Marine stone columns at Patras (Greece) Harbour Extension - Phase II

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ABSTRACT: Ground treatment is frequently required to improve the foundation of marine structures. The so-called dry-bottom-feed stone column construction technique can be used under water if a double-sluice stone delivery system is attached to the vibroprobe. The use of pneumatic stone transport from the barge into the vibroprobe receiver tank makes it possible to reach large water and treatment depths. Digital recording of all operations provides a very high level of quality assurance, including a diameter-over-depth profile for each stone column. The severe shortcomings of the existing marine stone column construction techniques are highlighted.

1 - Introduction

In harbour and offshore works ground improvement is increasingly required to avoid the dredging and disposal of large quantities of frequently contaminated marine mud layers.

Stone columns have already been used on a certain number of occasions. However, with the existing stone column construction techniques, marine site conditions make it difficult to provide an adequate level of quality.

In a radical move to change such a situation a patented Marine Double-Lock Gravel Pump is being used for the improvement of the ground under a breakwater and a quay wall on Phase II of the Patras Harbour Extension (Greece) leading to a definite breakthrough in offshore technology.

2 – Problem description

Figure No. 1 is a cross section of the Patras Harbour (Greece) new development.

At the breakwater the seabed is 34 m deep and is underlain by 14 to 16m of soft clays which require improvement before the rock embankment is placed with its reinforced concrete caisson on top. Prior to the construction of the stone columns under the width of the embankment a 2m thick sand blanket is spread on the seafloor.

At the quay wall site, water depth is in the order of 10 to 12m. Wick drains and pre-loading are implemented before stone column construction.

3 – Marine stone columns: the existing methods

Stone columns have been used in a certain number of occasions in marine conditions.

So far, two main techniques were proposed: the so-called “blanket” method and the single-batch bottom-feed technique.

3.1 – The blanket method.

The blanket method (Fig. No. 2) is a wet-top-feed stone column construction technique. It consists in the following construction steps:

- Place a thick gravel blanket on the seabed (typically, for 10m long and 90 cm diameter stone columns in a 2.5m square grid, up to 3m of stones are required),
- Position the barge with a crane-suspended vibroprobe over the gravel blanket,
- Lower the vibrator to the top of the blanket and start both vibrator and jetting pump,
- Penetrate the gravel blanket and the original ground to final depth,
- Carry out a few “washing” operations with full-depth up- and down-movements of the vibroprobe to create an annular space around it, into which stones from the blanket will be able to flow and eventually reach the bottom of the hole,
- Construct the column in short upward stages (not more than 50cm, typically) using the power consumption of the vibrator as a proof of the compacity and continuity of the column.

The advantages of the method are:

- ➢ The equipment needed is a standard vibrocompaction set-up (crawler crane, vibrator with follow-up tubes and jet-pipes, generator, high pressure jetting pump), with a total weight of about 10 to 15 tons for a 30 to 35m long vibrating probe,
- ➢ The stones can be in the usual 20/60mm range for wet-top-feed stone columns,
- ➢ Proper training of the operators and continuous parameter recording (depth and power consumption over time) should provide an acceptable proof of compacity and continuity of the columns.

The shortcomings of the method are many:

- ➢ In order to provide an easy downward flow of the stones around the vibroprobe large amounts of clay must be “washed” out of the hole, leading to large silt/clay deposits on the seabed and eventually within the gravel blanket and possibly leading also to larger column diameters than designed,
- ➢ The maximum stone column lengths that can be constructed with the blanket method are in the order of 10 to 15m, depending on the type of vibrator and on the skill of the operators,
- ➢ The longer the columns, the thicker the stone blanket required to make sure that no “starving” occurs while constructing the top meters of a column,
- ➢ In the occurrence of locally softer ground layers stone consumption may exceed the quantity of stones readily available in the blanket around the column under construction or may make the gravel blanket too thin for the neighbouring columns to come. This leads to great risk of leaving behind not thoroughly treated zones,
- ➢ Very inaccurate measurement of the overall stone consumption: only seabed soundings can be performed to try and determine the amount of stones consumed, which will only provide the Engineer with an average stone consumption over a large area,

- ➢ No measurement at all 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 whole column length.

3.2 – The single-batch bottom-feed technique

The single-batch bottom-feed technique has been used on a rather limited number of construction sites, among which: Aktio-Preveza crossing (Greece), Patras Harbour Phase I (Greece), Bali Wharf (Indonesia).

The method (Fig. No. 3) is a wet-bottom-feed stone column construction technique in which a special feeder pipe is attached to the vibroprobe (vibrator + follow-up tubes), with a large hopper at its upper end. The hopper has a capacity just in excess of the expected stone consumption for one column and it is equipped with a hydraulically operated gate that controls the discharge of the stones into the feeder pipe.

The method consists in the following construction steps:

- With the vibroprobe suspended from the crane and the discharge hydraulic gate closed fill the hopper with the stones needed for one stone column,
- Position the vibroprobe on the stone column to be constructed,
- Lower the vibroprobe to seafloor level, start both vibrator and jetting pump and open the hydraulic gate to allow the stones to flow from the hopper into the feeder pipe. The gate remains open thereafter throughout the construction of the column,
- Penetrate the original ground to final depth,
- Construct the column in upward stages using successive up- and down-movements to discharge and compact the stones and using the power consumption of the vibrator as a proof of the compacity and continuity of the column.

The theoretical advantages of the method over the blanket technique are:

- ➢ No depth limitation in principle, save for the limitations set by the barge and crane capacities,
- ➢ The method is a bottom-feed technique, which means that less “washing” is used (only a small annular space is needed around the probe),
- ➢ The quantity of stones to be used is fixed for each column by means of the single-batch hopper on top,
- ➢ Proper training of the operators and continuous parameter recording (depth and power consumption over time) should provide an acceptable proof of both compacity and continuity of the columns.

The shortcomings of the method are however also numerous:

- ➢ The total weight of the vibroprobe with the hopper full of stones is in excess of 20 to 30 tons (according to column length) leading to limited reach from the barge and a limitation to the number of columns that can be constructed from one barge position,
- ➢ The large weight of the probe also requires the use of multiple-line rope suspension from the crane, with slow operation as a consequence,
- ➢ The gravity flow of the stones through the feeder pipe is often quite slow, even if water flushing is used,

- In very soft or liquefiable ground it may occur that the inner and outer pressures at the tip of the feeder pipe are not balanced, leading to the intrusion of clay paste into the pipe with its immediate total clogging,
- In the occurrence of locally softer ground layers stone consumption may eventually exceed the quantity of stones readily available in the hopper. This leads to great risk of leaving behind not thoroughly treated zones,
- Largely inaccurate measurement of the quantity of stones remaining in the hopper when the column is completed (weighing devices are not precise enough under marine conditions), which means that the excess stones, if any, may just be discharged on the seabed while the probe is moved back to the barge for refilling,
- 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.

3.3 – Conclusions on the existing marine stone column construction techniques

Both the blanket method and the single-batch bottom-feed method have, among others, the severe shortcoming of not being able to accurately measure the volume of stones placed in each column and not being able at all to check the stone consumption over depth in each and every column.

Furthermore, in both methods there is great risk of leaving behind not thoroughly treated zones which, if spotted, can theoretically be repaired but, if not, may lead to excessive settlements or instability for the structure.

4 – Marine stone columns using the patented Marine Double-Lock Gravel Pump: a definite breakthrough in marine stone column technology.

4.1 - Field of application

A unique system was developed to install stone columns under water with the very same proven quality as in the land-based Double Lock Dry Bottom Feed system. The foundations of breakwaters or quay walls (typically up to 35 m water depth) and probably also of many other deeper offshore structures have come within the range of this unique foundation system.

4.2 - The patented installation process

The patented Marine Double Lock Gravel Pump (Fig. No. 4, 5 and 6) has a Schnorchel hose (6), which is attached at the air exhaust lock (16b) to the receiver tank (8). Schnorchel hose (6) and locks (16a, 16b, 9) are operated in such a way that during the gravel transport through hoses (5) there is always atmospheric pressure in the receiver tank (8), independent of the actual water depth, which might be 200 m or more. In this way a standard 7.5 bar compressor can accomplish the pneumatic gravel transport from the blow tank (4) to the receiver tank (8). A high pressure compressor that is not visible in the sketch, feeds directly into the pressure tank (10), and thus (since either lock 9 or locks 16 are closed at all times) supplies a sufficient pressure to surmount the water and soil pressures in the gravel tube (11) at the tip (18) of the vibroprobe (17).

The Marine Double Lock Gravel Pump has until now not explored the depth limit of its operation. It should be possible to reach a water depth of over 200 m, before the hoses (5 and 6) would collapse. In this way, a whole new field of application for stone columns is opened. Offshore platforms or dams under cyclic loading or earthquake loading can now be founded cost-efficiently and reliably on stone columns.

4.3 – First implementation of the technique at Patras (Greece) Harbour Extension – Phase II

The stone columns for the foundations of a breakwater and a quay wall in Patras serve as drainage for excess pore pressures that build up during construction of the embankment but also provide additional strength under earthquake loading.

The 1.0 m diameter stone columns in a 2.7 m to 3.3 m grid extend up to almost 20m into the soft silty and clayey marine sediments. The water depth at the treatment location reaches 32m.

Both the breakwater and the quay wall are treated with stone columns, using the following schemes:

Breakwater: 4'830 No. stone columns, 16m average length, 77'280lm, 60'665 m3 (1m diameter), average square spacing 2.7m.

Quay wall: 3'073 No. stone columns, 10m average length, 30'730lm, 24'123 m3 (1m diameter), average square spacing 3.3m

4.4 – The technology

The Marine Double Lock Gravel Pump has a total length of 24 m, which means that at all times the unit is fully submerged under water when installing dry-bottom-feed stone columns.

The special features of this patented unit are:

- Limited overall weight allowing far reach from the barge, hence more columns constructed from each barge position,
- No theoretical limitation in water depth and/or column length,
- Digital depth measurement with display in the crane cabin (the operator can only see the crane wire rope, while the whole unit is submerged),
- Differential GPS surveying to find column locations under water,
- The Double Lock assures that at the tip of the vibroprobe excess air pressure is applied at all times, avoiding the risk of clay intrusion into the gravel pipe and providing a very high discharge rate of the stones into the ground,
- The “Schnorchel” hose allows air transport of the gravel against atmospheric pressures, although the receiver tank is submerged some 30 m, and possibly more, under water,
- Fully automatic operation of the stone transport and discharge system,
- Very high installation speed, with up to 250m of 1m diameter columns per shift.

4.5 - Quality Control

In an offshore operation, the quality control output is of even higher importance than in a land operation. While in a land-based operation a stone column can be checked with load tests, or a borehole can be drilled into the column to check the continuous installation, such controls are not readily available under water.

The digital parameter recording system used here does provide the required level of quality that the Client is rightly asking for, with two types of outputs: parameters as a function of time and parameters as a function of depth.

4.5.1 - Output with control parameters as a function of time (Fig. No. 7)

Without Ampere and depth plots (two leftmost curves) it is theoretically possible that, by accident, no column or only a marginal column is constructed in the soil, while a large portion of the gravel supposed to end up in the column is actually lost on the seabed. This danger does not exist in a land based operation, where excessive spill of gravel on the surface can be visually controlled. It does not exist either with the Marine Double-Lock Gravel Pump and its digital control as shown on the printout.

On such a printout it becomes possible to identify at what depth in the column each and every batch of stones is placed through to the Double-Lock dry-bottom-feed process.

4.5.2 - Output with control parameters as a function of depth (Fig. No. 8)

The output of Stone Column quality control parameters over depth is somewhat uncommon, since traditional data loggers are not able to generate such output. Also, for the analysis of the Ampere behaviour of the vibroprobe, an Ampere-Time plot is much more readable than an Ampere-Depth plot. In an Ampere-Depth plot the Ampere from penetration and later from column installation would superimpose each other and a maze of Ampere traces would fill the plot. In order to avoid this, the Ampere graph on the left (middle of the three graphs) displays only the maximum amps peaks during column installation, all other Amps traces are discarded by the software.

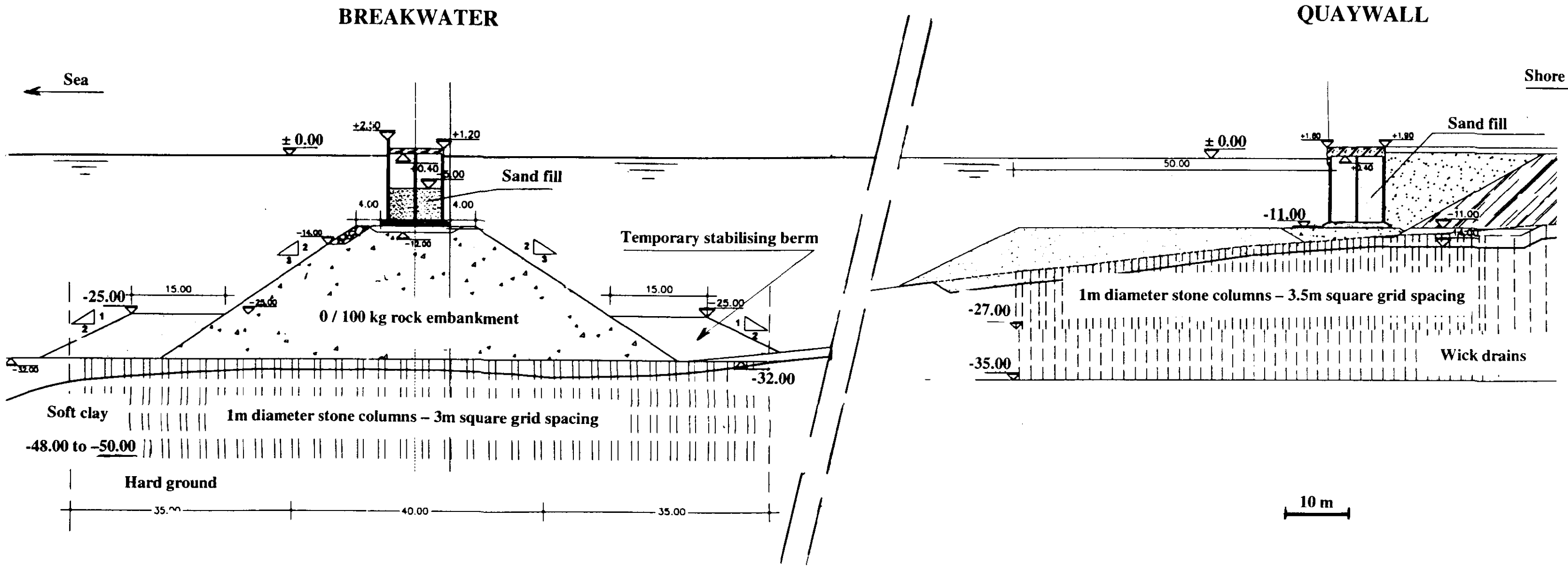
On the rightmost graph the stone column diameter is plotted over the depth. This is accomplished by the computer through a recording of the time and depth when each gravel batch has been sent through the Double-Lock mechanism. Out of these data a column profile over depth can be calculated and drawn.

5 – Conclusions

The patented Marine Double-Lock Gravel Pump is a landmark innovation in marine stone columns technology.

It provides fast and cost-effective stone column construction with a very high level of quality assurance and, in doing so, highlights the definite and severe shortcomings of the existing methods.

Such a quality standard should in turn lead to more savings through less conservative design.



PATRAS (GREECE) HARBOUR EXTENSION – PHASE II

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

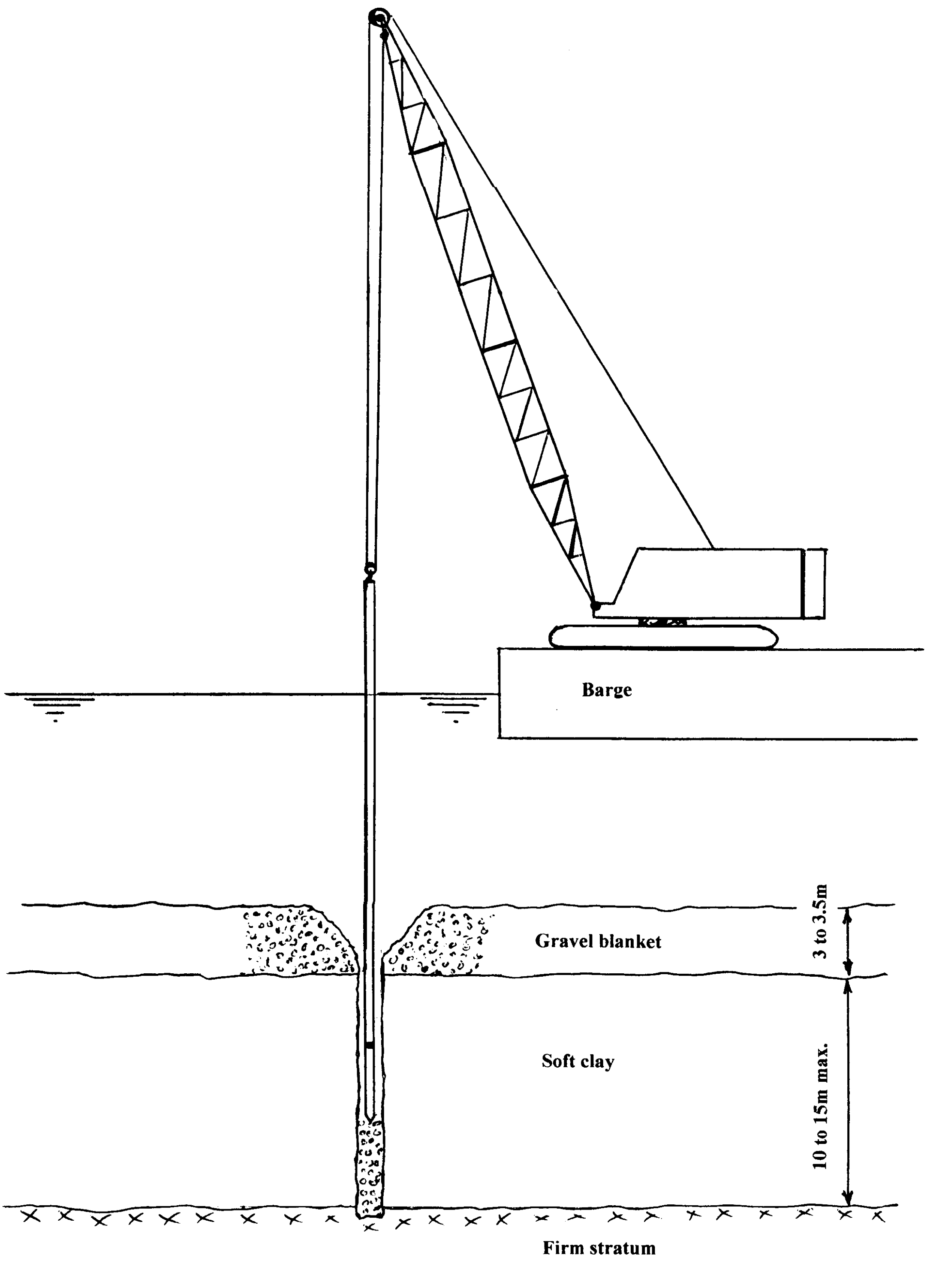


Fig. 2 – The blanket method

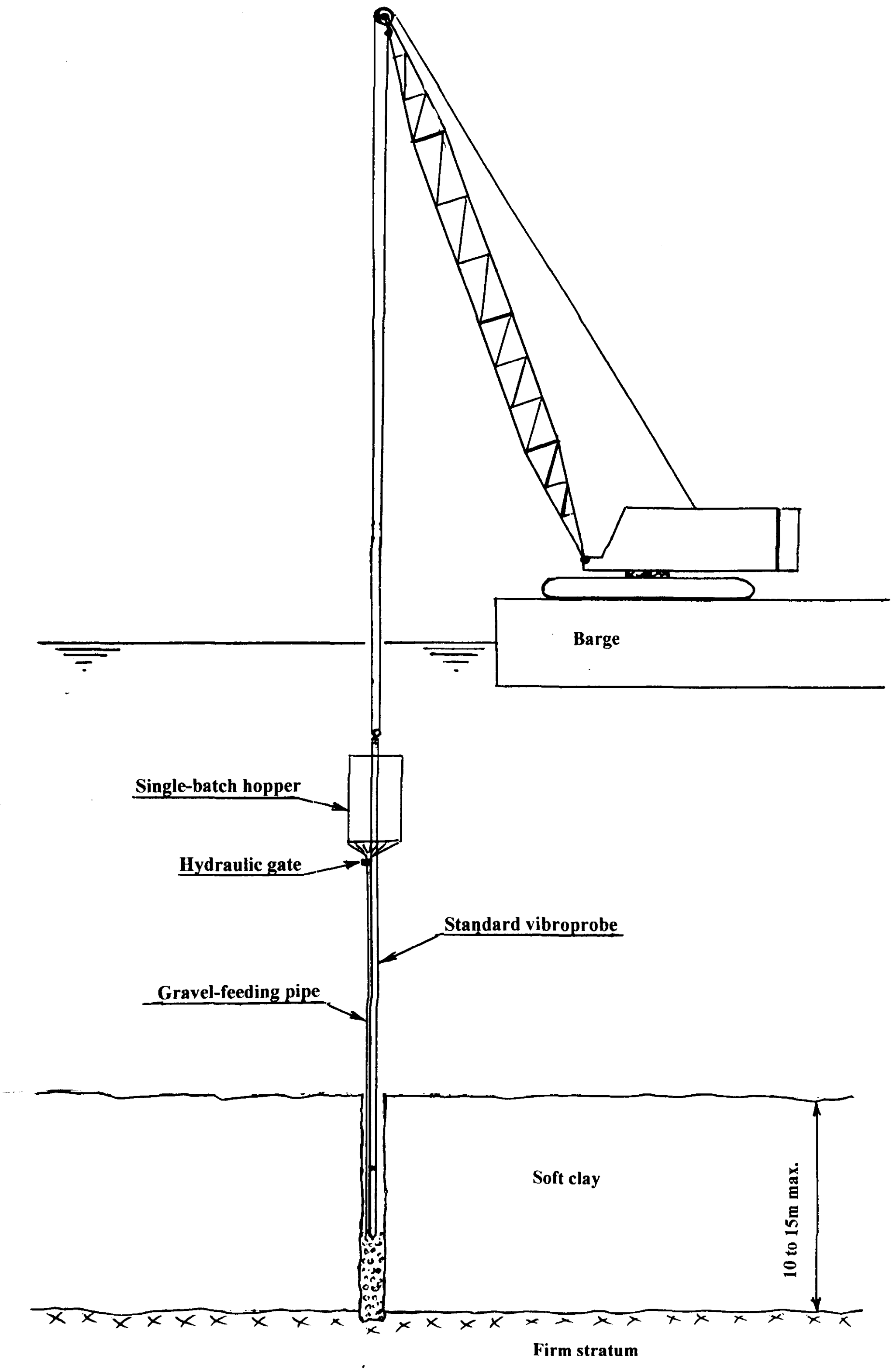


Fig. 3 – The single-batch bottom-feed method

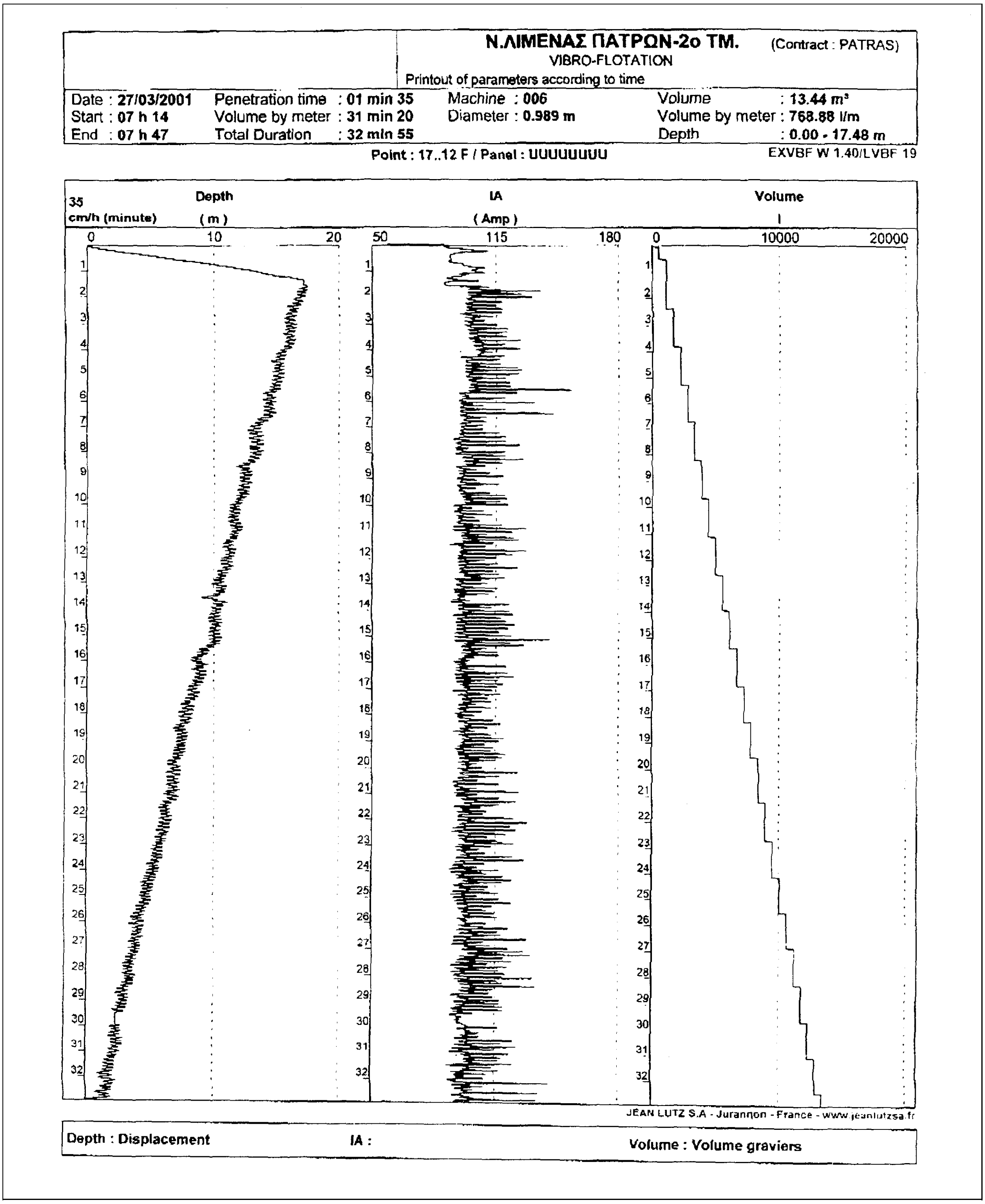


Fig. 7: Quality Control output over Time

Fig.5: Double lock batching tank with Schnorchel hose (left) and two gravel hoses (right)

Fig. 6: Gravel silo and conveyor belt (front), crane with 24 m long Marine Gravel Pump unit (back)

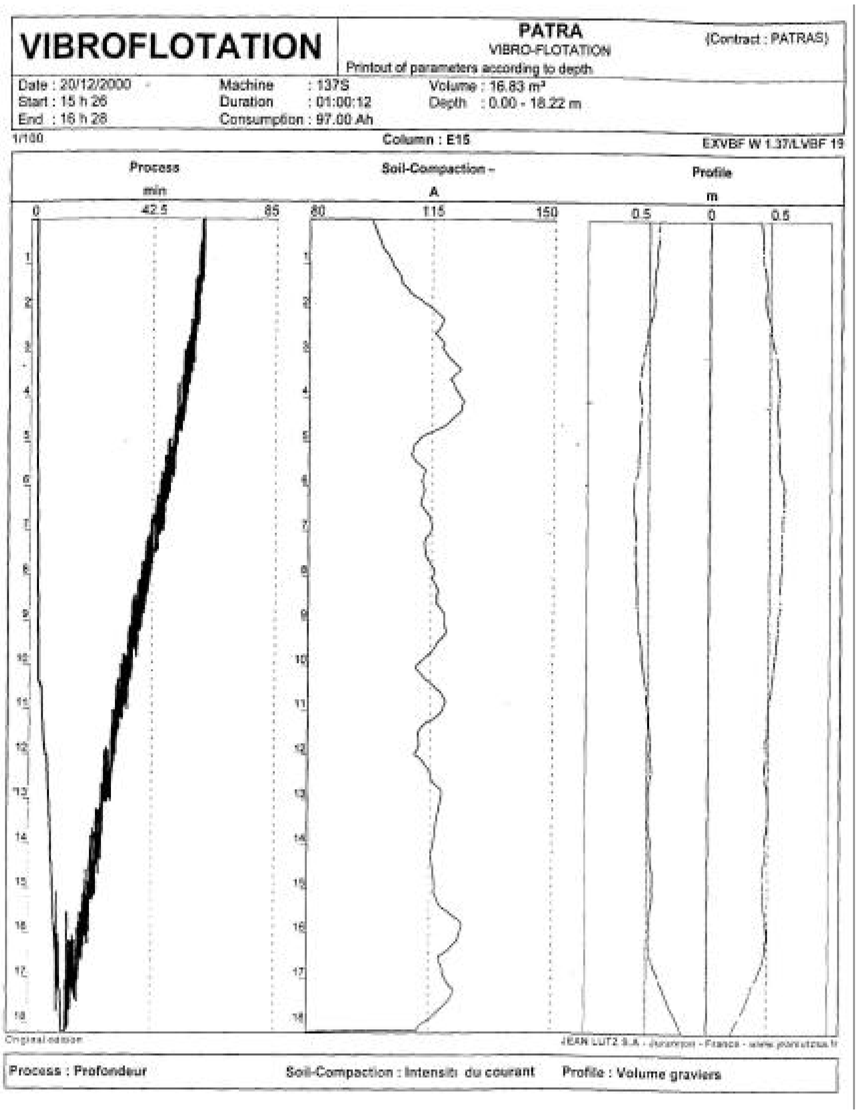


Fig. 8: Quality Control output over Depth

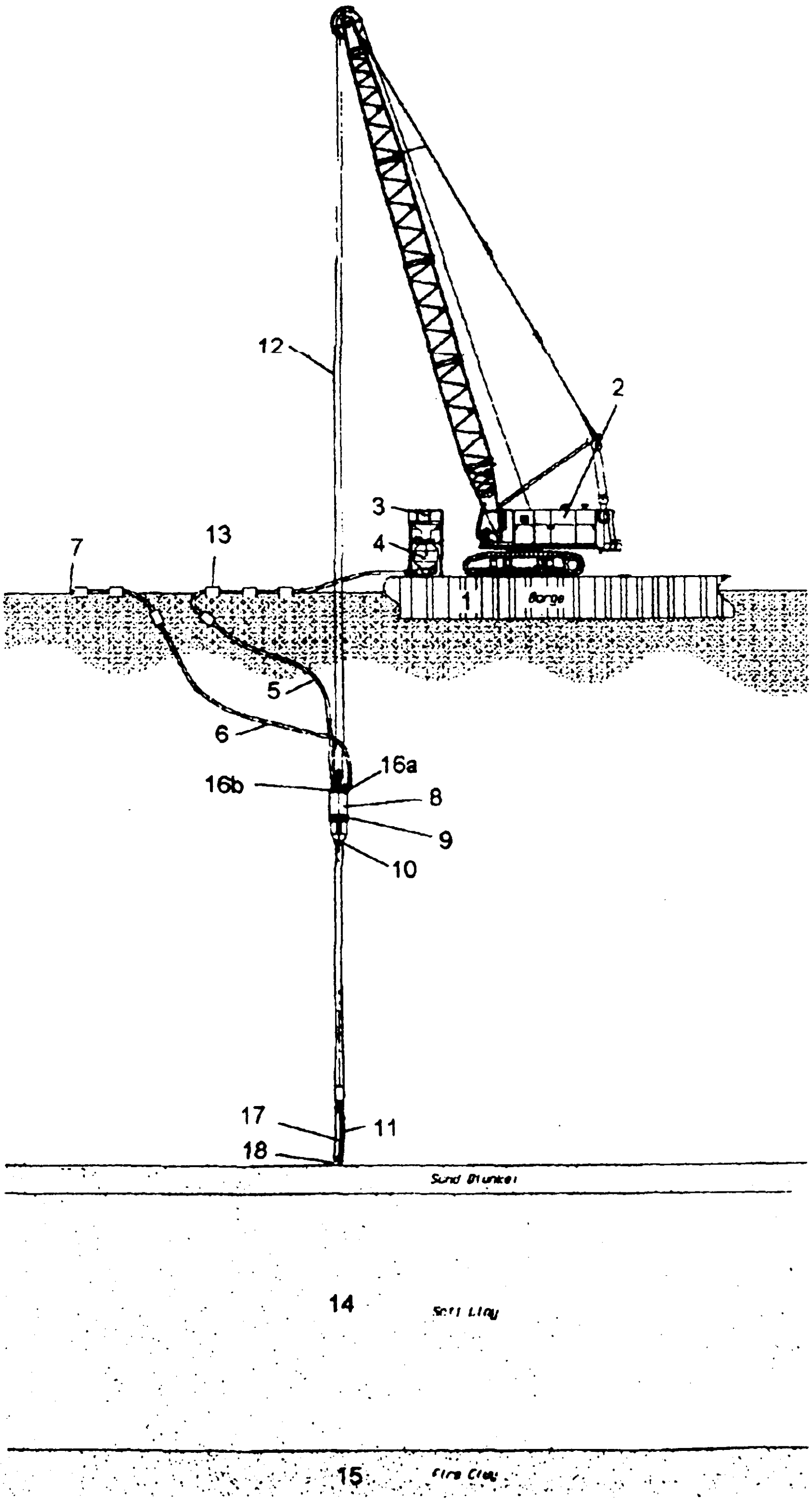


Fig. 4: The patented Marine Double-Lock Gravel Pump