Advances in equipment and quality control for offshore and onshore Stone Columns and Vibro Compaction

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ABSTRACT: This paper describes equipment for the installation of ground improvement by Vibro Compaction and offshore Stone Columns. Special emphasis is given to aspects of quality control and a novel system to guide the operator in the optimal installation process. Examples for quality control using the new approach are given.

Keywords: stone columns, vibro compaction, quality control, ground improvement, offshore

1 INTRODUCTION

Vibro Compaction and Stone Columns are well-established ground improvement techniques, their inception going back to 1934 and the late 1950ies respectively.

Both techniques have in the last two decades benefitted from the ever-increasing need for new land in coastal areas. The Palm Islands in Dubai and most land reclamations in Hong Kong and Singapore have been treated by these two methods.

In recent years two trends were clearly visible:

1) An increasing size of projects, squeezed into smaller construction time windows.
2) A trend to leave soft marine deposits in place, rather than dredge and replace, with the corresponding increased need for offshore stone columns serving as foundation reinforcement for sea walls and breakwaters.

Contractors answered to this demand by developing stronger vibroprobes for Vibro Compaction and new rigs for offshore stone columns. Parallel to this improvement of equipment, and resulting from an only limited number of field experts that are capable of installing these techniques with the highest quality, equipment has been developed to facilitate the installation process while at the same time more closely controlling the quality of workmanship and as-built documentation.

This paper will describe a few advances in both fields, equipment and quality control, but focus mainly on quality control.

2 EQUIPMENT

2.1 *Vibroprobes*

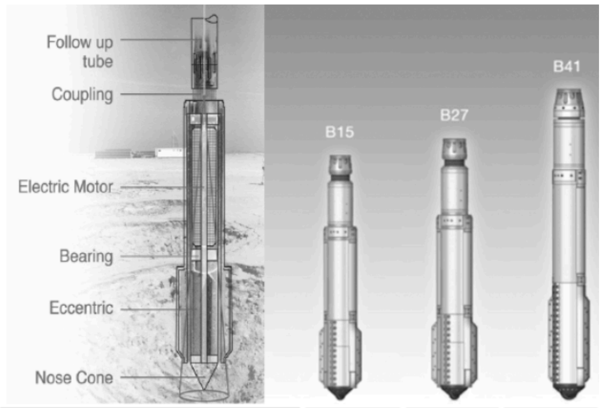
Depth Vibrators (Vibroprobes) produce a horizontally polarized shear wave that is optimally suited to compact granular soils. The maximum reach of such shear waves is dependent on the vibration amplitude of the vibroprobe but also on the vibration frequency. A machine vibrating at 1800 RPM (30 Hz) has a farther compaction reach sideways into the surrounding soils than a machine operating at 3600 RPM (60 Hz).

The manufacturers of such equipment have realized this very early. In the following three typical equipment examples are shown.

A small machine (B15), with limited compaction reach due to it's lower amplitude and higher frequency, optimally suited to install stone columns for load bearing applications, not quite as well suited for applications where soil near the columns must be compacted for liquefaction mitigation. This machine is also favored for work in the near range of existing structures.

A general-purpose machine (B27), running at 1800 RPM (or if operated at 50 Hz electricity at 1500 RPM). This machine is ideal for Stone Columns if the soil around the column needs maximum compaction, such as this is the case in liquefaction mitigation projects.

A machine for Vibro Compaction of large reclamation fills (B41), which can operate at low frequency while having very high vibration amplitude, both for maximum reach of the horizontal compaction waves.



Vibroflot		B15 electric	B27 electric	B41 electric
Motor Force	kW	105	140	250
Rotation Speed	rpm	3000	1800	1800
Eccentric Force	kN	190	270	520
Amplitude (at tip)	mm	12	24	42
Diameter (above wear plates)	mm	310	354	418
Length	mm	3430	3480	4250
Weigth	kg	2200	2200	3960

Figure 1. Vibroprobes for different applications.

2.2 *Wet Top Feed and Dry Bottom Feed Stone Column equipment*

Wet Top Feed is the original installation system. It requires less sophisticated equipment and columns can be installed quicker. It is used on sites where the ground water is not contaminated and flushing water needed for the process can be collected in sedimentation ponds.

Dry Bottom Feed is preferable for inner-city sites, sites on contaminated ground and for all offshore stone column applications.

Al-Homoud and Degen (2006) have described in detail why Wet Top Feed or any other Top Feed method is not recommended for offshore stone columns.

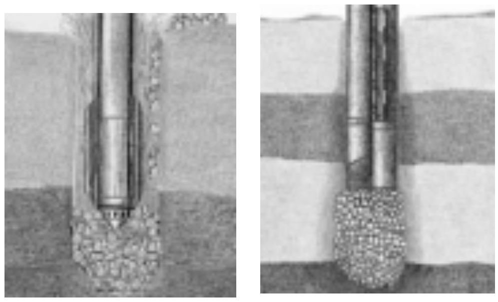


Figure 2. Wet Top Feed and Dry Bottom Feed.

The following Fig. 3 shows an offshore Bottom Feed Stone Column rig with a “double lock”. A similar rig is described in Debats and Degen (2001).

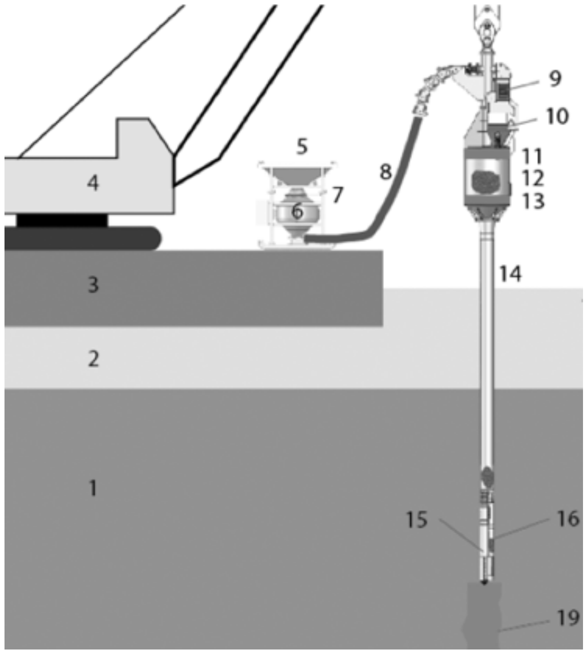


Figure 3. Offshore Stone Column rig.

The stone column (19) is installed by the vibroprobe (15). Gravel is transported into hopper (5) and from there through gate (7) into blow tank (6) of constant volume. Each blow tank volume is transported separately through hose (8) into a hopper (9) where the gravel waits for lock chamber (12) to become empty. As the gravel flows from the tremie pipe (16) into the soil, the lower silo tube (14) becomes empty and reports that to gate (13), which opens for a given time to fill the content of lock chamber (12) into lower silo (14). While gate (13) is open, gate (11) is closed (so called “double lock”), so that the gravel at the tip of the vibroprobe is always under excess air pressure and never shortcut to atmospheric pressure.

This complex gravel transport process is necessary to assure maximum stone column quality as follows:

1) No gravel is lost in the process. The gravel flow happens in a closed environment, until the tip of the tremie pipe is reached.
2) The gravel entering the soil is always under controlled excess pressure, avoiding reverse circulation, which would be very detrimental to column quality.
3) The transported gravel volume is measured batch by batch of approx. 1 m^3 each.

Given the effort made in assuring a perfect gravel flow, the perfect logging of such work is logically the next step.

3 QUALITY CONTROL

3.1 *Existing data logging systems*

In the past, data logging of process parameters for stone columns consisted of plotting in real time during the installation process Amps of the vibroprobe motor and depth. The following Fig. 4 shows an example from the 1990ies. The recording shows here a gap in the Amps at about mid depth of the profile. Later CPTs (right diagram in Fig. 4) shows the same gap in Post Treatment CPT. Sand with too high silt content was the reason in this case for the disappointing Post CPT results.

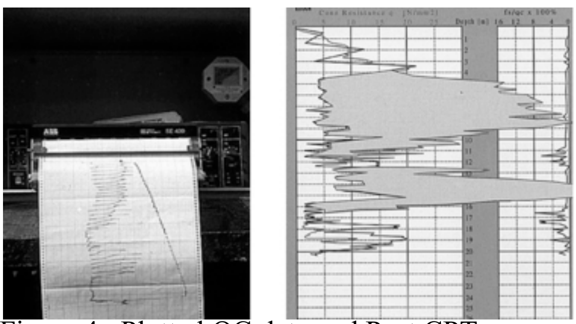


Figure 4. Plotted QC data and Post CPT.

Simple data plotters have been in the last 15 years replaced by computerized data loggers that do essentially the same, but store the data in ASCII format and therefore can during post processing print the data in all variations.

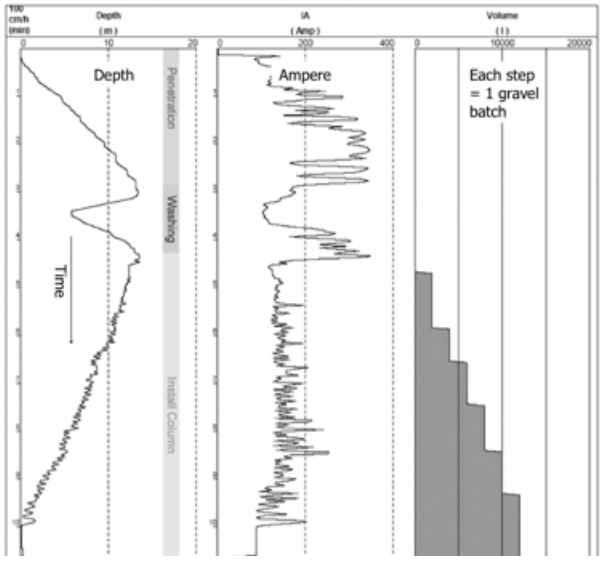


Figure 5. Wet Top Feed Stone Column record

Fig. 5 shows a typical record over time for Wet Top Feed Stone Columns. The gravel consumption is logged by the crane operator. Each time a loader shovel of gravel is filled into the annular space around the vibroprobe, a button is pressed and thereby depth and time is logged at which gravel was added.

3.2 *Novel Operator Guidance System*

The novel Operator Guidance System comprises all qualities of a modern data recorder but goes two important steps further.

Instead of just recording the process data during stone column or vibro compaction installation, the new system also interacts with the rig operator by giving precise guidance on the exact limits for every up and down movement of the rig and it modifies installation parameters such as water and air.

Figure 6. Quality Control Recorder

Fig. 7 and Fig. 8 show an example for an installation instruction pre programmed into the Operator Guidance System.
In this example the instructions to the computer have been as follows:

1) Switch on air pressure in tremie pipe.
2) Lower vibroprobe to 15.5 m depth.
3) While getting elevated Amps (over 160 A) soil is compactable coarse sand, hence build only a column of 80 cm diameter.
4) Once Amps drop below 130 A during column installation, build a 1.60 m diameter column, since low Amps signal presence of non-compactable silt.
5) However, if Amps would rise again above 175 A during column construction, reduce diameter accordingly, but not less than 80 cm, unless Amps would rise above 220 A, in which case very well compactable soils would allow smaller diameters.

Such a set of instructions is hard to teach to operators and even harder to faultlessly maintain during the repetitive work process.

This is the reason why in many Specifications up to 5 years of experience have been demanded from the operator.

To prove the superiority of the new Operator guidance system, the column shown in Fig. 7 has been installed by an operator that never before has worked on a stone column rig. The point in Fig. 7 was his first-ever stone column.

In this figure the depth is the dark curve and the Amps the light curve.

The perfectly inclined ramp with which the depth is moving upward after every up/down cycle is beyond the capability of even the most experienced operator.

In this case the operator was able to install this perfect point by watching a level in the bottom left of the screen (see Fig. 6) going up and down together with an arrow pointing up and down. The exact point where to turn the rig from downward motion to upward motion was governed by the instructions (see list 1 to 5 above) given by the Engineer to the operator guidance system. This is comparable to an instrument landing with a plane, the glide path is programmed, the pilot "just" has to keep the plane following two guide markers. In the installation of Stone Columns it is only one such marker, the one for up and down motion.

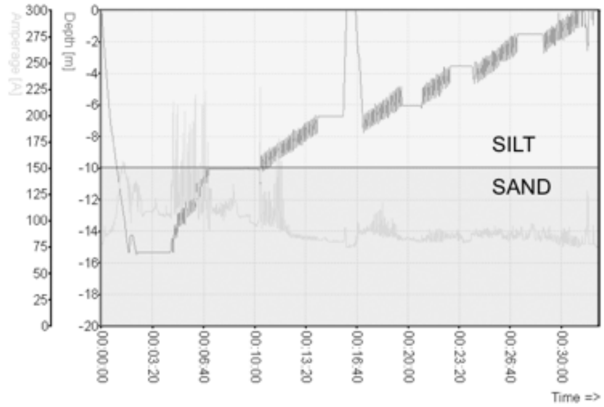


Figure 7. Wet Top Feed Stone Column record

Fig. 8 shows the perfect stone column diameter over depth. The two soil layers, sand in the lower 5 m and silt in the top 10 m are clearly distinguishable. Plots of this quality open new opportunities for the Engineer to check his soil mechanical model against the soil model derived from the as-built Amps and column diameter plots.

For the contractor, using this novel equipment, the requirement to have operators with over 5 years of experience can be waived. In fact, new operators were more ready to adopt the new superior technique than old hands that were often skeptical when their know how was so unceremoniously devalued.

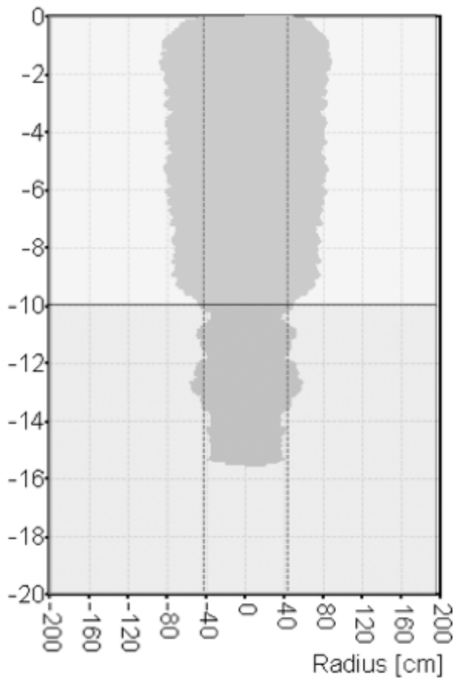


Figure 8. Column diameter over depth.

3.3 *Automatic Water-Air-Manifold*

While for the installation of Bottom Feed Stone Columns the control of water and air is rather simple and could in principle still be managed manually by the rig operator or a helper, for Vibro Compaction, in particular when using a tandem rig as shown in Fig. 10, the control of water and air for nose jets and side jets is a full time occupation and in a standard rig this has to be coordinated between rig operator and a very well trained helper on the water/air manifold.

In order to fully exploit the benefits of the new (patent pending) Operator Guidance System, the water-air-manifold had to be re-engineered to “talk” with the Operator Guidance System. Fig. 9 shows such re designed manifold with water and air pressure sensors, and flow meters as well as proportional valves, all controlled via a CAN BUS link by the Operator Guidance System.

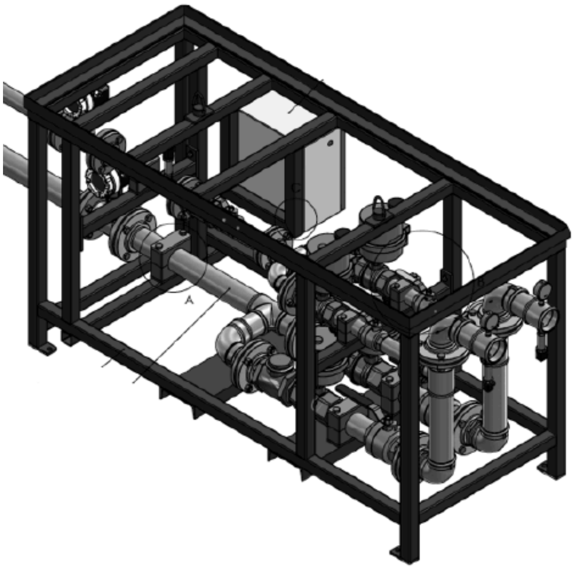


Figure 9. Automatic Air-Water-Manifold.

Consequent use of this novel technology has allowed the execution of projects with over 15 rigs in double shift, using over 30 previously untrained operators, producing stone columns of a quality better than any installed before by the most seasoned operators. This is therefore clearly a game changer in an industry that will in the future even more have to rely on personnel that is not since years already trained in the work that needs to be done while such work has to be accomplished in tighter schedules to more demanding quality standards than ever before.

Figure 10. Tandem Vibro Compaction, Dubai.

Figure 11. Operator guidance system offshore.

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