THE BRITISH GEOTECHNICAL ASSOCIATION

JOINT CFMS AND BGA MEETING

Une journée franco-britannique

Programme

Introductions

Hilary Skinner (BGA Chairman) & Alain Guilloux (Président du CFMS)

Session 1 (Chairman – Serge Varaksin, *Menard*)

Rigid Inclusions – Bruno Simon (Terrasol)

Vibro Stone Columns: Design Information and case histories – Barry Slocombe (Keller)

Session 2 (Chairman – Colin Serridge, *Pennine*)

Trenchmix process – Serge Borel (Solétanche Bachy)

Soil Mixing: Case Histories and Design Applications – Graham Thompson (Keller)

Session 3 (Chairman – Philippe Liausu, *Menard*)

Concept and Application of Ground Improvement for a 2,600,000 m^2 University Campus – Serge Varaksin (Ménard)

Physical stabilisation of deep fill – Ken Watts (Building Research Establishment)

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Amélioration des Sols par Inclusions Rigides verticales

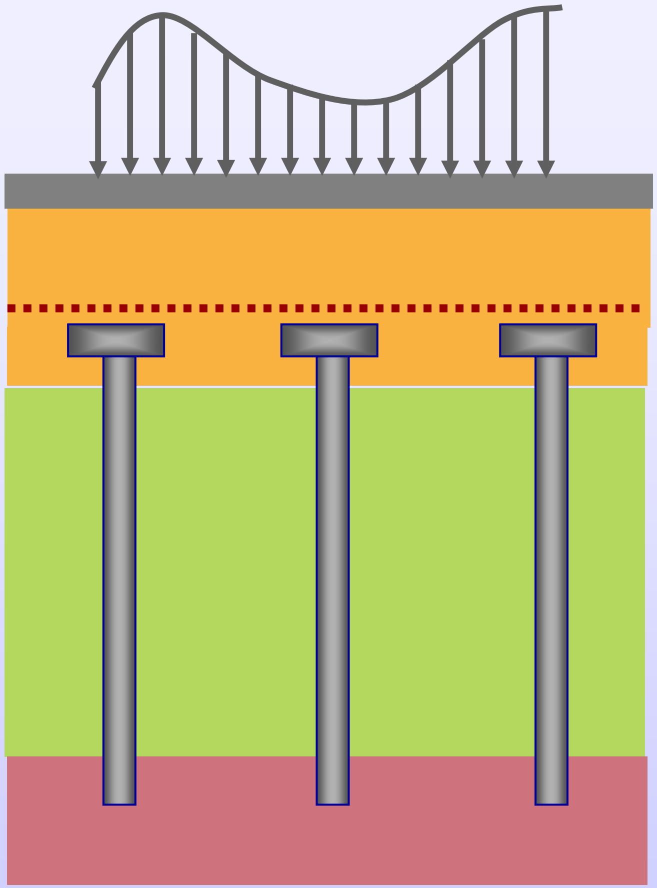
Soil improvement using pile-like inclusions

Bruno SIMON

TERRASOL

Joint BGA/CFMS meeting, London, December 7th, 2007

A compound foundation system



- ✓ Stiff inclusions
- ✓ Pile caps
- ✓ Reinforcement (occasionally)
- ✓ Granular mattress
- ✓ Floor slab (occasionally)

… Pile supported earth platform

… Piled embankment

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Development on the last 30 years

- Piled embankments for roads and railways
- Pile supported earth platforms
  - Floor slabs and rafts (warehouses, stores)
  - Bridge abutments
  - Tramway lanes
  - Dockyards
- …...
- Foundations of the Rion-Antirion cable-stayed bridge

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Main advantages

- Loading can be partly carried by soil
- No spoil if displacement technique used
- Connection between foundation and structure made easy by the transfer layer
- Smaller time period of construction than preloading
- Good seismic behaviour (ductility)

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Present situation

- No national standard
  - not a widely accepted technique for common works
- A wide range of design methods is used
  - No comprehensive model of all mechanisms involved
- Soil investigations often inappropriate

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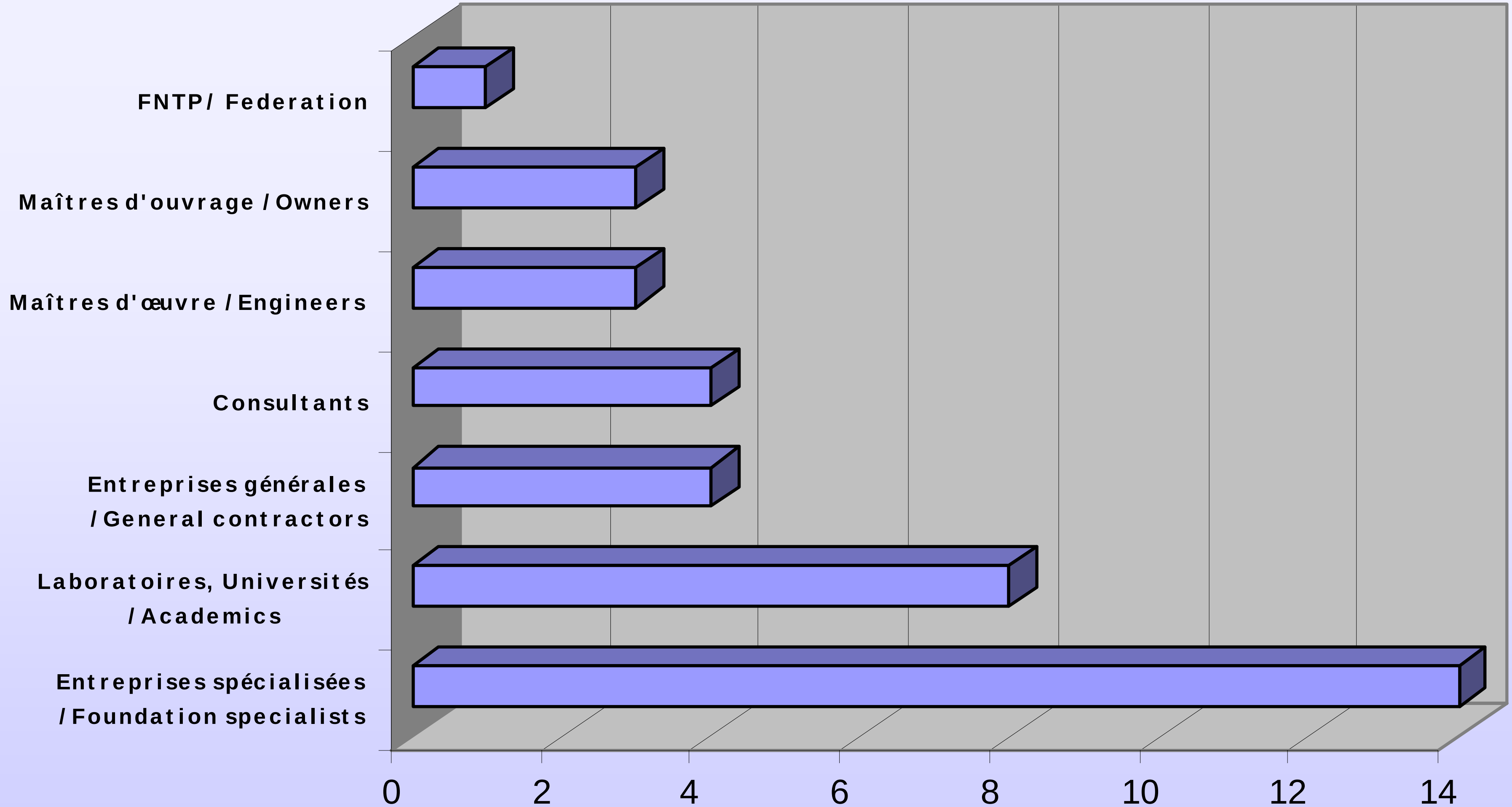
ASIRI project (2005- 2009)

2.4 M € state and industry funded research project

- Led by a non profit organization (IREX)
  - With managing and scientific committees
- Independent network of owners, consultants, contractors and academics
- Civil and Urban Engineering Research label

ASIRI project (2005- 2009)



- 39 members subscribing 155 k€/year
- 9 PhD in progress (4 with support of industrial partners)

General organisation and planning

Themes	Tr 1	Tr 2	Tr 3	Tr 4
1-Full scale experiments	Floor slab	Embank ment		
2 –Monitored works				
3 –Laboratory and physical modelling	characterizatio		Centrifuge & chamber testing	
4 –Numerical modelling				

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Président F. Schlosser

Vice -Président O. Combarieu

Directeur technique B. Simon

(Terrasol)

Theme 1

L. Briançon

(CNAM)

Theme 2

E. Haza

(CETE)

Theme 3

L. Thorel

(LCPC)

Theme 4

D. Dias

(INSA Lyon)

Theme 5 (Recommendations) : O. Combarieu

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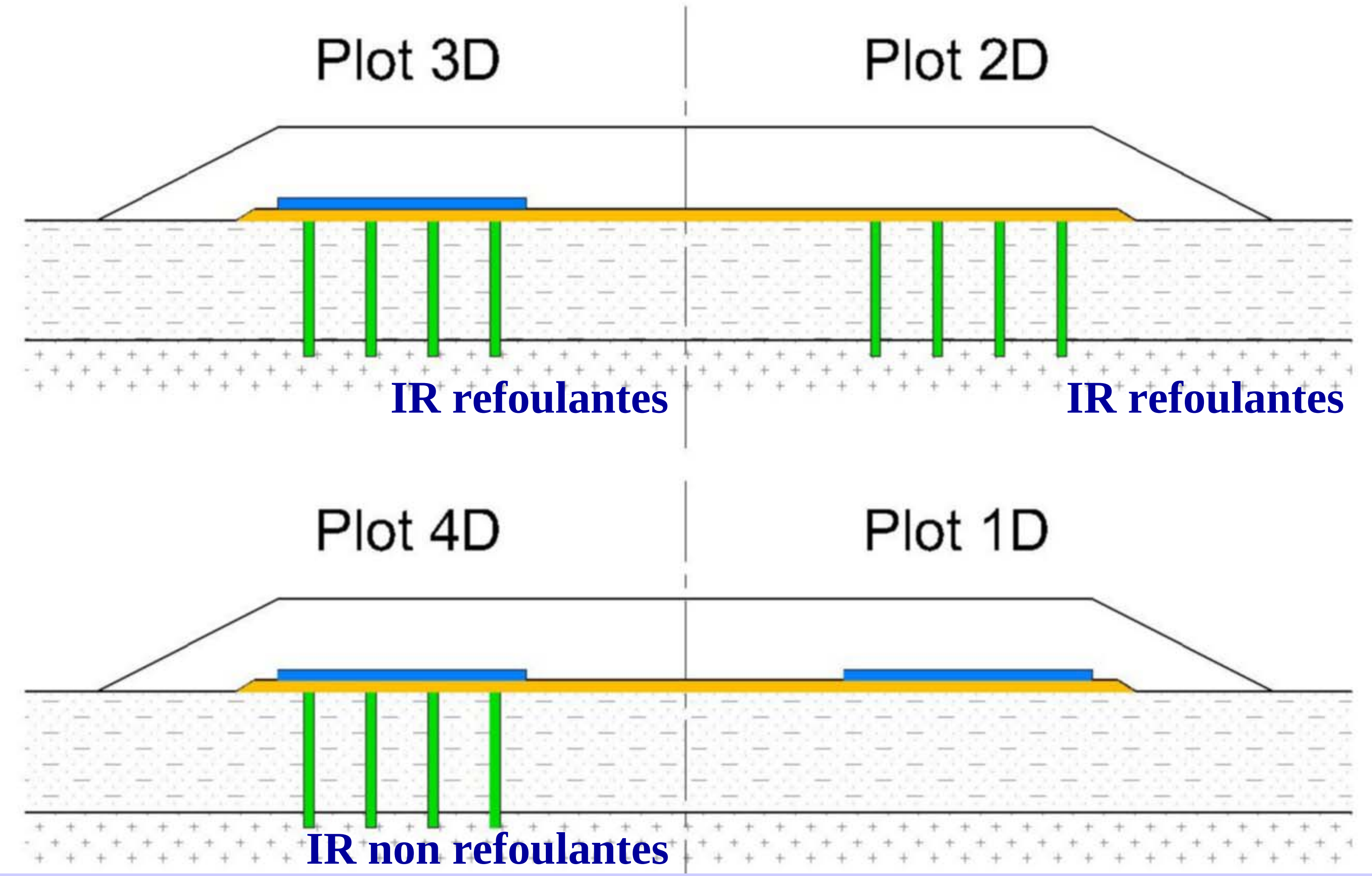
St Ouen full scale experiment (2006)

- Floor slab foundation



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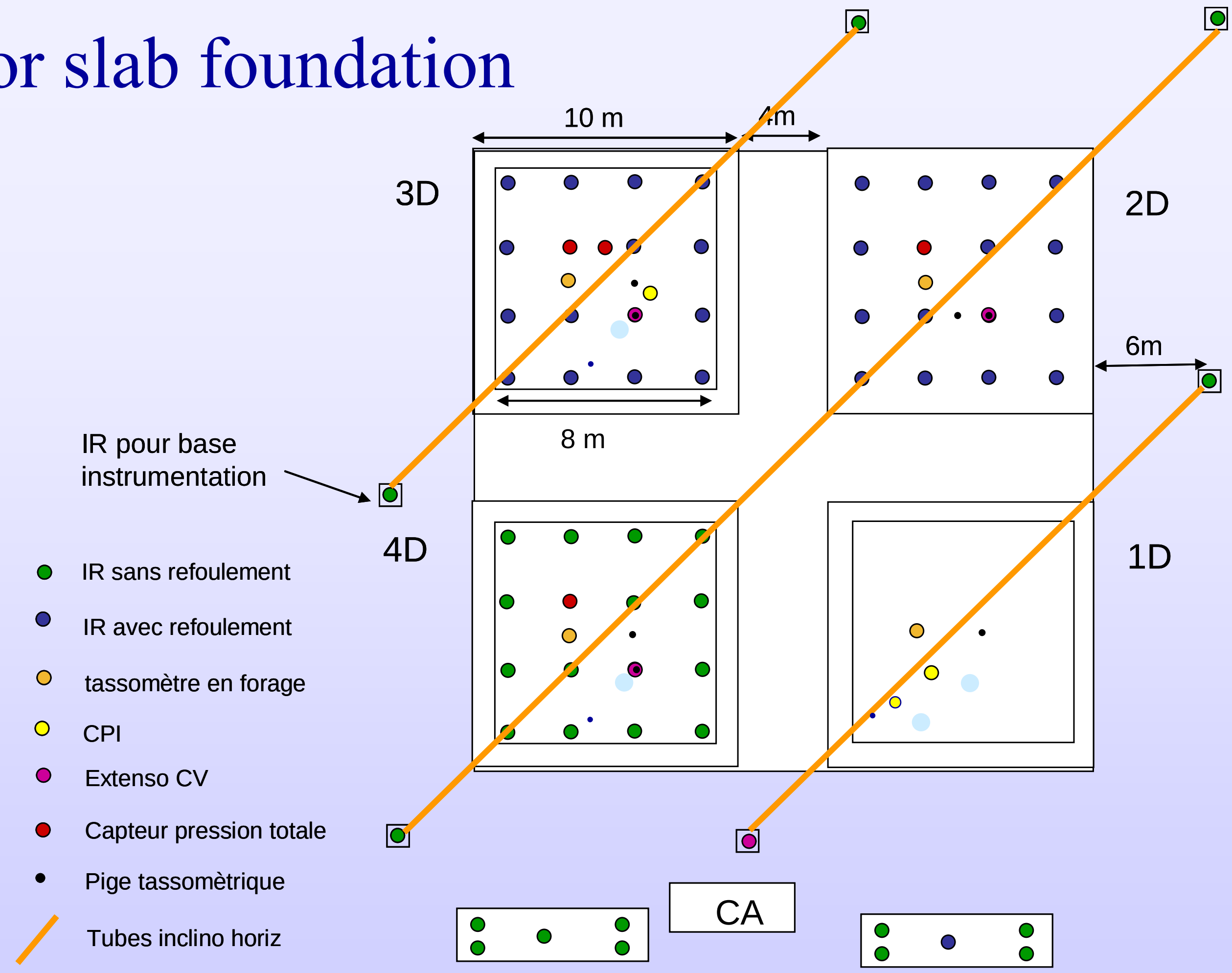
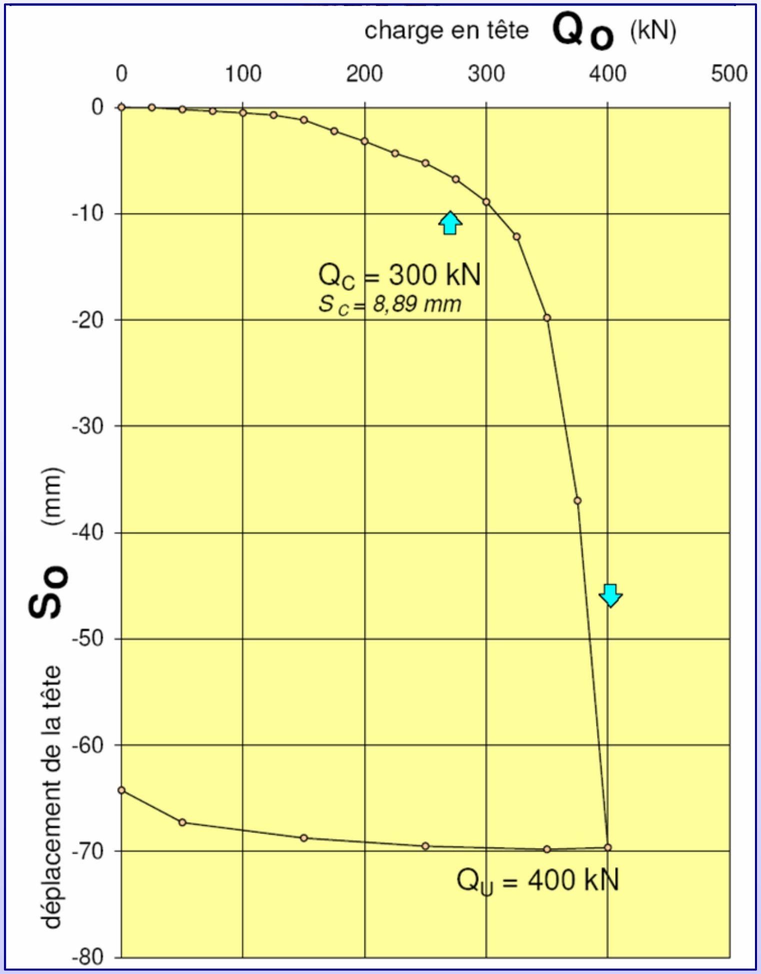
St Ouen full scale experiment (2006)

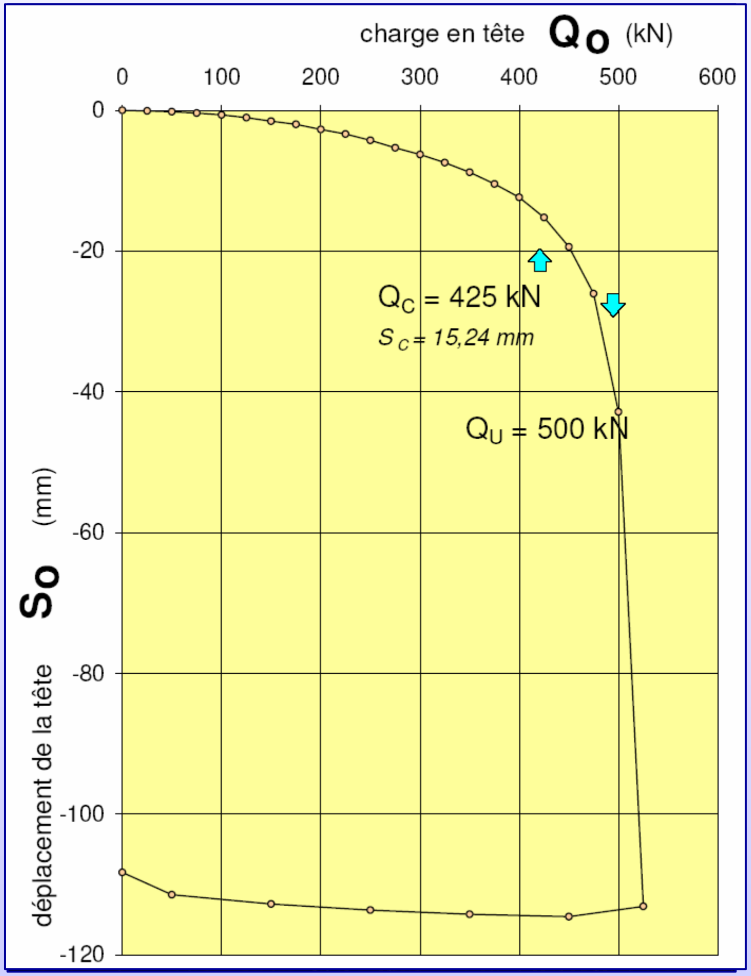
- Floor slab foundation



Two kind of inclusions



Non displacement inclusion



Displacement inclusion

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LCPC

St Ouen full scale experiment (2006)

4,0 m fill load

1,5 m fill load

0.17 m steel fibre reinforced floor slab

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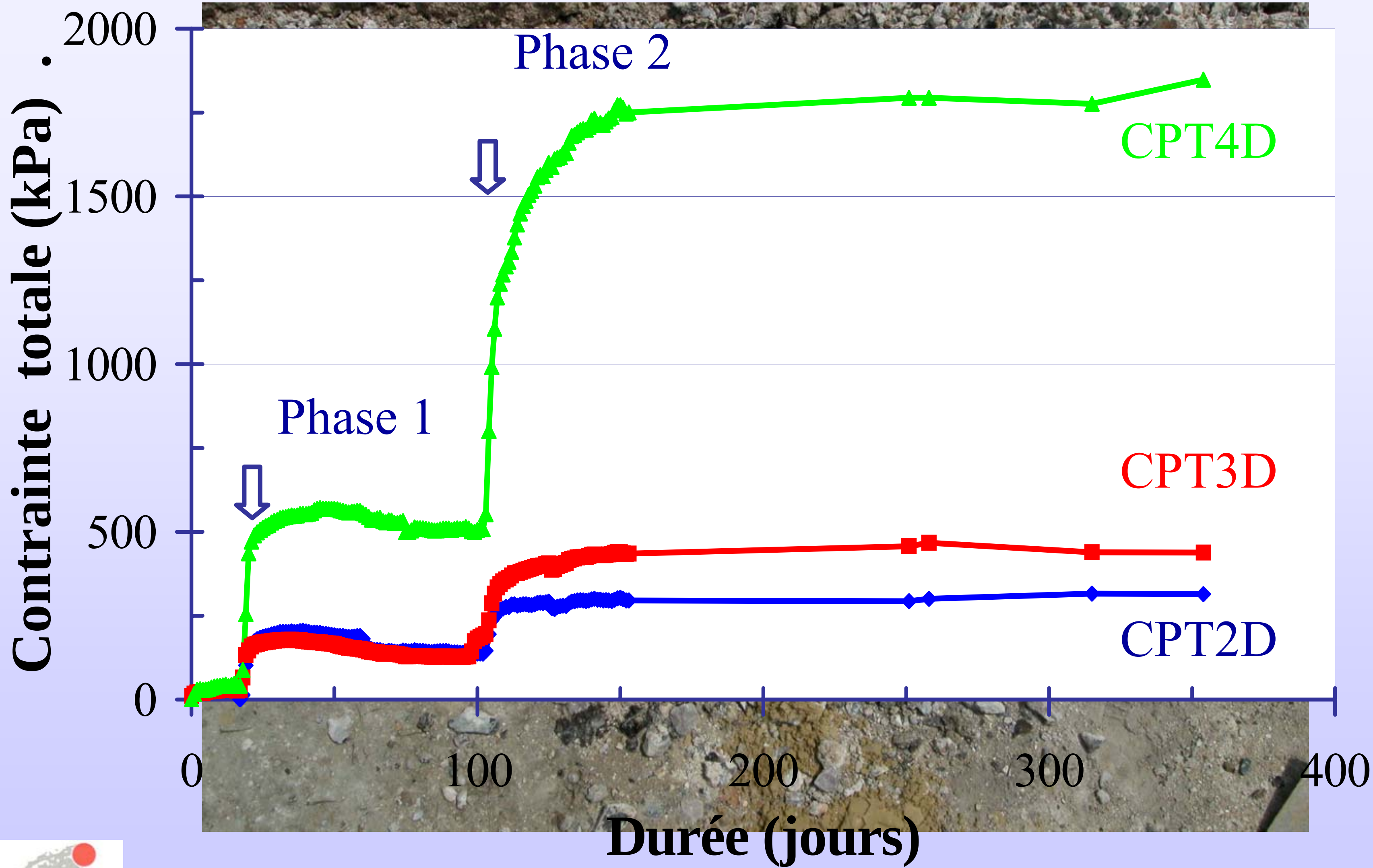
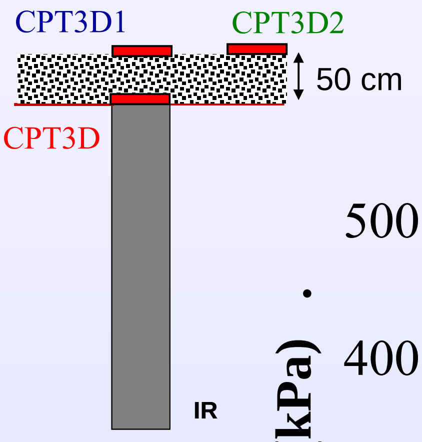
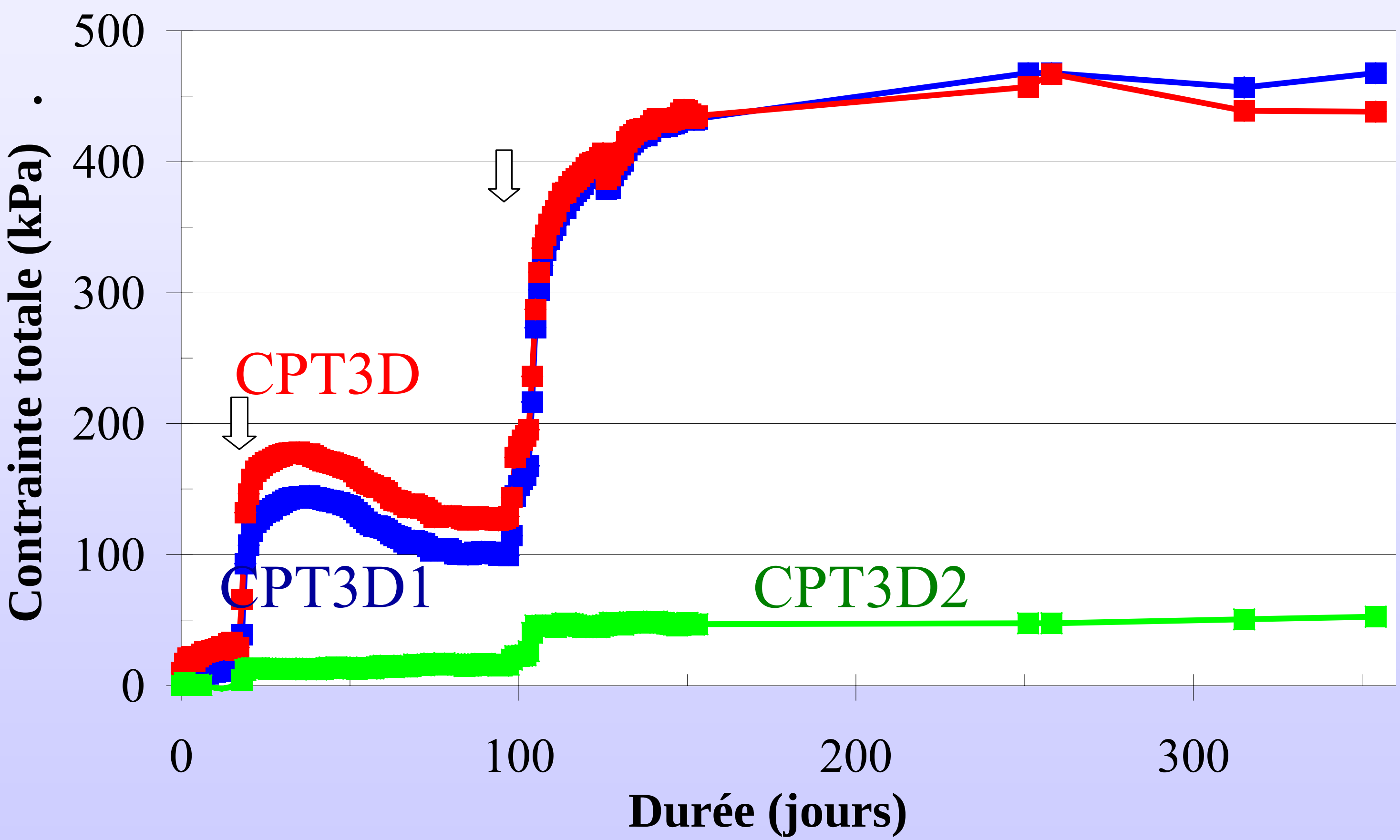
Load transfer onto inclusion heads



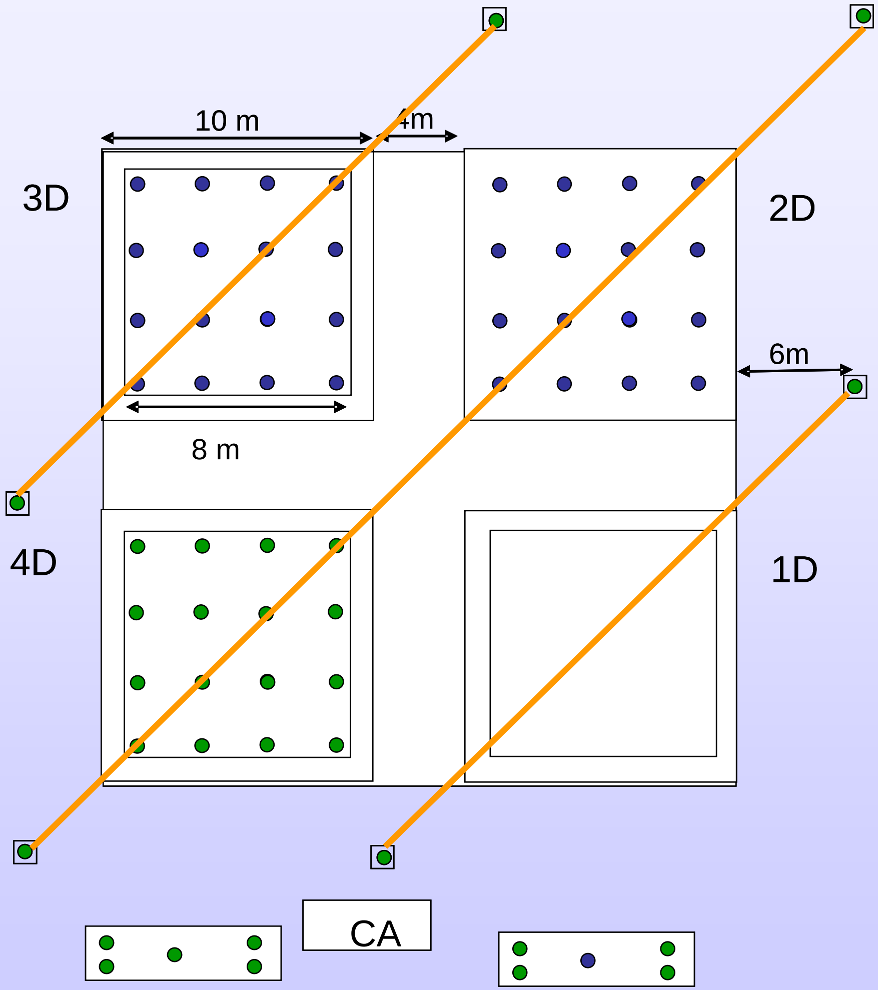
CNAM PhD work J. Andromeda

Load transfer onto inclusion heads



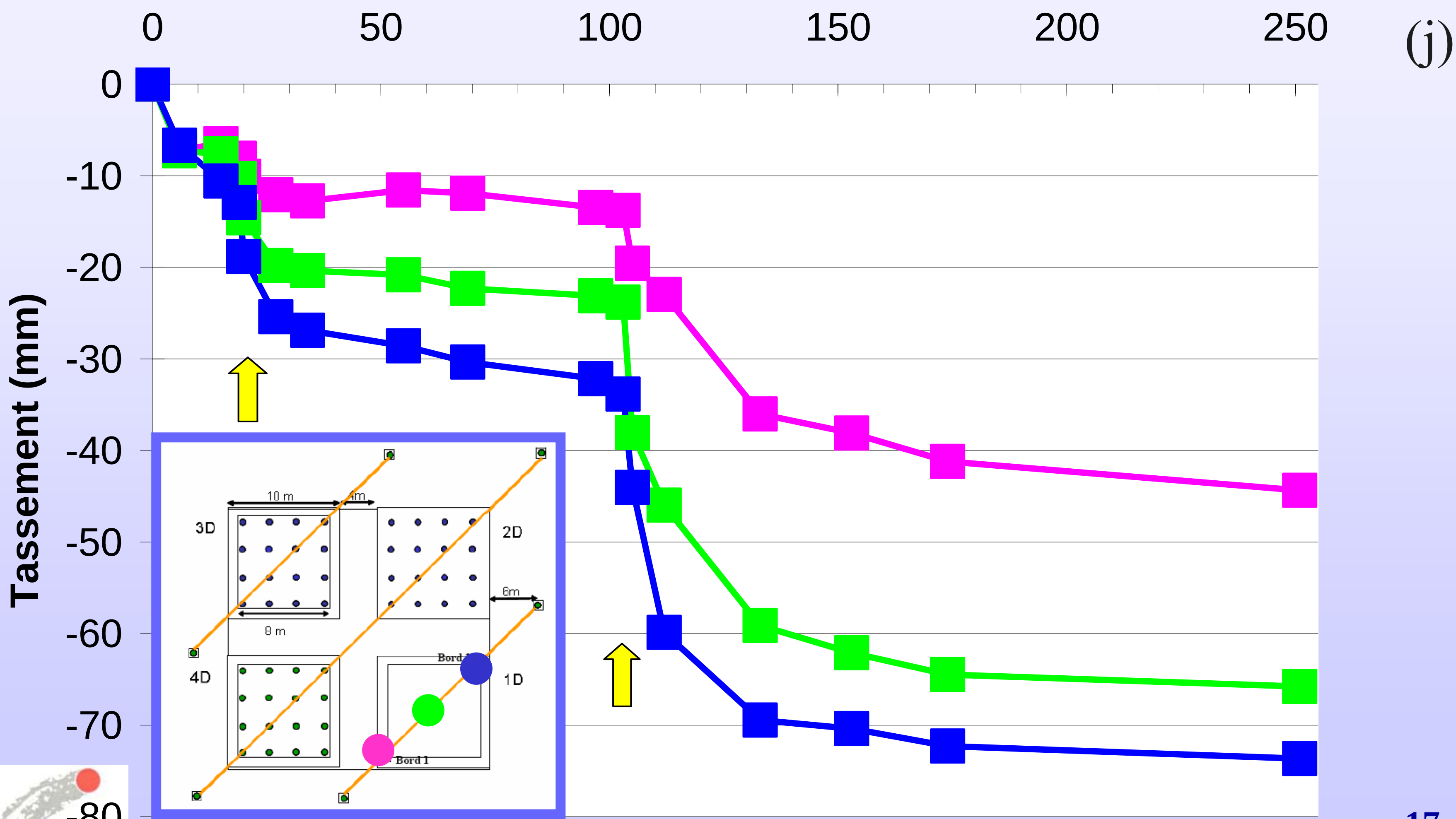


Settlement at base of the granular layer



Settlement at pile head elevation

- Plot 1D (unreinforced)



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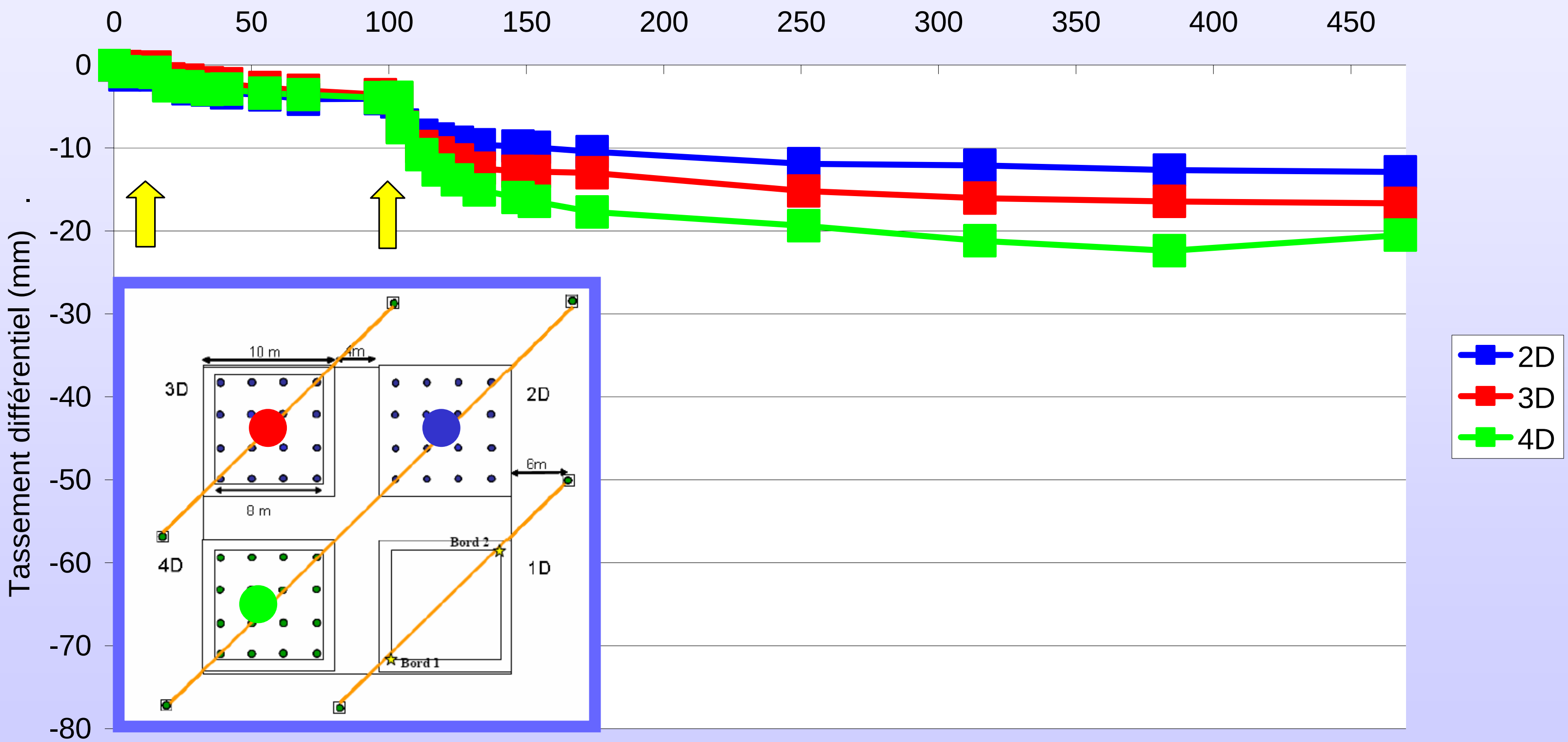
Settlement at pile head elevation

- Differential settlement / inclusion heads



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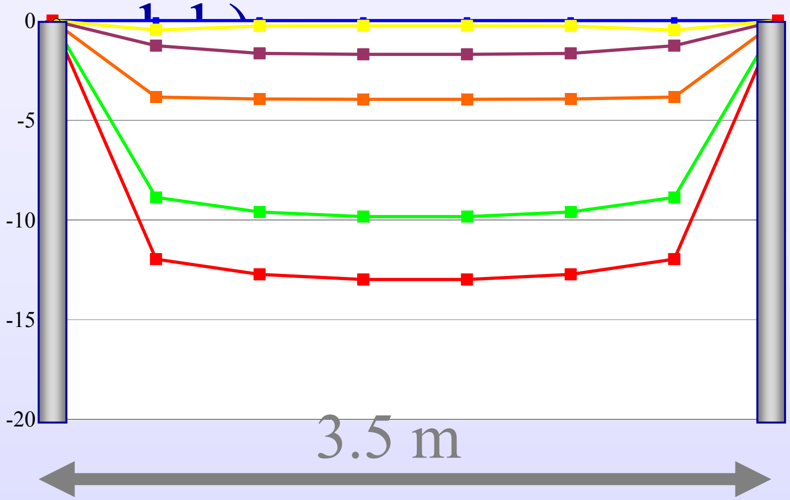
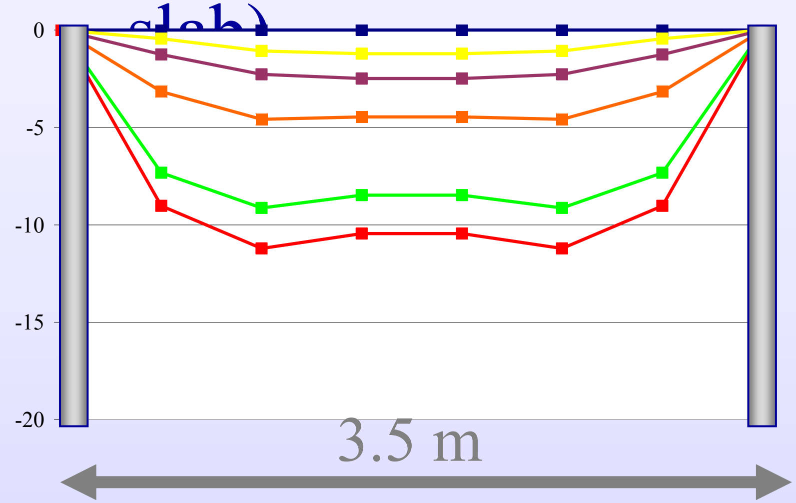
Differential settlement at pile head elevation

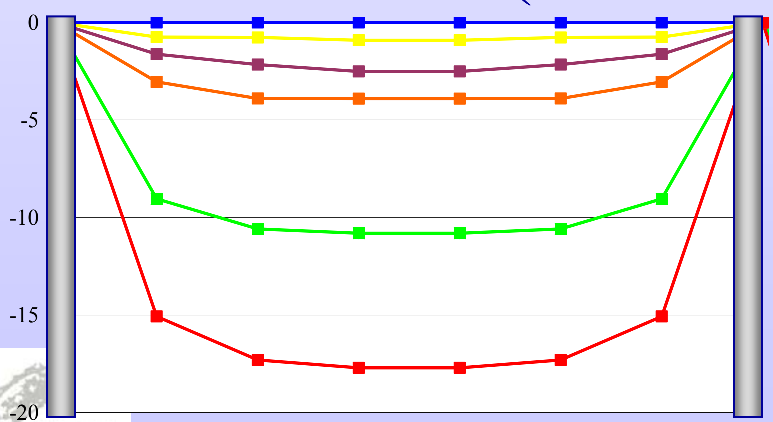
- Test unit 3D (ID with slab)

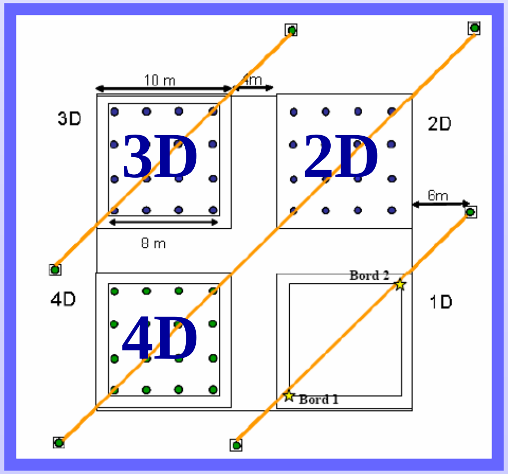


- Test unit 2D (ID without slab)



- Test unit 4D (I non D with





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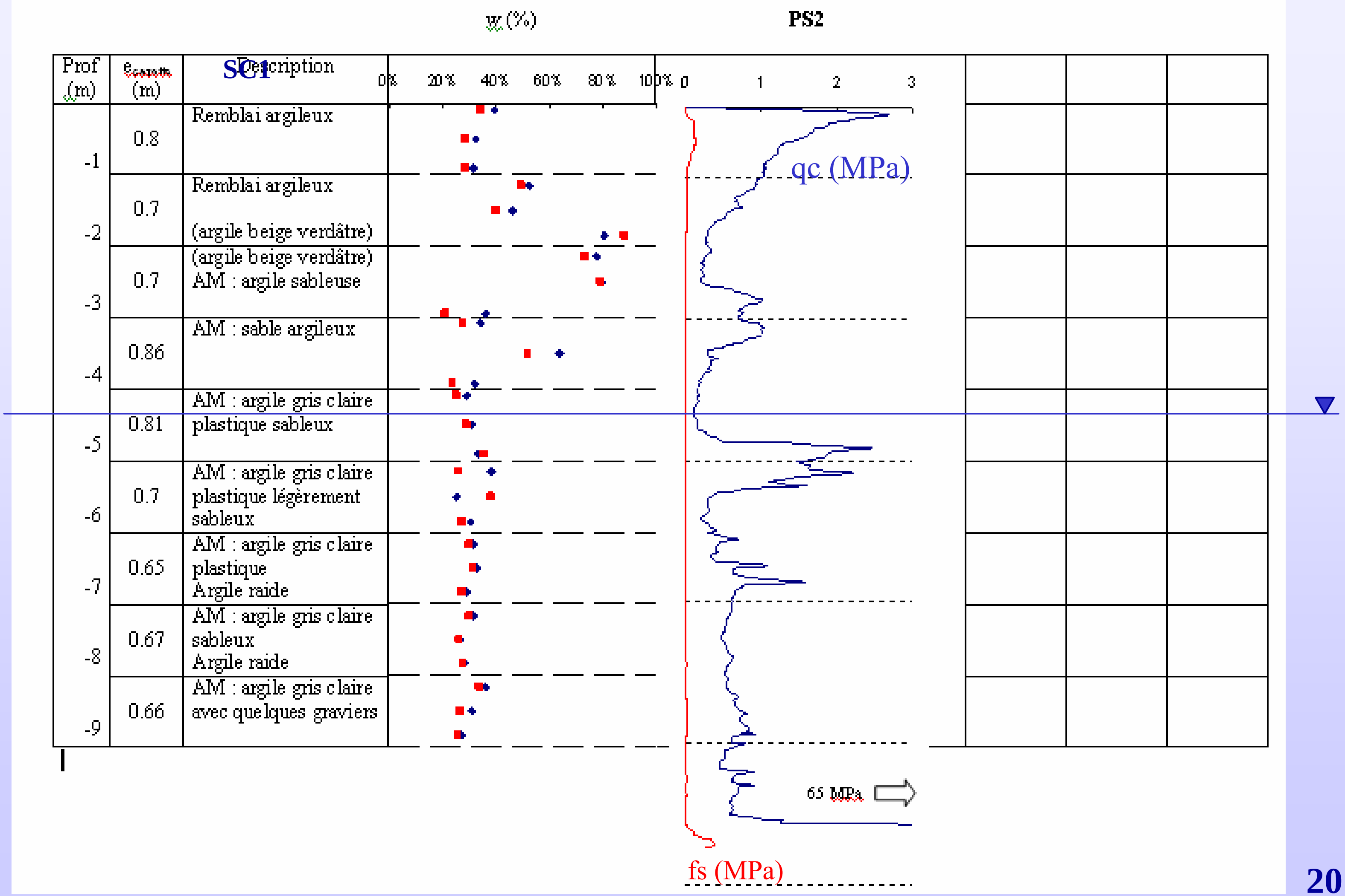
Chelles full scale experiment (2007)

- Piled embankment



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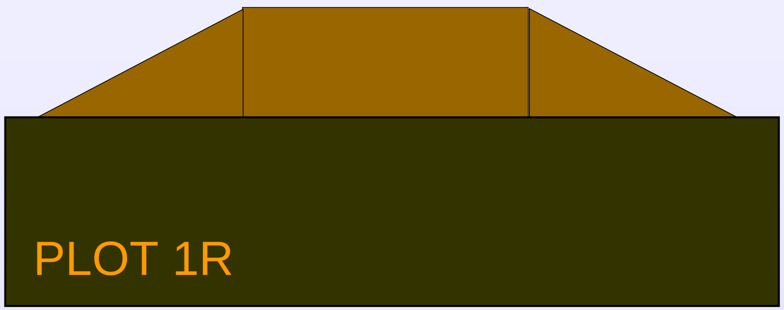
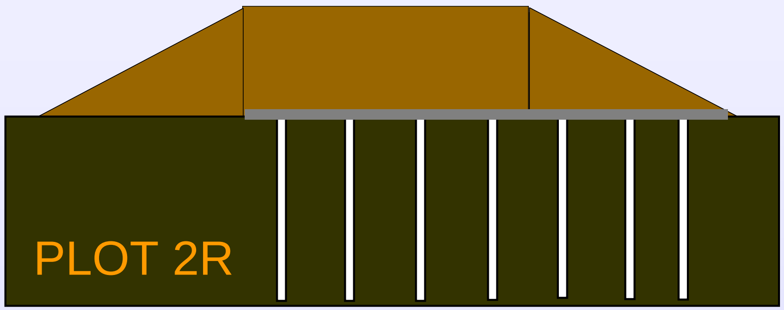
Chelles full scale experiment (2007)

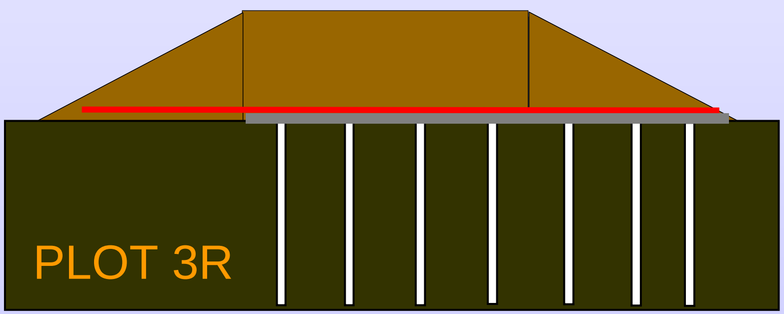
- Piled embankment



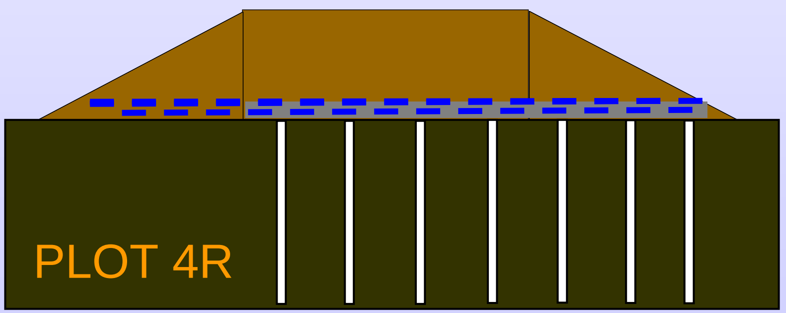
Unreinforced



Reinforced



Reinforced + 1 geotextile



Reinforced + 2 geogrids

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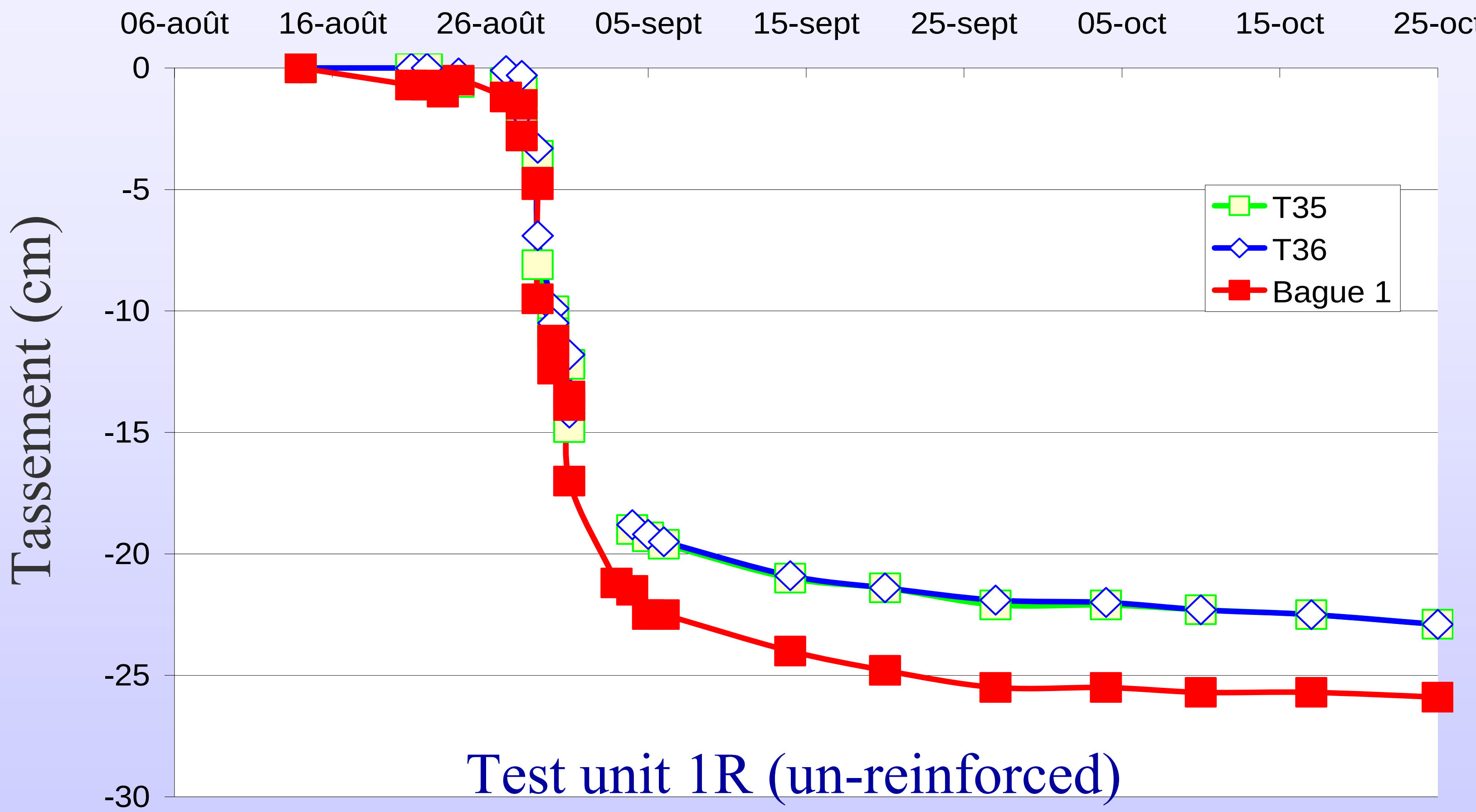
Surface settlement monitoring

- Multipoint extensometer/ surface transducers



Monitoring reinforced works

- Parking and pavement foundation (Carrières sous Poissy, 2006)

lles, 2007-2008)

- North western ring road (Tours, 2008)
  - 4 to 5 m high fill + phonic fill barrier 10 m close to existing railway line
  - 25000 inclusions (135000 ml)
  - ASIRI monitoring included in work specifications

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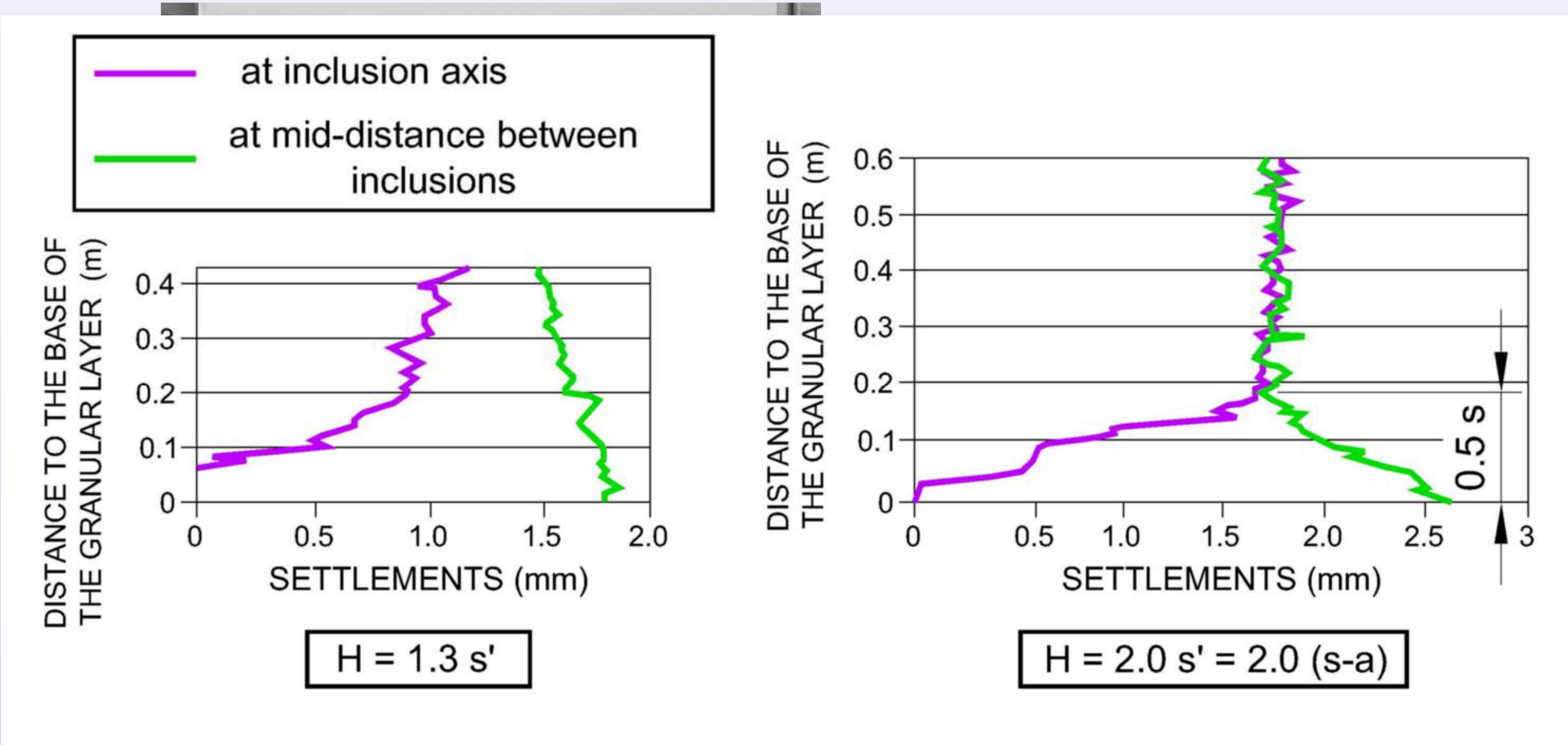
Physical and laboratory testing

- **2D analogical soil (Jenck, 2005)**



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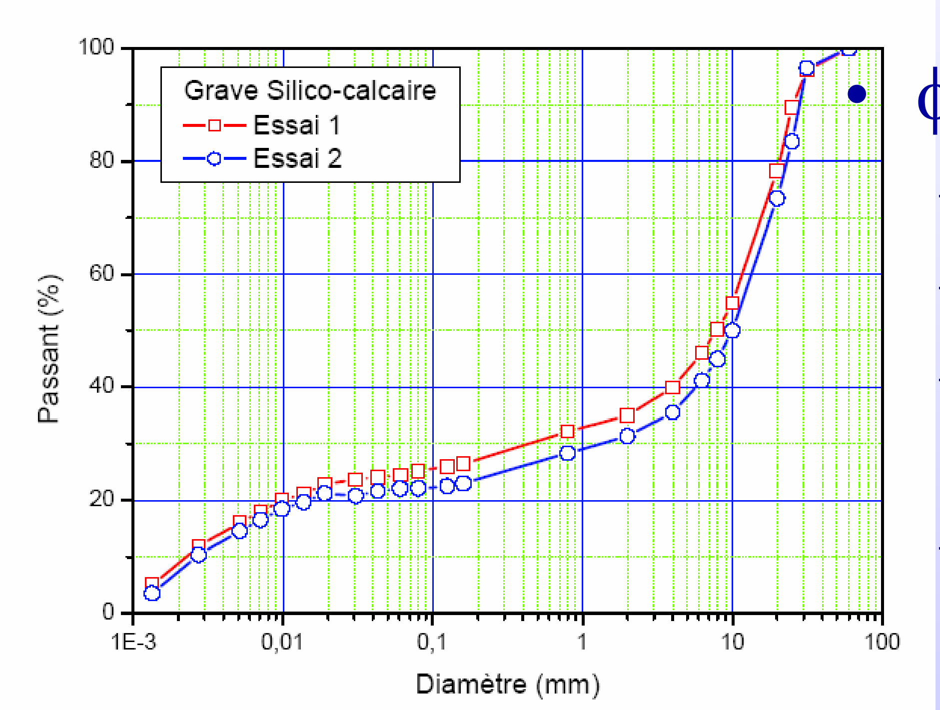
Transfer layer material (Saint Ouen)



- ϕ 300 mm triaxial testing
  - 85% et 95% OPM
  - confining stress (25 to 100 kPa)
  - compression and extension stress path
  - unload/reload loops

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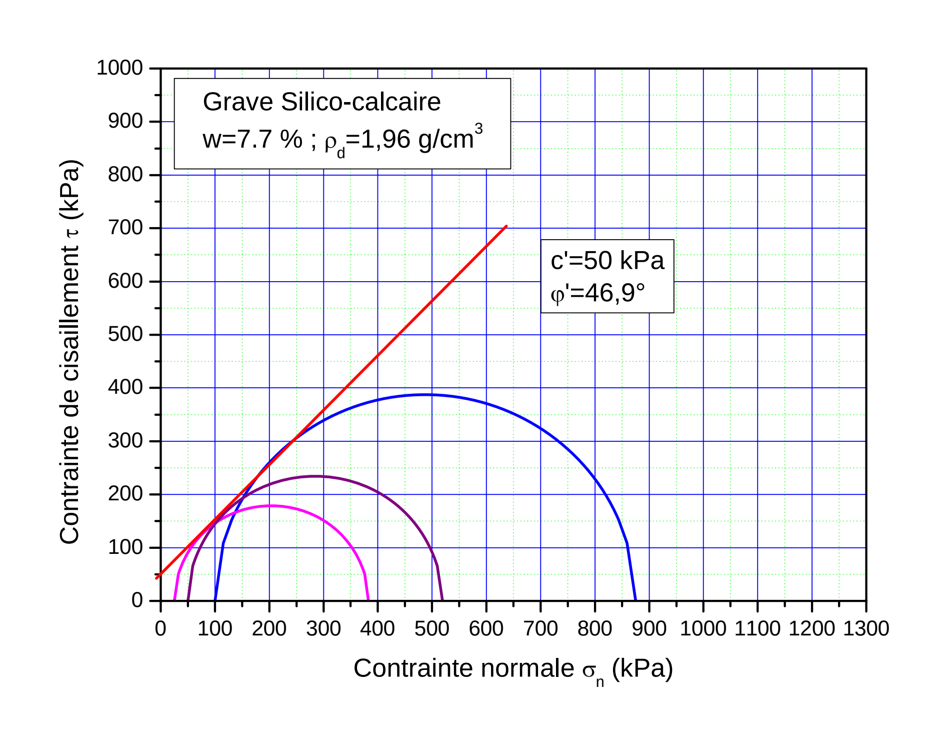
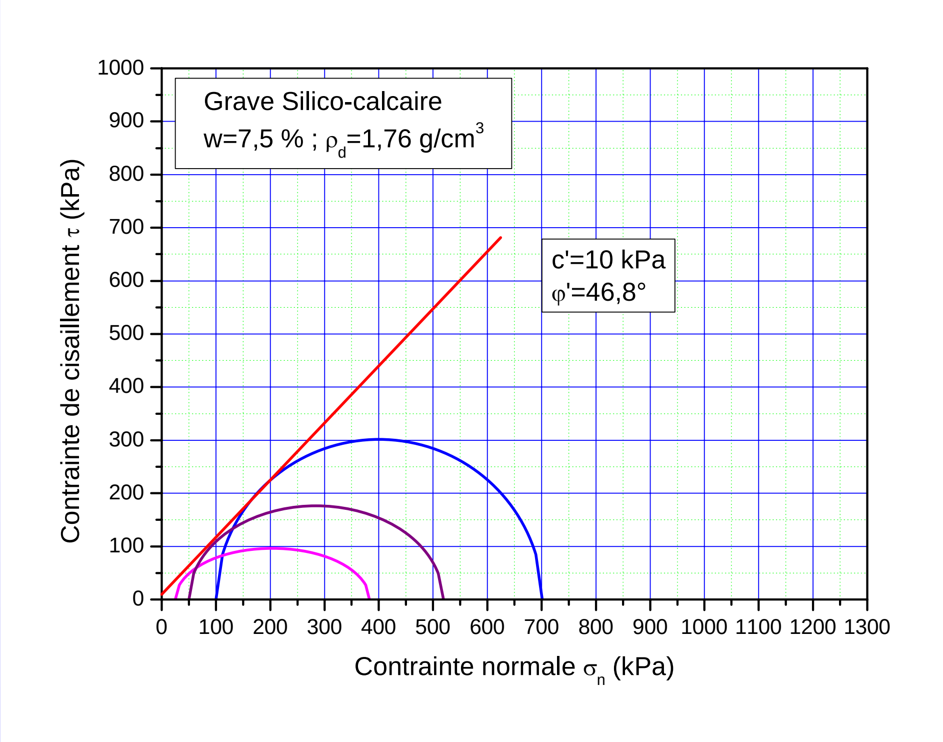
Transfer layer material (Saint Ouen)

ρ_d=95 % $\rho_{d,opm}$

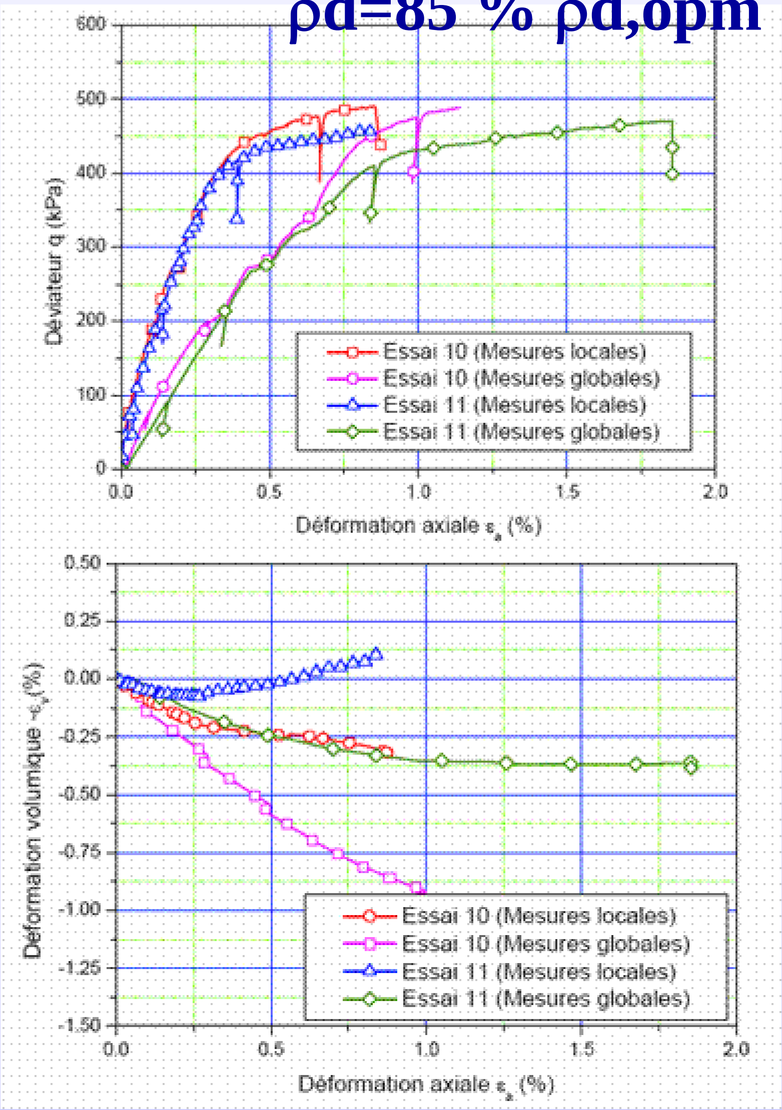


ρ_d=85 % $\rho_{d,opm}$



Global/local strain measurement

ρd=85 % ρd,opm



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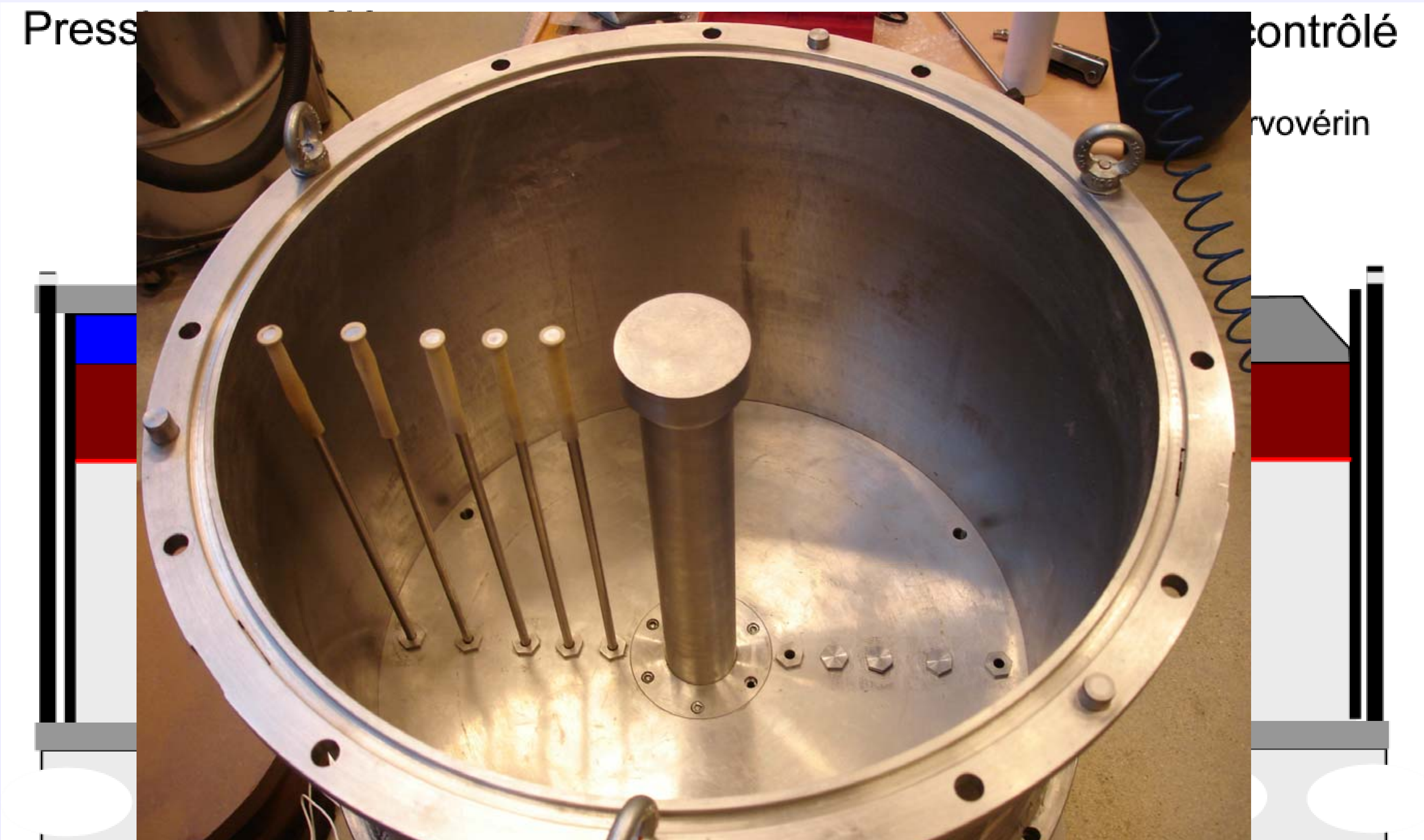
CERMES PhD work Anh Quan Dinh

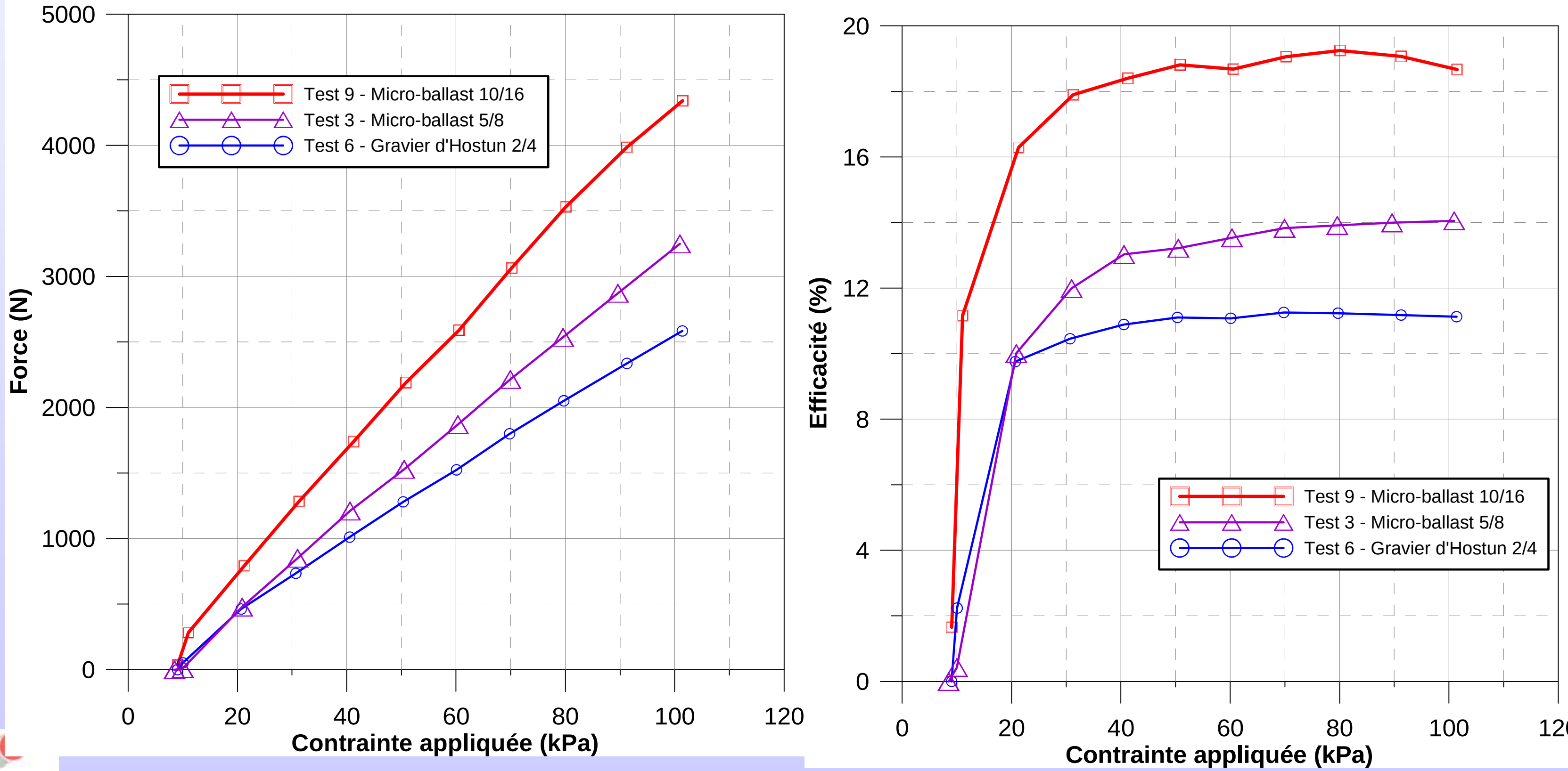
Calibration chamber testing (scale 1/5)



Calibration chamber testing (scale1/5)

- Influence of the transfer layer grain-size distribution

H_M = 10 cm



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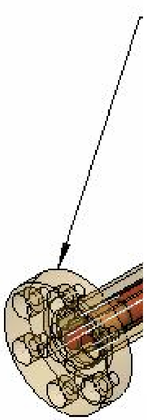
Centrifuge testing

- Elementary cell behaviour (acceleration 27,8 g)
  Load or displacement controlled loading



Inclusion	Prototype	Model
Diameter (m)	0.5	0.018
	Area ratio 3 % to 5%	
Spacing (m)	2.0 – 2.5	0.072 – 0.90
Length (m)	10 -15	0.36 – 0.54
Equivalent fill load (m)	5 - 10	0.18 – 0.36

Centrifuge testing

- Behaviour of an elementary cell

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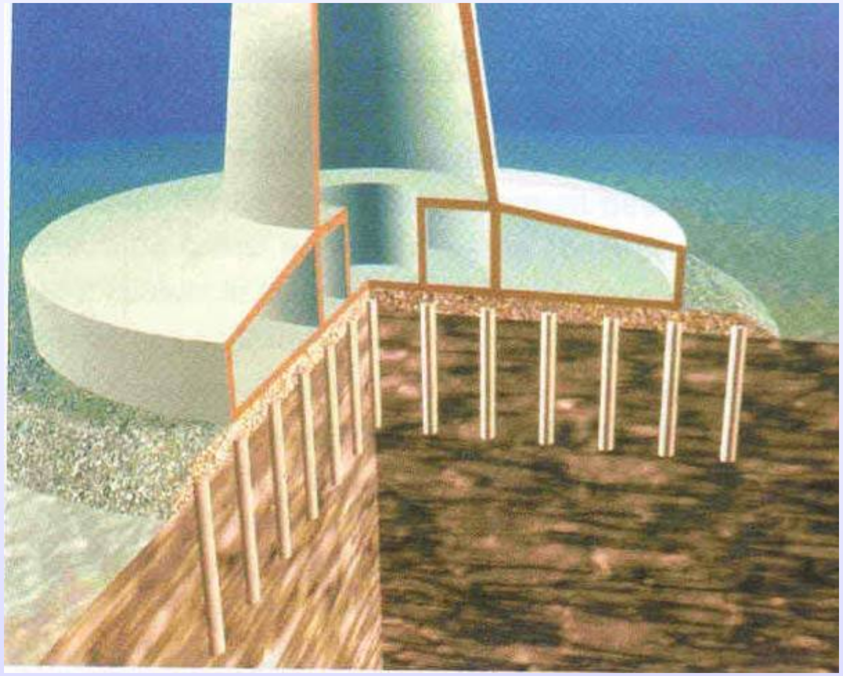
Centrifuge testing for outstanding work

- **Rion Antirion crossing**



- 2 m diameter open steel tubes
- 7 m x 7 m square grid
- 2.8 m gravel layer

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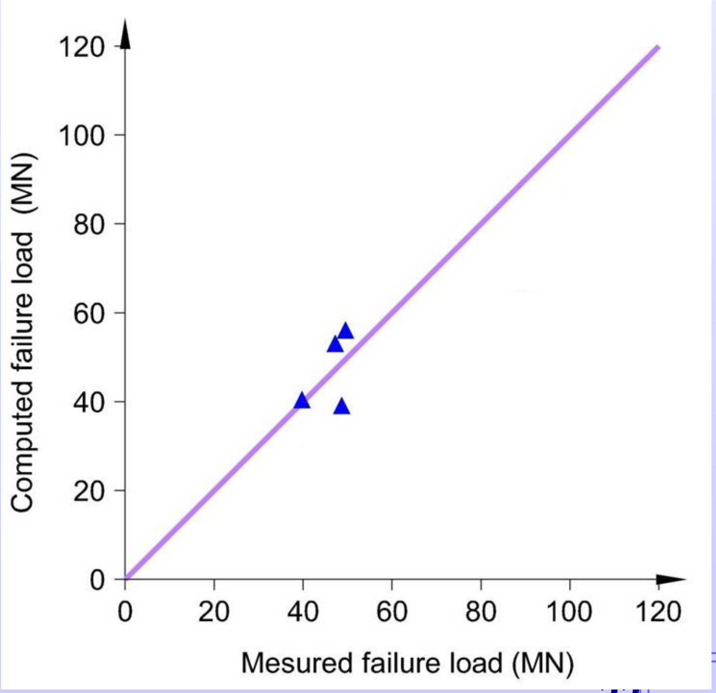
Centrifuge testing for outstanding work

Pecker A. : capacity design

- **Numerical modelling**
  - Yield design approach of limit loads
- **Physical modelling**
  - 100 g centrifuge testing (LCPC Nantes facility)
  - Reconstituted soil



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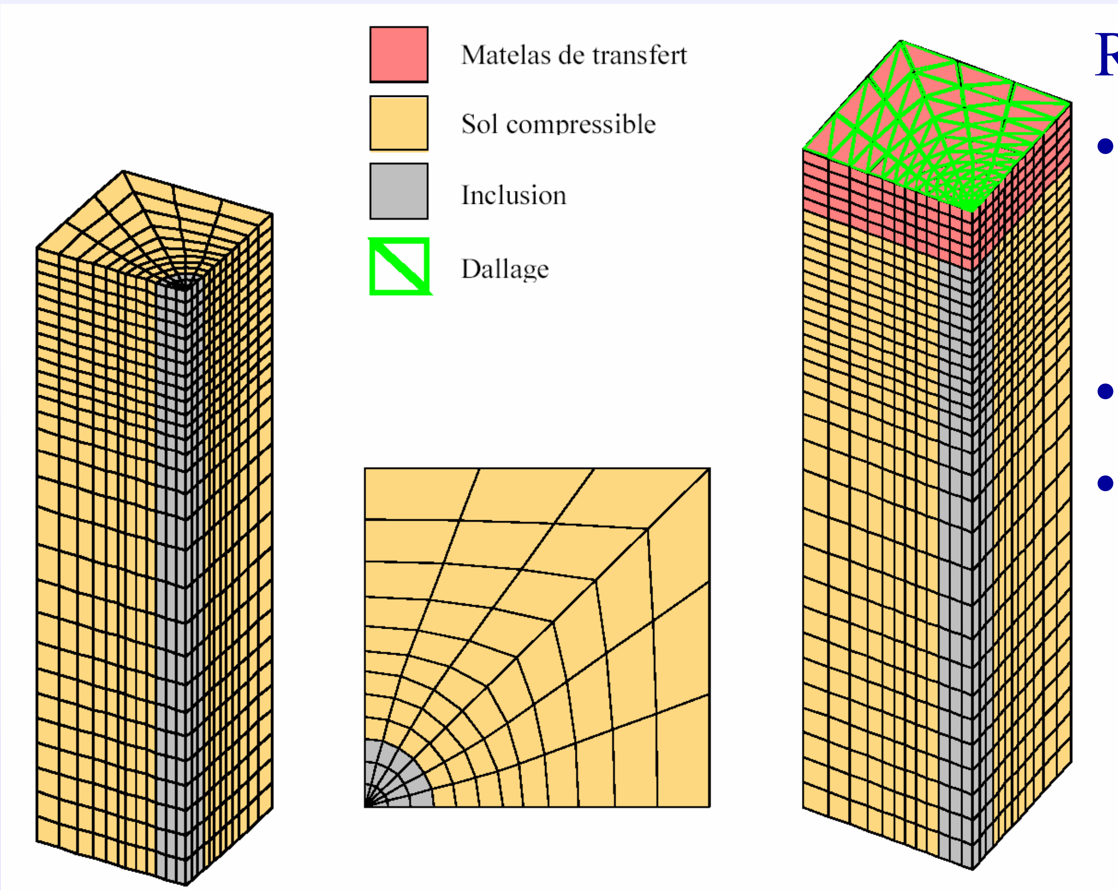
Numerical modelling

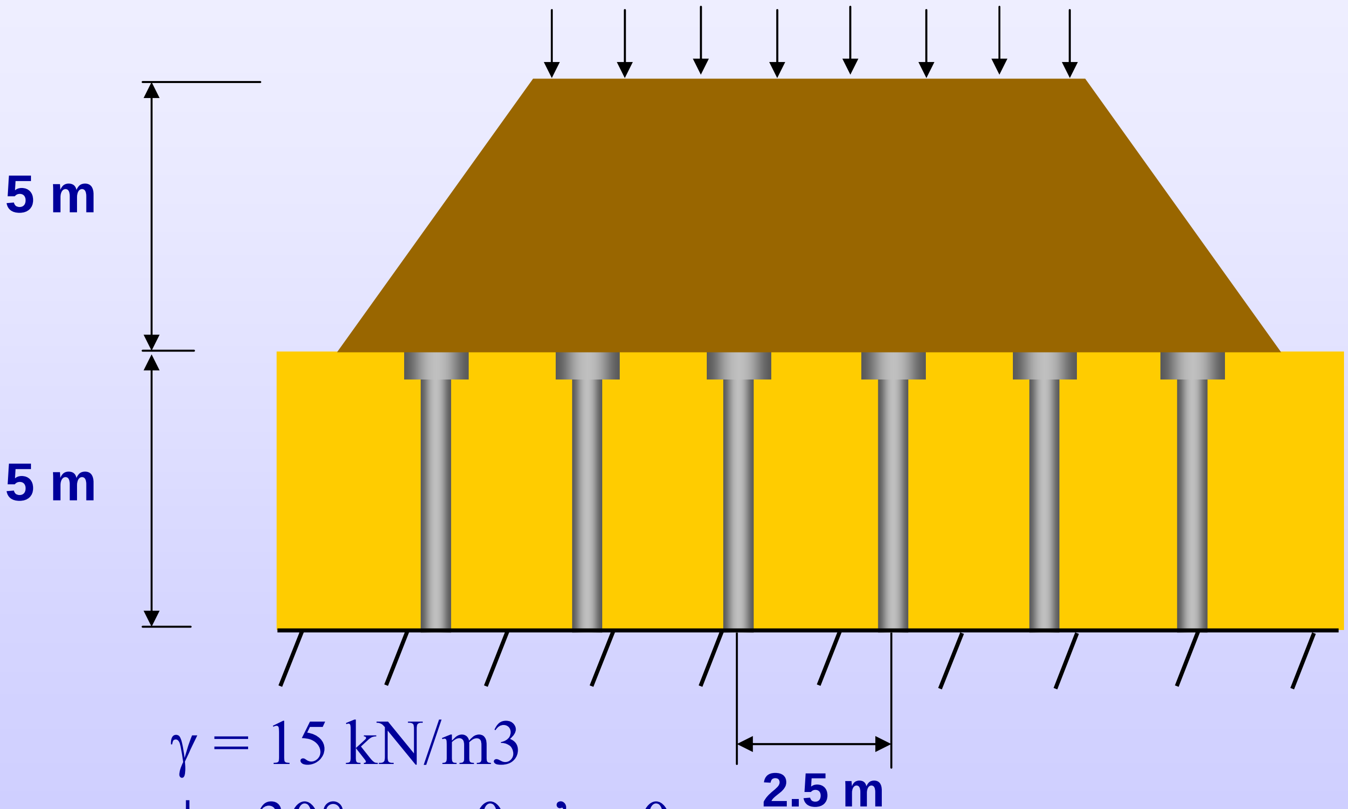
- 3D continuum model

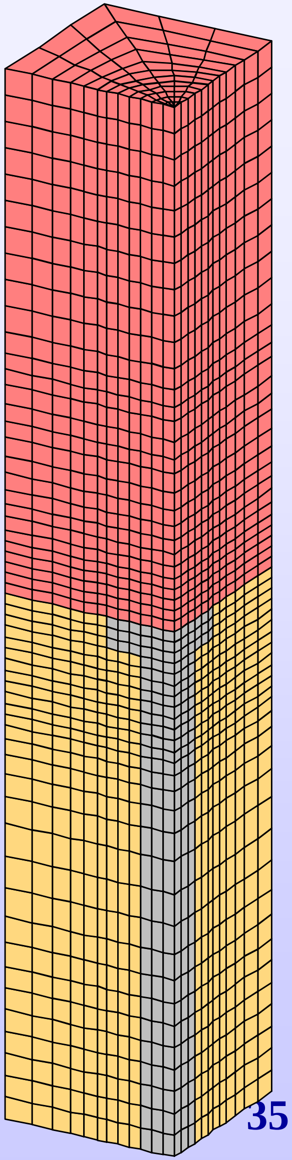


Reference model

- Parametrical study
  - Geometry
  - Constitutive model
- To simulate physical tests
- To evaluate
  - Analytical tools
  - 2D axisymmetric models
  - Biphasic models

Reference case : piled embankment





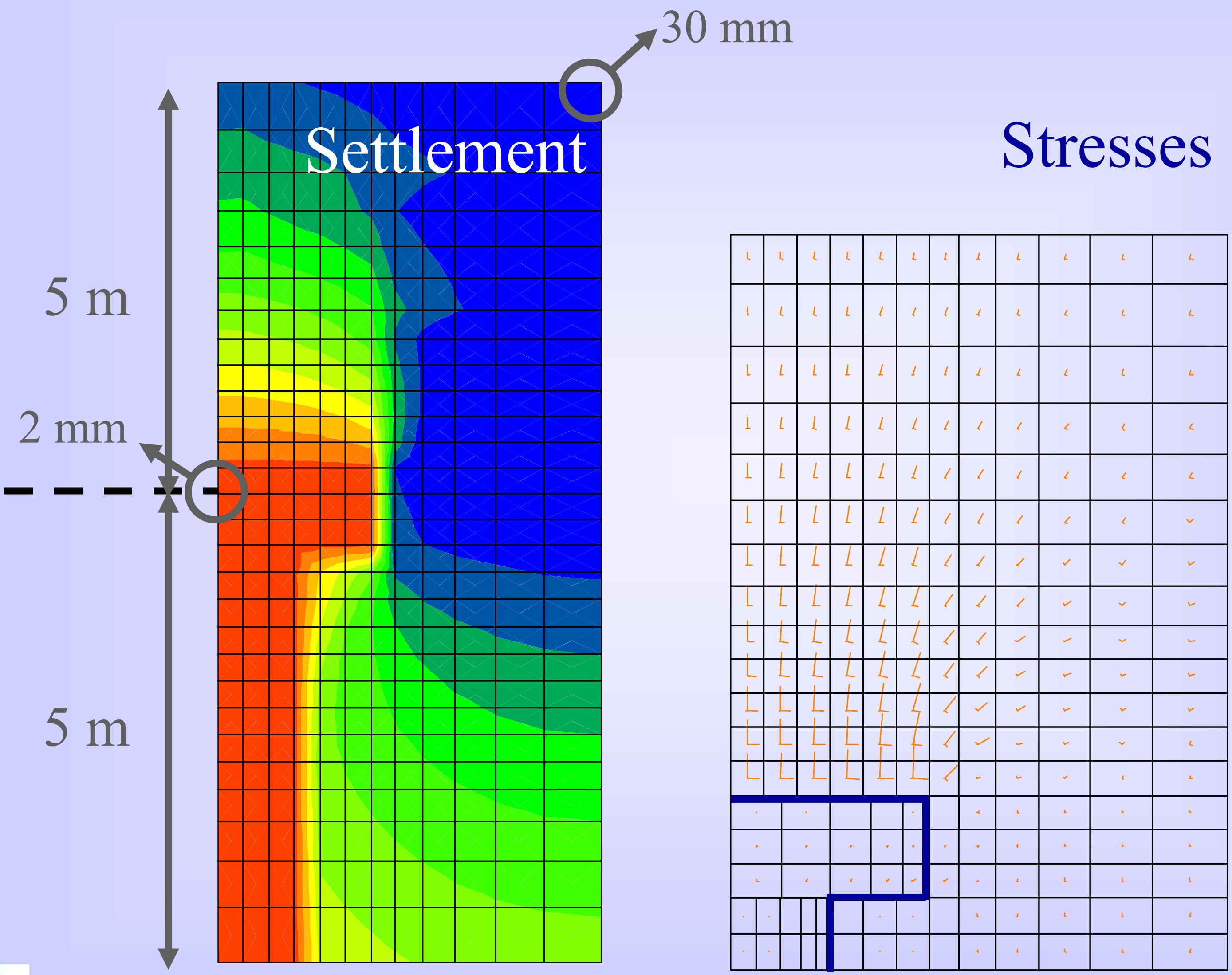
γ = 15 kN/m3

ϕ= 30° ψ = 0 c' = 0

E = 5 MPa υ = 0.3

URGC/INSA Lyon

Reference case : piled embankment



URGC/INSA Lyon

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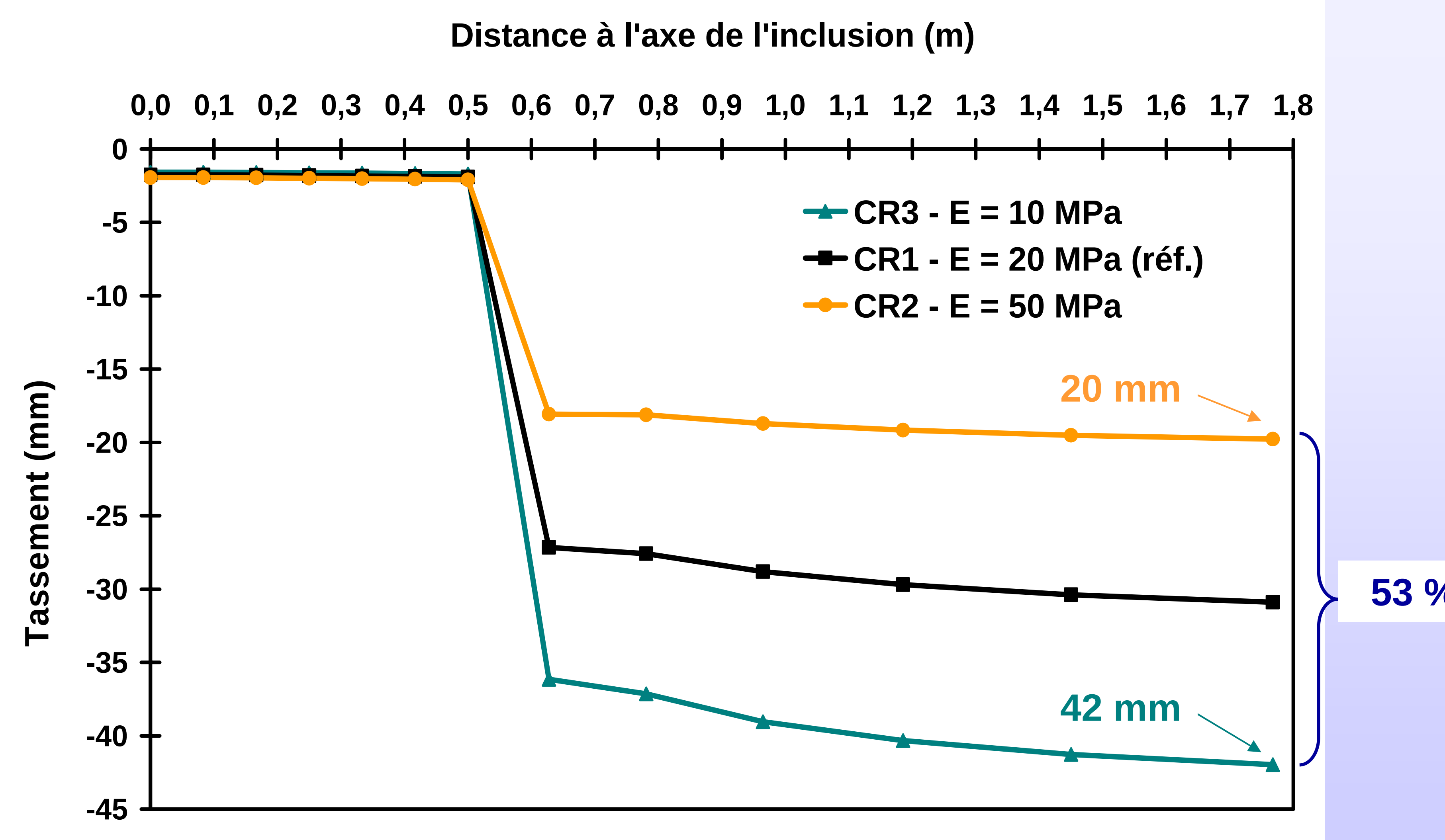
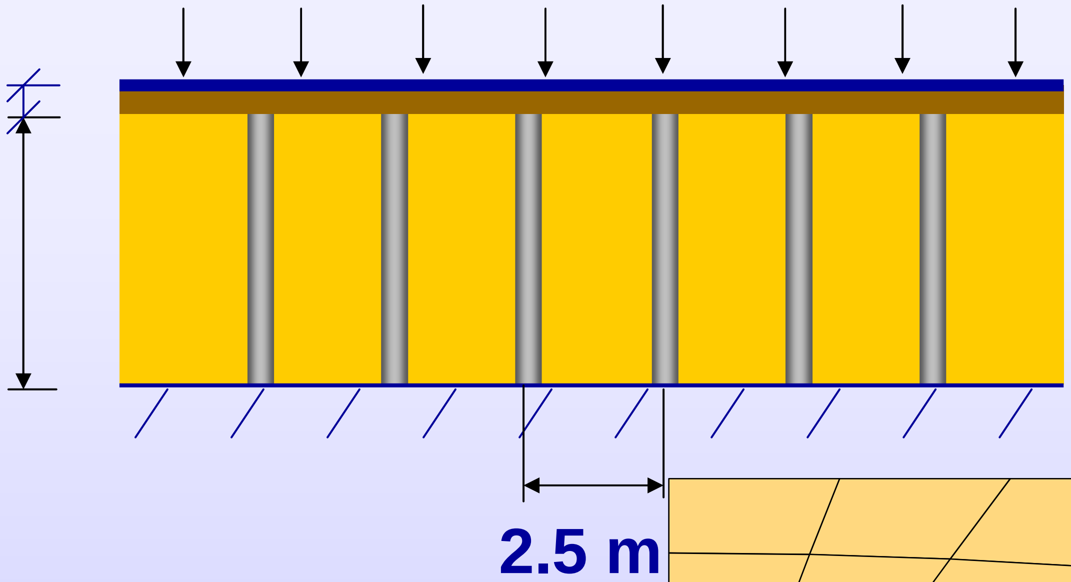
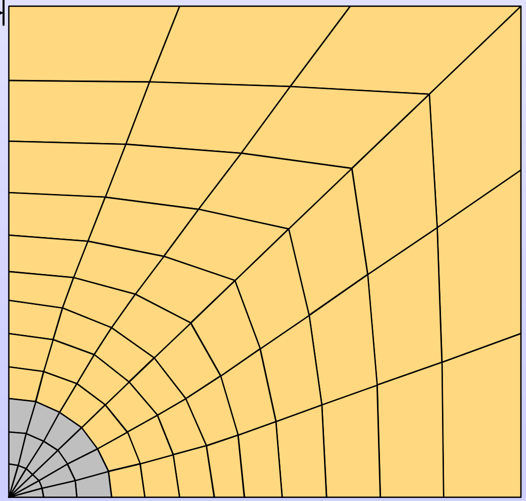
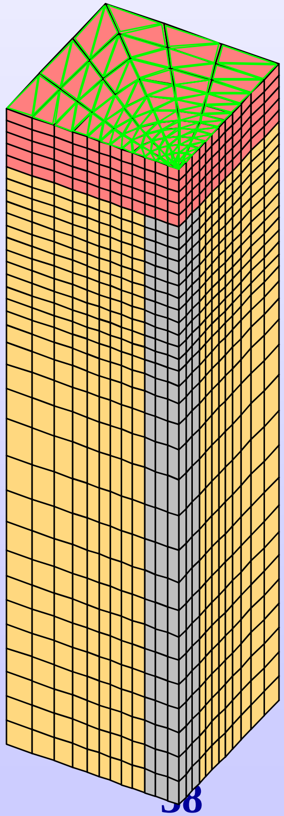
Reference case : piled embankment



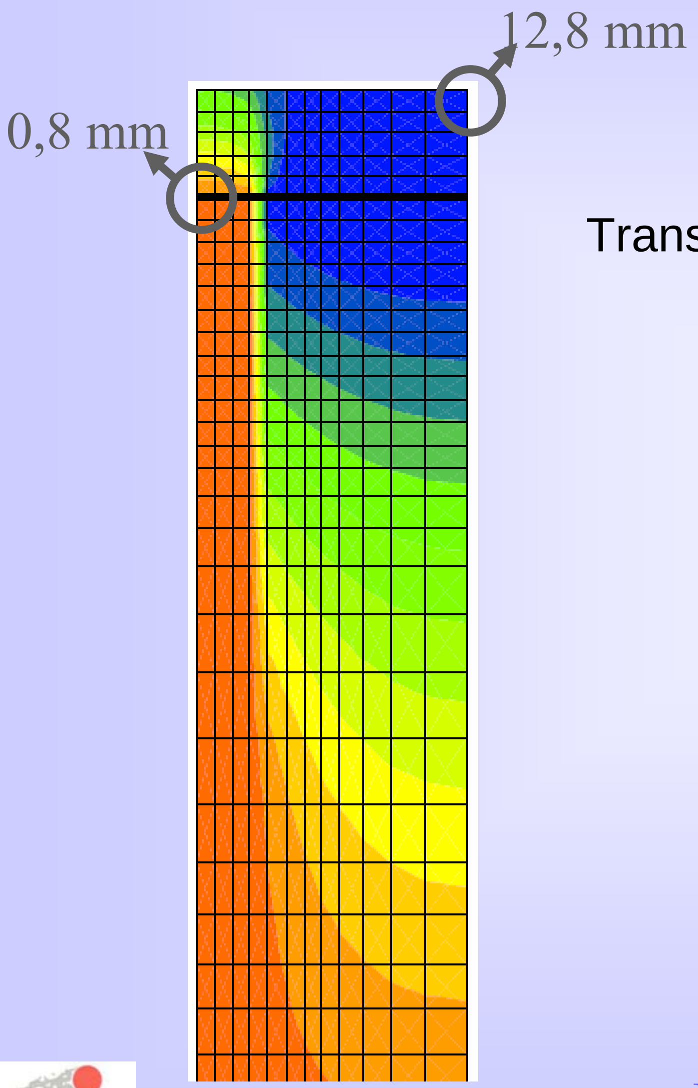
Reference case : floor slab

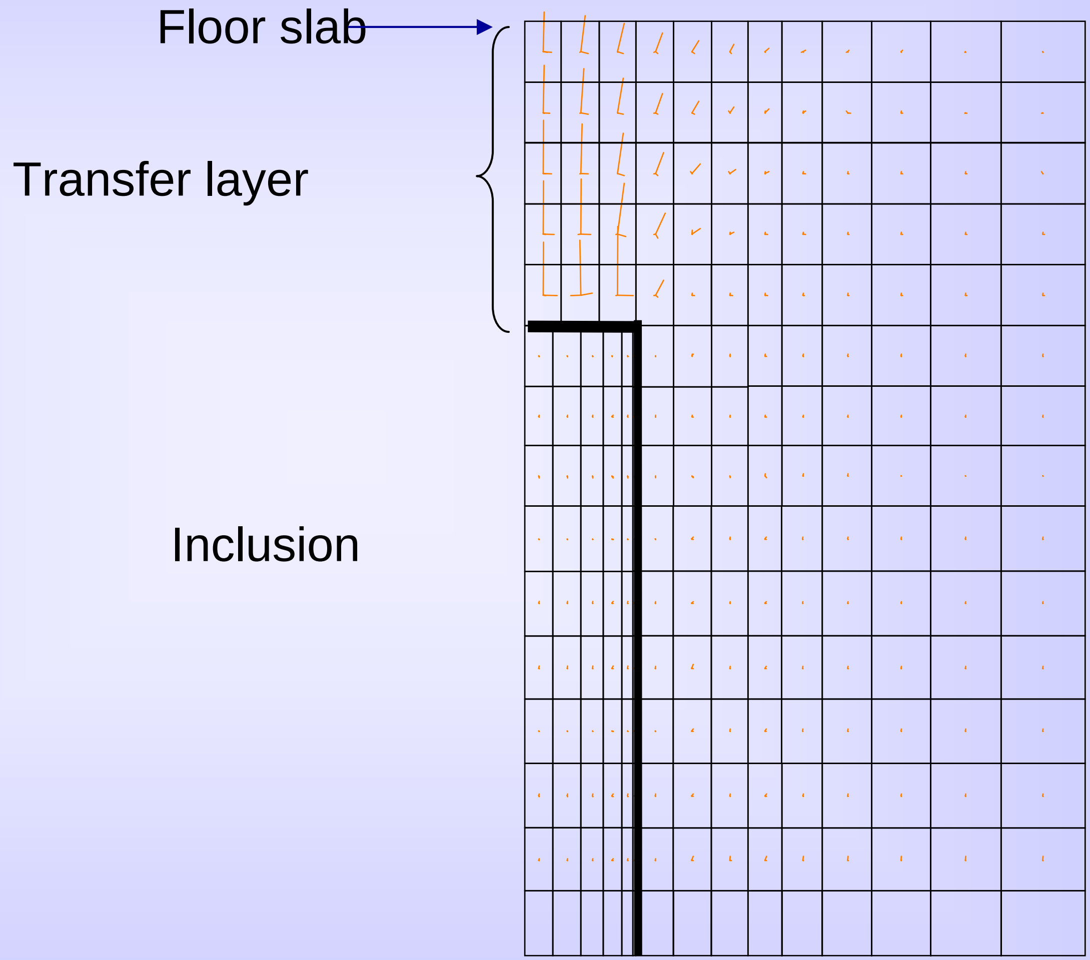




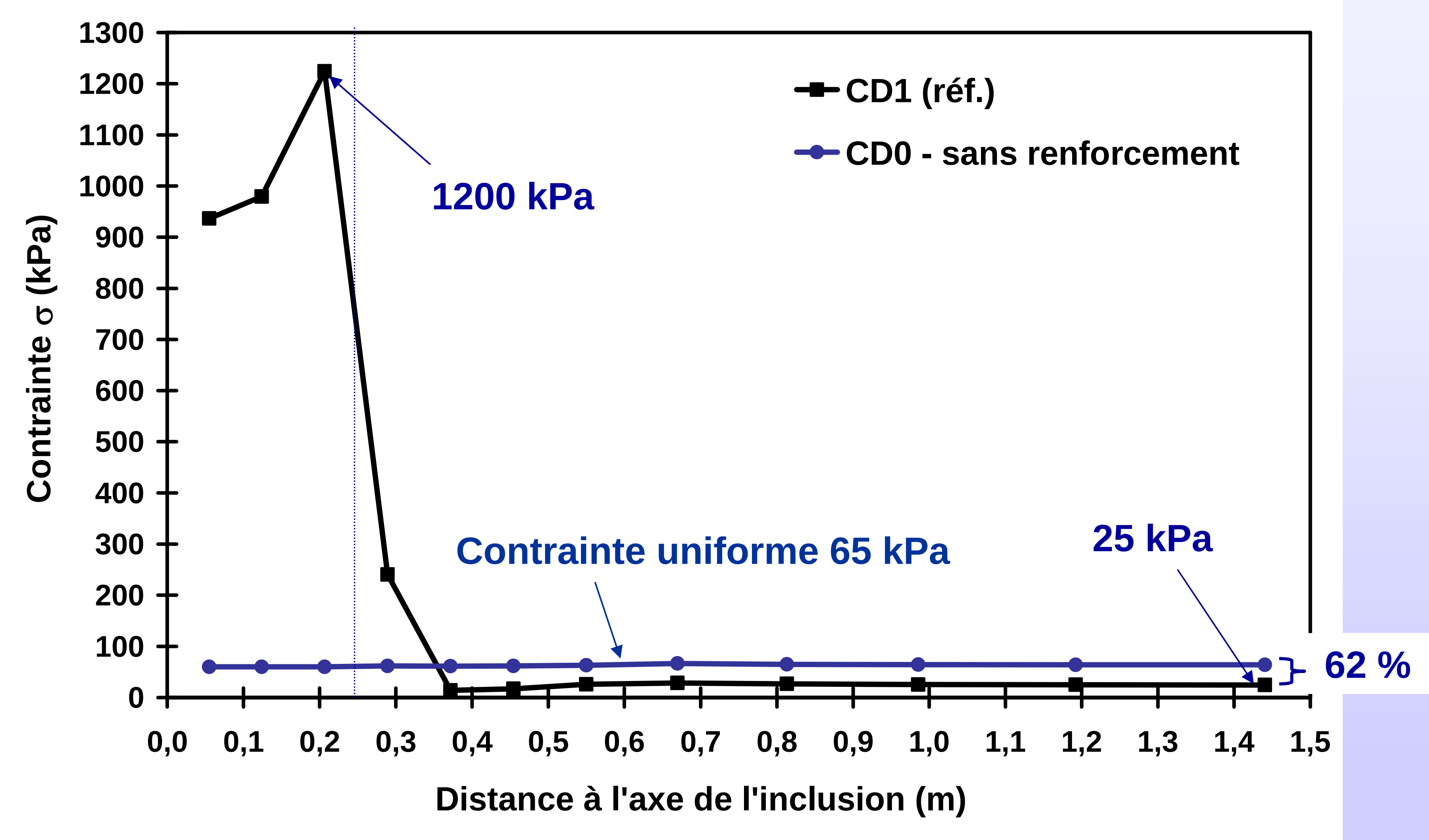


Reference case : floor slab



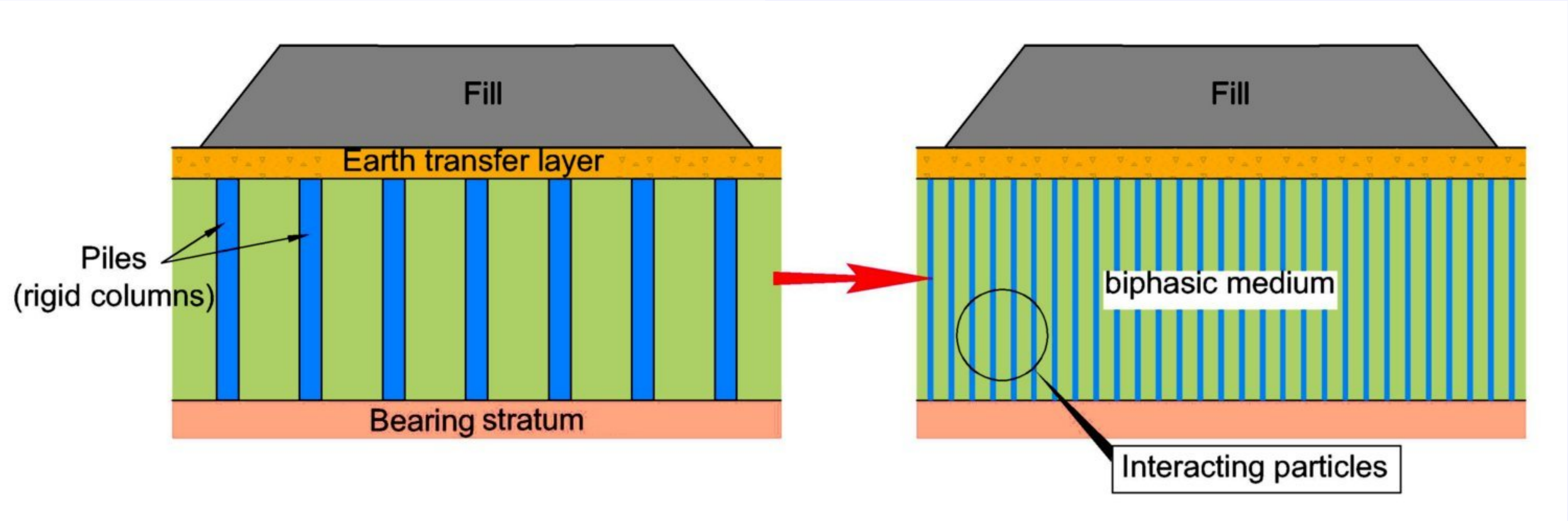


Reference case : floor slab

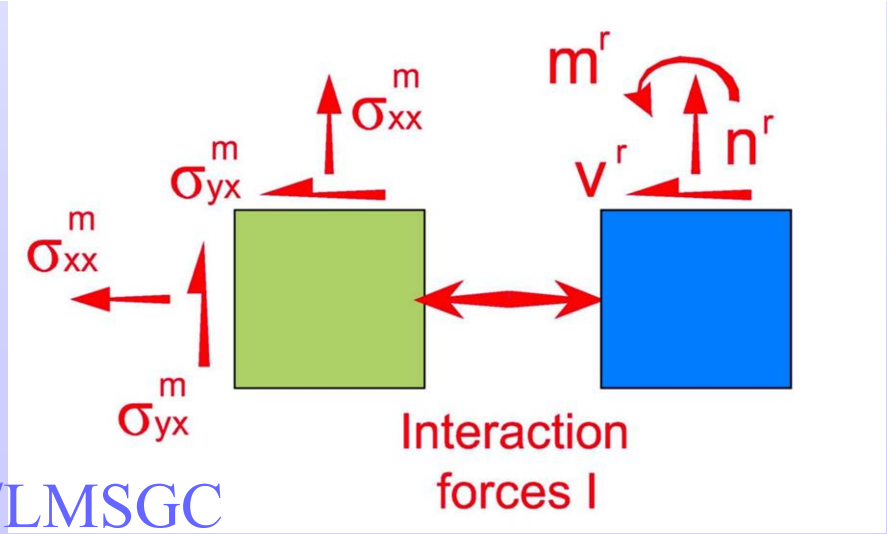


A simplified approach : the biphasic model

(Sudret, de Buhan, Hassen)

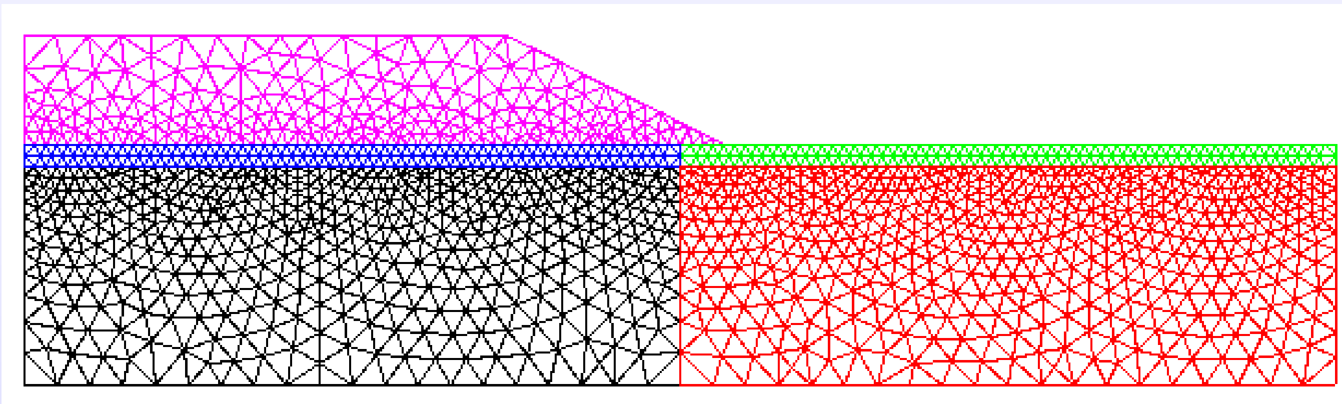


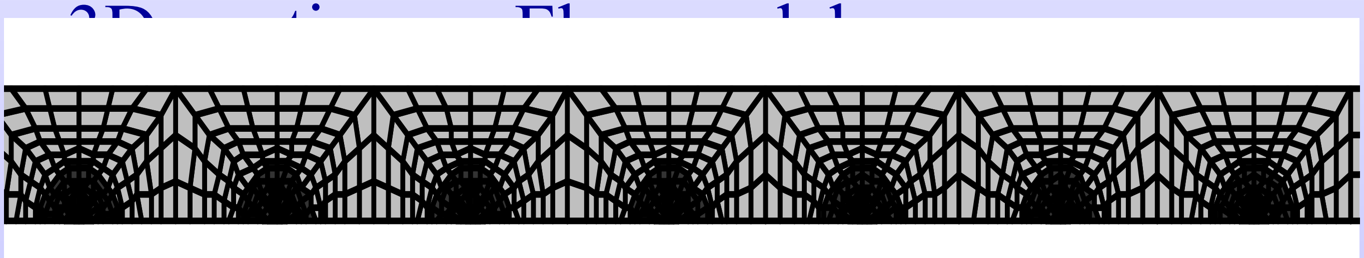
- All interactions treated
  - Specific factor α
- Boundary conditions
  - Load fraction λ



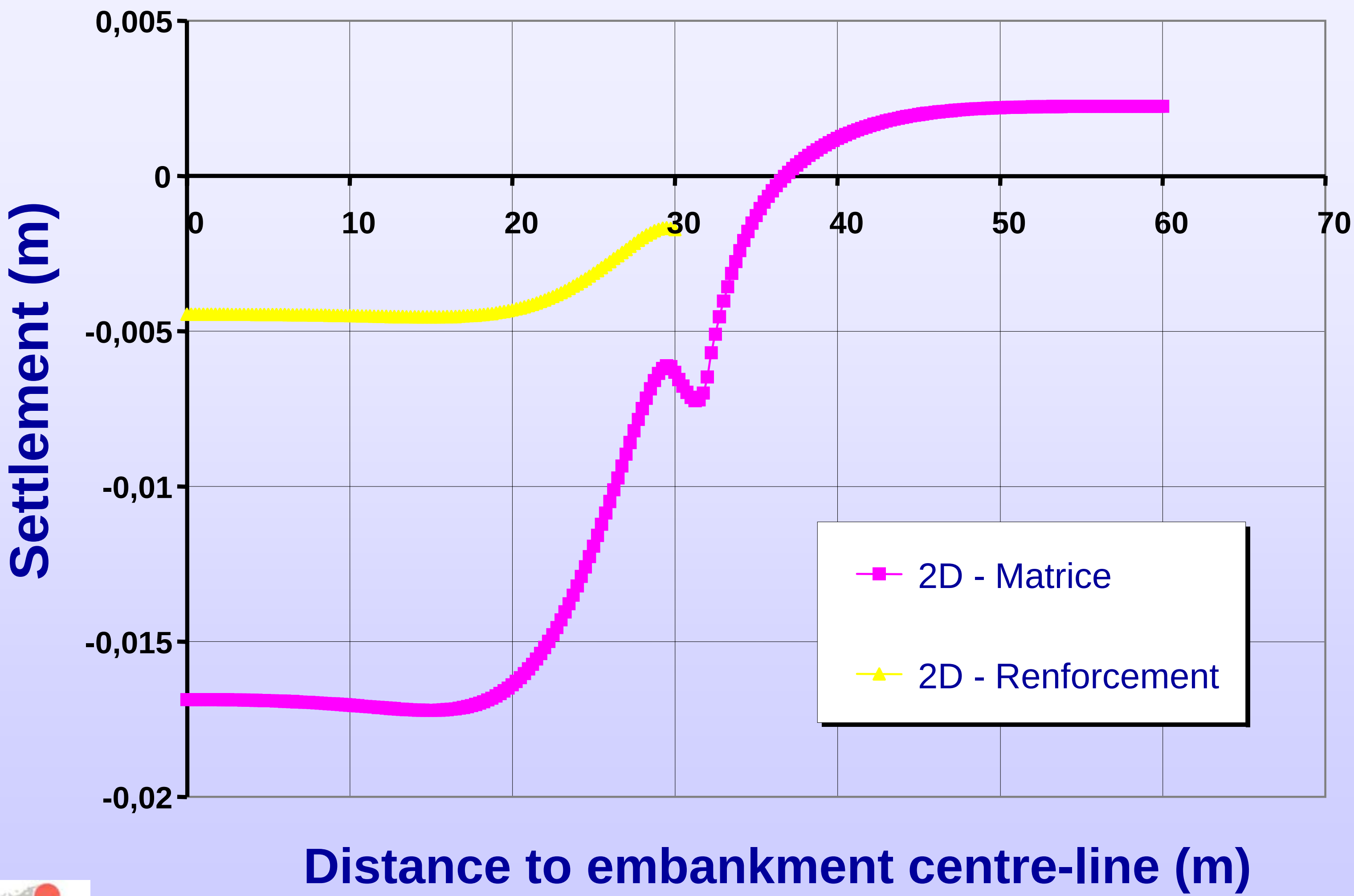
A simplified approach : the biphasic model

- 2D plane biphasic model

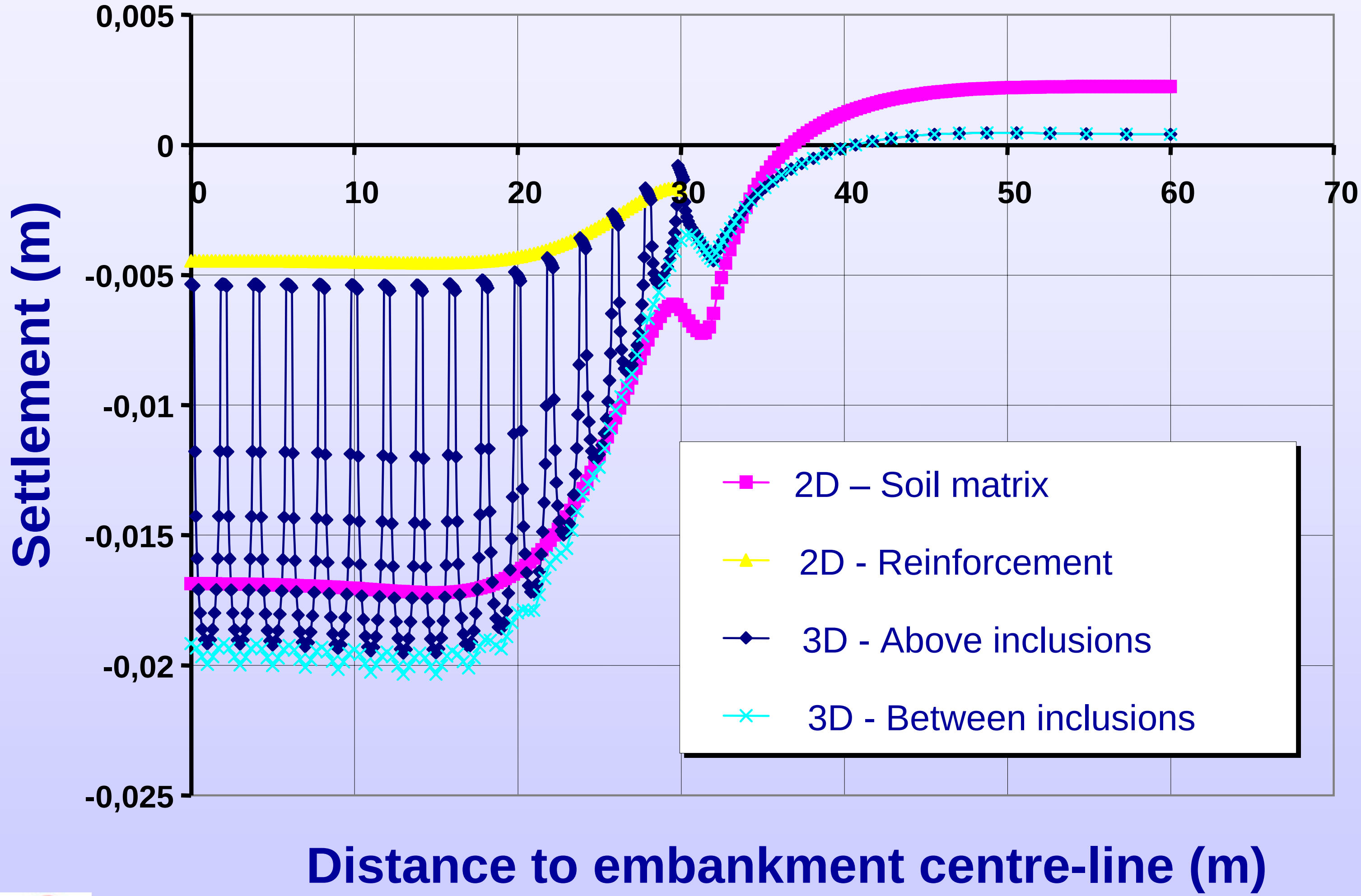




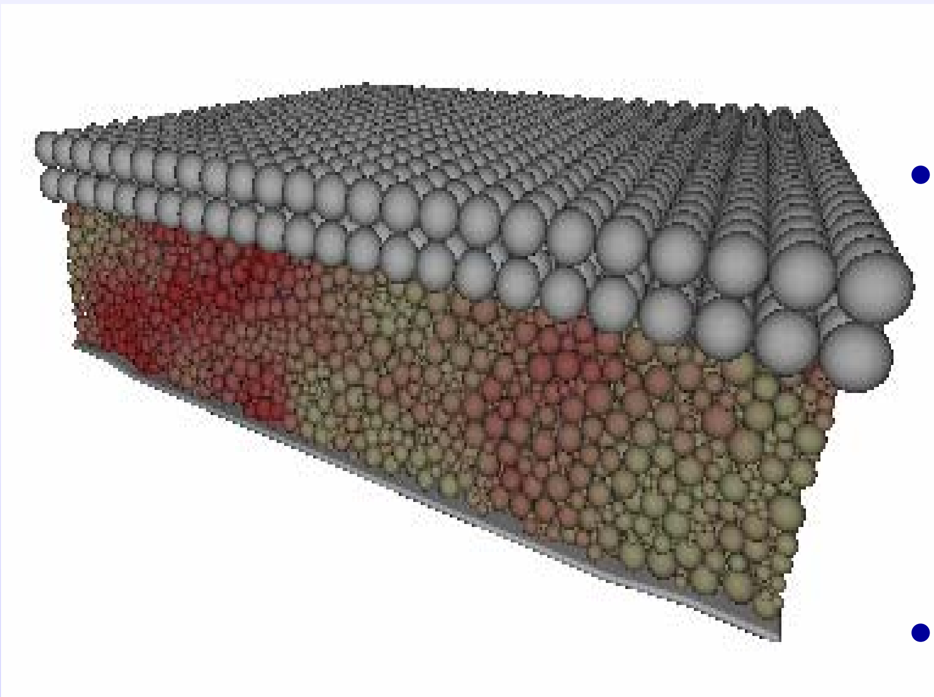
A simplified approach : the biphasic model

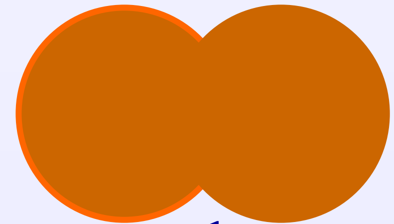


A simplified approach : the biphasic model



3D discrete numerical modelling

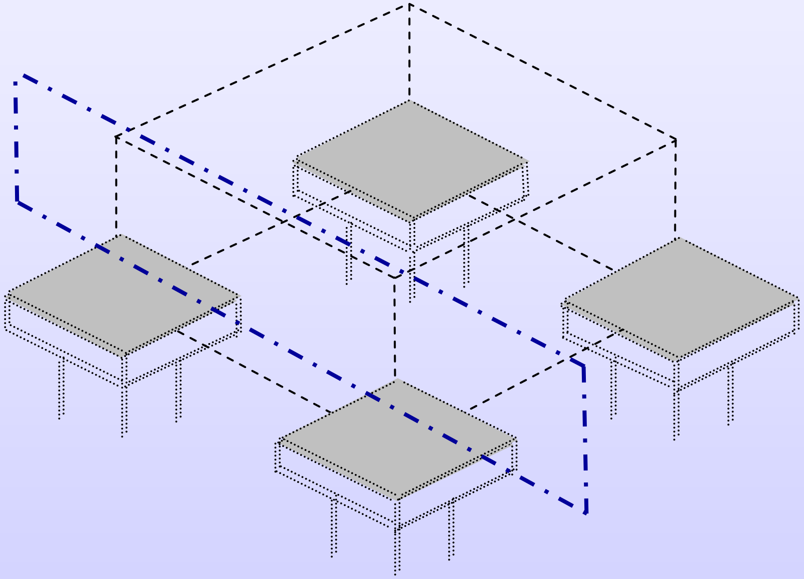




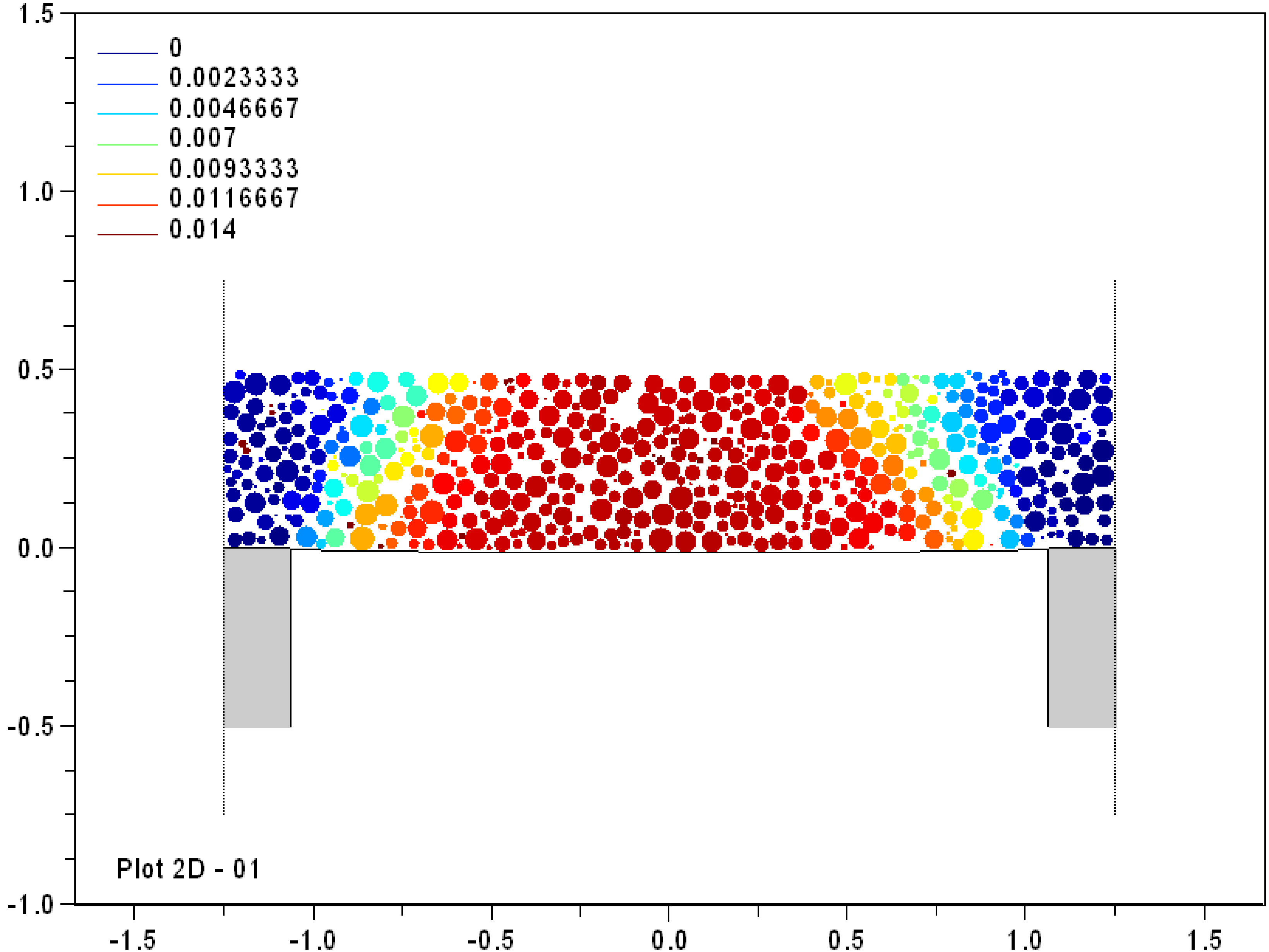
- Clusters (2 connected elements)
  - linear constitutive law of contact (normal, tangent)
  - adhesion (tensile strength)
- Micro-mechanical parameter values adjusted to fit triaxial test results

3D discrete numerical modelling

- An application example

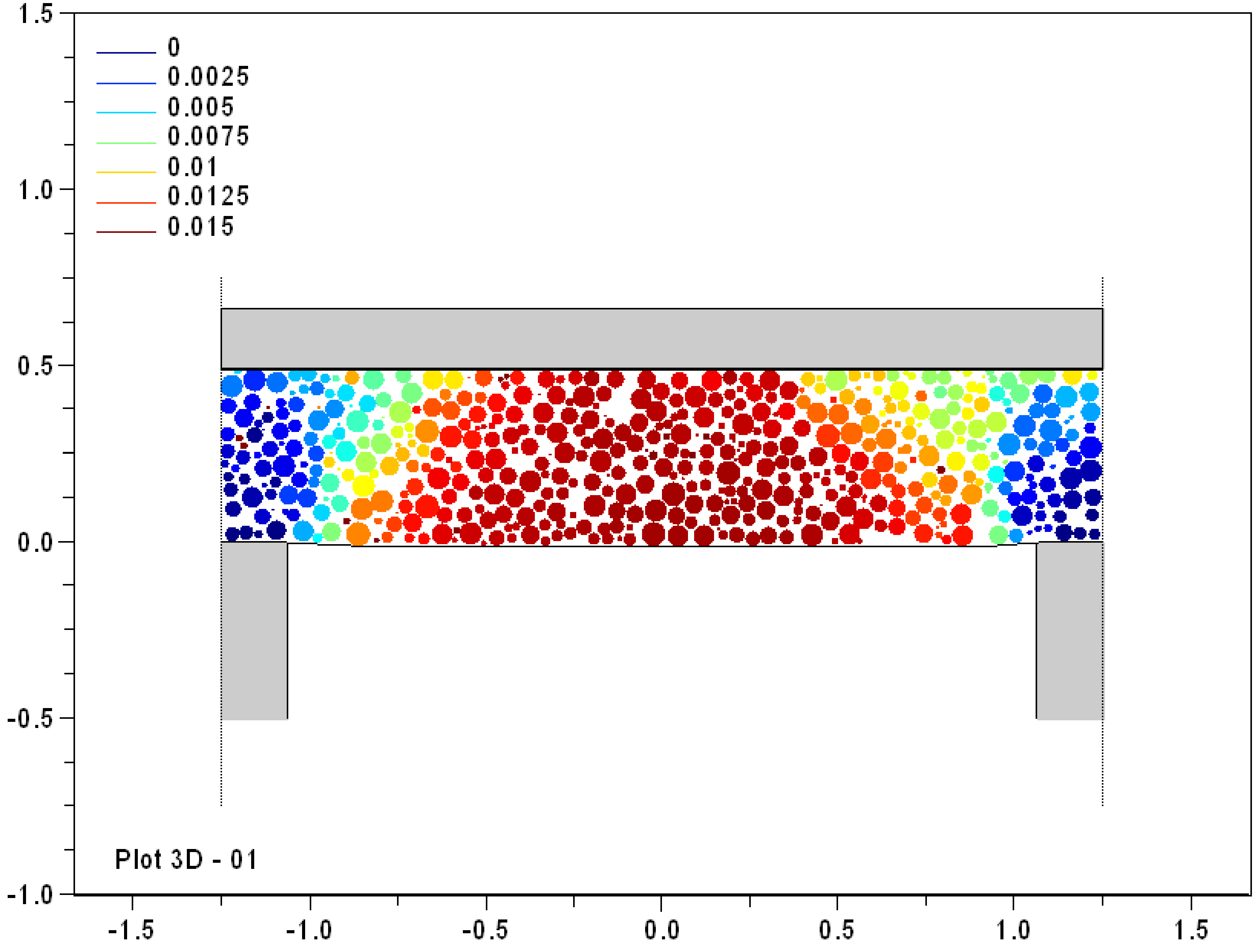


Displacement field in granular layer during loading - without concrete slab



3S-R UJF Grenoble (PhD work B. Chevallier)

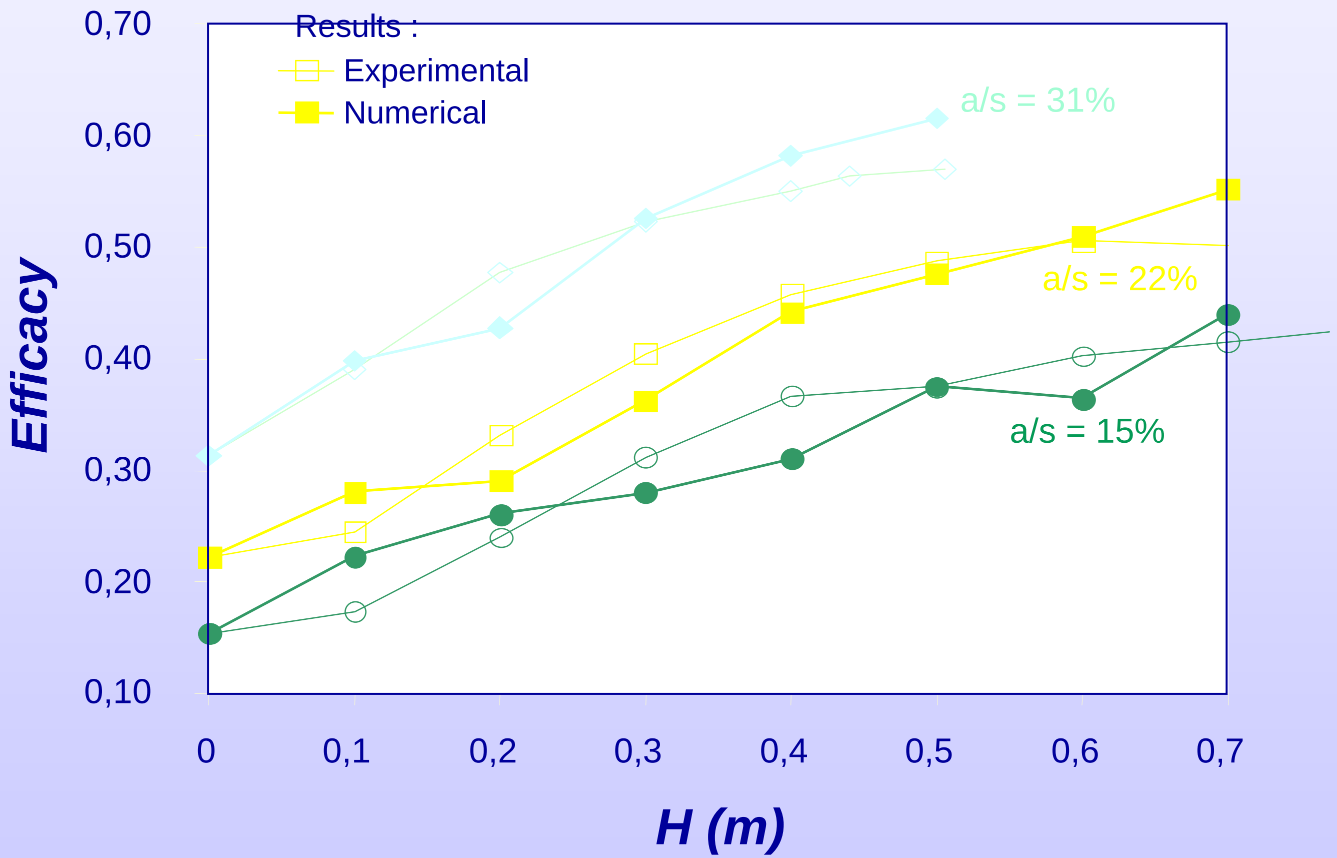
Displacement field in granular layer during loading - with concrete slab



3S-R UJF Grenoble (PhD work B. Chevallier)

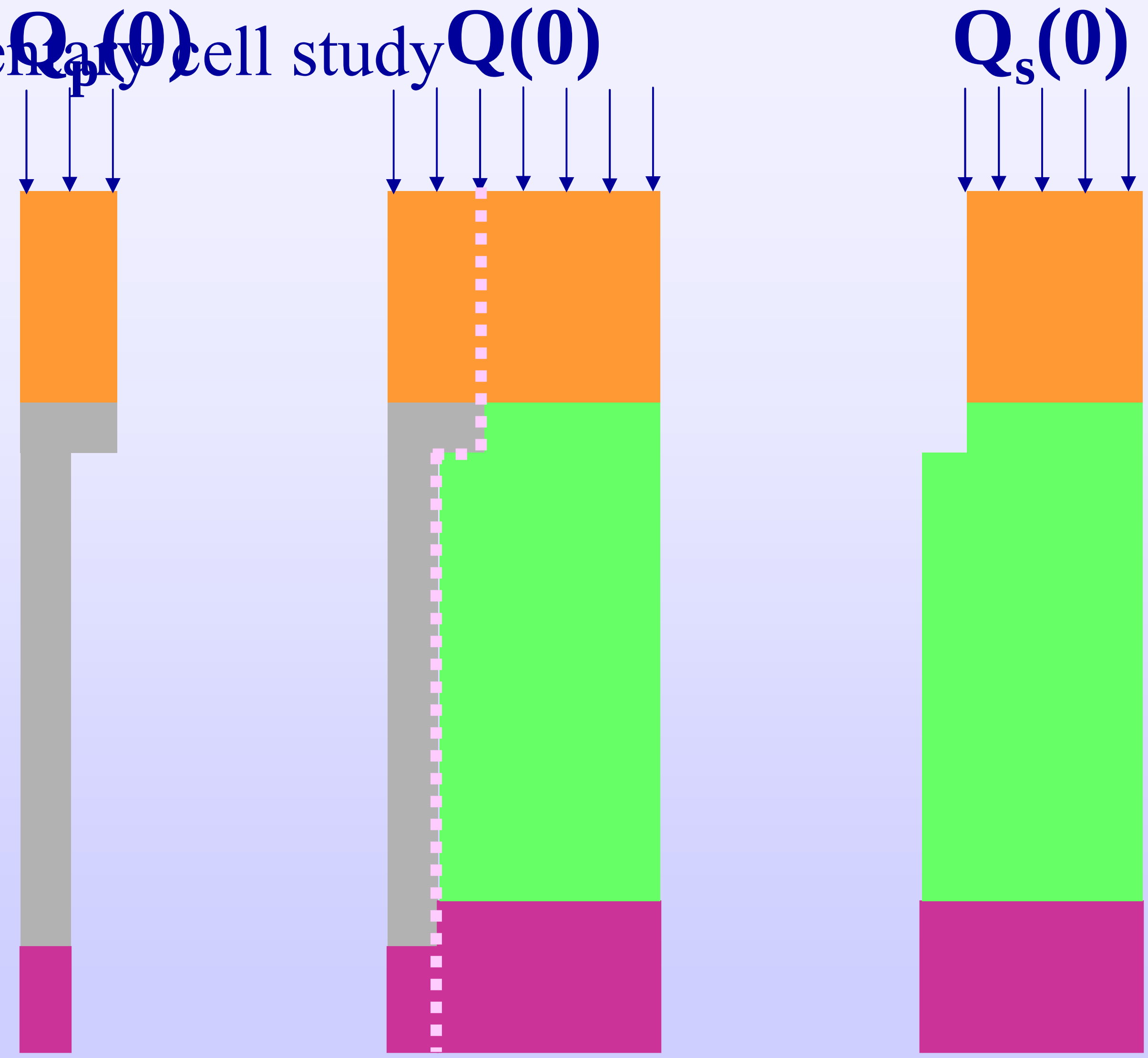
2D discrete numerical modelling (PFC2D)

- Physical model with the Schneebelli's analogical soil

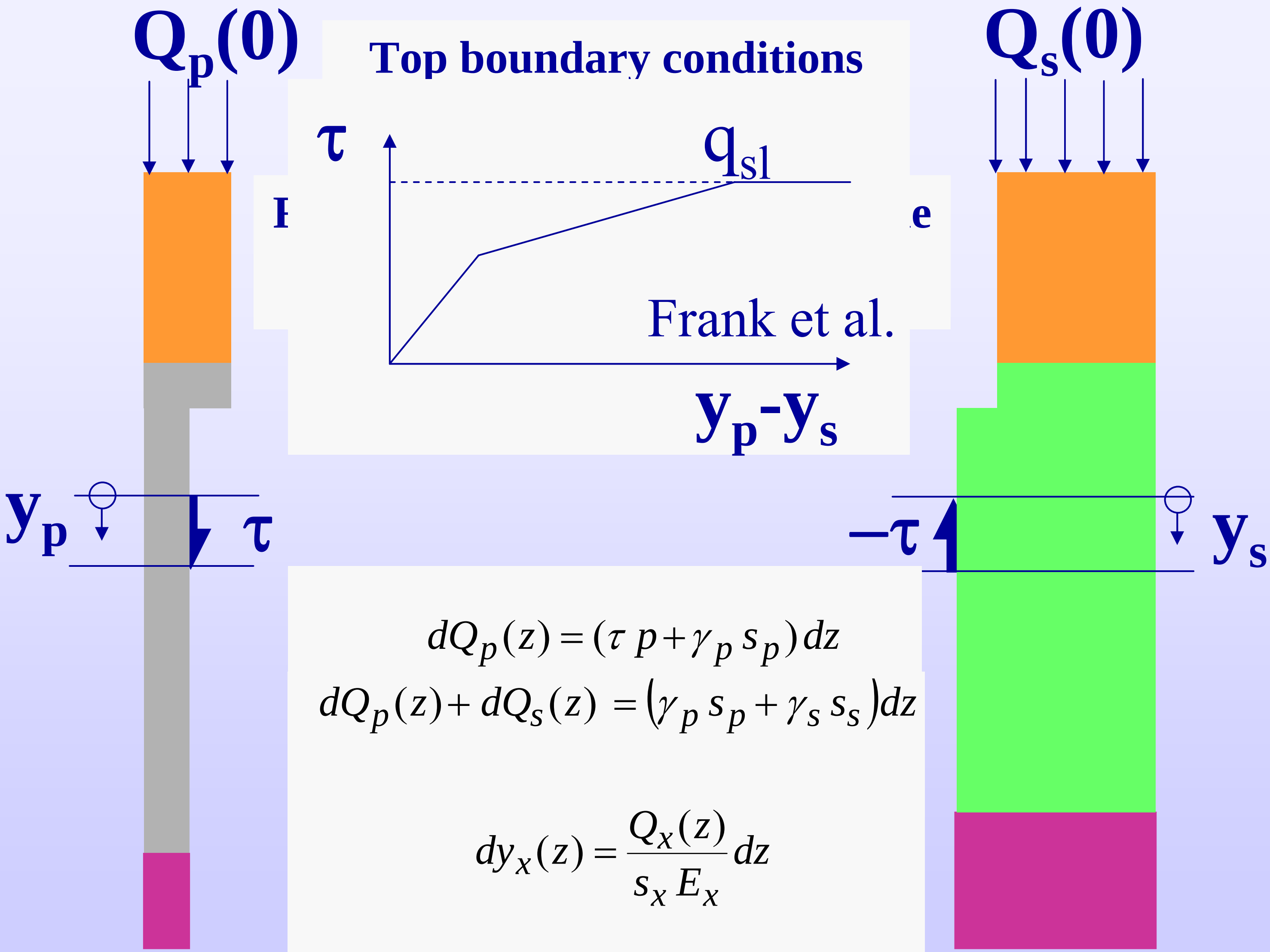


An analytical approach : Foxta (Taspie+)

- Elementary cell study



An analytical approach : Foxta (Taspie+)



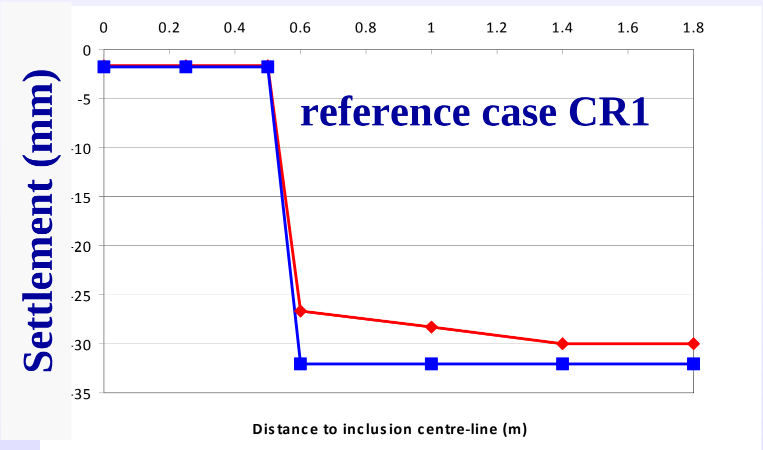
$$dQ_p(z) = (\tau\, p + \gamma_p\, s_p)\, dz$$

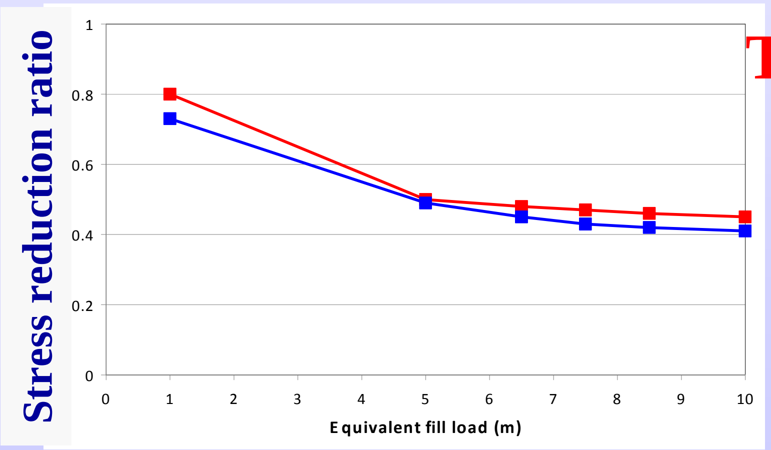
$$dQ_p(z) + dQ_s(z) = \left(\gamma_p\, s_p + \gamma_s\, s_s\right) dz$$

$$dy_x(z) = \frac{Q_x(z)}{s_x\, E_x}\, dz$$

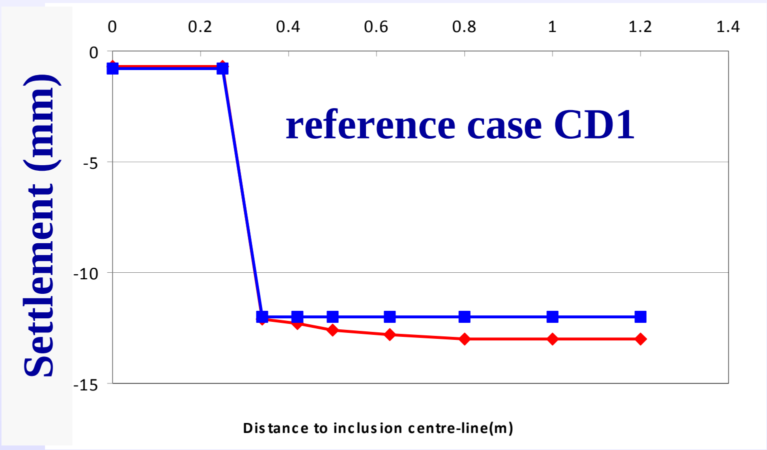
An analytical approach : Foxta (Taspie+)

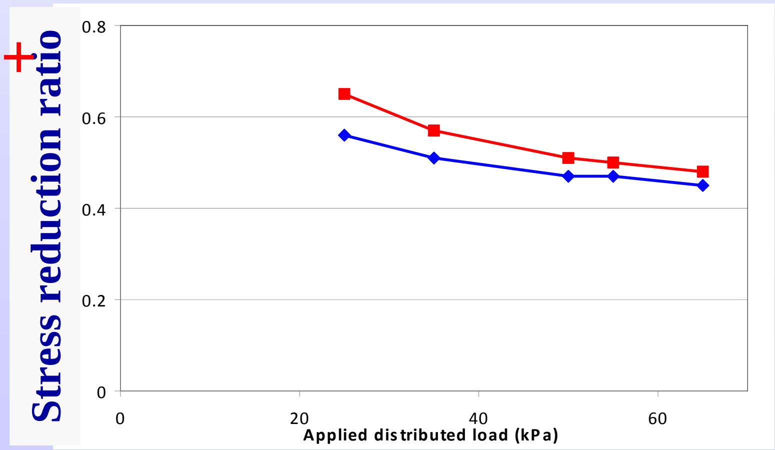
- **Piled embankment**





- **Floor slab**





Flac

Taspie+

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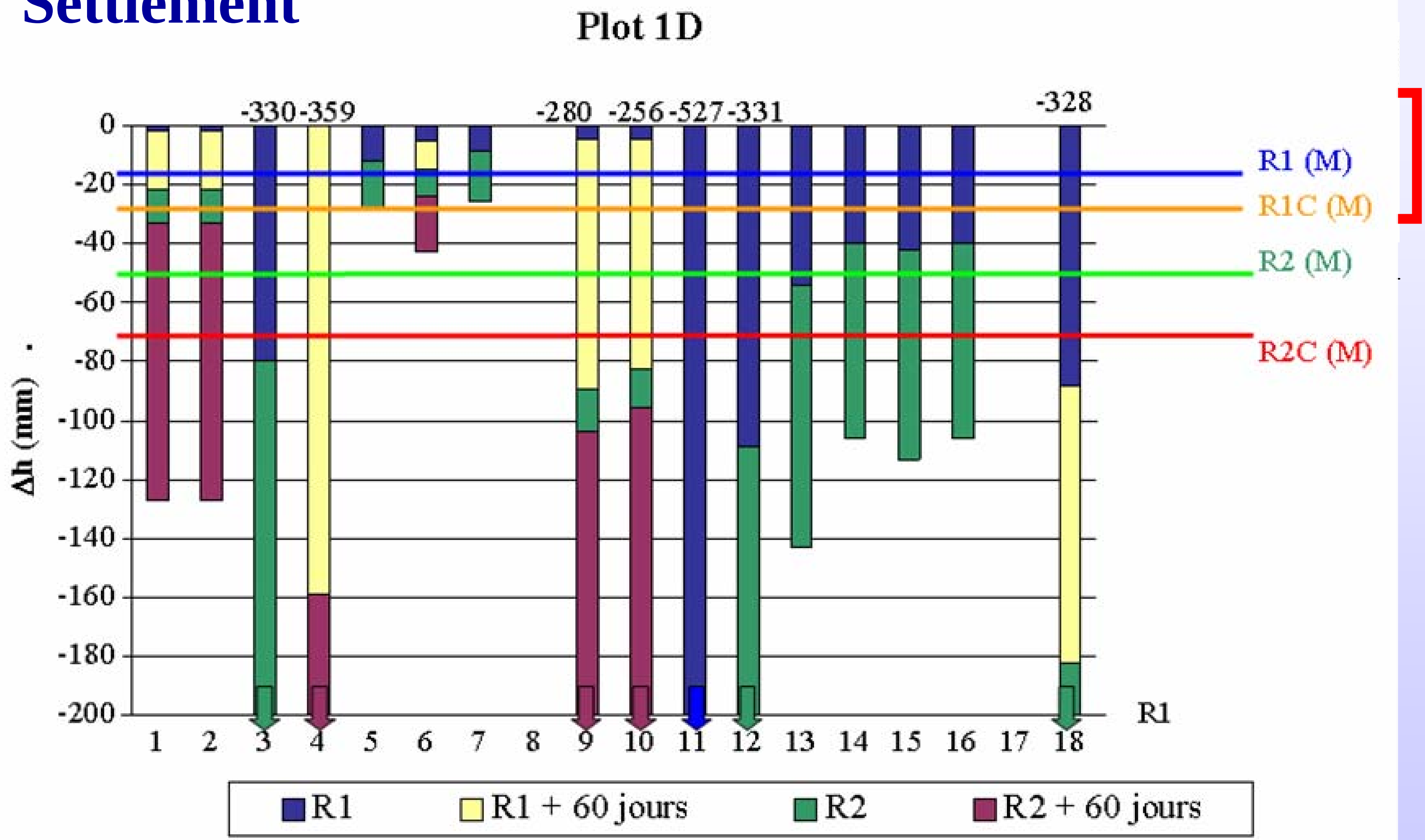
Benchmark exercise I (Saint Ouen)

- **Settlement**



A.S.I.RI
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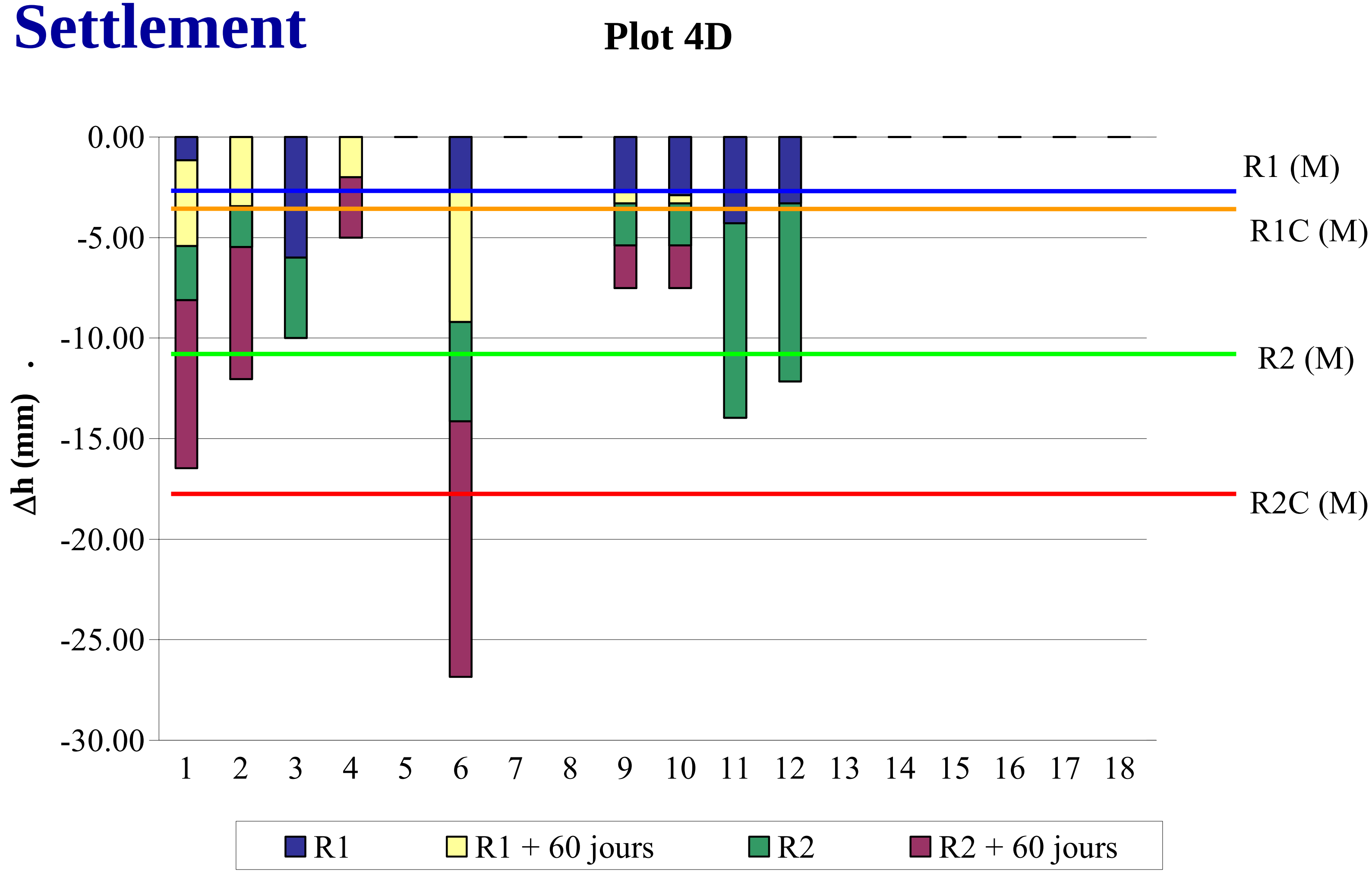
Benchmark exercise I (Saint Ouen)

- **Settlement**



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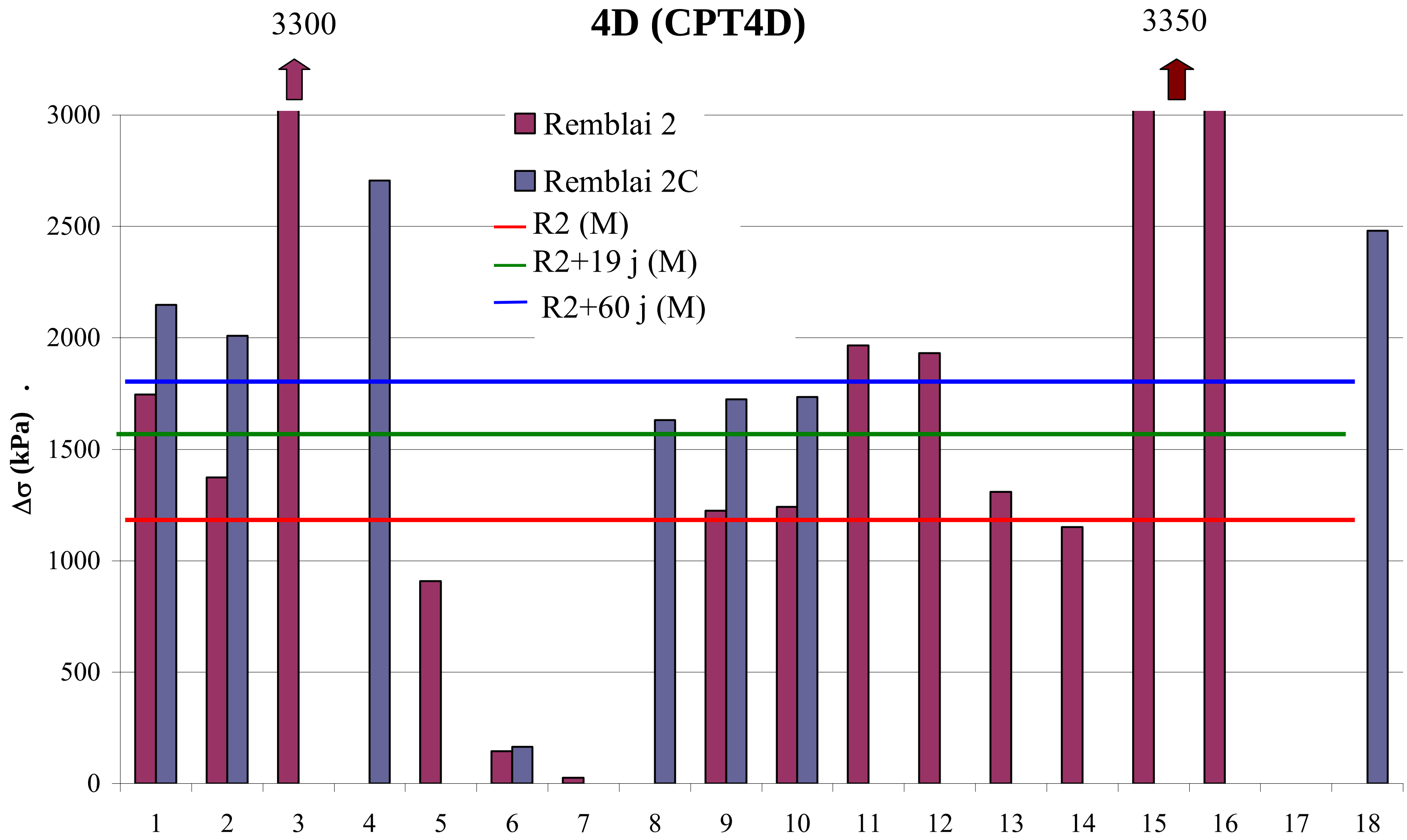
Benchmark exercise I (Saint Ouen)

- **Pile head vertical stress**



ASIRI Recommendations (2009)

A.S.I.RI
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Summary

- Description and developments
- Mechanisms and behaviour
- Conception and design
- Investigations and tests
- Construction
- Specifications and inspections

- Detailed review of present practice through
  - 6 working groups already at work
  - theoretical benchmark exercises
  - support of the « Numerical Modelling » theme

A.S.I.RI
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BALINEAU S.A.

LRPC ROUEN

METATTM

www.irex-asiri.fr

PINTO Entreprise

DURMEYER SA

QUILLE

A.S.I.RI
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Keller Ground Engineering

Barry Slocombe

Engineering Manager

BGA-CFMS 7th December 2007

- **Vibro Stone Columns: Design information and case histories**
  - 1. Site investigation
  - 2. Sustainability
  - 3. Vibro design issues
  - 4. Case histories
  - 5. Conclusions

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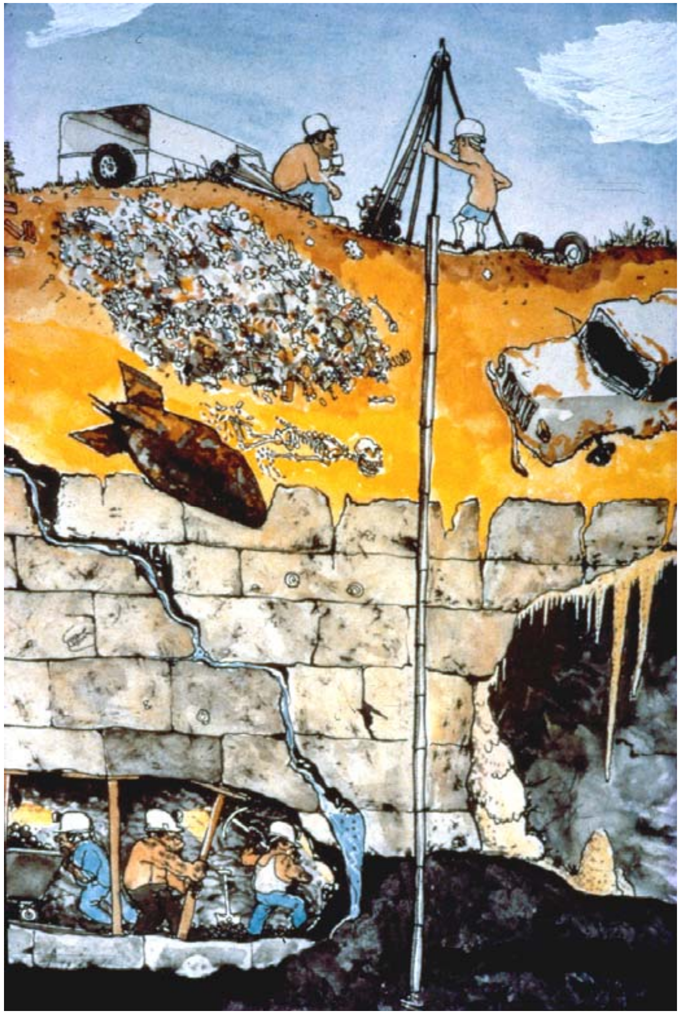
- **Site investigation**



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- **Site investigation**

- FPS Ground Investigation Survey (presented by Dr Egan at AGS meeting 2006):
  - Survey of **25%** of Piling and Vibro contracts July-August 2006
  - **14%** had no factual report
  - **45%** had no interpretative report
  - **16%** had no borehole location plan
  - **73%** had no levels (**83%** no co-ordinates)
  - **59%** had inadequate topographical information
  - **52%** had insufficent data to allow optimum judgement
  - See **www.fps.org.uk**

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- **Sustainability/Embodied energy**

- “Increased emphasis on sustainability has led the geotechnical industry to invest greatly in developing technically advanced and cost-effective ground improvement techniques” – Damon Schunmann, Ground Engineering

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- **Sustainability/Embodied energy**
- Vibro Stone Columns typically use “waste aggregate” from nearby quarries/cement works for normal lightly reinforced shallow foundations and ground-bearing slabs
- Little energy required to generate materials plus low transport energy
- Low embodied energy
- Currently approx. 50% of Keller English contracts use reclaimed materials, often from on-site demolition, see comments Ground Engineering, May 2004
- Have been re-developing/testing former Keller Vibro contracts for over 10 years, NB legal responsibilities

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- **Vibro Stone Column design**
- Densification of granular soils (esp. seismic)
- Reinforcement of mixed/clayey soils
- Natural soils and essentially inert fills/man-made materials
- Higher bearing capacity = conventional foundations at shallow depth
- Reduced, more homogeneous, settlements
- Understand “real” loads, notional loads, required settlement performance
- “Investigates” soils at close grid centres

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- **Vibro Stone Column design**
- Can act as drains to accelerate settlements
- Can act in shear for higher slope stability factor of safety
- Can pre-bore for consistent depth/diameter of column
- Can vent gas from landfill
- Can add VSC on top of concrete pile for more efficient slab design
- Can add concrete (Vibro Concrete Columns), admixtures, plugs
- Can confine within geogrids for very soft soils

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- **Vibro Stone Column design**
- Cannot influence long-term decay of degradable constituents within fills (max 10-15%, well distributed?)
- Cannot influence self-weight settlement of deep fills (DC can)
- Cannot influence inundation settlement of susceptible soils (DC can)
- Cannot “work miracles” with high loads/thick layers of weak soils
- Care with Chalk and Pulverised Fuel Ash
- Secondary compression??

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- **Vibro Stone Column design**
- Start with the capacity of an individual stone column – Hughes and Withers, Ground Engineering, May 1974
- Column capacity depends on the confining action of the soils (enhanced when densification occurs)
- Column capacity is increased when ground is surcharged since increases confinement of column eg embankment, raising site levels, floor loads
- Care with rapid load application due to development of excess pore water pressures eg slopes, silos, tanks, coal stockpiles
- Care possible undermining due to nearby excavation (take foundations deeper)
- Care decay of degradable constituents (extra reinforcement/cantilever/span?)

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- **Vibro Stone Column design**
- Settlement performance is a function of the density of stone column per unit area, normally termed “Area Ratio”
- Settlement is reduced within the depth of treatment, then add for other settlements below the treatment depth and self-weight movements
- Priebe, Ground Engineering, December 1995
- Typical UK Ratio 5 – 20%, reduces settlements by up to about 50%
- Have pre-bored for up to 50 – 60% Area Ratio
- Have “flushed out” up to 80% soft soil using larger more powerful vibrators with water-flush

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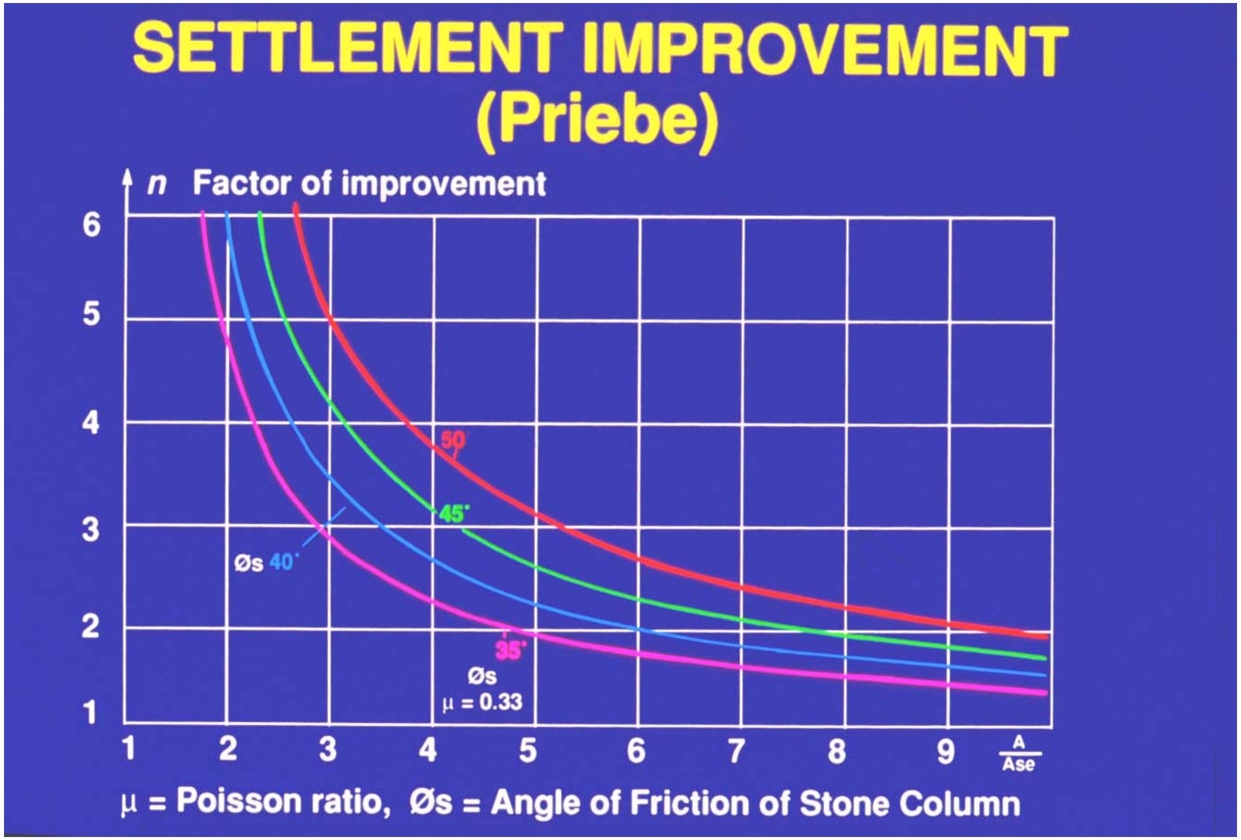
- **Vibro Stone Column Design**



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- **Vibro Rigs**

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- **Case history – Glasgow**
- 18,300 m^2 of whisky warehouses
- 1.0m upfill (real load) + 50/65 kPa
- Weak soils to 17m bgl
- Vibro to up to 8m depth at < 2.0m grid
- Predicted settlements 60 – 80mm
- Improvement factor 1.8 to 2.0

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- **Case history – Aberdeen**
- 5/6 – storey offices
- Foundations up to 4.5 x 4.5m @ 250 kPa
- Vibro from base of 2.3m deep basement
- 3m loose sands, N = 5 to 10, then 20+
- 2m “uncompact” wet silt at 10 – 12m bgl
- Predicted settlements 20-25mm
- Improvement factor 2.3 to 2.4

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- **Case history – Gloucester**
- Bridge approach embankments
- Up to 14m height
- Colluvium and Lias Clay
- Drainage design, 6 month period
- Pre-bored Vibro to up to 6m depth
- Residual settlement 10 to 40mm
- Factor of safety > 1.4

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- **Conclusions**
  - Vibro Stone Columns are very adaptable to a wide range of soils and developments
  - Vibro design is based on conventional geotechnical design
  - Vibro modifies the stiffness and drainage parameters within the depth of treatment
  - Settlements occur within the Vibro zone, beneath and possible other causes
  - Settlements are reduced by factors that depend on the Area Ratio replacement of the soils
  - Very sustainable/low embodied energy technique
  - Vibro Stone Column design is only as good as the site investigation data upon which it is based

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- **Questions?**

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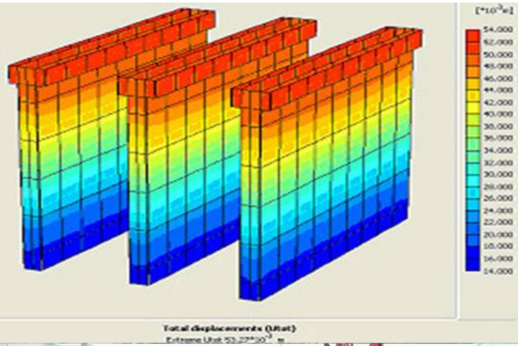
GEOTECHNICAL AND CIVIL ENGINEERING CONTRACTORS






Soil mixing innovations : Geomix, SpringSol and Trenchmix

Serge BOREL

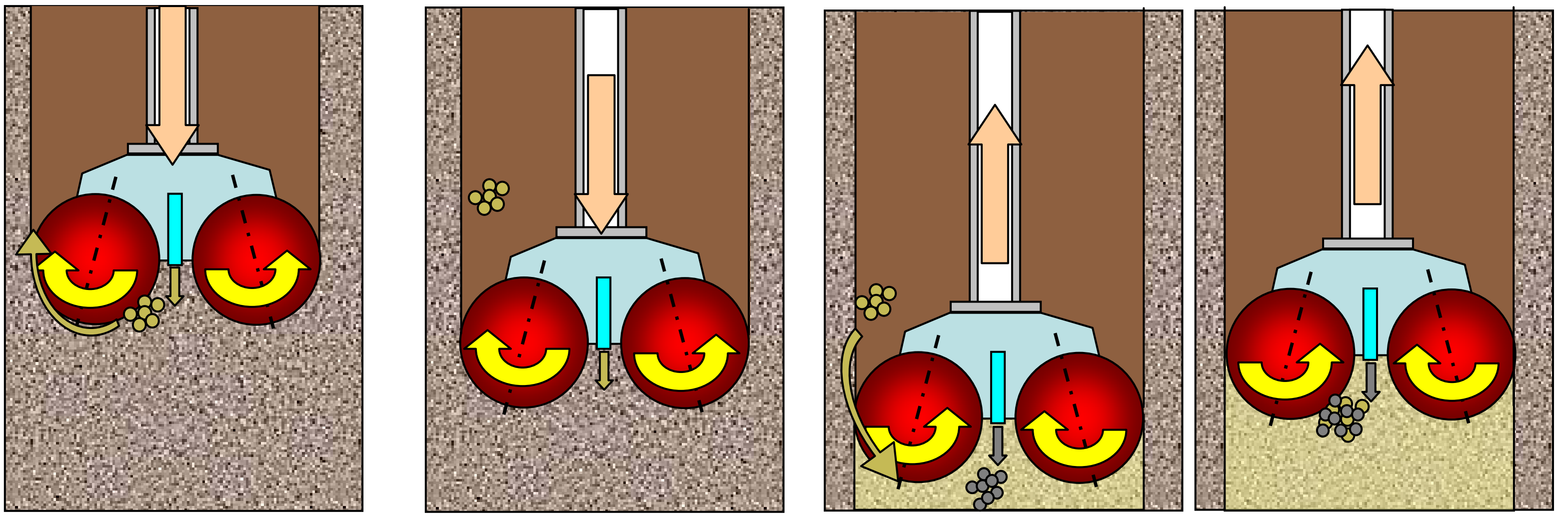
Soil mixing innovations : Geomix, Springsol and Trenchmix

- Geomix
  - Soil mix panel using a cutter (hydrofraise)
- SpringSol
  - Soil mix columns using an opening tool
- Trenchmix
  - Soil mix trenches

Geomix CSM basics

- CSM = Cutter Soil Mixing
- Based on Hydrofraise cutters
- Kelly mounted
- Low spoil technique

Geomix CSM basics



› Key factors:
  - Stability of the mix above the tool
  - Final soil mix caracteristics
  - Homogeneity


TEC
casagrande

CSM Geomix

- FNTP Innovation Prize 2007
- 4 No SBF CSM operating
- Application : Diaphragm & cut-off wall, soil improvement

- Eg : 10 000 m^2 in Pittsburgh (USA, 2007)

Soil mixing innovations : Geomix, Springsol and Trenchmix

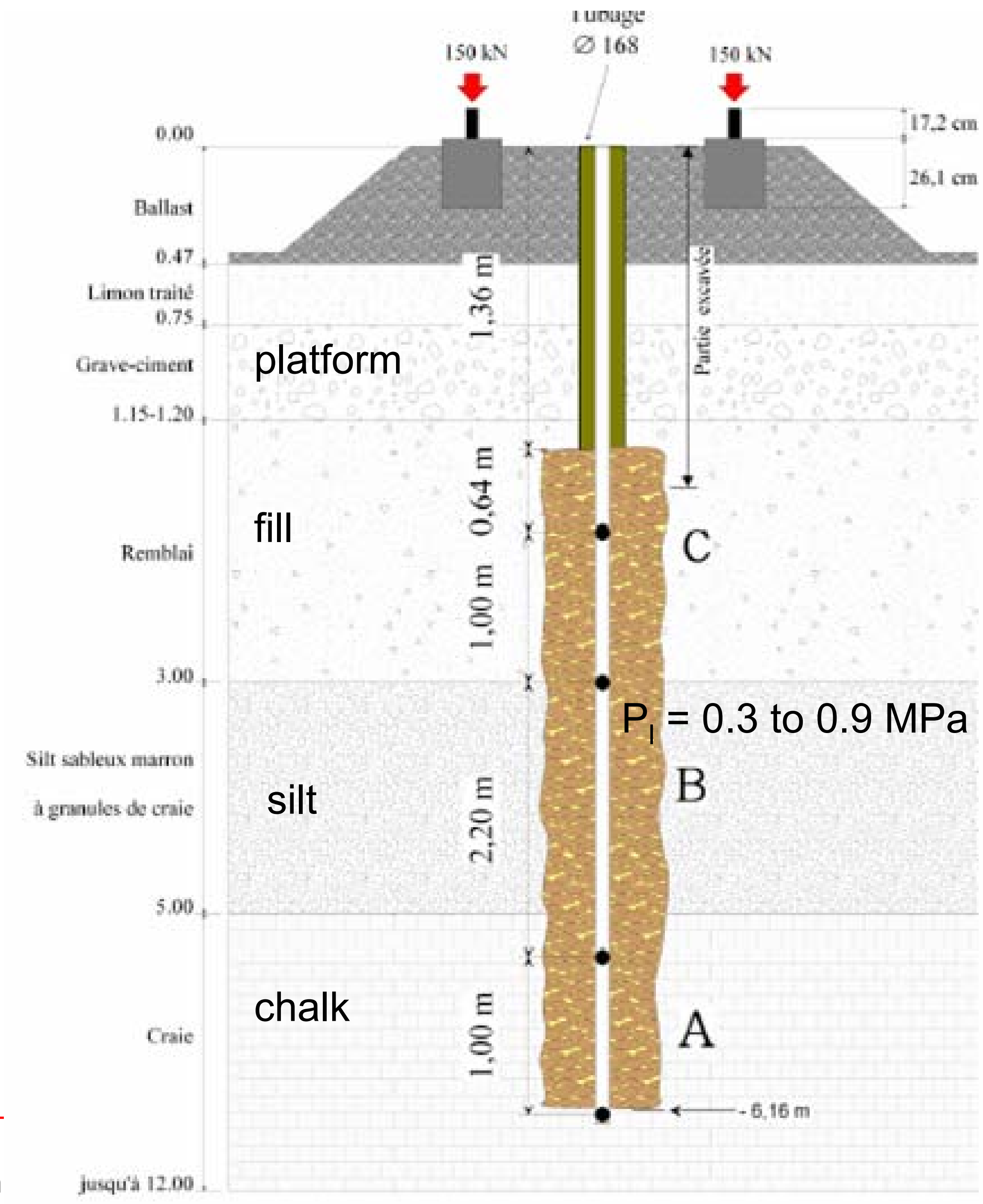
- › Geomix
  - Soil mix panel using a cutter (hydrofraise)
- › SpringSol
  - Soil mix columns using an opening tool
- › Trenchmix
  - Soil mix trenches

SpringSol

- Initialy developped to reinforce the soil under the railway tracks
  - Low headroom due to electric wires
  - Between sleepers
  - Through the ballast, without cementing it !
  - Low trafic disruption
- Improve soil stiffness
- Reduce risk of cavity collapse

The issue

- 400 mm column
- 150 mm ID tube



SpringSol (opening tool)

tool : 150 / 400 mm

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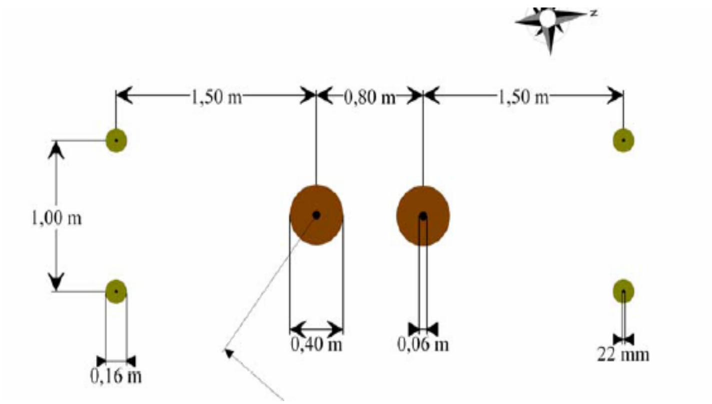
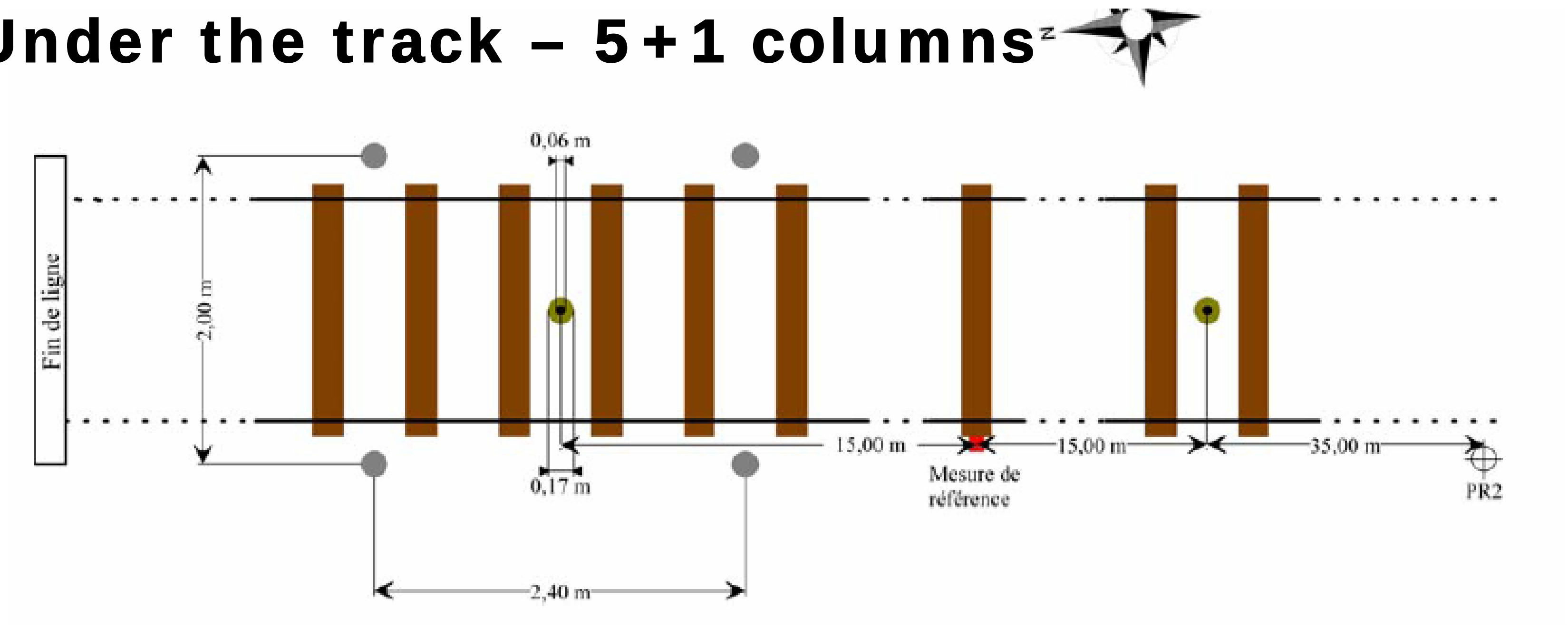
Nearby the track – 8 columns



Under the track – 5+1 columns



Typical material caracteristics
•Rc = 7.5 MPa
•E = 7 GPa

•C/E = 1
•40 l/m
•250 kg/m3

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Column load test

Loaded up to
275 kN
4 mm

Conclusions

- Capacity to work under railway tracks
  - Under electric wires and between sleepers
  - Through the ballast, without cementing it !
  - 400 mm OK
- Simple tool mounted on light rig
- Other applications
  - Improving raft foundation
  - Stabilising polluted soil
- The tool is patented

Soil mixing innovations : Geomix, Springsol and Trenchmix

- Geomix
  - Soil mix panel using a cutter (hydrofraise)
- SpringSol
  - Soil mix columns using an opening tool
- Trenchmix
  - Soil mix trenches

Trenchmix

- What is Trenchmix
- Example of applications : soil improvement
- Control of the works
- Design
- Other applications
  - Cut-off wall
  - Soil stabilisation

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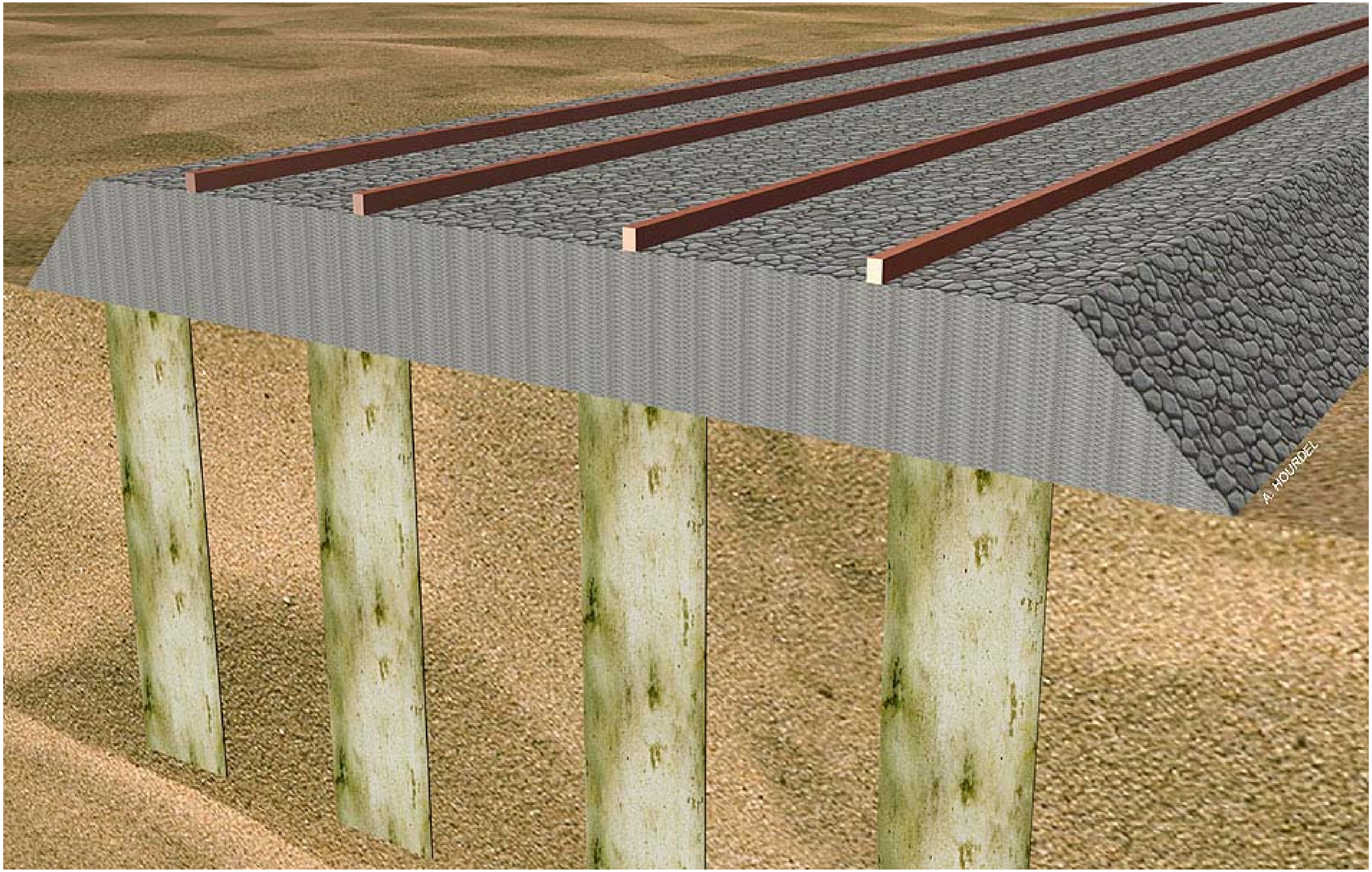
Trenchmix process

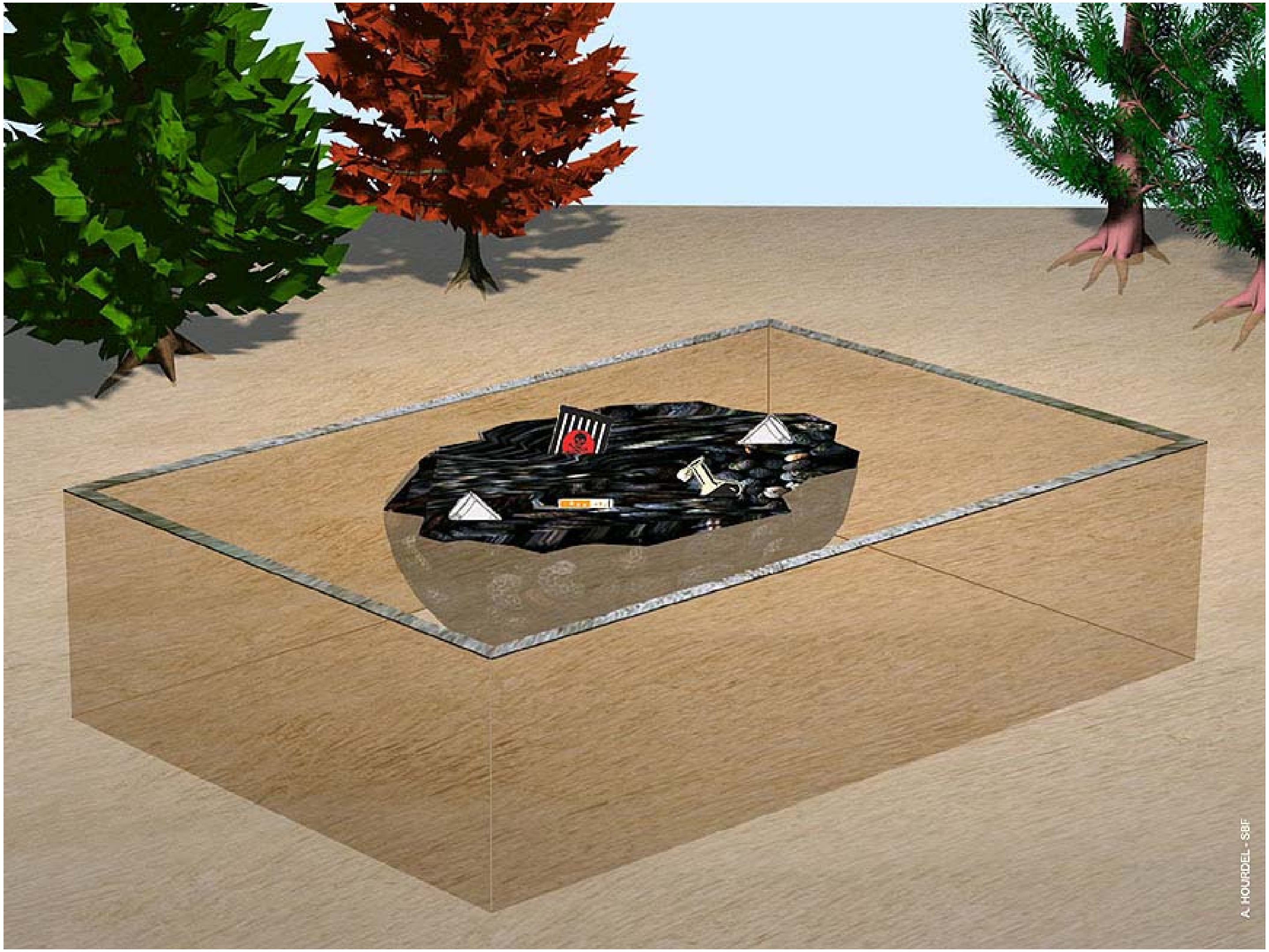
- Use a modified trencher
  - Specific kit developed with Mastenbroek
- Install soil mix trenches
  - Typically 400 mm thick, 4m to 10m deep
- Low spoil
- Wet or dry method

Soil improvement under spread load



Soil improvement under spread load

Cut-off walls



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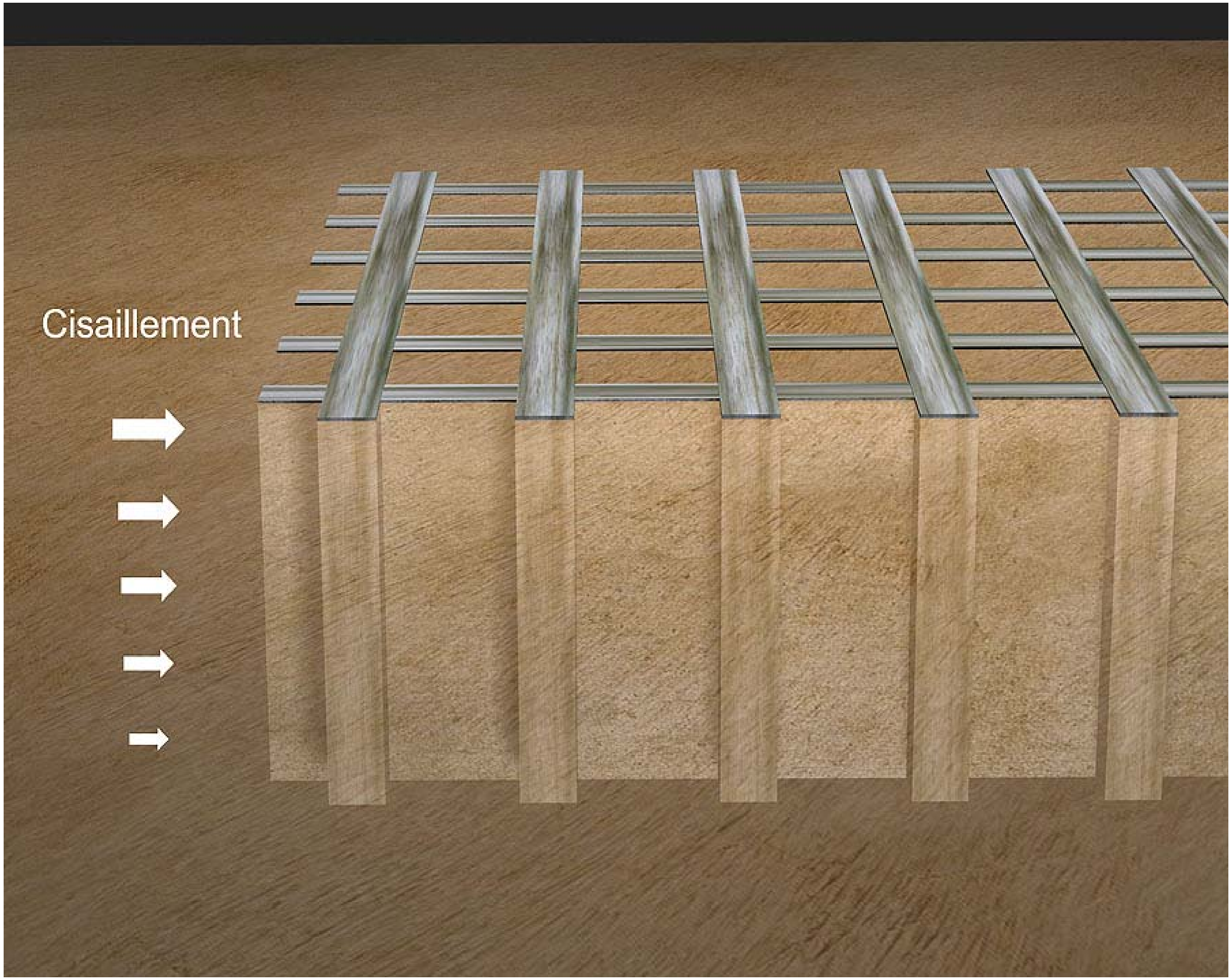
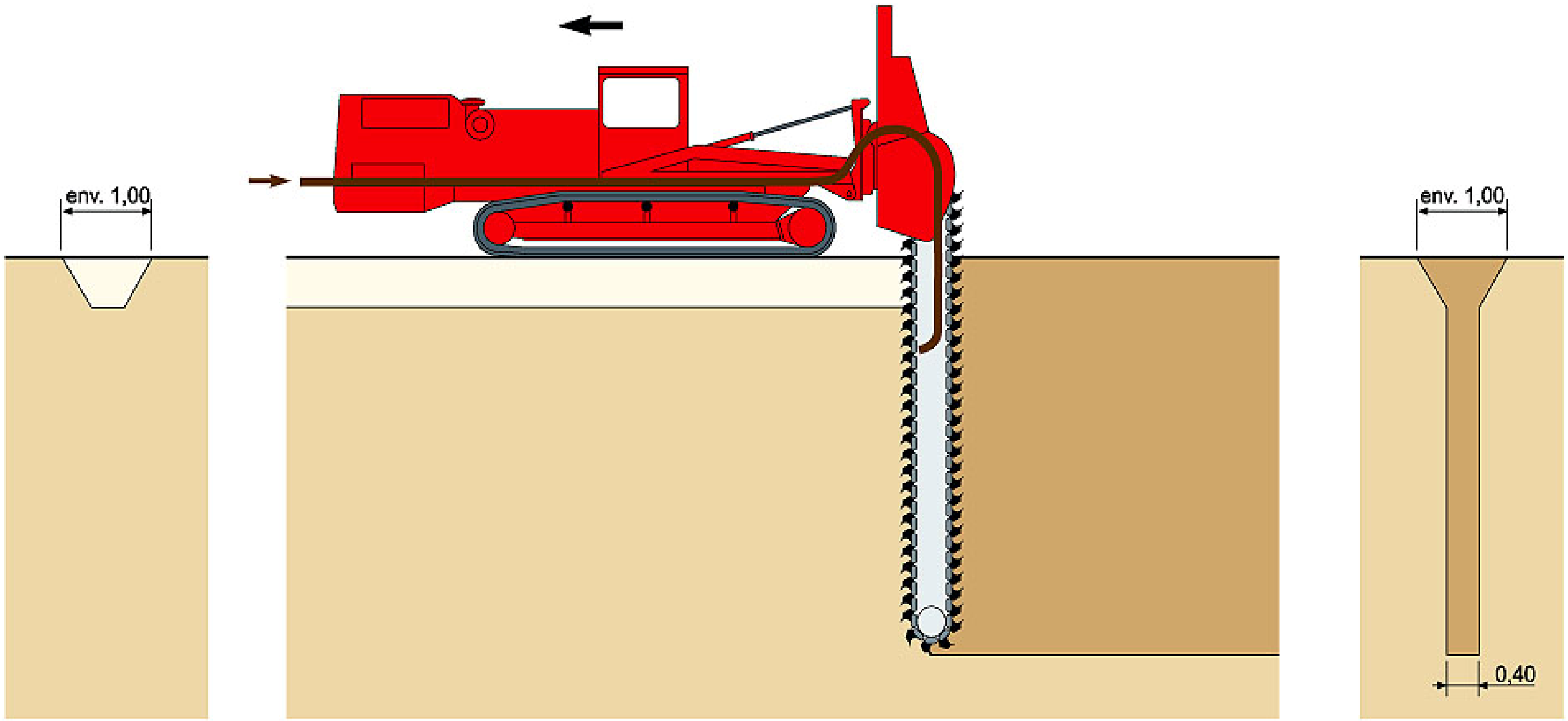
Liquefaction risk



Temporary retaining walls

Trenchmix : wet method



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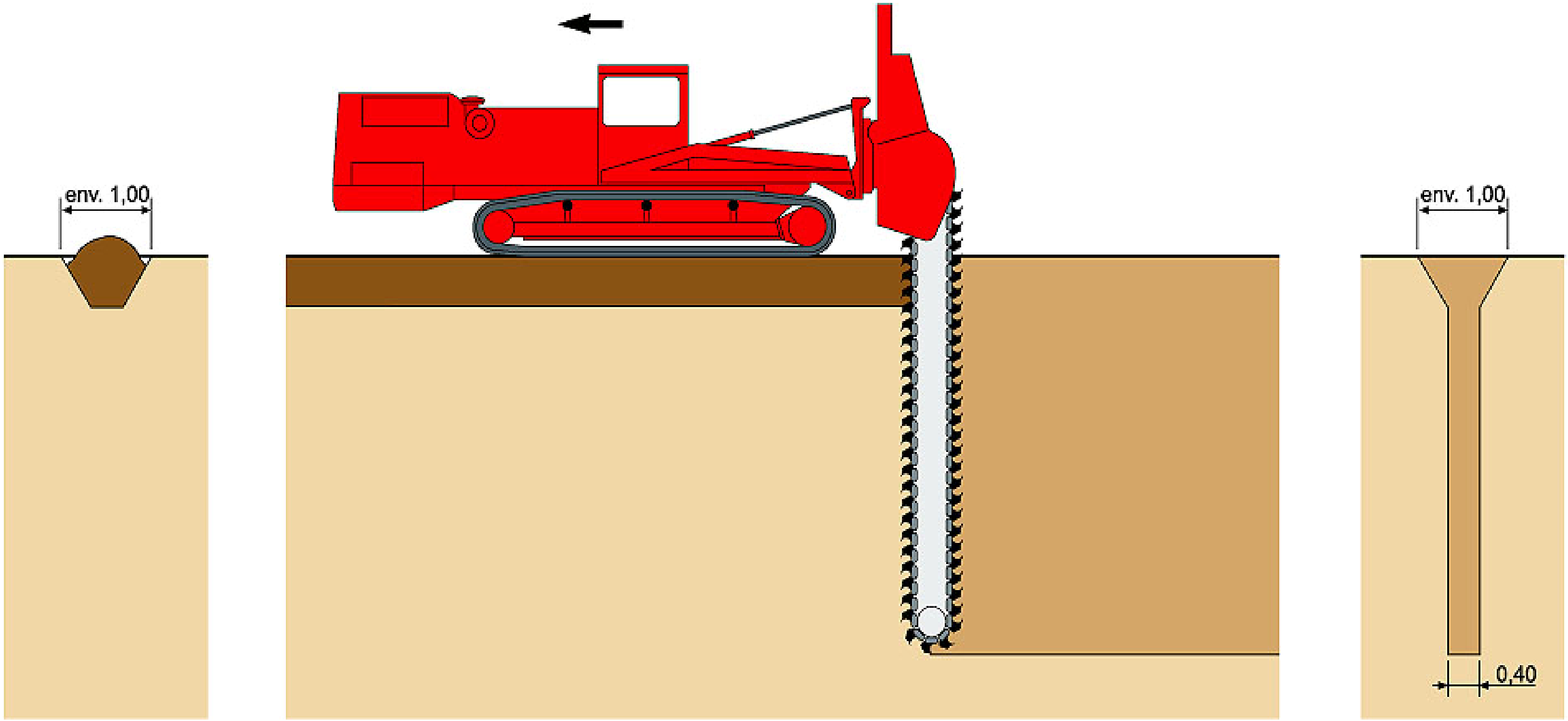
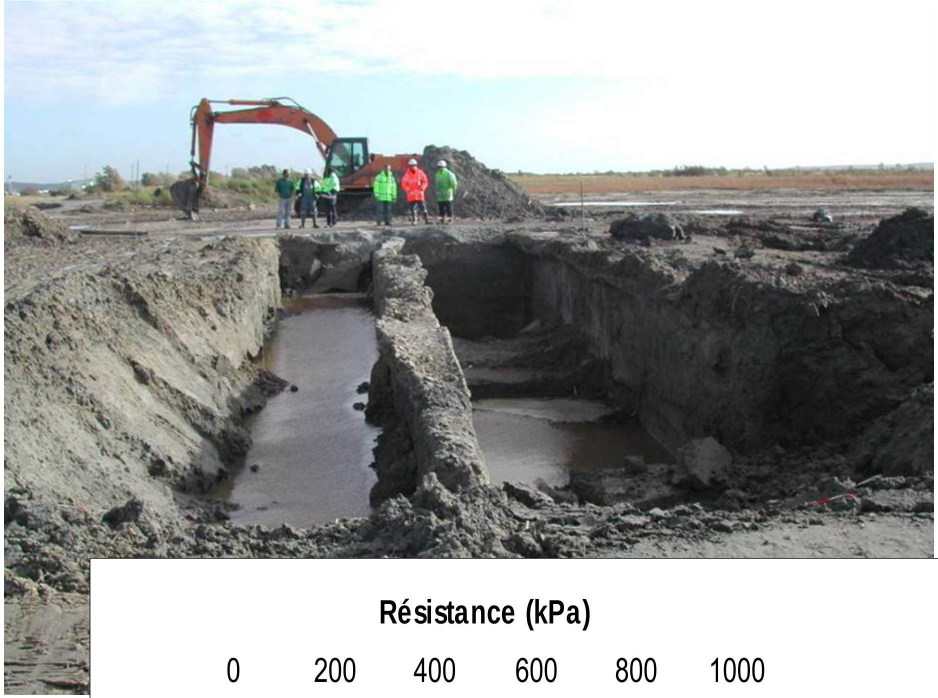
Trenchmix : dry method

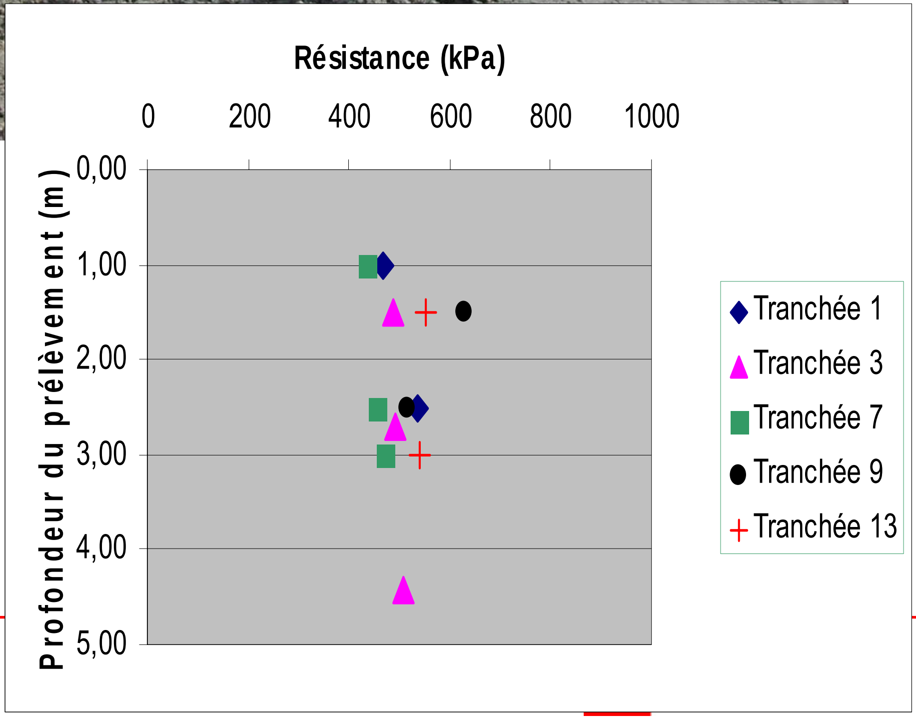


Trenchmix video

- Alfortville : Gaz de France
- Soil improvement under a future gaz dispatching center
- 1000 m of trenches @ 7m depth

First Trenchmix Trial (2005) – Le Havre





Soil improvement for a storage area (grape !)

- Pont de Vaux (2005)
- 4000 lm @ 5,5m depth

Soil Improvement under a road platform

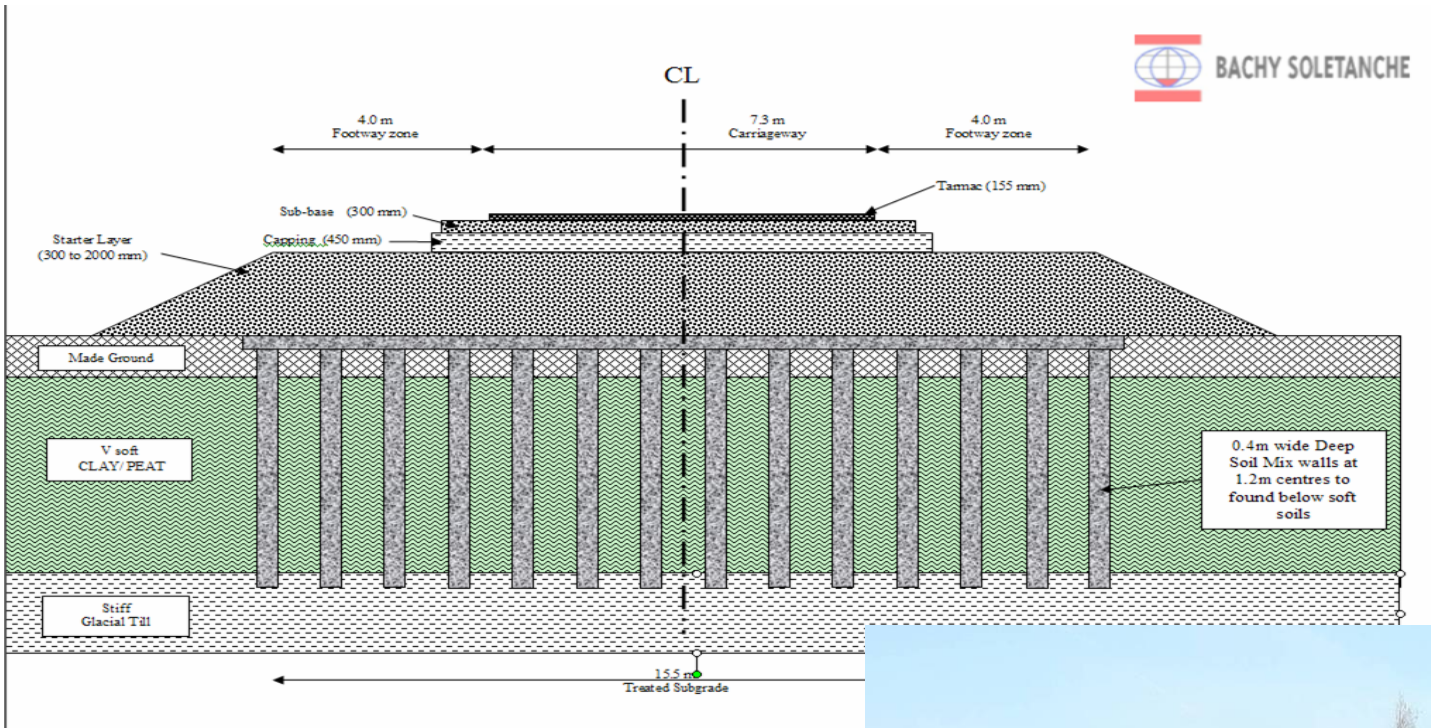


Figure H1 – Proposed Pavement Foundation Solution (Scale 1:100)

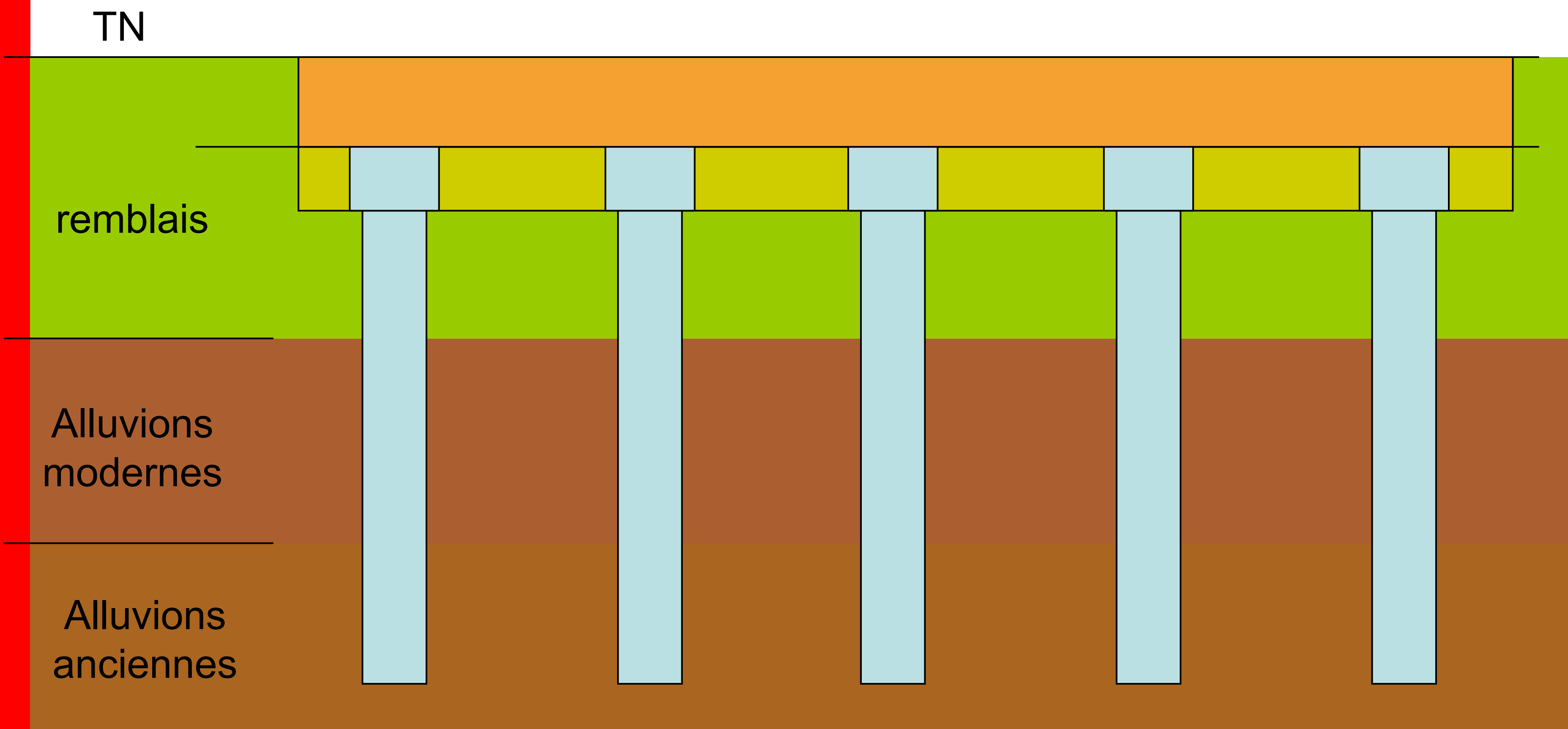
Scotland (2007)
4500 m @ 6m depth

Soil Improvement for a brick factory

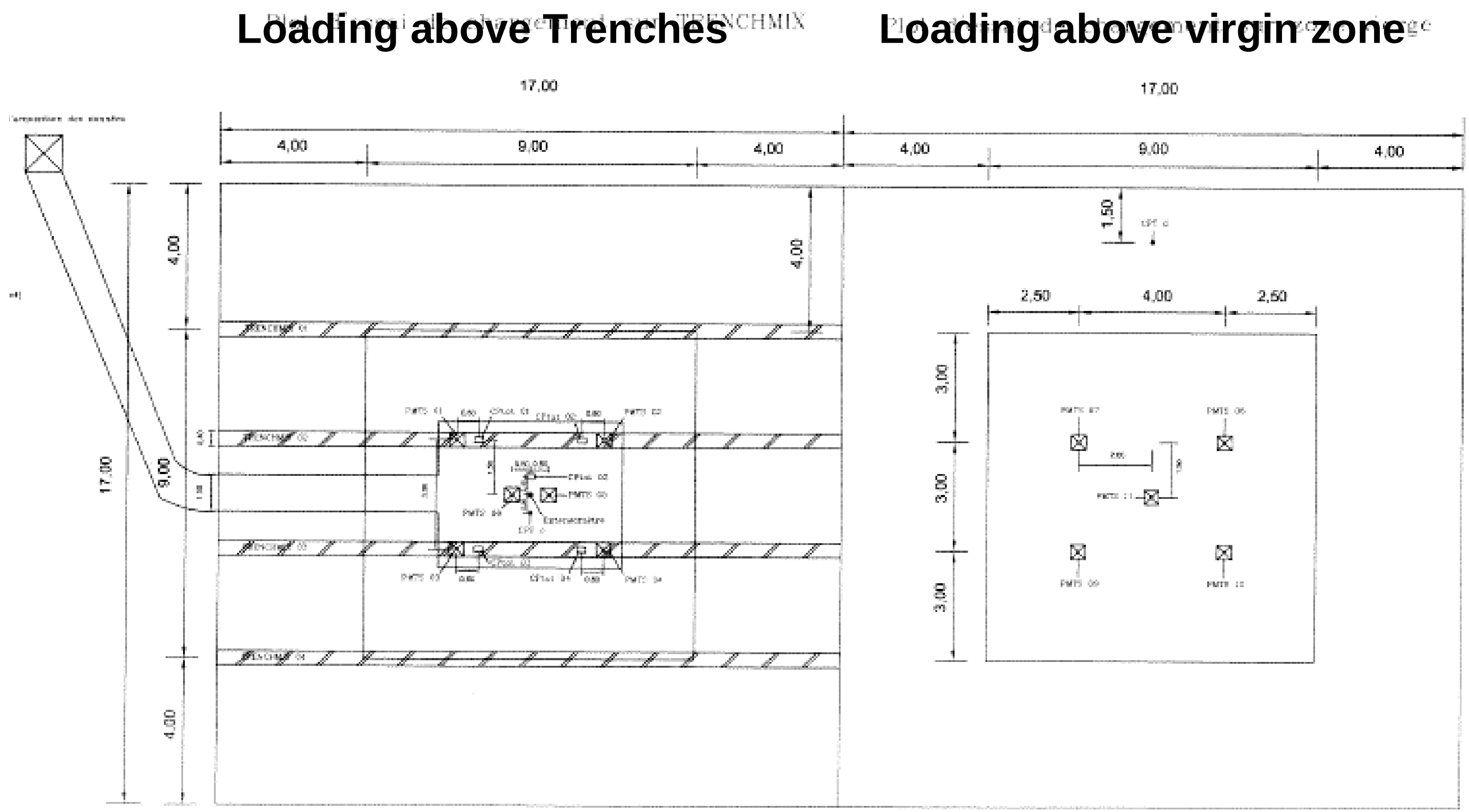
› Montereau (2007)
  - 9400 lm @ 4,5 m depth

Construction phases

1. Terrassement de - 60cm
2. Traitement à la chaux de la plateforme sur 40cm
3. Réalisation des tranchées depuis cette plateforme
4. Remise en place des 60cm mûris à la chaux et traité au ciment en place



Zone test in Montereau



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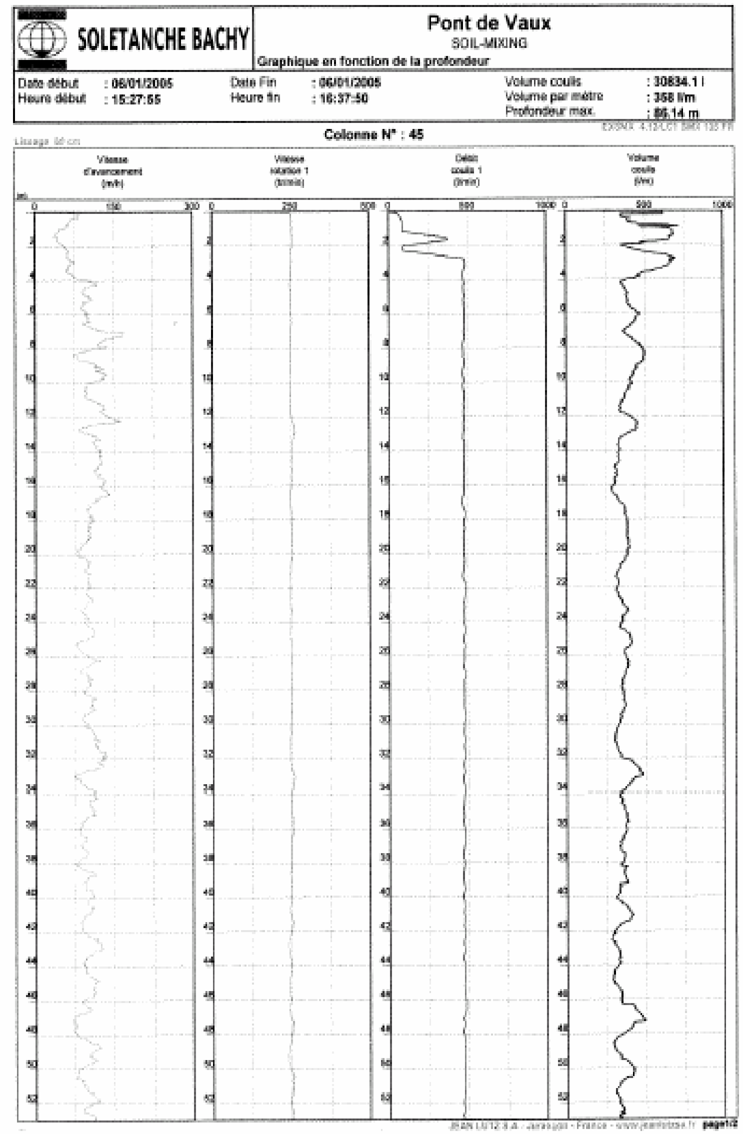
Trenchmix

- What is Trenchmix
- Example of applications : soil improvement
- Control of the works
- Design
- Other applications
  - Cut-off wall
  - Soil stabilisation

Quality control (1/4)



Monitoring :
- advance speed
- water flow
- mixing ratio

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Ensure suitable mixing parameters

Mesure de la vitesse d ’avance de la machine et de la vitesse de translation de la chaîne

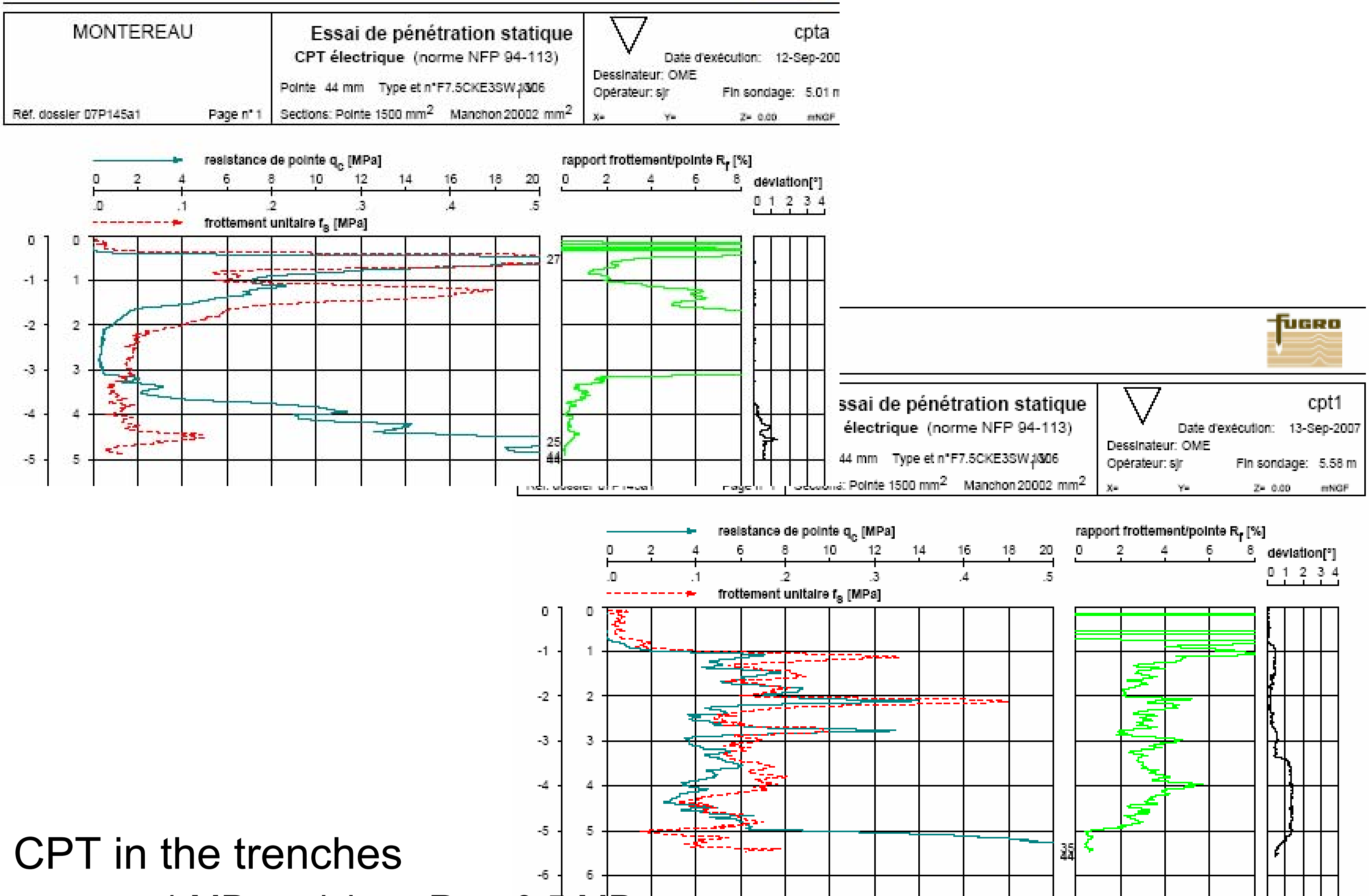
Par analogie avec les colonnes de sol traité, on définit un indice de malaxage correspondant au nombre total de passages de lames de malaxage pendant 1 mètre d ’avance:

$$Im = \text{Nombre de lames par mètre de chaîne} \times \text{Profondeur} \times \frac{\text{Vitesse de translation de la chaîne}}{\text{Vitesse d ’avance de la machine}}$$

Respect d’un indice de malaxage minimum:

	Sables	Limons et argiles
Méthode humide	300	500
Méthode sèche	450	750

Quality control (2/4)

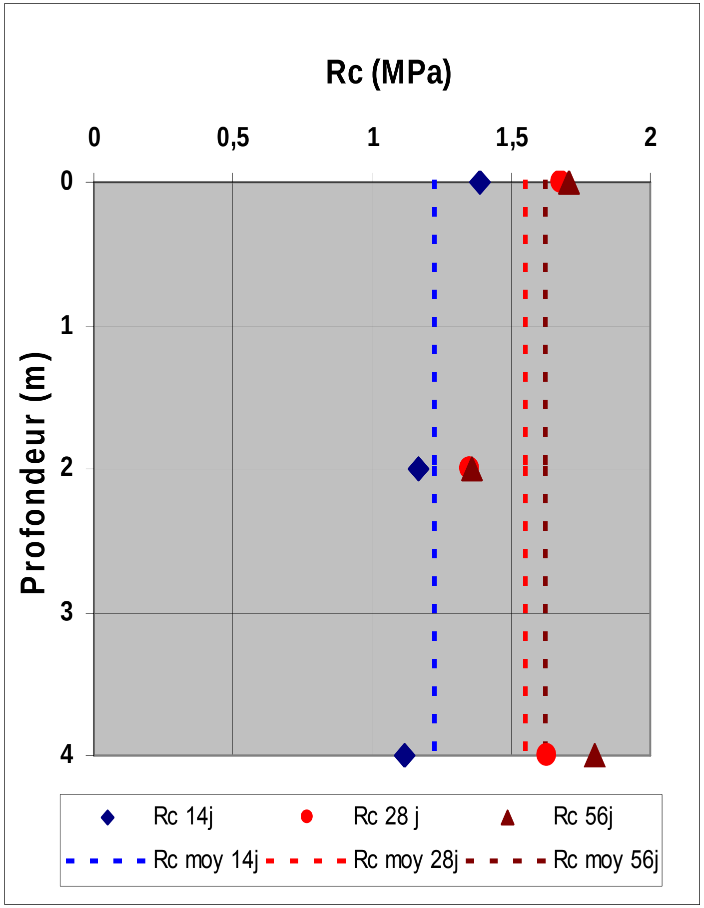


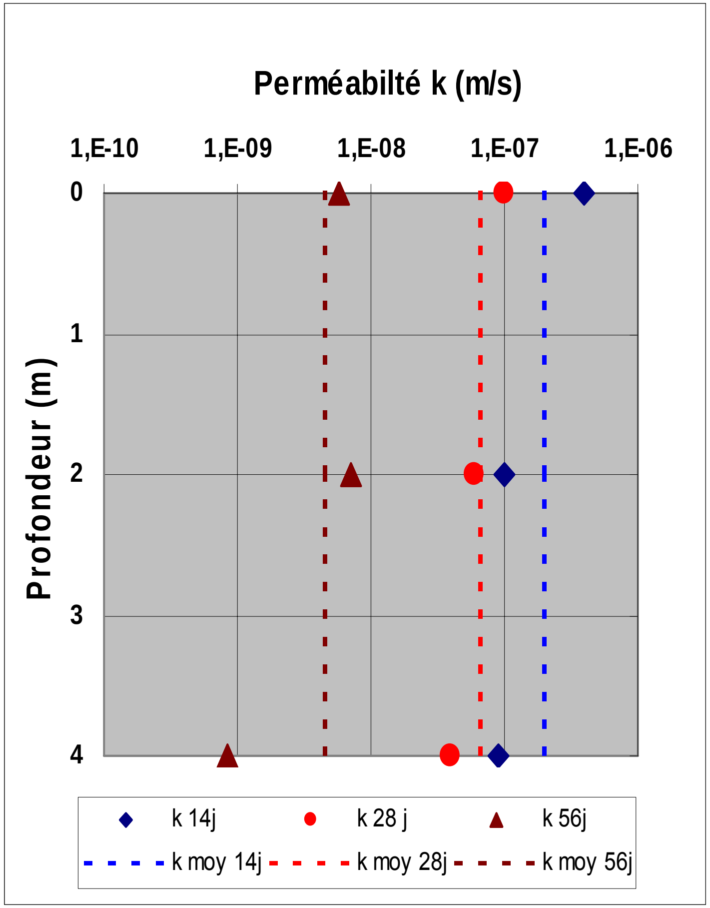
CPT in the trenches

$q_{c\ moy}$ = 4 MPa giving R_c = 0,5 MPa

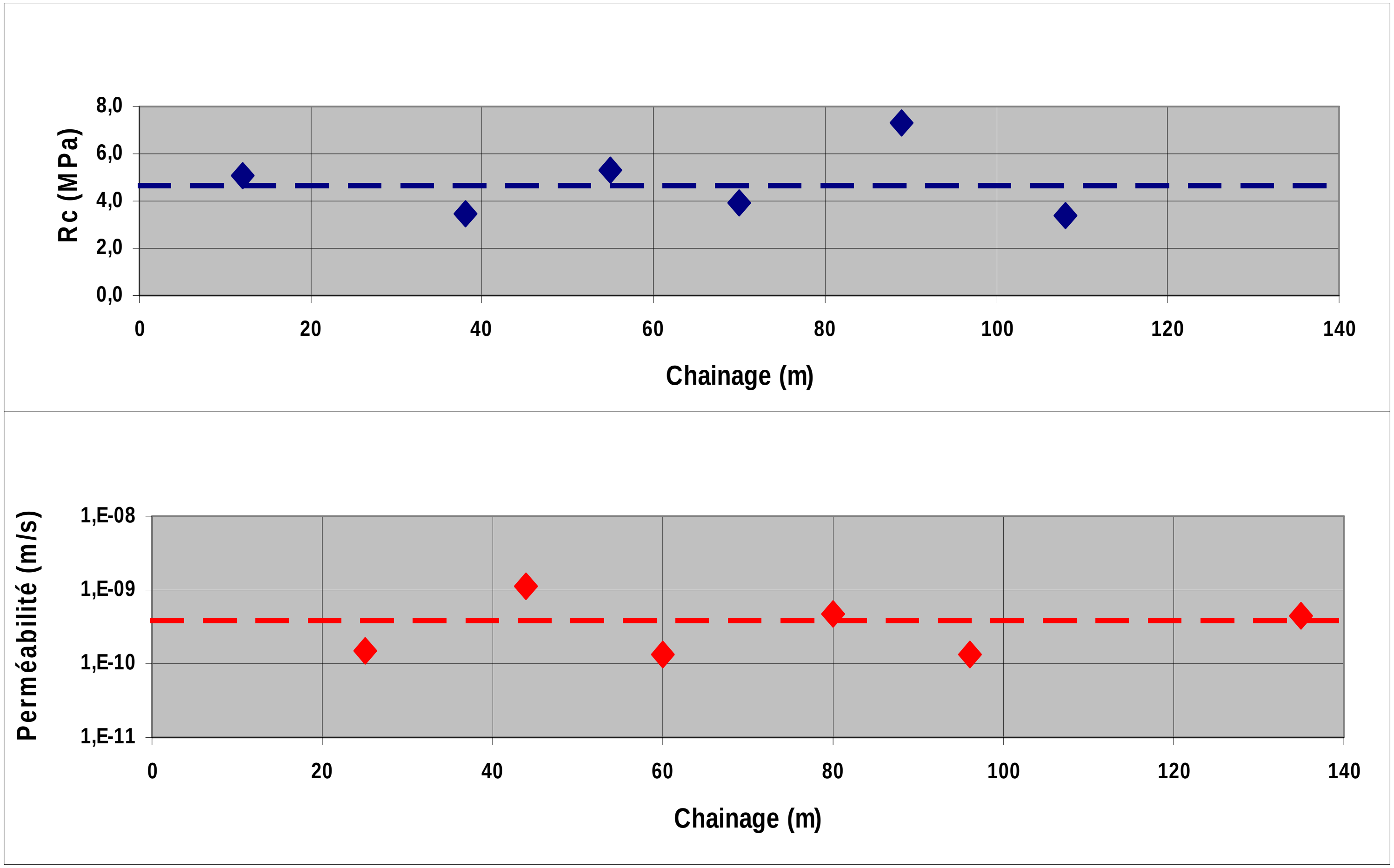
Quality control (3/4)

Testing samples





Quality control (4/4)



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Design principles

2D geometry…

- Pre-design :
  failure hand calculation → ULS checking
- Design :
  Finite elements calculation 2D or 3D
  → pre-design confirmation
  → SLS checking

Design principles

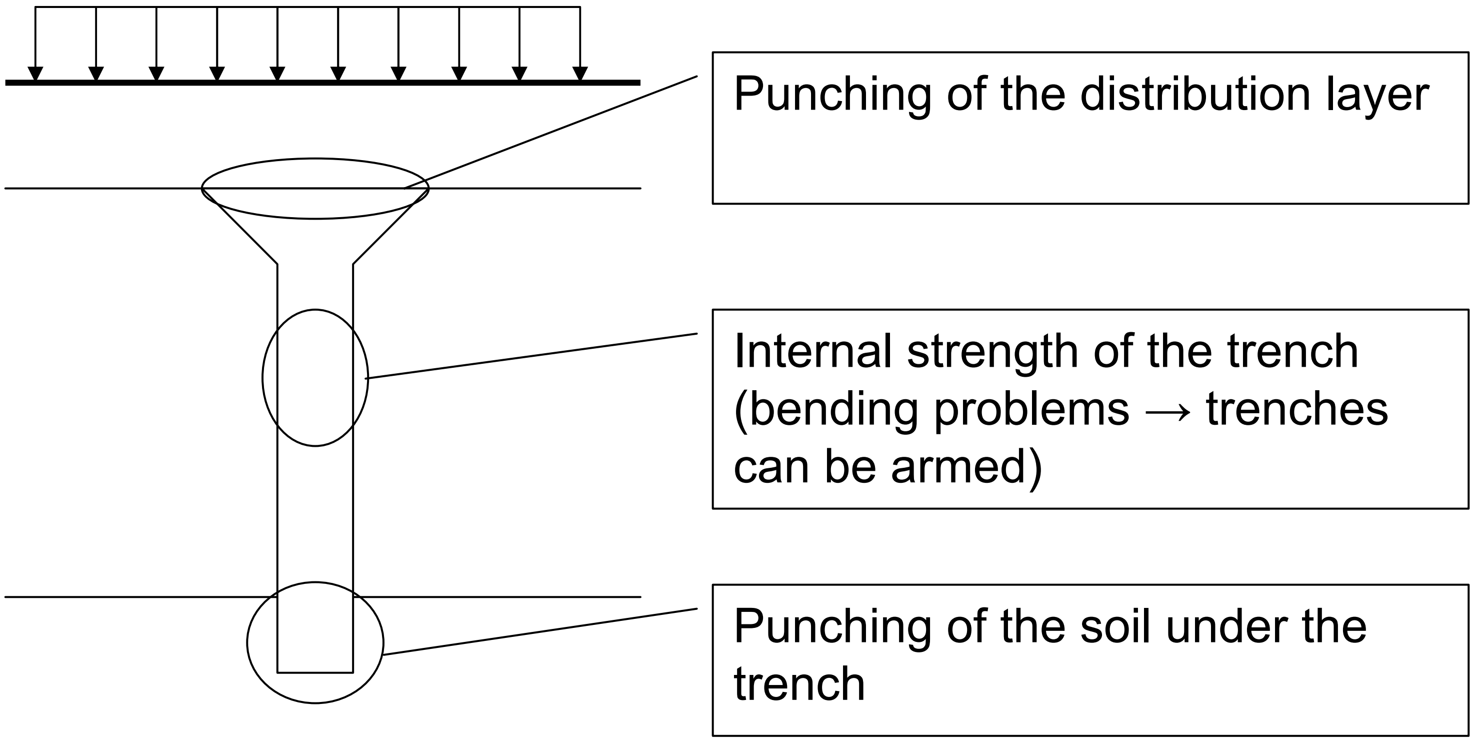
Trench = improved soil : Mohr-Coulomb criteria

→ calculation parameters = Φ, C

→ E, Rc deduced by correlations and controlled on-site (E = 50 MPa typ.)

Design principles

Load transfer and associated failure mechanism considered for preliminary design :



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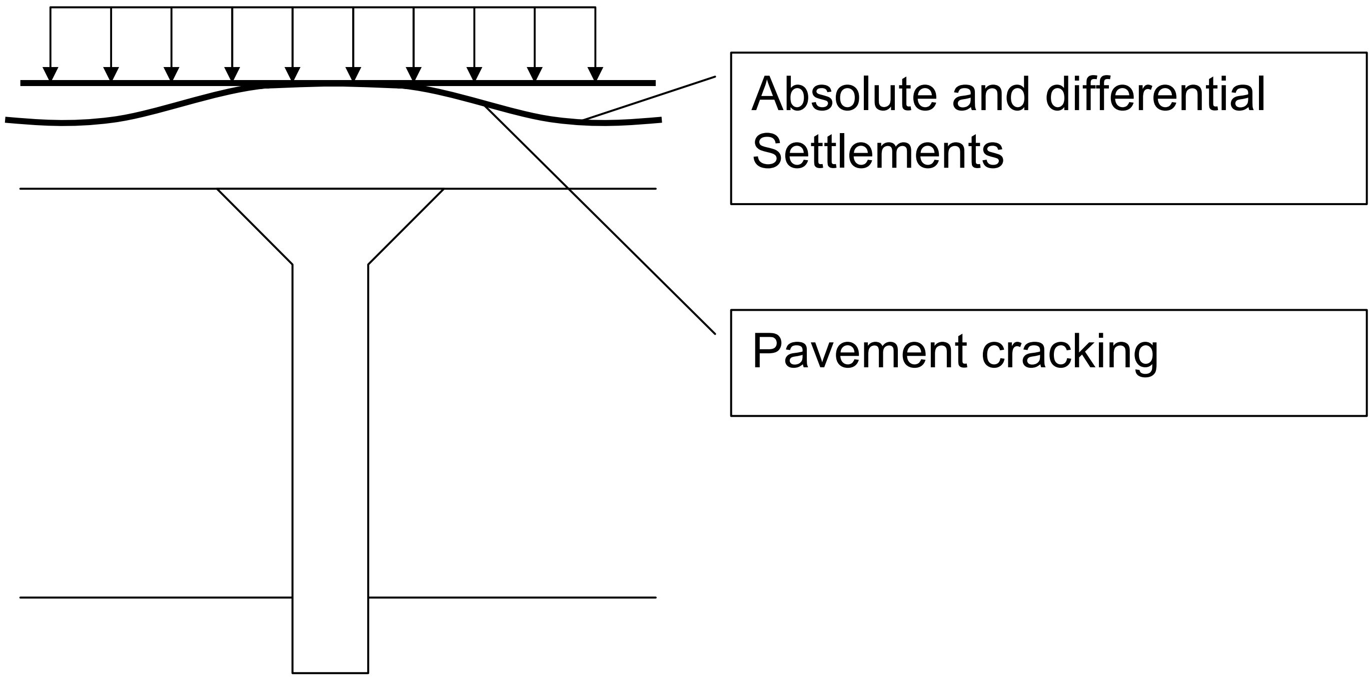
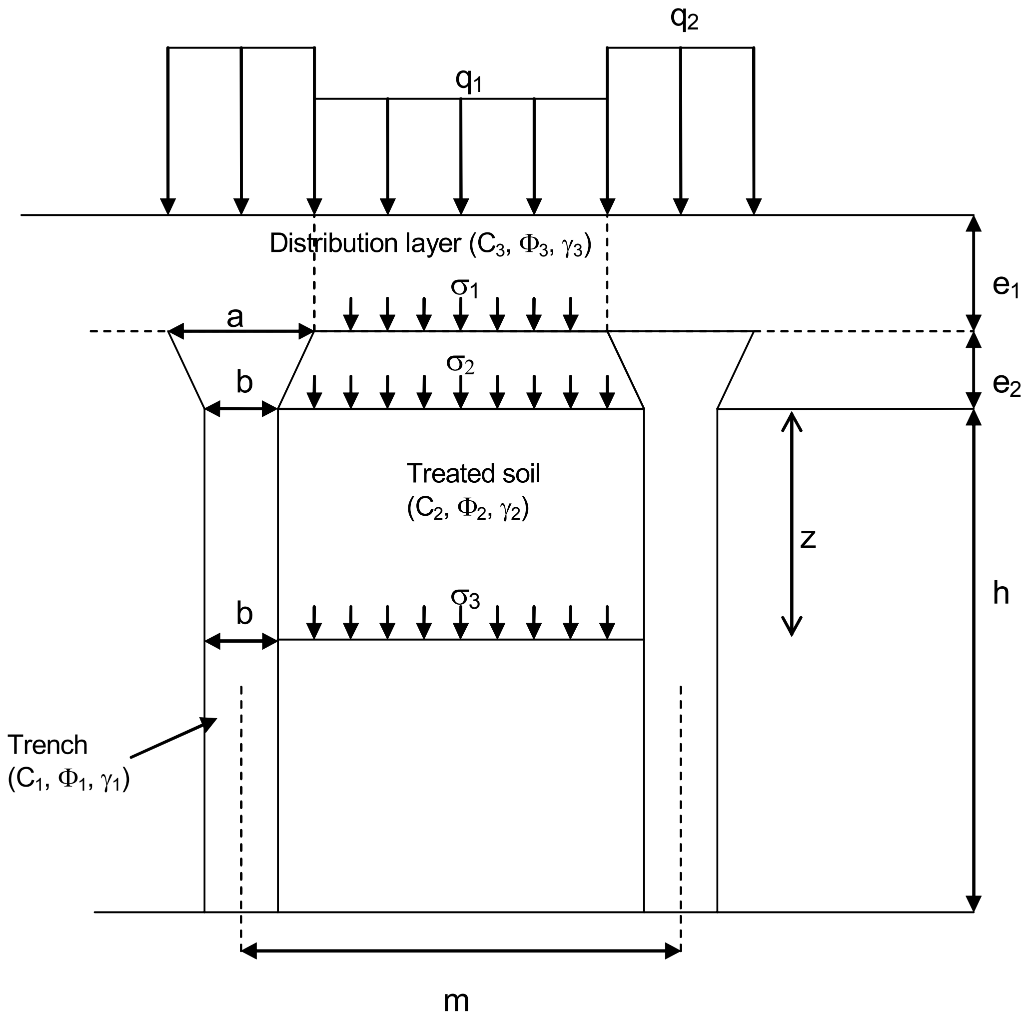
Design principles

Service Limit States :



Pre-design (loading estimation)

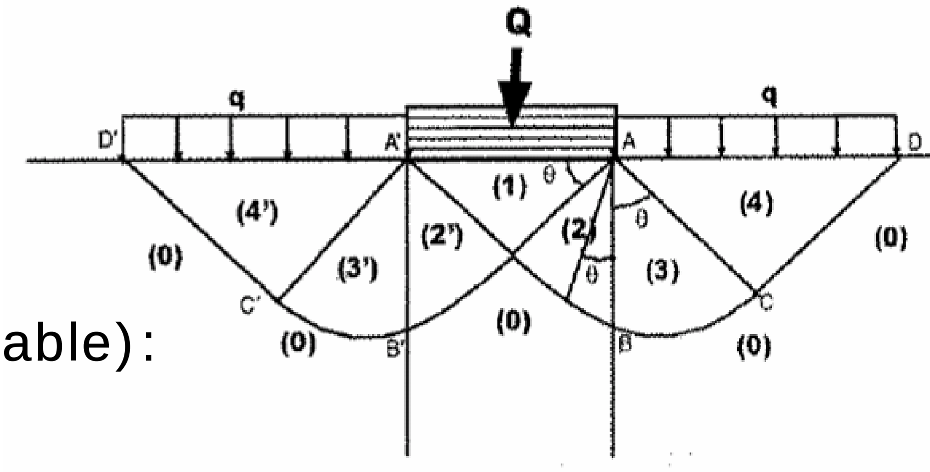
Terzaghi's method:



$$\sigma_{sol}(H) = \frac{\gamma \cdot B - 2 \cdot C}{2 \cdot K \cdot \tan(\Phi)} \cdot \left(1 - e^{-2 \cdot K \cdot \tan(\Phi) \cdot H / B}\right) + \sigma_0 \cdot e^{-2 \cdot K \cdot \tan(\Phi) \cdot H / B}$$

Pre-design (internal strength checking)

Stresses : σ_{soil} + σ_{trench} + Material Model + F (safety factor) → Φ, C of the trench



Bouassida's method

on the top (based on Prandtl's Failure – analytic formulas available):

Mohr-Coulomb criteria:

$$\sigma_1 = \sigma_3 \cdot \frac{1+\sin(\Phi)}{1-\sin(\Phi)} + 2 \cdot C \cdot \tan\left(\frac{\pi}{4} + \frac{\Phi}{2}\right)$$

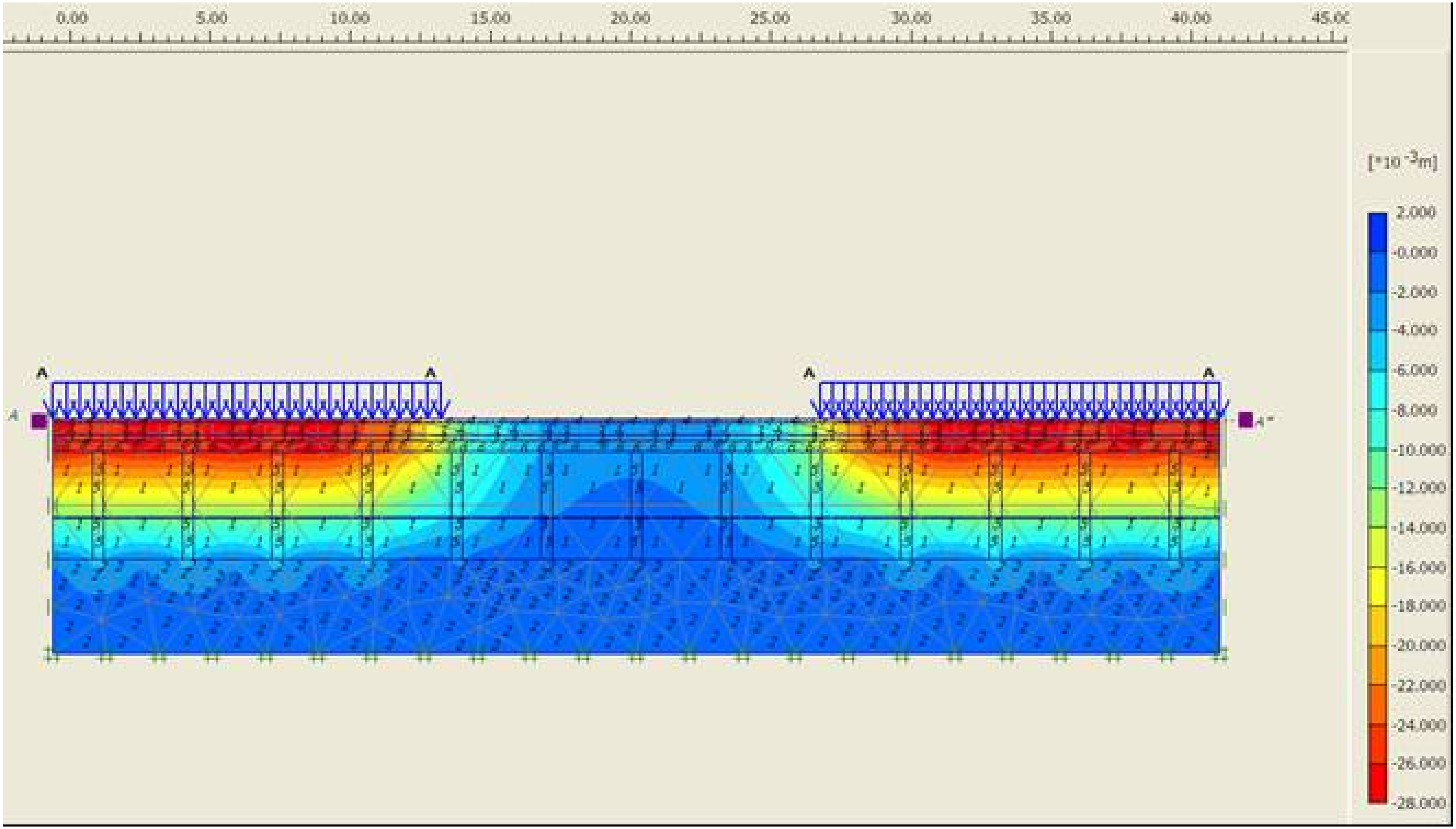
Design

Finite element calculcation :

- 2D in most of cases
- 3D in some cases

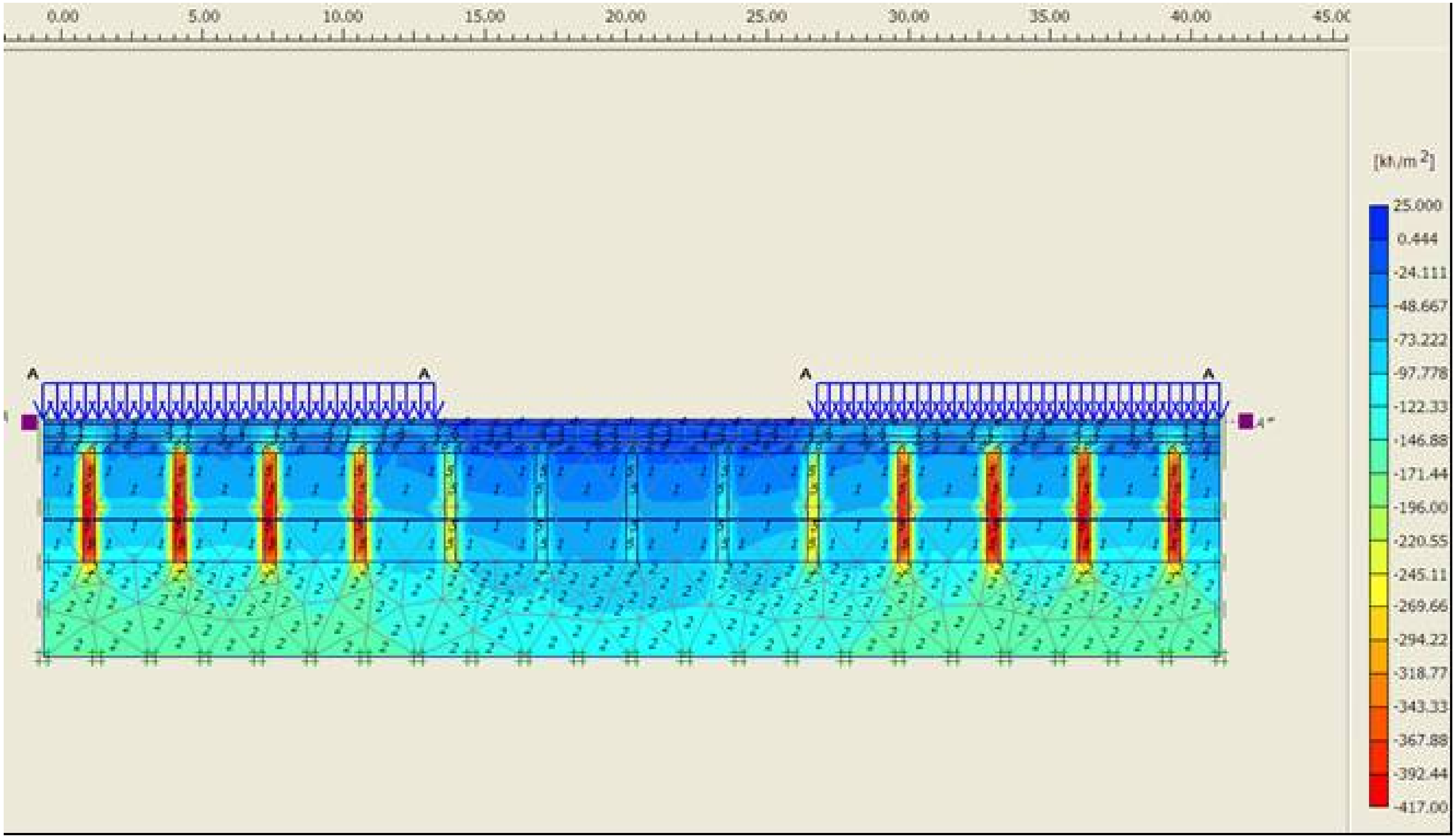
Geometry, loading

Settlements



Check absolute and relative settlement OK

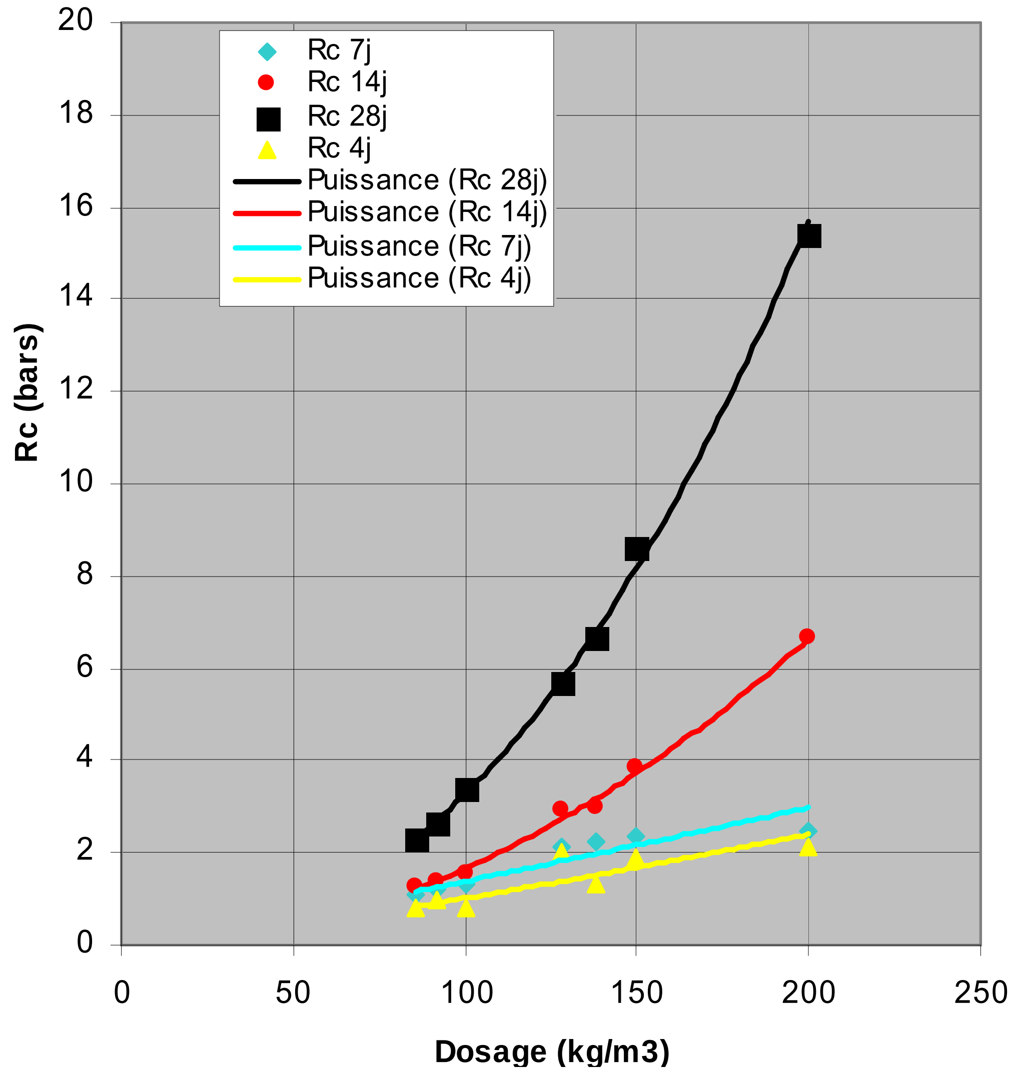
Stresses in the trenches



Give minimum Rc on site with a safety factor SF = 1.5 = 1.35 1.1
Check punching failure at the trench toe
Check pavement stresses

SOLETANCHE BACHY

Design

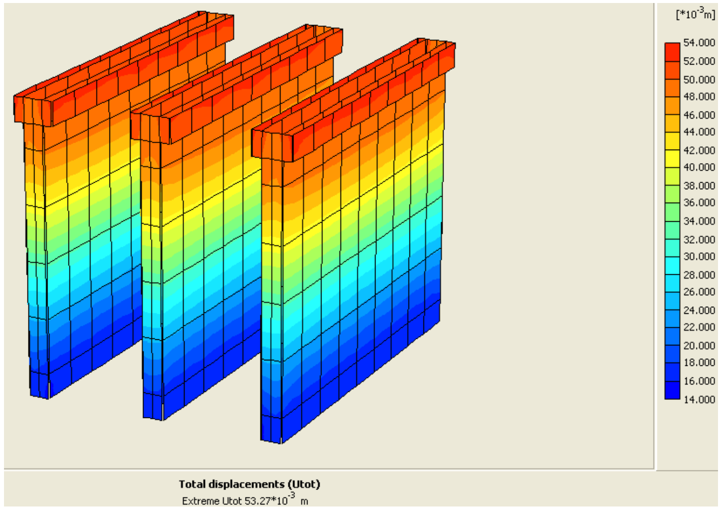


$$R_c = 2 \cdot C \cdot \tan\left(\frac{\pi}{4} + \frac{\Phi}{2}\right)$$

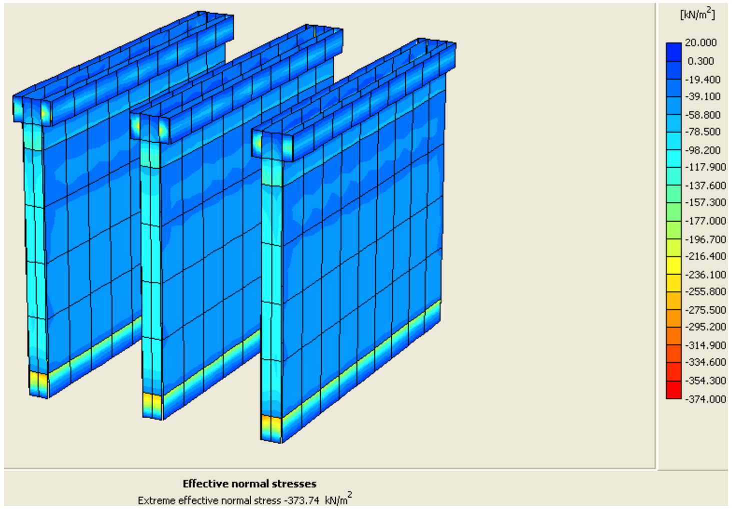
$$E\#150 \cdot R_c$$

SOLETANCHE BACHY

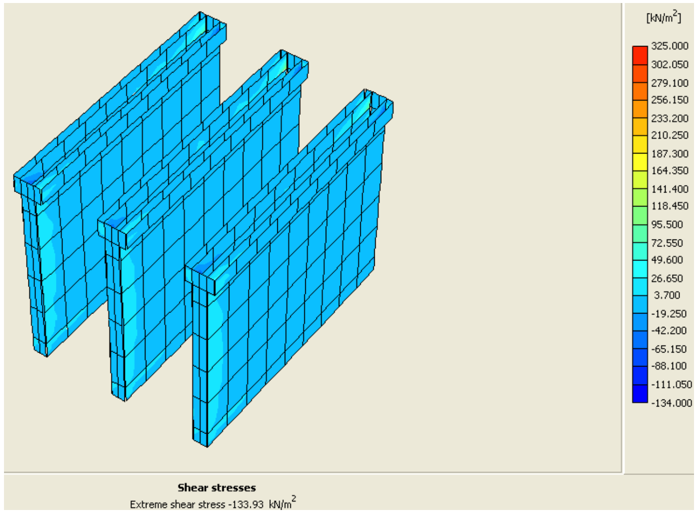
3D calculation example



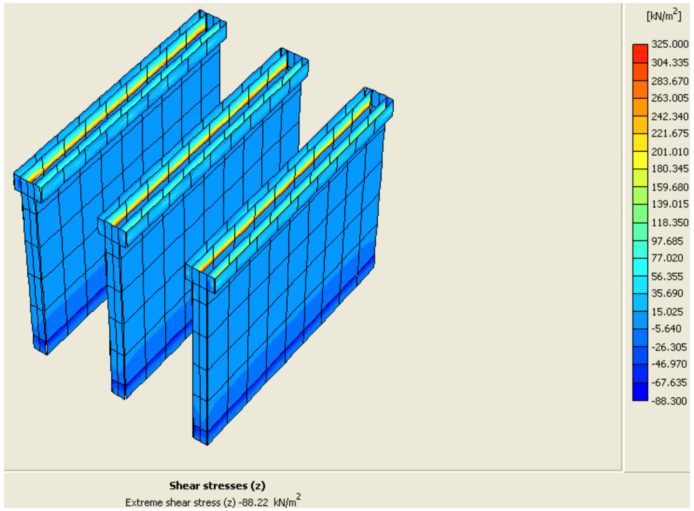
Total displacements (Utot)
Extreme Utot $53.27*10^{-3}$ m



Effective normal stresses
Extreme effective normal stress -373.74 kN/m^2



Shear stresses
Extreme shear stress -133.93 kN/m^2



Shear stresses (z)
Extreme shear stress (z) -88.22 kN/m^2

Trenchmix

- What is Trenchmix
- Example of applications : soil improvement
- Design process
- Control of the works
- Other applications
  - Cut-off wall
  - Soil stabilisation

Bletchley cut-off wall

- First Trenchmix cut-off wall
- Wet method (with grout)

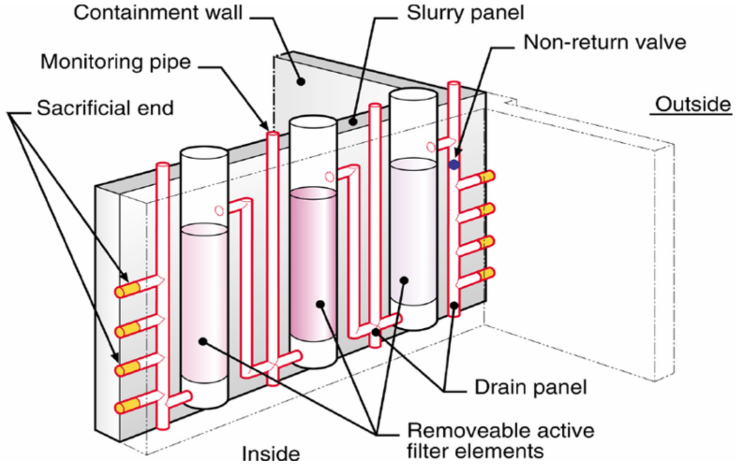
Cut-off around a waste

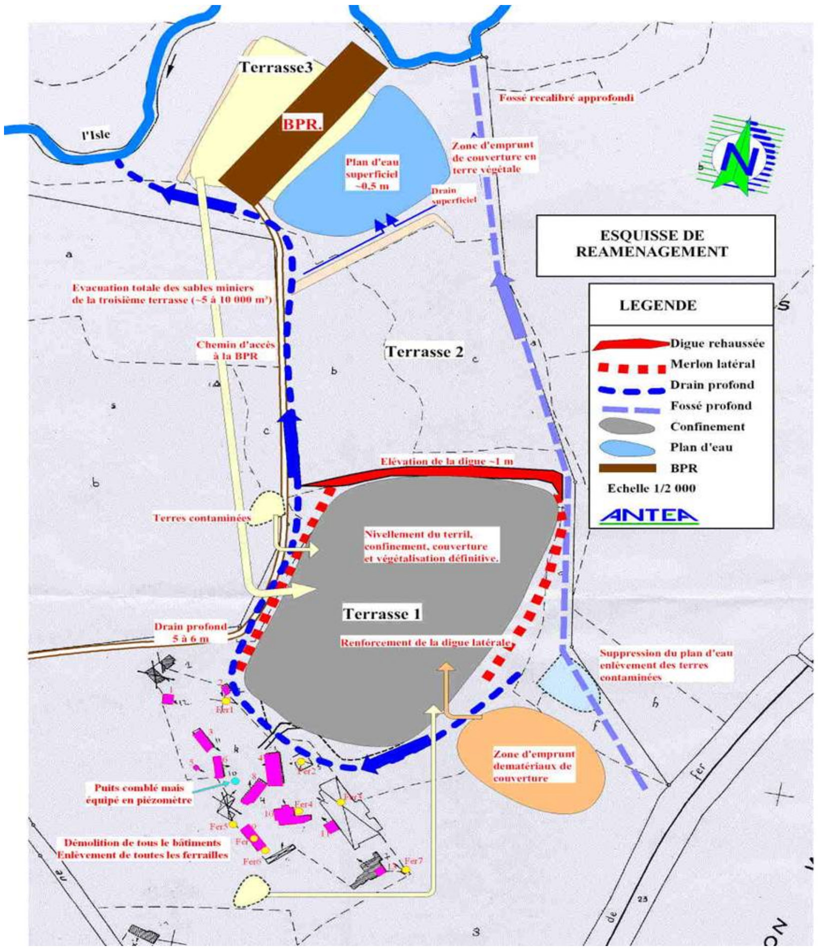
Legge Cap Ferret (F)
Length: 460 m
Depth 10m

Cut-off + permeable reactive barrier

Le Cheni Gold Mine (F):

- Design and long term control
- Watertight mixed wall L:180m D:7m
- Draining trench L: 180m D: 4m
- Filtering gate





Other examples

Viviez –Decazeville

-Trenchmix :
180 m x 7 m
-Draining trench :
180 m x 4 m

Sète- Raffinerie BP

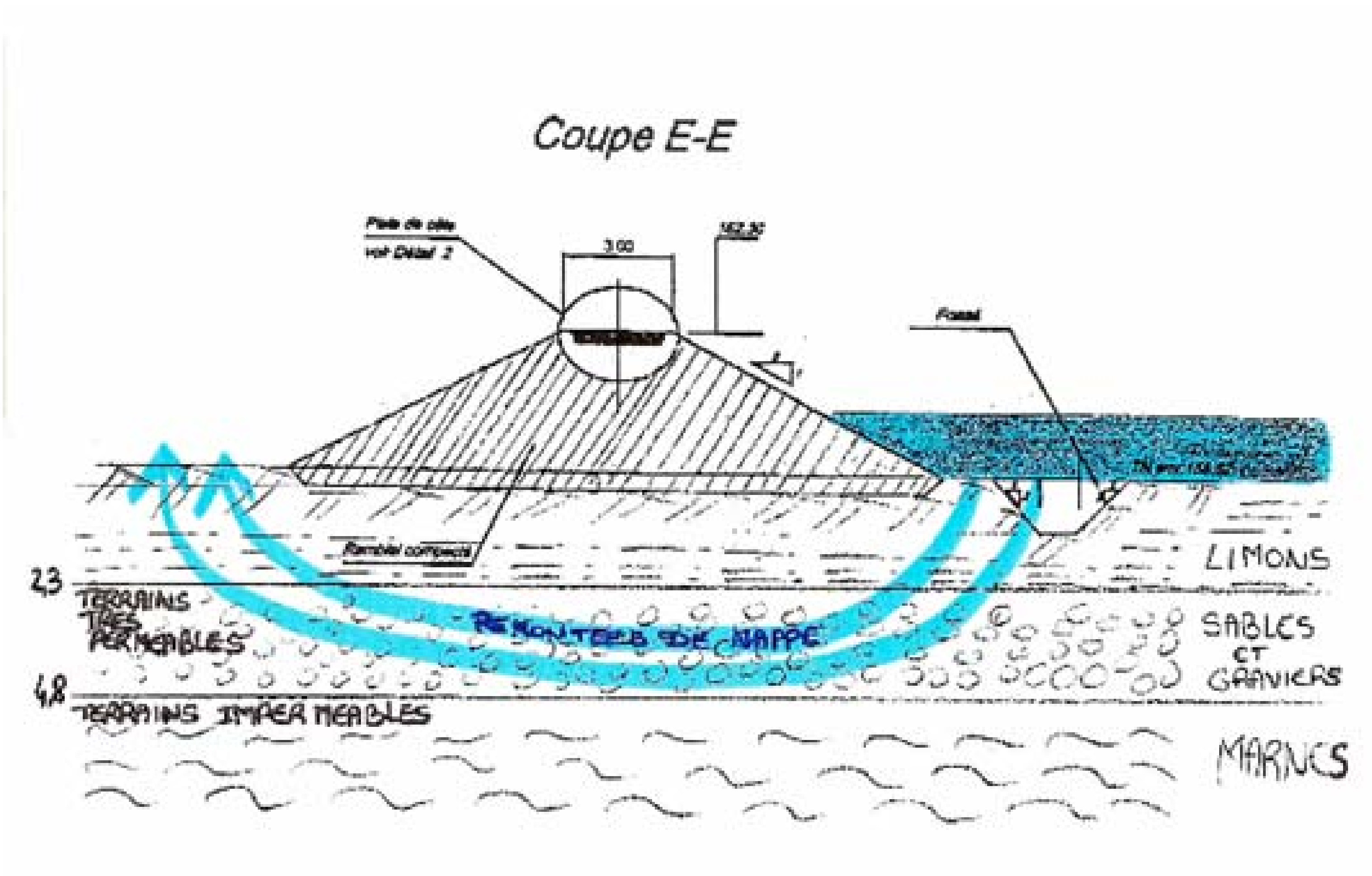
-Trenchmix :

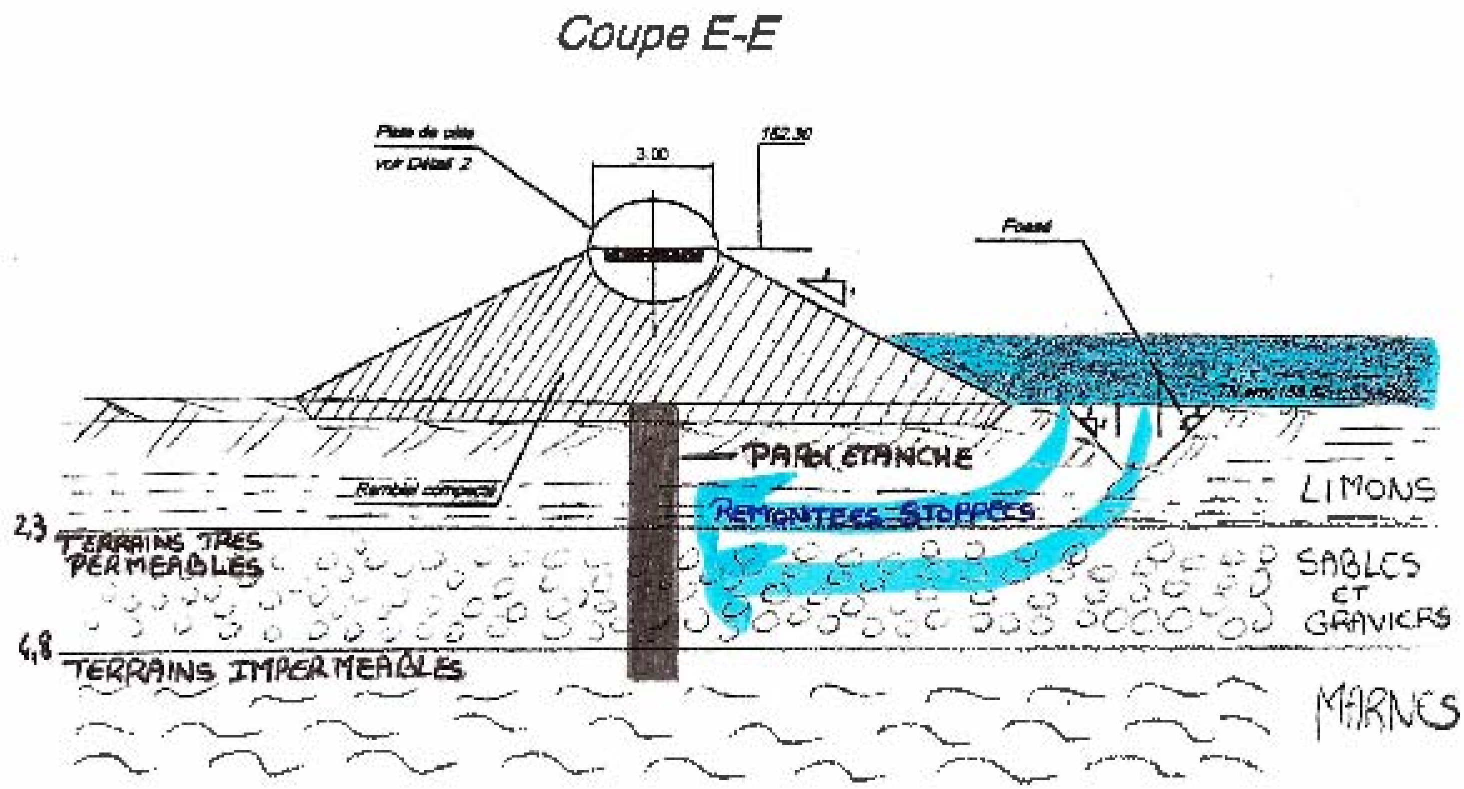
200 m x 6 m

Trenchmix in all its forms : A ongoing Story

Hauconcourt (F) :

Watertight trench under a floodprotecting dyke   L: 3500m   D: 6m


Coupe E-E
3.00
Remblai compacté
LIMONS
2,3
TERRAINS TRES PERMEABLES
REMONTEES DE NAPPE
SABLES ET GRAVIERS
4,8
TERRAINS IMPERMEABLES
MARNCS



Coupe E-E
3.00
PAROI ETANCHE
Remblai compacté
REMONTEES STOPPEES
LIMONS
2,3
TERRAINS TRES PERMEABLES
SABLES ET GRAVIERS
4,8
TERRAINS IMPERMEABLES
MARNES

Hauconcourt cut-off wall

Linéaire : 3 455 ml

Profondeur : 5,7 m moyen

Surface totale: 19 850 m^2

Incorporation de ciment : 120 kg / m^3
Débit d'eau ajusté pour : slump de 19-20

Durée du chantier : 5 semaines (+mob/demob)

Cadence instantanée : 130 m^2/h

SMiRT (Soil Mix Remediation Technology)

- R&D+I project funded by the Technology Strategy Board (DTI) 2007-2009

- £1.24M project led by Bachy Soletanche
  - academic institution : Cambridge University
  - engineering consultancies (Arcadis Geraghty & Miller, Arup, Merebrook Science & Environment),
  - trade associations (British Urban Regeneration Association, British Cement Association, UK Quality Ash Association)
  - materials Suppliers (Amcol Minerals Europe, Richard Baker Harrison, Kentish Minerals and Civil & Marine Holdings).

- integrated remediation and ground improvement, with simultaneous delivery of wet and dry additives, and with advanced quality assurance system
  - laboratory treatability studies (various binders and additives + soils and contaminants)
  - Extensive field trials + monitoring

Conclusions

- New tools for new applications :
  - Géomix (Cutter Soil Mixing)
  - SpringSol (opening tool)
  - Trenchmix (trenches)
- Advantages
  - Low spoil
  - Low resource consumption
- Need better knowledge of soil mix behavior (strength, modulus) depending on Soil type and mixing tool

KELLER

Deep Dry Soil Mixing

Design Applications

&

Case Histories

Graham Thompson (Technical Manager)

Keller Ground Engineering - Geotechnical Division

DEEP DRY SOIL MIXING (DDSM)

- Introduction
- The Process
- Aspects of Design
- Quality Assurance & Quality Control
- Applications
- UK Case Histories

DEEP DRY SOIL MIXING (DDSM)

- DDSM is an in-situ soil treatment whereby soft soils are mechanically mixed with a ‘dry’ binder material.
- Binder consists of cement, lime, gypsum, blast furnace slag or PFA.
- Typically used in alluvial soils (soft silts, clays, organic clays and peat).
- Column diameters typically between 0.6 to 1.0 m

THE DDSM COLUMN INSTALLATION PROCCESS

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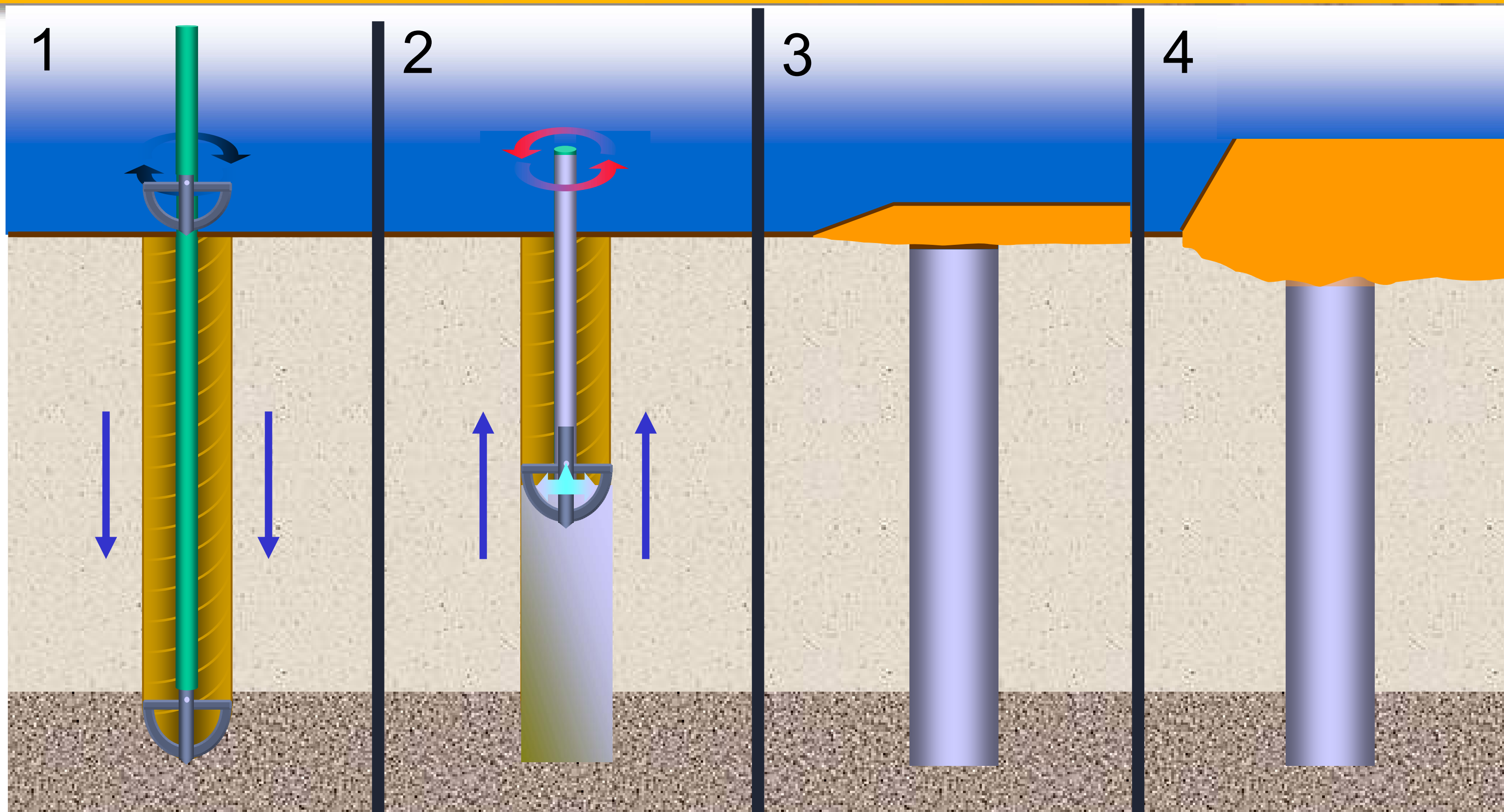


1. Rotating mixing tool penetrates to desired depth of treatment
2. Binder is injected as mixing tool is extracted with reversed rotation
3. Columns achieve initial set and working platform can be placed
4. Embankment fill & temporary surcharge placed - followed by removal of surcharge

VARIOUS MIXING TOOLS EMPLOYED IN DDSM

600mm STD-Tool

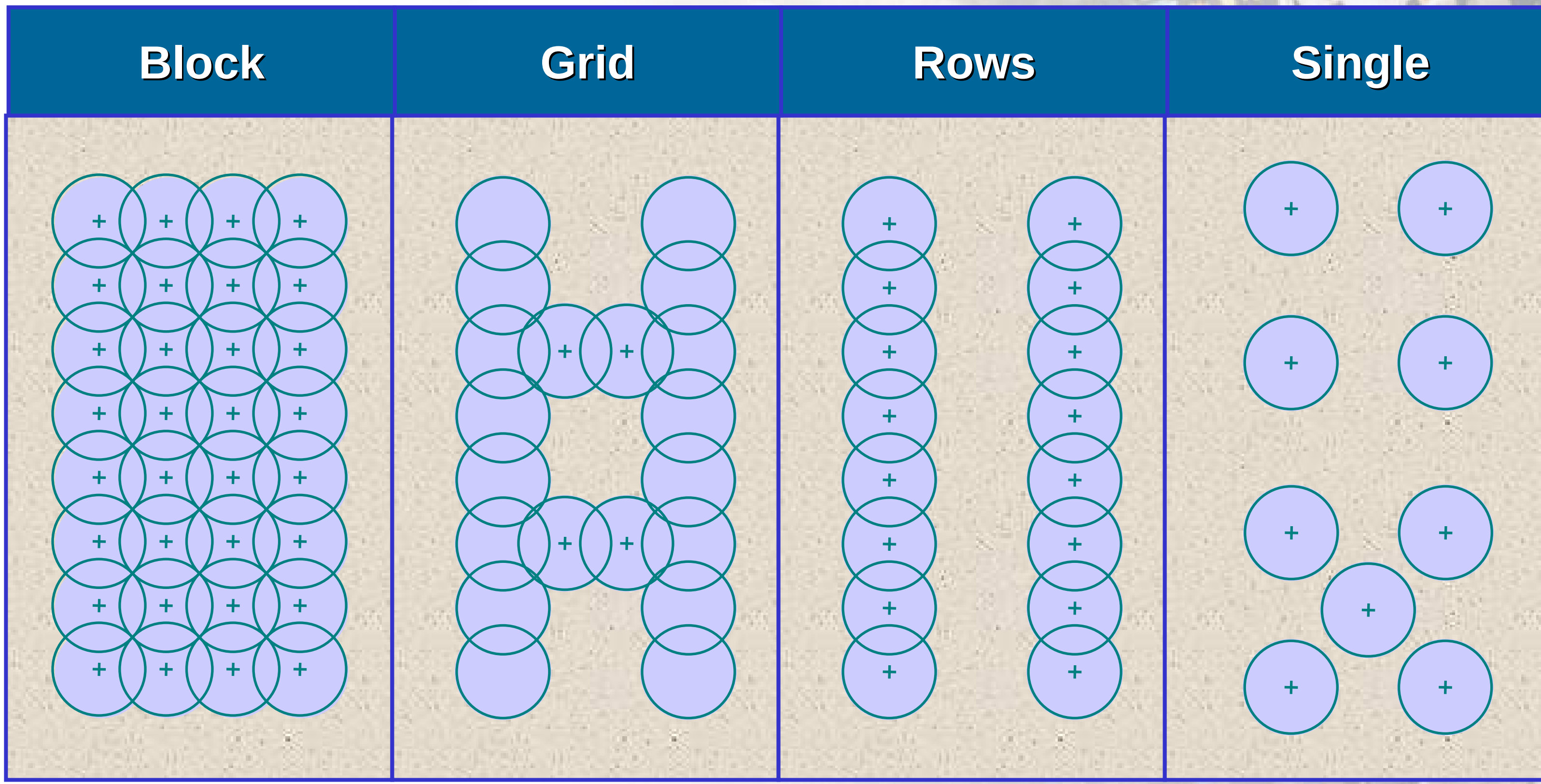
800mm PB3-Tool

Peat Tool

- Levels of blades = 4-8
- Lift Speed = 10-30mm/rev
- Rotation speed = 100-200 rpm

VIDEO CLIP OF DDSM PROCCESS

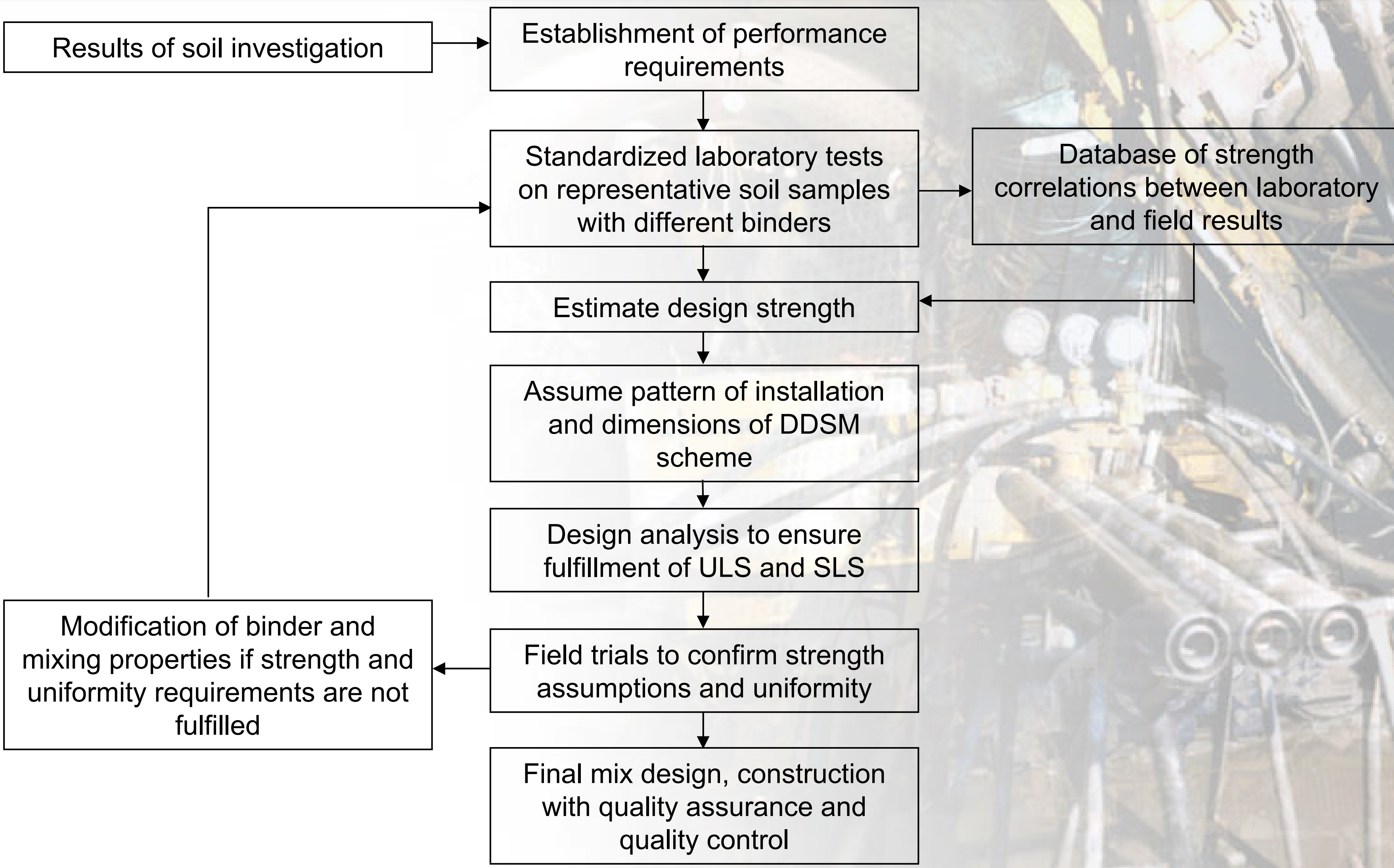
EXAMPLES OF TREATMENT PATERNS FOR DDSM



DDSM DESIGN CONSIDERATIONS

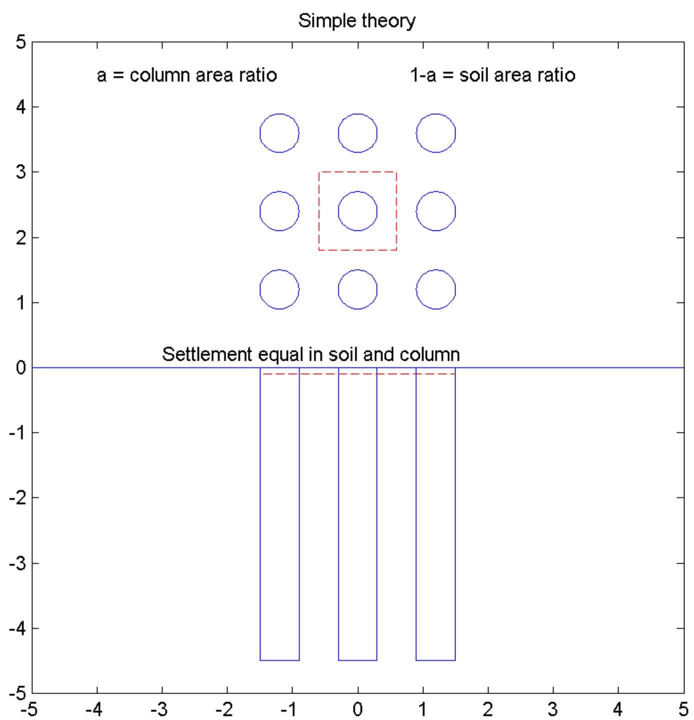
- Performance requirements
- The soil type(s) being mixed
- The in-situ soil strength
- The moisture content and groundwater conditions
- The plasticity of the soil
- The organic content
- The aggressive nature of the soil

ITERATIVE DESIGN PROCESS



DESIGN THEORY FOR DDSM

- Ground improvement technique – not piles
- Composite material
- Combined shear strength and stiffness



$$c_{U\,(mass)} = a.c_{U\,(column)} + (1-a).c_{U\,(soil)}$$

(similarly for c’ & tanϕ')

$$E_{(mass)} = a.E_{(column)} + (1-a).E_{(soil)}$$

where: a = ratio of column area to total area

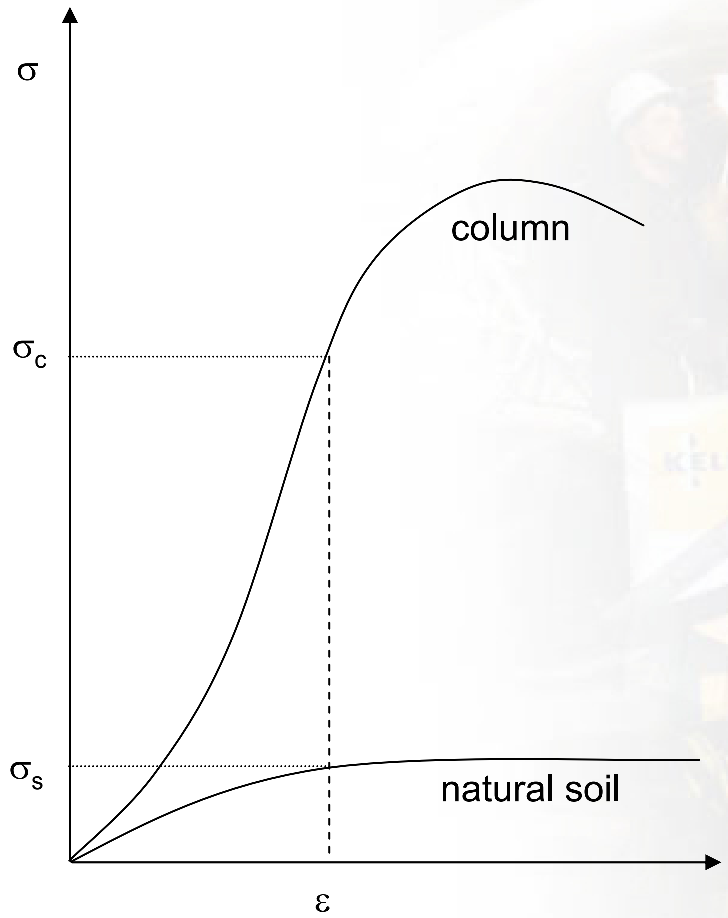
DESIGN THEORY FOR DDSM

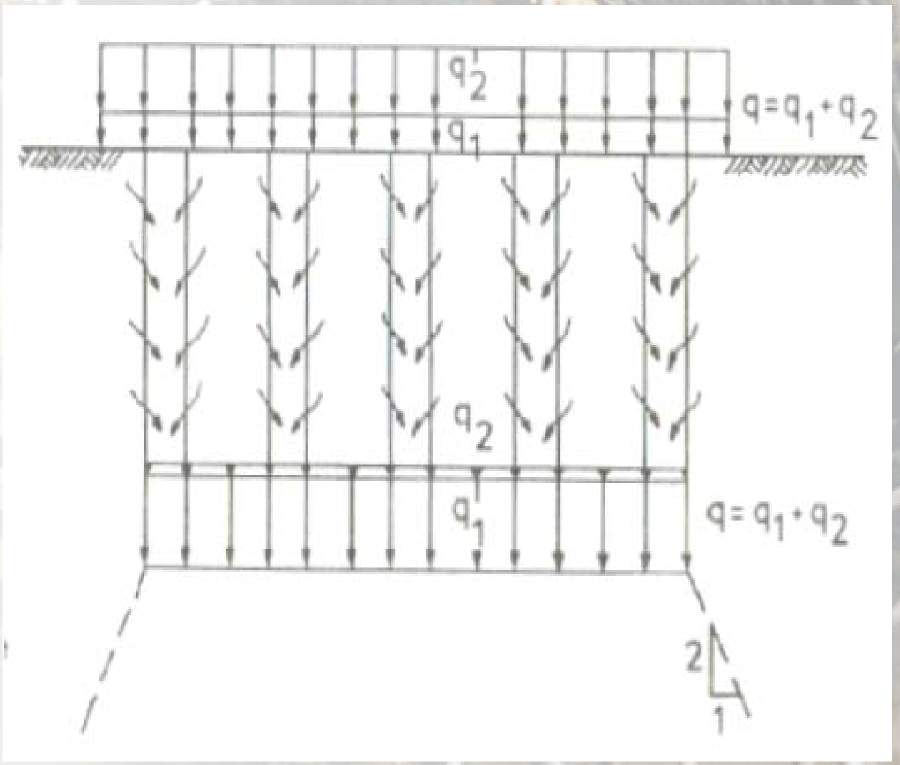
Typical properties for DDSM columns:

- $c_{U\ (column)}$ 50kPa to 300kPa (dependent upon soil type & binder)
- Typically limited to 100kPa to 150kPa for design
- $c'_{(column)} = \beta . c_{U\ (column)}$ where: $\beta = 0$ to 0.3
- $\phi_{d\ (column)} = 30° - 40°$ (dependent upon binder)
- $$\sigma_{ult} = \frac{2.\cos\varphi'_{col}}{(1 - \sin\varphi'_{col})} . c'_{col} + \frac{(1 + \sin\varphi'_{col})}{(1 - \sin\varphi'_{col})} . \sigma'_h$$

where: $\sigma'_h = \sigma'_{v0} + m_{soil} \Delta\sigma_v$

THE DESIGN PHILOSOPHY FOR DDSM





TYPES OF BINDER

Most common binders are:

- Cement
- Lime
- Blast Furnace Slag
- Gypsum

Geotechnical and chemical properties of natural soil affect the choice of binder.

Specific regard should be given to:

- Required strength and stiffness
- Durability
- Environmental impact of the binder

RELATIVE STRENGTH INCREASE BASED UPON LABORATORY TESTS (after EUROSOILSTAB 2001)

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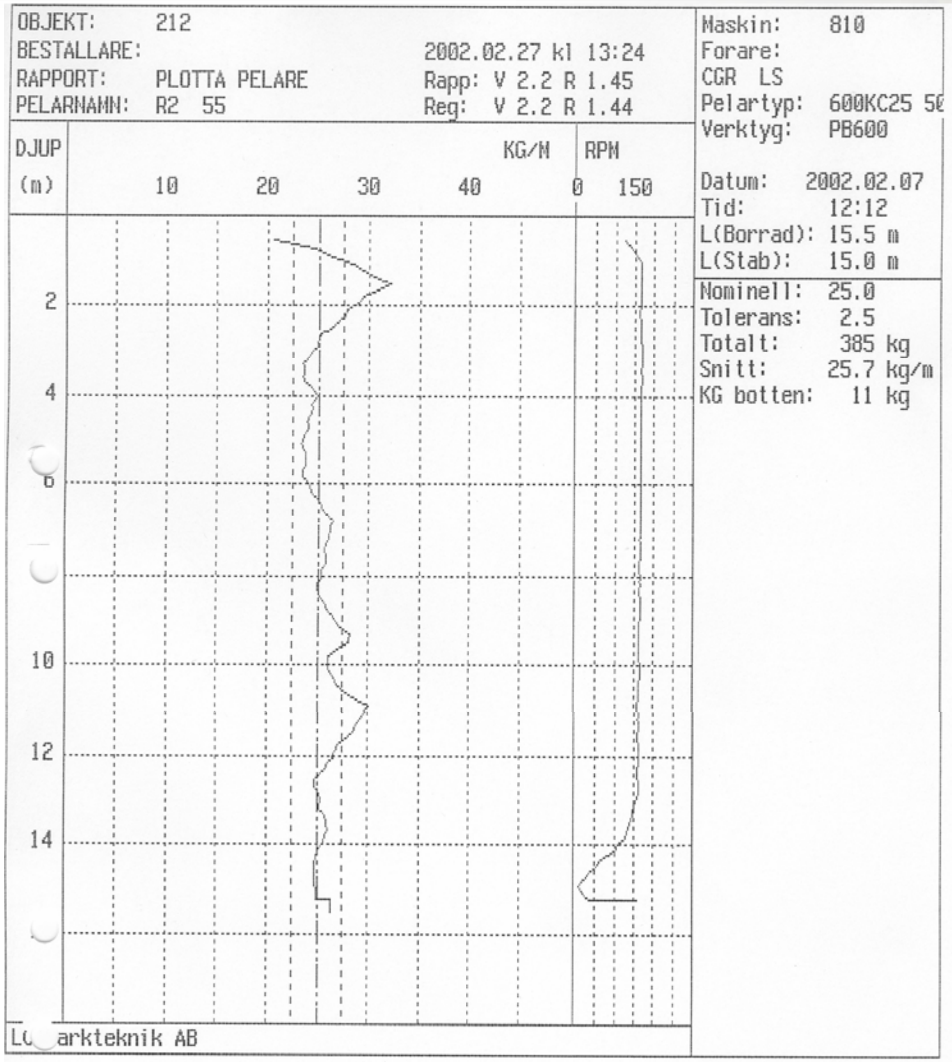
	Soil Description			
Binder	Silt Organic Content 0-2%	Clay Organic Content 0-2%	Organic Clay Organic Content 2-30%	Peat Organic Content 50-100%
Cement				
Cement + Gypsum				
Cement + Blast Furnace Slag				
Lime + Cement				
Lime + Gypsum				
Lime + Slag				
Lime + Gypsum + Slag				
Lime + Gypsum + Cement				

	Very good binder in many cases
	Good binder in many cases
	Good binder in some cases
	Not suitable

Based upon relative strength increase at 28 days



Data automatically logged by onboard computer

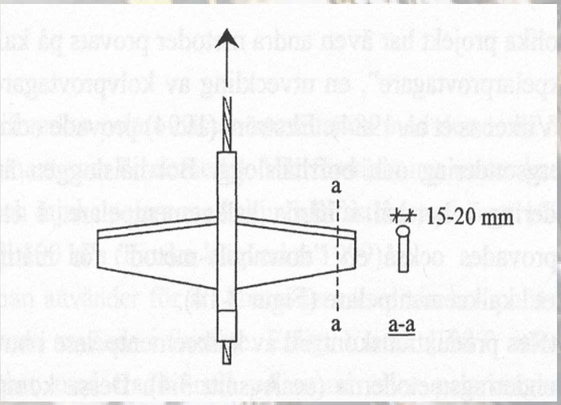
- Column reference
- Mixing tool
- Diameter (m)
- Drilled depth (m)
- Rotation rate (rpm)
- Lift speed (m/s)
- Binder dosage rate (kg/m)
- Total binder in column (kg)
- Treated length of column (m)

POST CONSTRUCTION QUALITY CONTROL

- Pull Out Resistance Tests (PORT)
- Push In Resistant Tests
- Cone Penetration Tests (CPT)
- Undisturbed Sampling & Laboratory Testing
- Load Testing (Plate & Zone Testing)
- Column Exhumation

PULL OUT RESISTANCE TEST (PORT)

- Installed at the same time as installation of the column.
- Vane is pulled up by a wire through column
- Pull out rate 20mm/sec.
- Shear strength = $P/(N_c*A)$



Advantages

- Test is robust and correlated by large database of test results.
- No problems with test deviation.
- High strength columns can be tested (<600 kPa).

Disadvantages

- The columns to be tested must be selected in advantage.
- The bottom part (about 1 m) of the column can not be checked when installed to firm ground.

PUSH IN RESISTANCE TESTS

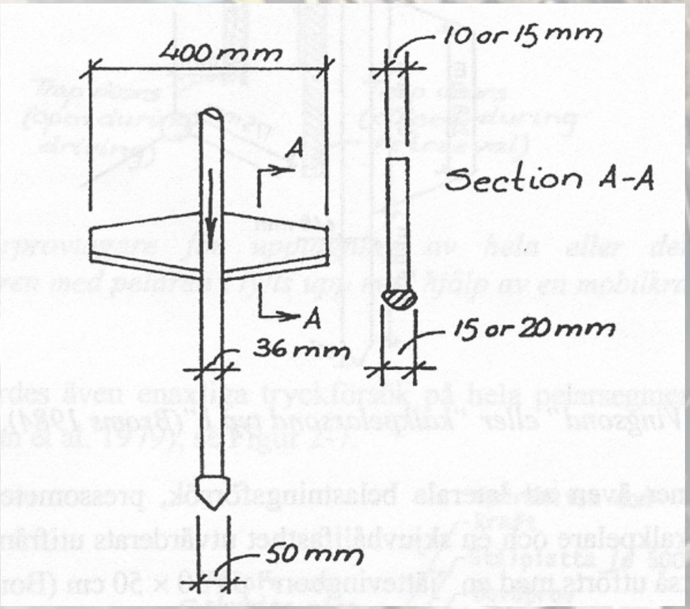
- Penetration rate 20mm/sec.
- Shear strength = $P/(N_c*A)$

Advantages

- Equipment is simple and cheap
- Works well in columns <5m long with shear strength 150 – 300 kPa

Disadvantages

- Have a tendency to deviate from the column at depth larger then 5 – 8m.
- Length > 8m requires a guide hole in the column

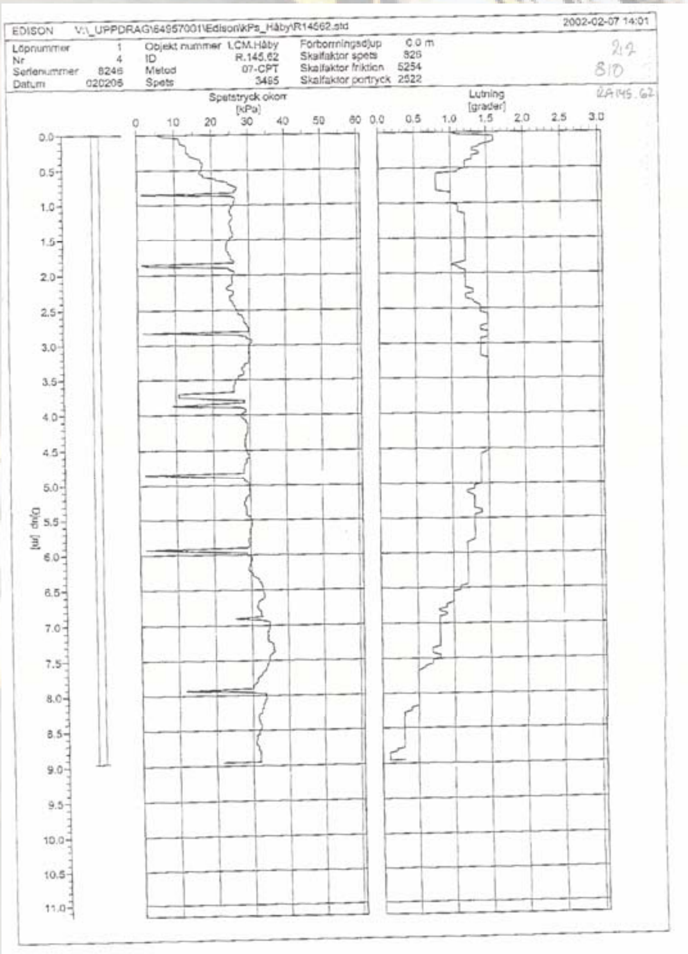


Advantages

- Common method
- Easy to use

Disadvantages

- Tendency to deviate from the column at depths > 5 – 8m and in columns with high shear strength.
- Testing on a very local part of the column
- The shear strength may vary through the column, which is not representative for the whole column



Advantages

- Evaluation of many parameters
- Evaluation of the amount of binder in the sample
- Unconfined compression and elasticity modules can be evaluated

Disadvantages

- Only discrete sections of the columns can be tested
- Requires a great amount of samples to give a proper mean value of the column
- The properties in the columns vary a lot between the samples

EXCAVATION & EXHUMATION OF TRIAL COLUMNS

SOIL MIXED COLUMN STRENGTH VERIFICATION

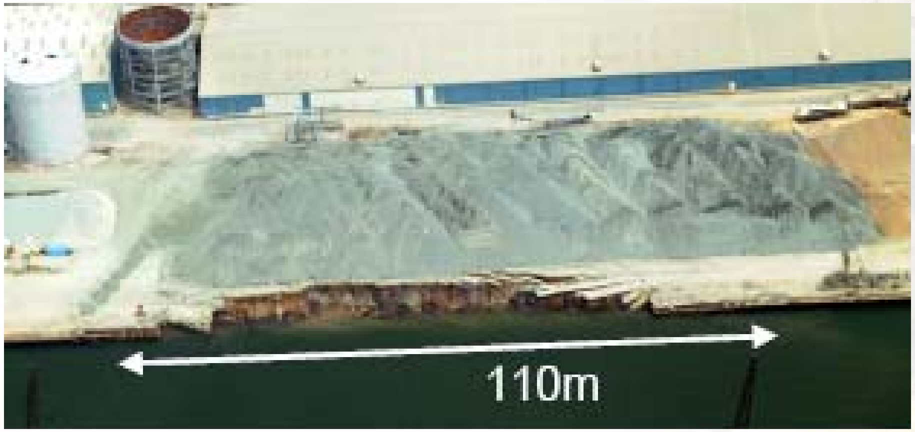
Soil Mixed Column at 5 Days

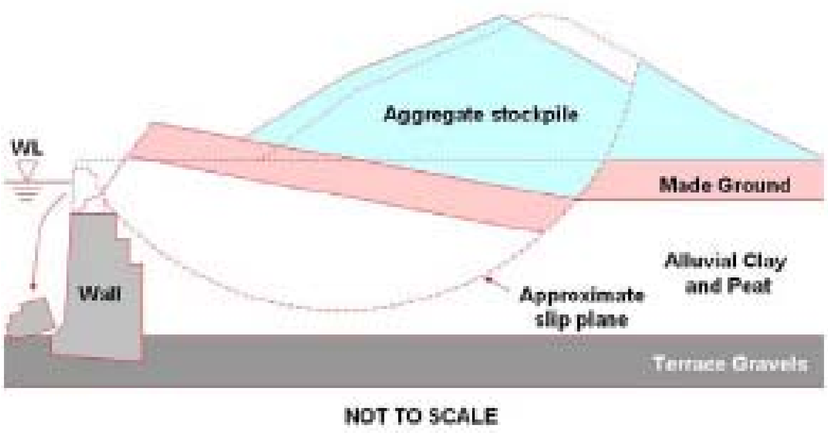
Unmixed Material Adjacent to Columns

APPLICATIONS OF DDSM

- Improved bearing capacity
- Reduce settlements
- Increase the stability in embankments & slope areas.
- Reduce active/increase passive earth pressures on retaining walls
- Excavation support.
- Land reclamation
- Encapsulate contaminated material on site (e.g. heavy metals)

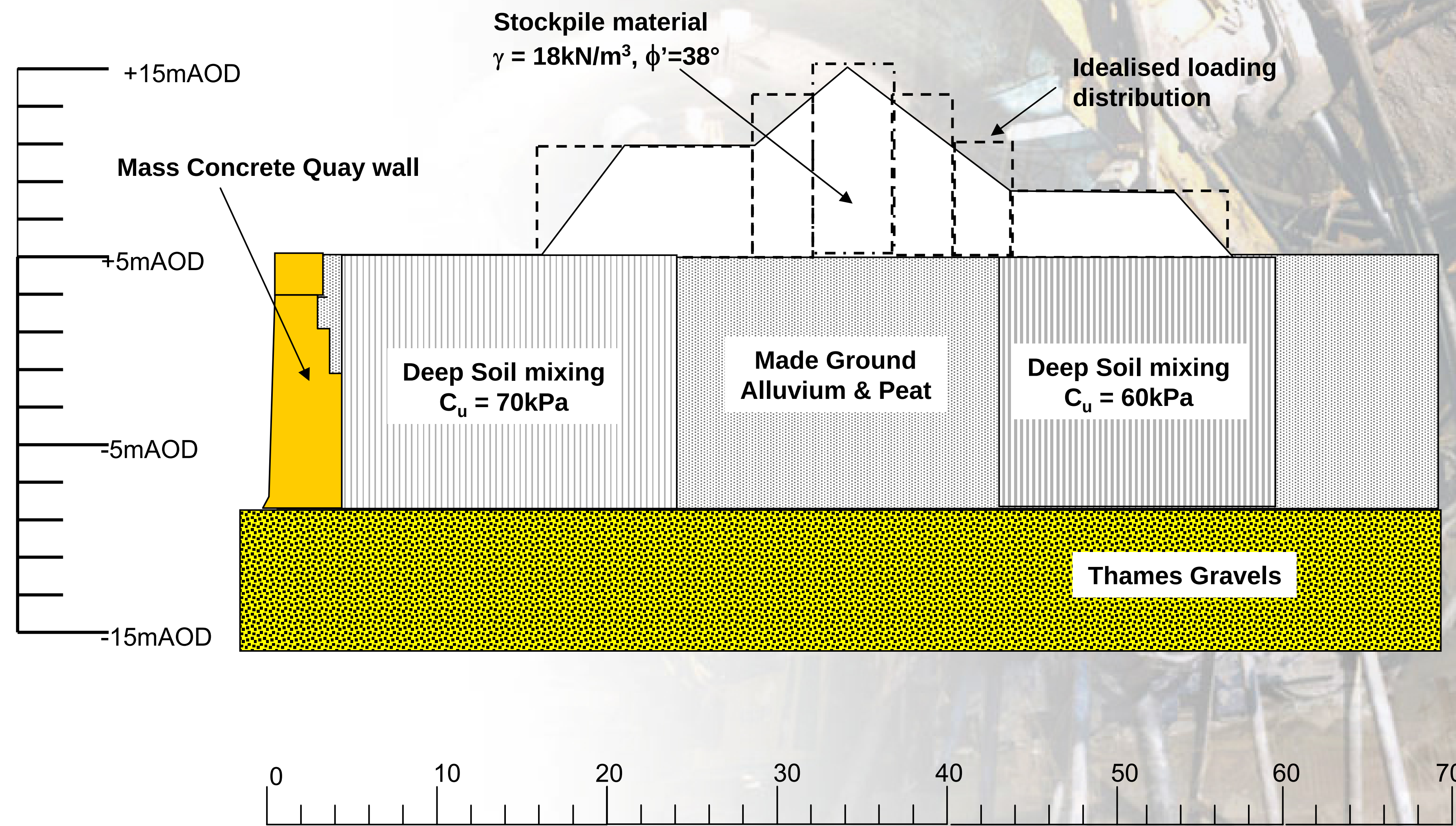
TILBURY DOCKS BERTHS 7 & 8
DDSM CASE HISTORY





- 100 m length of the original gravity quay wall progressively collapsed following the stockpiling of aggregate.
- DDSM ground improvement works to intercept potential deep-seated slip circle failures & reduce active pressures on wall.
- Mott MacDonald – Responsible for overall design of remedial scheme
- Keller Ground Engineering – Responsible for the DDSM works

TILBURY DOCKS BERTHS 7 & 8
THE DESIGN SOLUTION



TILBURY DOCKS BERTHS 7 & 8
SUMMARY

- 12m long 800mm DDSM columns installed in rows.
- 3100 columns installed in rows at 2.3m to 2.8m c/c
- Post construction validation testing using both CPT and PORT techniques
- Column strength exceeded design requirement.
- Many CPTs failed due to deviation out of columns
- DDSM was used effectively to improve engineering properties of very soft to soft alluvial deposits as part of remedial works

NEWPORT DOCKSWAY LANDFILL, GWENT
DDSM FOR TEMPORARY WORKING PLATFORM

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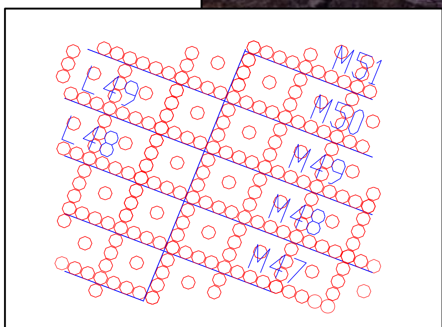
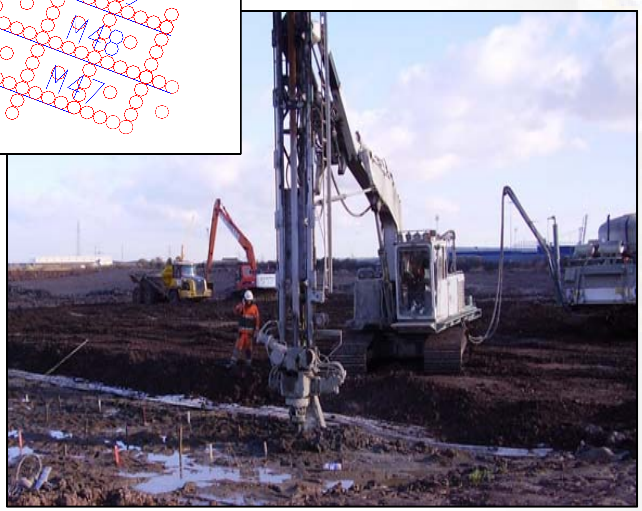




- Ground improvement required to permit heavy earth moving plant to access the site.
- Site underlain by 6m of very soft silty clay overlying river gravels.
- 2m long 900mm diameter DDSM columns installed at 800mm c/c on 4m square grid.
- Load transfer platform comprised geotextile rolled out onto completed columns with 300mm thick granular layer.
- 38,300m of DDSM column installed within an 11 week programme

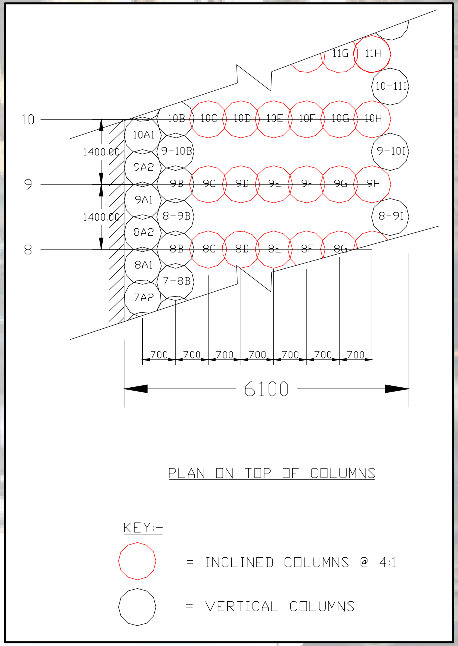
PHASE 2 NORWICH CITY FOOTBALL CLUB STABILISATION OF ACCESS ROAD

- New access road constructed across site underlain by up to 4.5m of fibrous peat with moisture contents between 300-400%.
- DDSM required to limit settlements to less than 25mm.
- 800mm diameter DDSM columns were installed on 1.2m c/c square grid, to 0.5m into underlying terrace gravels.
- Load transfer platform comprised lime/cement stabilised site-won made ground.
- 2,300 columns were installed in 3 week programme to limit disruption to football season.

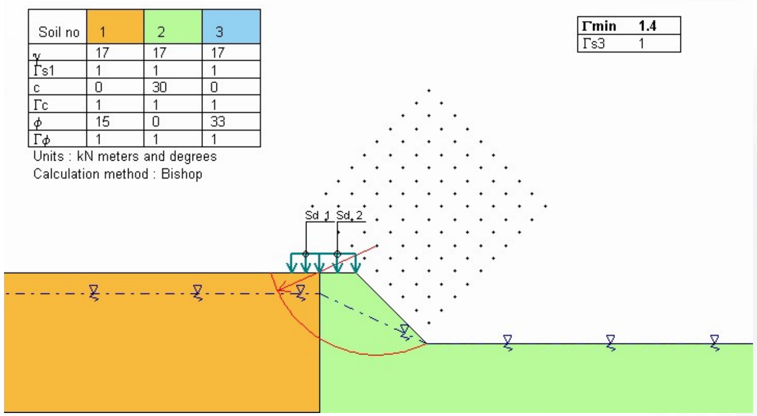
WASHLANDS FLOOD STORAGE RESERVOIR EMBANKMENT STABILISATION

- Foundation soils beneath two flood defence embankments improved by DDSM.
- Existing flood protection embankments widened & raised.
- Settlement of banks to be limited to 100mm over 55 year design life.
- Embankments founded on organic alluvial clays and clayey fibrous peat with moisture contents between 100-350%.
- DDSM columns installed in panels perpendicular to the line of the embankment.
- 5,546 DDSM columns installed within 11 week programme.

- Remedial works to river wall to enable construction of 4-storey residential block.
- Site underlain by River Roding alluvial deposits.
- Wall was partially continuing to perform its function, it was decided to provide a mass gravity structure to improve its stability.
- 2 vertical rows of 7m long 800mm diameter columns.
- 1 vertical row of 5m long 800mm diameter columns.
- 6 inclined rows of 7m long 800mm diameter columns at 1.4m spacing.



CLEY TIDAL SLUICE, NORFOLK
SLOPE STABILISATION FOR TEMPORARY EXCAVATION



- New tidal sluice required to replace an existing culvert.
- Site underlain by very soft sandy organic clay/silt with moisture contents between 25-123%.
- Required to form 4m deep temporary excavation approx. 17m x 37m to allow the construction of the sluice base slab.
- DDSM used to provide temporary stability for the proposed 1:1 side slopes and base of the excavation.
- Interlocking columns formed panels around the sides of excavation with individual columns on a square grid across the base.
- 1,070 columns installed within a 3 week programme.

SUMMARY

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- DDSM is flexible ground improvement technique.
- Able to tailor strength & configuration of columns with respect to ground conditions & design requirements.
- Method promotes sustainability
- Low noise and vibration levels
- Low or no spoil generation
- High Production (300-600 column metres per shift)
- Cost effective
- Less use of natural resources like aggregate by improving in-situ soil
- Lower life cycle costs - based on less transportation of materials
- Recycling materials - binders use industrial by-products

KELLER

www.keller-ge.co.uk

ISSMGE Technical Commitee 17
Ground Improvement

WORKSHOP

Overview TC 17 activities

S. Varaksin, Ménard Soltraitement
J. Maertens, Jan Maertens bvba & KULeuven

Monday 24 September 2007
XIVth ECSMGE venue, Madrid, Spain

1. Terms of Reference & WG

Terms of Reference:

1. Creation of the following Working Groups:
   WG A – Concept & Design
   (Co-ordinator: H. Schweiger, Austria)
   WG B – Ground Improvement without admixture in non cohesive soils
   (Co-ordinator:--)
   WG C – Ground Improvement without admixture in cohesive soils
   (Co-ordinator: Jian Chu, Singapore)
   WG D – Ground Improvement with admixtures
   (Co-ordinators: R. Essler, UK & M. Kitazume, Japan)
   WG E – Ground Improvement with grouting type admixtures
   (Co-ordinators: C. Oteo, Spain & M. Chopin, France)
   WG F – Earth reinforcement in fill
   (Co-ordinator: Ph. Héry, France)
   WG G - Earth reinforcement in cut
   (Co-ordinator:Turan Durgunoglu, Turkey)
2. Working Groups to prepare brief descriptions of the appropriate techniques and a list of publications before end 2006 in order to put this information on the website of TC 17 (= ISSMGE Website);
3. Working groups to prepare a state-of-the art report on the appropriate and available techniques in ground improvement and subject (for WG A) for the next ISSMGE conference in 2009. In order to gather the necessary information each working group shall organize at least 1 workshop in 2008. Only invited persons and persons writing a contribution will be allowed to attend these workshops;
4. The state-of-the art reports prepared by the different working groups will be used as the bassis of a number of regional conferences in 2010 and 2011.

1. Terms of Reference & WG (cont.)

Planned activities:

Meetings:
At least every year a meeting of ITC 17 will be organized. The chairmen of the working groups will be invited to these meetings to report on their activities.
A first meeting will take place at the occasion of the European Conference on Numerical methods in Geotechnical Engineering in Graz, where there is a special session on Numerical modeling of ground improvement. The TC 17 meeting in Graz is provided on 9 september 2006 at 9h30 am.
Other meetings will be organised at the occasion of 16th SEAGC (8-11 May 2007, Kualu Lumpur) and at the occasion of the 14th ECSMGE (24-27 September 2007, Madrid).
The meetings of the working groups are organized by the WG chairmen.

2. Formal TC 17 Meetings

MEETING 1 - 9 Sept. 2006, TU-Graz, Austria
(NUMGE06)

MEETING 2 – 10 May 2007, Kuala Lumpur, Malaysia
(16th SEAGC)

MEETING 3 – 25 Sept. 2007, Madrid, Spain
(XIVth ECSMGE)

3. TC 17 involvement/representation

8th IGS, 18-22 Sept. 2006, Yokohama, Japan

TC 17 Specialty Session ‘Reinforced slopes & walls”

Young-ELGIP Workshop “Innovation in Soil Improvement Methods”, 26-27 October 2006, Delft,The Netherlands

Szechy Karoly Symposium, November 2006, Hungary

Touring Lectures on Ground Improvement, 2-5 May 2007, Hanoi & Ho Chi Minh, Vietam

16th SEAGC, 8-11 May 2007, Kuala Lumpur, Malaysia

3. TC 17 involvement/representation (cont.)

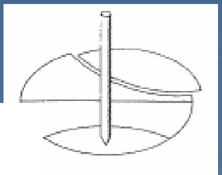
TC 17 Workshop, 24 Sept. 2007, ECSMGE, Madrid, Spain

5th Int. Symposium on Earth Reinforcement, “IS Kyushu 2007”, 14-16 November, Fukuoka, Japan (under auspices of the Japanese Society & TC 17)

4. TC 17 Website

http://www.bbri.be/go/tc17

5. Canvas ground improvement techniques



Deep Vibratory Compaction:

1. Definition:

Type of ground treatment by deep vibration in which the main purpose is to densify the soil. The treatment is applicable to many granular soils and normally results in increased strength and stiffness, reduced permeability and reduced susceptibility to liquefaction (= defintion of EN 14631).

2. Method statement:

Vibrators, containing oscillating weights which cause horizontal and/or vertical vibrations, are inserted into the ground, with or without water and/or air.

When a depth vibrator is used the vibrating poker consists of the vibrating unit, follower sections and a lifting head. The source of the vibration is an eccentric weight mounted at the bottom of a shaft linked to a hydraulic or electric motor.

Top vibrators are connected to a special compaction probe, designed to transfer the vibrations to the soil as efficiently as possible. Although the vibrator usually vibrates vertically, the probe will cause horizontal accelerations which may be locally larger than the vertical ones.

5. Canvas ground improvement techniques

3. Applications:

Deep vibratory compaction is used to densify saturated or unsaturated natural sands as well as hydraulic fills. The process is often used to reduce the risk of liquefaction from a seismic event.

Deep vibratory compaction can be performed on land and over water. Depths of about 30m can be treated normally.

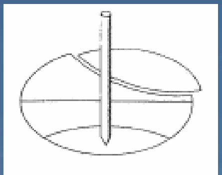
Deep vibratory compaction cannot be employed effectively when the fines content (=particles smaller than 74µm) exceeds 12%, pending on the clay fraction.

4. Geotechnical parameters:

The following properties may be relevant for the granular soils to be compacted:

- grain size distribution and fines content
- in situ density
- permeability
- crushability of particles
- inter-par
- ticle bond caused by cementation, suction or cohesion.

5. Canvas ground improvement techniques



5. Concept and design:

The spacing of the compaction points can be determined based on:

- the results of the geotechnical investigation
- former experience in similar conditions
- empirical graphs.

For foundation works the deep vibratory compaction normally extend beyond the area of the foundation to be constructed.

6. Execution parameters records:

During the execution of the deep vibratory compaction the following data can be monitored:

- depth of penetration at each location
- vibrator power consumption during penetration and compaction
- the quantity of imported fill material and/or the settlement of the ground surface.

5. Canvas ground improvement techniques

7. Quality control:

Several types of in situ tests can be carried out:

- cone penetration tests (CPT and CPTU)
- standard penetration tests (SPT)
- pressuremeter tests (PMT)
- dilatometer test (DMT)
- dynamic probing (DP).

8. Standards:

EN 14631 Execution of geotechnical works - Ground treatment by deep vibration

9. Literature:

Mitchell J. & Jardine F. (2002), A guide to ground treatment, CIRIA Report C 593, CIRIA

6. Core Member Country reports

→ see TC 17 website + tabel uit website

ISSSMGE TECHNICAL COMMITTE 17 – GROUND IMPROVEMEN

TC 17 WORKSHOP – 24 SEPTEMBER 2007

XIVth ECSMGE venue: Palacio de Congresos y Exposiciones de Madrid - ROOM 9bis

PROGRAM

11h15 – 11h30 **Welcome & Introduction** by the TC 17 Chairmen *S. Varaksin & J. Maertens*

11h30 – 12h00 **Working Group A "Concept & Design" & Overview AMGISS**

Introduction by the WG A coordinator *H. Schweiger*

Contribution 1 : Results from a field trial of a foundation supported by floating stone colums
H. Schweiger, TU Graz, Austria

Contribution 2 : New design Methodology for column reinforced soil
M. Bouassida, ENIT, Tunisia

12h00 – 12h30 **Working Group B "Ground Improvement without admixture in non cohesive soils"**

Introduction by the TC 17 Chairmen

Contribution 1 : Surface compaction of hydraulic fills of limited thickness
P. Mengé, Dredging International, Belgium

Contribution 2 : Vibro compaction of reclaimed land (S 700, Palm Island I + III, and Singapore)
J. Wehr, Keller Grundbau, Germany

12h30 – 14h15 : Lunch (ECSMGE)

14h15 – 15h00 **WG C Ground Improvement without admixture in cohesive soils**

Introduction by *J. Kirstein* representing theWG C coordinator *Jian Chu*

Contribution 1 : Vertical drains & vacuum consoldation – Project Airbus Hamburg
J.Kirstein, Dyniv, Germany

Contribution 2 : New European Standard: Vertical drainage TC 288 WI 012
N. Cortlever, The Netherlands

15h00 – 15h45 **WG D "Ground Improvement with admixtures"**

Introduction by the WG D coordinator *R. Essler (5 minutes)*

Contribution 1 :The use of statistical techniques to refine ground improvement layouts
R. Essler, RD Geotech, UK (10 minutes)

Contribution 2 : Soil mixing topic (to be advised)
Masaki Kitazume (10 minutes)

Contribution 3 : Measurement of downhole pressures during jet-grouting
Bas Obladen, Central Station, Amsterdam Steering Group (10 minutes)

Contribution 4 : Global trends in Ground Improvement in Portugal and Lisbon Case History
A. Pinto, JetSJ Geotecnia, Portugal (10 minutes)

ISSMGE TC-17

15h45 – 16h30 WG E "Ground Improvement with grouting type admixtures"

Introduction by the WG E co-ordinator *M. Chopin*

Contribution 1 : Grouting of soils and rocks – progress during the last 10 years
M. Chopin, MC Consulting, France

Contribution 2 : Microfine cements for permeation grouting
I. Markou, DUTH, Greece

16h30 – 17h00 Coffee Break (ECSMGE)

17h00 – 17h45 Working Group F "Earth reinforcement in fill"

Introduction by the WG F co-ordinator *Ph. Héry*

Design and construction of steepened embankment at Gerald's International Airport, Montserrat,
Chris Jenner,Tensar, UK

Design and construction of MSE Tall Walls for the Seattle Tacoma Airport 3rd Runway Project
John Sankey, Reinforced Earth Company, USA

17h45 – 18h30 Working Group G "Earth reinforcement in cut"

Introduction by the WG F co-ordinator T. *Durgunoglu*

Contribution 1, Application of very deep temporary soil nailed walls in Istanbul,
T. Durgunoglu, ZETAS, Turkey

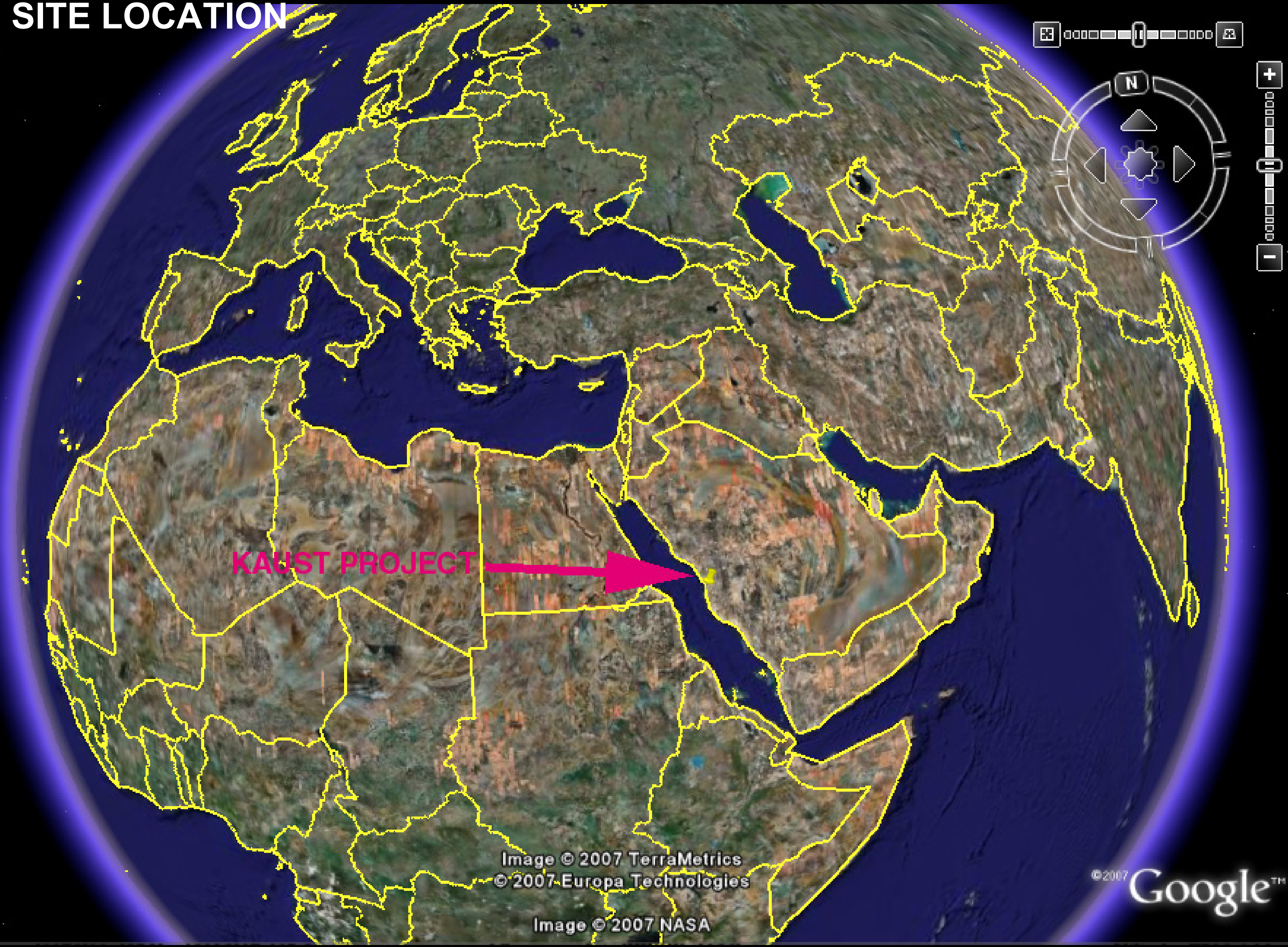
Contribution 2 , US practice in Soil Nailing
Contibution 2 will be presented by WG F co-ordinator T. Durgunoglu

Concept and application of ground improvement for a 2,600,000 m2

FUTURE UNIVERSITY CAMPUS

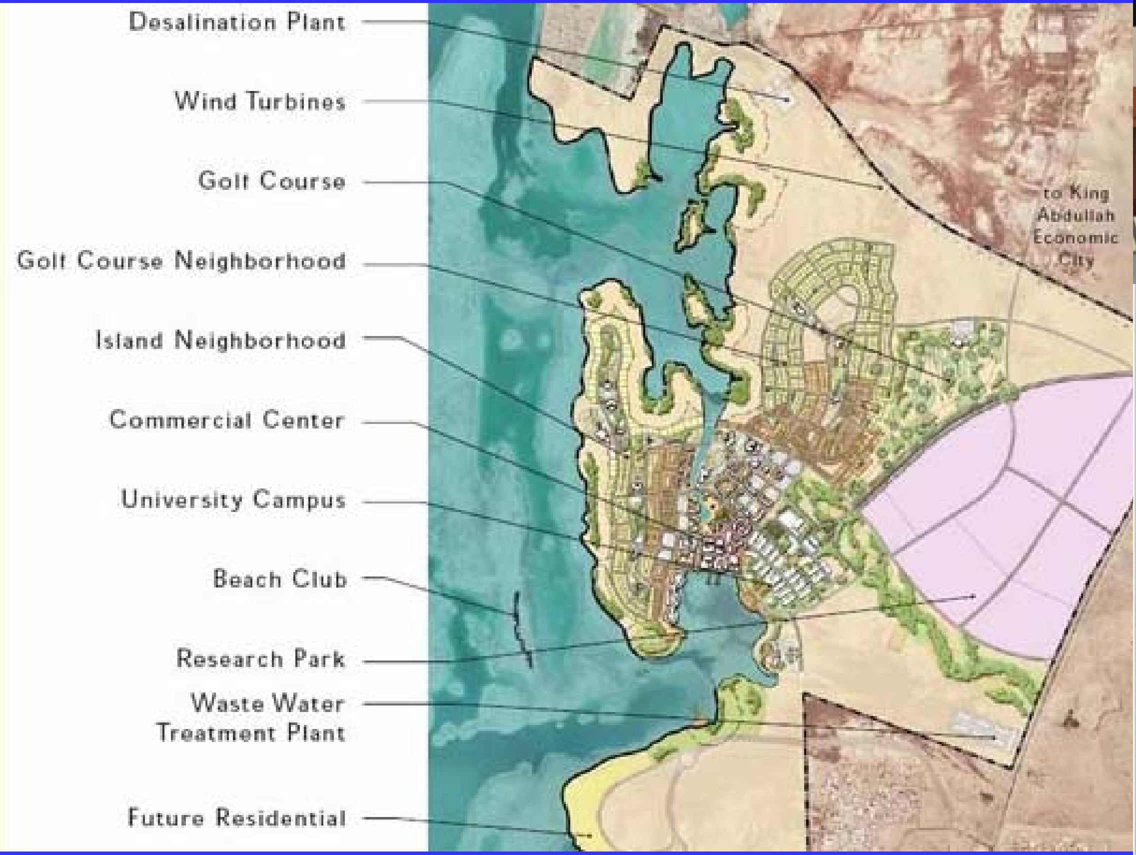
Presented by Serge VARAKSIN
chairman of ISSMGE Technical Committee 17 - Ground improvement
Deputy general manager of MENARD

SITE LOCATION



JEDDAH, a modern city

TYPICAL MASTER PLAN

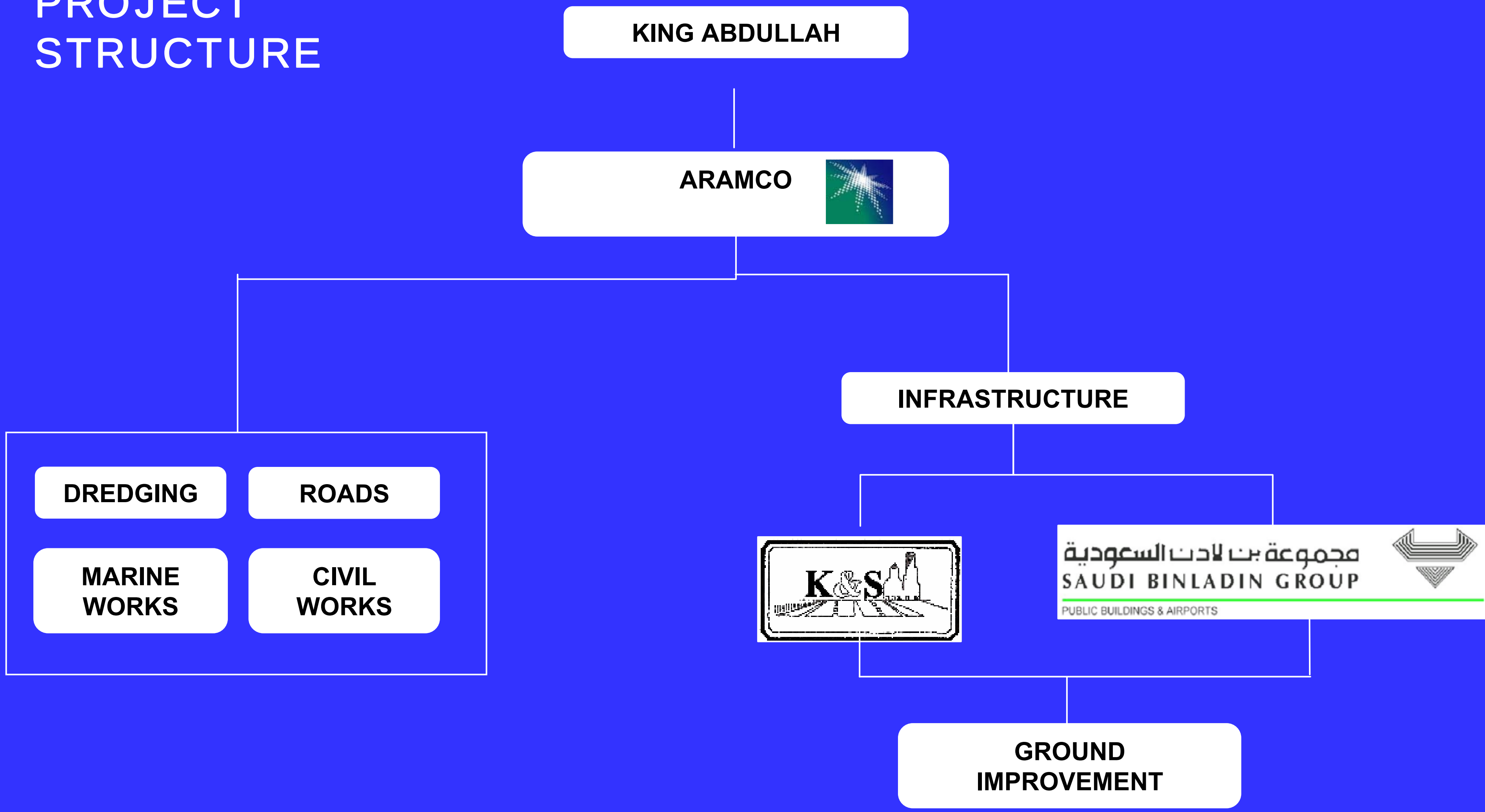


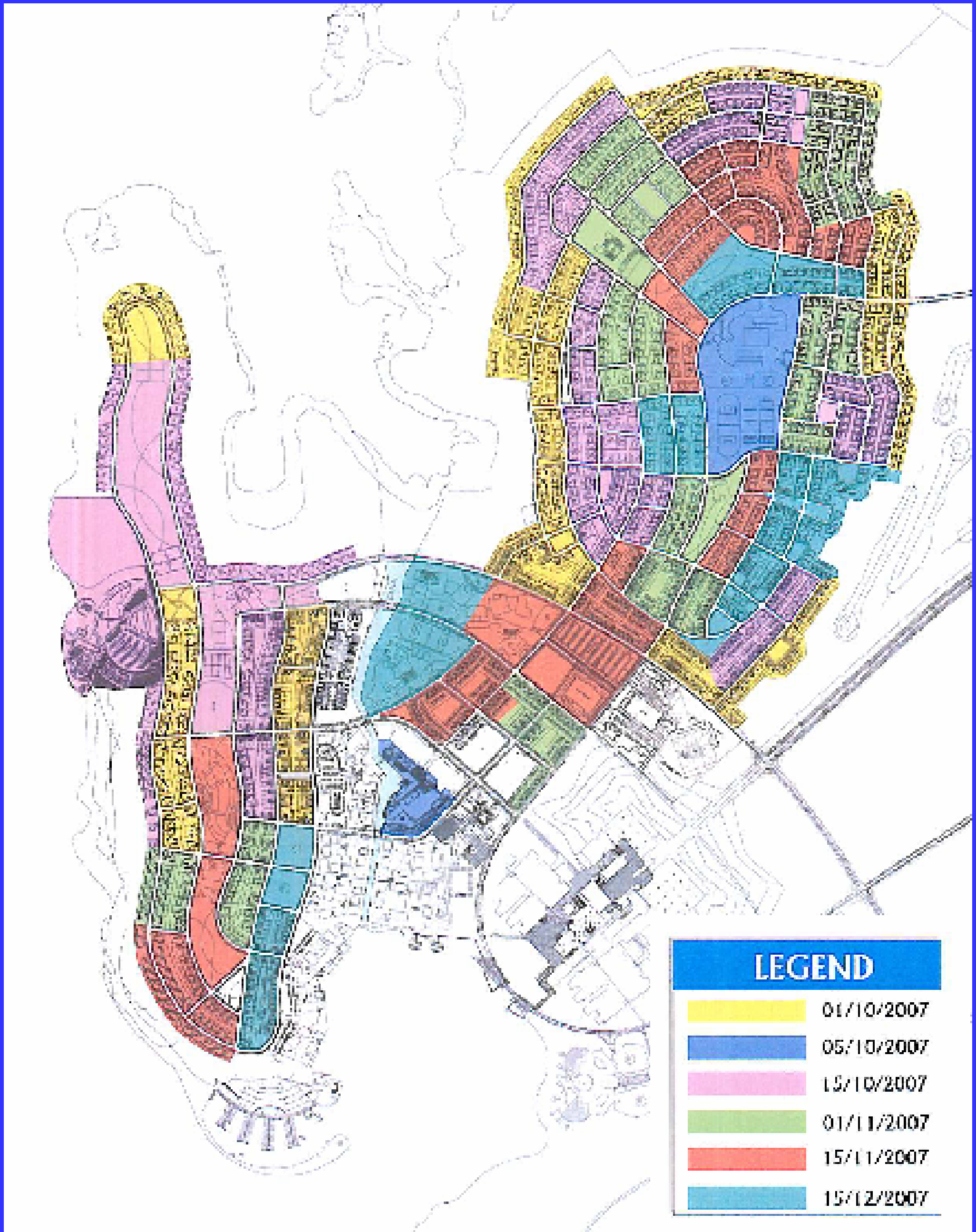

THE FUTURE SITE



DISCOVERING THE HABITANTS


PROJECT STRUCTURE





AREAS TO BE TREATED

- AL KHODARI (1.800.000 m2)
- BIN LADIN (720.000 m2)

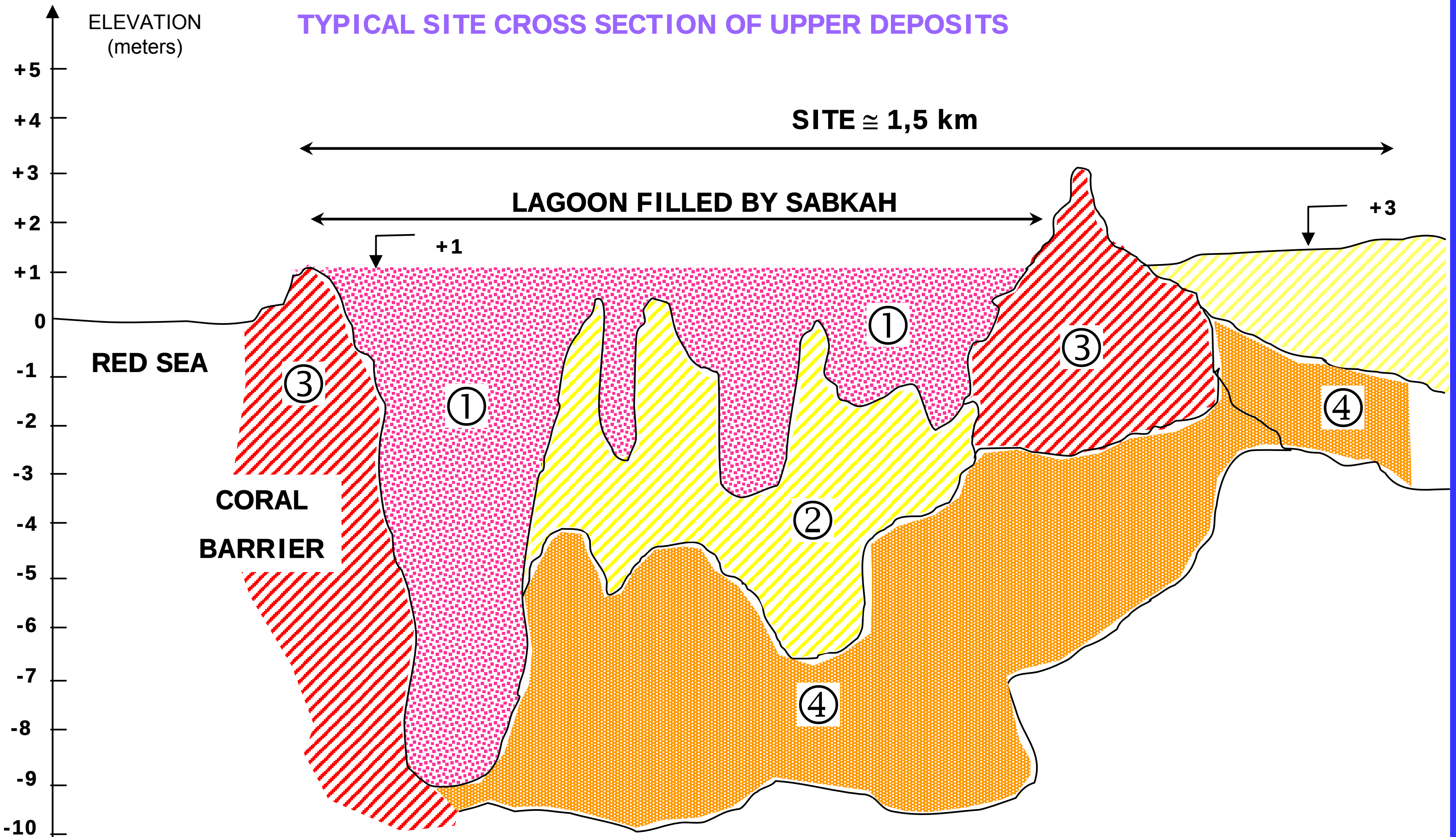
SCHEDULE

- 8 month

SPECIFICATIONS

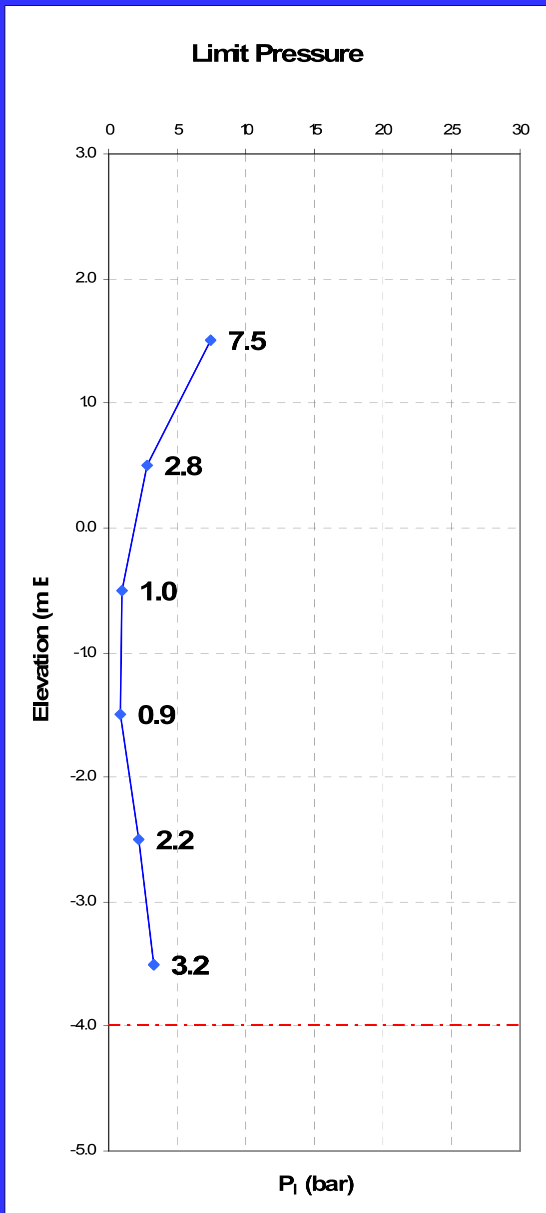
- Isolated footings up to 150 tons
- Bearing capacity 200 kPa
- Maximum footing settlement 25 mm
- Maximum differential settlement 1/500
- Footing location unknown at works stage

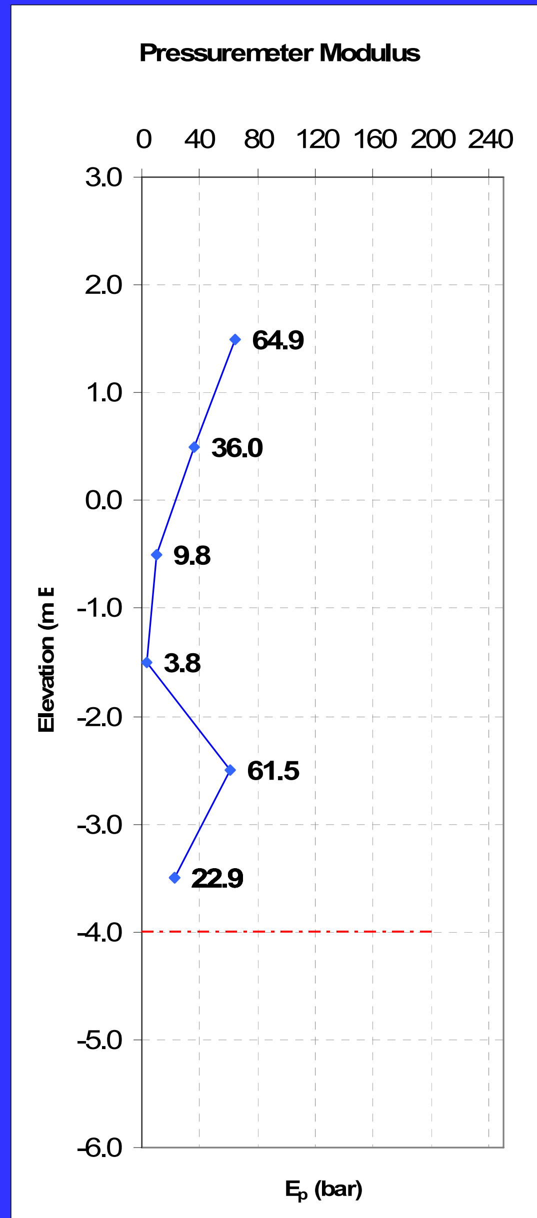
TYPICAL SITE CROSS SECTION OF UPPER DEPOSITS

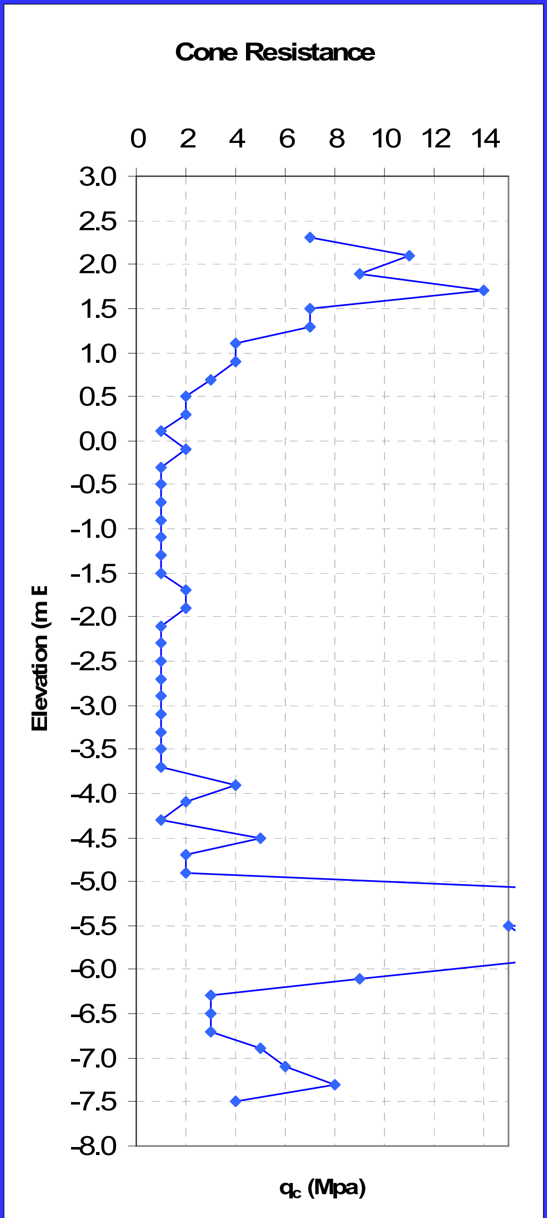


LAYER	USC	w %	% fines	N	Qc BARS	F_R %	P_L BARS	E_P BARS
1 - SABKAH	SM + ML	35-48	28-56	0-2	0-2	1,2-4	0,4-1,9	avr-17
2 - LOOSE SILTY SAND	SM	-	15-28	3-9	12-45	0,5-1,2	2,1-4	18-35
3 - CORAL	-	26-35	-	6-12	-	-	5,1-7,2	35-60
4 - LOOSE TO MED DENSE SAND	SM	-	12-37	3-18	15-80	0,5-1,8	4-12	28-85

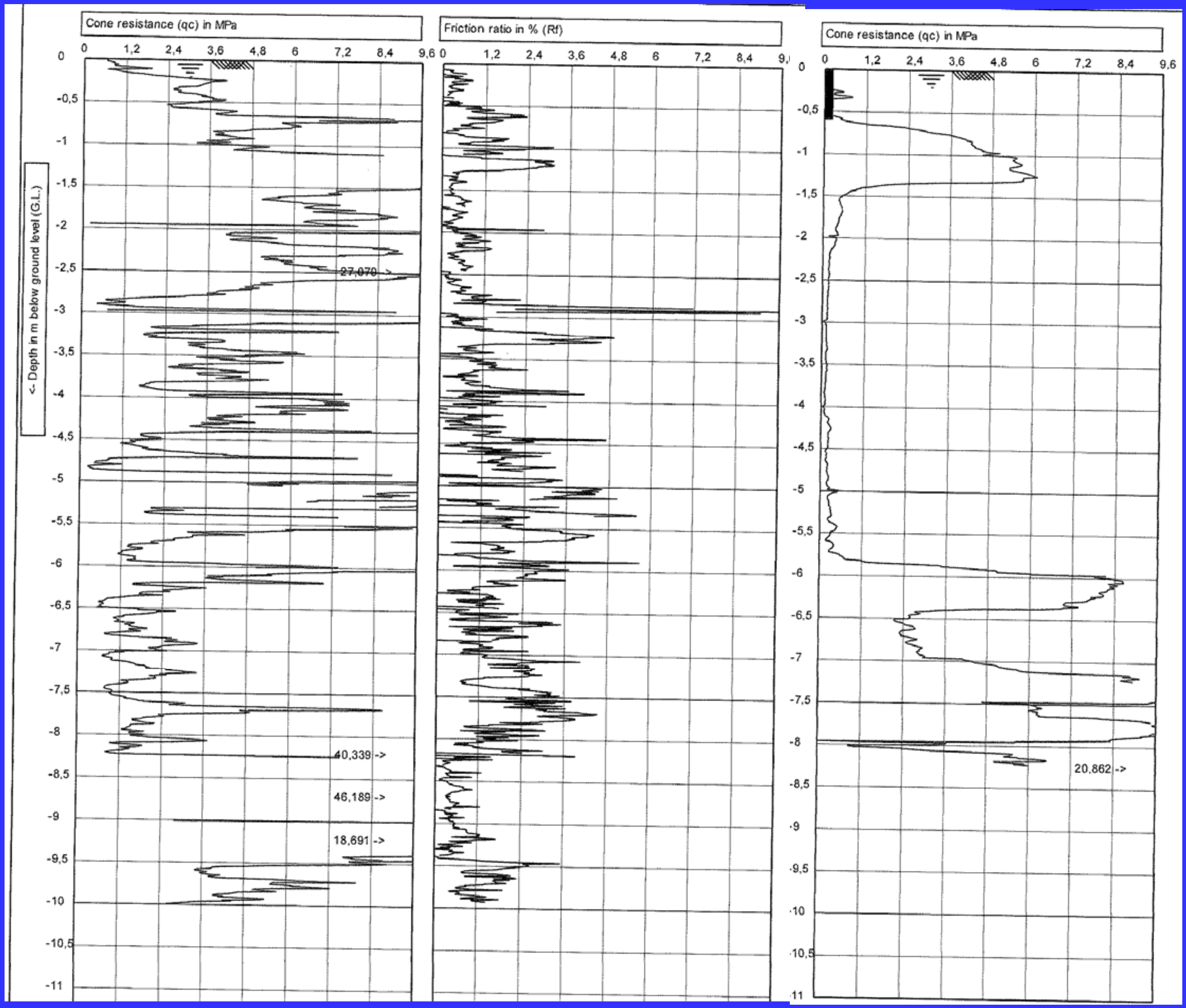
TYPICAL SOIL PROFILE



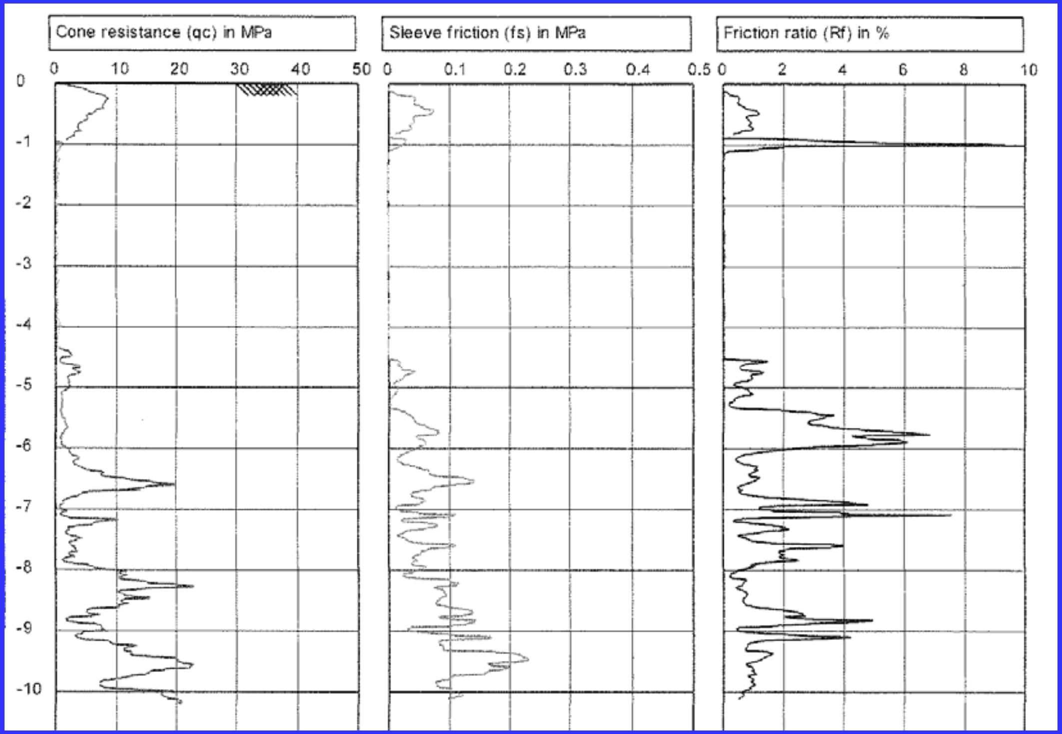


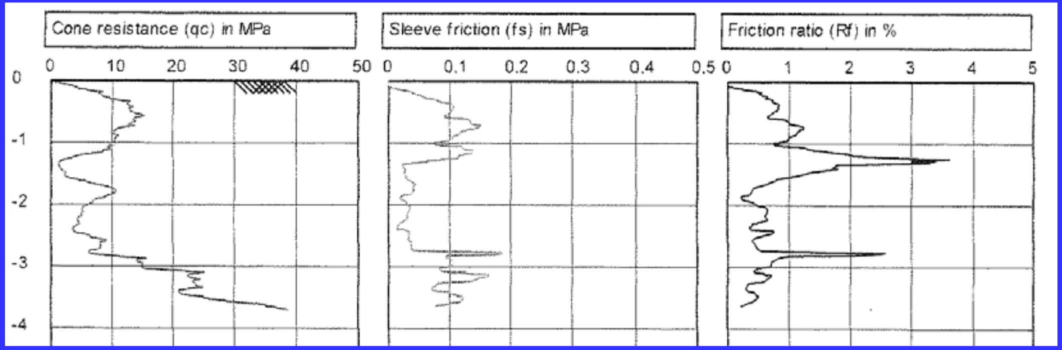


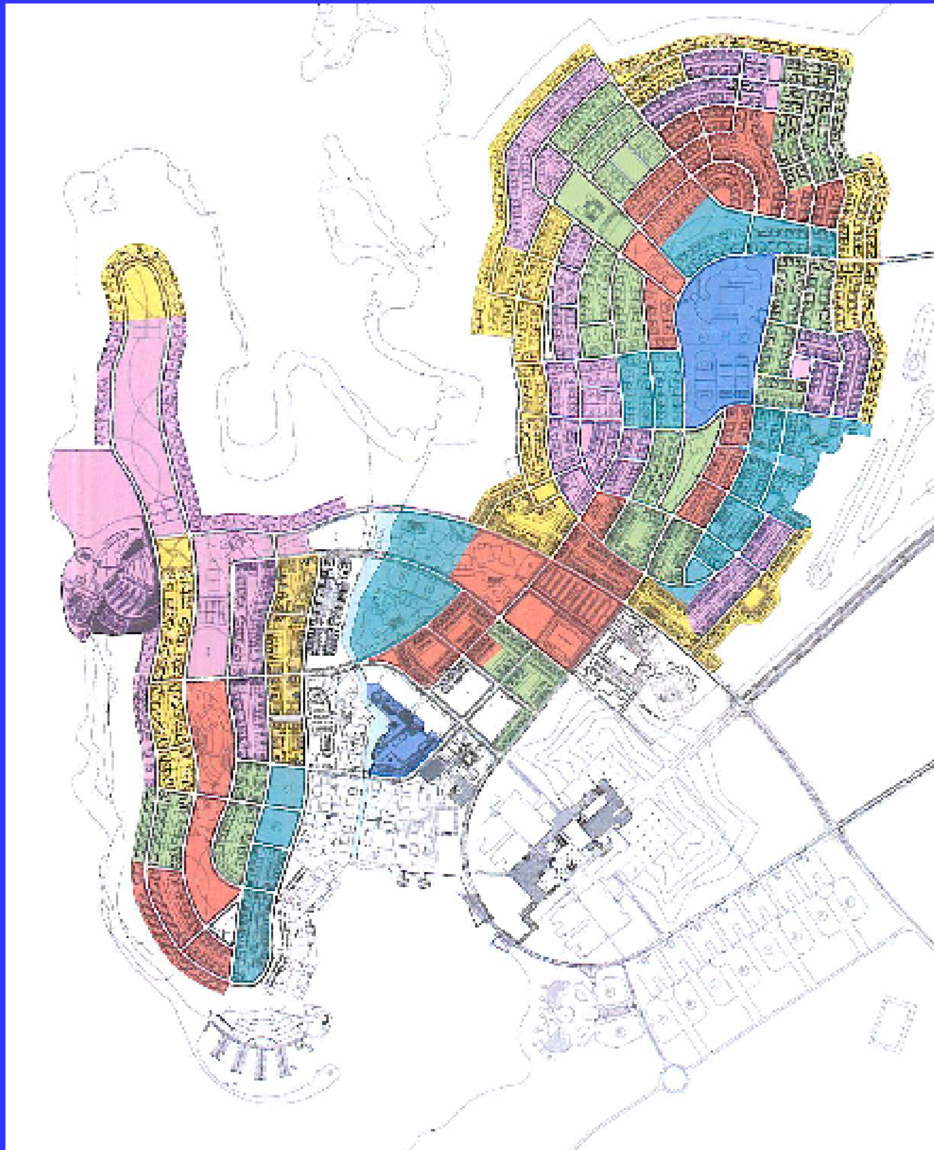
VARIATION IN SOIL PROFILE OVER 30 METERS



CPT AT 30 METERS DISTANCE





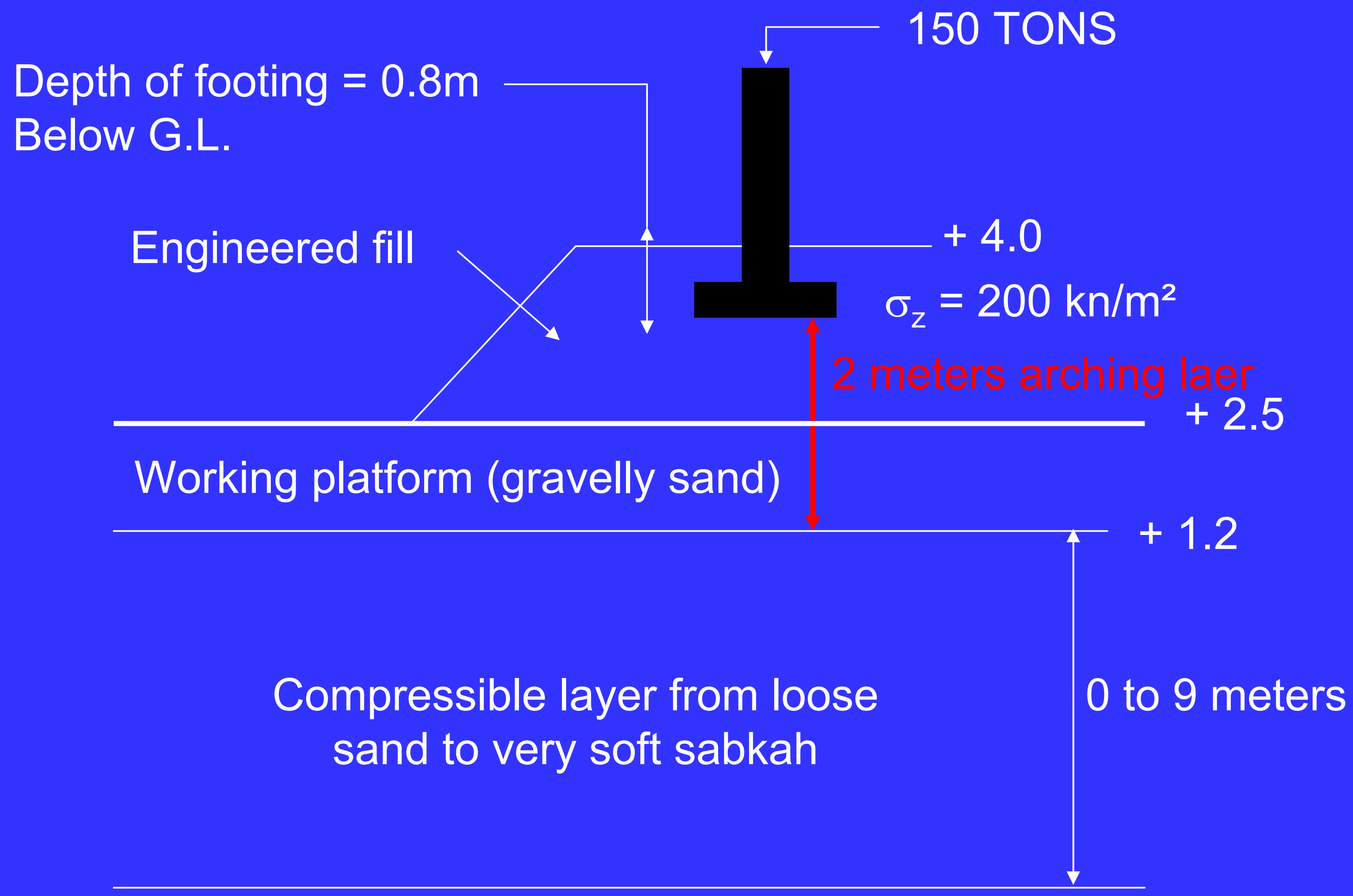


LEGEND

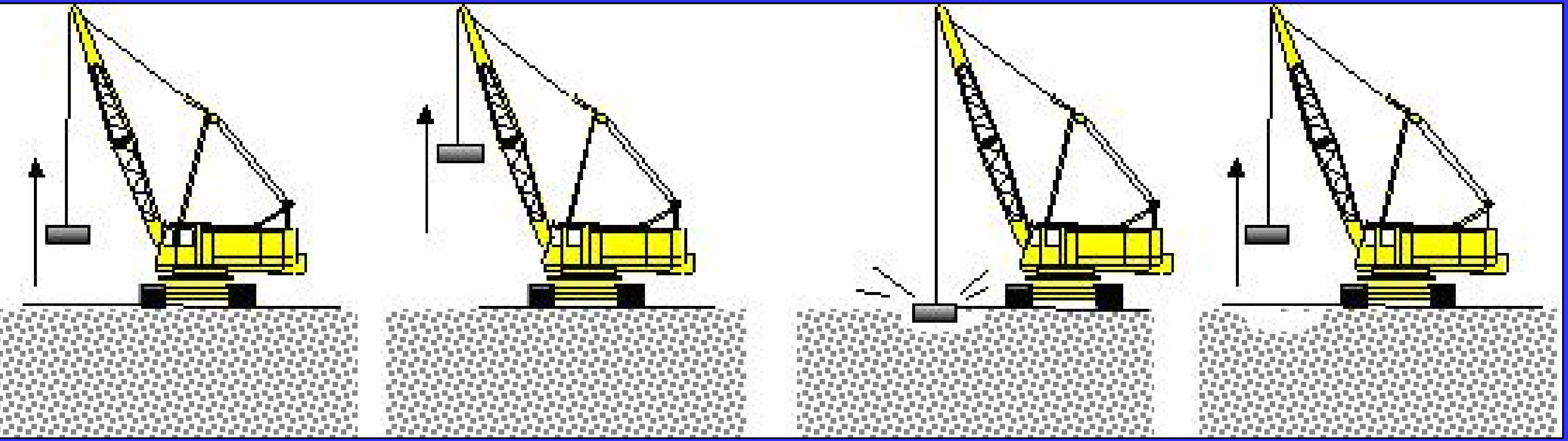
- 01/10/2007
- 05/10/2007
- 15/10/2007
- 01/11/2007
- 15/11/2007
- 15/12/2007

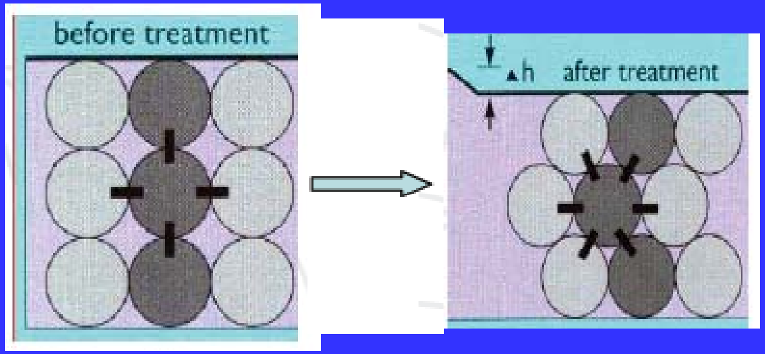
KAUST
Dates for Soil Improvement

Concept


150 TONS
Depth of footing = 0.8m
Below G.L.
Engineered fill
+ 4.0
σz = 200 kn/m²
2 meters arching laer
+ 2.5
Working platform (gravelly sand)
+ 1.2
Compressible layer from loose
sand to very soft sabkah
0 to 9 meters

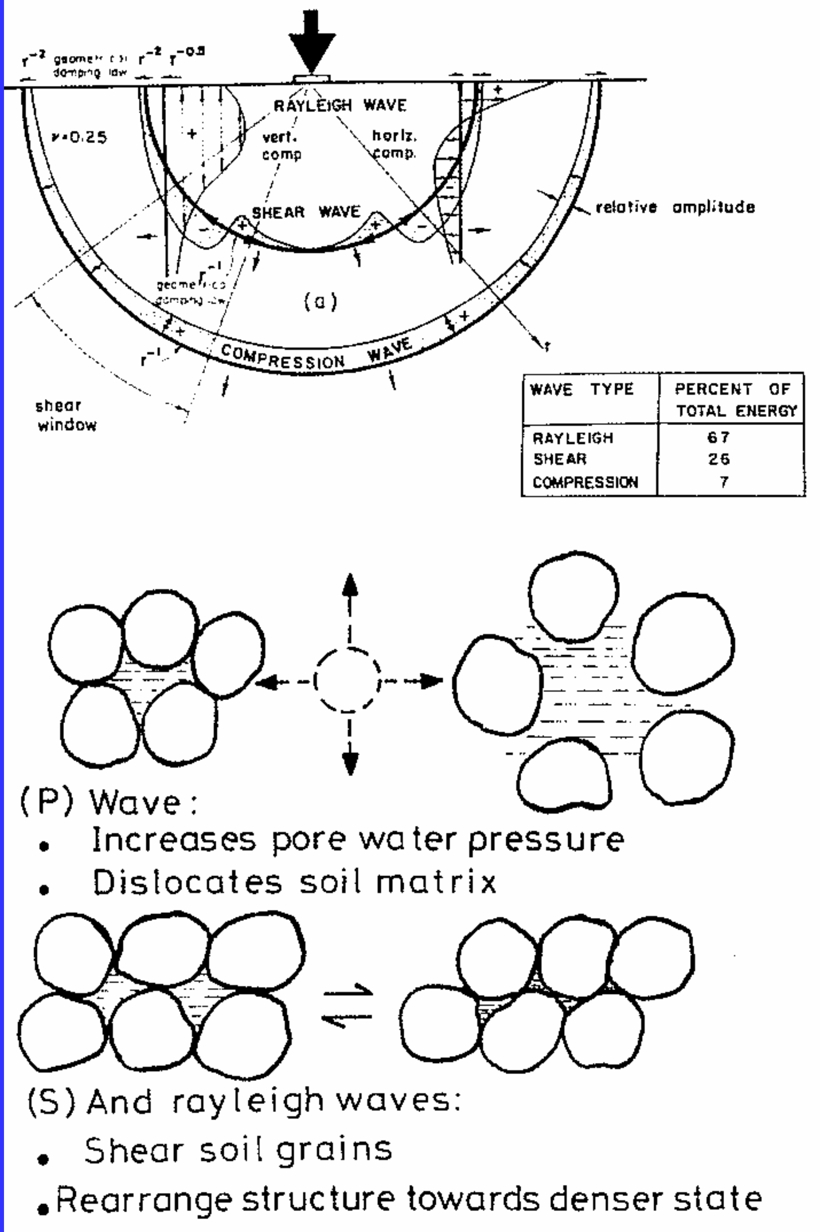
SELECTION OF TECHNIQUE



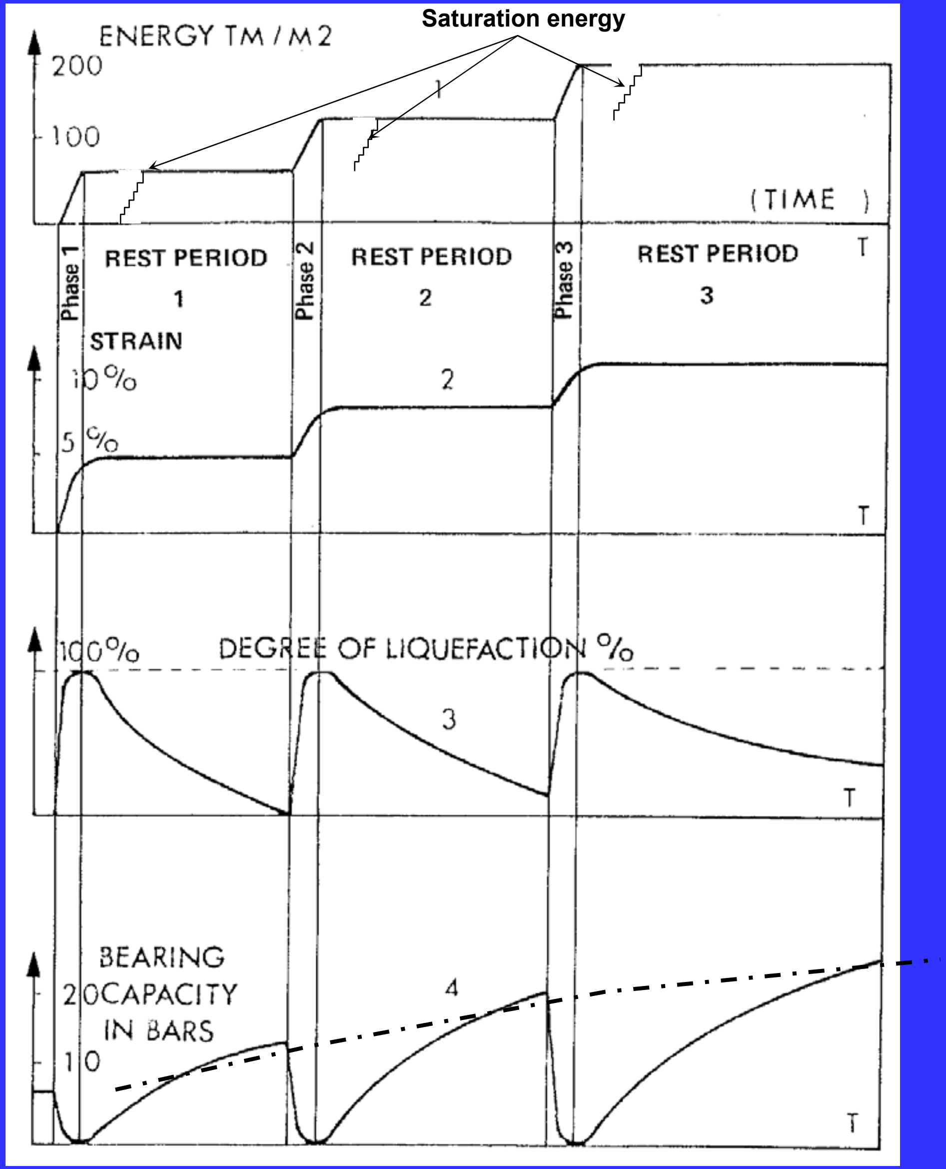


DC (Dynamic Compaction)

Shock waves during dynamic consolidation – upper part of figure after R.D. Woods (1968).



WAVE TYPE	PERCENT OF TOTAL ENERGY
RAYLEIGH	67
SHEAR	26
COMPRESSION	7



1. Applied energy in tm/m²
2. Volume variation as a function of time
3. Ratio of pore pressure to liquefaction pressure
4. Variation of bearing capacity
5. - · - · - · - · Envelope of improvement

$$h(m) = C\delta\sqrt{E}$$

(E, in ton.meters)

Where C is a function of type of tamping rig (to be measured for each equipment)

C = 1, free fall

C = 0,8 cable drop, mechanical winches

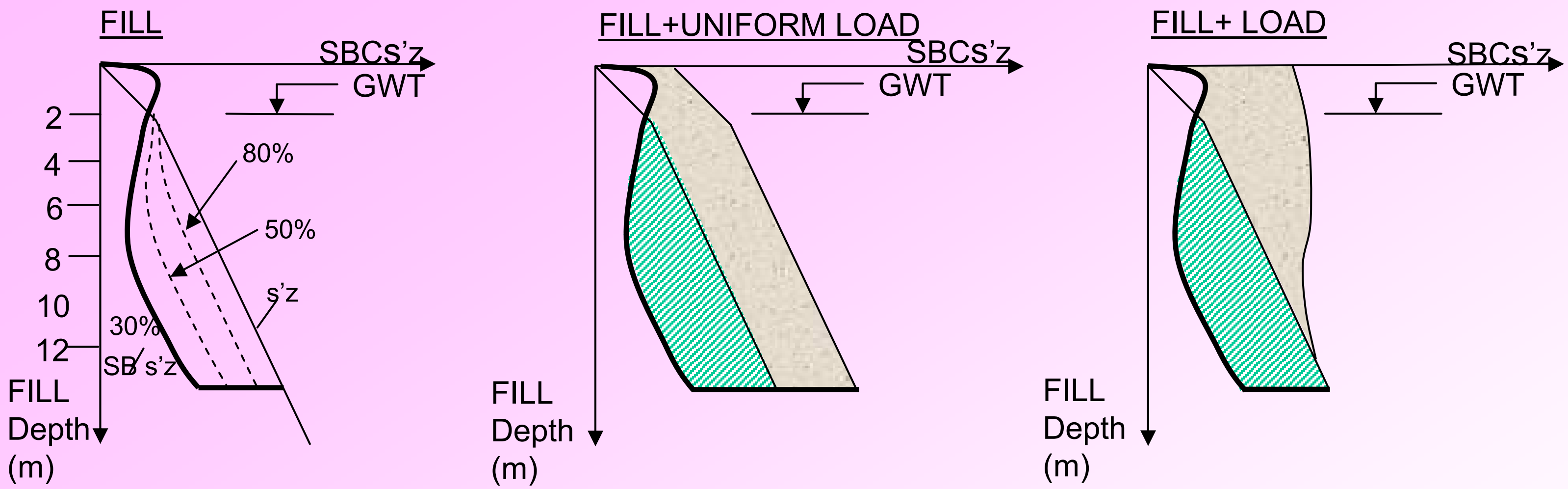
C = 0,65 cable drop hydraulic winches

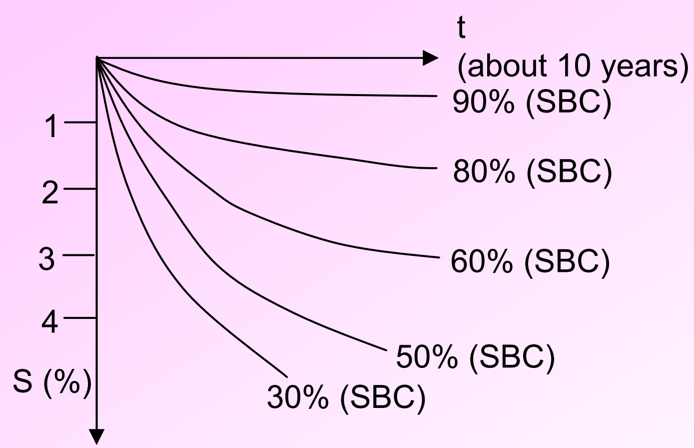
σ is a function of nature of soil, location of the pound water

σ ≅ 1,0 in metastable recent fills to reach self bearing level

σ ≅ 0,5 in normally consolidated deposits.

SELF BEARING BEHAVIOUR AND IMPROVEMENT REQUIREMENTS IN SAND FILL





DC : h(m) ∈ $\delta\sqrt{E}$

C(menard) = 0.9-1

C(hydraulic) = 0.55

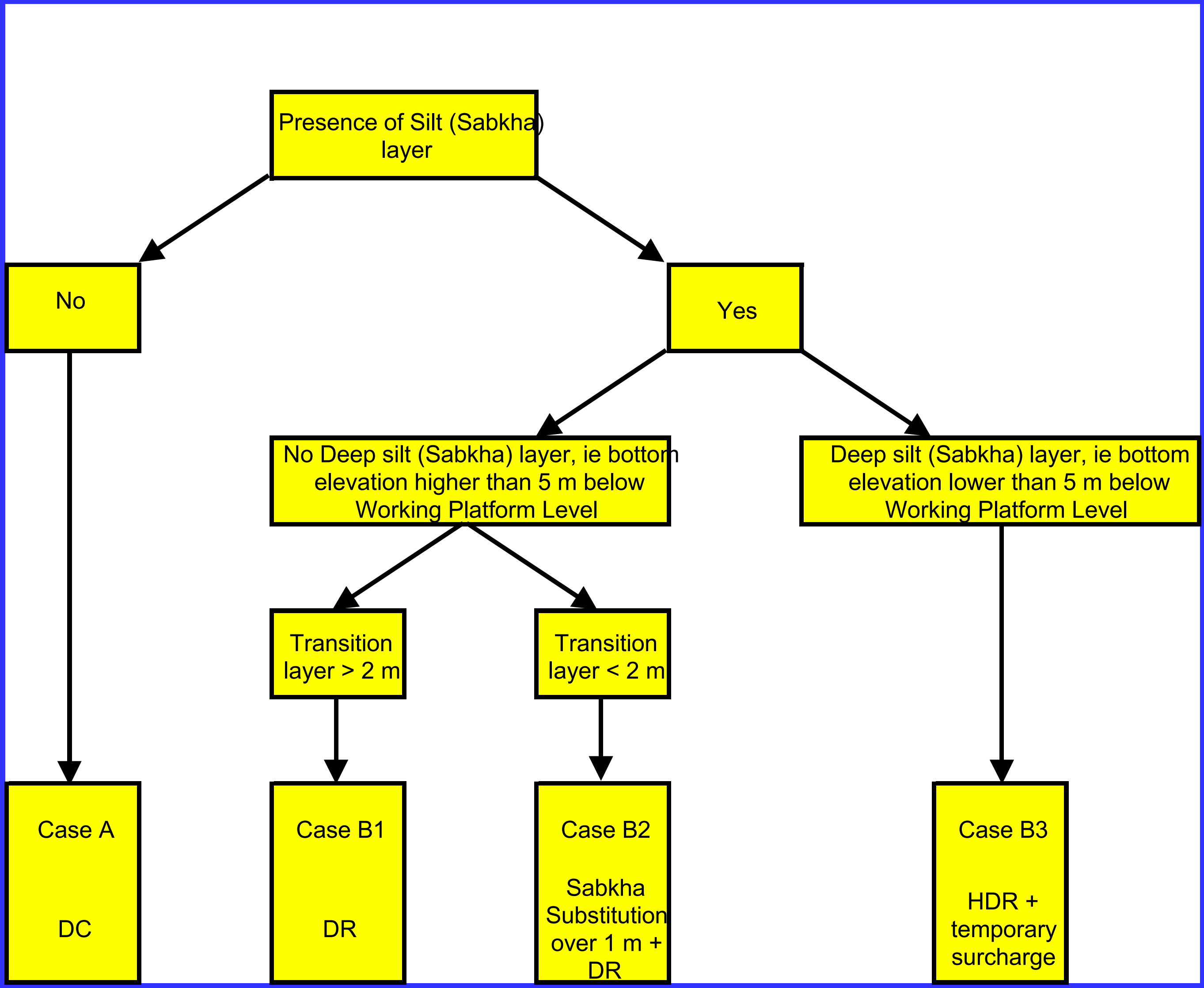
δ → SBC → = 0.9-1 (SILICA SAND)

δ → LOAD → = 0.4-0.6 (SILICA SAND)

S.B.C. = Self Bearing Coefficient

S.B.C. = $\frac{S(t)}{S(\infty)}$

DECISION PROCESS OF SELECTION OF TECHNIQUE



PRESSUREMETER TEST (PMT)

In-situ ***stress controlled loading test*** to measure the ***in-situ*** strength and stress-strain (deformation) characteristics of soil at depth.

(ASTM D4719-87; N.M.IS2; NEN-EN-ISO 22476-4:2005; Eurocode 7)

A ***direct design procedure*** using PMT test data for the calculation of:

- ***Bearing capacity*** of shallow and deep foundations
- ***Settlement*** of foundations

TYPICAL LOADING TESTS

Typical ***load tests*** conducted on foundations :

(i) PBT; and
(ii) PMT
(*not CPT or SPT*)

PBT – vertical load test

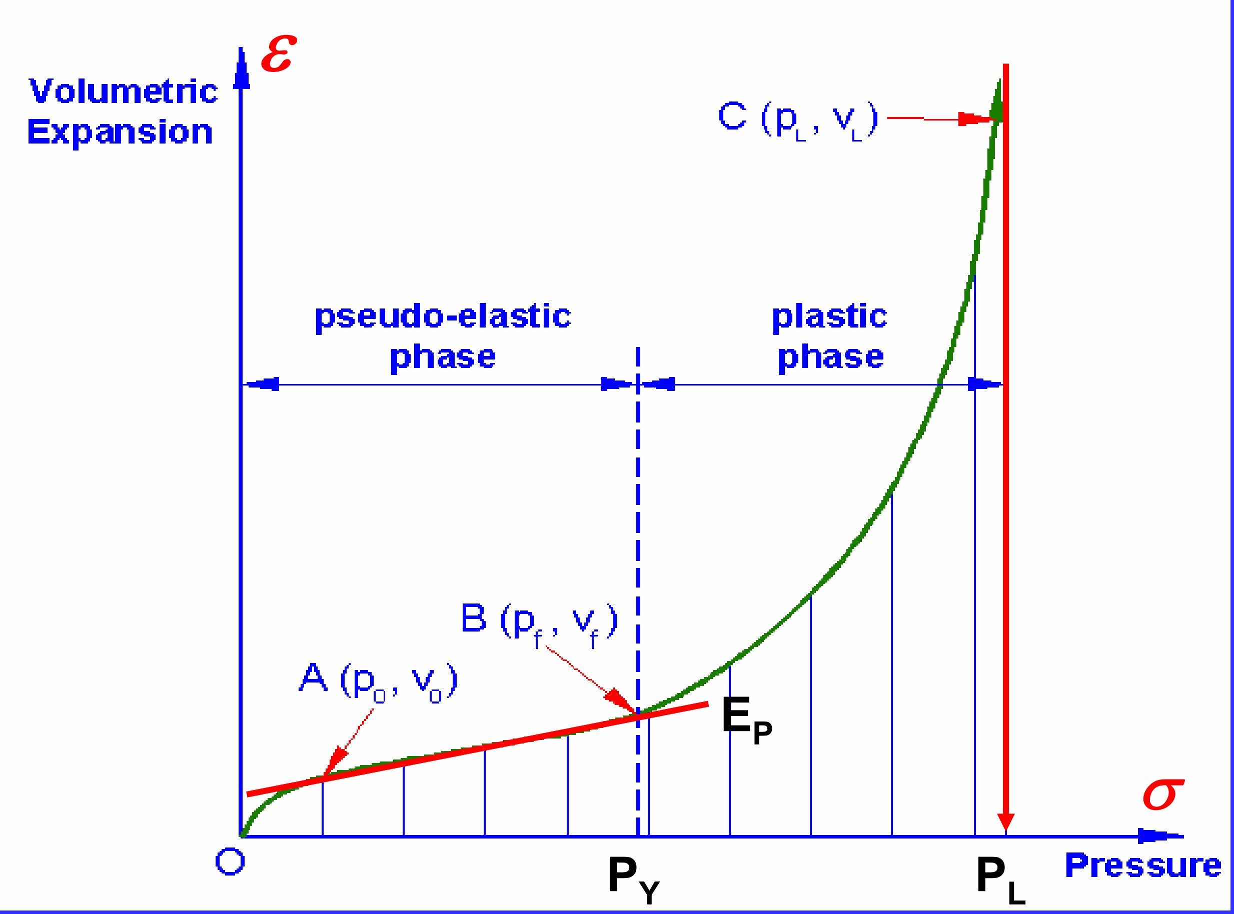
PMT – shear test

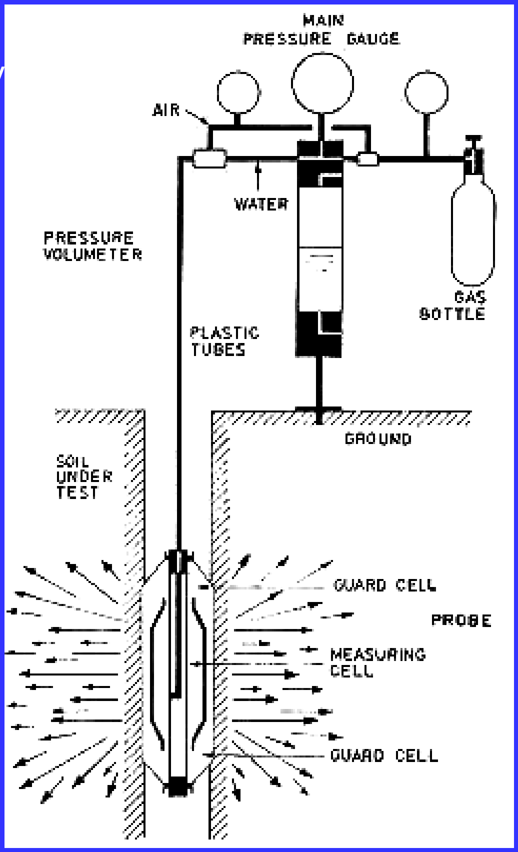
STRESS – STRAIN CURVE OF PMT RESULTS

From the stress-strain (σ vs. ε) curve:

1. ***Limit Pressure (P_L)***
   – for bearing capacity (= $5.5C_u$).

2. ***Pressuremeter Modulus (E_P)*** – for settlement (E_y
   (*α = 2/3 for clay; 1/2 for silt and 1/3 for sand*)

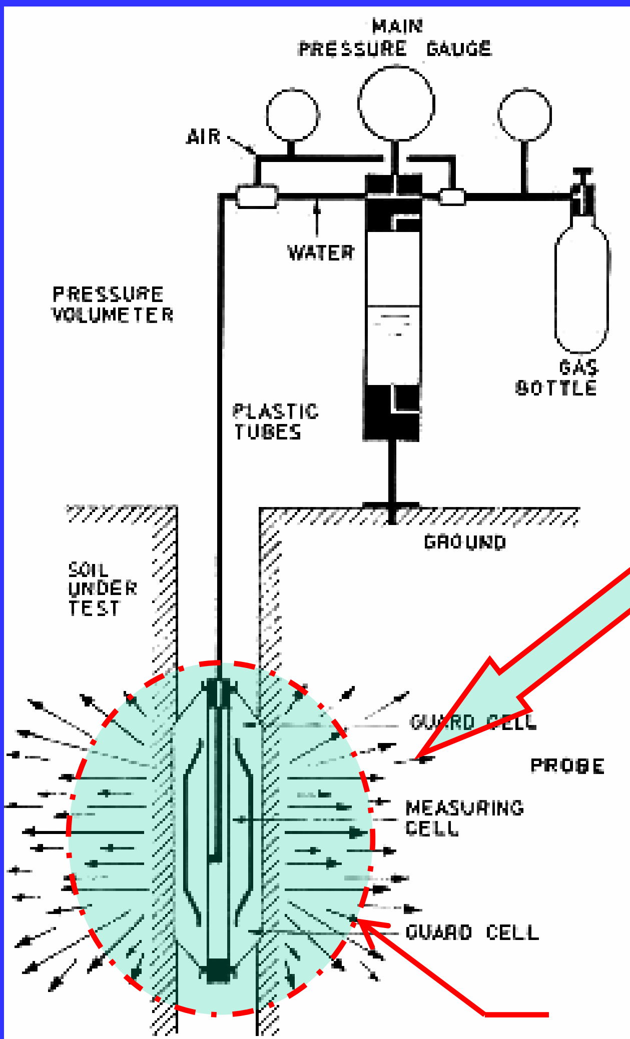


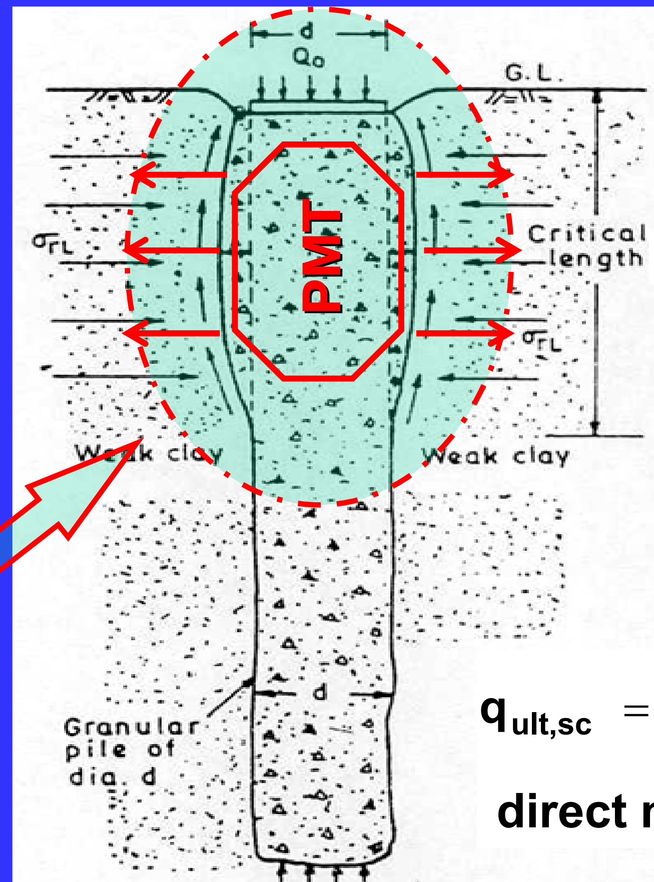


Pressure up to 40 bars acting on surrounding soil = shear deformations test.

PMT COMPARED WITH LOADING OF COLUMN

PMT loading test applies the ***cavity expansion theory*** which is similar to granular column bulging under applied vertical load.



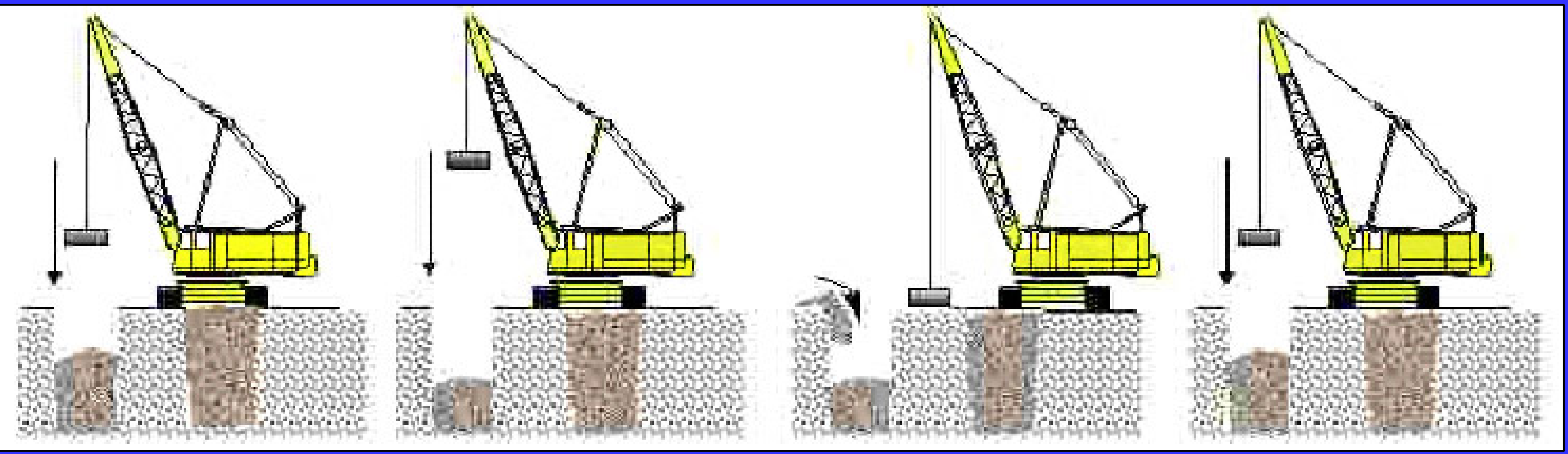


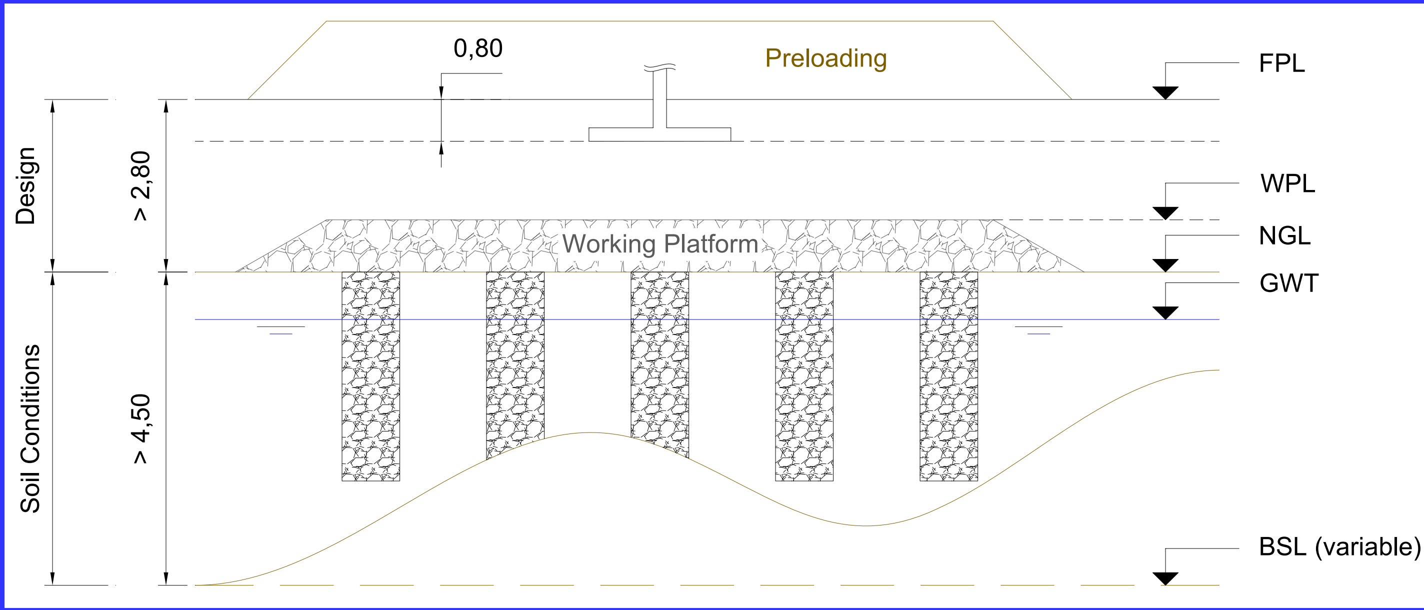
$$q_{ult,sc} = \tan^2\left(\frac{\pi}{4} + \frac{\varphi_{sc}}{2}\right)P_L$$

direct measurement of P_L

Pressure induced to fail the surrounding soil = ultimate bearing capacity of column supported by lateral pressure of the surrounding soil.

SELECTION OF TECHNIQUE





DR (Dynamic Replacement)
HDR (High Energy Dynamic Replacement) + surcharge

HUMAN RESOURCES

1. Project management (4)
2. Production team (32)
3. Mecanical team (18)
4. Survey team (16)
5. Administrative team (6)
6. Geotechnical team (8)
7. Safety and Quality (2)
8. Logistic team (4)

EQUIPMENT RESOURCES

- 13 DC/DR Rigs of 95 to 120 tons
- 15 pounders from 12-23 tons
- 30 vehicles (bus, 4x4, pick-up, berlines)
- 1 truck with crane
- 1 forklift
- 3 CPT rigs
- 1 drill + pressuremeter
- 15 containers
- 1 set of site offices

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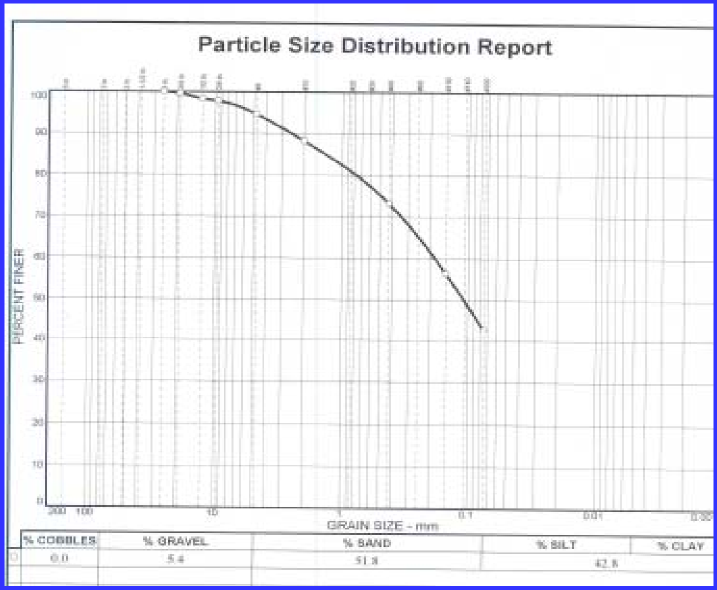
TYPICAL SURFACE CONDITIONS

TYPICAL TEST PITS (120) AND GRAIN SIZE



TYPICAL WORK SEQUENCE

		DC (300 Txm)	DR / HDR (300-500 Txm)
PHASE 1	Pass 1	6 – 10 blows	1 – 2 blows
	Pass 2	2-3 blows	2 blows
	Pass 3	NA	5 blows (densify DR column)
PHASE 2	Pass 1	NA	2 blows
	Pass 2	NA	2 blows
	Pass 3	NA	5 blows

PARAMETERS QUALITY CONTROL VISUAL

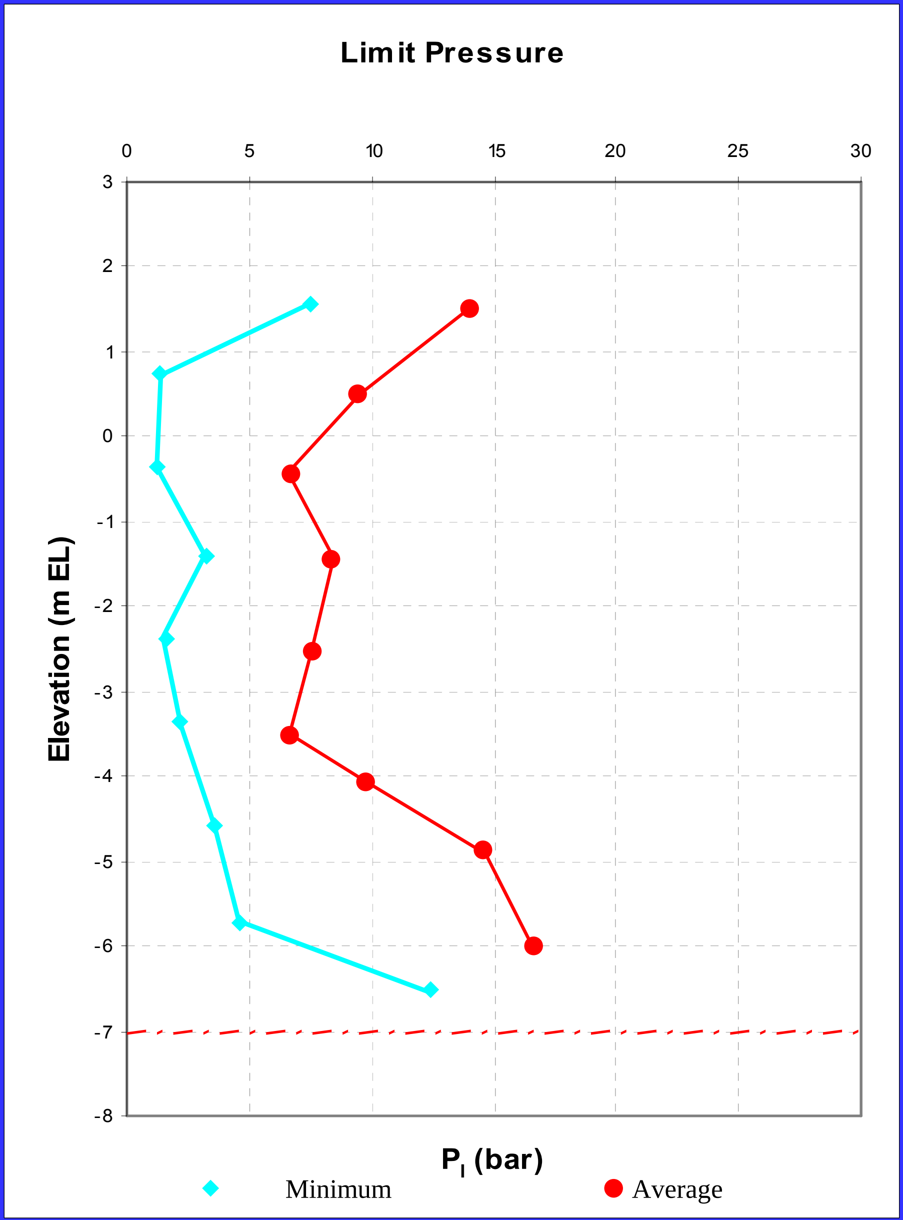
	DC	DR / HDR
Description of impacts	High intensity	Soft in 2 first blows
Selection of pounder	4 m² - 15-23 tons	3 m² variable weight
Drop hight	20 m	Adapted to heave intensity (5-20 m)
Heave	negligable	High during first to passes decreasing
Diameter of prints	3.5 – 4 m	2.3 – 3.5 m
Penetration	≅ 25 cm / blow	100 cm / blow
Water observed	frequent	rare
Rest period between phases	1-3 days	7 to 21 days
Transition layer	Not required	Required to form arching
Surcharge	NA	Required for HDR

TYPICAL DC FIELD (6 BLOWS)

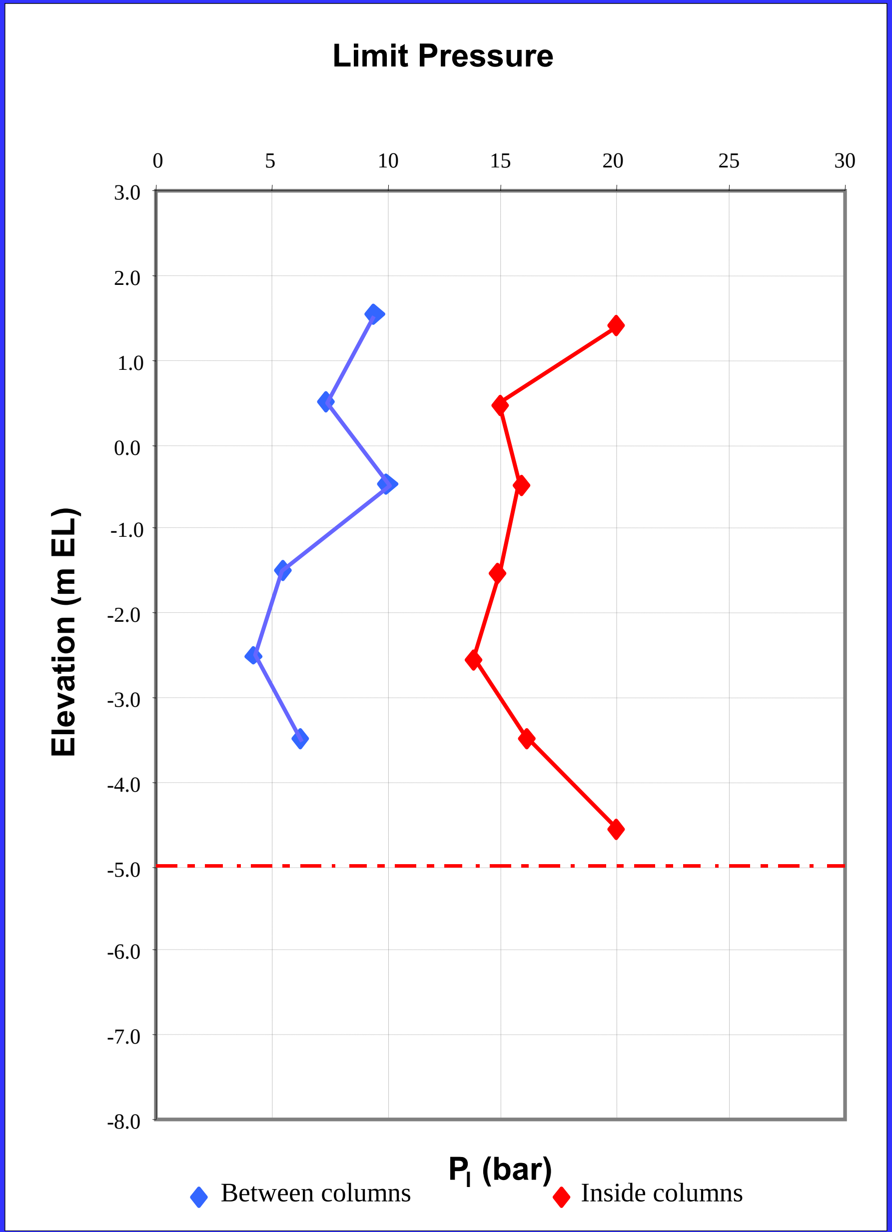
TYPICAL DR (1 to 2 blows)

DUMPING SAND FROM POUNDER

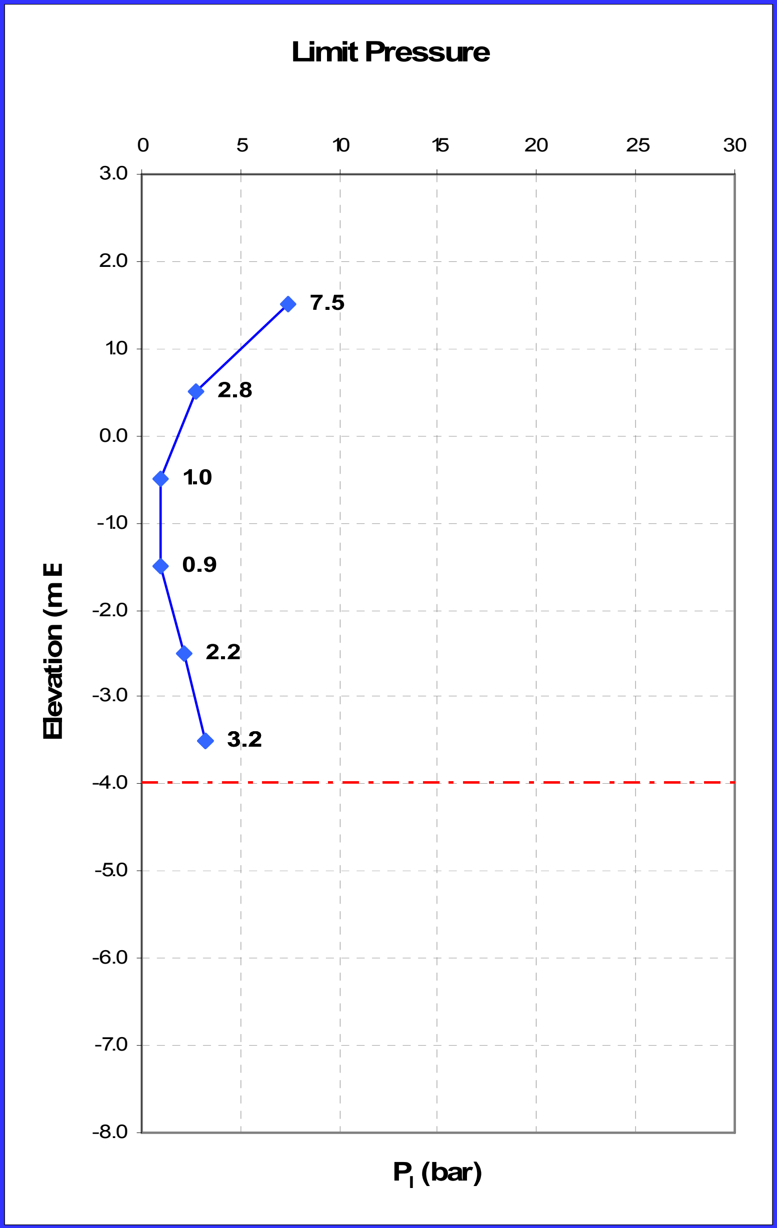
Before DC



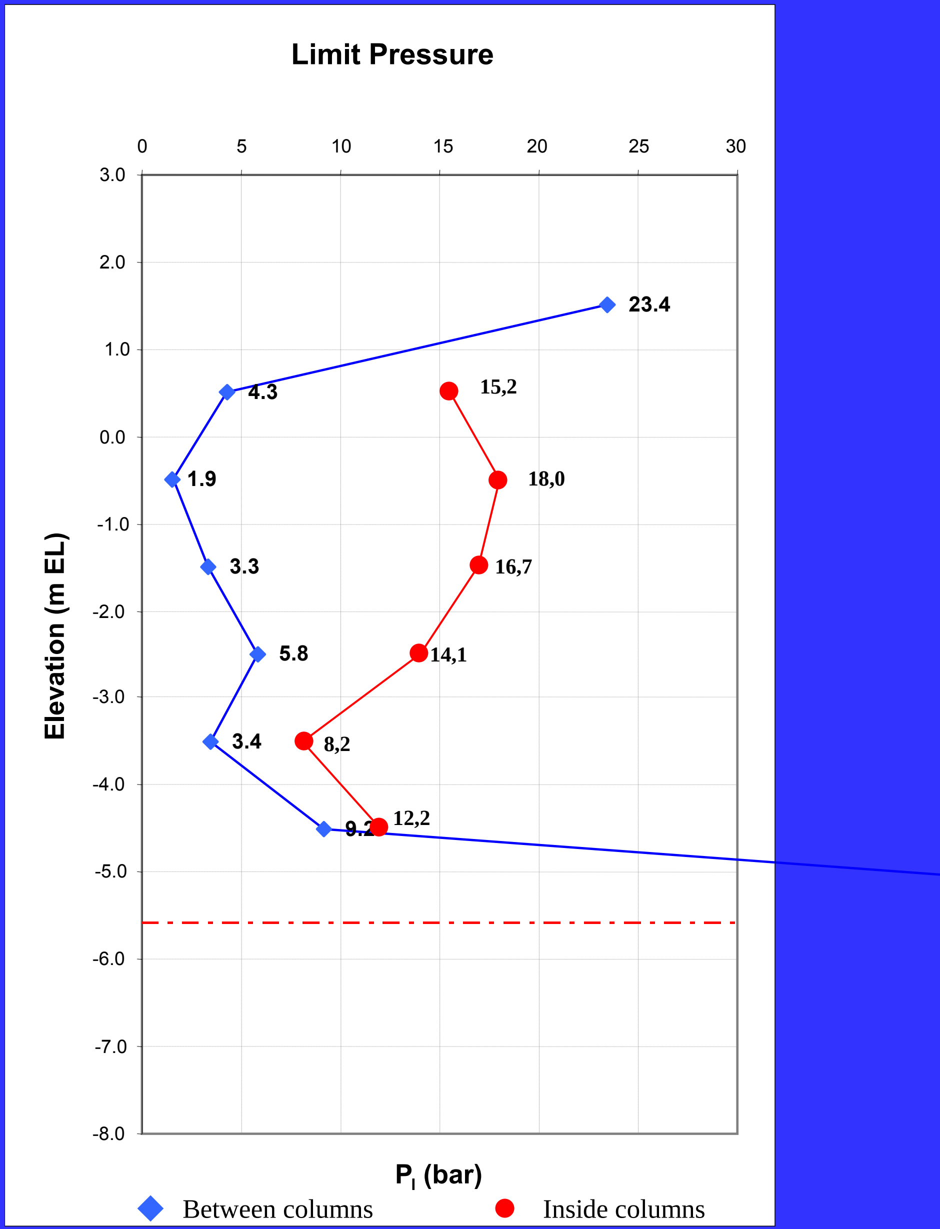
After DC – Between columns



Before DR

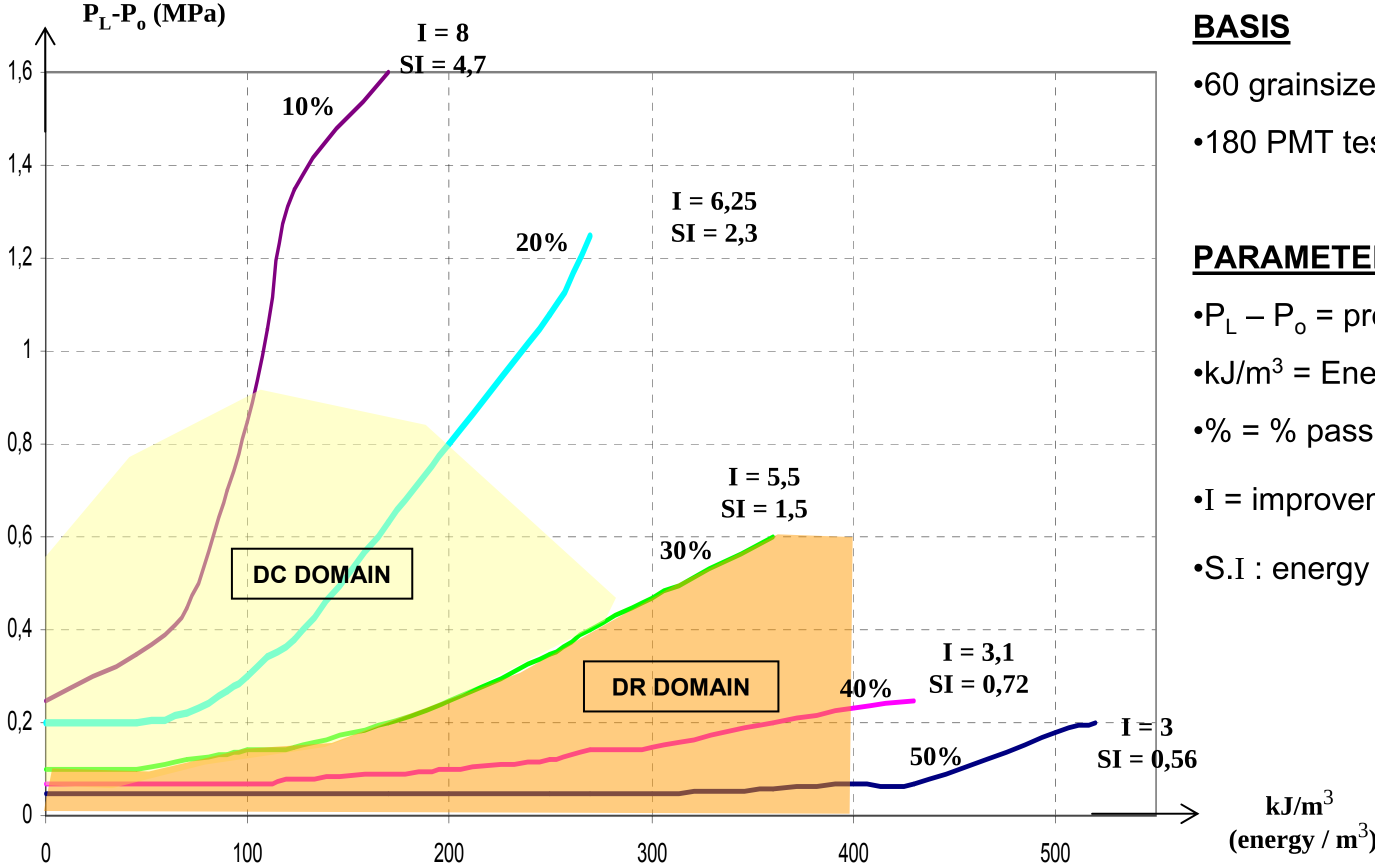


After DR – Between columns



ANALYSIS OF (P_L-P_o) IMPROVEMENT AS FUNCTION OF ENERGY AND FINES

K.A.U.S.T. – Saudi Arabia



BASIS

- 60 grainsize tests
- 180 PMT tests

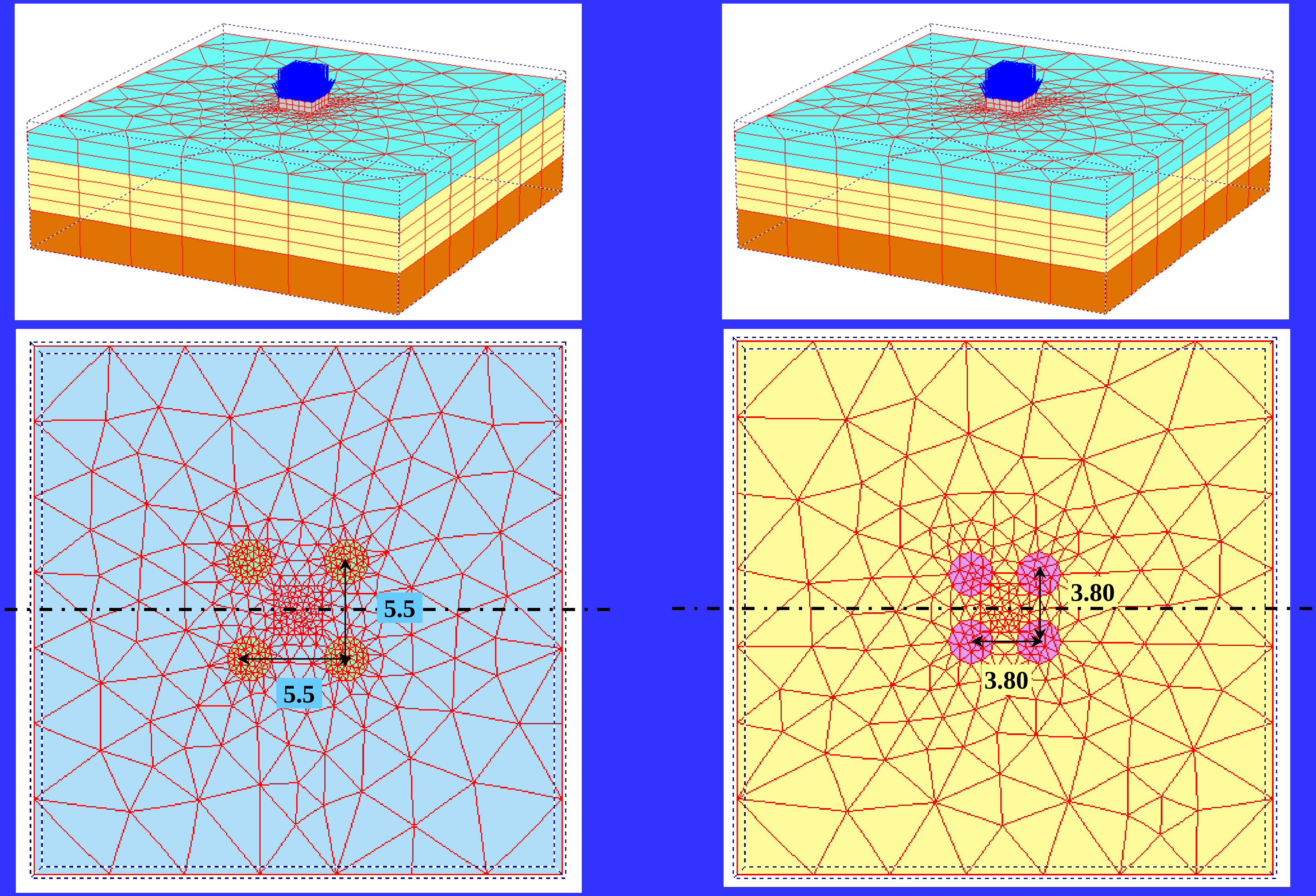
PARAMETERS

- $P_L - P_o$ = pressuremeter limit pressure
- kJ/m³ = Energy per m³ (E)
- % = % passing n°200 sieve
- I = improvement factor $\frac{P_{LF}}{P_{Li}}$
- S.I : energy specific improvement factor

$$\frac{I \times 100}{E}$$

STRESS DISTRIBUTION

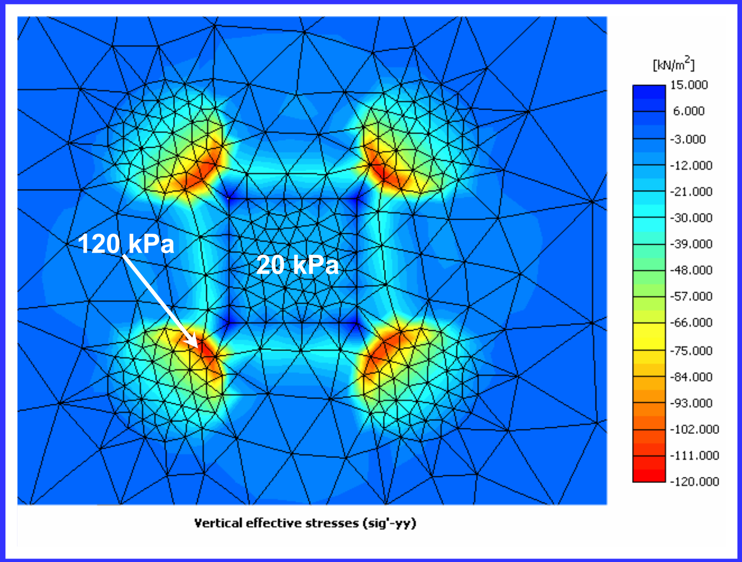
ANALYSIS OF WORST CASE FOR VARIOUS GRIDS

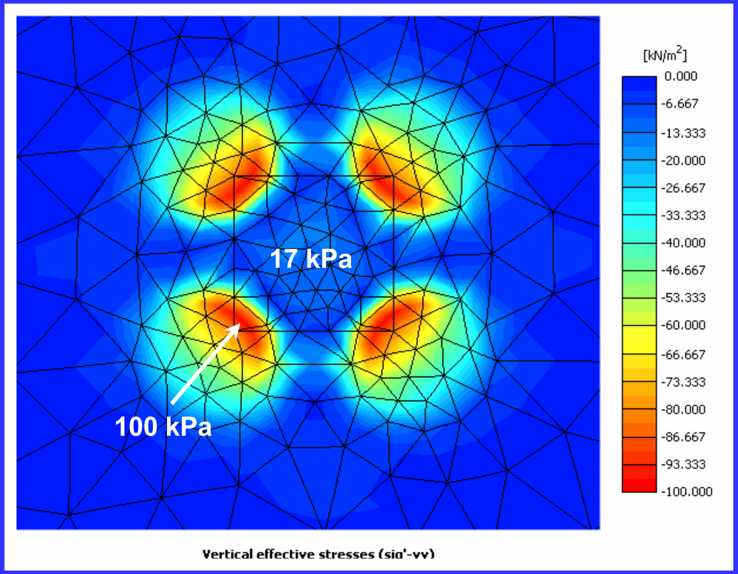


STRESS DISTRIBUTION

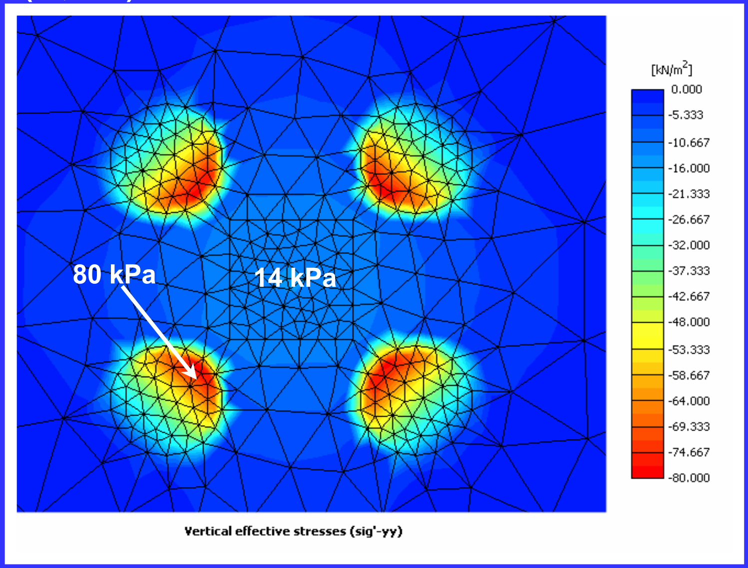
Grid 5,50 x 5,50 | Grid 3,80 x 3,80

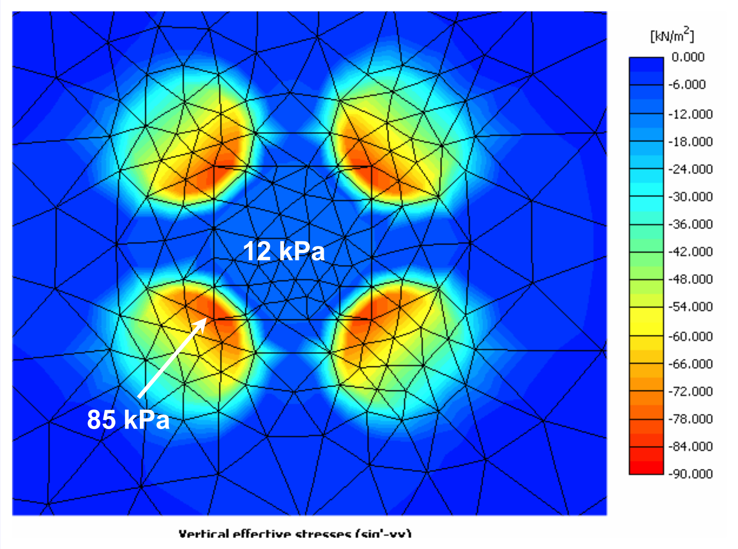
Stresses at El (0)





Stresses at El (-1,0 m)

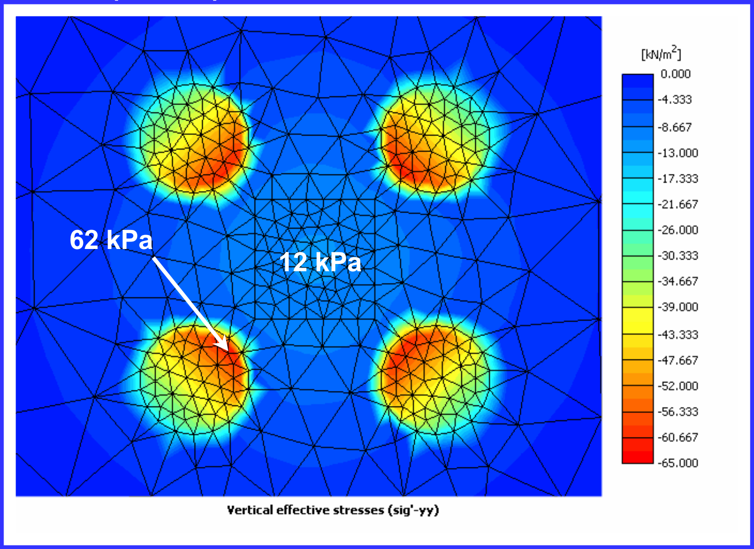


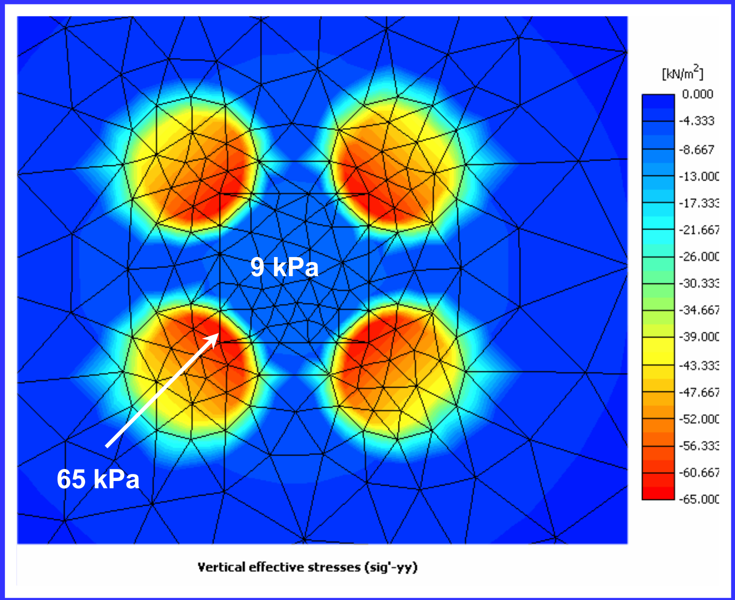


STRESS DISTRIBUTION

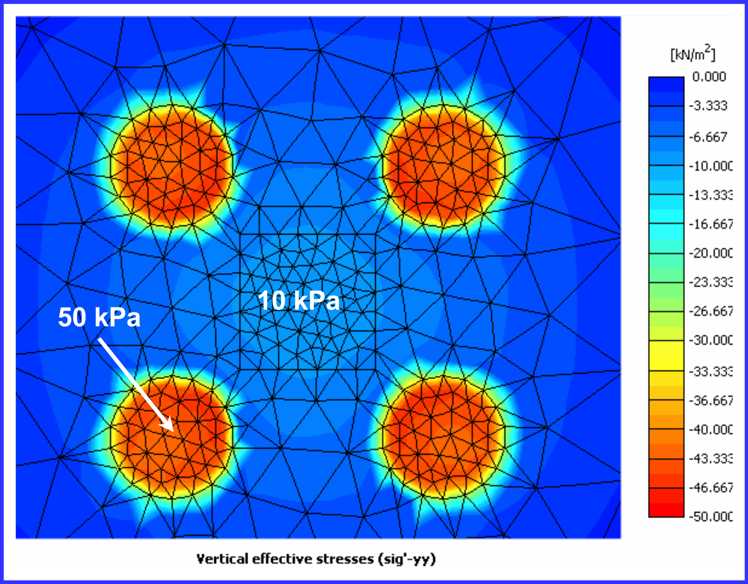
Grid 5,50 x 5,50 | **Grid 3,80 x 3,80**

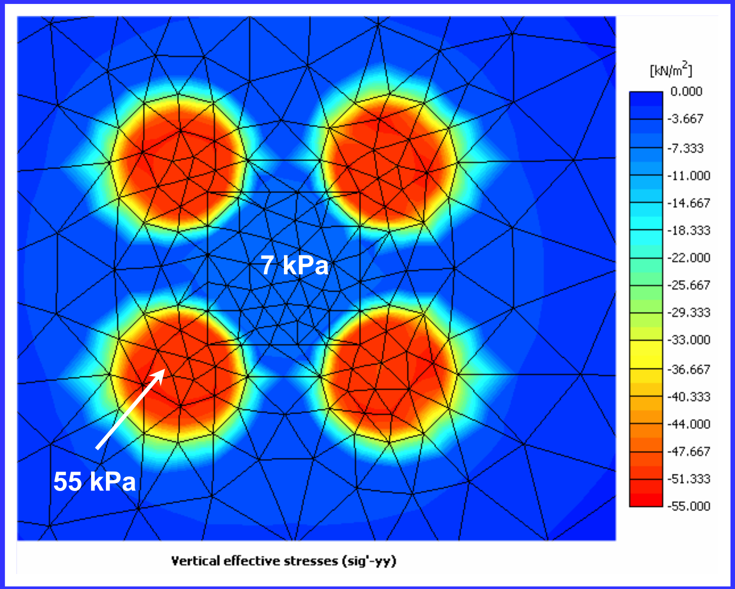
Stresses at El (-2,0 m)





Stresses at El (-3,0 m)





SITE PROCEDURE

A – Identify depth trend of SABKAH by CPT Tests

B – Closely eywitness the penetration of pounder to **confirm** **DC** or **DR** treatment

C – Verify by PMT that factor of safety is at least 3 for bearing capacity

D – Verify by stress analysis that limit pressure at any depth exceeds factors of safety of at least 3 in order to safely utilize the settlement analysis (no creep)

E – Vary the grid to obtain at any location the condition D

F – Test the gravelly sand columns and check if specified settlement is achieved

G – Monitor surcharge if HDR is required

SPREAD SHEET OF CALCULATION OF SETTLEMENT AND BEARING CAPACITY

Calculation of the Settlement and Bearing Capacity of a foundation
According to D60

MENARD

Project Name:		**According to PMT #:**				**Dated:**	
Zone Ref #		**X**		**Y**		**Z**	

DESCRIPTION OF SOIL, TREATMENT AND FOOTING TYPE

Footing Characteristics

Load		150	tons			
Mean contact stress	p	0,20	MPa	Hence:	L/B =	1,0
Length of the footing	L	2,74	m	And:	λ_3 =	1,10
Width of the footing	B	2,74	m		λ_2 =	1,12
Embedment	D	0,80	m			

DR Description

Mesh 5,50 m
Diameter 2,20 m
Hence, a = 12,6%
Pressuremeter characteristics
According to calibration #
$E_{m\text{-}DR}$ 10,0 Mpa
$P_{l\text{-}DR}$ 1,5 Mpa
α_{DR} 1/3

Soil Description

Layer #	Description	Soil category	DR	Thickness (m)	Depth from FPL (m)	γ (kN/m3)	Pressuremeter characteristics: Inter Prints (after Soil Improvement, as per above mentionned PMT) E_m (MPa)	Pl (MPa)	α	Homogeneized soil E_m (MPa)	Pl (MPa)	α
1	Engineering fill	III		1,5	1,5	20	20,0	2,5	1/3	20,0	2,50	1/3
2	Working platform	III		1,0	2,5	20	17,0	2,4	1/3	17,0	2,40	1/3
3	Soft Material	II		1,0	3,5	20	11,1	1,3	1/3	11,1	1,30	1/2
4	Soft Material	II		1,0	4,5	20	6,3	1,0	1/3	6,3	1,00	1/3
5	Soft Material	II		1,0	5,5	20	16,3	2,5	1/3	16,3	2,50	1/3
6	Soft Material	II		1,0	6,5	20	12,2	2,1	1/3	12,2	2,10	1/3
4	Soft Material	II		1,0	7,5	20	3,7	0,6	1/3	3,7	0,60	1/3
5	Sandy material	III		20	27,5	20	35,0	5,0	1/3	35,0	5,00	1/3

Remark: The depth described is sufficient

$$P_{l-eq} = aP_{l-DR} + (1-a)P_{l-soil} \qquad \alpha_{eq} = a\alpha_{DR} + (1-a)\alpha_{soil} \qquad E_{m-eq} = aE_{m-DR}\frac{\alpha_{eq}}{\alpha_{DR}} + (1-a)E_{m-soil}\frac{\alpha_{eq}}{\alpha_{soil}}$$

D60 MODELISATION

Modulus

E1 18,41 MPa
E2 11,84 MPa
E3,5 7,20 MPa
E6,8 35,00 MPa
E9,16 35,00 MPa

$$E_A = E_1$$

$$E_B = \frac{4}{\frac{1}{E_1} + \frac{1}{0.85E_2} + \frac{1}{E_{3,5}} + \frac{1}{2.5E_{6,8}} + \frac{1}{2.5E_{9,16}}}$$

E_A 18,41 MPa (spherical modulus)
E_B 12,68 MPa (deviatoric modulus)

α_1 0,33 Spherical component
$\alpha_{2,16}$ 0,34 Deviatoric component

Limit Pressure

pl'2	2,46 MPa	Hence	pl'e	1,81 MPa	Thus	he/R	0,83
pl'3	1,33 MPa	And	he	1,13 m	And	k	1,07

CALCULATION RESULTS

Bearing Capacity

$$q_a = \frac{k}{3} p'_{le}$$

qa 643 kPa

Higher than 200 kPa => Specification reached

Settlement

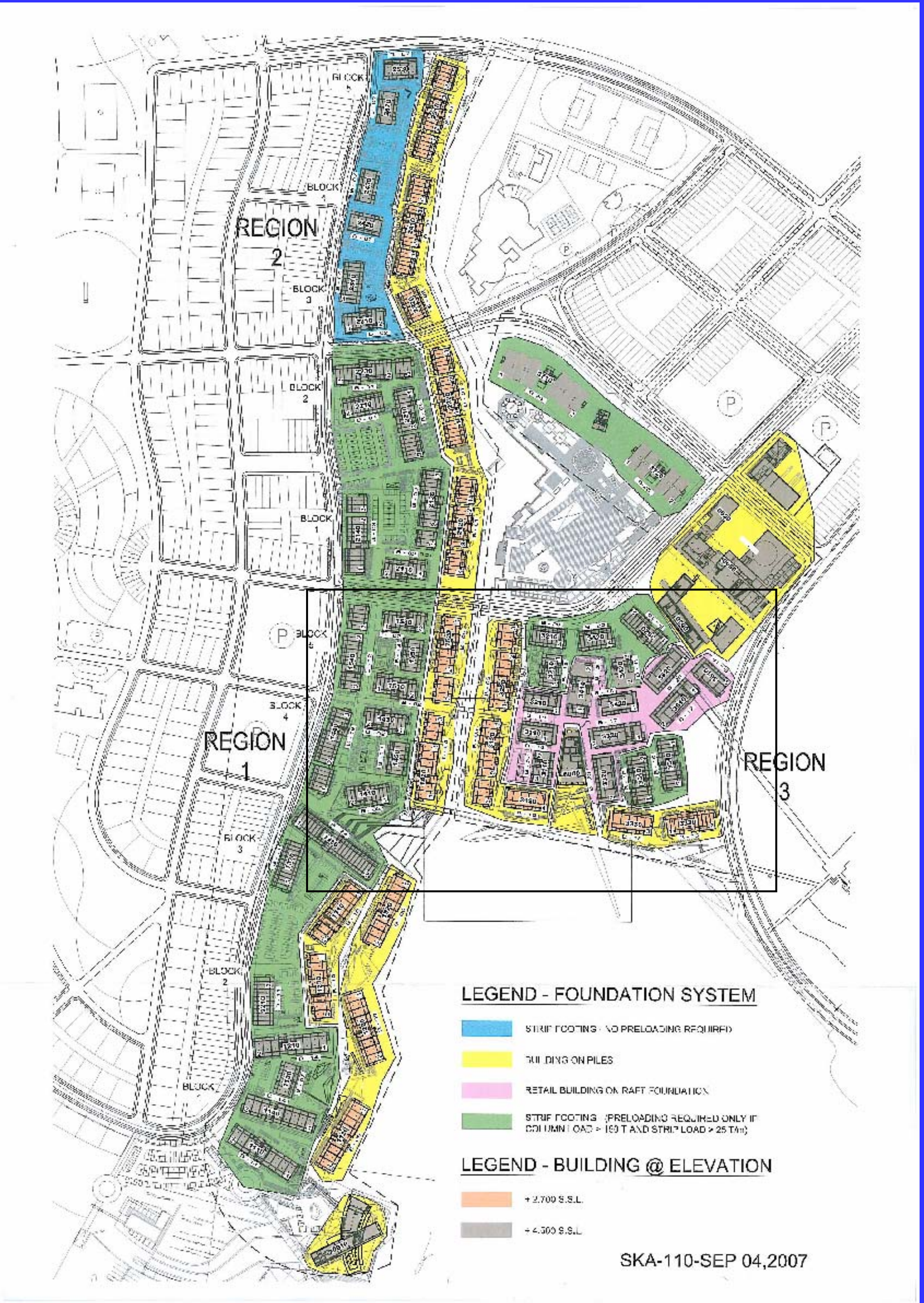
$$w = \frac{1.33}{3E_B} pR_0 \left(\lambda_2 \frac{R}{R_0}\right)^{\alpha_{2,16}} + \frac{\alpha_1}{4.5E_A} p\lambda_3 R$$

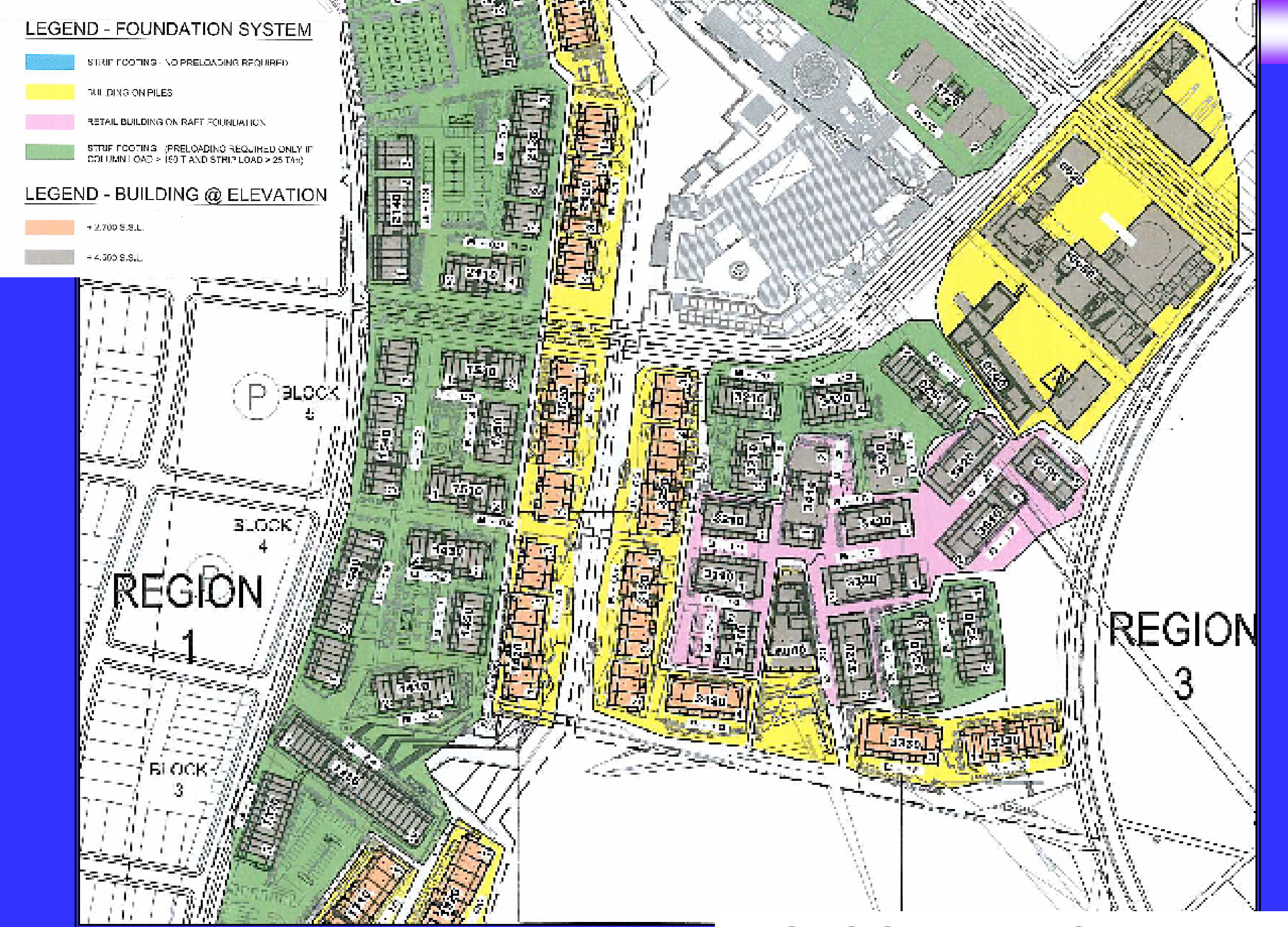
w 5,83 mm

Lower than 25 mm => Specification reached

PROVISIONNAL

MASTER PLAN





PROVISIONNAL MASTER PLAN

It can be assumed that those impacts du generate a pore pressure at least equal to the pore pressure generated by the embankment load.

This new consolidation process with the final at a time t'_f, where

$$T_V = 0,848 = \frac{C'_v(t'_1 - t_1)}{H^2} + \frac{C_v T_1}{H^2}$$

With

$$C'_V = C_V \left[1 + \frac{du}{\Delta\sigma(1 - U_1)} \right]$$

the following equation allows to compare the respective times of consolidation being :

t'_f with impact
t_f without impact

$$t'f = \frac{du}{du + \Delta\sigma(1 - U_1)} t_1 + \frac{\Delta\sigma(1 - U_1)}{du + \Delta\sigma(1 - U_1)} t_f$$

For this considered case,

$$du = U\Delta\sigma$$

and thus $t'_f = U_1 t_1 + (1-U_1)t_f$

The Table allows to compare the gain in consolidation time, at different degrees of consolidation.

U_1	10%	20%	30%	40%	50%	60%	70%	80%	90%
t_1/t_f	0.009	0.037	0.083	0.148	0.231	0.337	0.474	0.669	1.00
t'_1/t_f	0.901	0.807	0.725	0.659	0.615	0.602	0.632	0.735	1.00

Supposing primary consolidation completed
$U = 0.9$ or $T = 0.848$ if $du=U_1\Delta\sigma$,
then $t'_f = U_1 t_1 + (1-U_1)t_f$

The optimal effectiveness occurs around $U_1 = 60\%$.
One can thus conclude that, theoretically the consolidation time is reduced by 20% to 50%, what is for practical purpose insufficient.

THANK YOU !

ISSMGE TC - 17

MENARD
Sustainable Technology

CFMS / BGE Joint Meeting

7th December, 2007

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Physical stabilisation of deep fill

Stabilisation physique de remblai profond

Ken Watts

Building Technology Group

Contents
Contenu

- Deep fills and land re-generation – *Remblais profonds et regén ération de terrain*
- Foundation problems on non-engineered fills
  Problèmes de foundation sur des remblais non contrôlés
- Collapse compression
  Compression d'affaissement
- Current solutions
  Solutions courantes
- Alternative solution - Laboratory and field studies
  Solution alternative – études de laboratoire et sur le terrain

Deep fills and land re-generation

Remblais profonds et regén ération de terrain

- UK National Land Database identified 66,000 ha of brownfield land
- English Partnerships (UK National Regeneration Agency) manages 107 former coalfield sites and many contain substantial deposits of deep, poorly compacted fill
- Former open cast mining sites have produced the deepest deposits of non-engineered fill
- Approximately 15m^3 of overburden extracted to produce 1tonne coal

Deep fills and land re-generation

Remblais profonds et regén ération de terrain

- Former ironstone opencast mine, Corby
- Depth of fill 24m
- Small experimental site
- Whole area now restored for housing

- Formerly Orgreave deep / opencast mine
- Depth of fill 80m - 129m
- 280 ha restored site
- UK Coal will develop approximately 93,000 sq m of business space and up to 4,000 new homes in a new community close to Sheffield.

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Foundation problems on non-engineered fills

Problèmes de foundation sur des remblais non contrôlés

- Self-weight creep settlement
- Excessive settlement under applied loads
- Differential settlement where depth varies
- Most serious hazard for low-rise buildings on fill – collapse compression on wetting

Collapse compression

Compression d'affaissement

- Widespread phenomenon affecting both fills and natural soils and can occur without any change in applied stress
- Most partially saturated fills are susceptible if placed in a sufficiently loose and/or dry condition
- Triggered by rise in ground water or downward percolation of surface water
- Mudstone/sandstone = 1-2%, stiff clay fill = 3-6%, colliery spoil = 7% (20m @ 5% = 1m at surface)
- Passage of time does not eliminate collapse potential

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Causes

Mechanisms of collapse:

- Inter-granular bonds within the fill may be weakened or eliminated by an increase in moisture content
- Parent material from which the fill is formed may lose strength as its moisture content increases and approaches saturation
- Where a fill is formed of aggregations of fine particles, such as lumps or clods of clay, these aggregations may soften and weaken as the moisture content increases

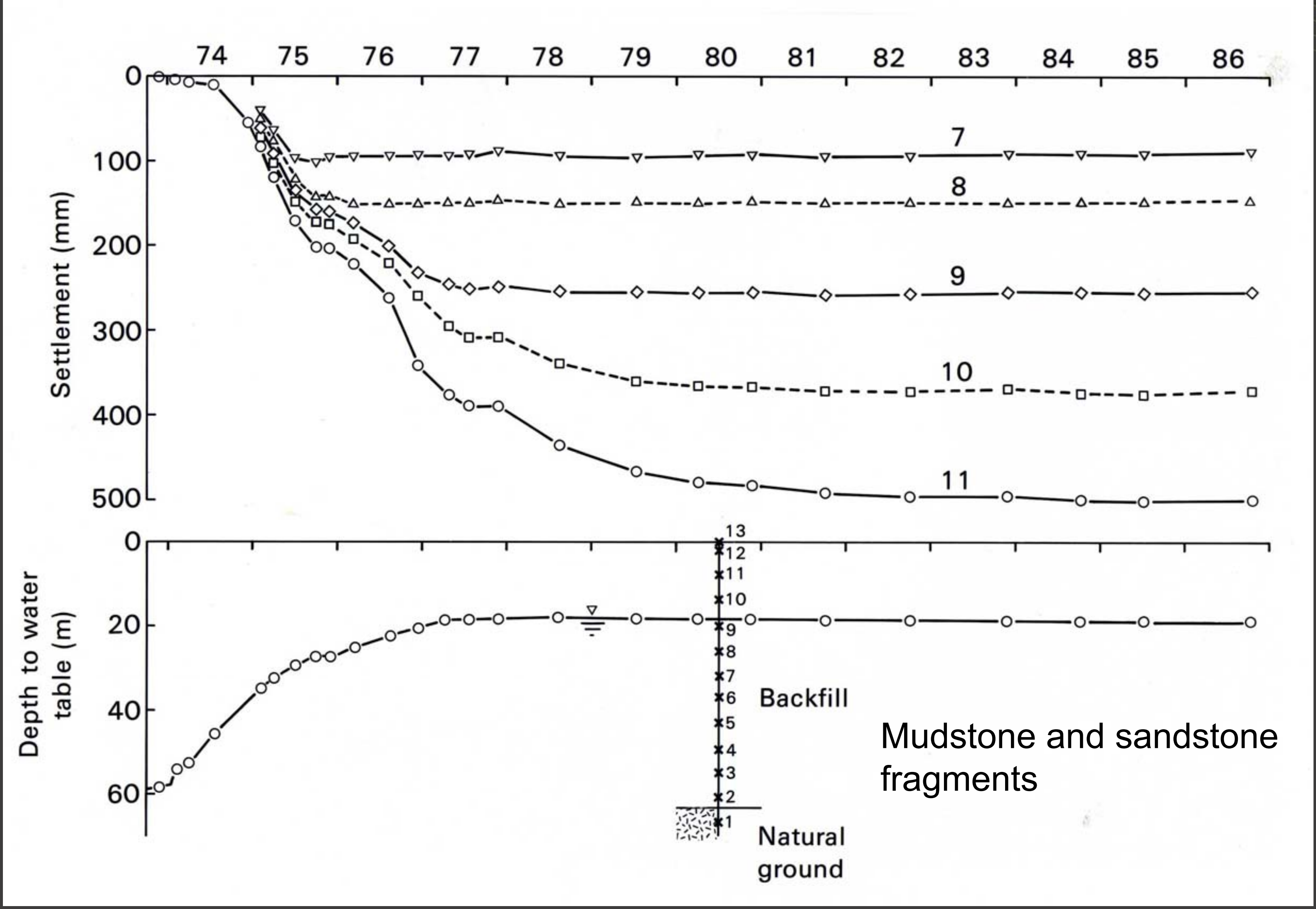
Inundation through rising ground water

Inondation par élévation du niveau de la nappe d’eau

- Mudstone, siltstone and sandstone
- Dragline and face shovel
- Loose tipped with top 16m systematically compacted for highway corridor

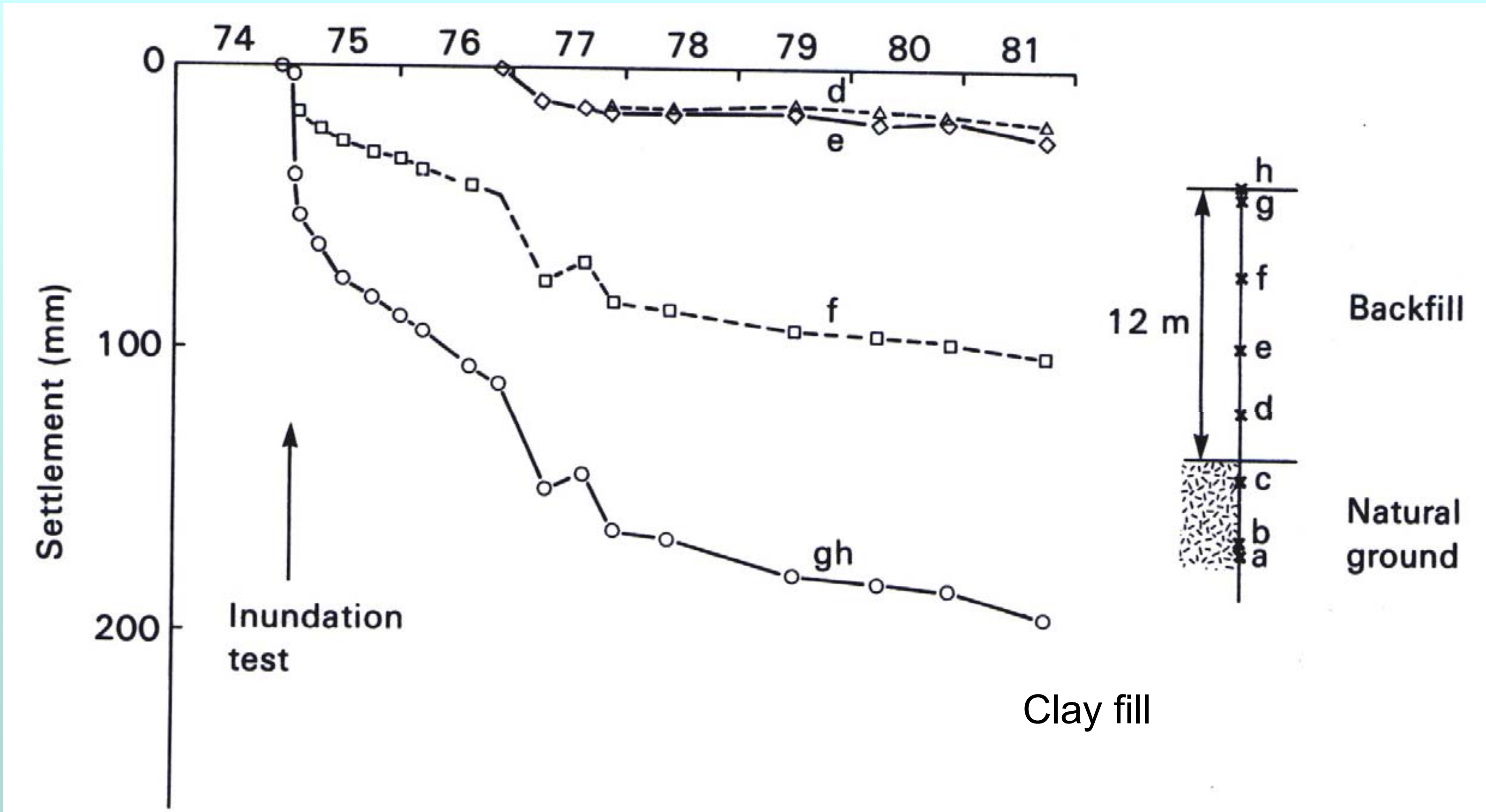
Inundation through rising ground water

Inondation par élévation du niveau de la nappe d'eau



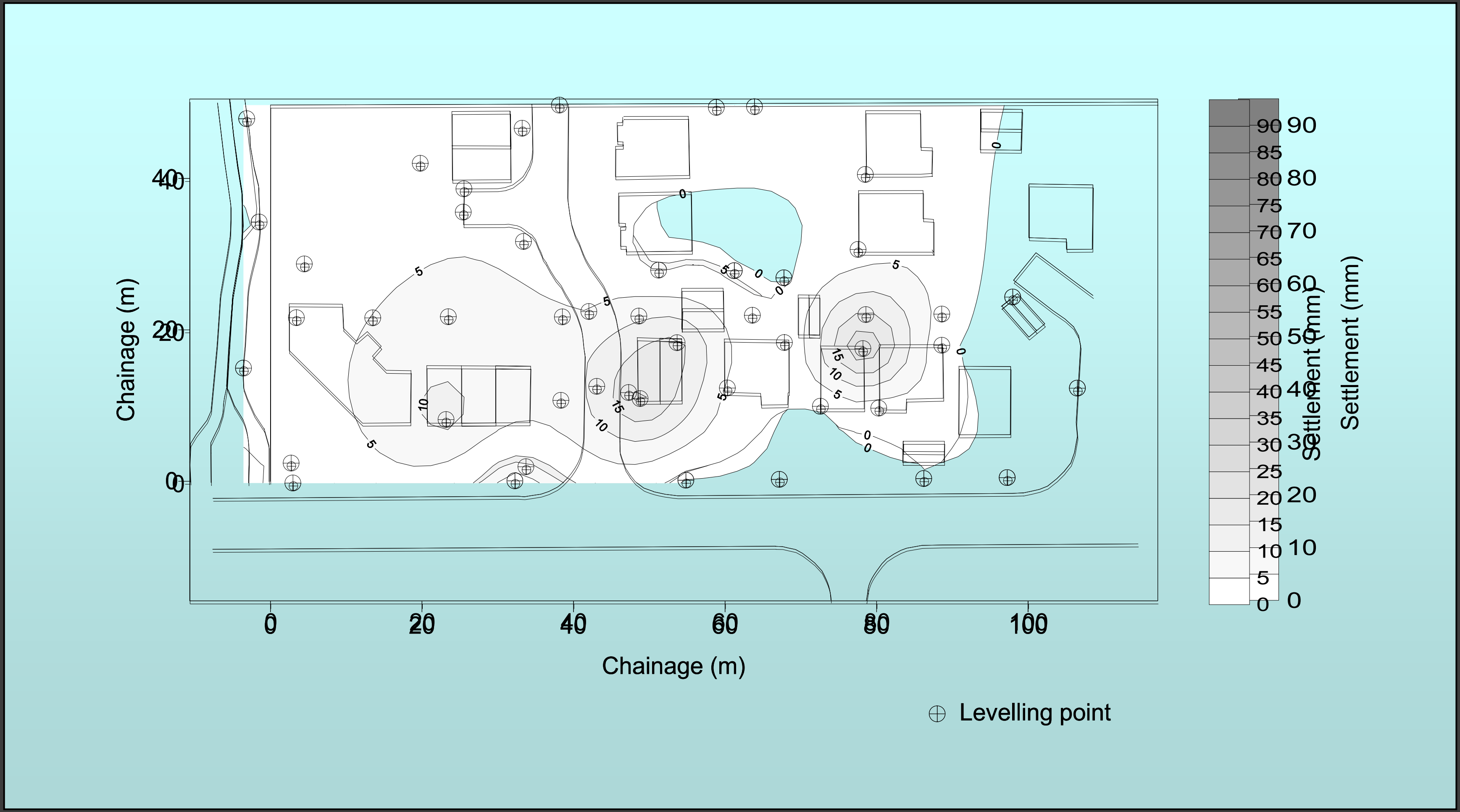
Collapse compression - percolation into fill

Compression d'affaissement – percolation dans le remblai



Collapse compression - percolation into fill

Compression d'affaissement – percolation dans le remblai



Damage to structures

Dommage aux structures

Collapse compression - research

Compression d'affaissement - recherche

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Prevention

Empêchement

Reduce air voids to the point:

- Potential for further volume reduction is greatly reduced or preferably eliminated
- Lower the permeability to prevents water entering the fill

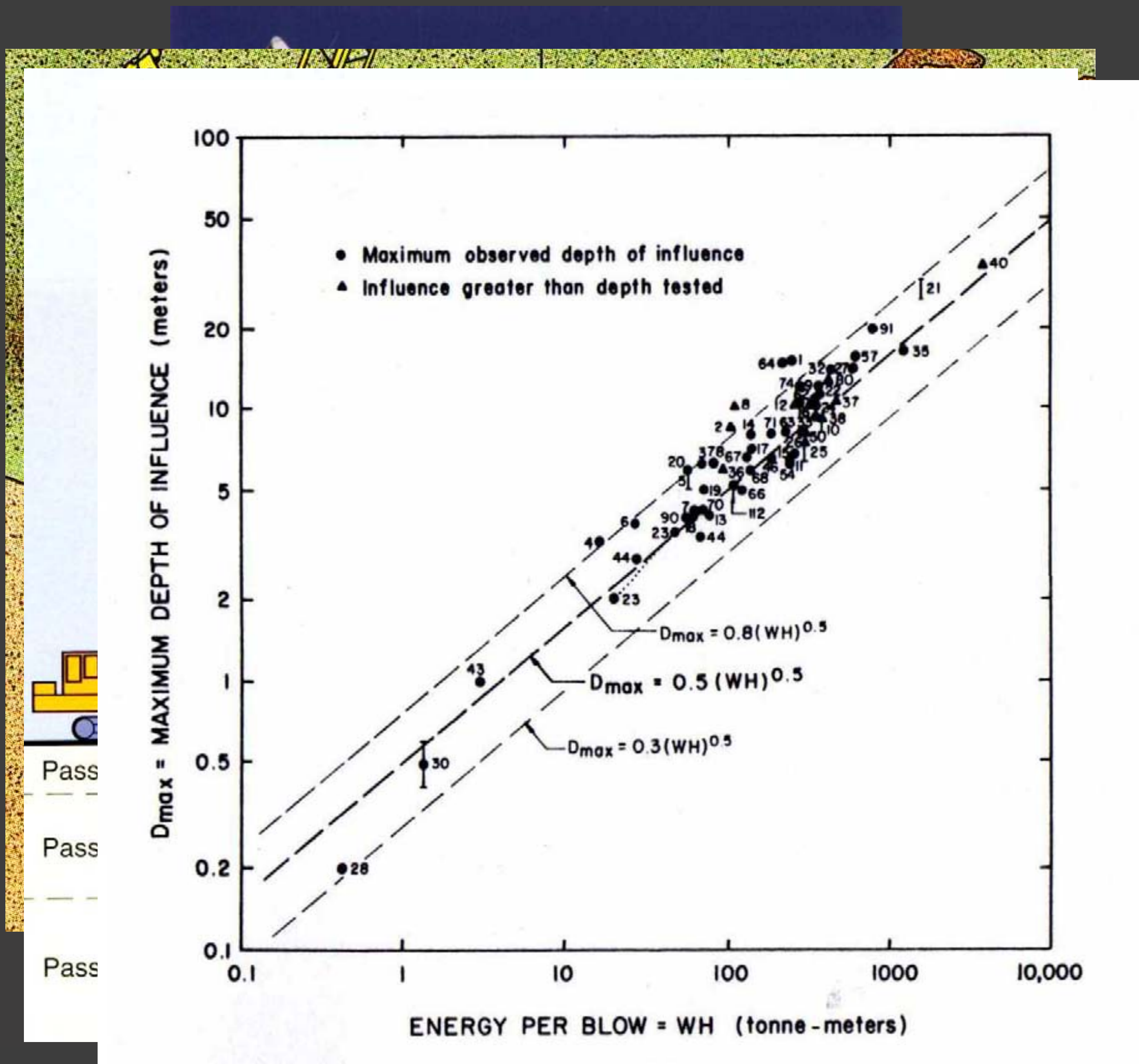
Current solutions

Solutions courantes

- Re-engineer to a suitable specification
- Surface compaction
- Surcharge (preloading)

Current solutions – dynamic compaction

Solutions courantes – compactage dynamique



- Commonly used in UK to treat unsaturated fills
- Object to reduce voids between particles
- Increase in density and overall improvement in properties
- Typical tamper 5 to 20 tonnes, dropping from heights of up to 25 metres.
- Highest energy suggest max. depth of improvement approx. 10m

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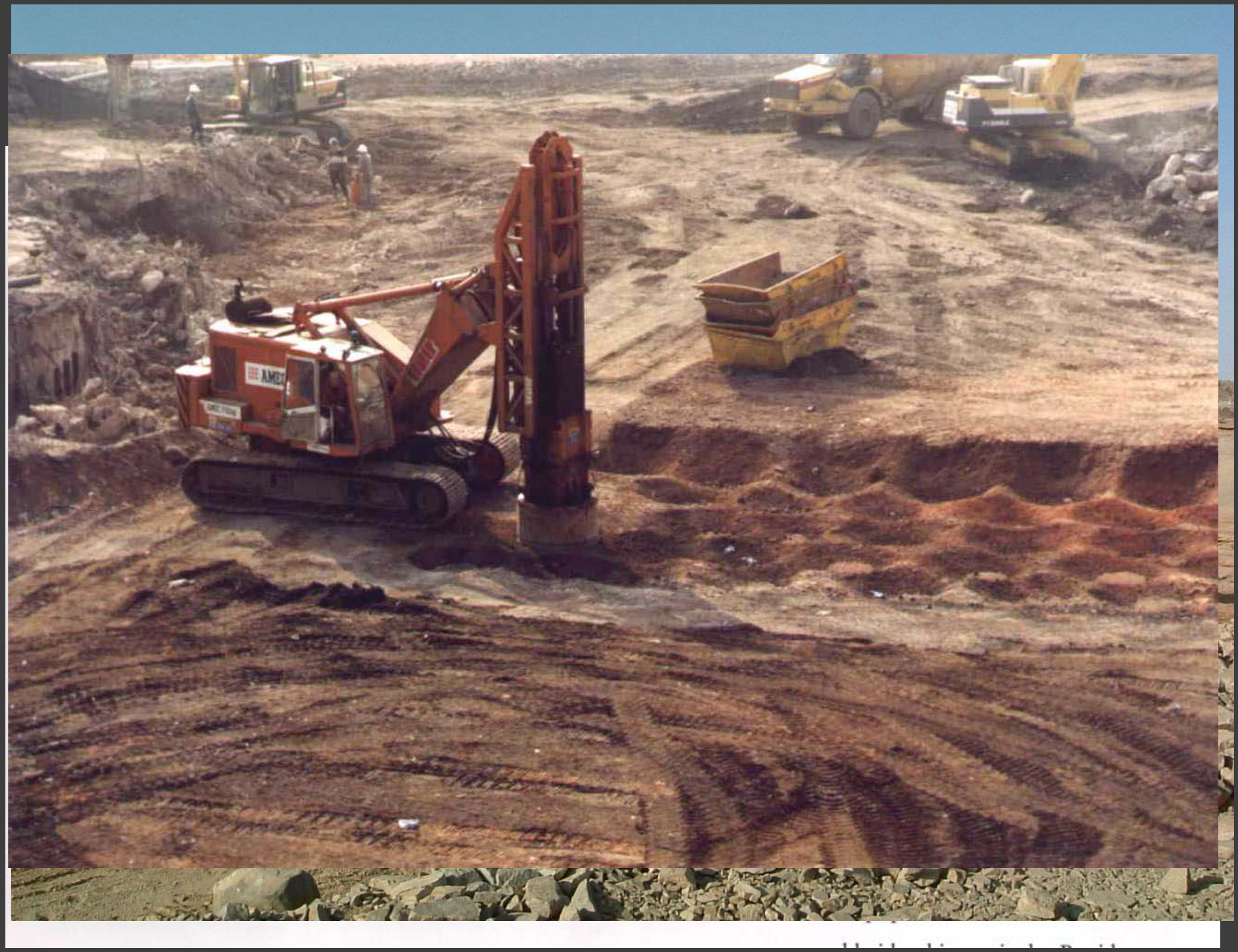
Current solutions – dynamic compaction

Solutions courantes – compactage dynamique



- Other techniques using surface impact compaction
- Rapid impact compactor developed generally to compact relatively shallow fills
- Now used in the UK and increasingly globally
- 7-9 tonne mass dropped 1.2m at 40 blows/min
- Total energy similar. Generally effective to 4m but considerably better in suitable conditions

Current solutions - surcharge

Solutions courantes – surcharge (préchargement)

- Boulder clay overlying oolitic limestone
- 9m high surcharge
- Stresses during pre-loading were much greater than later applied by foundation loads
- The surcharge was effective down to a depth of 10m
- Subsequent movements due to creep in fill, not foundation loads

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Alternative solution - objectives

Solutions alternatives - objectifs

Fill voids using in-situ grouting technique

Overall:

- To enable deep fill sites suitable for redevelopment through the innovative use of grouting using waste materials.

Specifically:

- To develop suitable economic grout using pfa or other waste such as quarry dust
- To demonstrate that, at laboratory scale, grout can permeate and stabilise fill by reducing collapse potential
- To develop an economic grouting technique to eliminate collapse potential in loose fills

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Potential advantages

Avantages potentiels

- Re-engineering to a suitable depth is unlikely to be economic for many developments
- Depth and therefore degree of effectiveness of surface compaction or preloading is limited technically and/or by economic constraints
- Grouting depth can be specified and effectiveness would not diminish with depth
- Likely to be quicker and less disruptive than alternative solutions

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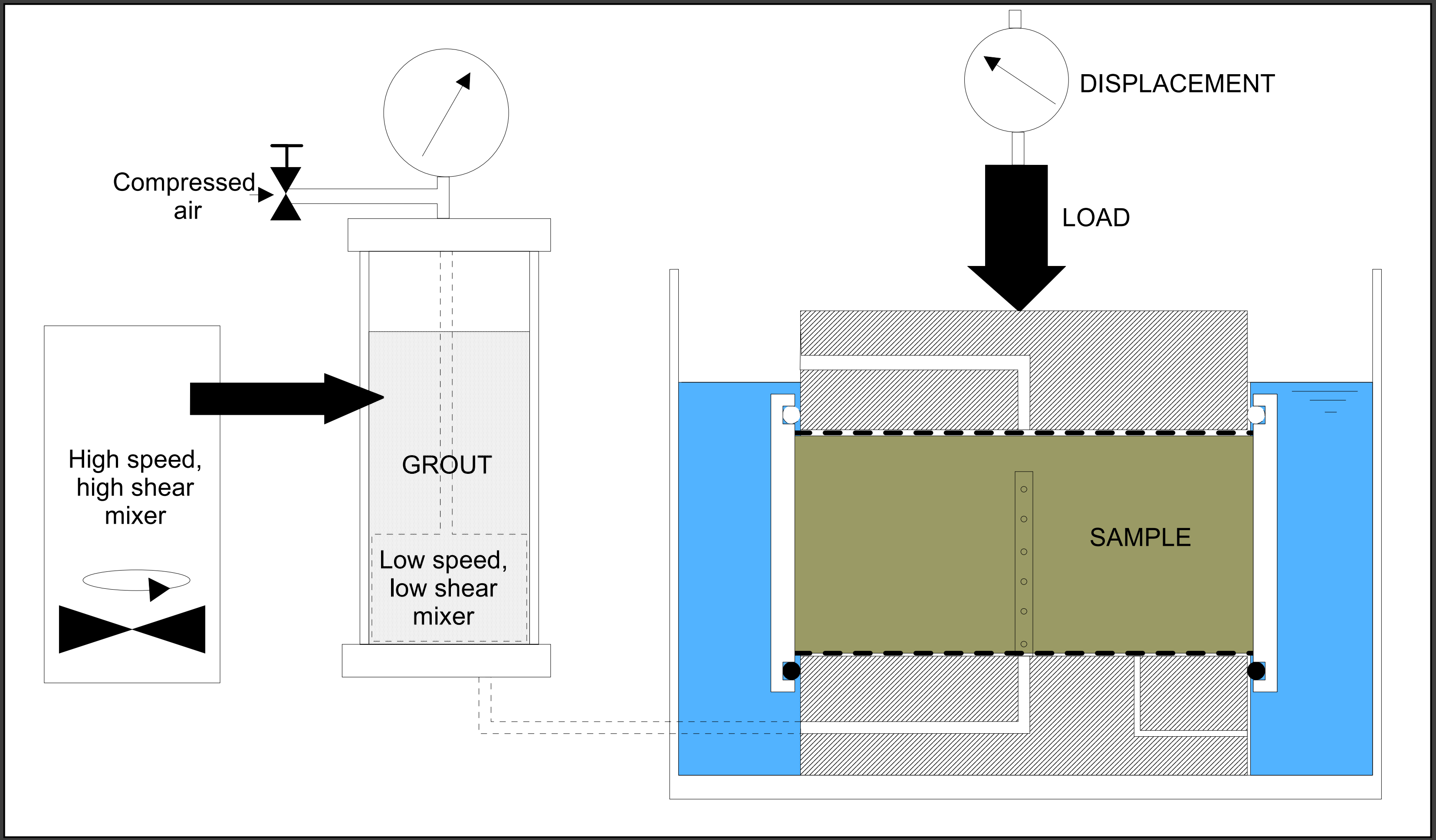
Testing - small scale

Test à petite échelle

152mm oedometers



Testing - small scale

Test à petite échelle

152mm oedometers - jetting

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Testing - small scale

Test à petite échelle

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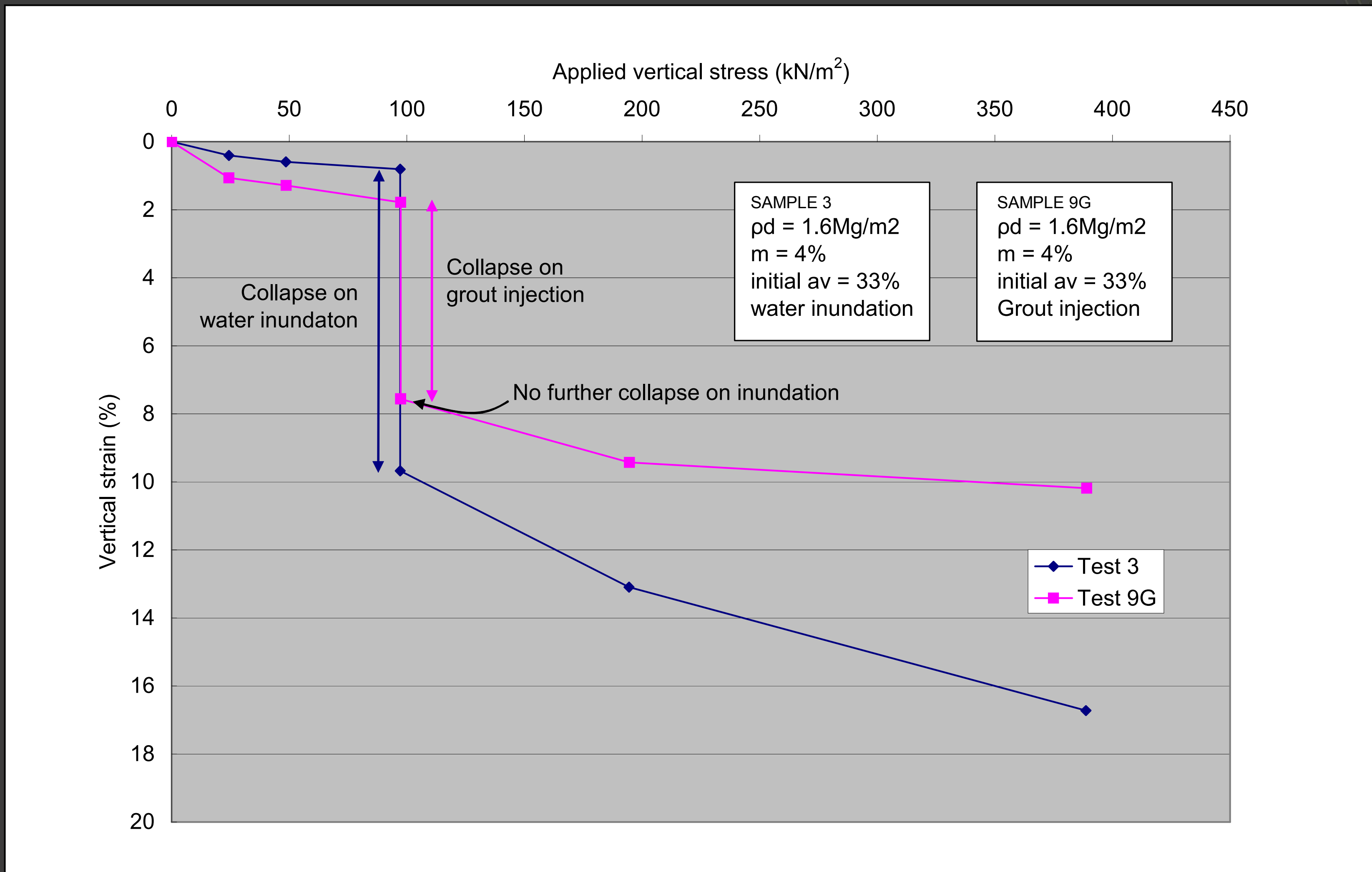
Testing - small scale

Test à petite échelle



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Field studies
Études de terrain

Full-scale field trial

- 50m deep fill comprising mudstones, shale, sandstone, glacial gravel and coal held in a clay matrix
- WL at 35m BGL – potential to rise to 15m BGL
- Potential 5% collapse – 1m at surface
- At risk fill below economically viable surface treatment
- Trial and later pilot scale trial carried out

Field studies
Études de terrain

Full-scale field trial

- Water/pfa grout (later addition of cement)
- Simple rotary drilling with injection through bit at 3m vertical intervals
- Grout points on 6m grid
- Treated 15m to 33m, later 12m to 27m
- Surface precise levelling
- Sub-surface monitoring (borehole magnet gauges)
- Standpipe piezometers
- Water infiltration wells – treated + untreated

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Field studies

Études de terrain

Full-scale field trial

Field studies
Études de terrain

Full-scale field trial – preliminary findings

- Grout could be successfully injected into semi-cohesive fill
- Grout travelled further than 6m radially
- Collapse was triggered in grouted zones
- Some residual creep when water added
- Area pre-loaded with 20m surcharge could not be grouted and had no collapse potential during water infiltration

Conclusions

- The improvement of deep fills is of increasing importance in Great Britain - *L'amélioration des remblais profonds est d'une importance de plus en plus grande en Grande Bretagne*
- Established and innovative surface solutions - *Des solutions de surface établies et innovantes*
- Existing techniques offer limited depth solutions - *Les techniques existantes n'offrent que des solutions de profondeur limitée*
- A new grouting technique shows some promise but requires further research - *Une nouvelle technique d'injection semble prometteuse mais nécessite de plus amples recherches*