Niels Krebs Ovesen

His Legacy in Physical Modelling

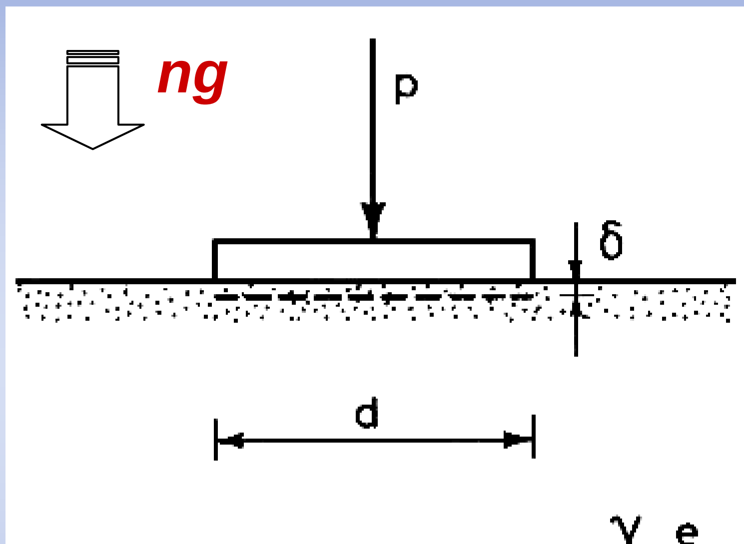
Sarah Springman
Chair, ISSMGE TC2

Legacy is an important word when one describes what is left behind after the living of a life. It can be defined in terms of influence on people (students, undergraduate and postgraduate, colleagues) and knowledge (papers, theory, methodology, data….) as well as the less tangible human characteristics that make up the man

Niels Krebs Ovesen was undoubtedly a net contributor on all those fronts, in physical modelling and particularly as a teacher and bringer of research to application in practice, all of which was conducted with consummate 'management skills, craftsmanship and rigour' (after Steenfelt, 2006)

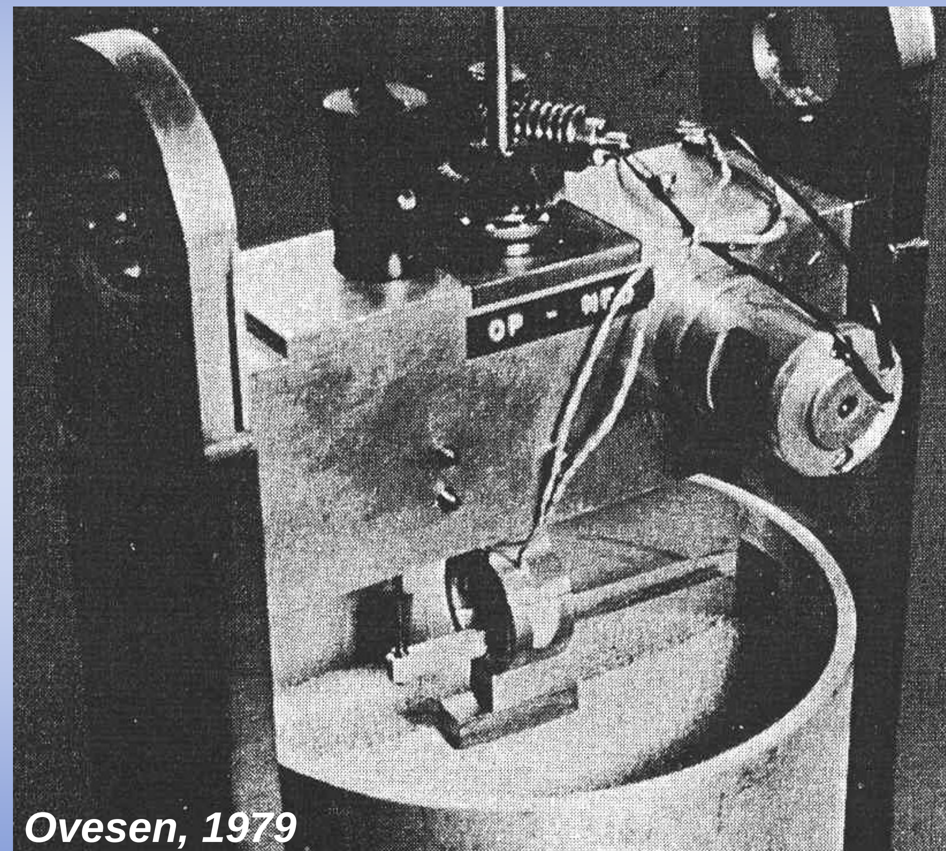
He was a man who made time for people and he was both a gentleman and a gentle man

Dimensional analysis, similitude & footings



Ovesen, 1979

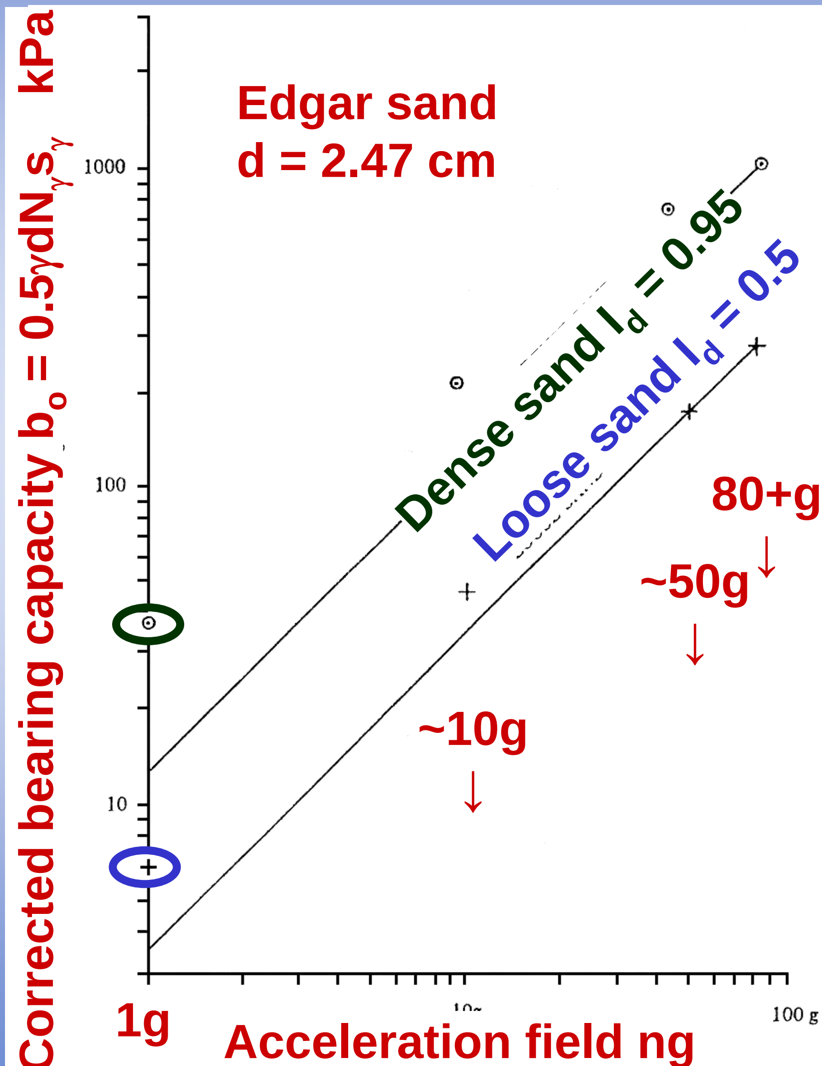
Is it possible to model soil structure interaction accurately with small scale (1/n, n >> 1) models?



Ovesen, 1979

A model of a footing on sand built to a length scale $1/n_1$ subjected to an acceleration field n_1g yields the same bearing capacity as an equivalent model built to a length scale $1/n_2$ subjected to n_2g – at least for $1 \leq n_1 / n_2 \leq 3$

Vertically loaded footings on sand: scale effects



The Florida experience, 1971-2

$b_o = 0.5\,\gamma\,d\,N_\gamma\,s_\gamma$

↑

$f(\phi)$

Danish Code

$$\phi \approx 30° - 3/U + (14 - 4/U) I_d$$

Loose sand $I_d = 0.5$, $\phi \sim 34^o$

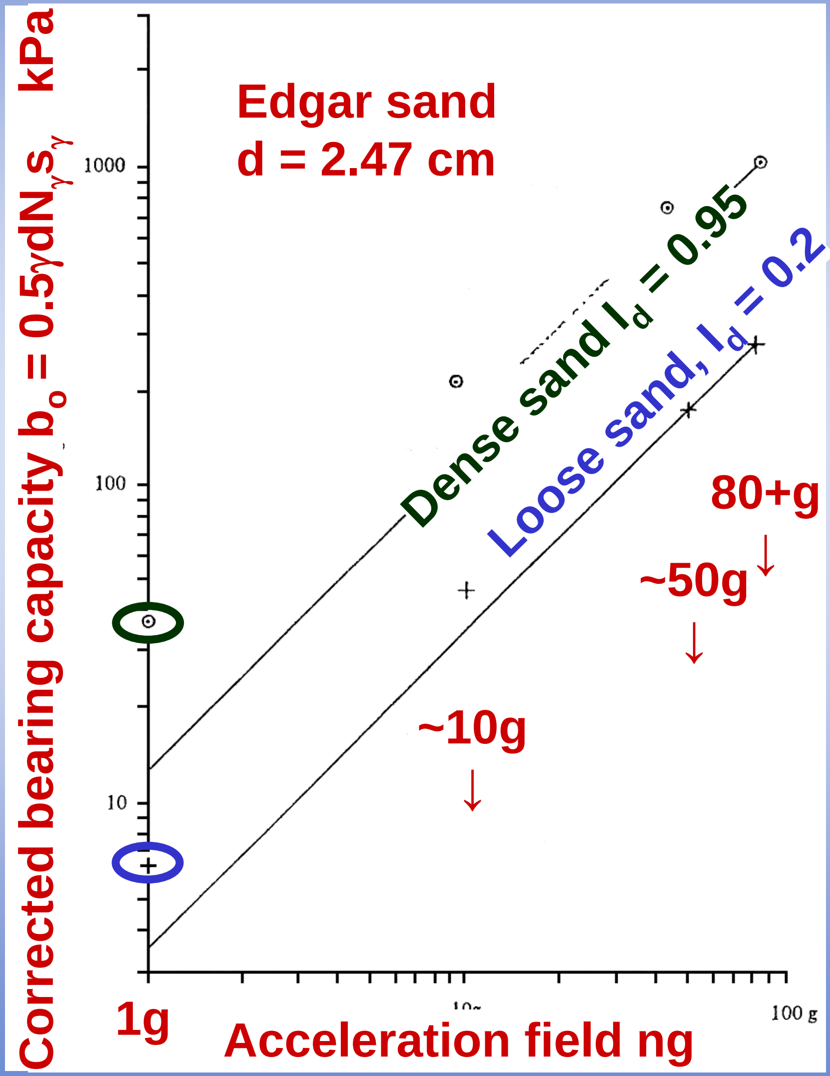
Dense sand $I_d = 0.95$, $\phi \sim 39^o$

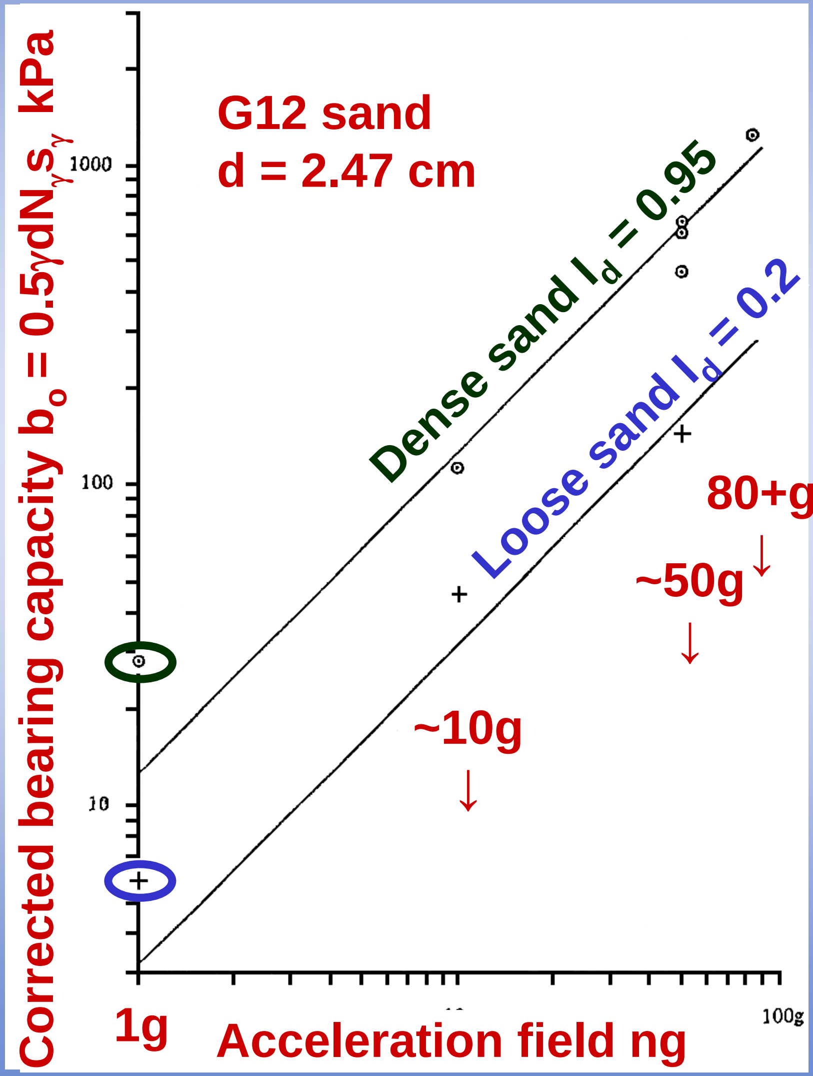
But no dependency on stress level allowed for in defining ϕ

=> a scale effect has been observed

This is not the only example……

Vertically loaded footings on sand: scale effects





$$\varphi \approx 30° - 3/U + (14 - 4/U) I_d$$

Krebs Ovesen, 1975

Amendment for dilatancy

$I_R = I_d\,(Q - \ln p') - 1$ — Bolton, 1986

Dilatancy Index I_R = f (Relative Density I_d, Particle crushing strength Q, mean effective stress p‘)

Under triaxial conditions (e.g. for a circular footing): $\psi = 3I_R$

$\phi'_{max} = \phi'_{crit} + 0.8\psi$ => will influence value of N_γ hence b_o

	G12 sand	G12 sand
Density I_d	Loose 0.2	Dense 0.95
ϕ‘ (°) Danish code Result / Predicted (1g)	31 270%	39 220%
ϕ‘ (°) Bolton 1g – 80+g Result / Predicted 1g – 80+g	36 – 34 93% 90%	55 – 45 76% 91%

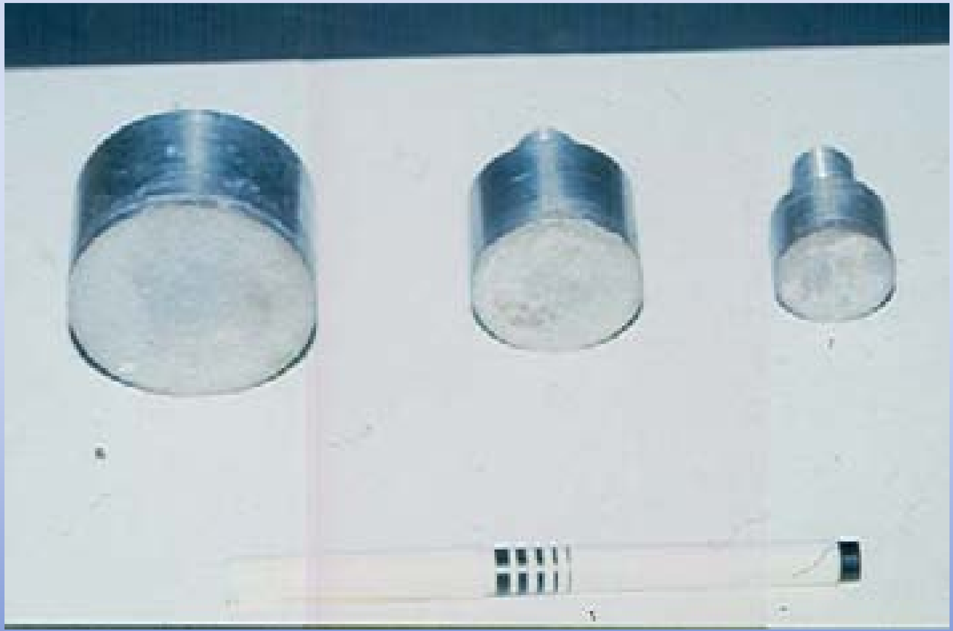
DIAB Large Centrifuge

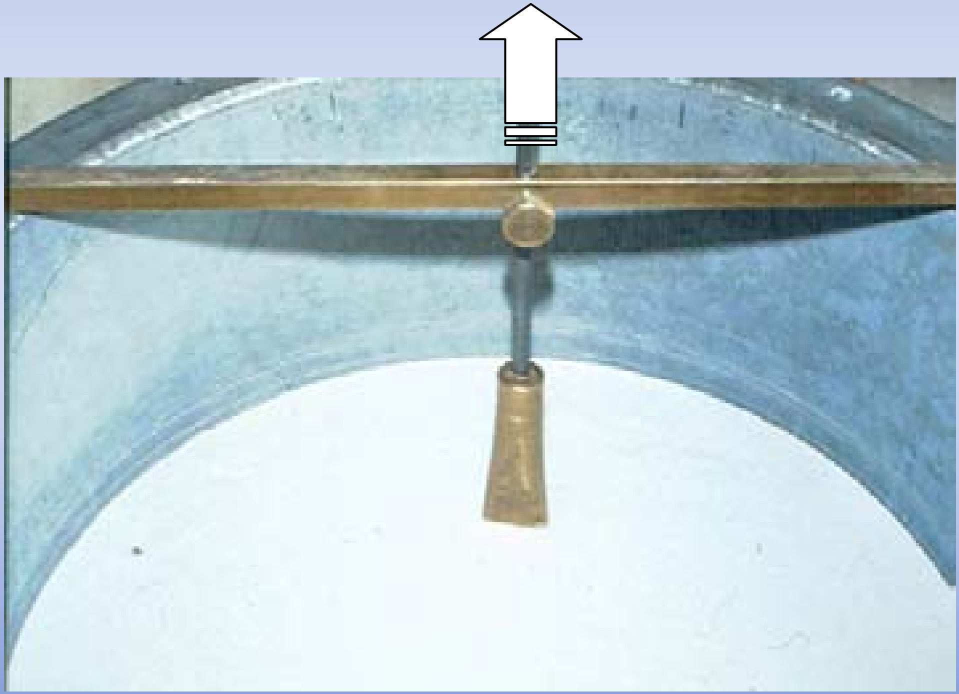
Specification: radius 2.3 m, 100 gton

Photos: Jacques Garnier

DIAB Accessories: model footings & sand surface preparation

Vacuum applied to suck away sand particles to form level surface





Photos: Jacques Garnier

Dimensional analysis & similitude

- the complete set of similarity requirements must be established by means of dimensional analysis
- departure from complete similarity must be justified by means of experimental evidence

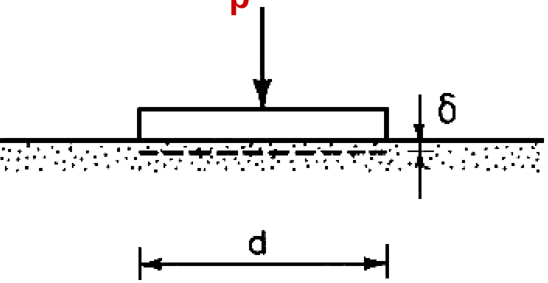
Ovesen, 1979

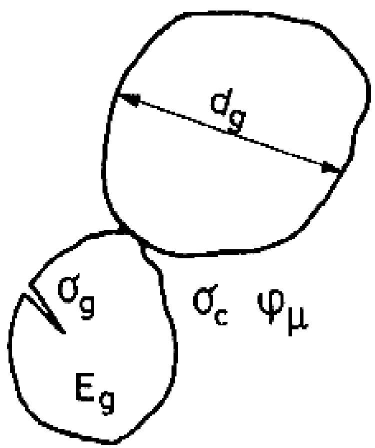
Sarah Springman

Dimensional analysis

$$\frac{P_p}{\gamma d} = F\left[e, \phi_\mu, \frac{\sigma_c}{\gamma d}, \frac{\sigma_g}{\gamma d}, \frac{E_g}{\gamma d}, \frac{d_g}{d} \right]$$

P_p Peak Load

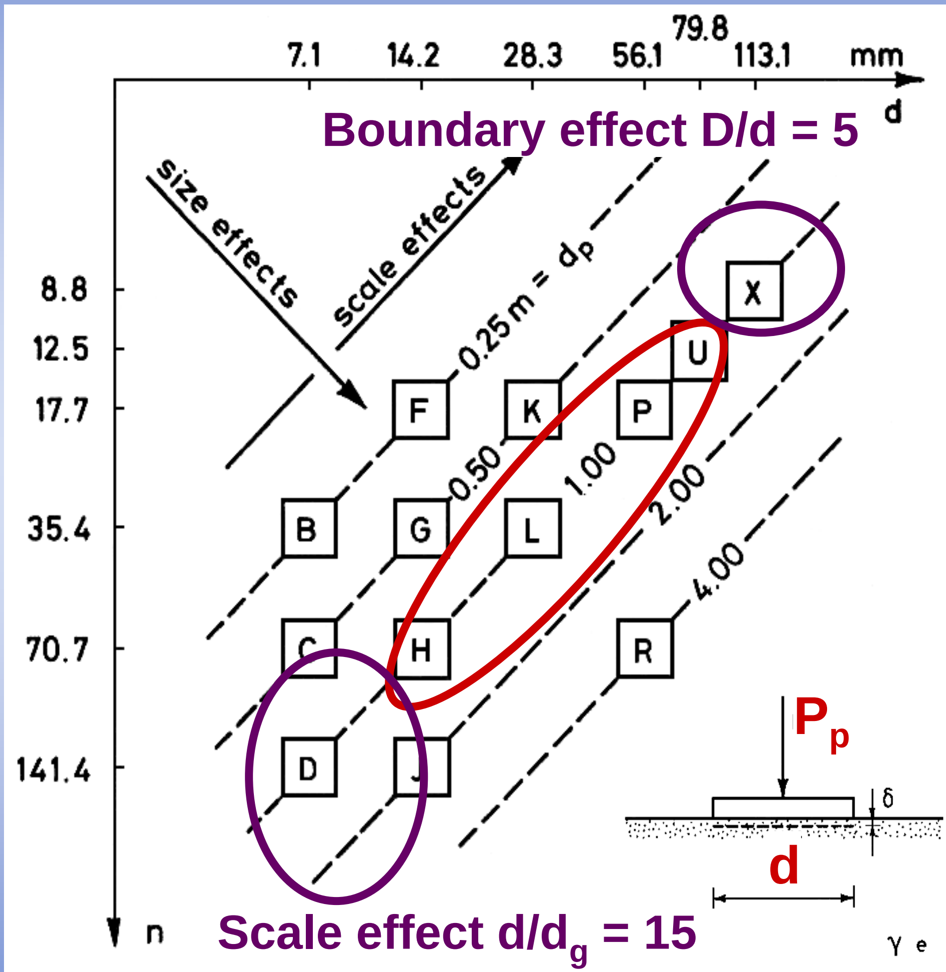


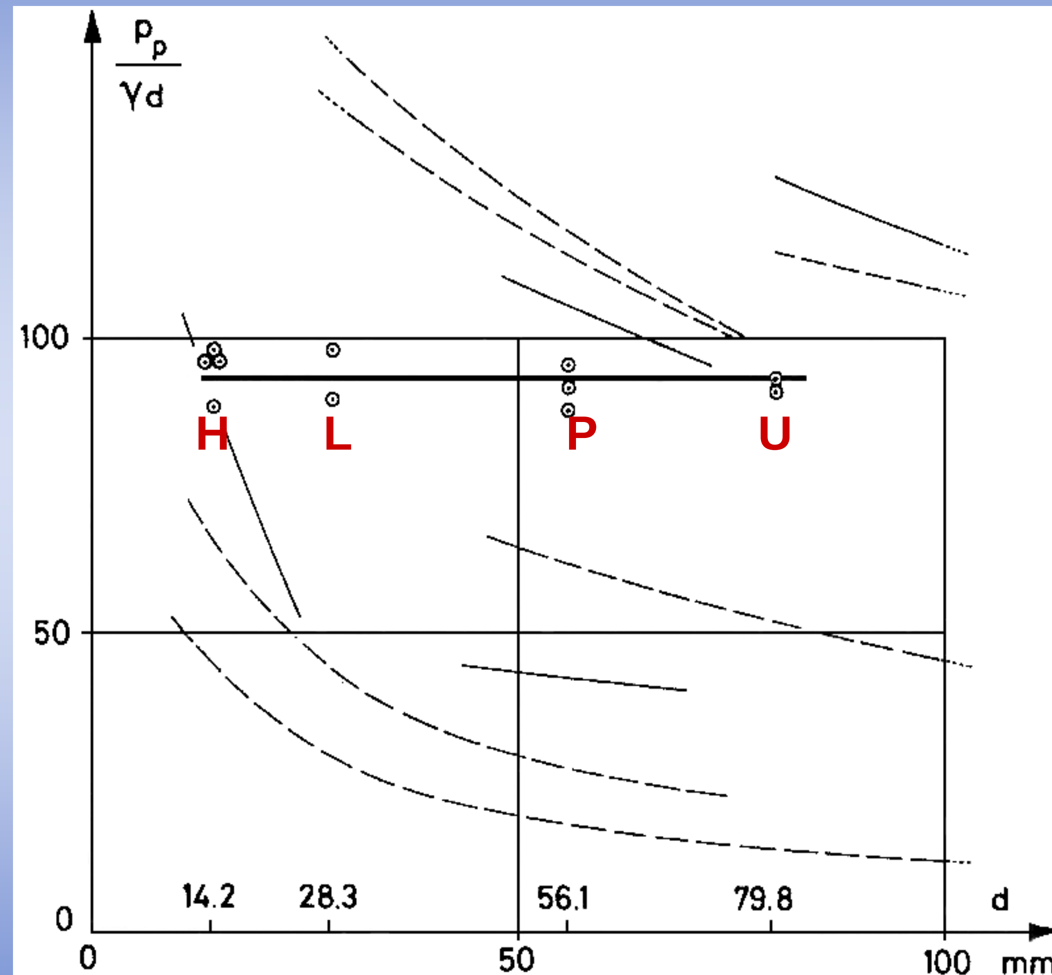


Ovesen, 1979

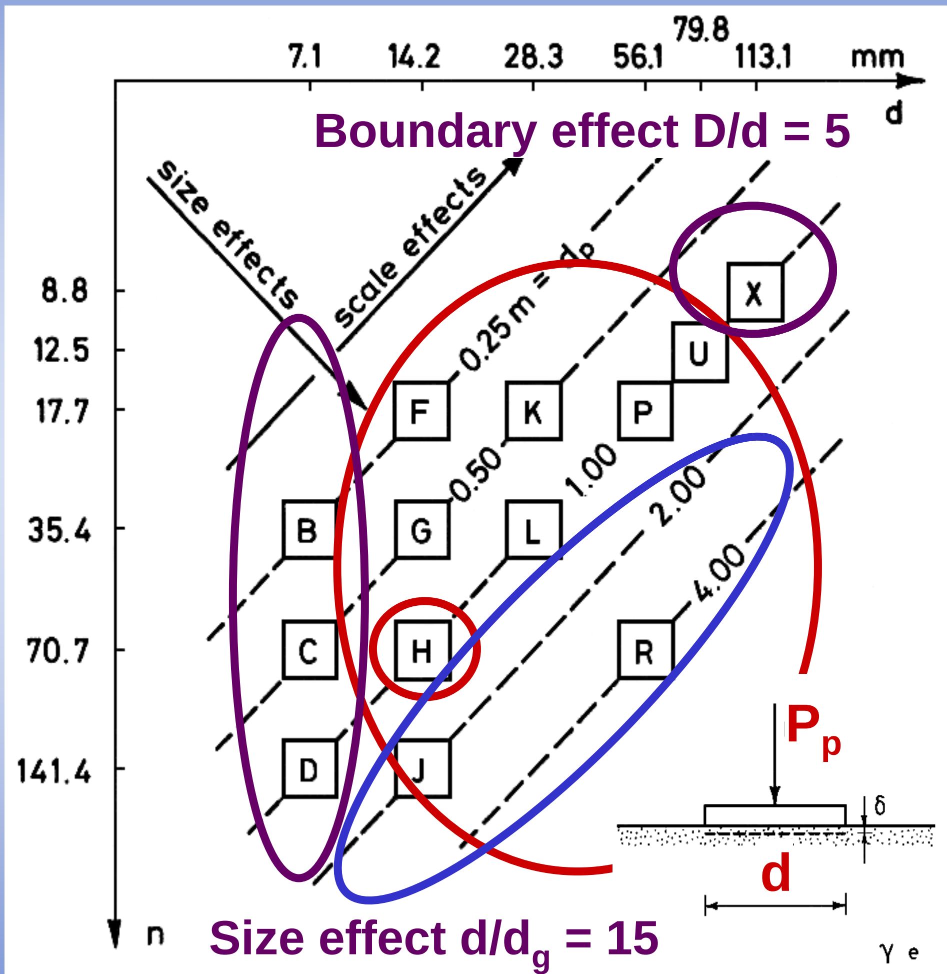
PROTOTYPE Scale: 1:1 Gravity: g	CONVENTIONAL MODEL Scale: 1 / n Gravity: g		CENTRIFUGE MODEL Scale: 1 / n Gravity: ng	
e	e	similar	e	similar
ϕ_μ	ϕ_μ	similar	ϕ_μ	similar
$\frac{\sigma_c}{\gamma d}$	$\frac{\sigma_c}{\gamma d/n}$	not similar	$\frac{\sigma_c}{\gamma nd/n}$	similar
$\frac{\sigma_g}{\gamma d}$	$\frac{\sigma_g}{\gamma d/n}$	not similar	$\frac{\sigma_g}{\gamma nd/n}$	similar
$\frac{E_g}{\gamma d}$	$\frac{E_g}{\gamma d/n}$	not similar	$\frac{E_g}{\gamma nd/n}$	similar
$\frac{d_g}{d}$	$\frac{d_g}{d/n}$	not similar	$\frac{d_g}{d/n}$	not similar

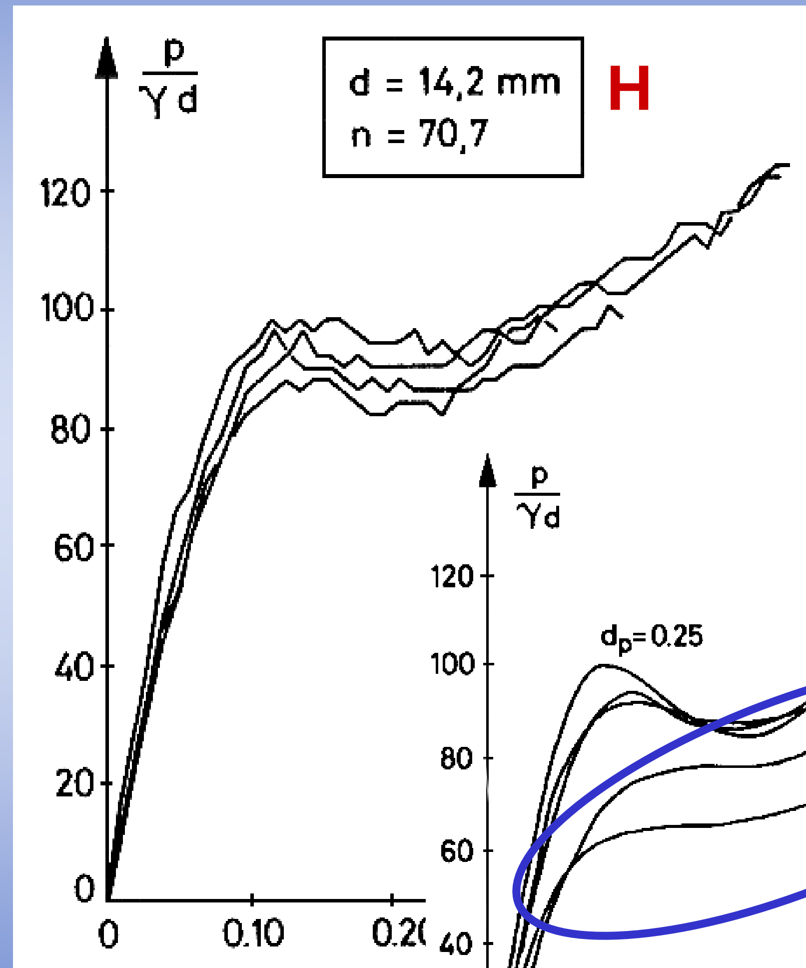
Modelling (verification) of models

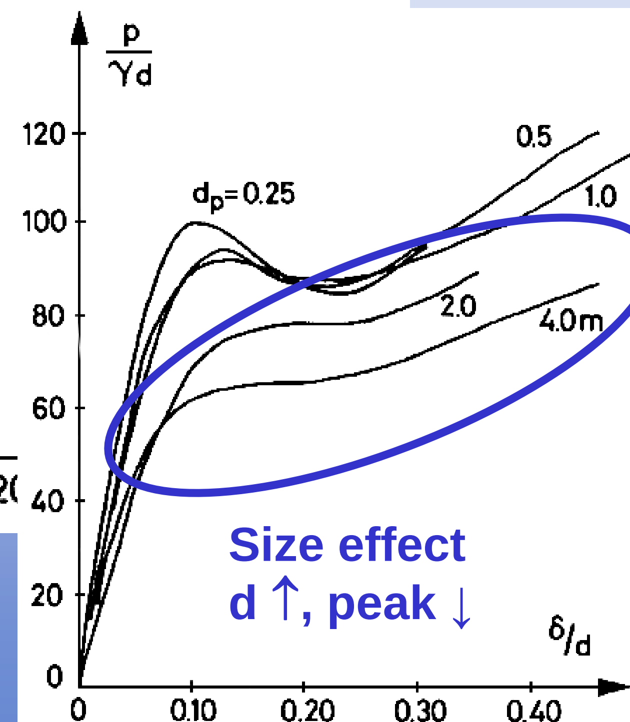




Modelling of prototypes







Ovesen, 1979

APPLICATIONS

Axisymmetric footings on layered ground (Nater, IGT, ETHZ)

2 examples from Niels Krebs Ovesen's work
Anchors & Reinforced walls

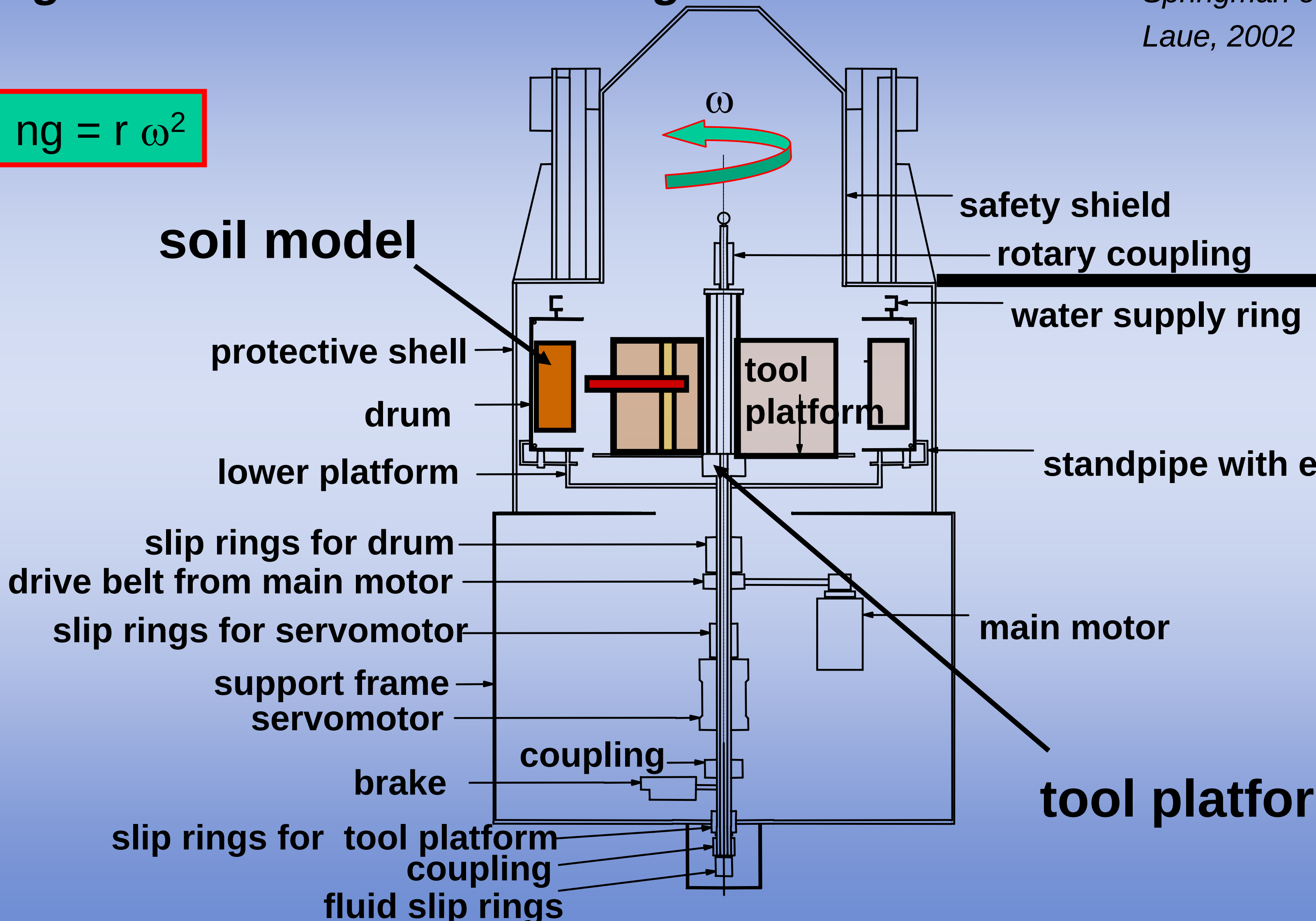
Embankment on improved ground (Weber, IGT, ETHZ)

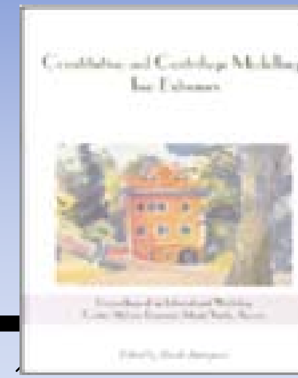
ETHZ geotechnical drum centrifuge

Springman et al., IJPMG 2001

Laue, 2002

$$ng = r\,\omega^2$$





Axisymmetric foundations on layered soils

Doctoral researcher: Philippe Nater

Supervisors: Sarah Springman, Jan Laue

Publications:

ICSMGE, Istanbul: 2001

Const. & Cent. Mod., 2 extremes, Monte Verita: 2001

Int. Conf. Phys. Mod. Geot., St Johns, (2): 2002

Foundations, Dundee: 2003

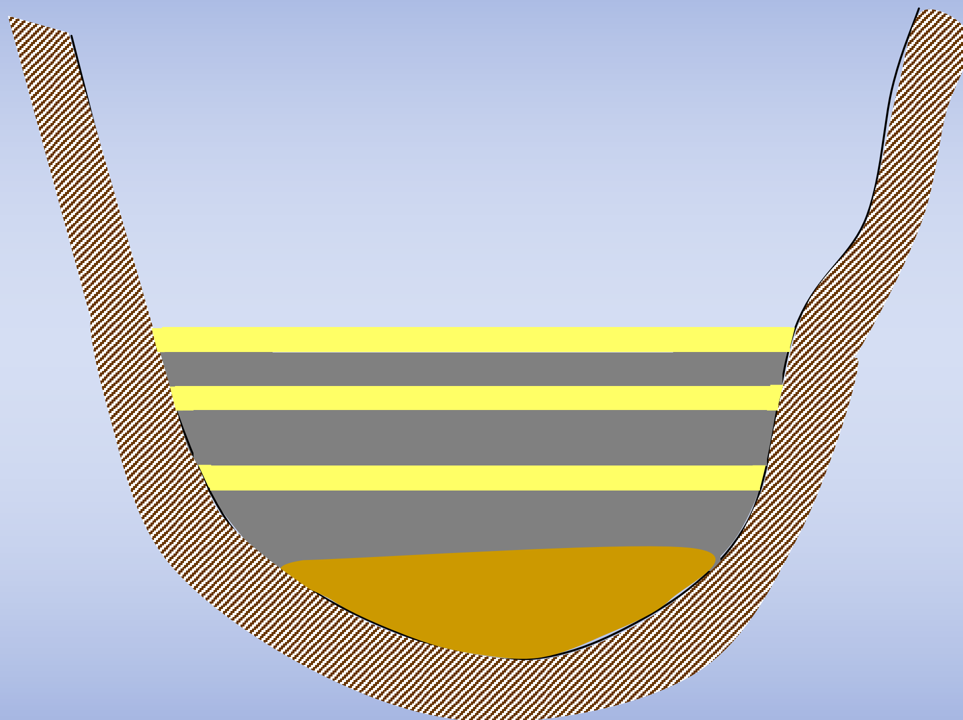
Fondsup, Paris: 2003

ICSMGE, Osaka: 2005

Dissertation: 2005

Partner:
ETH Research Fund

Infilled valleys in Switzerland & 2005 floods



Schematic section

Alternating layers:coarse/finegrained deposits

© Swiss airforce, 2005

Footings on layered soils

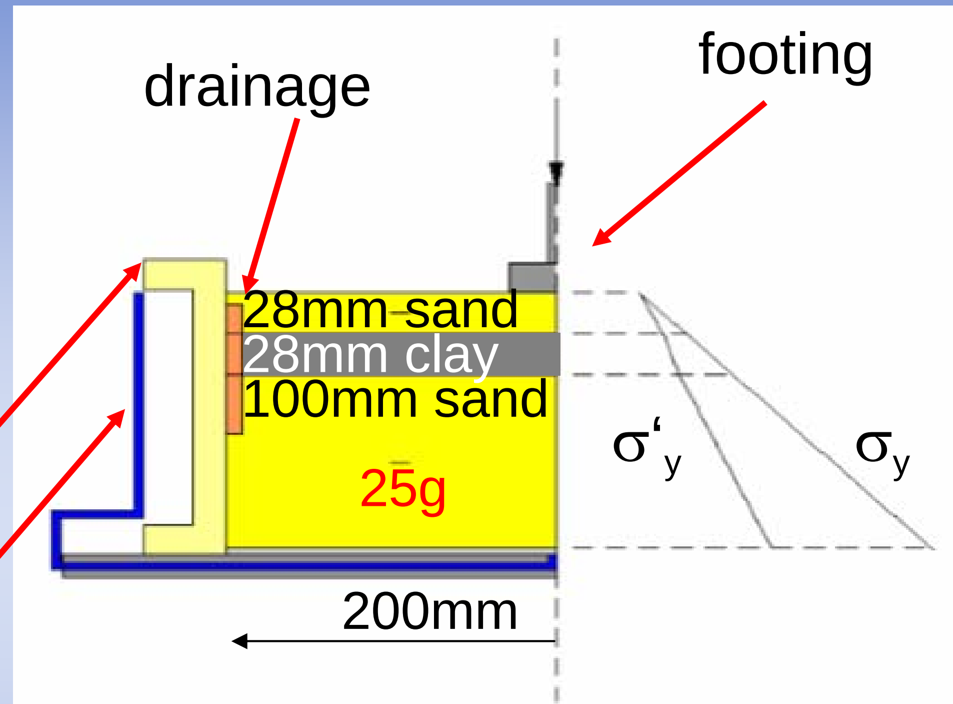
Prototype

foundation diameter: 1.4 m

Modelling

…of models

…of prototypes

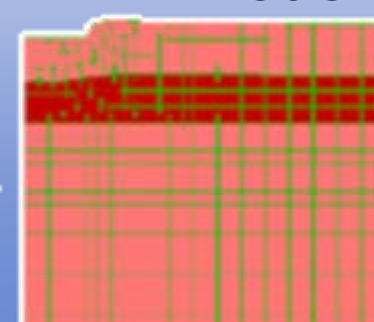


container

standpipe

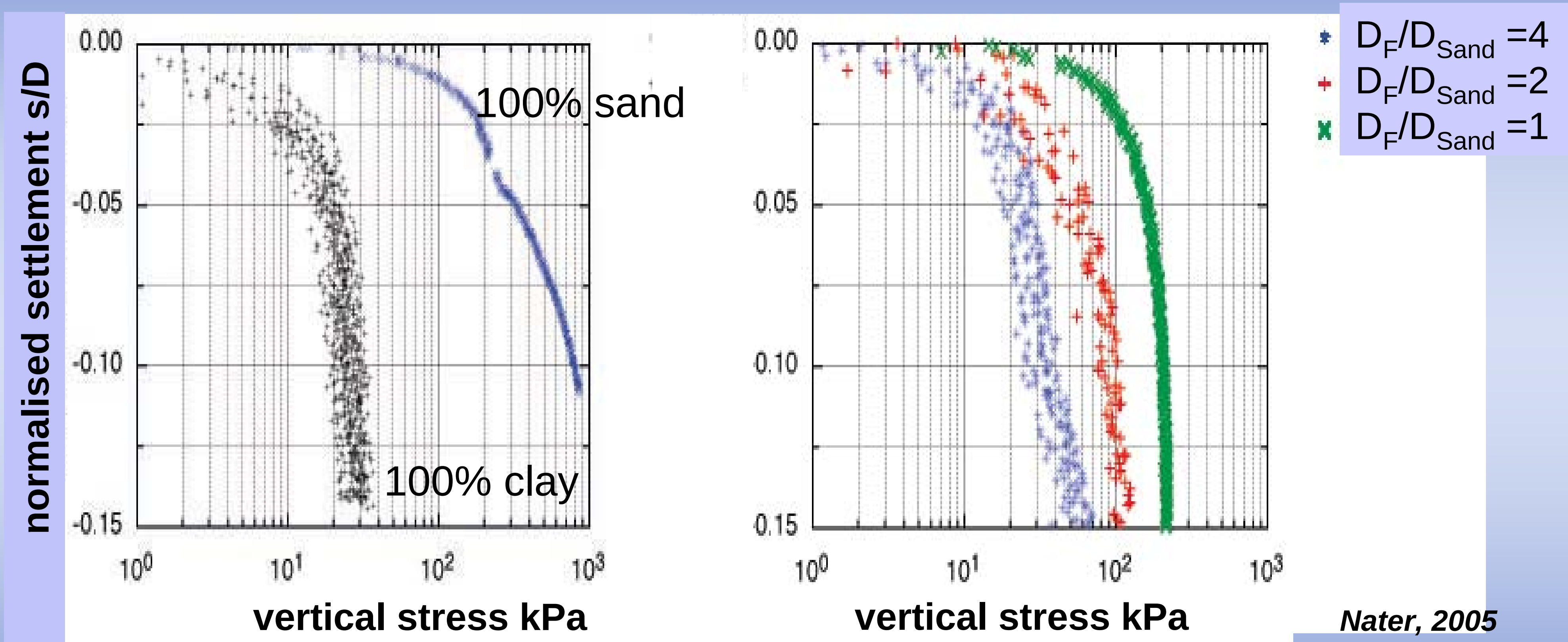
physical model

numerical model



Nater, 2005

Results load-settlement curves: physical modelling



Nater, 2005

boundaries for clay and sand

variation of layer thickness

- small increase of bearing capacity compared to equivalent single layer test on clay
- behaviour of complete system is more ductile i.e. larger settlement for same load than in single layered system => stress distribution change!

Modelling: physical

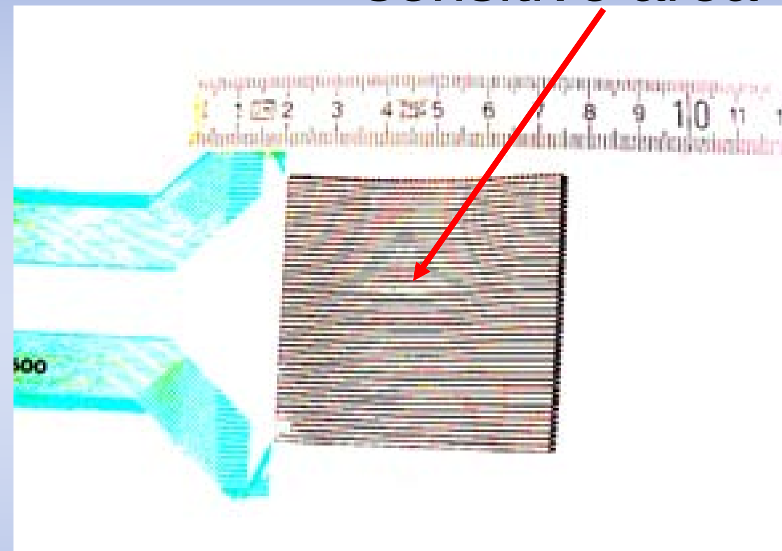
actuator setup:

footing

& load cell

loading device mounted on actuator tower

sensitive area

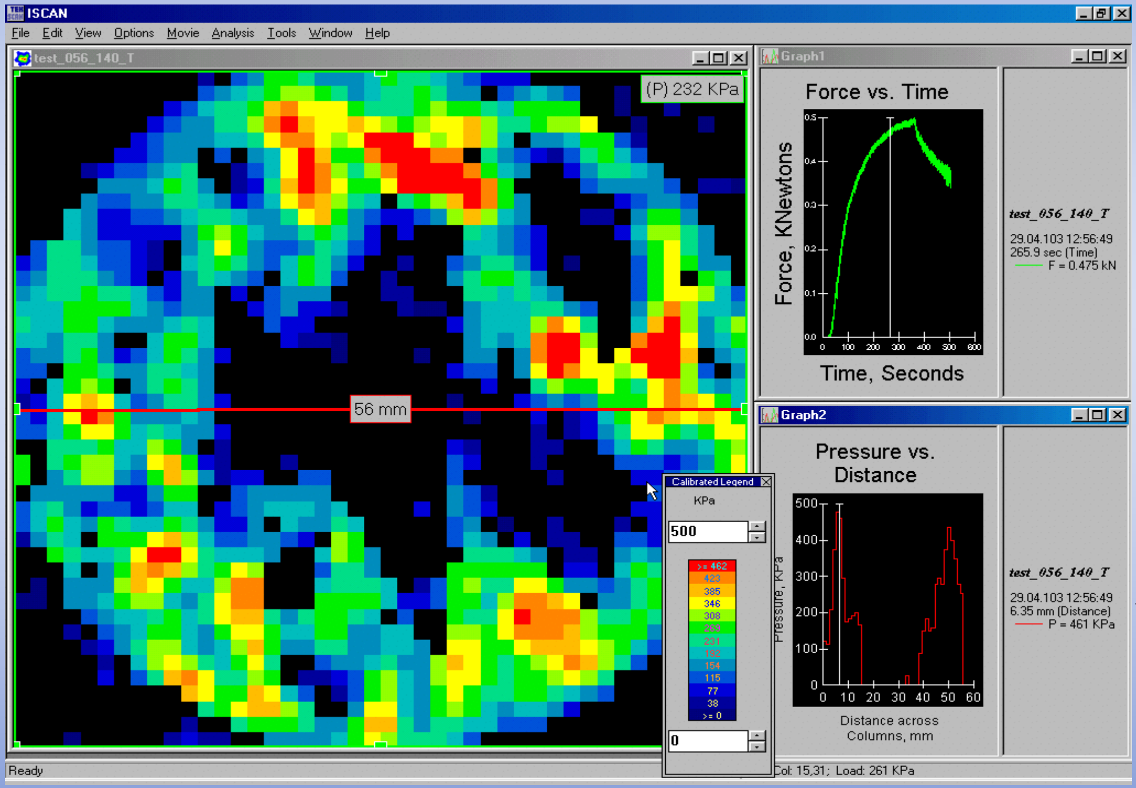


TekScan pressure pad

standard test at 25g with footing diameter 0.056m (1.4m prototype diameter)

Nater, 2005

Stress distribution directly under footing: physical modelling



contact zone

load vs. time

results confirmed by load cell data

stress profile

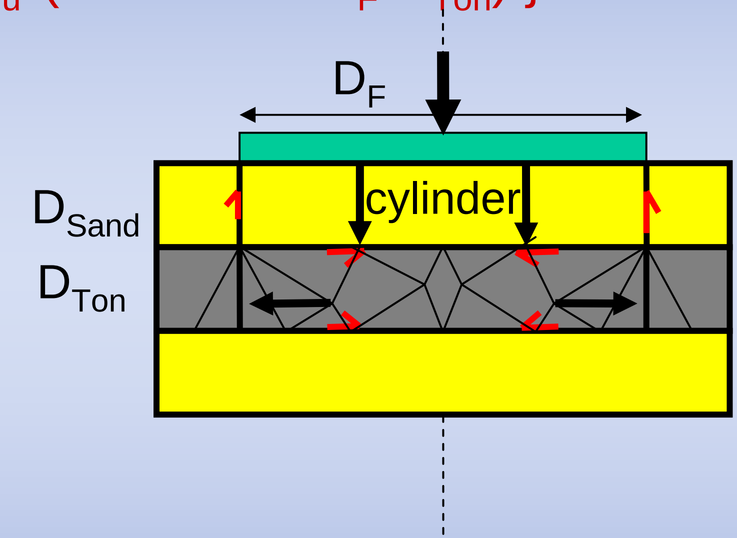
stress distribution measured with TekScan (*Nater, 2006*)

Design equation for failure load (unfactored)

$$\sigma_f = \sigma_{fSand} + \sigma_{fTon}$$

$$\sigma_f = \{(K_p - (D_{Sand}/D_F))*(2*\gamma'_{Sand}*D^2_{Sand}*K_p*\tan\phi')/D_F\} + \{s_u*(4.25+0.26*D_F/D_{Ton})\}$$

- load transferred through sand layer
- cylinder moves vertically downwards
- friction mobilised



- clay extruded outwards

with ϕ' [°] = angle of friction

K_P [-] = tan(45° + ϕ'/2)

s_u [kPa] = undrained shear strength

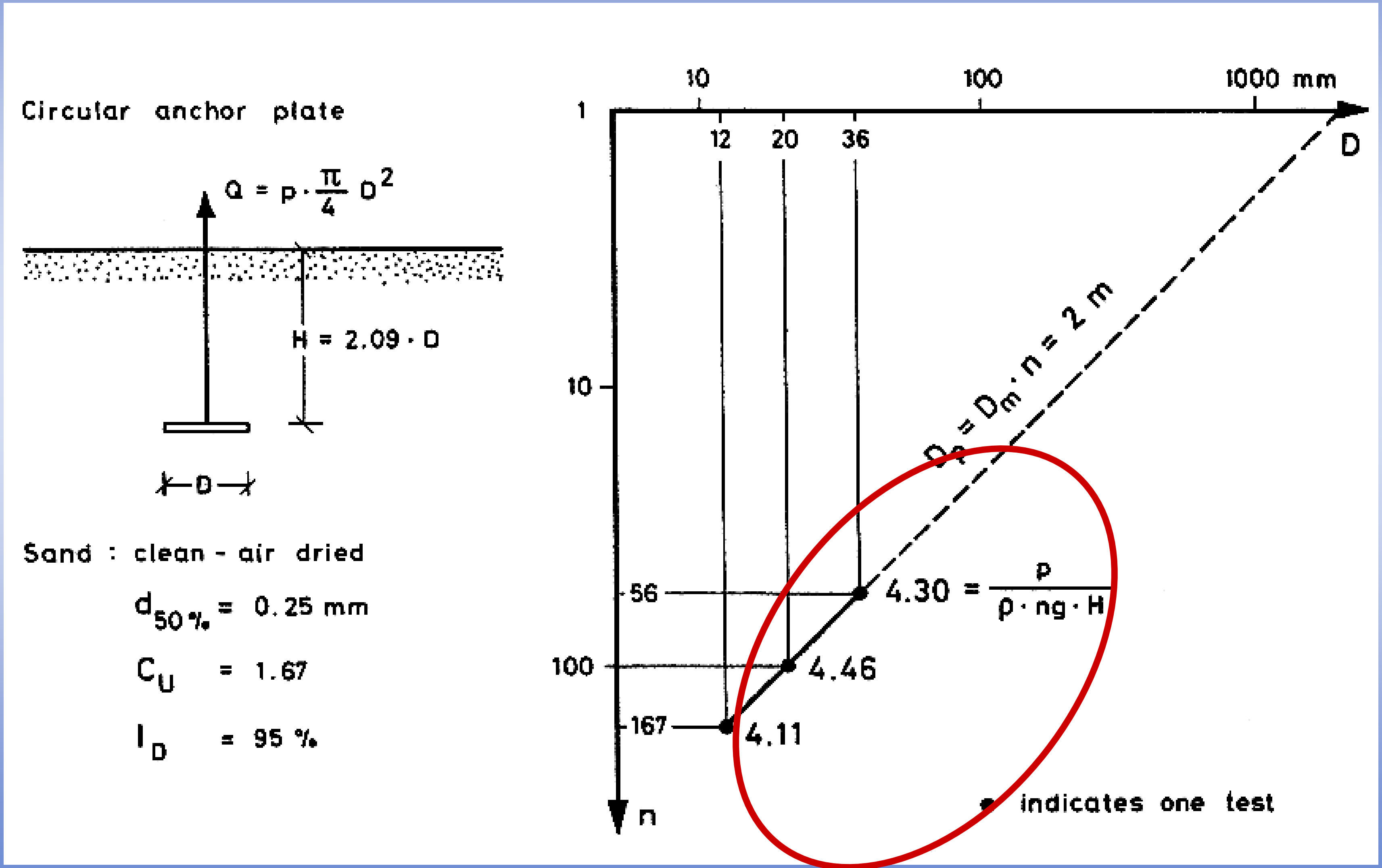
γ'_{Sand} [kN/m³] = eff. unit weight of sand

Nater, 2005

Design considerations

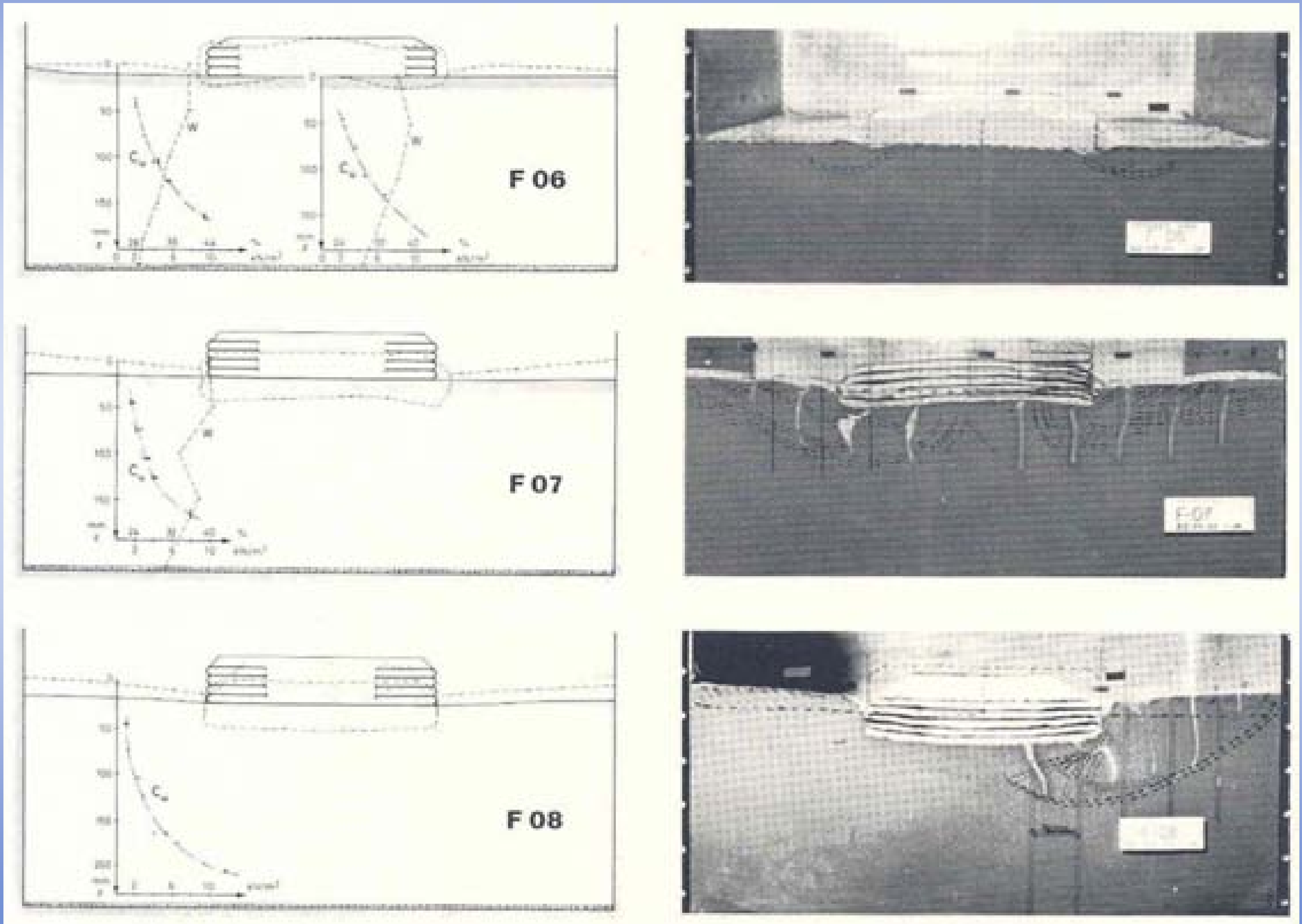
- compared to homogeneous soils, layered systems show different bearing capacity failure mechanisms
- influence of the absolute layer thickness is small: behaviour is controlled by ratio of layer thickness & foundation diameter
- use of the undrained bearing capacity formula is always safe
- calculations with drained bearing capacity formula for sand layer thicknesses < 0.5*D_F is always unsafe for thin clay layers => use of extrusion mechanism advised
- bearing capacity from numerical analyses and the extrusion mechanism agree well for all layer thicknesses < 0.5*D_F => use of extrusion mechanism advised

Uplift capacity of anchor plates in sand



Ovesen, 1981

Reinforced walls on soft clay



Ovesen & Krarup, 1983

Modelling the inflight construction of sand compaction piles in the centrifuge

Doctoral researcher: Thomas Weber

Supervisors: Sarah Springman, Jan Laue

Publications:

Int. Conf. SMGE, Osaka: 2005

Int. Conf. Yng. Geot. Eng. Eur., Vienna: 2005

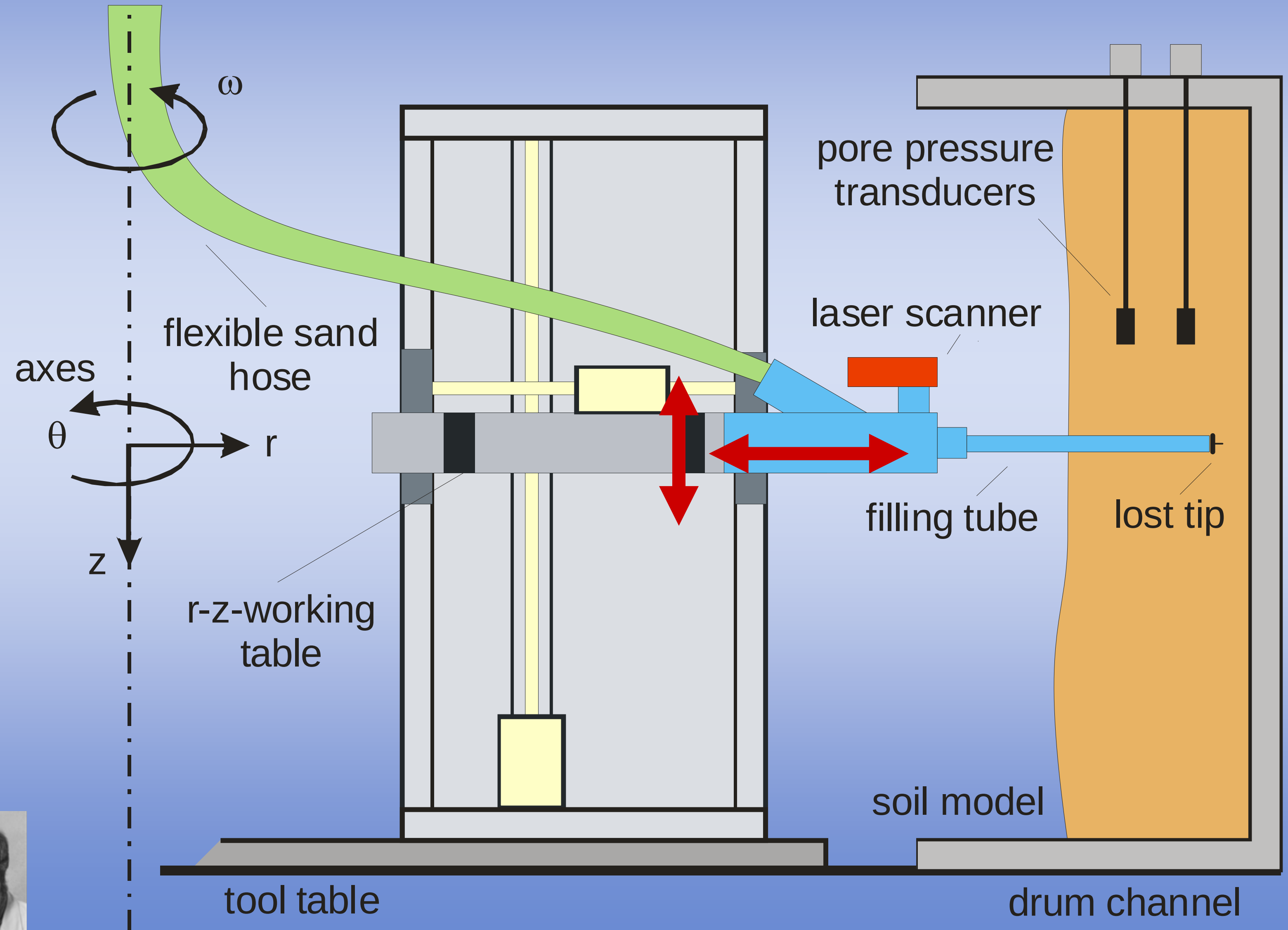
Pollack Periodical, Hungary: 2006

Dissertation: 2007

rs in preparation for Int. Jnl. Phys. Mod., Géotechnique etc.

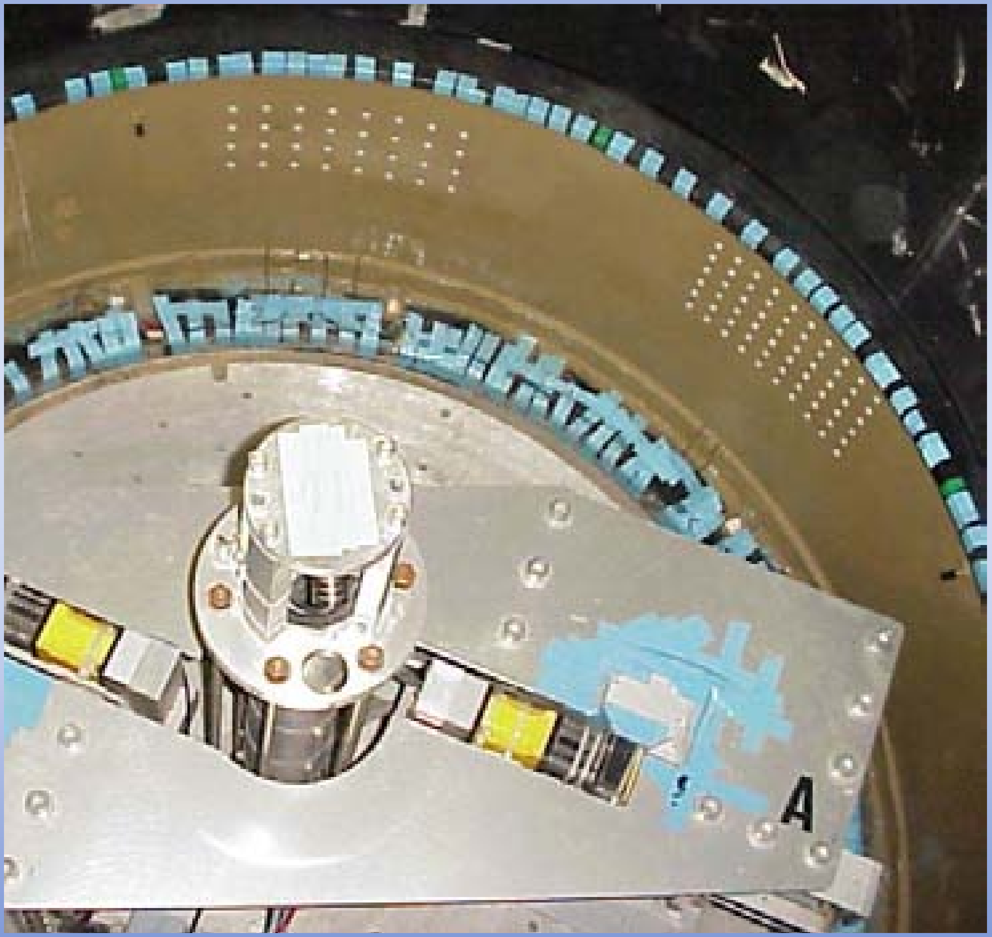
Partners:
Swiss National Science Foundation, Marie Curie Training Network (AMGISS)
Federal Office of Transportation Research Fund

Sand pile construction



Weber, 2007

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

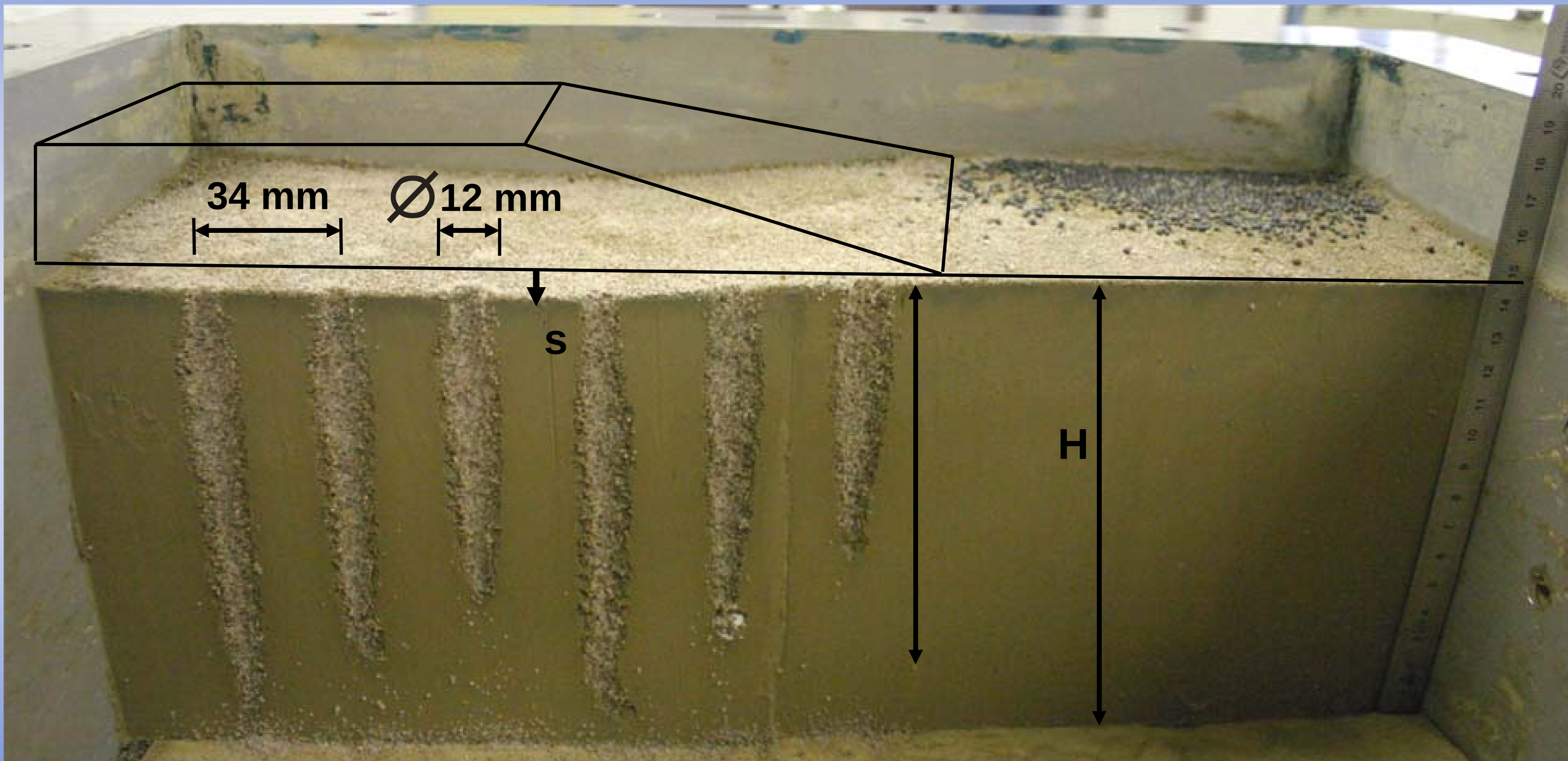


area ratio of improvement - f_s = 10%

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

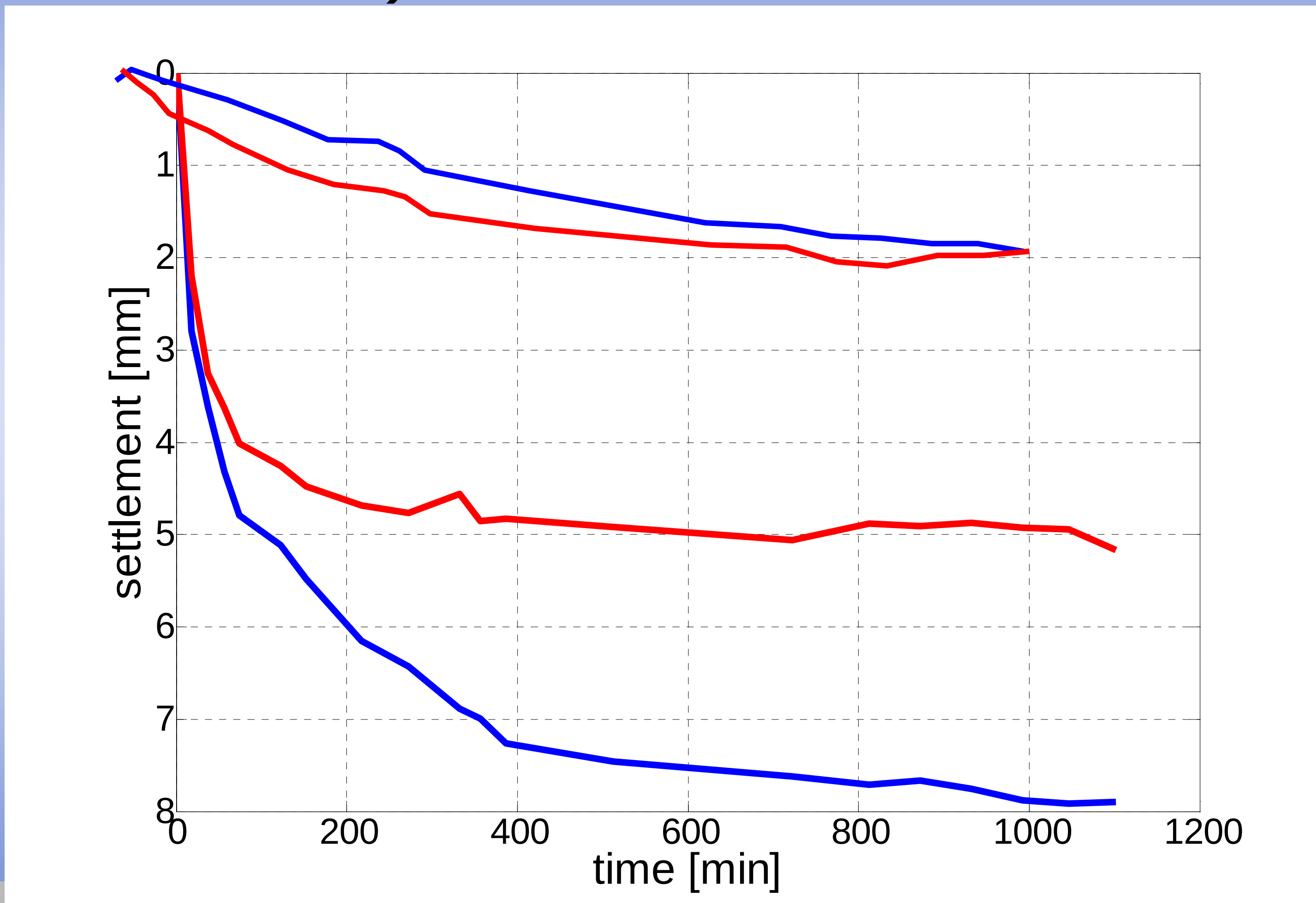
Weber, 2007

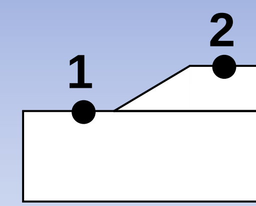
Section of soil model in the tub



Weber, 2007

Time-settlement curves after embankment construction (plane strain tests)





improved

not improved

factor of settlement reduction, n = 1.75

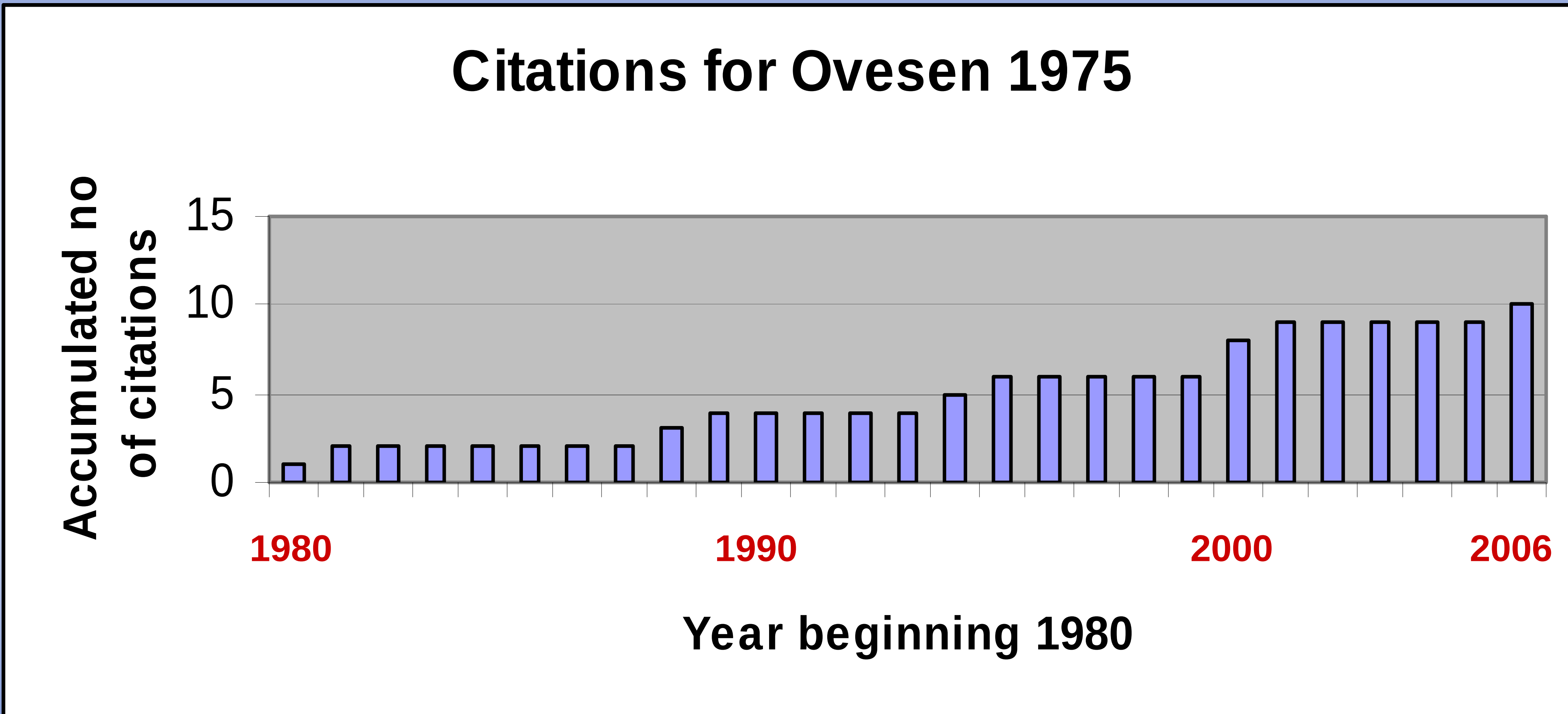
embankment height 35 mm lead balls
$\Delta\sigma$ = 100 kPa

10 % area ratio of improvement

Weber, 2007

Conclusions

- installation of sand compaction piles in flight in the drum centrifuge achieved for plane strain & drum models
- development of excess pore water pressure due to sand pile installation → indication of lateral stress change
- embankment test with base geotextile and 10% area improvement ratio in plane strain tests
  - reduction of settlements – factor 1.75
  - acceleration of consolidation – factor 5
  - Semi-linear relationship dependent on area improvement ratio
- smear zone around sand compaction piles is important to quantify & consider in design



Centrifugal Testing applied To Bearing Capacity Problems Of Footing On Sand
Géotechnique 1975, Vol 25, 2, pp. 394-401
CLEOPATRE Keywords : Data acquisition, Device in flight, Experimental

The Last Word(s)

Had Niels stayed in within the physical modelling community, => more stunning insights into geotechnical phenomena,
but sadly for us, he was 'poached' by partial factors….

'Niels took his yearning for the exposition of "best practice" and coupled it with his genuine sense of European identity to motivate his chairmanship of the Eurocode process that led ultimately to EC7'…… 'although many would argue that the setting-in-stone of Euronorms runs counter to the spirit of the European Enlightenment - social progress driven by scientific advance - Neils at least fought to include physical modelling in EC7 as a means of verification for novel designs…. It will be a fitting testament to Niels if this provision can be used one day.' ***Bolton (2007)***

It is certainly a key statement in the new Swisscode 267 (2003)

The Last Word(s)

'His textbook on soil mechanics and his fundamental research published …… and his centrifuge work on modelling of models are considered by his peers to have been unique achievements'

(After Steenfelt, 2006)

This rather reflects the closing remarks made by the late Peter Wroth, to the 1979 ECSMFE in Brighton, who picked out Niels' contribution on centrifuge testing as one of the highlights of the conference

Andrew Schofield gave the vote of thanks after Niels had made a lecture at the British Geotechnical Society in the late 70s, in which Niels had emphasised the confidence that could be gained by performing variously scaled centrifuge tests of a unique prototype - the modelling of models. Andrew dwelled on the title Professor, and said that Niels always professed his subject with great clarity

Many thanks for your attention!

Acknowledgements

The Organising Committee of the ECSMGE, Madrid,

The Danish Geotechnical Society

ISSMGE TC23 & TC2

Jørgen Steenfelt, Jacques Garnier, Leif Fuglsang, Jan Laue, Brian Simpson, Malcolm Bolton, Mengia Amberg, Osamu Kusakabe, Trevor Orr & Andrew Schofield