

# **INTELLIGENT COMPACTION: AN OVERVIEW**

**By**

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# ACKNOWLEDGEMENTS

- Chris Dumas, FHWA
- Hans Kloubert, BOMAG
- Roland Anderegg, AMMANN

**1 MPa = 150 psi**

**10 kN = 1 ton**

**25 mm = 1 inch**

# **INTELLIGENT COMPACTION: AN OVERVIEW**

**Current practice**

**Future practice**

**Modulus and dry density**

**Compactions methods**

**Intelligent Compaction**

**Principle**

**Equipment and instrumentation**

**How to get the stiffness**

**How to get the modulus**

**Specs**

**Future needs**

# CURRENT PRACTICE

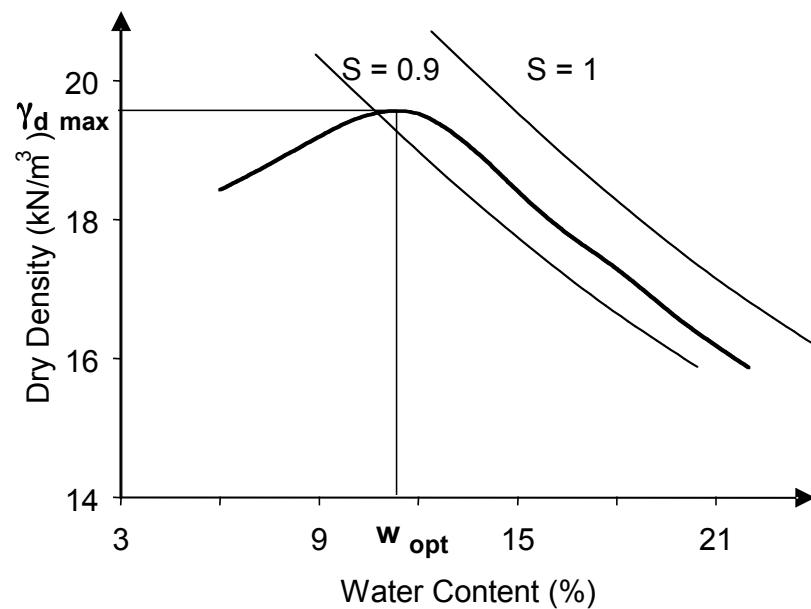
## Based on Density

- LAB: Proctor test to get dry density vs. water content curve
- SPEC: x% of  $\gamma_d$  max within range of  $w_{opt}$
- FIELD: Compact and check that  $\gamma_d$  and w meet the specs

# CURRENT PRACTICE

## Based on Density

- LAB : Proctor Test



# CURRENT PRACTICE

## Based on Density

- SPECIFICATIONS.

X % of  $\gamma_d$  max within range of  $w_{opt}$

- FIELD



# **Dry Density: Advantages and Disadvantages**

## **1. Advantages**

**Accumulated knowledge**

**Well defined parameter**

**Indication of solids per unit volume**

## **2. Disadvantages**

**Not related to design**

**Not very sensitive**

**Not easy to measure quickly in field**

# FUTURE PRACTICE

## Based on Modulus

- LAB: Modulus test to get modulus vs. water content curve
- SPEC:  $x\%$  of  $E_{max}$   
within range of  $w_{opt}$
- FIELD: Intelligent compaction and check  
that  $E_{max}$  and  $w$  meet the specs

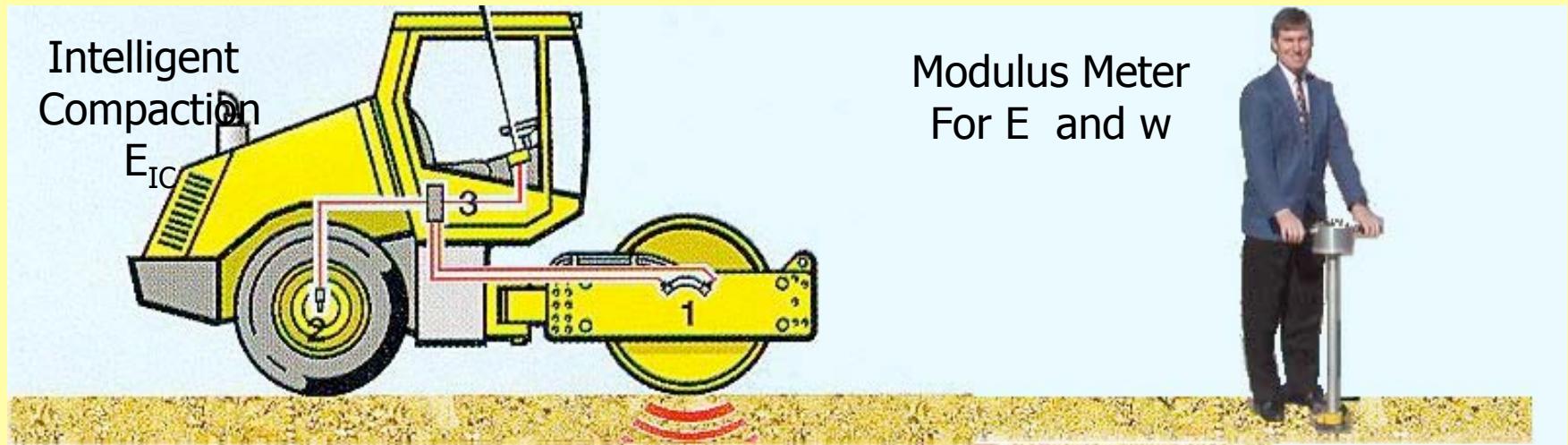
# FUTURE PRACTICE

## Based on Modulus

- SPECIFICATIONS

$X\% \text{ of } E_{\max}$  within range of  $w_{\text{opt}}$

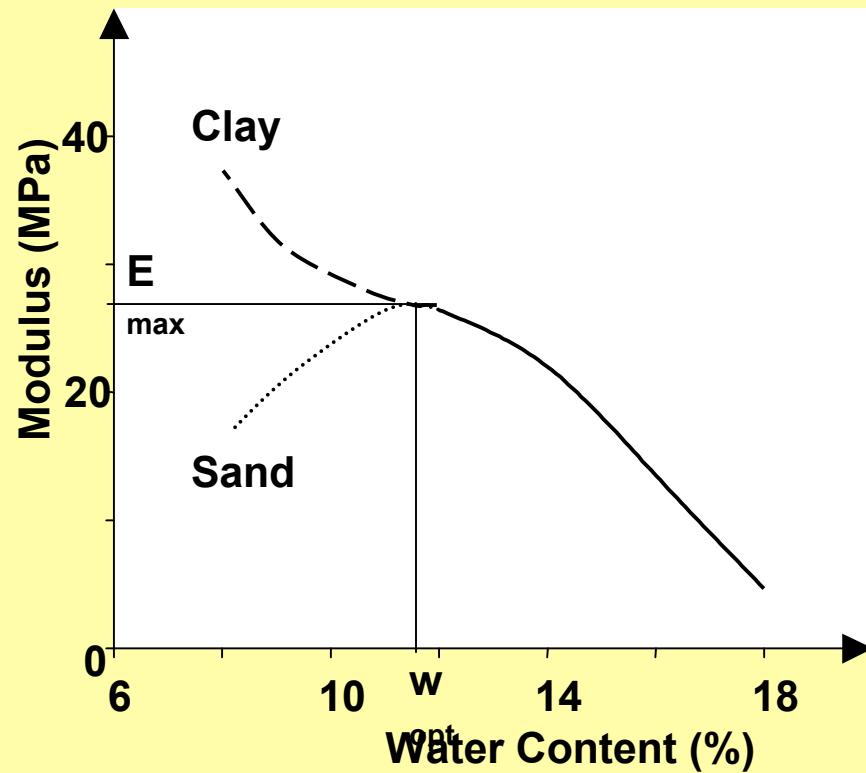
- FIELD



# FUTURE PRACTICE

## Based on Modulus

- LAB : Modulus Test



# **Modulus: Advantages and Disadvantages**

## **1. Advantages**

**Directly related to design**

**Very sensitive to water content**

**Easy to measure quickly in field**

## **2. Disadvantages**

**Many influencing factors**

**No lab test to get E vs. w**

**No target values**

**New concept**

# **Which Modulus?**

## **DEFINITION**

**Initial**

**Secant**

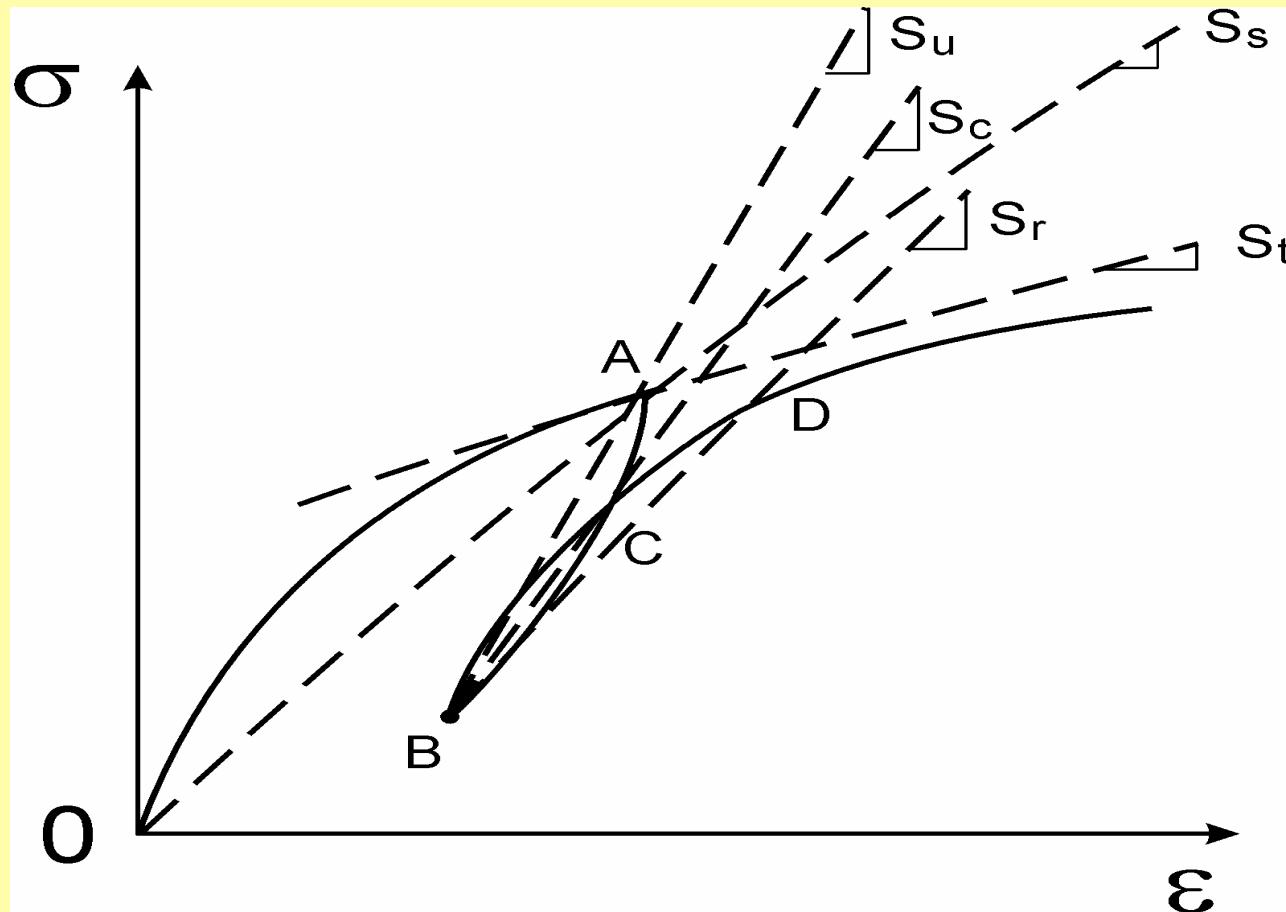
**Tangent**

**Unload-Resilient**

**Cyclic**

**Reload**

# Which Modulus?



# **Which Modulus?**

## **STATE FACTORS**

**Density**

**Structure**

**Water content**

**Stress history**

**Cementation**

# **Which Modulus?**

## **LOADING FACTORS**

**Stress level**

**Strain level**

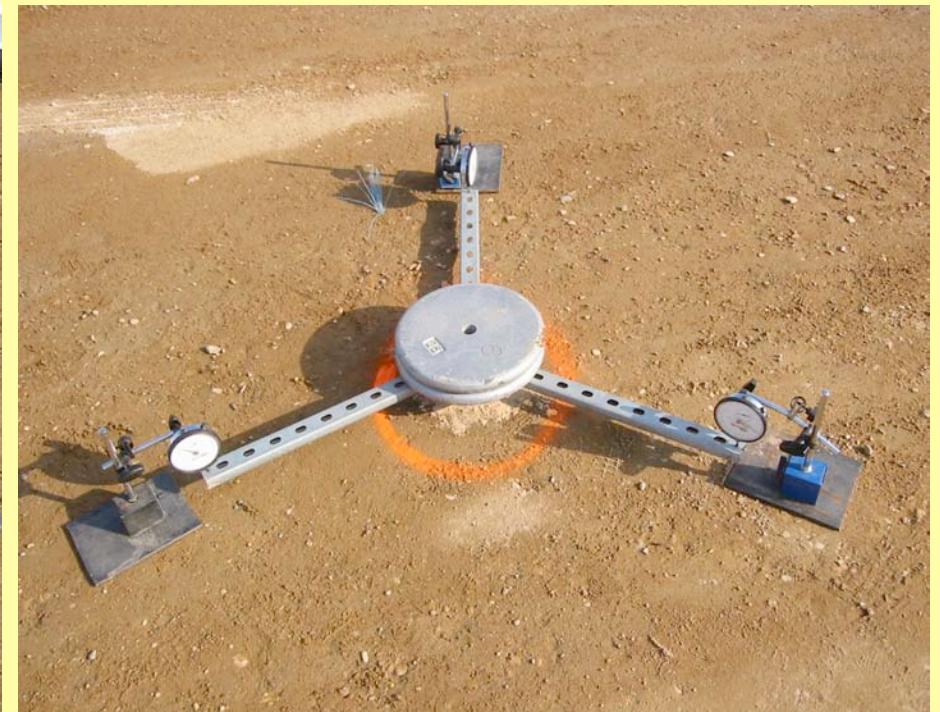
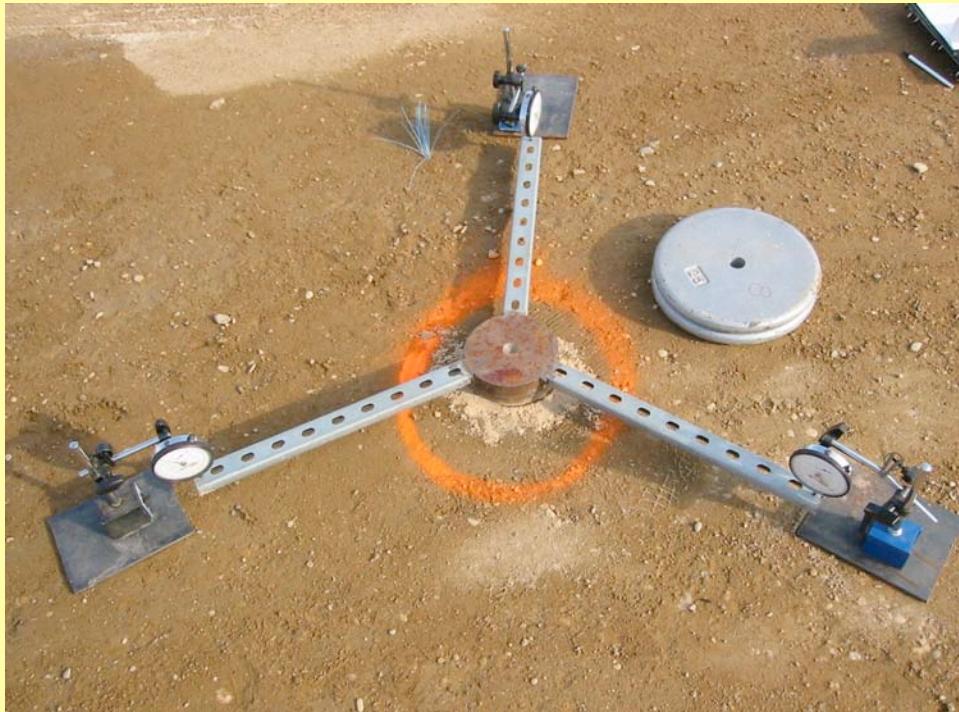
**Strain rate**

**Number of cycles**

**Drainage**

# Which Modulus?

## PLATE MODULUS in FIELD

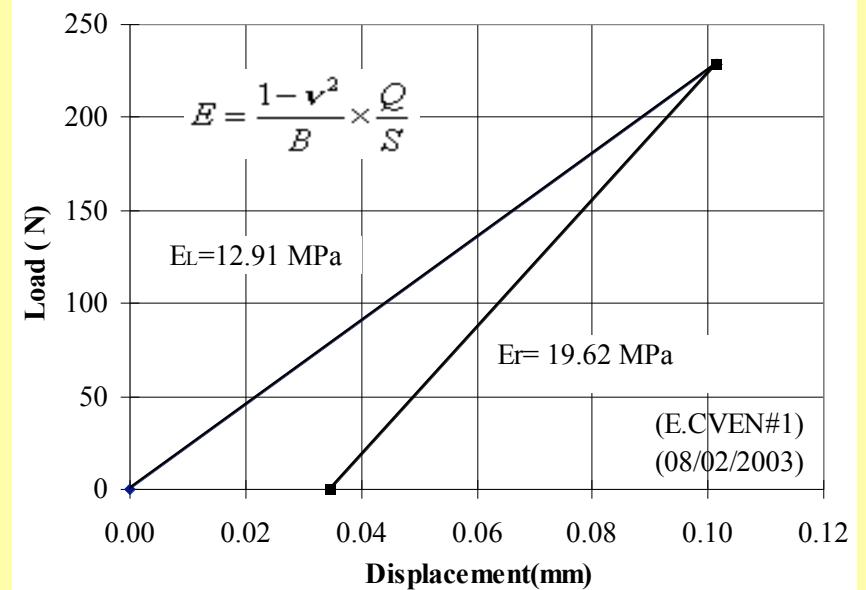


**BPT: Briaud Plate Test**

**J-L Briaud, Texas A&M University**

# Which Modulus?

## PLATE MODULUS in LAB



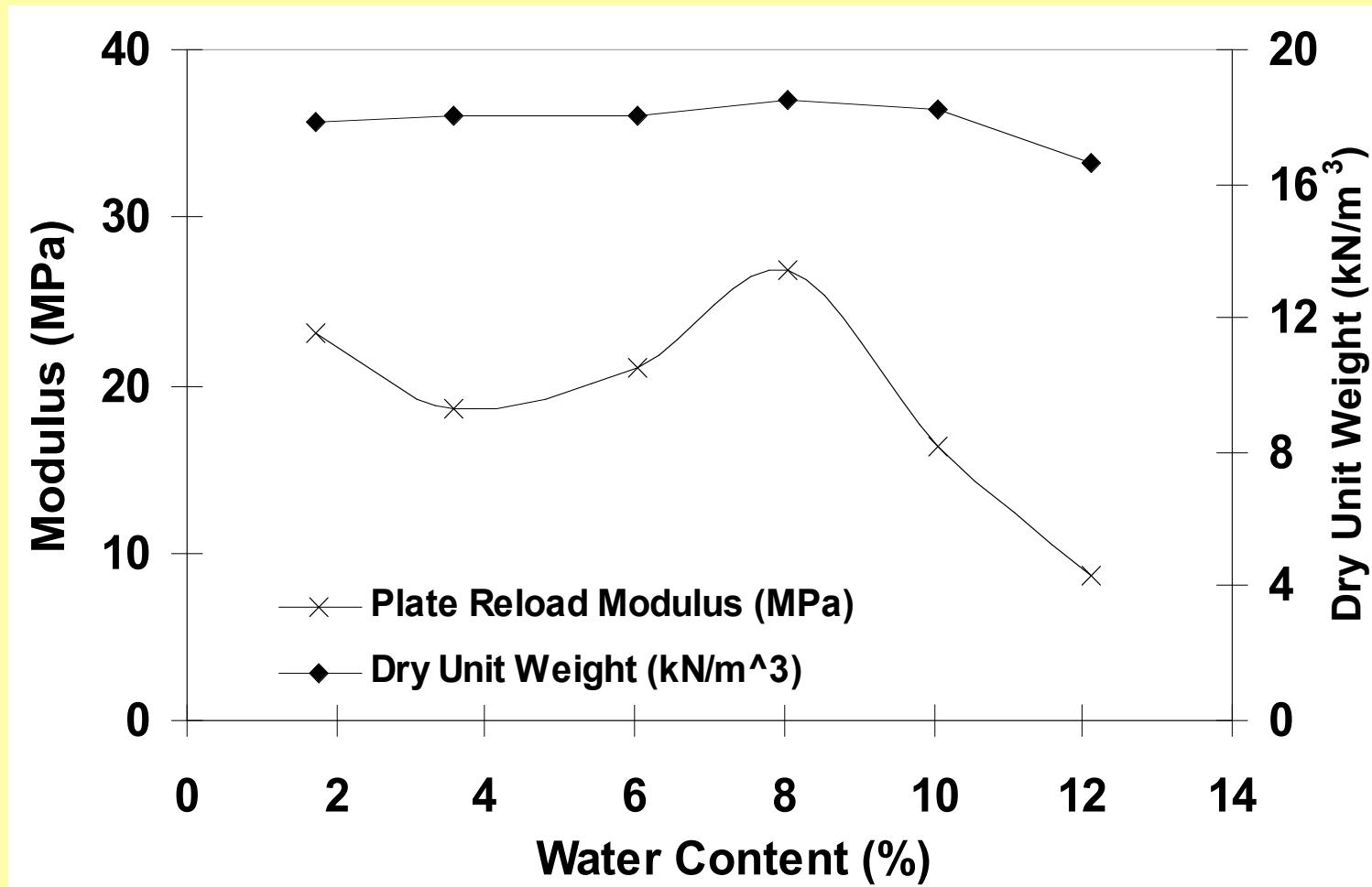
BPT: Briaud Plate Test

J-L Briaud, Texas A&M University

# **Range of Modulus**

<b>Steel:</b>	<b>200,000 MPa</b>
<b>Concrete:</b>	<b>20,000 MPa</b>
<b>Wood, Plastic:</b>	<b>13,000 MPa</b>
<b>Rock:</b>	<b>2,000 to 30,000 MPa</b>
<b>Asphalt:</b>	<b>150 to 25000 MPa</b>
<b>Soil:</b>	<b>5 MPa to 1000 MPa</b>
<b>Mayonnaise:</b>	<b>0.5 MPa</b>

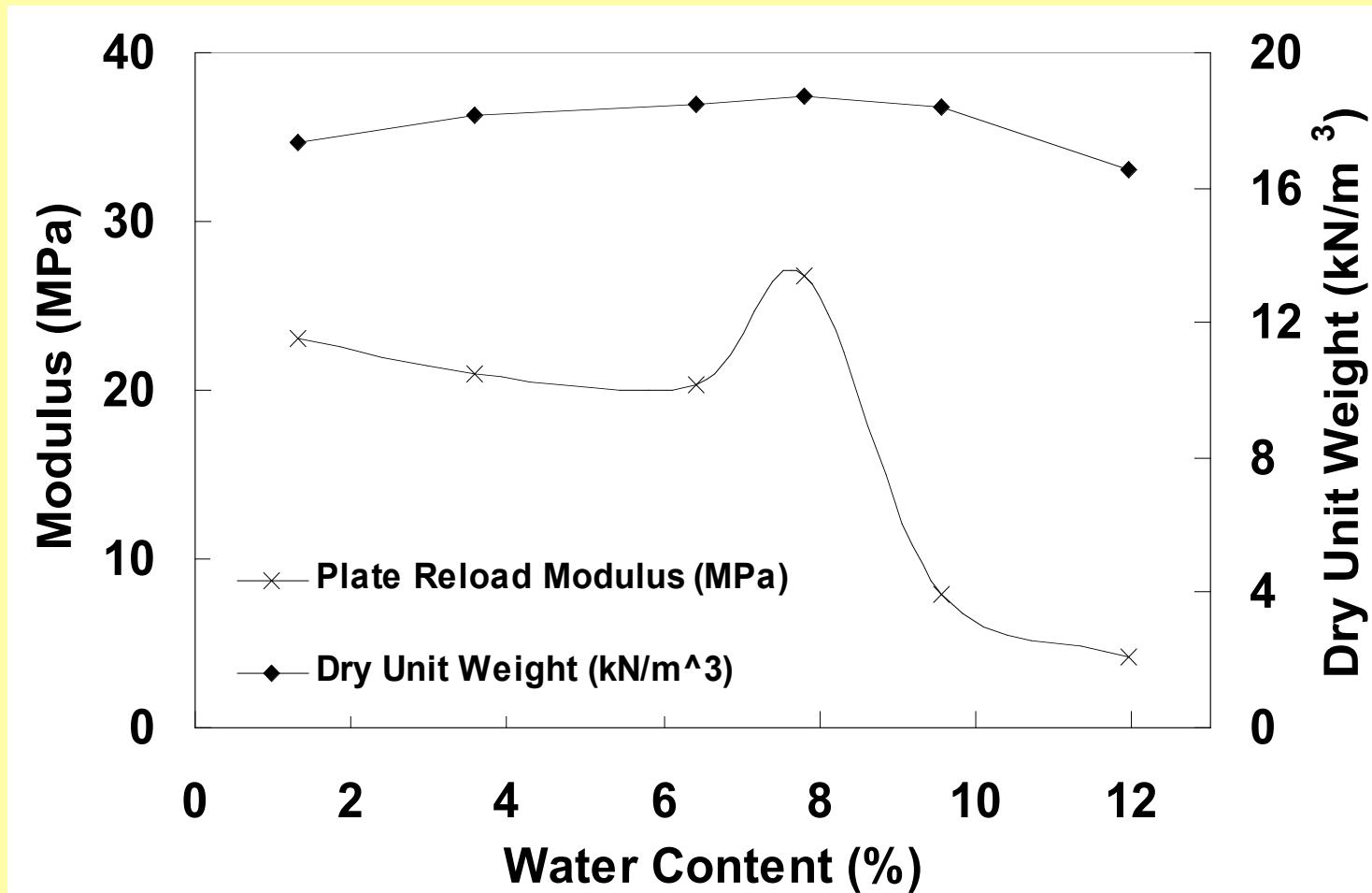
# NGES Silty Sand (Mold #5)



Modulus measured with BPT: Briaud Plate Test

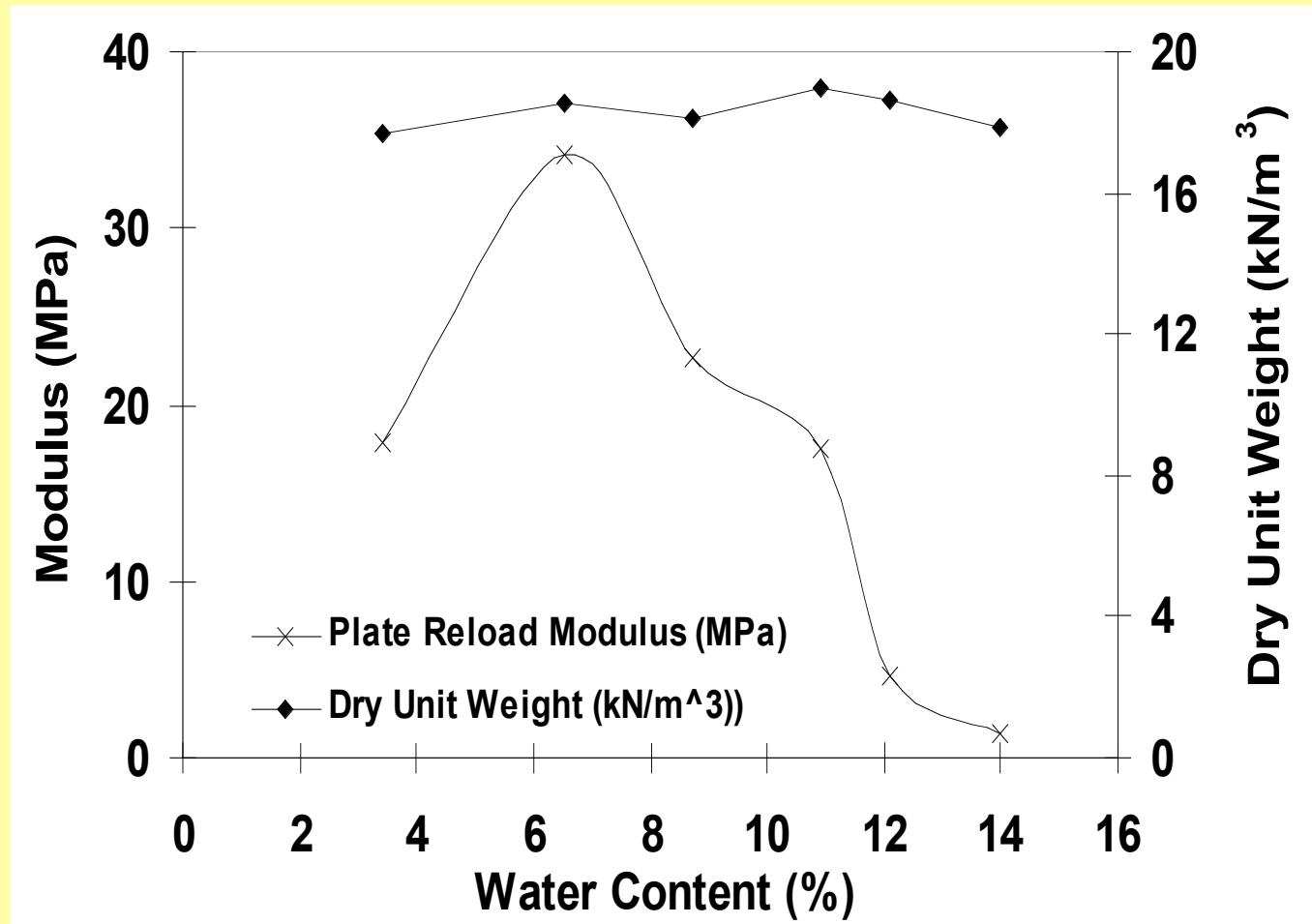
J-L Briaud, Texas A&M University

# NGES Silty Sand (Mold #6)



Modulus measured with BPT: Briaud Plate Test

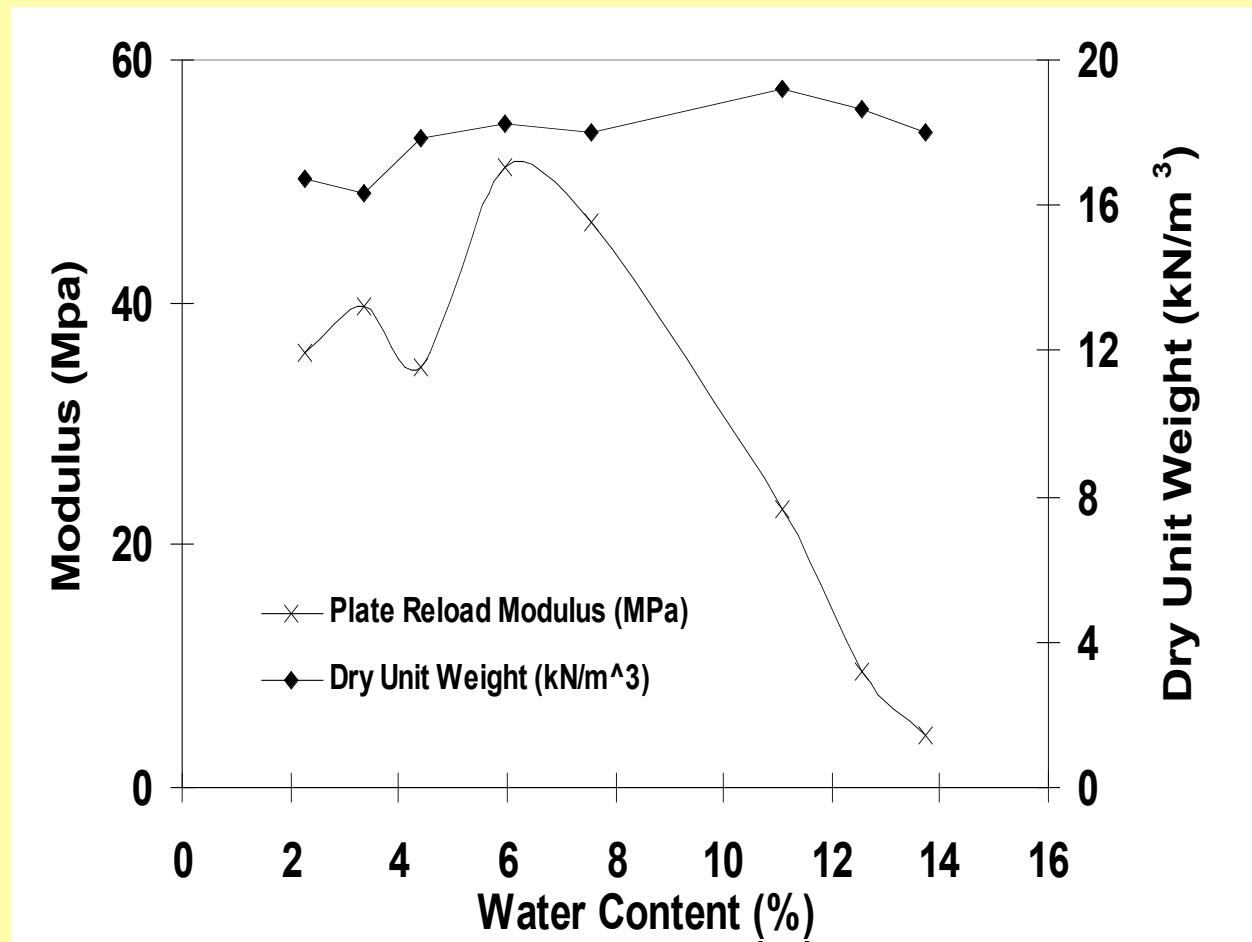
# NGES Sand + Porcelain Clay (Mold #5)



Modulus measured with BPT: Briaud Plate Test

J-L Briaud, Texas A&M University

# NGES Sand + Porcelain Clay



Modulus measured with BPT: Briaud Plate Test

1. Density?
2. Modulus?
3. Water Content?

- Only one of those three is not enough
- Two of those three are sufficient
- All three would be nice

# Three Compaction Control Methods

- Conventional Compaction
- Continuous Control Compaction
- Intelligent Compaction

# Conventional Compaction

(static or vibratory smooth drum  
or sheep-foot)



J-L Briaud, Texas A&M University

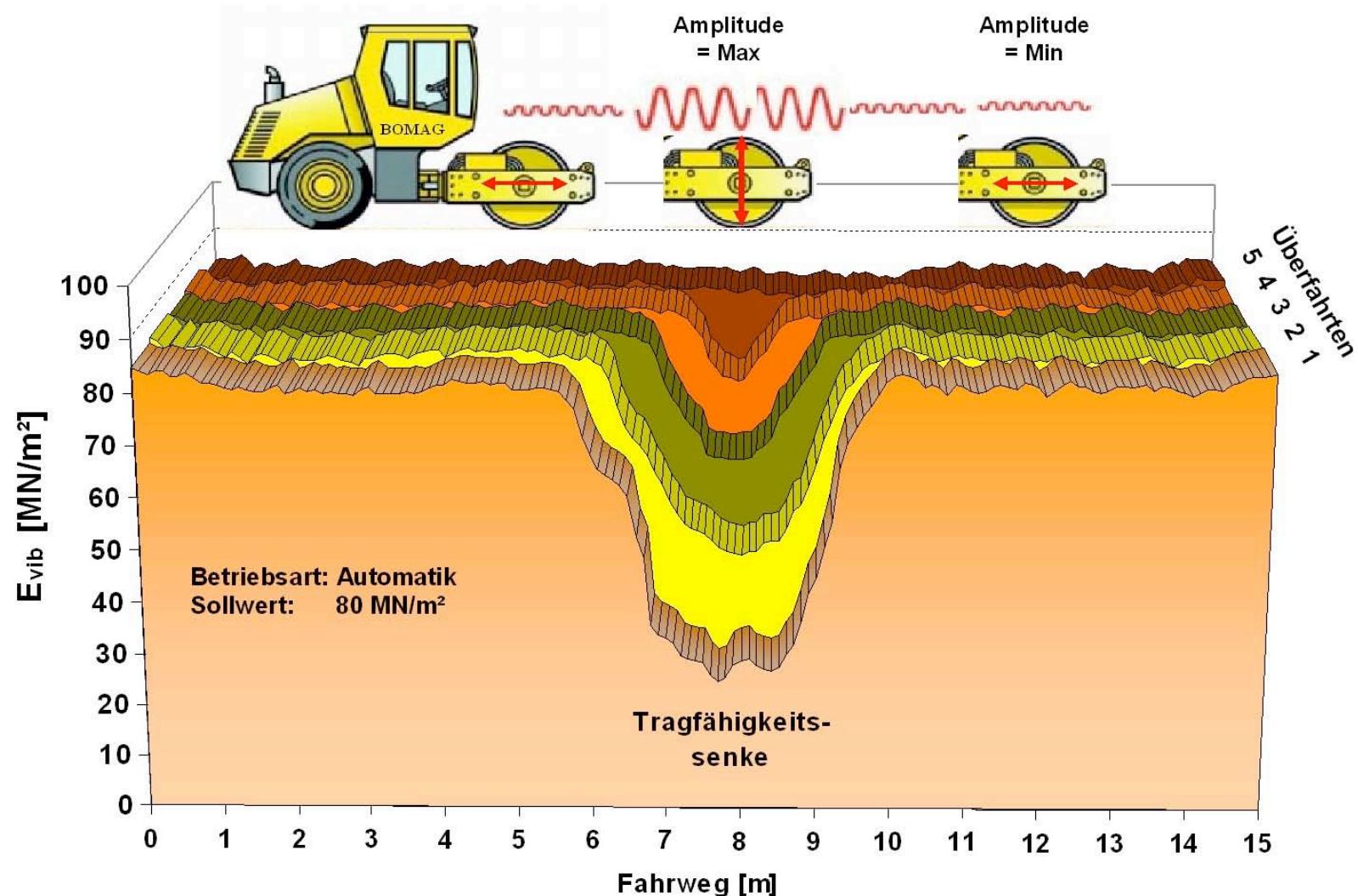
# Continuous Vibratory Compaction Control

- Instrumented vibrating rollers
- Measure roller accel. as a function of time
- Calculate a soil stiffness or modulus
- Modulus is compared to target value (specs)
- The modulus value tells the operator if the specified compaction level is reached

# Intelligent Vibratory Compaction

- Instrumented vibrating rollers
- Measure roller accel. as a function of time
- Calculate a soil modulus
- Intelligent roller modifies automatically and instantaneously settings (force, ampl., freq.) to meet the target modulus

## Recompaction of soft formation area with VARIOCONTROL automatic mode, presetting ( target value ) $E_{VIB} = 80 \text{ MN/m}^2$



**BOMAG**

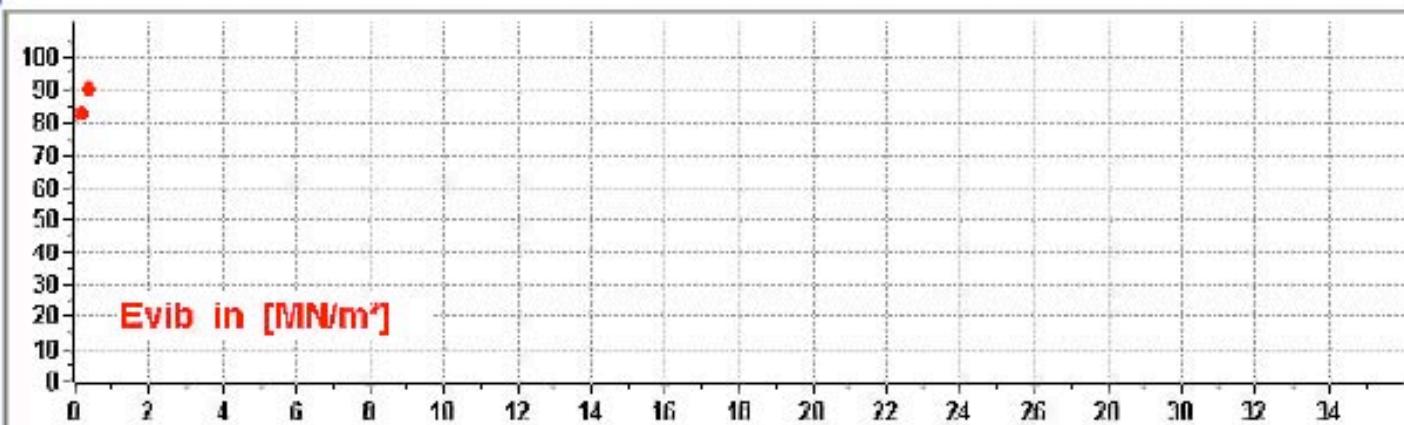
Dynamischer Steifigkeitsmodul "Evib"  
als flächendeckende Verdichtungskontrolle beim Fahren



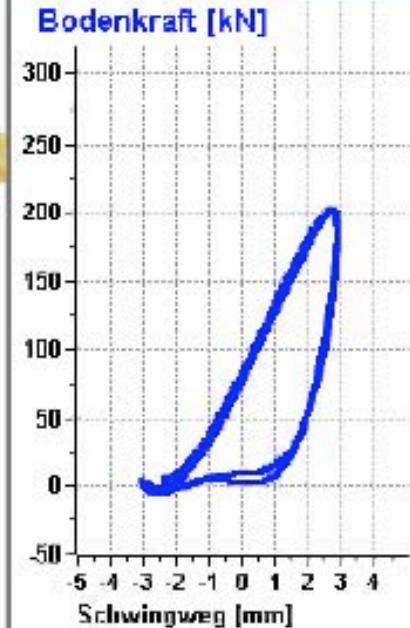
Amplitude [mm]

Evib [MN/m<sup>2</sup>]

Frequenz [Hz]



Indikatordiagramm



## Intelligent Compaction

**AMMANN**



**ACE**  
Ammann  
Compaction  
Expert



### Intelligent Compaction Tests in the U.S.A.

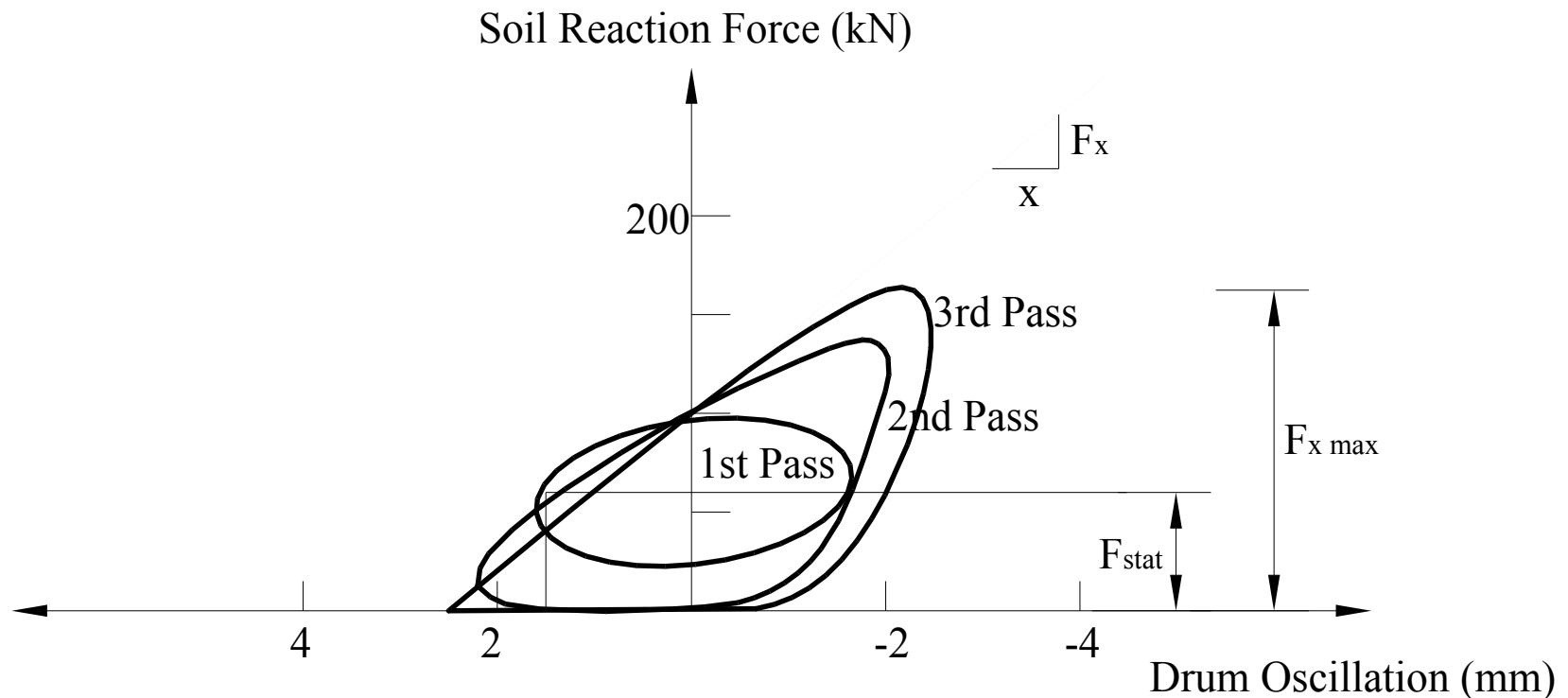


**ACE**  
Ammann  
Compaction  
Expert





# Force-Displacement Curves



From BOMAG

J-L Briaud, Texas A&M University

$\ddot{x}_d$ 

# From Acceleration to Stiffness

$$F_B \cong -m_d \ddot{x}_d + m_u r_u \Omega^2 \cos(\Omega t) + (m_f + m_d)g$$

$$F_B \cong k_B x_d + d_B \dot{x}_d$$

$F_B$ : soil-drum-interaction-force

$x_d$ : vert. disp. of drum (m)

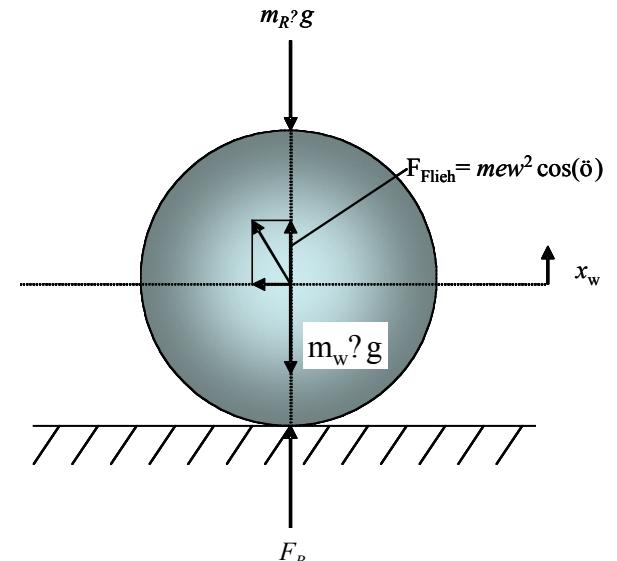
$m_f$ : mass of the frame (kg)

$r_u$ : radial distance for  $m_u$

$g$ : acc. due to gravity ( $\text{m/sec}^2$ )

$\dot{x}_d$ : velocity of drum

$d_B$ : damping coefficient ( $d_B \sim 0.2$ )



$m_d$ : mass of the drum (kg)

$\ddot{x}_d$ : acceleration of drum

$m_u$ : unbalanced mass (kg)

$\Omega = 2\pi f$

$f$ : frequency of rotating shaft (Hz)

$k_B$ : stiffness of soil

# Stiffness or Modulus?

$K = F/x$       in MN/m

$E \sim \sigma/\epsilon$       in MN/m<sup>2</sup> or MPa

$E = \alpha F/Bx$

$K = F/x = EB/\alpha$

# Stiffness or Modulus?

Stiffness depends on the size of the roller.

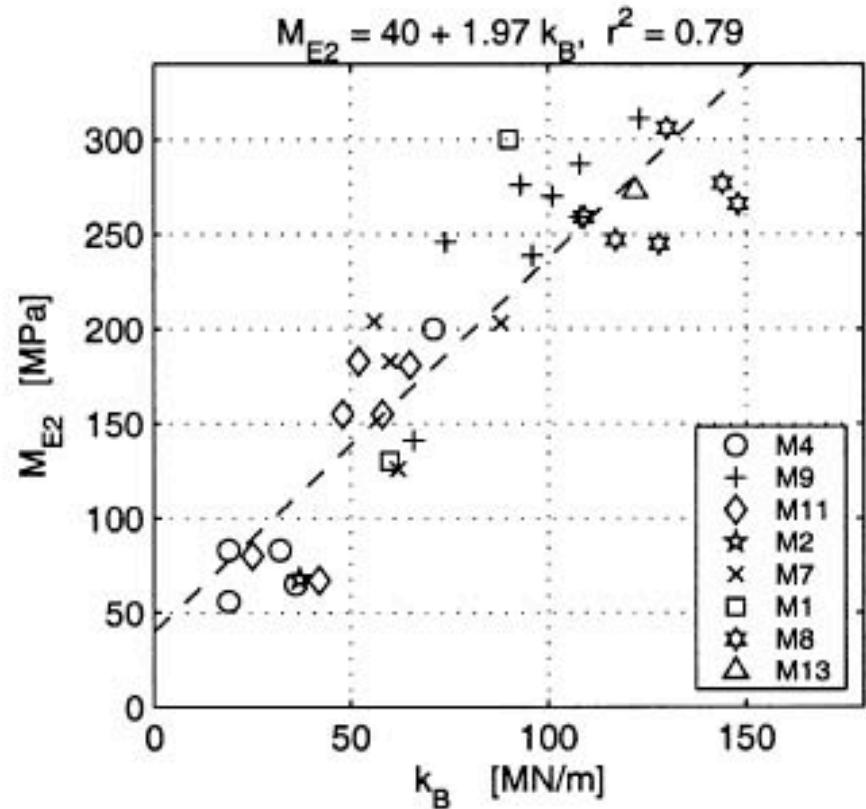
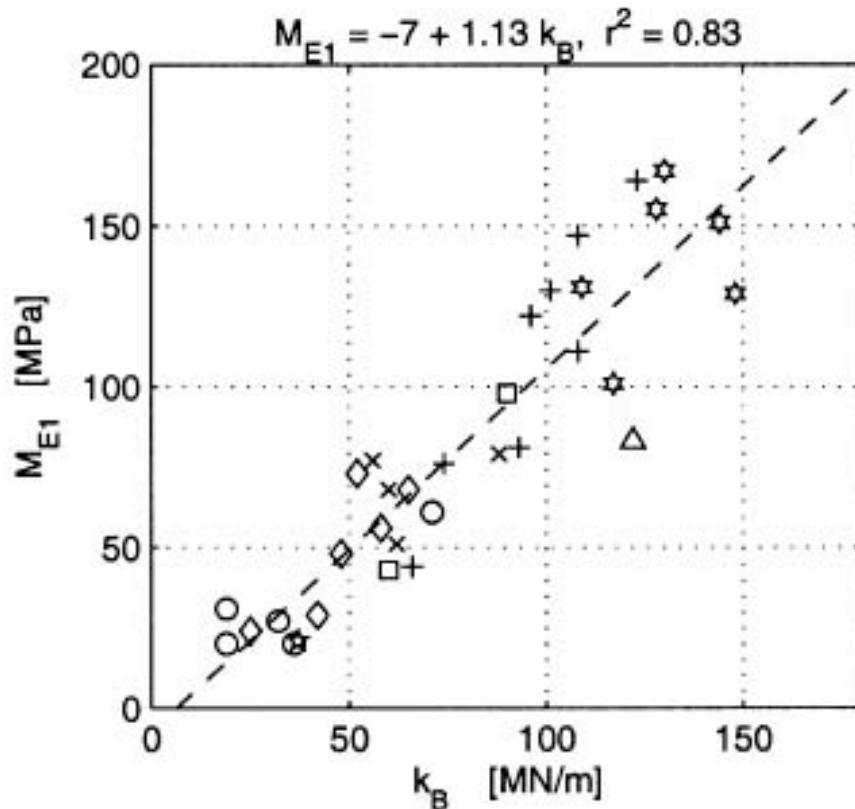
Modulus does not; it is a property of the soil only.

**Use the modulus, not the stiffness**

# From Stiffness to Modulus (theoretical)

$$k_B = \frac{E \cdot L \cdot \pi}{2 \cdot (1 - \nu^2) \cdot \left( 2.14 + \frac{1}{2} \cdot \ln \left[ \frac{\pi \cdot L^3 \cdot E}{(1 - \nu^2) \cdot 16 \cdot (m_f + m_d) \cdot R \cdot g} \right] \right)} \quad [\text{MN/m}]$$

# From Stiffness to Modulus (experimental)



From AMMANN

J-L Briaud, Texas A&M University

# **Soil Modulus for Intelligent Compaction**

**Soil:    5 MPa unacceptable  
                        200 MPa excellent**

# Specifications based on Modulus

Laying and compaction specification for road construction in Germany

<b>Soil layers</b>	<b>Density</b> (Standard Proctor)	<b>Bearing capacity</b> (load bearing test, EV2)	<b>Eveness</b> (4 m straight edge)
Subbase	100 - 103 % *	100 - 150 MN/m?*	20 mm
Capping layer	100 - 103 % *	100 - 120 MN/m?*	40 mm
Formation	97 - 100 % *	45 - 80 MN/m?*	60 mm

\* depending on road classification and road design

From BOMAG

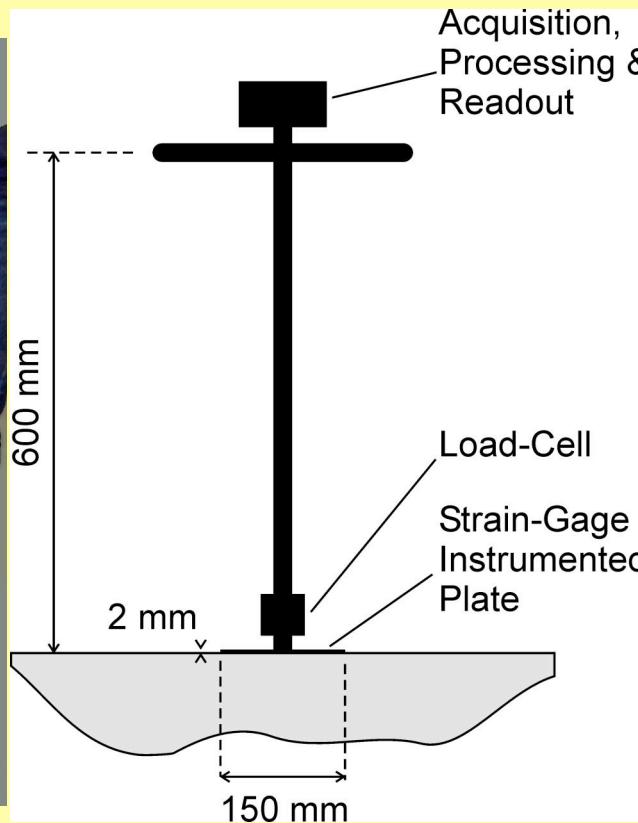
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# FUTURE NEEDS

1. Reference modulus = plate test?
2. Develop simple lab modulus test
3. Study modulus vs water/asph. Content
4. Demonstrate that IC is better than CC
5. Calibrate rollers against plate modulus
6. Use same modulus test (lab and field)

# Example of same modulus test in lab and in field

## BCD Test: Briaud Compaction Device



BCD on Proctor Mold

BCD in the Field

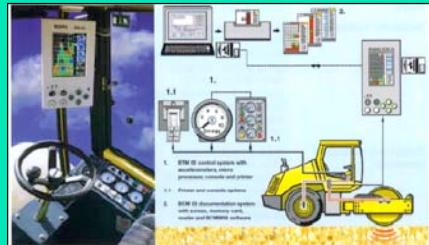
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## FUTURE NEEDS

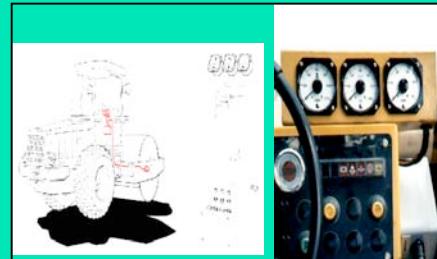
7. Develop specs based on modulus for diff. pavement cond.
8. Can the asphalt modulus be isolated from the soil modulus
9. Use modulus control equipment
10. Demonstrate the IC equipment
11. First International Conference on Compaction

# INTELLIGENT COMPACTION: OVERVIEW AND RESEARCH NEEDS

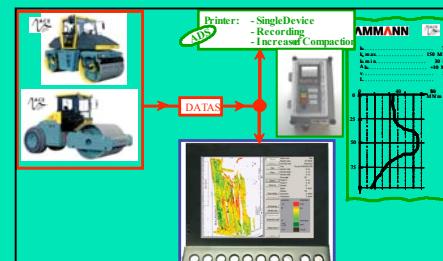
Jean-Louis Briaud ([briaud@tamu.edu](mailto:briaud@tamu.edu))  
and Jeongbok Seo



From BOMAG



From GEODYNAMIK



From AMMANN

December, 2003  
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# THANK YOU

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