Universidade de Coimbra

Universidade do Minho

SIMSG ISSMGE

TC 211

Guimarães, Coimbra October 16th and 17th 2015

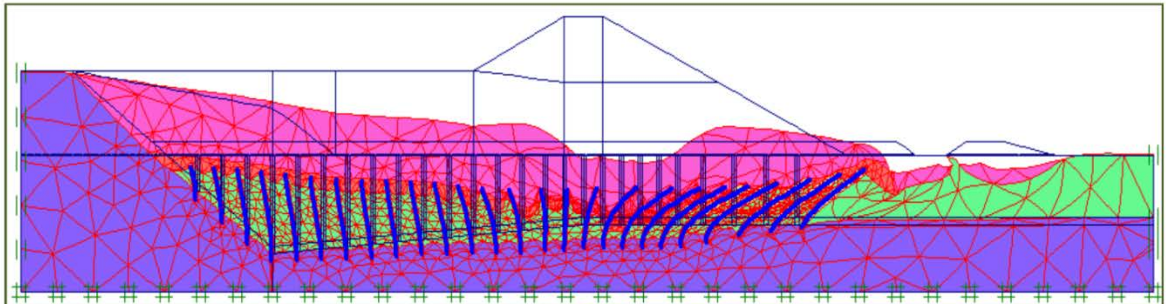
Ground improvement techniques, quality control and case histories

By Serge Varaksin M.sc.
Vice Chairman TC 211

Menard matériels

INTERNATIONAL SYMPOSIUM & SHORT COURSES

TC 211 IS-GI Brussels 2012



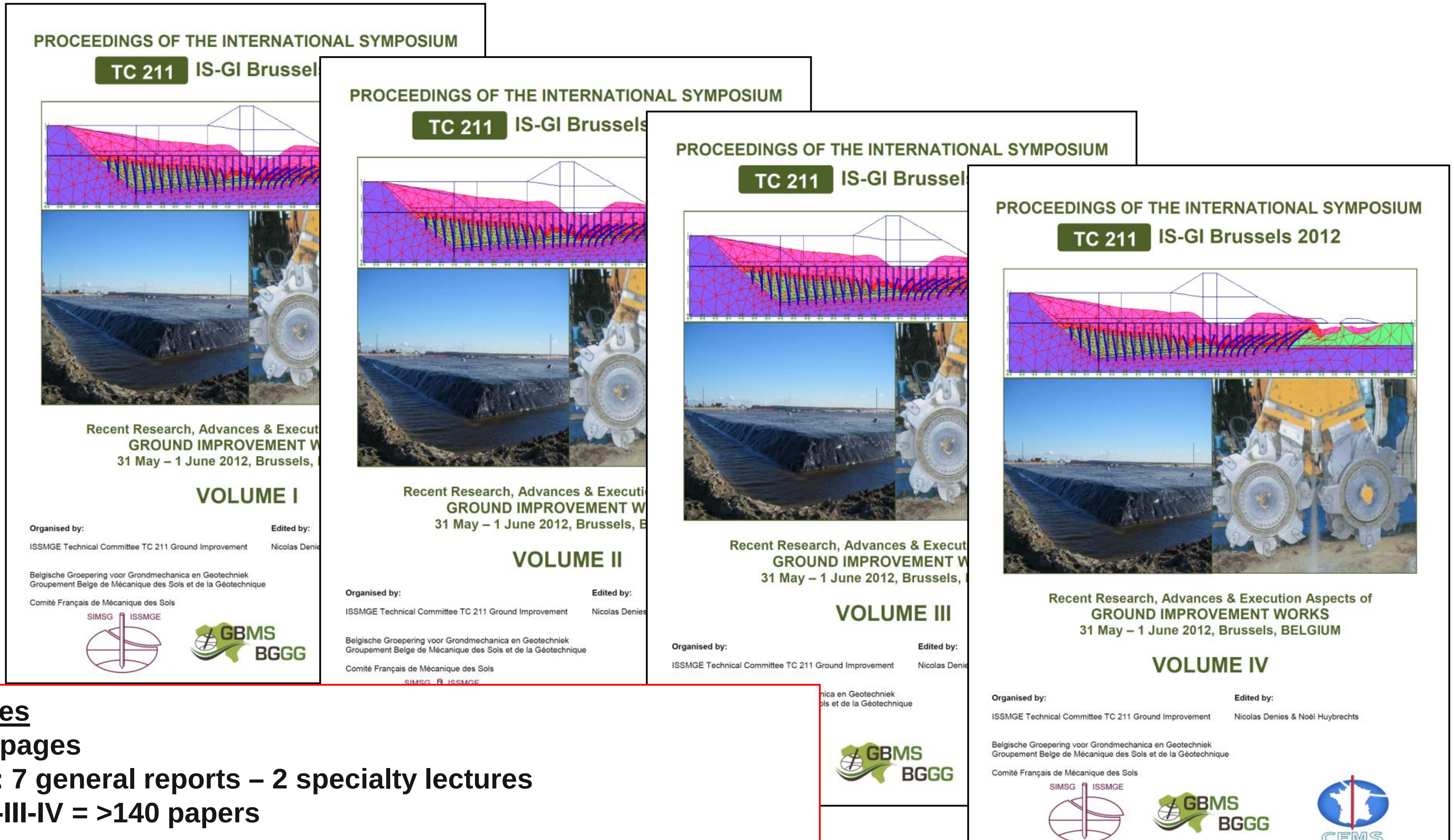
Recent Research, Advances & Execution Aspects of GROUND IMPROVEMENT WORKS

30 May – 1 June 2012, Brussels, BELGIUM

SIMSG ISSMGE GBMS BGGG CFMS

TC 211 IS-GI Brussels 2012

Thursday 31 May & Friday 1 June - International Symposium : Publications



4 Volumes

- >1600 pages
- VOL I : 7 general reports – 2 specialty lectures
- VOL II-III-IV = >140 papers

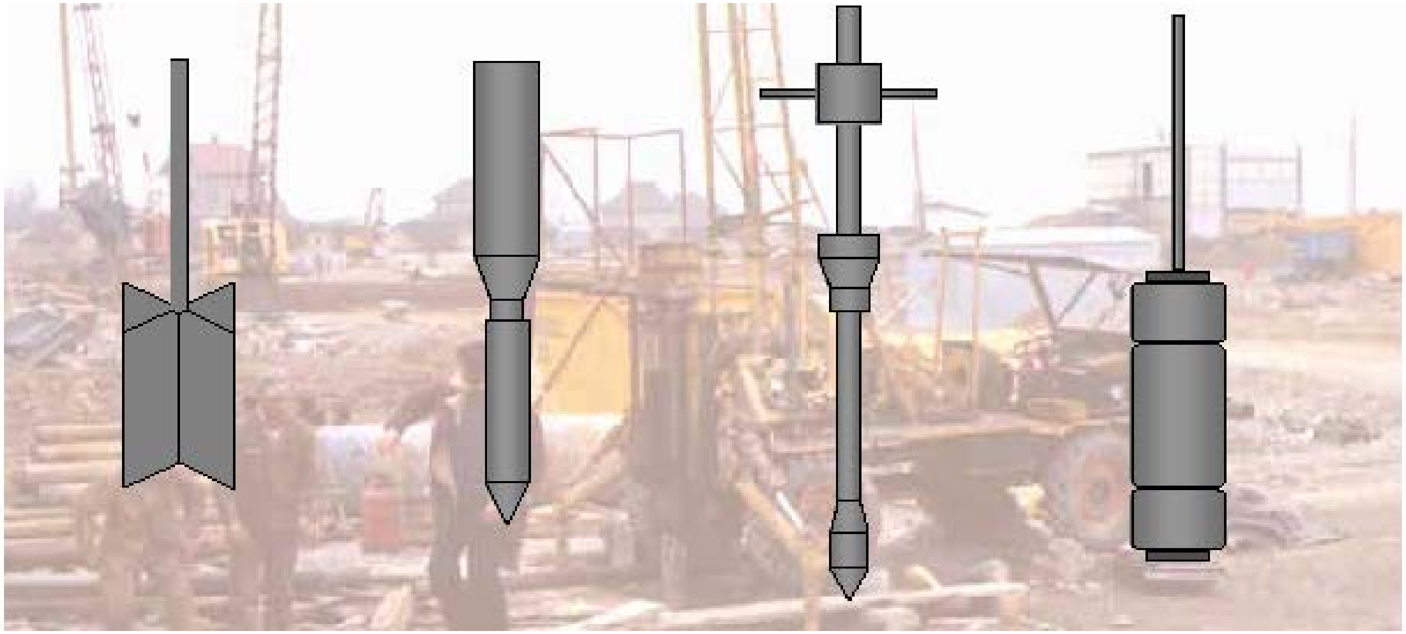
Contribution WTCB-CSTC

- Edition of the 4 Volumes (N. Denies & N. Huybrechts)
- Vol I :General report "Deep mixing" – 40 p. summary of 30 papers
- Vol III : 4 publications with regard to BBRI soil mix research (54 p.)

www.bbri.be/go/tc211

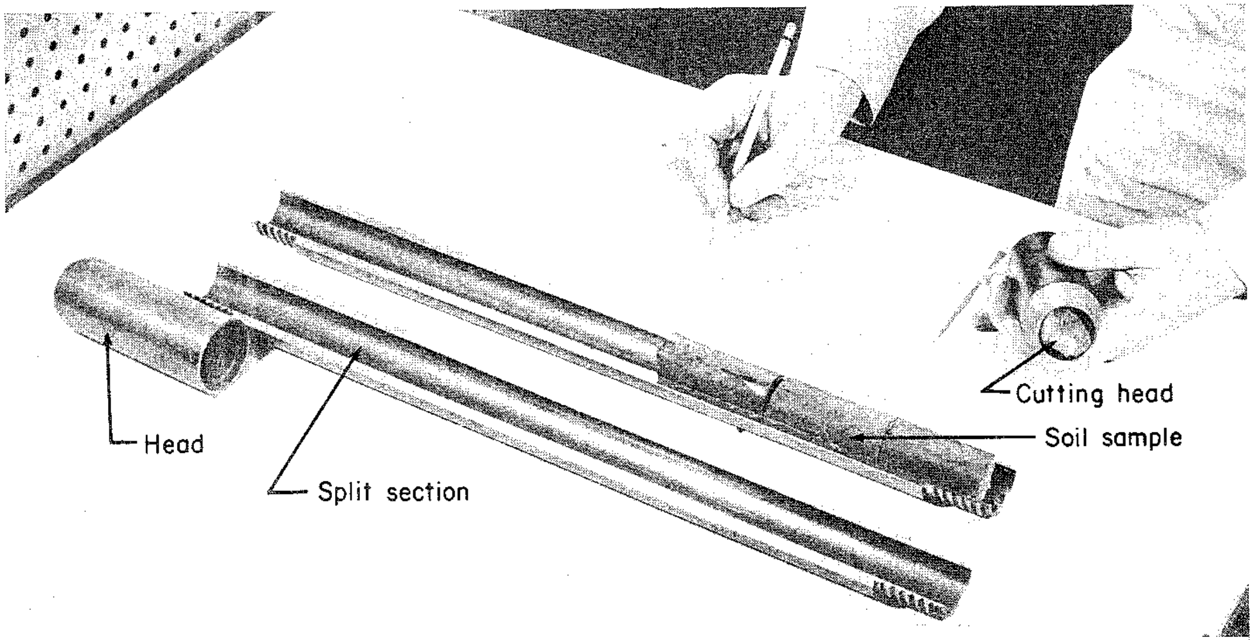
cgo@bbri.be

Parameters related to ground improvement : Differents types of in situ tests

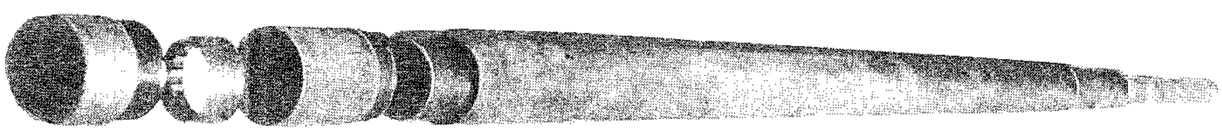


Vane test (VT)	Static Cone Penetration Test (CPT)	Dynamic Penetration Test (SPT)	Pressuremeter (PMT)

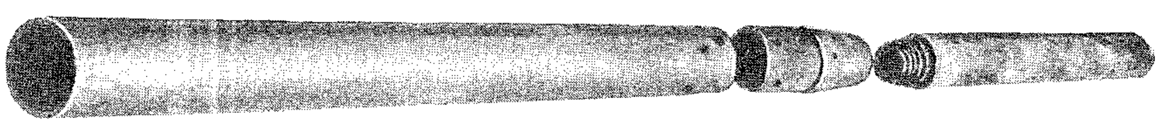
Dynamic Penetration Test
Parameters : N blows; soil identification



(d)

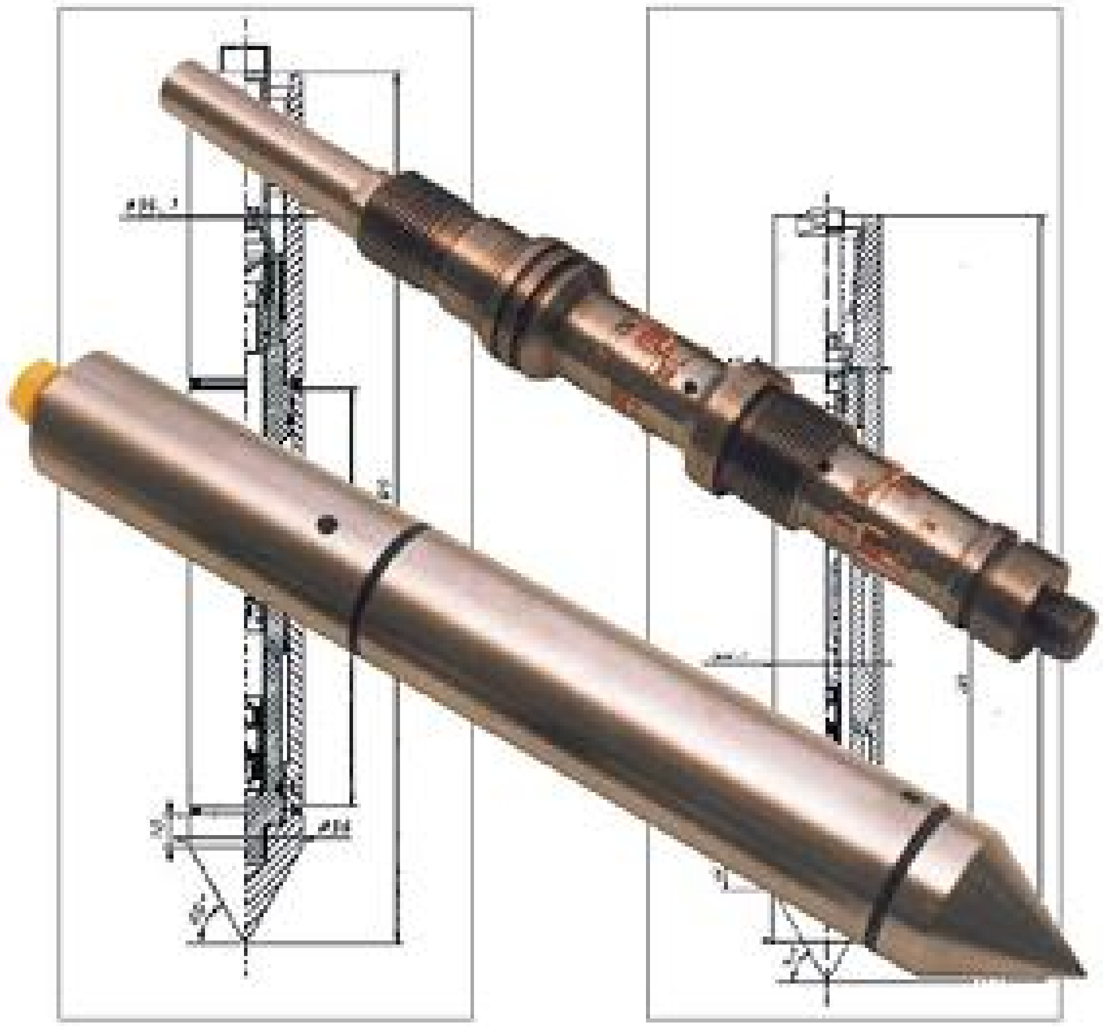


(e)



(f)

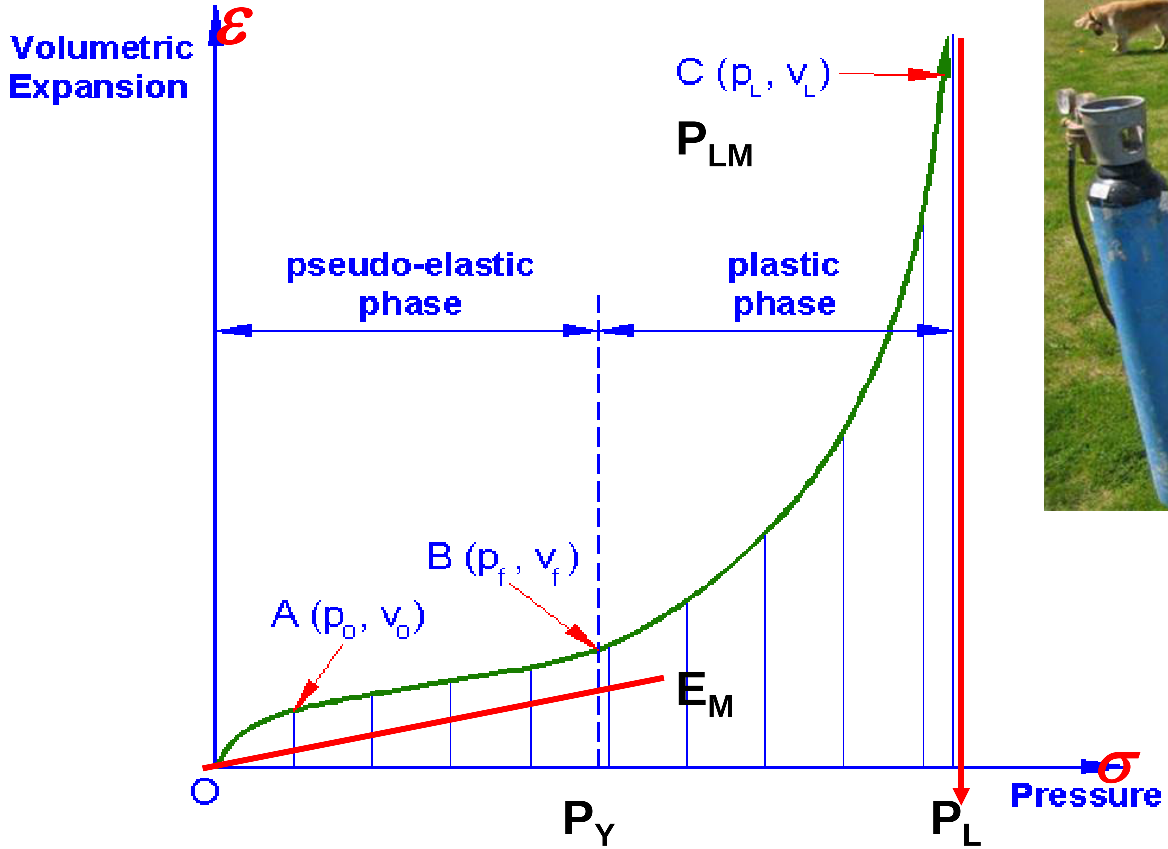
Static penetrometers
Parameters : Cone resistance, friction ratio, occasionally pore pressure



The Menard Pressuremeter : Stress – Strain curve
Parameters : pressuremeter modulus E_M, Limite Pressure P_{LM}

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

1. ***Limit Pressure (P_{LM})*** – for bearing capacity (= $5.5C_u$).
2. ***Pressuremeter Modulus (E_M)*** – for settlement ($E_y = E_P/\alpha$).
   (*α = 2/3 for clay; 1/2 for silt and 1/3 for sand*)



Pressure up to 40 bars acting on surrounding soil = lateral load tests.

State of the Art Report

17[TH] International Conference on
Soil Mechanics & Geotechnical Engineering

State of the Art Report

Construction Processes
Procédés de Construction

Jian Chu
Nanyang Technological University, Singapore
Serge Varaksin
Menard, France
Ulrich Klotz
Zublin International GmbH, Germany
Patrick Mengé
Dredging International n.v., DEME, Belgium

NOTA : TC 17 meeting ground improvement – 07/10/2009
Website : www.bbri.be/go/tc17

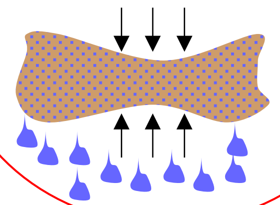
Why Soil improvement ?

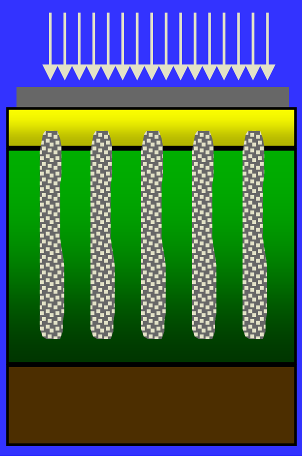
- To increase bearing capacity and stability (avoid failure)
- To reduce post construction settlements
- To reduce liquefaction risk (sismic area)

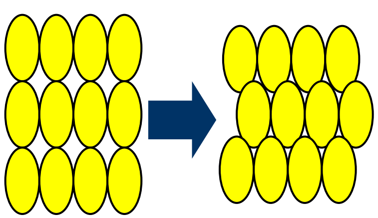
Advantages / classical solutions

- avoid deep foundation (price reduction also on structure work like slab on pile)
- avoid soil replacement
- save time
- Avoid to change site
- Save money !

Soil Improvement Techniques

<table>
<tr><th></th><th>Without added materials</th><th>With added materials</th></tr>
<tr><td>Cohesive soil
Peat , clay …</td><td>1 Drainage
2 VAcuum
</td><td rowspan="2">4 Dynamic replacement

5 Stone columns
6 CMC
7 Jet Grouting
8 Cement Mixing
</td></tr>
<tr><td>Soil with friction

Sand , fill</td><td>3 Dynamic consolidation
4 Vibroflottation
</td></tr>
</table>

Parameters For Concept

-Soil caracteristics
 -cohesive or non cohesive
 - blocks ?
Water content, water table position
- Organic materials
-Soil thickness
-Structure to support
 -Isolated or uniform load
 -Deformability

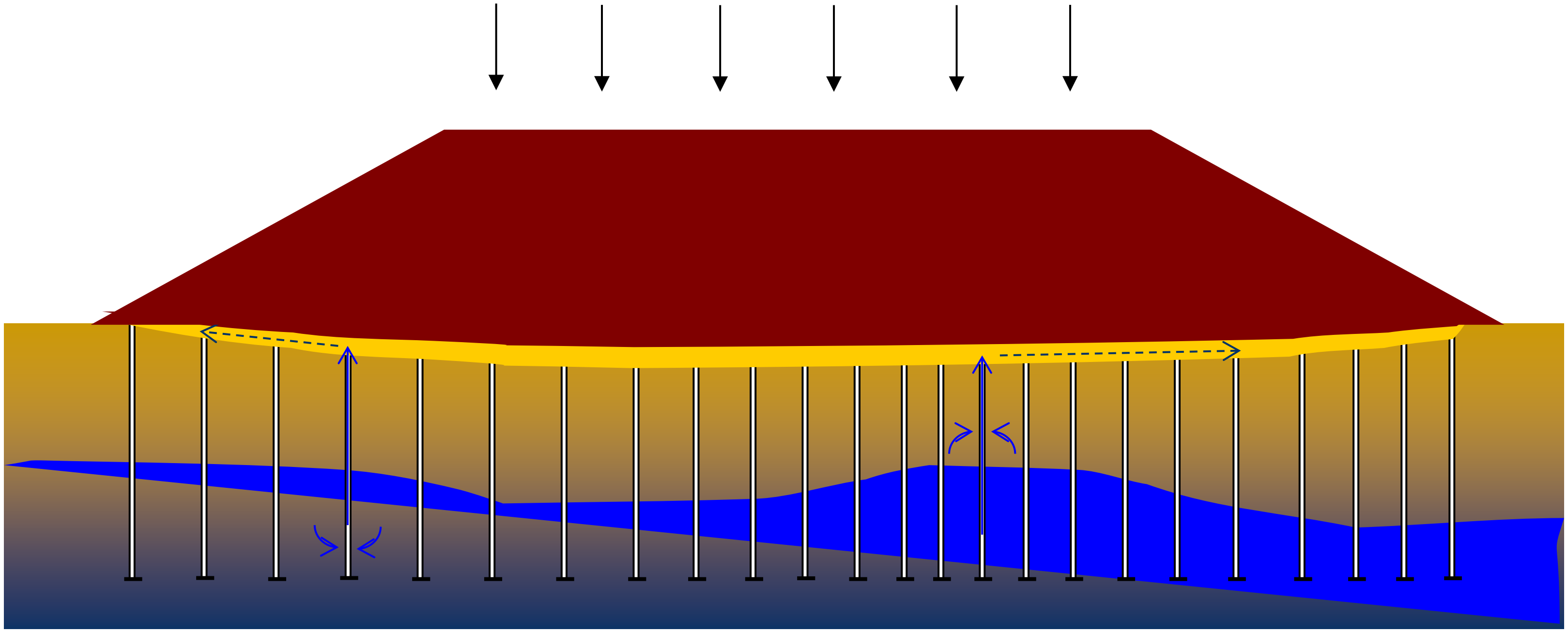
-Site environment
 -Close to existing structure
 -Height constraints

-Time available to build

Preloading with vertical drains

high fines contents soils

$$\sigma=\sigma'+u$$



Vertical drains

CONCEPT

-Stable subsoil for surcharge

-Soil can be penetrated

-Time available is short

-Some residual settlement is allowed

PARAMETERS

1 – Depth

2 – Drainage path

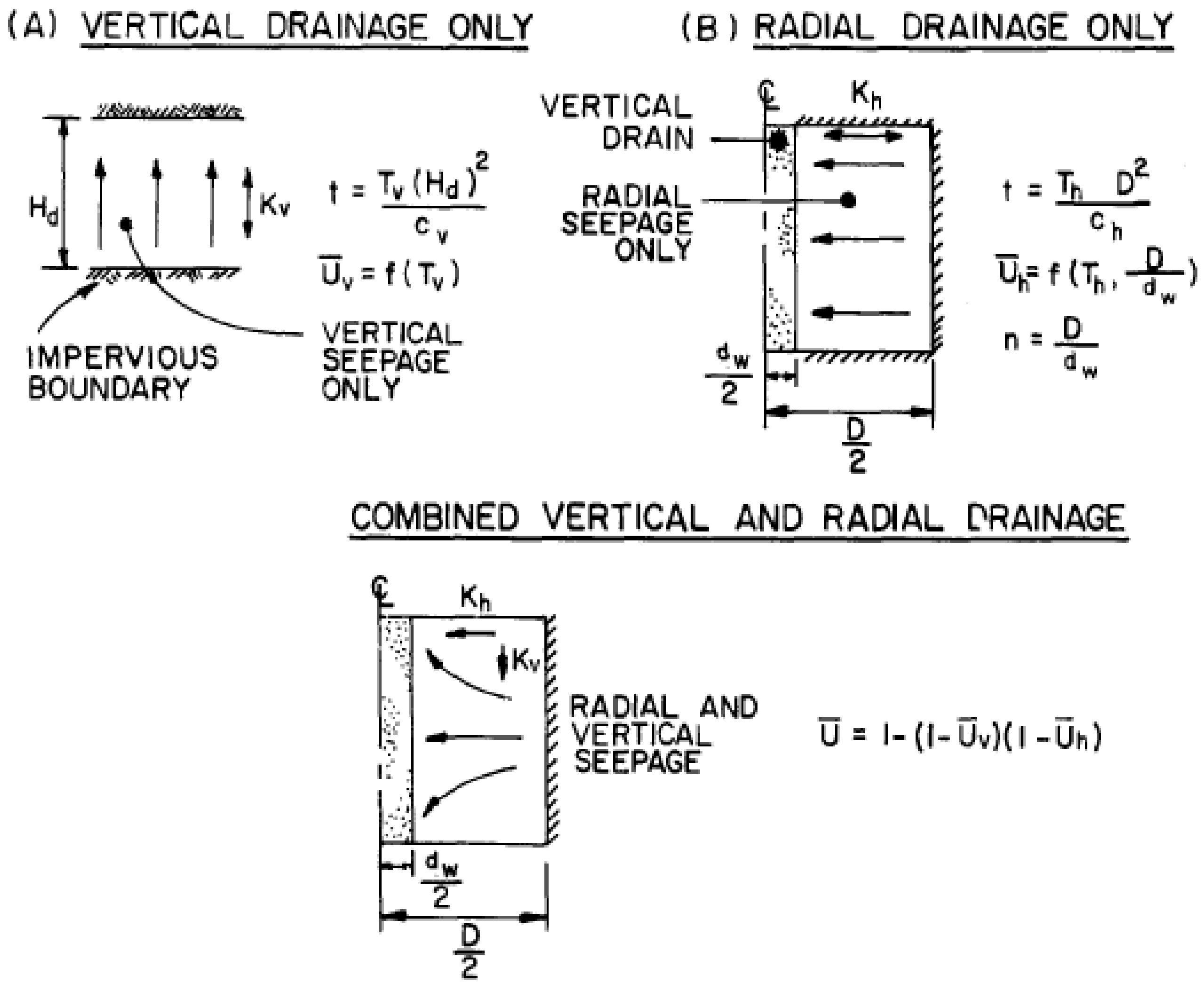
3 – Cohesion

4 – Consolidation parameters (oedometer, CPT)

e_O, C_C, C_V, C_R, C_α, t,

CPT dissipation test

Radial and Vertical consolidation



Vertical drains: material

High fines contents soils

5 cm , PVC

Flat drain | circular drain | *vertical drain + geotextile*

Vacuum Consolidation

CONCEPT

-Soil is too soft for surcharge

-Time does not allow for step loading

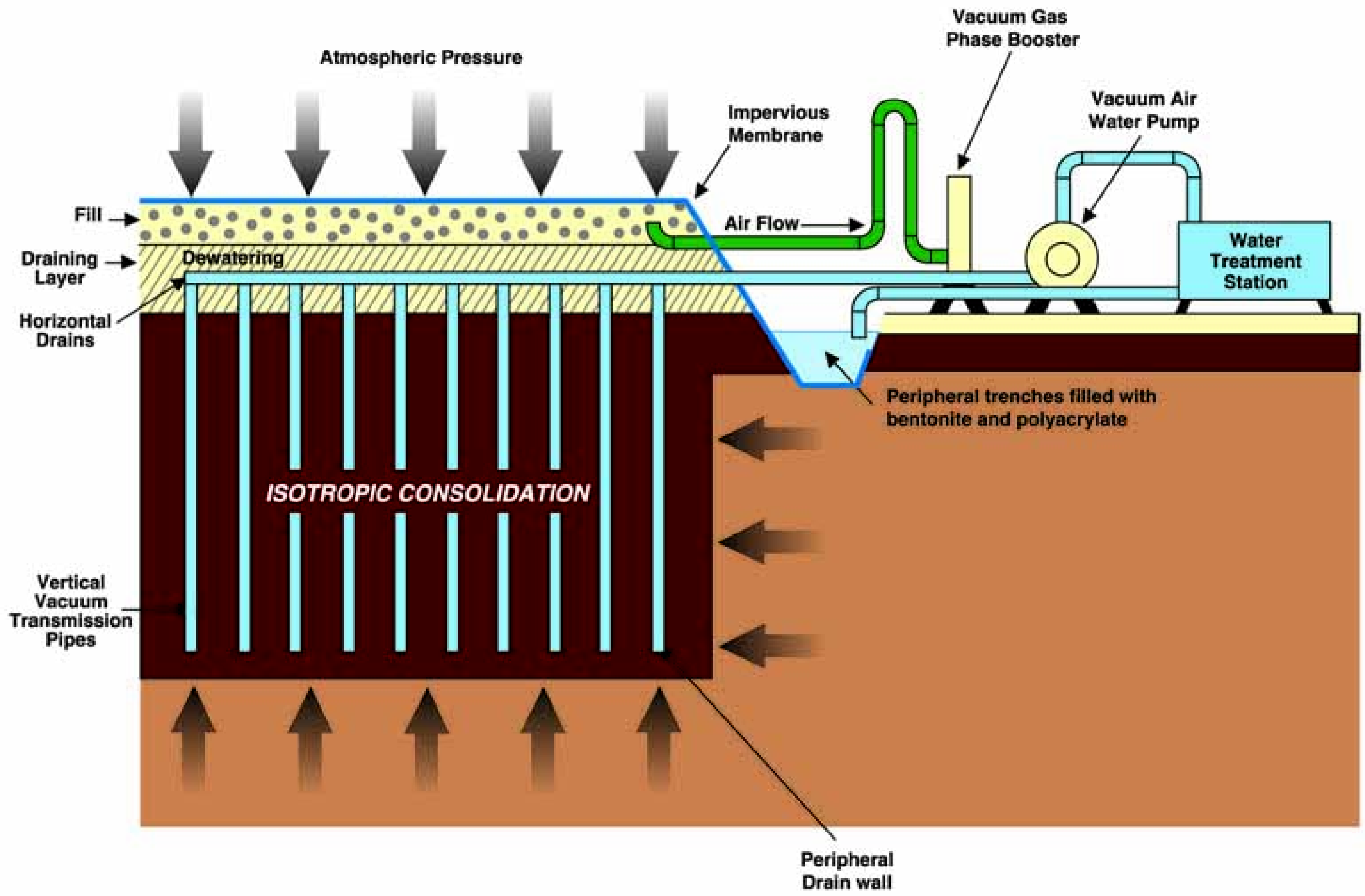
-Surcharge soil not available

-Available area does not allow for berns

PARAMETERS

1 – Depth
2 – Drainage path
3 – Condition of impervious soil
4 – Watertable near surface
5 - Absence of pervious continuous layer
6 – Cohesion
7 - Consolidation parameters (oedometer, CPT)
e_O, C_C, C_V, C_R, C_α, t,
CPT dissipation test
8 – Theoretical depression value
9 – Field coefficient vacuum
10 – Reach consolidation to effective pressure in every layer
11 – Target approach

Vacuum Consolidation (high fines contents soils)



VACUUM (J.M. COGNON PATENT)

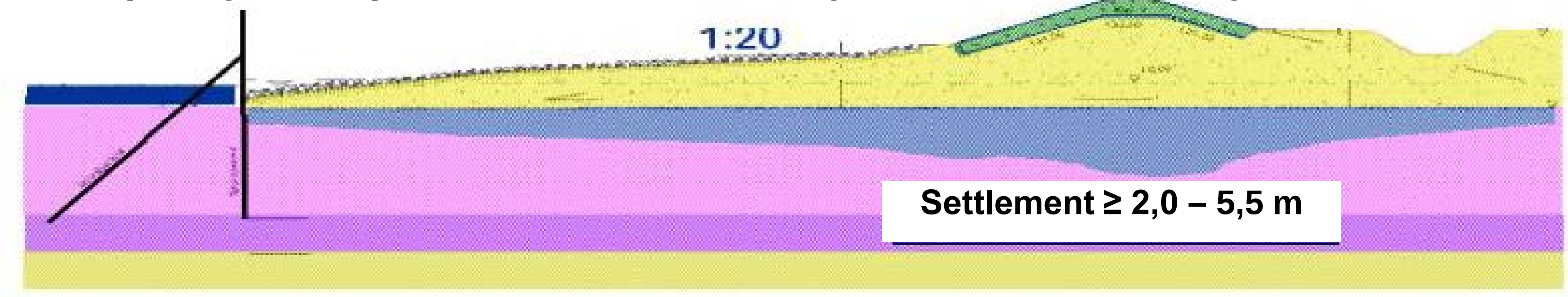
Case history – EADS Airbus Plant, Hamburg

Case history – EADS Airbus Plant, Hamburg

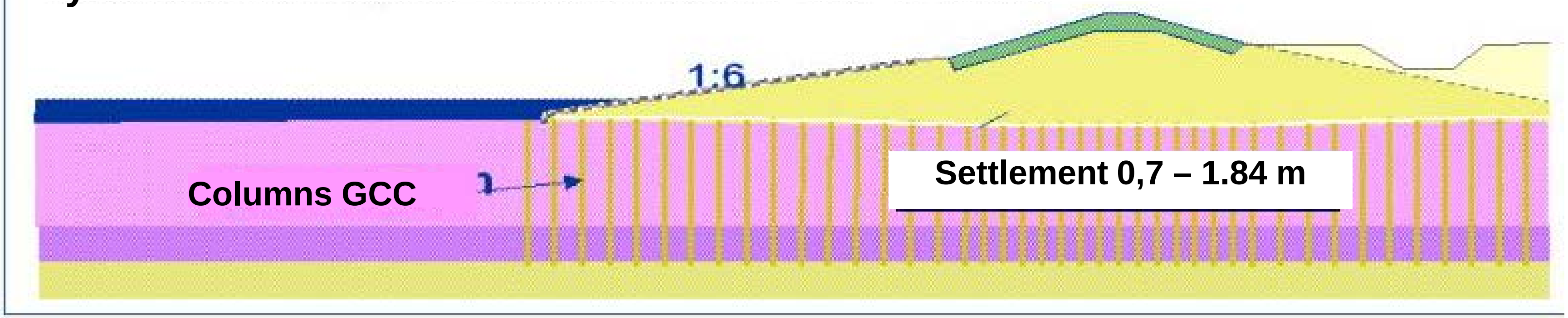
General overview of Airbus site

Basic design and alternate concept of Moebius–Menard

Temporary sheet pile wall – in 5 month – dyke construction in 3 years



Dyke construction to +6.5 in 8.5 month and to + 9.00 in 16 month



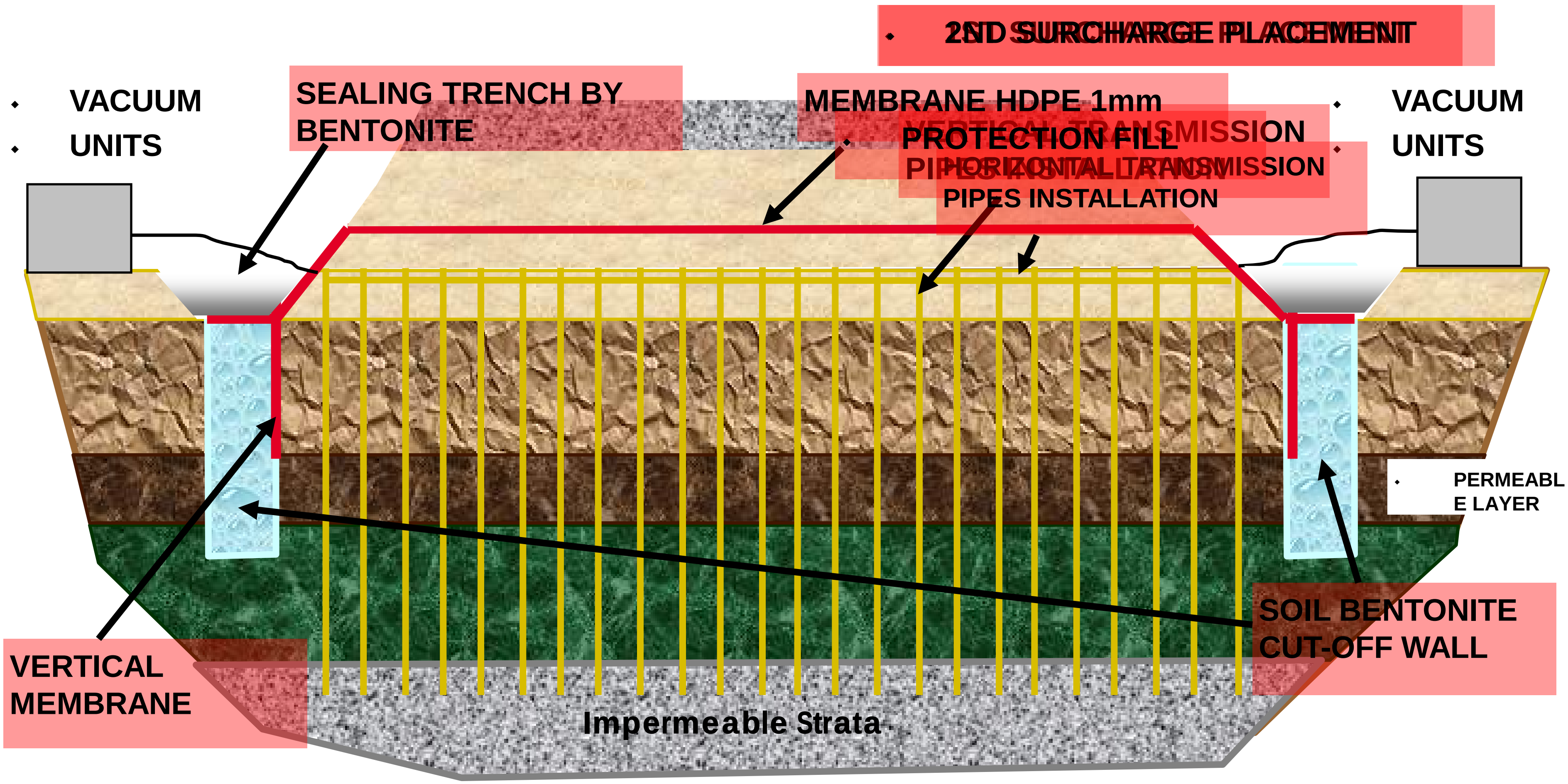

How to move on the mud !

Case history – EADS Airbus Plant, Hamburg

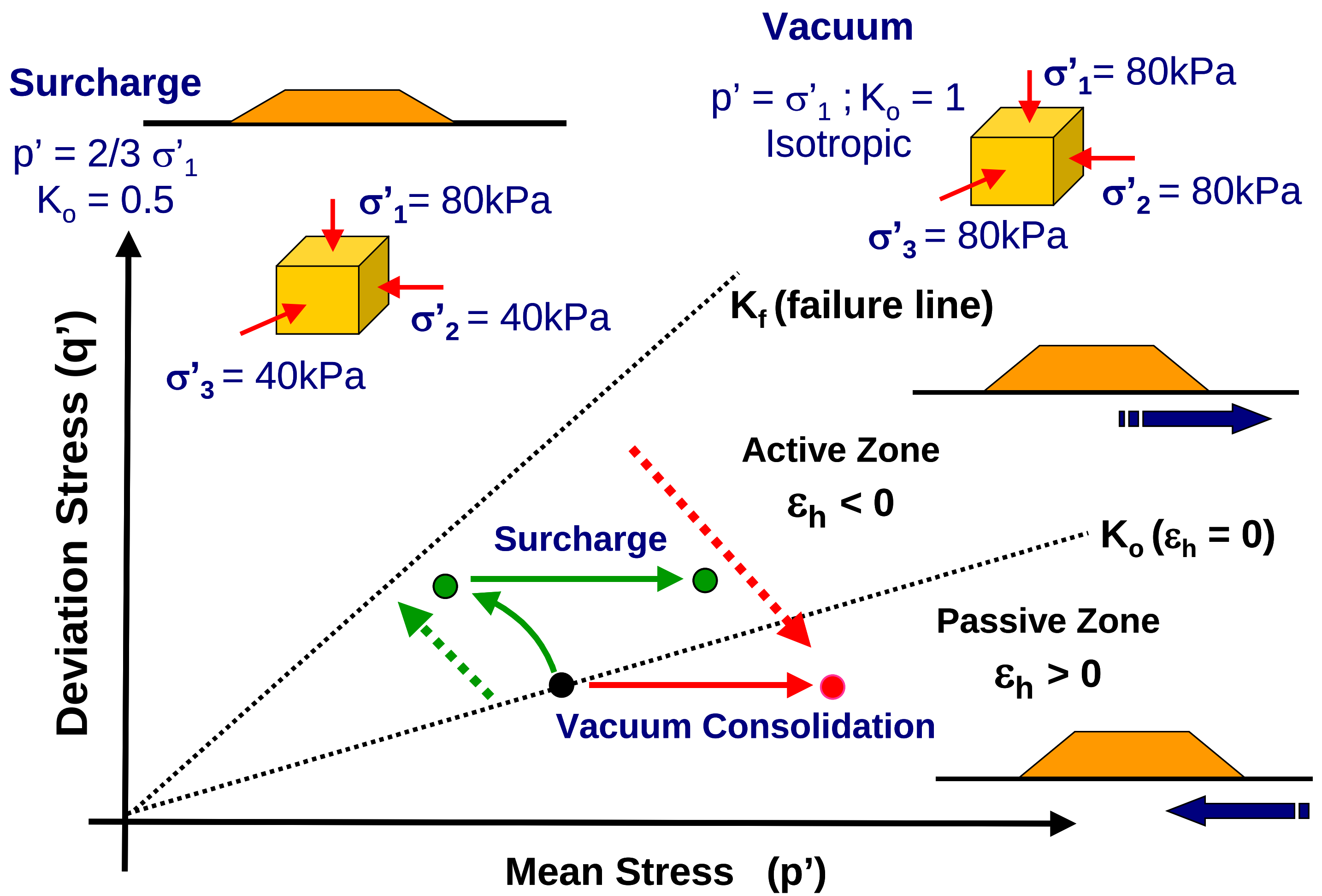
Case history – EADS Airbus Plant, Hamburg

PORT OF BRISBANE – PADDOCK S3B

CONSTRUCTION SEQUENCE

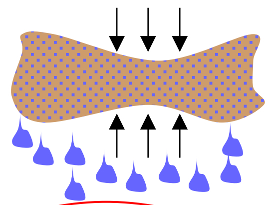
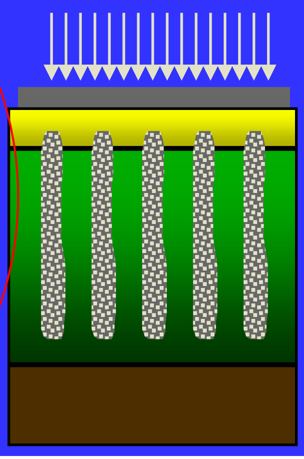
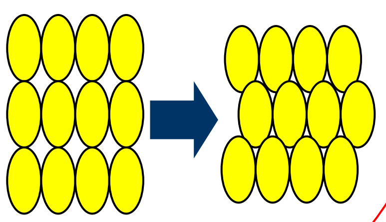


Stress path for Vacuum Process



Case history : Kimhae (Korea) - 1998

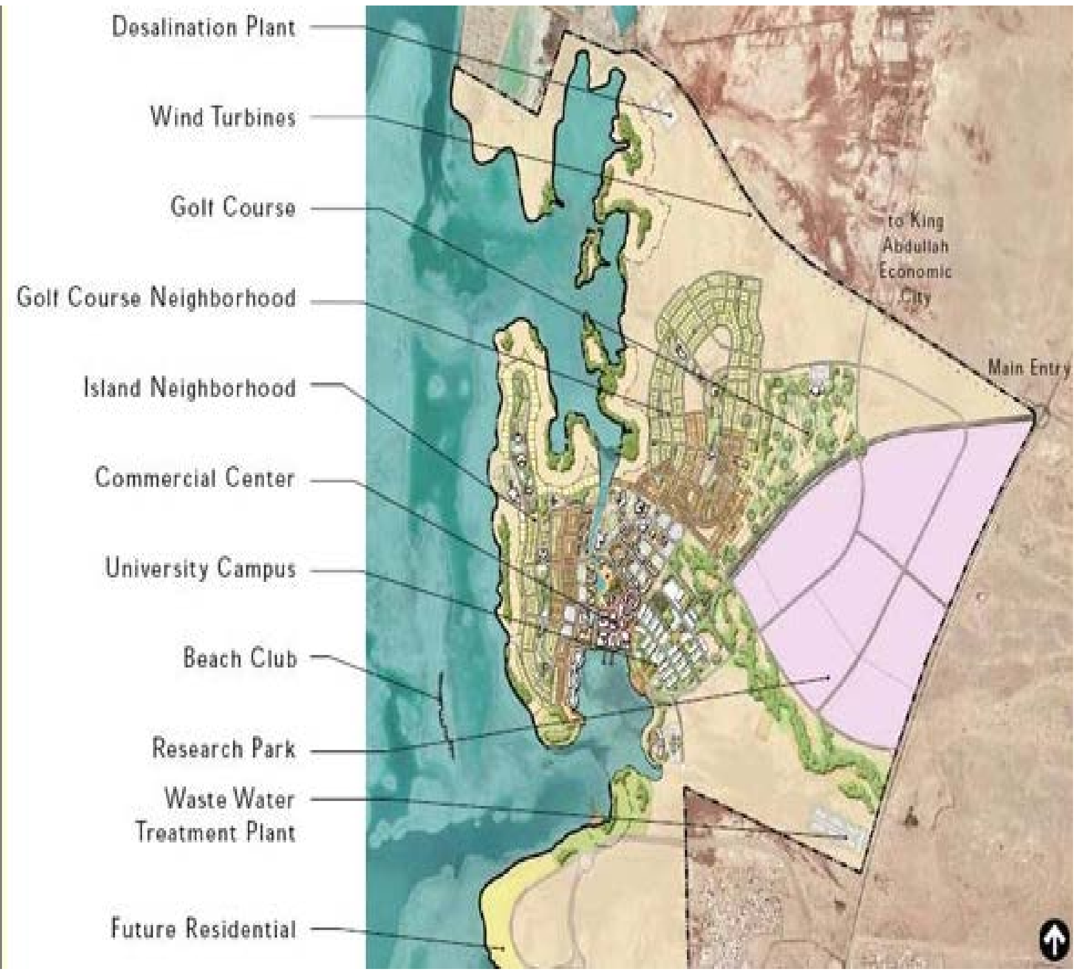
Soil Improvement Techniques

	Without added materials	With added materials
Cohesive soil **Peat , clay …**	1 Drainage 2 VAcuum 	4 Dynamic replacement 5 Stone columns 6 CMC 7 Jet Grouting 8 Cement Mixing 
Soil with friction **Sand , fill**	3 Dynamic consolidation 4 Vibroflottation 	

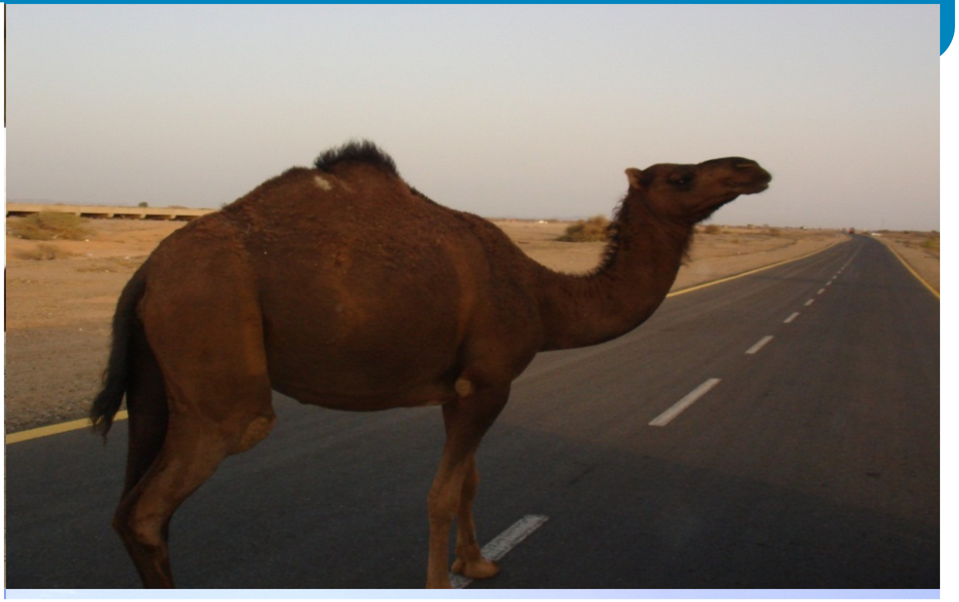
Nice airport runway consolidation
Granular soil

Very high energy (200 t , 24 m)

Typical Master Plan



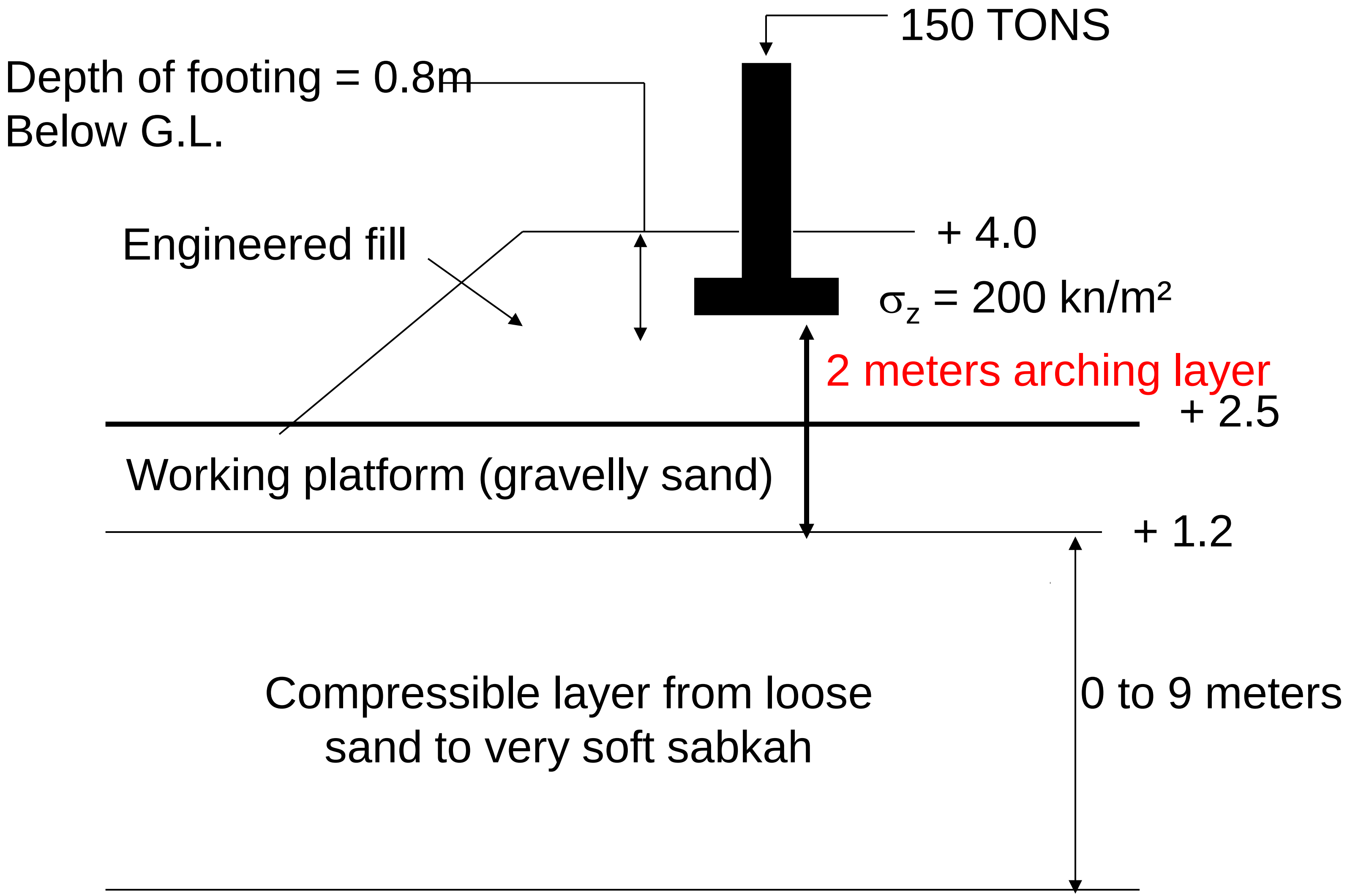
Discovering the Habitants

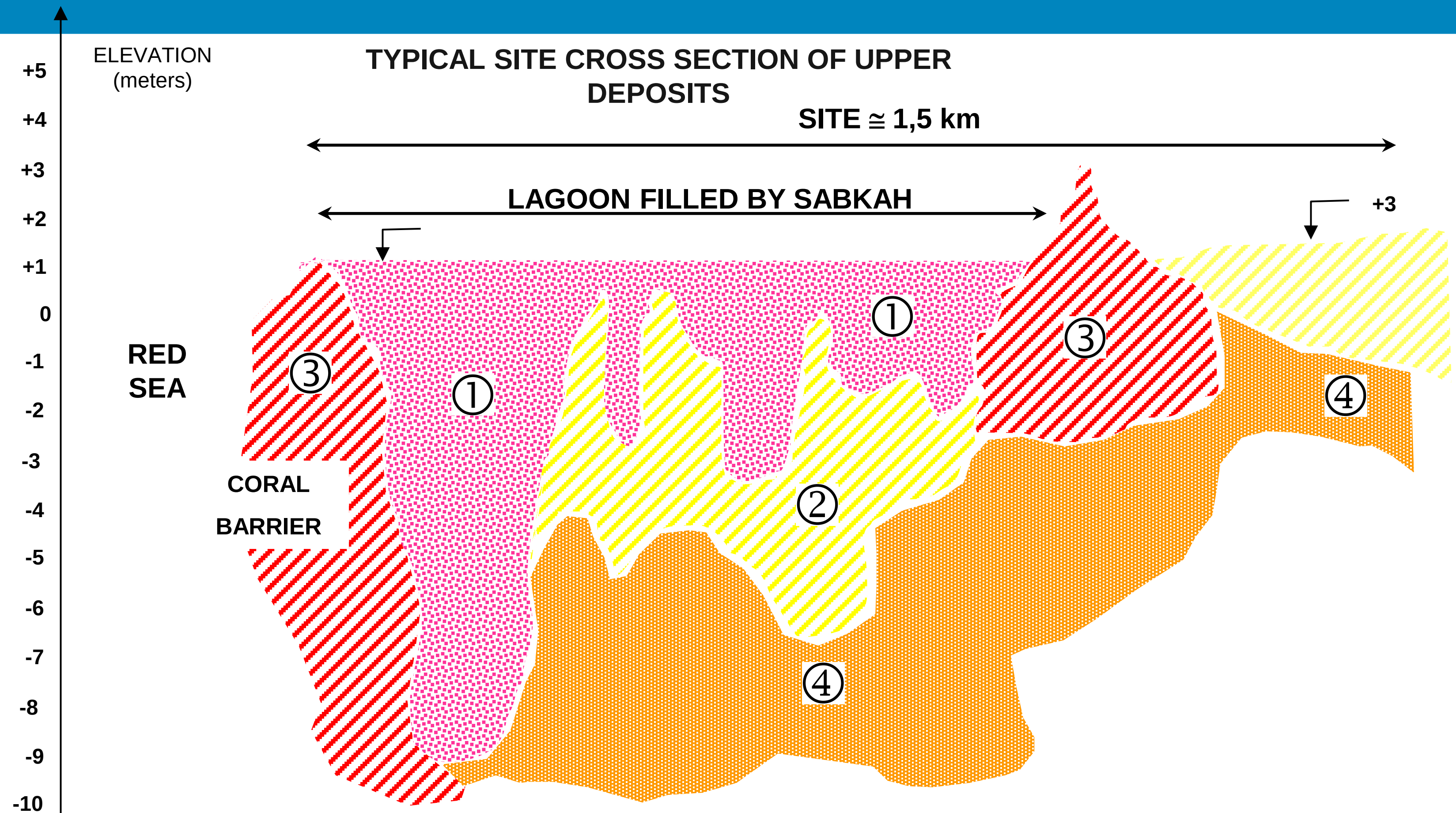
Specifications

- 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

Concept

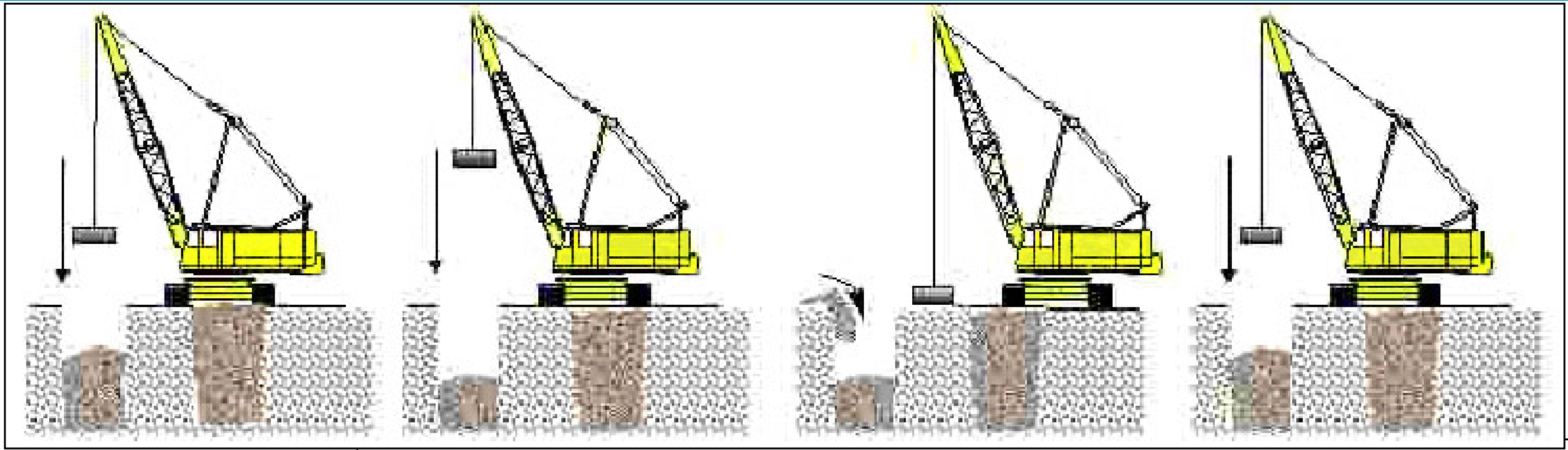

150 TONS
Depth of footing = 0.8m
Below G.L.
Engineered fill
+ 4.0
σz = 200 kn/m²
2 meters arching layer
+ 2.5
Working platform (gravelly sand)
+ 1.2
Compressible layer from loose
sand to very soft sabkah
0 to 9 meters

Specifications



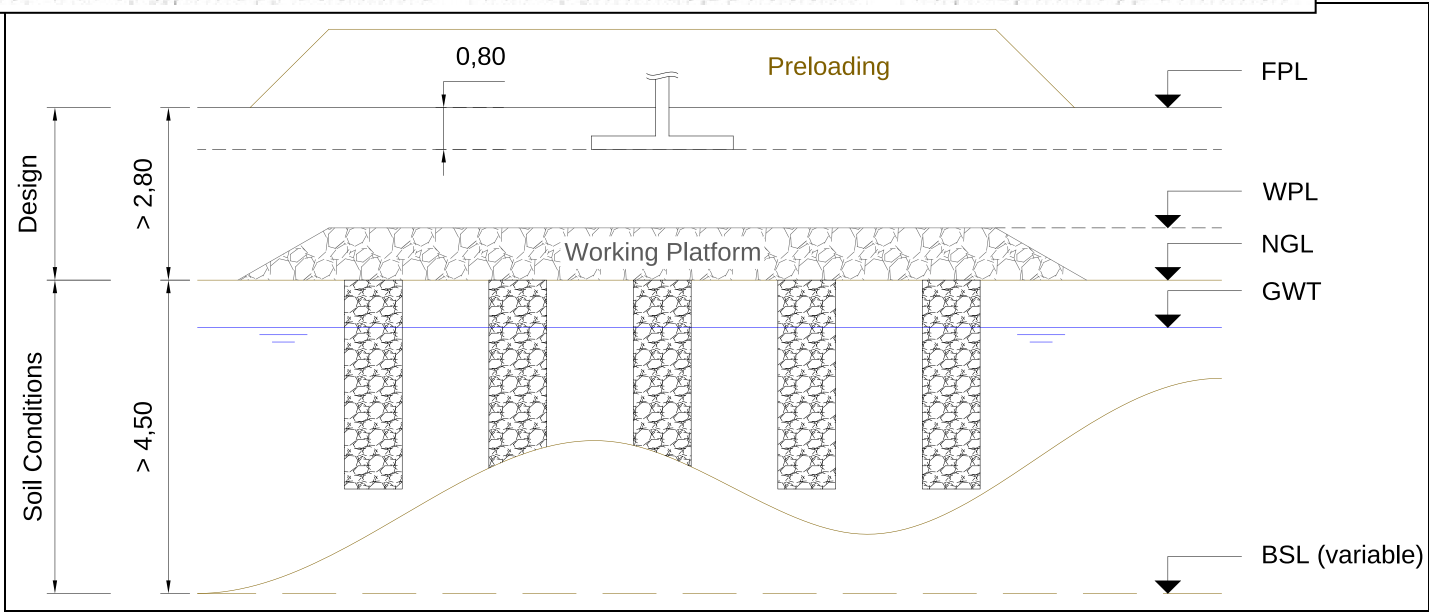
LAYER	USC	w %	% fines	N	Qc BARS	F_R %	P_L BARS	E_P BARS
1 - SABKAH	SM + ML	35-48	28-56	0-2	0-2	1,2-4	0,4-1,9	avr-17
2 - LOOSE SILTY SAND	SM	-	15-28	3-9	12-45	0,5-1,2	2,1-4	18-35
3 - CORAL	-	26-35	-	6-12	-	-	5,1-7,2	35-60
4 - LOOSE TO MED DENSE SAND	SM	-	12-37	3-18	15-80	0,5-1,8	4-12	28-85

Selection of technique

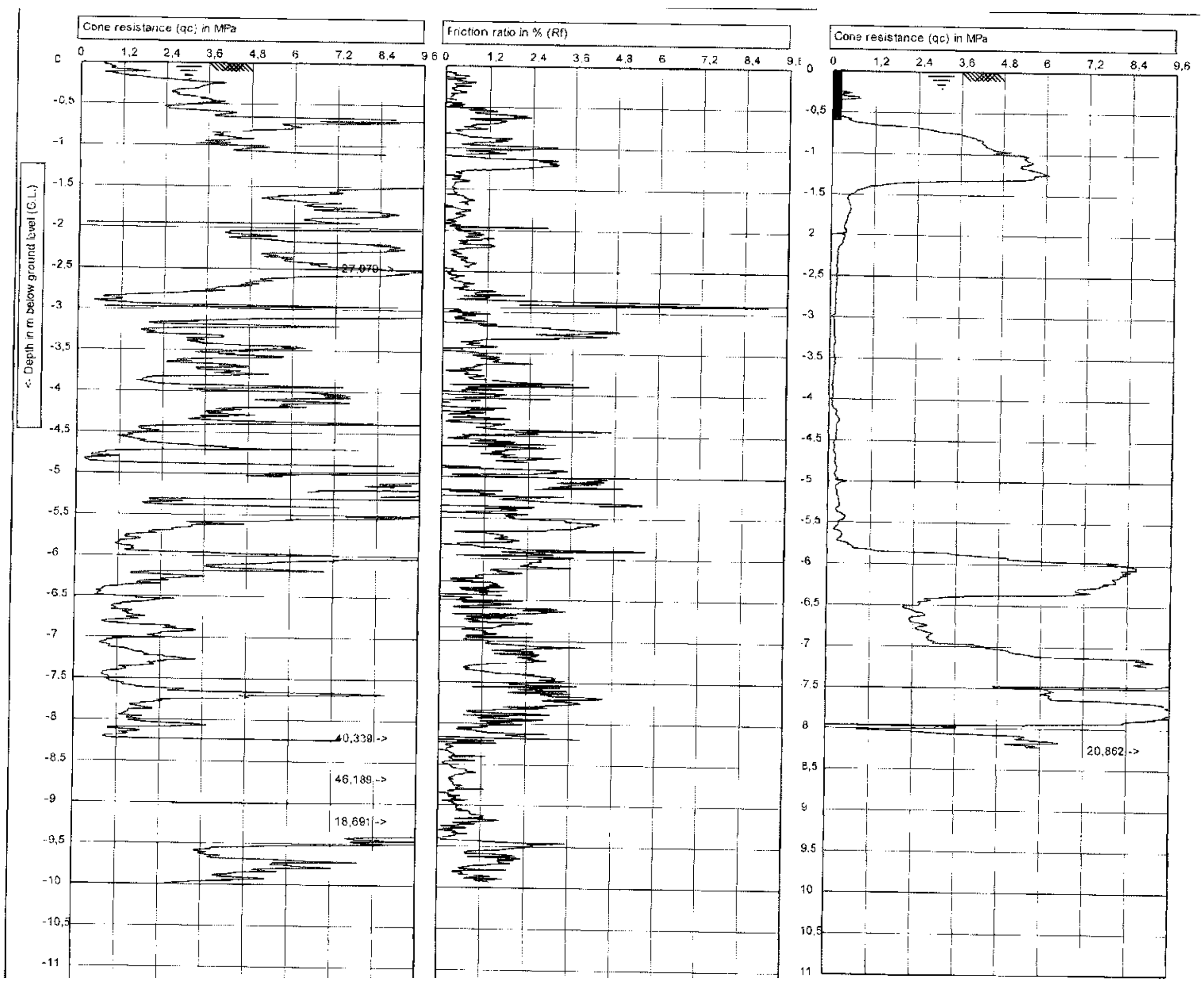


DR (Dynamic Replacement)

HDR (High Energy Dynamic Replacement) + surcharge

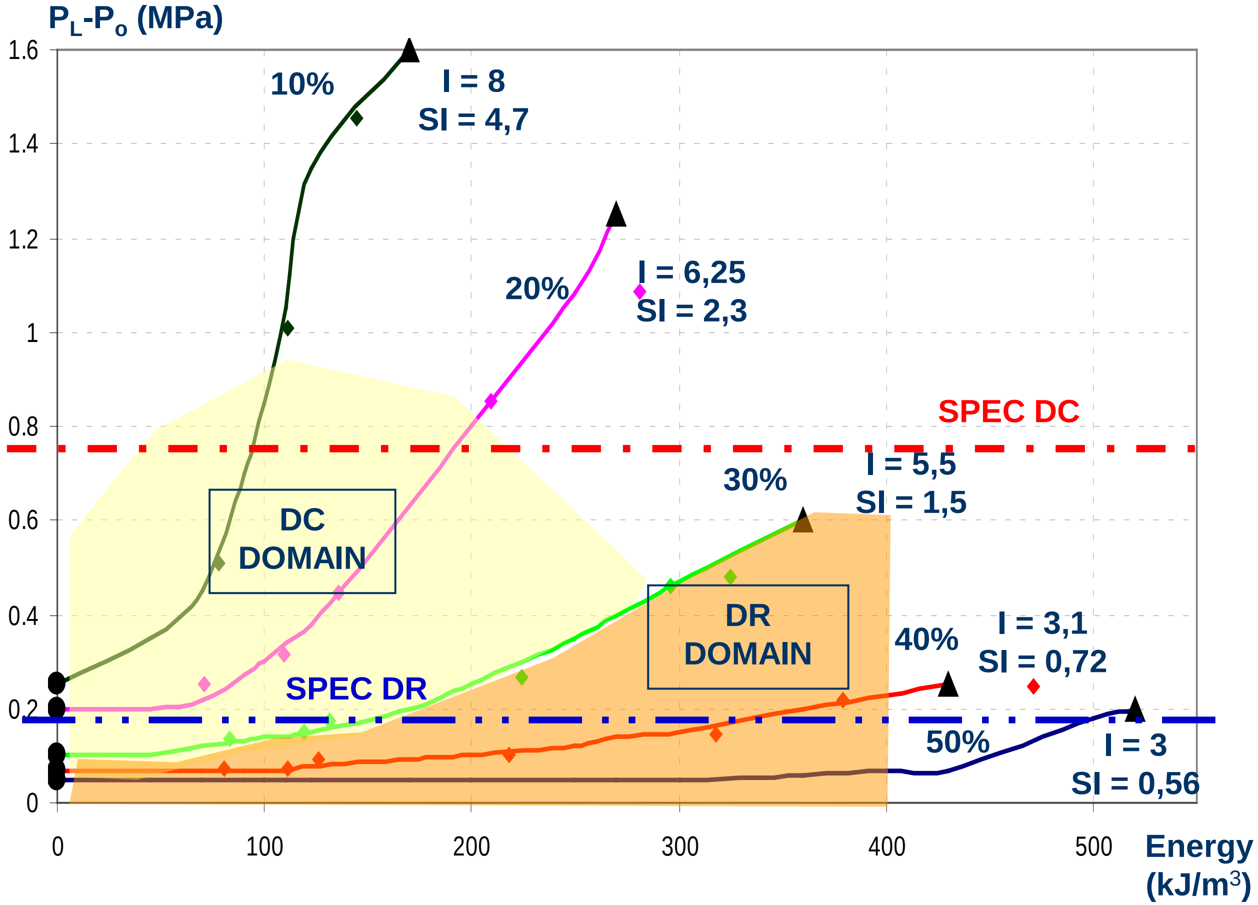


Variation in soil profile over 30 meters



ANALYSIS OF (PL-Po) IMPROVEMENT AS FUNCTION OF ENERGY AND FINES

K.A.U.S.T. – Saudi Arabia



BASIS

- 60 grainsize tests
- 180 PMT tests

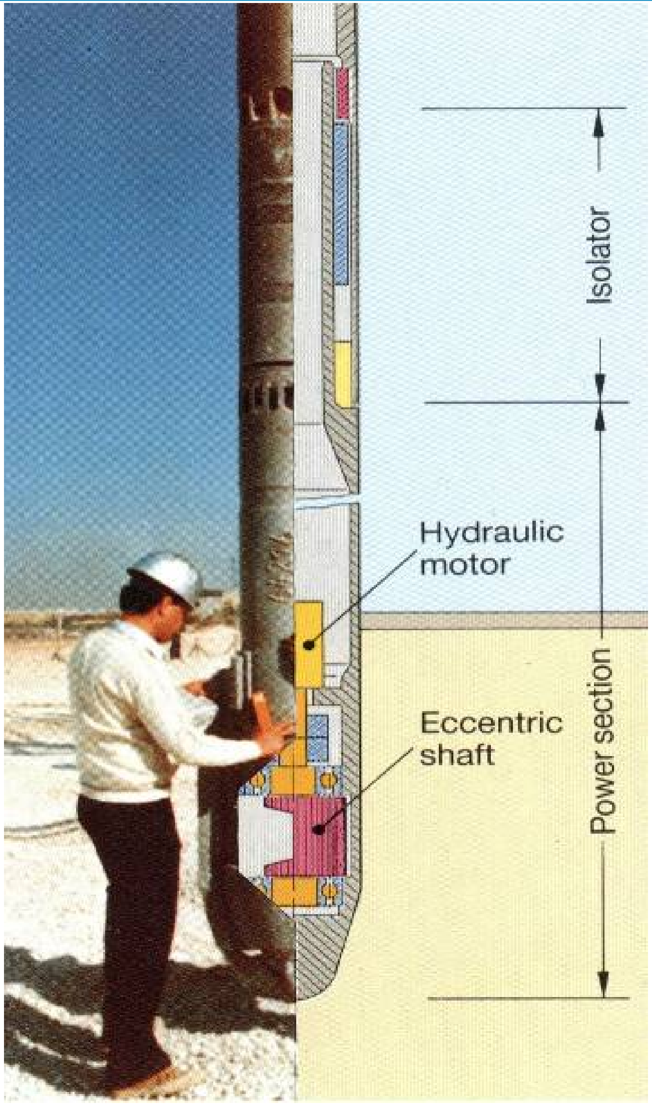
PARAMETERS

- $P_L - P_o$ = 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 $\frac{I \times 100}{E}$

LEGEND

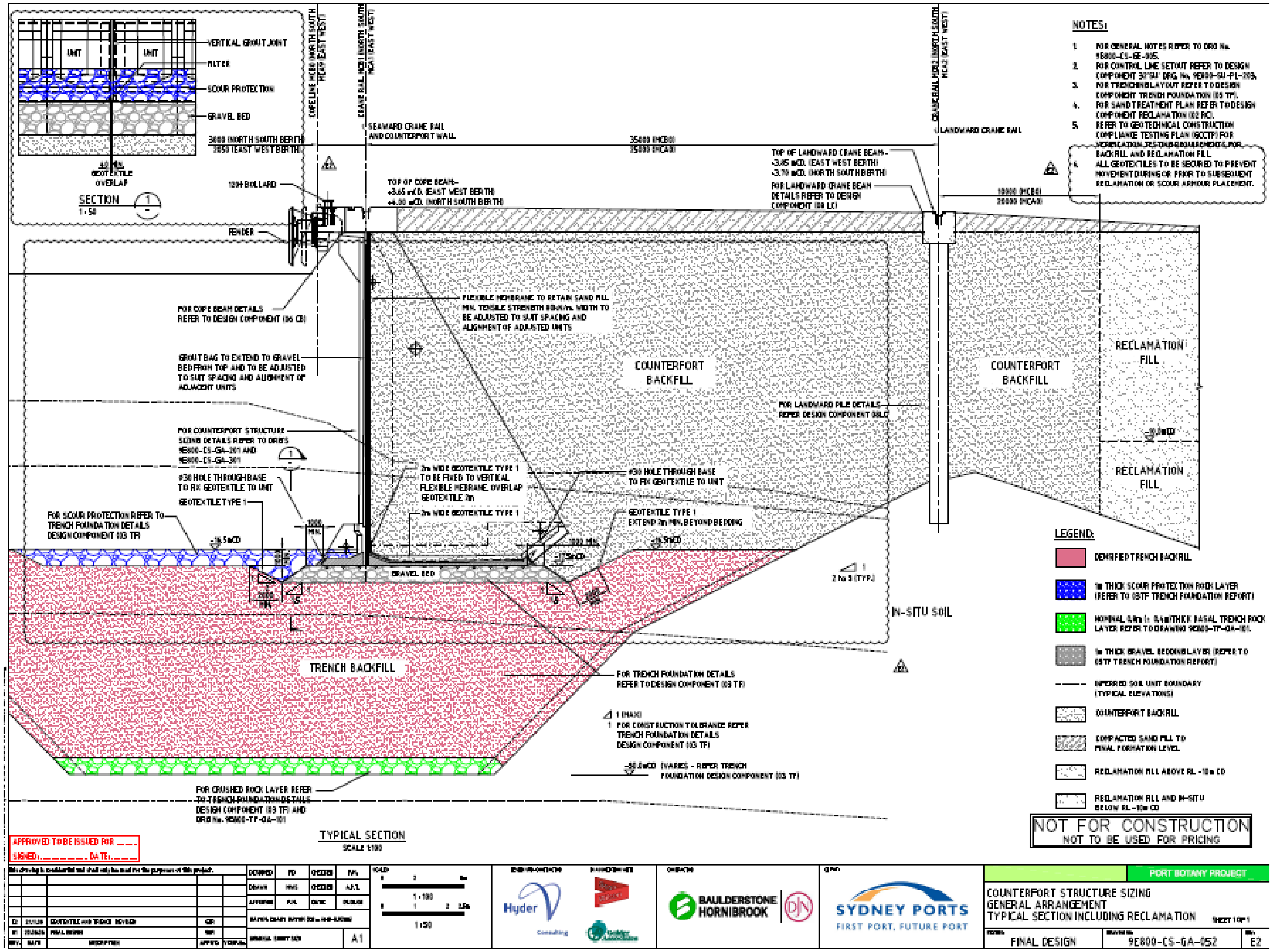
- ● Average pre-treatment values
- ◆ Average values between phases
- ▲ Average post-treatment values
- SPEC DC : $P_L - P_o \geq 0.75$ MPa
- SPEC DR : PL – Po ≥ 0.18 MPa

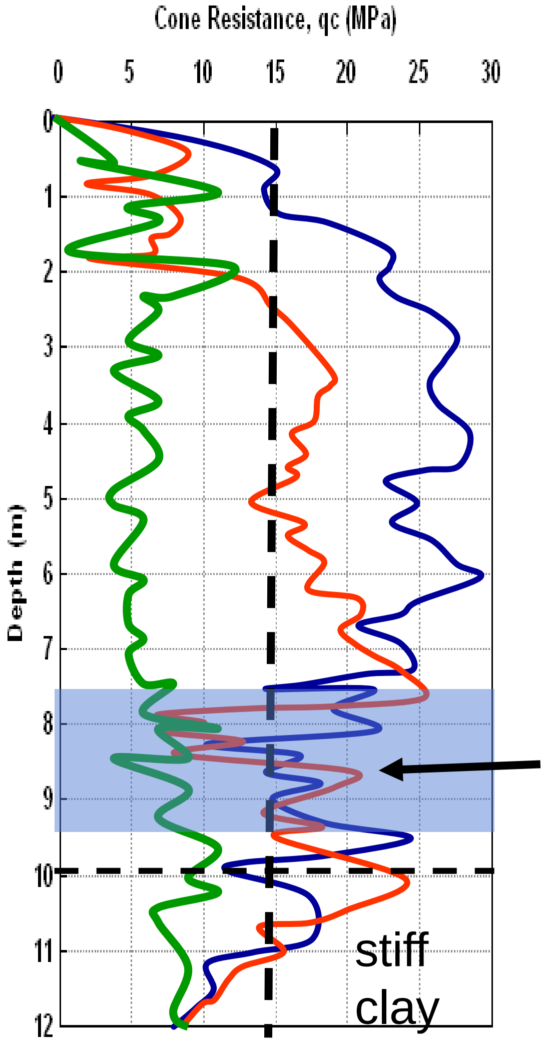
VIBROFLOTS


Isolator
Hydraulic motor
Eccentric shaft
Power section


Amplitude
28 – 48mm

GENERAL ARRAGEMENT COUNTERFORTS INCLUDING RECLAMATION



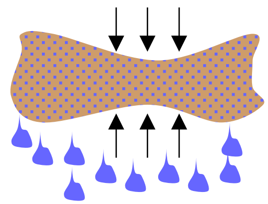
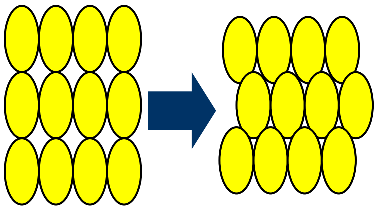
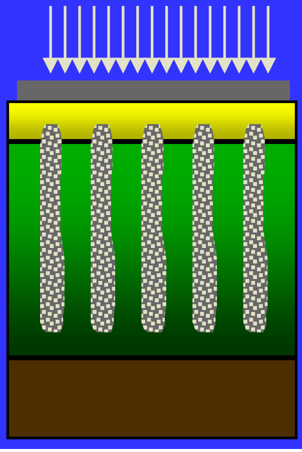


RESULTS

1. Except for the upper 50cm, the combination of VC and DC satisfied the q_c = 15 MPa (upper 0.5m requires surface roller compaction).
2. Enforced settlement:
   After VC – 47cm
   After DC – 27cm
   Total – 74 cm (~ 10% of treatment depth)

Compaction was less effective in this layer!

Soil Improvement Techniques

	Without added materials	With added materials
Cohesive soil **Peat , clay …**	1 Drainage 2 VAcuum 	4 Dynamic replacement 5 Stone columns 6 CMC 7 Jet Grouting 8 Cement Mixing
Granular soil **Sand , fill**	3 Dynamic consolidation 4 Vibroflottation 	

Deep mixing

CONCEPT

-soft soils to (stiff) clay, silts & sands

-Depths up to 24 m (or more)

-Mixing tool & process (dry or wet)

-Mix soil &binder: UCS [0.2 – 15 MPa]

PARAMETERS

Depending on the functionality

-GI of soft soils (c',φ', C, E_{oed})

-block stabilisation (c',φ', C, E_{oed})

-Land levees – slope stabilisation (c',φ')

-Earth &/or water retaining (UCS, E, k, t)

-Vertical bearing function (UCS, E, durability,t)

-Liquefaction barrier, in situ remediation, …

-Binder type and composition,

-Mixing energy (blade rotation number)

Construction principles and equipment

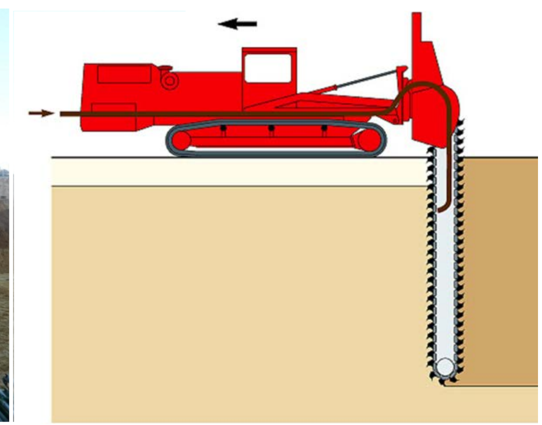
Execution process and ground improvement patterns

- Two types of installation method: wet and dry mixing

- Ground improvement patterns:
  - Soil-cement columns
  - Rectangular soil mix panels
  - Continuous barriers
  - Global mass stabilization

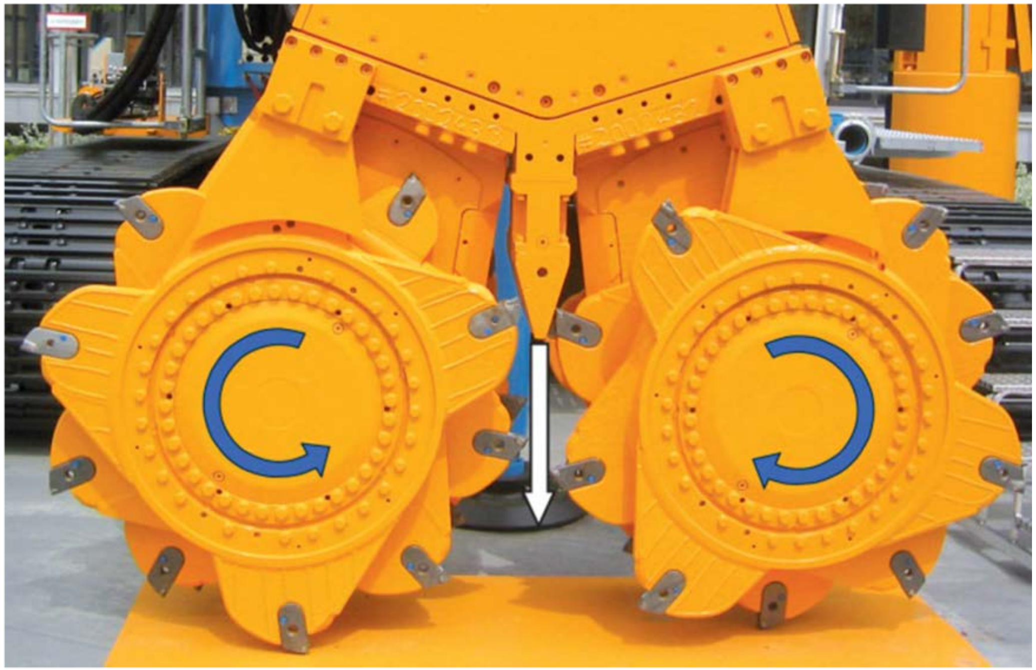
Quasthoff. State of the art in "Dry Soil Mixing" – Basics and case study . IS-GI 2012






Construction principles and equipment

Cutter Soil Mixing (CSM®) system for soil mix panels



Gerressen and Vohs. CSM-Cutter Soil Mixing – Worldwide experiences of a young soil mixing method in challenging soil conditions. IS-GI 2012

Several case histories in the proceedings of the IS-GI 2012

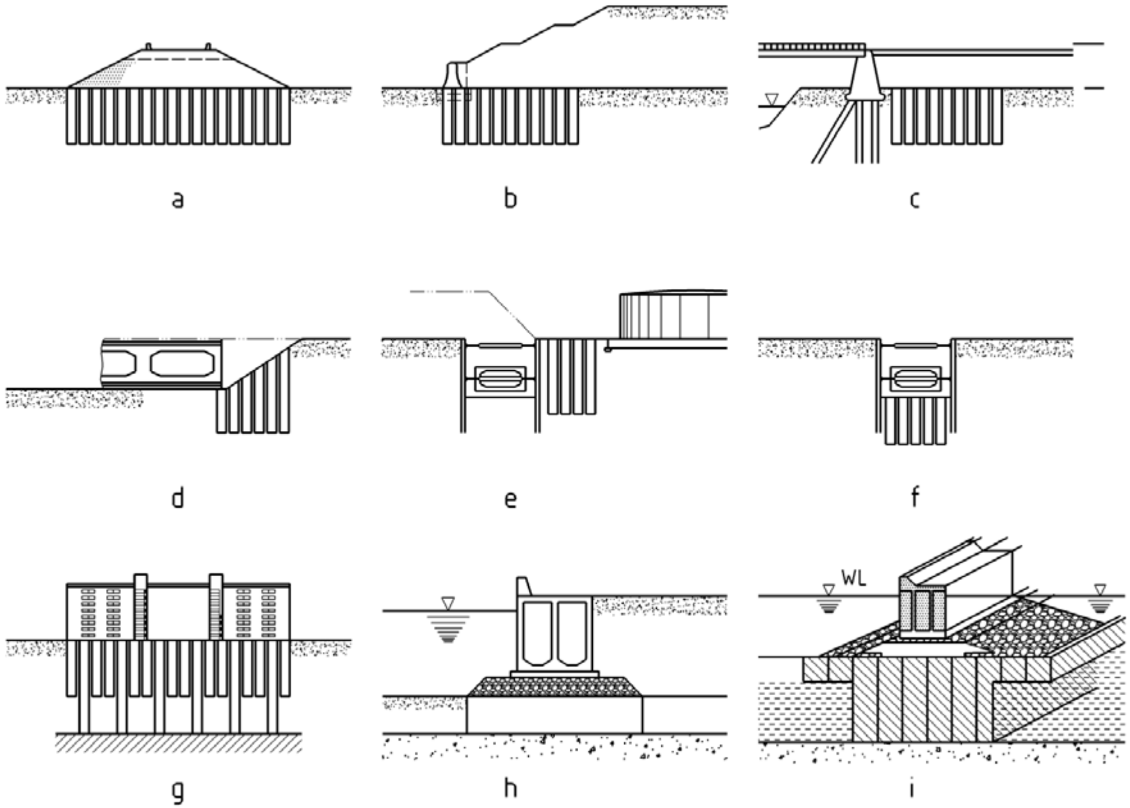
Typical characteristics in Belgium:

Water/Cement weight ratio (W/C): 0.6 to 1.2 (-)

Amount of cement: 200 to 400 kg/m3

Spoil return: up to 30%

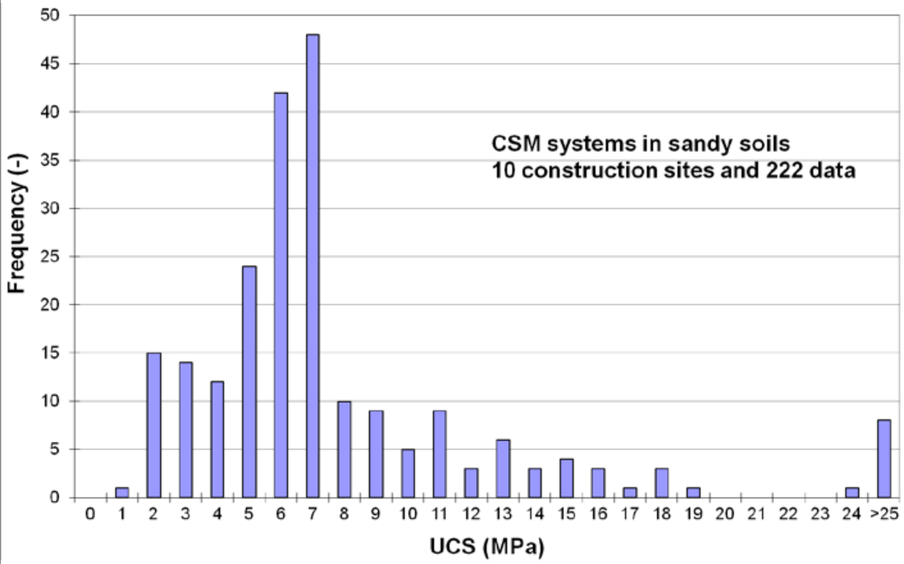
Deep mixing – EN 14679 (CEN TC 288) : field of application



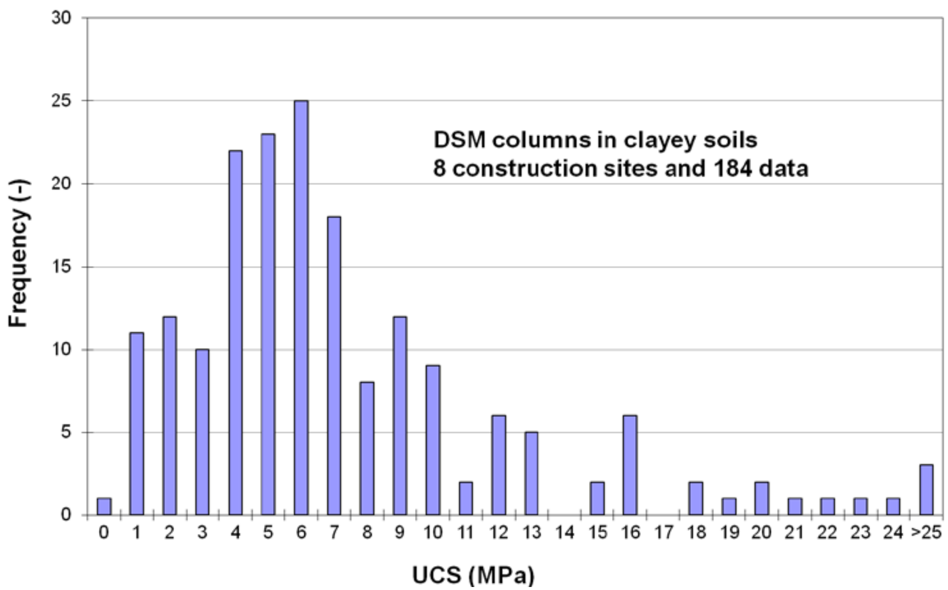
- a Road embankment stability/settlement
- b High embankment stability
- c Bridge abutment uneven settlement
- d Stability of cut slope
- e Reducing the influence from nearby construction
- f Braced excavation earth pressure/heave
- g Pile foundation lateral resistance
- h Sea wall bearing capacity
- i Break-water bearing capacity

Hydro-mechanical characterization of DSM material: some results form the research project in B

Typical UCS values



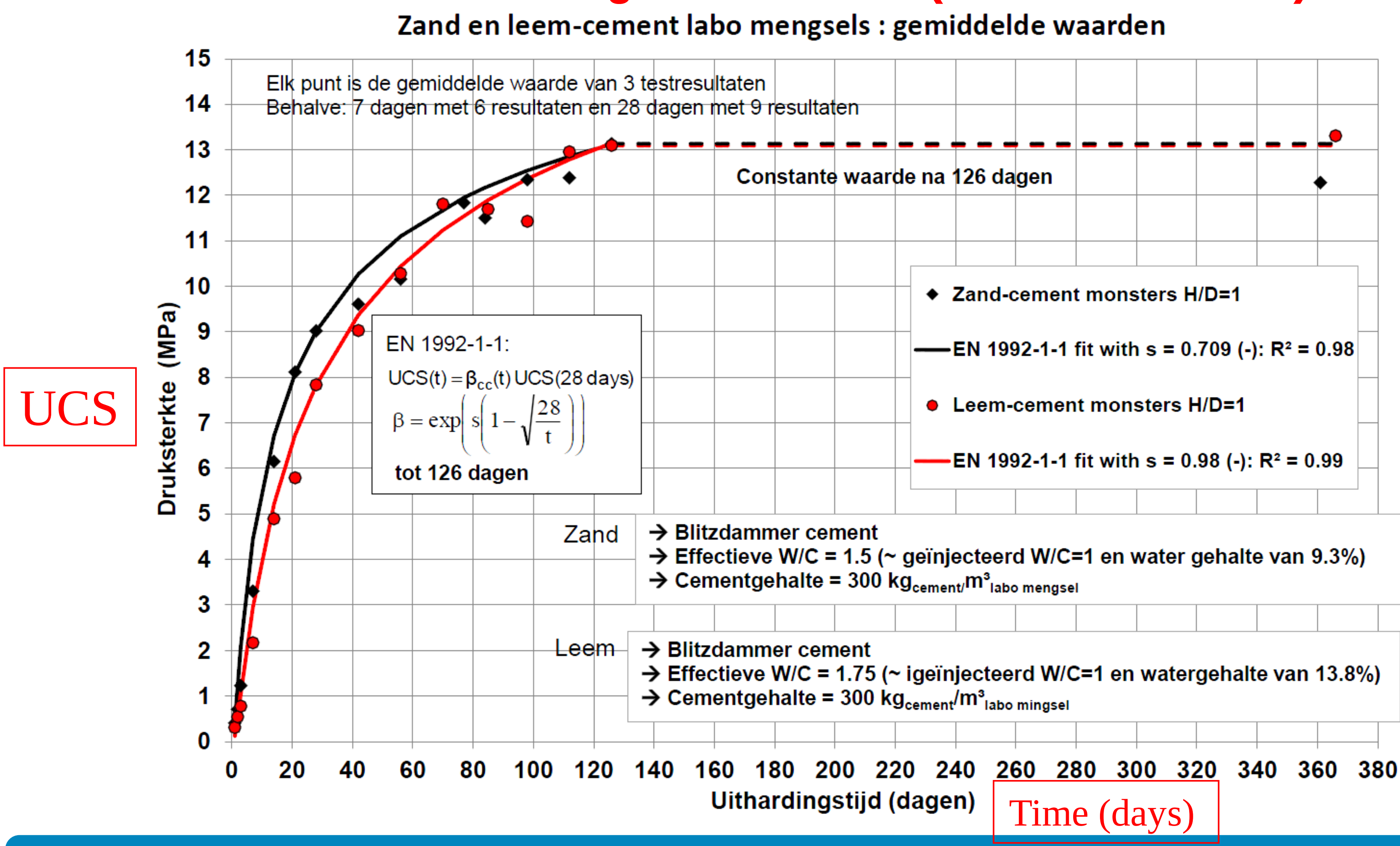
DSM core samples



Denies et al. SOIL MIX WALLS as retaining structures – mechanical characterization. IS-GI, Brussels 2012

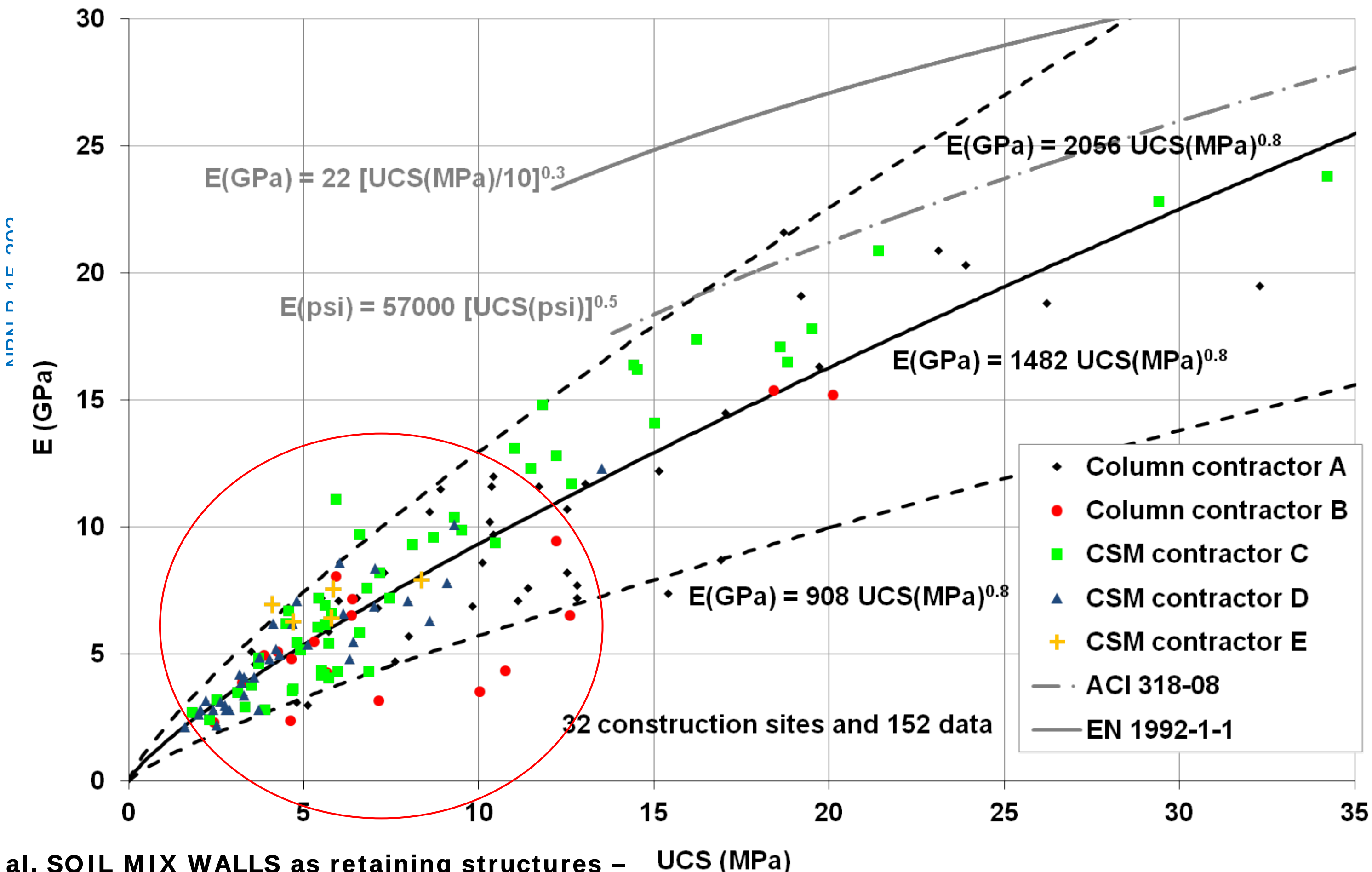
Hydro-mechanical characterization of DSM material: some results form the research project in B

UCS and curing time effect (NEW RESULTS)



Hydro-mechanical characterization of DSM material: some results form the research project in B

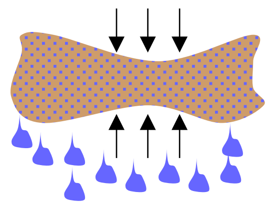
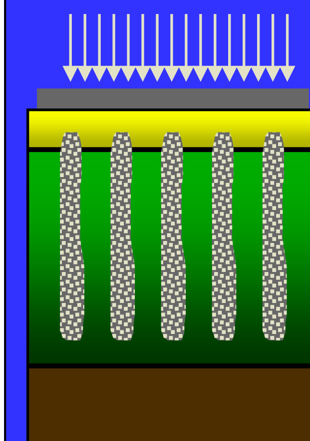
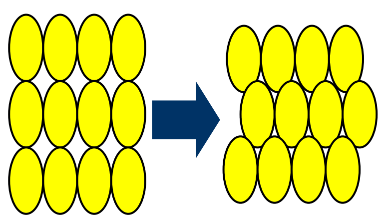
UCS and Modulus of Elasticity (E)



Denies et al. SOIL MIX WALLS as retaining structures – mechanical characterization. IS-GI, Brussels 2012

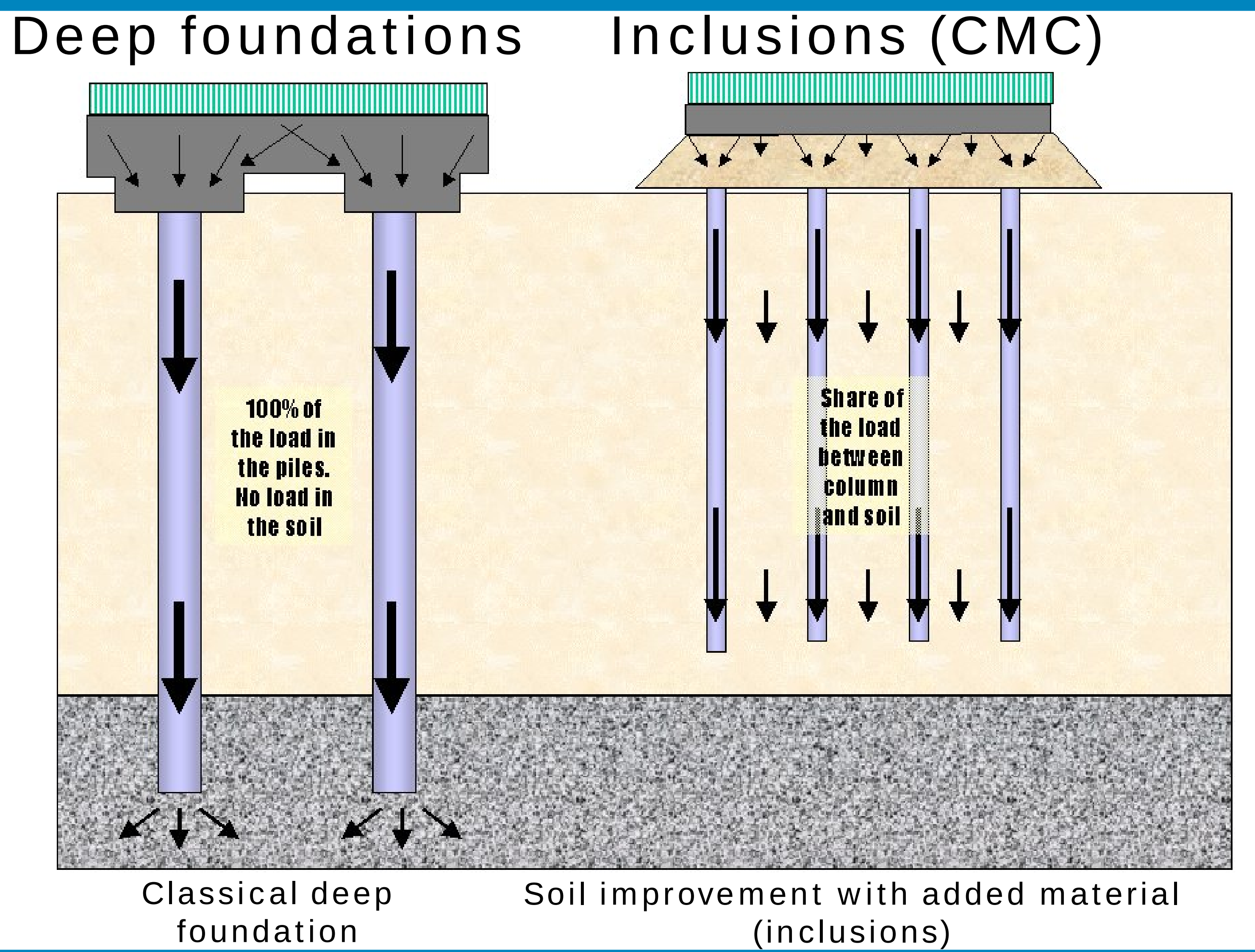
NBN EN 12390-3: 2008

Soil Improvement Techniques

	Without added materials	With added materials
Cohesive soil **Peat , clay …**	1 Drainage 2 VAcuum 	4 Dynamic replacement 5 Stone columns 6 CMC 7 Jet Grouting 8 Cement Mixing 
Granular soil **Sand , fill**	3 Dynamic consolidation 4 Vibroflottation 	

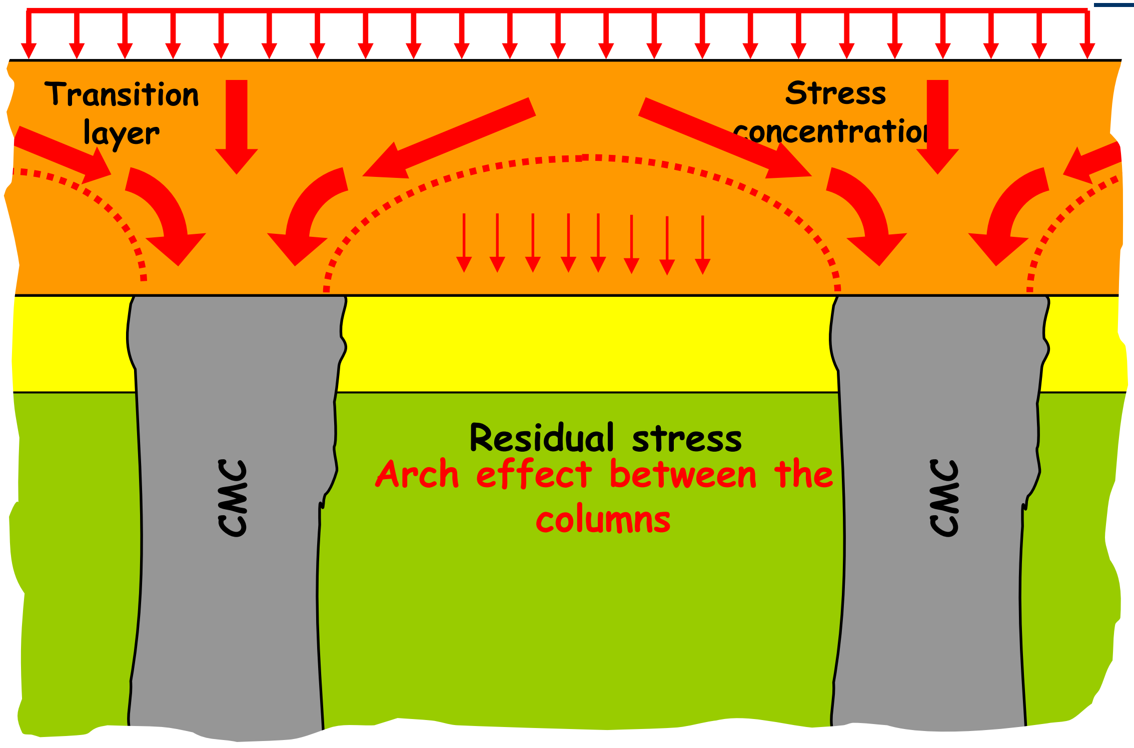
CMC – Execution

Difference between deep foundations and rigid inclusions

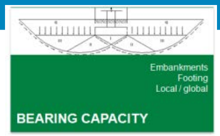


CMC Principle

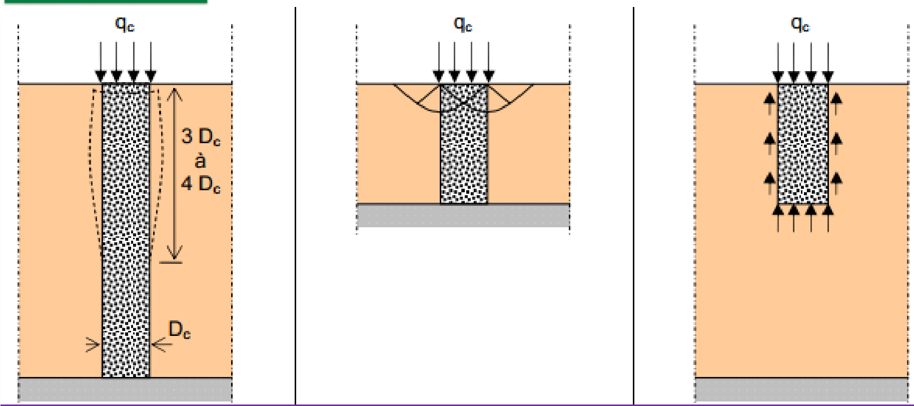
- Create a composite material Soil + Rigid Inclusion (CMC) with:
  - Increased bearing capacity
  - Increased elastic modulus
- Transfer the load from structure to CMC network with a transition layer

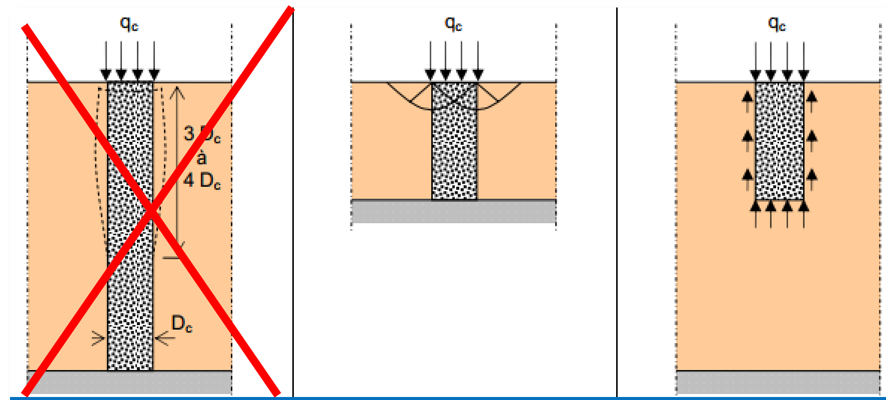


Differences in Design Methodology between Granular & Grouted Inclusions



Internal Stability of the Inclusions :





Failure by Lateral Expansion (bulging)
Failure by Shearing
Failure by Punching

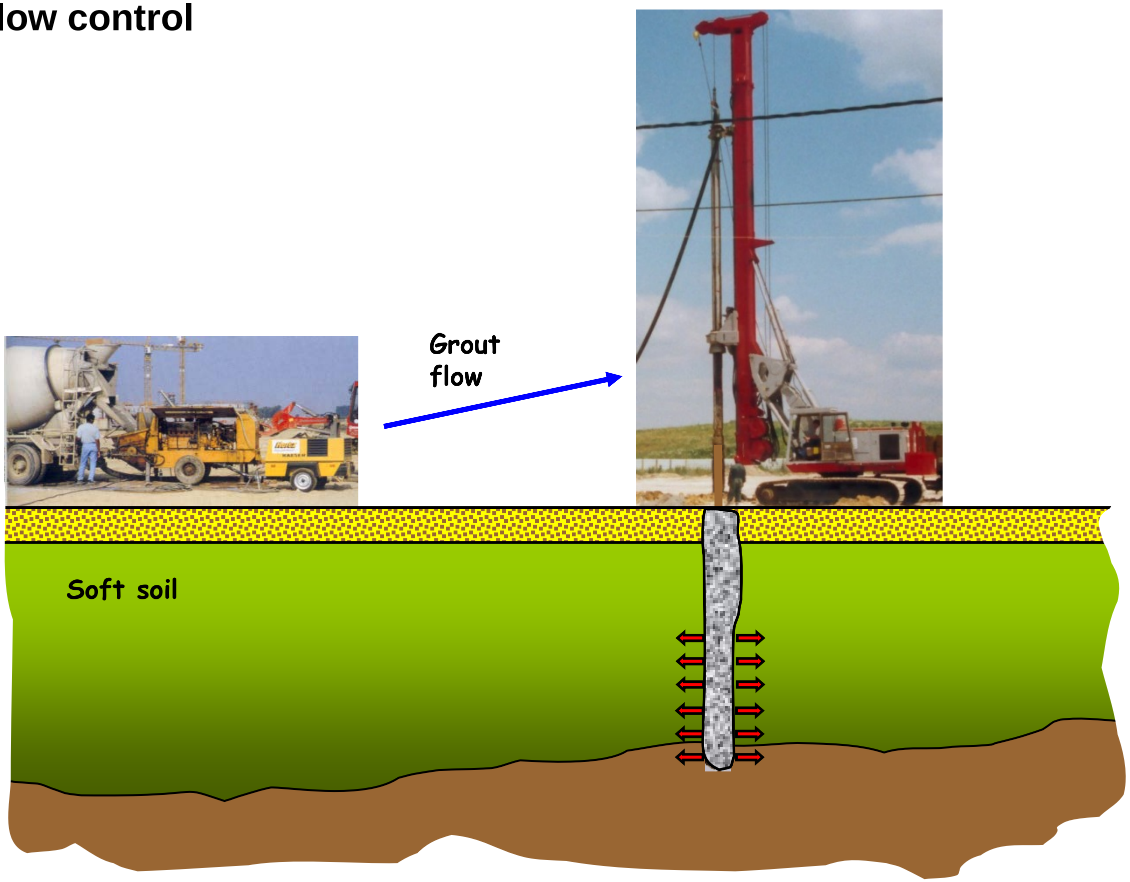
GRANULAR INCLUSIONS

~~Failure by Lateral Expansion (bulging)~~
Failure by Shearing
Failure by Punching

RIGID INCLUSIONS

CMC – Execution

- Fleet of specilized equipment
  - Displacement auger => quasi no spoil
  - High torque and pull down
- Fully integrated grout flow control



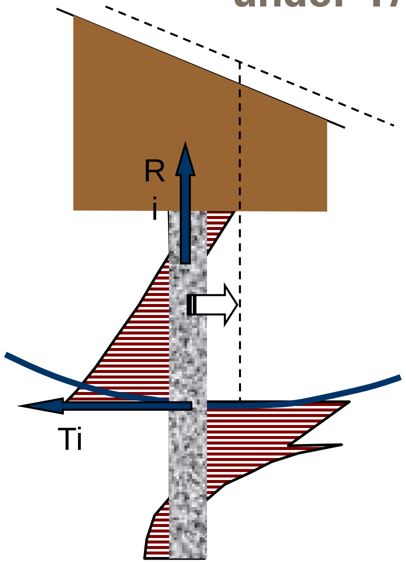
Calculation principle

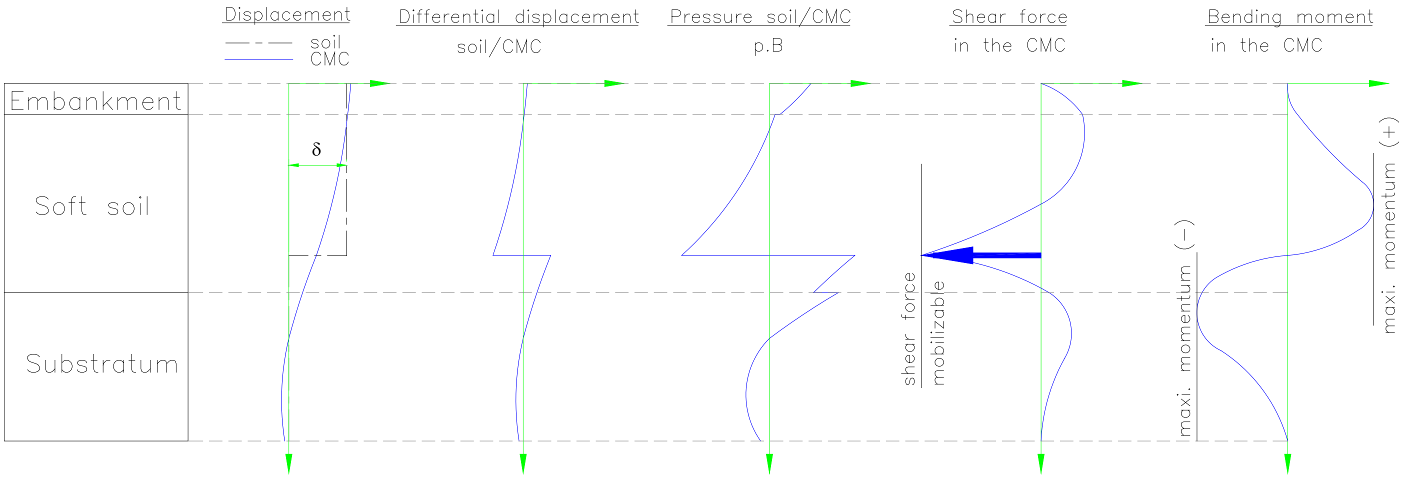
1/ Estimation of the vertical stress in the column (% of the embankment load),

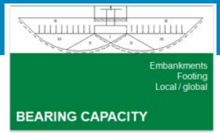
2/ Thus maximum momentum so that M / N ≤ D / 8 (no traction in the mortar),

3/ Thus maximum shear force taken by the inclusion (similar to a pile to which a displacement is applied),

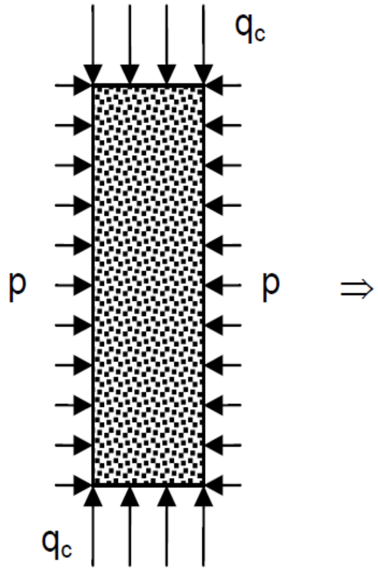
4/ Modeling of the CMC as nails working in compression + imposed shear force under TALREN software (or equivalent).







Internal Stability of the Inclusions :



$$q_c = tg^2\left(\frac{\pi}{4} + \frac{\varphi_c}{2}\right) \cdot p = Kp_c \cdot p$$

or

$$q_c = \frac{1 + \sin\varphi_c}{1 - \sin\varphi_c} \cdot p$$

The column is assimilated to a cylinder under triaxial conditions (Greenwood, 1970) under a compressive vertical stress qc and a maximum confining stress p = s’h

Since the column is made of a draining material, we assume that we are under drained conditions.

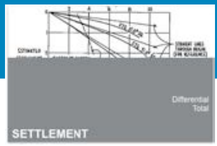
Failure by Lateral Expansion (bulging)

Failure by Shearing

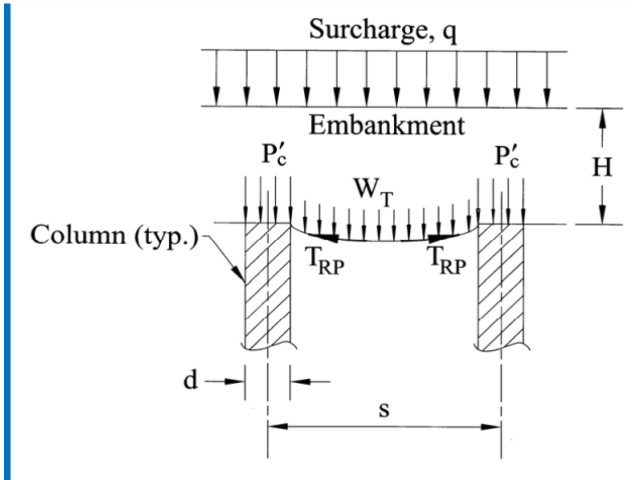
Failure by Punching

GRANULAR INCLUSIONS

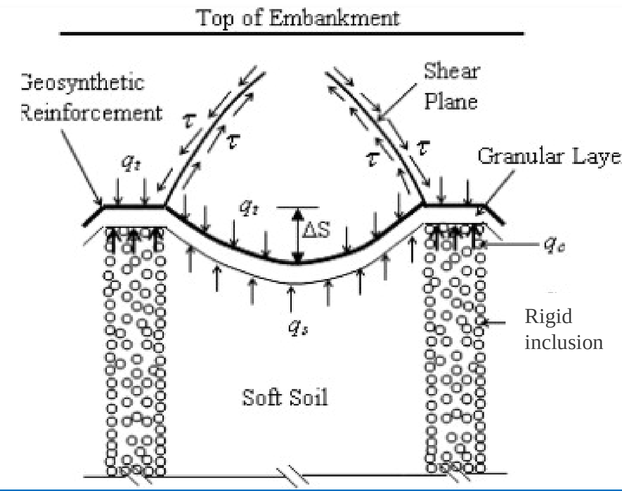
Differences in Design Methodology between Granular & Grouted Inclusions



Settlement



Britsh Standard



German Standard

The British Standard Recommends that the thickness of the LTP be at least 1.4 times the clear span.
The German method assumes some reaction from the soil.

The British Standard Method uses a catenary approach.
The geotextile is placed directly above the top of the rigid inclusions.
The geotextile spanning between columns carries the load to the rigid inclusion through tension. Tension in the geotextile is calculated based on membrane theory.

SETTLEMENT UNDER A SLAB

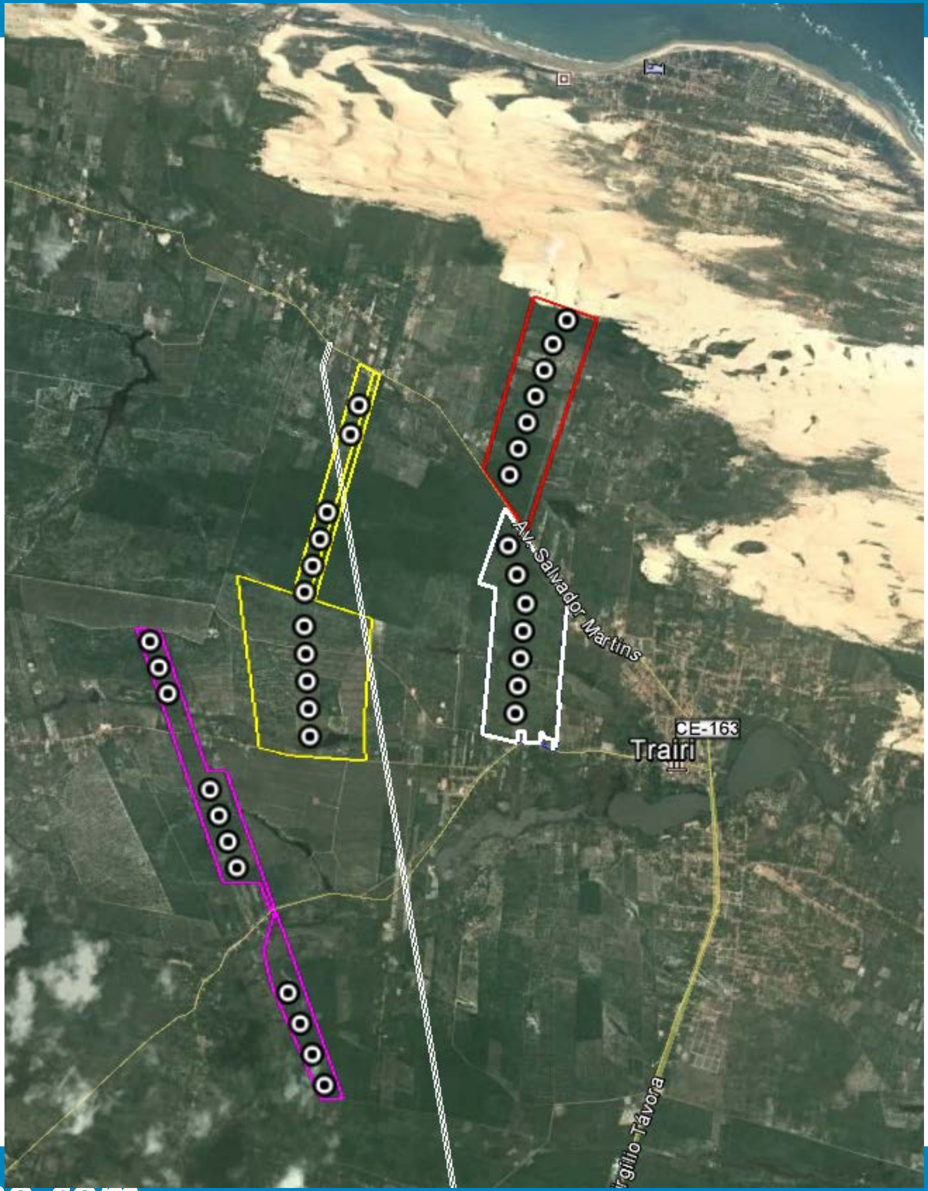
RIGID INCLUSIONS

Differences in Design Methodology between Granular & Grouted Inclusions

CONCLUSION

	Slab / Embankment	Footing	Slab / Embankment	Footing
BEARING CAPACITY	HOMOGENEI – -ZATION METHOD	HOMOGENEI – -ZATION METHOD	RIGID INCLUSIONS AS NAILS OR 2D OR 3D FEM / CHECK BENDING	RIGID INCLUSIONS UNLOAD THE SOIL / CHECK INTERNAL STABILITY
SETTLEMENT	HOMOGENEI – -ZATION METHOD PRIEBE…	MODIFIED PRIEBE METHOD	FEM AXISYMETRICAL	ANALYTICAL ITERATIVE SOLUTION OR 3D FEM AXISYMETRICAL
LIQUEFACTION	SHEAR HOMOGENEIZATION METHOD NCEER (1996)		??? SHEAR REINFORCEMENT OF PANEL SOLUTION	

TRAIRI WIND FARM
Ground Improvement Solutions : stone columns

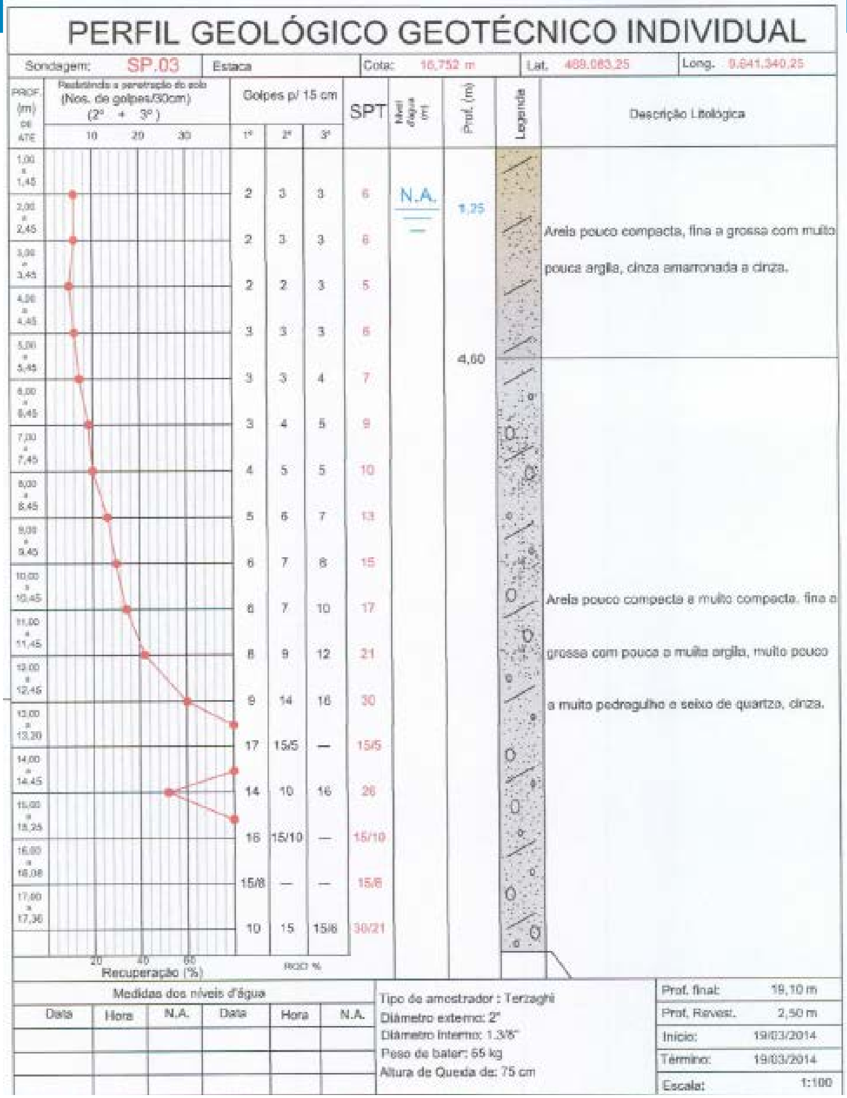


Construction of wind farm with 36 WTG (3 MW – 120 m high)

The project is divided in four different areas:

- Cacimbas: 7 WTG
- Santa Monica:7 WTG
- Estrela: 11 WTG
- Outro Verde:11 WTG

TRAIRI WIND FARM
Soil Conditions / Soil Improvement



PERFIL GEOLÓGICO GEOTÉCNICO INDIVIDUAL

Sondagem: SP.03 | Estaca | Cota: 16,752 m | Lat. 489.083,25 | Long. 9.641.340,25

PROF. (m) DE ATÉ	Golpes p/ 15 cm 1º	2º	3º	SPT
1,00 a 1,45	2	3	3	6
2,00 a 2,45	2	3	3	6
3,00 a 3,45	2	2	3	5
4,00 a 4,45	3	3	3	6
5,00 a 5,45	3	3	4	7
6,00 a 6,45	3	4	5	9
7,00 a 7,45	4	5	5	10
8,00 a 8,45	5	6	7	13
9,00 a 9,45	6	7	8	15
10,00 a 10,45	6	7	10	17
11,00 a 11,45	8	9	12	21
12,00 a 12,45	9	14	16	30
13,00 a 13,20	17	15/5	—	15/5
14,00 a 14,45	14	10	16	26
15,00 a 15,25	16	15/10	—	15/10
16,00 a 16,08	15/8	—	—	15/8
17,00 a 17,30	10	15	15/8	30/21

Resistência à penetração do solo (Nos. de golpes/30cm) (2º + 3º): 10, 20, 30

Nível d'água (m): N.A. 1,25

Prof. (m): 4,60

Descrição Litológica:
- Areia pouco compacta, fina a grossa com muito pouca argila, cinza amarronada a cinza.
- Areia pouco compacta a muito compacta, fina a grossa com pouca a muita argila, muito pouco a muito pedregulho e seixo de quartzo, cinza.

Recuperação (%): 20, 40, 60 — RQD %

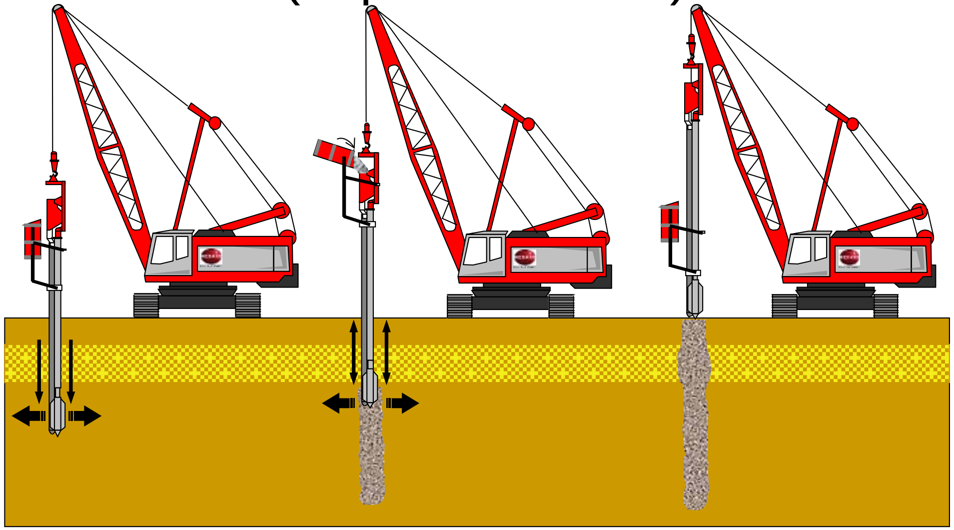
Medidas dos níveis d'água

Data	Hora	N.A.	Data	Hora	N.A.

Tipo de amostrador : Terzaghi
Diâmetro externo: 2"
Diâmetro Interno: 1.3/8"
Peso de bater: 65 kg
Altura de Queda de: 75 cm

Prof. final:	19,10 m
Prof. Revest.:	2,50 m
Início:	19/03/2014
Término:	19/03/2014
Escala:	1:100

- loose to medium silty sands and clays overlying dense sand and weathered bedrock
  - Loose to medium sand : N = 7 to 25
  - Silty sand /silty clay : N = 3 to 14
  - Dense sand : N = 30 to 60
  - Bedrock
- Soil Iprovement with Stone Columns (depth 5 to 15 m)

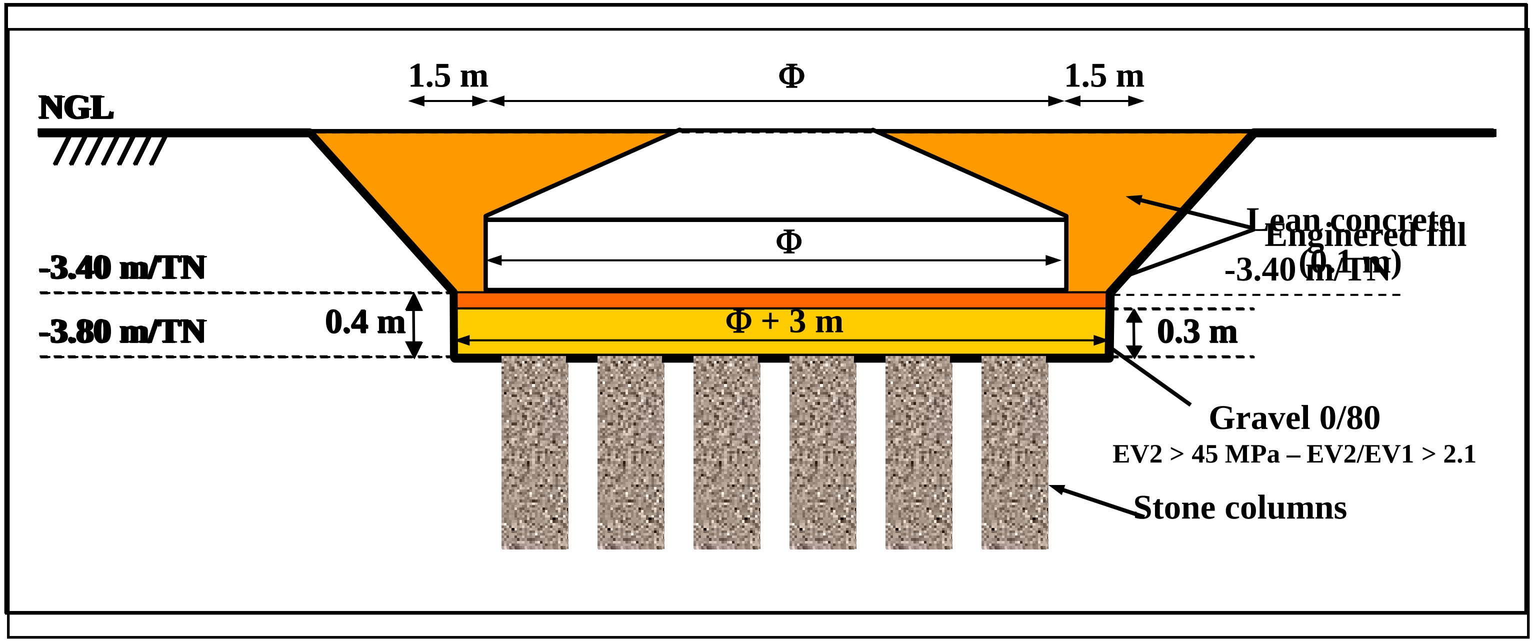


1 – Vibro-penetration with air jetting

2 – Insertion of stone and column compaction

3 – Executed Columns

TRAIRI WIND FARM
Foundation design

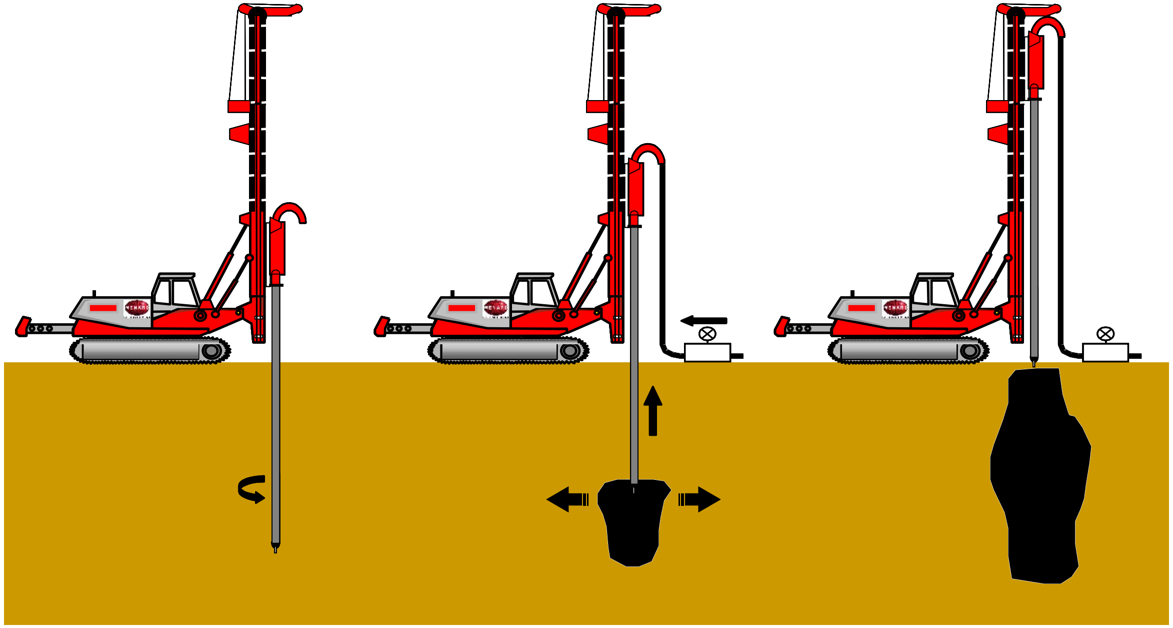


- Maximum characteristic edge bearing pressure (SLS): 312 kN/m².
- Maximum characteristic edge bearing pressure (ULS): 468 kN/m².
- Maximum characteristic average bearing pressure (SLS): 250 kN/m².
- Maximum characteristic average bearing pressure (ULS): 375 kN/m².
- Minimum dynamic stiffness in rotation of the foundation: Kφ = 462 047 MN.m/rad.

- Same type of equipment as for CMC
  - Soil displacement rig and Pump,

- Key points
  - Quality of grout (grain size distribution, workability, consistancy)
  - Injection speed and successive phases

- Final Testing = CPT



Future Caisson Stability Analysis

底部のみをSCPで改良した場合

File Name: Future Caisson at operation stage (undrain) SCP+Sandkey10.gsz

Future Caisson (Type-B) Slip Stability Analysis
At Operation Stage (Undrain) **(Undrained)**

Factor of Safety: 1.498

改良範囲全体のφは、仕様書により32° を用いる。
Sandkeyのφは35° 。

Name: Caisson
Model: Mohr-Coulomb
Unit Weight: 20.6 kN/m³
Cohesion: 10000 kPa
Phi: 60 °

Name: Concrete Deck
Model: Mohr-Coulomb
Unit Weight: 24 kN/m³
Cohesion: 6000 kPa
Phi: 45 °

Name: RS -Undrain- (4<N<20)
Model: Mohr-Coulomb

Name: Sand Fill
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: 30 °

Name: Rock Mound
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: 40 °

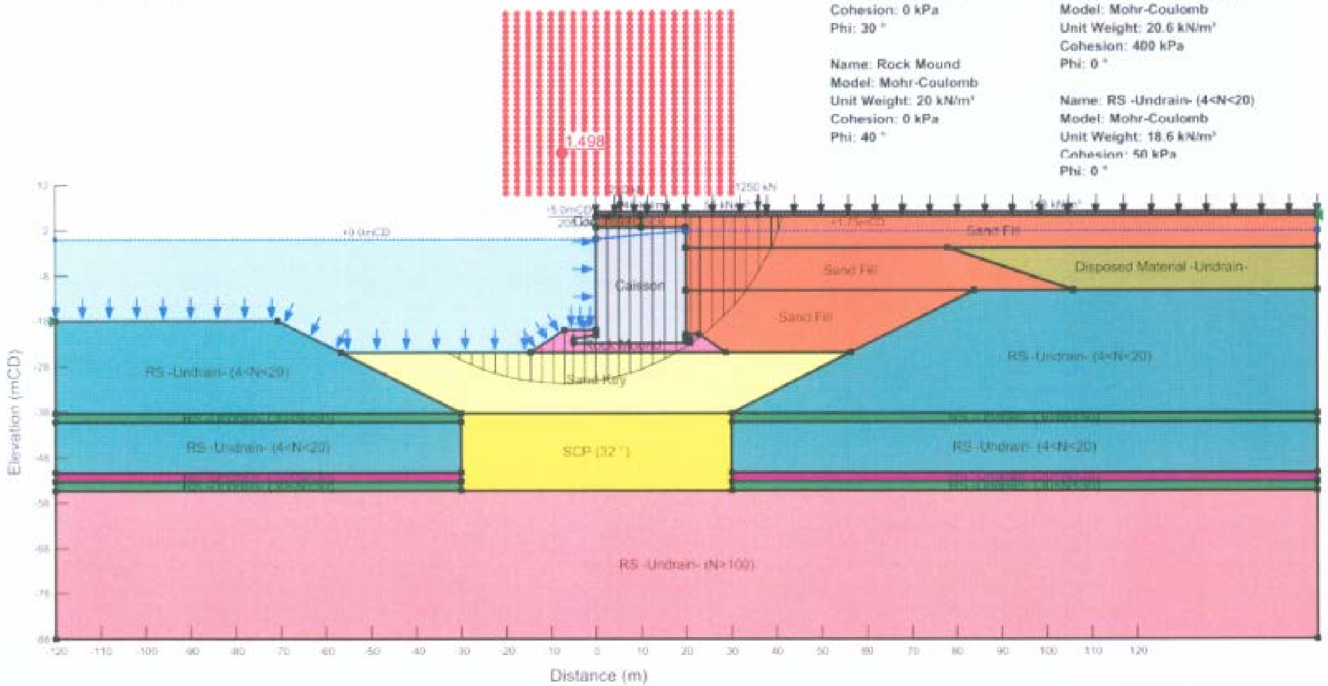
Name: RS -Undrain- (4<N<20)
Model: Mohr-Coulomb
Unit Weight: 18.6 kN/m³
Cohesion: 50 kPa
Phi: 0 °

Name: RS -Undrain- (20<N<30)
Model: Mohr-Coulomb
Unit Weight: 19.1 kN/m³
Cohesion: 125 kPa
Phi: 0 °

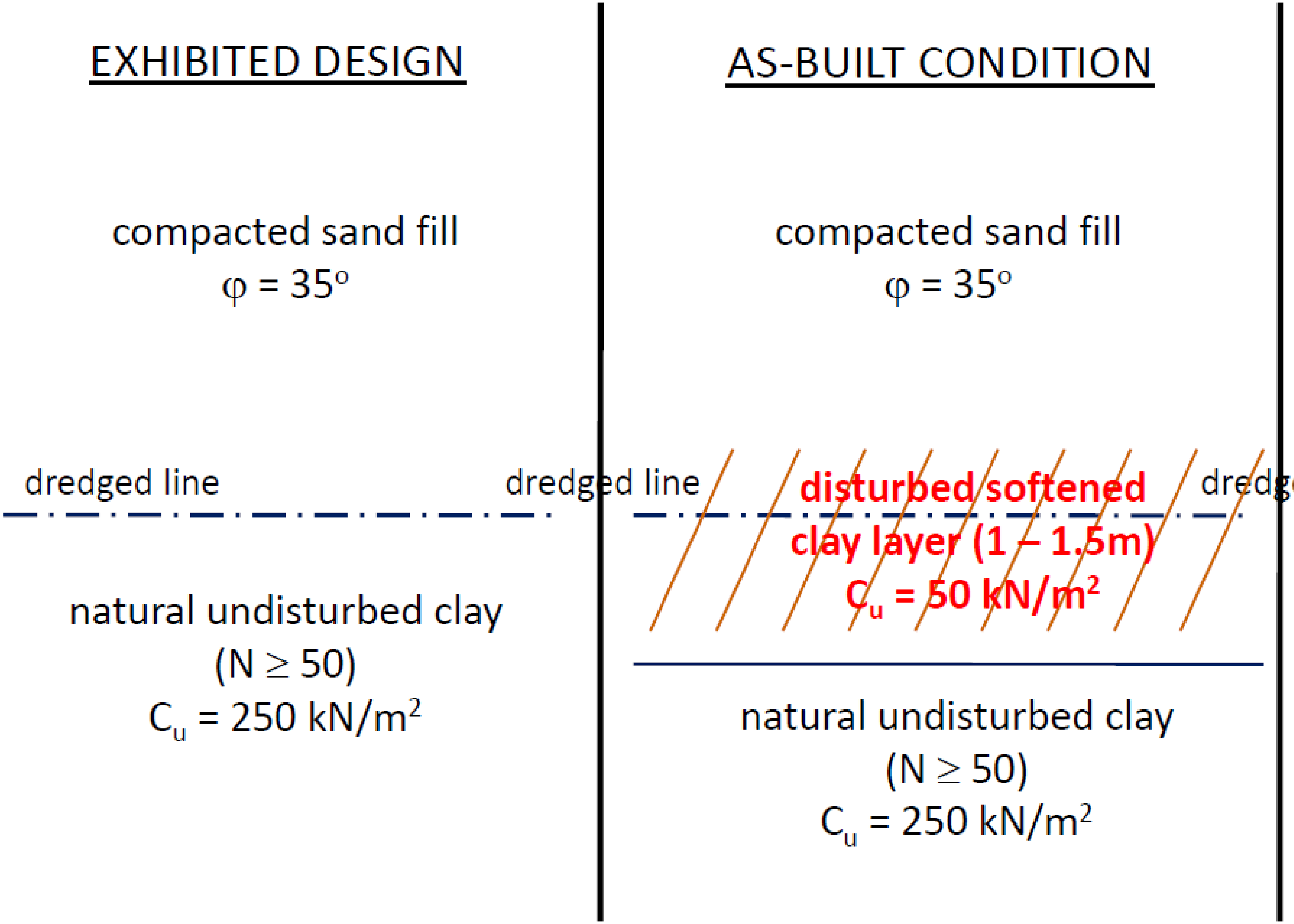
Name: RS -Undrain- (30<N<50)
Model: Mohr-Coulomb
Unit Weight: 19.6 kN/m³
Cohesion: 200 kPa
Phi: 0 °

Name: RS -Undrain- (N>100)
Model: Mohr-Coulomb
Unit Weight: 20.6 kN/m³
Cohesion: 400 kPa
Phi: 0 °

Name: RS -Undrain- (4<N<20)
Model: Mohr-Coulomb
Unit Weight: 18.6 kN/m³
Cohesion: 50 kPa
Phi: 0 °



As built conditions

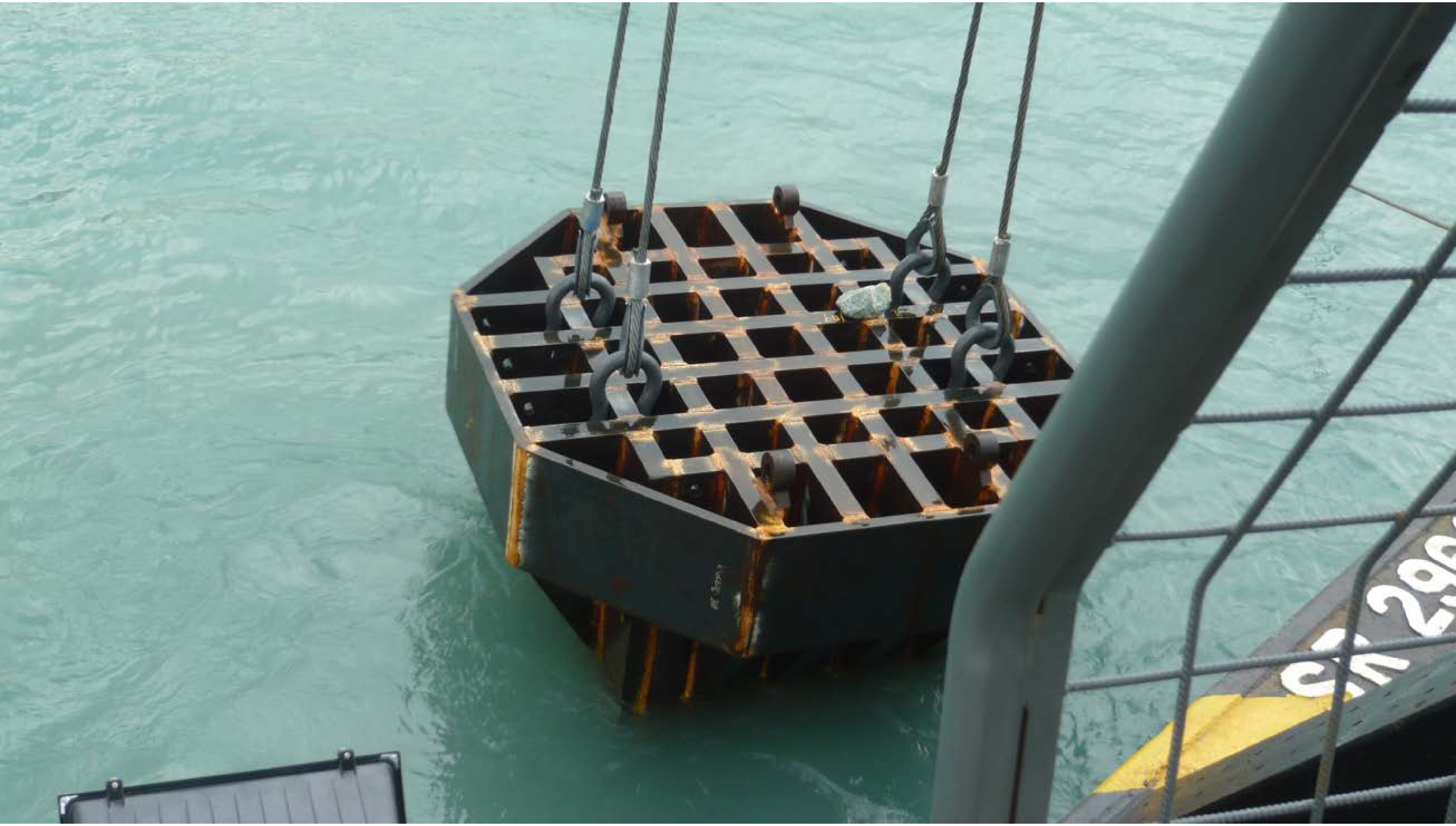


Proposed solution

EXHIBITED DESIGN		PROPOSED SOLUTION	
	compacted sand fill $\varphi = 35^o$	compacted sand fill $\varphi = 35^o$	
1.3m	compacted sand fill $\varphi = 35^o$ C = 0	compacted rock mat ($\varphi = 45^o$ C = 0)	1.3m
	dredged line		
1.5m	undisturbed clay $\varphi = 0^o$ C_u = 250 kN/m^2	15% rock ($\varphi = 45^o$) + 85% clay (C_u = 80 kPa)	1.5m
	natural undisturbed clay (N $\geq$ 50) $\varphi = 0^o$ C_u = 250 kN/m^2	natural undisturbed clay (N $\geq$ 50) $\varphi = 0^o$ C_u = 250 kN/m^2	

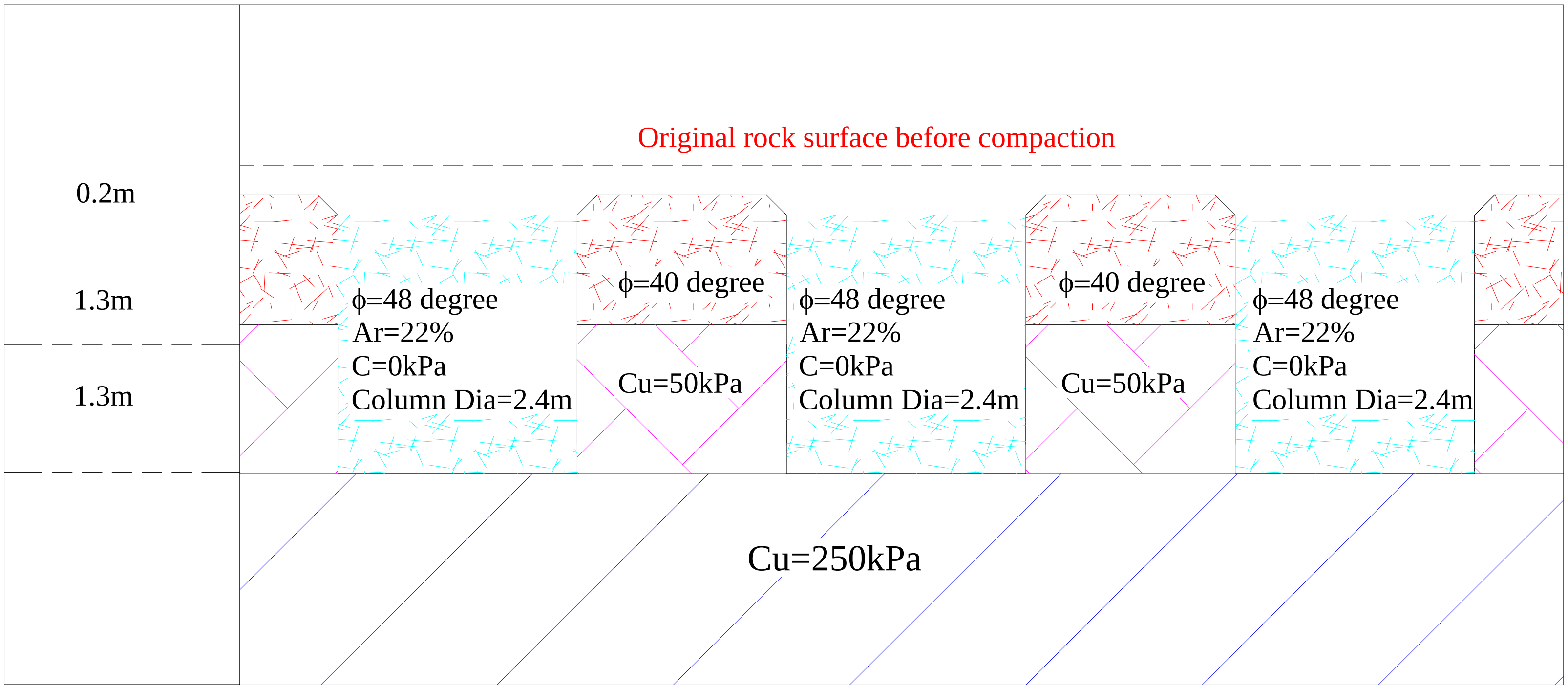
View of pounder construction

View of pounder ready to work



General SFT up

After compaction actual results



UNIVERSIDADE DE COIMBRA

Universidade do Minho

SIMSG ISSMGE

TC 211

OBRIGADO
MERCI
THANK YOU

ménard matériels