University of BRISTOL

International Workshop

ExchangeRisk

System modeling of cyclic loaded embedded geostructures in natural soil conditions

Wuttke, F., Kafle, B., Stutz, H., Basnet, M.

Kiel University / Chair of Geomechanics and Geotechnics

August 31, 2016, Bristol, UK

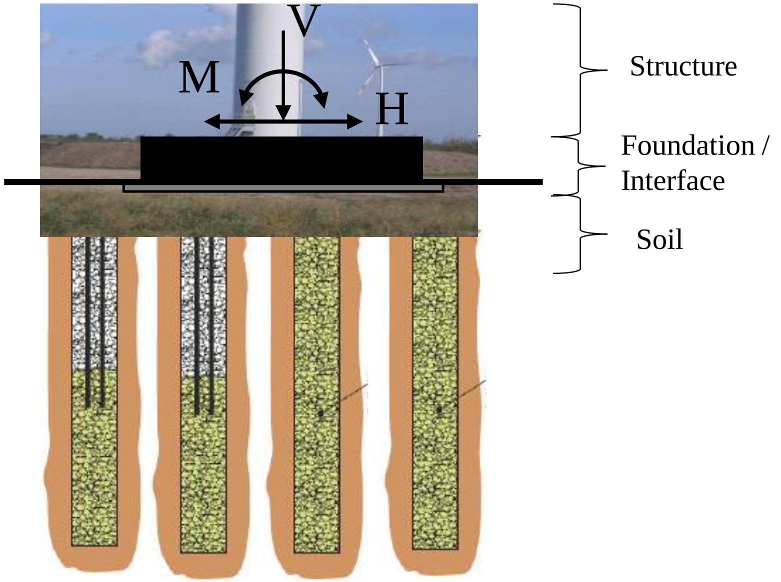
Introduction

Natural site conditions

- Small until medium strain condition
- Water table / unsaturated soil conditions
- Zementation
- Seasonal variation

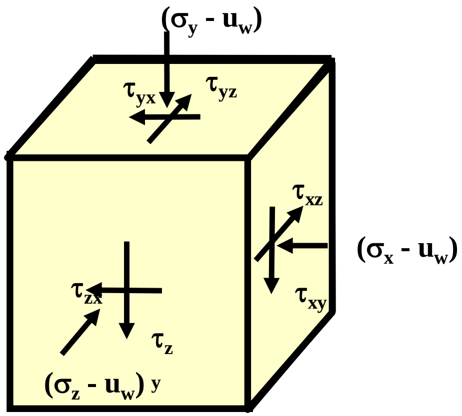
Active and Passive Cyclic/ dynamic sources

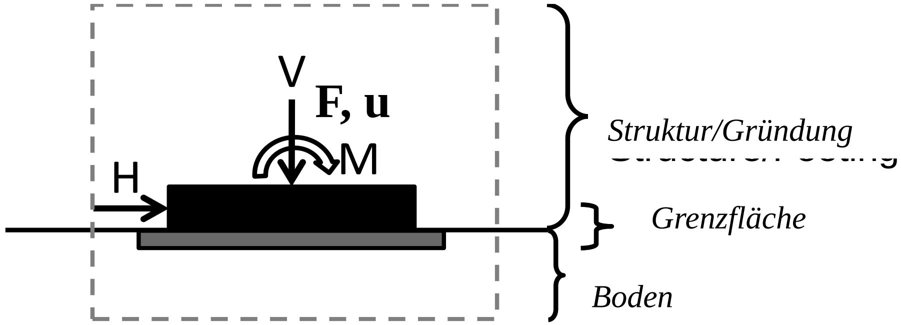
Repowering



Model concept

Modell reduction





Measure of System response - 6 degree of freedoms under multi-phase and zementation condition

Elementtest

1g Technikumstest

Model concept / unsaturated conditions

Soil usually a Multi Phase System

Dry soil: solid & air (filled most pore) → Zero pore-water pressure

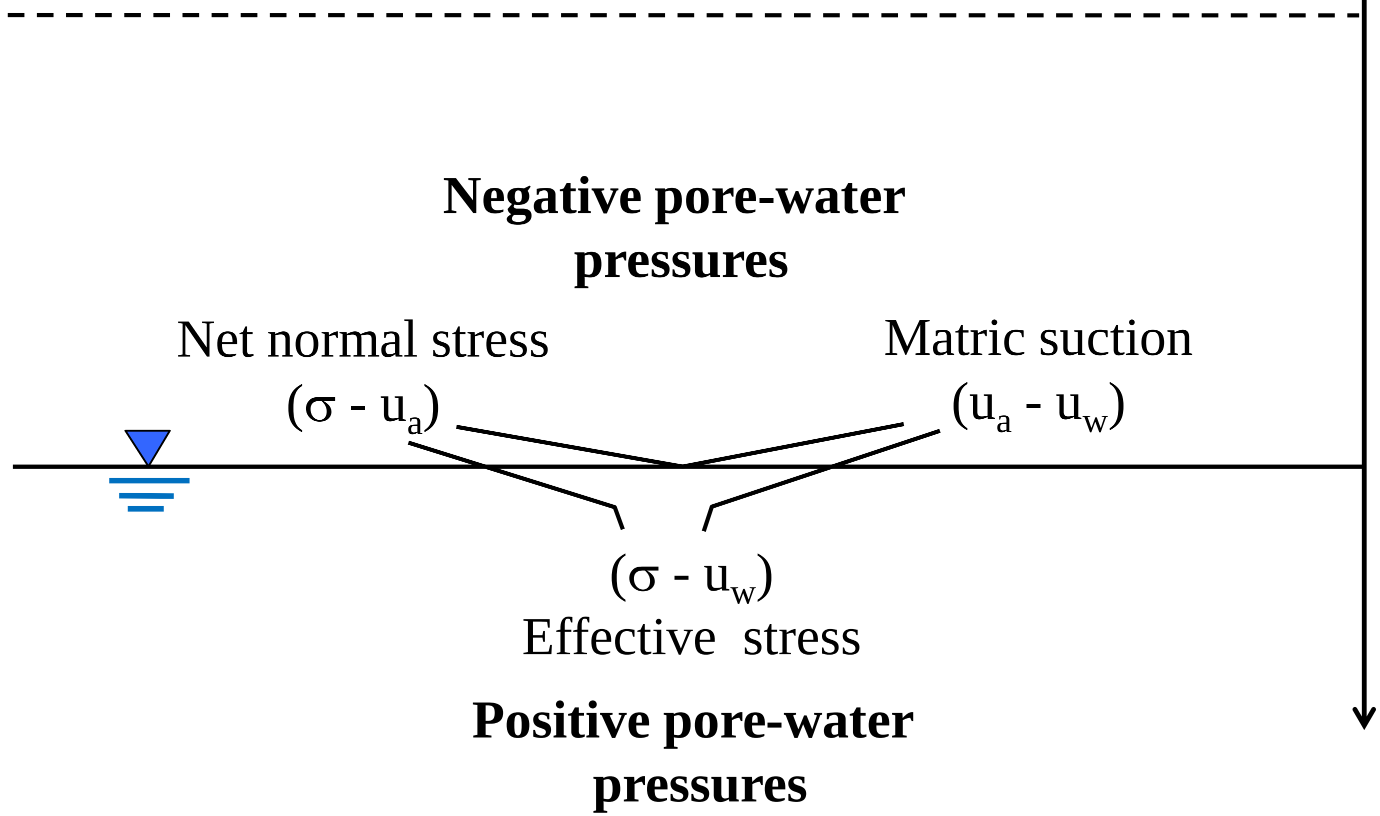
Three phases:

solid, water and air

⇩

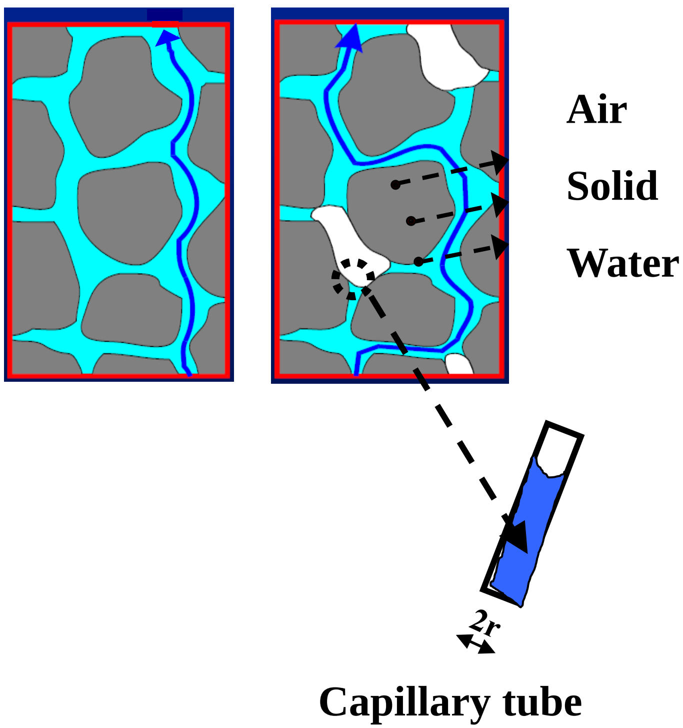
Positive & Negative

pore-water pressure



Model concept / unsaturated conditions

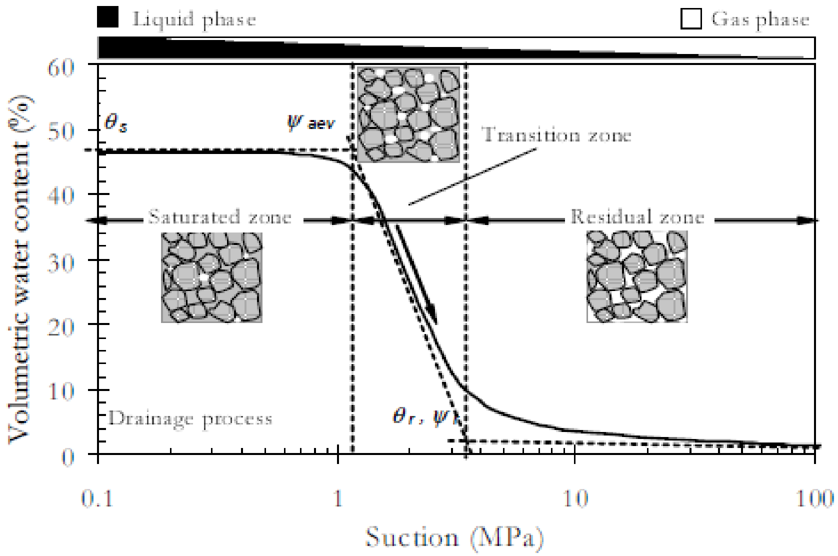
Unsaturated Soil as a Three Phase System



- **Three** phases: solid, water and air
- Type of soil – different type of suction

Total Suction = $\sum$ *Matric suction & Omotic suction*

$$\psi = \psi_{matr} + \psi_{osm} = (u_a - u_w) + \psi_{osm}$$

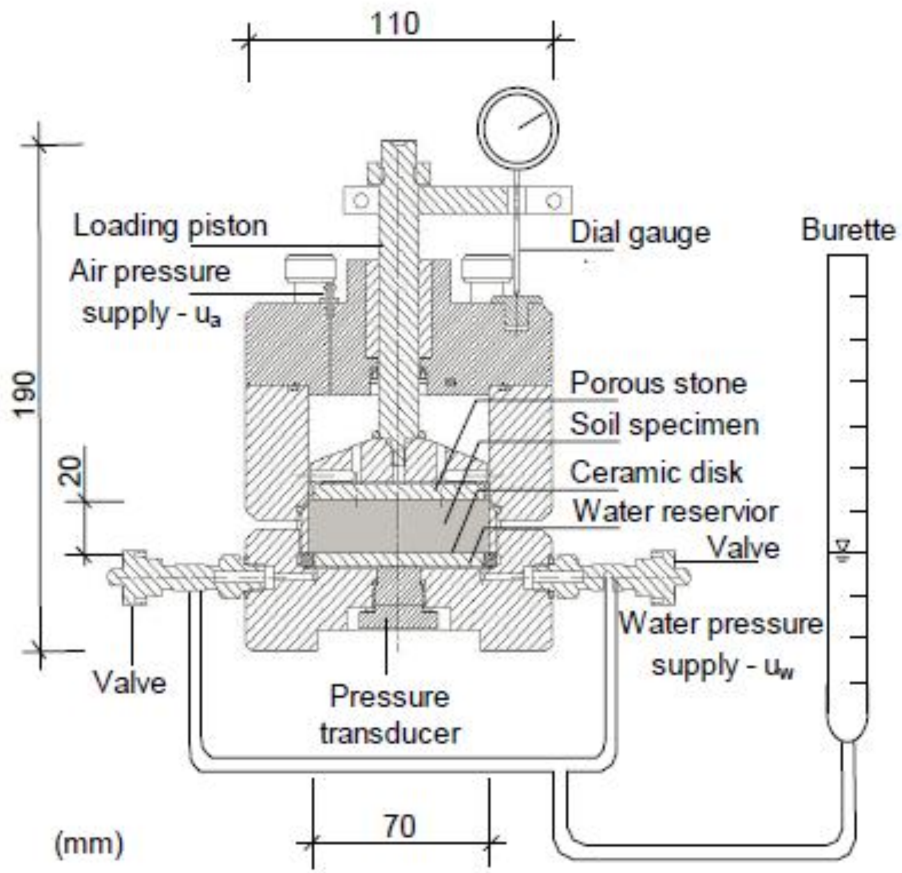


Soil-Water Characteristic Curve – SWCC

→ **Main influence on Load-Deformation characteristics**

Model concept / unsaturated conditions

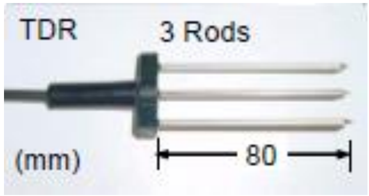
Laboratory



Axis translation principle

Field / 1g Test

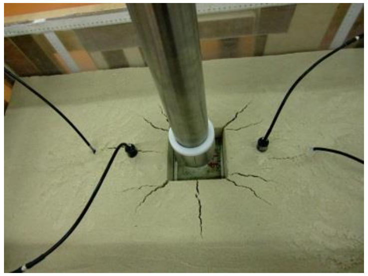
Tensiometer - Suction

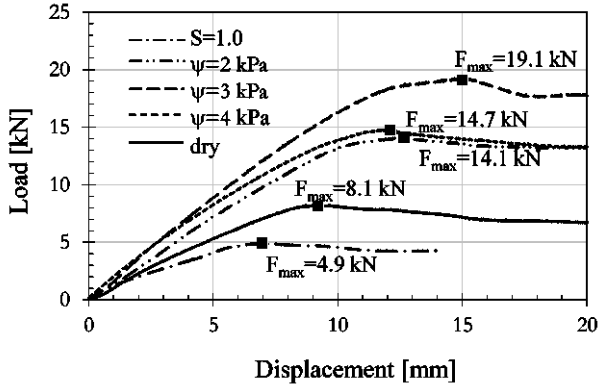


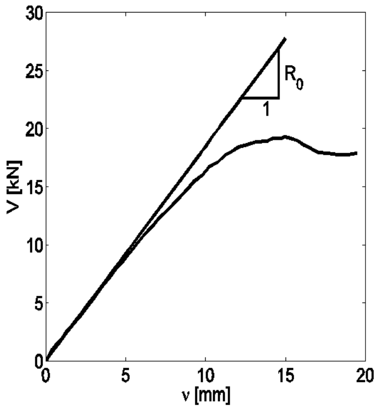
TDR – Water content

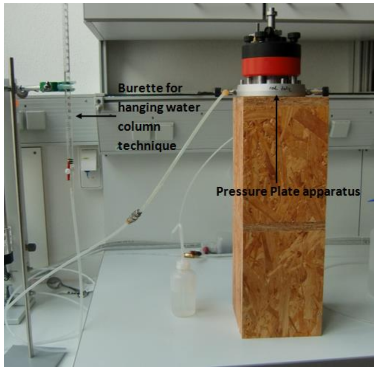
Model concept / unsaturated conditions - Experiment

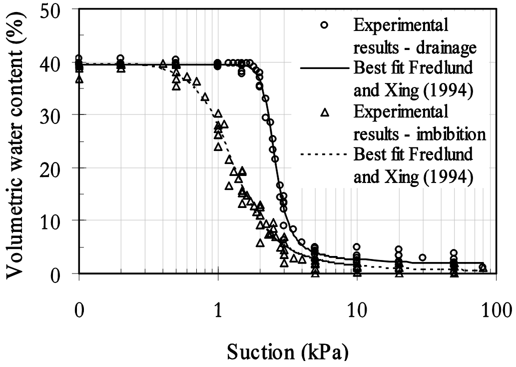
1g Box text with unsaturated condition

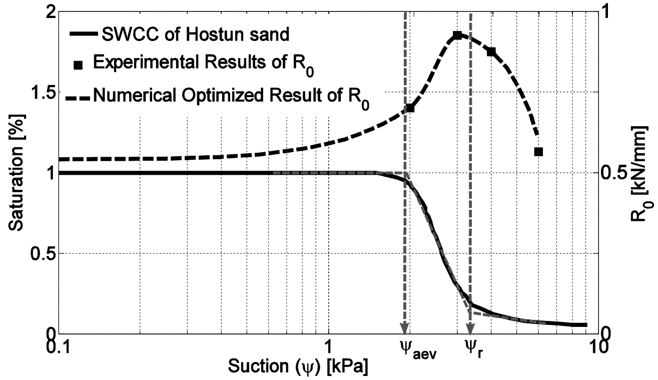






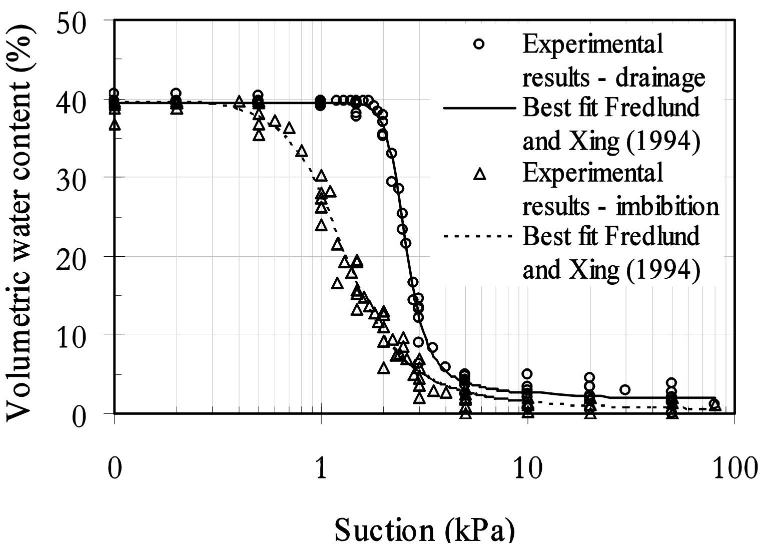


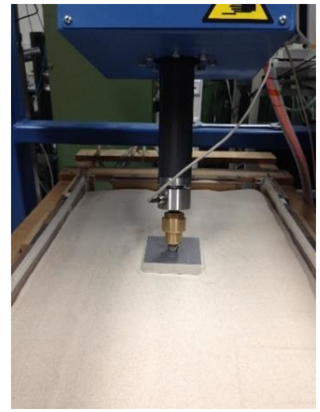


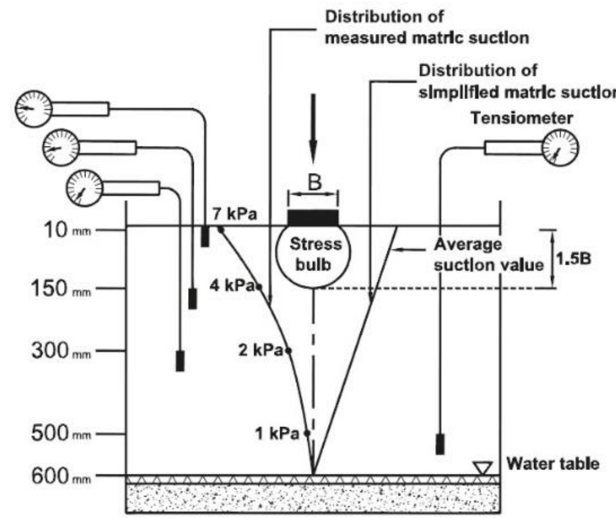


Apparent initial stiffness

Static load, partially saturated soil condition - Theory







$$\delta q = \delta q^{elast} + \delta q^{plast}$$

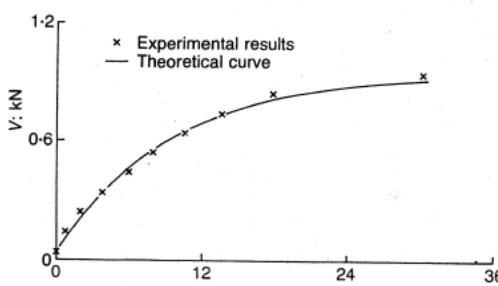
$$\mathrm{Q} = \left\{ \begin{array}{c} \bar{V} \\ \bar{H} \\ \bar{M} \end{array} \right\} = \frac{1}{V_m} \left\{ \begin{array}{c} V \\ \frac{H}{\mu} \\ \frac{M}{\psi_m B} \end{array} \right\}$$

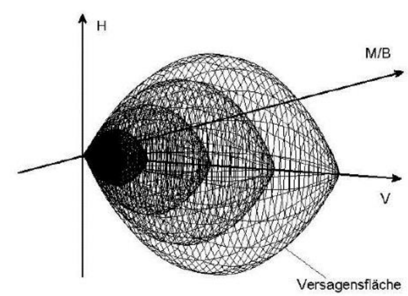
$$\mathrm{q} = \left\{ \begin{array}{c} \bar{v} \\ \bar{u} \\ \bar{\theta} \end{array} \right\} = V_m \left\{ \begin{array}{c} v \\ \mu u \\ \psi \theta_m B \end{array} \right\}$$

$$\bar{H}^2 + \bar{M}^2 - \bar{V}^2 \left(1 - \bar{V}\right)^{2\beta} = 0,$$

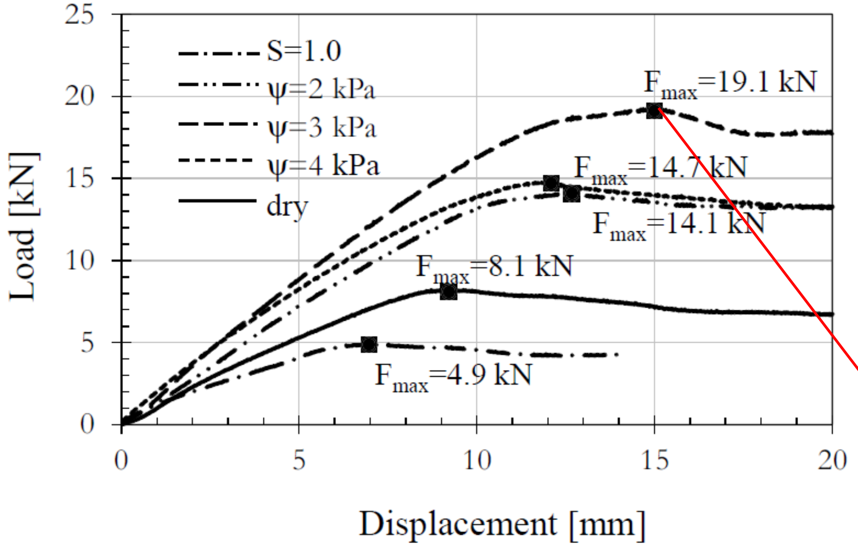
$$\rho_c(\psi) = 1 - \exp\left(- \frac{R_0(\psi) \sqrt{\upsilon^2 + (\alpha_h u)^2 + (\gamma_h(\psi).B\theta_m)^2}}{V_m(\psi)} \right),$$

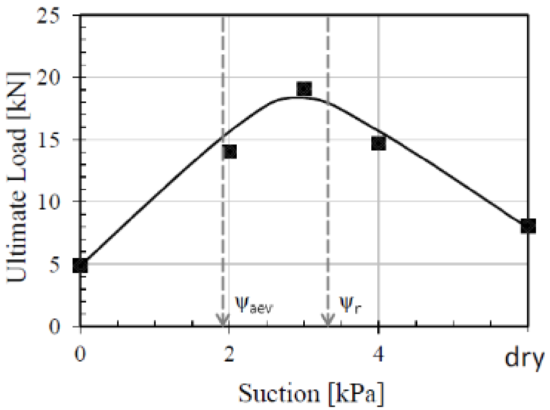
$$\mathrm{d}\mathbf{q}^{\mathrm{p}}(\psi) = - \frac{ \frac{\partial \mathrm{f}(\psi)}{\partial \mathbf{Q}(\psi)}^{\mathrm{T}} \frac{\partial \mathrm{g}(\psi)}{\partial \mathbf{Q}(\psi)} \mathrm{d}\mathbf{Q}(\psi) }{ \left[\frac{\partial \mathrm{f}(\psi)}{\partial \rho_c} \right] \left[\frac{\partial \rho_c(\psi)}{\partial \left| \mathbf{q}(\psi)^{\mathrm{T}} \right|} \right] \left[\frac{\partial \mathrm{g}(\psi)}{\partial \mathbf{Q}(\psi)} \right] }.$$

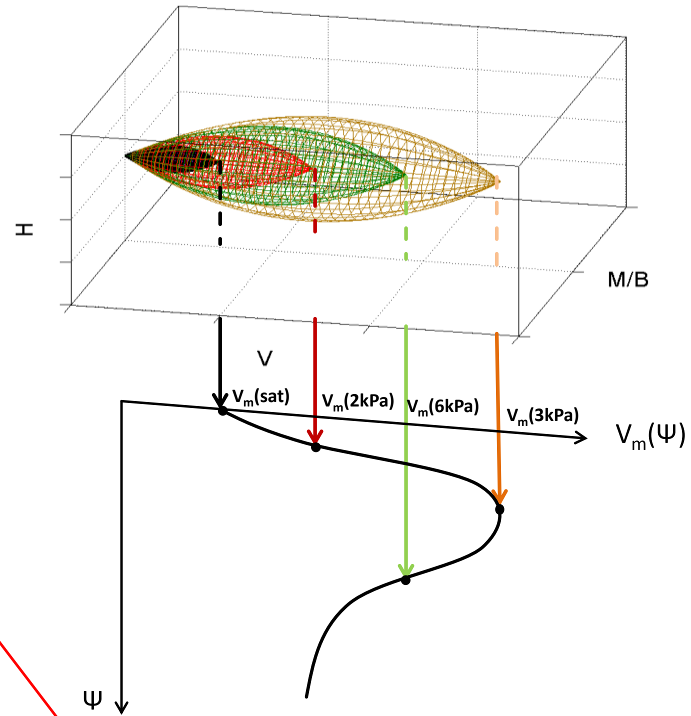




Static load, partially saturated soil condition - Validation

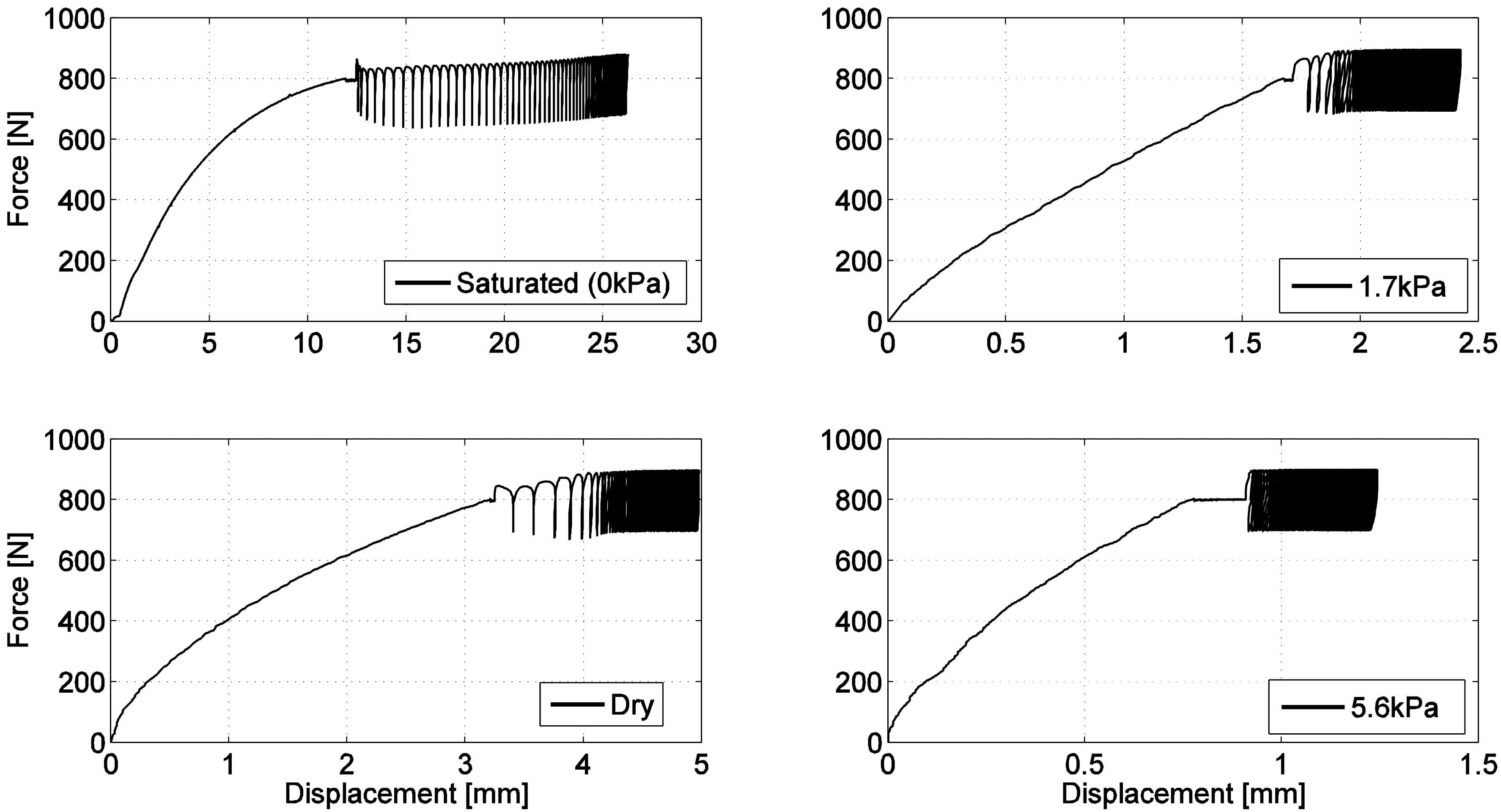




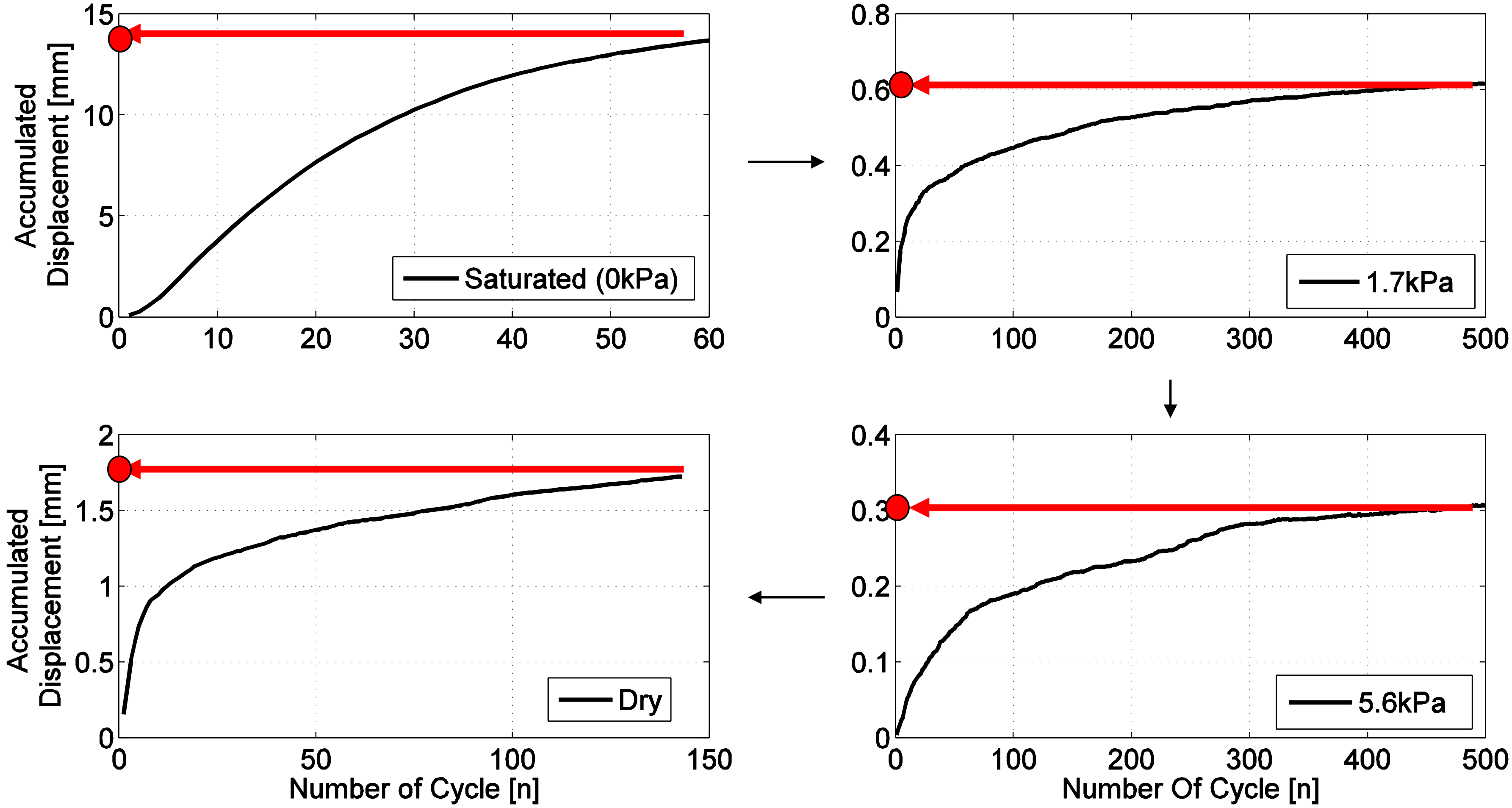


Cyclic load, partially saturated soil condition - Experiment

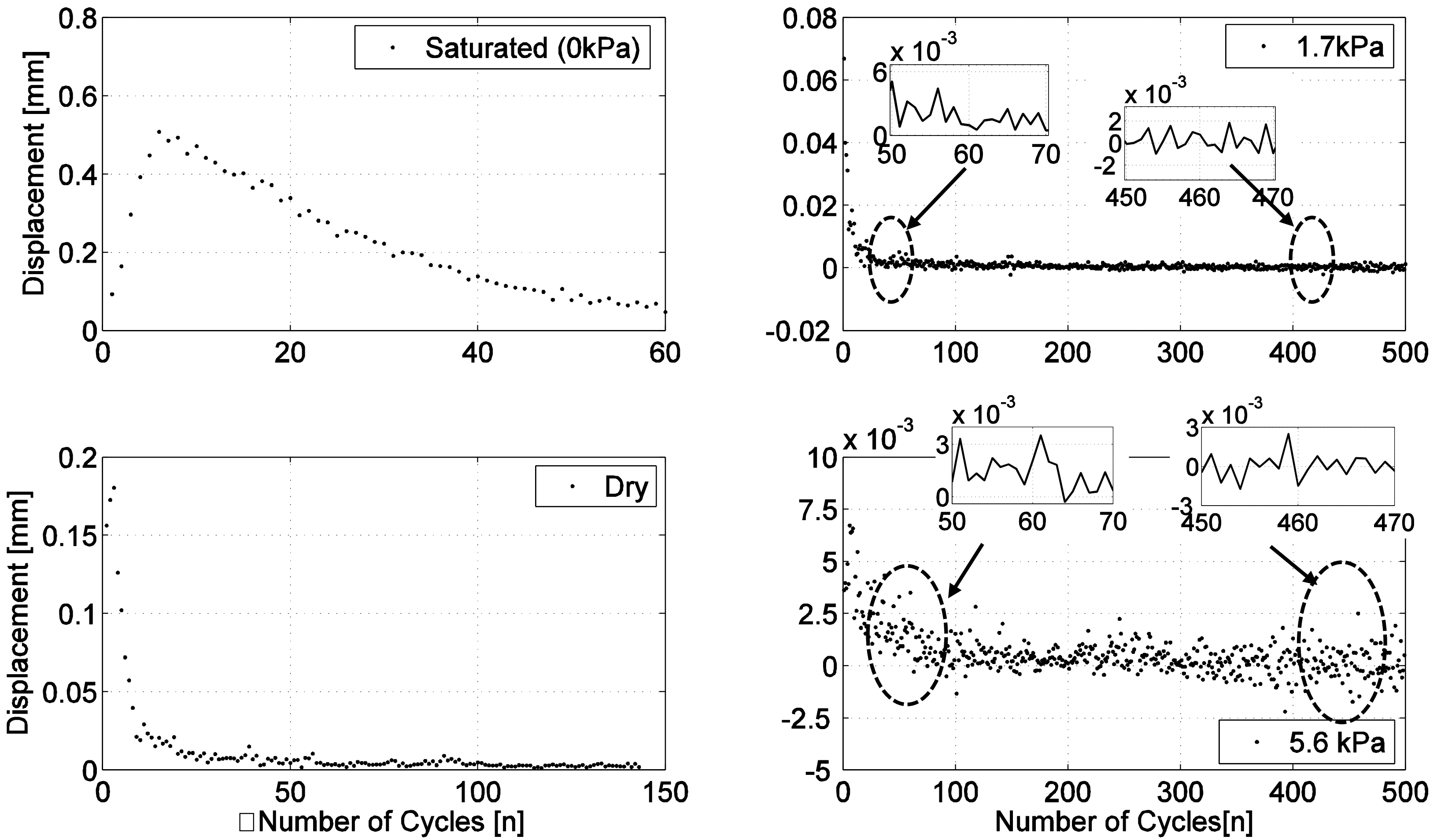
Cyclic Amplitude: 100 N, f = 0.1 Hz, Static load: 800 N



Cyclic load, partially saturated soil condition - Experiment



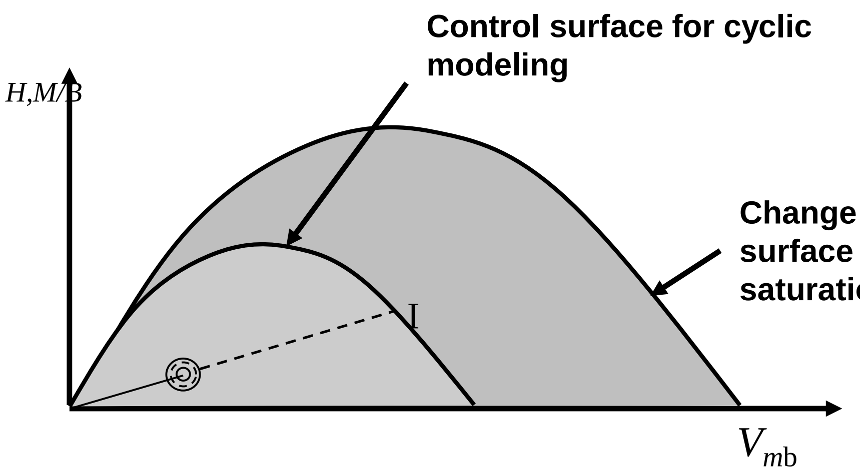
Cyclic load, partially saturated soil condition - Experiment



Cyclic load, partially saturated soil condition - Theory

Extended implicite accumulation macro model (C. di Prisco, 2002)

$$dq(\psi)^p = \Lambda\left(\mathbf{Q}_I\right)\phi_c(\psi)\left(\delta,\rho_k\right)\frac{\partial g(\psi)}{\partial \mathbf{Q}(\psi)}\mathbf{Q}(\psi)_I$$



Plastic deformation inkrement

$d\mathbf{q}_b = \mathbf{\Lambda}_b\ \mathbf{\Phi}_b\ (\partial g/\ \partial \mathbf{q})$

$\mathbf{\Phi}_b = f(\rho_{kb}, \delta_b, \varsigma, V_b)$

"***Memory***" parameter – function of

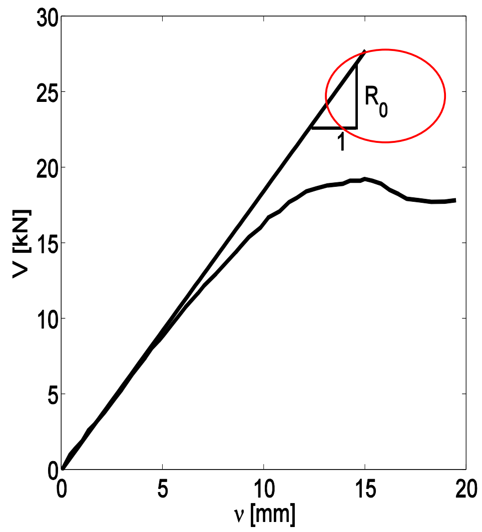
Saturation and small strain stiffness

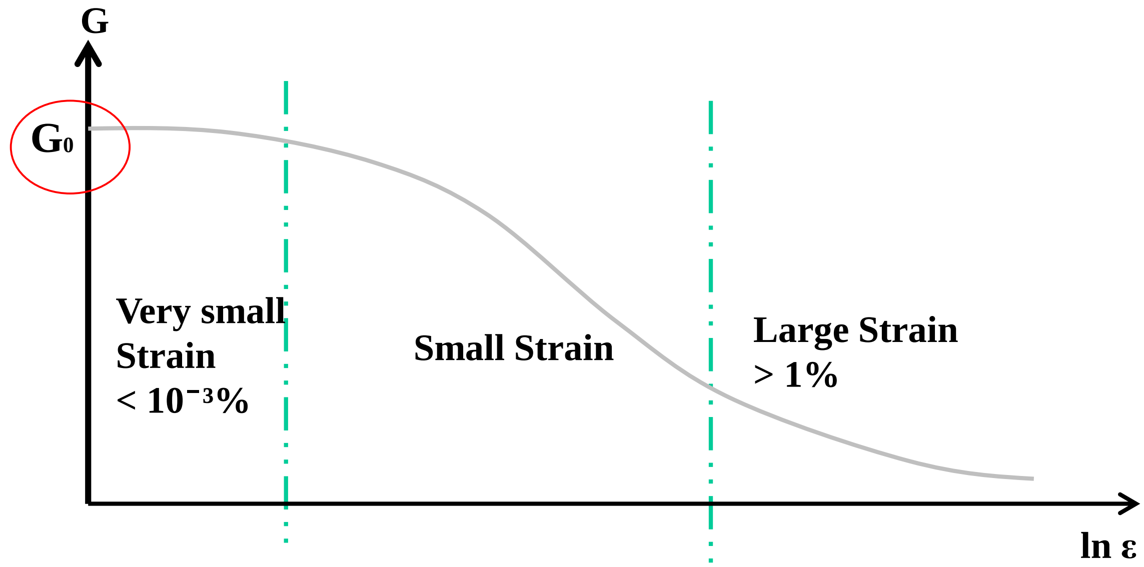
Cyclic load, partially saturated soil condition - Theory

Small strain approach

Hardening Function

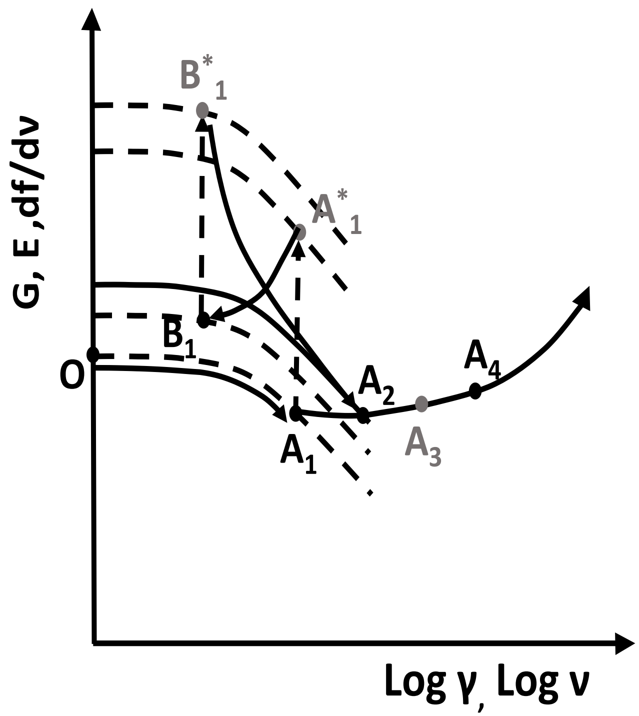
$$\rho_c = 1 - \exp\left[-\frac{R_0}{{V_m}^2}\sqrt{\eta^2 + \left(\alpha\frac{|\epsilon|}{\mu}\right)^2 + \left(\gamma\frac{|\zeta|}{\psi}\right)^2}\right]$$

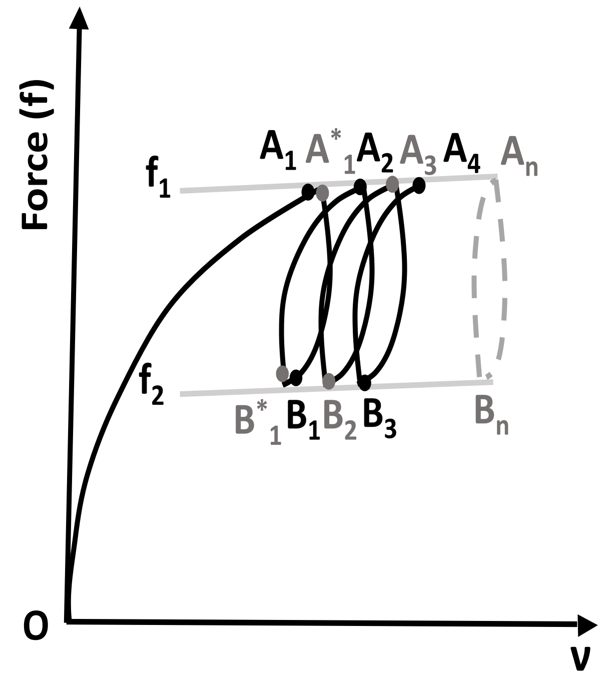




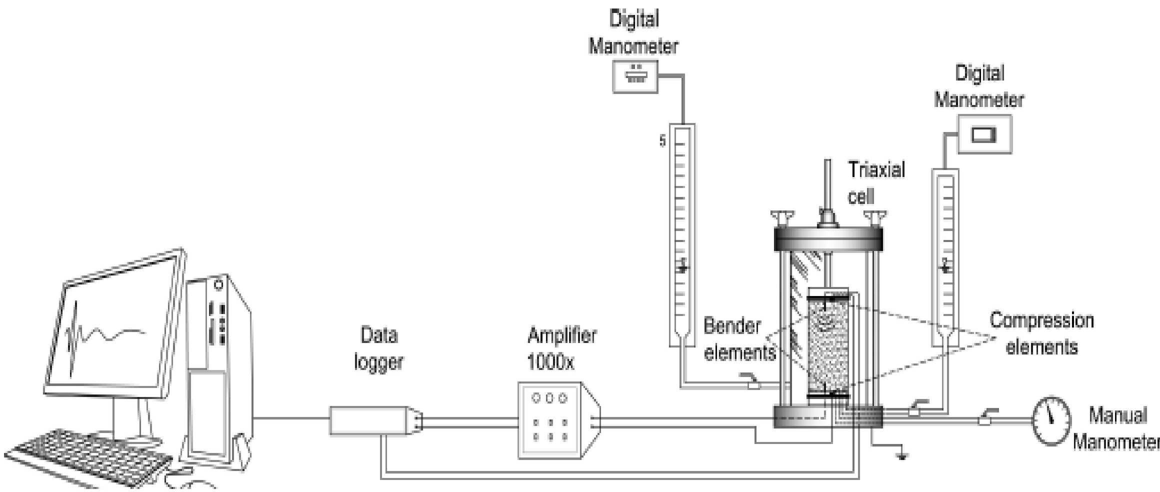
Cyclic load, partially saturated soil condition - Theory

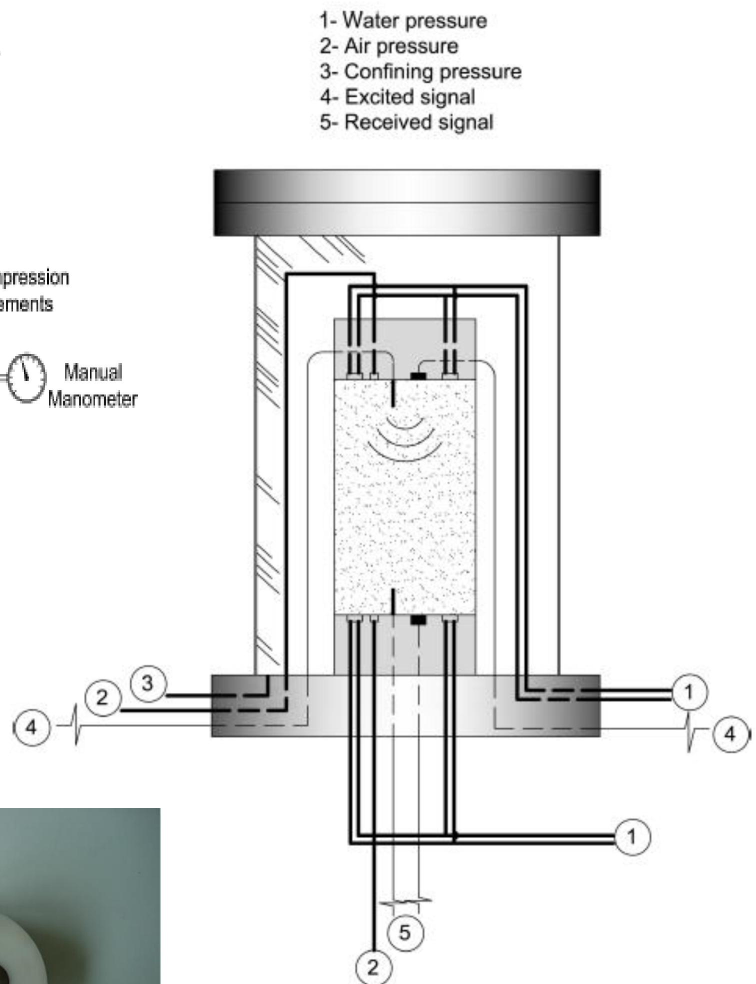
Small strain approach

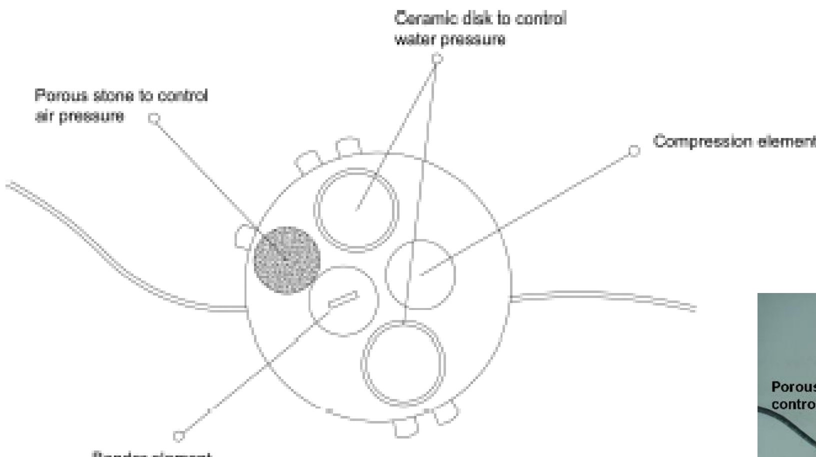


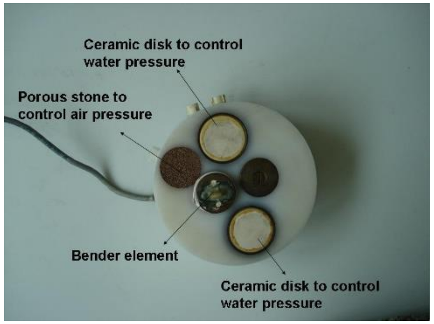


Model concept – unsaturated small strain parameter





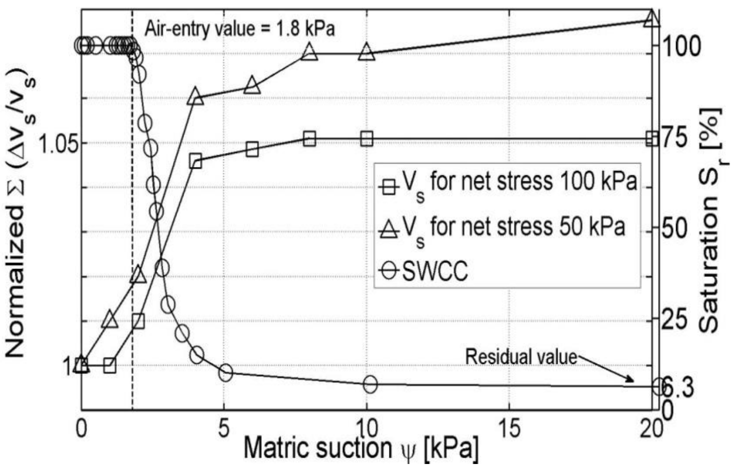




Model concept – unsaturated small strain parameter / function

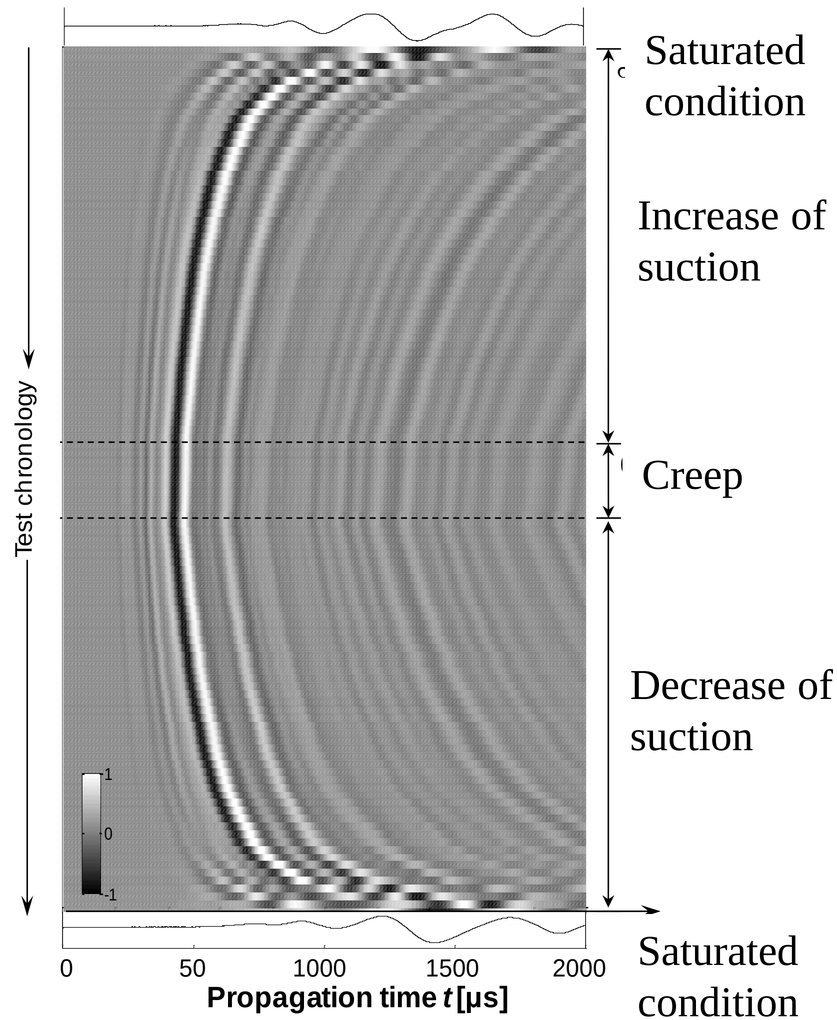
Small strain & unsaturated condition → Process monitoring during saturation

Relationship between small strain stiffness and suction by coda wave analysis



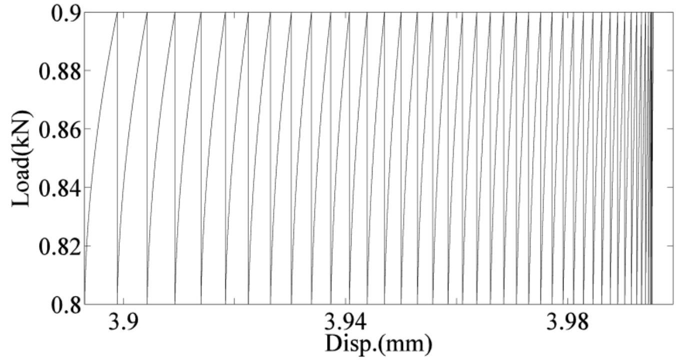
Velocity-saturation relation
→ *Humidity Change*

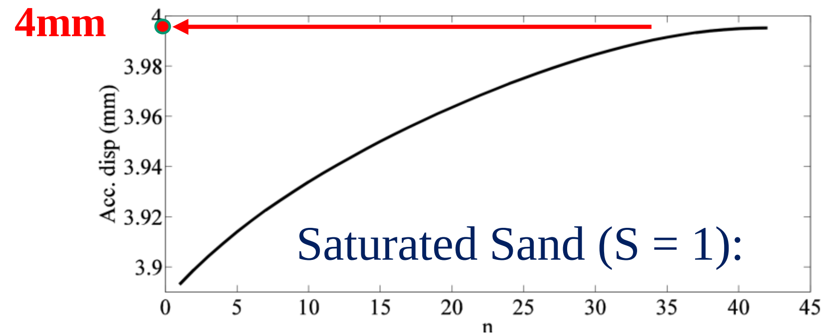
$$\frac{\delta v}{v} = \frac{\delta \theta}{\theta} = 1 - \frac{\left(1 + \alpha \psi_1^n\right)^m}{\left(1 + \alpha \psi_{i+1}^n\right)^m}.$$

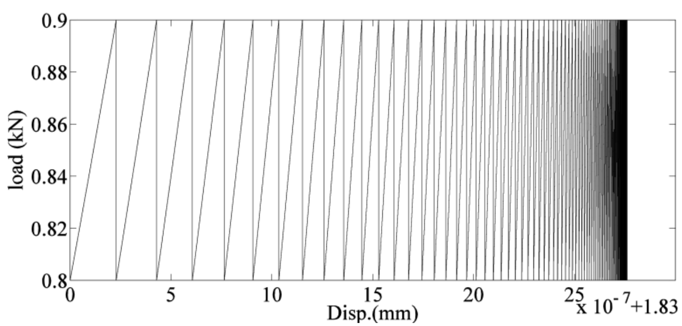


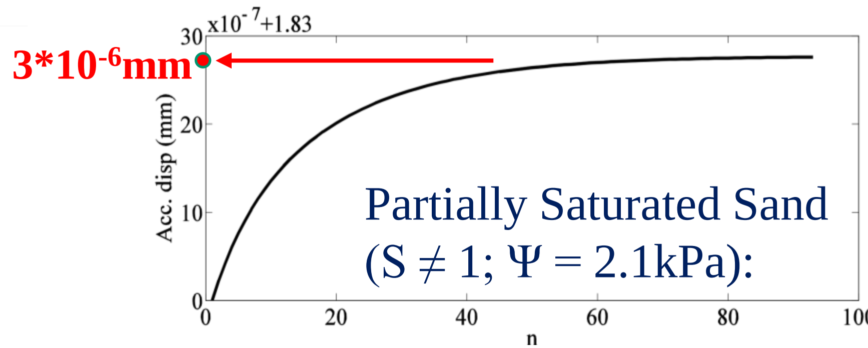
Cyclic load, partially saturated soil condition - Theory

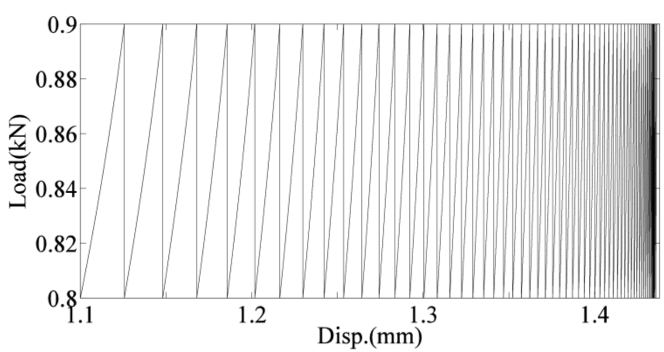
Cyclic Amplitude: 100 N, f = 0.1 Hz, Static load: 800 N

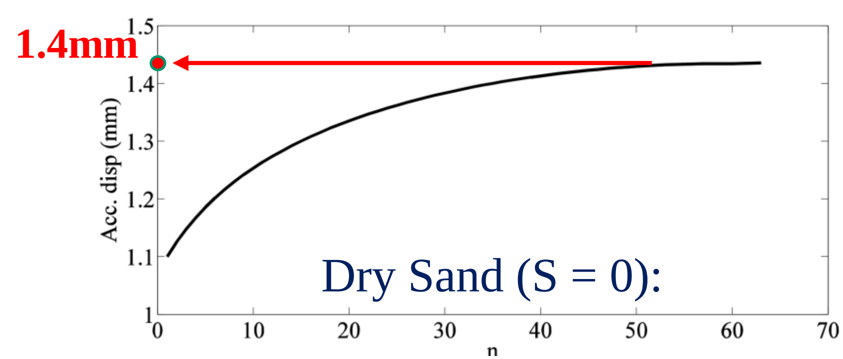








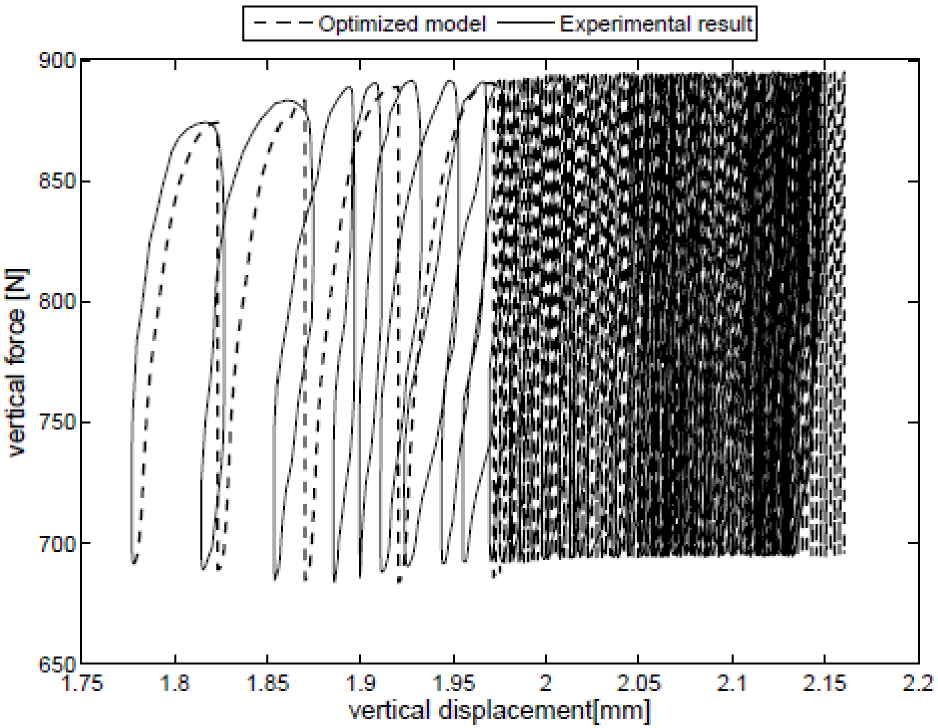


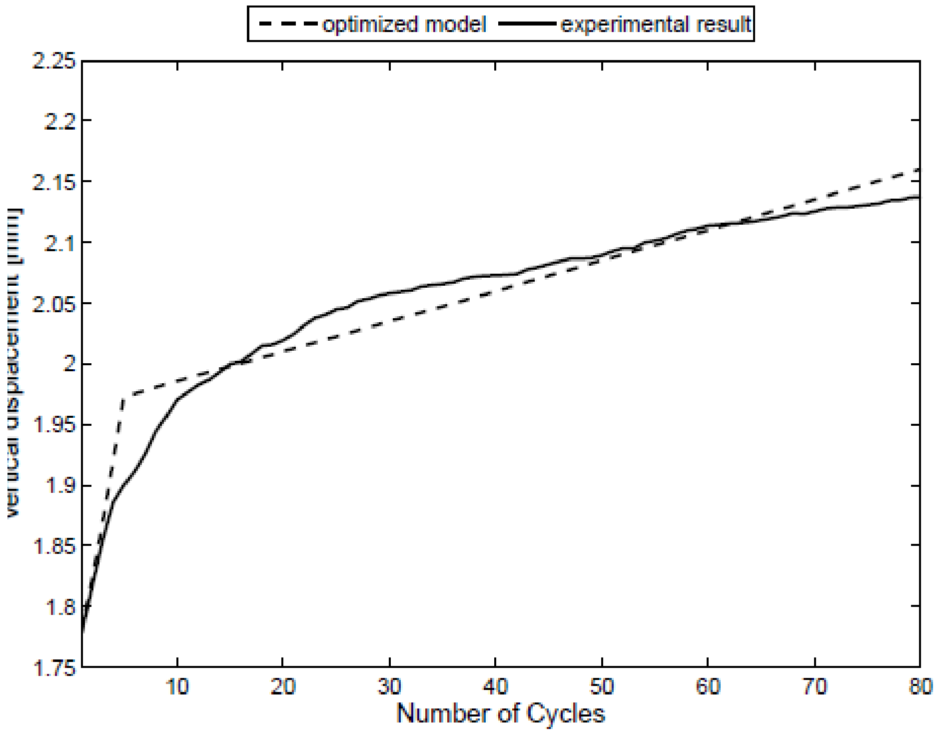


Cyclic load, partially saturated soil condition - Calibration

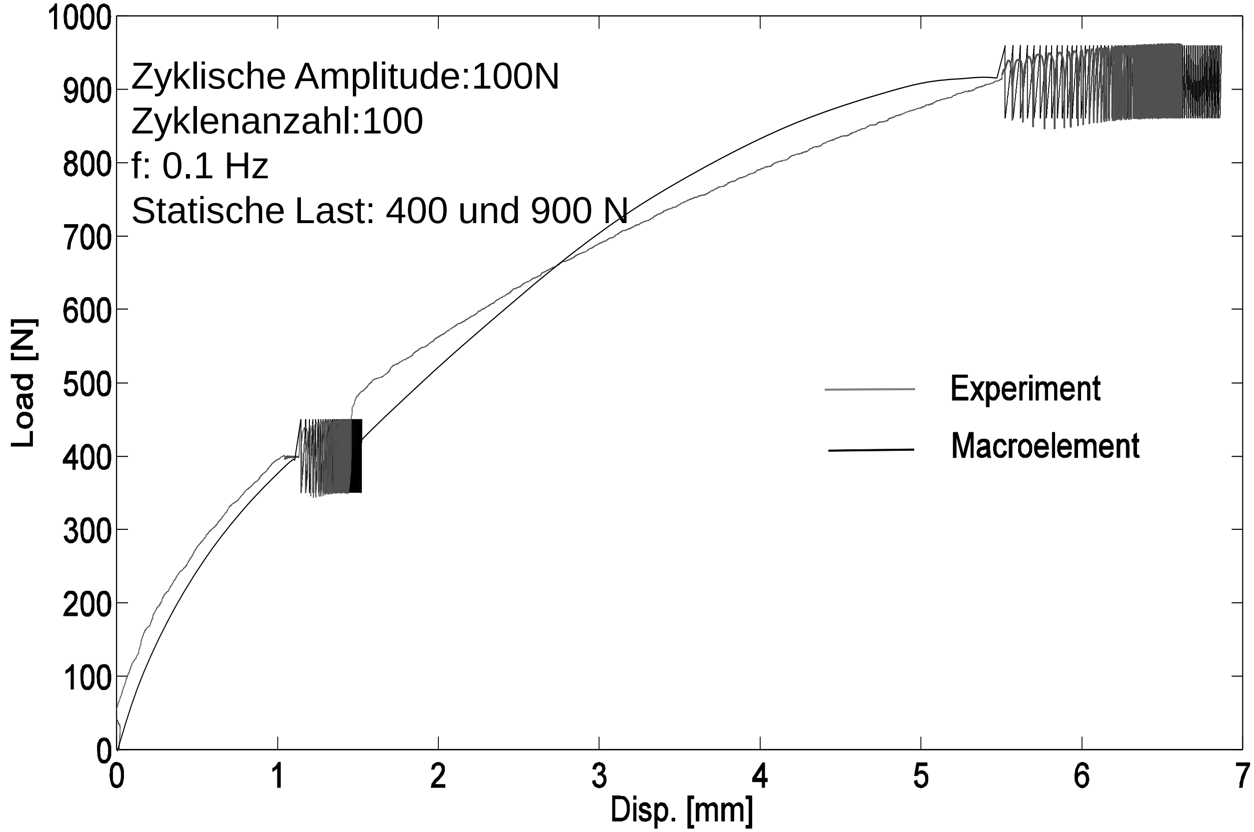
Cyclic Amplitude: 100 N, f = 0.1 Hz, Static load: 800 N

after constitutive parameter calibration (suction 1.7 kPa)





Cyclic load, partially saturated soil condition - Validation




Thank you
very much
for your attention
Kiel / Germany