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SUSTAINABLE TECHNOLOGY

ON-SHORE AND OFF-SHORE COMPACTION FOR A RECLAMATION PROJECT

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ON-SHORE AND OFF-SHORE COMPACTION FOR A RECLAMATION PROJECT

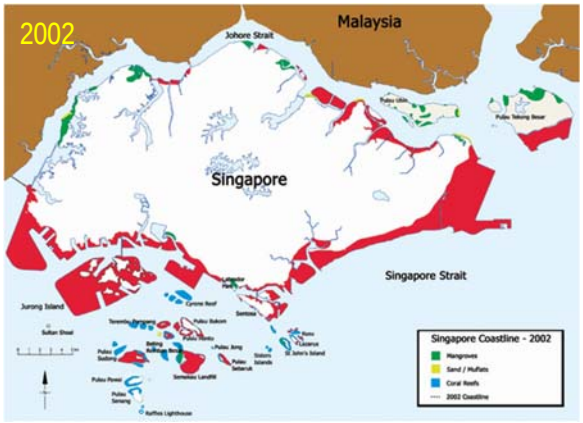
- Land Reclamation in Singapore
- A Case History
- Conclusion


Tekong Reclamation

LAND RECLAMATION IN SINGAPORE

Land reclamation started as early as 1820s on small scale (reclamation of swamps).

By 1960s – land reclamation started to be large scale (reclamation along the coasts & reclamation of offshore islands).

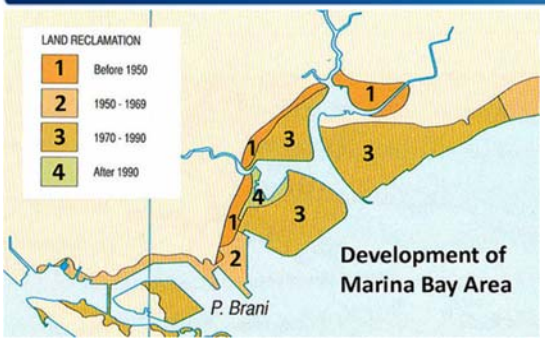


Prior to 1960: total area was about 582 km^2

By 1990: total area was 633 km^2 (increase of ~ 9%)

By 2030: total area may increase to 733 km^2 (increase of ~ 26%)

NEW DOWNTOWN DEVELOPMENT AT MARINA BAY



Reclamation for the New Downtown @ Marina Bay on *360 hectares* of land reclaimed in the 1970s and completed in *1994* changing the skyline of Singapore to include Marina Bay Sands and the coming Marina Bay Financial Centre.

PETROCHEMICAL HUB IN JURONG ISLANDS

Reclamation of Jurong Islands (7 islands into 1) to create a petrochemical hub on an area of *500 hectares*. Completed in *Sept. 2009* (20 years earlier than planned). Jurong Island is home to over 88 leading petroleum / petrochemical companies with more than S$24 billion in fixed asset investment.

MEGA-CONTAINER PORTS IN PASIR PANJANG

PSA Singapore Terminals operates 5 container terminals at Tanjong Pagar, Keppel, Brani and Pasir Panjang with a total of 54 container berths.

Pasir Panjang Terminals 1 and 2 are PSA's most advanced terminals. The area is *335 hectares* of reclaimed land with 23 container berths and 87 quay cranes. Started construction in 1993 and completed in *late 2000s*.

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CASE HISTORY: PASIR PANJANG RECLAMATION 1 & 2

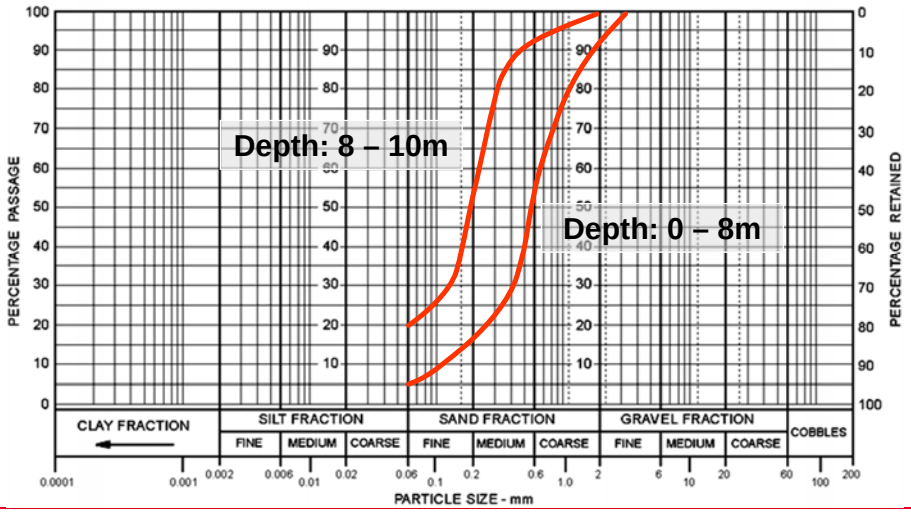
Construction of Pasir Panjang Terminal Phase 1 started in *1993* and Terminal Phase 2 started in *1995*. Both terminals 1 and 2 were completed in *late 2000s*.

Ground improvement consists of ***consolidation*** of the underlying soft marine clay using vertical drains with fill surcharge; and ***compaction*** for the loose hydraulic reclaimed sand fill.

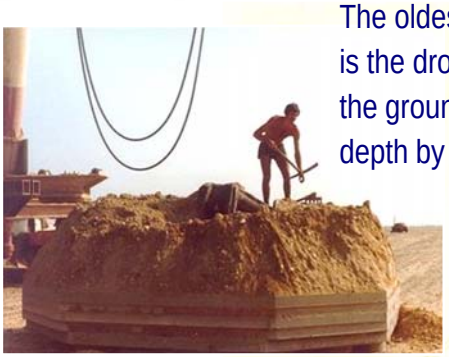
COMPACTION: QUALITY OF RECLAIMED SAND

To densify the 8 – 10m thick hydraulic sand fill

- 0 – 8m: fine to coarse sand with 3 – 7% fines and occasionally up to 14% fines.
- 8 – 10m: marginal coarse sand with 17 – 20% fines
- > 10m: silt and clay strata (high CPT R_f values)



COMPACTION BY DYNAMIC COMPACTION



The oldest form of ground improvement is the dropping of heavy weights on to the ground surface to densify soils at depth by *impacts.*

1976

NICE AIRPORT, FRANCE

4,800 ton.m. DC rig

Weight = 200 tons

Drop height = 24 m

Effective depth ~ 30 m

1,600 ton.m DC RIG

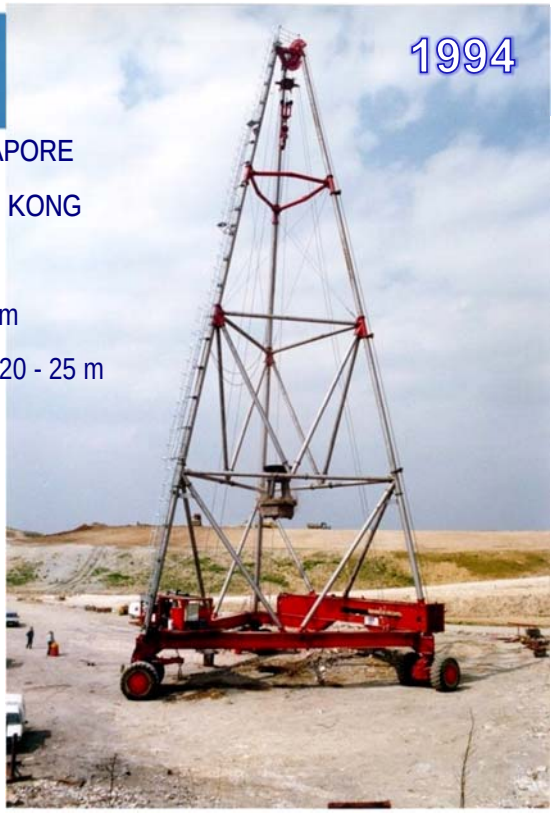
CHANGI , SINGAPORE

TSING YI, HONG KONG

Weight = 40 tons

Drop height = 40 m

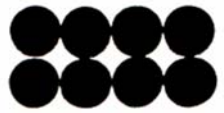
Effective depth ~ 20 - 25 m



300 – 750 ton.m DC rigs

COMPACTION BY VIBRO COMPACTION

To densify soils at depth by *vibration* using a *vibroflot*.



H Before compaction

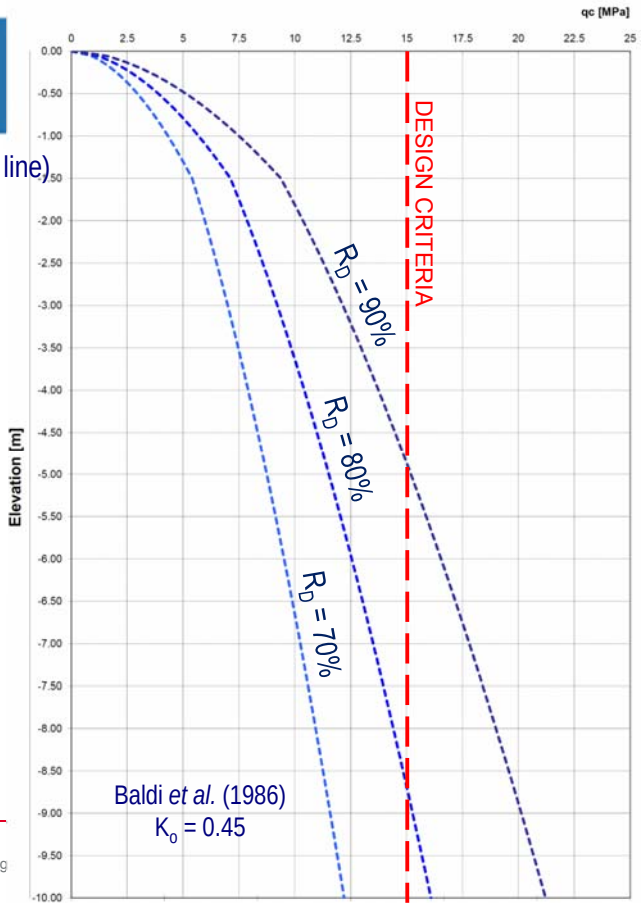
SHEAR

After compaction

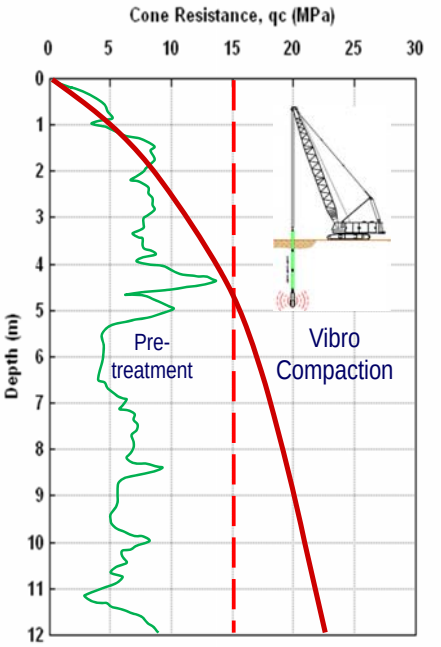
h (< H)

ACCEPTANCE CRITERIA

Acceptance criteria of CPT: q_c = 15 MPa (straight line)



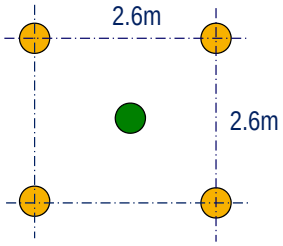
CHOICE OF COMPACTION METHODS



Option 1:

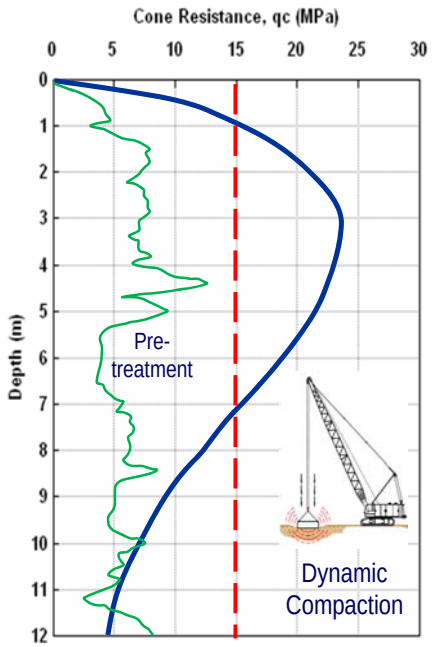
Vibro Compaction

- Compaction grid of 2.6 m ■ down to 10m with a mid point down to 5m depth using a hydraulic vibroflot of 130 kW @ 50 Hz.



- Greater compaction effect at lower depth

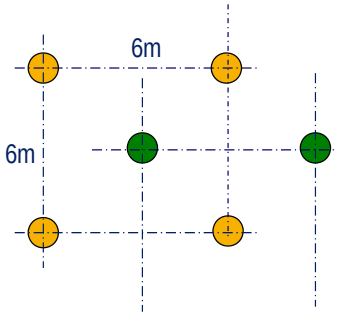
CHOICE OF COMPACTION METHODS



Option 2:

Dynamic Compaction

- High compaction energy using 18 tons x 22 m drop height x 16 blows over 2 main phases with total DC energy of 430 ton.m/m^2 incl. ironing phase.



- Greater compaction effect at shallower depth

STAGE 1: Ddensification from 5m to 10m EL

Vibro Compaction – taking advantage of ***overburden*** effect to increase the ease of compaction.

BD400 (PM345) vibroflots:

- 215 kW @ 30 Hz frequency for fine sand
- 34.5 tons centrifugal force.

Triangular grid of 2.8m *(instead of 2.6m)*:

(i) compaction pressure of 260 bars.

(ii) time interval of 60 seconds per lift.

STAGE 2: DENSIFICATION FROM 0m to 5m EL

Dynamic Compaction – taking advantage of ***higher compaction*** effect at shallower depths.

Energy per blow: 15 tons (*instead of 18*) x 22m drop

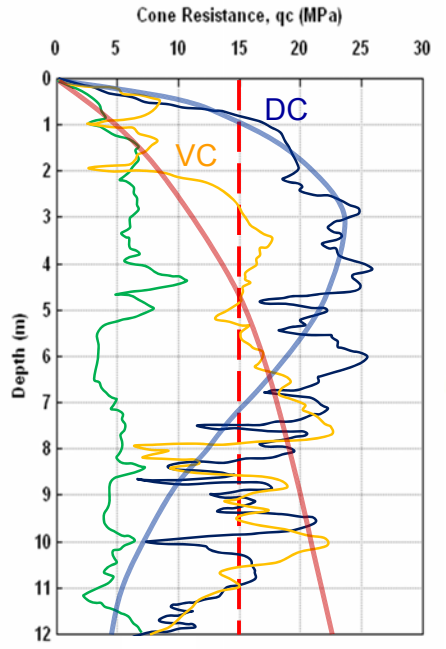
Phase 1: 6m x 6m grid x 14 blows (*instead of 16*)

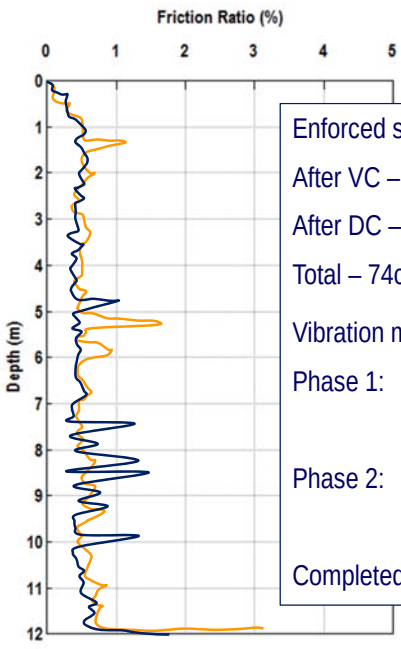
Phase 2: 6m x 6m grid x 14 blows (*instead of 16*)

Ironing: 2m x 2m grid x 1 blow

Total DC energy: 339 ton.m / m^2 (*instead of 430*)

POST TREATMENT RESULTS





Enforced settlement:

After VC – 47cm

After DC – additional 27cm

Total – 74cm

Vibration monitoring (PPV):

Phase 1: 4.4 mm/s at 40m distance

1.4 mm/s at 60m distance

Phase 2: 6.1 mm/s at 40m distance

1.7 mm/s at 60m distance

Completed 90,000m^2 in 9.5 months

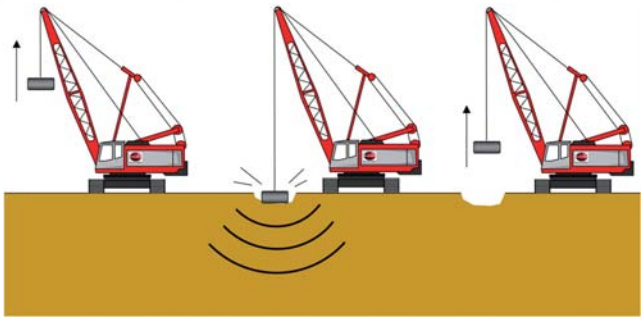
PASIR PANJANG RECLAMATION – TERMINAL 3 & 4

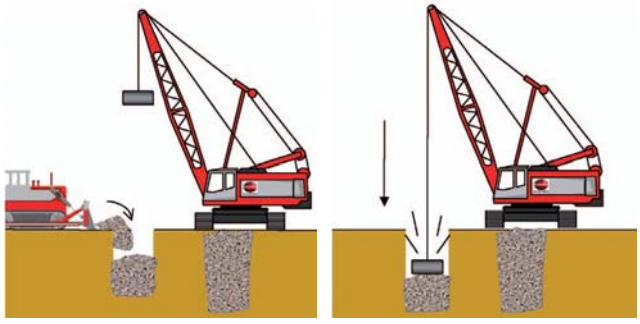
Pasir Panjang Terminal Phase 1 and 2 (with 23 container berths) was completed in late 2000s.

Singapore spends S$2 billion to expand its port to increase annual capacity by more than 50%.

Phase 3 and 4 started in *Oct 2007* and to be completed by late *2013* to add 16 container berths and 6km quay length.

DYNAMIC COMPACTION / DYNAMIC REPLACEMENT

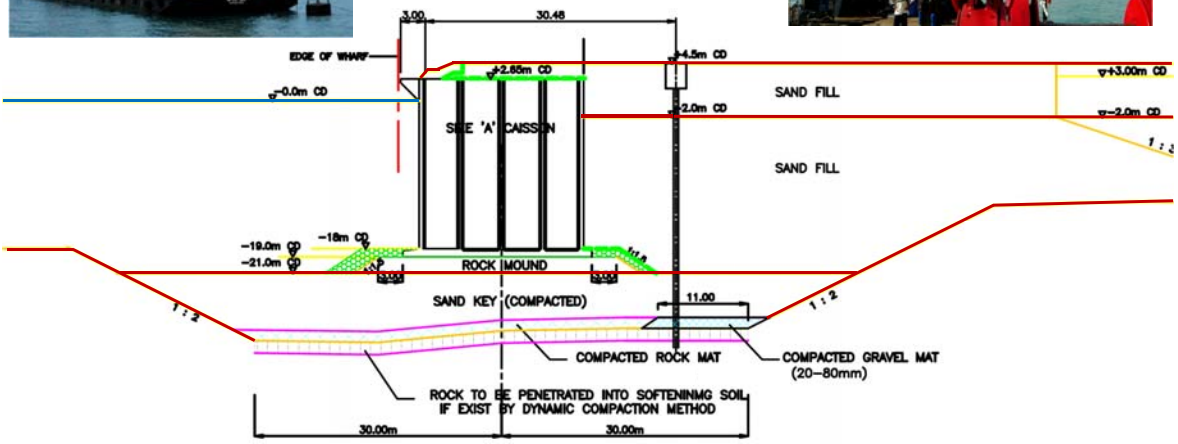




DC – ground improvement by *compaction*

DR – ground improvement by *reinforcement*

FIELD IMPLEMENTATION SCHEME



VARIOUS STAGES OF CONSTRUCTION

OFF-SHORE DC/DR POUNDER

Daily inspection of pounder after works

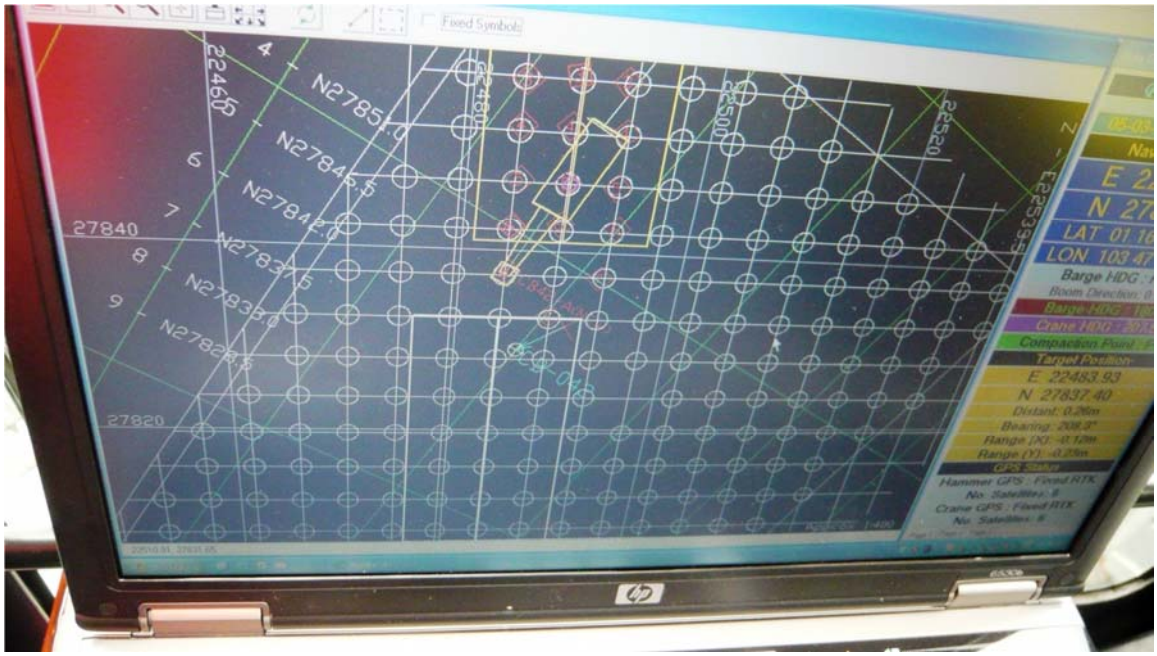
OFF-SHORE DC/DR POUNDER

OFF-SHORE DYNAMIC REPLACEMENT

OFF-SHORE DYNAMIC COMPACTION

ON-BOARD QA/QC – DC/DR SYSTEM

ON-BOARD QA/QC – GPS SYSTEM



PMT JACK-UP PONTOON

OFF-SHORE CYCLIC PRESSUREMETER TESTING

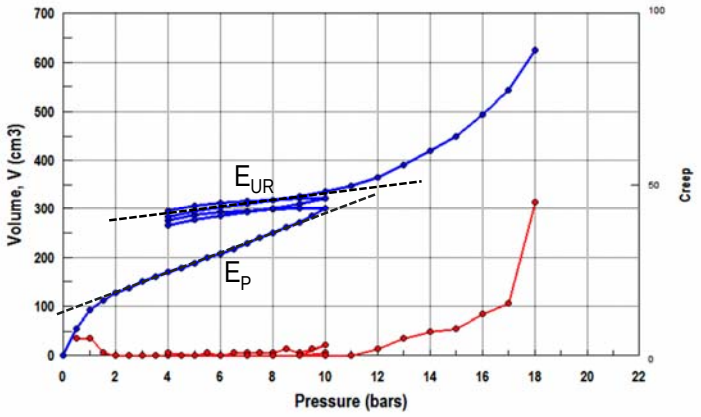
To determine the *stress-strain behaviour* and *strength properties* of the soil for *bearing capacity* and *settlement* analysis.

CYCLIC PRESSUREMETER TEST RESULTS

MENARD PRESSUREMETER TEST

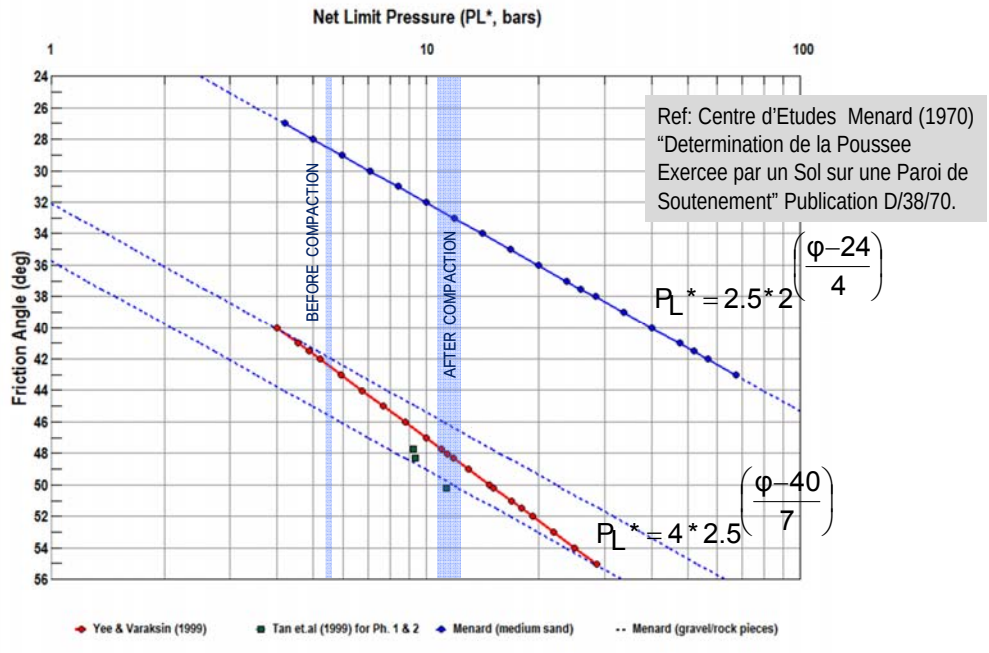
DEPTH = - 30.2 m

Project:	Pasir Panjang Terminal P 3 & 4	PMT No.:	OPMT-Post-02
Job No.:	S 23	Date:	20-Mar-09
Client:	Penta Ocean	Chainage/East:	E 22,492.8
Specialist Contractor:	Menard Geosystems(S) PTE LTD.	Offset/North:	N 27,819.5
Operator:	Jamal/Otto	Barge Level:	+ 3.90 m



- During test, when there is no return of drilling fluid, it indicates that the test is carried out at the free-draining rock material.
- When testing in impervious clay, there is return of drilling fluid.

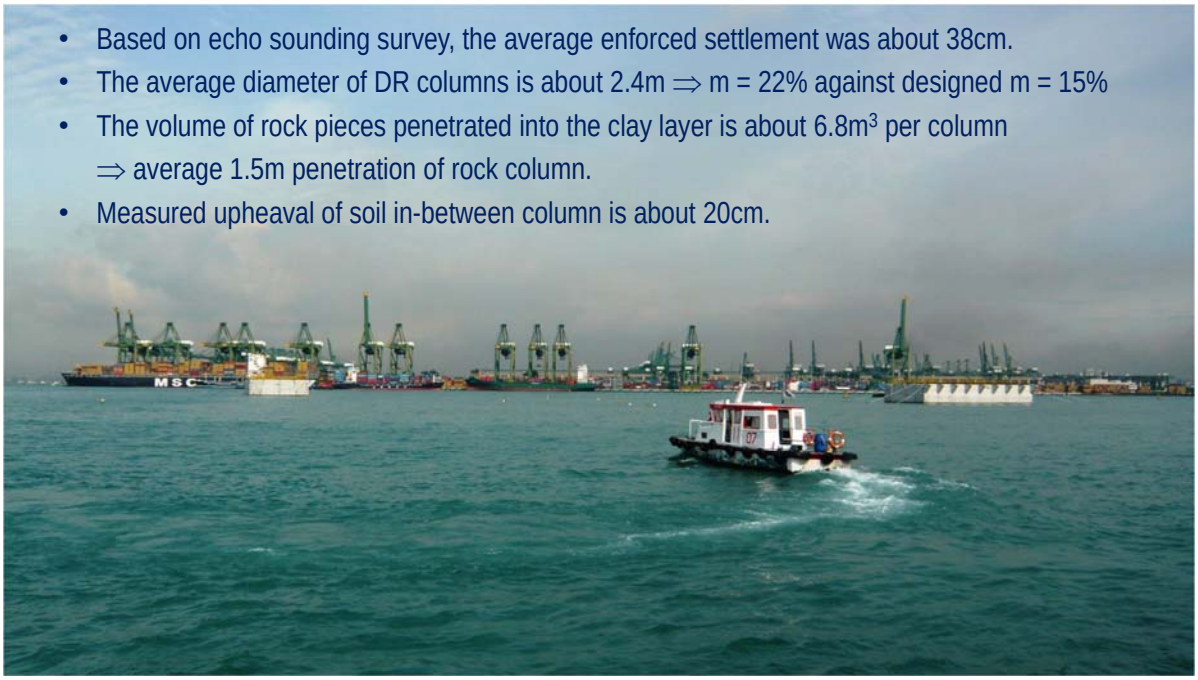
ESTIMATING φ-ANGLE FROM PMT



Lowest $P_{L,\,ROCK}$ = 0.55 bars taken from pre-treatment PMT ⇔ possible lowest $\varphi \approx 42^{o}$

POST TREATMENT RESULTS

- Based on echo sounding survey, the average enforced settlement was about 38cm.
- The average diameter of DR columns is about 2.4m ⇒ m = 22% against designed m = 15%
- The volume of rock pieces penetrated into the clay layer is about 6.8m^3 per column ⇒ average 1.5m penetration of rock column.
- Measured upheaval of soil in-between column is about 20cm.



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CONCLUSION

- Pasir Panjang Terminal 1 & 2 demonstrated the successful combination of *on-shore dynamic compaction* and *vibro compaction* for a very high compaction criteria using *CPT* as the QA/QC tool.
- Pasir Panjang Terminal 3 & 4 demonstrated the successful application of *off-shore dynamic compaction* and *dynamic replacement* at 30m below water using *PMT* as the QA/QC tool


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