GROUND IMPROVEMENT WORKSHOP 11-12 JUNE 2010

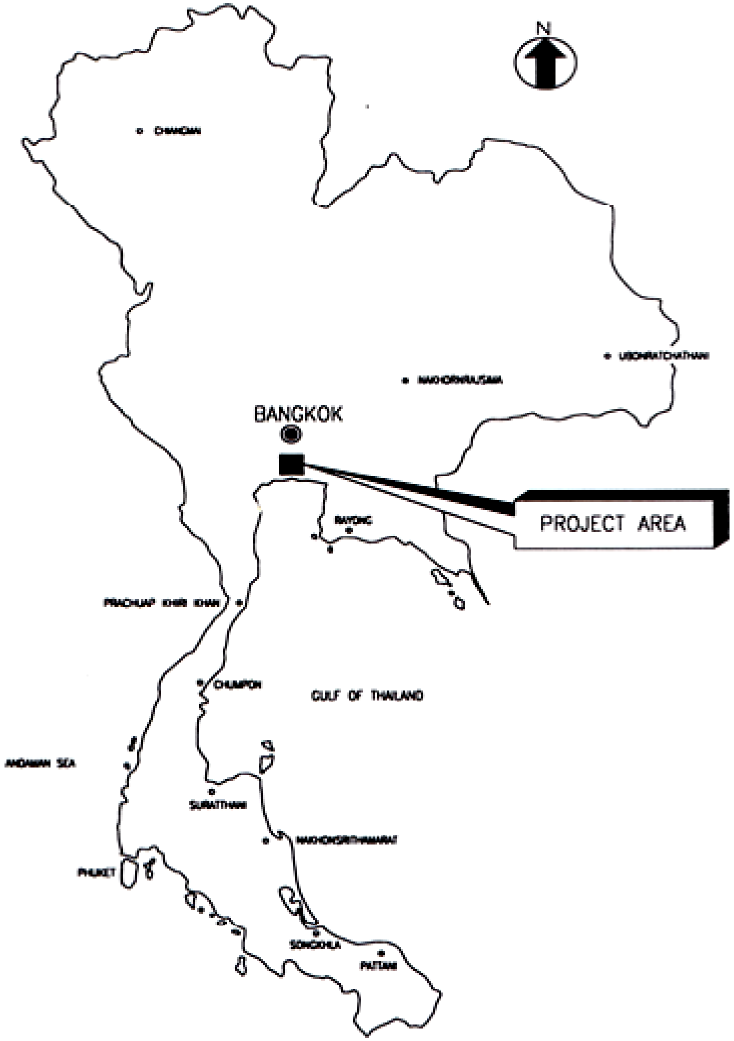
PERTH, AUSTRALIA

GROUND IMPROVEMENT IN EXTREME GROUND CONDITIONS

Presented by Serge VARAKSIN

CHAIRMAN OF T.C. Ground Improvement

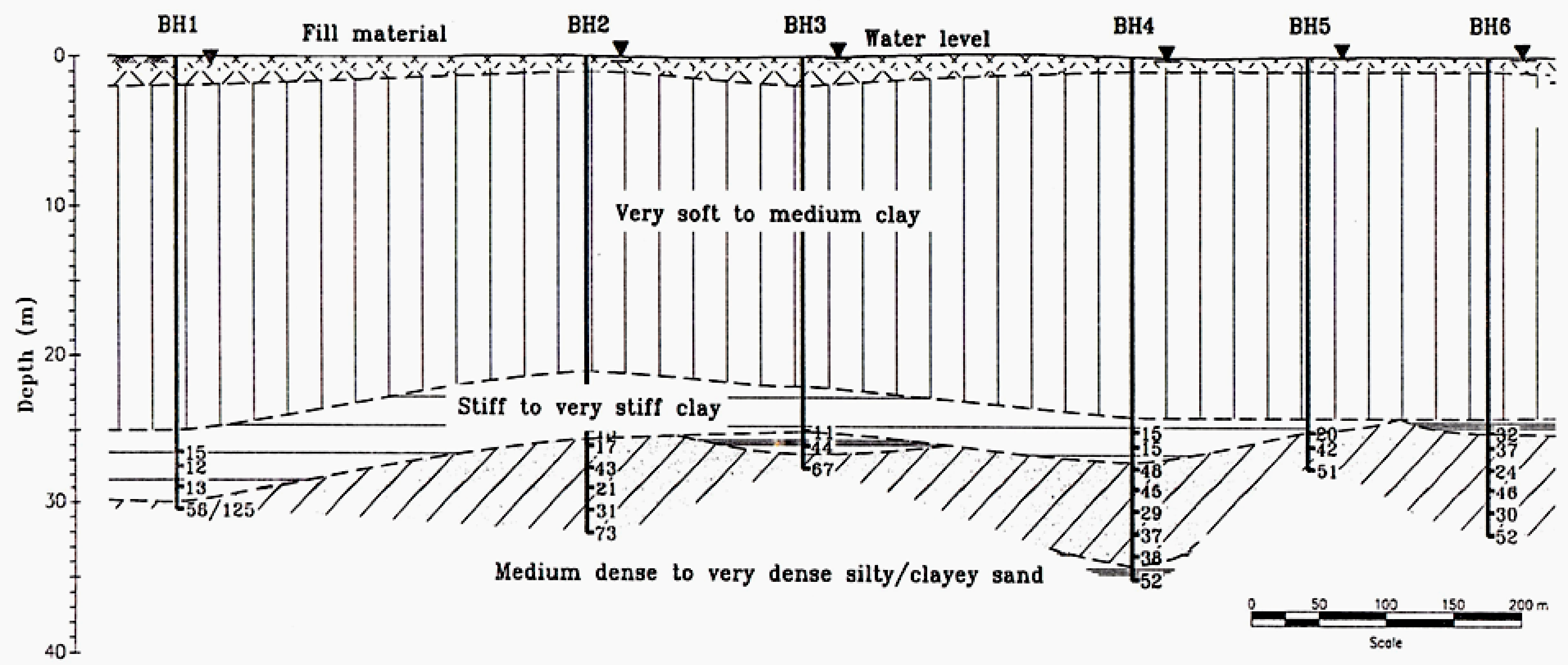
menard



MAP OF THAILAND

Gulf of Thailand

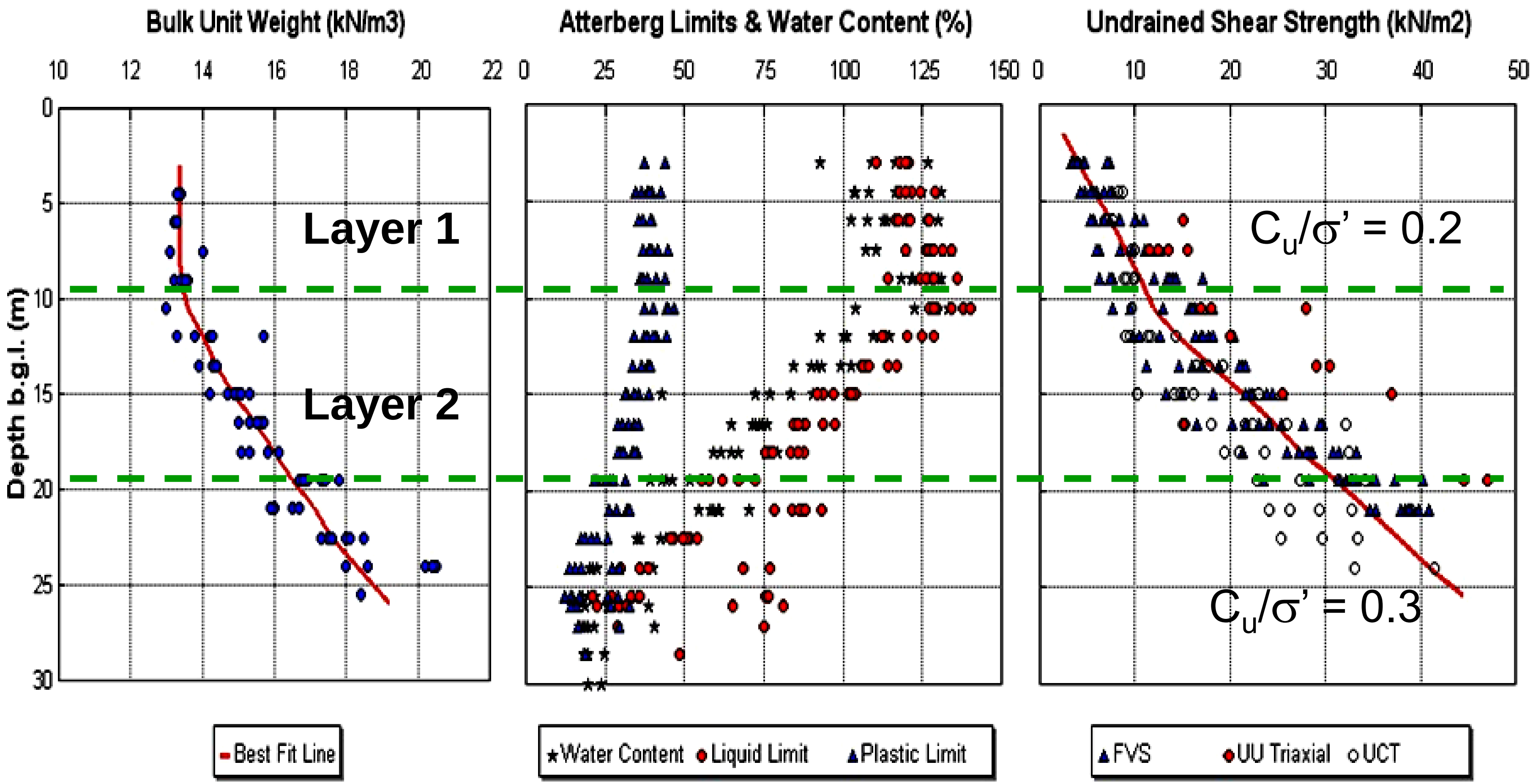
Construction of a 2-km road embankment , 1.33m thick



Layer 1: Weathered crust (OC clay) ~ 1 - 2m thick

Layer 2: Soft Bangkok clay (NC clay) ~ 20m thick

Layer 3: Firm / stiff clay (overlying alt. sand layers) > 25m



Soft layer 1: 0 – 10m highly plastic very soft Bangkok clay

(av. C_r ~ 0.35; av. C_v ~ 0.5 – 1 m²/y)

Soft layer 2: 10 – 20m soft to medium firm clay

Final embankment height = 1.33m
Fill to compensate settlement = 3m
Total fill to be placed = 4.33m 2m
Surcharge ?

Contract period of 12 months including consolidation and pavement works.

LONG TERM CRITERIA

Post construction performance (t = 25 years):

- Differential settlement < 1:750
- Residual settlement < 40cm
- Stability : Factor of safety > 1.5

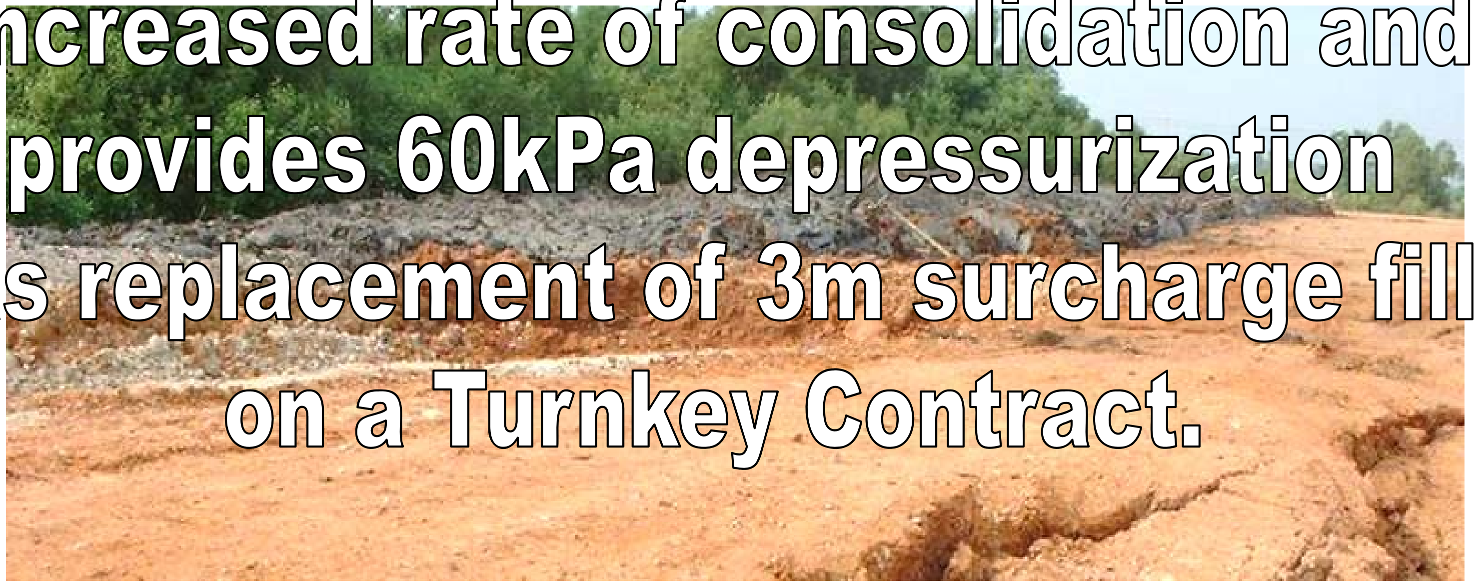
SHORT TERM CONCERNS

- Stability during construction (most critical)
- Handover date for turbine & other heavy structures (time constraint)
- Inadequate local source of fill materials and high price (reduce or eliminate surcharge ?)

Preparation of Working Platform

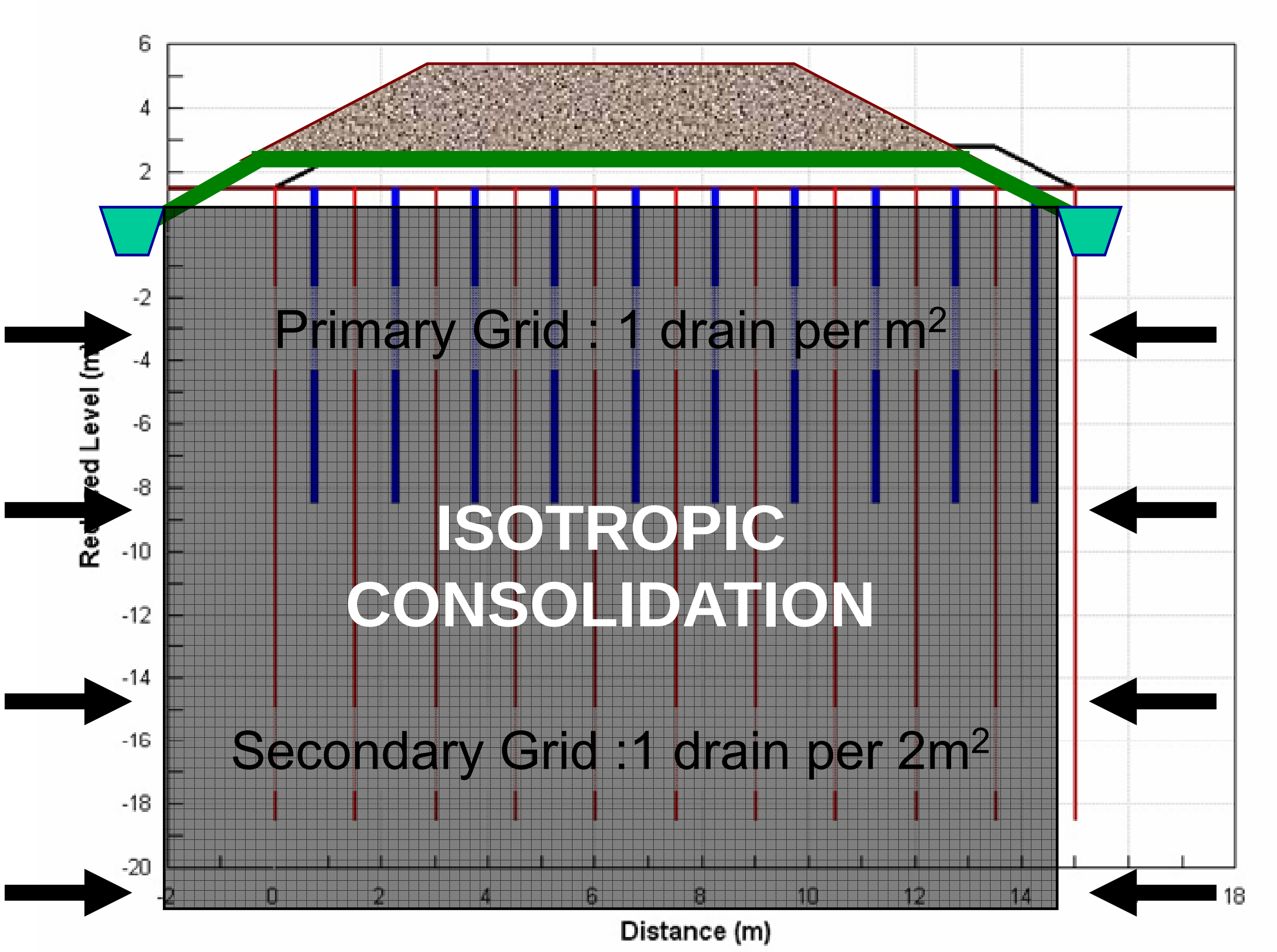
Encounter slip failures and lateral flows !

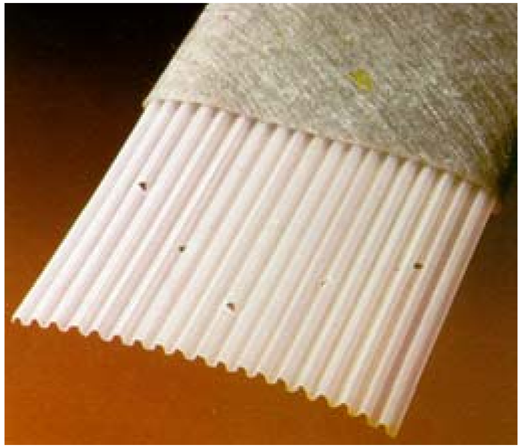
Menard Vacuum was designed for enhanced stability, increased rate of consolidation and provides 60kPa depressurization as replacement of 3m surcharge fill on a Turnkey Contract.



Double drain grid design for layer 1 and layer 2 soft clay.

Vacuum depressurization at 60 kPa for 7 months

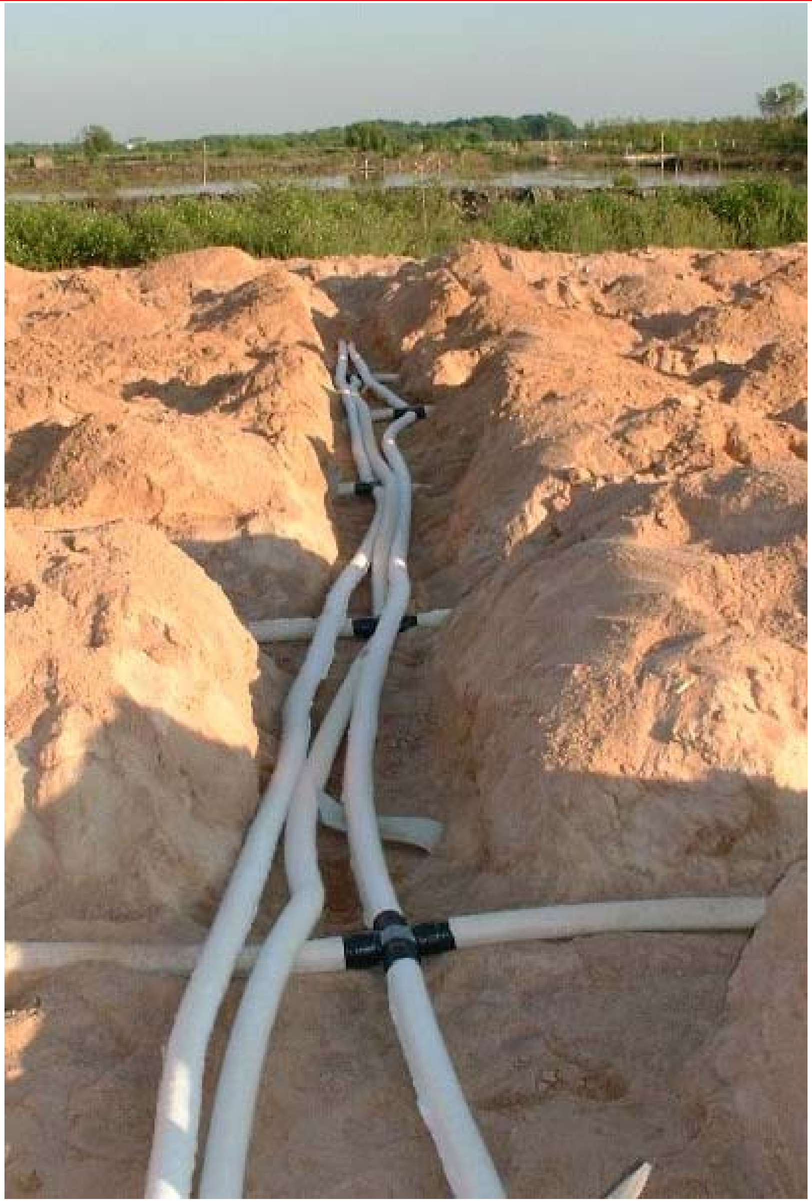




Initial Conditions

Pre Engineering Tests

Horizontal Drains Connection

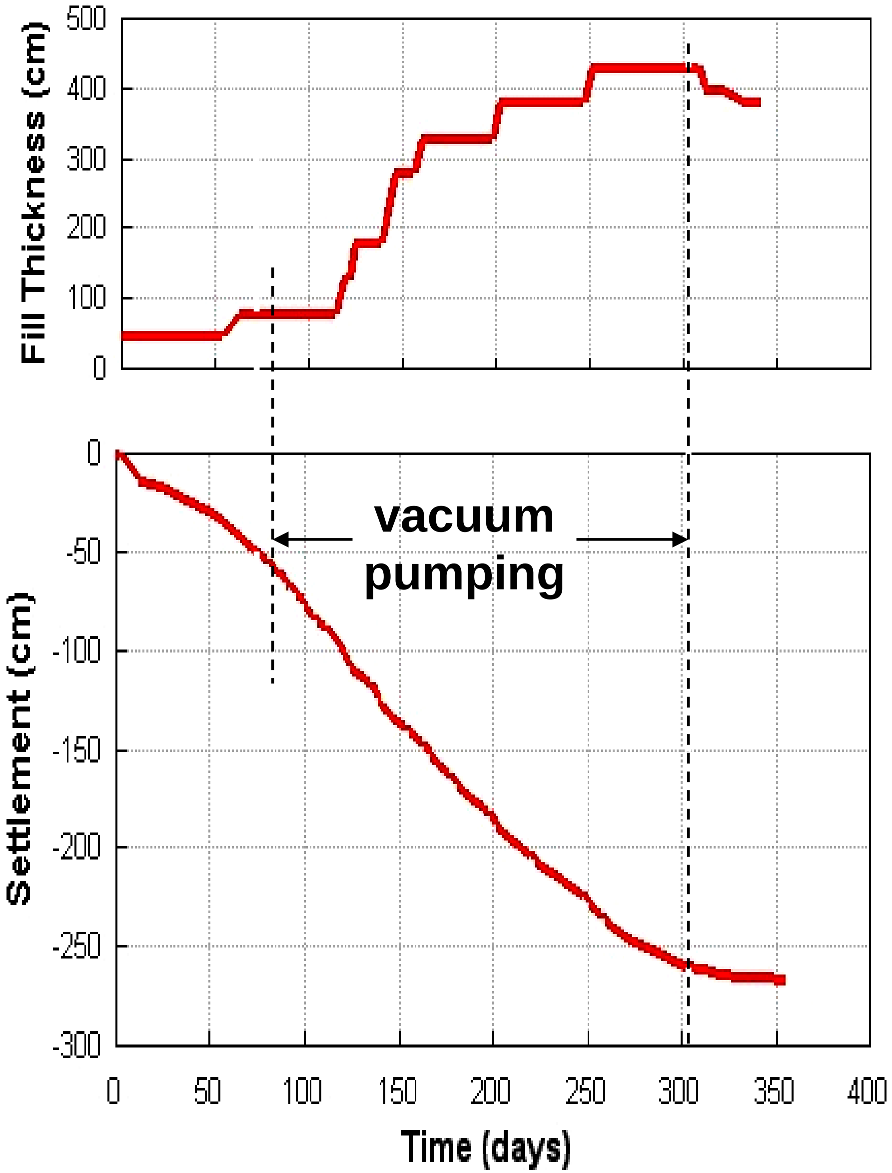


Installation of Geotechnical Instruments

Initial Depressurization

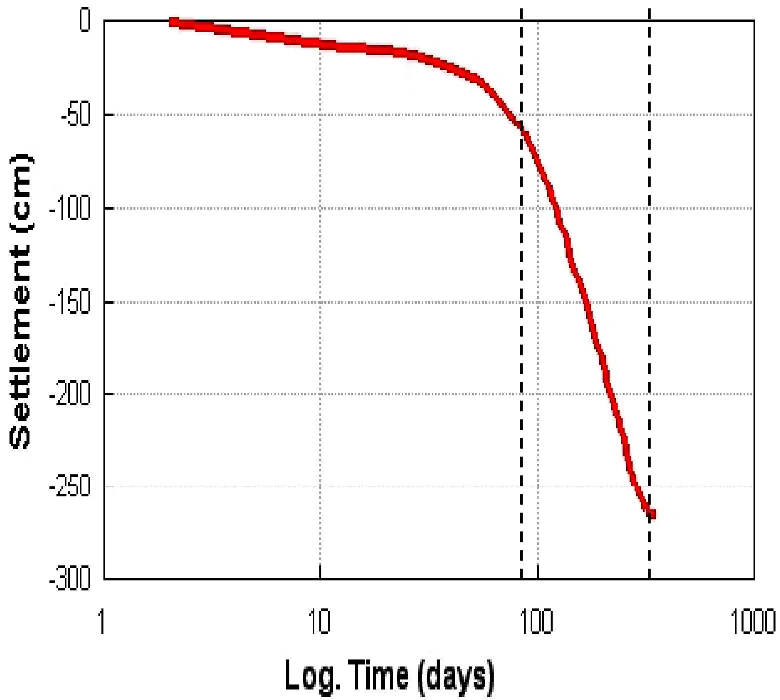
Initial depressurization of 0.3 bar (30 kPa) achieved in 3 - 5 days.
Then, proceed with embankment construction.

Advanced Stage of Consolidation

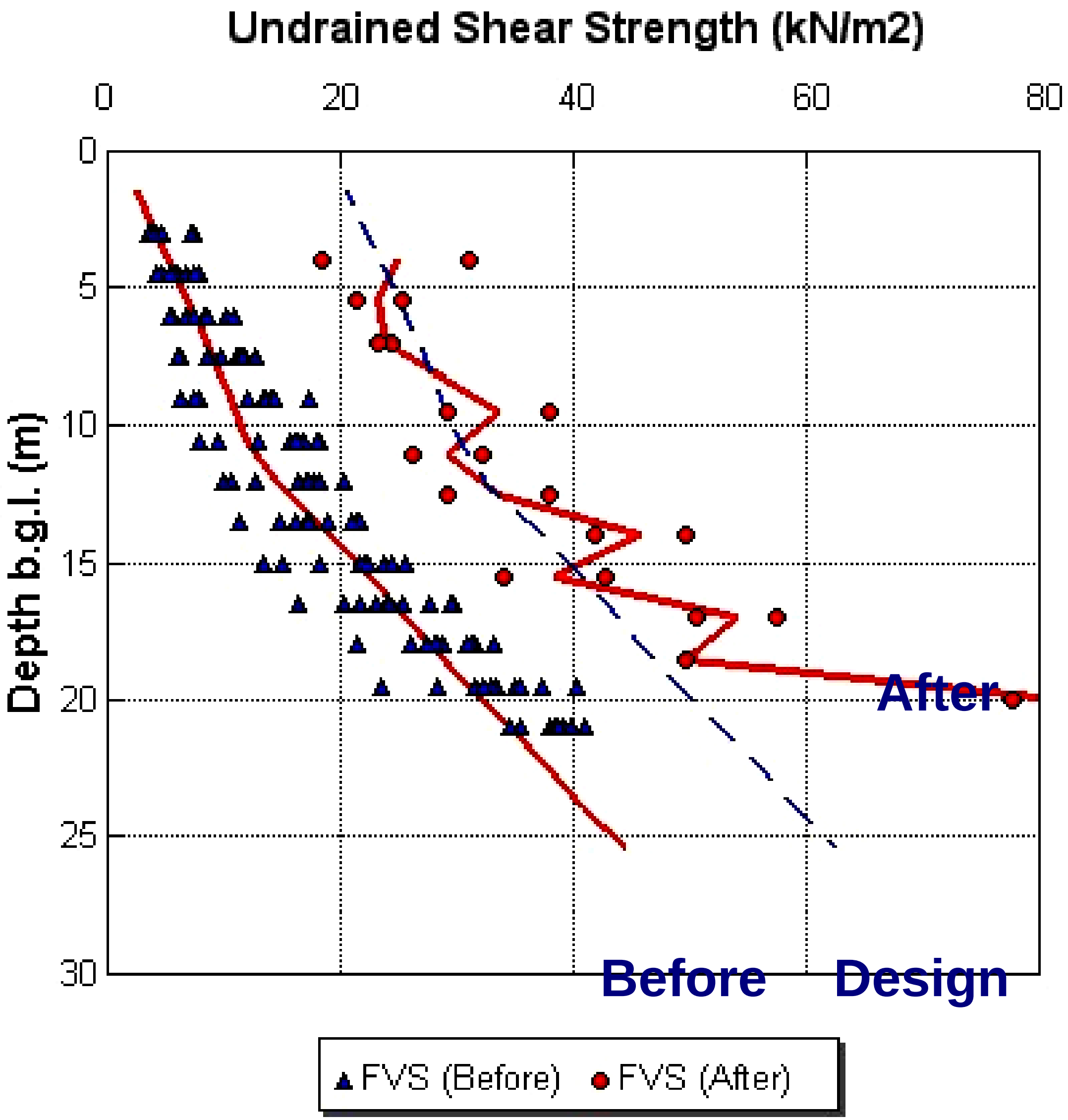


Settlement: Mean $_{(40)}$ = 2.63m

Most critical was embankment remained STABLE !



Post Treatment Strength



Before
Menard Vacuum

1m fill : FS < 1

During
Menard Vacuum

4m fill : FS > 1.5

1st Successful Vacuum Project in Thailand

Client: EPEC / Consultant: SEATEC / M.Contractor: ABB Alstom

Total area treated by MV: 30,000 m2

Drains:

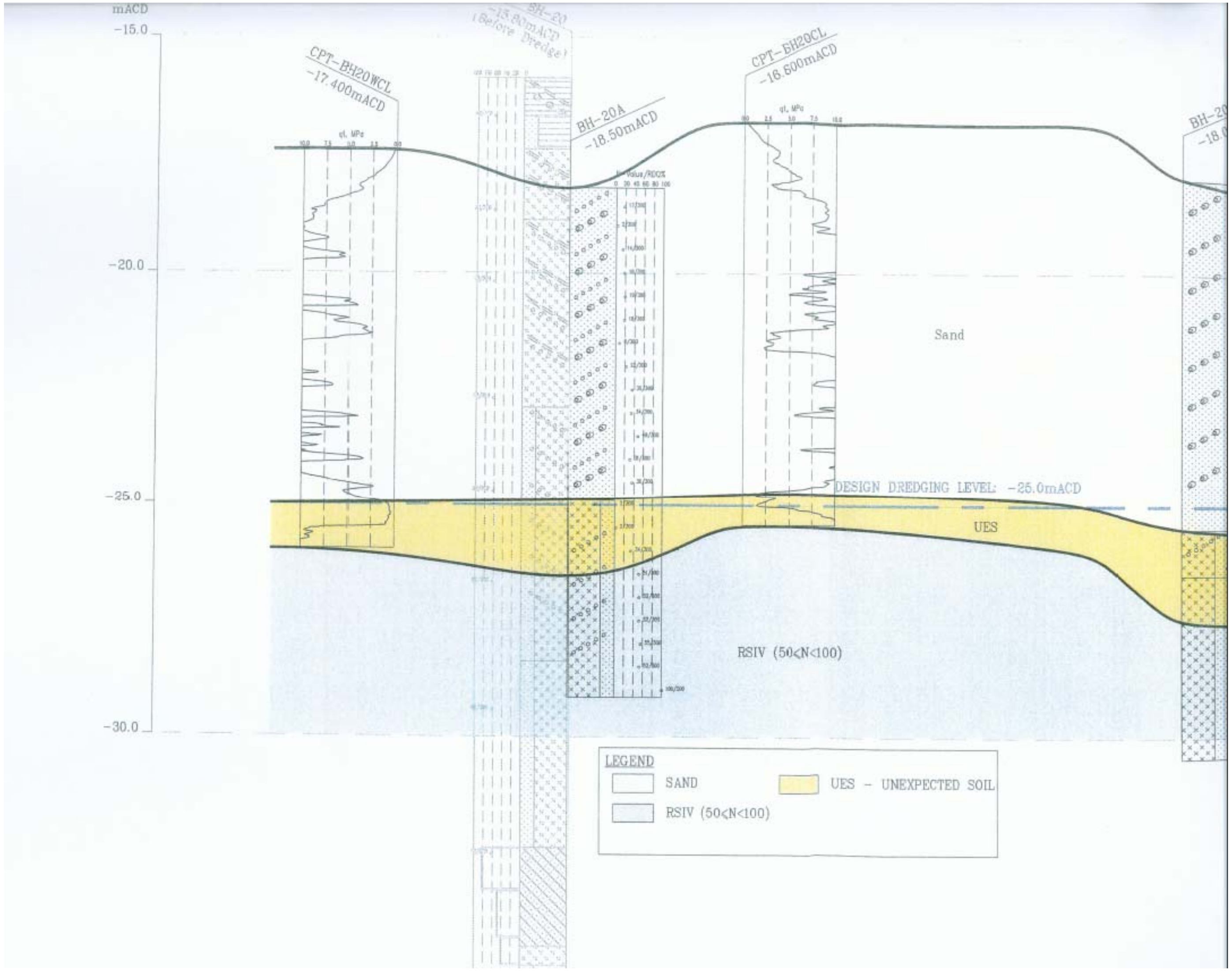
Total length of drains:	600,000 m (V+H drains)
•Equipment:	4 rigs + 2 vibro
•Working time:	3 months

Vacuum:

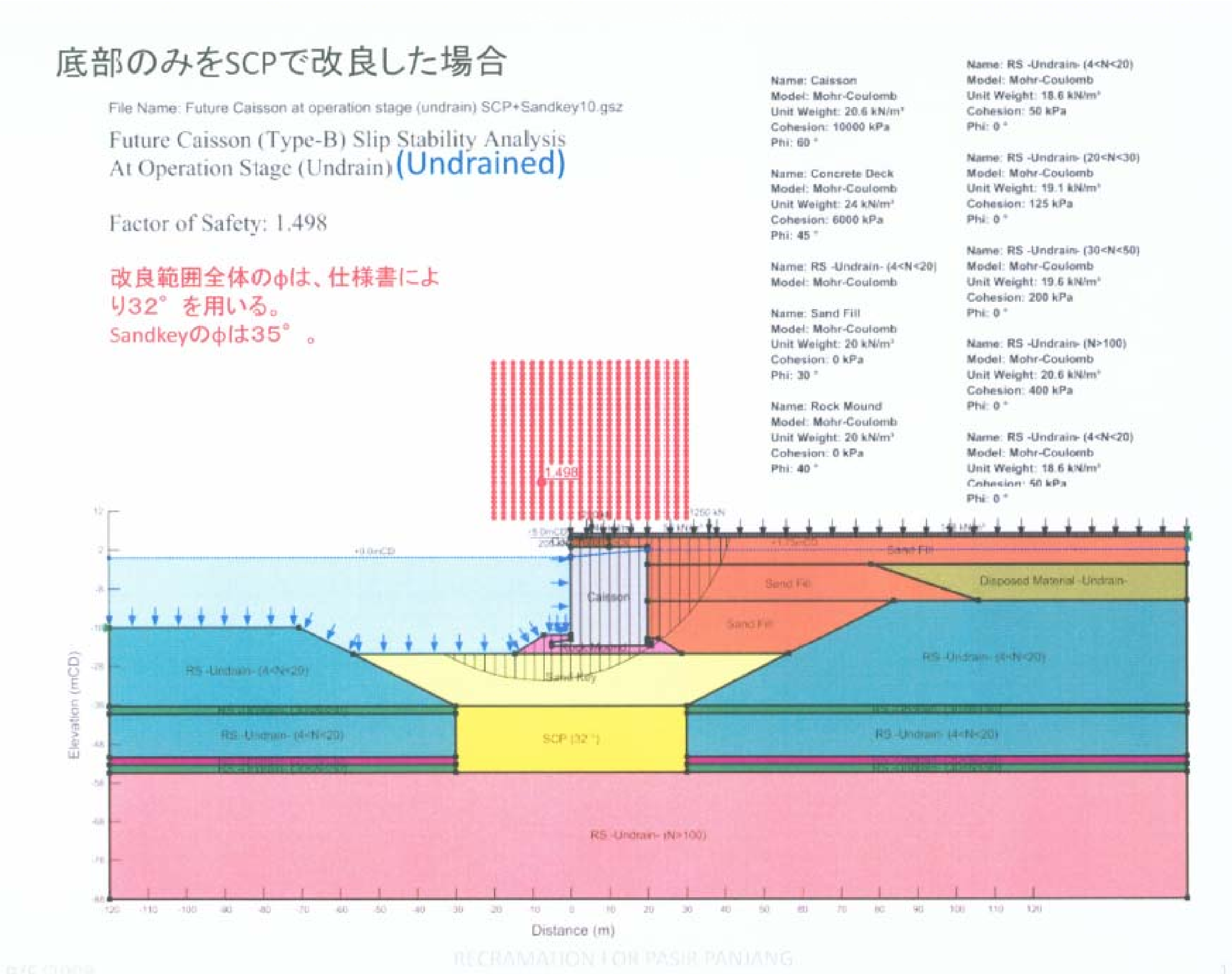
Pumping equipment:	15 pumps
Pumping duration:	7 months
Average total settlement:	2.65 m

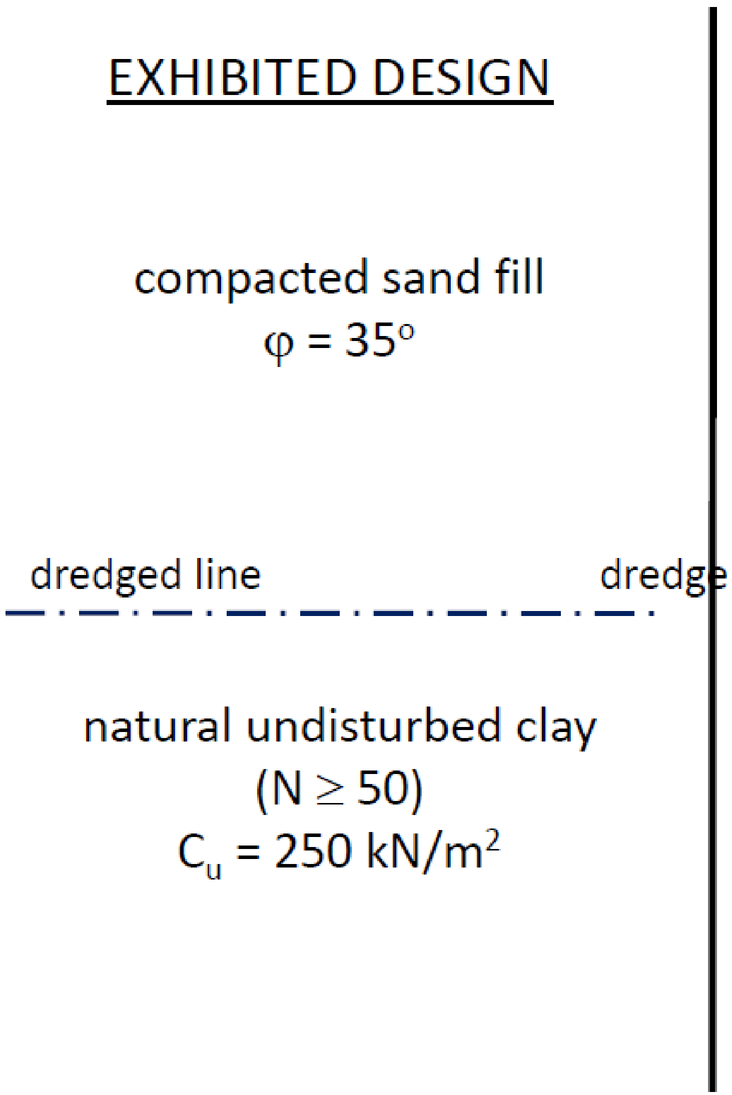
Total working time:	**10 months**

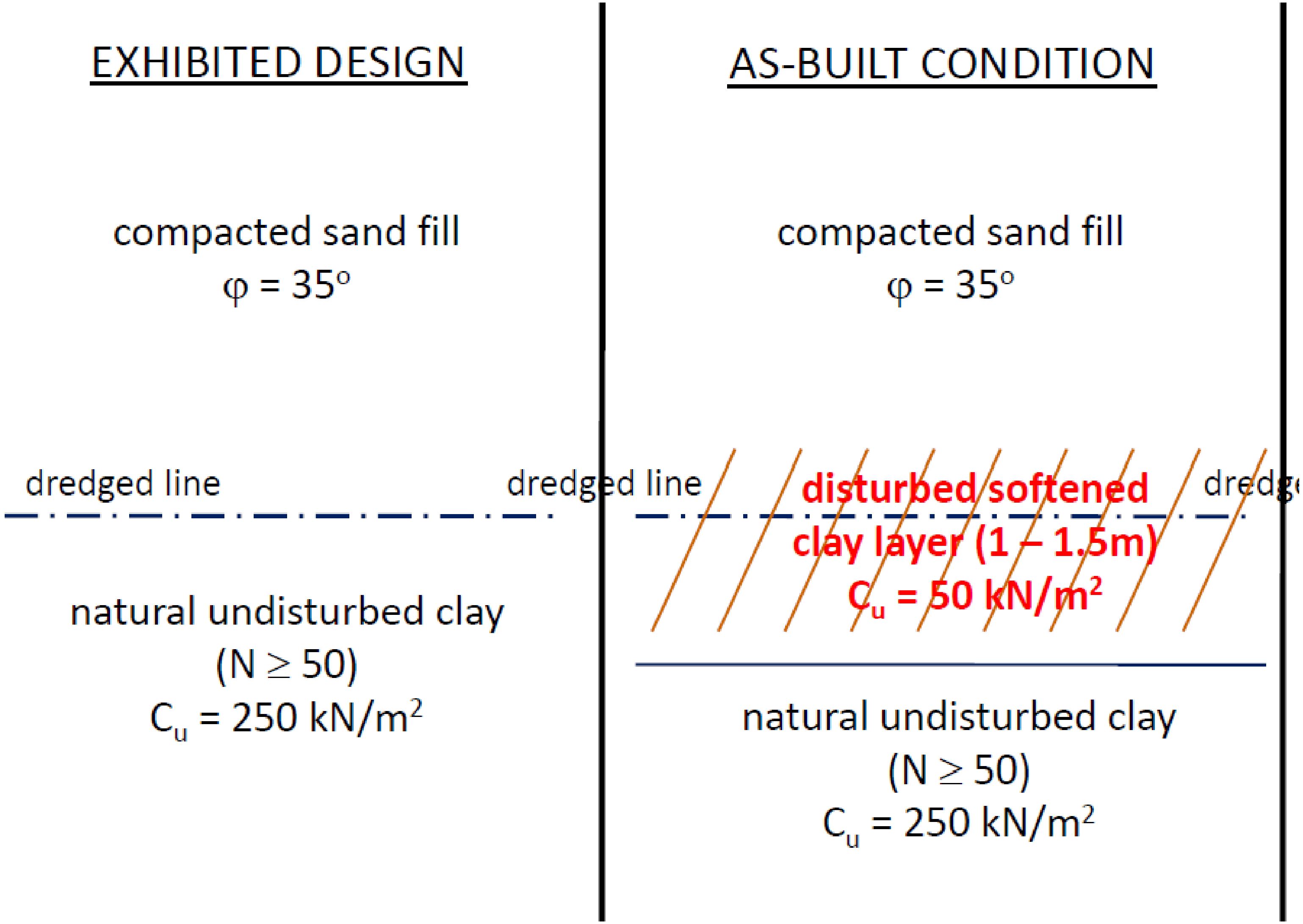
Soil Profile



Future Caisson Stability Analysis




EXHIBITED DESIGN
compacted sand fill
$\varphi = 35^{o}$
dredged line
dredge
natural undisturbed clay
$(N \geq 50)$
$C_u = 250\ kN/m^2$


EXHIBITED DESIGN
compacted sand fill
φ = 35°
dredged line
natural undisturbed clay
(N ≥ 50)
Cu = 250 kN/m2
AS-BUILT CONDITION
compacted sand fill
φ = 35°
dredged line
disturbed softened
clay layer (1 – 1.5m)
Cu = 50 kN/m2
dredg
natural undisturbed clay
(N ≥ 50)
Cu = 250 kN/m2

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

Shear strength mobilised in exhibited design

The upper layer I consists of compacted sand fill of 1.3m thick ($\varphi = 35^o$; C = 0) and the lower layer II consists of natural undisturbed clay of 1.5m thick ($\varphi = 0^o$; C = 250 kN/m^2). Assuming an overburden effective stress (σ') of 275 kN/m^2, we have the following:

Layer I: $\tau = C + \sigma \tan\varphi = 275 * \tan(35^o) = 192\,kN/m^2$

Layer II: $\tau = C + \sigma \tan\varphi = 250\,kN/m^2$

Shear strength mobilised for proposed solution

The upper layer I consists of compacted rock mat of 1.3m thick with 30% of rock size 150mm to 200mm and 70% of rock size 200mm to 300mm ($\varphi = 45^o$; C = 0) and the lower layer II consists of composite rock-clay soil layer of 1.5m thick with an area replacement ratio m = 15%. The rock inclusions with similar grading as above has $\varphi_r = 45^o$ ($C_r = 0$) and the surrounding clay soil has $C_s = 50$ kN/m^2 ($\varphi_s = 0^o$). Taking the same overburden effective stress (σ') of 275 kN/m^2, we have the following:

<u>Case 1</u>: Without considering consolidation effect with no gain in shear strength

Layer I: $\varphi = 45^o$; C = 0

Layer II: Computation for composite φ and C

Using equation (7): $C = C_r(m) + C_s(1-m) = 50(1-0.15) = 42.5 kN/m^2$

Using equation (10):

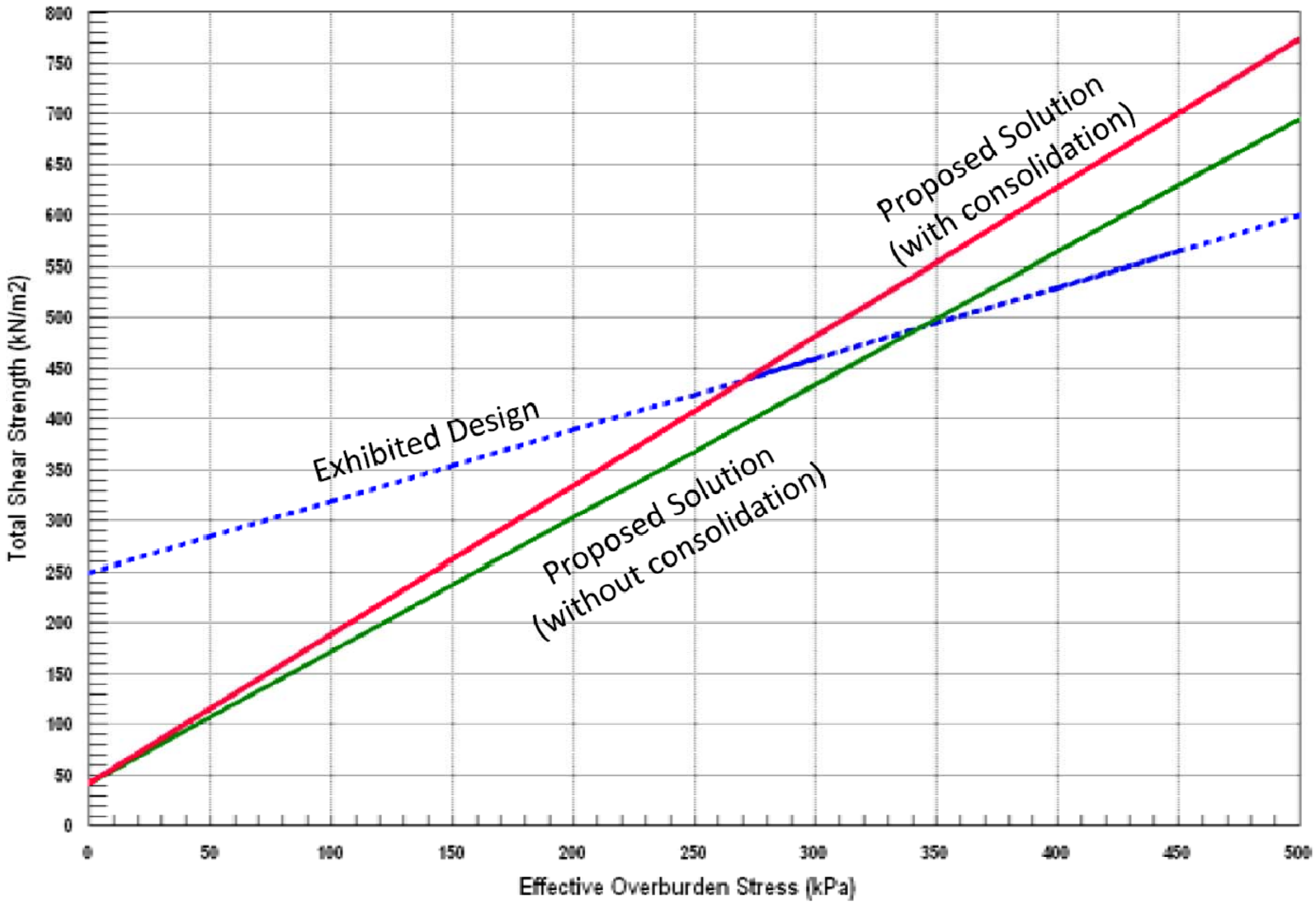
$$\tan\varphi = m\left(\frac{\sigma_r}{\sigma}\right)\tan\varphi_r + (1-m)\left(\frac{\sigma_s}{\sigma}\right)\tan\varphi_s = 0.15(2.04)\tan 45^o + 0$$

$\tan\varphi = 0.306 \Rightarrow \varphi = 17^o$ (for $\sigma_s/\sigma = 2.04$ – see calculation on page 8 below)

Layer I: $\tau = C + \sigma\tan\varphi = 275 * \tan(45^o) = 275 kN/m^2$

Layer II: $\tau = C + \sigma\tan\varphi = 42.5 + 275\tan 17^o = 127 kN/m^2$

Total shear strength for exhibited design and proposed solution



Criteria retained for pounder design

A
- 35 tons submerged
- 1.75 X 1.75 meter DR section

B
Design a stabilisation part that will rest on the side of print and guarantee penetration until stabilising part hits the crater side

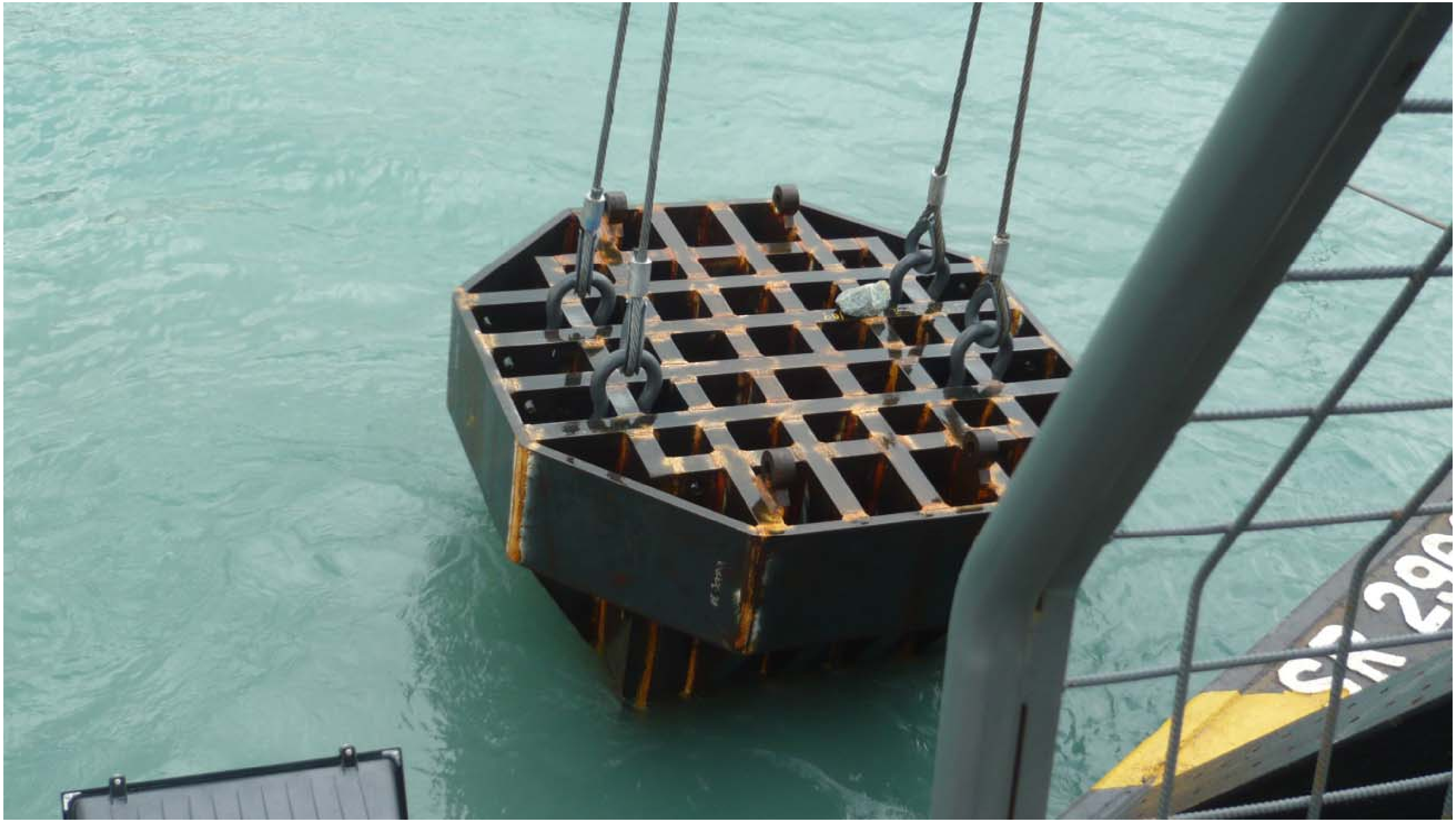
C
Final design with final objective,
-penetrating part 1.7 x 1.7
-length of penetration 1.7 m
-stabilising part 2.4 x 2.4 m
-ironing or compaction by turning over the pounder

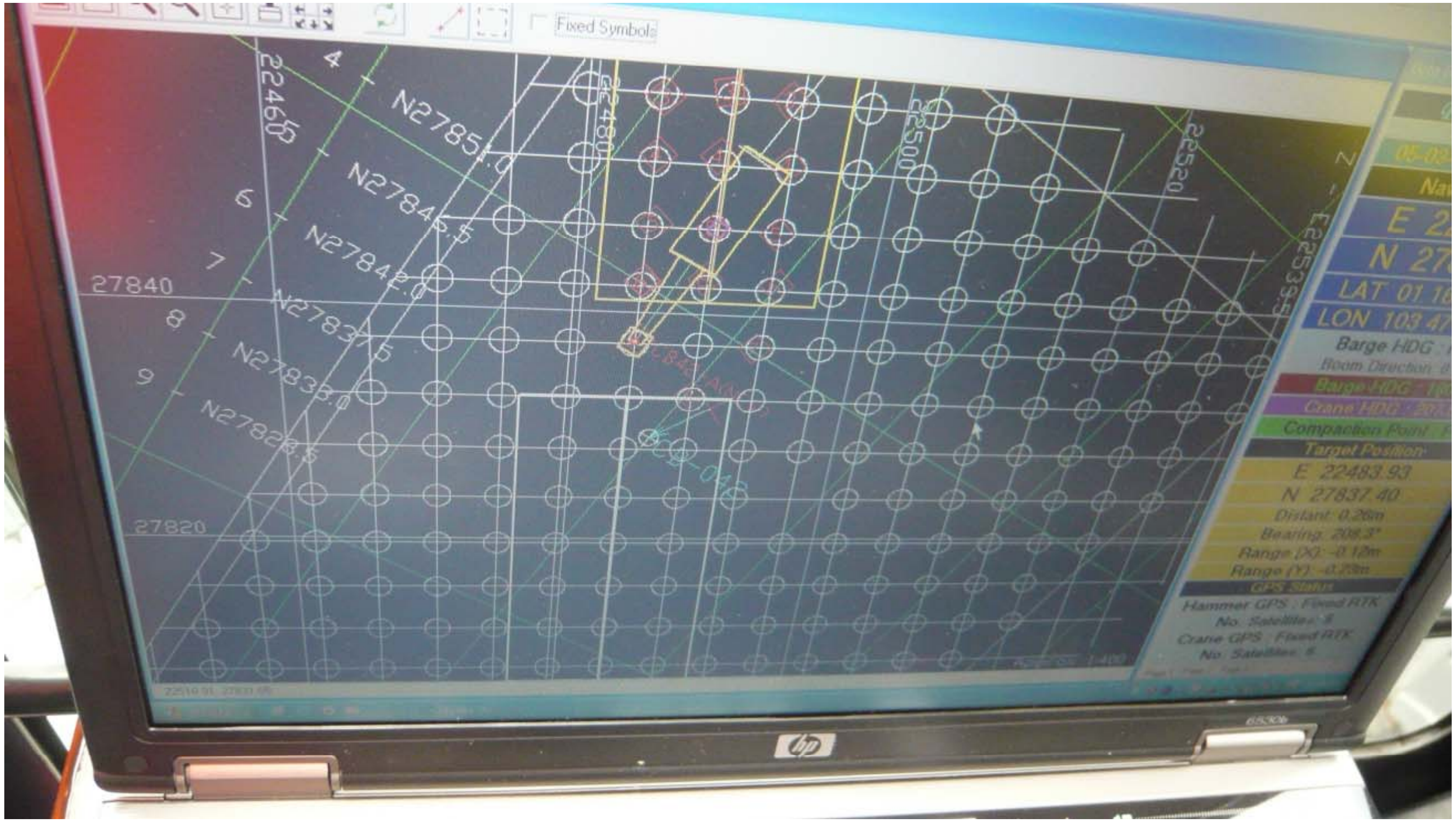
View of pounder construction

Caisson construction yard

Pontoon PMT Testing

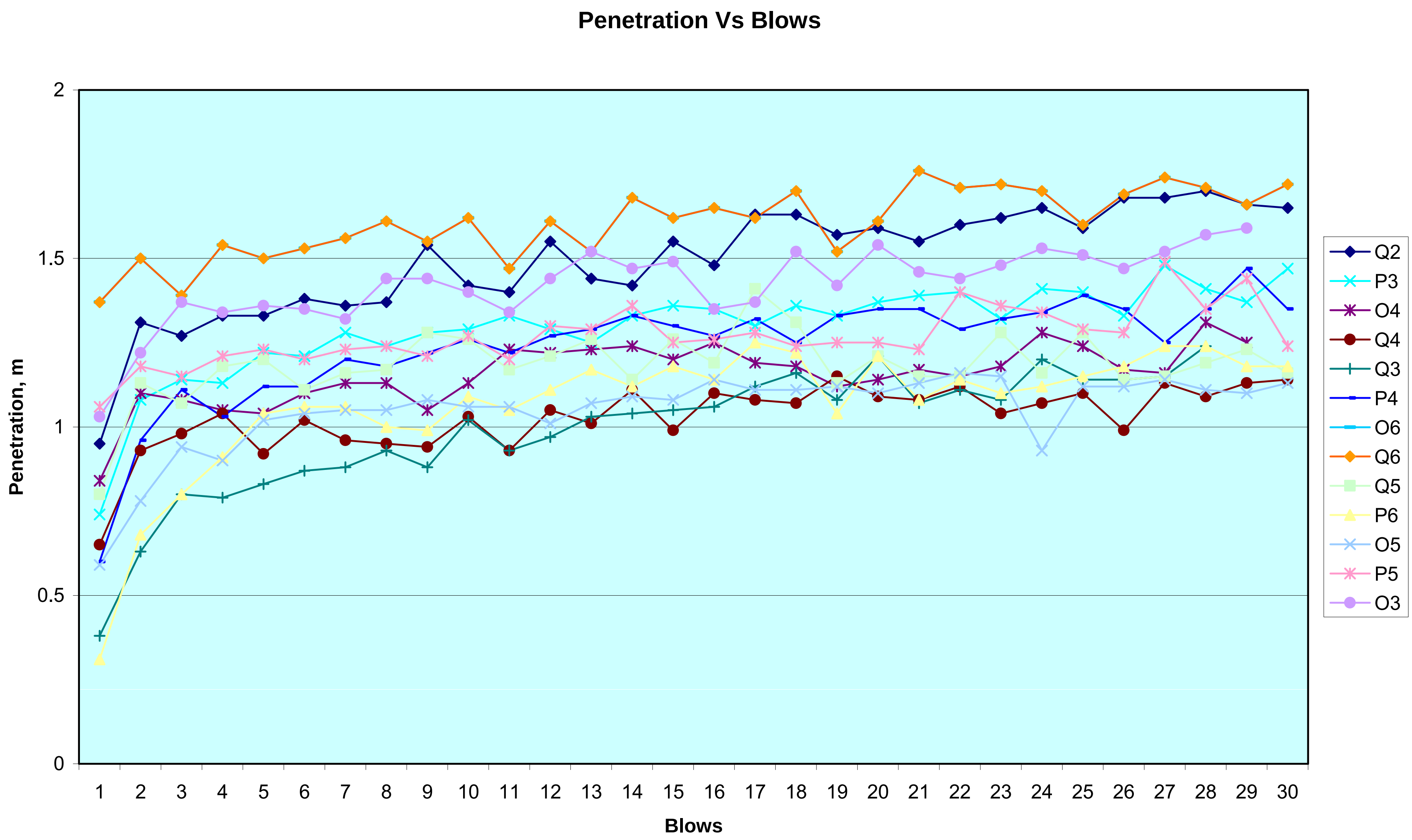
View of pounder ready to work




Fixed Symbols
N27851.0
N27846.5
N27842.0
N27837.5
N27833.0
N27828.5
27840
27820
22460
22480
22500
22520
Barge HDG
Compaction Point
Target Position
E 22483.93
N 27837.40
GPS Status
Hammer GPS : Fixed RTK
Crane GPS : Fixed RTK
hp


-0.21 m
-0.24 m
comp: 1.2 / 0.0 m
beats: 22 / 38
5.0 m
35.8
35.0max.
2.0 m
12 m
3
22 m
125%
100%
75%
50%
25%
0%
2100
1800
1500
1200
800

Depth of penetration versus number of blows



Danger of offshore pounding

V_{max} of pounder measured by radar
8 m/sec

$V_{effective}$ reached after 6 m drop
6 m/sec

Weight below water 35 tons

$$V = \sqrt{2gh}$$

36 = 20 h

Equivalent drop height$\cong$ 2 m

Equivalent Energy: 70 Tm

Compaction Depth According to Classical Formula
D = 8,3 m

If δ = 0,5 D = 4,15 m !!!

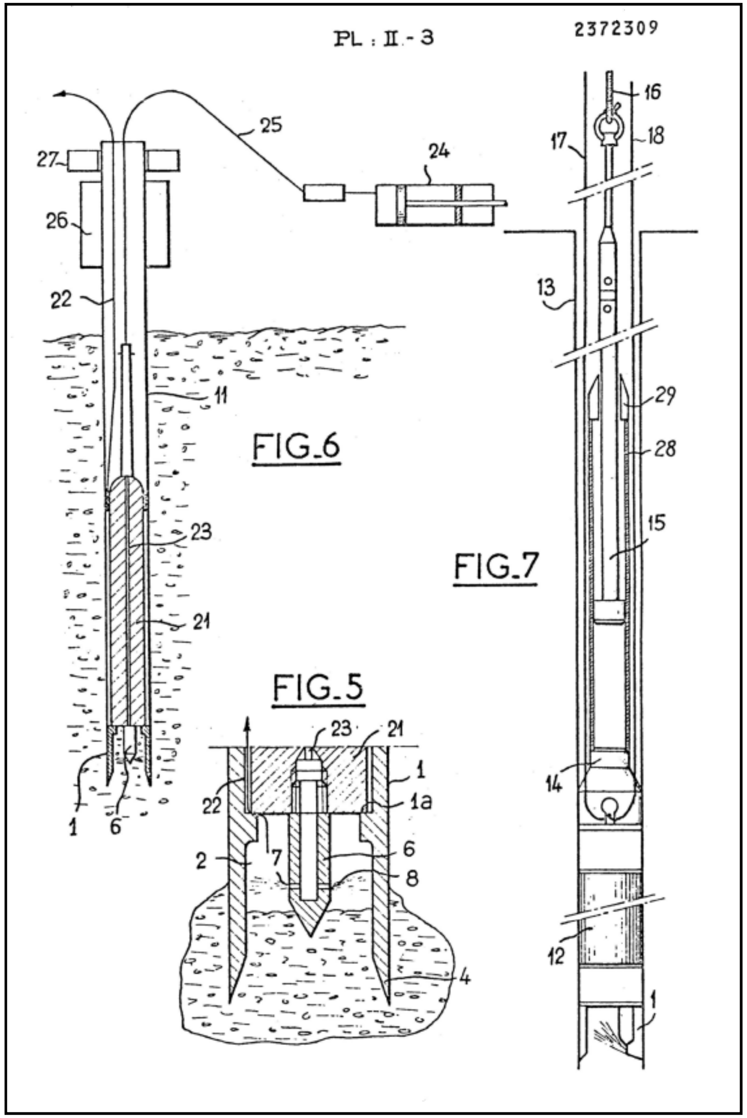
General Set up

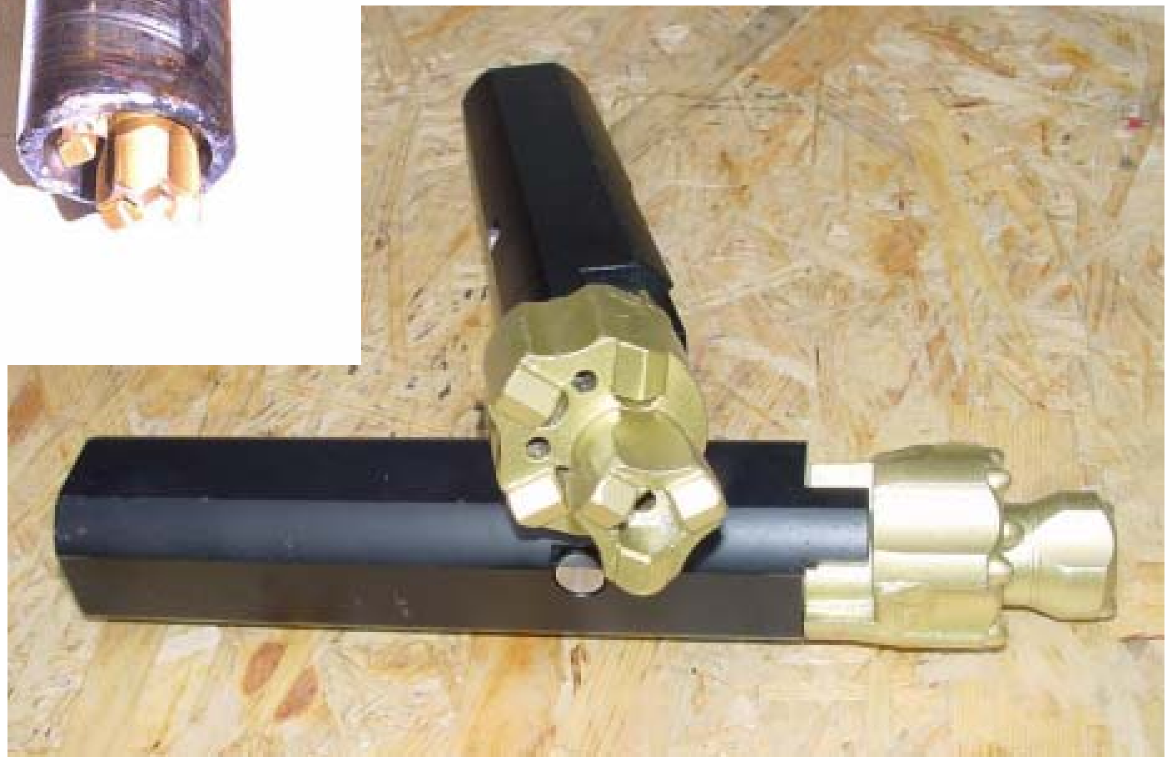
Testing pontoon

View on staff system

Self bored slotted tube : first experiment of Menard

RETROJET SYSTEM





Staff dulling equipment

Sequences of self boring staff system

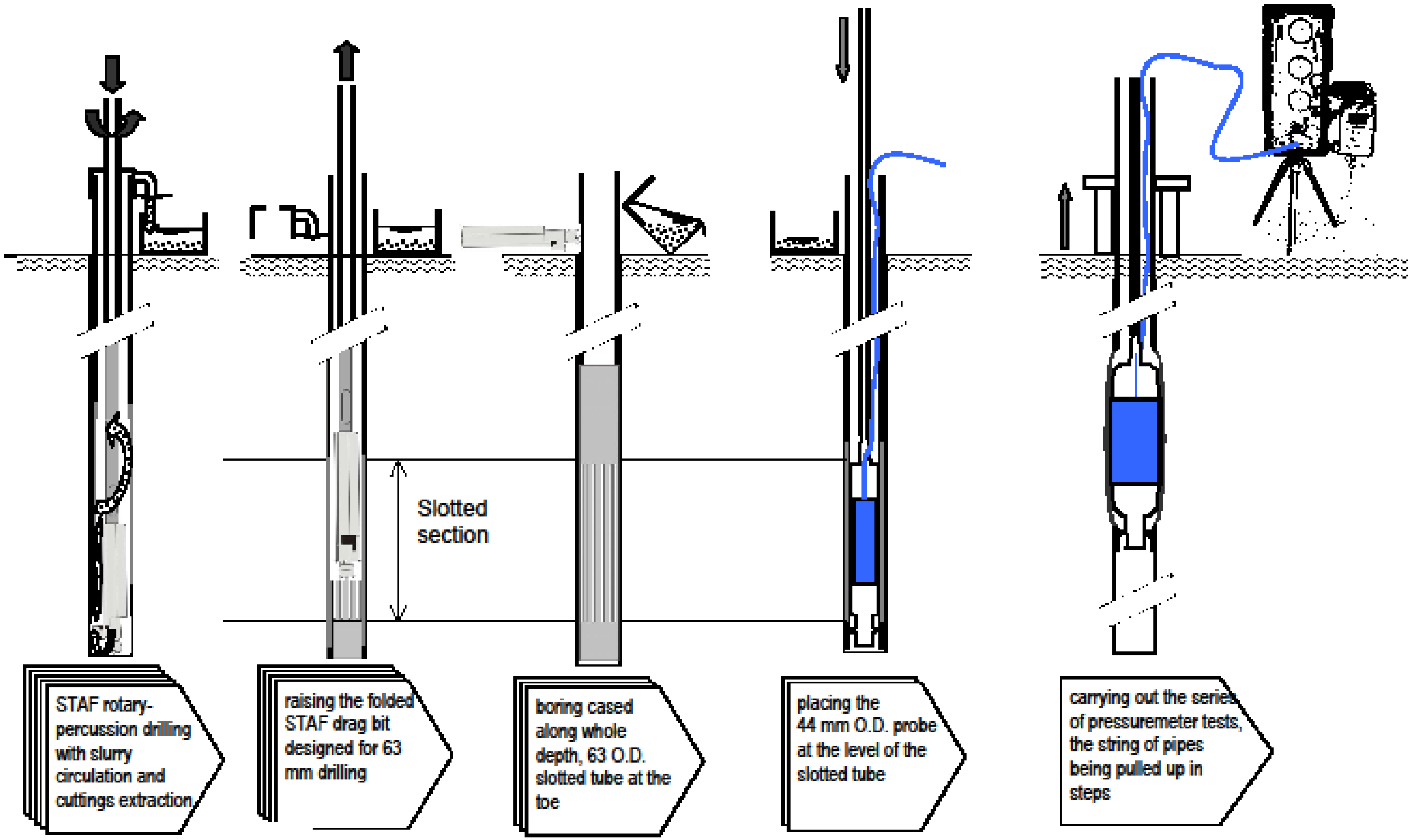
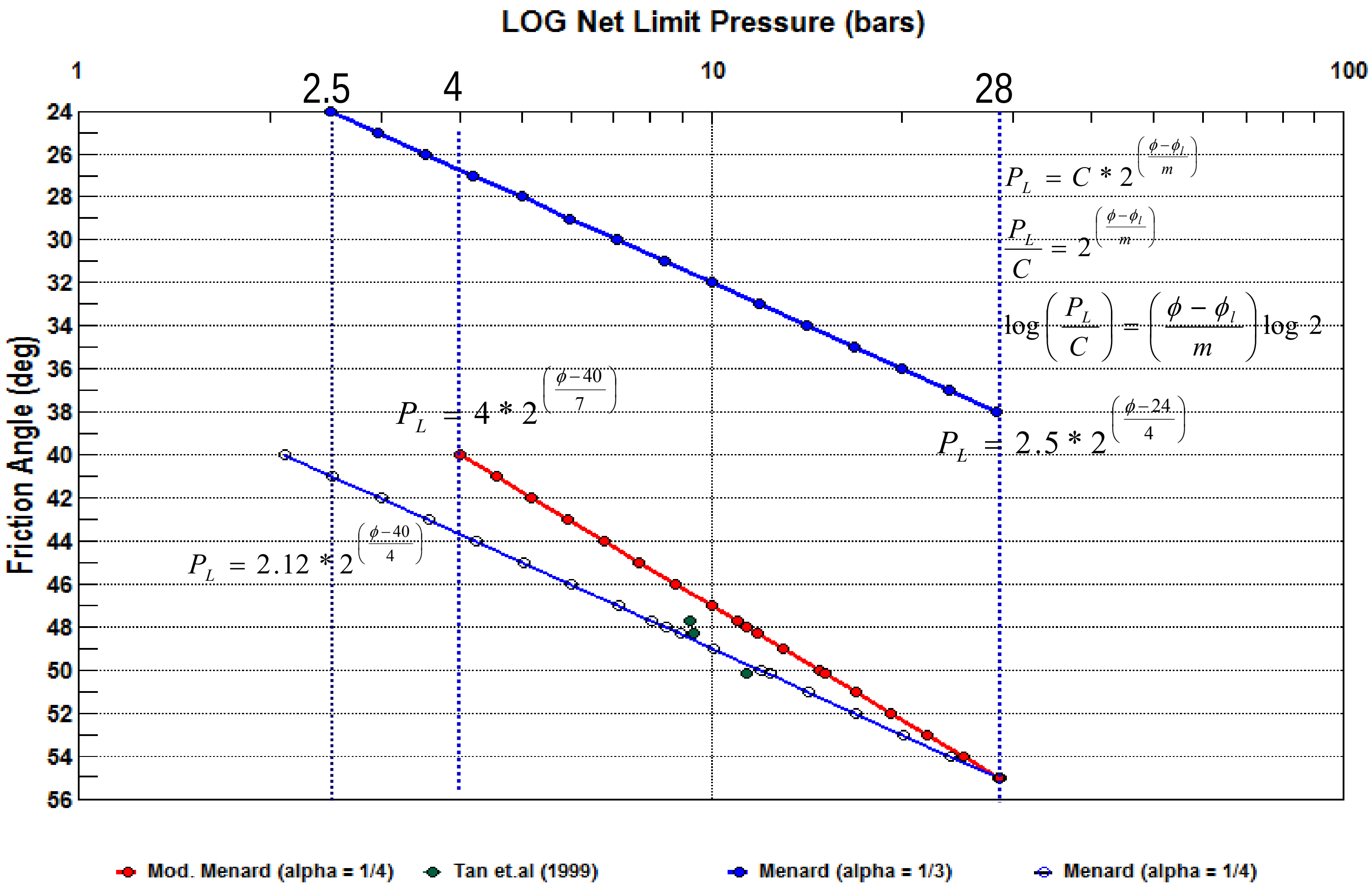


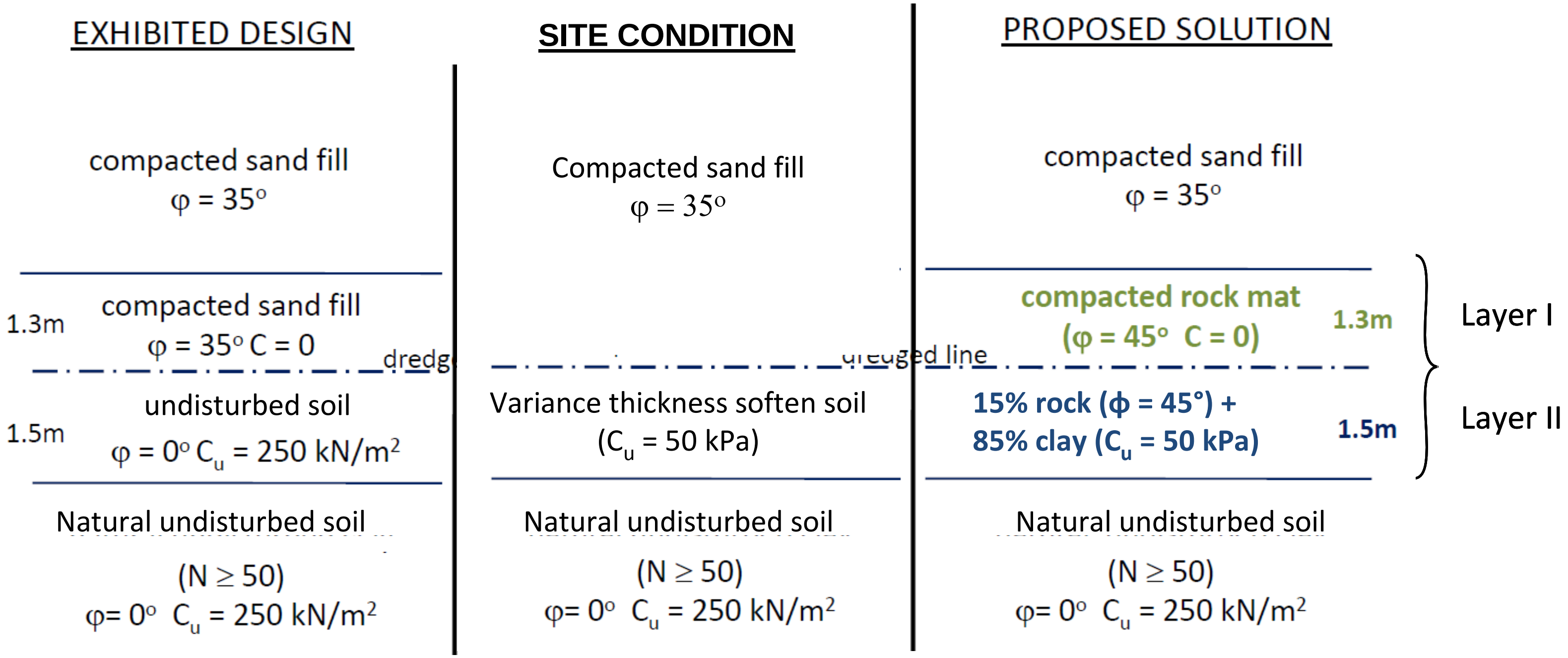
Figure 4. Sequences of the STAF® technique to perform Ménard pressuremeter tests by self-boring of a slotted tube

Actual method for drilling PMT in rock mound (100 mm – 300 mm)

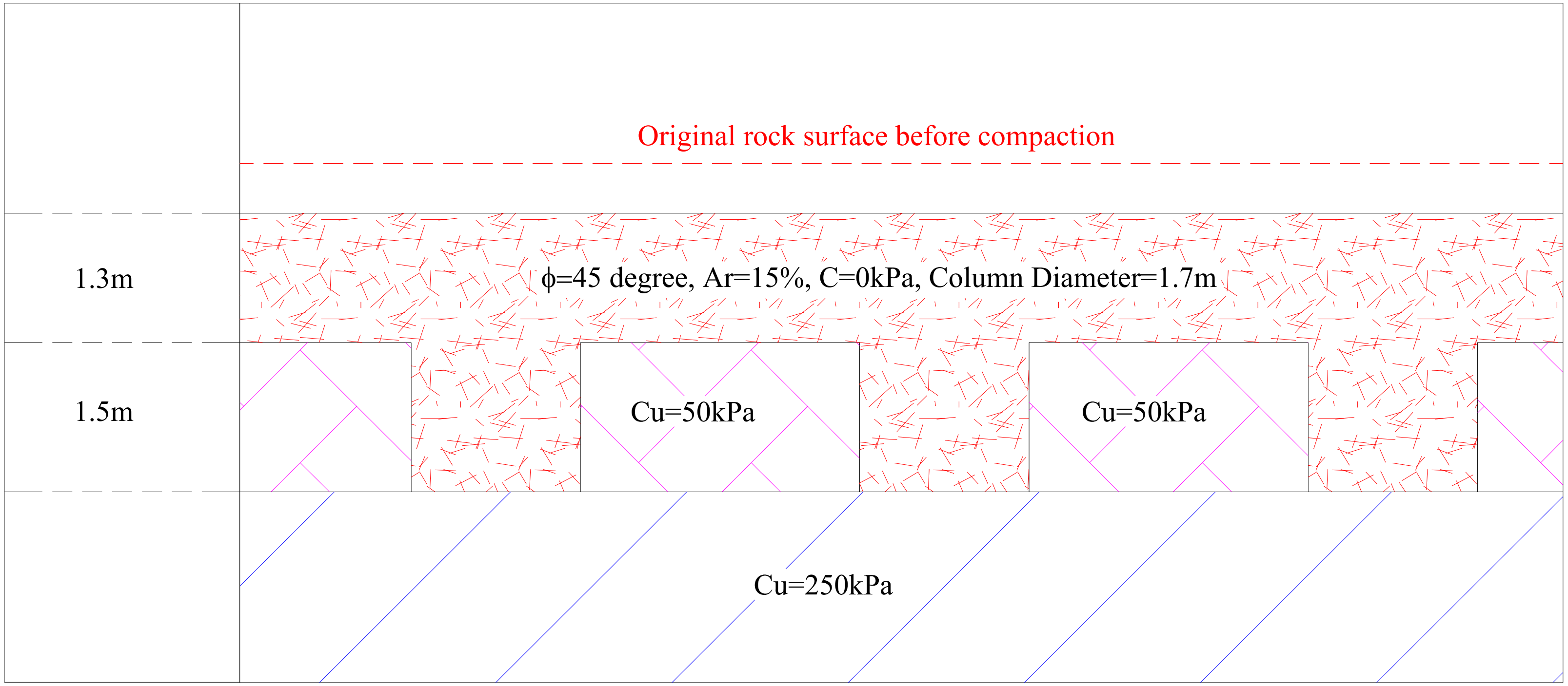
Empirical determination of friction angle by PMT (Yee & Varaksin method)



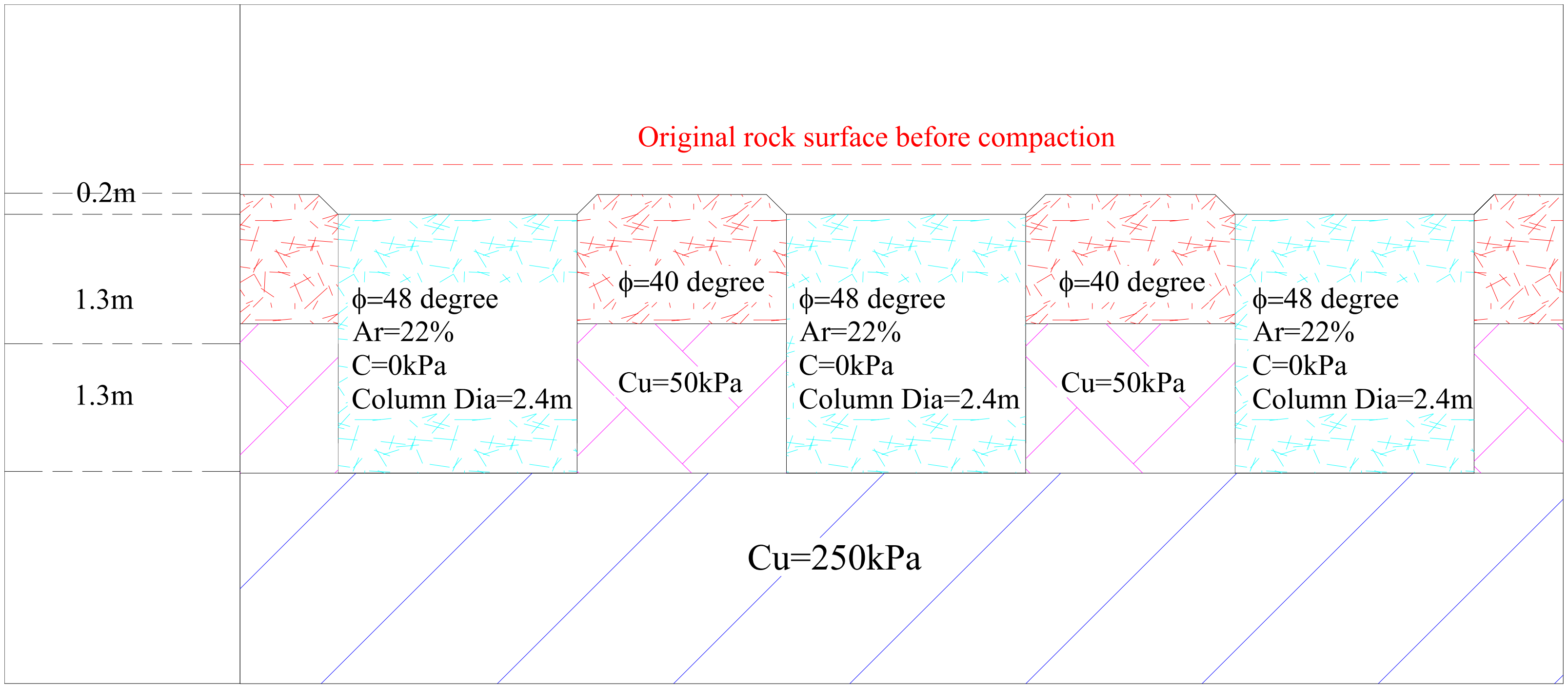
Reminder of technical solution



Preliminary concept



After compaction actual results



In summary, layer I and layer II shall have the following characteristics.

Layer I : $\varphi = 49^{o}$ (harmonic mean value); C = 0, m=0.22 (22% of total area) – For column

Layer I: $\varphi = 40^{o}$; C = 0, m=0.78 (78% of total area) – For in-between columns assuming lowest internal friction angle of 40^{o}.

Layer I: Computation for composite φ and C

C=0

$$\tan\phi_{comp} = m\tan\phi_c + (1-m)\tan\phi_{oc} = 0.22\tan 49^{o} + 0.78\tan 40^{\circ}$$

$$\phi_{comp} = 42.2^{\circ}$$

Strength of layer II and total share strength

Layer II: Computation for composite φ and C

$$C = C_r(m) + C_s(1-m) = 50(1-0.22) = 39kN/m^2$$

$$\tan\phi = m\left(\frac{\sigma_r}{\sigma}\right)\tan\phi_r + (1-m)\left(\frac{\sigma_s}{\sigma}\right)\tan\phi_s = 0.22(1.88)\tan 49^o + 0$$

$\tan\phi = 0.48 \Rightarrow \varphi = 25.4^o$ (for $\sigma_s/\sigma = 1.88$)

Hence, layer I and layer II shall have the shear strength as below:

Layer I: $\tau = C + \sigma\tan\phi = 275 * \tan(42.2^o) = 249kN/m^2$ (compared with proposed concept =275kN/m^2)

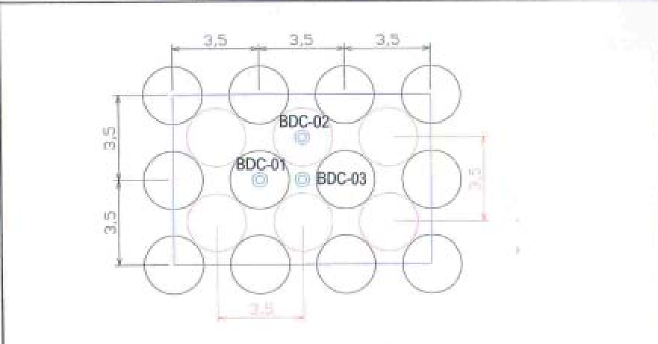
Layer II: $\tau = C + \sigma\tan\phi = 39 + 275\tan 25.4^o = 170kN/m^2$ (compared with proposed concept = 127kN/m^2)

Layout of CPT in sand area

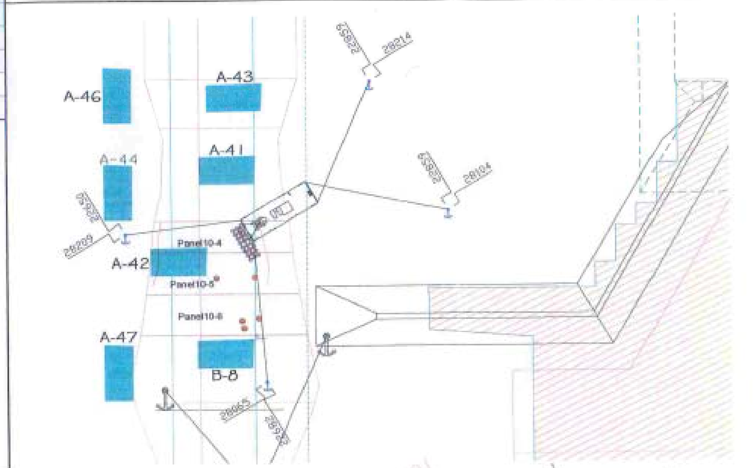
Dynamic compaction trial for sandkey

Pounder Weight	37.5	ton
Drop Height	3.0	m
Improved Depth	3.5	m
Drop Interval	3.5	m
Drop times	18.0	times / point
Number of Drop	18.0	nos @ 2type = 36 nos

Drop pattern



Trial Location

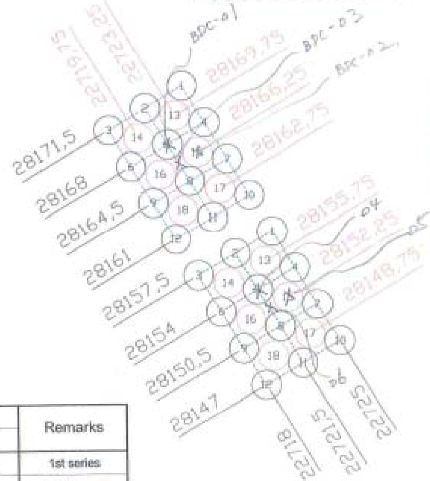


Trial Schdule

from Feb 23th to 26th	Barge Modification
26-Feb-09	PreCPT (6 nos)
27-Feb-09	Dynamic Compaction (with Wire Mesh)
28-Feb-09	Dynamic Compaction (without Wire Mesh)
7-Mar-09	PostCPT (6 nos)

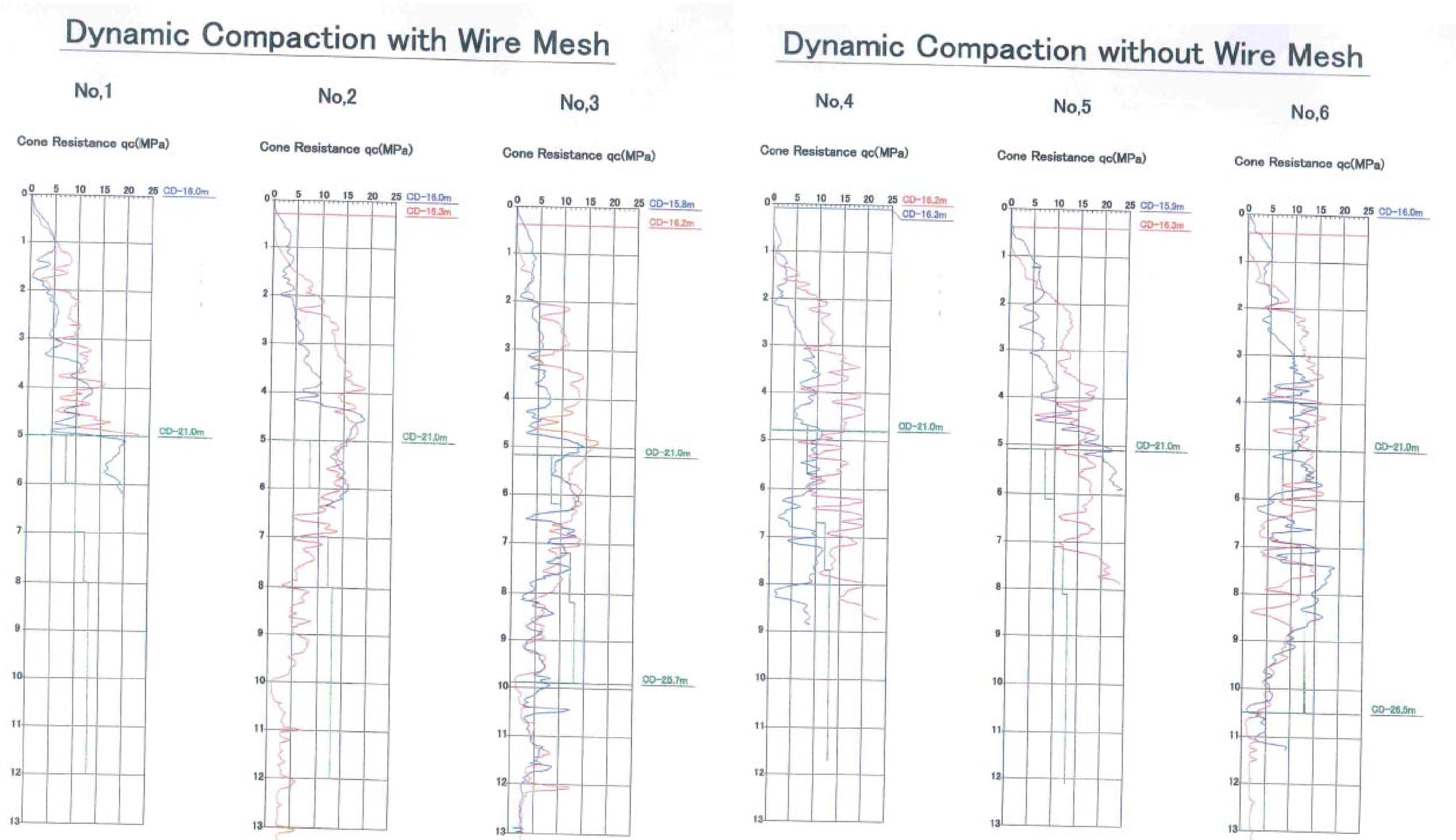
Coordinate

with Wire Mesh			without Wire Mesh		
No,	N	E	No.	N	E
1	28171.50	22725.00	1	28157.50	22725.00
2	28171.50	22721.50	2	28157.50	22721.50
3	28171.50	22718.00	3	28157.50	22718.00
4	28168.00	22725.00	4	28154.00	22725.00
5	28168.00	22721.50	5	28154.00	22721.50
6	28168.00	22718.00	6	28154.00	22718.00
7	28164.50	22725.00	7	28150.50	22725.00
8	28164.50	22721.50	8	28150.50	22721.50
9	28164.50	22718.00	9	28150.50	22718.00
10	28161.00	22725.00	10	28147.00	22725.00
11	28161.00	22721.50	11	28147.00	22721.50
12	28161.00	22718.00	12	28147.00	22718.00
13	28169.75	22723.25	13	28155.75	22723.25
14	28169.75	22719.75	14	28155.75	22719.75
15	28166.25	22723.25	15	28152.25	22723.25
16	28166.25	22719.75	16	28152.25	22719.75
17	28162.75	22723.25	17	28148.75	22723.25
18	28162.75	22719.75	18	28148.75	22719.75



CPT test			Remarks
No,	N	E	
BDC01	28168.00	22721.50	1st series
BDC02	28166.25	22723.25	2nd series
BDC03	28166.25	22721.50	no compaction
BDC04	28154.00	22721.50	1st series
BDC05	28152.25	22723.25	2nd series
BDC06	28152.25	22721.50	no compaction

Results of CPT in sand fill after DC



Before Dynamic Compaction

After Dynamic Compaction

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