Concept and Parameters related to Ground Improvement illustrated by Case Histories

Presented by
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Chairman of T.C.G.I.

17TH International Conference on
Soil Mechanics & Geotechnical Engineering

State of the Art Report

Construction Processes
Procédés de Construction

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

Category	Method	Principle
A. Ground improvement without admixtures in non-cohesive soils or fill materials	A1. Dynamic compaction	Densification of granular soil by dropping a heavy weight from air onto ground.
	A2. Vibrocompaction	Densification of granular soil using a vibratory probe inserted into ground.
	A3. Explosive compaction	Shock waves and vibrations are generated by blasting to cause granular soil ground to settle through liquefaction or compaction.
	A4. Electric pulse compaction	Densification of granular soil using the shock waves and energy generated by electric pulse under ultra-high voltage.
	A5. Surface compaction (including rapid impact compaction).	Compaction of fill or ground at the surface or shallow depth using a variety of compaction machines.
B. Ground improvement without admixtures in cohesive soils	B1. Replacement/displacement (including load reduction using light weight materials)	Remove bad soil by excavation or displacement and replace it by good soil or rocks. Some light weight materials may be used as backfill to reduce the load or earth pressure.
	B2. Preloading using fill (including the use of vertical drains)	Fill is applied and removed to pre-consolidate compressible soil so that its compressibility will be much reduced when future loads are applied.
	B3. Preloading using vacuum (including combined fill and vacuum)	Vacuum pressure of up to 90 kPa is used to pre-consolidate compressible soil so that its compressibility will be much reduced when future loads are applied.
	B4. Dynamic consolidation with enhanced drainage (including the use of vacuum)	Similar to dynamic compaction except vertical or horizontal drains (or together with vacuum) are used to dissipate pore pressures generated in soil during compaction.
	B5. Electro-osmosis or electro-kinetic consolidation	DC current causes water in soil or solutions to flow from anodes to cathodes which are installed in soil.
	B6. Thermal stabilisation using heating or freezing	Change the physical or mechanical properties of soil permanently or temporarily by heating or freezing the soil.
	B7. Hydro-blasting compaction	Collapsible soil (loess) is compacted by a combined wetting and deep explosion action along a borehole.

C. Ground improvement with admixtures or inclusions	C1. Vibro replacement or stone columns	Hole jetted into soft, fine-grained soil and back filled with densely compacted gravel or sand to form columns.
	C2. Dynamic replacement	Aggregates are driven into soil by high energy dynamic impact to form columns. The backfill can be either sand, gravel, stones or demolition debris.
	C3. Sand compaction piles	Sand is fed into ground through a casing pipe and compacted by either vibration, dynamic impact, or static excitation to form columns.
	C4. Geotextile confined columns	Sand is fed into a closed bottom geotextile lined cylindrical hole to form a column.
	C5. Rigid inclusions (or composite foundation, also see Table 5)	Use of piles, rigid or semi-rigid bodies or columns which are either premade or formed in-situ to strengthen soft ground.
	C6. Geosynthetic reinforced column or pile supported embankment	Use of piles, rigid or semi-rigid columns/inclusions and geosynthetic girds to enhance the stability and reduce the settlement of embankments.
	C7. Microbial methods	Use of microbial materials to modify soil to increase its strength or reduce its permeability.
	C8 Other methods	Unconventional methods, such as formation of sand piles using blasting and the use of bamboo, timber and other natural products.

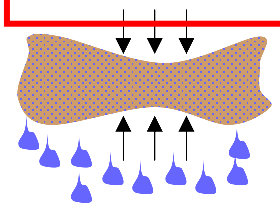
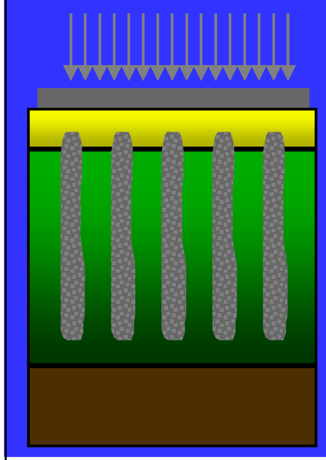
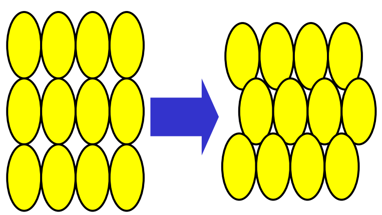
D. Ground improvement with grouting type admixtures	D2. Chemical grouting	Solutions of two or more chemicals react in soil pores to form a gel or a solid precipitate to either increase the strength or reduce the permeability of soil or ground.
	D3. Mixing methods (including premixing or deep mixing)	Treat the weak soil by mixing it with cement, lime, or other binders in-situ using a mixing machine or before placement
	D4. Jet grouting	High speed jets at depth erode the soil and inject grout to form columns or panels
	D5. Compaction grouting	Very stiff, mortar-like grout is injected into discrete soil zones and remains in a homogenous mass so as to densify loose soil or lift settled ground.
	D6. Compensation grouting	Medium to high viscosity particulate suspensions is injected into the ground between a subsurface excavation and a structure in order to negate or reduce settlement of the structure due to ongoing excavation.
E. Earth reinforcement	E1. Geosynthetics or mechanically stabilised earth (MSE)	Use of the tensile strength of various steel or geosynthetic materials to enhance the shear strength of soil and stability of roads, foundations, embankments, slopes, or retaining walls.
	E2. Ground anchors or soil nails	Use of the tensile strength of embedded nails or anchors to enhance the stability of slopes or retaining walls.
	E3. Biological methods using vegetation	Use of the roots of vegetation for stability of slopes.

Why Soil improvement ?

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

	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 Vibroflotation 	

Parameters For Concept

-Soil characteristics
- -cohesive or non cohesive
- - blocks ?

Water content, water table position

- Organic materials

-Soil thickness

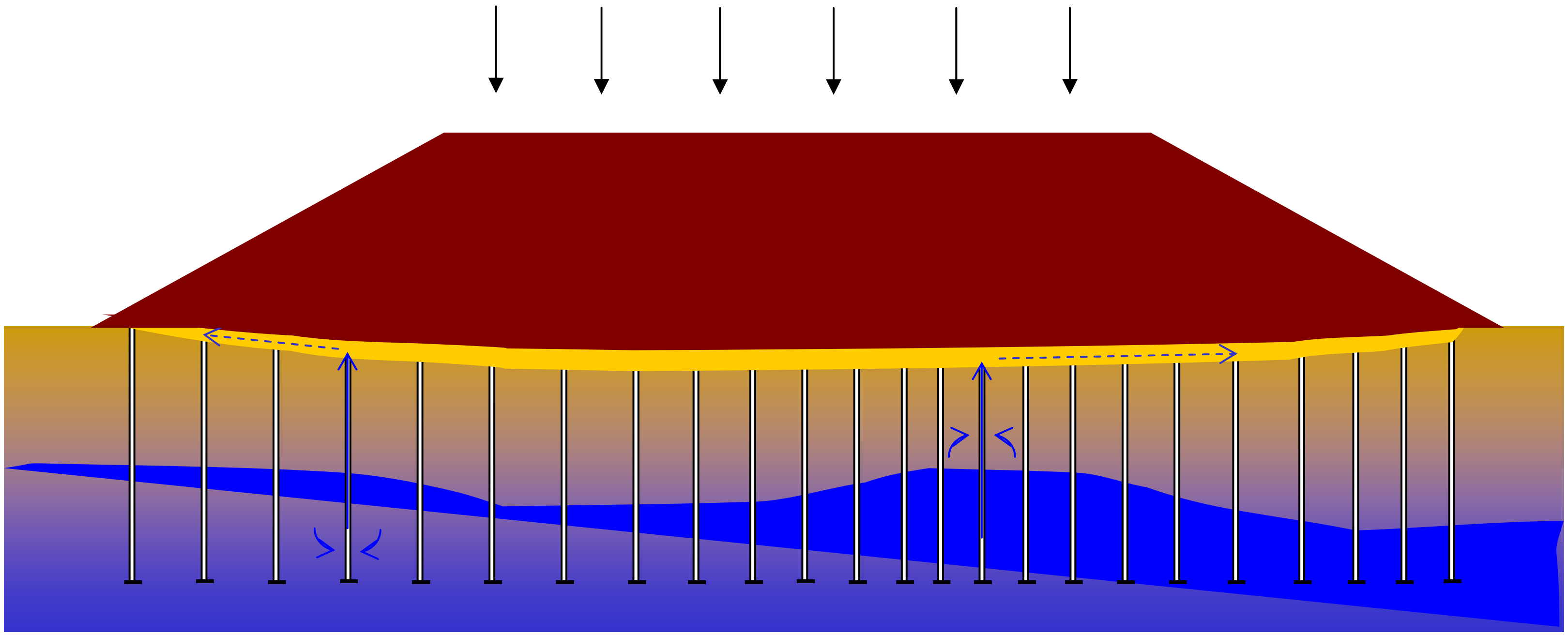
-Structure to support
- -Isolated or uniform load
- -Deformability

-Site environment
- -Close to existing structure
- -Height constraints

-Time available to build

high fines contents soils

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



CONCEPT

-Stable subsoil for surcharge

-Soil can be penetrated

-Time available is short

-Some residual settlement is allowed

PARAMETERS

1 – Depth

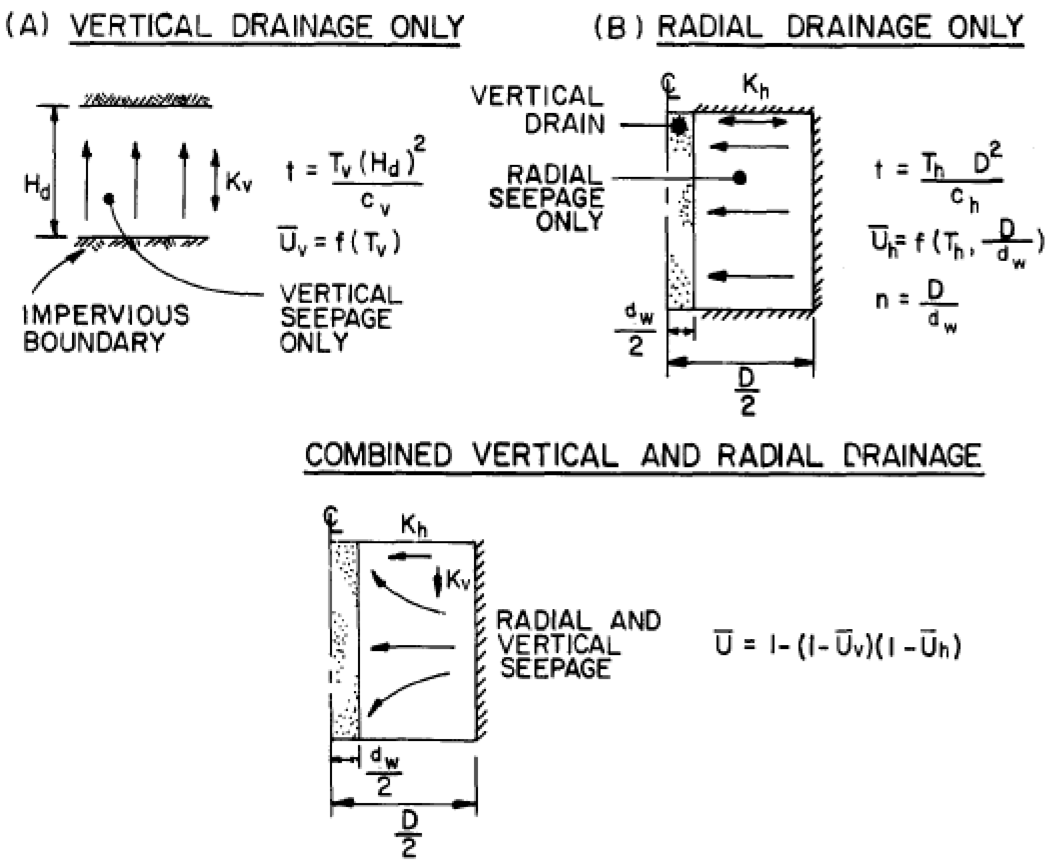
2 – Drainage path

3 – Cohesion

4 – Consolidation parameters (oedometer, CPT)

e_O, C_C, C_V, C_R, C_α, t,

CPT dissipation test

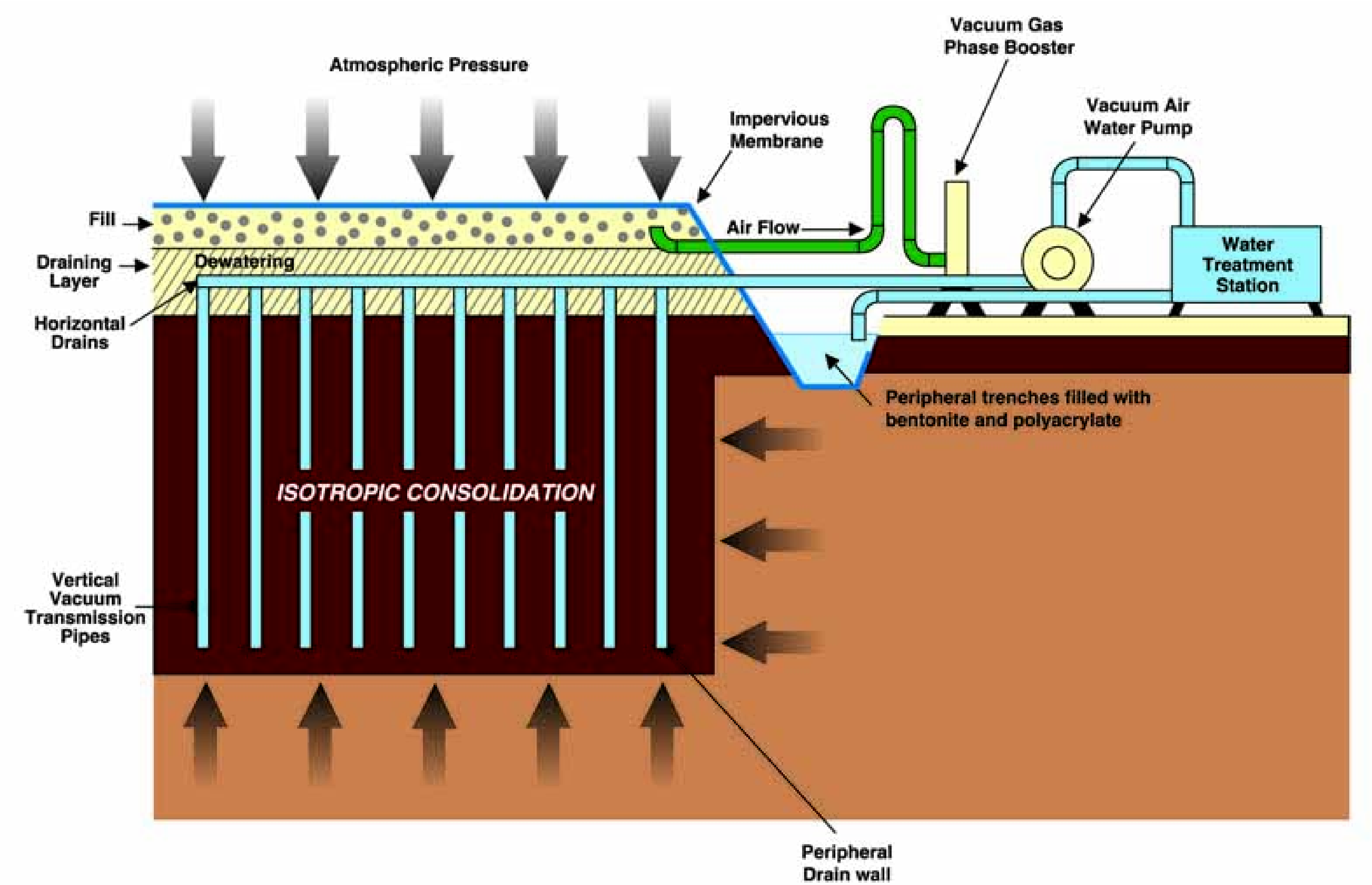

(A) VERTICAL DRAINAGE ONLY
Hd
Kv
t = Tv (Hd)2 / cv
Uv = f (Tv)
IMPERVIOUS BOUNDARY
VERTICAL SEEPAGE ONLY
(B) RADIAL DRAINAGE ONLY
VERTICAL DRAIN
RADIAL SEEPAGE ONLY
Kh
dw/2
D/2
t = Th D2 / ch
Uh = f (Th, D/dw)
n = D/dw
COMBINED VERTICAL AND RADIAL DRAINAGE
Kh
Kv
RADIAL AND VERTICAL SEEPAGE
dw/2
D/2
U = 1- (1- Uv)(1 -Uh)

High fines contents soils

5 cm , PVC

Flat drain circular drain *vertical drain + geotextile*

Vertical Drians



VACUUM (J.M. COGNON PATENT)

CONCEPT

-Soil is too soft for surcharge

-Time does not allow for step loading

-Surcharge soil not available

-Available area does not allow for bems

PARAMETERS

1 – Depth
2 – Drainage path
3 – Condition of impervious soil
4 – Wate rtable 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

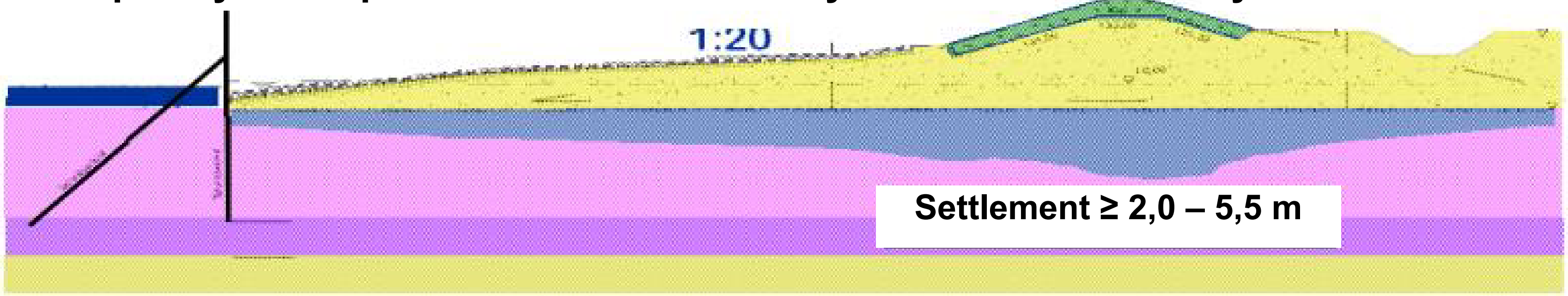

A380
A380

Case history – EADS Airbus Plant, Hamburg

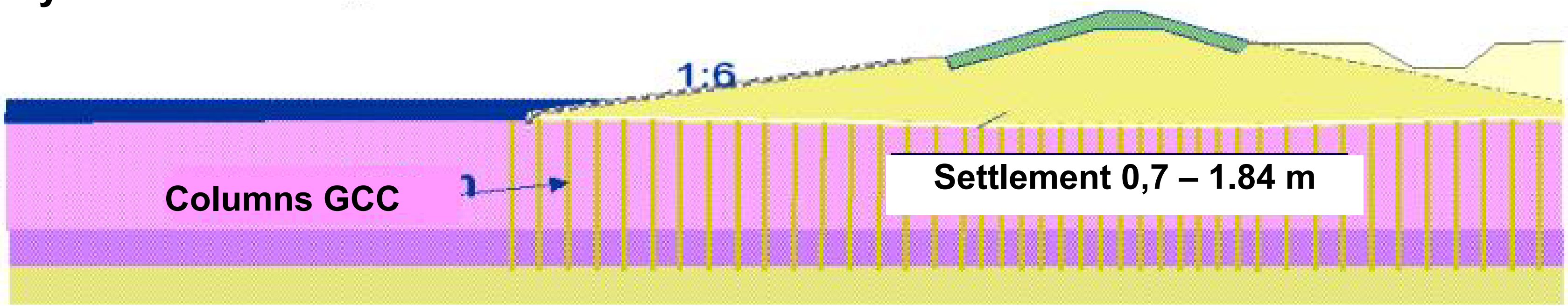
General overview of Airbus site

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



Subsoil characteristics

Soil type	Water content	Density	Shear strength		Deformation Modulus (under σ_z = 100 kN/m²)	Coefficient of consolidation	Coefficient of secondary consolidation
	W (%)	γ/γ' – kN/m³	$\delta'(°)/c'$ (kN/m²)	C_u (kN/m²)	E_S (MN/m²)	C_V (m²/year)	$C\alpha$ (-)
Mud	142	13/3	20/0	0.5-5	0.8	0.35	0.03
Young clay	119	14/4	20/0	2-10	0.9	0.35	0.03
Clay	70	15/5	17.5/10	5-20	1.5	0.5	0.02
Peaty clay	139	14/4	20/5	5-20	0.9	0.4	0.03
Peat	240	11/1	20/0	5-15	0.5	$\geq$ 0.4	0.04

Case history – EADS Airbus Plant, Hamburg

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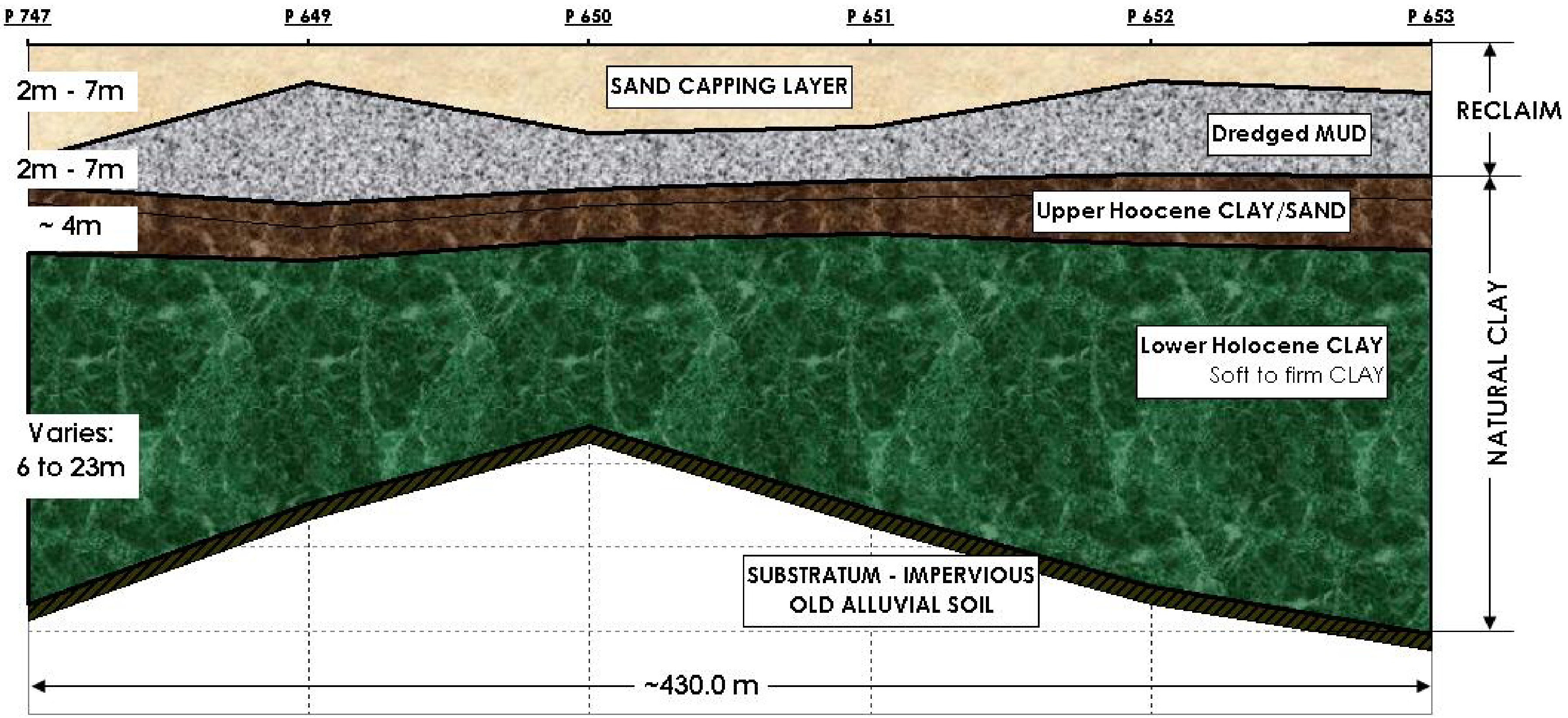
Case history – EADS Airbus Plant, Hamburg

PROJECT OVERVIEW

- **Located at the mouth of the Brisbane river;**
- **New reclamation area:** 234 ha **enclosed in the Port Expansion Seawall;**
- **Part of the new reclaimed area to be ready in 5years;**
- **Seawall construction completed in 2005;**

GEOTECHNICAL LONG SECTION



GEOTECHNICAL LONG SECTION
SCALE N.T.S

GEOLOGICAL PARAMETERS

Parameter	Unit	Dredged Material	Upper Holocene Sand	Upper Holocene Clay	Lower Holocene Clay
$C_c/(1+e_0)$	[-]	0,235	0,01	0,18	0,235
$C_\alpha/(1+e_0)$	[-]	0,0059	0,001	0,008	0,0076
γ	[kN/m^3]	14	19	16	16
C_v	[m^2/y]	1	10	10	0.9
C_h	[m^2/y]	1	10	10	1.8
S_u	[kPa]	4	-	20	28
S_u / σ'_v	[-]	0,25	0,3	0,3	0,2

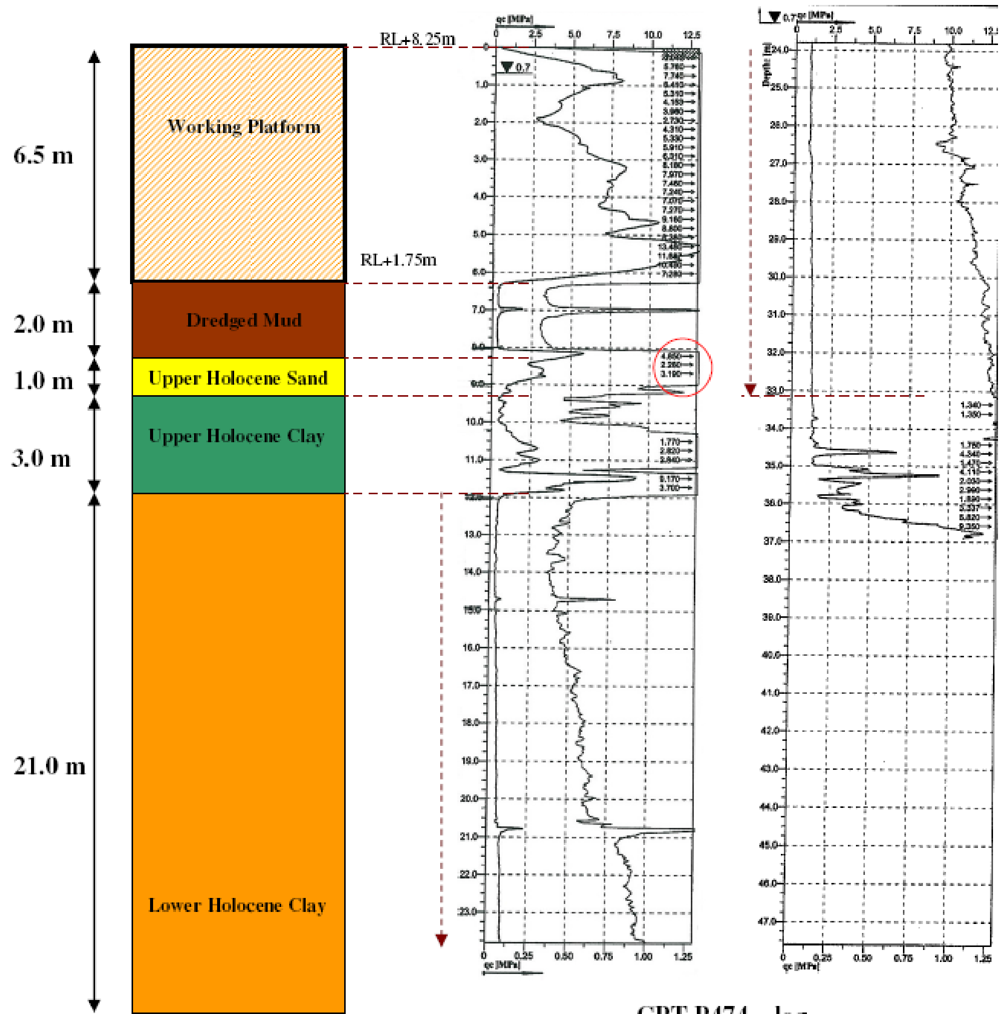
GEOLOGICAL SOIL PROFILE

AREA 2a

P474 location

- Water level during construction: RL+7.1m and RL+8.3m at vacuum start

- Working platform at RL+8.6m (thickness=6.8m) as of 22/12/08



Simplified Soil Profile for Consolidation Calculation

CPT P474 – log As of 06/09/06

DESIGN CRITERIA & ASSUMPTIONS

Service Load:

- **Zone 1: 36kPa**
- **Zone 2: 25kPa**
- **Zone 3: 15kPa**
- **Zone 4: 5kPa**

Residual Settlement (20y):

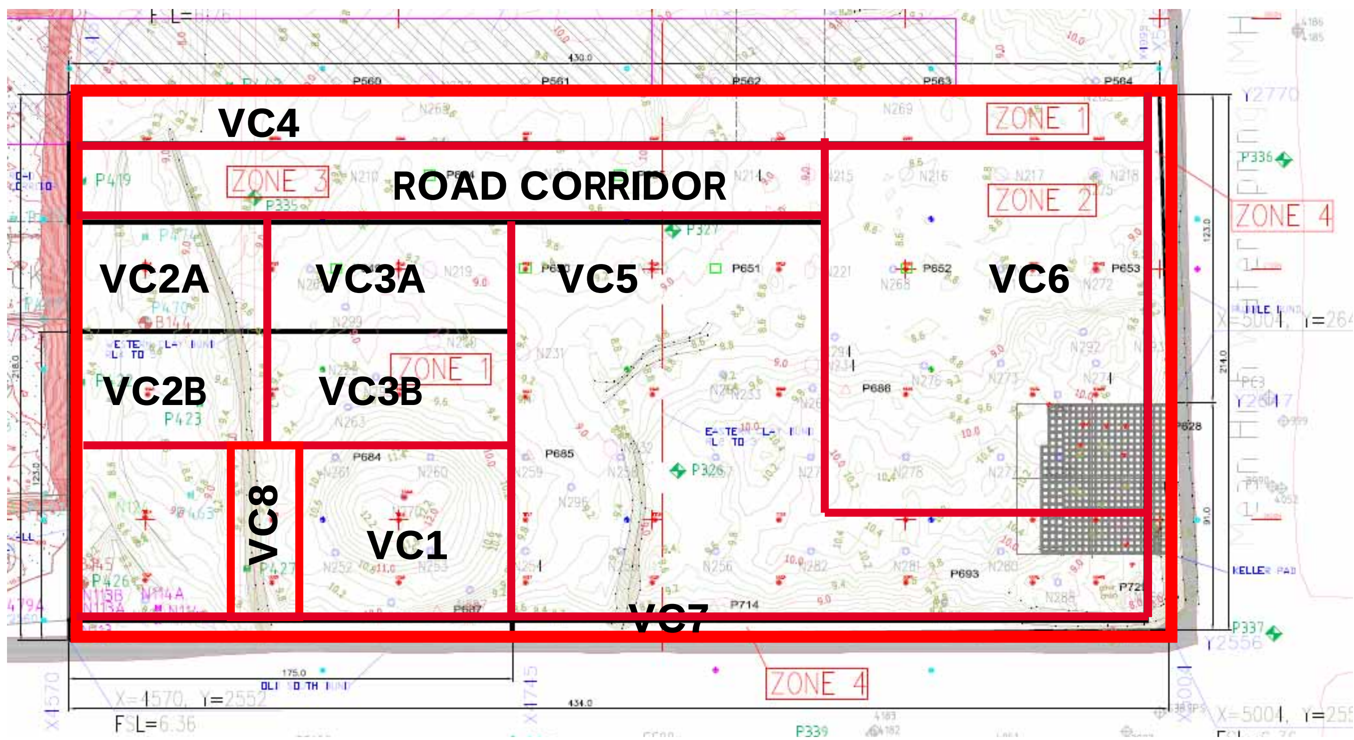
- **Zone 1 to 3: 150mm**
- **Zone 4: 300mm**

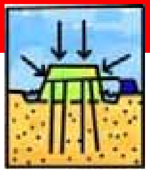
Vacuum pumping operation:

- **18 months**

Vacuum depressure:

- **75.0 kPa**





DESK STUDY – NUMERICAL ANALYSIS USING EXCEL SPREADSHEET *SETTLEMENT CALC.XLC*

Calculation of *primary and secondary* **settlement;**

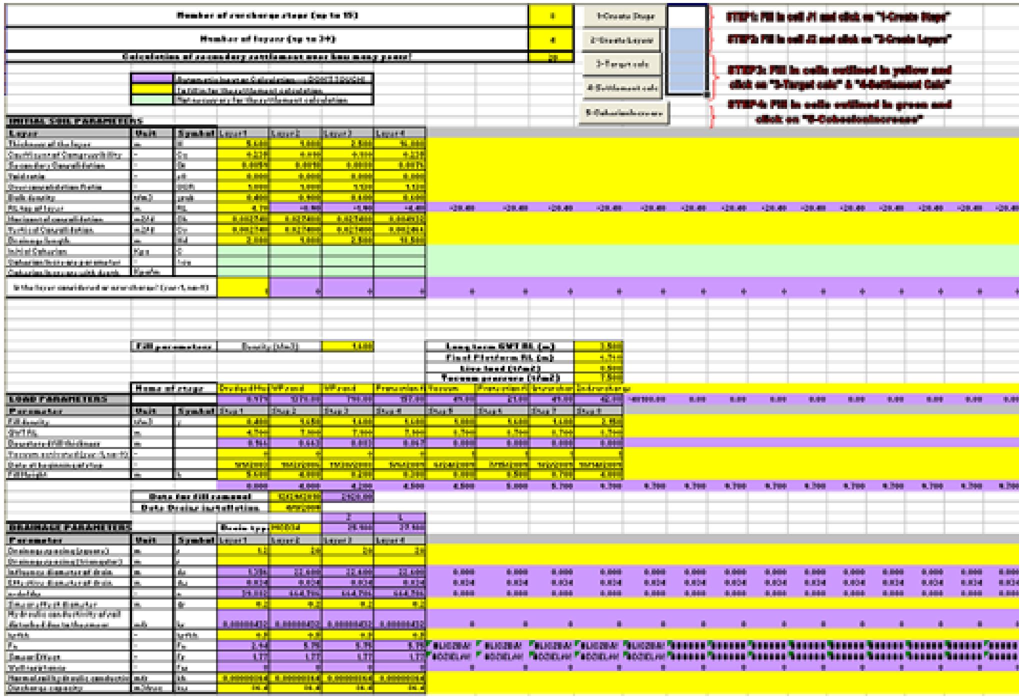
•Secondary settlement to commence after primary settlement;

•Change in vertical stress is constant over the depth of the stratum;

•*Buoyancy effect* **on the fill below the groundwater level due to settlement**

•Fill to be removed instantaneous at the end of preloading period;

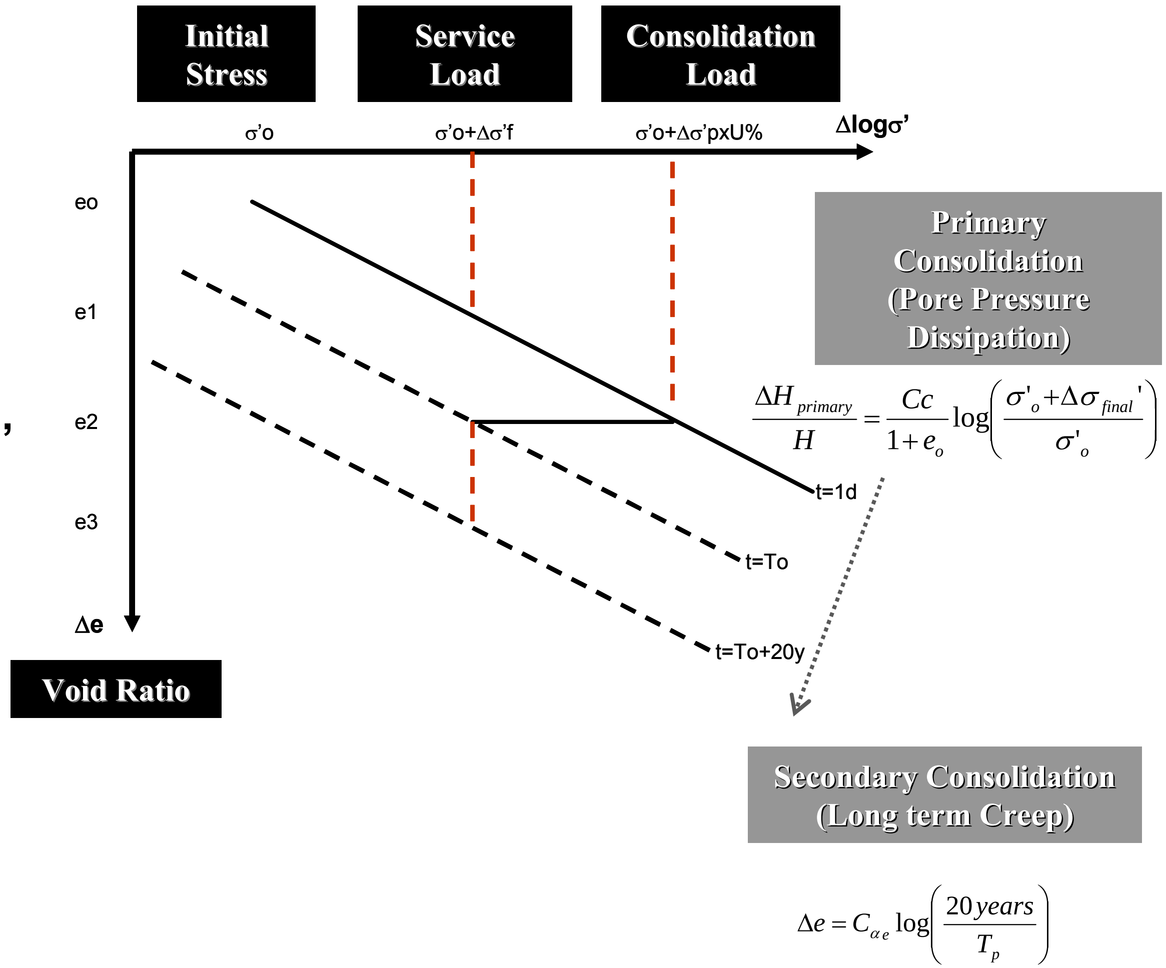
•Design load immediately applied at end of pre-loading period;



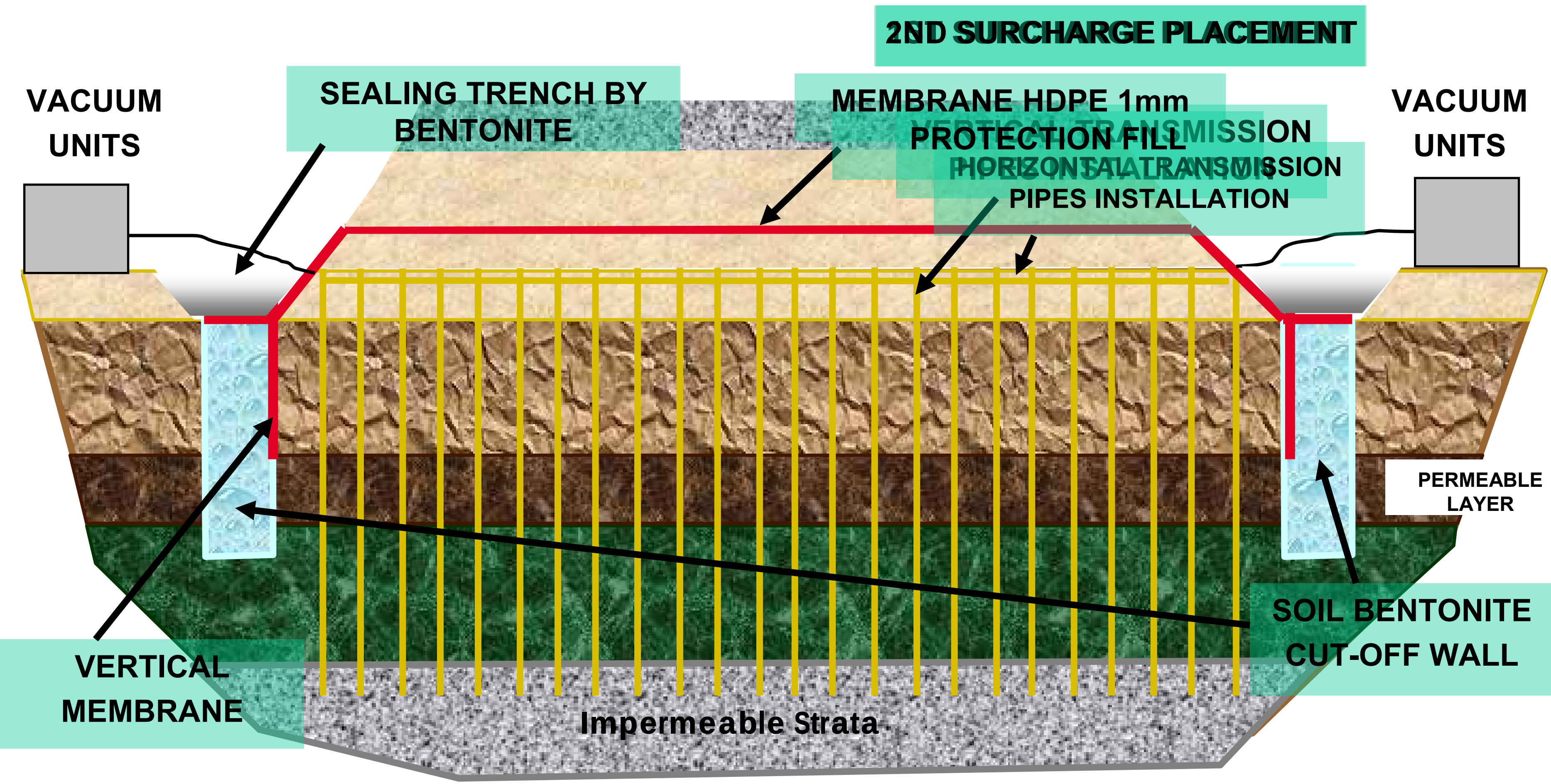
ANALYSIS METHOD

•***Secondary Settlement***

Program uses a method based on Bjerrum's concept to calculate instantaneous and delayed consolidation (Bjerrum, 1967).



CONSTRUCTION SEQUENCE



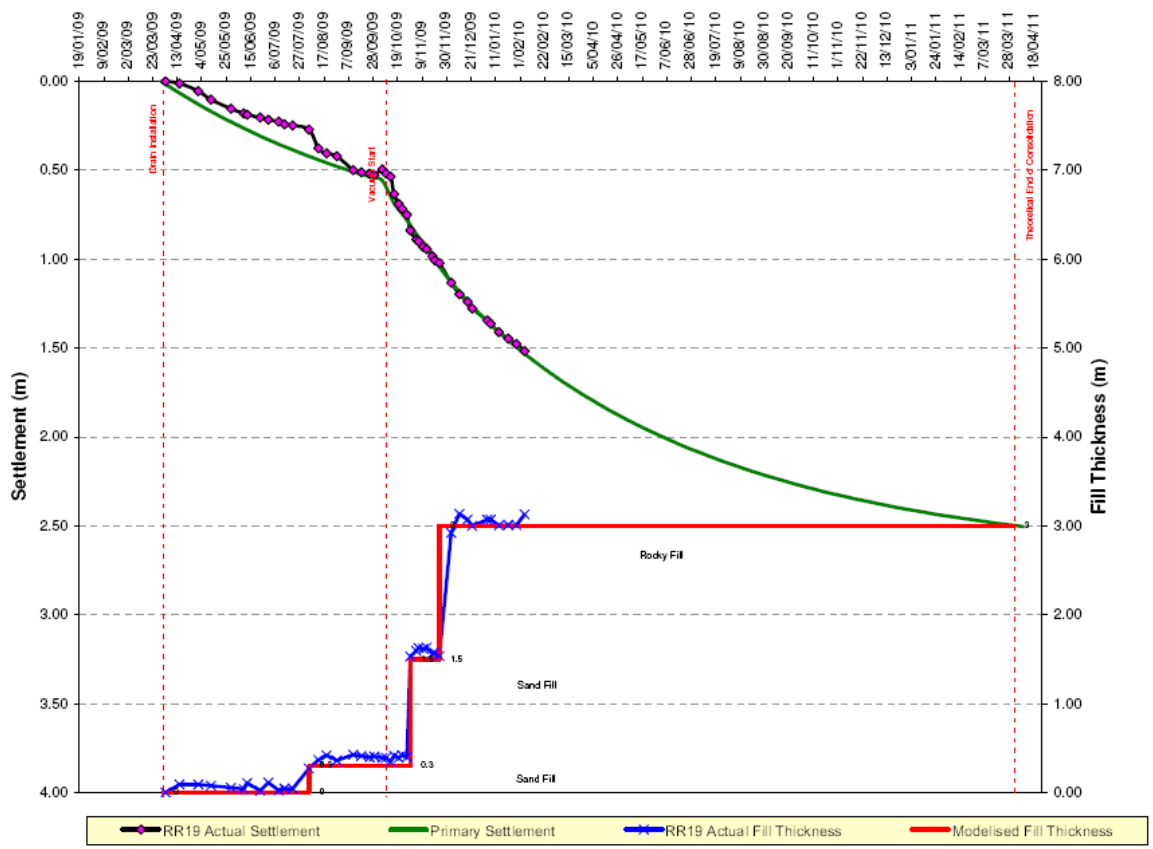
PORT OF BRISBANE – PADDOCK S3B

PORT OF BRISBANE – PADDOCK S3B

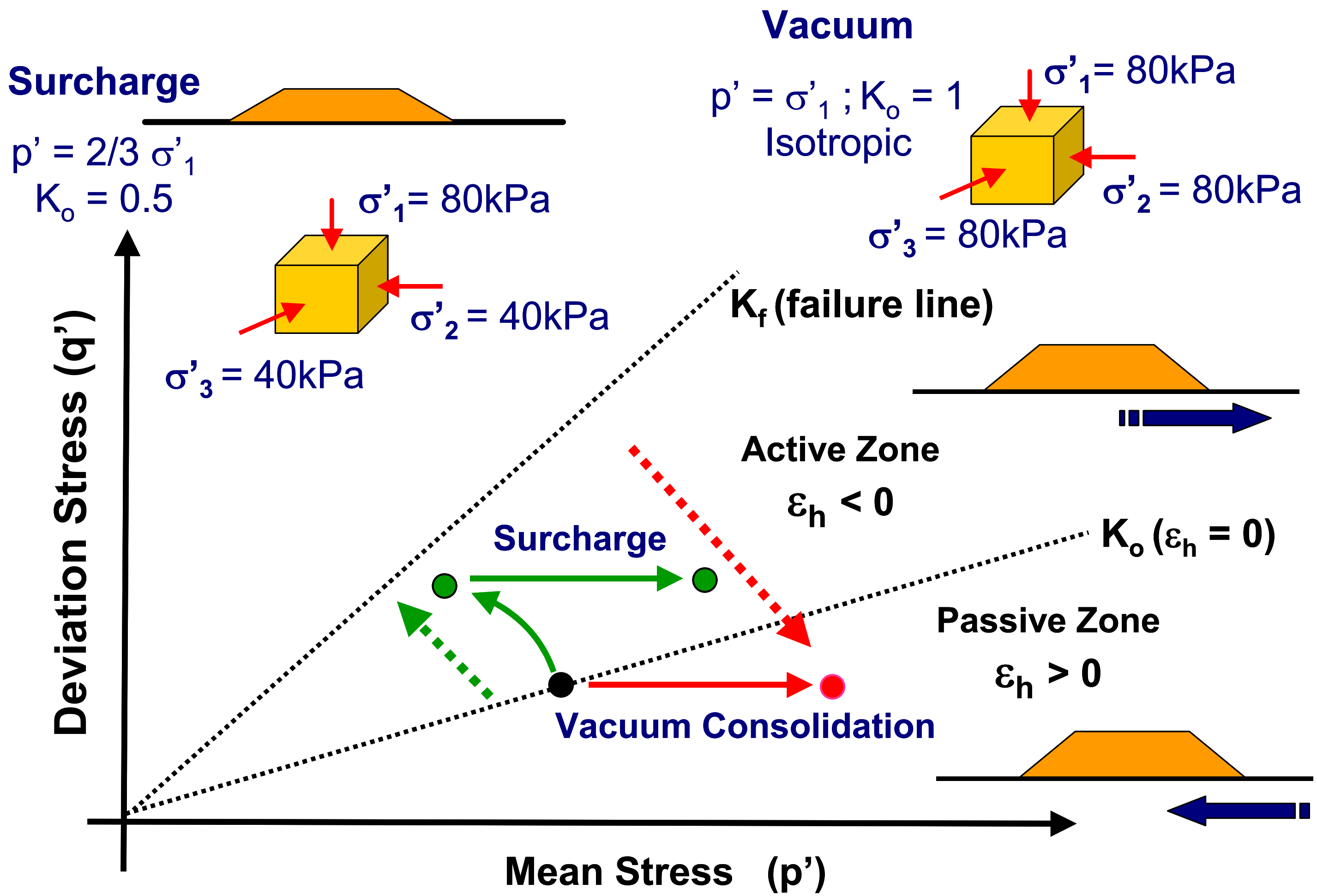
Project: **Vacuum Consolidation of Paddock S3B**
Proj. No.: **5040101**
Section: **RR19**

SIMPLIFIELD SOIL PROFILE

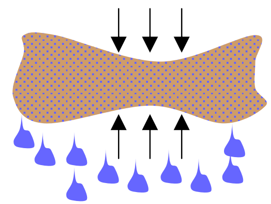
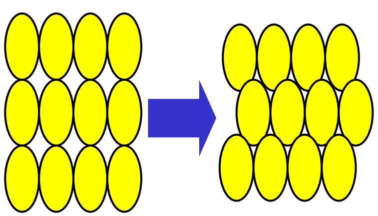
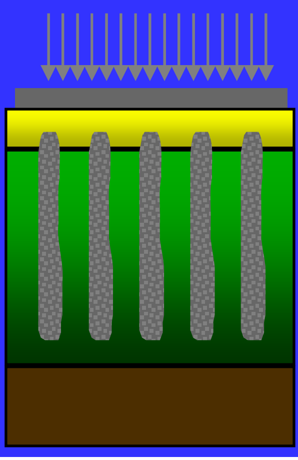
SETTLEMENT / FILL THICKNESS



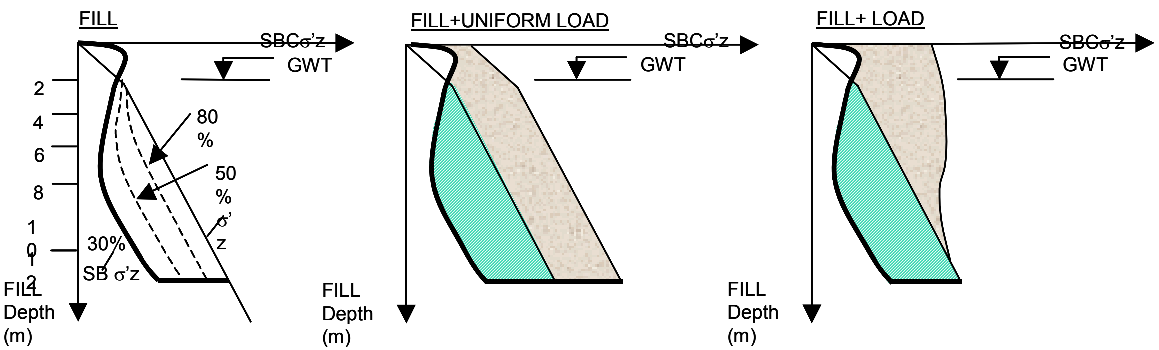
WATER LEVEL: **R.L. +7.10**
DURING PUMPING: **R.L. +8.80**
WORKING PLATFORM: **R.L. +9.00**
SOIL PROFILE: CPT: **P651**

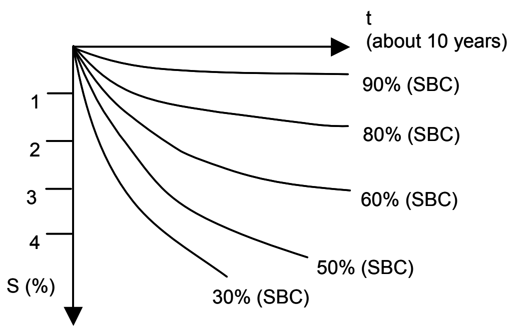

Surcharge
p' = 2/3 σ'1
Ko = 0.5
σ'1= 80kPa
σ'2 = 40kPa
σ'3 = 40kPa
Vacuum
p' = σ'1 ; Ko = 1
Isotropic
σ'1= 80kPa
σ'2 = 80kPa
σ'3 = 80kPa
Kf (failure line)
Active Zone
εh < 0
Ko (εh = 0)
Surcharge
Passive Zone
εh > 0
Vacuum Consolidation
Deviation Stress (q')
Mean Stress (p')

Case history : Kimhae (Korea) - 1998

	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 Vibroflotation 	

CONCEPT





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

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

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

PARAMETERS

- Age if fill saturated or not
- P_L
- Selfbearing level
- $\varnothing$
- E_P or E_M
- Q_C, F_R,
- N
- R.D. (???)
- Shear wave velocity
- Seismic parameters
- Grain size

Nice Airport runway consolidation

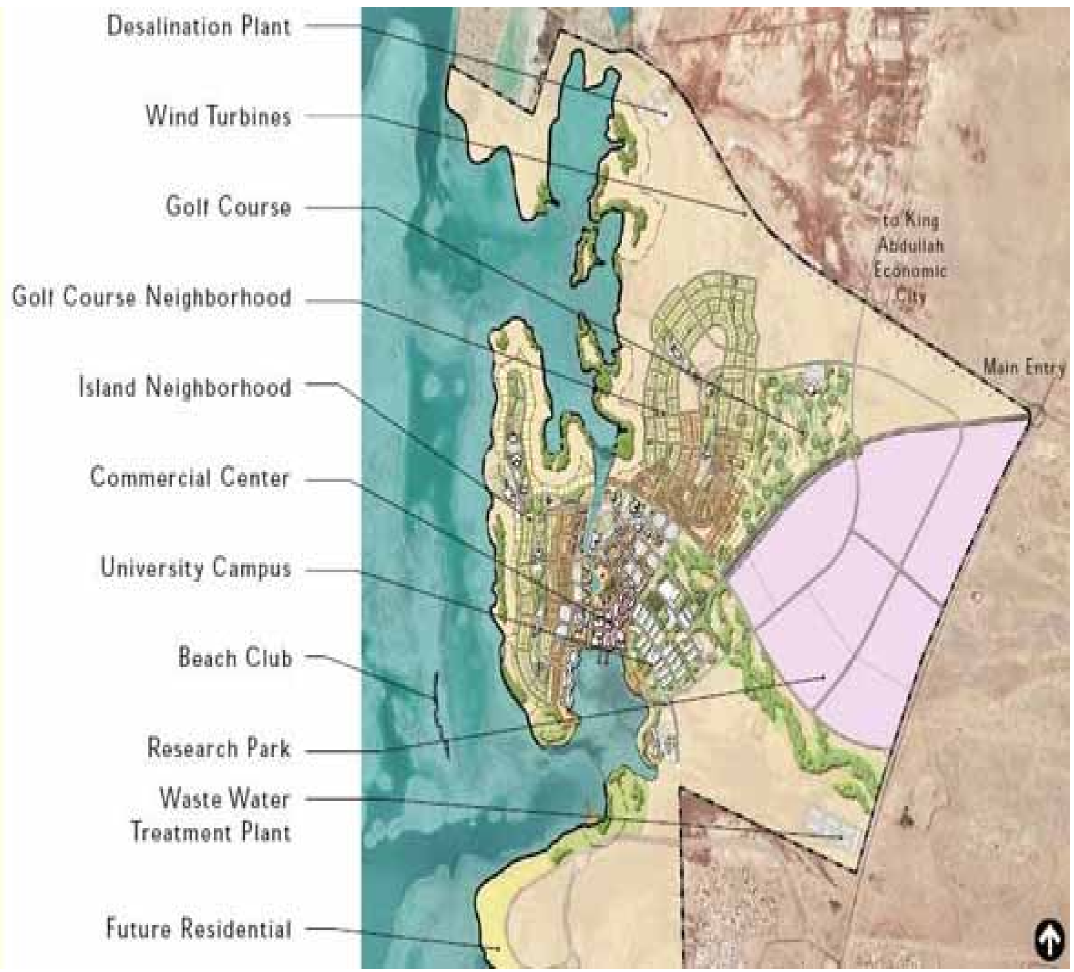
Granular soil

Very high energy (170 t, 23 m)

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

FUTURE UNIVERSITY CAMPUS

Typical Master Plan



Discovering the Habitants

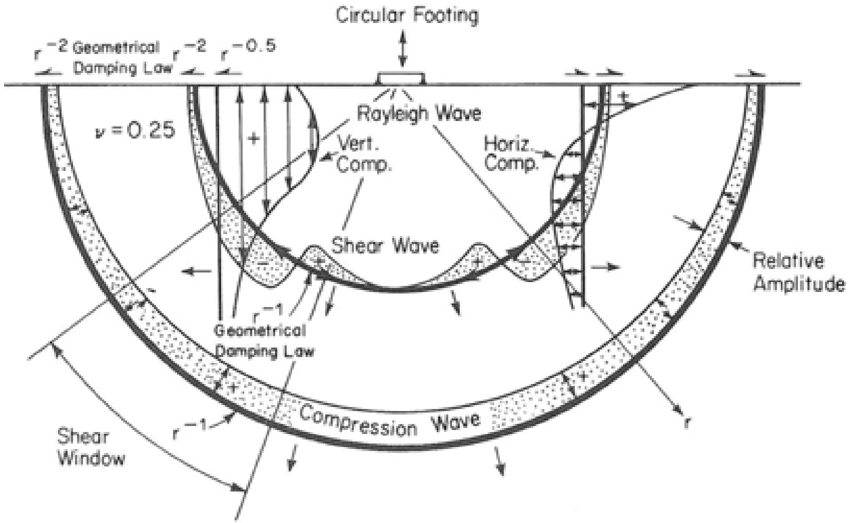



Areas to be treated

- Al Khodari 1,800,000 m²
- Saudi Bin Ladin 720,000 m²

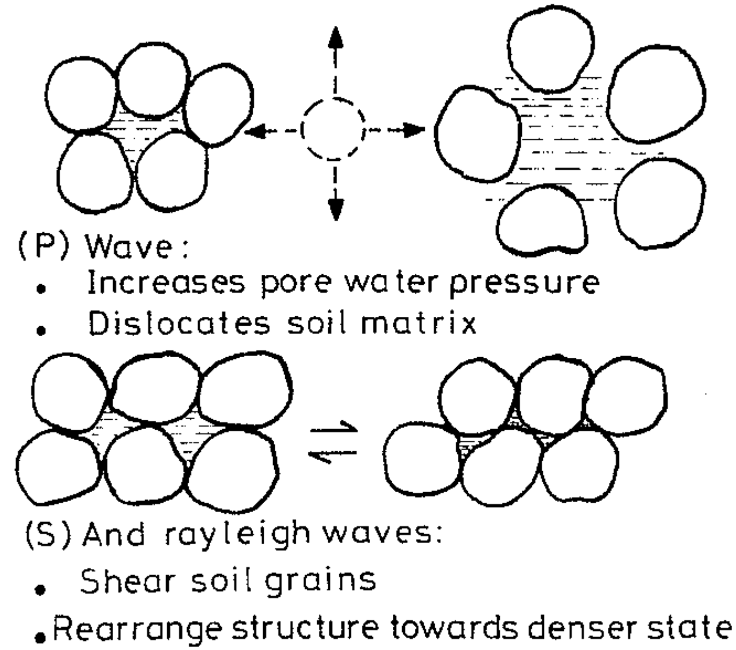
Schedule

- 8 months

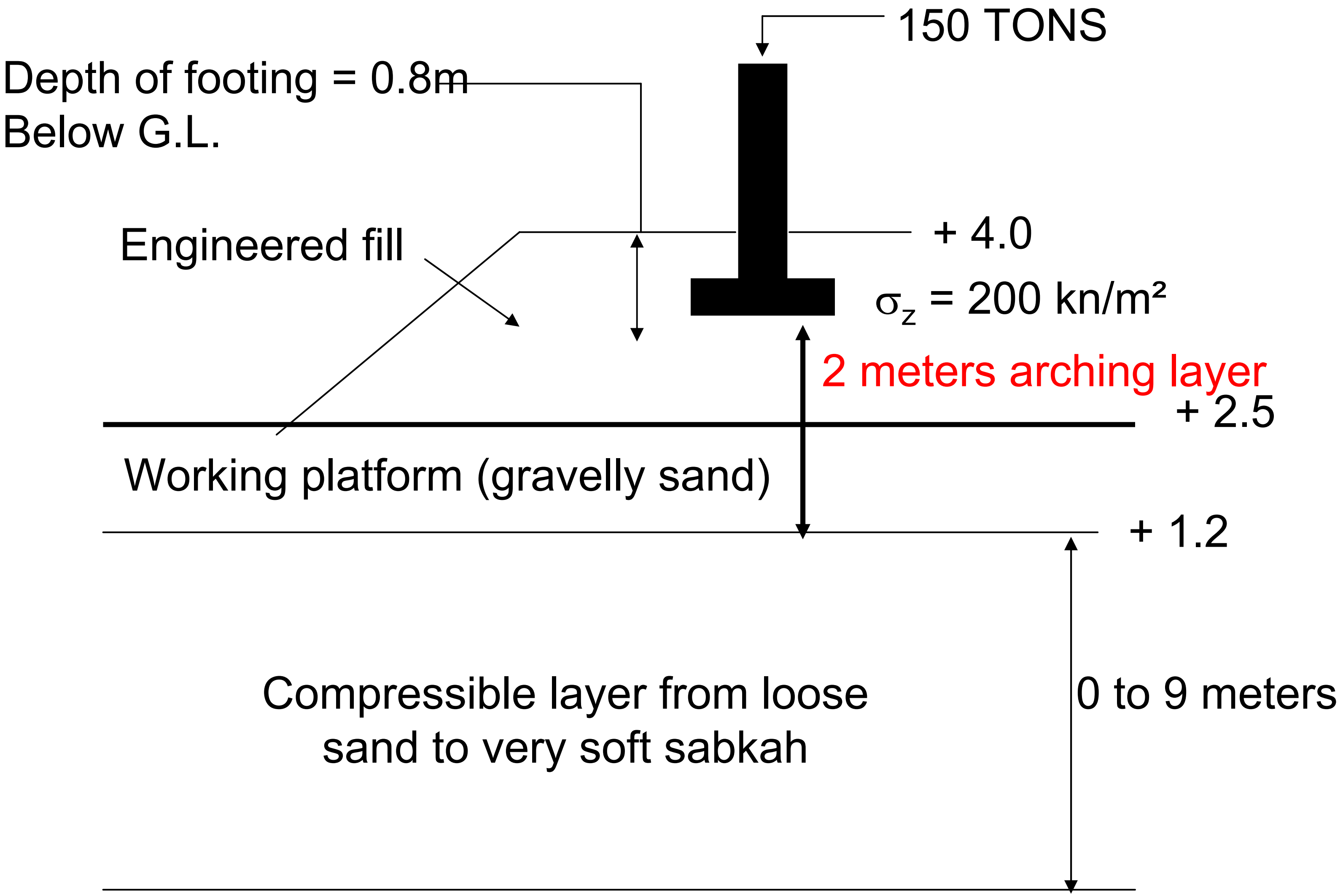


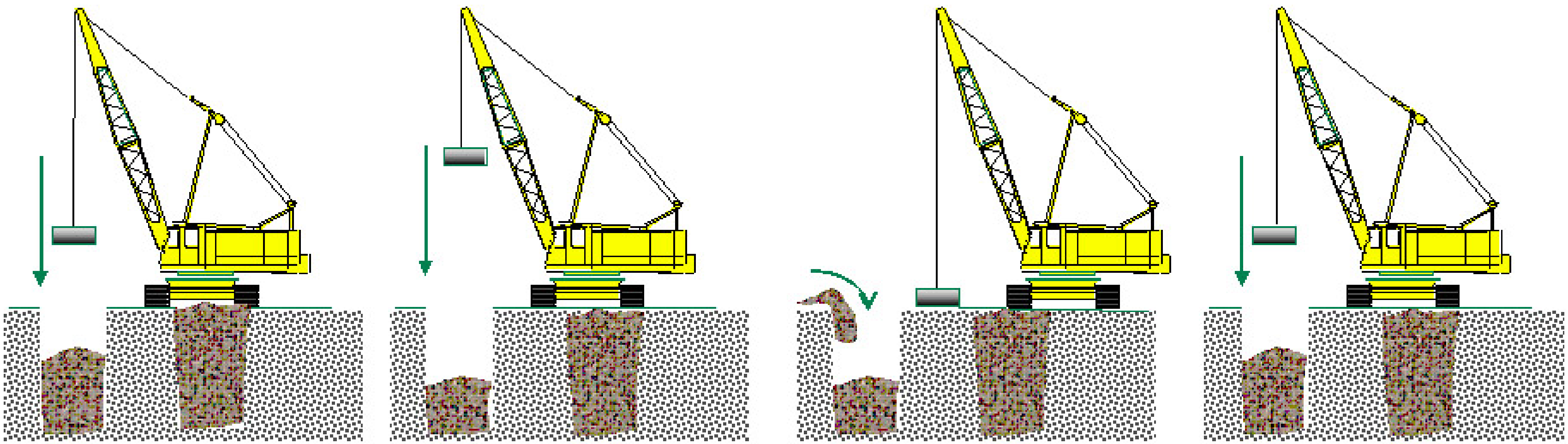
Wave Type	Percent of Total Energy
Rayleigh	67
Shear	26
Compression	7

After R.D. Woods (1968)



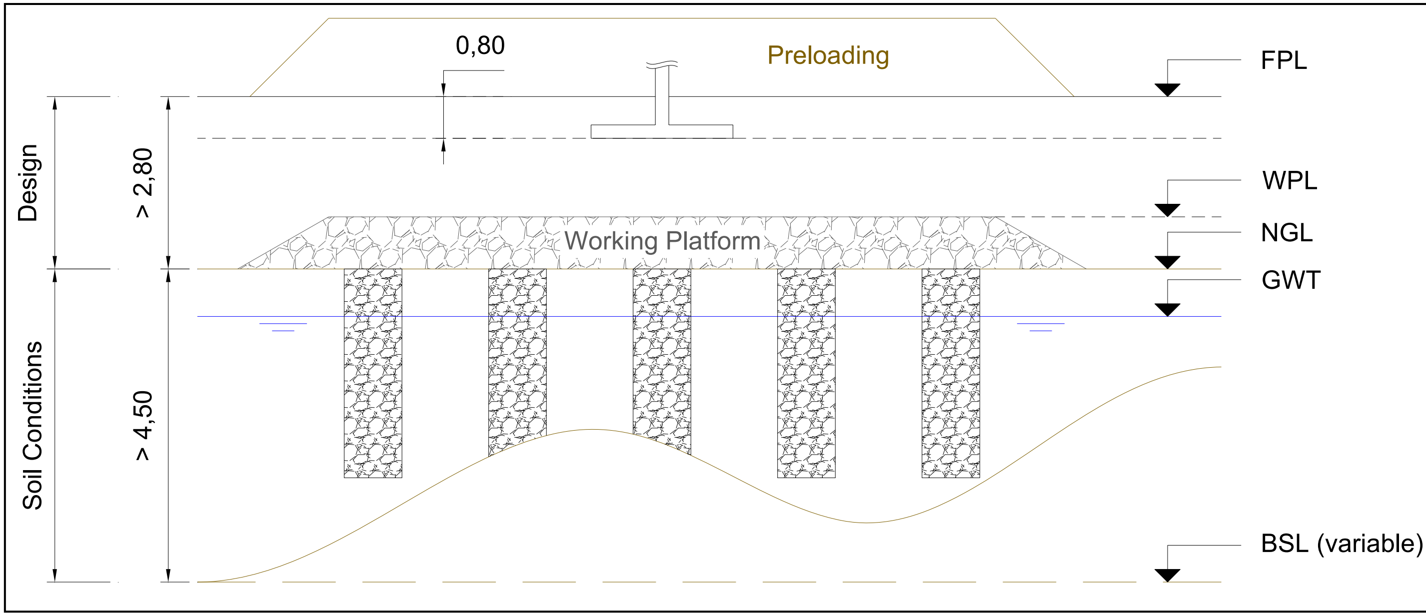
- Isolated footings up to 150 tons
- Bearing capacity 200 kPa
- Maximum footing settlement 25 mm
- Maximum differential settlement 1/500
- Footing location unknown during soil improvement phase


150 TONS
Depth of footing = 0.8m
Below G.L.
Engineered fill
+ 4.0
σ_z = 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

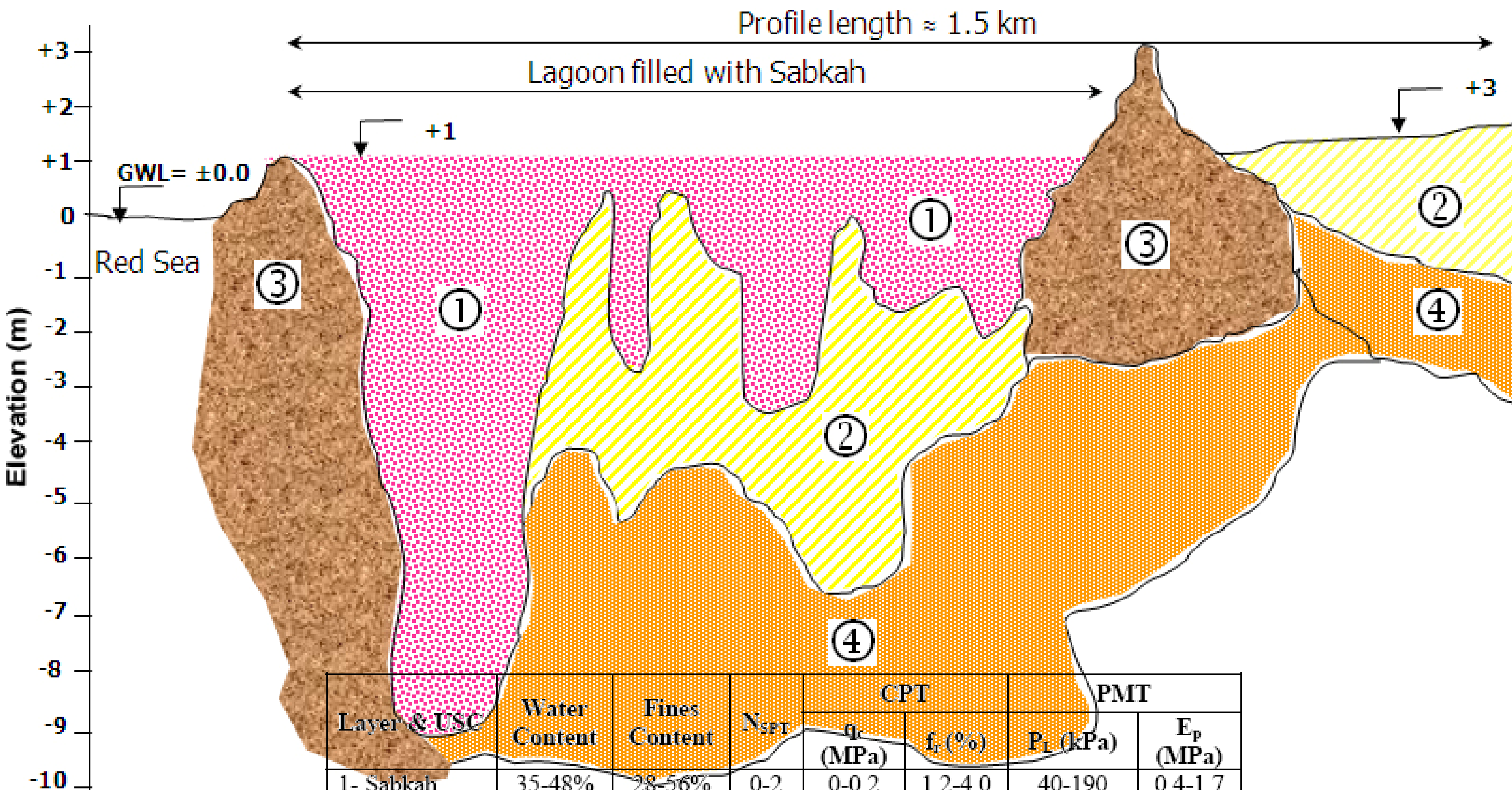


DR (Dynamic Replacement)

HDR (High Energy Dynamic Replacement) + Surcharge

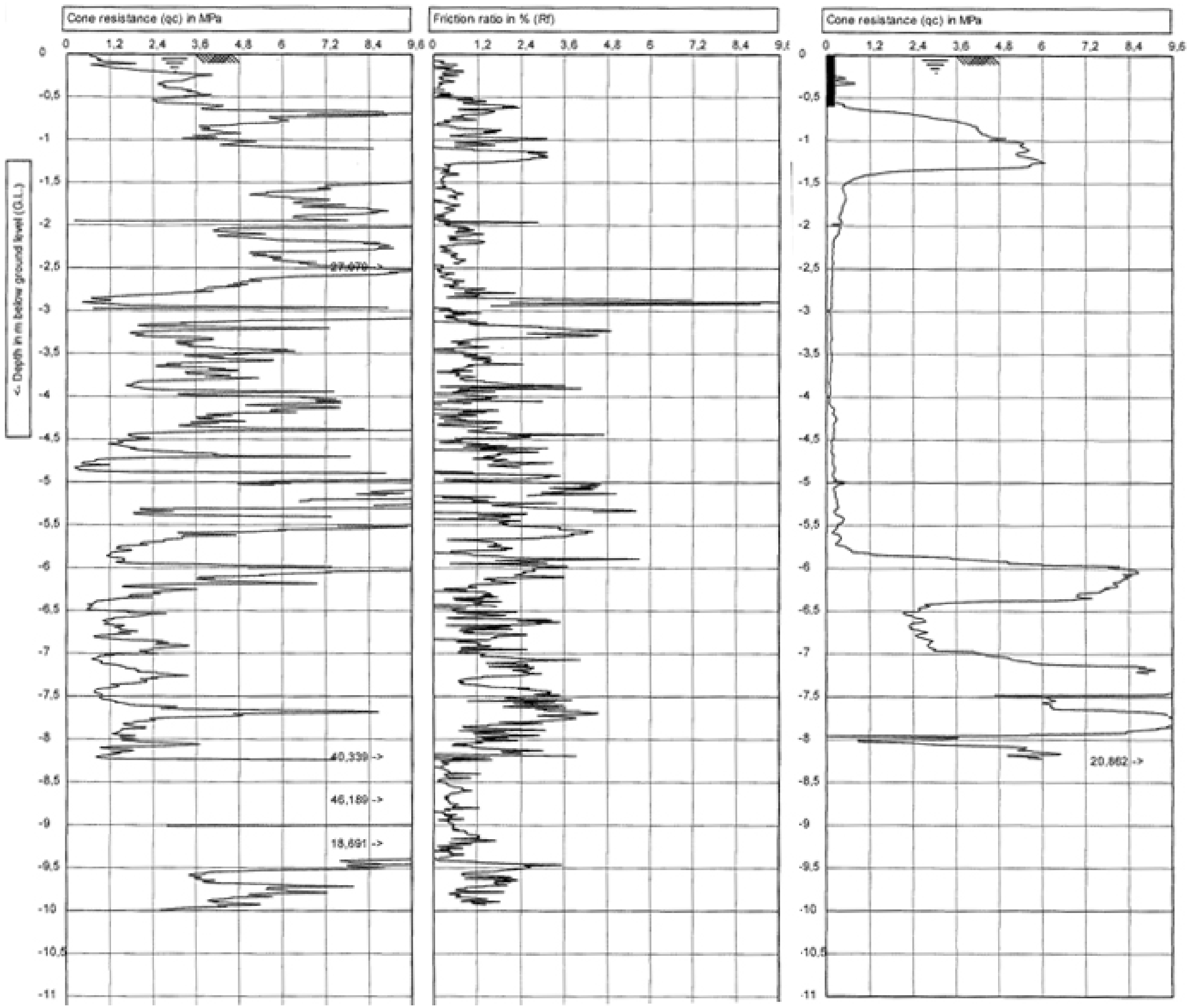


Typical Site Cross Section of Upper Deposit



Layer & USC	Water Content	Fines Content	N_{SPT}	CPT		PMT	
				q_c (MPa)	f_r (%)	P_L (kPa)	E_p (MPa)
1- Sabkah (SM+ML)	35-48%	28-56%	0-2	0-0.2	1.2-4.0	40-190	0.4-1.7
2- Silty Sand (SM)	-	15-28%	3-9	1.2-4.5	0.5-1.2	210-400	1.8-3.5
3- Coral	26-35%	-	6-12	-	-	510-720	3.5-6.0
4- Sand (SM)	-	12-37%	3-18	1.5-1.8	0.5-1.8	400-1200	2.8-8.5

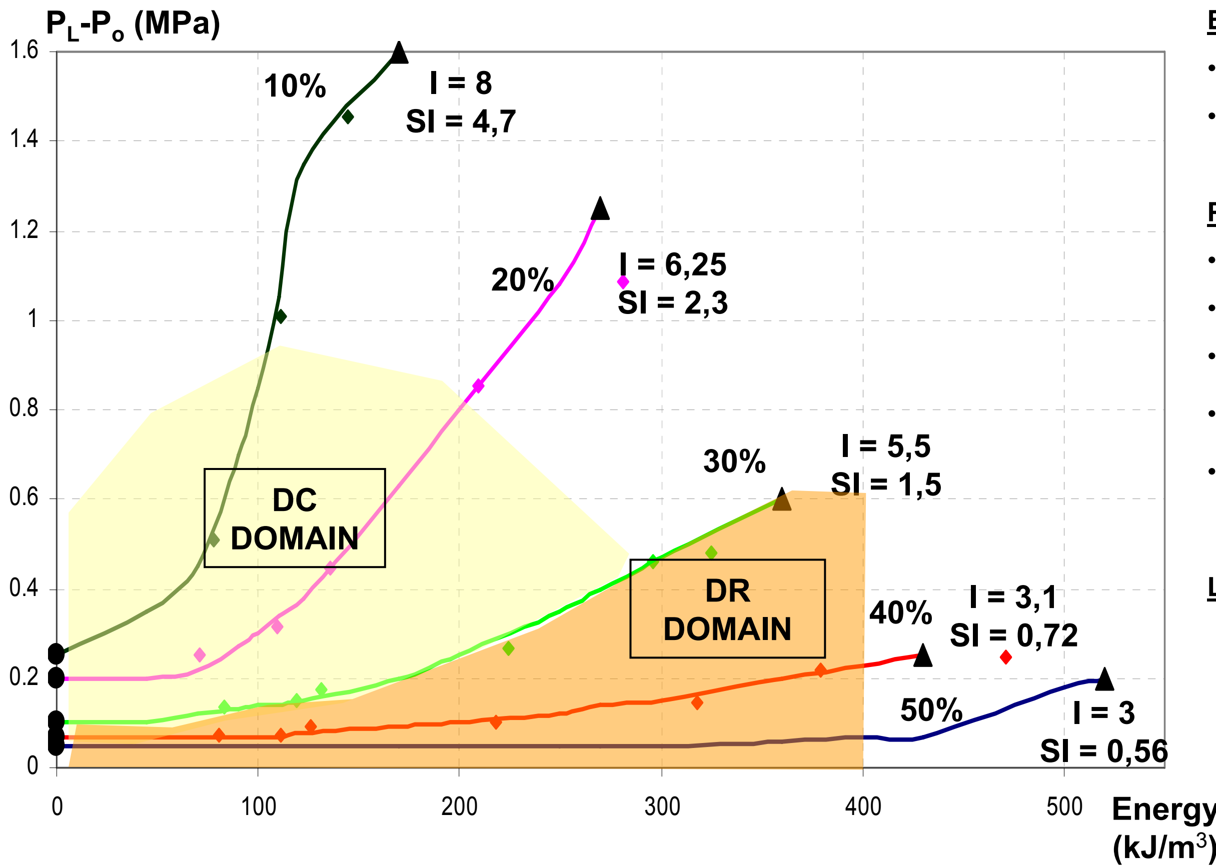
Variation in soil profile over 30 meters



Typical surface conditions

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

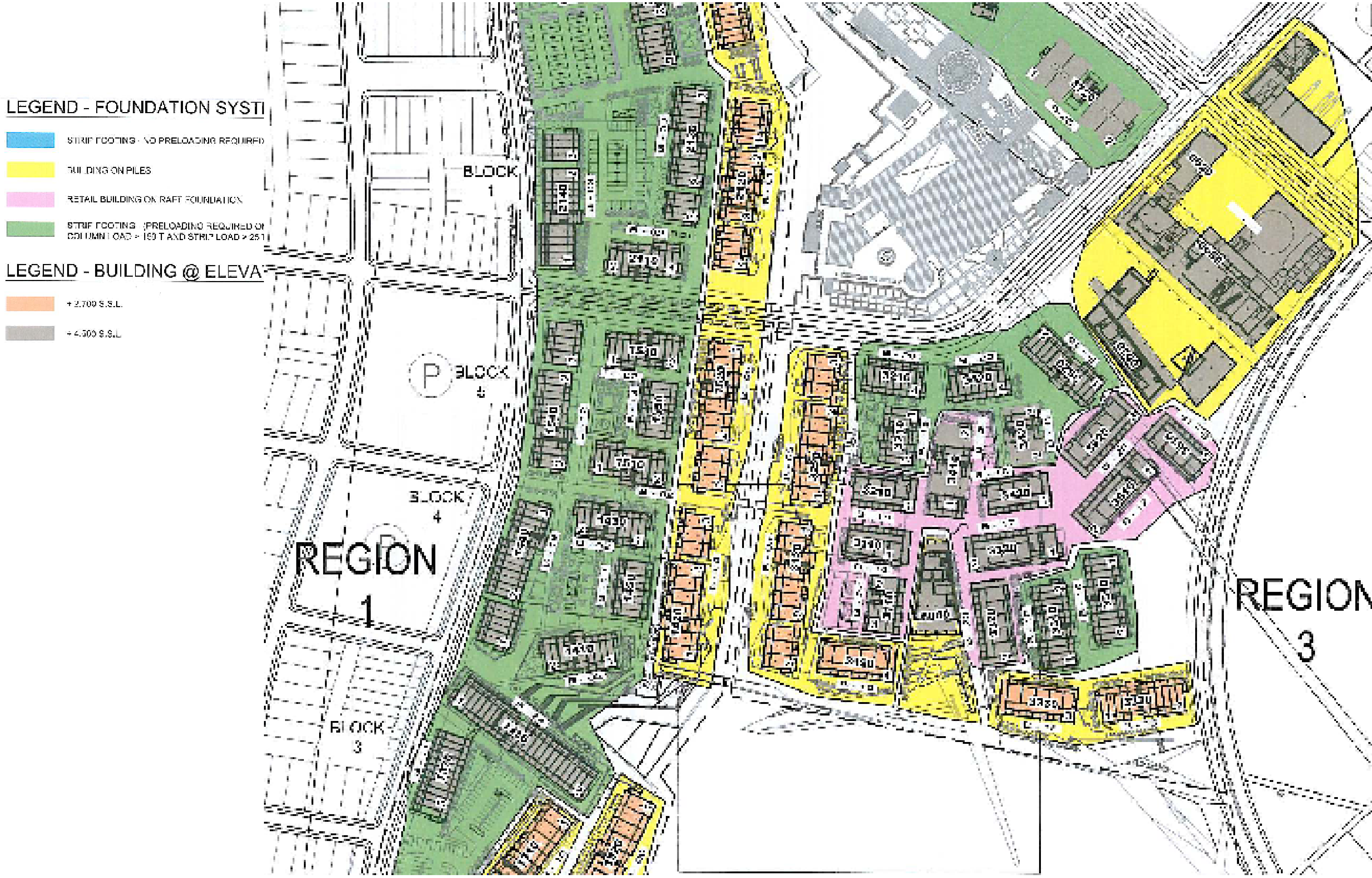
PARAMETERS

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

LEGEND

- ● Average pre-treatment values
- ◆ Average values between phases
- ▲ Average post-treatment values

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 embankement 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 the 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

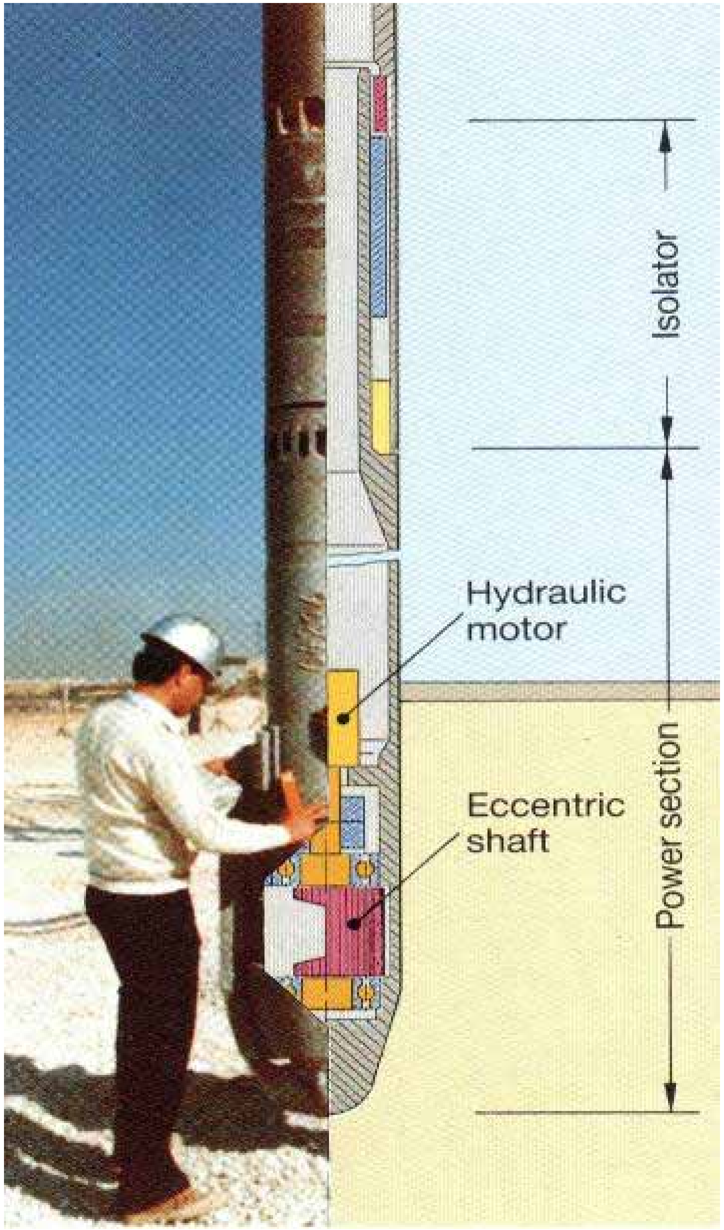
Supposing primary consolidation completed

$U = 0.9$ 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.

Dynamic surcharge

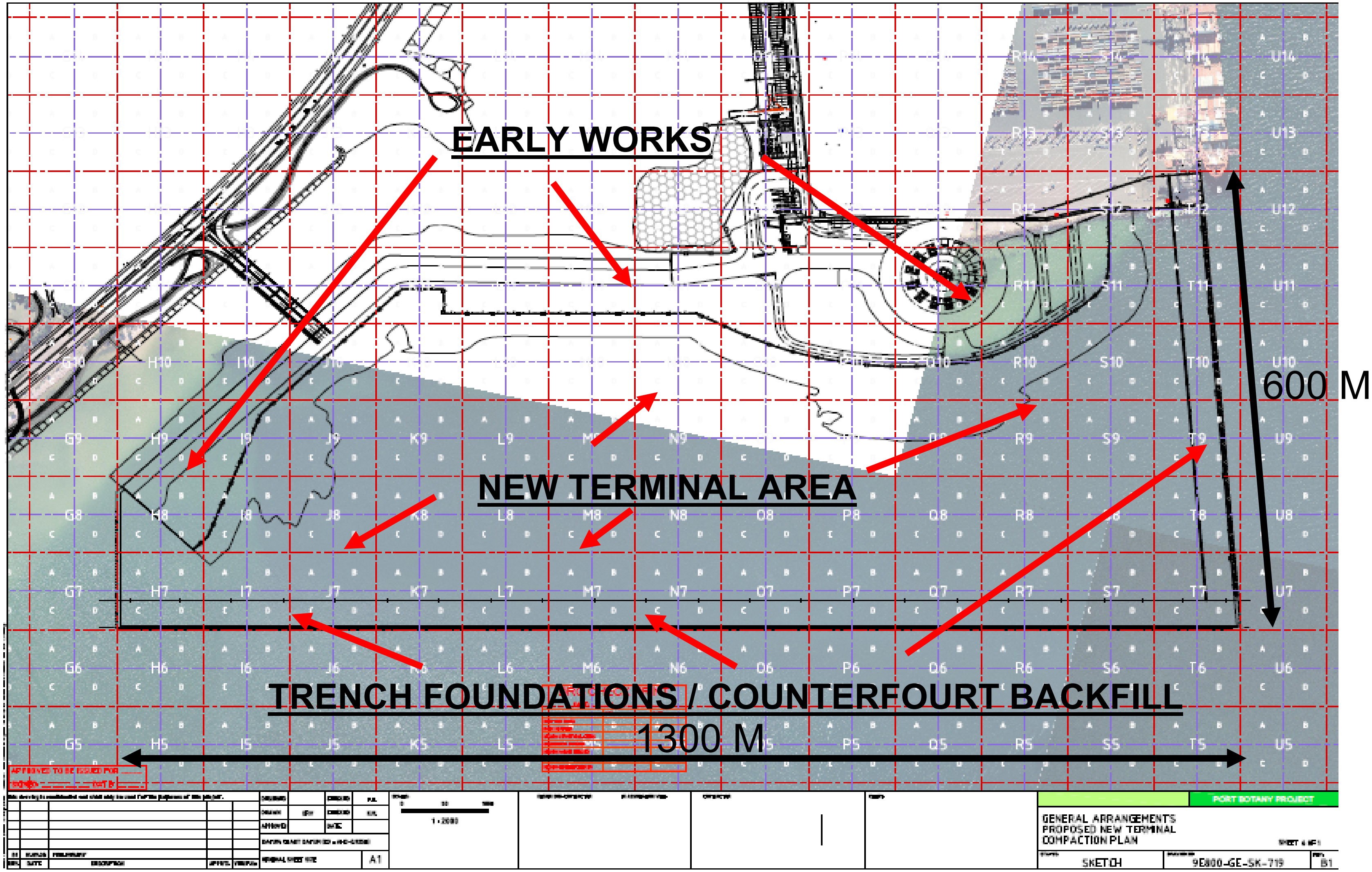
VIBROFLOTS


Isolator
Hydraulic motor
Eccentric shaft
Power section


Amplitude
28 – 48mm

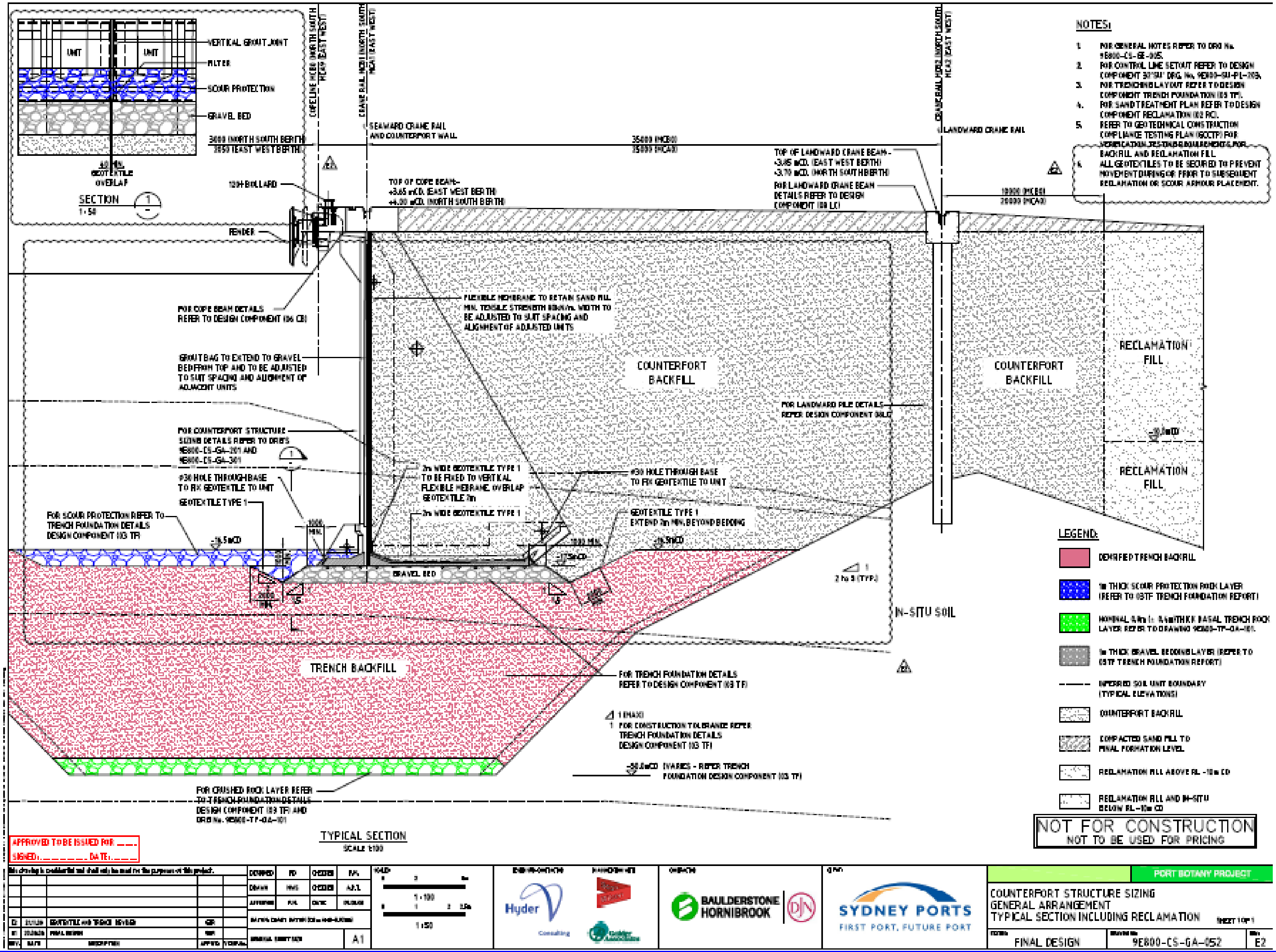
GROUND COMPACTION WORKS

GROUND COMPACTION WORKS



PORT BOTANY EXPANSION PROJECT

GENERAL ARRAGEMENT COUNTERFORTS INCLUDING RECLAMATION



RESUME / QUANTITIES

PHASE	AREA (M2)	VOLUME (M3)	TECHNIQUE
EARLY WORKS	90,000	650,000	DYNAMIC COMPACTION / VIBRO COMPACTION
TRENCH FOUNDATIONS	64,000	800,000	OFFSHORE VIBROCOMPACTION
COUNTERFOURT BACKFILL	92,000	1,330,000	ONSHORE TANDEM VIBRO COMPACTION
NEW TERMINAL AREA	404,000	5,250,000	DYNAMIC COMPACTION
TOTAL	650,000	8,000,000	DC / VC

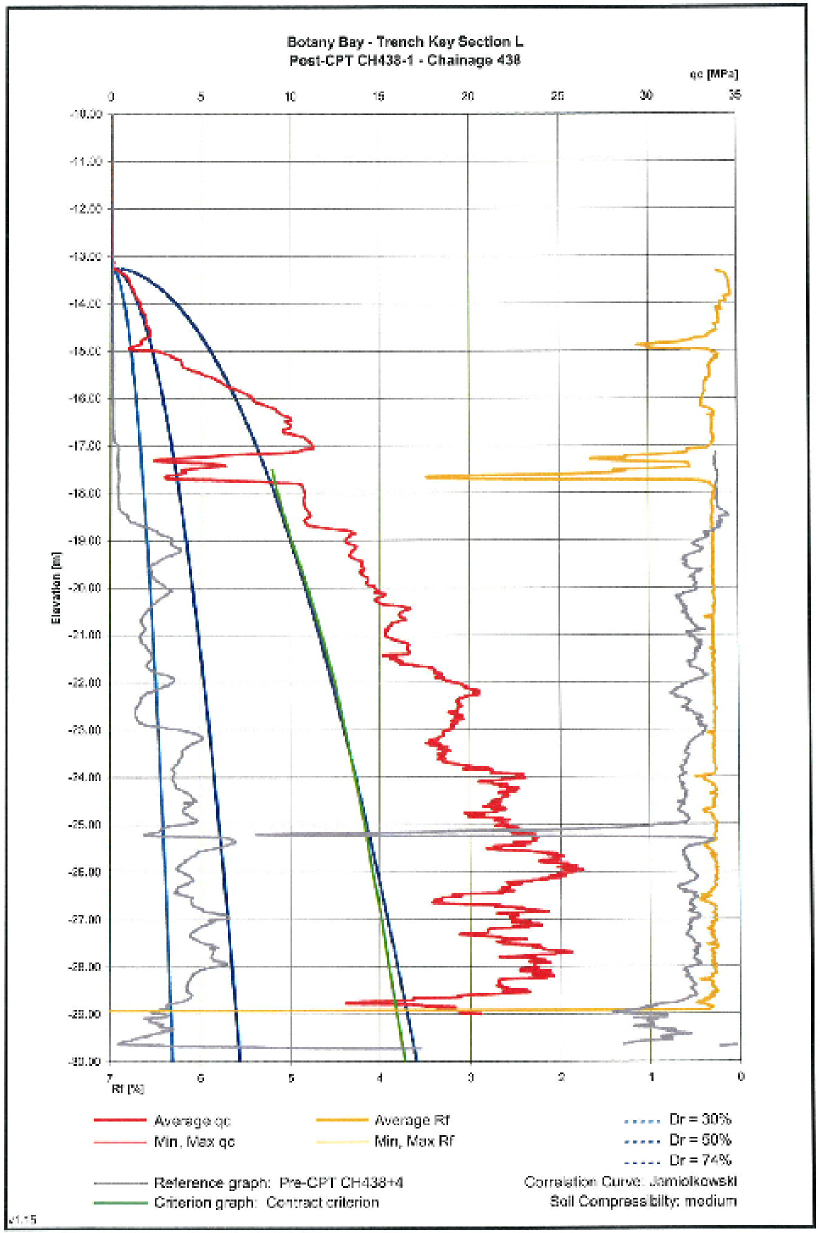
Dynamic Compaction & Vibro Compaction

POUNDER WEIGHT 25 TON / 23 METERS DROP HEIGHT

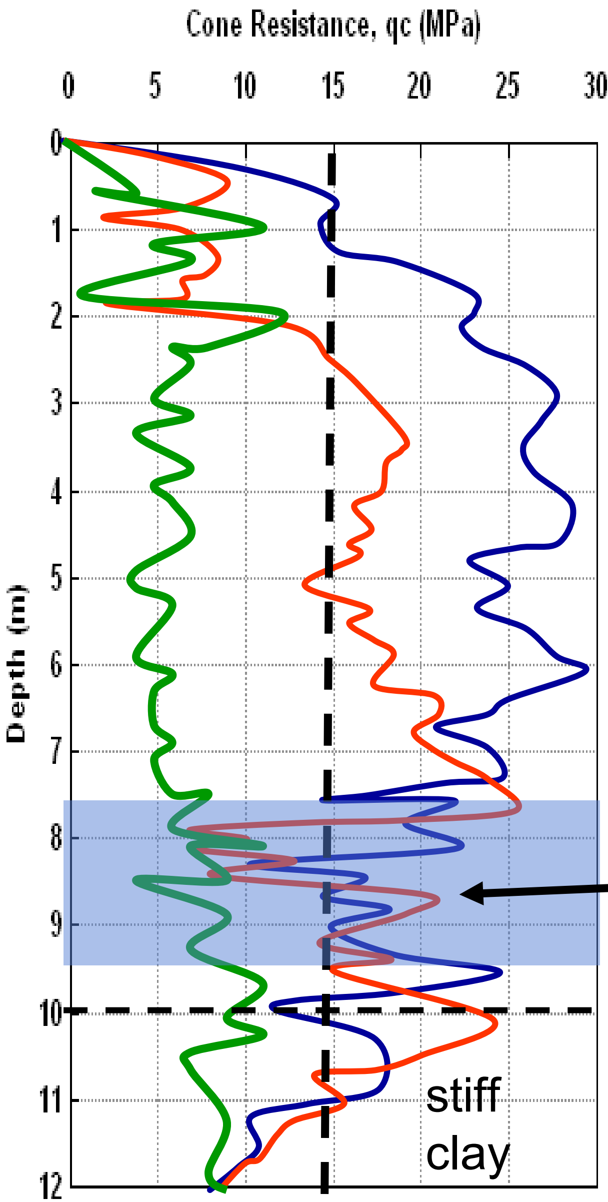
5 m X 5 m GRID / 3 PHASES – 10 BLOWS

VIEW OF LOAD OUT WHARF – DC / VC WORKING

PORT BOTANY EXPANSION PROJECT



Pasir Panjang Container Terminal, Singapore

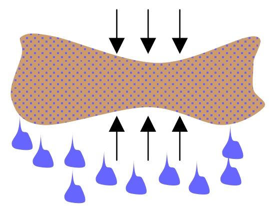
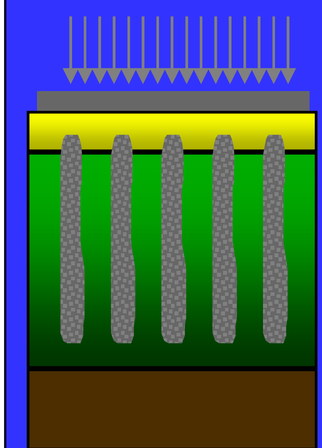
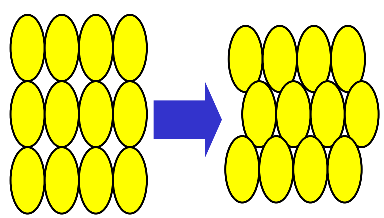


RESULTS

1. Except for the upper 50 cm, the combination of VC and DC satisfied the q_c of 15 MPa (upper 0.5 m requires surface roller compaction).

2. Enforced settlement:
   After VC – 47 cm
   After DC – 27 cm
   Total – 74 cm (~ 10% of treatment depth)

Compaction was less effective in this layer!

	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 Vibroflotation 	

CONCEPT

-Very soft to stiff soils

-Unsaturated soft clays

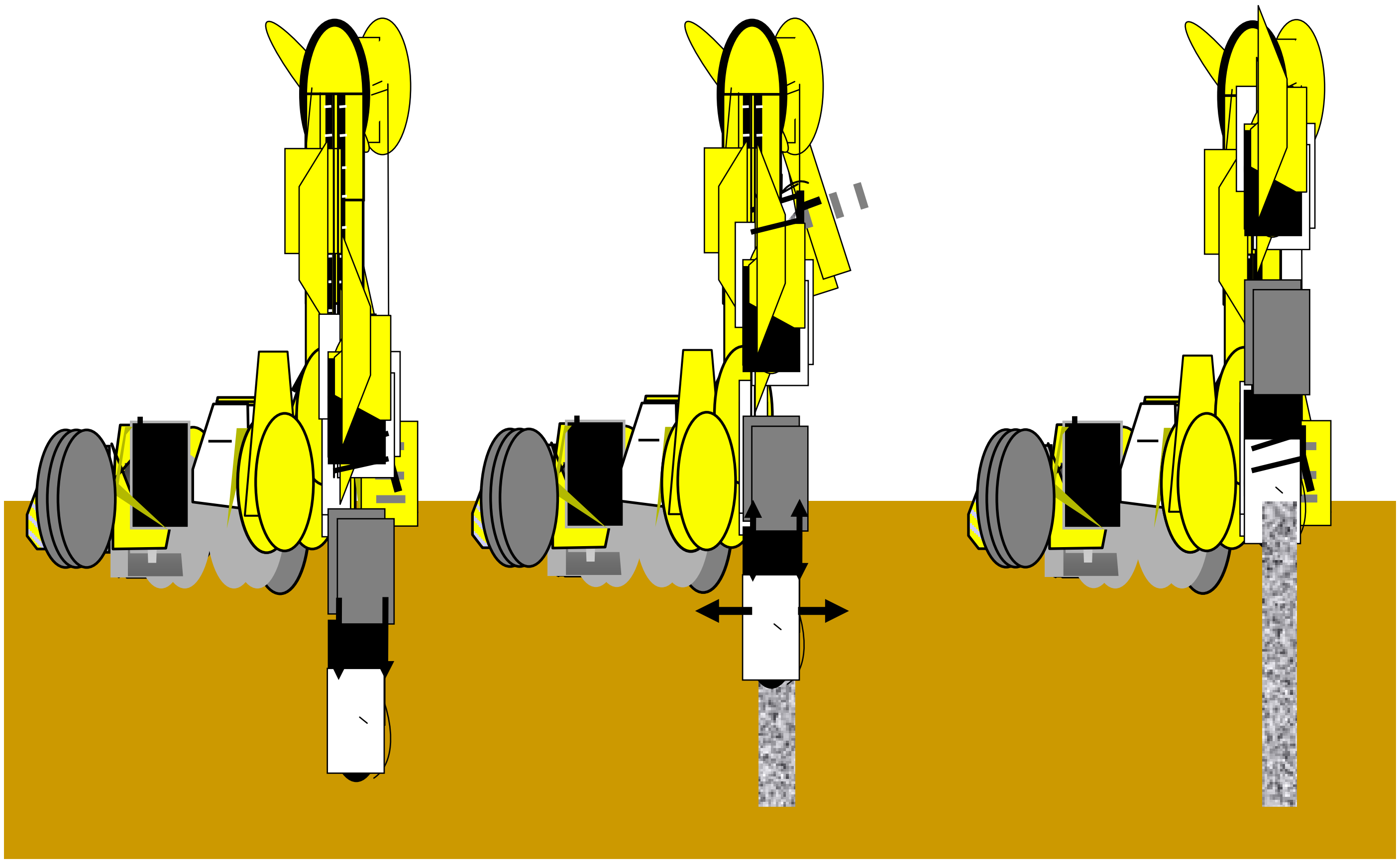
-Thickness of less than 6 meters

-Arching layer available

PARAMETERS

-C, ∅, μ, E_y of soil, column and arching layers, grid

-or P_L, E_P, μ of soil, column and arching layers, grid



Vibrator penetration

Material feeding

Vibration of material during extraction

Principle of the technology - bottom feed with air tank

Stone Columns – Bottom Feed

Stone Columns bottom feed to 22 m depth

CONCEPT

-Soft to stiff clays

-Thickness up to 25 meters

-Arching layer available

PARAMETERS

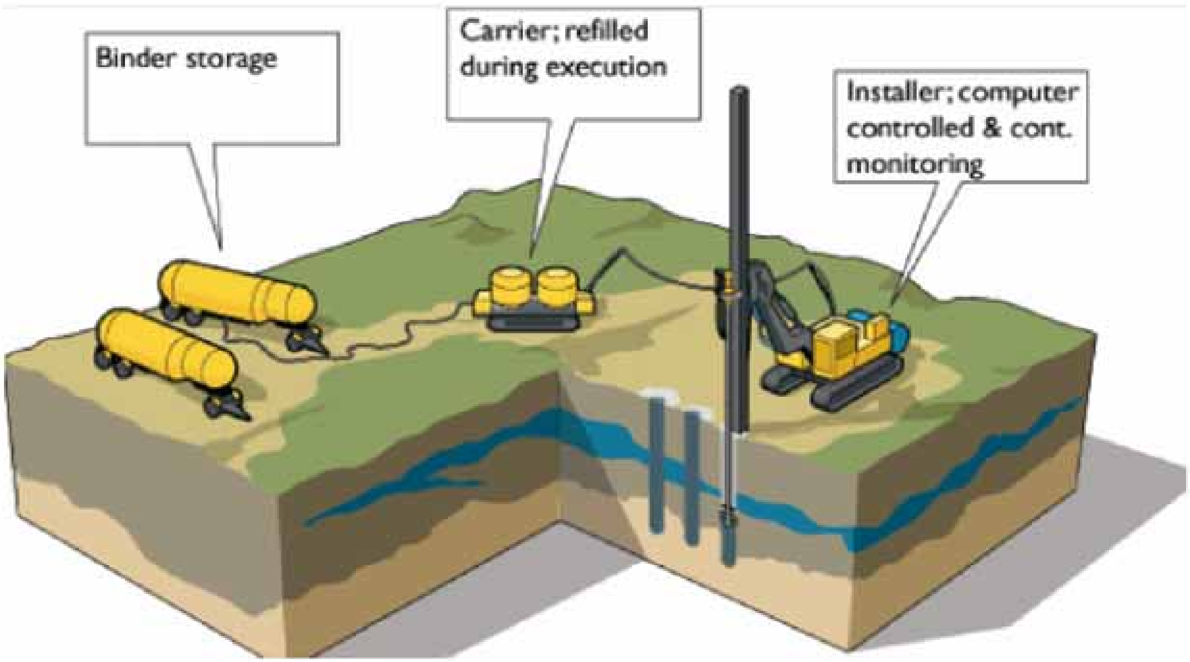
-C, ∅, μ, E_y of soil, column and arching layers, grid

-or P_L, E_P, μ of soil, column and arching layers, grid

CONCEPT

The MDM process (1)

Site logistics

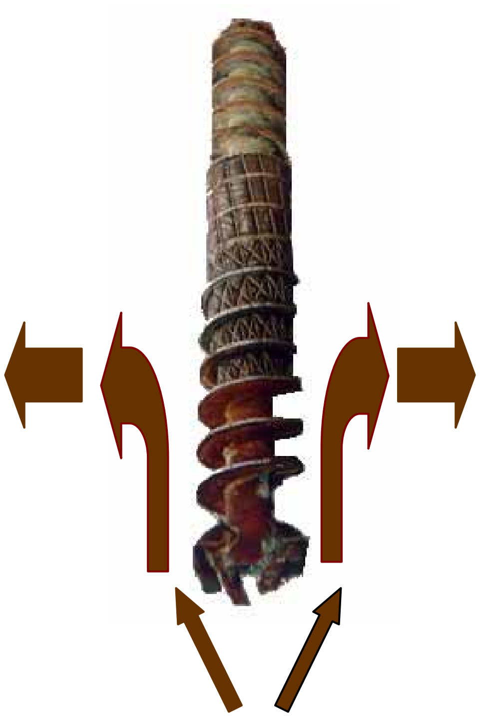


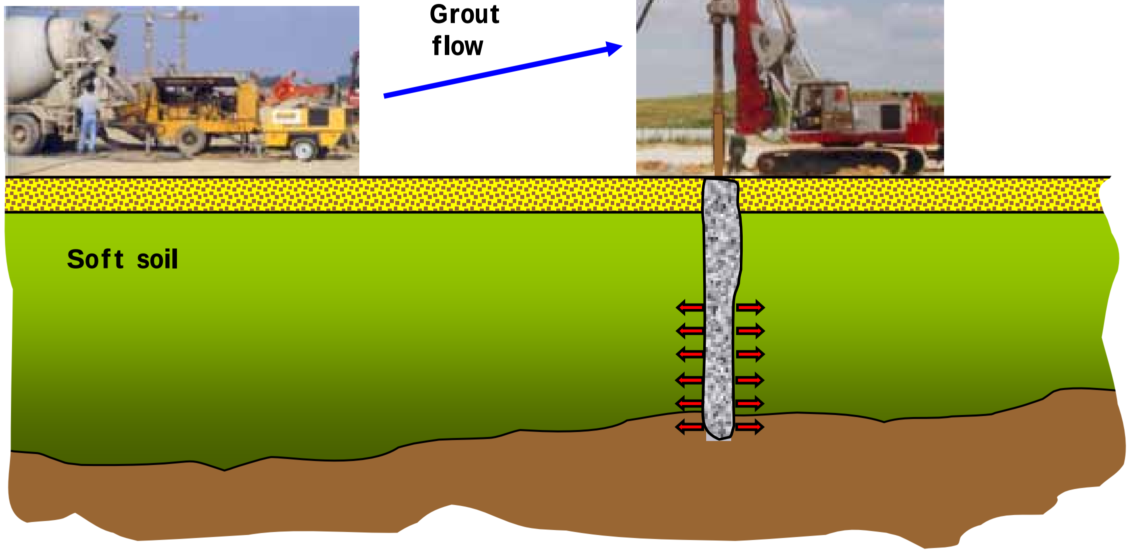
Fleet of specialized equipment

Displacement auger → quasi no spoil

High torque and pull down

Fully integrated grout flow control





- **Load testing on isolated CMC**
  - Checking of individual capacity,
  - Checking of adequate soil parameters taken into account.

- **Compression tests on material**
  - Checking of good grout resistance

- **Data recording system during execution**
  - Recording of drilling parameters → Checking of anchorage,
  - Recording of grouting parameters → No necking

SOIL

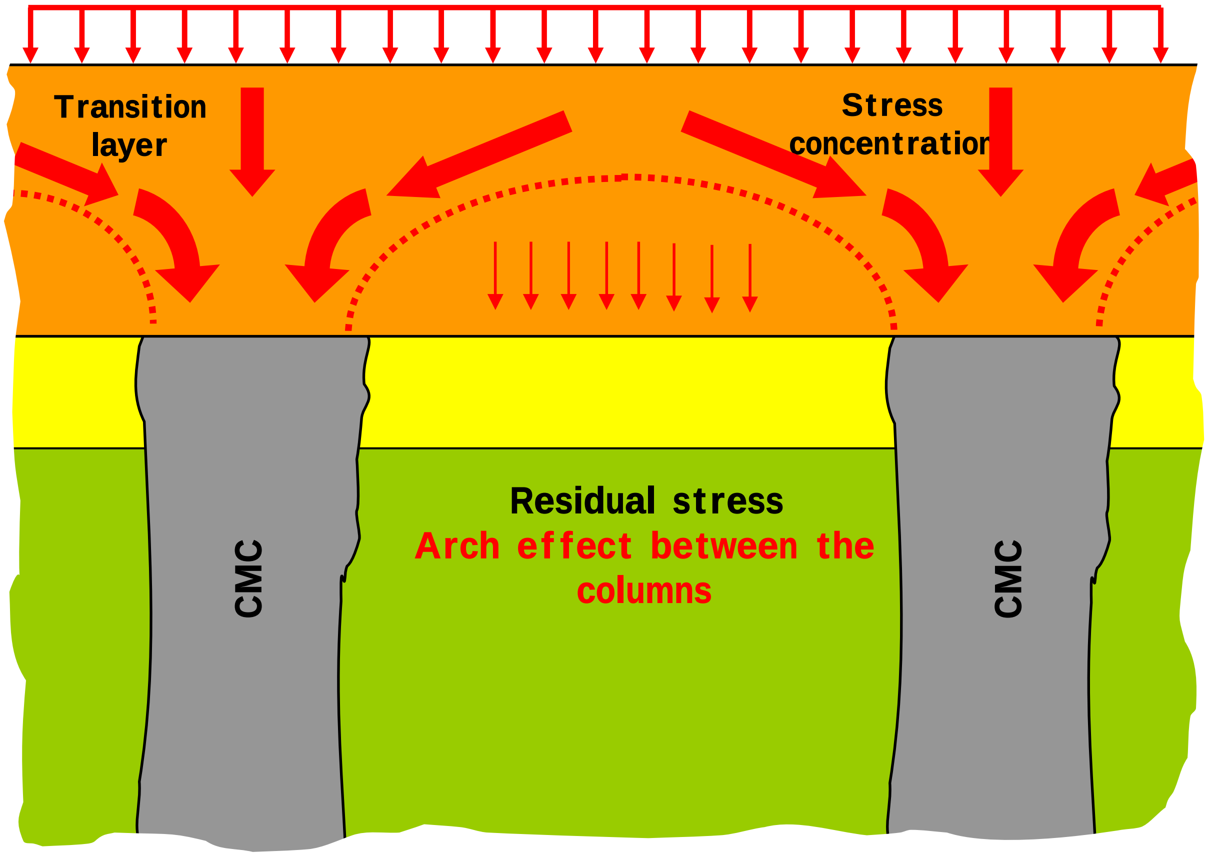
-C', ∅', E_y, μ, γ, φ

-K_v, K_h if consolidation is considered

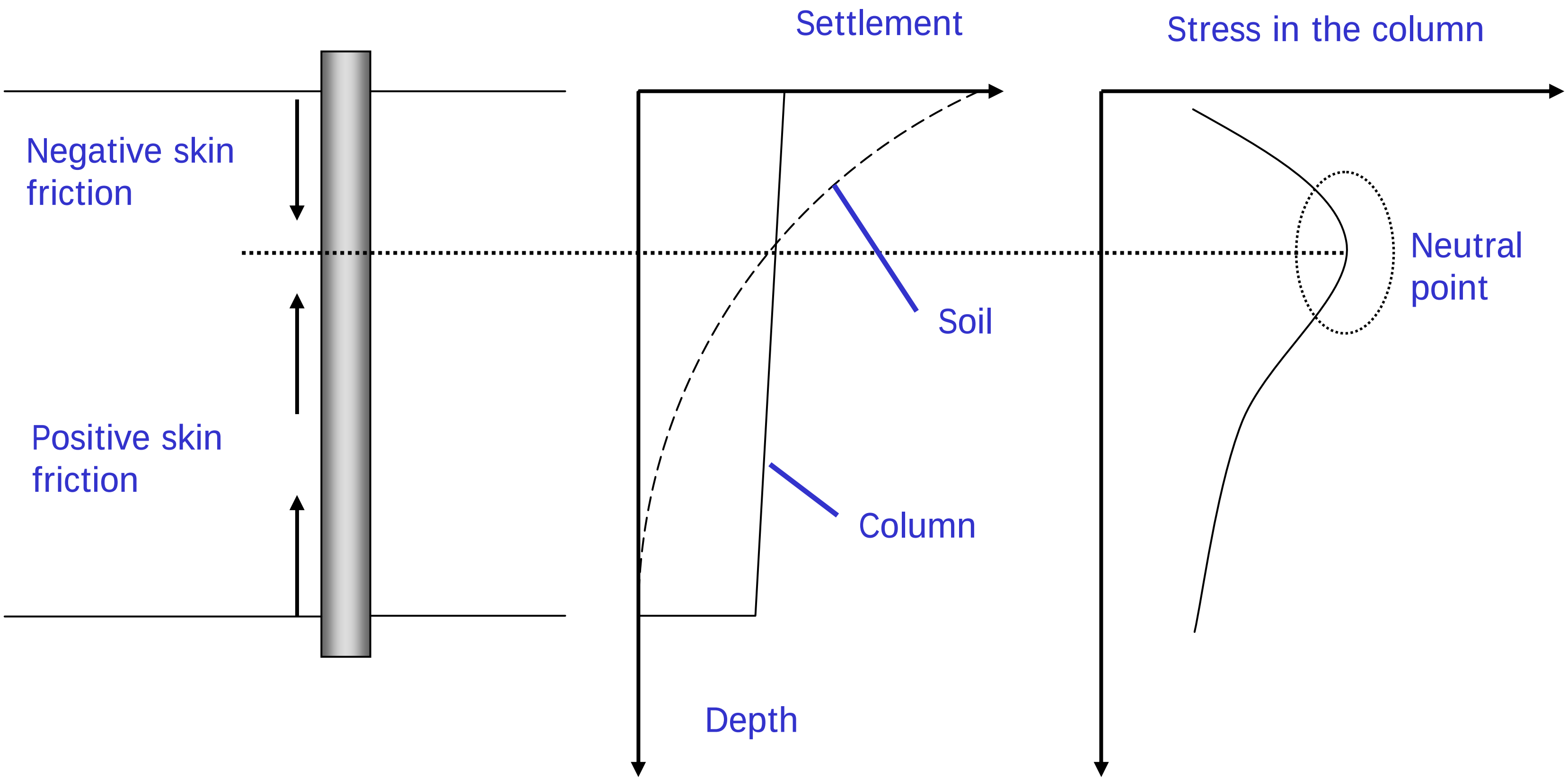
INCLUSION

-E_y, μ, γ, D (non porous medium)

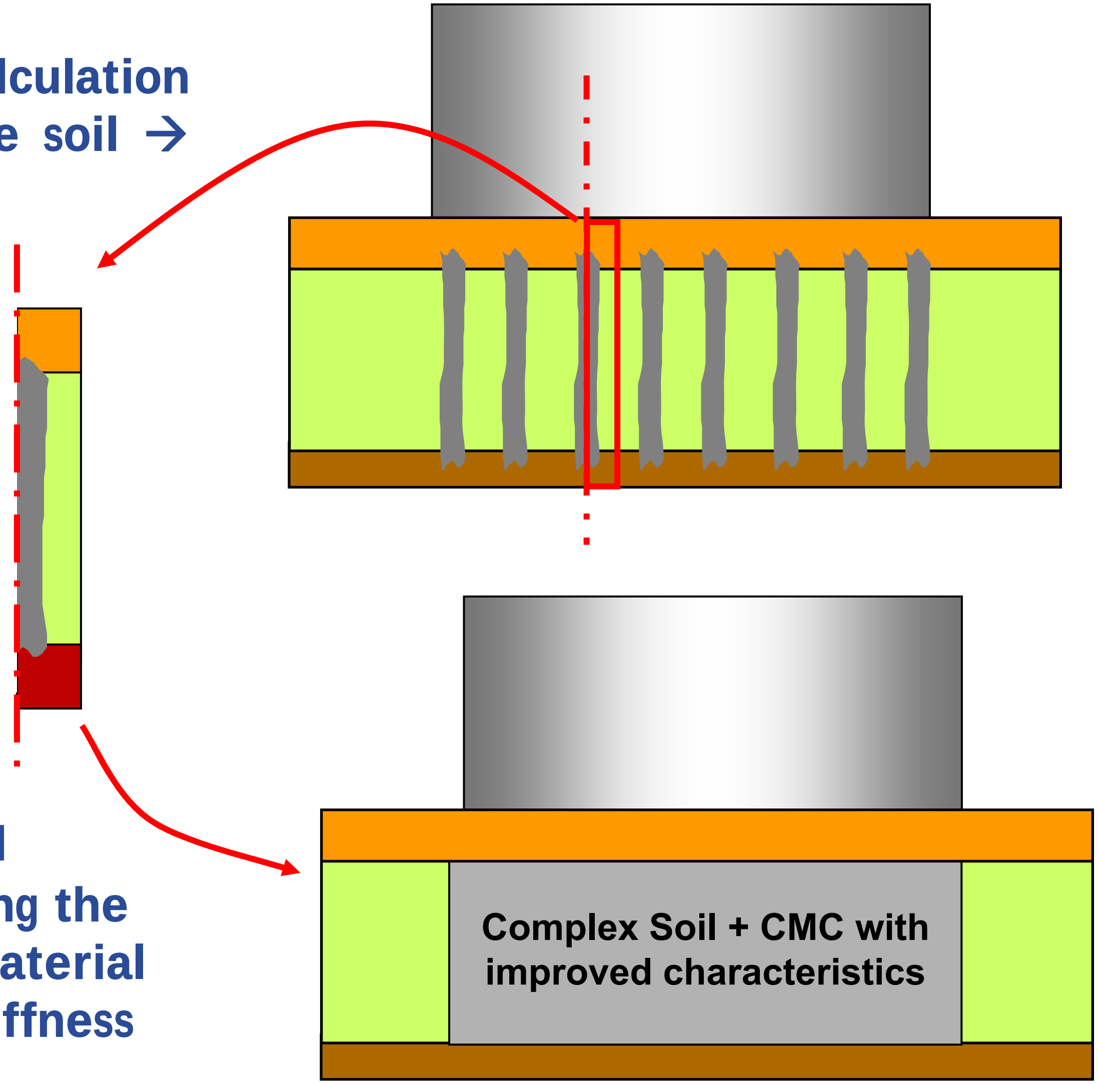
- Create a <u>composite material</u> Soil + Rigid Inclusion (CMC) with:
  - Increased bearing capacity
  - Increased elastic modulus
- Transfer the load from structure to CMC network with a <u>transition layer</u>



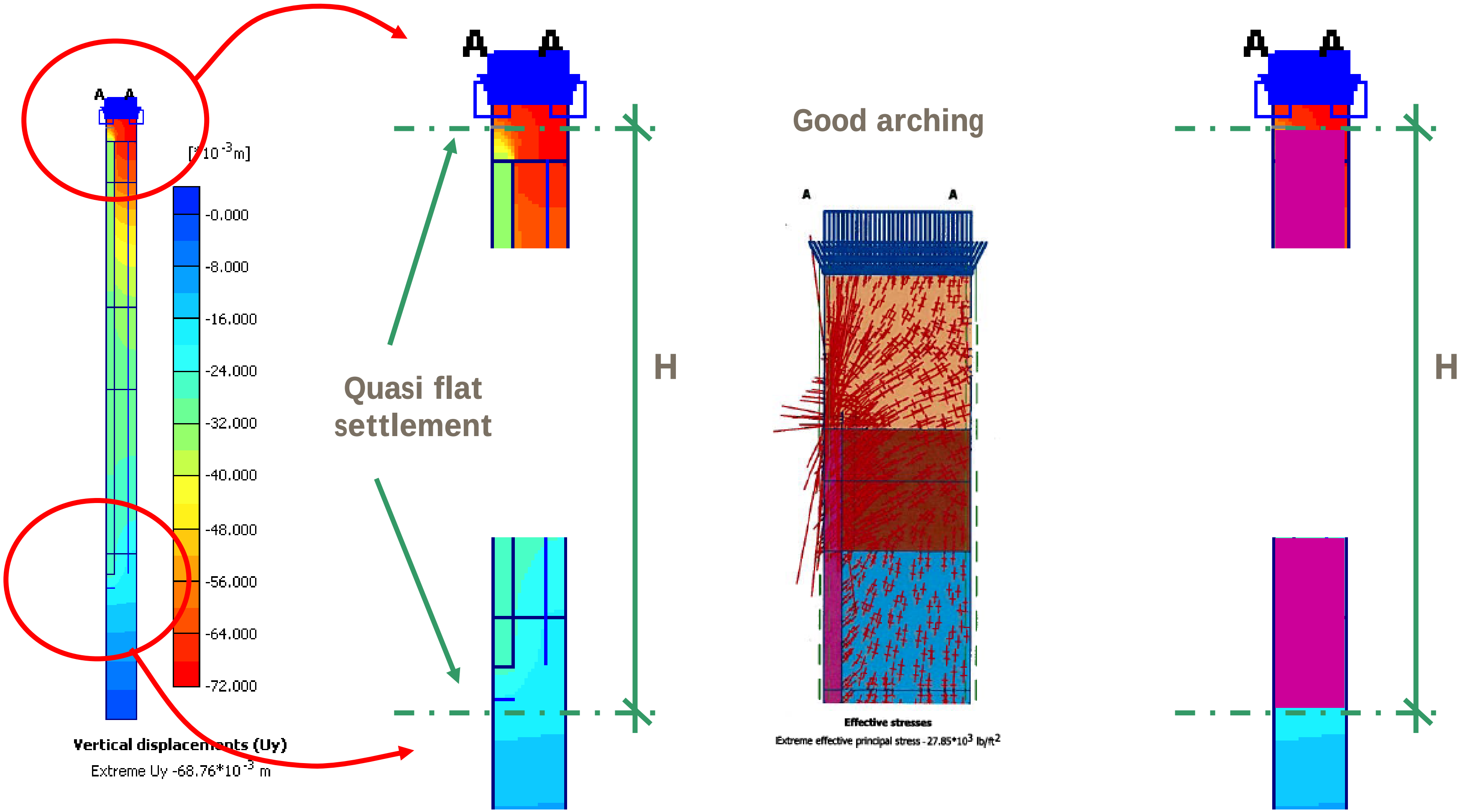
- **Negative skin friction allows to develop a good arching effect**



Axi-symmetric FEM calculation with one CMC and the soil → eq. Stiffness



Global axi-symmetrical calculation by modelling the improved ground by material having an improved stiffness

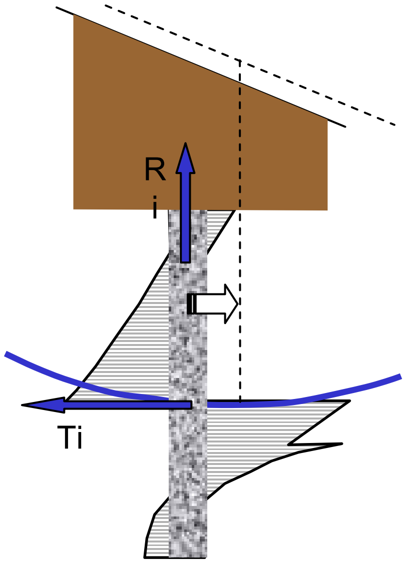


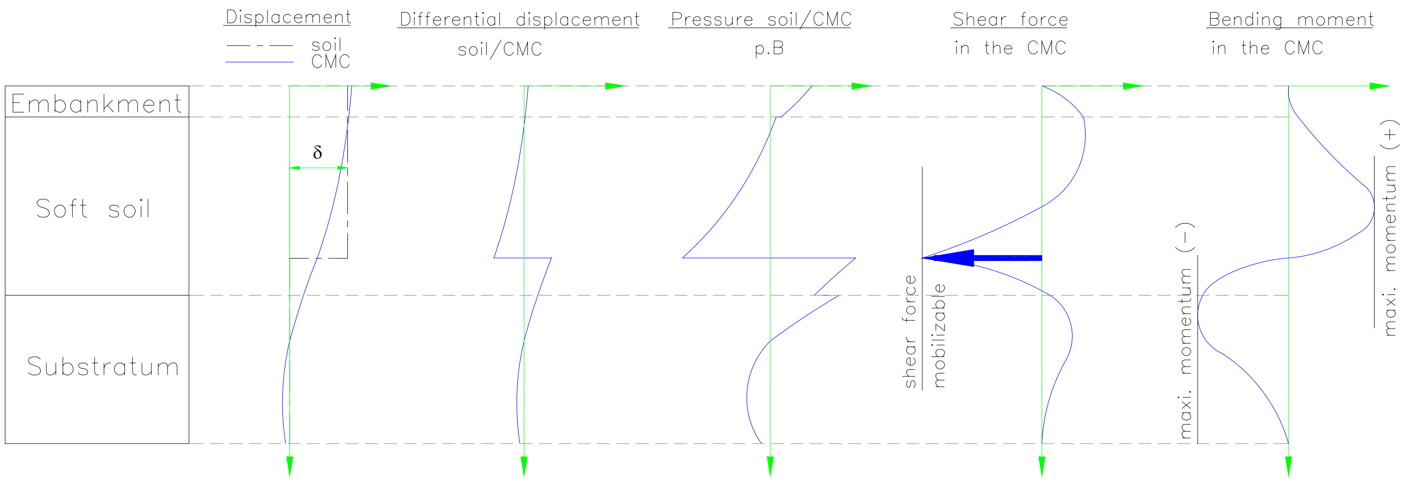
- **Checkings:**
  - Quasi flat settlement
  - Good arching as shown by principal stress direction

The structure « see » the complex [soil + CMC] as a uniform soil with improved parameters

- **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. **Modelling of the CMC as nails working in compression + imposed shear force under Talren software (or equivalent)**



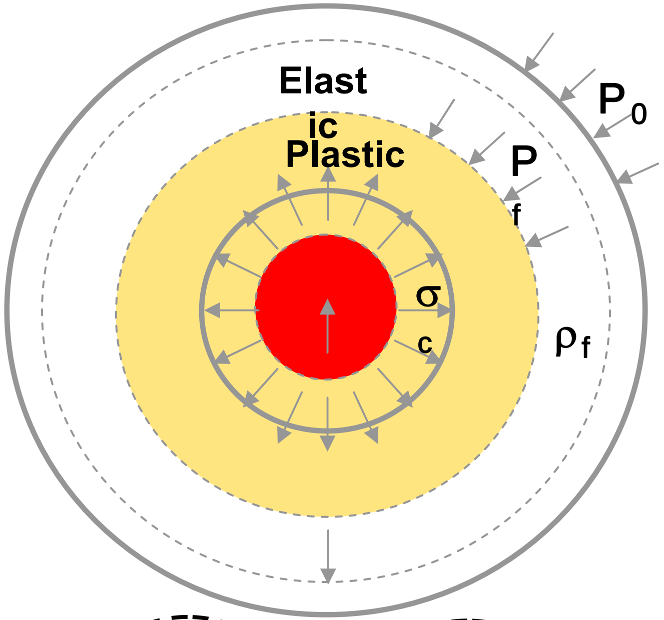


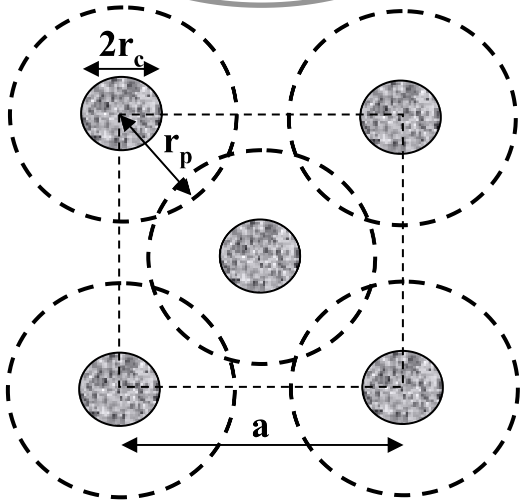
CMC Design – Benefits for the structure

- **Structure shall be designed as if soil was of good quality**
  - **Specialist contractor provides structural designer with bearing capacity, k, etc…**
- **No connection between foundation and structure**
  - **Structure is less complex to be designed,**
  - **No stiff connection, thus no increase under seismic analysis,**
  - **Structure very simple to be built: footings and slab on grade, no pile cap, thus benefit in terms of cost and speed of execution**

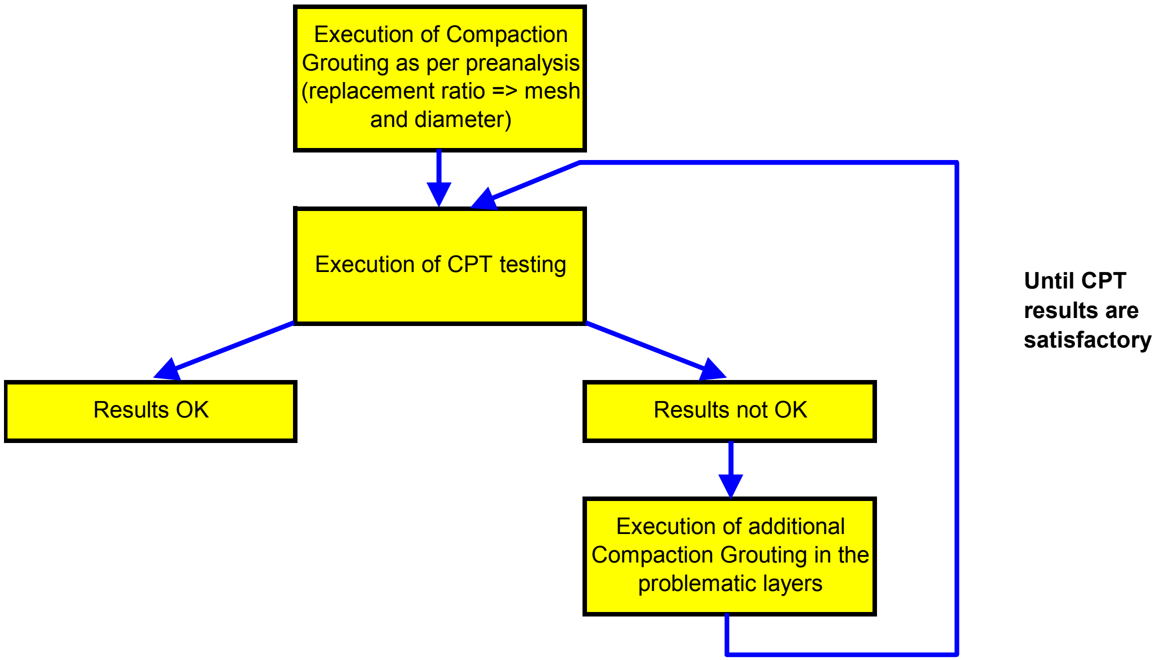
- **Aim of CMC to compact granular material to decrease liquefaction potential**

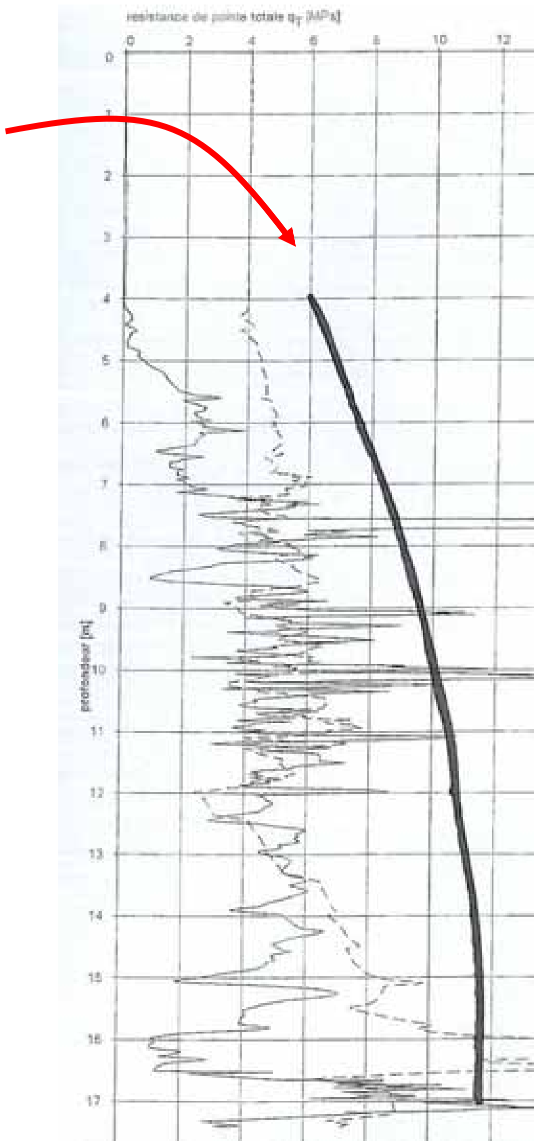
- **Method of densification**
  - Injected mortar used to displace and compact the soil around the injection point
  - Successive injection according to a regular grid induce a global compaction of the soil
  - Mesh and diameter designed so as to achieve a given replacement ratio





- **Principle: Execution and testing procedure**
  - Seismic parameters (PGA, Magnitude) → q_c soil profile to be achieved (NCEER)
  - Estimation of replacement ratio to achieve required q_c
  - Execution of Works and testing by CPT
  - Additional grouting if necessary

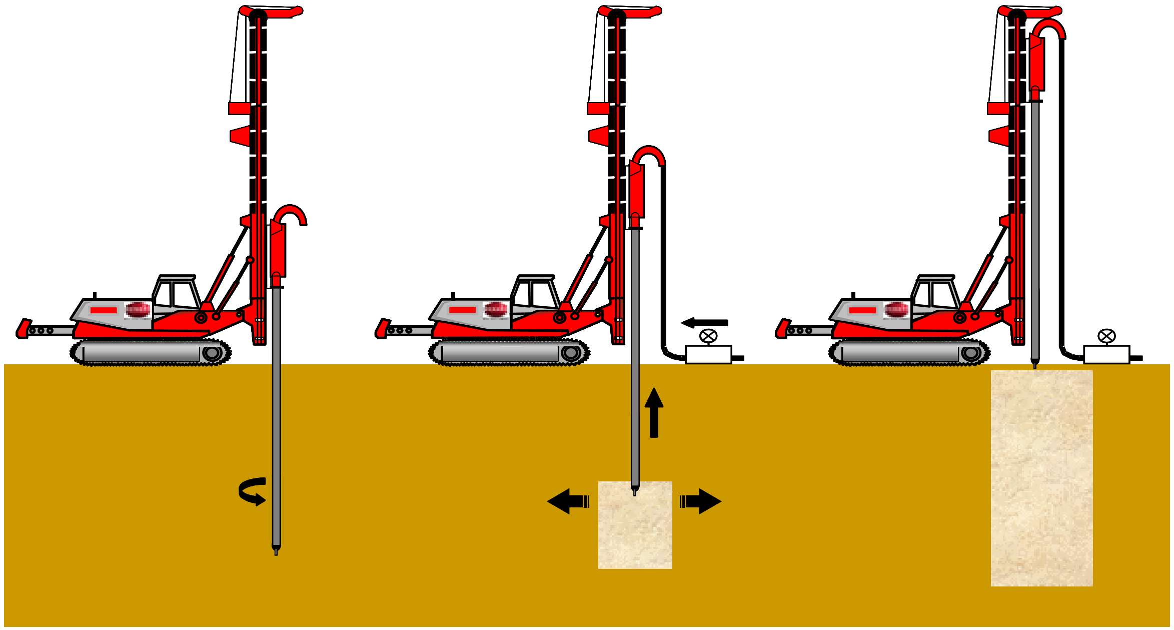




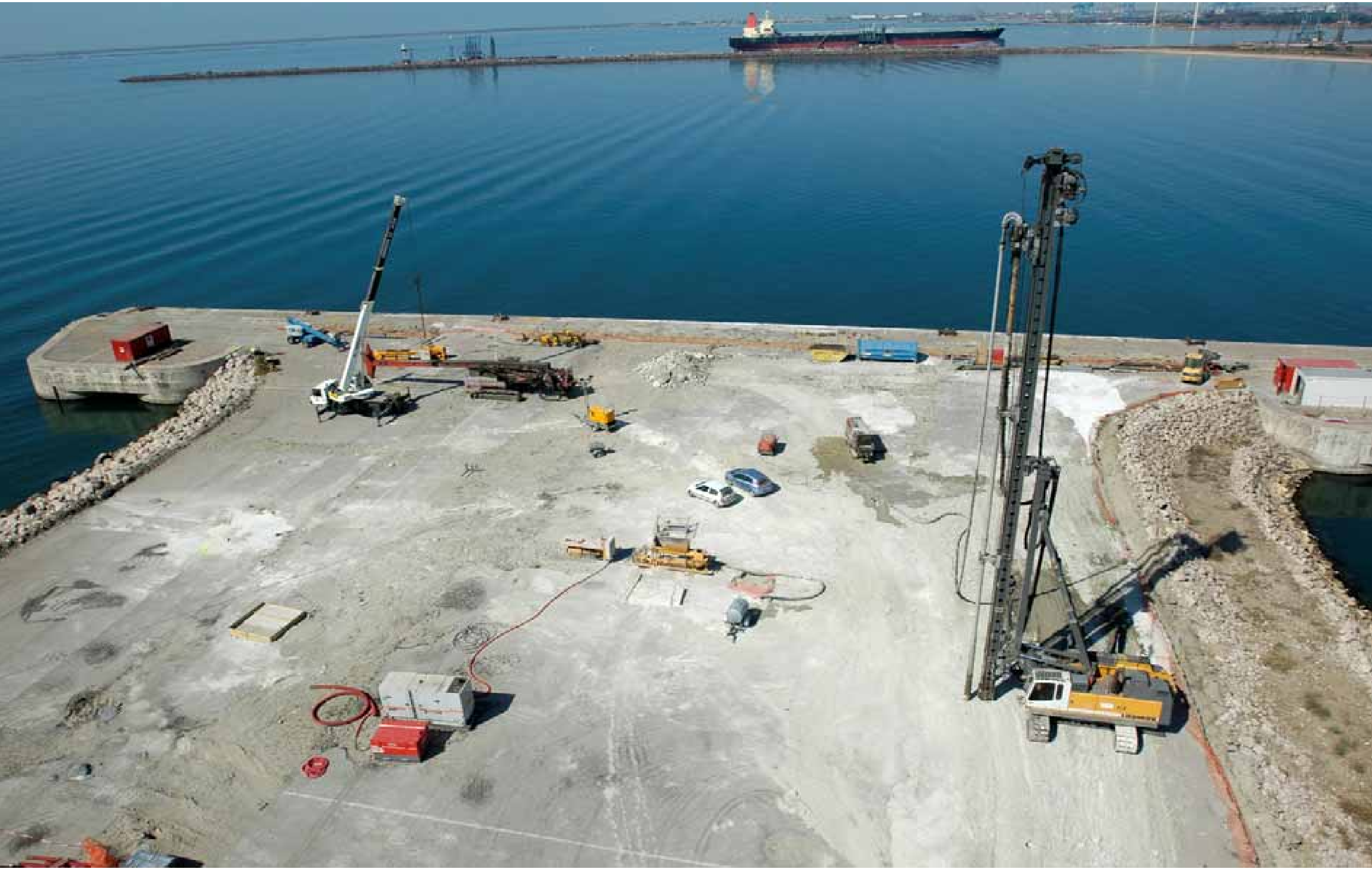
- **Same type of equipment as for CMC**
  - **Soil displacement rig and pump,**

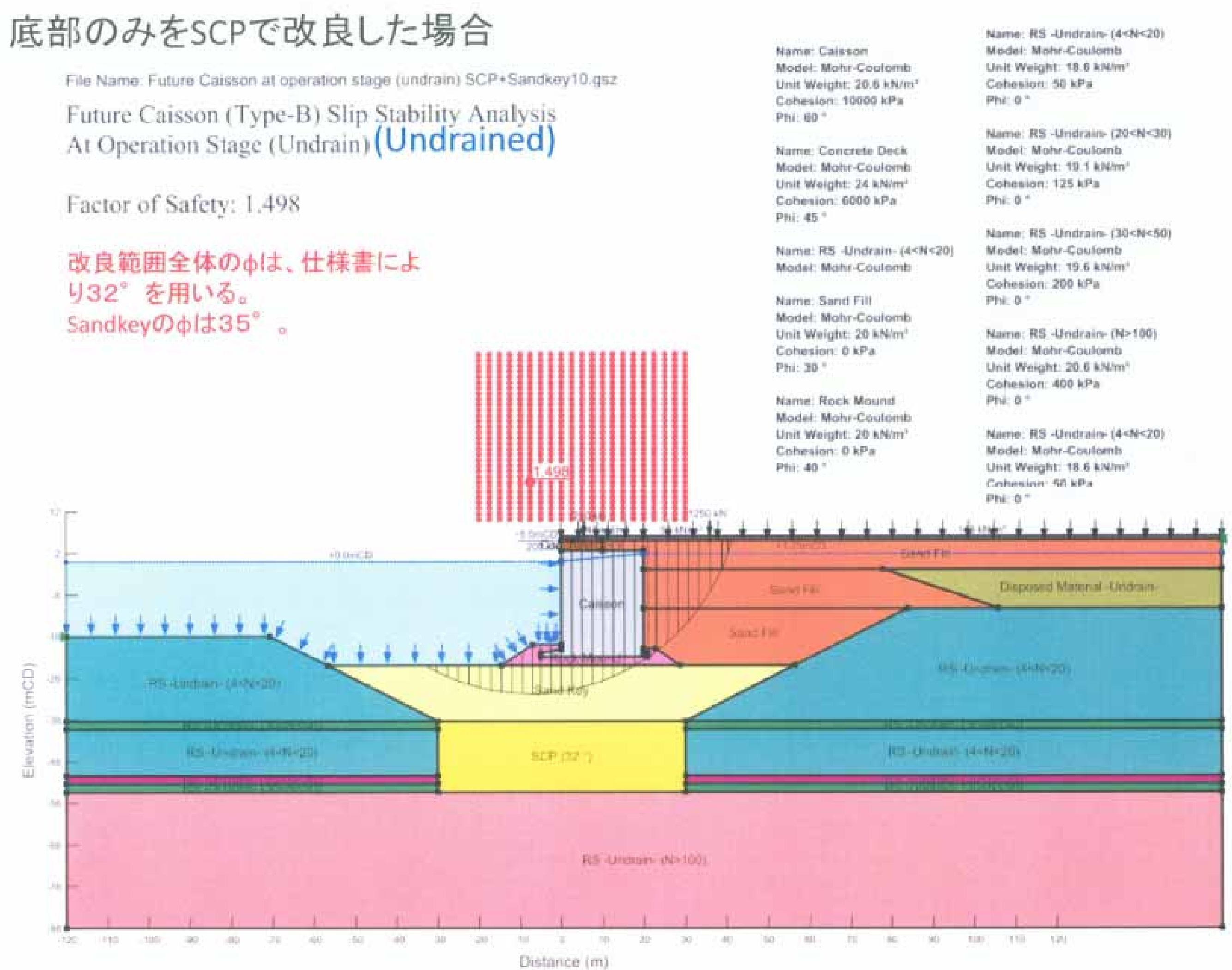
- **Key points**
  - **Quality of grout (grain size distribution, workability, consistency)**
  - **Injection speed and successive phases**

- **Final Testing = CPT**

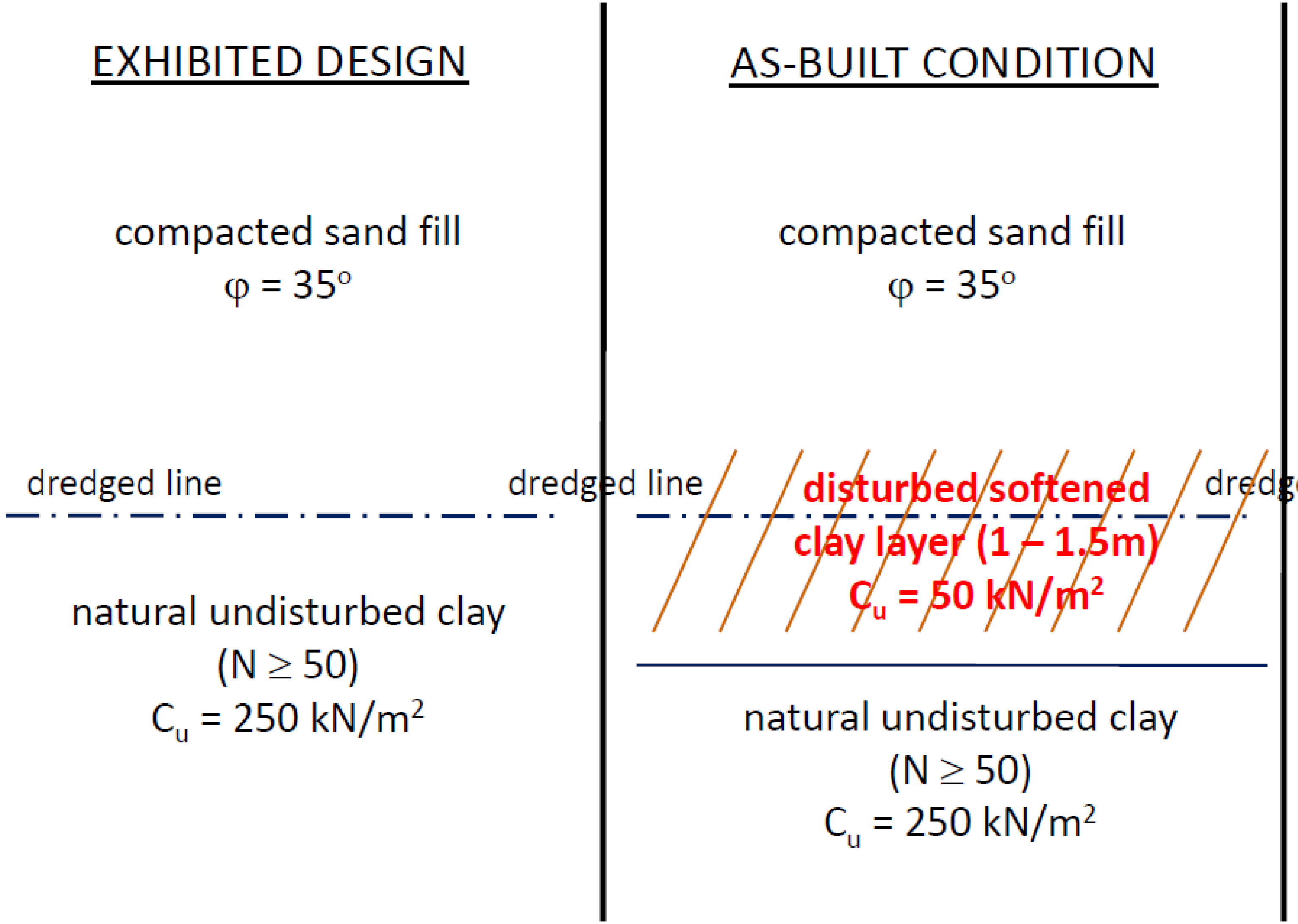


New Development - CMC Compaction – Fos LNG Terminal




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
Phi: 0 °
1.498
Sand Fill
Disposed Material -Undrain-
Caisson
Sand Key
SCP (32°)
Elevation (mCD)
Distance (m)

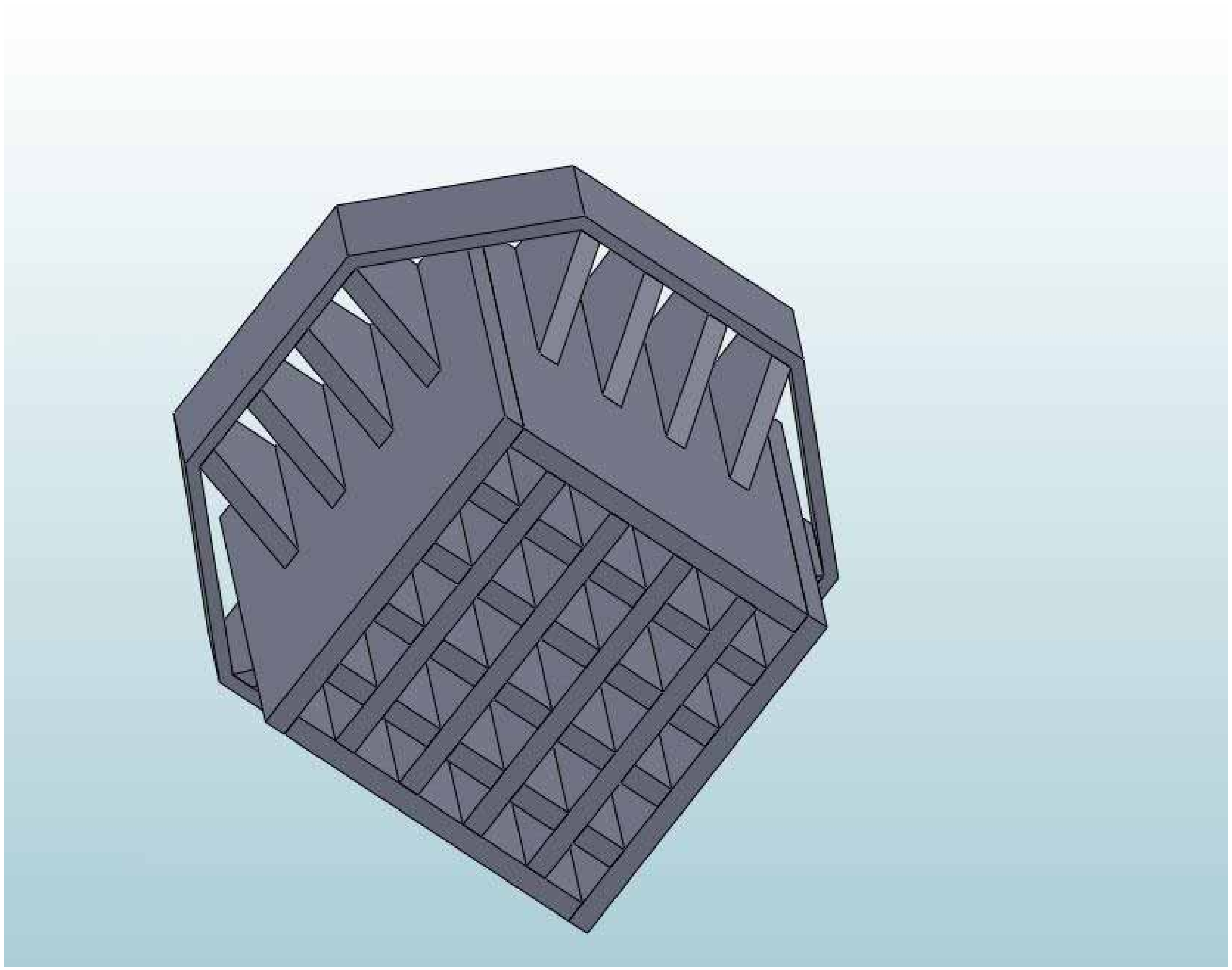
As built conditions



Proposed solution

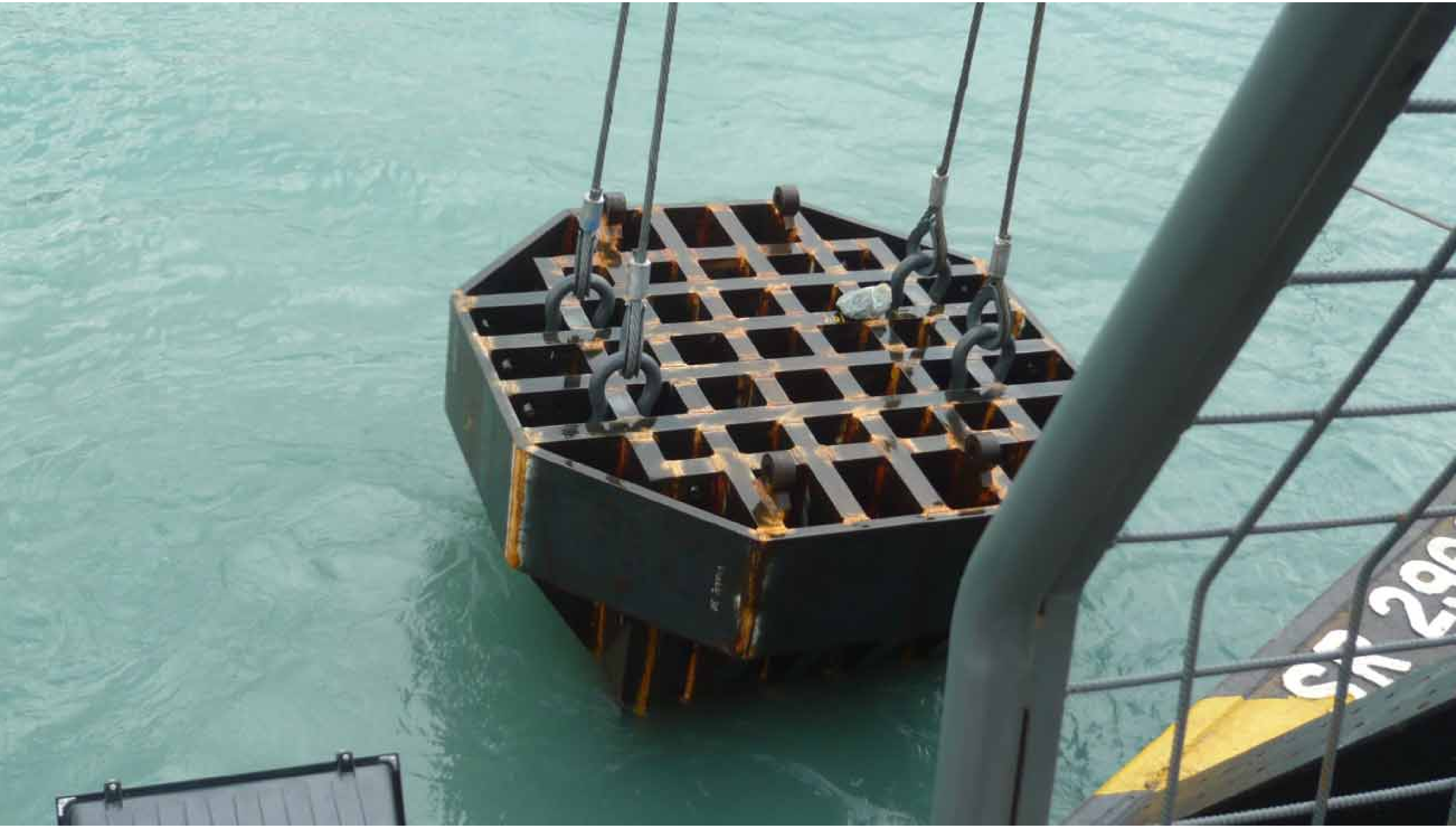
	EXHIBITED DESIGN	PROPOSED SOLUTION	
	compacted sand fill $\varphi = 35^o$	compacted sand fill $\varphi = 35^o$	
1.3m	compacted sand fill $\varphi = 35^o$ $C = 0$	**compacted rock mat** **($\varphi = 45^o$ $C = 0$)**	**1.3m**
	dredged line	dredged line	
1.5m	undisturbed clay $\varphi = 0^o$ $C_u = 250$ 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	

Marine Pounder



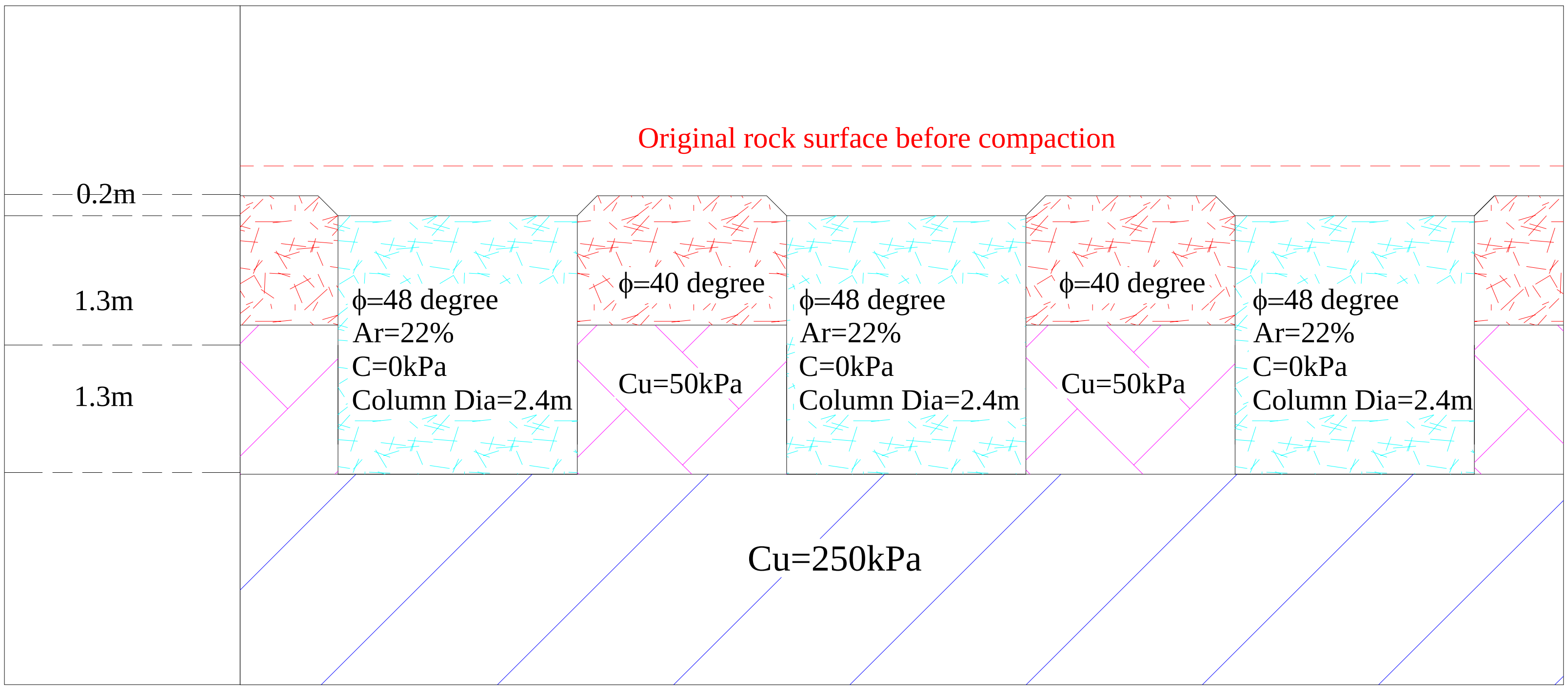
View of pounder construction

View of pounder ready to work

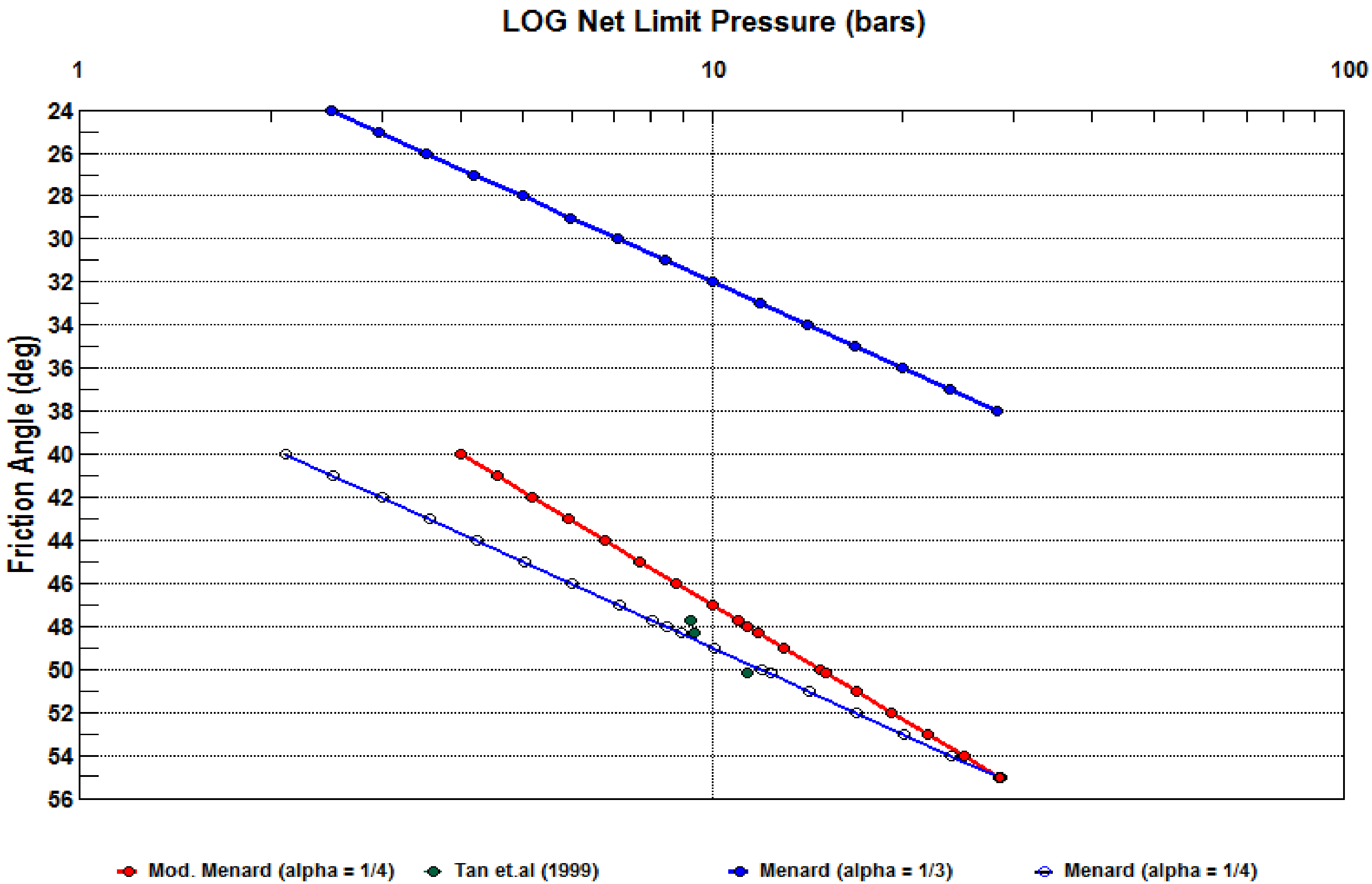


General Set up

After compaction actual results



Determination of Friction Angle by PMT



TOURING LECTURES T.C. GROUND IMPROVEMENT AUSTRALIA

Perth, Adelaïde, Melbourne, Hobart, Sydney, Newcastle, Brisbane

THANK YOU