References

Over the last 20 years, members of our team have bee involved in the following ground improvement projects, worldwide:

Hong Kong Border Crossing Facility, Hong Kong
Port of Patras, Phase III, Greece
BART Trans Bay Tube Retrofit Trial Stone Columns, USA
Central Reclamation, Hong Kong
Changi Airport, Singapore
Chek Lap Kok Airport, Hong Kong
Choctaw Point Cool Terminal, Mobile, USA
Hanoi-Haiphong Expressway, Vietnam
Kaiser Hospital, Irvine USA
Lausitz Coal Mine Restoration, Germany
Leroy Selmon Expressway, Tampa USA
Light Rail Transit, Denver, USA
Muscat Airport, Oman
Norderney Ferry Terminal, Germany
Palm Jumeirah, Dubai, UAE
Palm Jebel Ali, Dubai, UAE
Palm Deira, Dubai, UAE
Pasir Panjang Container Terminal, Singapore
Pemex Minatitlan Refinery, Mexico
Penny's Bay Reclamation (Disneyland), Hong Kong
Peribonka Dam, Canada
Pier 400 Phase II, Port of Los Angeles, USA
Port of Patras Expansion, Patras, Greece
Port of Stockholm Extension, Sweden, France
Puerto Rico Convention Center, Puerto Rico
Quay 4, Jebel Ali Freezone, UAE
Richards Bay Coal Terminal Extension, South Africa
Rio Bianco Dam, Puerto Rico
Tai Ho Expressway, Hong Kong
West Kowloon Expressway, Hong Kong
World Islands Breakwater, Dubai, UAE
Yacht Haven Grande, St Thomas

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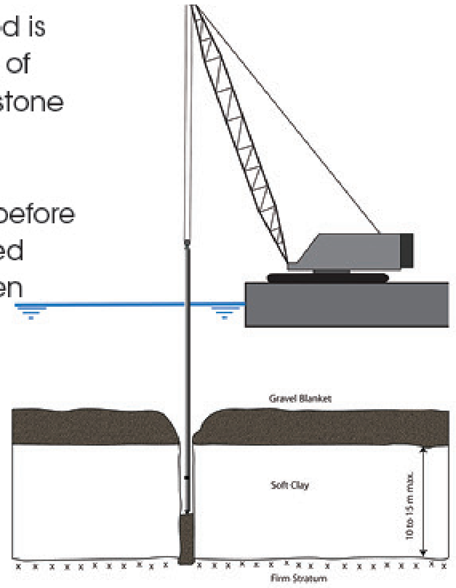
Engineered Ground Improvement

OFFSHORE GROUND IMPROVEMENT

THE BLANKET METHOD

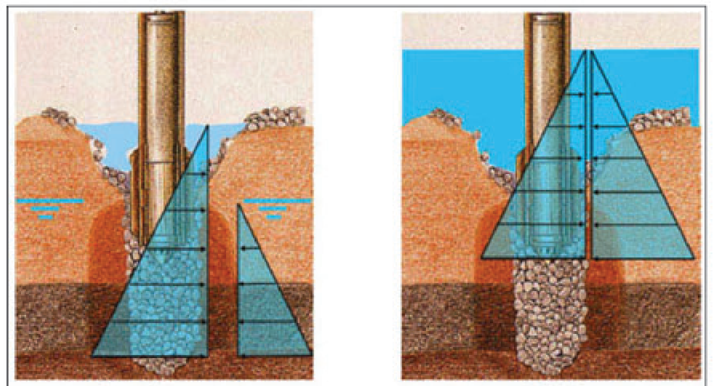
The blanket method is the oldest method of installing offshore stone columns.

It had been used before reliable bottom feed methods have been invented.



Shortcomings of the blanket method:

- In the Top-Feed technique on land, an annular specie is kept free around the vibroprobe as a result of the stabilizing effect of a differential water head between the annular space and the surrounding ground. Such difference in water head does not exist under the sea.

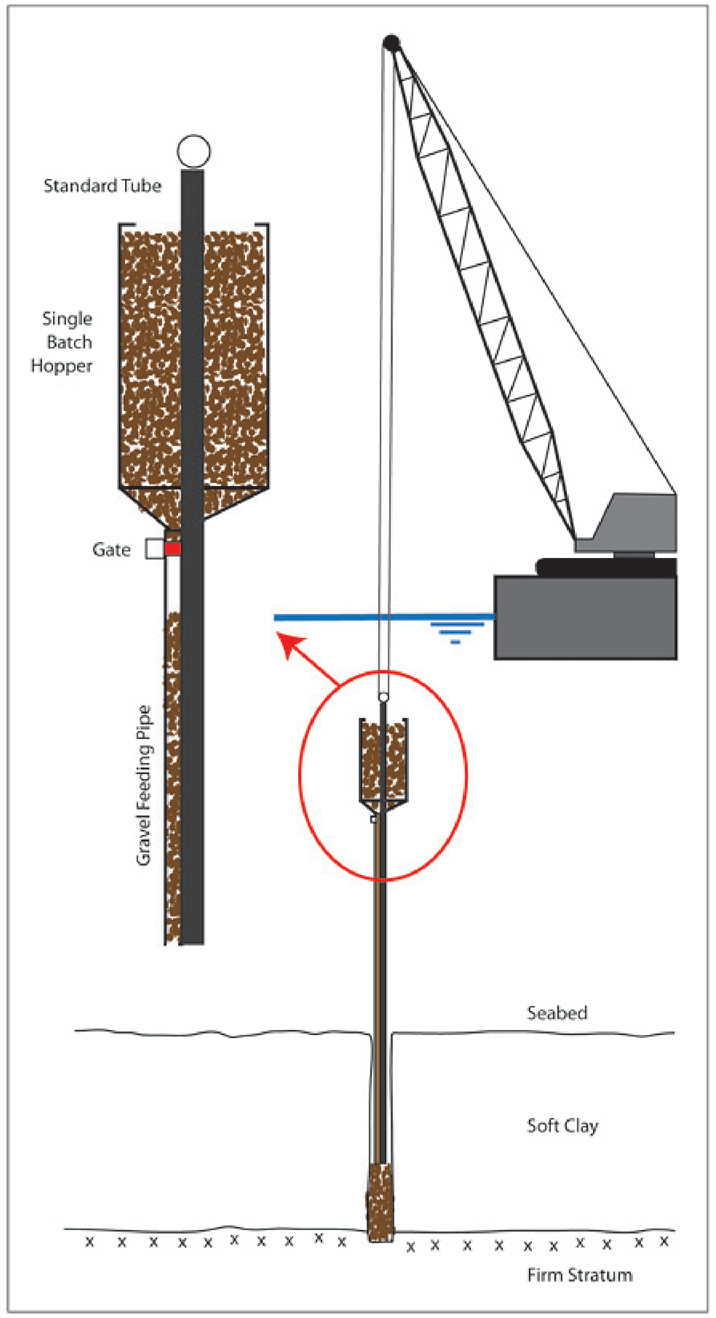


On shore — Offshore

- Locally softer ground layers may require a higher stone consumption than the quantity of stones readily available in the blanket around the column under construction. This may result in poorly treated zones or even non-continuous columns.

- No measurement of the variations of stone consumption over depth in an individual stone column, with no possibility to check that the minimum diameter required by design is really achieved over the column length.

THE OPEN TANK METHOD



Shortcomings of the open tank method:

- This method allows extremely inaccurate measurement of the quantity of stones remaining in the hopper when the column is completed

- No measurement at all of the variation of the stone consumption over depth in an individual stone column, with no possibility to check that the minimum diameter required by design is really achieved over the whole column length.

Pressure Chamber Injection System (PCIS)

The PCI as shown in the sketch is the newest evolution of marine bottom feed stone column installation equipment.

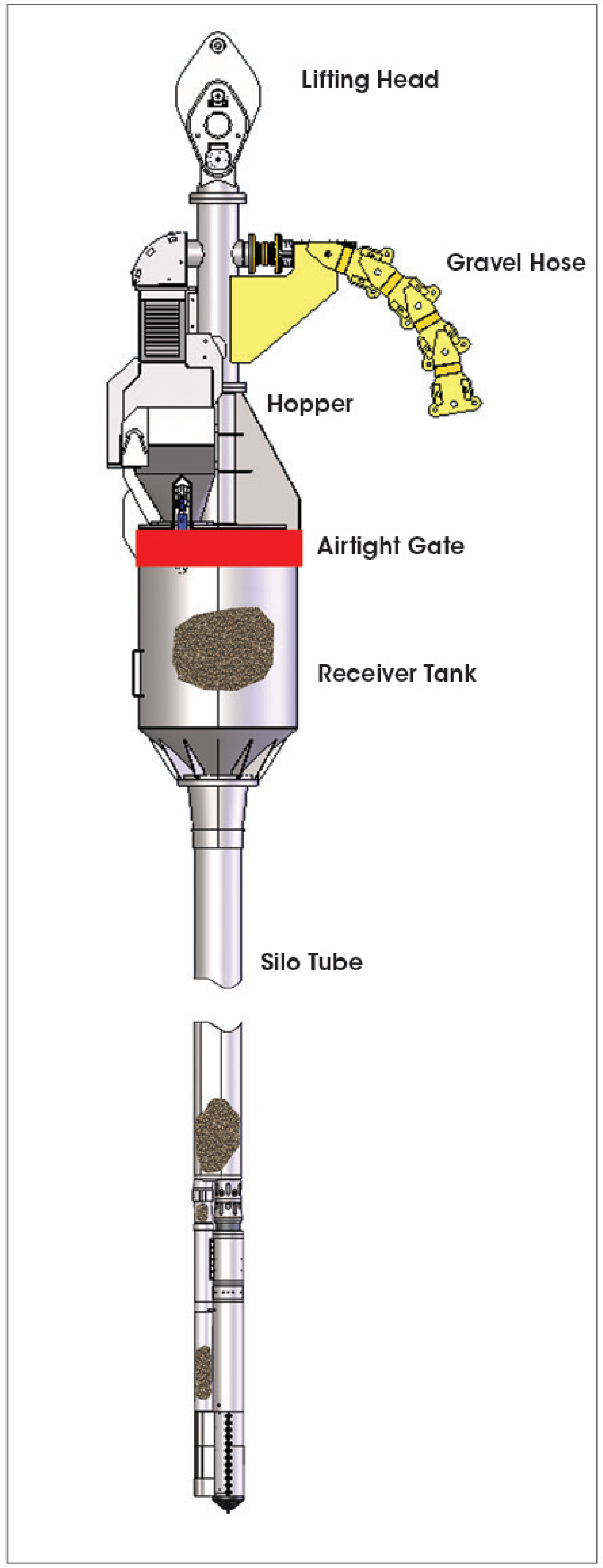
In the example shown here the gravel is transported via a 6 inch flexible gravel hose. In a variant of this system the gravel can alternatively be placed by a bucket into the hopper.

Key to the the high quality installation capability of the PCIS is the airtight gate on top of the receiver tank that locks the gravel from atmospheric pressure and puts it under an over-pressure that ranges between 2 to 6 bars and is dependent on the operating depth of the rig.

Under the applied excess air pressure in the interconnected chamber consisting of receiver tank, silo tube and tremie pipe, gravel is injected into the soil at the tip of the tremie pipe near the vibroprobe's nose, hence the name "pressure chamber injection system".

Compared with the Single Large Tank system, the advantage of the PCIS is that below the gate there is always exactly ONE full batch of gravel filled in with each opening of the airtight gate. This not only allows for less number of open-close cycles of this gate, but also for an as exact as possible recording of gravel batches placed in the ground at defined depths.

In a so called "Double Lock" variant of the same system, two airtight gates enclose the receiver tank on it's top and bottom.

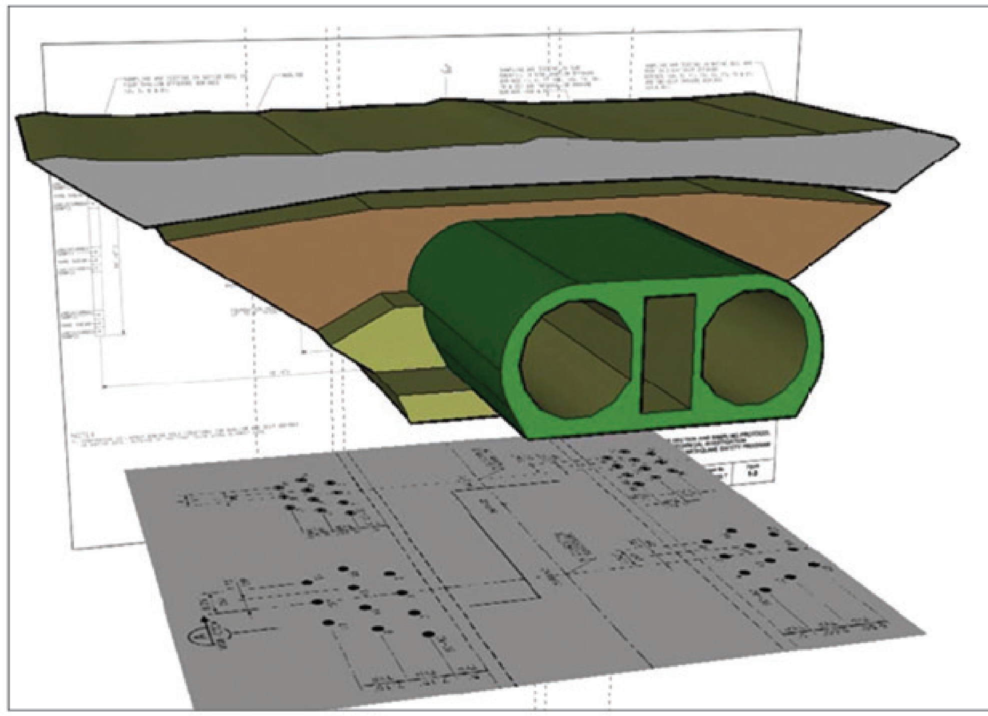


BART Trans Bay Tube Retrofit

In 2006 the Bay Area Rapid Transit Authority (BART) has procured the pilot trial for the retrofit of the subway tunnel that connects San Francisco with Oakland since the late 1960s to a joint venture of the three companies Traylor, Hayward Baker and Soletanche Inc.

For the specialty know-how of marine vibro compaction and marine stone columns the JV employed the resources of The Vibroflotation Group supported by Dr. Wilhelm Degen on site as a specialty consultant.

The rig was equipped with D-GPS and Gyroscope navigation tools to assure the correct location of stone column positions in over 30 m of water.

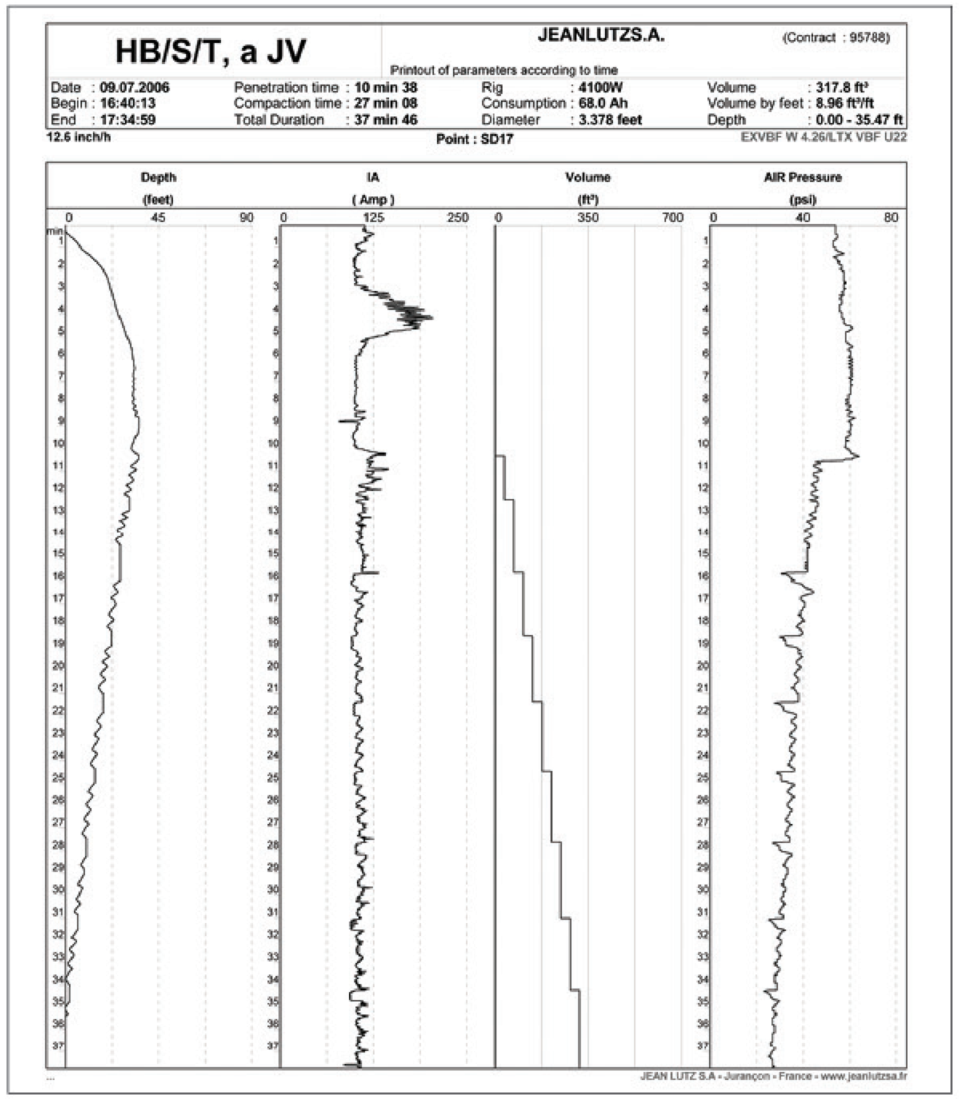


The sketch to the left shows the trial grid locations.

Some Stone Columns had to be installed only 5 ft (1.52 m) away from the tunnel in which subways were travelling at the time of stone column installation.

Quality Control

The quality control recordings showing Ampere of the vibroprobe motor and column diameter over depth were essential for later interpretation of the trial results.

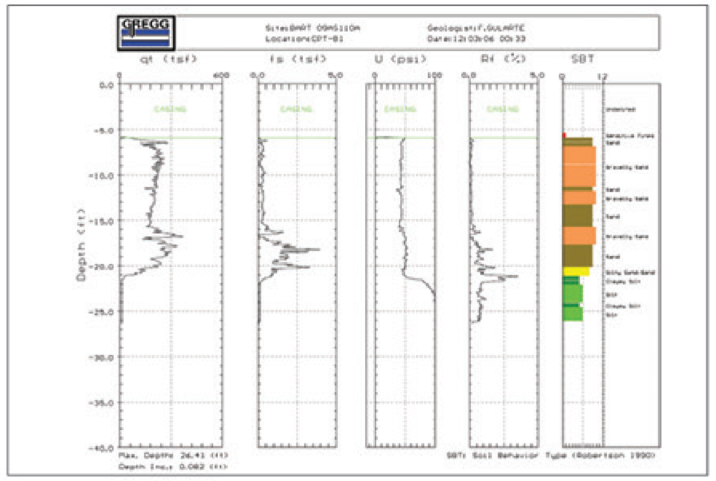


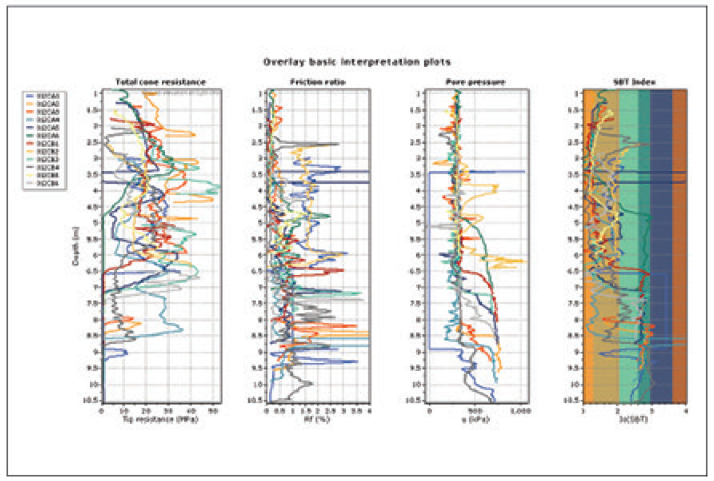
Marine Wildlife Protection

The behavior of seals was observed during the installation of stone columns by a scientist from a nearby marine research facility. No negative impact due to the operation of the stone column barge was observed.

CPT testing

After installation of the trial stone columns several offshore CPTs have been conducted. The left graph demonstrates that compactable sand and gravel layers improved to values of 250 tsf to 300 tsf (25 MPa to 30 MPa). The summary plot to the right gives an overview over all Post CPTs in the test section. It reveals that in the top 6 m the sands are cleaner (Ic-values mostly smaller 1.0) while below the situation is more irregular, with some Ic-values indicating sandy and clayey silt.





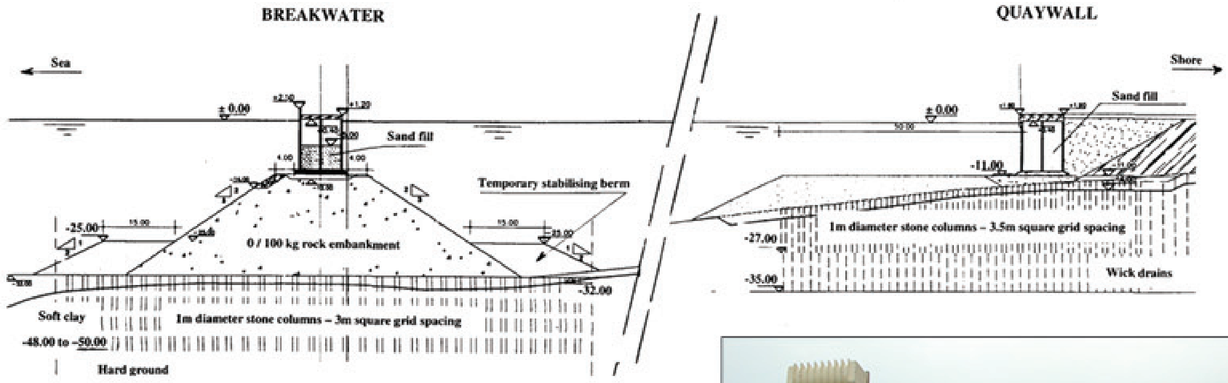
PORT OF PATRAS LIQUEFACTION MITIGATION

Liquefaction mitigation
In the 1990s soil liquefaction caused by an earthquake destroyed parts of the Port of Patras, it needed therefore no convincing to install stone columns for liquefaction mitigation on this project.

Below: Aerial photo shows the completed project with the wave breaker seawalls and the new berth structures.

QUANTITIES:

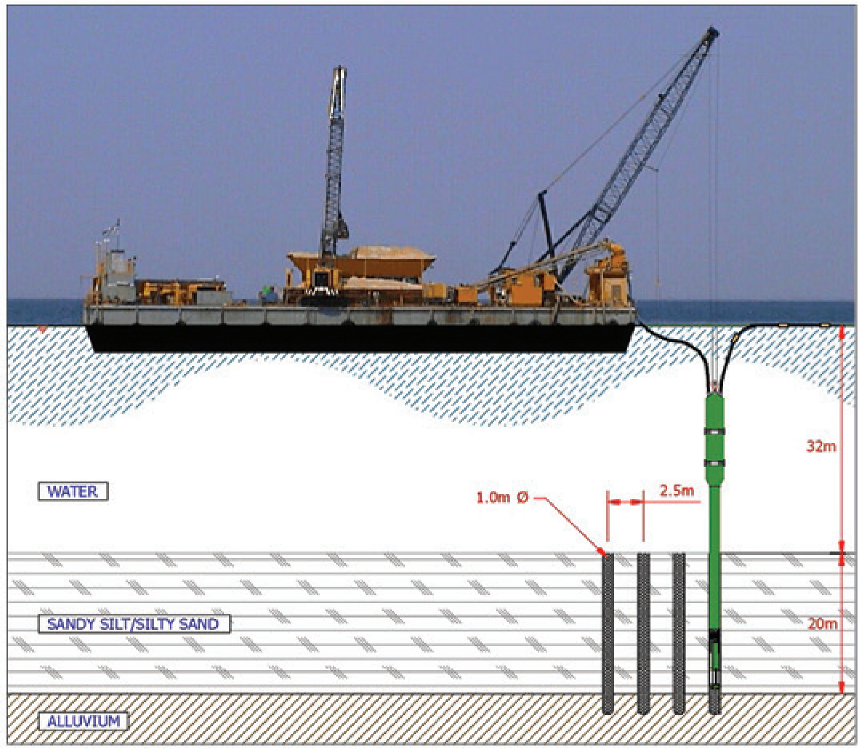
Breakwater:
4'830 No. stone columns, 16 m average length, 77'280 lm, 60'665 m3 (1 m diameter), square spacing 2.7 m.
Quaywall:
3'073 No. stone columns, 10 m average length, 30'730 lm, 24'123 m3 (1m diameter), square spacing 3.3 m.

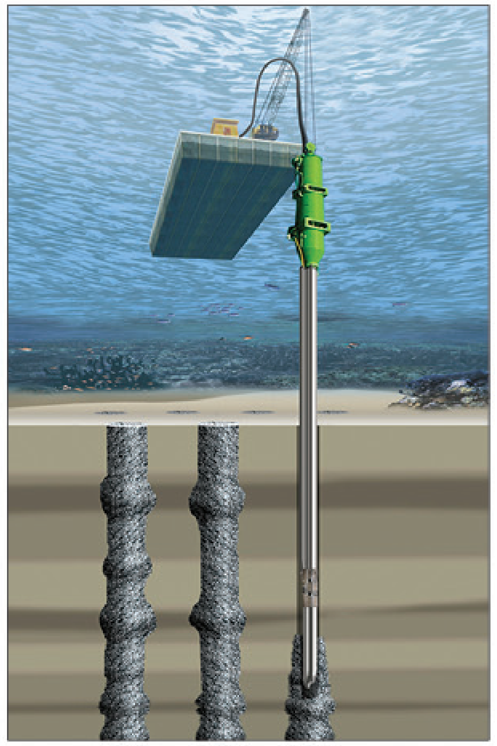


Barge setup
The barge of approx. 55 m x 35 m carried the 150 to main crane that hoisted the vibroprobe.

The photo on the bottom left shows that the gravel supply was organized via silos and two conveyor belts that filled the gravel pump's hopper. The silos where refilled using a small auxilliary crane that unloaded the gravel barges into the silos on the main barge.

SEAWALL CROSS SECTION WITH STONE COLUMNS





Submerged receiver with air discharge to the surface
The underwater receiver tank with "schnorchel hose" for the pressure discharge of excess stone transport air to the surface was invented in 2000 by Alexander and Wilhelm Degen and patented in some countries.

For sites in deep waters in relation to the soil treatment depth, this system allows the classic double lock gravel pump to pneumatically transport the stones into an underwater receiver without counteracting water pressure while a receiver above water traditionally simply releases the excess air via a short tube or a venting cover on top of the receiver.

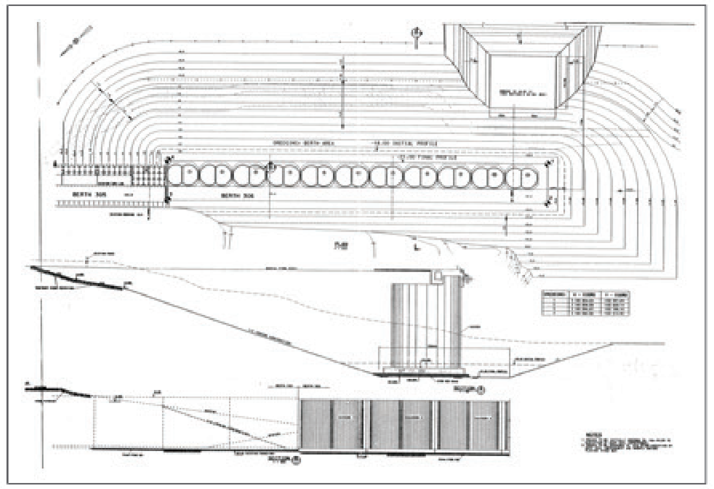
Current new developments like water transport of the stones can avoid the relatively expensive pneumatic stone transport. The patented air discharge hose is now obsolete.

PORT OF RICHARDS BAY, EXTENSION OF BERTH 306

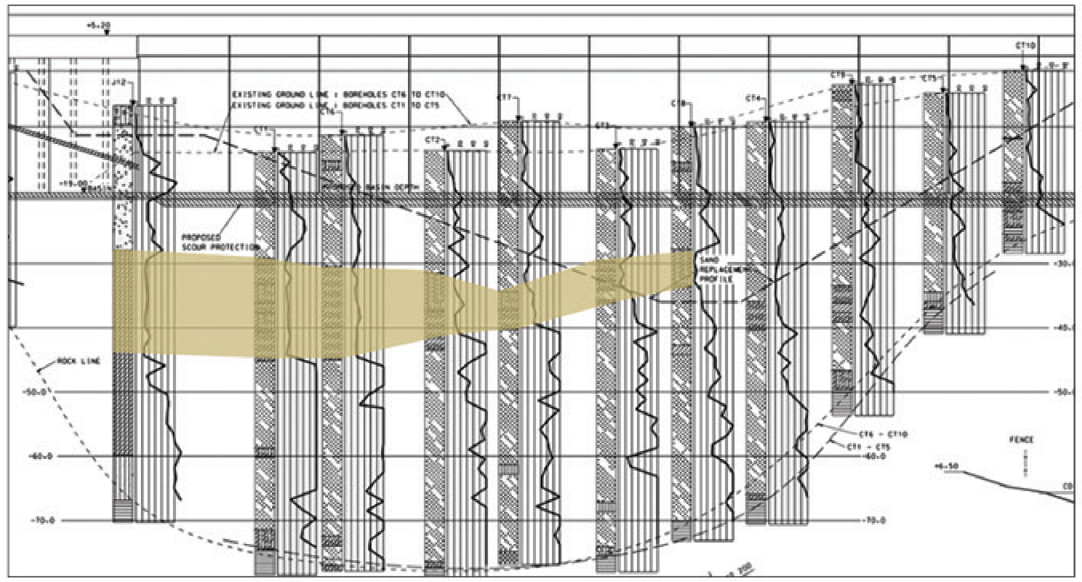
Geology

The site crosses a palaeo-channel which has been formed in the Cretaceous bedrock. A portion of the upper channel in-fill material comprising high proportions of silt and clay has been removed and replaced with inert soils by dredging methods. However, not all the silt and clay material was removed, according to the borehole records. The replacement.soil is essentially a sand with varying proportions of silt and clay. The water depth in the area of the quay wall is variable, to a maximum in the order of 15m.

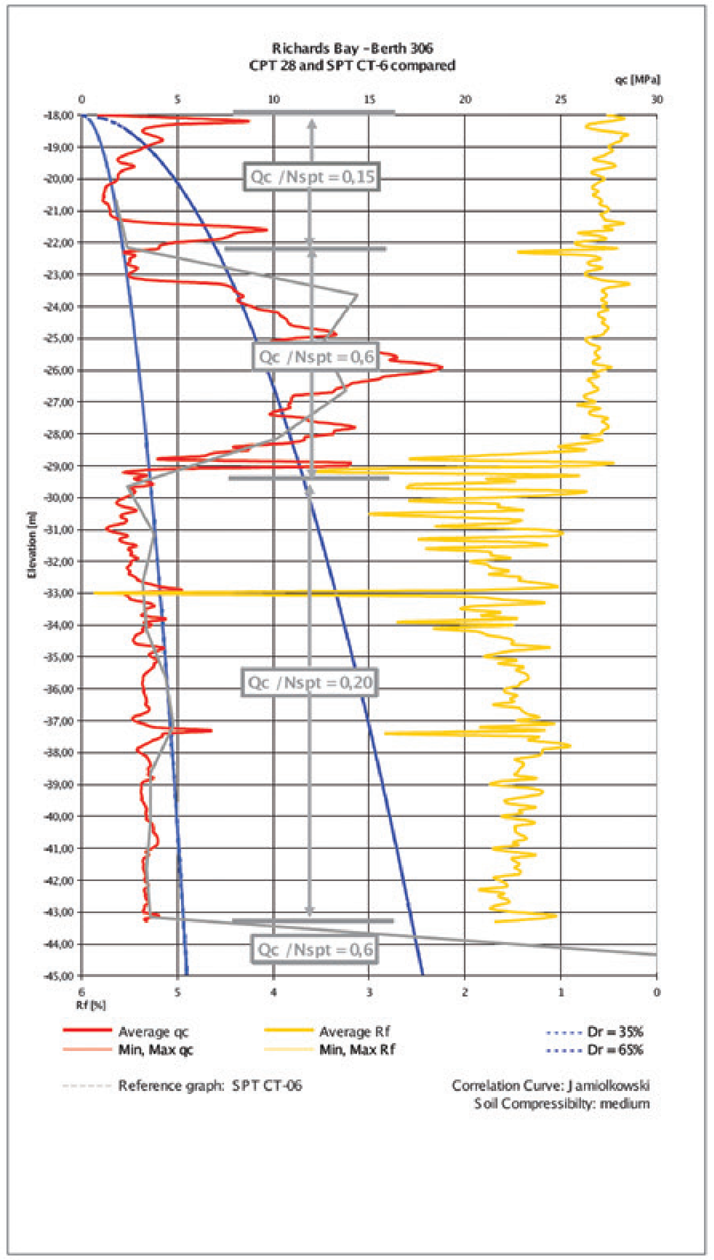
Below: The plan view shows the existing berth 306 and the planned extension.



Right: View on the barge from above
Rigging up the Bottom Feed Stone Column rig on a confined space of a barge requires experience. This photo was taken from the top of the auxilliary crane



The graph on the left shows the soil profile and in particular the brown shaded zone identifies the soft silty layer that requires stone columns.



Left: CPT and SPT comparison. The left CPT shows the qc-values (red) and the corresponding friction ratio in percent (yellow).

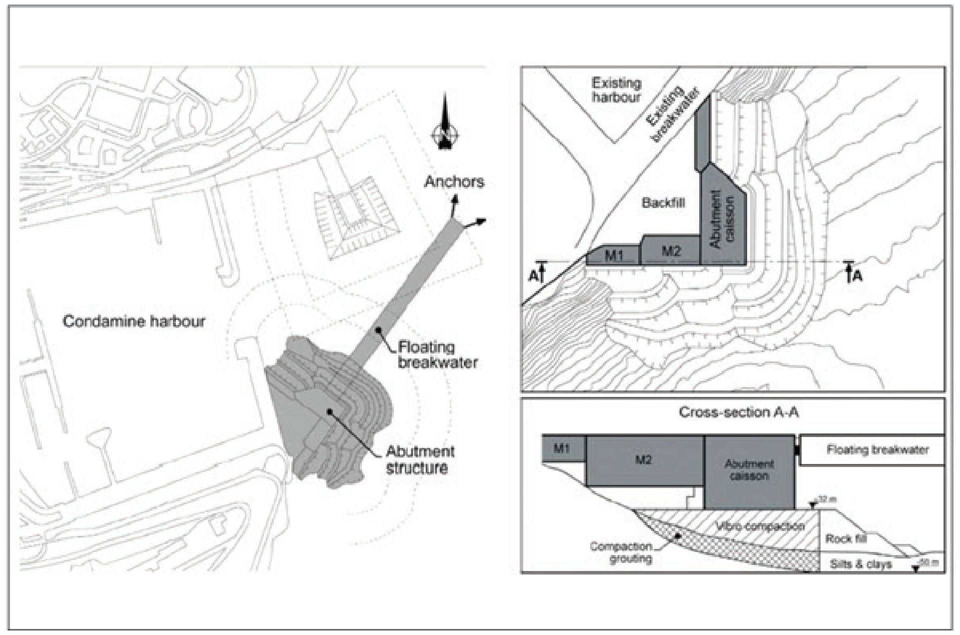
The two blue curves are the Dr=35% and Dr=65% relative density after Jamiolkowski.
In the upper sands (friction ratio <1%) there are zones with relative density of 35% and even smaller.
In the lower silts (below elevation -29) the concept of relative density does not apply but stone columns can be useful as reinforcement for settlement reduction. Interesting is also the correlation between SPT and CPT.

The gray values show that there is no consistent correlation of the full depth range, not even within the same soil type.

As experienced from many reclamations before, the two sounding methods do not correlate as well as one would expect from literature.

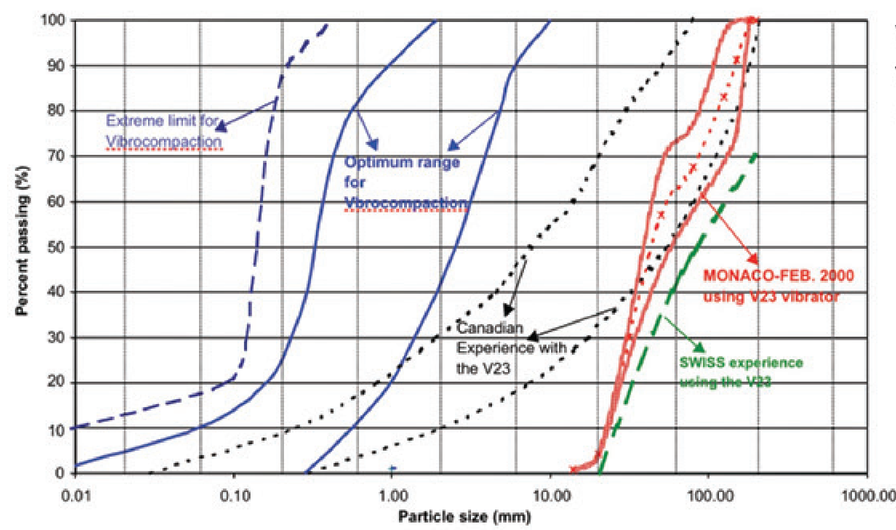
FLOATING BREAKWATER: PORT HERCULES, MONACO

Offshore Vibro Compaction
For the moveable storm barrier for Port Hercules in Monaco a rubble fill under the main gate hinge had to be vibro compacted from offshore.



QUANTITIES:

Vibro Compaction of a 15 m thick cobble fill from a barge through 32 m water depth.
Vibro Compaction Phase 1: 26,010 m3
Vibro Compaction Phase 2: 66,180 m3

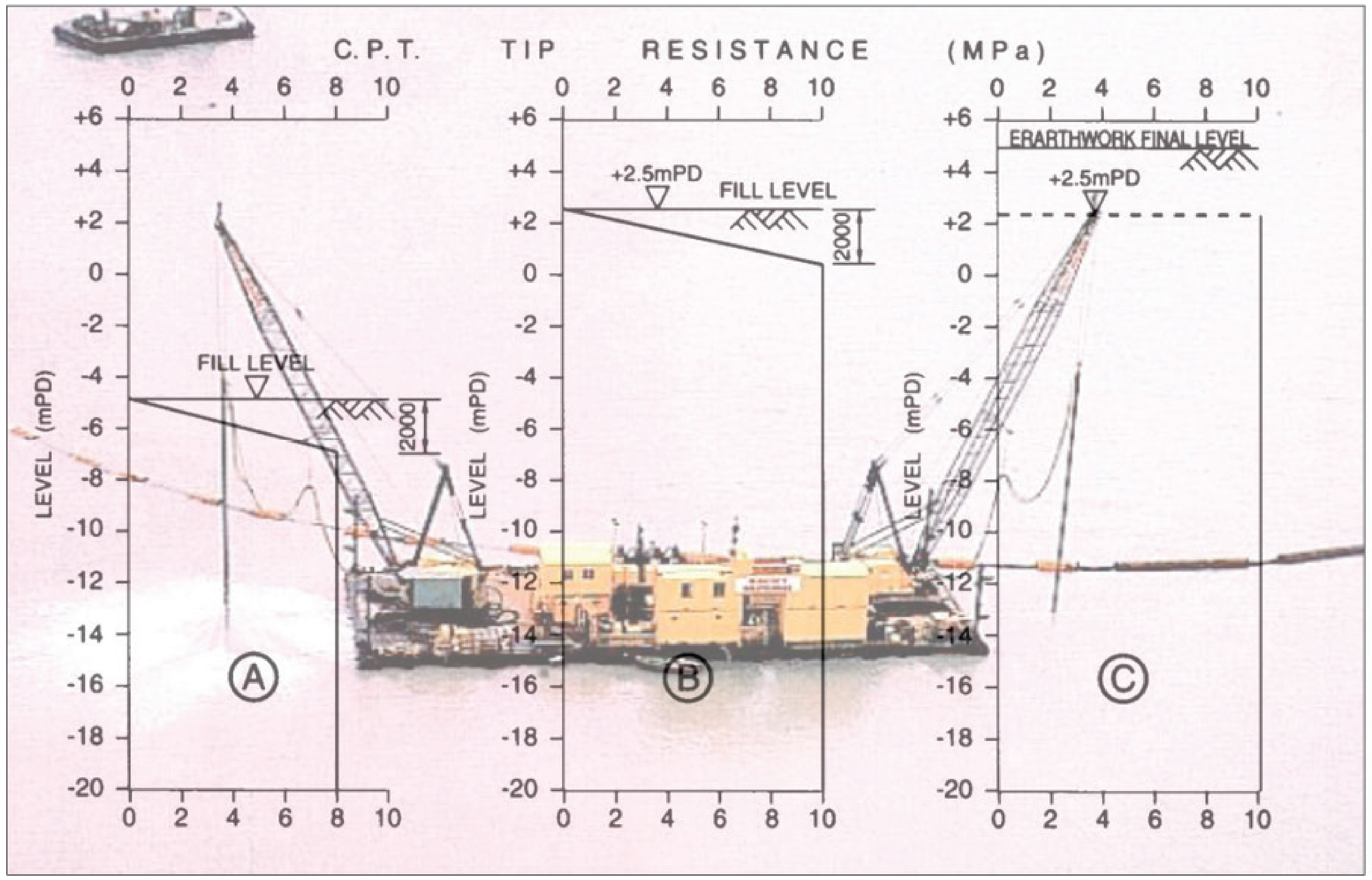


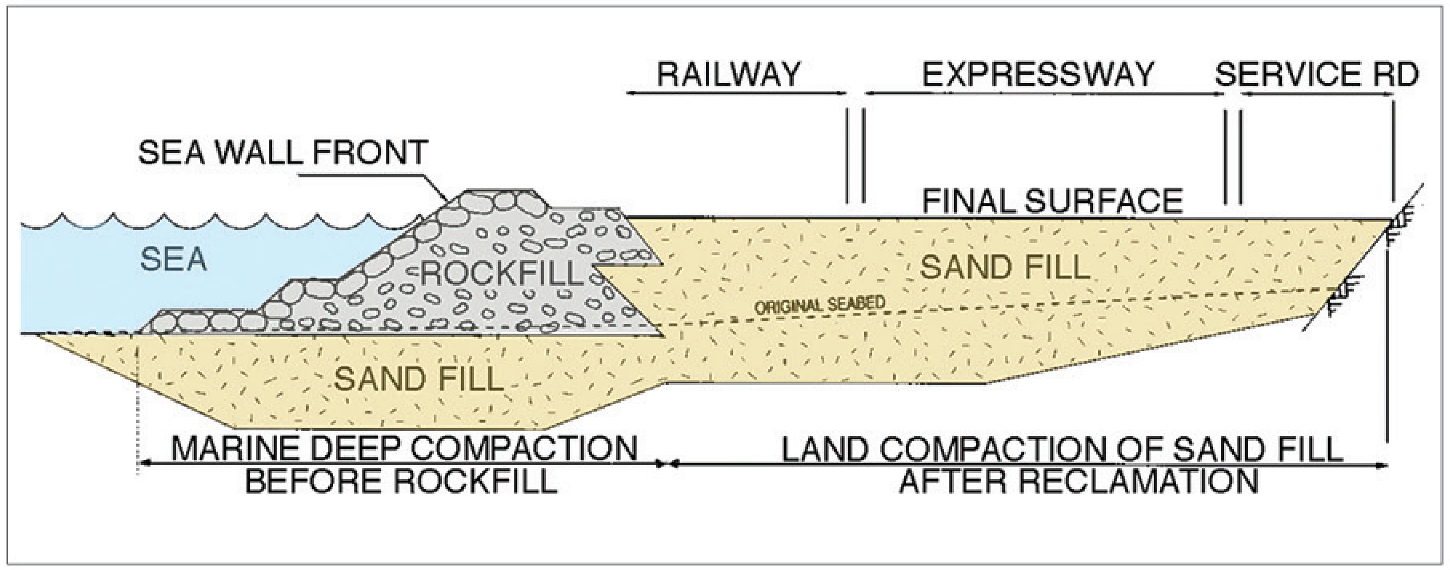
The challenge was penetration through the very coarse rubble (see RED curve in the following graph).

NORTH LANTAU EXPRESSWAY: TAI HO SECTION HONG KONG

QUANTITIES:

The 7 km long Tai Ho section of the North Lantau Expressway was built mainly on reclaimed land. As shown on the below sketch, the sand fill underneath the later placed rockfill dike had to be compacted offshore.
Offshore Vibro Compaction: 1,700,000 m3
Land based Vibro Compaction: 6,700,000 m3





A 1.5 km x 1.5 km non-dredged island is created just east of Hong Kong's Chek Lap Kok airport as part of the Hong Kong - Shenzhen - Zhuhai Corridor.

Aerial Photo with new island on right (yellow hatched)

3D rendering of the island with airport in the back

The biggest challenge, besides a very tight time schedule, is the height restriction imposed on the rigs due to the nearby airport. The land based rig with filling bucket looses over 5 m on the top that cannot enter the ground and hence add to the total required length of the rig. The Betterground design team had to design from scratch and under enormous time pressure a dedicated low headroom rig that can partially submerse with its upper section into the Marine Deposit and thereby reduce the lost length to zero.

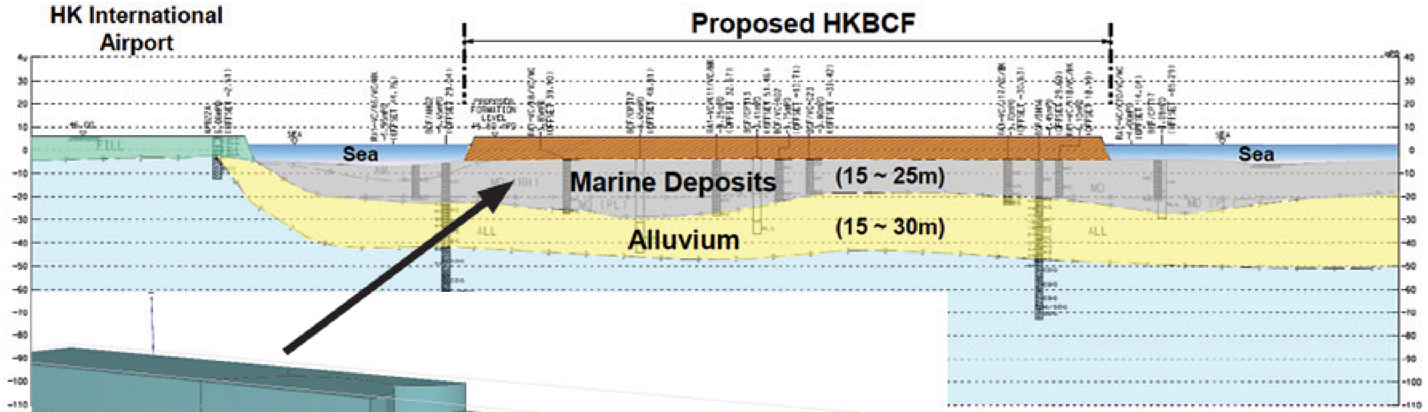
Airport height restriction

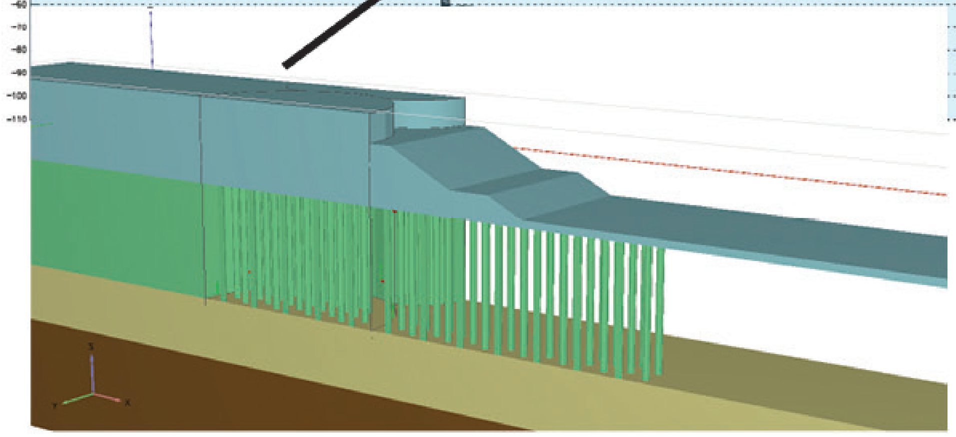
Offshore double lock low headroom rig with in soil submersible pressure chambers.

Conventional double lock rig with more than 7m high pressure chambers

The island will be constructed from sand fill placed on top of 15 m to 25 m soft Marine Deposit. Most of the island is surrounded by a sloped sea wall, with the crest of the sea wall additionally protected by up to 31 m diameter caissons formed by sheet piles.

The inside of the caissons as well as large parts of the slope are reinforced by 1.0 m diameter stone columns. These columns increase the shear strength of the soft clay and accelerate con-solidation, i.e. the dissipation of excess pore pressures in the soil upon loading. A total of over 1 million lineal meters of such stone columns are installed for this project in an offshore installation process.





The left sketch shows the input for a PLAXIS 3D Finite Element analysis of the sloped seawall. The green zone is the Marine Deposit, with the stone columns. The beige zone is the alluvium, brown the lower marine deposits, blue the sand fill and caissons.

Barge setup with Gravel pumps, stone barge and another double-rig barge in the background

Airport height restriction

STONE COLUMN INSTALLATION MONITORING

Betterground quality monitoring and control system

The quality control recorder is a touchscreen located in the rig operator cabin. (see on right).

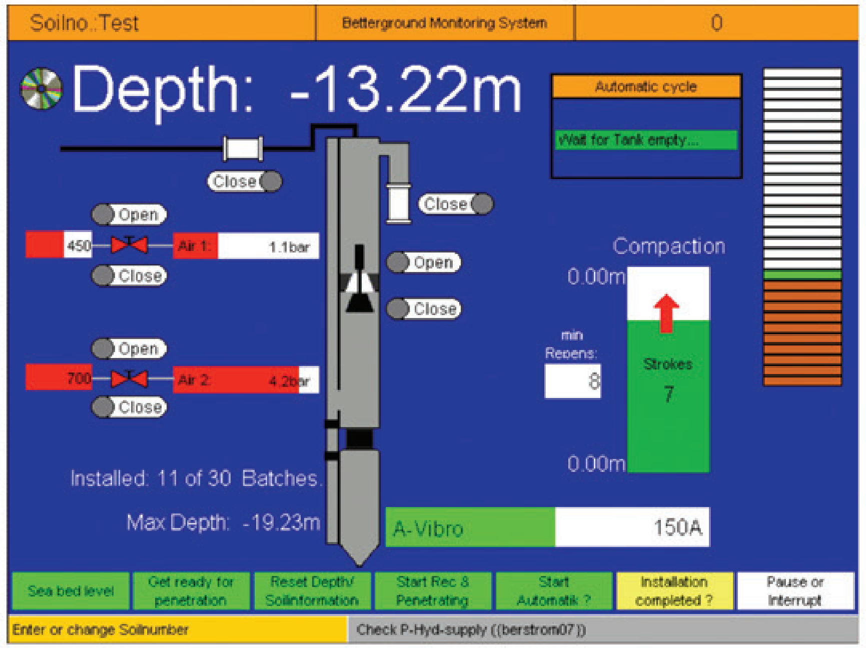
Control of valves and similar auxilliary components

The unit can act as a remote control for regulating the pressure or flow of water, air, or even cement grout. This regulation can be programmed to follow an automatic or semi-auto-matic rule where these flows are regulated depending on depth level.

Operator guidance system

The software guides the operator to install a specified column diameter or achieve required ampere layer by layer as required. This is accomplished by the green bar graph on the right of the display (titled "Compaction"). As the operator moves the vibroprobe up and down to install the column, this green bar empties or fills and at both ends the red arrow reverses direction to indicate to the operator to also reverse direction from, say, upward movement to downward movement.
The bar on the far right shows in orange the already installed column, green the present depth interval, and white the remaining intervals till completion of this column.

The valve controllers for the various air lock chambers of the Double Lock rig are shown in the left part of the display, indicating status of the valve, flow rate and pressure.



At the bottom of the screen a row of buttons (green, last one yellow) shows the present position of the control computer in the process of installing an offshore stone column. The operator works sequentially from the leftmost to the rightmost button during the installation process, with the presently available selection in Yellow and the already completed steps Green.
This way we are able to teach most operators to run the system error free without ever reading a manual.

STONE COLUMN INSTALLATION MONITORING

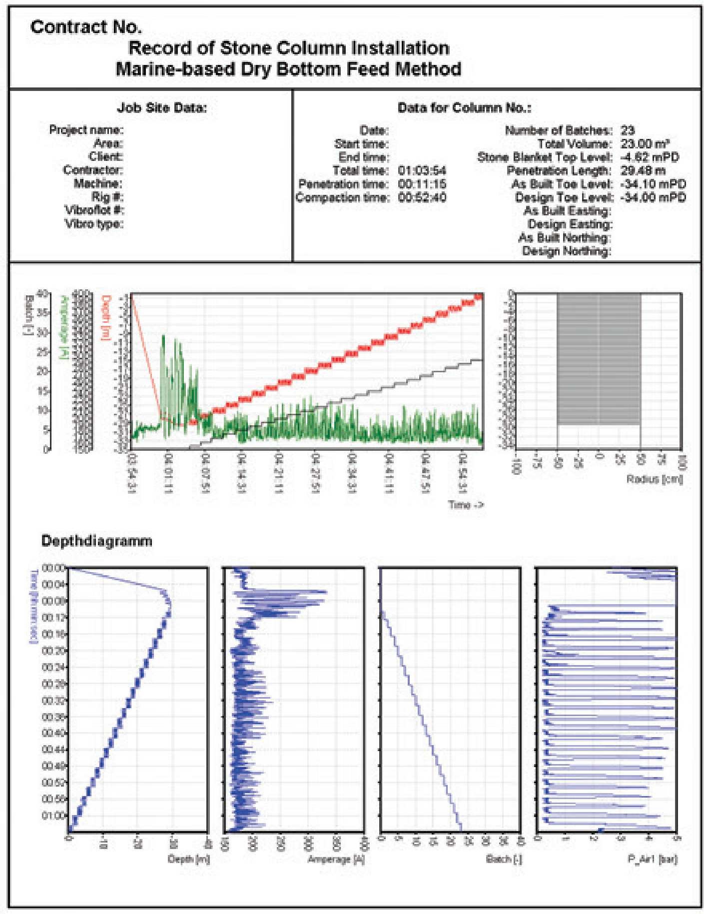
QUANTITIES:

Output for Stone Columns

Continuously Recording of:
- Depth
- Amperage
- Air pressure in double lock system
- Inclination

The recorder can be connected to sensors for
- Depth (with deflection rollers or laser)
- Hydraulic pressure (crowd force)
- Concrete, grout or water pressure
- Flow rate
- Inclination of mast in x- and y- direction
- Frequency measurement at the vibroprobe

Below: The output can be analyzed in a custom made software or in Excel. Below a magnified plot was created to better study the build up of Ampere during rig penetration and subsequent column installation.


Contract No.
Record of Stone Column Installation
Marine-based Dry Bottom Feed Method

Job Site Data:	Data for Column No.:	
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Client:	End time:	Stone Blanket Top Level: -4.62 mPD
Contractor:	Total time: 01:03:54	Penetration Length: 29.48 m
Machine:	Penetration time: 00:11:15	As Built Toe Level: -34.10 mPD
Rig #:	Compaction time: 00:52:40	Design Toe Level: -34.00 mPD
Vibroflot #:		As Built Easting:
Vibro type:		Design Easting:
		As Built Northing:
		Design Northing: