CONCEPTION DES CHAUSSÉES: Approache mécanique, caractérisation des matériaux et leur évaluation dans les plates-formes routières

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PRESENTATION

- ❒ INTRODUCTION
- ❒ PAVEMENT MODELLING AND DESIGN
- ❒ NON LINEAR BEHAVIOUR OF SOILS AND UGM
- ❒ QUALITY ASSESSMENT - LABORATORY
  - ❒ Simple tests
  - ❒ Functional tests
    - ❒ Mechanical behaviour - Cyclic triaxial tests
- ❒ QUALITY ASSESSMENT - FIELD
  - ❒ Routine analysis
  - ❒ Advanced analysis
- ❒ FINAL REMARKS

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EMPIRICAL PAVEMENT DESIGN

↓

MECHANISTIC PAVEMENT DESIGN

↓

MOVE FROM EMPIRICAL SPECIFICATIONS – INDEX PROPERTIES
TO
PERFORMANCE-BASED SPECIFICATIONS
MECHANICAL PROPERTIES

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PAVEMENT MODELLING & DESIGN

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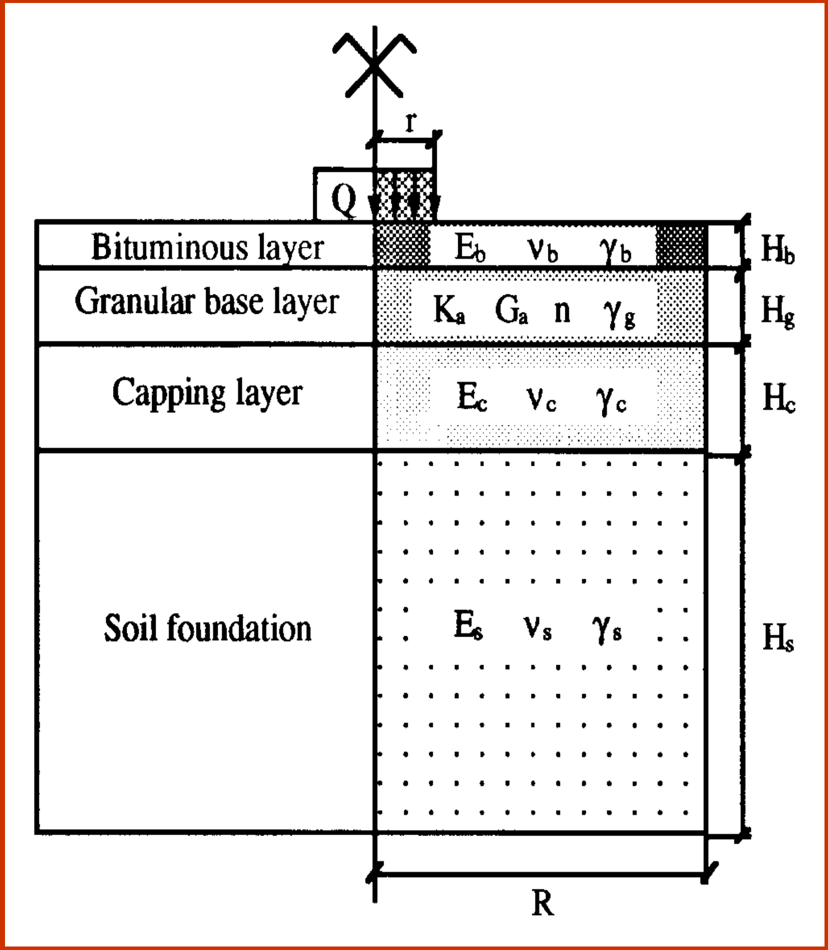
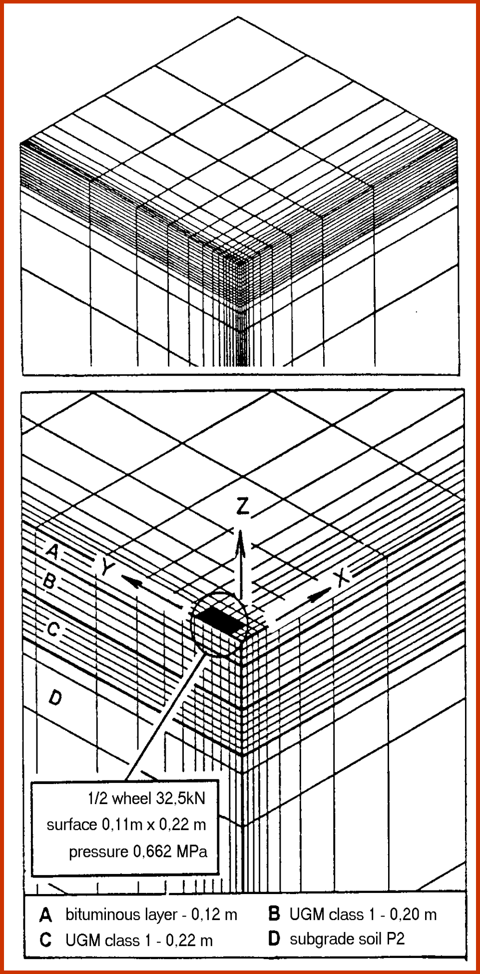
PAVEMENT MODELLING – 2D / 3D





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MECHANISTIC PAVEMENT DESIGN

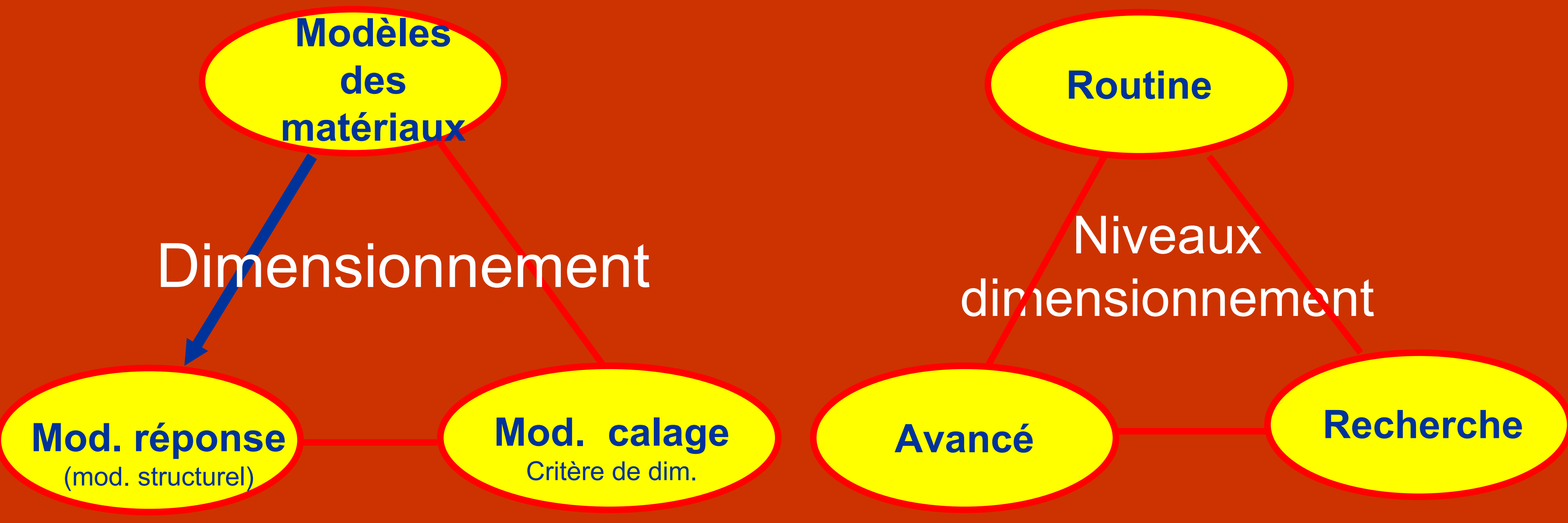
1. Multi linear elastic systems calculations - linear elastic models - most widely used for pavement design and back analysis calculations. Material properties: Modulus (E) and Poisson ratio (ν).

2. - FEM calculations (2D / 3D) Elastic non-linear models - Available in some codes after Science-EC project (1993). Material properties: Elastic and elastic non-linear stress-strain relationships (K(p,q); G(p,q)) – variants of Boyce model.

Visco-elastic and elastic non-linear stress-strain models - Implemented in FEM codes during COURAGE (1999). Material properties: Elastic non-linear stress-strain; temperature and strain rate dependent.

3. FEM calculations (2D / 3D) - Visco-elastic and elastoplastic models - Implemented in FEM codes and still in development to predict permanent deformations. Material properties: General stress-strain.

PAVEMENT DESIGN PROCESS



Besoin d'une coopération entre le responsable de la modélisation et le responsable des investigations in-situ et en laboratoire

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QUALITY ASSESSMENT

LABORATORY

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QUALITY ASSESSMENT
Laboratory tests

- **SIMPLE TESTS:** to general material assessment (petrography, flakiness, plasticity) and fragmentation assessment (LA, MBg, DSC, MDE, Gyratory) - Uses a limited portion of material's parent grading curve - ***Not able to predict the overall behaviour of the material.***

- **FUNCTIONAL TESTS:**

  - **Construction level** - to assess the bearing capacity of UGM to carry loading applied (shear strength test) and spreading the loading (RLT- stifness).

  - **Long term behavior** - to assess stifness - capacity of spreading the loading (RTL stifness) and resistance to permanent deformation (RLT - permanent deformation)

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SELECTION OF MOST APROPRIATED MATERIAL

based in simple tests (SOIL AND UGM)

for most part experienced based

Similar to AC – volumetric design

(Marshall method)

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A RATIONAL APPROACH TO LABORATORY STUDY OF MECHANICAL BEHAVIOUR

Strength & Stiffness

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NON LINEAR BEHAVIOUR OF SOILS AND UGM

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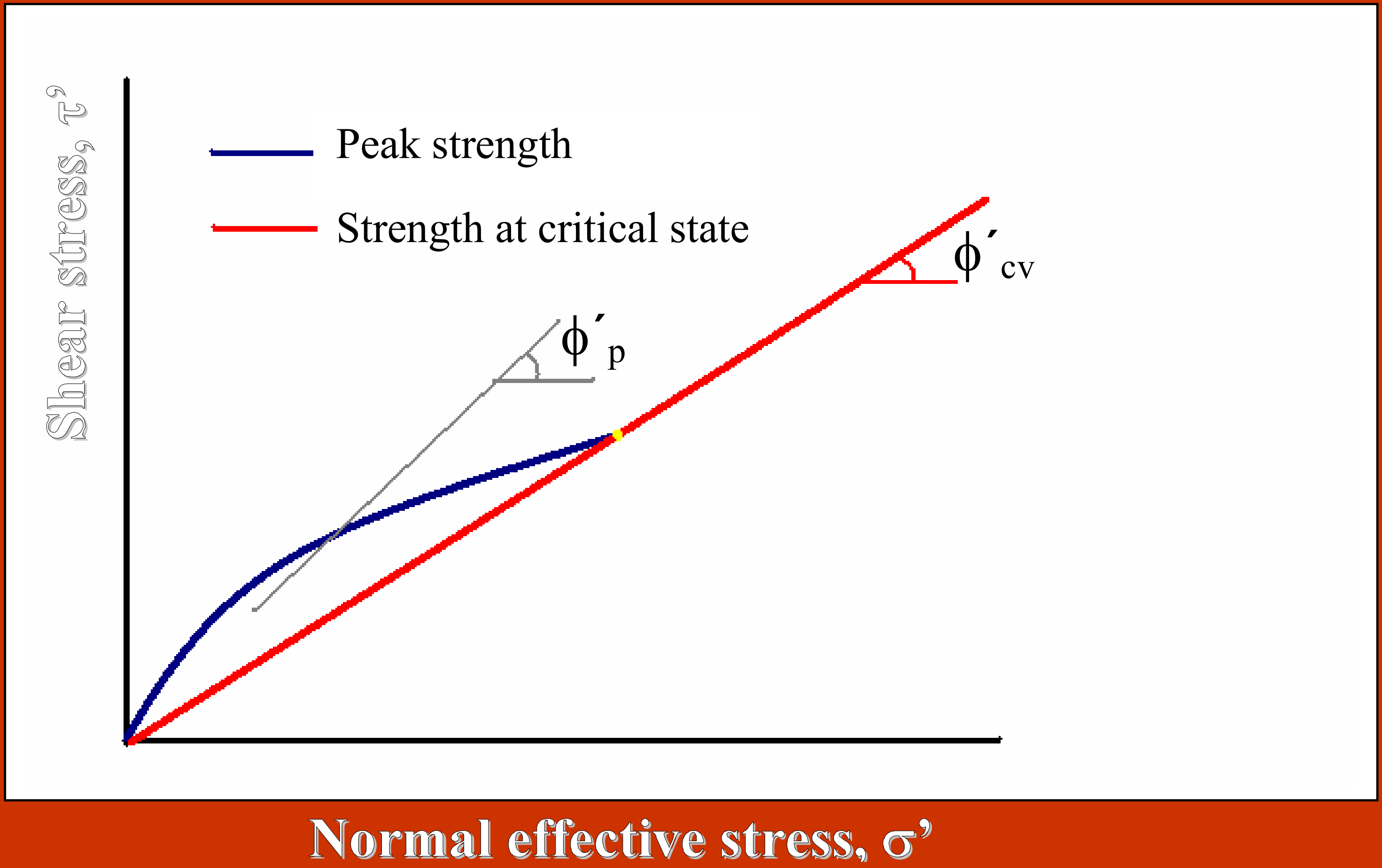
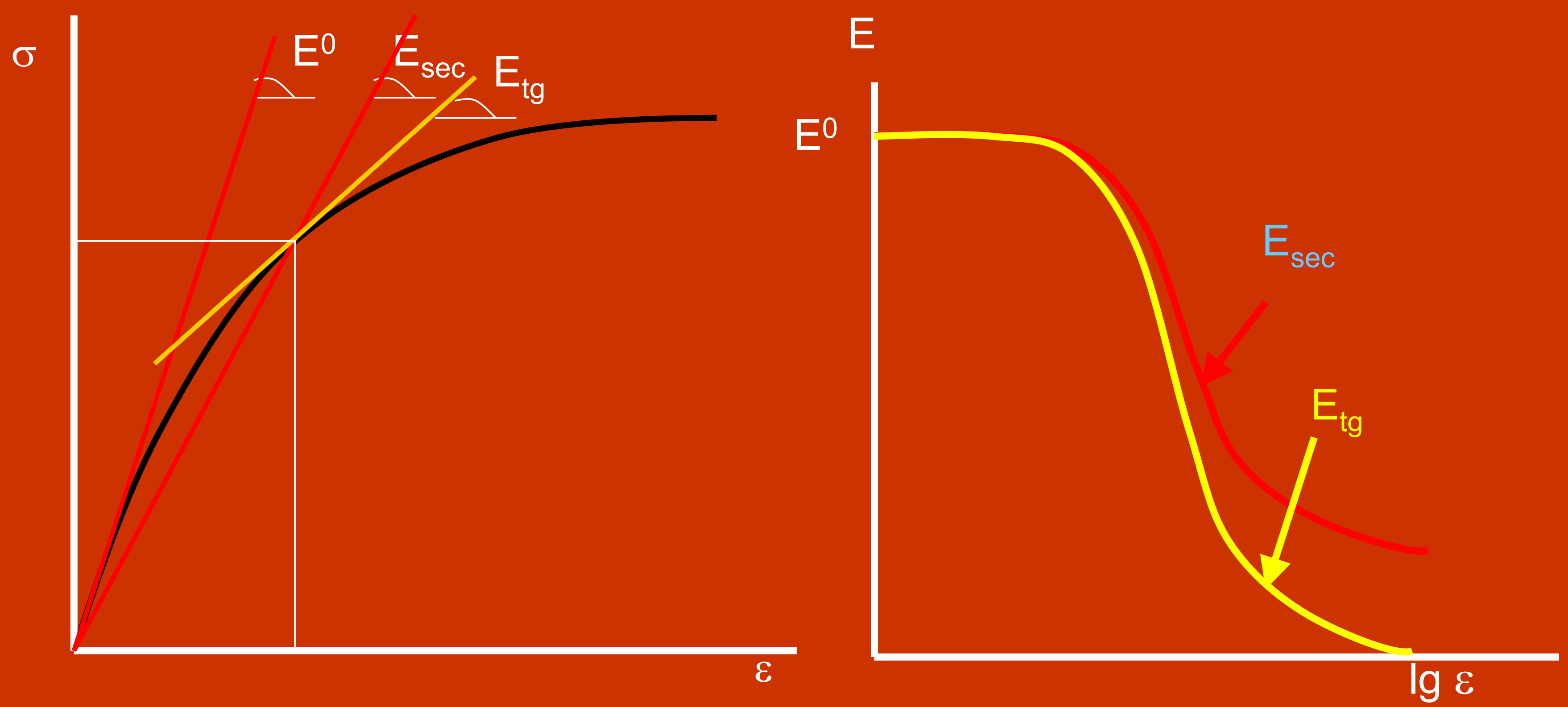
NON LINEAR ENVELOPE OF MAXIMUM SHEARING STRENGTH - UGM



NON LINEARITY INCREASES WITH INCREASING RELATIVE DENSITY AND GRAIN CRUSHABILITY

NON LINEAR BEHAVIOUR DEFINITIONS OF MODULUS



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CYCLIC TRIAXIAL TEST
PERFORMANCE TEST

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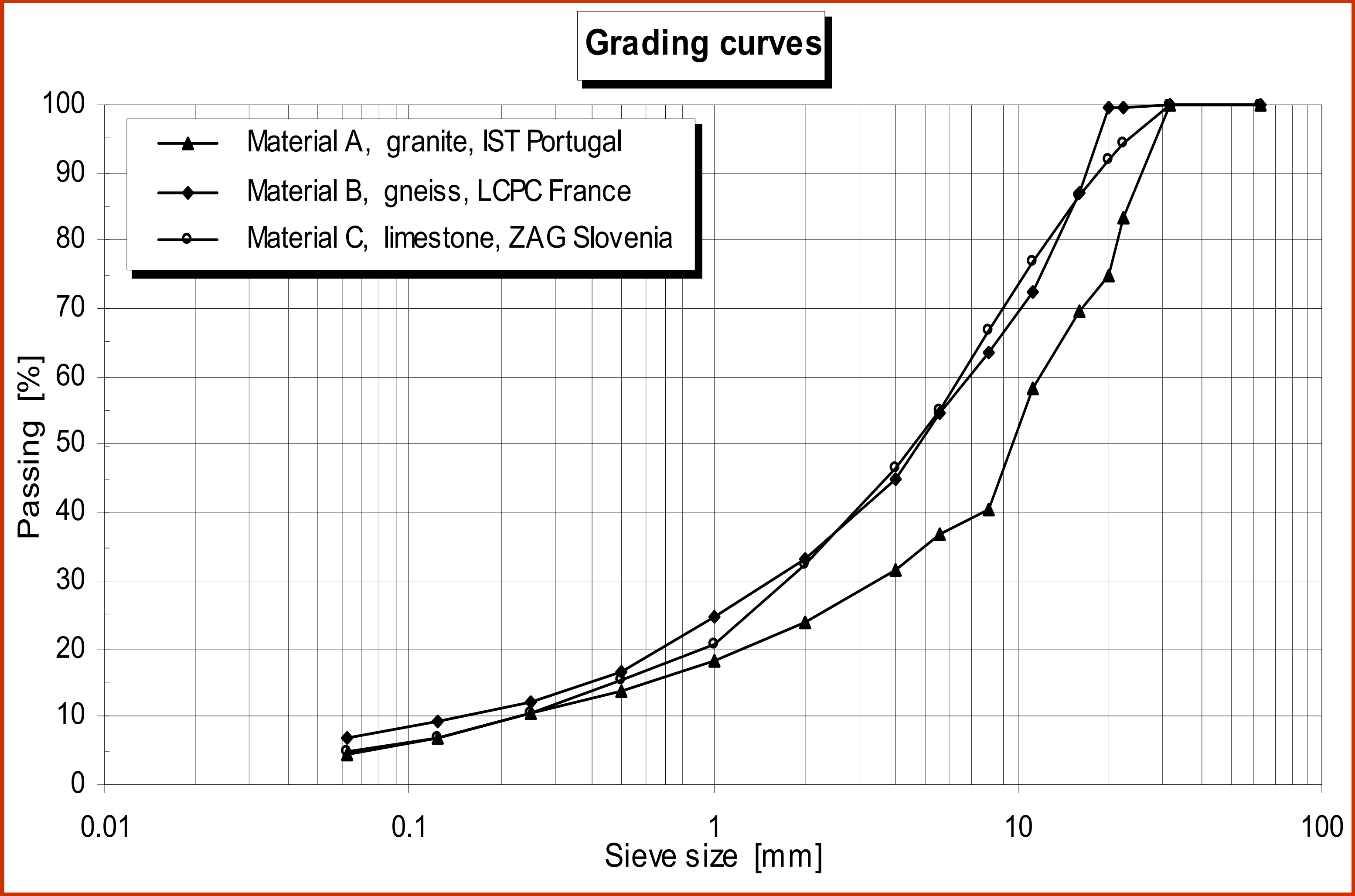
EUROPEAN STUDY - COURAGE



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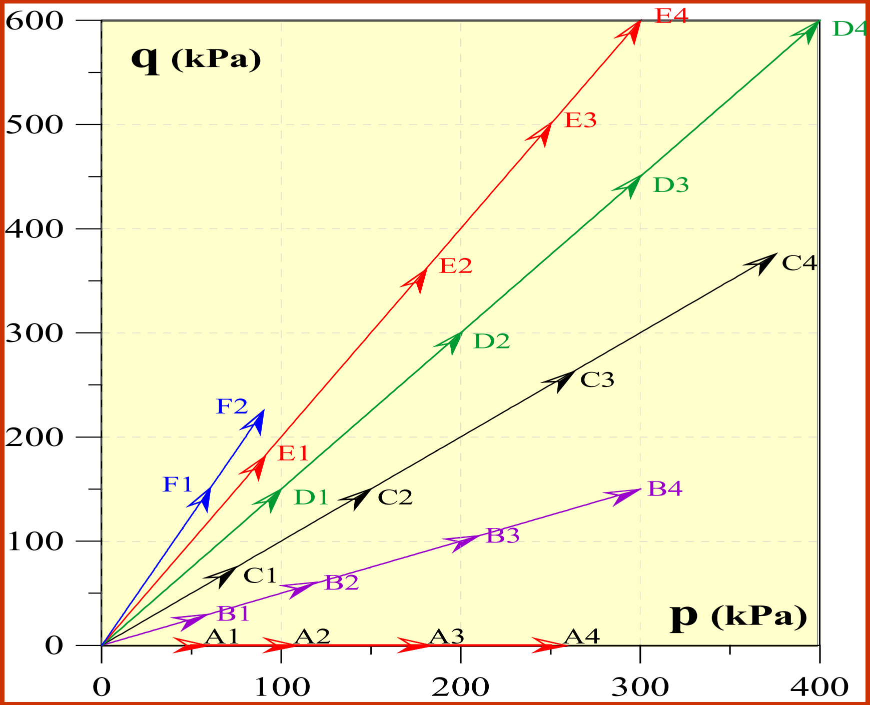
CYCLIC STRESS PATHS

CYCLIC TRIAXIAL TESTS OF UGM

(CEN prENV 00227413 - 1997)



VARIABLE CONFINING PRESSURE   CEN - method A

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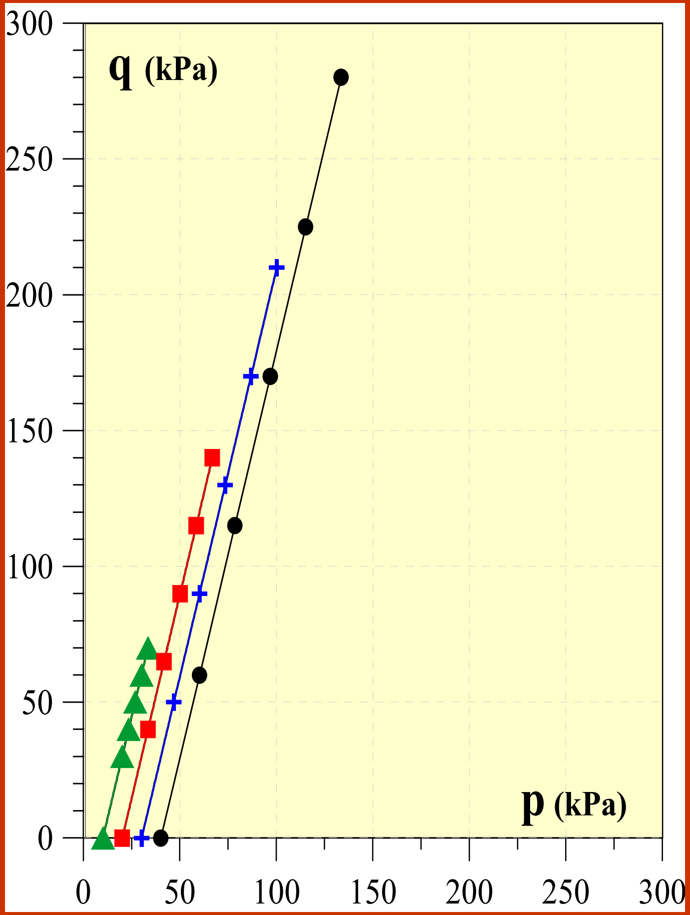
CYCLIC STRESS PATHS

CYCLIC TRIAXIAL TESTS OF UGM

(CEN prENV 00227413 - 1997)



CONSTANT CONFINING PRESSURE
CEN - method B

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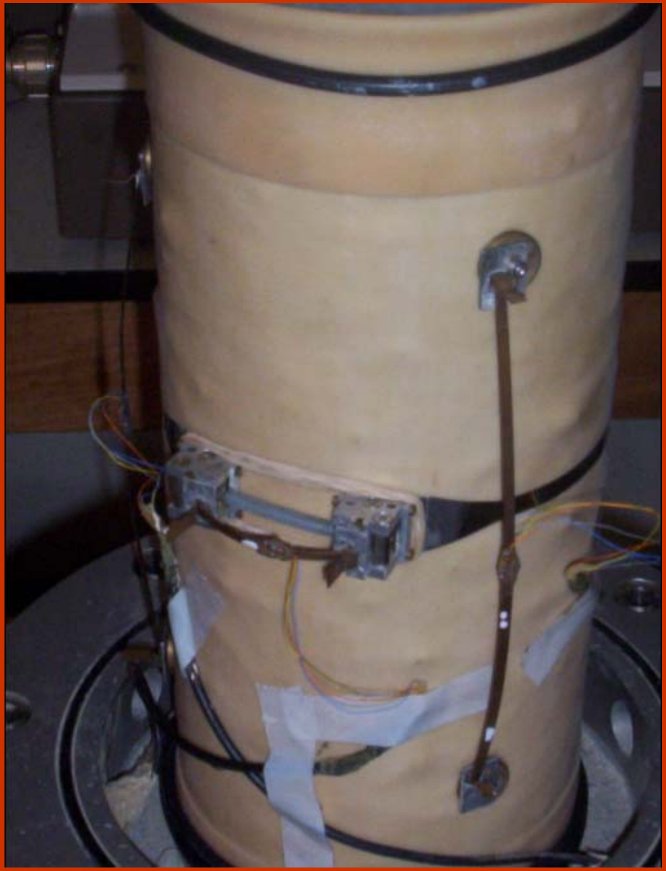
CYCLIC TRIAXIAL TEST (ECP)
Local strain measurements



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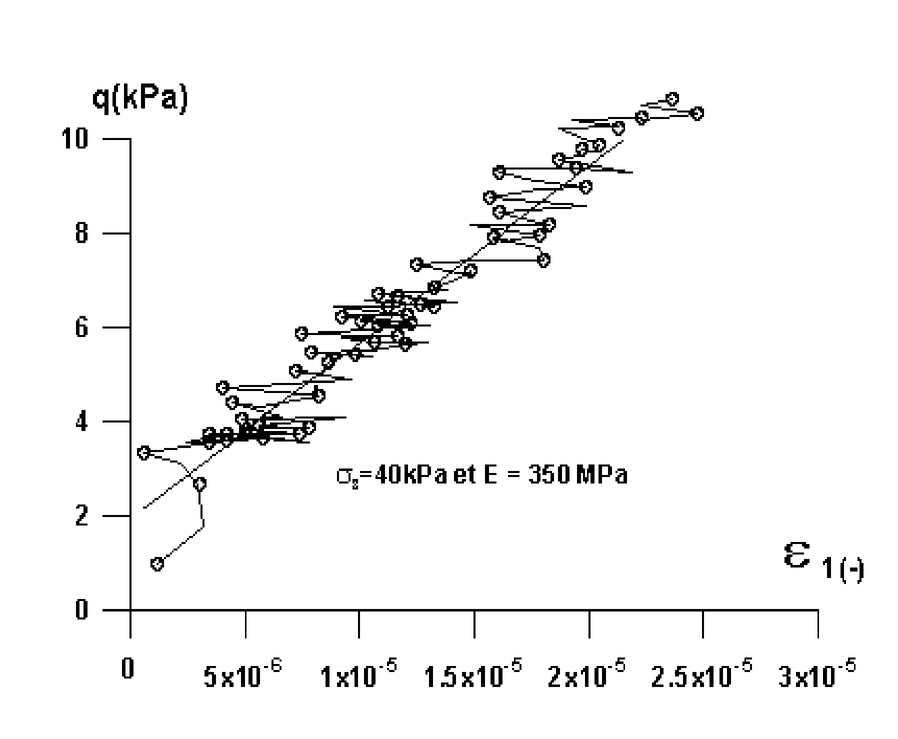
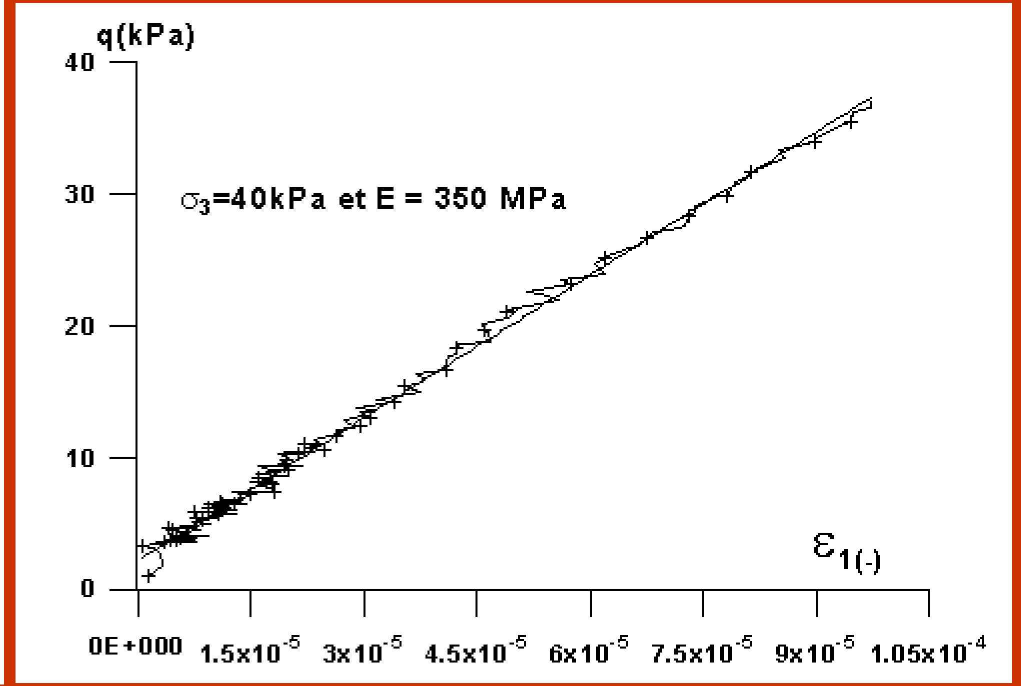
CYCLIC TRIAXIAL TEST (ECP)
Results of strain measurements





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CYCLIC TRIAXIAL TEST (LPC)

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CYCLIC TRIAXIAL TEST (UMinho)

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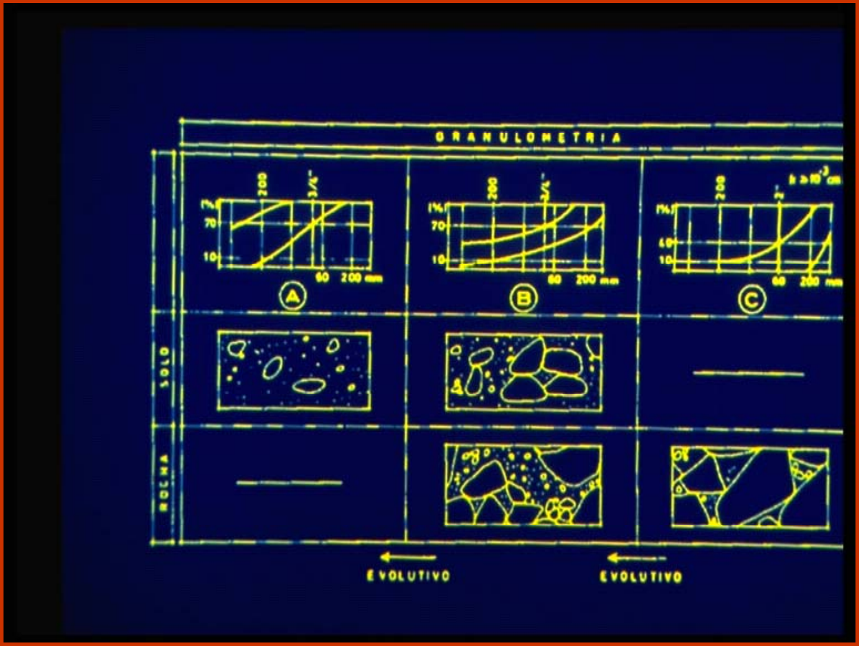
SOIL / SOIL+ROCK / ROCK



TYPICAL MOISTURE & DENSITY CONDITIONS FOR UGM - BASE

WATER CONTENT w			DRY DENSITY
$w_{OPM} - 4$	$w_{OPM} - 2$	$w_{OPM} - 1$	
	1 Specimen		100 % $\rho_{d\,OPM}$
1 Specimen	2 Specimens	1 Specimen	97 % $\rho_{d\,OPM}$
	1 Specimen		95 % $\rho_{d\,OPM}$

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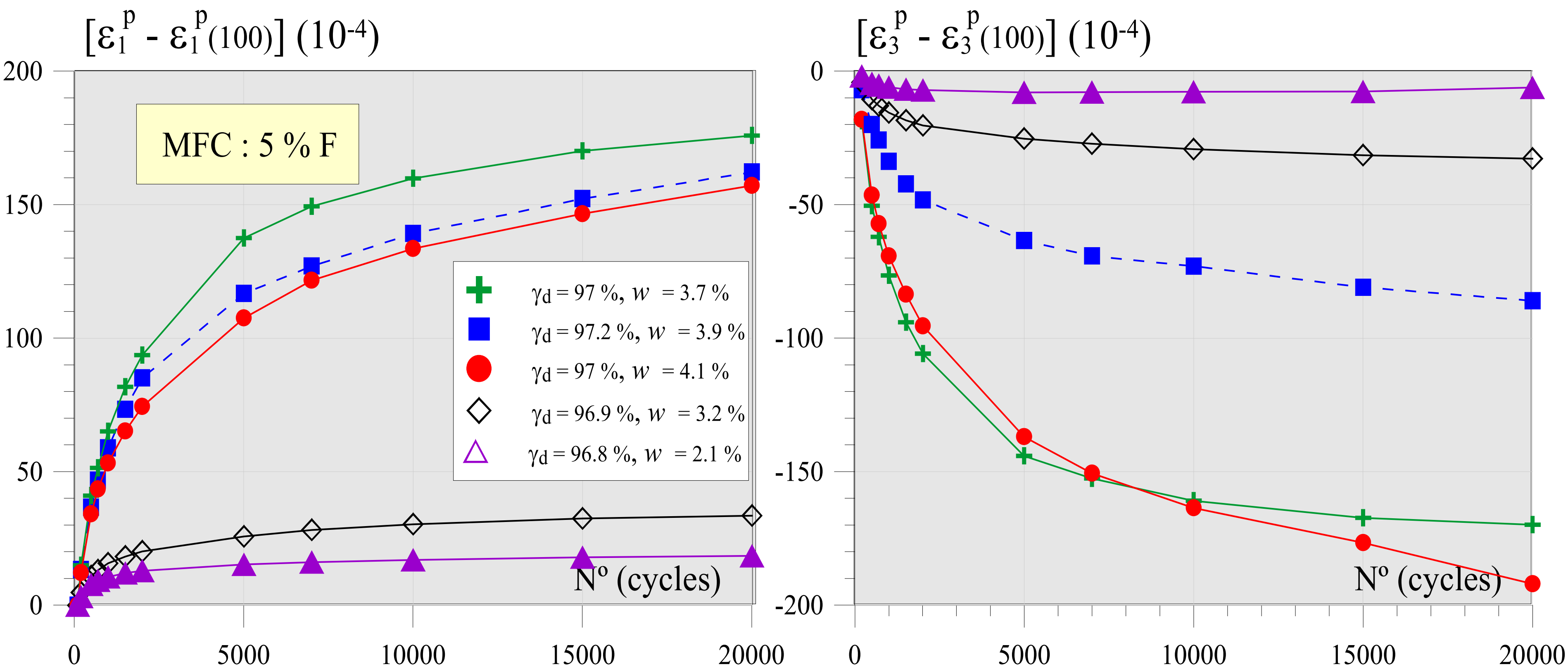
TYPICAL RESULTS OF CYCLIC TRIAXIAL TEST – Plastic strains

STABILISATION AFTER A NUMBER OF CYCLES ?

QUASI-ELASTIC BEHAVIOUR ?



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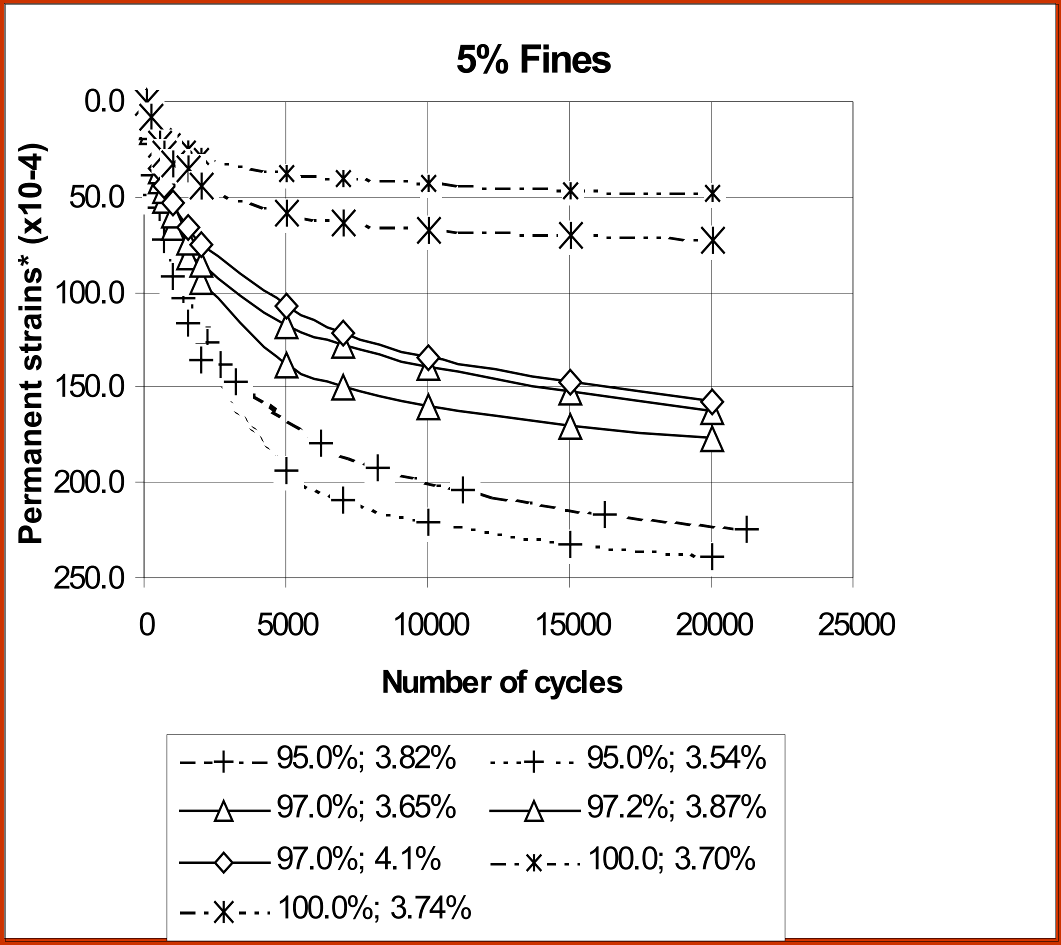
TYPICAL RESULTS OF CYCLIC TRIAXIAL TEST – Plastic strains



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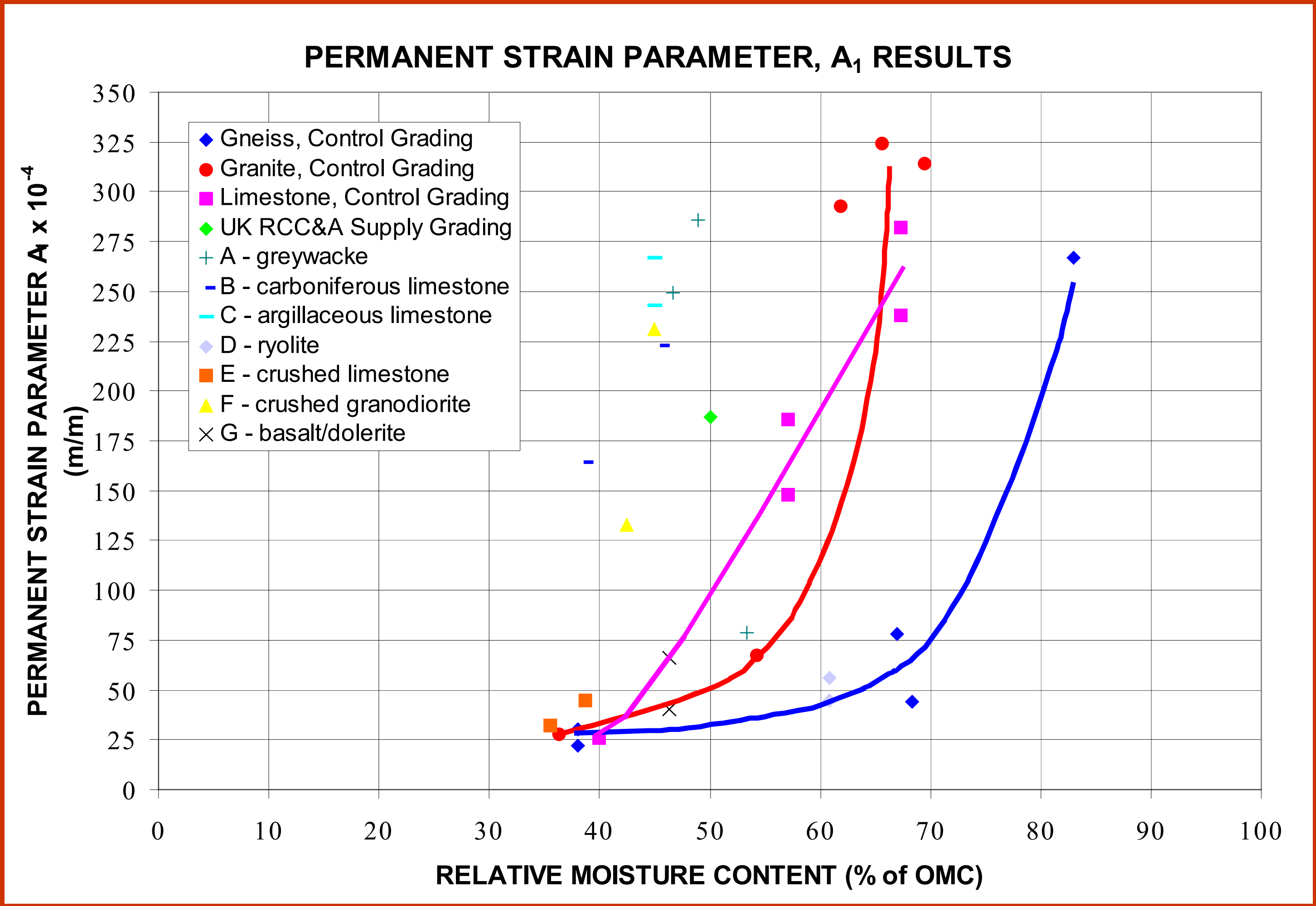
Courage test results



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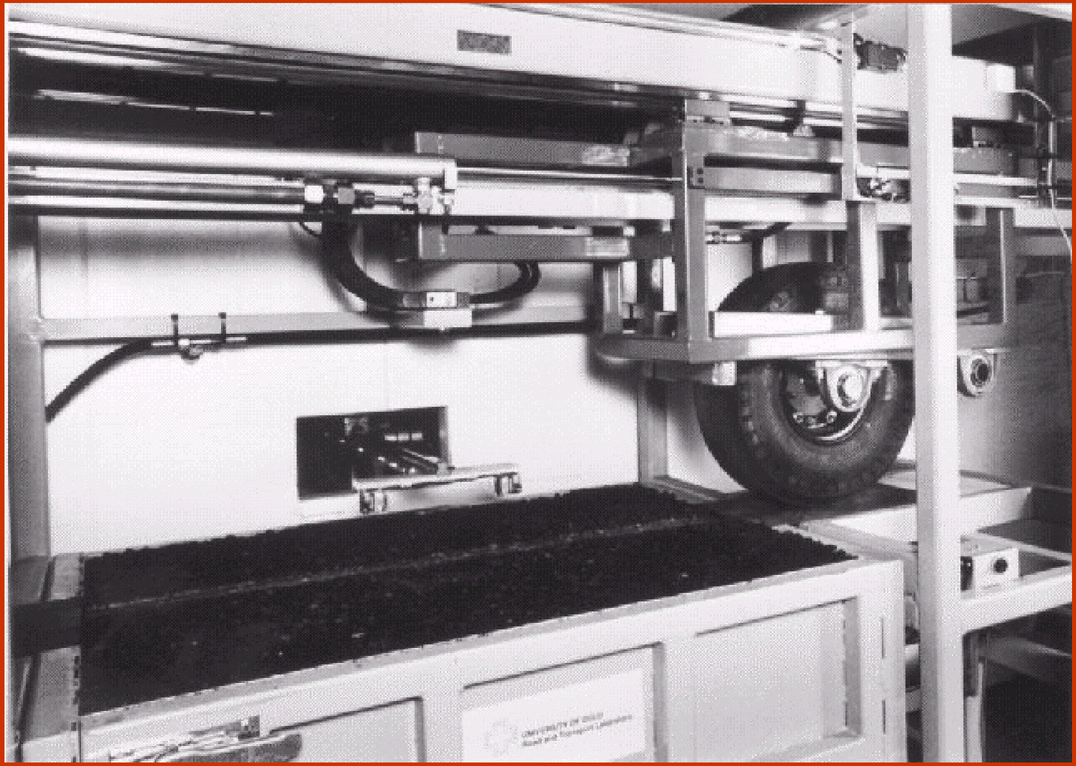
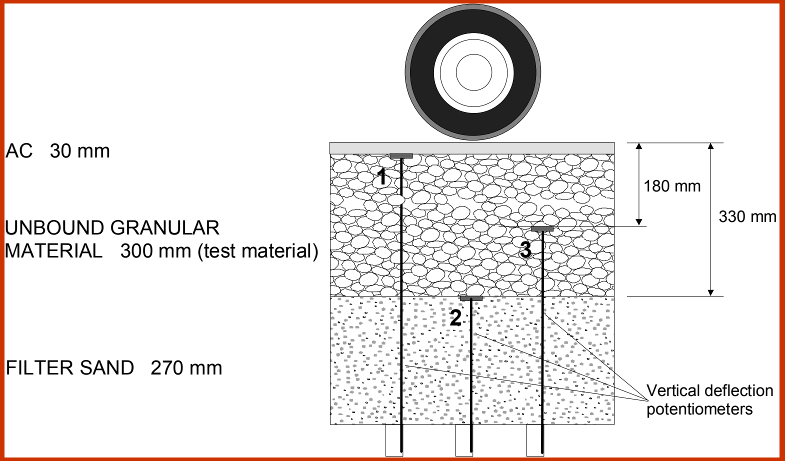
Wheel track – **University of Oulu – Fil.**





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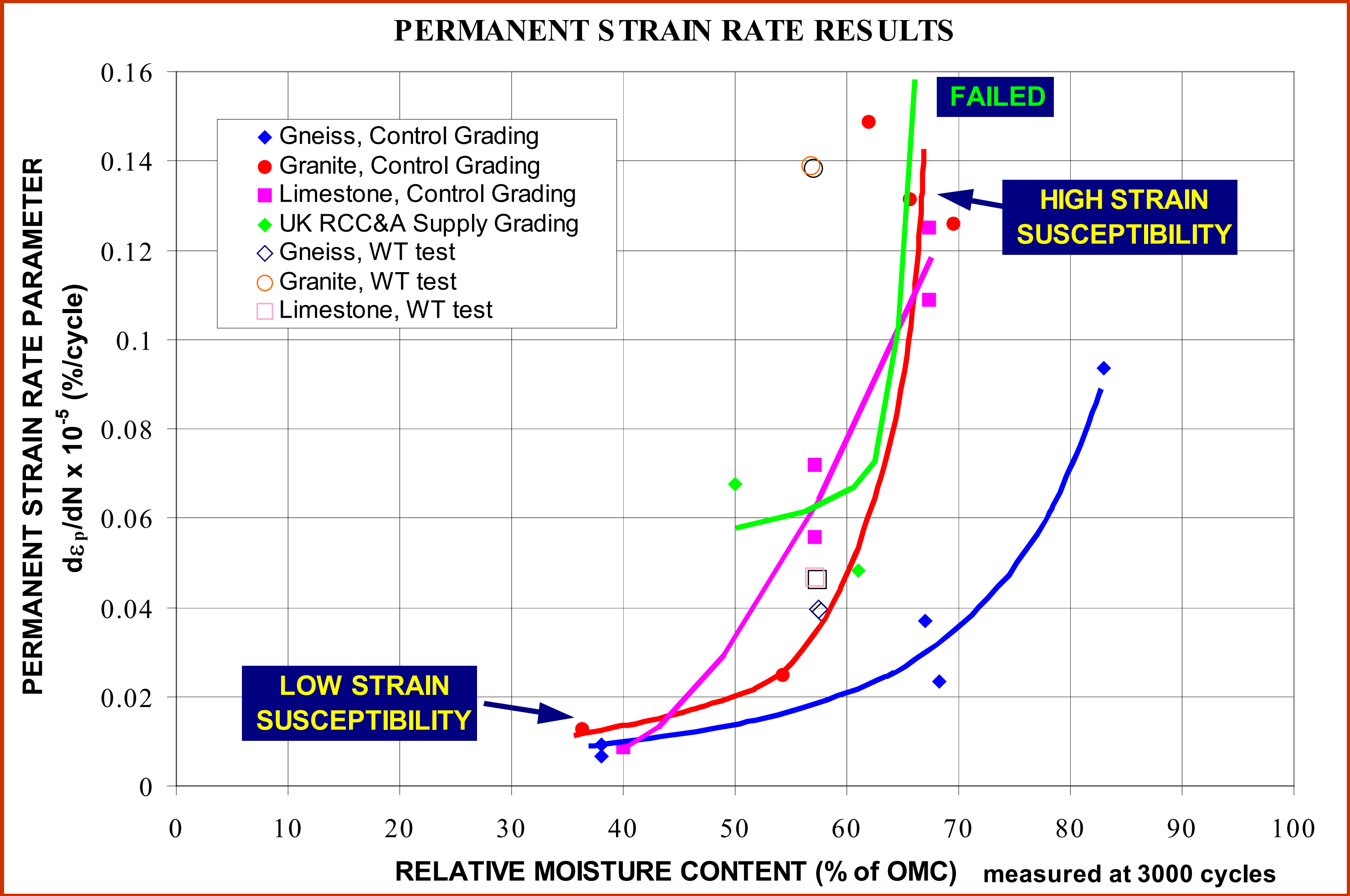
Courage test results



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TYPICAL RESULTS OF CYCLIC TRIAXIAL TEST- VCP

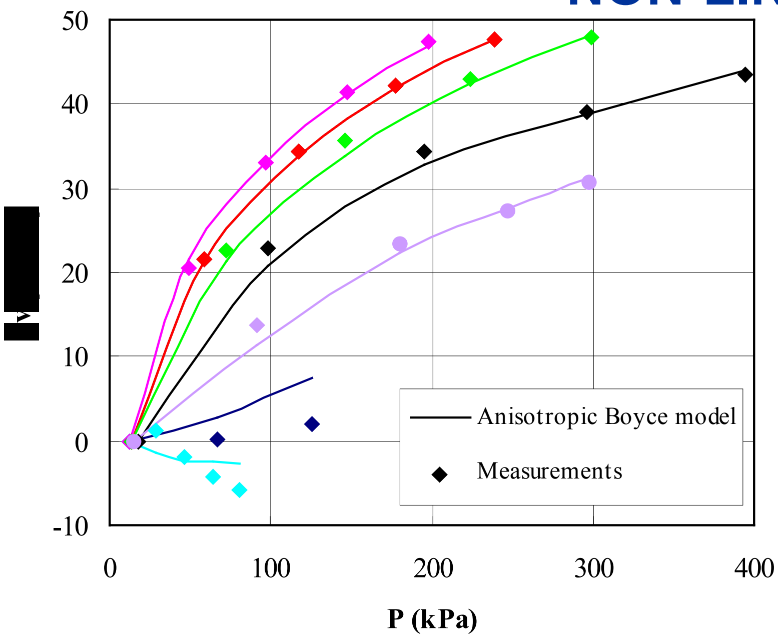
Un.-Rel. Strains (Anisotropic Boyce model; Hornych et al., 2000)

$$\varepsilon_v = \frac{p^{*n}}{p_a^{n-1}}\left[\frac{\gamma+2}{3K_a} + \frac{n-1}{18G_a}(\gamma+2)\left(\frac{q^*}{p^*}\right)^2 + \frac{\gamma-1}{3G_a}\left(\frac{q^*}{p^*}\right)\right]$$

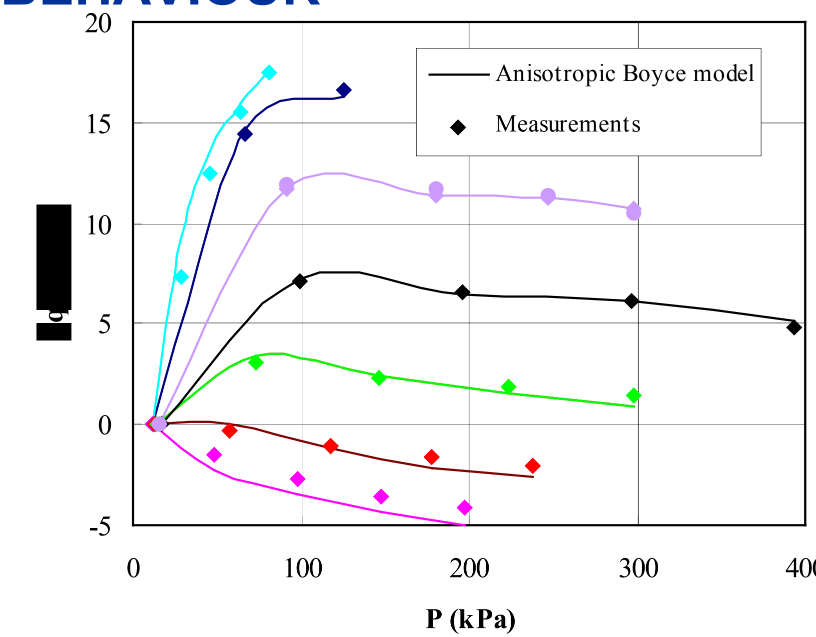
$$\varepsilon_q = \frac{2p^{*n}}{3p_a^{n-1}}\left[\frac{\gamma-1}{3K_a} + \frac{n-1}{18G_a}(\gamma-1)\left(\frac{q^*}{p^*}\right)^2 + \frac{2\gamma+1}{6G_a}\left(\frac{q^*}{p^*}\right)\right]$$

NON-LINEAR BEHAVIOUR

Volumetric strains



Shear strains



$$p^* = (\gamma\sigma_1 + 2\sigma_3)/3$$

$$q^* = (\gamma\sigma_1 - \sigma_3)$$

$$\varepsilon_v^* = \varepsilon_1/\gamma + 2\varepsilon_3$$

$$\varepsilon_q^* = \frac{2}{3}(\varepsilon_1/\gamma - \varepsilon_3)$$

$$K^* = \frac{\left(\frac{p^*}{p_a}\right)^{1-n}}{\frac{1}{K_a} + \frac{(n-1)}{6G_a}\left(\frac{q^*}{p^*}\right)^2}$$

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

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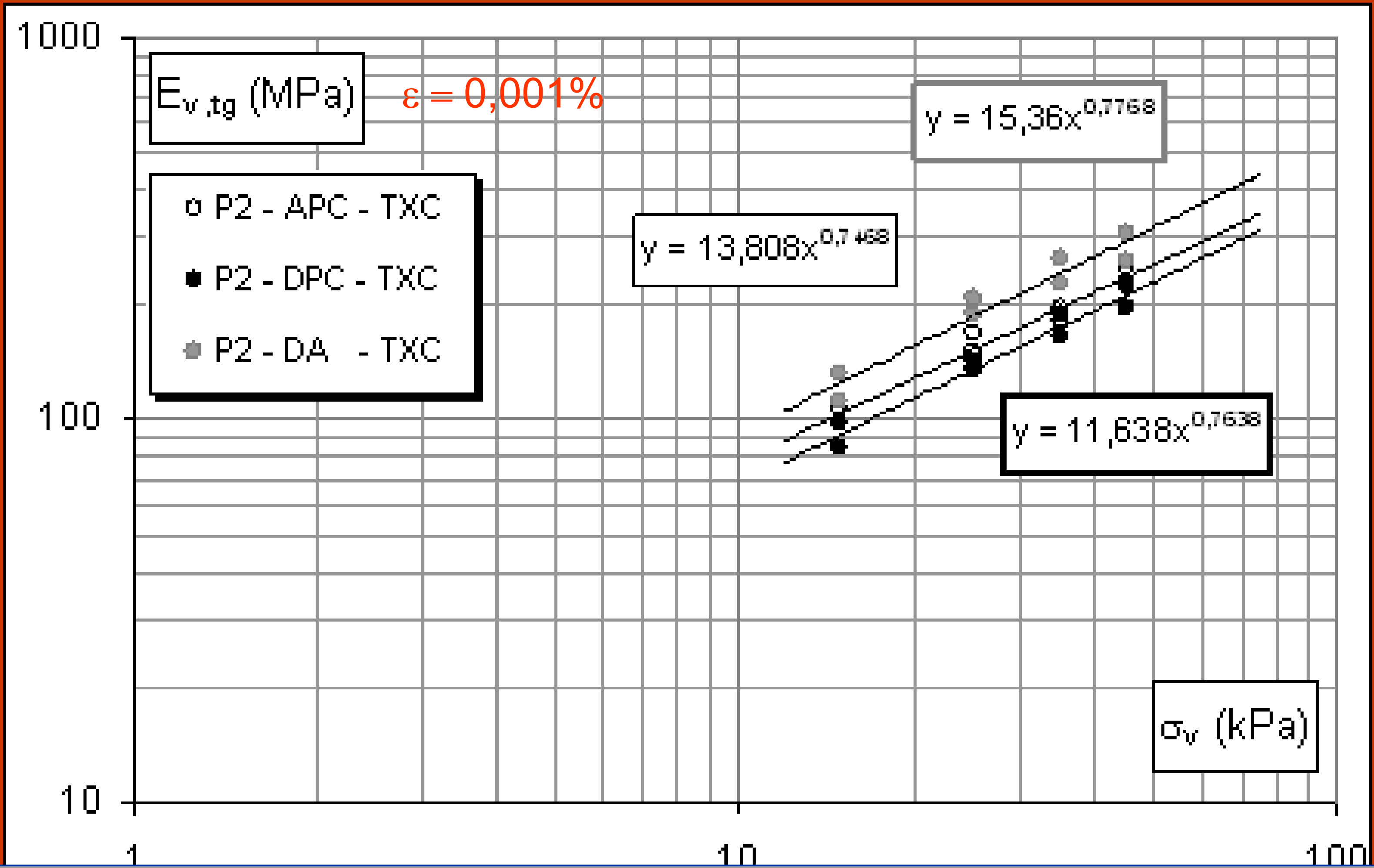
TYPICAL RESULTS OF CYCLIC TRIAXIAL TEST- CCP
Un.-Rel. Strains



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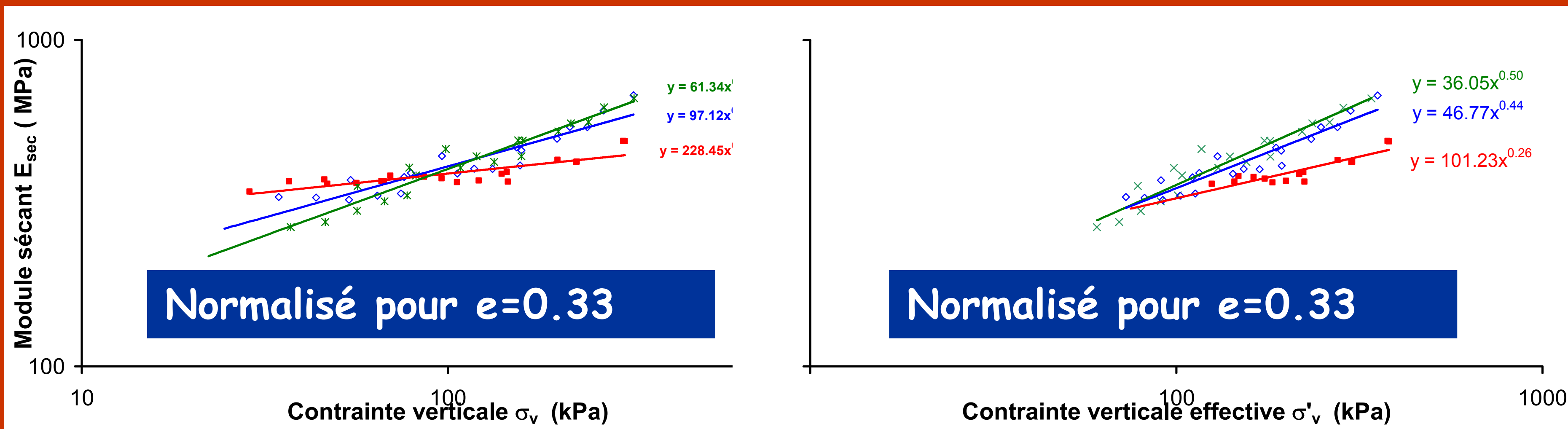
UGM – STIFFNESS RANKING
TOTAL STRESSES – EFFECTIVE STRESSES
(ECP, Coronado, 2005)



Soacha 30% fins d_{10}=20μm

E plus grand en contrainte totales

Servita 20% fins, d_{10}=45μm
Vista H. 10% fins, d_{10}=80μm

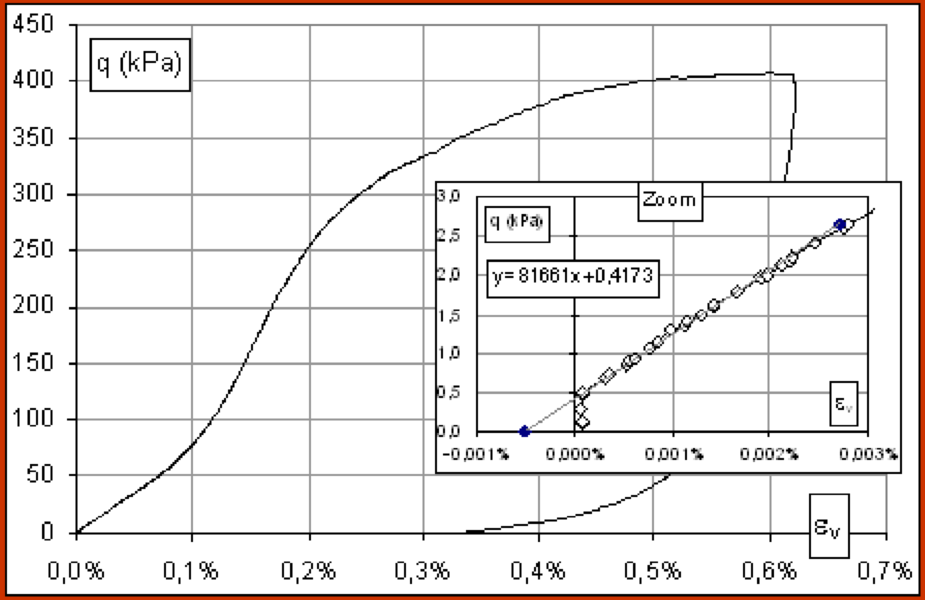
Soacha 30% fins d_{10}=20μm

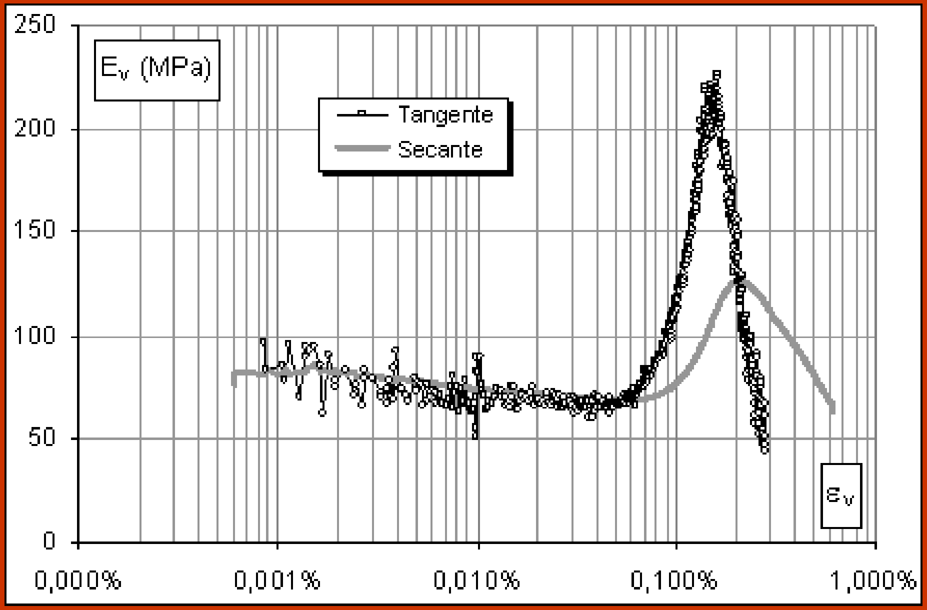
E plus petit en contrainte effectives

Servita 20% fins, d_{10}=45μm
Vista H. 10% fins, d_{10}=80μm

TYPICAL RESULTS OF COMPRESSION TRIAXIAL TEST- CCP

PECULIAR BEHAVIOUR OF COMPACTED UGM





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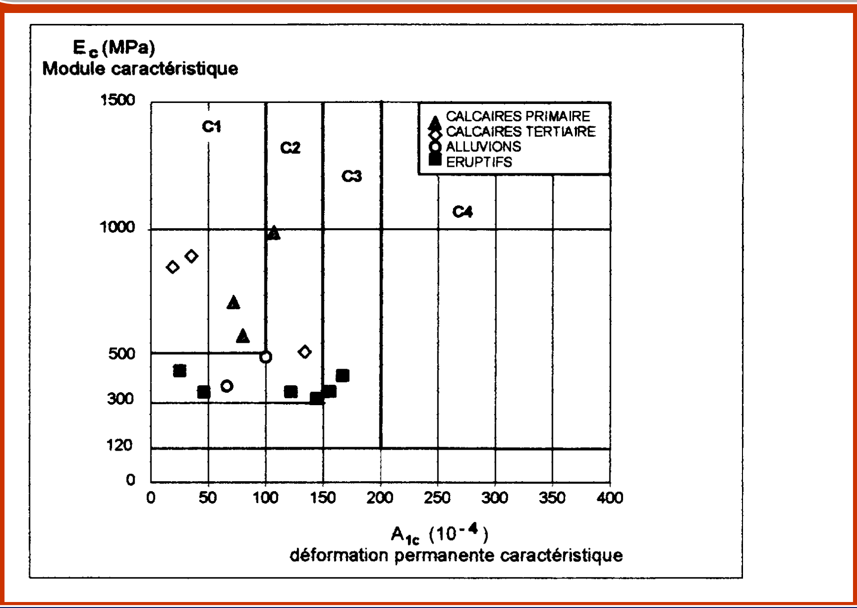
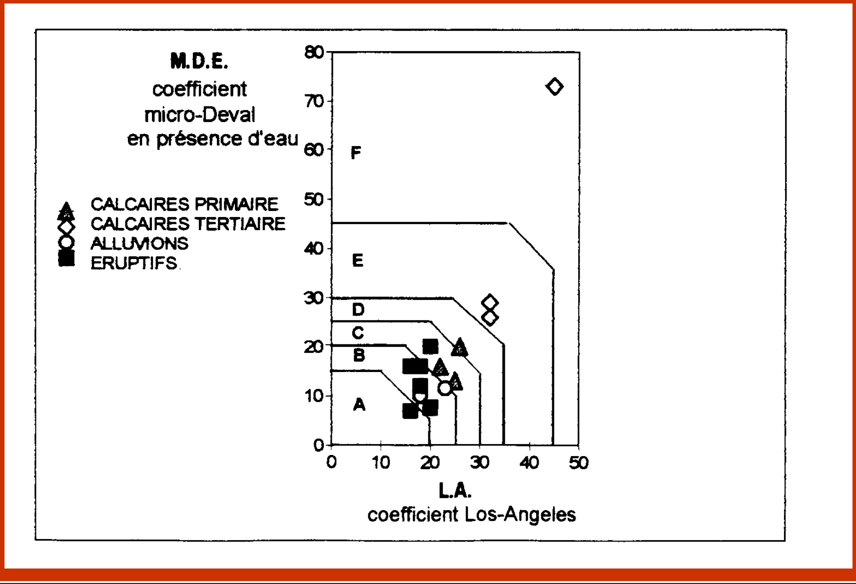
EMPIRICAL versus MECHANICAL PARAMETERS

QUALITY ASSESSMENT





DIFFERENT RANKING !

Processed materials behave in a different way to natural materials - Los Angelos and Micro-Deval.

They generally give better mechanical performance in the field than would be expect from the results of such tests.

Therefore performance-related tests (CLTx)

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QUALITY ASSESSMENT

FIELD

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UGM – QUALITY ASSESSMENT BY IN-SITU TESTS

- **SIMPLE TESTS:** to density and moisture content material assessment
- **FUNCTIONAL TESTS:**
  - **Construction level -** to assess the bearing capacity of UGM to carry loading applied and the capacity of spreading the loading (LPT, FWD, SASW, …).
  - **Long term behavior -** to assess stifness - capacity of spreading the loading (LPT, FWD, … -representative state conditions?) and resistance to permanent deformation (LPT - permanent deformation).

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NEED TO MOVE FROM EMPIRICAL TO MECHANISTIC-BASED SPECIFICATIONS

MECHANISTIC-BASED SPECIFICATIONS

(focus on the mechanical properties)

FACILITATE QUANTITATIVE EVALUATIONS

(necessary to alternative construction practices and materials – reclaimed materials)

Performance-based specification is required to control the long-term functional and structural performance

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MECHANICAL-BASED IN SITU TESTS, AIPCR, C12, 1995

- *PLATE BEARING TEST*
- CALIFORNIA BEARING RATIO TEST - CBR
- DYNAPLAQUE
- *FALLING WEIGHT DEFLECTOMETER – FWD*
- DEFLECTOGRAPH
- CLEGG IMPACT HAMMER
- MEXECONE PENETOMETER
- DYNAMIC CONE PENETROMETER
- *COMPACTION METERS*
- *DYNAMIC PLATE BEARING TESTS*
- VARIABLE IMPACT TESTER

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STIFFNESS - TARGET VALUES

(Chaddock & Brown, 1995); Zaghloul, 1997; Flemming, 2000; Nunn et al., 1997; GTR, 1997)

STIFFNESS

- **50 MPa – Formation** (GTR, 1997)
- **50 to 65 MPa – Formation** (Flemming et al., 1998)
- **100 MPa – Foundation** (Flemming et al., 1998)
- **80 MPa – Formation - FWD – stress=200 kPa; D=450 mm** (Chaddock & Brown, 1995)
- **45 MPa – E_{v2} – DIN - Foundation**
- **120 MPa – E_{v2} – DIN – Sub-base (light traffic)**
- **150 MPa – E_{v2} – DIN – Sub-base (heavy traffic)**

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CONSTRUCTION TECHNOLOGIES

- **Rockfill** (experience from dam construction)

Soil and rock mixtures

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ROCKFILL COMPACTION
Punctual control: density+water content

SOIL COMPACTION
Punctual control: density+water content

REQUIREMENTS FOR HOMOGENEITY

Brandl (1977)

Parameters	Coefficient of variation v (%)		
	Subgrade	Sub-base	Base
Dry density	5	4	3
Moduli (Ev1, Ev2)	30	20	15

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ROUTINE ANALYSIS

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MODULUS 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

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

DEPENDANT ON:

Strain level

Stress history

Relative density

Ambient stress

Compressibility

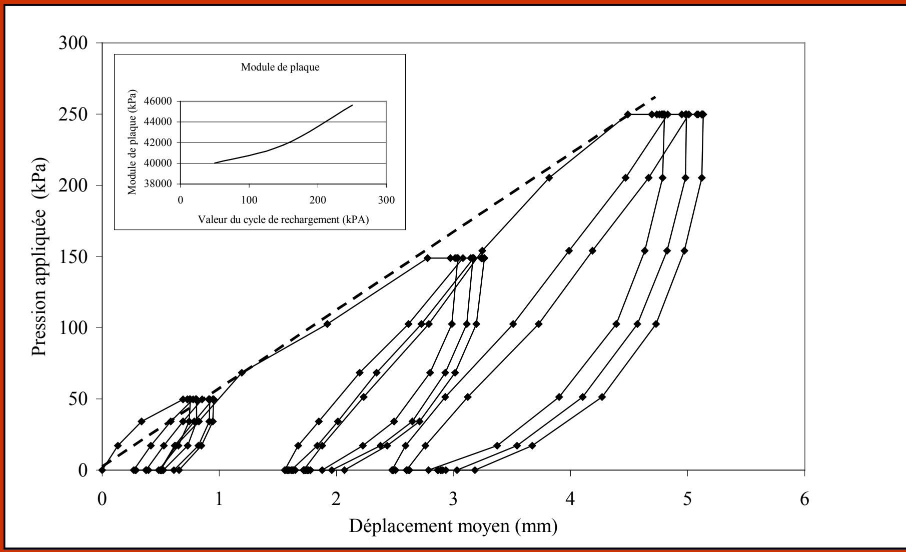
Aging & Fabric

Strain rate

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

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

Punctual control: LPT (ASTM, DIN, LCPC)



$$E = \frac{1{,}5\, Q_{appl}\; D/2\left(1 - \upsilon^{2}\right)}{\delta}$$

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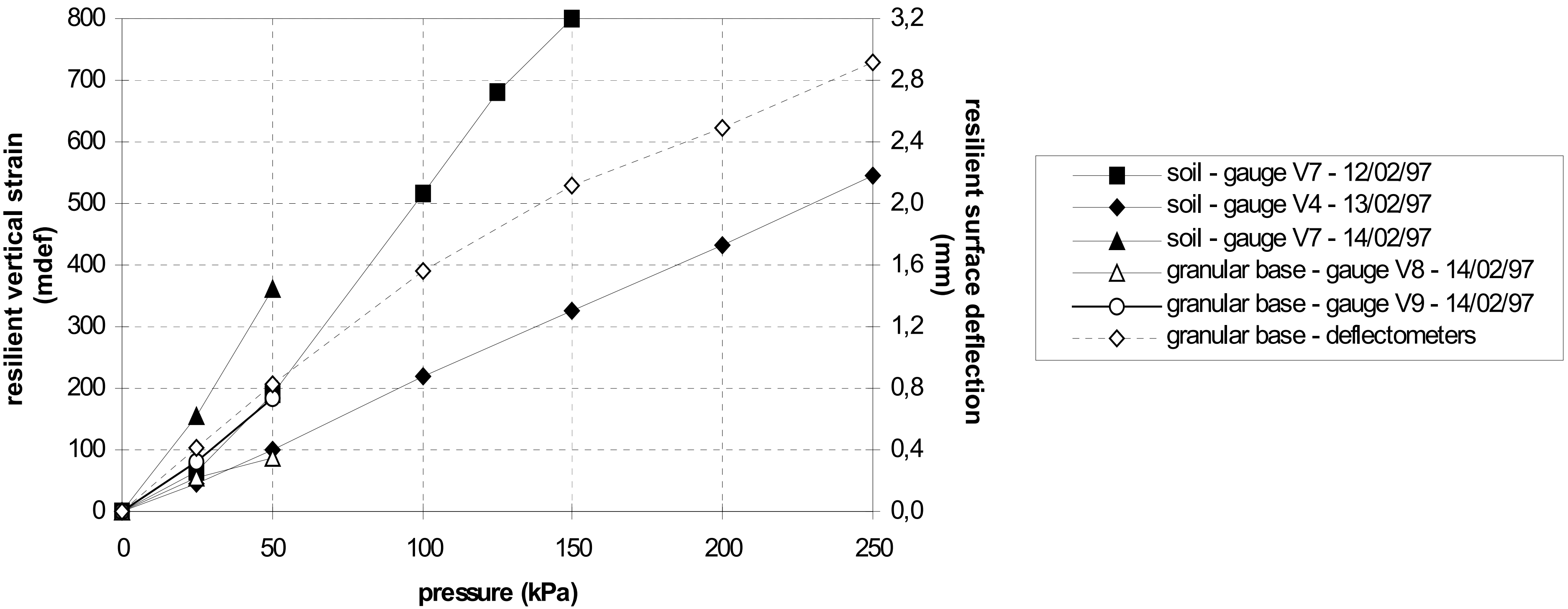
PLATE LOAD TESTS ON THE UGM BASE
Response of Soil and Granular Base



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

(Nazarian et al., 1987; Rix & Stokoe, 1990; Stokoe, 2004; Allen et al., 2000)

- ***Principle:***
  - Measuring the propagation velocity of surface waves of Rayleigh type, generating an experimental dispersion curve (wave velocity versus frequency), and evaluating shear wave velocity profile (G_0) by matching theoretical dispersion curve with experimental curve.

- ***Advantages:***
  - It is non destrutive.
  - Any layer thikness can be evaluated.
  - Soft layers after compaction may be detected after construction.
  - Stiffness evaluations represent moduli values which are independent of strain level (e<0,001%).
  - Stiffness is a mechanical property showing how pavement will deflect under traffic loads.
  - Reduction factor can be applied to convert the small strain shear modulus in a serviceability modulus.

DENSITY TESTS AND SASW TESTS COMPLET EACH OTHER AND CAN BE USED TOGETHER TO GAIN A COMPREHENSIVE ASSESSMENT OF THE QUALITY OF THE FINAL COMPACTED MATERIAL

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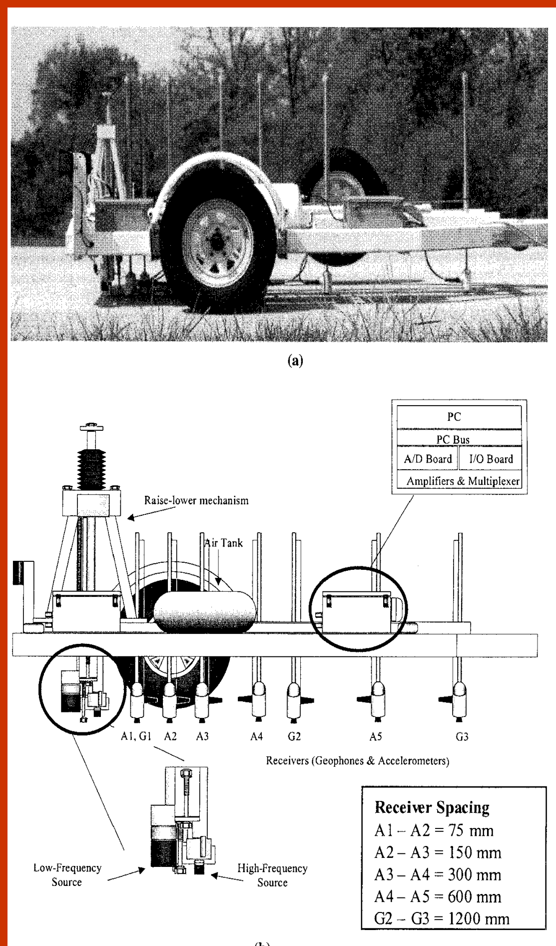
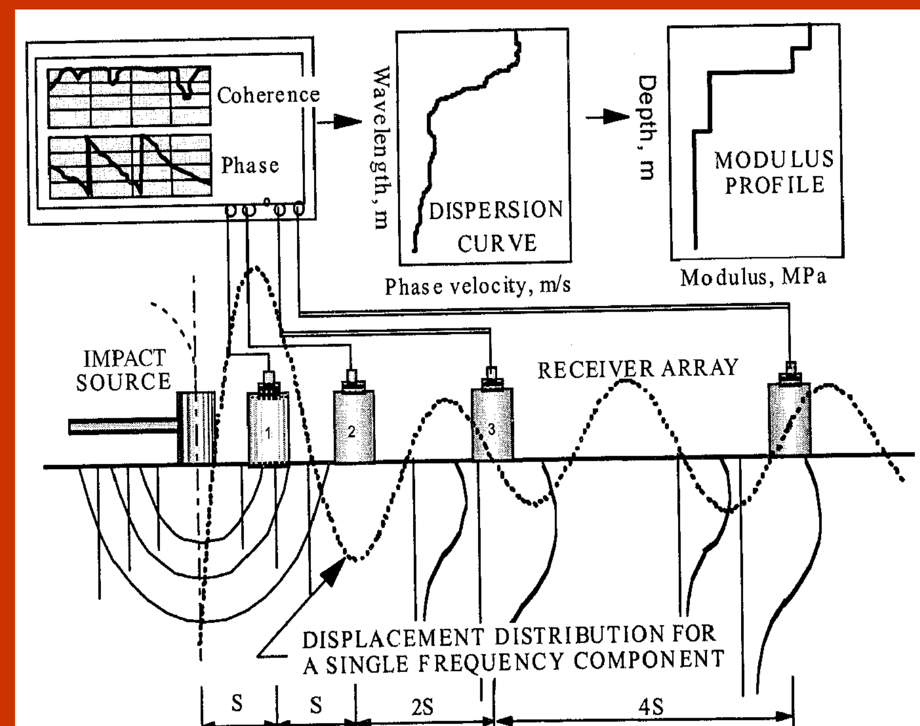
PAVEMENT EVALUATION
Punctual control: Stiffness

Seismic pavement analyser (SPA)





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(FWD)
Punctual control: Stiffness

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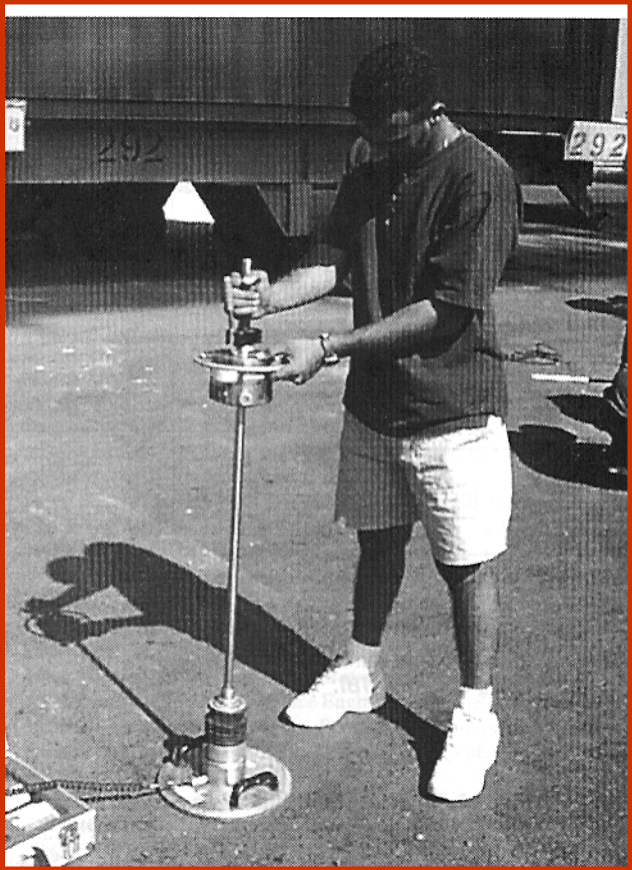
SOIL COMPACTION
Punctual control: Stiffness (**LDW**)



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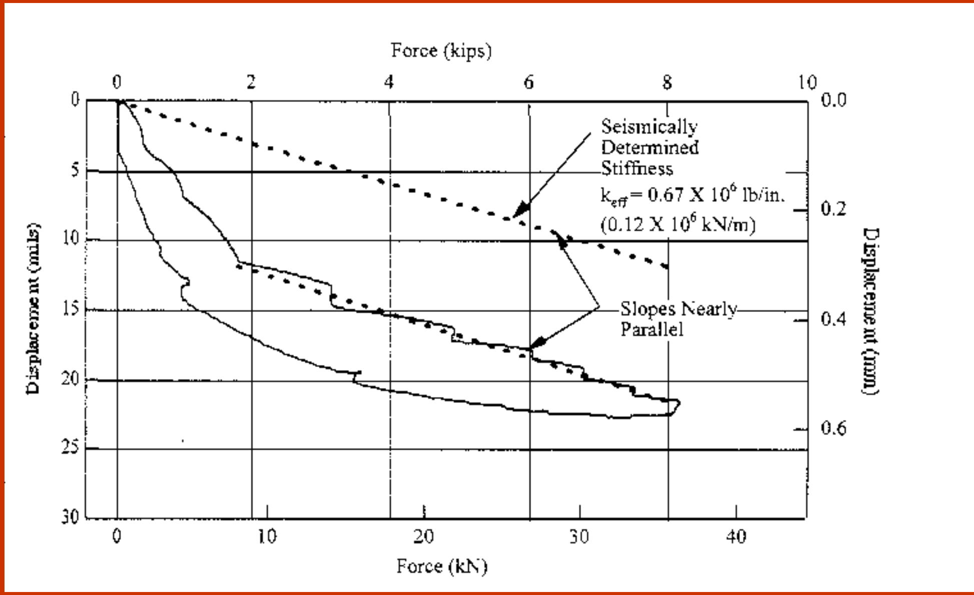
SASW versus LPT

(Allen et al., 2000)



STIFFNESS FROM SASW MAY NEED TO BE CORRECTED TO THE SAME STRAIN LEVEL OF LPT

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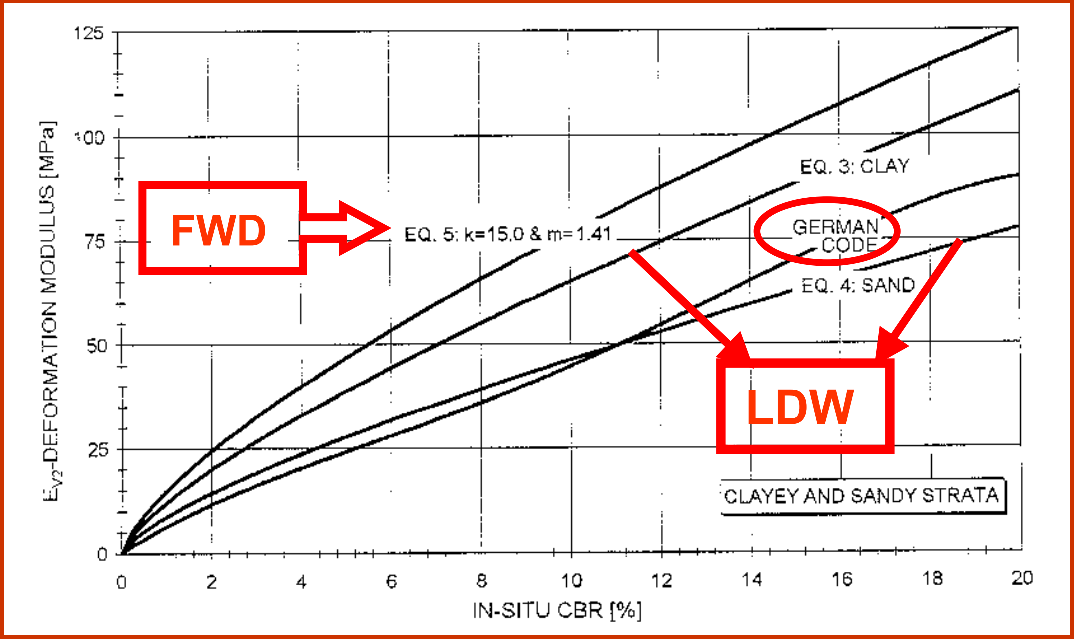
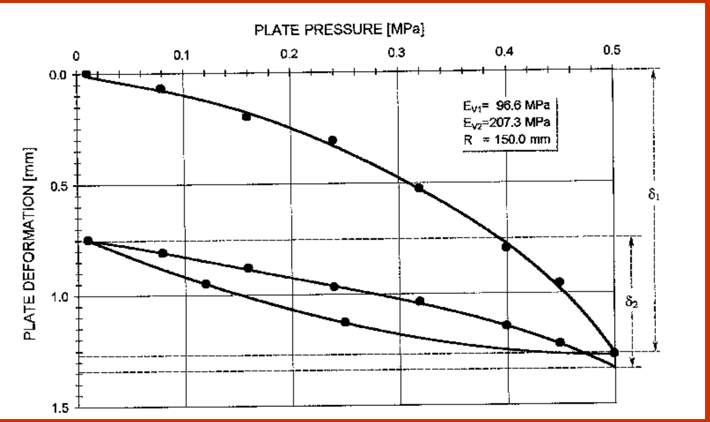
FWD versus LDW
E_{v2} (FWD, LDW) - $CBR_{in\ situ}$ (DCP)

(Livneh & Goldberg, 2001)





(3) $$E_{v2} = 600 \times \ln \frac{300}{300 - 6{,}019 \times CBR^{(1/1{,}41)}}$$

(4) $$E_{v2} = 600 \times \ln \frac{300}{300 - 4{,}0354 \times CBR^{(1/1{,}41)}}$$

(5) $$CBR = \left(\frac{E_s}{k}\right)^m$$

German code: Ev2 LPT

DISCREPANCY IN THESE RESULTS SHOW THE NEED TO USE MORE MECHANISTIC APPROACH

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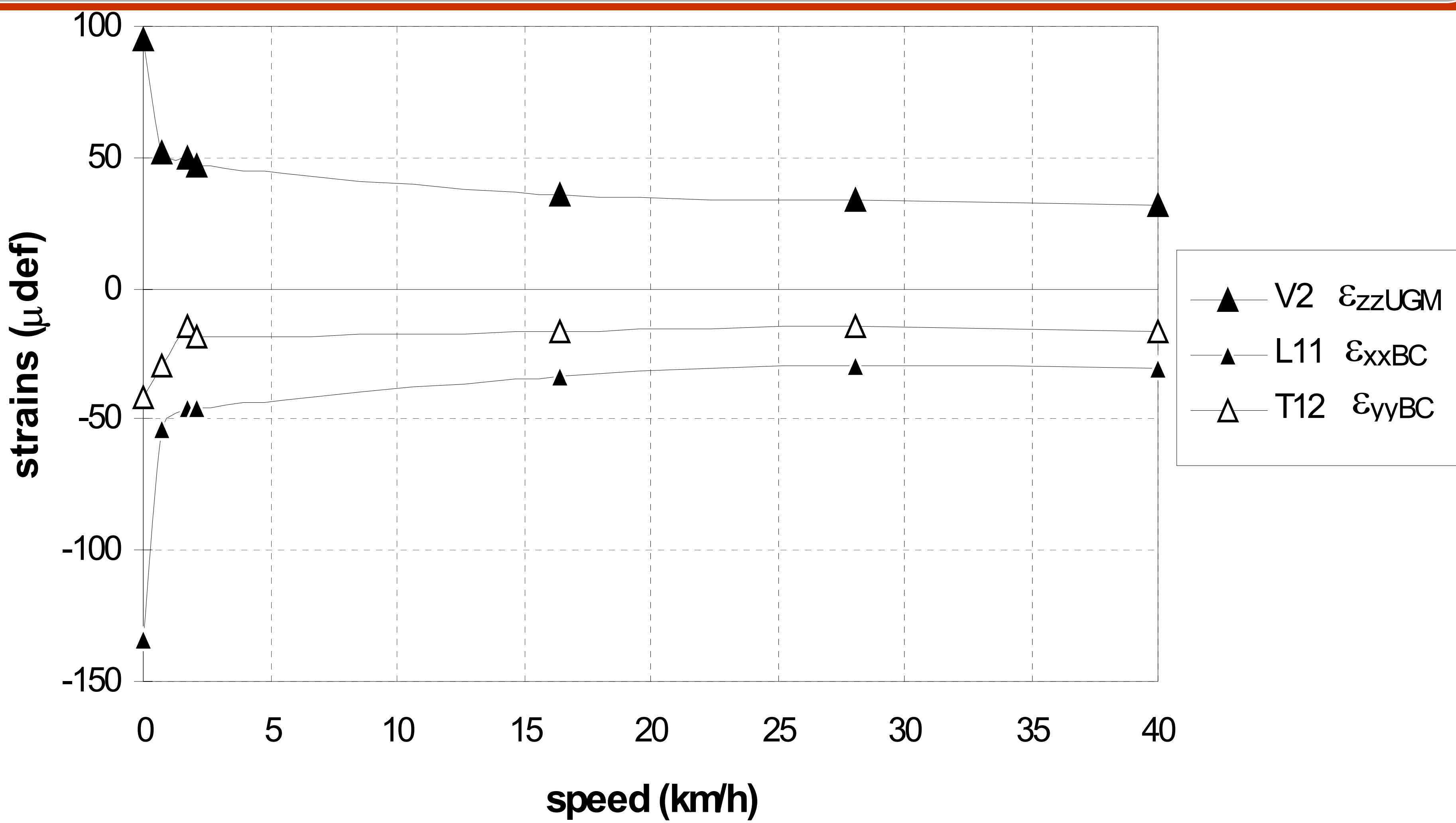
EFFECT OF LOADING SPEED ON BC & UGM STRAINS



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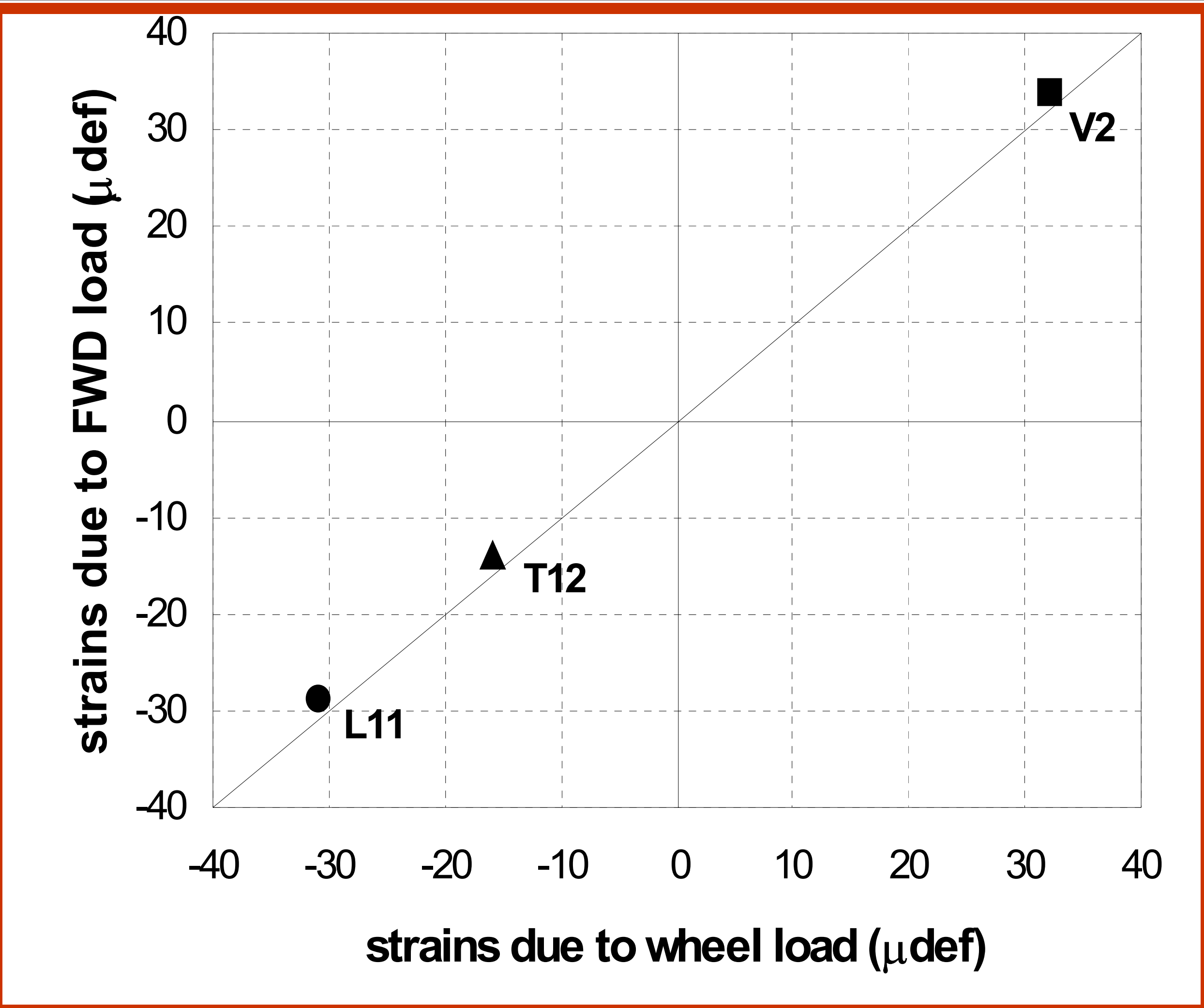
STRAINS MEASURED BY FWD AND WHEEL LOAD TESTS (40 km/h)



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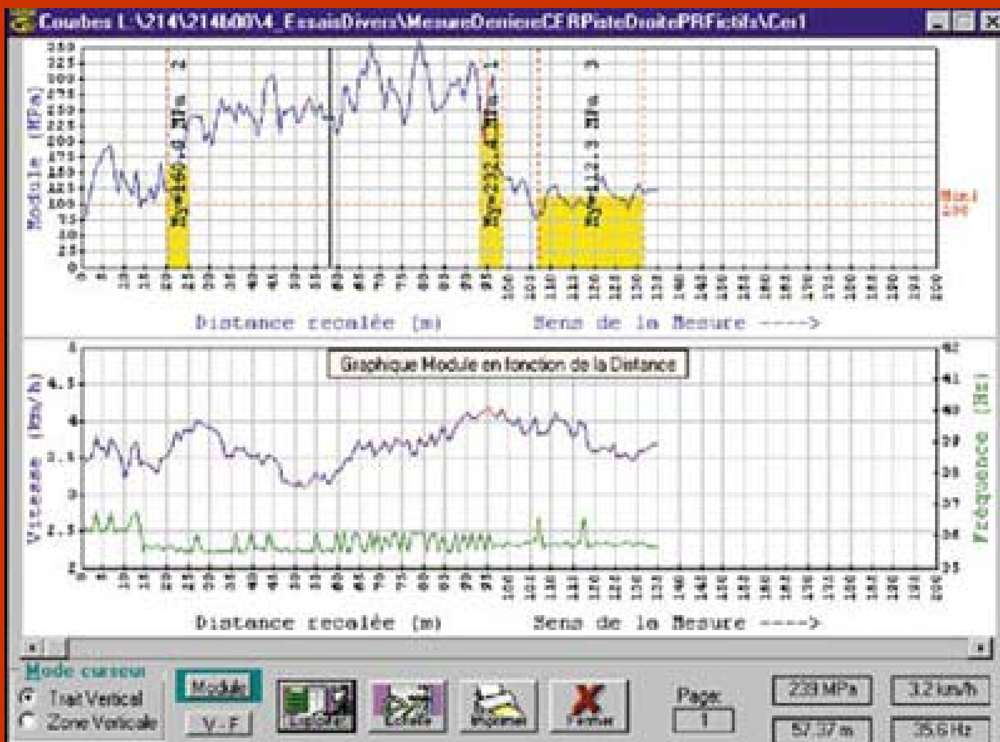
CONTINOUS COMPACTION CONTROL
(LPC; Quibel, 1998)



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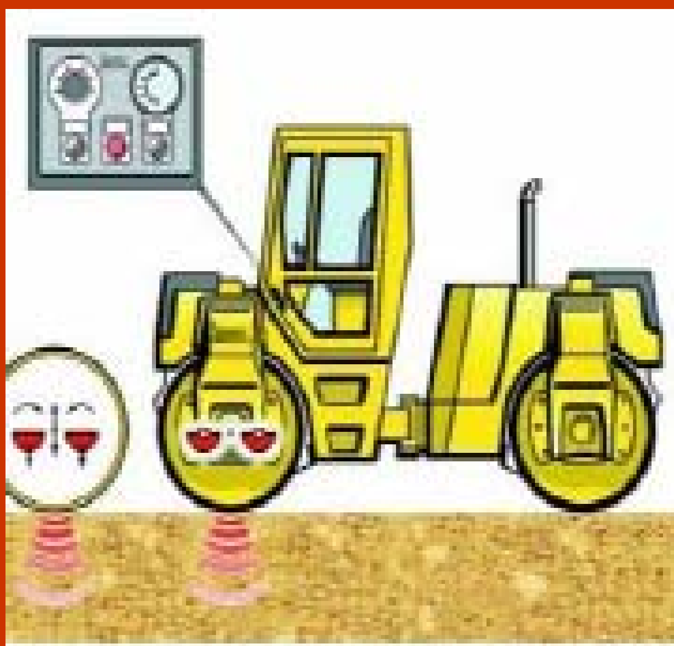
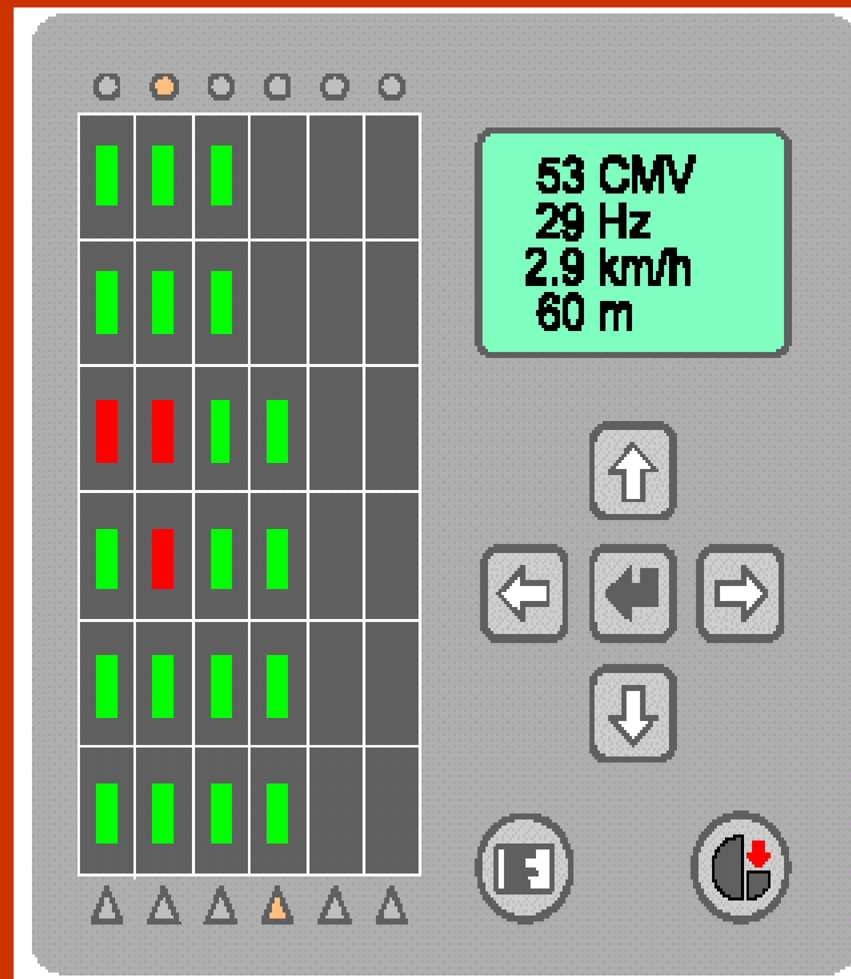
OPTIMISATION OF COMPACTION





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Reduce differential settlements (for H until 120m total relative settlement is less of 1/1000)

- In many cases embankments exhibit significant advantages over bridges:
  - facilitate balance of cut and fill volume during construction;
  - environment-friendly
  - negligible long term maintenance
- Reduce differential settlements between bridge deck and adjacent embankment fill.

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ADVANCED ANALYSIS

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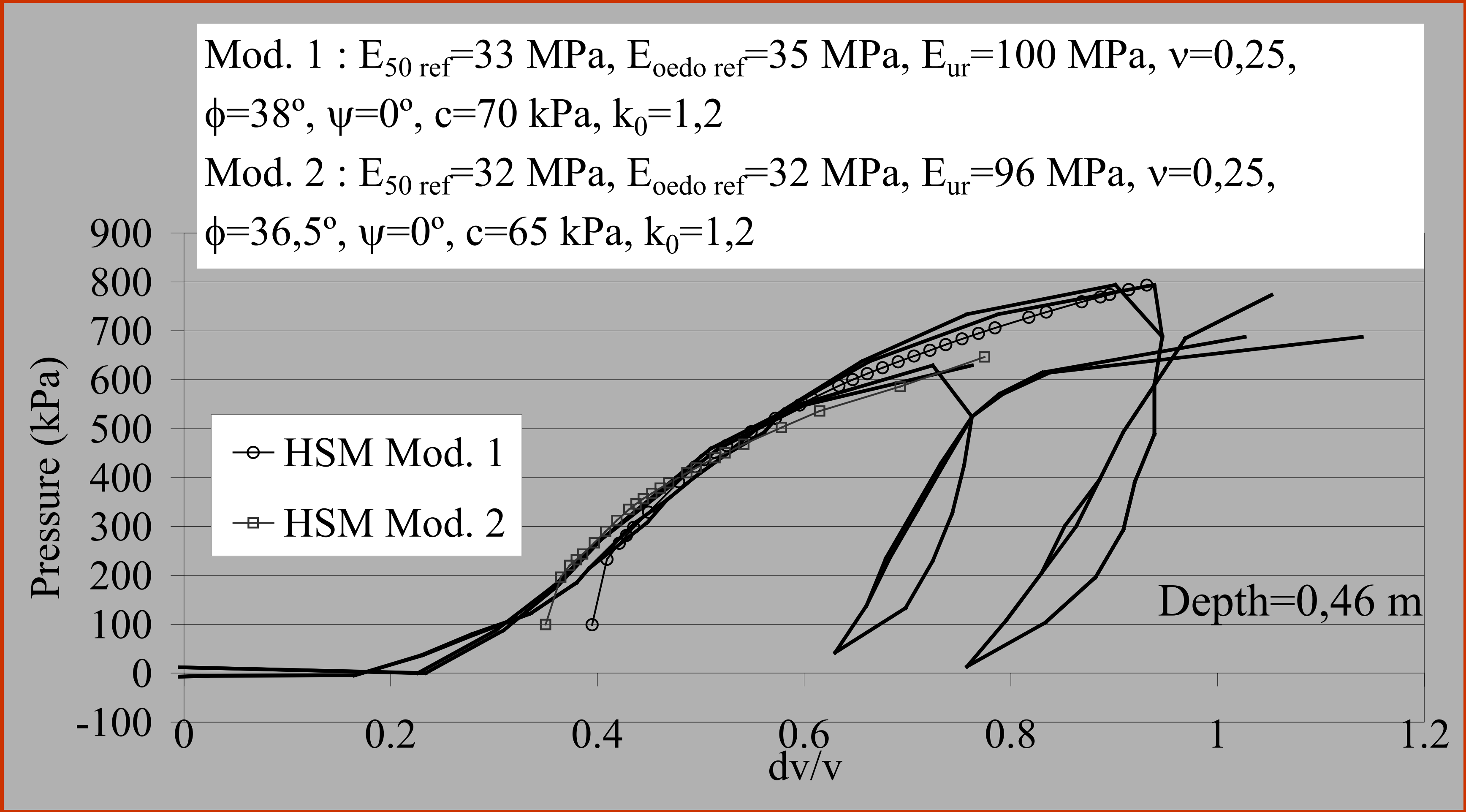
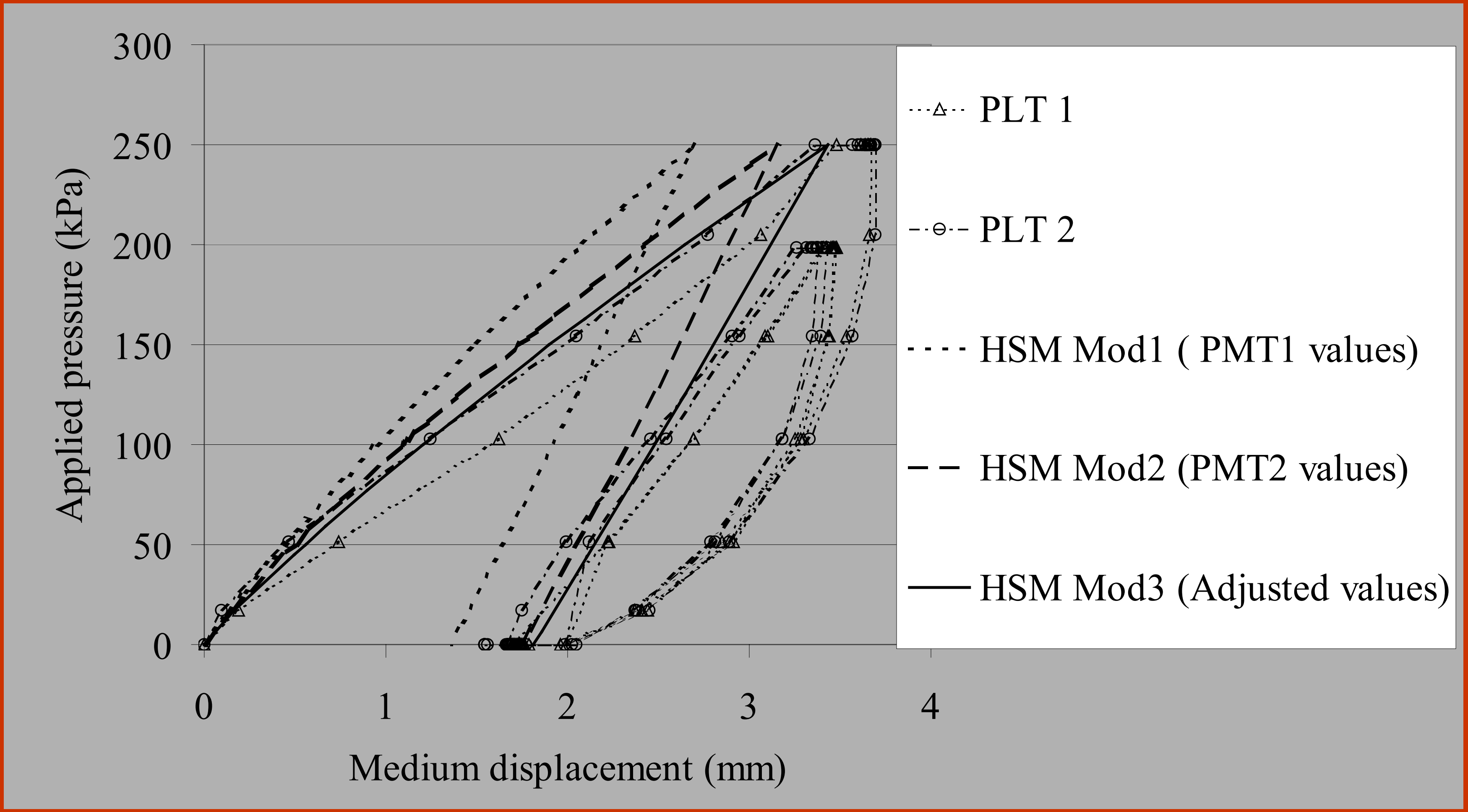
PMT

HSM - PLAXIS



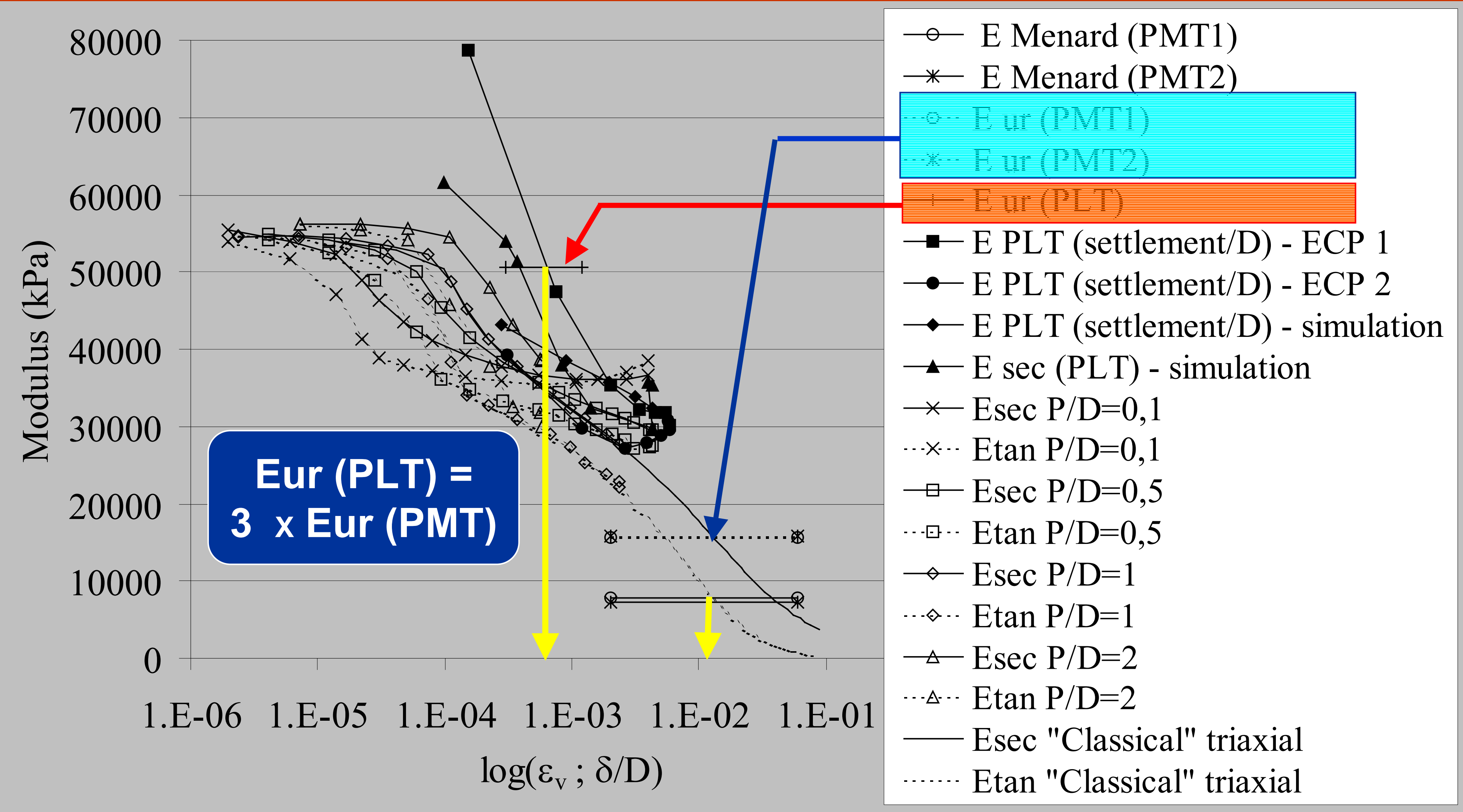
PLT

HSM - PLAXIS



HSM Mod3: γ=18 kN/m3, E50ref =27,5 MPa, Eoedoref =27,5 MPa, Eur=82,5 MPa, m=0,5, c=70 kPa, ϕ=38º, ψ=0º, n=0,25, k0=1,2

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



FINAL REMARKS

FINAL REMARKS (1/4)

- NEED TO MOVE FROM EMPIRICAL APPROACH TO MECHANISTIC APPROACH
- MOVE FROM SIMPLE TESTS TO FUNCTIONAL TESTS – USE OF NEW MATERIALS IN ROAD CONSTRUCTION
- SELECTION OF MATERIALS MUST BE BASED IN MECHANICAL TEST RESULTS USING INTEGRAL MATERIAL AT THE STATE CONDITIONS EXPECTED IN THE FIELD

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FINAL REMARKS (2/4)

- NON-LINEAR BEHAVIOUR OF SOILS AND UGM COMPLICATES IN-SITU TEST INTERPRETATION

MAY CONFLICT WITH SIMPLIFIED ASSUMPTIONS IN THE PAST

DIRECT USE OF MODULI IN PRACTICE ONLY IF:
OBTAINED FOR THE SERVICEABILITY STRESS-STRAIN CONDITIONS

ANY CORRELATION OF IN-SITU TEST RESULTS SHOULD SPECIFY THE TYPE OF EQUIPMENT AND TEST PROCEDURE, THE TYPE OF MODULUS OR ANGLE OF SHEARING RESISTANCE

FINAL REMARKS (3/4)

- CURRENT PRACTICE HAS TO BE SUPPLEMENTED BY TEST METHODS THAT WILL PROVIDE CONTINUITY BETWEEN DESIGN (laboratory) AND CONSTRUCTION (field)
- G_0 IS THE BEST PARAMETER TO BE USED

Incorporation of Seismic in the different tests will be of valuable use

CORRELATIONS MUST BE ESTABLISHED WITH G0 AND NOT WITH CBR

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FINAL REMARKS (4/4)

- COMPARISON BETWEEN TEST RESULTS – MODULI- IS ONLY POSSIBLE BY NORMALISING STRESS & STRAIN LEVELS OF TESTS

EXPERIMENTAL AND ANALYTICAL STUDY IN A GRANITE SHOW THAT:

E_{UR} (PLT) ~3 x E_{MUR} (PMT)

E_M (PMT) ~1%; E(PLT) ~ 0,1% (ASTM STANDARDS)

COMPAIRISON OF TEST RESULTS

BACK ANALYSIS OF STRESS-STRAIN CURVES OR LOAD-DISPLACEMENT RESULTS

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