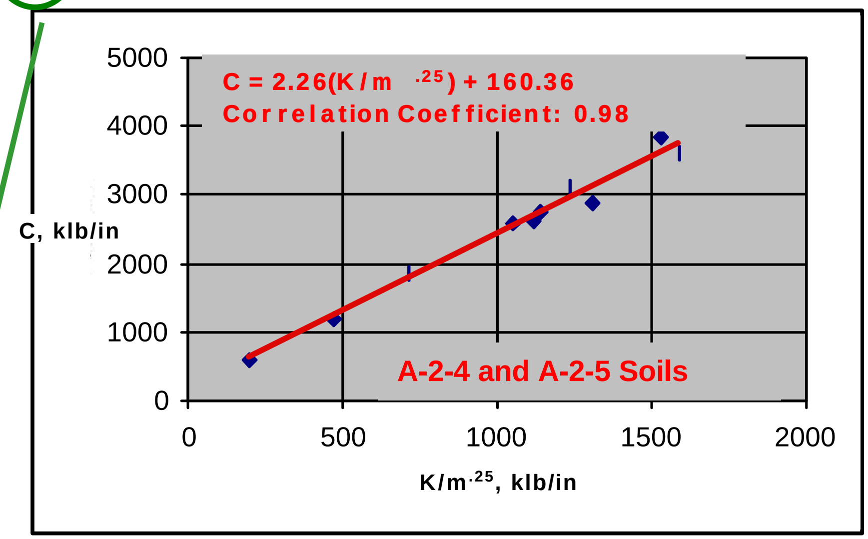
$$C = (K/m)\left\{\left[(\rho_0/\rho_D - 1)/1.2\right]^2 + 0.3\right\}$$

Analytical-Empirical Relationship

$$\frac{\rho_0}{1 + 1.2\left[\frac{mC}{K} - .3\right]^{.5}}$$

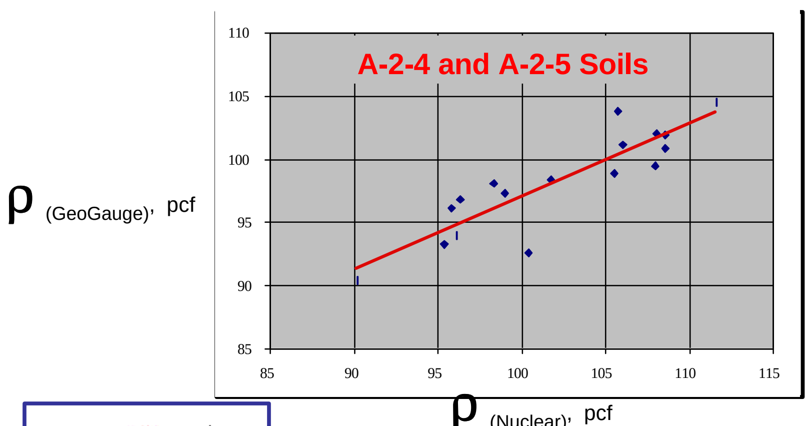
3

Define Several Linear Relationships Between C and K/m $^{.25}$ For Groups of Regional Soil Classes



4

Estimated Density Re Measured Density



From Measurements of Stiffness & Moisture Content And A Calculated C, Estimate Dry Density Using the Same Analytical-Empirical Relationship

$$\rho_{(GeoGauge.)} = 0.58(\rho_{(Nuc)}) + 39.39$$

Correlation Coefficient: 0.78

Data from MODOT, November, '99

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Other Correlations

- **Resilient Modulus**
- **Unconfined Compressive Strength**
- **California Bearing Ratio (CBR)**
- **Dynamic Cone Penetrometer (DCP)**
- **Static Cone Penetrometer**
- **Plate Load**

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GeoGauge Alternatives

Method *	
In-Place Stiffness or Modulus	Sp

*Production Test: One that does not delay or interfere with construction

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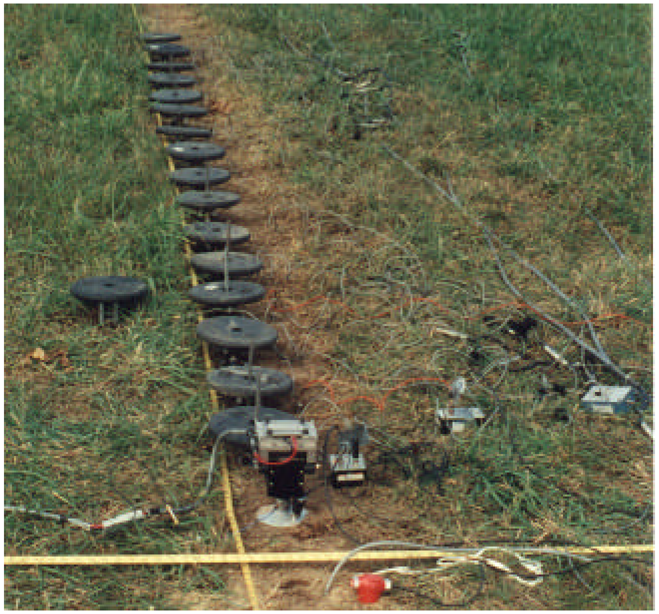
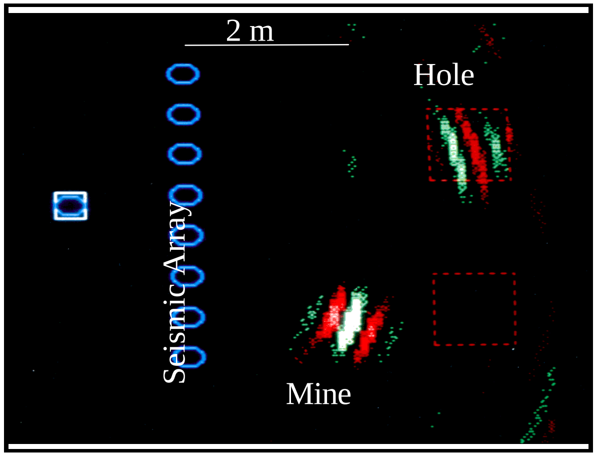
Development: BBN Shallow Soil Seismic/Acoustic Research

- **Soil Physics & Measurements**
  - **Soil Impedance**
  - **Wave Propagation**
- **Transducer Coupling Research**
- **System Development & Displays**



BBN Proprietary Weight-biased Geophones and Compact Vibrator Source



Seismic Sonar Display of Response of Mine

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Design Validation

- **Alpha**
  - **Field Trials: MN, NY & TX**
  - **Construction Noise: Freq. Shift & Improved Filtering**
  - **Calibration: Soil vs. Elastomer vs. Mass**
  - **Relationship Between Density & Modulus**
- **Beta**
  - **Field Trials: MN, TX, NC, FL, OH, CA, NJ & MO**
  - **Usability & Reliability**
  - **Manufacturing & Test Methods Development**
  - **Establish Precision & Bias**
- **Standards Development**
  - **ASTM**
  - **AASHTO**

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Benefits of Stiffness & Modulus Today

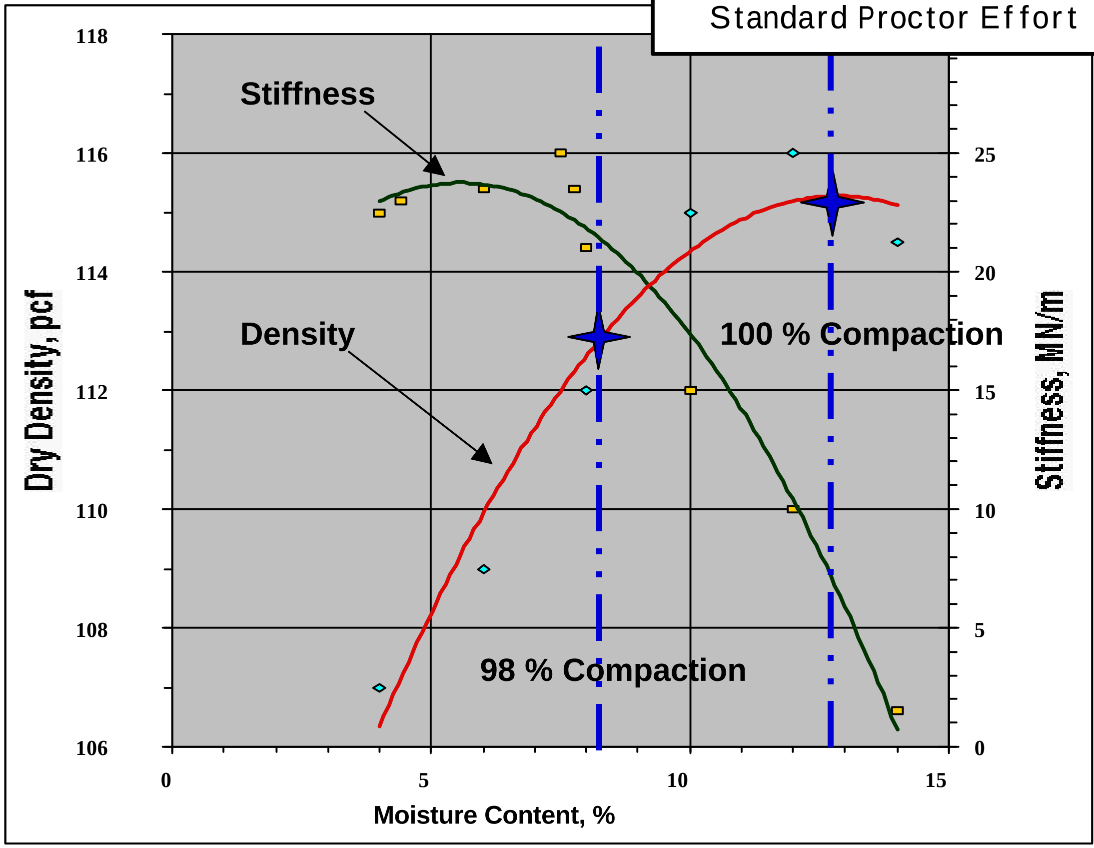
- Control of Compaction
- Mitigating the Risk of Pavement Failure
- Control of Stabilized Fill Quality

Control of Compaction Quality

Density or Stiffness

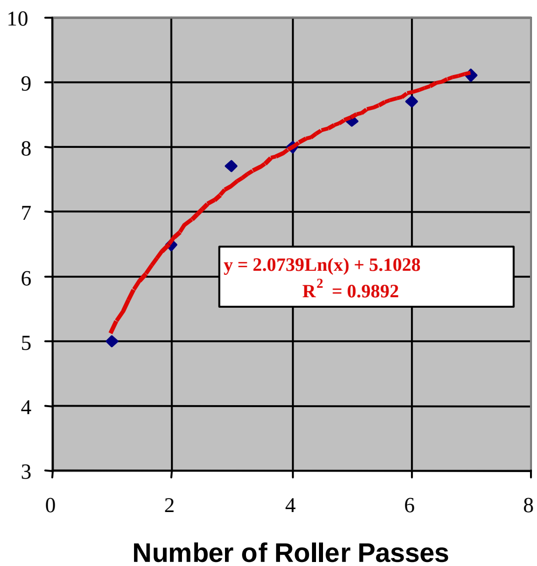
- Job by Job / Material by Material Evaluation
- Stiffness added to Proctor or Proctor Like Testing
- Empirical Relationship vs. Moisture Determined
  - "Unique" Stiffness of each Moisture & Density Pair
- Stiffness Lab / Test Strip Correction (Proctor Mold)
- Conditions for Using Stiffness
  - Lift Thickness: $\geq$ 8"
  - Awareness of Variability from Lift Support

Univ. of NM, ATR Inst.
Silty Sand
Unified SM
AASHTO A-2-4
Standard Proctor Effort



Control of the Compaction Process

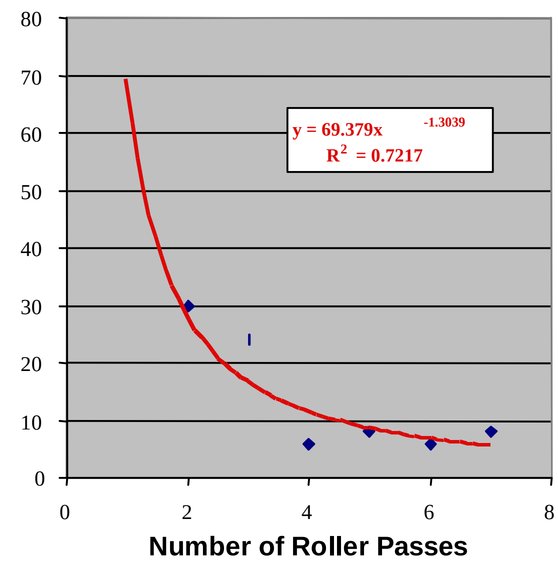
- Compaction of A Layer Is Only As Good As the Supporting Material Will Allow
- Directly Measure Compaction (Rate of Increase in Stiffness) As a Function of Effort
- When the Rate Is Approx. Constant, the Compaction Is Optimized
- ~ 30% Reduction inCompactive Effort Possible



Compaction of 2” of HMA

Mangum Asphalt, Inc.

June, 2000



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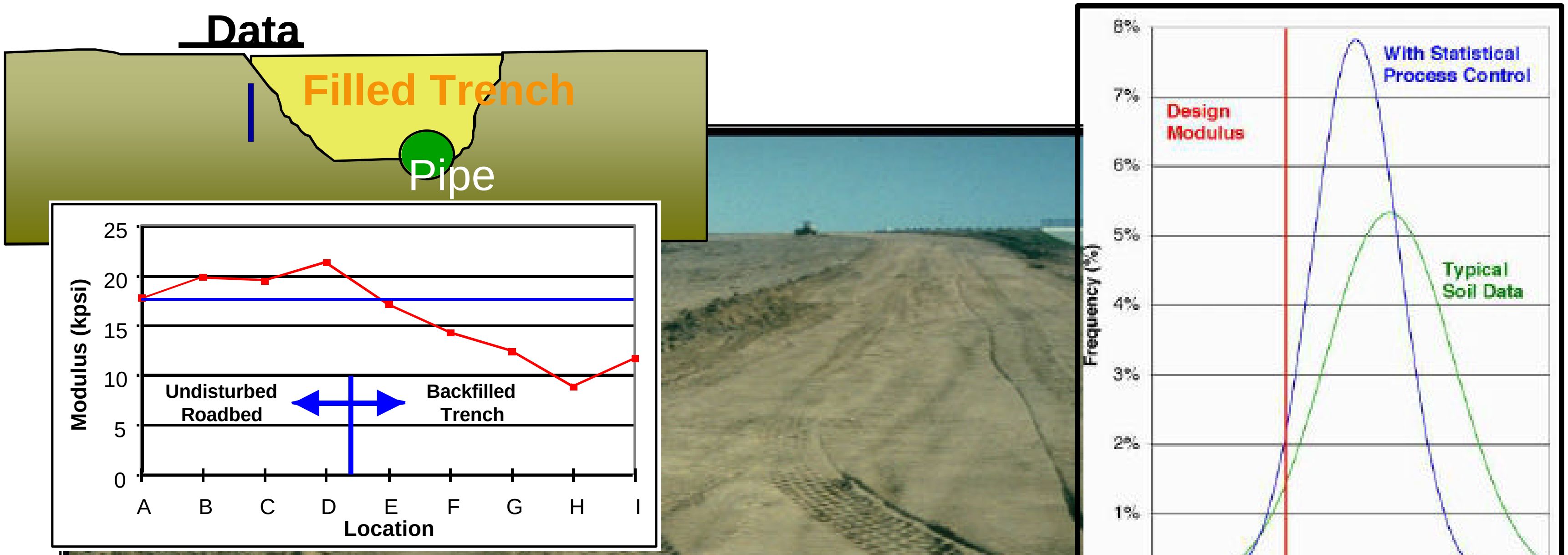
Optimum Compaction With Minimum Effort

Mitigating the Risk of Pavement Failure

More Uniform Stiffness = More Time Between Failures



- Sharp Stiffness Changes = Near Term Failures
- Experience Is Indicating:
  - ± 50% Stiffness Tolerance, Fewer Near Term Failures
  - ± 25% Stiffness Tolerance, Fewer Long Term Failures

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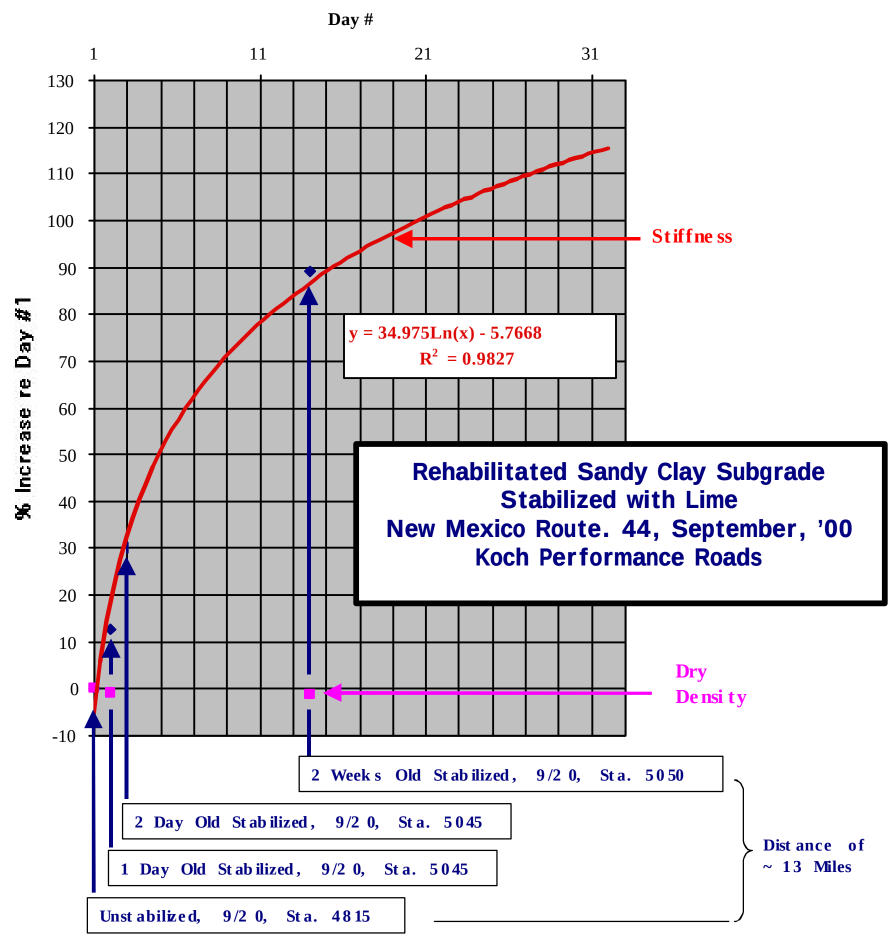
Control of Stabilized Fill Quality

- **"Is the Fill Hard Enough?"**
- **"Has Rain Inhibited Stabilization?"**
- **"Can I Customize Stabilization?"**
- **GeoGauge Can Enable:**
  - **Monitoring of Material Cure Rate**
  - **Direct Measurement of Material Modulus**
  - **Laboratory Design of Custom Mixes & Determination of Indexes for Evaluating Construction**
- **GeoGauge Specified By USAF for Runway Infield Stabilization**
  - **Used to Estimate Increases in CBR**

Evaluation of Stabilization



Other Applications

- **Specification Development**
- **Mechanistic Design Validation**
- **Buried Structures QC**
- **Utility Back-Fills QC**
- **Determination of HMA “Tender Zone”**
- **Evaluation of Controlled Low Strength Materials**
- **Quantification of Soil-Cement Micro-Cracking**
- **Cold Mix Asphalt QC**

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