Modelling of Ground Improvement in a Drum Centrifuge

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Ground Improvement

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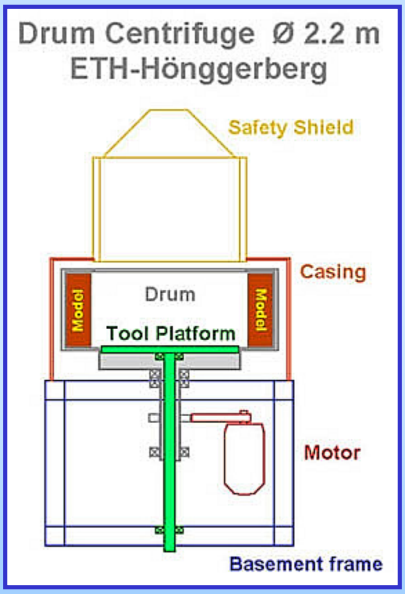
ETH Drum Centrifuge

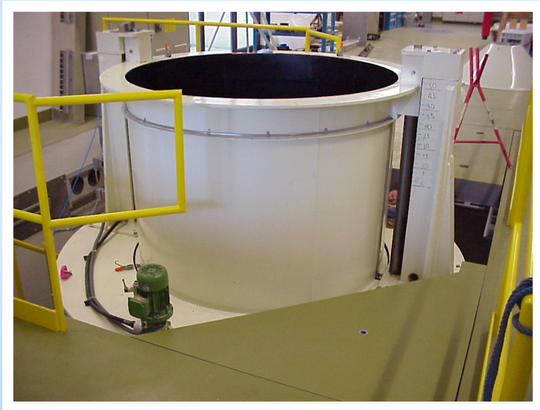
Inflight Construction of Sand Compaction Piles

- for Ground Improvement under Embankments

Heavy Tamping as Improvement Measure for Double Porous Materials

The Drum Centrifuge at ETHZ

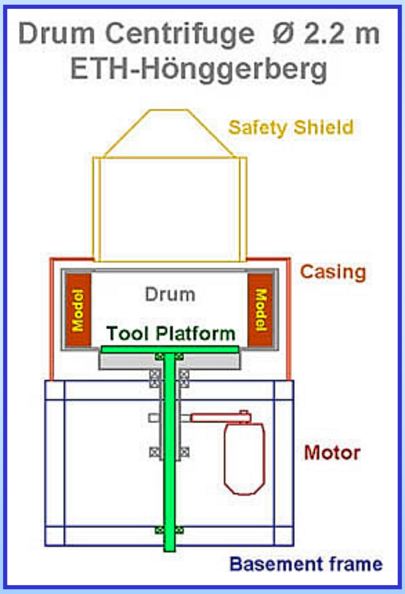


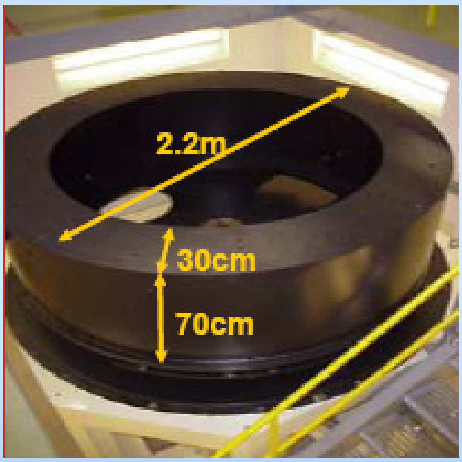


View on the safety shield of the

ETH Zürich Drum Centrifuge
(Springman et al. 2001)

The Drum Centrifuge at ETHZ

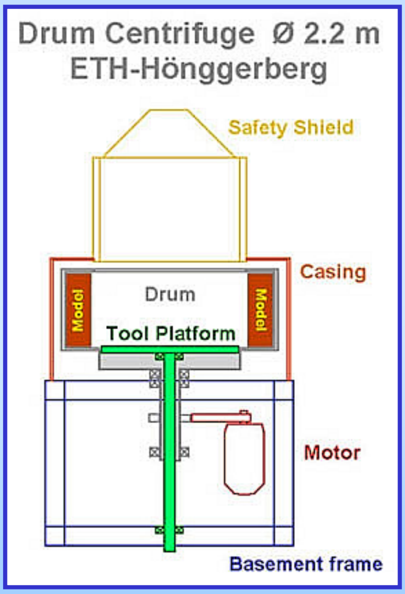




Channel of the

ETH Zürich Drum Centrifuge

The Drum Centrifuge at ETHZ

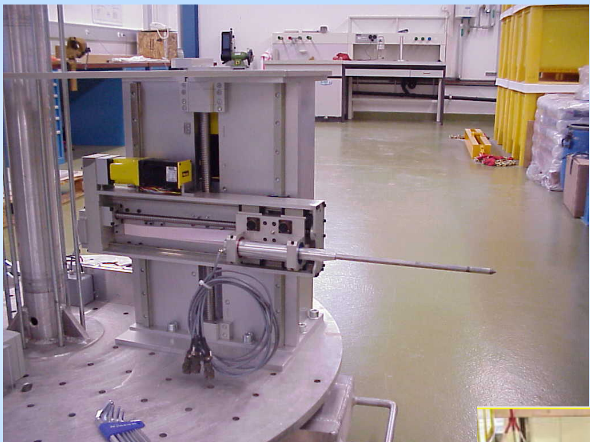


- **Drum specification**

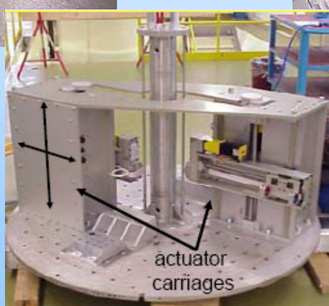
Diameter: 2.2 m
G max: 440
Drum dimensions:
- Depth: 300 mm
- Max diameter: 2200 mm
- Height: 700 mm

maximum payload: 2000 kg
Out of Balance: 10 kgm @ 440 g

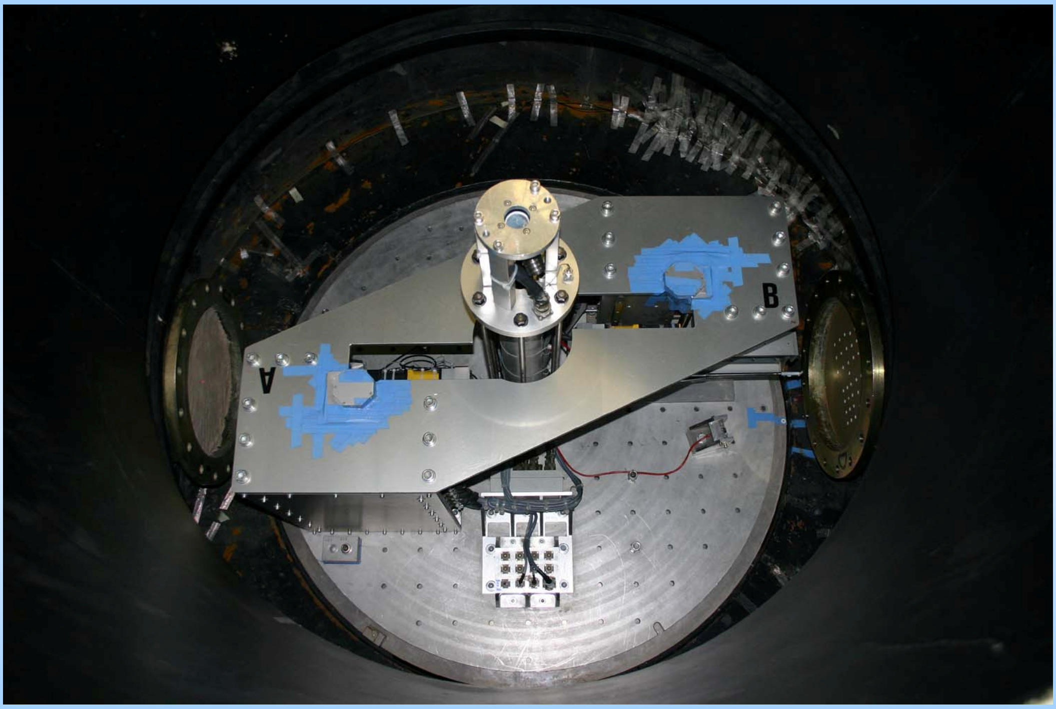
The Drum Centrifuge at ETHZ



Actuator with CPT tool



Actuator with scraping tool at work



Test setup using the drum centrifuge with two strong boxes

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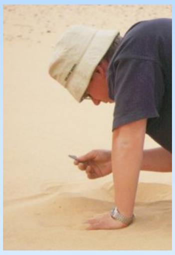
Modelling the inflight construction of sand compaction piles in the centrifuge



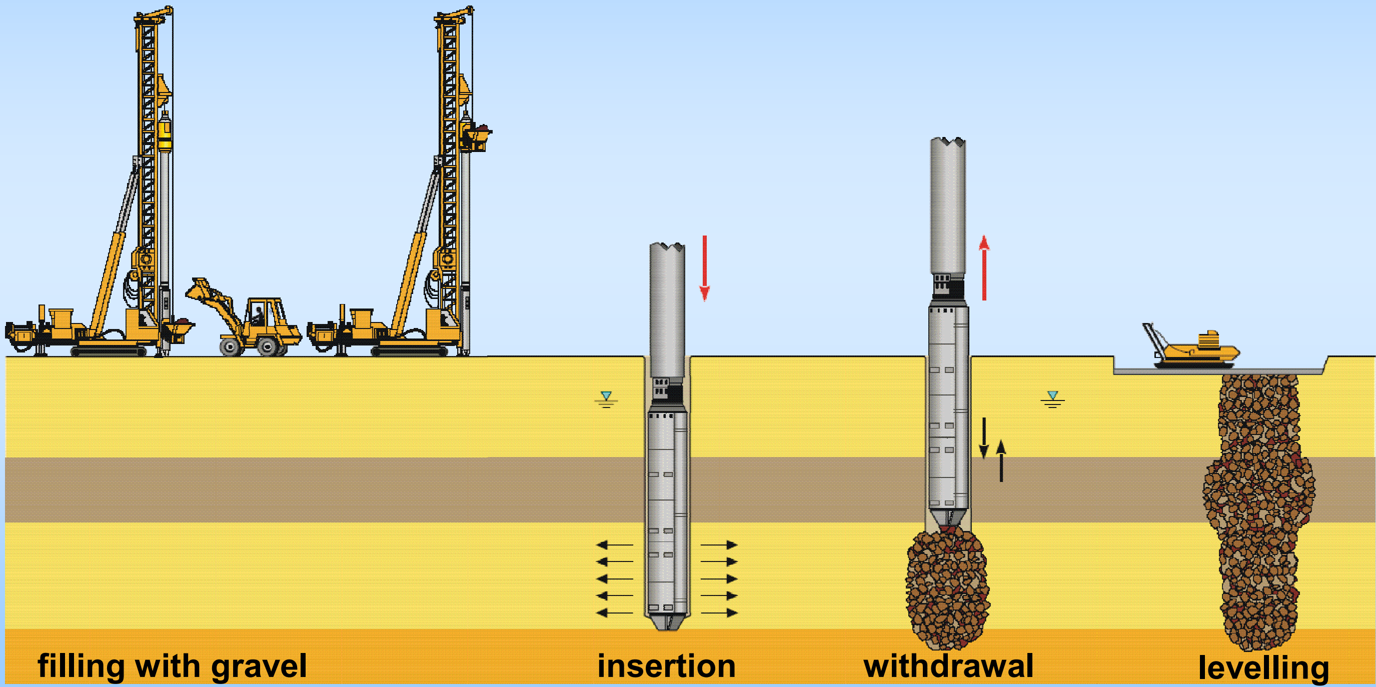
PhD Thesis of Thomas Weber

Reference to pictures:

Weber, T. 2008: Modellierung der Baugrundverbesserung mit Schottersäulen, IGT Report 232, vdf publisher, ETH Zurich

Weber, T.M., Plötze, M., Laue, J., Peschke, G. & Springman, S.M. (2010). Smear zone identification and soil properties around stone columns constructed in-flight in centrifuge model tests, *Géotechnique*, 60 (3), pp. 197-206

Partners:
Swiss National Science Foundation
EU Marie Curie Training Network (AMGISS)
Federal Office of Transportation Research Fund



Installation of a sand compaction pile (vibro)

Keller Grundbau

Installation of stone columns

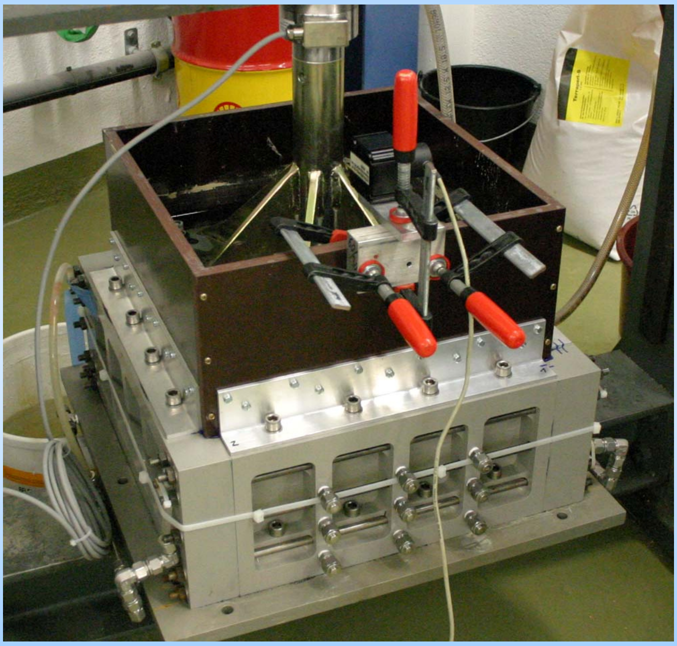
Preparation of soil models

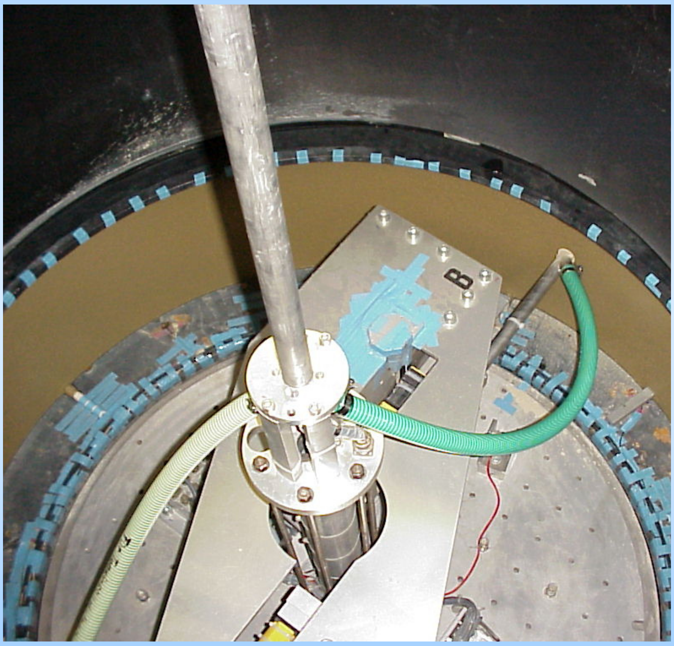
Development of a stone column installation tool

Influence of the installation

Testing of various grids under embankments

Model making from clay slurry: in strong boxes (2D) & in drum channel (3D)





construction outside the centrifuge
consolidation under the press

construction in the centrifuge
consolidation in flight

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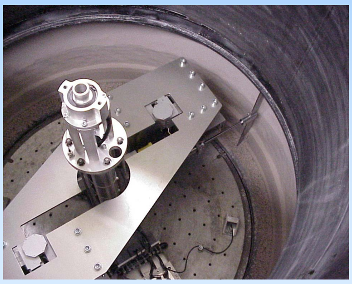
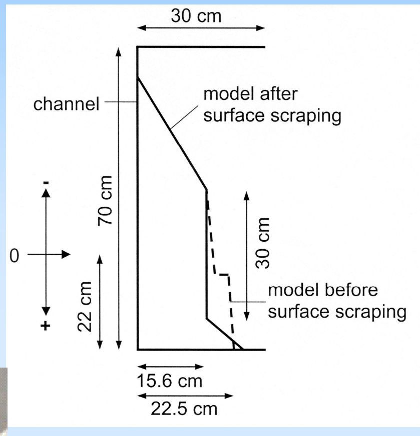
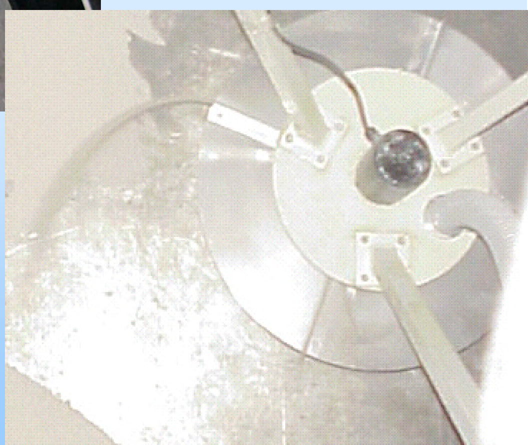
Off topic: How to built a sand model in flight







Densities between D = 25 to 80 % can be reached by air pluviation

Densities as low as D = -20% can be reached by water pluviation

Pluviation of sand on a spinning disk

Properties of materials

- Clay model: remoulded clay from Birmensdorf
  - classification: CH
  - clay content: ∅ < 2 μm = 42 %
  - plasticity:
    w_L = 58 %
    w_p = 19 %
    I_P = 39 %
  - sensitivity: 1.3 - 2
  - friction angle φ': 24.5°
  - cohesion c': 0 kPa
- Stone columns: sieved quartz sand
  - grain size 0.5 mm < ∅ < 1.0 mm
  - semi rounded grains, slightly angular
  - friction angle φ': 37°
- Embankment: lead balls due to limited height in tub
  - ∅ = 2.0 mm
  - density ρ = 6.72 g/cm³

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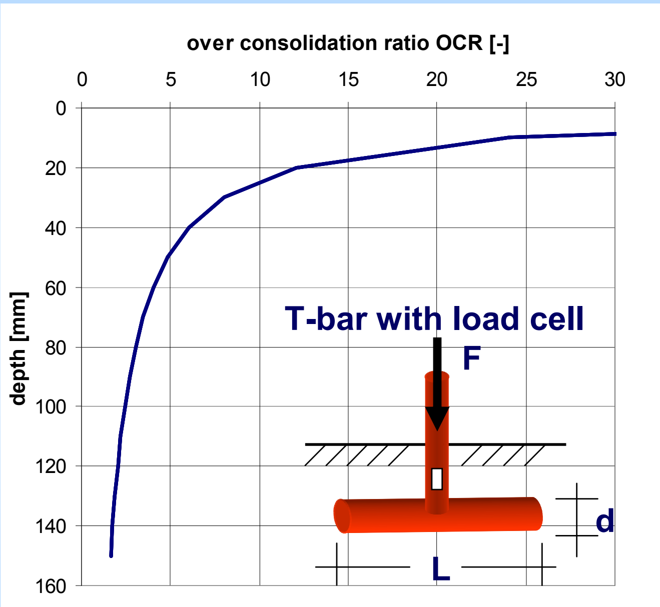
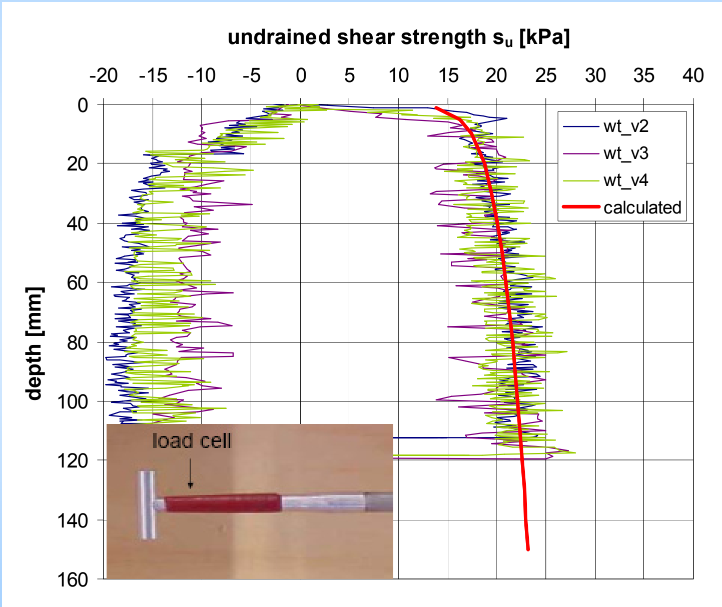
Centrifuge test on clay model in the strong box

preloaded at 100 kPa → test at 50 g

T-Bar-testing





$$s_u = \frac{F}{N_b \cdot d \cdot L}$$ **(Stewart & Randolph 1994)**

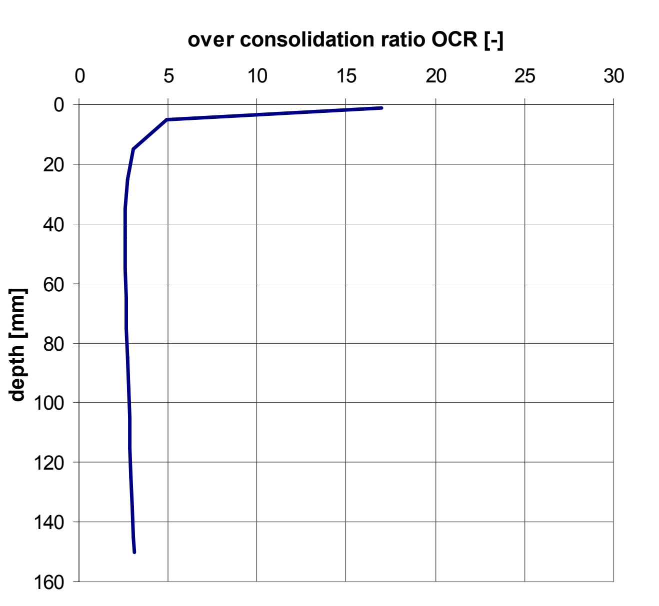
$$s_u = a \cdot OCR^b \cdot \sigma'_v$$

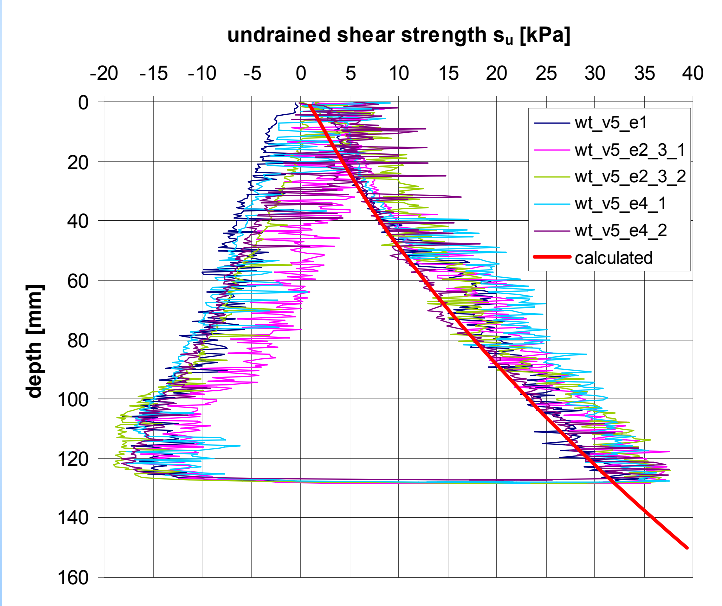
a = 0.24
b = 0.9

Centrifuge test on clay model in the drum channel

constructed in flight at 60 g → test at 50 g

T-Bar-testing





$$s_u = a \cdot OCR^b \cdot \sigma'_v$$

a = 0.24
b = 0.9

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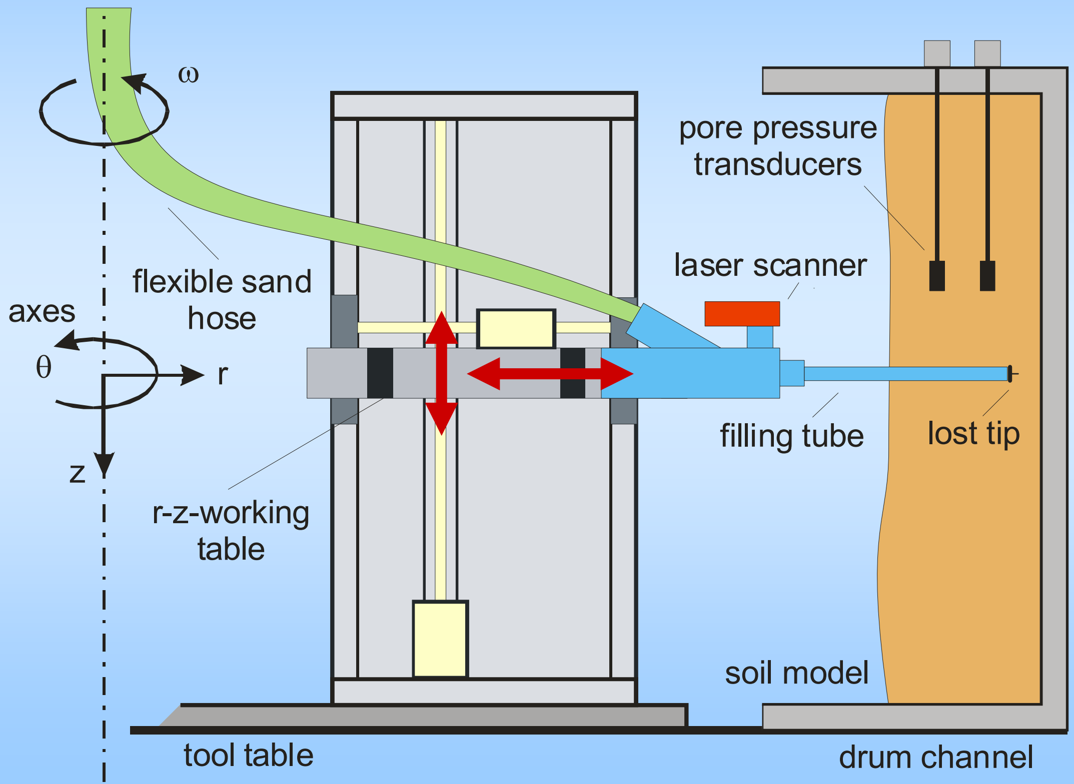
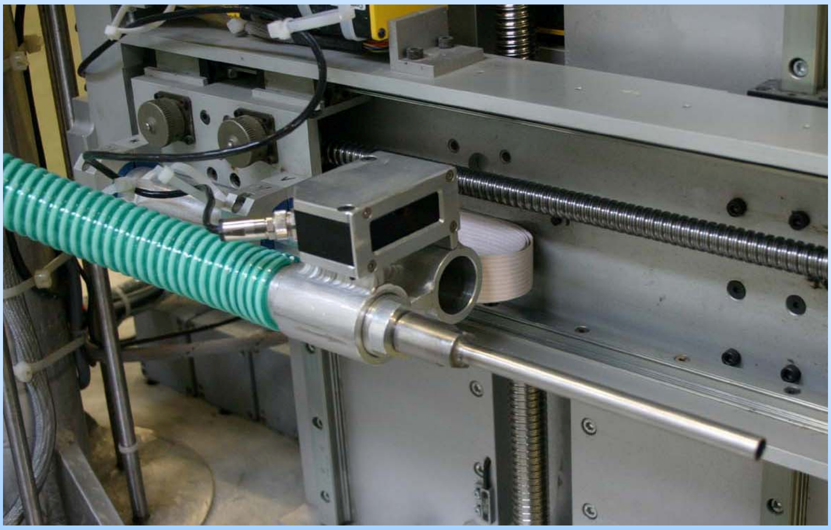
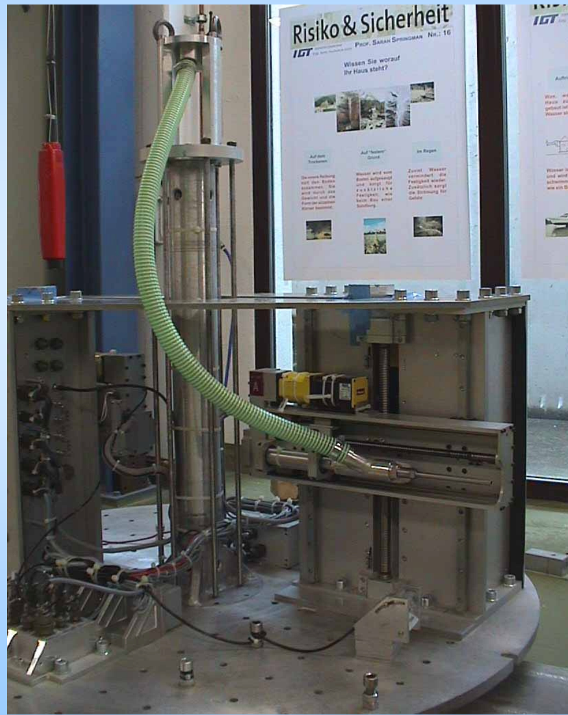
Stone column construction in the drum centrifuge

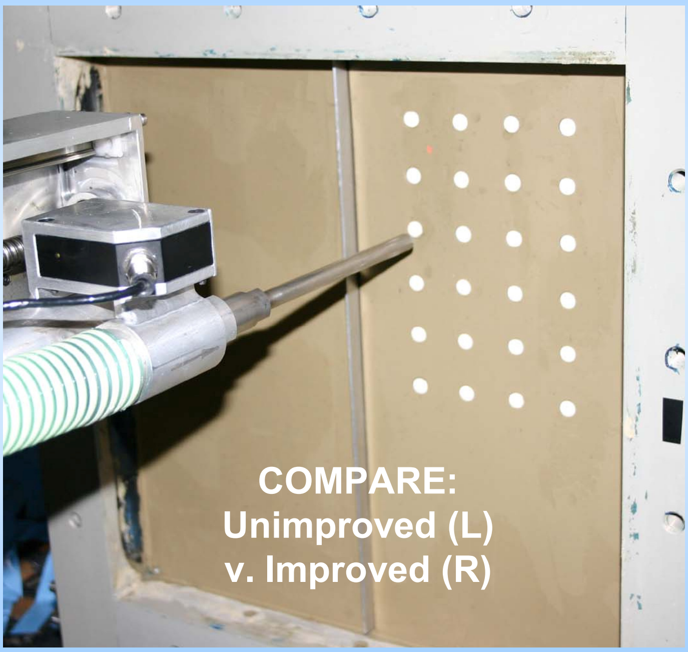


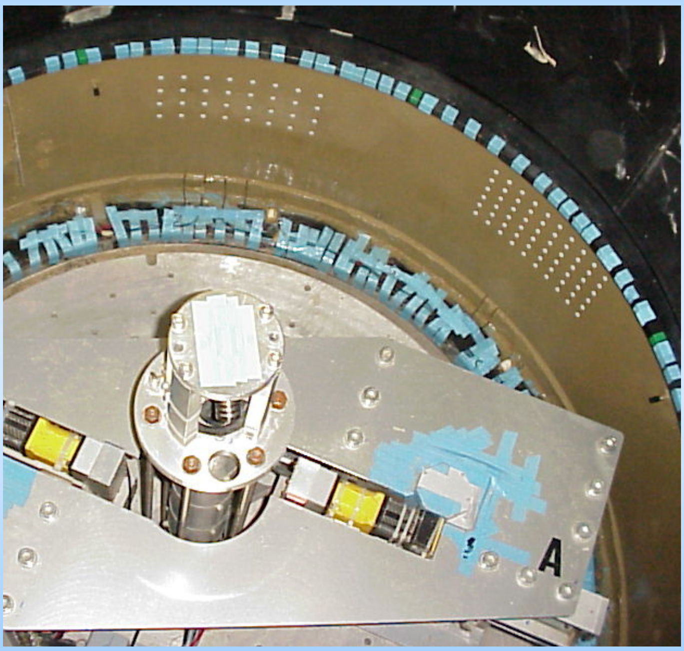
Stone column installation tool





Model preparation in tub (2D) and drum (3D): placing column grid

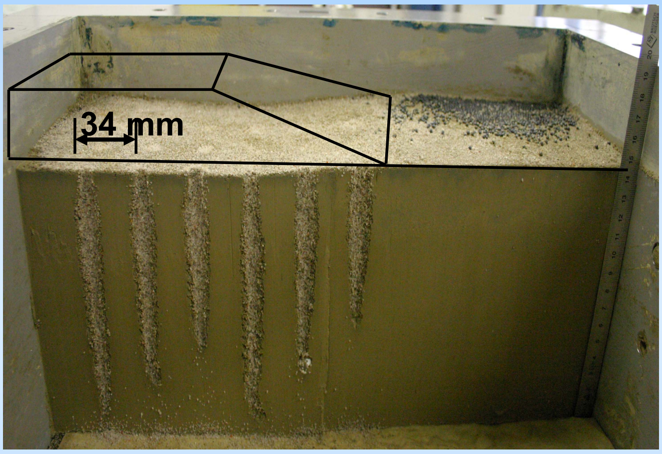




area ratio of improvement - f_s = 10%

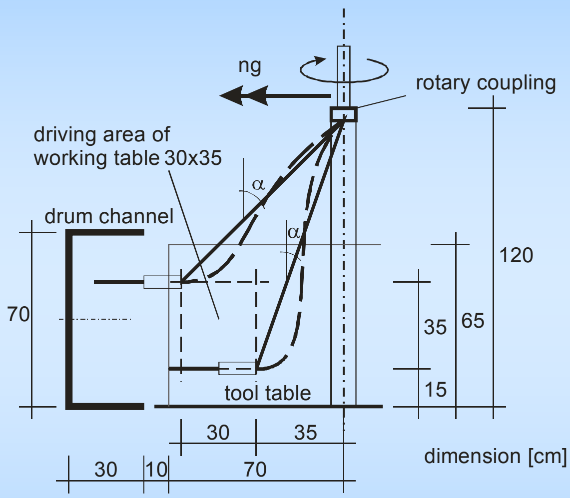
area ratio of improvement - f_s = 5% & 10 %

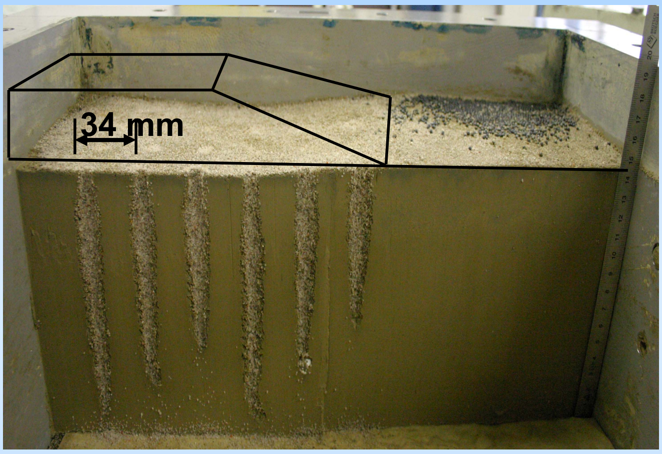
Columns without compaction



Columns built with additional compaction, e.g. 15mm out – 10mm in

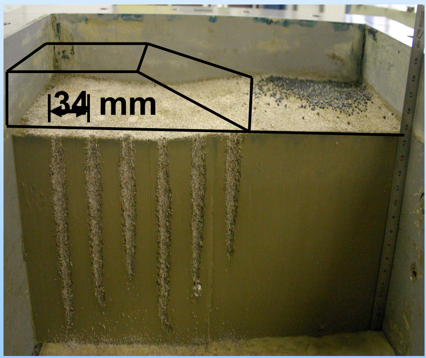
Densification	Dry density of column [g/cm^3]	Relative density [%]
nill	1.50 ± 0.02	48
15 / 10 [mm]	1.77 ± 0.07	165 ???? Clay fills pores in the column

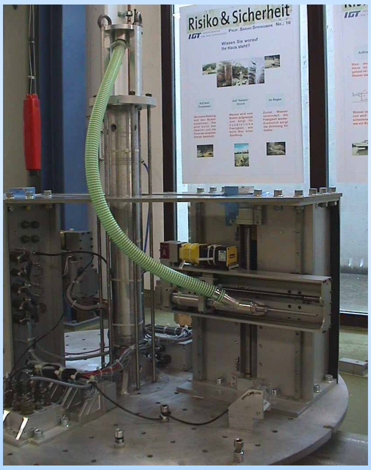




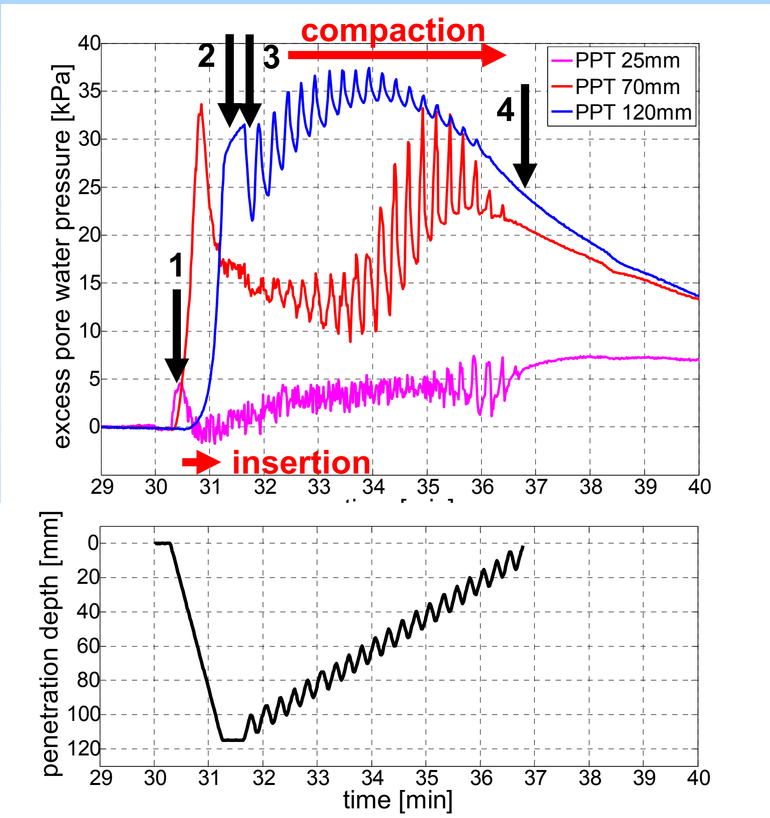
Different lengths of columns occur because of different available lenght of the tube

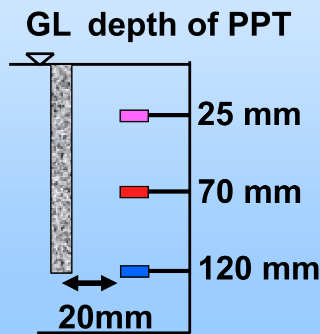
Building the embankment



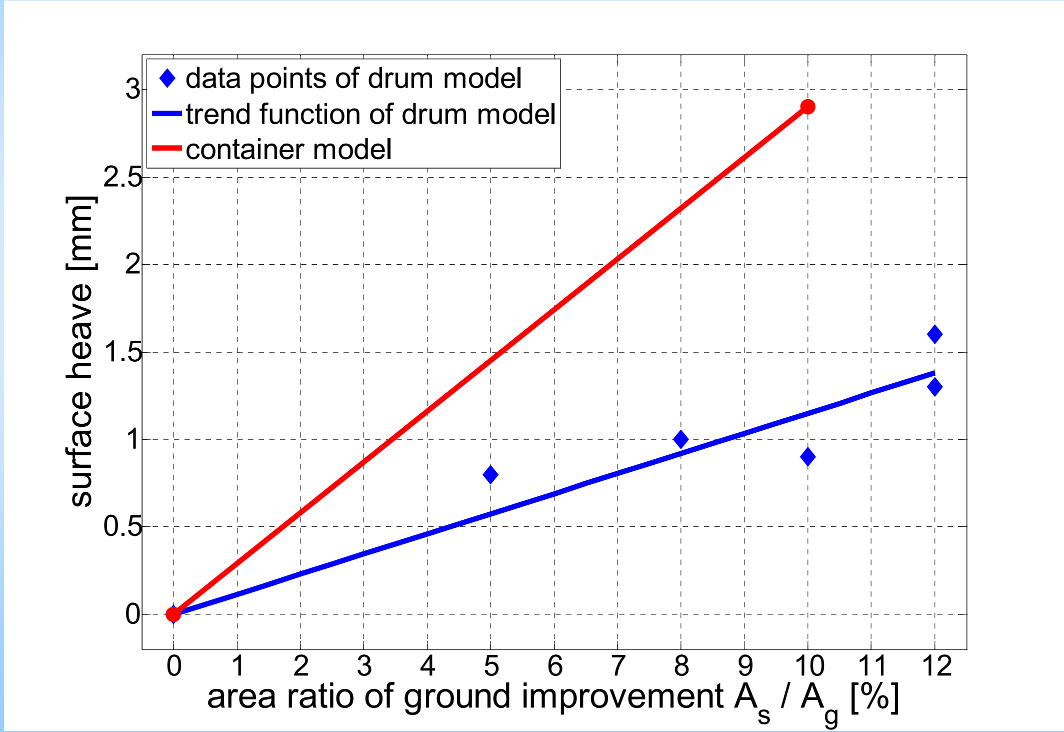


Installation effects: Excess pore water pressure during column construction (2D)





Installation effects: heave of clay surface



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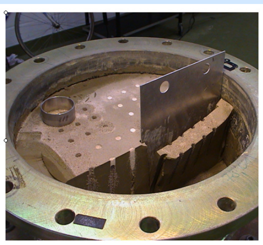
Installation effects: on clay structure

6 2 2 [mm]



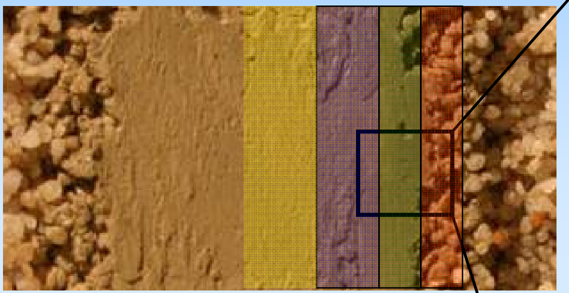
Zone 1 – sand penetrates the clay, mixing of sand and clay - 2 mm thick

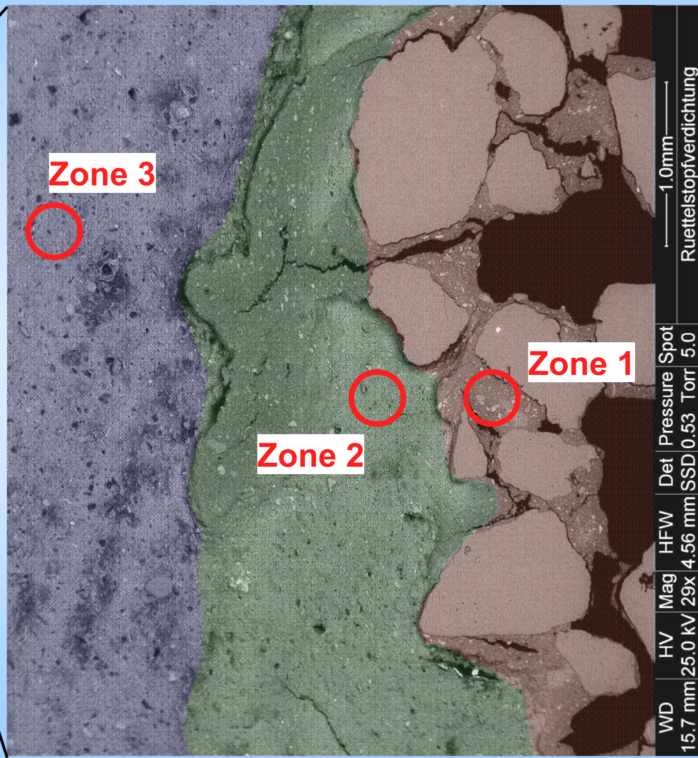
Zone 2 – high shear strain due to pile installation - max. 2 mm thick

Zone 3 – high confining stresses and densification after consolidation - 6 mm

Zone 4 – moderate confining stresses and no measurable densification

Installation effects





50x

3.5 mm

ESEM pictures –
Environmental Scanning
Electron Microscopy

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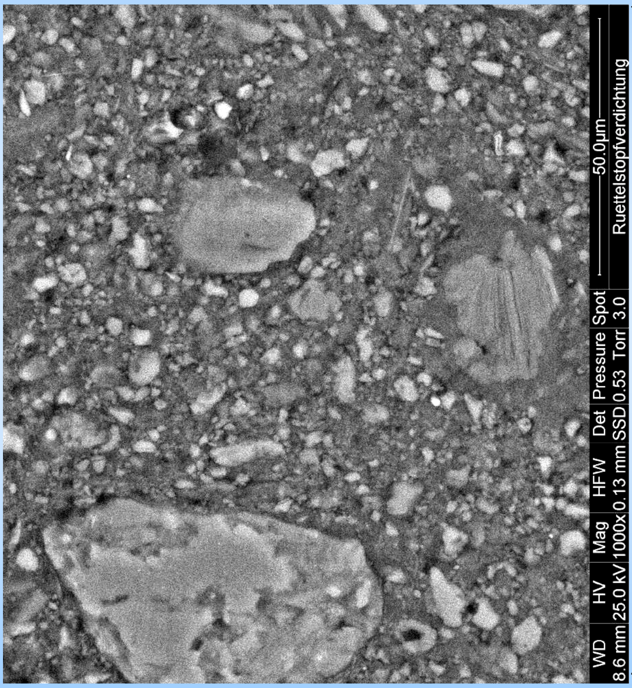
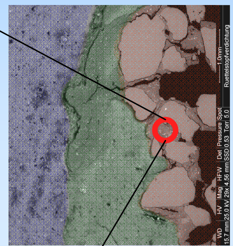
ESEM picture of zone 1 – clay between sand grains

150 μm



800x

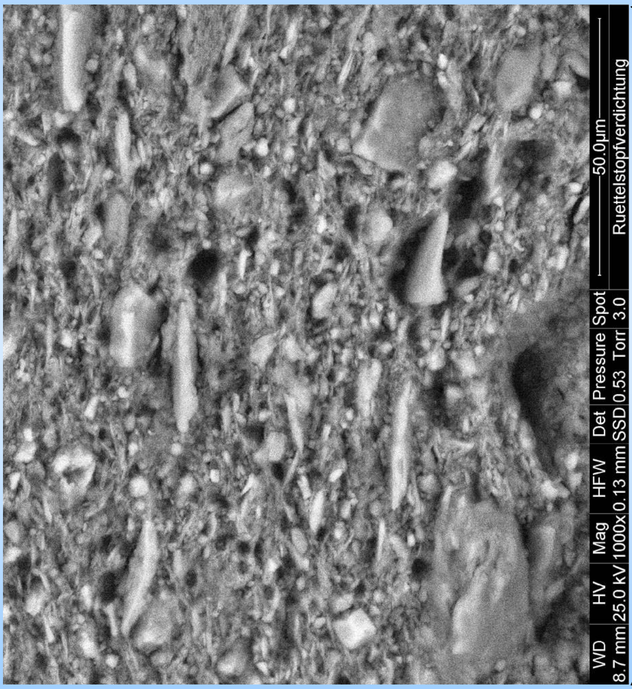


50x

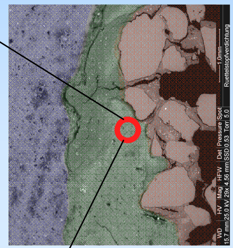
randomly oriented structure of the clay

ESEM picture of zone 2 – clay close to sand grains

150 µm



800x



50x

orientation of clay particles due to high shear strain parallel to column axis

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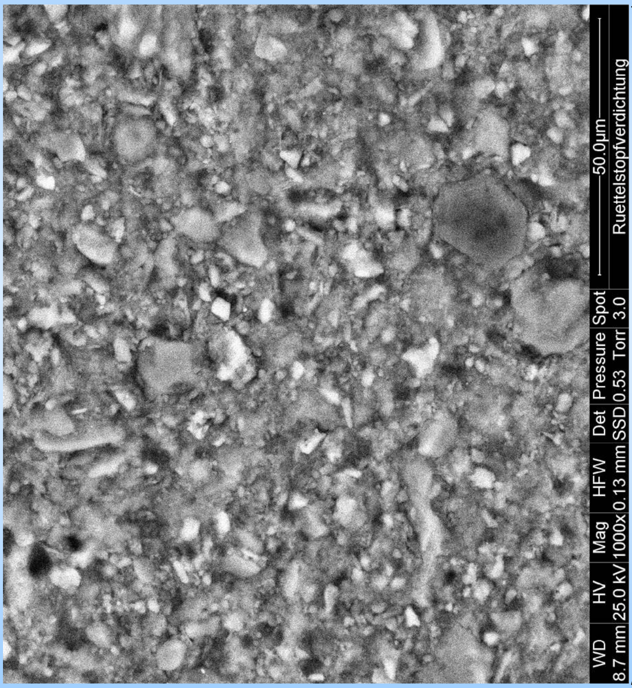
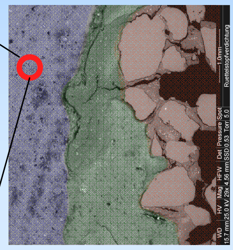
ESEM picture of zone 3 and 4 – clay far away from sand grains

150 µm



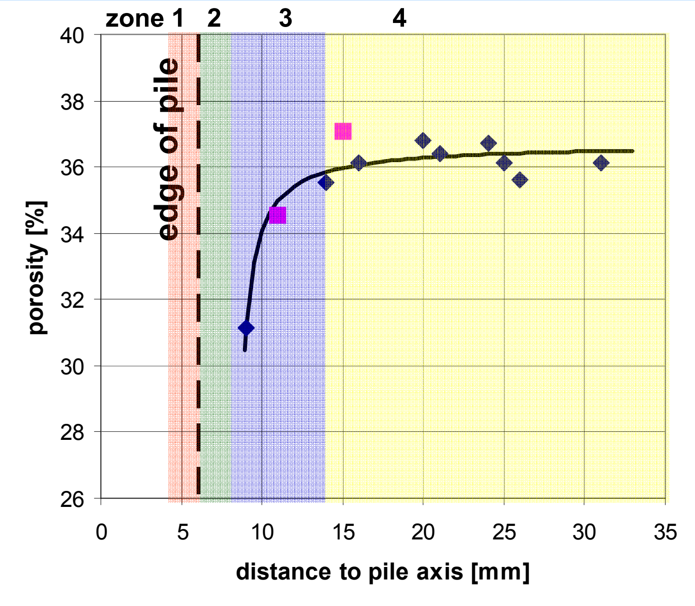
800x

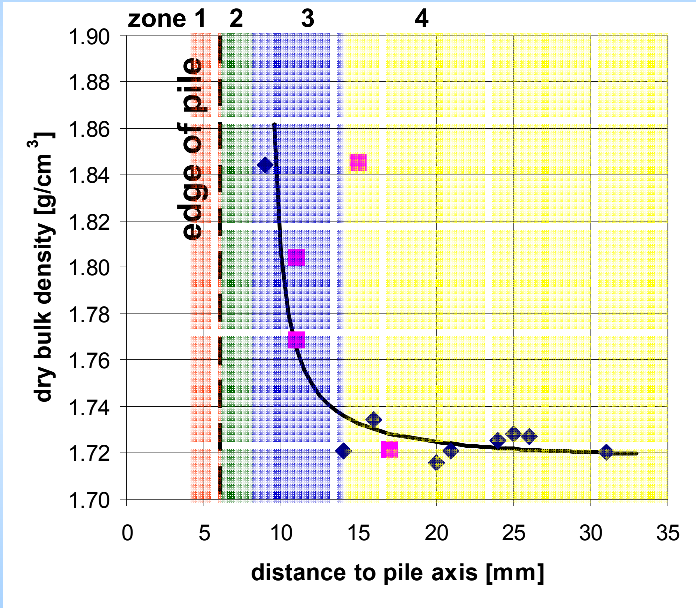


50x

randomly oriented structure of the clay

Results from mercury intrusion porosimetry analysis of clay





hyperbolic trend function

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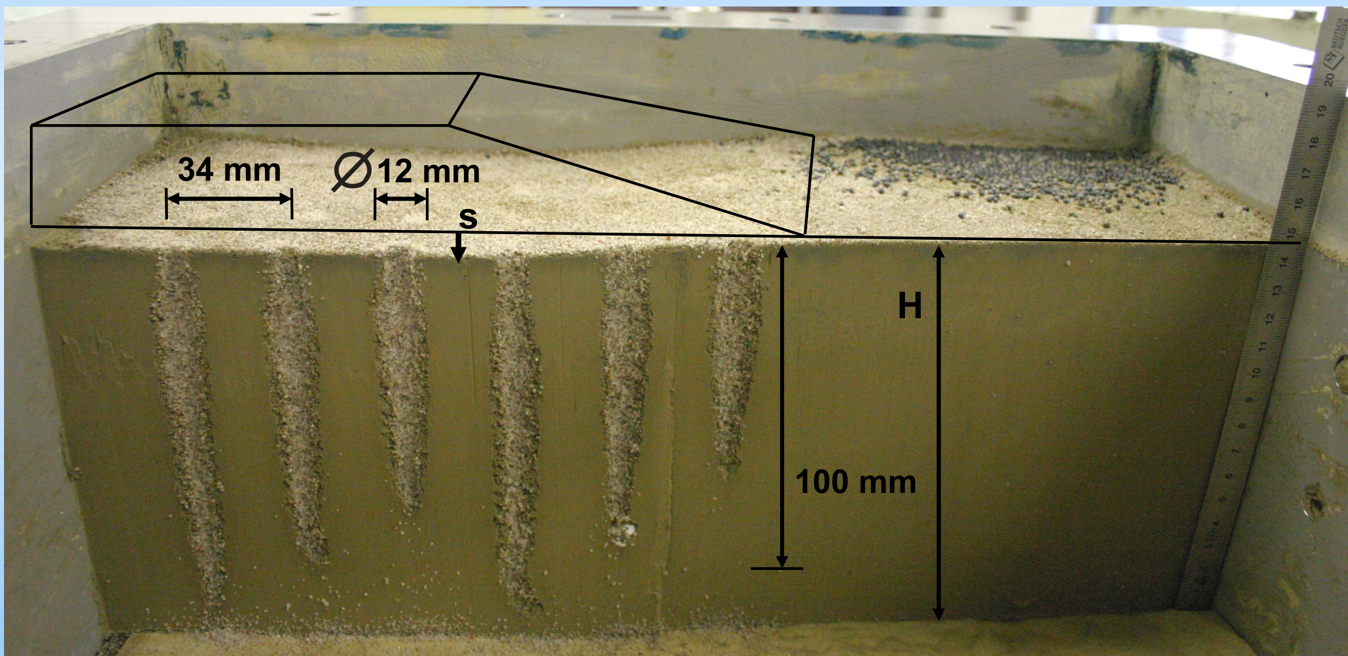
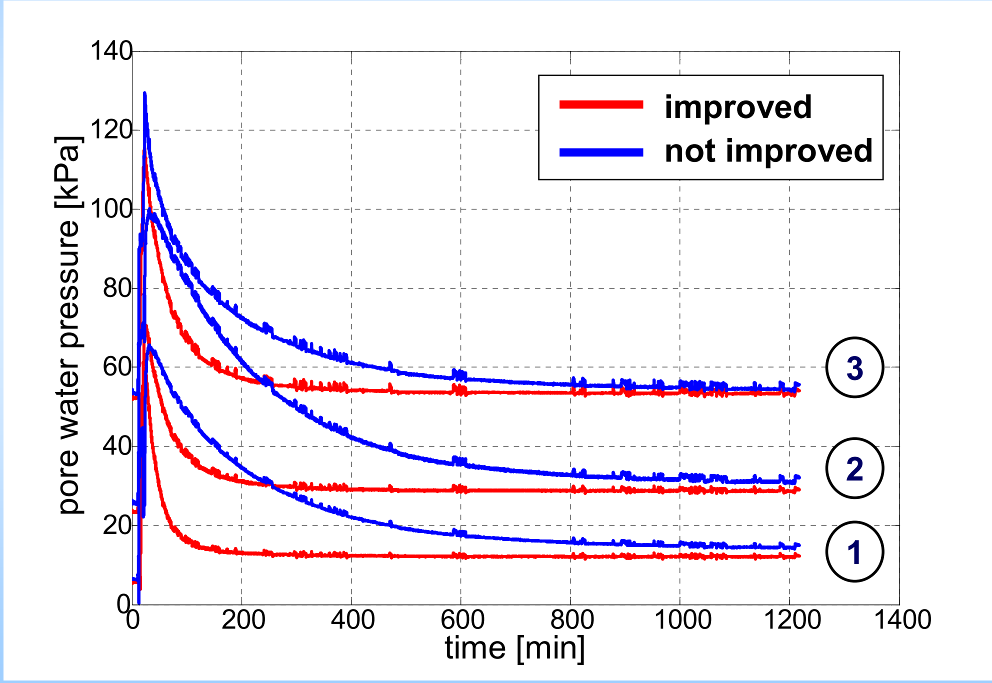
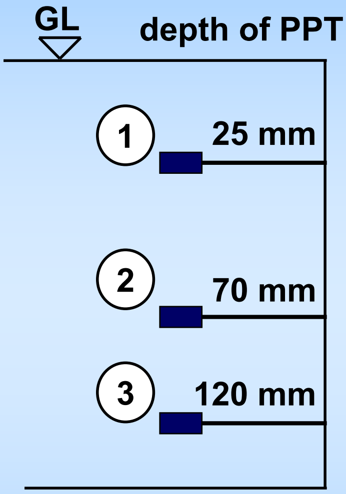
Section of soil model in the tub (2D)



Pore water pressures after embankment construction (2D)



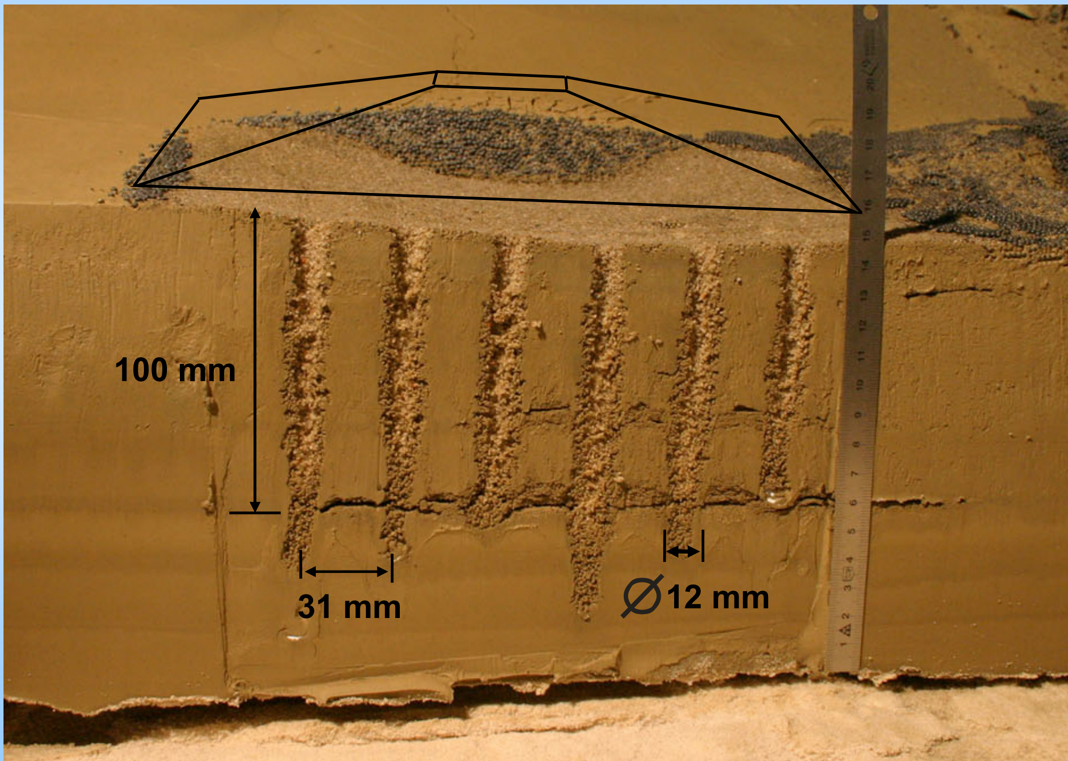


unimproved
t_{90} = 401 min
improved
t_{90} = 99 min

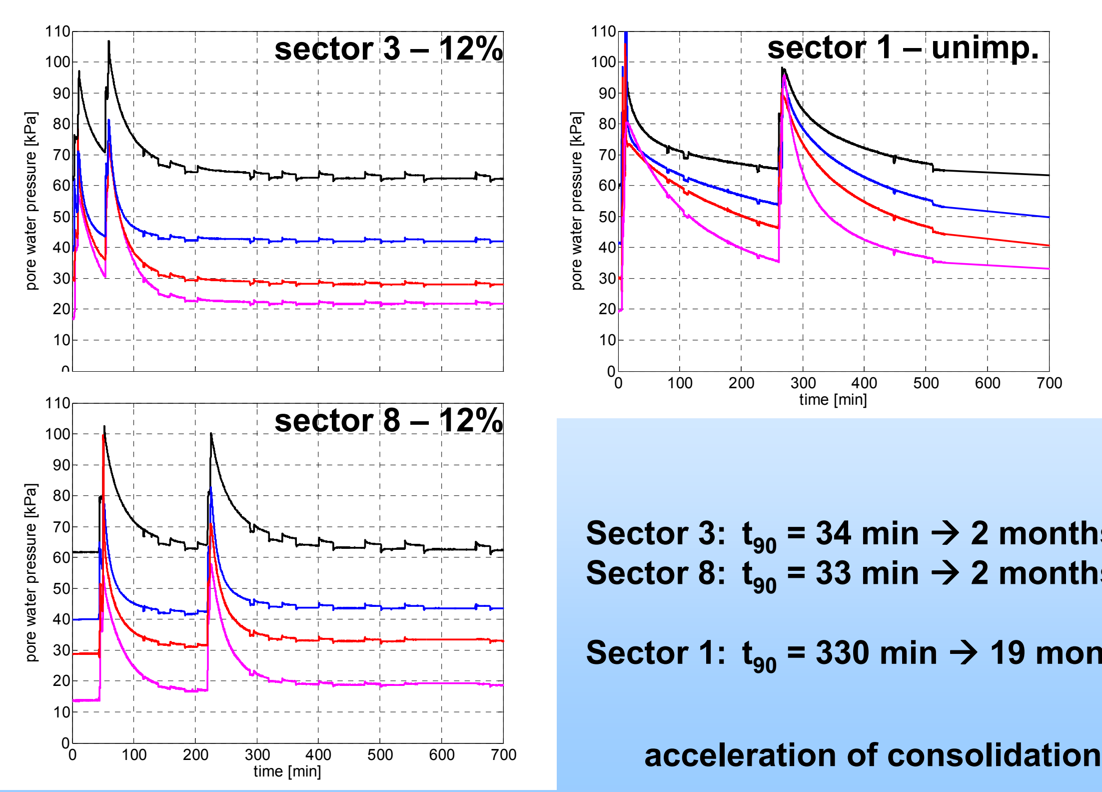
10 % reinforcement

acceleration of consolidation by factor 4

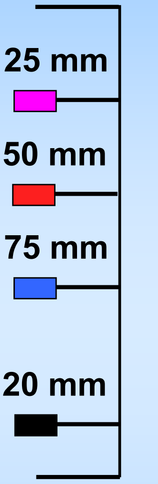
Section of soil model in the drum



Pore water pressures after embankment construction (3D)



depth of PPT

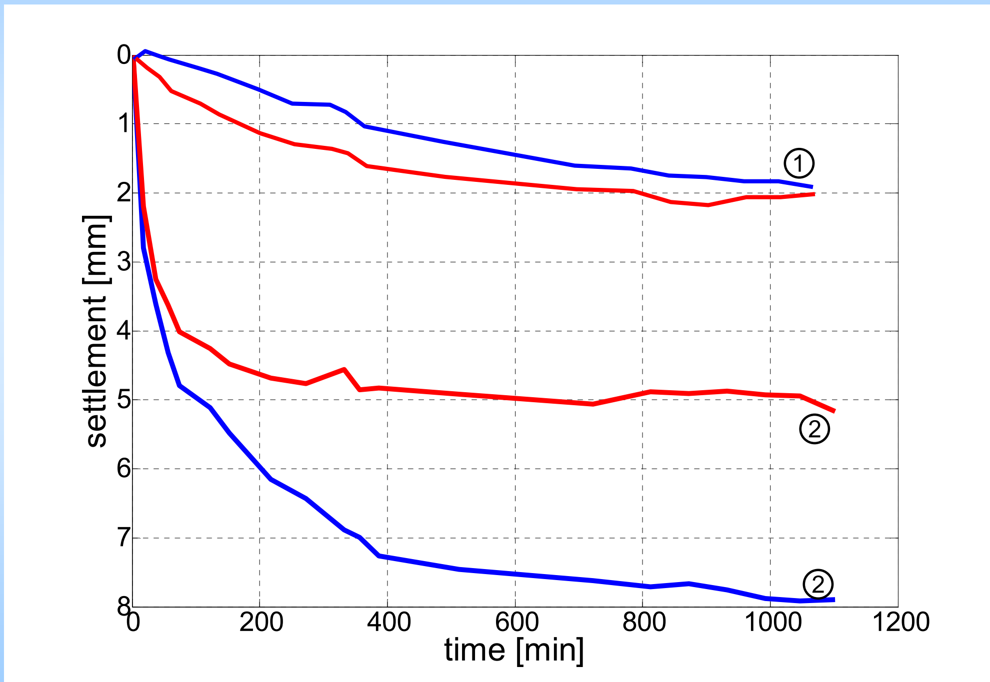


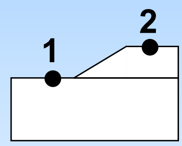
Sector 3: t_{90} = 34 min → 2 months (prototype)
Sector 8: t_{90} = 33 min → 2 months (prototype)

Sector 1: t_{90} = 330 min → 19 months (prototype)

acceleration of consolidation by factor 10

Time-settlement curves after embankment construction (2D)





improved

not improved

factor of settlement reduction, n = 1.75

embankment height 35 mm lead balls
$\Delta\sigma$ = 100 kPa

10 % area ratio of improvement

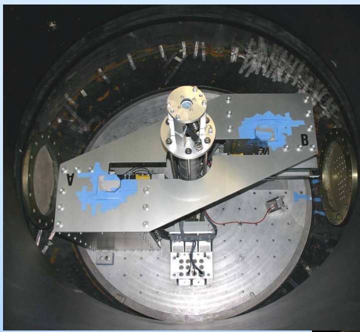
Weber, 2007

Ground Improvement of double porous material

(AMGISS, Marie Curie EU program)

- **Reuse of oben cast deposits**
- **Use of the drum centrifuge to establish load settlement behaviour in comparison to a field test (PhD thesis Jan Najser, Charles University Prague) and different ground improvement measures (PhD thesis Emma Pooley, ETHZ)**

Fresh landfill. (photograph M. Větrovský)



Centrifuge set Up

Modelled clay lumps made from real material

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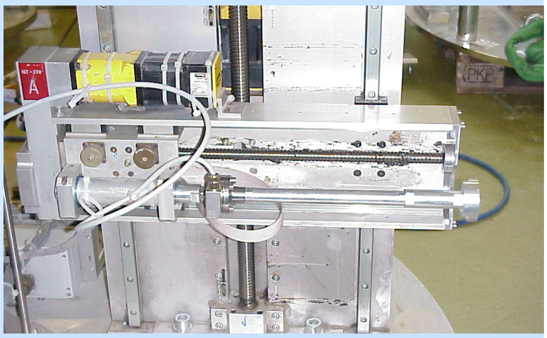
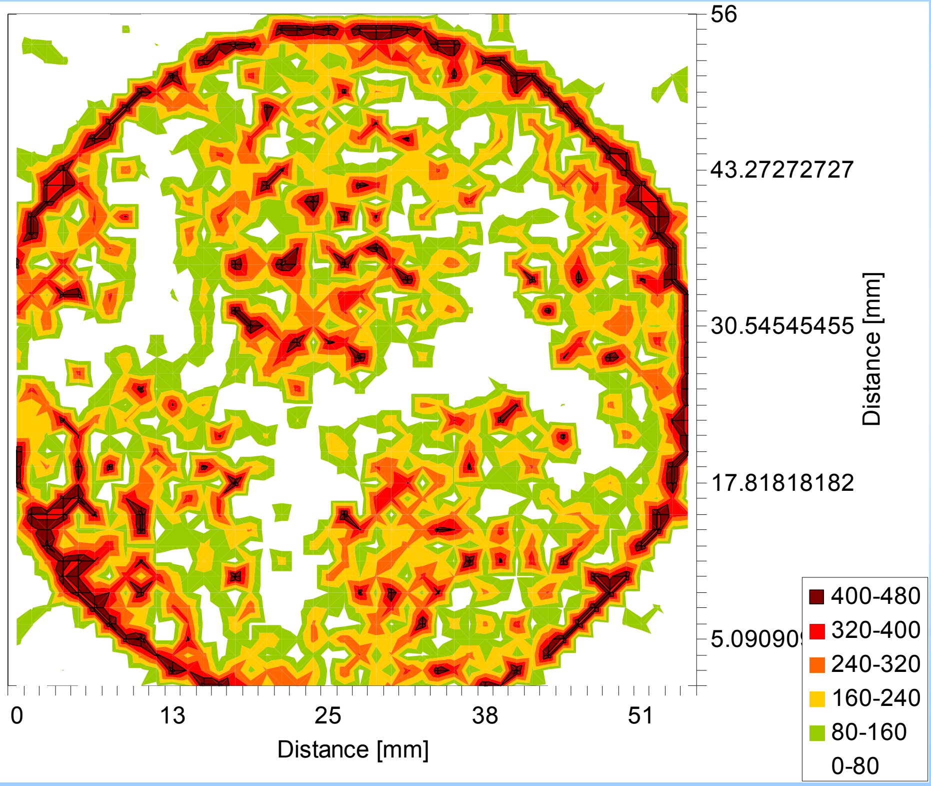
Stone columns placed in double porosity soils (2D)





Pressure distribution under the foundation: Test D (7 sand columns)

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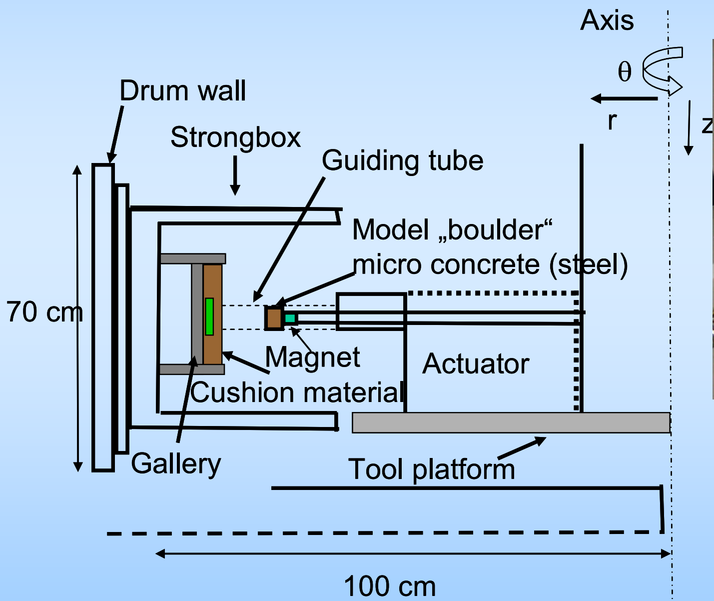
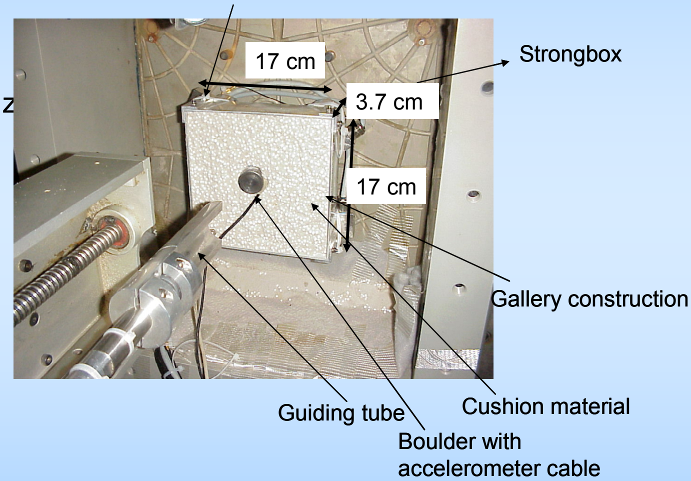
Ground Improvement by Heavy Tamping





Heavy Tamping tool is based on rockfall tool (Chikatamarla et al. 2005)

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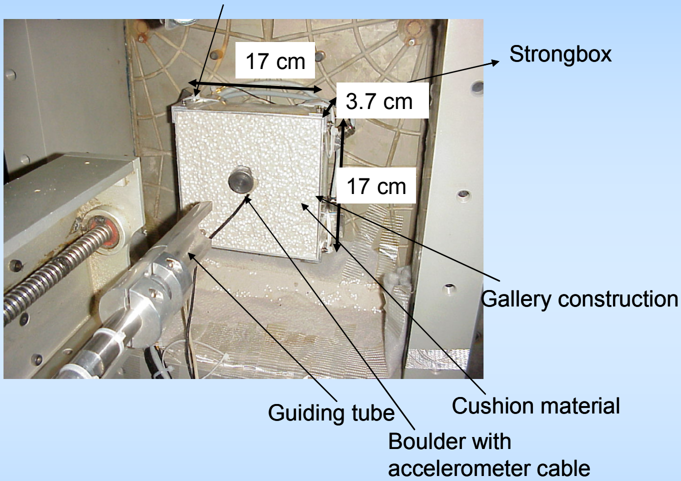
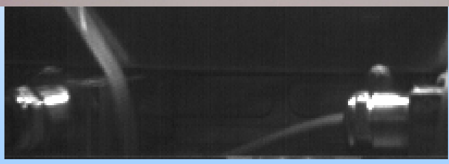
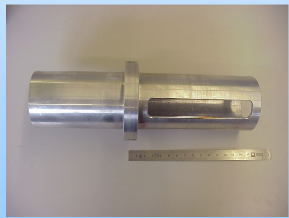
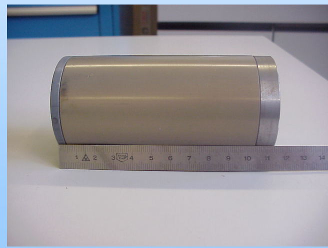








Adaptions

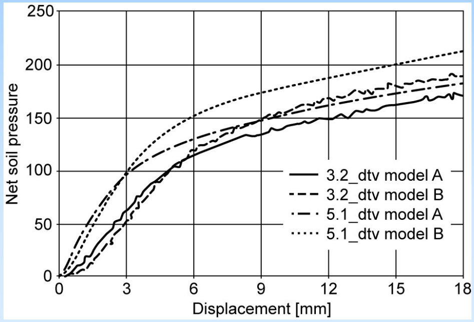
Professorship for Geotechnics
Modèles Physiques en géotechnique
Dr. Jan Laue
Ground Improvement

Heavy Tamping tool in use

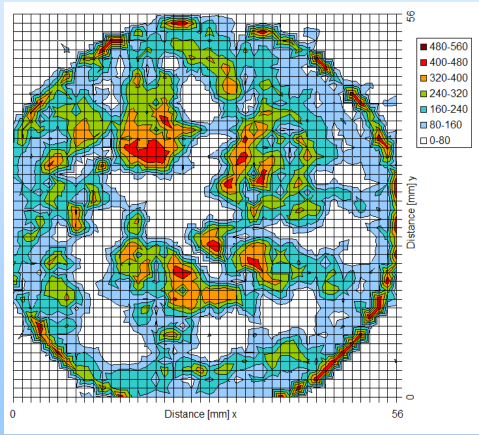
Erste Ergebnisse

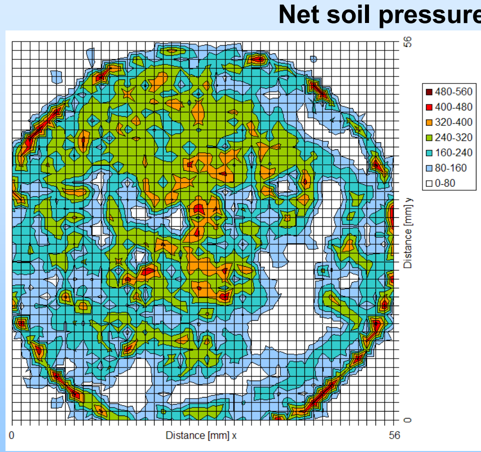
Test	Fall height (model scale)	Approximate input energy (prototype scale)
3.2_dtv model A	60 mm	1.6 kJ
3.2_dtv model B	100 mm	2.7 kJ
5.1_dtv model A	80 mm	2.1 kJ
5.1_dtv model B	120 mm	3.2 kJ

Energy reached in 4 tests (for comparison, 1t falling from 10m heigth equivalent to 100kJ)



Net soil pressure vers settlement





Without improvement the foundation reached a net soil pressure of 60kPa at a reference settlement of 15mm

Footprint of foundation: 3.2 model A *3.2 Model B*

Thank you very much for your attention