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

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- 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 km²
By 1990: total area was 633 km² (increase of ~ 9%)
By 2030: total area may increase to 733 km² (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.
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.
**COMPACTON: 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 Rₖ values)

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**COMPACTON BY DYNAMIC COMPACTON**

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

**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.

**ACCETANCE CRITERIA**

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

- **Design Criteria**
  - $R_d = 90\%$
  - $R_d = 80\%$
  - $R_d = 70\%$

Baldi et al. (1986)

$$K_o = 0.45$$
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

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/m² incl. ironing phase.
- Greater compaction effect at shallower depth
STAGE 1: DENSIFICATION 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 / m² (instead of 430)
POST TREATMENT RESULTS

Enforced settlement:
After VC – 47 cm
After DC – additional 27 cm
Total – 74 cm

Vibration monitoring (PPV):
Phase 1: 4.4 mm/s at 40 m distance
1.4 mm/s at 60 m distance
Phase 2: 6.1 mm/s at 40 m distance
1.7 mm/s at 60 m distance
Completed 90,000 m² in 9.5 months

PASIR PANJANG RECLAMATION – TERMINAL 3 & 4

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 6 km quay length.

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

DC – ground improvement by compaction
DR – ground improvement by reinforcement

FIELD IMPLEMENTATION SCHEME
VARIOUS STAGES OF CONSTRUCTION

Offshore DC/DR

Offshore PMT

Caisson Fabrication Yard

Launching Caisson

OFF-SHORE DC/DR POUNDER

Daily inspection of pounder after works
OFF-SHORE DC/DR POUNDER

OFF-SHORE DYNAMIC REPLACEMENT

DR grid of 4.5m square with 30 – 40 blows
OFF-SHORE DYNAMIC COMPACTION

DC overlapping with 3 - 6 blows

ON-BOARD QA/QC – DC/DR SYSTEM
ON-BOARD QA/QC – GPS SYSTEM

PMT JACK-UP PONTOON
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
- **Job No.:** 523
- **Client:** Penta Ocean
- **Specialist Contractor:** Menard Geosystems(S) PTE LTD.
- **Operator:** Jamal/Otto
- **PMT No.:** OPMT-Post-02
- **Date:** 20-Mar-09
- **Chainage/East:** E 22,492.8
- **Offset/North:** N 27,819.5
- **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 $\phi$-ANGLE FROM PMT

Lowest $P_L_{ROCK} = 0.55$ bars taken from pre-treatment PMT $\Rightarrow$ possible lowest $\phi \approx 42^\circ$

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 $\Rightarrow m = 22\%$ against designed $m = 15\%$
- The volume of rock pieces penetrated into the clay layer is about 6.8m$^3$ per column $\Rightarrow$ 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.
Thank You