Sustainable Reclamation

Initiatives and Geotechnical Issues on Land Supply for Future Development

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Reclamation History in Hong Kong

- Total reclaimed area: 6824ha
Reclamation
The Good Old Days.....
Fully Dredged Reclamation Method

Existing Profile

Dredging of Marine Deposit at Seawall and Main Reclamation Area

Construction of Seawall and Filling at Main Reclamation Area
Fully Dredged Reclamation Methods

- MD within the reclamation area was dredged
- Sandfill was used to fill the dredged trench and reclamation filling
- Vibro-compaction of sandfill
Dredging and Disposal of Marine Sediment

**Dredging**

**Disposal**

A) Open Sea Disposal of Dredged Sediment
- Sea floor disposal areas at South Cheung Chau and East Ninepin or other empty marine borrow pits have been used for disposal of uncontaminated mud.

B) Confined Disposal of Dredged Contaminated Sediment
- Contaminated mud is being disposed of at East Sha Chau.
- Compliance on environmental monitoring and until 2 years after closure of all the pits to ensure that there is no adverse impact on the environment.
Sandfilling
Vibro-compaction of Sandfill

- Compaction of granular soils by depth vibrators.
- Reclaimed sands can be compacted to a depth of 70m and the intensity of compaction can be varied to meet need of various projects.
- Its improvement effect includes reduction of creep settlement, increase of shear strength of soils and reduction of permeability of soils.

**Penetration**
The Vibroproble penetrates by vibration and aid of compressed air or water to the required depth.

**Compaction**
The Vibroproble is retracted from the maximum depth in 0.5m intervals. The in-situ sand or gravel is flowing towards the Vibroproble.

**Completion**
After compaction, the working platform needs to be levelled and eventually roller compacted.
Historical Projects with Dredged Reclamation

- **Hong Kong International Airport Reclamation**
  - Area of reclamation is approx. 950 hectare
  - Dredging volume is approx. 70 million m³

- **Container Terminal No. 9 Reclamation**
  - Area of reclamation is approx. 120 hectare
  - Dredging volume is approx. 18 million m³

- **West Kowloon Reclamation**
  - Area of reclamation is approx. 330 hectare
  - Dredging volume is approx. 32 million m³

- **Penny’s Bay Reclamation Stage 1**
  - Area of reclamation is approx. 200 hectare
  - Dredging volume is approx. 42 million m³
Fully Dredged Reclamation

- **Advantages**
  - Good for fast tracking
  - Settlement risk is lower

- **Disadvantages**
  - Large amount of marine deposits to be disposed
  - Large amount of sandfill and rockfill is required
  - Adverse environmental impact due to dredging work and filling works
Reclamation

Not too long ago...
Reclamation with Fully Dredged Seawall

**Existing Profile**

<table>
<thead>
<tr>
<th>Sea</th>
<th>Marine Deposits</th>
<th>Alluvium/CDG</th>
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</table>

**Dredging of Marine Deposit at Seawall Area**

**Construction of Seawall and Filling at Main Reclamation Area**

- Reclamation Area
- Seawall
- Band drains
Reclamation with Fully Dredged Seawall

- Only MD under seawall is dredged
- Sandfill is used to fill the dredged trench for seawall
- No dredging is required for main reclamation
- Sandfill is used for main reclamation filling
- Ground treatment (mainly band drain and surcharging) is applied to accelerate the left-in-situ soft marine deposit and reduce long term settlement
- Dredging would still be significant particularly when the area of reclamation is small
Band Drain and Surcharge

- Typically used in soft ground to accelerate consolidation of the compressible soils for the drained reclamation.

- In reclamation areas with thick soft marine clay/silt, long term consolidation under reclamation loads can continue for many years.

- With band drains and surcharge load, the soft compressible soils can be pre-consolidated prior to development in a matter of weeks or months.
Past Reclamation with Fully Dredged Seawall

Penny’s Bay Reclamation Stage 2 (for Disneyland Theme Park)

Area of reclamation is approx. 60 hectare

Siu Ho Wan MTR Depot
The Change

Rationale for Dredging

project proponents shall plan their projects on the assumption of keeping the mud in place.

generic guidelines for considering waste management options, waste characterization, dump site selection, assessment of potential effects of disposal options, permit issue and monitoring.

Dumping at Sea Ordinance Cap. 466 (DASO)

approval of dredging/excavation proposals and marine disposal of dredged/excavated sediment.
Diver of Change - *Increased Environmental Concerns*

- **Enforcement of Environmental Impact Assessment Ordinance (1 April 1998)**
  - Air Quality
  - Water Quality
  - Noise Control
  - Waste Management
  - Nature Conservation
  - Marine habitats & associated fauna e.g. marine mammals, fish, corals, & others

- **Increased Public Concerns**
Driver of Change - Lack of Contaminated Sediment Disposal Facilities
Driver of Change - Lack of Sand Borrow Area in HK

Legend:
- Borrow areas – worked out
- Borrow areas – sand remaining

Tap Shek Kok, Brothers, South of Tsing Yi, East Lamma Channel, Po Toi, East of Tung Lung Chau, South of Victor Rock
And the Mitigation………..

Systematically manage impacts that our works may have on the environment for the benefit of community
Available of Advanced Technology

- Advanced technology of ground treatment methods have been developed overseas in recent years
- Successful application of various ground treatment method for reclamation in overseas projects
- Innovative seawall schemes have been developed in overseas projects in recent years
Recent Implementation of Innovative Ideas...
Stone Column
Stone Column

- Typically used in soft soil applications in order to accelerate consolidation of the compressible soils for the drained reclamation
- Increase the shear strength of the soil dealing
- Achieved by the use of vibro-displacement or vibro-replacement method
- Involve the installation of gravel compacted piles commonly referred to as “stone columns”
Stone Column Installation Process

<table>
<thead>
<tr>
<th>Preparation</th>
<th>Charging</th>
<th>Penetration</th>
<th>Compaction</th>
<th>Finishing</th>
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</thead>
<tbody>
<tr>
<td>The Vibrocat positions the vibrocat over the required location of the compaction point and stabilizes itself using hydraulic supports. A wheel loader fills the skip with aggregate.</td>
<td>The skip is lifted and empties its contents into the air chamber. Once the air lock is closed, the material flow towards the vibrocat's tip assisted by pressurized air.</td>
<td>The vibrator displaces the soil and is lowered to the designed depth, aided by the compressed air and by the vibrocat's pull-down.</td>
<td>After reaching the maximum depth the vibrator is pulled up slightly, causing the aggregate to fill the cavity so created. During re-penetration the aggregate is compacted and pressed into the surrounding soil.</td>
<td>The stone column is built up in alternating steps up to the designed level. During the final levelling, the surface requires to be re-compacted or alternatively a blinding layer is provided.</td>
</tr>
</tbody>
</table>
Vibroprobe

23mm amplitude
Sand Compaction Pile
Use of Sand Compaction Pile

- Install large diameter compacted sand piles in soft clay/mud. Diameter of sand piles is 1.2m to 2.0m
- Non-dredged method for seawall base
- Improve bearing capacity, slope stability and consolidation settlement by replacing the soft clay/mud by the compacted sand piles
- Widely adopted in Japan and Korea
Installation cycle of SCP

Step 1 - Casing driving
Step 2 - Pour the sand inside the casing
Step 3 - Drive the casing to the required level
Step 4 - Extract the casing by a fixed distance and fill up the bored hole by sand
Step 5 - Re-drive the casing to compress the sand pile. Supply the sand continuously
Step 6 - Repeat Steps 4 and 5 until the sand pile is built
Operation of SCP plant

1. Delivery and store the sand on SCP barge

2. Conveyor to send the sand to travelling bucket
Operation of SCP plant

3. Travelling bucket to send the sand in vertical direction

4. Load the sand to the hopper at top of casing
Operation of SCP plant

1. Discharge of sand into ground via the casing
Casing Driving

Vibrator

Hopper
Installation Control

Top and bottom level of SCP piles measured by Auto-electronic Sand Level System

Pressure inside the casing controlled by Pressure Control System
Up-heaving of Soil after SCP Installation

- In case of marine mud 20 to 25 m thick, specialist contractor advised based on their experience that the thickness of up-heaved soil after SCP installation could be:

1) For SCP replacement ratio of 70%

- Thickness of up-heaved soil could be 7 to 8 m

2) For SCP replacement ratio of 40%

- Thickness of up-heaved soil could be 4 to 5 m
Height of SCP Plant

- Surely the minimum height of the SCP plant is based on the envisaged maximum thickness of marine mud, depth of water plus a bit.
Original Height of SCP Plant

~50 – 60m advised by Specialist Contractor
Reduced Height of SCP Plant

Specialist contractor advised that SCP plant can be modified by cutting out top frame if height is a problem.

Mean Water Level ~ +1.7 mPD

40m
(Min height that could be reduced by specialist contractor)
Possible SCP Application for Seawalls in Recent Large Scale Reclamation Project – Airport Height Restriction Constraint

Legends

- AHR above +45mPD
- Seawall w/o restriction on the use of SCP due to AHR

Remaining Phase of HKBCF

AHR in mPD

HKBCF
Possible SCP Application for Seawalls in Recent Large Scale Reclamation Project – Soil Up-heaving Constraint

- Use SCP at seawalls with sufficient water depth. Also use low replacement ratio of SCP + surcharge to reduce the thickness of up-heaved soil.
Possible SCP Application for Seawalls in Recent Large Scale Reclamation Project – Hong Kong Boundary Crossing Facilities

- About 25% of seawall (temporary + permanent) without restriction on the use of SCP due to up-heave and AHR.
Deep Cement Mixing
Typical DCM Barge Setup

1. Operation Room
2. Grout Pump
3. Mixing Shafts
4. Mixing Blades (under sea water)

Cement Slurry Mixing Plant

Operation Room

Mixing Shafts
Mixing Blades

Illustrative Details of Mixing Blade
DCM Plants

Land Based DCM Equipment

Control System of DCM method

Mixing Plant

Marine Based DCM Equipment
Previous Development of DCM in Hong Kong

- Port Works Manual Part 4 – Guide to Design of Seawalls and Breakwaters introduced this for the use of supporting seawall
- DCM has been mentioned in many proposals in last 20 years but never been adopted in Hong Kong
- Relevant authorities has no objection in principle on the use of DCM as long as proposer illustrate previous experience in Hong Kong
  ---meaning a Trial!
Why there is no DCM Trial in HK previously?

- Not possible for a Government project to do a field trial before going forward i.e. no gazetted land, no funding…etc

- Lengthy process to carry out field trial due to:
  - Gazetting under Foreshore and Seabed (Reclamation) Ordinance
  - Long mobilization period of the plant from overseas i.e. over 4 months (excluding ordering which depends on how busy the DCM industry is)

- High mobilization cost
Why DCM have not been adopted in Hong Kong?

1. **Field trial** – demonstrate strength and environmental performance?

2. **Residual ground settlement** – any precedent case?

3. **Ground heave during treatment** – would this impose any constraint?

4. **Leachability of contaminants from mud (if contaminated)** – would the contaminants or contaminated pore water still be leached after treatment?

5. **Environmental impact during construction** - what measures were done in previous projects?
Ground Heave during Installation

- Ground heave = ~ 70% of injected slurry volume
- Yokohama Port
- For 20m thick mud (DCM replacement ratio of 50%), estimated ground heave = 1.5m

Water Depth ~ 3.0m
Min. underkeel clearance = 1m
Max barge draft = 2m
<table>
<thead>
<tr>
<th>Vessel Name</th>
<th>Class</th>
<th>Picture</th>
<th>Dimensions</th>
<th>Vessel Name</th>
<th>Class</th>
<th>Picture</th>
<th>Dimensions</th>
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<tbody>
<tr>
<td></td>
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<td>Draft (m)</td>
<td>Tower Height (m)</td>
<td>Treatment Plan</td>
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<td>3.2</td>
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<td>2.5</td>
<td>53.5</td>
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</tbody>
</table>

- Draft of common DCM plants = 1.5m to 3.3m (impose constraint if shallow water + heaving)
- Height of common DCM plants = 35.7 to 72.7m (impose constraint if Height Restriction)
Key Environmental Concerns - Marine

- Possible cement slurry leakage from the preparation plant / slurry pump and mixing shaft
- Possible seepage during soft soil and cement slurry mixing
- Undefined heat emission during the chemical reaction
- Long term deterioration of soil/cement mix and dissolution into seawater is not well defined
Possible Mitigation

- **Heaving** – i) dredge and dispose of upheaved soil; ii) improve the upheaved soil up to surface

- **Possible seepage during soft soil and cement slurry mixing** – DCM operation will stop some distance below the seabed level (i.e. 1 to 2m)

- **Possible cement slurry leakage from mixing shaft during extracting the blades from the mud** – Place a layer of sand / stone blanket above sea bed in advance for “washing” the mixing shaft and blades while passing through this layer
Cofferdam Type Seawall
Use of Cofferdam Type Seawall

- A series of circular or rectangular cell formed by interlocking of steel sheet piles / pipe piles
- Directly vibrated into existing seabed without dredging
- Act as a massive gravity retaining structure when backfilled to its top level
- Used for overseas maritime structures in South Korea, Japan, Singapore, Egypt, Chile, Canada, U.S, etc
Reclamation with Non-Dredged Seawall

1. Existing Profile:

| Sea | Marine Deposits | Alluvium/CDG |

2a. Ground Improvement (e.g. Stone Column, Deep Cement Mixing), Construction of Seawall and Filling at Reclamation Area

2b. Cofferdam Type Seawall with Ground Improvement, Filling at Reclamation Area
Design Consideration of Non-dredged Seawall

- **Overall stability:**
  - Sliding Failure
  - Overturning Failure

- **Internal stability:**
  - Tension failure of sheet pile when subjected to hoop force
  - Failure of interlocks between sheet piles
  - Combined tension and bending failure of sheet piles
Benefit of Non-dredged Seawall

- Eliminates dredging and disposal of marine sediment
- Largely reduce the amount of fill materials for dredged trench
- Reduce marine risk by reduce number of barge trip for fill materials logistic
- Environmental Friendly
Other Overseas Use of Non-dredged Seawall

Montgomery Point Lock and Dam, Arkansas, USA

Collision Protection Structures for the Inchon Bridge, South Korea

Artificial Island for Trans Tokyo-bay Highway

Ohio River, USA

Port at Voisey’s Bay, Labrador, Canada

Quay Construction at Anping Port, Taiwan
Comparison
## Comparison

<table>
<thead>
<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
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<tbody>
<tr>
<td>Fully-dredged</td>
<td>• Good for fast tracking</td>
<td>• Large amount of marine deposits to be disposed</td>
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<tr>
<td></td>
<td>• Settlement risk is lower</td>
<td>• Large amount of sandfill and rockfill is required</td>
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<td></td>
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<td>• Adverse environmental impact due to dredging work and filling works (especially if rainbowing of sand is adopted)</td>
</tr>
<tr>
<td>Non-dredged: Stone Column</td>
<td>• No dredging is required</td>
<td>• Large amount of rockfill is required</td>
</tr>
<tr>
<td></td>
<td>• Environmental friendly</td>
<td>• No preferable if strength of surrounding soil is very low</td>
</tr>
<tr>
<td>Non-dredged: Sand Compaction Pile (SCP)</td>
<td>• No dredging is required</td>
<td>• Special plant required from overseas and long booking period required</td>
</tr>
<tr>
<td></td>
<td>• Environmental friendly</td>
<td>• No track record in HK</td>
</tr>
<tr>
<td></td>
<td>• Require lesser rockfill/sandfill</td>
<td>• Up-heaving of soil</td>
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<td></td>
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<td>• Working height limit</td>
</tr>
<tr>
<td>Non-dredged: Deep Cement Mixing (DCM)</td>
<td>• No dredging is required</td>
<td>• Similar to the Cons of SCP except up-heaving of soil</td>
</tr>
<tr>
<td></td>
<td>• Require lesser rockfill/sandfill</td>
<td>• Significant environmental impacts: grout leakage</td>
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<tr>
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<td></td>
<td>• Expensive</td>
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<td>• Slow construction rate</td>
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<tr>
<td>Non-dredged: Cofferdam Type Seawall</td>
<td>• No dredging is required</td>
<td>• Require considerable amount of steel</td>
</tr>
<tr>
<td></td>
<td>• Reduced Marine Traffic</td>
<td>• Less track record in HK</td>
</tr>
<tr>
<td></td>
<td>• Use for disposal of public fill</td>
<td>• Working height limit</td>
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</table>
Newer Attributes
A 2-D hydrodynamic modeling can be carried out to develop an optimum offshore reclamation configuration such that sufficient tidal flushing can be maintained during ebb and flood tide for control of water quality in the development area.
Creation of Eco-shoreline

Tidal Water Level

Tidal Basin Cross-section
Disposal Area for Public Fill

- Cell of cofferdam type seawall can be filled by public fill
- Treated as alternative disposal site for public fill
Today

Dawning of a new era....
First Fully Non-dredged Reclamation in HK

- Non-dredged cellular steel sheetpile seawall with a diameter of 26.9m to 31.2m
- Formed by straight web sheetpile
- Penetrate through over 25m thick of marine deposits into underlying alluvium.
- Stone column installed to strengthen the soft marine deposit providing lateral support to the cellular seawall cell.

Schematic Layout of Non-dredged Seawall

Isometric View of Similar Seawall Construction
Airport Height Restriction

Height limit = +30mPD

+20

+50  +40  +30

+40  +30  +20
Conclusions

- Advocate Sustainability onto Reclamation
- Innovate the best solution for Reclamation
- Nothing is generic as far as today’s Reclamation is concerned
Principles of Sustainability For Reclamation

- Strive to reduce burden on existing mud pits
- Strive to reduce potential sites as borrow pits
- Strive to reuse public fills
- Strive to meet environmental restrictions
- Strive to reduce cost of construction
- Strive to achieve quality reclamation

These guiding principles itself, though not exhaustive, set the major challenge to implement sustainable reclamation in Hong Kong.
Thank You