Curtin University

Review and Feasibility Assessment of Offshore Ground Improvement Methods

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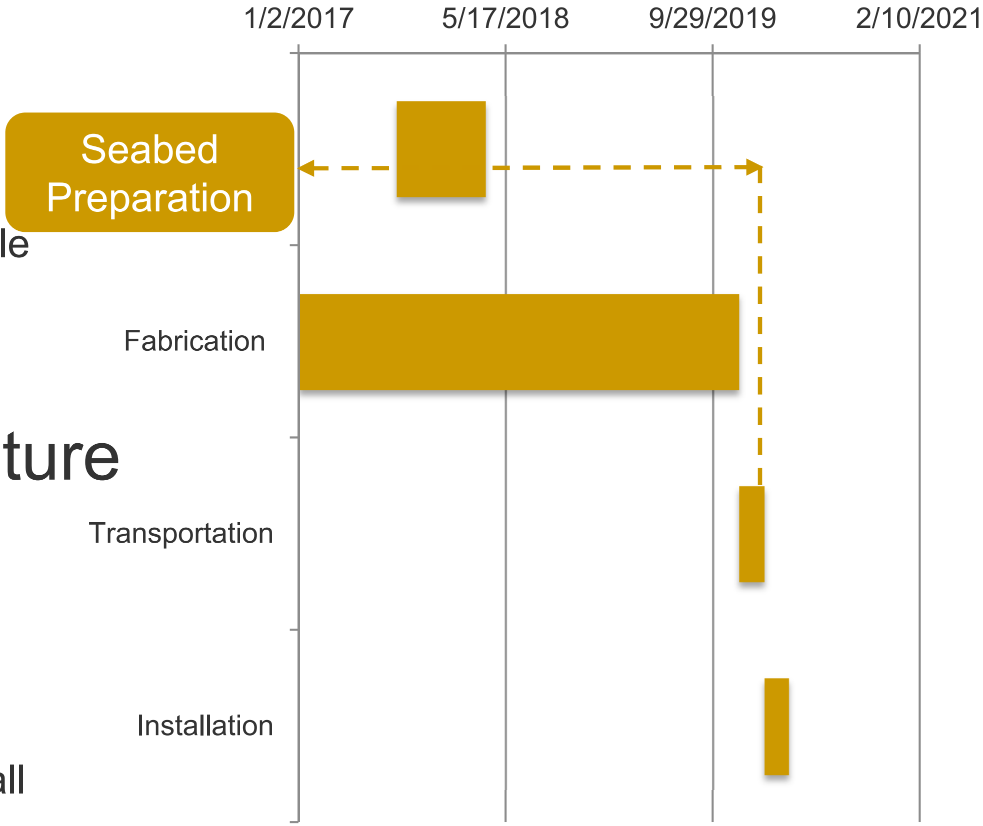
Background

- Final semester study project (6 months)
- Course completion fulfillment
- Master of Subsea Engineering (MC-SBSENG)
- Project Supervisor: Dr. Alireza Gholilou
- Aim to publish a paper based on this topic

Motivations and Challenges

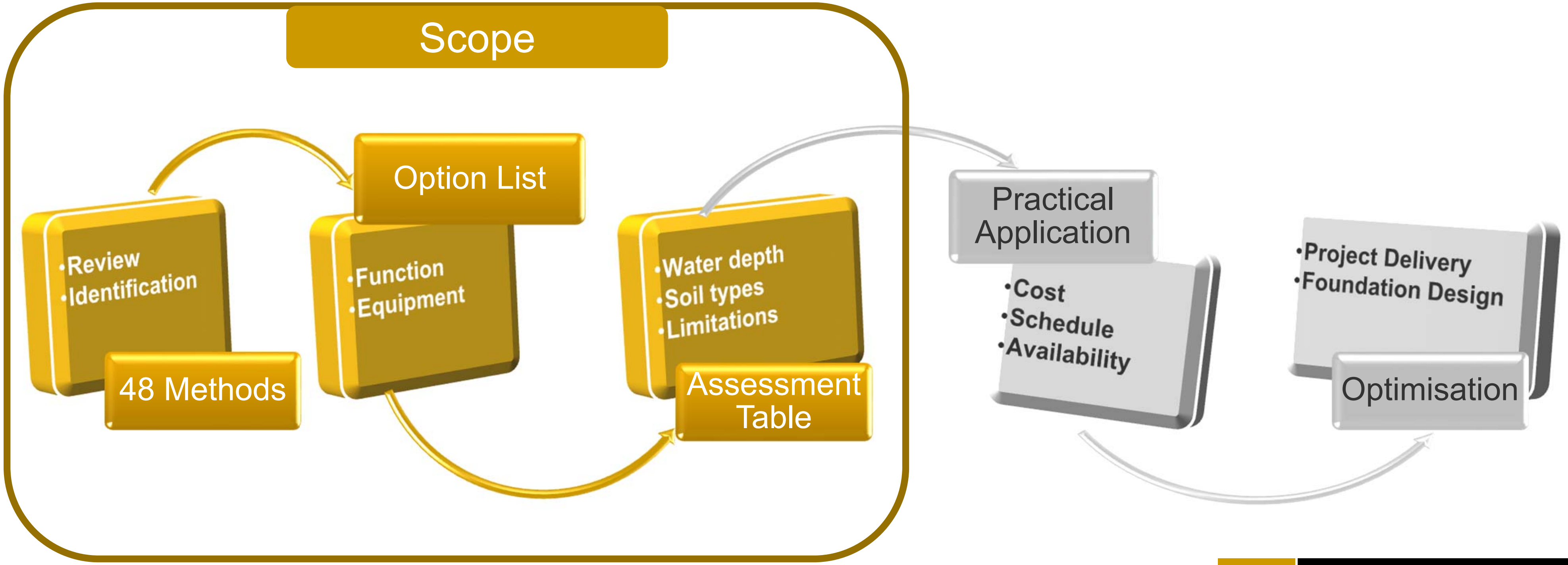
- Increasing demand to consider seabed preparation in foundation design
  - Optimise project delivery – Flexibility in schedule
  - Efficient foundation design – Competent and reliable seabed
  - Malampaya DCP Seabed Preparation, 2015
- Limited up-to-date collective literature
  - In establishing full context of offshore ground improvement
  - More than 200 abstracts read
  - More than 100 literatures reviewed
  - Difficult for practitioners to immediately recognize all relevant methods
  - Possibility to overlook more suitable solutions to geotechnical challenges

Time Allowed for Seabed Preparation in Project Schedule



Objectives

1. Collect and review offshore ground improvement methods
2. Establish a list of available methods
3. Expand the list into an assessment table
4. Identify and assess state-of-the-art of specific methods



Scope

- Review
- Identification

48 Methods

Option List

- Function
- Equipment

- Water depth
- Soil types
- Limitations

Assessment Table

Practical Application

- Cost
- Schedule
- Availability

- Project Delivery
- Foundation Design

Optimisation

Overview of Methods

Offshore Ground Improvement Methods

Soil Consolidation/ Strengthening
- Surcharging
- Chemical grouting
- Jet grouting
- Lime injection
- Electro-osmosis
- Soil nailing
- Freezing

Obstruction Removal
- Drag-off with trawlers
- Shaped charges
- Underwater burning
- Thermic lancers
- Clamshell buckets
- Underwater chisels
- Hydraulic and Pneumatic breakage

Rock Placement
- Tremie dumping
- Bucket dumping
- Skip dumping
- Chute dumping
- Ladder dumping

Dredging
- Tailing suction hopper dredge
- Cutter-head suction dredge
- Grab dredge
- Hydraulic backhoe dredge
- Dragline
- Continuous bucket ladder dredge
- Plow
- Jet sled
- Airlift
- Eductors
- Remotely controlled dredge
- Screeding

Soil Compaction
- Dynamic compaction
- Surface vibration
- Deep vibration (vibro compaction)
- Surface explosive/airgun compaction

Scour Protection
- Filter fabrics
- Articulated mattress
- Sand bags
- Artificial seaweed
- Rock blankets

Liquefaction Prevention
- Sand drains
- Wick drains
- Rock columns

Soil Replacement
- Dynamic replacement
- Vibro replacement (stone columns)
- Concrete Injection
- Deep cement mixing

Quantification of Function Groups

47 Offshore Ground Improvement Methods

Soil Consolidation/ Strengthening
7

Seafloor obstruction removal
7

Dredging
12

Soil replacement
4

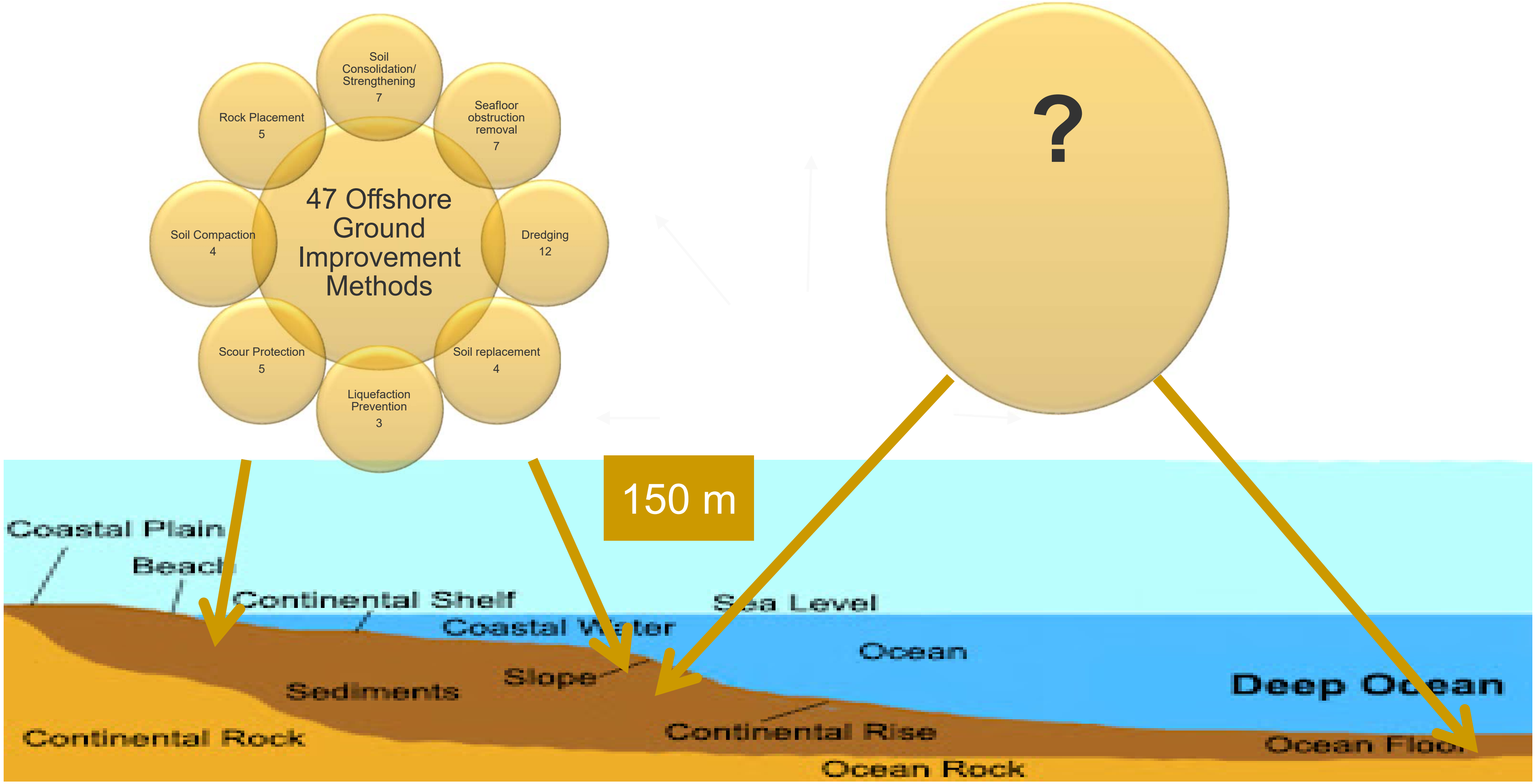
Liquefaction Prevention
3

Scour Protection
5

Soil Compaction
4

Rock Placement
5

Locations of Applications



47 Offshore Ground Improvement Methods

- Soil Consolidation/ Strengthening 7
- Seafloor obstruction removal 7
- Dredging 12
- Soil replacement 4
- Liquefaction Prevention 3
- Scour Protection 5
- Soil Compaction 4
- Rock Placement 5

?

150 m

Assessment Table (Partial)

Function Group	Method	Water Depth (Maximum)	Soil Types	Limitations
Soil Consolidation/ Strengthening	1. Surcharging	20 m	• Silty or possibly clayey soils • Anisotropic – natural horizontal permeable stratification	• Slow consolidation process, typically 6 - 12 months
	2. Chemical grouting	125 m	• Calcareous sand	• Toxicity of chemicals
	3. Jet grouting	20 m	• Weak to cohesive soils	• Lack of pressure differential to retain the annulus
	4. Quicklime injection (CaO)	Unknown	• Weak clay and organic soils	• Require permeable surrounding to draw water for reaction
	5. Electro-osmosis	Concept	• Permeable soils	• Localisation effects
	6. Soil nailing	70 m	• Gravel, silty sand, silty clay • Strong seismic activities	• Long duration of installation • Costs associated
	7. Freezing	Concept	• Sufficient water content	• Uncertain frozen soil properties • Energy and costs

1. Marine Dynamic Replacement

0 ⟷ 30 m water depth

- Container terminal construction, SE Asia, 2009
- Drop height 5 m above seabed to reach 7 m/s
- Penetration depth of 1.1 m - 1.7 m
- 118% increase stiffness modulus (E_Y)
- Self-sustainable as granular backfills provide drainage paths to dissipate excess pore pressure

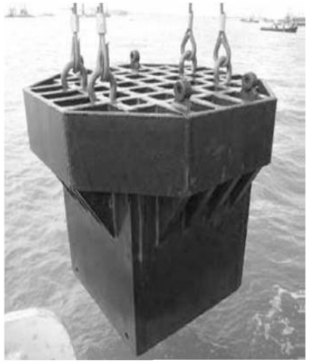
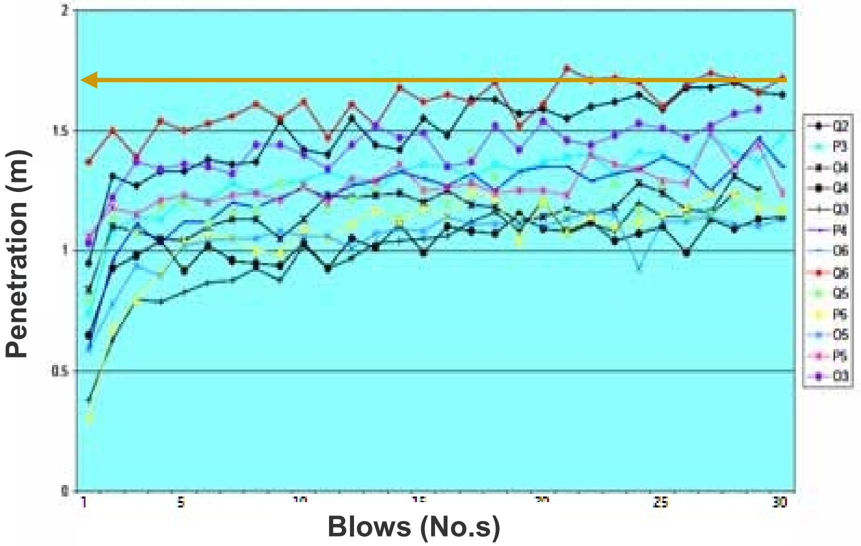


Image Courtesy of Yee & Varaksin



2. Marine Stone Columns

0 ⟷ 50 m water depth

- Port of Patras Phase II, Greece, 2001
- Frequent earthquake experienced
- Liquefaction risk
- Normally consolidated clay strata
- Innovative “double lock gravel pump”
- Average column length of 16 m
- Potential application ~ 200 m water depth

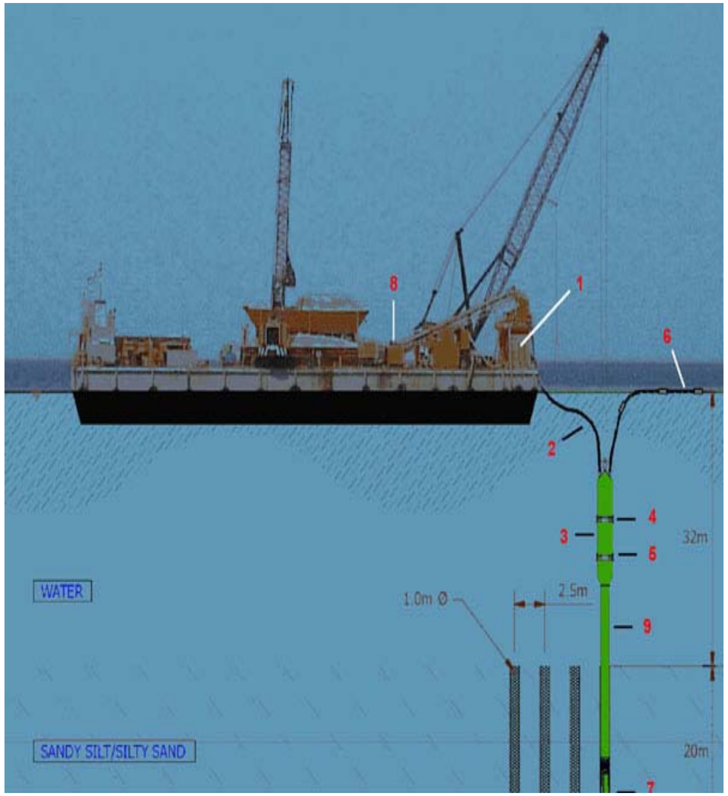
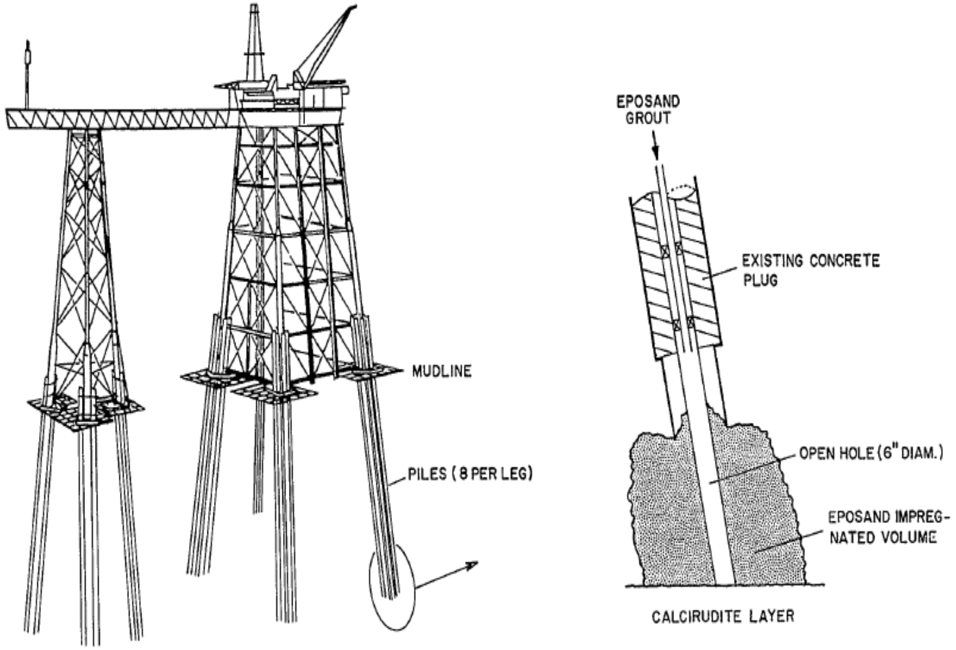


Image Courtesy of Degen Engineering

3. Chemical Grouting

0 ⟷ 125 m water depth

- North Rankin ‘A’ Platform, 1987
- Piles installed 113 m below mudline, calcareous sandy silts
- Epoxy-resin Grout (Eposand)
  - Temporarily stabilise the foundation
  - Low viscosity – no fracturing needed
- Concrete Injection (Tremie)
  - Provide a reinforced bearing
  - Concrete strength (UCS): 60 MPa
  - Cement content: 156 kg/m^3
  - Fine aggregate: 750 kg/m^3
  - Coarse aggregate (7mm):745 kg/m^3

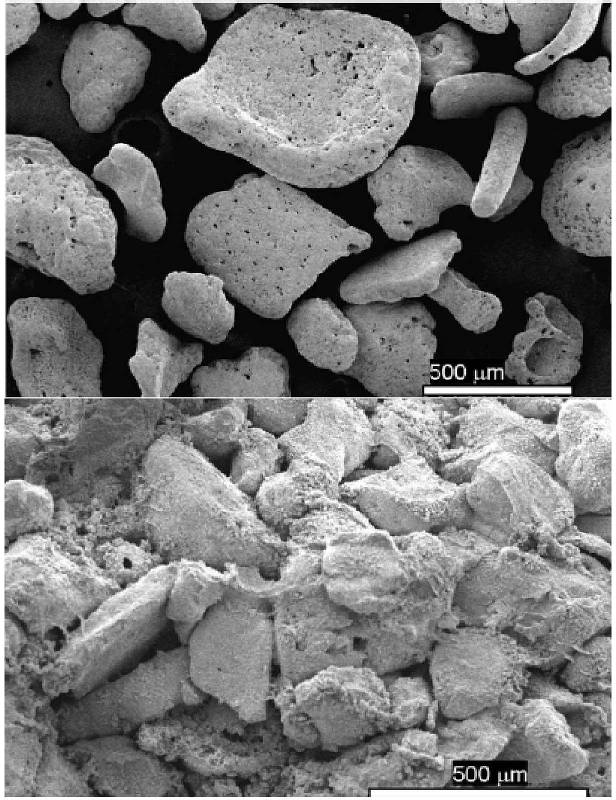


North Rankin ‘A’ Platform Chemical Injection

4. Electro-osmotic Treatment

0 ↔ **Deep water potential**

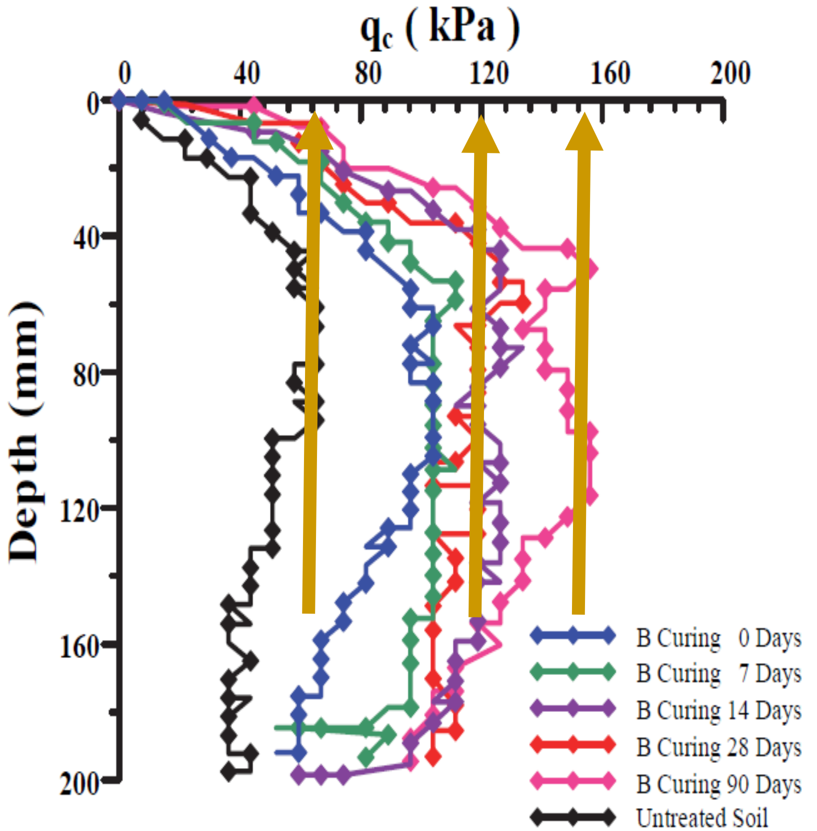
- Electro-osmosis
  - Displace water through porous space
- Chemical injection
  - Localised improvement effects
  - Some chemicals are toxic and hazardous
- Electrolyte leaching (electrode decomposition)
  - Experiment on marine clay, 2006
  - Tremendous costs associated in metal electrodes consumed



Electro-osmotic cementation in calcareous sands (Rittirong et al, 2008)

4. Electro-osmotic Treatment cont.

- Electro-osmotic Microbial Injection (experiment, 2016)
  - Bacteria can penetrate into low permeable clayey materials such as kaolinite
  - Microbe induced bonds
  - 100% increase in tip resistance after 28 days curing
  - A further 80% increase after 90 days curing



CPT results for each curing period (Chien et al, 2016)

Summary

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Potential Application

- **Chemical Grouting**
- **Electro-osmotic Treatment**