Les modules et leurs applications au dimensionnement et contrôle de qualité des structures de chaussée et des voies ferrées

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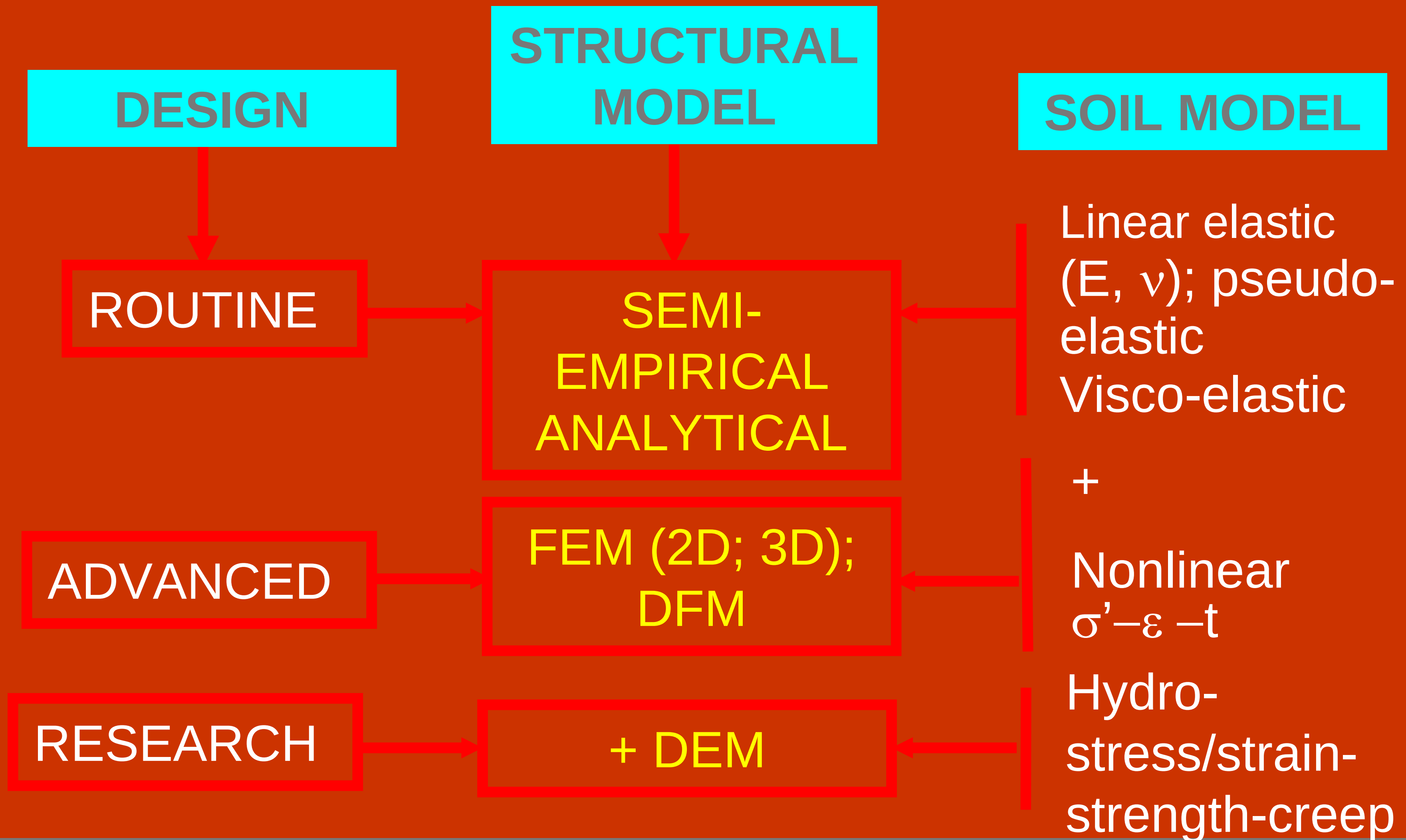
LECTURE OUTLINE

- INTRODUCTION
- DESIGN PROCESS
- LABORATORY TECHNOLOGIES
- MODULI FROM LABORATORY
- FIELD TECHNOLOGIES
- MODULI FROM FIELD
- CONCLUSION

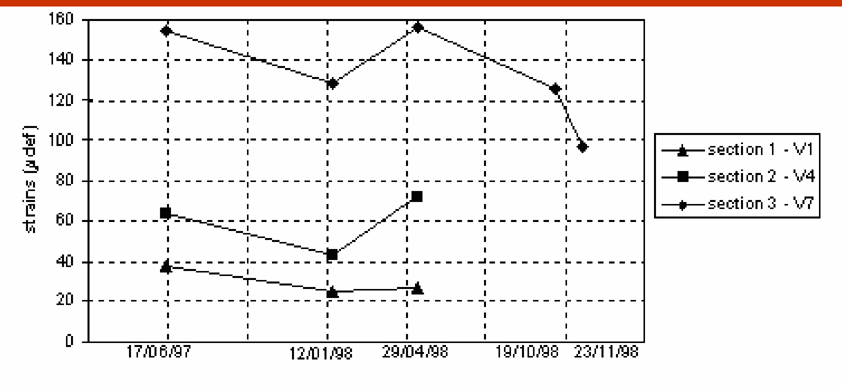
DESIGN PROCESS

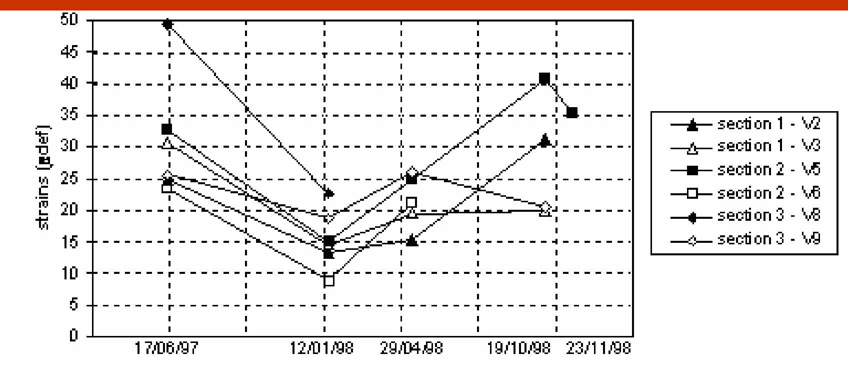


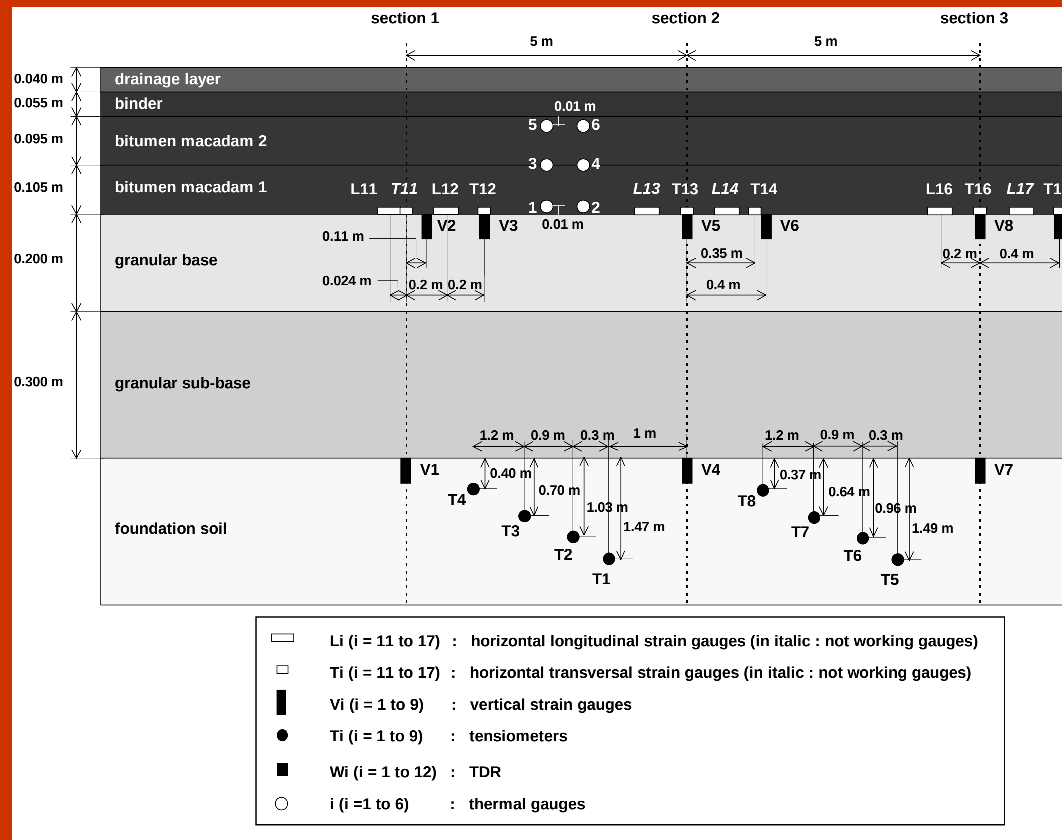
DIFFICULTY: Identification of model parameters

IN SITU STRAIN MEASUREMENTS IN FLEXIBLE PAVEMENT STRUCTURES

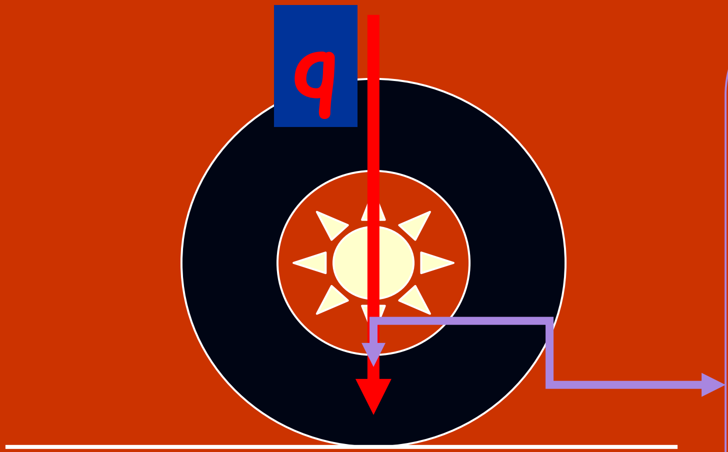
FWD – 65 kN

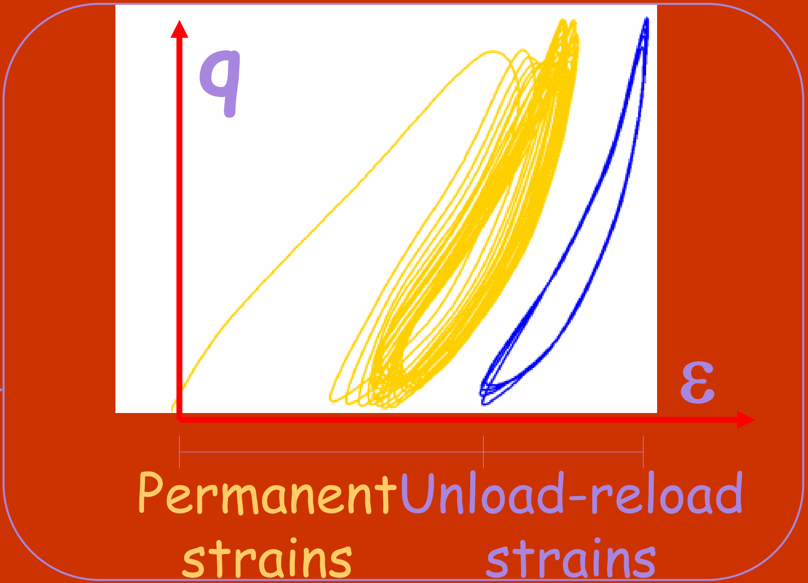






STRAINS DUE TO MOVING LOADS



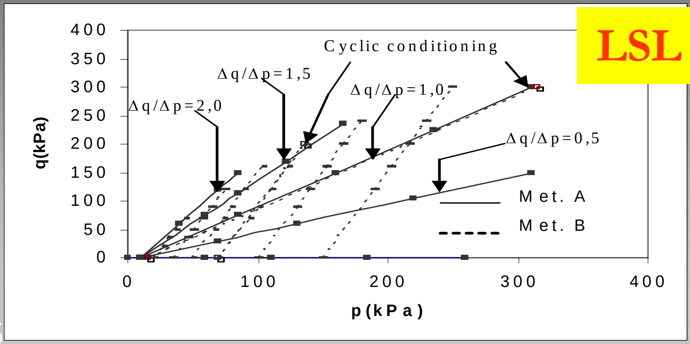


$$\varepsilon^t = \varepsilon^p + \varepsilon^e$$

The increment of residual or permanent strain over 1 cycle is much smaller than the elastic strain (unload-reload strain)

CYCLIC LOAD TRIAXIAL TEST FOR UGM

(EN 13286-7)

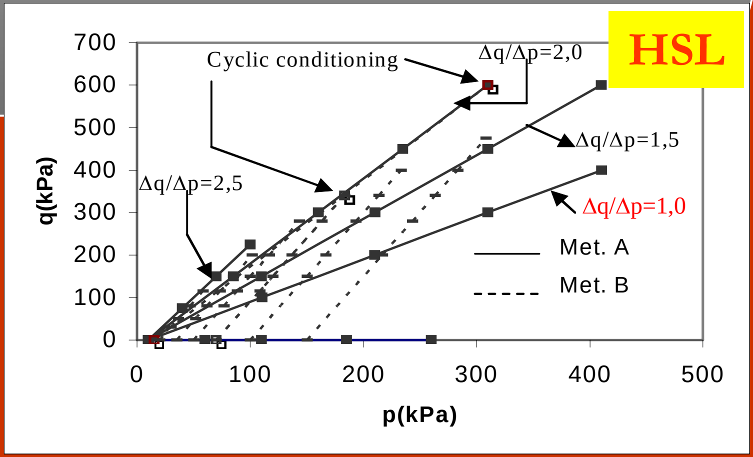


EVALUATION OF
QUASI ELASTIC BEHAVIOUR

- √ Cyclic conditioning (20 000 cycles)
- √ Series of short unload-reload cycles (100 cycles/stress level)

EVALUATION OF
RESISTANCE TO PERMANENT DEFORMATION

- √ Single stage procedure (80 000 cycles)
- √ Multi-stage procedure (10 000 cycles/stress level)

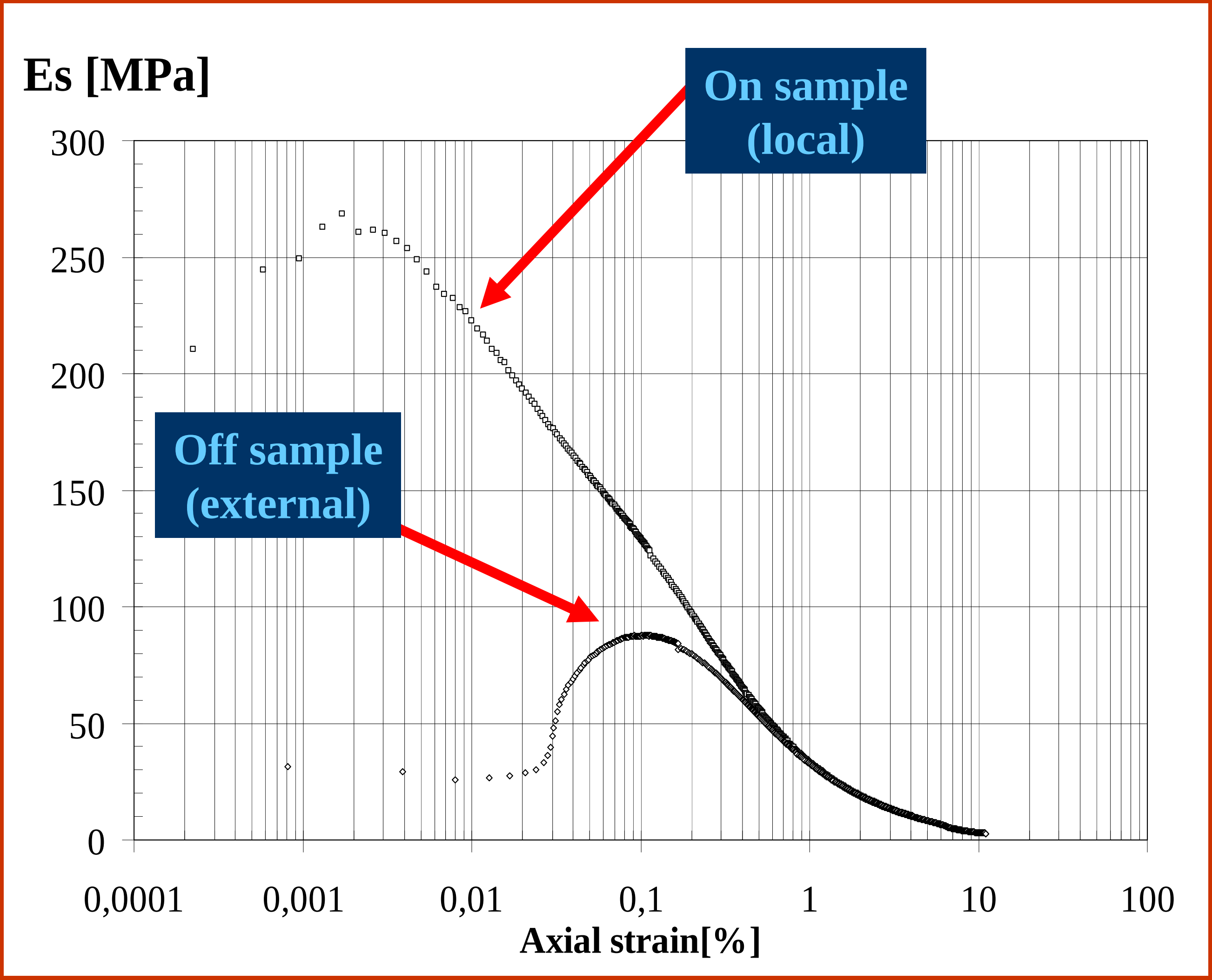


- ❑ Ranking materials
- ❑ Parameters for modelling and design

LABORATORY TECHNLOGIES

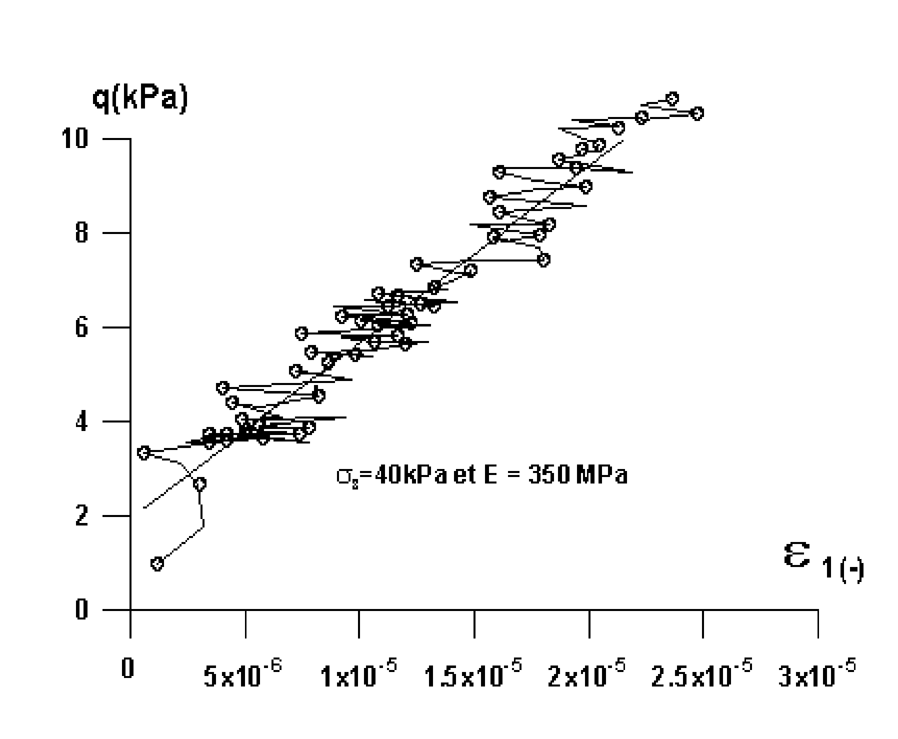
Strains from 0,0001% are necessary

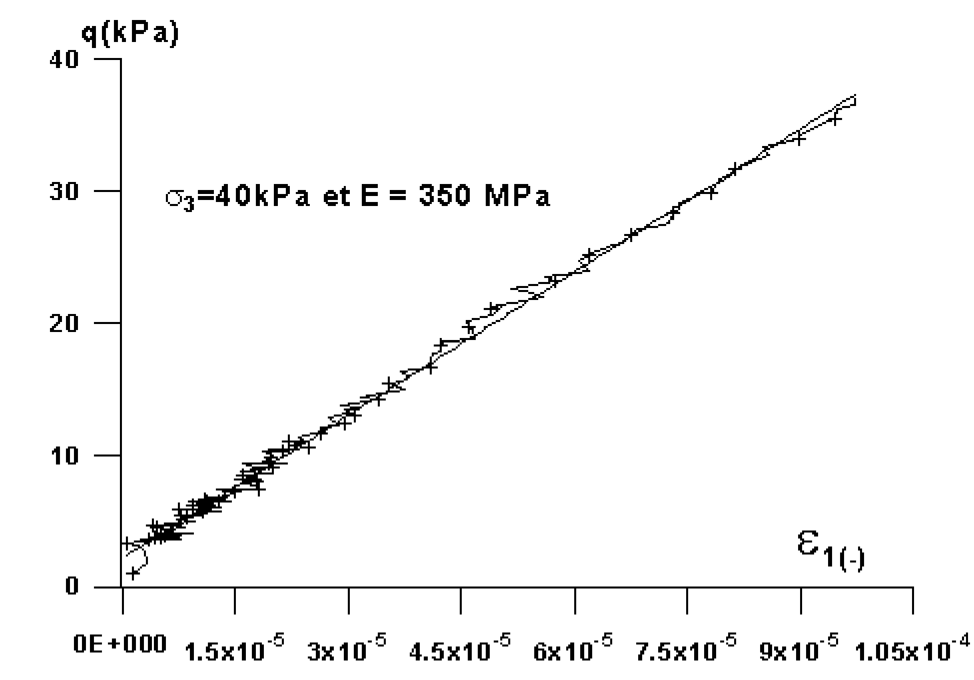
ON AND OF SAMPLE MEASUREMENTS



CYCLIC TRIAXIAL TEST (UMinho)

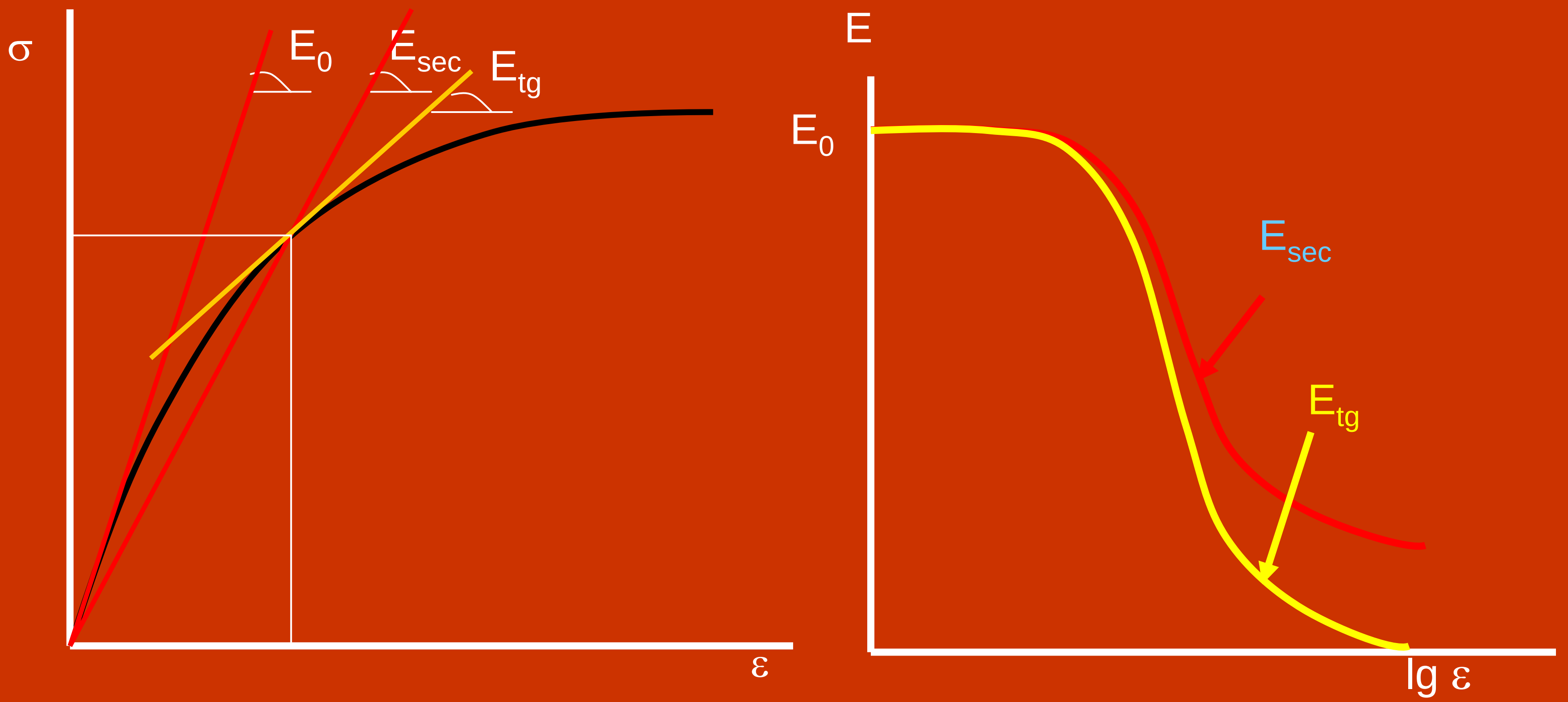
CYCLIC TRIAXIAL TEST
Typical results of strain measurements





MODULI FROM LABORATORY

NON LINEAR BEHAVIOUR DEFINITIONS OF MODULI



QUASI-ELASTIC PARAMETERS FOR CONSTITUTIVE LAWS OF SOILS

Calculation of constitutive relations for a continuum based on the properties of a discontinuum composed of spheres

Biarez

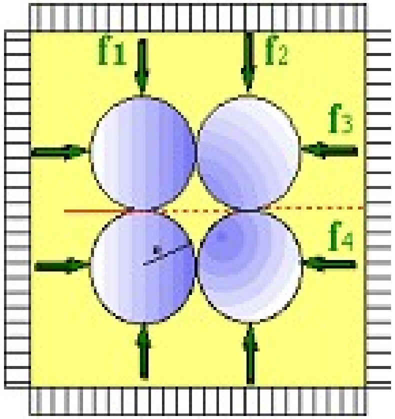
① General equations $\sum \tilde{F} + m\vec{\Gamma} = 0$

+

② Constitutive equations of grains (E_g, ν_g, ...)

+

③ Boundary Conditions (*initial conditions, "history"*)



3a - Geometric boundary conditions

- ✓ *Geometry of each grain (Size, Form, ...)* — $d = 2R$
- ✓ *Geometry of the arrangement of grains*
  - *Isotropic aspect (void ratio, dry density, ...)* — e
  - *Anisotropic aspect (orientation of tangent planes, ...)* — A

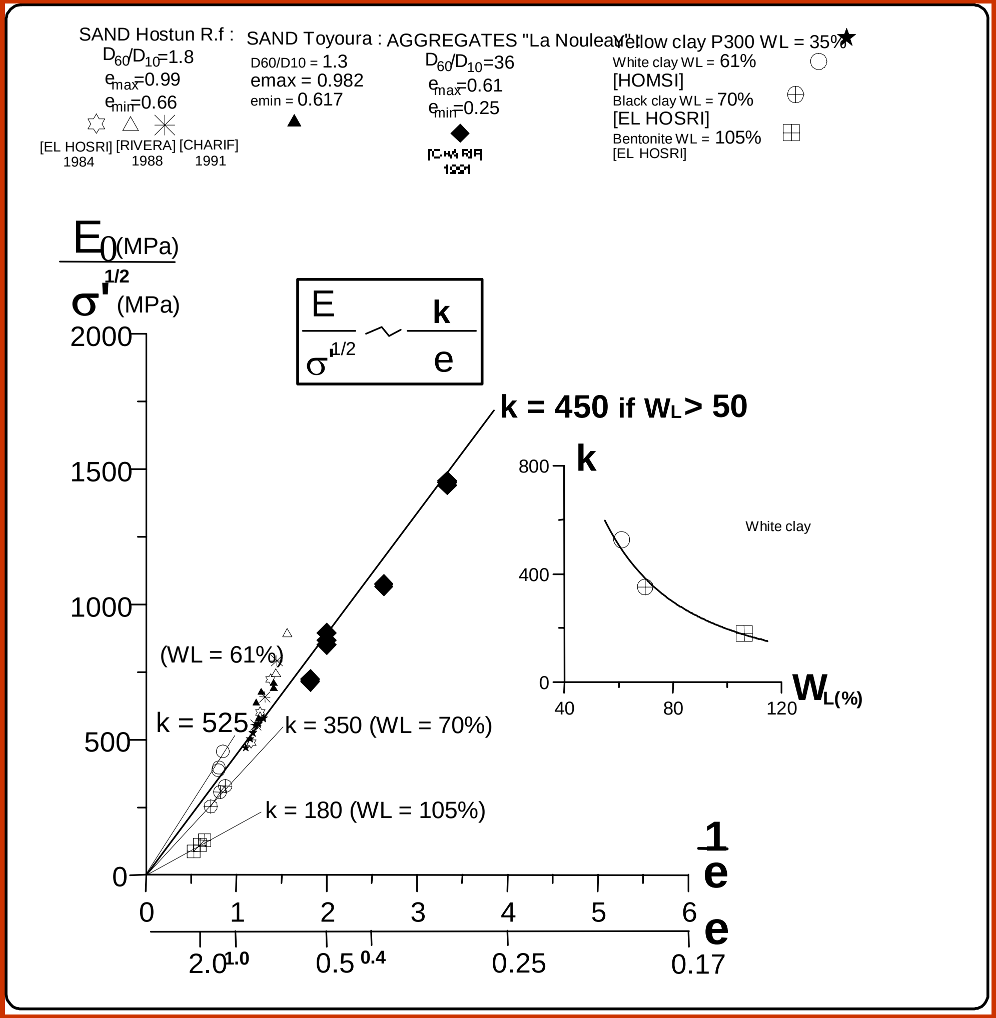
3b - Mechanical boundary conditions (f1 = f2 = f3 = f4 = p)

Solution: $$E_{iso} = \frac{3}{2}\left[\frac{4}{3}\frac{E_g}{(1-\nu_g^2)} \quad \frac{1}{G(e)}\right]^{2/3} p^{1/3}$$

$$E = k(W_L) \quad e^{-m} \quad p^n$$

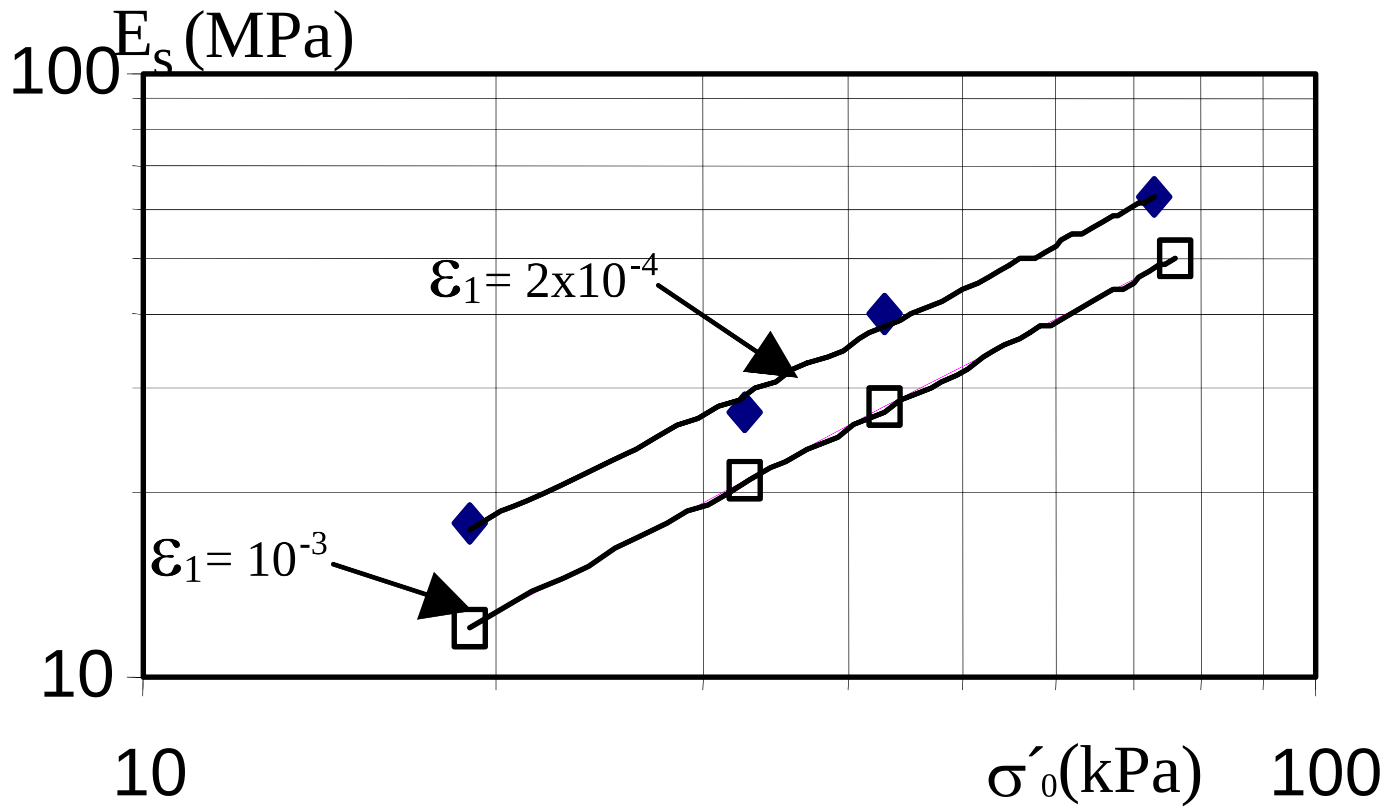
SMALL STRAIN MODULUS FOR CLAYEY SOILS

(Biarez et al., 2003)



IMPORTANCE OF STRAIN LEVEL IN SECANT MODULUS

(Gomes Correia, 2000 (data from Loach, 1987))



QUASI-ELASTIC PARAMETERS FOR CONSTITUTIVE LAWS OF UGM

TRIAXIAL TEST RESULTS MODELLING

NON-LINEAR MODELS

k-θ model
CCP

$$M_r = k_1 p_a \left(\frac{3p}{p_a}\right)^{k_2}$$

$$\nu = 0.35$$

$$p = \frac{\frac{\sigma_1 + 2 \times \sigma_3}{3}}{3}$$

$$q = \sigma_1 - \sigma_3$$

$$\varepsilon_v = \varepsilon_1 + 2 \times \varepsilon_3$$

$$\varepsilon_q = \frac{2}{3}\left(\varepsilon_1 - \varepsilon_3\right)$$

Boyce model
VCP

$$\varepsilon_v = \frac{1}{K_a} p_a^{1-n}\, p^n \left(1 - \beta\left(\frac{q}{p}\right)^2\right)$$

$$\varepsilon_q = \frac{1}{3G_a} p_a^{1-n}\, p^n \left(\frac{q}{p}\right)$$

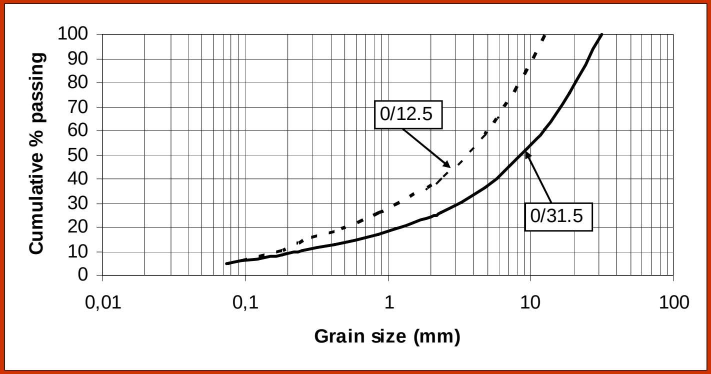
$$K = \frac{\left(\frac{p}{p_a}\right)^{1-n}}{\frac{1}{K_a} - \frac{\beta}{K_a}\left(\frac{q}{p}\right)^2}$$

$$G = \frac{\left(\frac{p}{p_a}\right)^{1-n}}{\left(\frac{1}{G_a}\right)}$$

$$\beta = (1-n) \cdot \frac{Ka}{6 \cdot Ga}$$

RECENT FINDINGS - UGM

MATERIALS & PRECISE LARGE TRIAXIAL TESTS



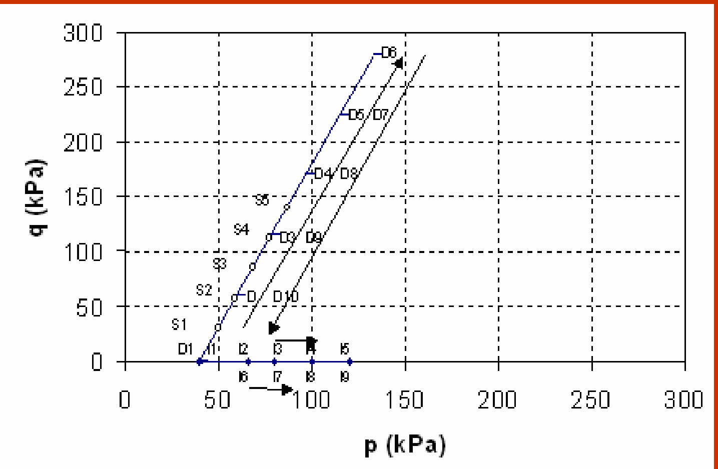
Material	D_{50} (mm)	U_c	Modified Proctor		G_s
			w (%)	γ_d (Mg/m³)	
0/31.5	8.5	53	5.9	2.310	2.71
0/12.5	3.5	28	6.2	2.125	2.71

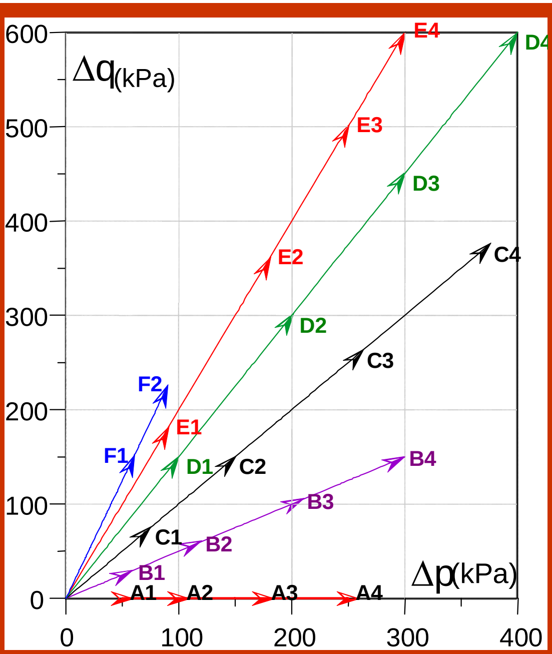
Material	Compaction conditions		
	w_0 (%)	γ_{d0} (Mg/m³)	e_0
0/31.5	3.9	2.193	0.236
0/12.5	4.1	2.216	0.223

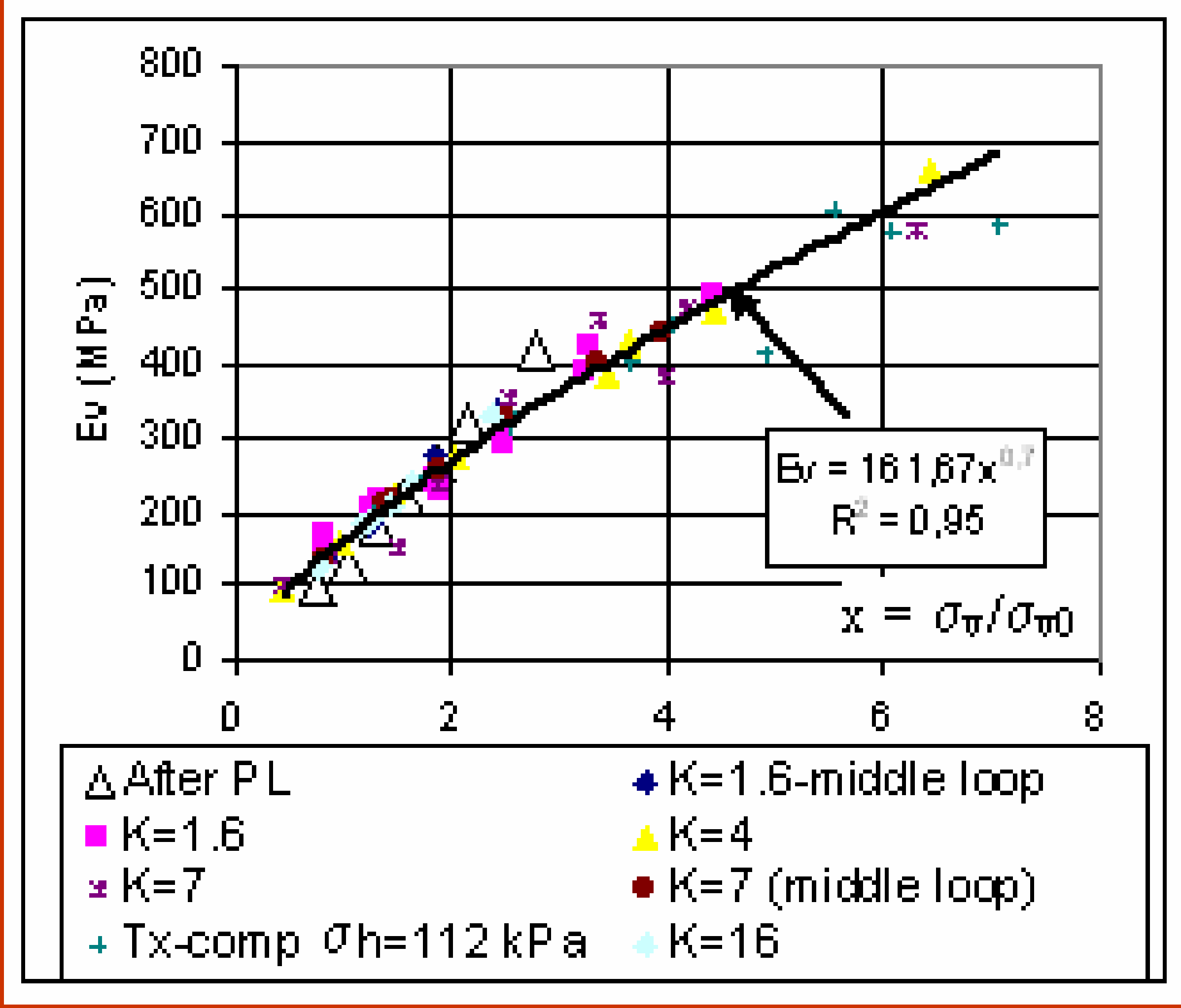
23x23x57 cm

STRESS-DEPENDENCY OF YOUNG'S MODULUS AT SMALL STRAINS, E_v: a function of σ_v only

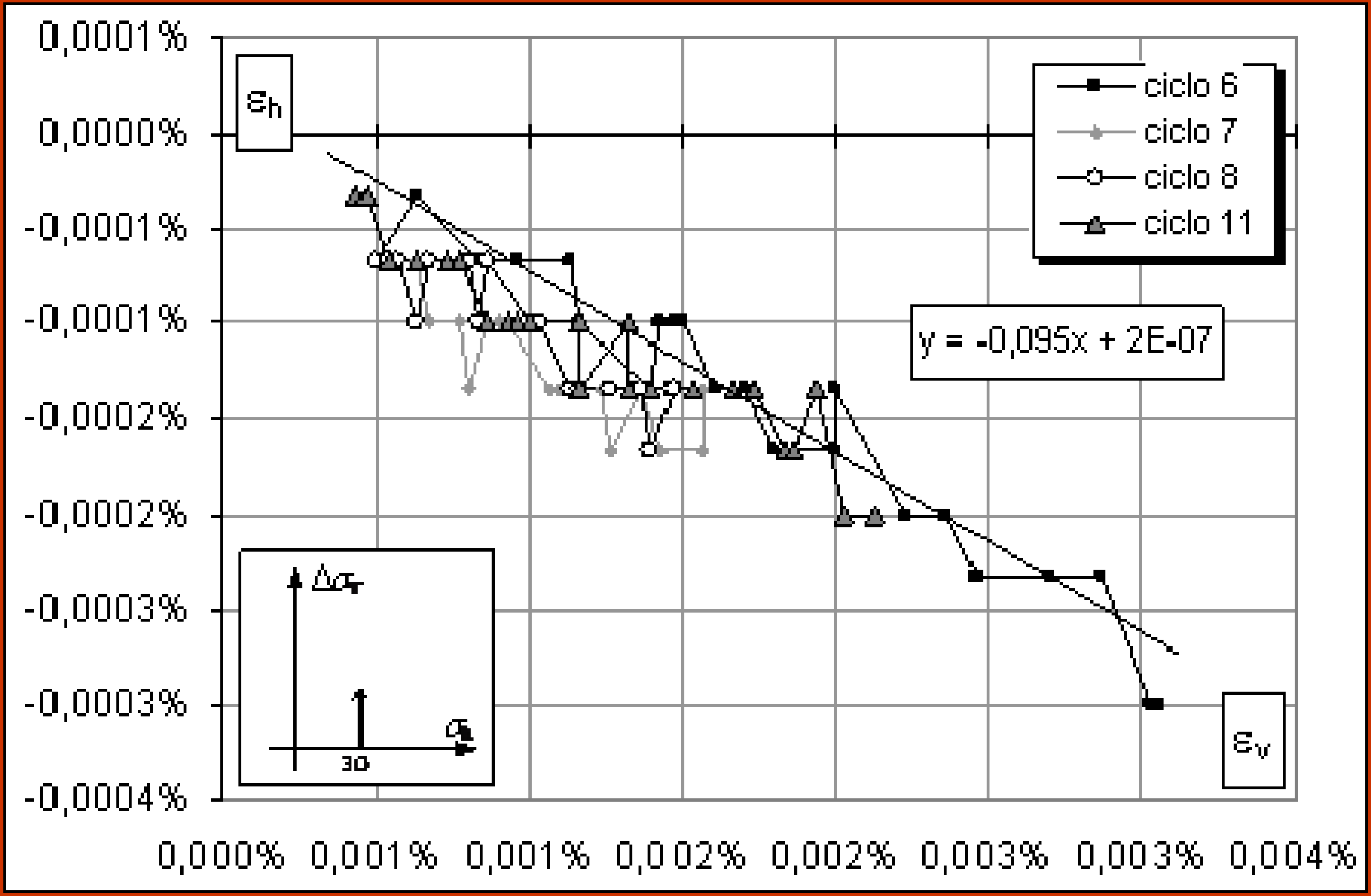
(Gomes Correia et al., 2005)



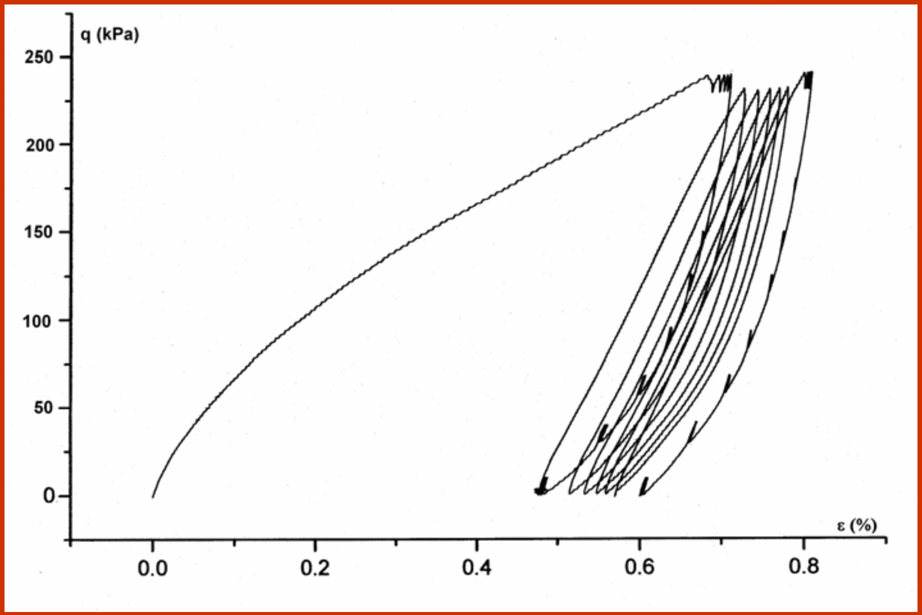


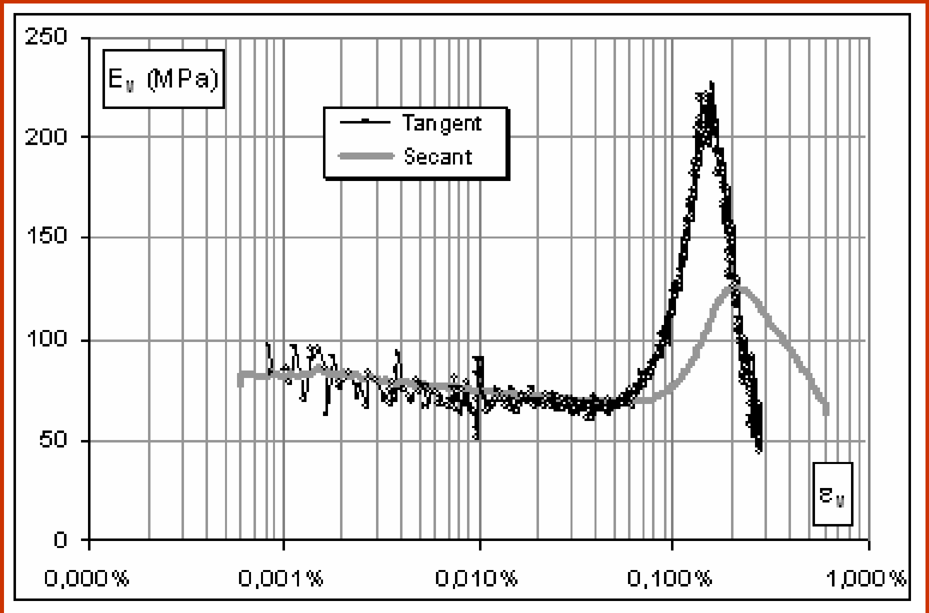


TYPICAL RESULTS OF CYCLIC TRIAXIAL TEST- CCP
Un.-Rel. Strains – Poisson ratio



"S" SHAPED STRESS-STRAIN CURVE UNDER TRIAXIAL COMPRESSION AFTER CYCLIC PRE-STRAINING *(Gomes Correia et al., 2005)*





Stress-strain behaviour under cyclic loading, showing:

- large inelastic strains & a typical degradation of the modulus with strain during the first cycle; and
- S-shaped S-S curve after cyclic prestraining

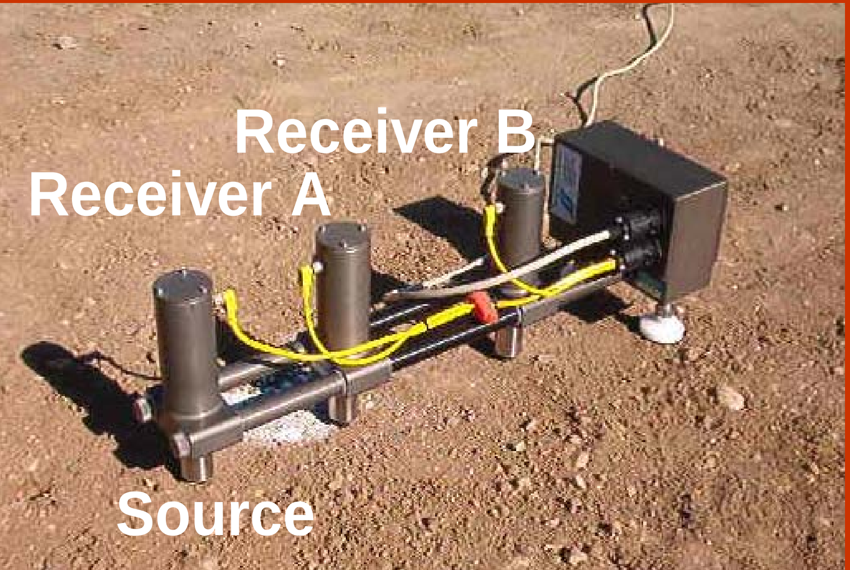
Peculiar but natural trends of the tangent and secant moduli as a function of strain level for a very dense compacted after pre-straining of 21.000 cycles of a constant cyclic deviator stress of 230 kPa

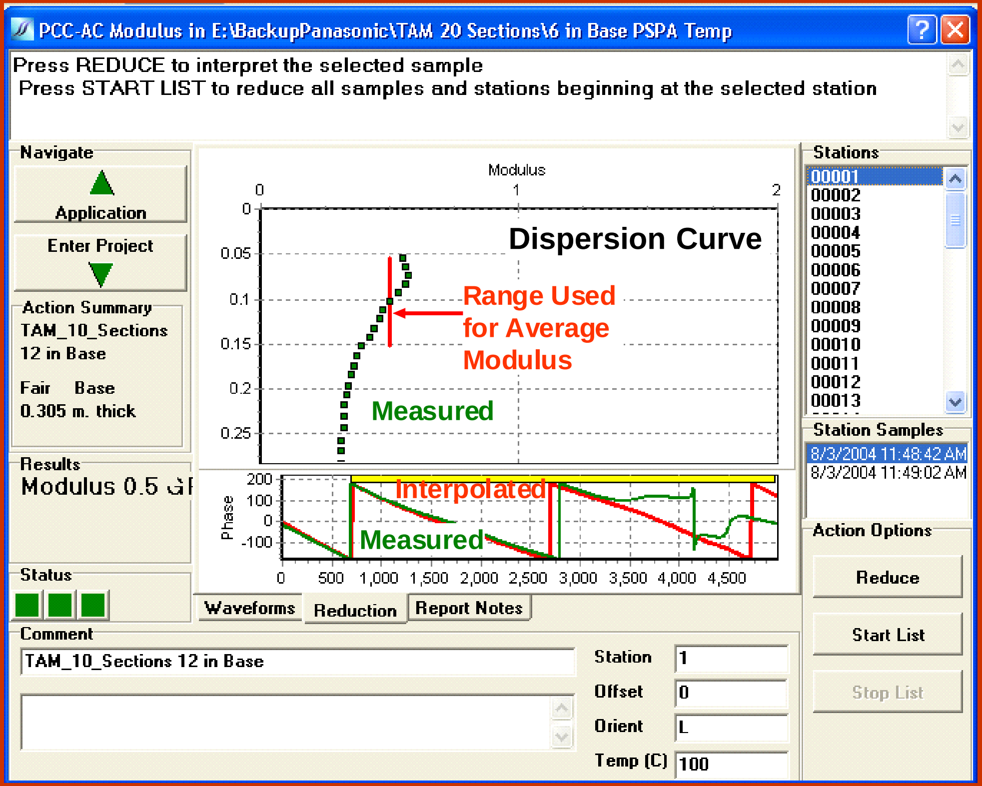
FIELD TECHNOLOGIES

Spectral-Analysis-of-Surface-Waves (SASW)

(Nazarian, 2005)

Seismic Portable Device





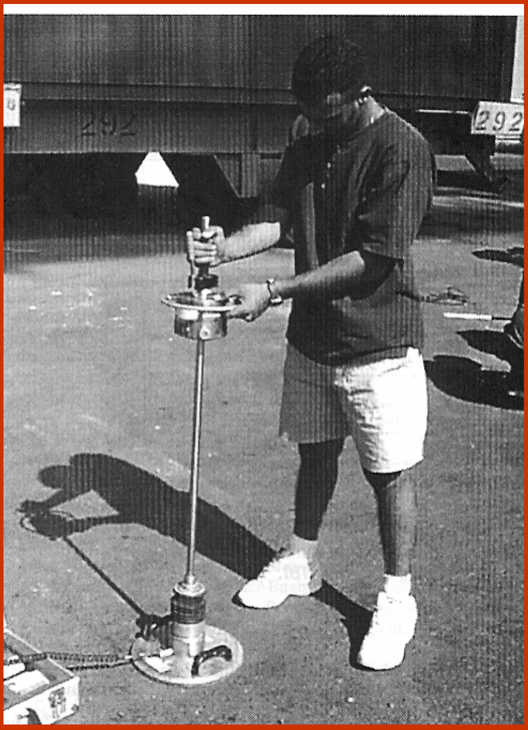
("Spot" tests) : Stiffness (**LDW**)

*Dynamic plate loading tests – **increase:***

simpler and faster than static PLT

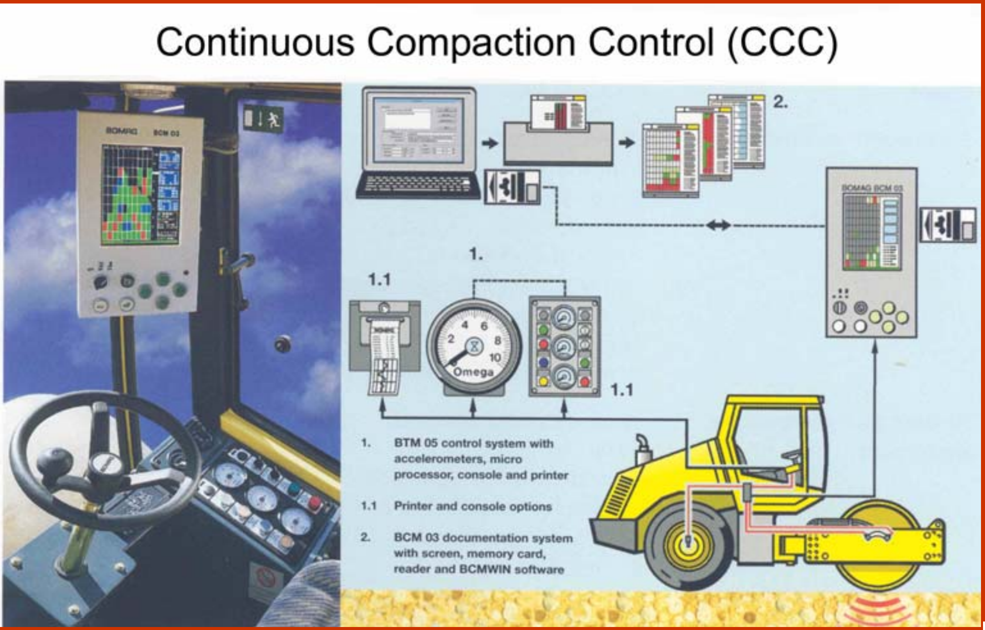
Different equipments: size, measurement principle, parameters determined, …

Different tests results (Flemming & Rogers, 1995, Gomes Correia et al, 2004)



Soil stiffness gauge *(Edil & Sawangsuriya, 2005)*

CONTINOUS COMPACTION CONTROL (Brandl, 2001; Adam, 2004)



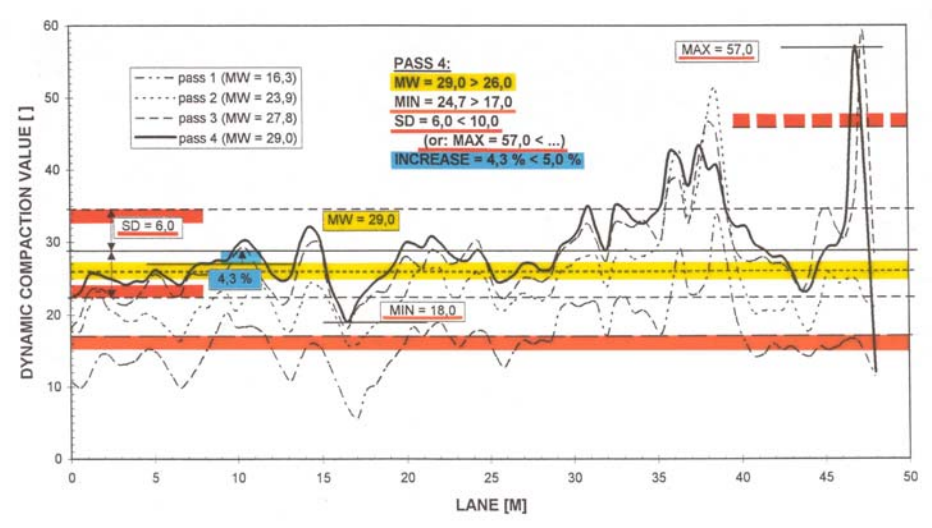
CCC-systems

Compactometer

CMV is based on the evaluation of the acceleration in the *frequency domain*

Terrameter

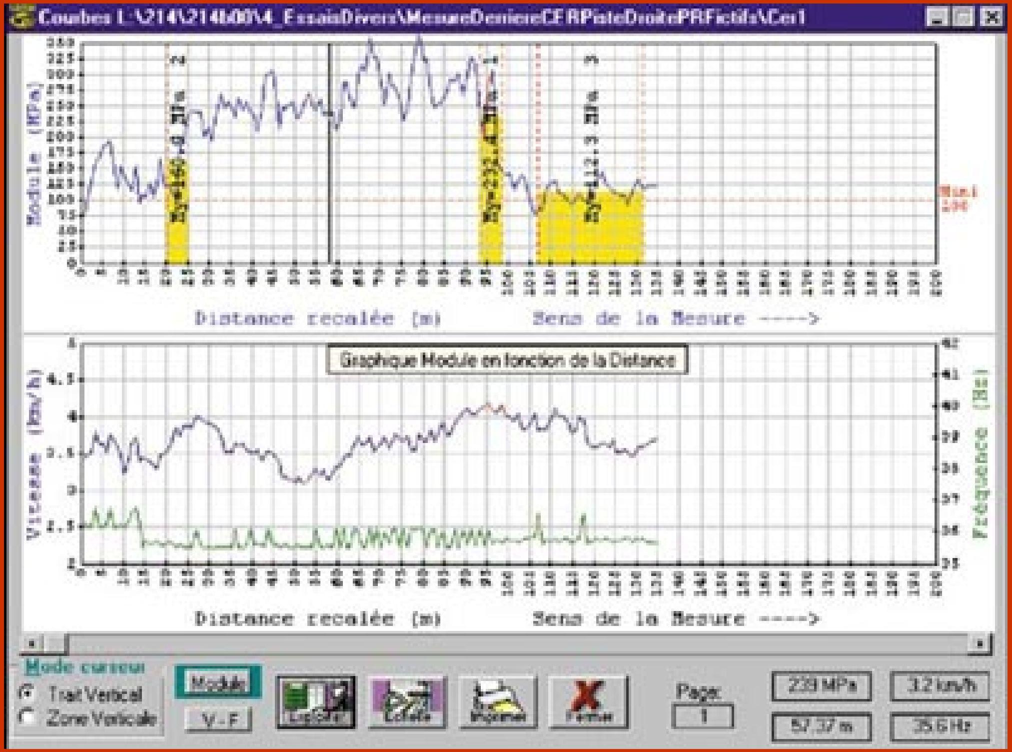
OMEGA is based on the evaluation of the energy transmitted to the soil in the *time domain*

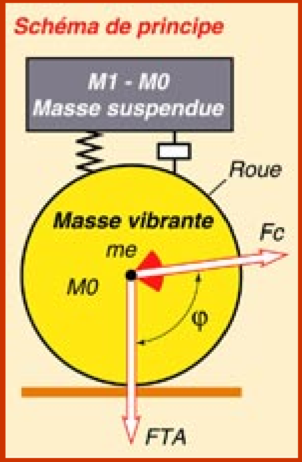


CONTINOUS COMPACTION CONTROL (LPC; Quibel, 1998)

Wheel 1 m, 200 mm wide equipped with a vibratory loading system and instrumented with accelerometers.

Continuous determination of stiffness (3 km/h)





MODULI FROM FIELD

MODULI FROM FIELD TESTS

(Jamiolkowski et al., 1988, 2003)

G_{0}, E_0 ($\varepsilon < \varepsilon^{l}$)

INDEPENDANT FROM:

Strain level

Stress history

DEPENDANT ON:

Relative density

Ambient stress

Compressibility

Aging & Fabric

$$G_0 = S \cdot p_a^{1-n} \cdot F(e) \cdot p'^{n}$$

G_{sec}, E_{sec} ($\varepsilon_{sec} > \varepsilon^{l}$)

DEPENDANT ON:

Strain level

Stress history

Relative density

Ambient stress

Compressibility

Aging & Fabric

Strain rate

CORRELATIONS WITH G_0, E_0 are more reliable than with G_{sec}, E_{sec}

SERVICEABILITY STIFFNESS

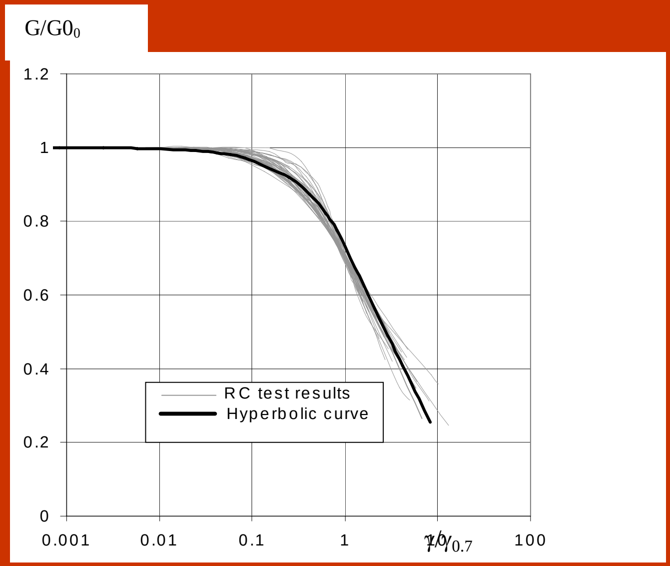
Factoring G_0 or E_0

$$\frac{G_s}{G_0} = \frac{1}{\left[1 + a \cdot \left(\frac{\gamma}{\gamma_{0,7}}\right)\right]}$$

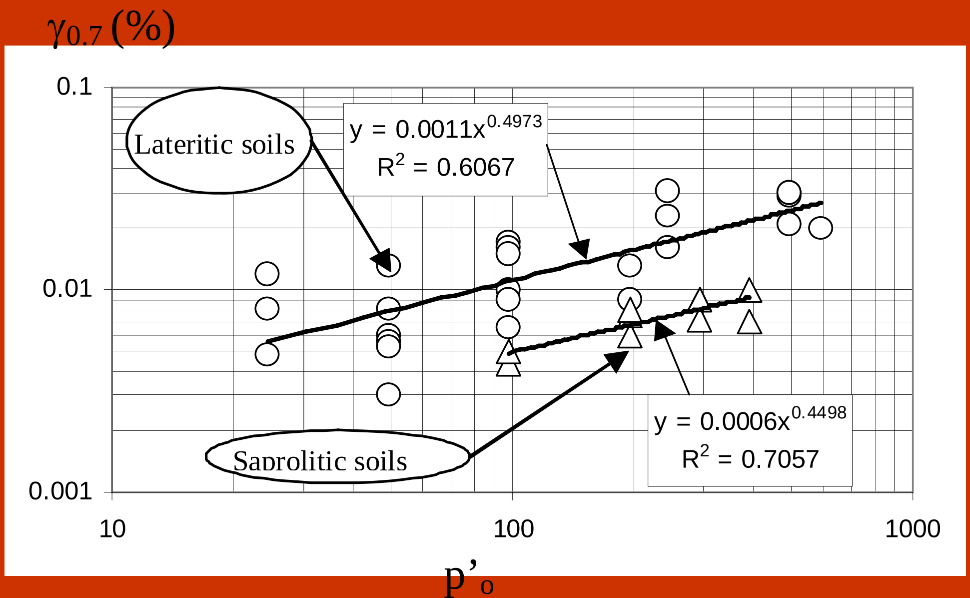
where γ is shear strain;
$\gamma_{0,7}$ is the shear strain for a stiffness degradation factor of $G/G0=0.7$ and
a is a constant ($a \approx 0,385$, for the database used)

Fahey & Carter, 1993; Mayne, 2001

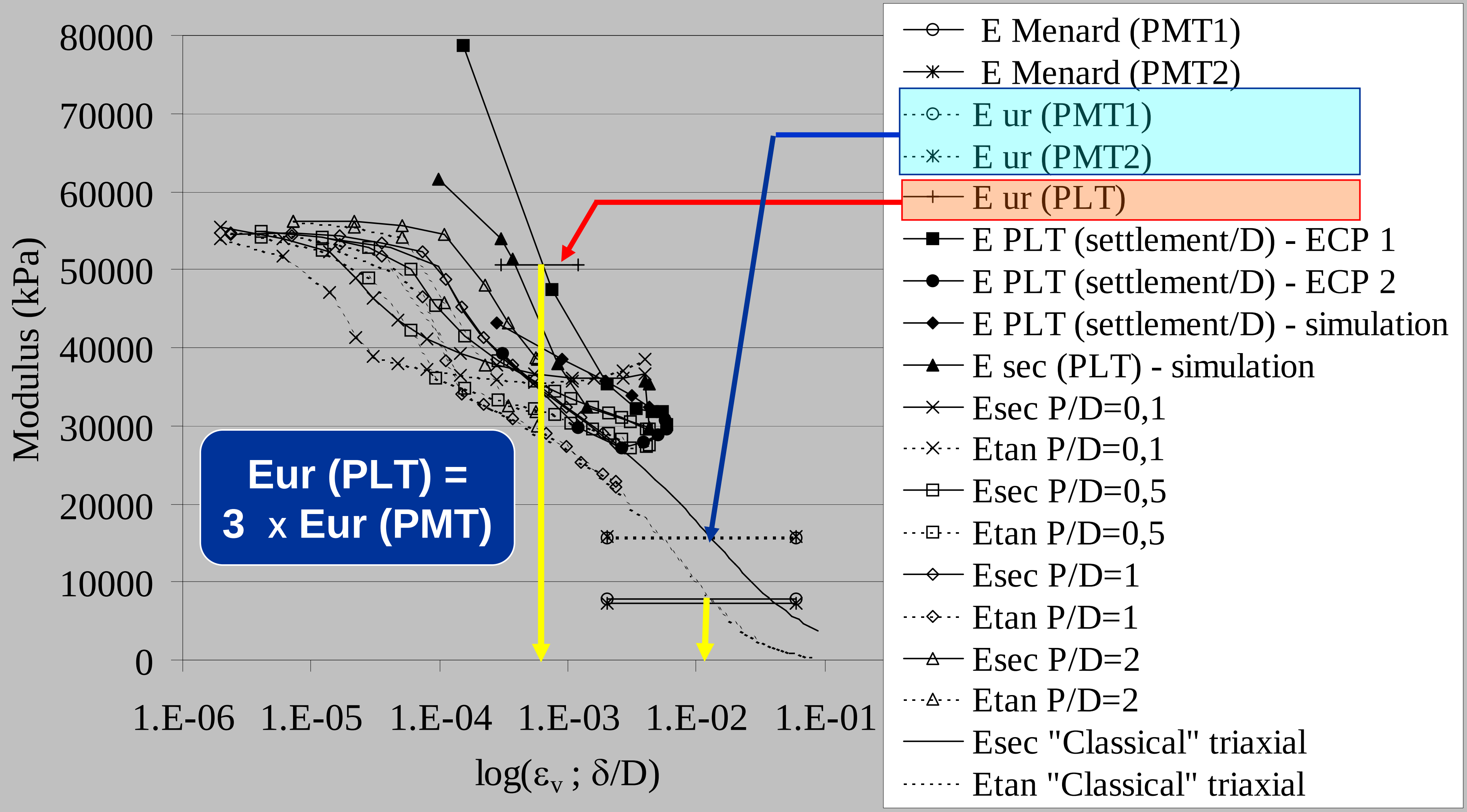
$$\frac{E}{E_0} = 1 - f\left(\frac{q}{q_{ult}}\right)^g$$



Gomes Correia et al., 2001



PMT – PLT - TXSimulation
ROUTINE & ADVANCED ANALYSIS (*HSM – PLAXIS)*
(Gomes Correia et al., 2004)



CONCLUSION

INTEGRATION SYSTEM

« Pensé du Professeur Jean Biarez »