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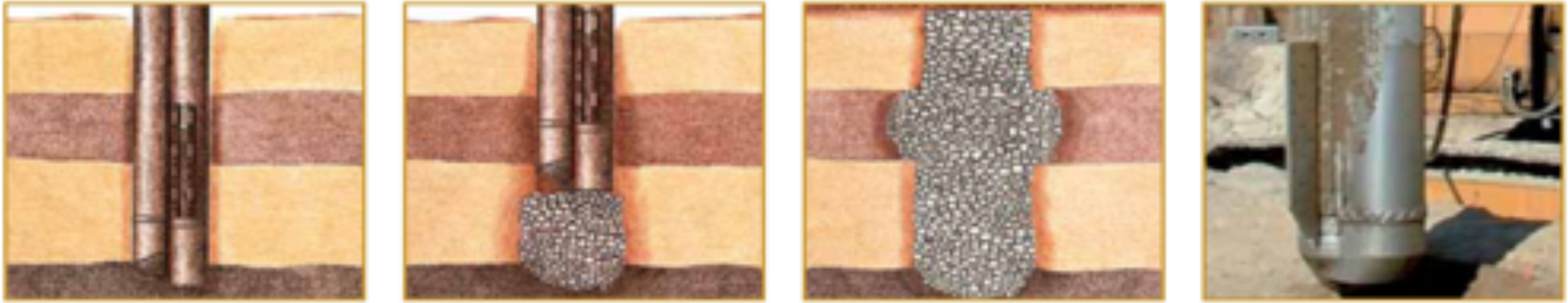
Engineered Ground Improvement

# Ground Improvement for Port Structures Stone Columns and Vibro Compaction

# Bottom Feed
# Stone Columns
# (Vibro Displacement)

## Dry Bottom Feed Stone Column Installation

### BOTTOM FEED STONE COLUMNS:

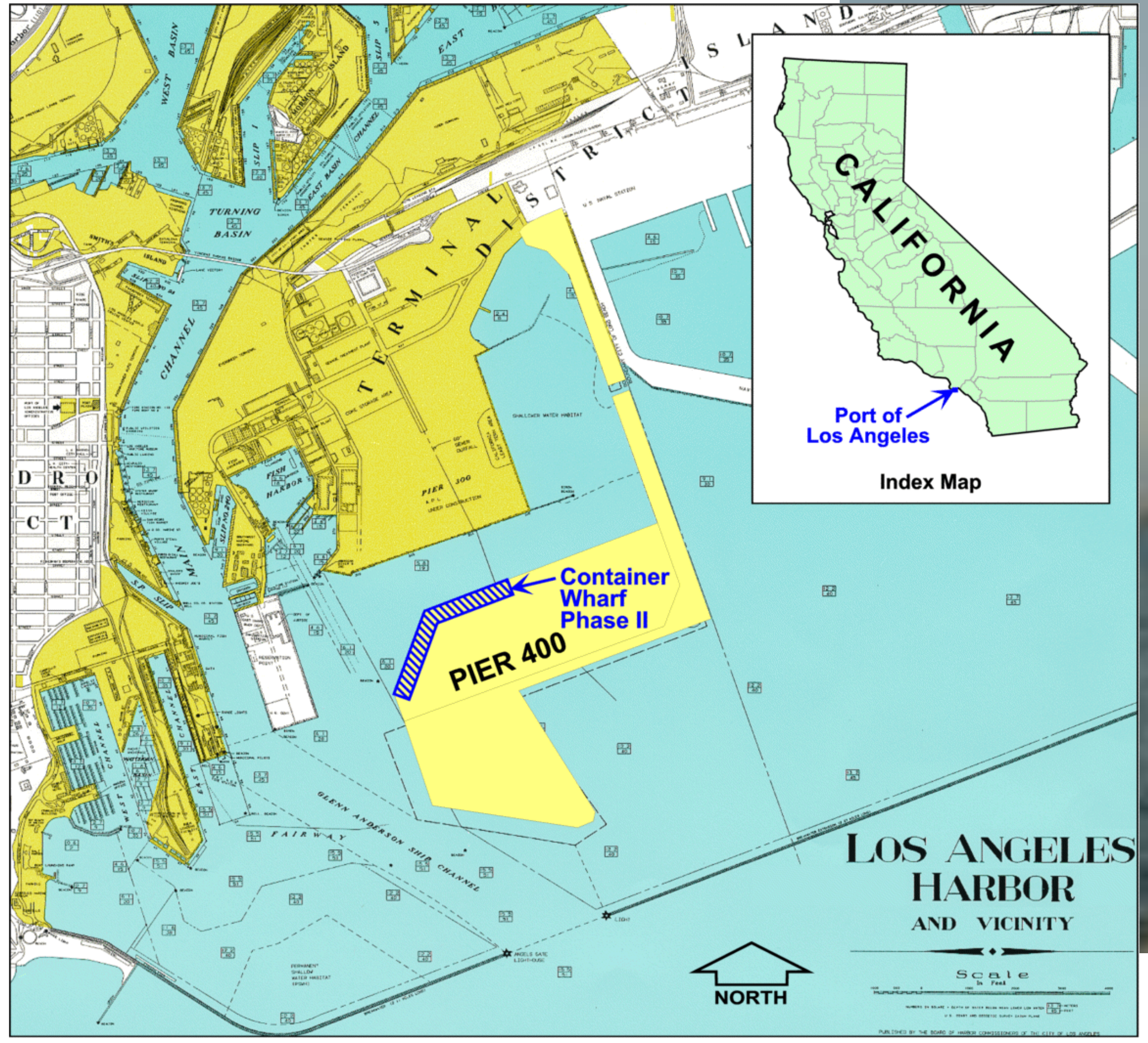


The vibroflot penetrates with the help of vibration and air flushing. (sometimes a minimal water lubrication is helpful to overcome high friction from the soils)

The stones are introduced via a tremie pipe along the vibroflot and the aid of pressurized air.

The vibroflot is frequently moved up and down in order to form and compact a column. Thereby, the surrounding ground is horizontally compressed and improved. The column is able to support high vertical loads.

# Port of Los Angeles – Pier 400 Phase II




# Port of Portland, Terminal 6 - Berth 604 and 605 : Treatment Depth 30.5 m

## 2011 and in 2022: Pier Tango and Uniform and Lima - US Navy, Guam


**Catalina Power Plant, Dominican Republic**

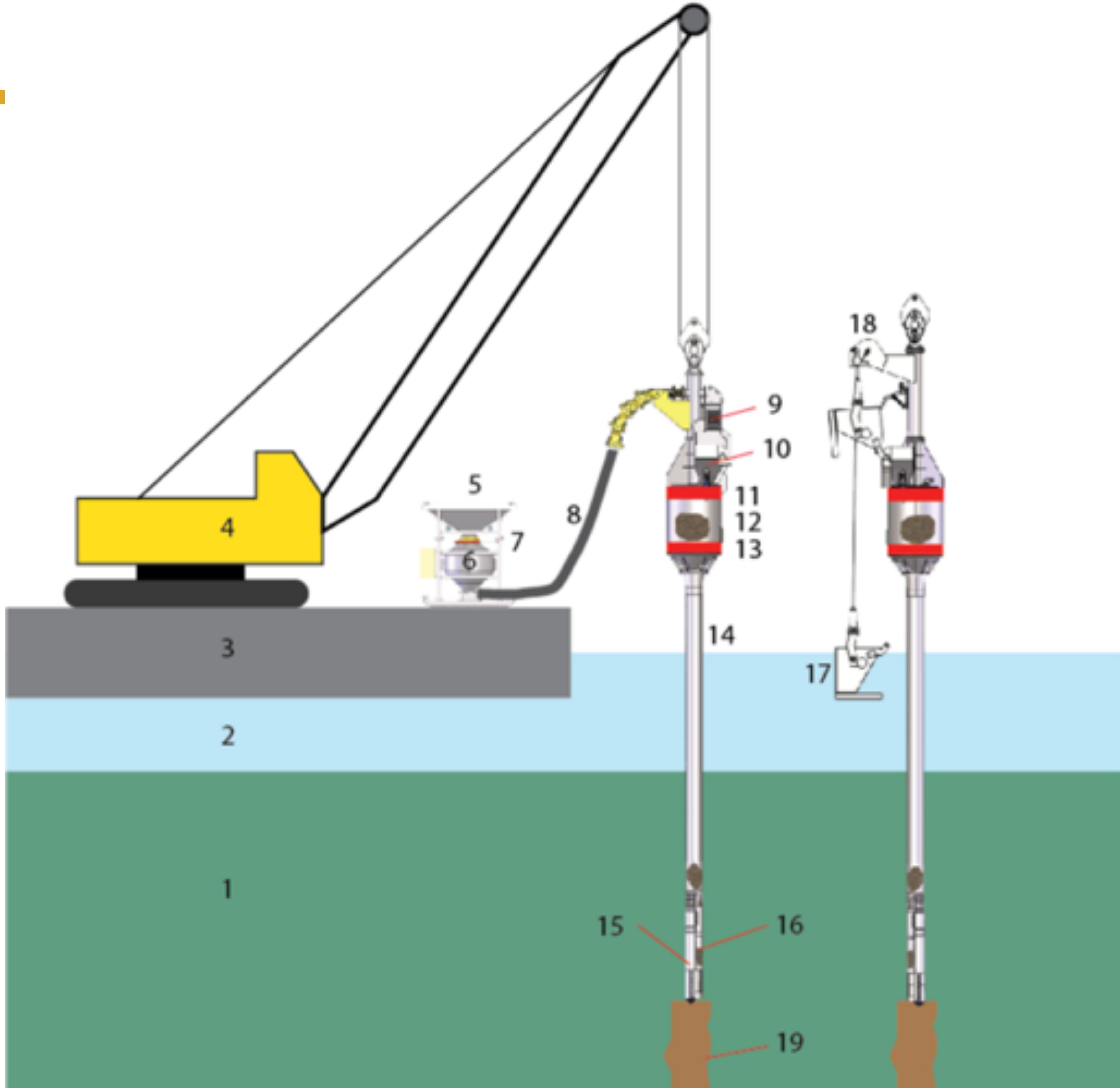
- Column Diameter: ≈ 91 cm
- Penetration to 20 m: 6 min
- Installation of 7 x 2 m3 in 27 min

- 14m3/27min = 0.52 m3/min

- Typically we calculate with 0.45 m3/min

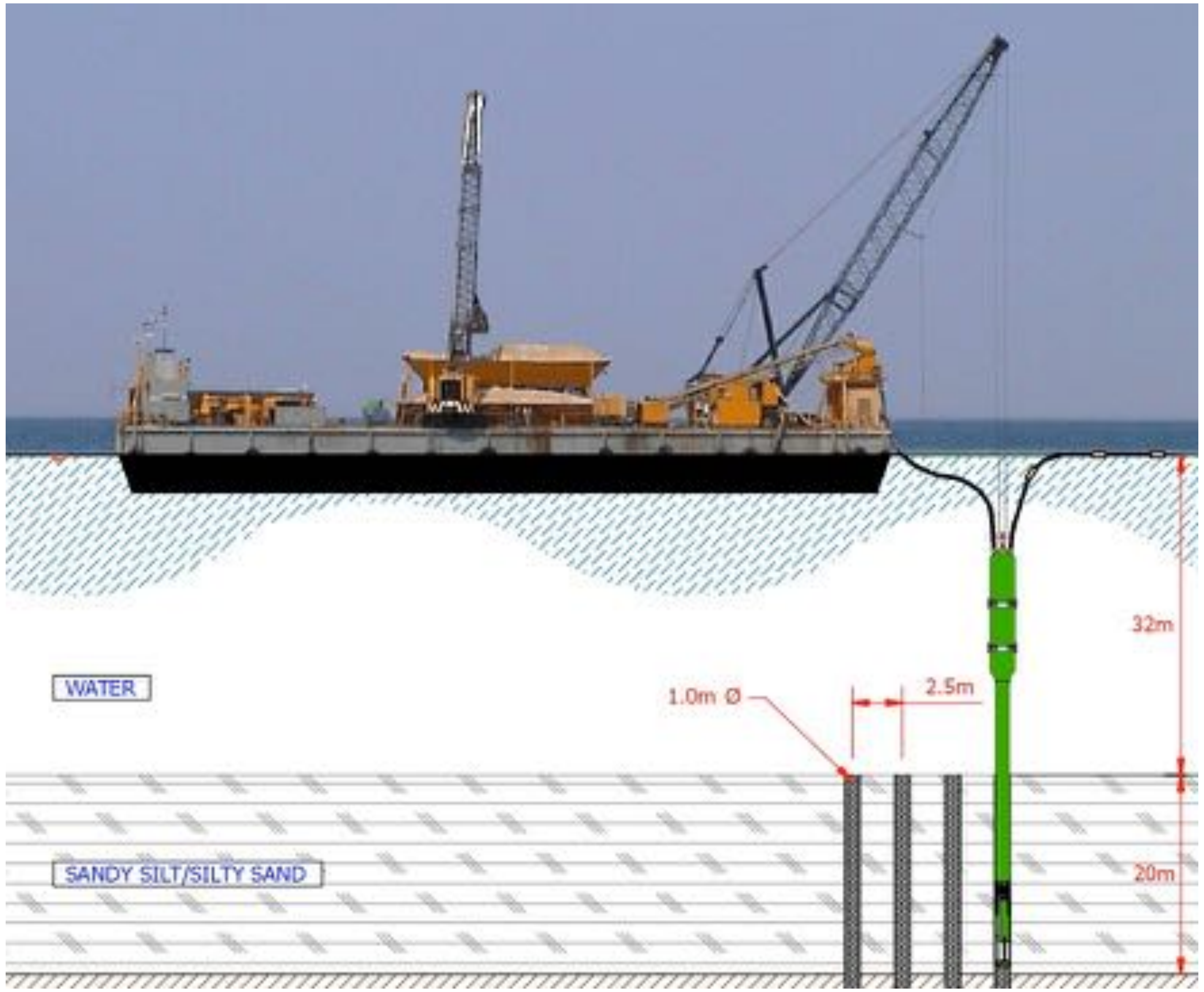
# Offshore Bottom Feed Stone Columns

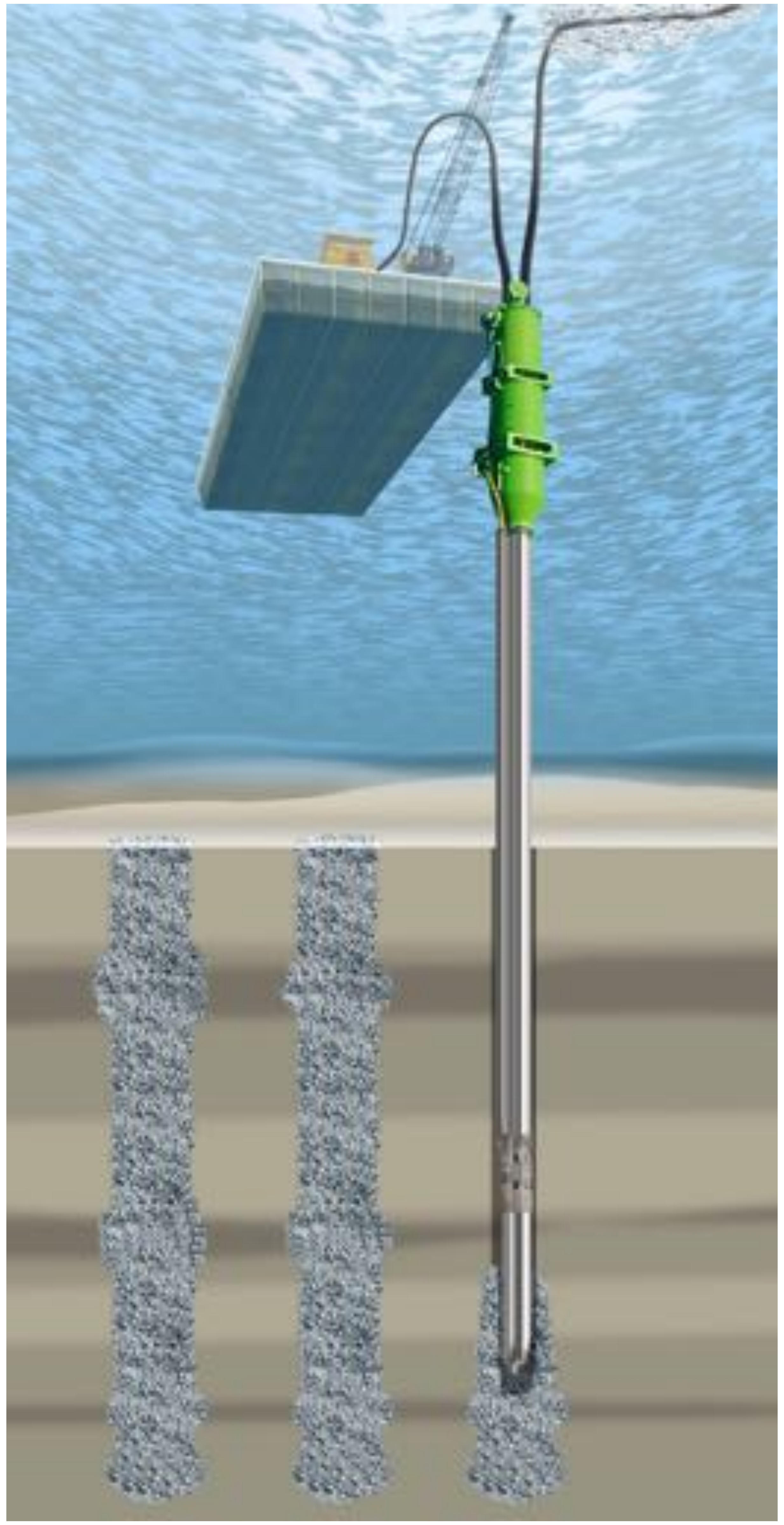
## Bottom Feed Rig without AP Height Restriction



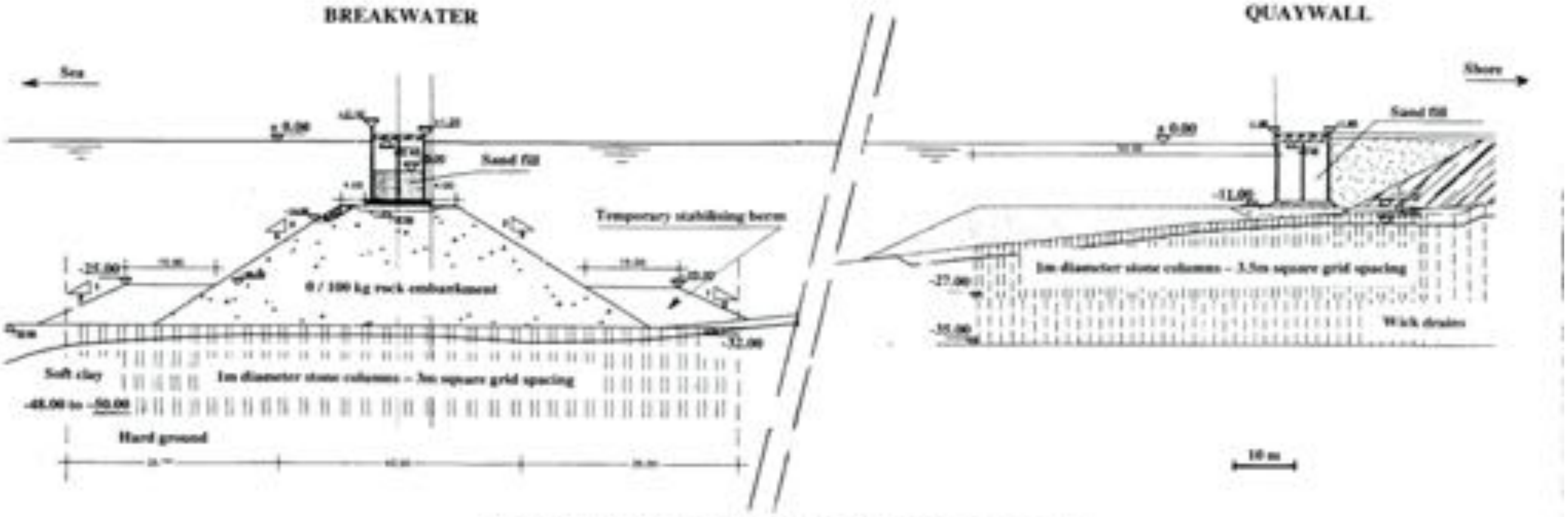
## 2000: Port of Patras, Greece

- Betterground's principals and equipment designers were instrumental for the success of the Marine Gravel Pump installing offshore stone columns in Patras, Greece.



# Breakwater and Quaywall Design




PATRAS (GREECE) HARBOUR EXTENSION – PHASE II

Fig. 1 Foundation ground treatment with stone columns and wick drains

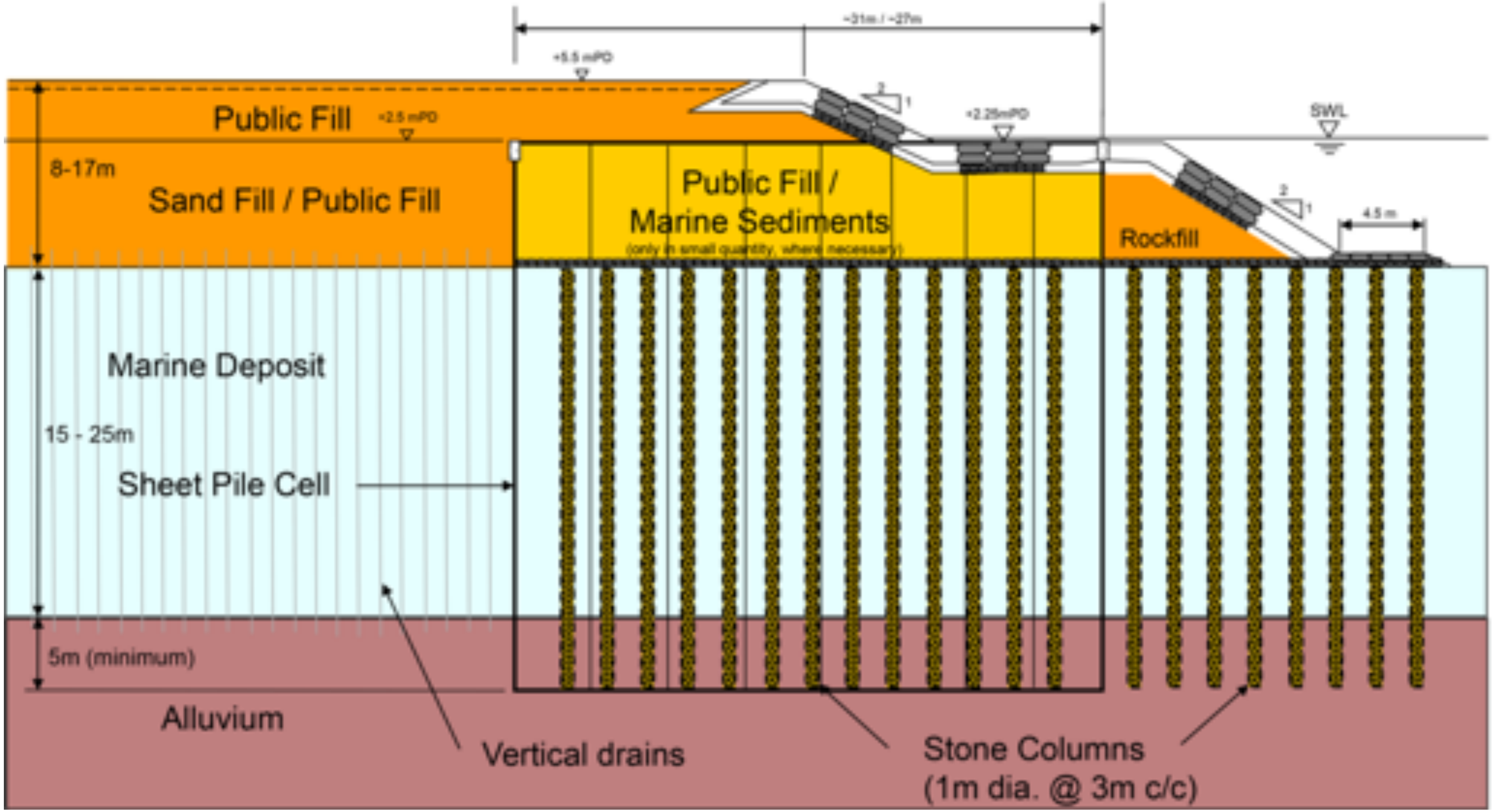
## BART - View from the barge

# Richards Bay, South Africa

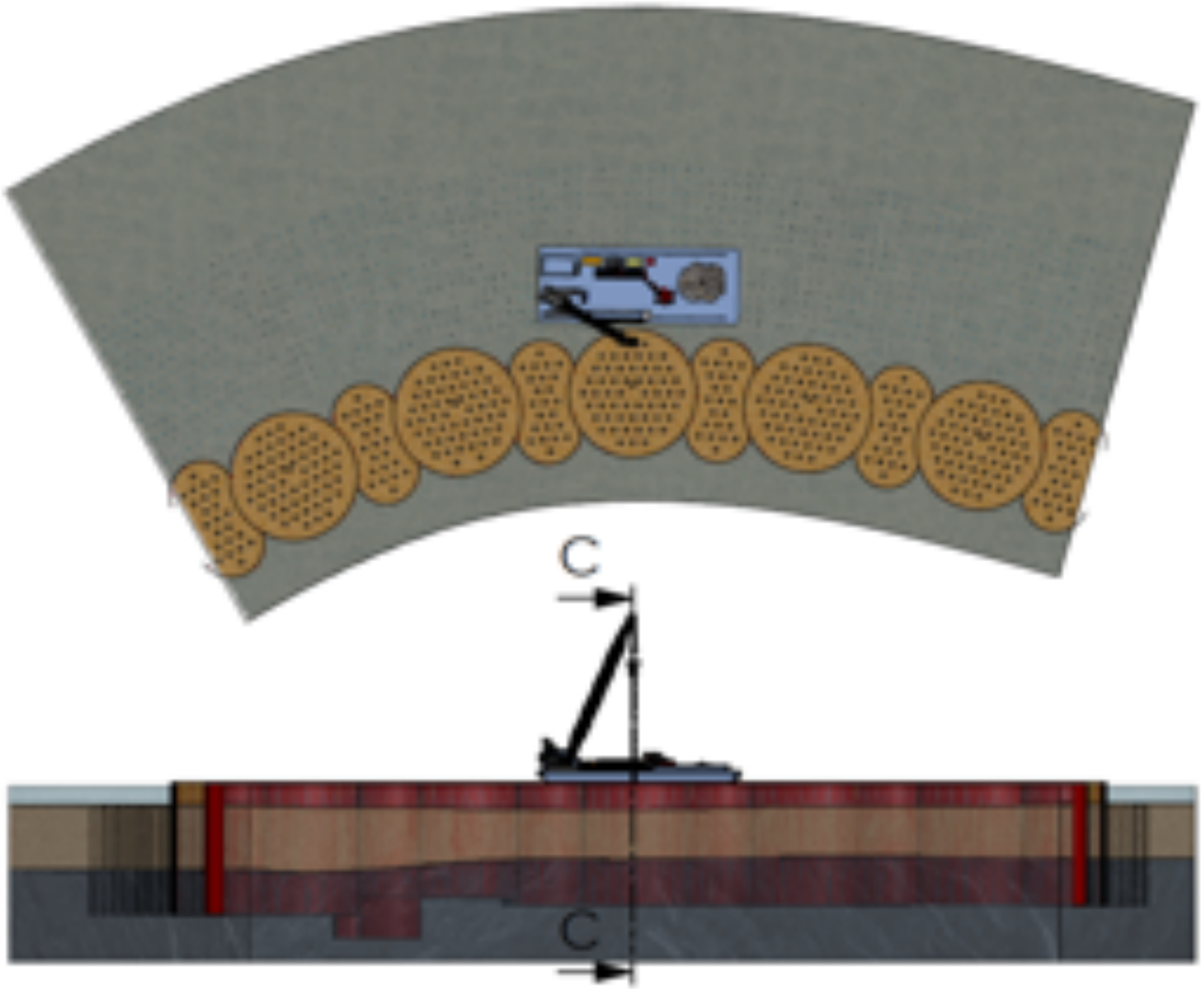
# 2012: Hong Kong Boundary Crossing Facility

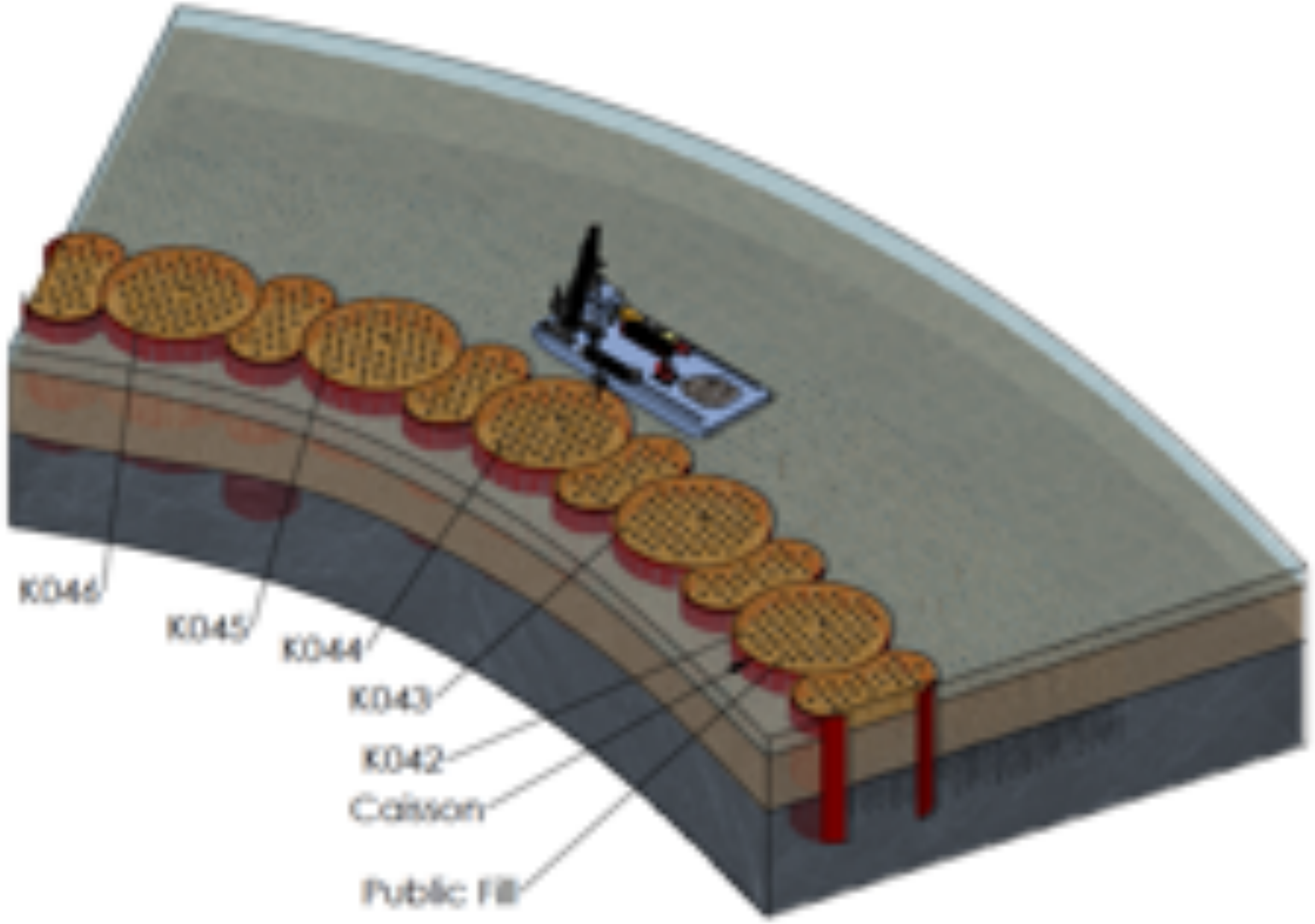
# Hong Kong Boundary Crossing Facility - Status in April 2014

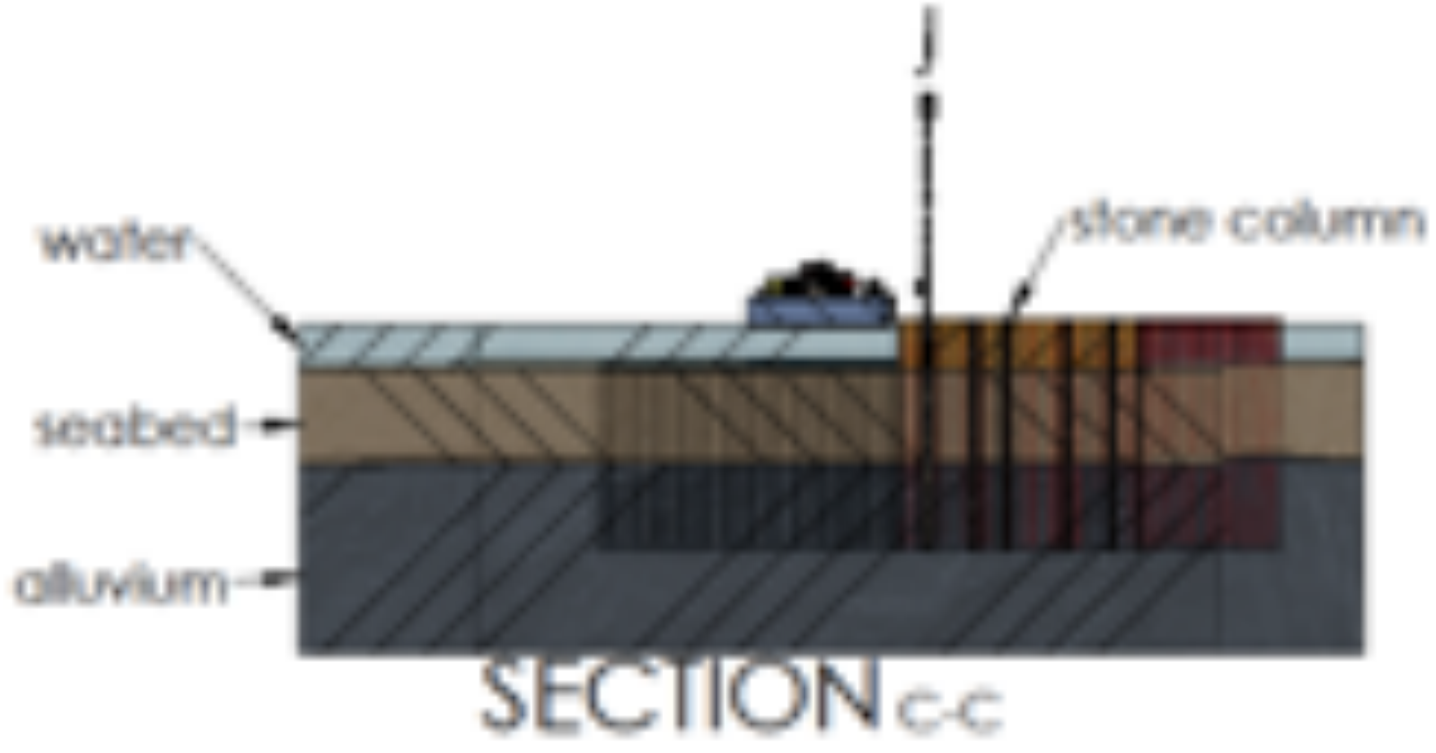
## HKBCF Cross Section: Specification requests 1.0 m constant diameter columns



## HKBCF , work inside caisson



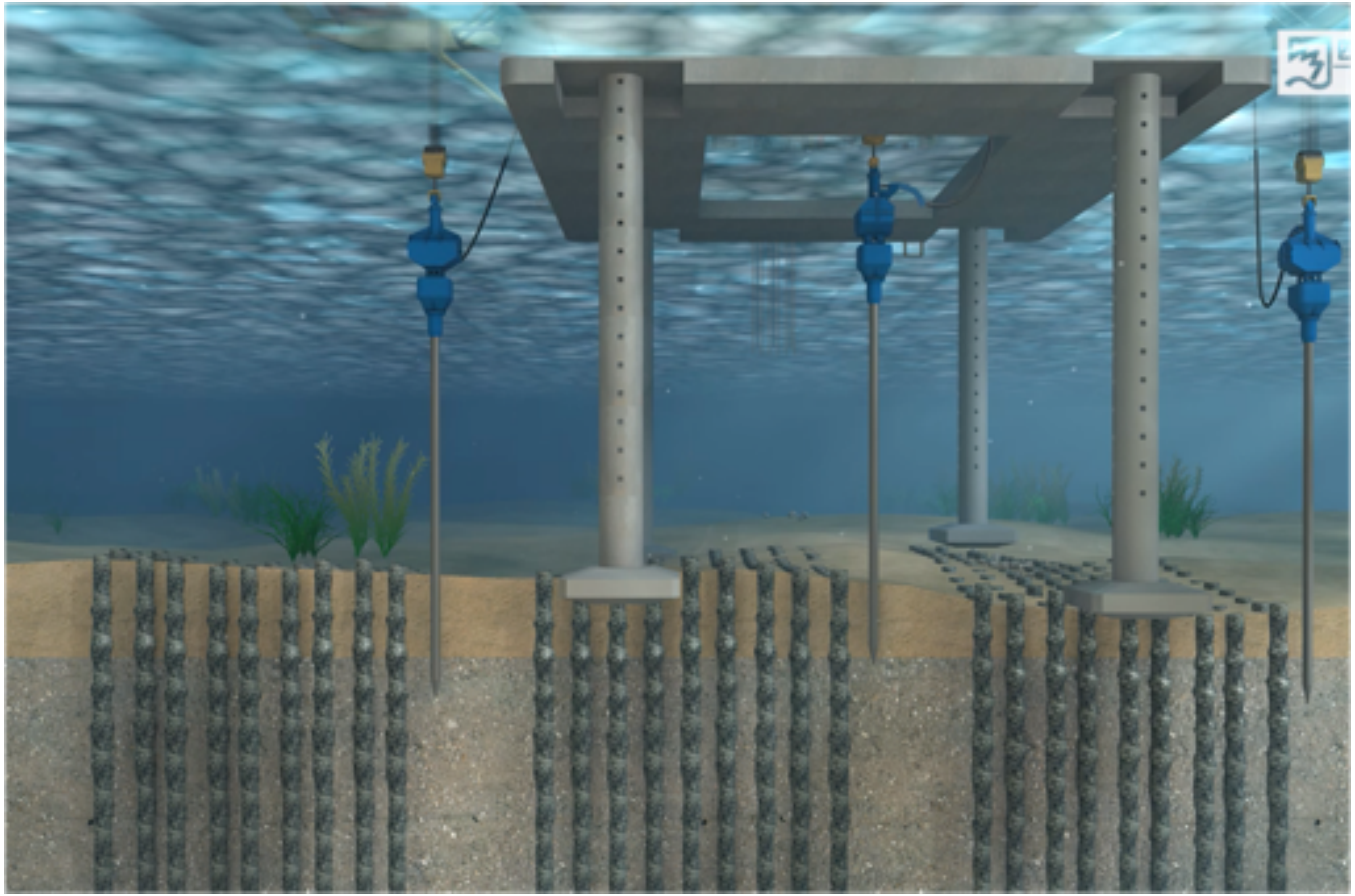



# Airport Height Restriction

Betterground designs and builds custom rigs suited for the requirements of the project.
Here, a very strict Airport Height Restriction had to be fulfilled.

## Port of Ashdod: Underwater view of the simultaneous installation with three rigs




中 交 二 航 局
THE SECOND HARBOR ENGINEERING COMPANY

# Offshore Stone Columns with GP1 (Gravel Pump)

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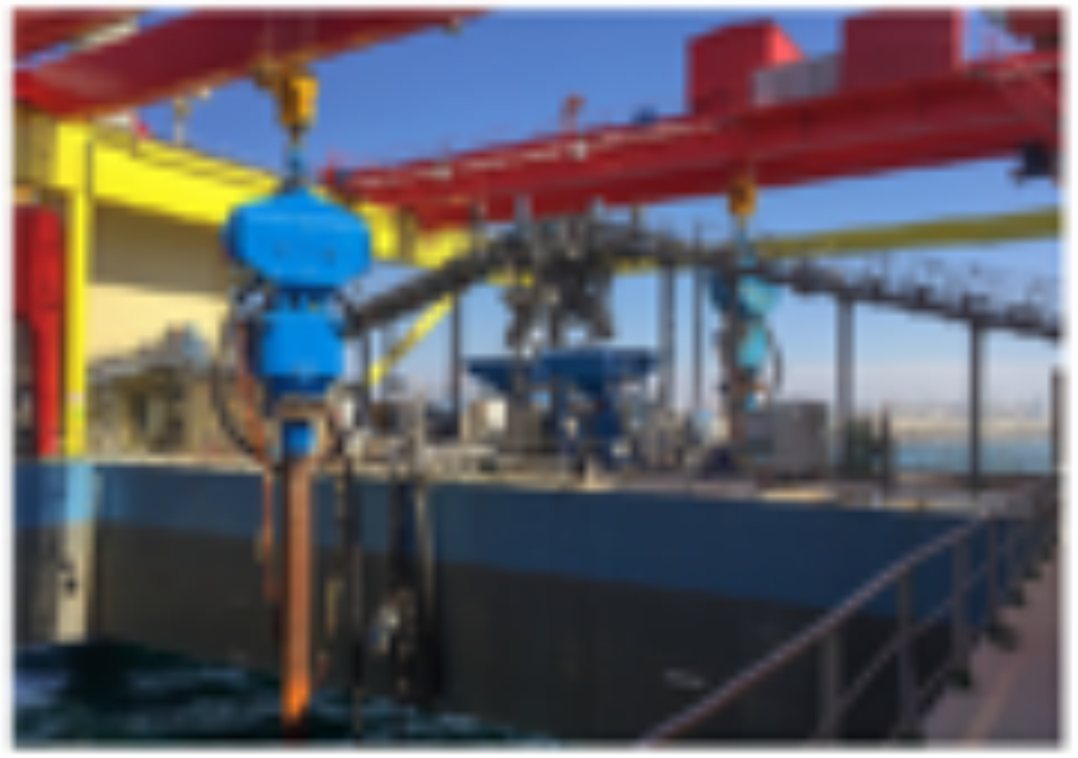
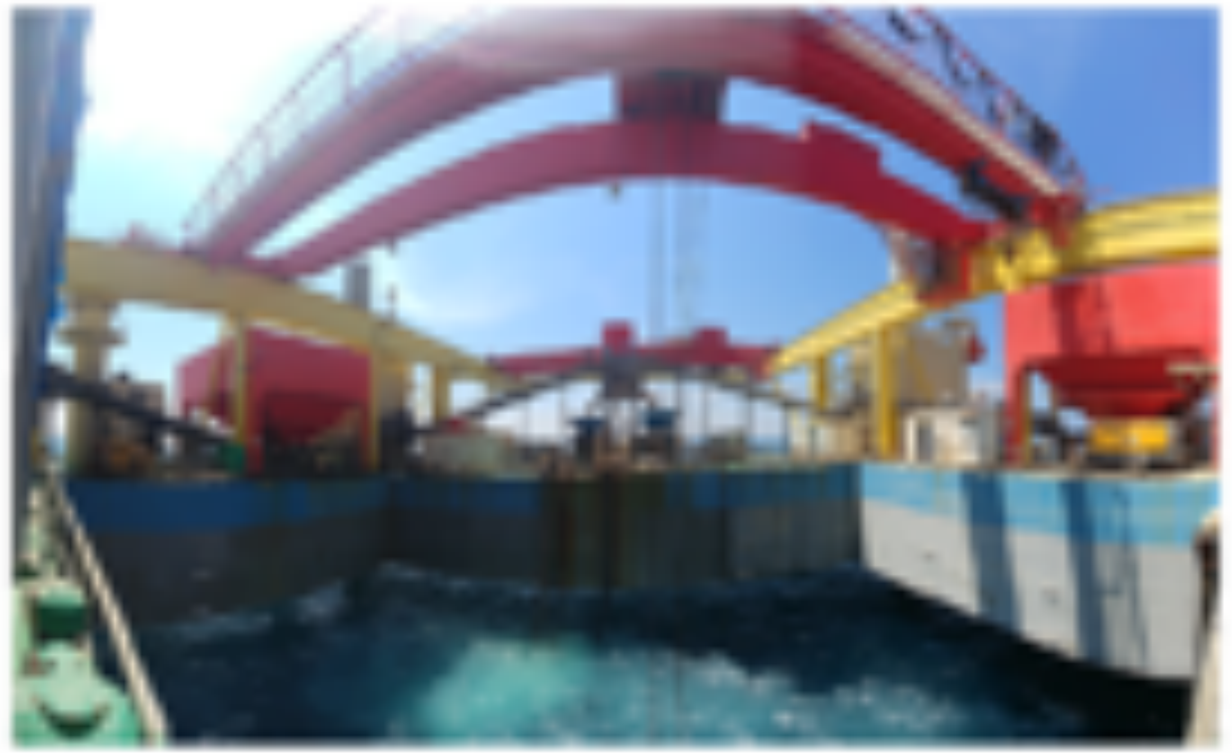
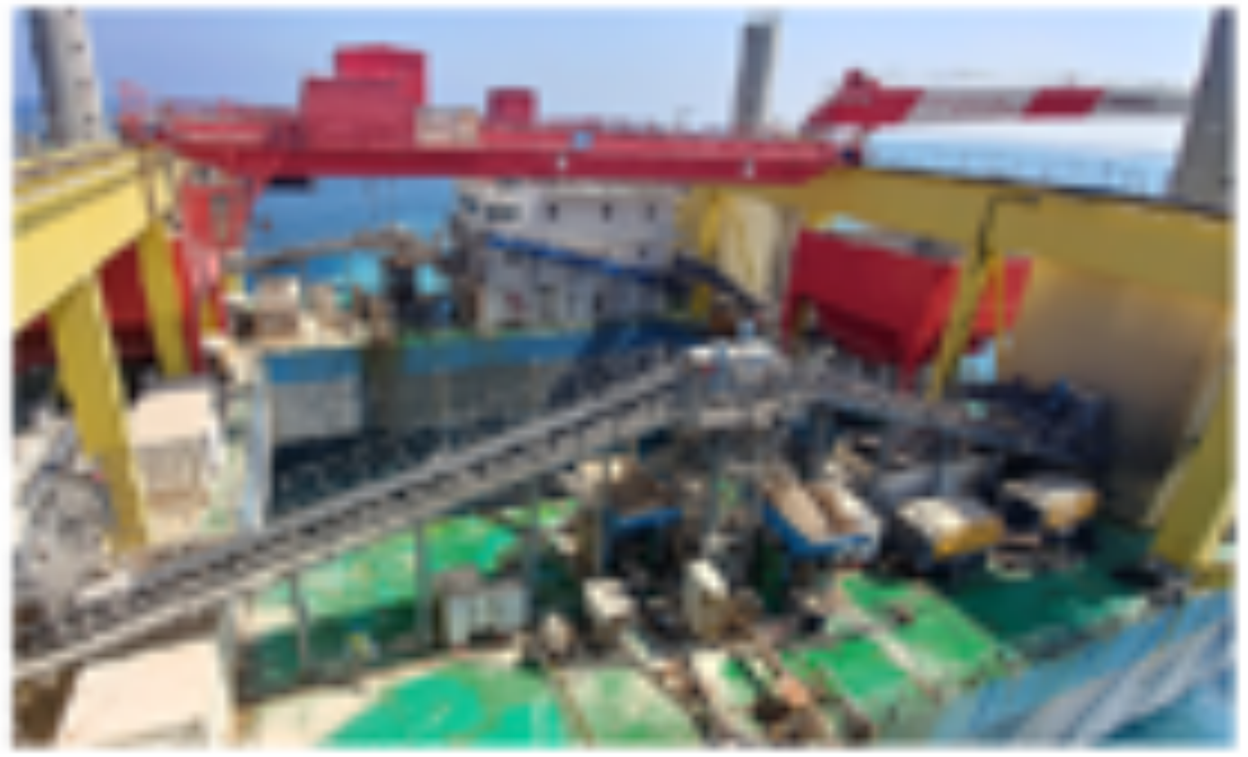
Three Betterground GP1 rigs worked for over two years from a jack up barge. This allowed for the installation of over 3000 stone columns of up to 20 m length in up to 23 m water depth.
Using a jack up barge made the operation more weather independent.







Emergency STOP
START
STOP
Soil no
m-1768b
Depth: -32.41m
79 A
Compaction
Strokes
7
Reset
Automatic cycle
Close lower Gate
Check Air valve position
Open upper gate
Fill Vibro
RD
REC ON/OFF
Pause
Start Auto 1
Start Comp
Error
F1
F2
F3
F4
F5
F6
F7
F8
F9
F10
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# Project Specific Slides

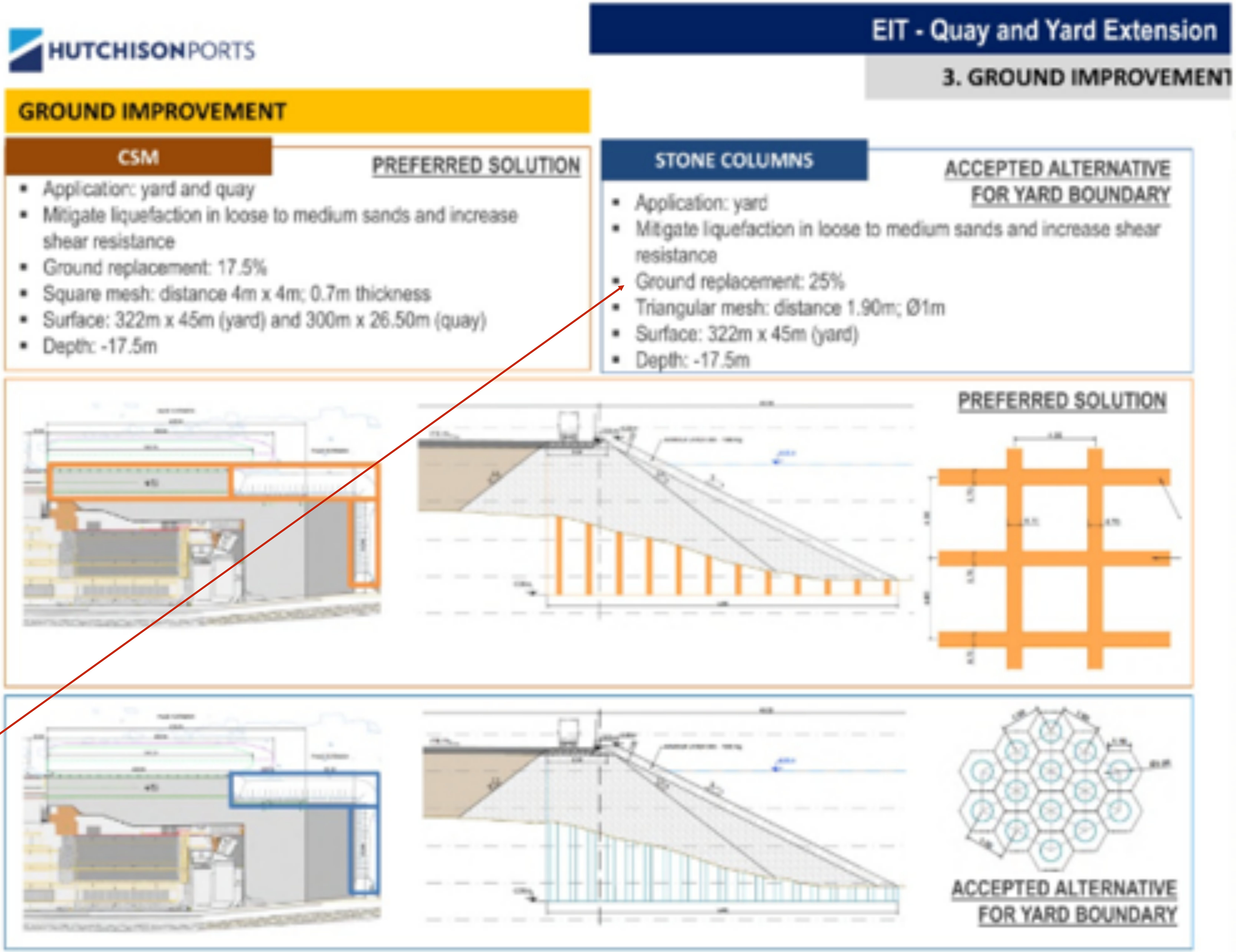
## Project Specific Slides

Project: Ensenada Port, Mexico
Client: Hutchison Ports
Master Planner: Royal Haskoning
Detail Design: Sener, Spain

## Overview

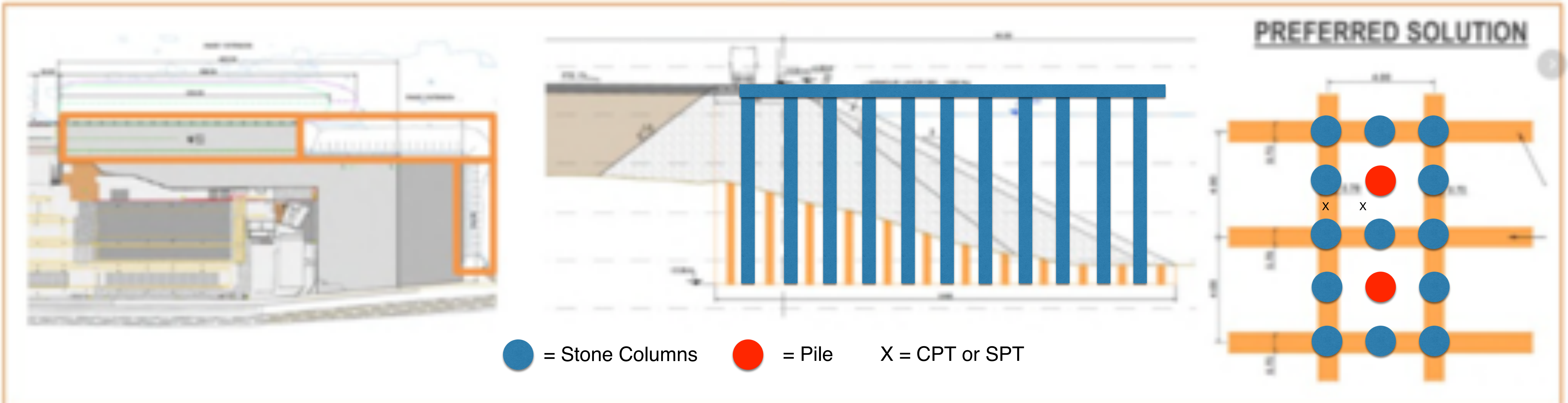
- This is all the information we have per today

Using the Bottom Feed method, clean sand is “dis”-placed and not “re”placed.
If the Sand is already medium dense and has a fines content under 15%, then displacing 25% of the volume is geotechnically impossible. If the sand has a higher than 15% fines content and behaves more like a silt, it could be possible to install 25% Area Ratio but it needs to be seen in trials.



**Soil Mixing: Preferred Solution**

- We do not understand why this method is preferred. It has various disadvantages:
  - Use of cement as compared to no cement with Stone Columns.
  - Min. 30 % reflux of surplus mix material onto seabed -> Environmental issues.
  - Higher cost than Stone Columns.
  - In any future change of geometry the soil mix material, being a very brittle material, would not survive any cutting into it or removal of parts of it.
  - No compaction of the sand by this method.



## Leading Contractors claim that CSM has "O N L Y" 30% excess material reflux

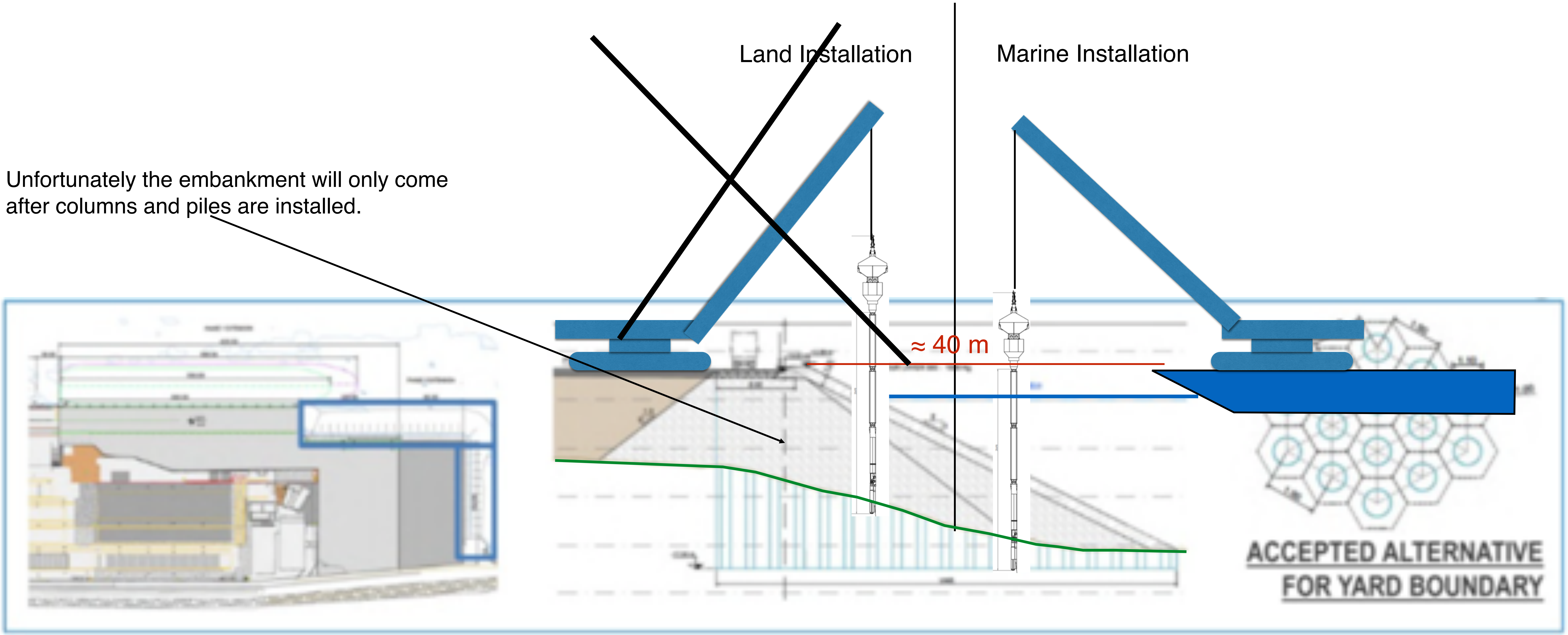
In soil mixing, soil is mixed in place with hydraulic binder.
=> less materials required compared to similar construction methods

**Geomix**
Excess material < 30% of treated volume

**Slurry wall**
Excess material = 100% of treated volume

# Installation: All from barge or part from land ?

Unfortunately the embankment will only come after columns and piles are installed.



# With 300 to crane full project can be done from embankment with Gravel Pump

## Manitowoc 2250
Product Guide

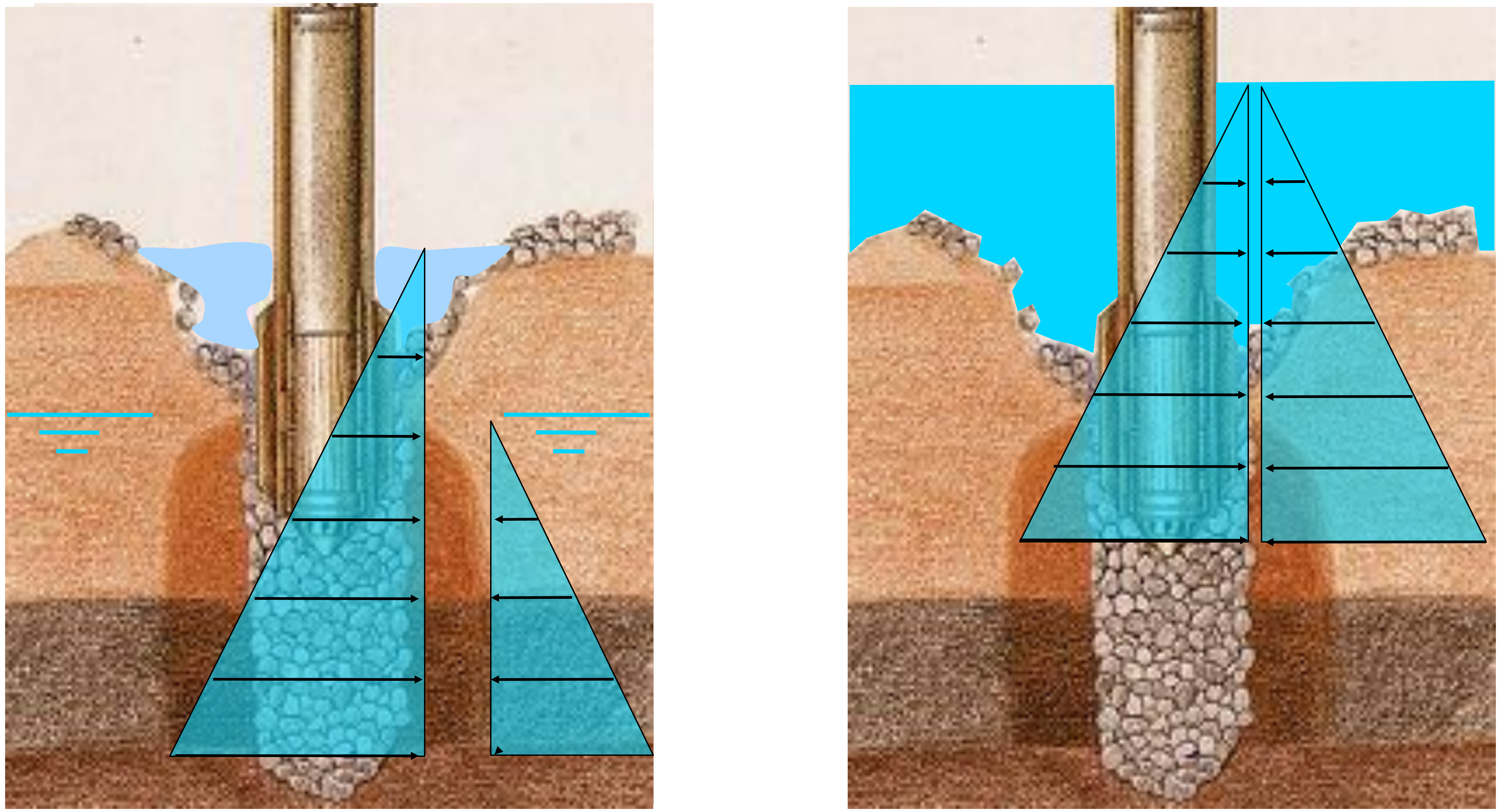
**Features**
- 1300 t (1,433 USt) capacity with RINGER® attachment
- 450 t (500 USt) capacity with MAX-ER® attachment
- 272 t (300 USt) capacity
- 91,4 m (300 ft) heavy-lift boom
- 112,8 m (370 ft) fixed jib on heavy-lift boom
- 122 m (400 ft) luffing jib on heavy-lift boom

**Liftcrane boom capacities - 2250 Series 3**
**Boom No. 44 with heavy lift top**

113 040 kg (249,200 lb) Crane counterweight 54 430 kg (120,000 lb) Carbody counterweight
360° Rating kg (lb) x 1 000

| Boom m (ft) / Radius | 21,3 (70) | 27,4 (90) | 33,5 (110) | 39,6 (130) | 45,7 (150) | 51,8 (170) | 57,9 (190) | 67,1 (220) | 73,2 (240) | 79,2 (260) | 85,3 (280) | 91,4 (300) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5,5 (18) | 272,1 (600.0) | | | | | | | | | | | |
| 7,0 (22) | 239,3 (541.5) | 223,4 (495.6) | 169,8 — | | | | | | | | | |
| 8,0 (26) | 210,8 (469.1) | 210,4 (468.1) | 166,2 (367.0) | 158,8 (350.7) | | | | | | | | |
| 9,0 (30) | 188,2 (408.7) | 187,8 (407.7) | 162,9 (358.2) | 155,9 (343.0) | 135,8 (298.6) | — (284.1) | | | | | | |
| 11,0 (36) | 154,1 (340.9) | 154,2 (340.9) | 153,8 (339.8) | 150,9 (333.2) | 130,7 (288.3) | 124,9 (275.6) | 108,2 (238.8) | | | | | |
| 12,0 (40) | 135,9 (293.0) | 140,7 (304.2) | 140,4 (303.9) | 138,0 (298.3) | 128,4 (282.3) | 123,1 (270.7) | 106,5 (234.2) | 97,7 (214.8) | — (185.8) | | | |
| 14,0 (46) | 109,0 (239.8) | 113,0 (248.7) | 112,8 (248.3) | 112,6 (247.9) | 110,9 (244.2) | 107,4 (236.4) | 103,1 (227.2) | 90,8 (200.2) | 80,9 (178.4) | 73,8 (162.8) | 64,4 (142.0) | 55,9 (123.3) |
| 15,0 (50) | 98,6 (212.6) | 102,5 (221.2) | 102,3 (220.8) | 102,2 (220.4) | 101,9 (219.6) | 99,1 (214.7) | 96,1 (207.8) | 87,5 (191.2) | 78,3 (171.3) | 71,5 (156.5) | 63,4 (138.6) | 55,6 (122.6) |
| 18,0 (60) | 74,7 (160.4) | 79,8 (172.4) | 79,5 (171.8) | 79,4 (171.4) | 78,9 (170.5) | 78,8 (169.8) | 77,7 (168.3) | 74,4 (160.5) | 70,5 (153.9) | 64,4 (140.7) | 58,5 (129.1) | 53,0 (116.0) |
| 22,0 (70) | — (110.2) | 59,4 (137.4) | 60,7 (139.5) | 60,4 (139.0) | 60,0 (138.1) | 59,7 (137.4) | 59,2 (136.4) | 58,4 (133.8) | 56,5 (129.5) | 55,4 (125.9) | 55,0 (125.0) | 48,4 (108.3) |
| 24,0 (80) | | 51,6 (110.7) | 54,0 (116.6) | 53,8 (116.1) | 53,3 (115.1) | 53,0 (114.5) | 52,5 (113.4) | 51,9 (112.0) | 50,9 (110.2) | 50,1 (108.3) | 48,9 (105.8) | 46,4 (101.7) |
| 28,0 (90) | | | 42,8 (97.6) | 43,6 (99.0) | 43,2 (98.0) | 42,8 (97.3) | 42,3 (96.2) | 41,7 (94.8) | 41,2 (93.7) | 41,3 (93.6) | 40,2 (91.1) | 38,8 (88.0) |
| 30,0 (100) | | | 37,8 (80.9) | 39,6 (85.6) | 39,2 (84.7) | 38,9 (84.0) | 38,4 (82.9) | 37,8 (81.5) | 37,2 (80.3) | 37,3 (80.5) | 36,7 (79.5) | 35,4 (76.6) |
| 34,0 (110) | | | | 32,1 (72.7) | 32,9 (74.1) | 32,6 (73.4) | 32,1 (72.3) | 31,4 (70.8) | 30,9 (69.6) | 30,9 (69.8) | 30,7 (69.2) | 29,8 (67.2) |
| 36,0 (120) | | | | 28,7 (61.1) | 29,9 (64.1) | 30,0 (64.7) | 29,5 (63.6) | 28,8 (62.1) | 28,3 (60.9) | 28,4 (61.1) | 28,1 (60.5) | 27,5 (59.4) |
| 42,0 (140) | | | | | 21,9 (46.3) | 22,9 (49.1) | 23,2 (49.5) | 22,6 (48.8) | 22,1 (47.6) | 22,2 (47.8) | 21,9 (47.1) | 21,3 (45.4) |
| 50,0 (160) | | | | | | — (35.5) | 15,8 (37.1) | 16,0 (37.4) | 15,8 (37.0) | 16,3 (38.0) | 15,2 (35.8) | 13,9 (32.8) |
| 56,0 (180) | | | | | | | | 11,8 (27.8) | 11,7 (27.4) | 12,2 (28.6) | 11,2 (26.4) | 9,8 (23.3) |

## Why the Blanket Method doesn't work!



Left Sketch: The Wet Top Feed stone column installation method works only if there is a differential water head that stabilizes the water filled ring room around the vibroprobe. Only then can the gravel from the ground surface safely reach the tip of the vibroprobe. Otherwise the gravel feeding may get blocked where the walls of the ring room have collapsed.

Right Sketch: Under water there is no differential water head between the ring room around the vibroprobe and the rest of the soil profile. Therefore the Wet Top Feed method is not recommended for offshore applications.

# Gravelpump GP1

The Gravelpump GP1 is an attachment for the installation of Bottom Feed Stone Columns.

It pneumatically transports gravel via 6-inch sludge hoses from a defined volume blow tank to the Bottom Feed Stone column rig.

## First Questions

- Who can we contact to bid this project?
- Is the Main Contractor already selected?
- Soil information missing: Need grain size curves of the soil that is called “sand” in the one page we got. Also: SPT or CPT if they have.
- Geometries: What is the soil profile at the time when the columns shall be installed? Are they planning to install first ALL columns from water or as we sketched it in a previous slide, part from land, part from water?
- Time Table: Start of works? Allowed work duration?
- Technical Specs: Are there any EQ design requirements that we can Design/Build for, or must we just install that ø1.0 m column in 1.90 m grid? Typically, in soils with variable consistency and density an average target diameter and not a constant diameter is specified.

## Missing Information

- Performance Specification
  - Maybe such Specification defines trials and how they determine the final grid and ø.
- Soil information
  - Field: Sounding profiles (SPT, CPT, other), boreholes
  - Lab: Soil types (fines content, clay content), grain shape (round, edgy)
- Project characteristics
  - Wind and wave data to evaluate type of barge and type of vibro equipment.
  - Earthquake design Magnitude Mw and Peak Ground Acceleration (PGA) to evaluate if Performance Specifications have ”room for interpretation” if needed. For example: There could be hard layers but the Spec says to install constant diameter, but it also says that goal is mitigation of liquefaction risk. -> Possibly diameter can be lower in already hard/dense layers.
- Schedule
  - Bidding date, Start of compaction works, milestones, finish date.

## Discussion

- PGA = 0.40 g , Mw ≈ 6.0
- Soil Type: Launching complementary survey in next months. Until now sands we want to treat fines percent 15% to 30%. Have no PSD curves yet. Expect no compaction or little compaction only.
- Vibrocompaction was discarded due to high fines content.
- Aim of the treatment: 1) Increase overall slope stability 2) Liquefaction mitigation. Prelim. Design : Liquefaction was relevant.
- Issue in design: How to implement the stone columns with the piles in-between?

# Offshore Vibro Compaction

# (Vibroflotation)

# Offshore Vibro Compaction
## Anse du Portier, Monaco

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Two Betterground TC1 units with B41 vibroflots worked in the port of Monaco to install over 2200 vibro compaction points of up to 30 m length in up to 30 m water depth. The compaction was accomplished in a cobble fill with particle sizes of up to 300 mm. Soil friction along follower tubes was helped to overcome by specially designed extra weights of over 15 tons located in the top portion of the rigs.

## Vibro Compaction at Port of Calais, France

## B41 Vibroflot with Tandem setup

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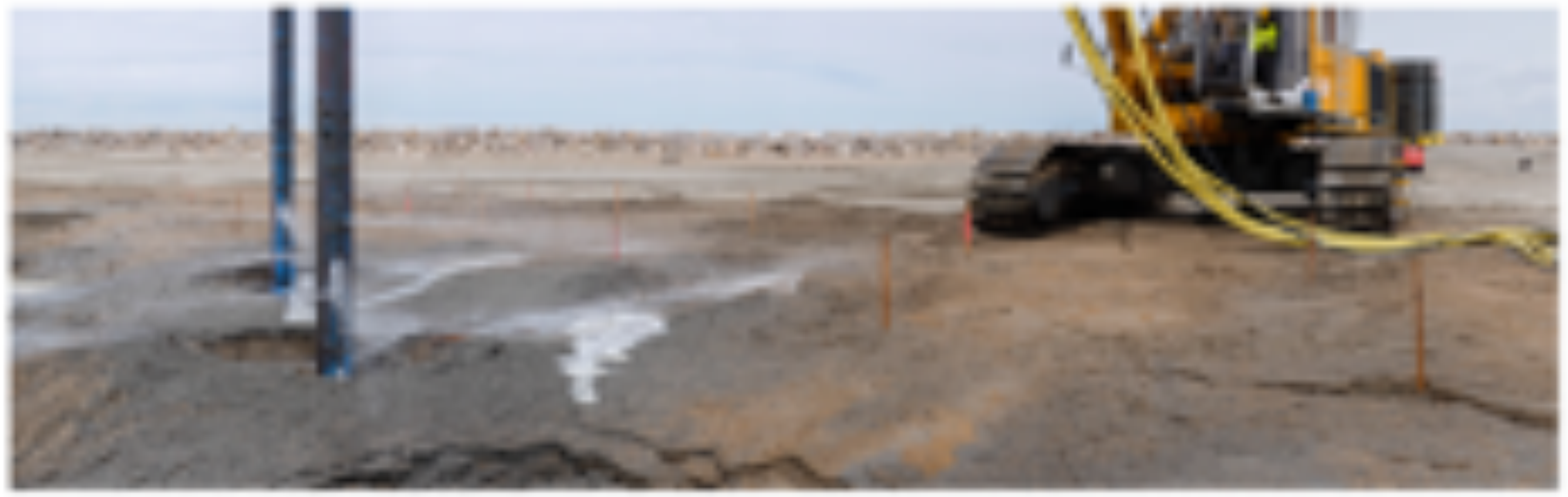
Over 180,000 lineal meters of Vibro Compaction to 17 m depth have been installed by B41 Tandem Vibro Compaction rigs. Installed triangular compaction grids ranged from 4.40 m to 5.10 m. Quality was tested with CPT and DMT (Dilatometer Test).

# Quality Control

- Visual inspection
- Site records
- Cone penetration tests
- Monitoring of induced settlement
- Load tests

# Control during Installation

**Puerto Rico, Convention Centre**

# Dug out stone columns

## Quality Control Recorder turned into Operator Guidance System

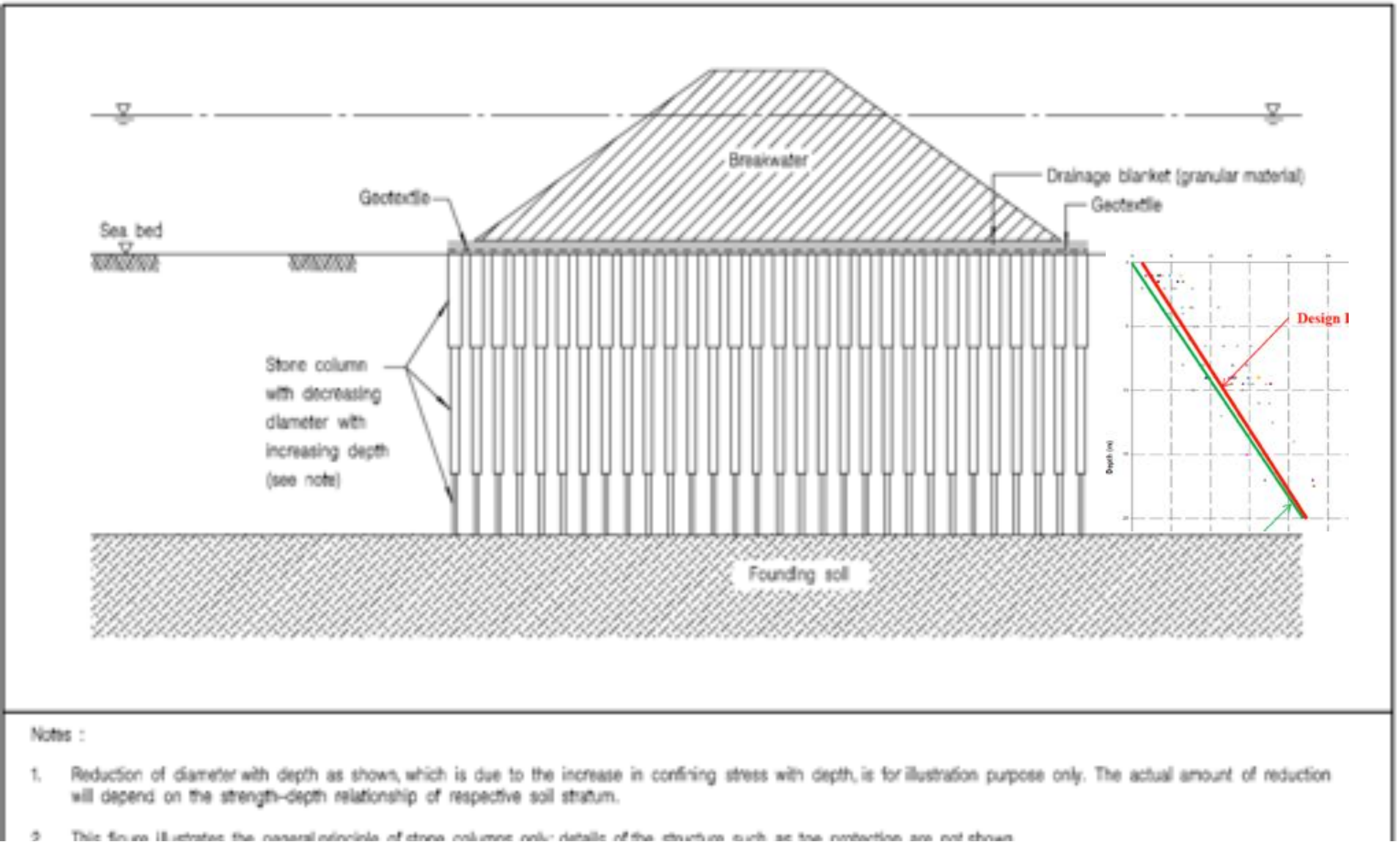
- Operator follows the up/down arrow.
- The program decides on the column diameter,  based on input from the Engineer and controlled by the Ampere response.


Depth

# Variable Diameter Stone Columns and their particular Quality Control Requirements

## Tapered Stone Column are recommended in HK Port Works Design Manual

- The Hong Kong marine clay has usually undrained shear strength of around 5 to 10 $kN/m^2$ in the top 5 m and 10 to 20 $kN/m^2$ from 5 m to 15 m depth. This means between seabed and 15 m depth we can have a difference in stiffness of a factor of 2 to 4. This suggests that constant diameter stone columns are not well adapted to local soil conditions. Instead, columns should become smaller with depth as this is indicated in one of the Hong Kong Port Design Manuals.



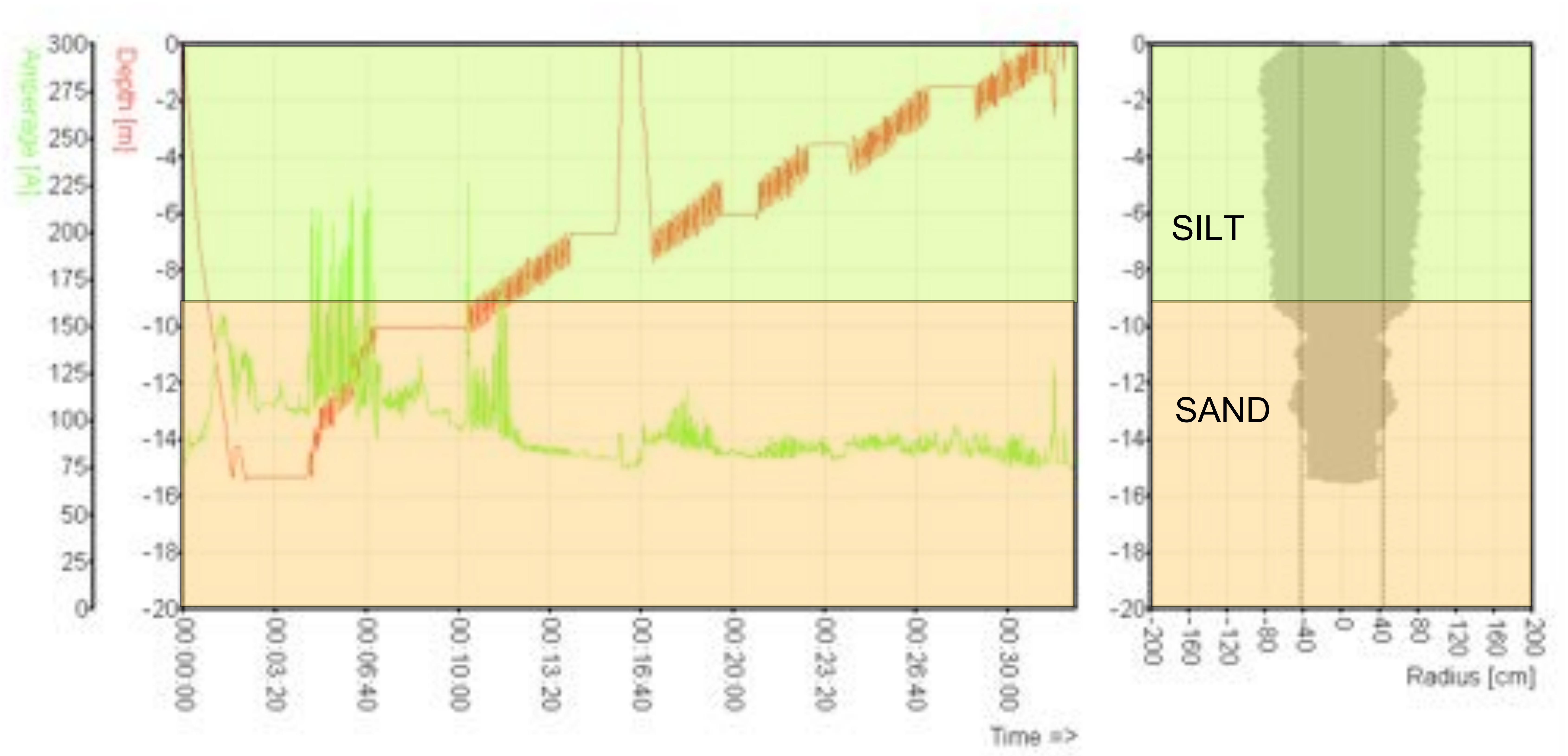

Sketch on left from : **PORT WORKS DESIGN MANUAL PART 4**
**Guide to Design of Seawalls and Breakwaters**

Weak soil = big columns

Average soil = average columns

Stiff soil = small columns

## Variable Diameter Stone Columns based on Soil Profile but detected by Ampere Response



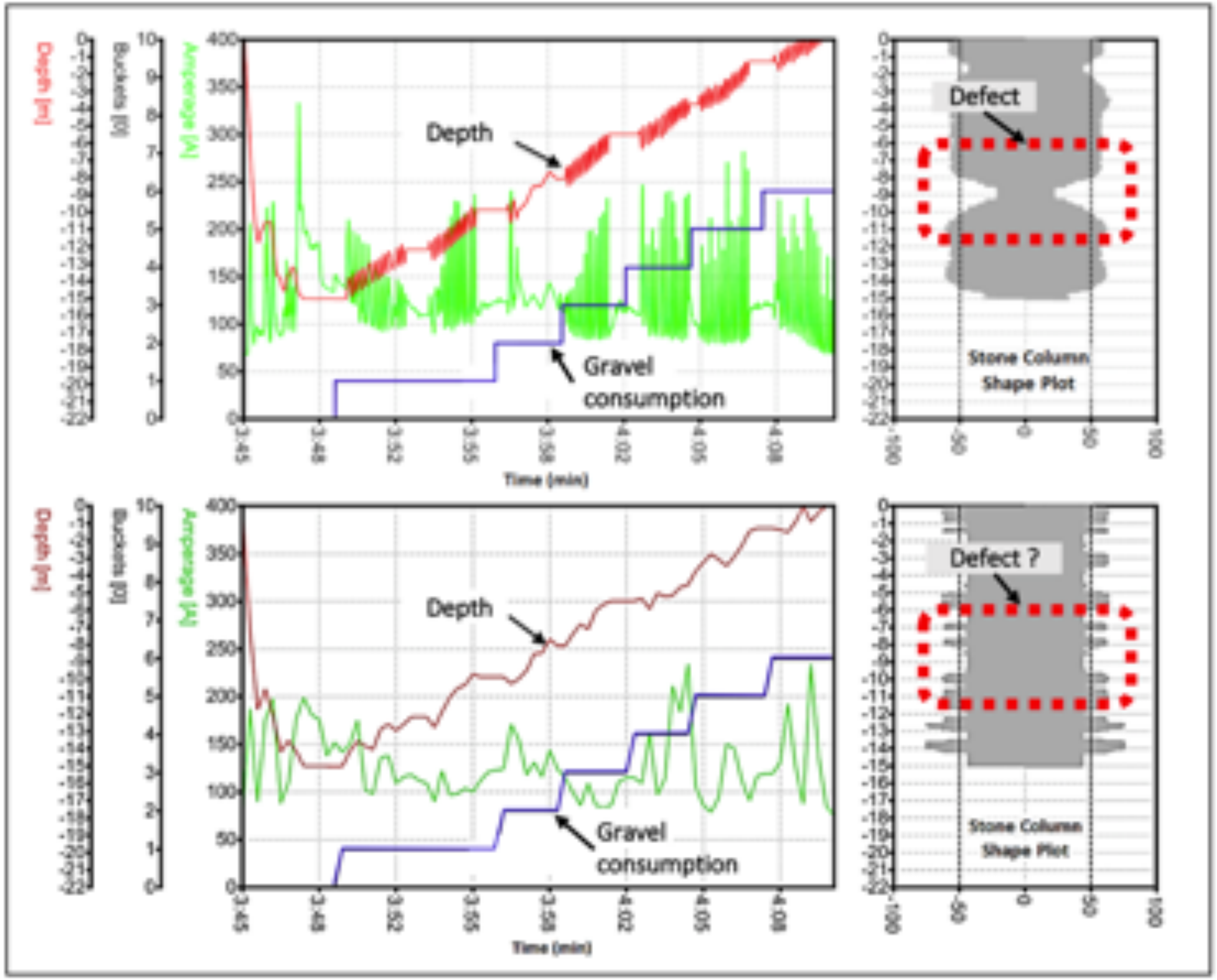
## Time Interval of Data Logging for Stone Columns: 1 Reading per Second is a good rule

✓ Logging step

= 1 second!

× Logging step

= 20 second!



**Definition for "Dry Bottom Feed Stone Columns"**

- The Bottom Feed system was originally developed in Germany in the late 1960ies to early 1970ies for projects not deeper than 12 m.
- The target of such development was to avoid for inner city projects problems with water sludge that was regularly produced by the Top Feed method.
- "Dry" Stone Extraction means that compressed air is used in a tremie pipe that transports gravel to the tip of the vibroflot.
- "Dry Bottom Feed" does not mean waterless penetration of the vibroflot to depth.
- "Marine (Dry) Bottom Feed" includes from case to case transport of stones in hoses using water-stone slurry or in same hoses but using air-stone mix without water. In both cases water and/or air jetting at the tip of the vibroflot are used to aid penetration.

# Matrix Water Depth VS Treatment Depth VS stone transport air or water

| Water Depth [m] \ Treatment Depth [m] | 0-10 | 10-20 | 20-30 | >30 - 70 m*) |
|---|---|---|---|---|
| 0 - 10 | Water | Water | Air | Air |
| 10 - 20 | Water | Water | Water | Air |
| >20 m - 99 m | Water | Water | Water | Water/Air |

IF (Treatment Depth - Water Depth > 25 m) THEN use Air

*) so far world record