VIBRO-TECHNIQUES FOR GROUND IMPROVEMENT

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ABSTRACT

The South American construction industry has been slower than many of its European counterparts to realise the technical and economic advantages that vibro-techniques can provide. In places where there is an abundance of soft alluvial and estuarine soils, many of these may be improved sufficiently by vibro-techniques to allow standard foundations to be constructed at relatively shallow depth, without the need to resort to deep piling. Where ground conditions are suitable, the vibro-techniques have been shown to be more cost effective than traditional foundation techniques. While other ground improvement techniques, such as surcharging and band drains, can seriously delay a contract programme, vibro-techniques generally do not provide such a stumbling block.

Keywords: ground improvement, earthquakes, liquefactions, soft ground, vibro-techniques

1. INTRODUCTION

Ground improvement techniques are widely adopted in Europe, Asia and USA and are increasingly being used in South America and world-wide for a vast variety of projects with particular emphasis on infrastructure projects such as ports and harbours.

Ground improvement schemes work with the existing ground rather than bypassing it. They can be tailored to meet specific bearing capacity and/or settlement requirements and are generally much more cost-effective than other traditional methods such as piling. The process:

- Reduces foundation settlement
- Increases bearing capacity
- Mitigates liquefaction potential
- Provides slope stabilization
- Prevents earthquake-induced lateral spreading

Along this document, will be described some of the most used ground improvement methods. These techniques, known as vibro-techniques are Vibro Stone Columns and Vibrocompaction with their different methods of application.

Vibro techniques consist of large depth vibrators, typically about 300 to 500mm in diameters, which penetrate the ground to suitable depth and then constructing continuous columns up to the ground surface.

Depending on soils type and water level table we can differentiate between Vibro Replacement, Stone Columns formed by wet technique, and Vibro Displacement, Stone columns formed by dry technique. Vibro stone columns are constructed within the seabed where the added granular material is compacted using depth vibrators. These relatively rigid columns of stone then form a composite structure with the surrounding soils to achieve increased strength and reduced settlements under applied load. The stone columns develop their capacity from the confining action of the soils in which the columns are constructed. Stone columns are inclusions of material with high angle of friction that can be used to enhance the stability of slopes.

When the soils are of a clean granular nature, they will be densified by the horizontal vibrations to provide even greater column rigidity. The applied loads are then supported by an array of generally stronger stone column springs surrounded by weaker springs representing the soil. The density of

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column construction grid centres to residual volume of soil will then dictate the degree of improvement that can be achieved.

Vibrocompaction known also as Vibroflotation in some references and countries consist on the in-situ densification of loose granular soils, such as loose sand, gravel and hydraulic fills, using similar equipment but without the addition of granular material.

2. VIBRO-TECHNIQUES

2.1. Four basic systems available:

2.1.1) Wet Top-Feed or Blanket Feed Method

The wet top-feed system is the original construction method which has been largely replaced by the other systems for land based projects but continues to be the most useful system for marine works. The wet top-feed system (Figure 1) can be used for the improvement of soft soils below the water table where larger column diameters are required.

A layer of granular material is deposited over the seabed layer; the vibroflot is lowered through this layer while the penetration is assisted by water flushing. On attaining the required depth the vibrator can be partially withdrawn to then surge and flush out to further increase the column diameter. Following formation of the open hole the water pressure is reduced and vibrator kept in the ground. Clean inert granular material was placed on the top at seabed level. This then falls under gravity against the slight upward flow of water in the annulus between sides of vibrator and soil down to the base of the bore. The vibrator is then slightly withdrawn and pushed back into the stone at the base of the bore to construct the stone columns in a series of lifts.

It is however important that the water flow be maintained to ensure stability of the soils and to avoid potential contamination of the stone column. The wet top-feed system is normally used when improving soils above, and below the water table of greater than about Cu = 15kPa soil strength (Greenwood & Kirsh, 1983). Typical grading of the granular material is about 20 to 75mm with stone column diameters of about 600 to 1000mm being constructed.
2.1.2) Wet Bottom-Feed Method (Aquacaster System)

The wet bottom-feed system combines the benefit of improving very weak soils below the water table with all the added advantages of the original and well-proven water-flush construction technique with the added ability over dry bottom-feed to surge for larger column diameter (Moseley & Priebe, 1993).

When performed over water from a barge the disadvantages encountered on land such as provision of an adequate working platform, water supply, drainage ditches, settlement lagoons, disposal of effluent and contamination of the site surface disappear.

The Aquacaster vibroflot is specially adapted for marine projects. The vibroflot is penetrated to the required design depth and once design depth is reached, water jetting is used to flush away loose materials and clear a 1m diameter cavity. As the water flush clears the cavity the aquacaster's hopper gate is opened to deliver a charge of stone that exits from the tip of the vibroflot. The vibroflot is then re-inserted to compact the stone tightly into the seabed, before being lifted slowly back to the surface. The sequence is repeated with the Aquacaster re-inserted and withdrawn until a dense stone column has been formed to the surface as shown on Figure 2.

![Figure 2: Aquacaster System](image)

2.1.3) Marine Vibrocompaction

Shock waves and subsequent oscillation cause loose sands to act like a liquid - a process referred to as liquefaction – where soils spread apart quickly and bearing capacity is severely reduced. Vibro-treatment can mitigate these effects by improving soil density and compacting loose sands and granular particle.

Vibro compaction is an established technique for stabilising fine granular soils prevalent in marine environments, and is especially effective for sand compaction (Figure 3). The method is highly effective for land reclamation projects and mitigating the risk of liquefaction in areas of the world subject to seismic activity.
With the vibrator motor running, water is discharged from the vibrator nose, and the vibrator slowly lowered to the required design depth under its own weight. In the immediate vicinity of the vibrator the soil is saturated and liquefies locally and temporarily under the influence of vibrations, the soils particles surrounding the vibrator rearranged free from stress to a dense state of compaction as shown schematically on Figure 4.

The area of soil affected by the vibrations, increase to a maximum value, depending on soil properties such as particle size distribution and particle shape. This technique became increasingly more difficult as the content of silt and clay fines increase and could only achieve the densification target if the fines content is not higher than 10-12%. Brown (1977) introduced a suitability number (SN) to identify the sands that are suitable to treat by vibrocompaction in relation with fines contents.
2.1.4) **Dredged Trench Method**

For marine structures requiring large bearing capacities and settlement performance Pennine can install stone columns within dredged ground to provide additional densification prior to placement of concrete caissons.

A trench is dredged from the seabed to remove soft soils and sands before being replaced with crushed rock. As shown on Figure 5, this crushed rock fill is then densified to provide a solid foundation layer to support future marine structures.

![Figure 5: Dredged Trench Method](image)

An ‘overbuild’ layer of aggregate ballast is firstly deposited above the filled trench before a vibroflot is penetrated through the overbuild stock and into the rock mattress. The vibroflot is lowered into the water and allowed to penetrate to the base of the rock mattress, with water jetting from the tip of the vibroflot used to aid penetration. The vibroflot penetrates to the required depth, and then is slightly withdrawn and pushed back into the stone at the base of the bore to construct the stone columns in a series of lifts in similar manner to the top-feed system.

By repetition of this process, stone columns are constructed within the trench to provide a densified layer of rock mattress and the increased bearing capacities required for large marine structures.

2.2) **Vibro Design**

On any of the vibro techniques explained above, the degree of improvement will depends on many more factors including: soil conditions, type of vibro equipment, cranes used, procedures adopted, day & night shifts, and skills of site staff.  
The soil being treated, the degree of densification, the settlements required, loads, type of vibrator, production rates all have an influence on spacing required to use between columns.  
Exist a wide range of soils where this techniques works successfully (Figure 6)

![Figure 6: Stone Columns Vs Vibro Compaction](image)

2.3) Equipment

All four systems may be performed using similar types of hydraulically driven depth vibrator (Fig 7 & 8). The eccentric weight assembly is housed in the base of a heavy tubular steel casing with tapered nose to assist penetration and vertical fins to prevent rotation as shown in the pictures below.

![Figure 7: Aqucaster Vibroflot](image)  ![Figure 8. Series BD400](image)

Steel follower tubes are then added to extend the length of the vibrator up to 60m. The vibrators are suspended from crawler cranes working from barges or attached to the Pennine purpose built Stratacaster or Terrafirmer crawler rigs.
All the rigs can be equipped with the Pennine data logger computer to monitor each column installation (Fig 9).

![Pennine Data Logger System](image1.png)

Figure 9: Pennine Data Logger System

The logger captures depth and hydraulic pressures. This data is processed in a local PVA database that allows QA/QC (Quality Assurance / Quality Control) to verify that the constructions sequence for each individual column was followed and providing detailed records of the construction (Fig 10).

![Columns installation Graphs](image2.png)

Figure 10: Columns installation Graphs

2.4) Testing

The densification can be readily checked using standard penetration test or cone penetration test, comparisons can be made between pre- and post-compactions testing (Moseley & Priebe, 1993). Pennine can undertake cone penetration testing (CPT) as a fast and safe method to verify design accuracy.

As with all construction projects, a good site investigation is essential, with information on compressibility and strength of the soils being particularly important for ground improvement design. Good supervision and experienced site personnel are essential to ensure that ground improvement design is implemented correctly in the field.

4. REFERENCES

