

Vibro techniques for ground improvement

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In places where there is an abundance of soft alluvial and estuarine soils, slow and expensive foundation construction techniques are typically used. However, many of these soils may be improved sufficiently by modern 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 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.

En lugares donde existe abundancia de suelos blandos aluviales y estuarinos se utilizan típicamente técnicas de construcción de fundaciones que son lentas y onerosas. Sin embargo, muchos de estos suelos podrían ser suficientemente mejorados por medio de técnicas de vibrado modernas, lo cual permite la construcción de fundaciones superficiales tradicionales sin tener que recurrir a fundaciones profundas. En determinadas condiciones de suelo, las técnicas de vibrado han demostrado ser más económicas que las técnicas de fundación tradicionales. En comparación con otros métodos de mejoramiento de suelos, tales como sobrecarga y mechas drenantes, los cuales pueden atrasar seriamente un proyecto, las técnicas de vibrado generalmente no provocan tal escollo a un proyecto.

Keywords: ground improvement, vibro techniques, vibro stone column, deep vibro compaction, blanket feed, aquacaster

Palabras clave: mejoramiento del suelo, técnicas de vibrado, vibrado de columnas de agregado grueso, compactación por vibrado profundo, blanket feed, aquacaster

Introduction

Ground improvement techniques are widely adopted in many European countries and are increasingly being used in South America and world-wide for a wide variety of projects, with particular emphasis on infrastructure projects such as ports and harbours where there is significant risk of earthquakes. Figure 1 shows that the tectonic plates of Nazca and South America make contact along the Pacific coast, which explains the high seismic activity.

Ground improvement schemes work with the existing ground rather than bypassing it as concrete piles technique. 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

Of the many different ground improvement techniques, we are going to talk about Vibro Stone Columns and Deep Vibratory Compaction. 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.

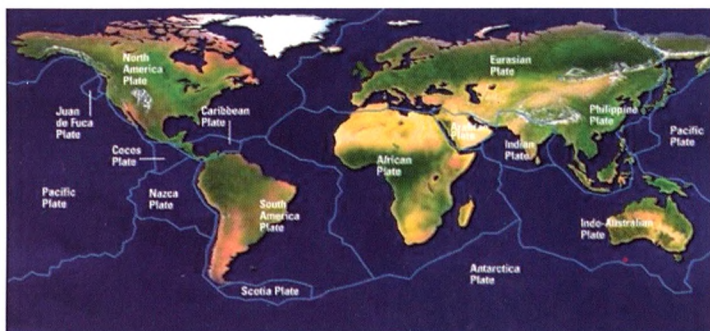


Figure 1: Distribution of the tectonic plates around the world

Deep Vibratory Compaction is the in situ densification of loose granular soils using similar equipment but without the addition of stone.

Vibro techniques use large depth vibrators, typically about 300 to 500 mm in diameter, which penetrate the ground to suitable depth, after which continuous columns are constructed up to the ground surface (Greenwood and Kirsch, 1984; Moseley and Priebe, 1993).

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

Figure 2 shows the scope of the vibro techniques, depending on the grain size. The stone columns have a wider application range than vibrocompaction, as it includes fine soils.

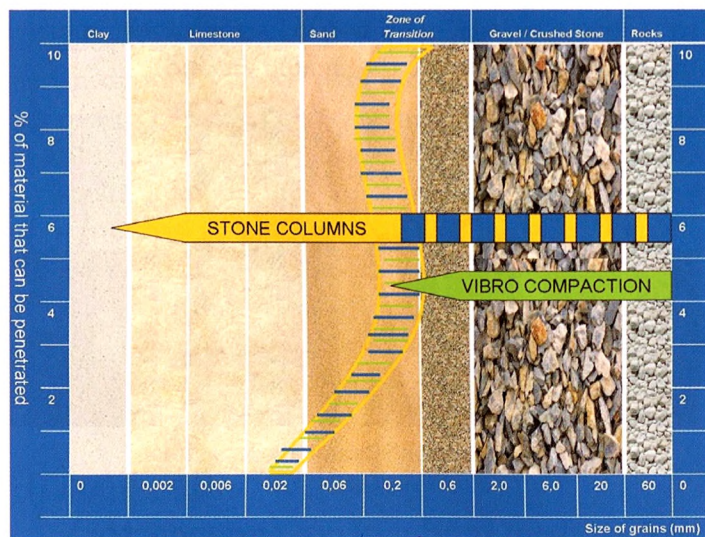


Figure 2: Vibro Stone versus Vibro Compaction

The spindle streak on Figure 2 shows the sands with a potential possibility of suffer liquefaction. As mentioned earlier, this type of soil can be improved with vibro techniques. There are four basic vibro systems available.

Dry top-feed system

The dry top-feed system is generally used where the bore is formed using air flush assisted penetration of the vibrator and would remain stable after withdrawal of the vibrator. A charge of suitable granular material is then fed from the ground surface into the base of the bore (Figure 3). The vibrator is re-inserted into the bore to compact the stone and again withdrawn. This sequence is then repeated to compact the column in stages up to the surface to form a continuous column of stone that interlocks tightly with the surrounding soils.

The dry top-feed system (Figure 3) is normally used when improving soils above the water table with shear strength greater than about $c_u = 30$ kPa (Greenwood and Kirsh, 1984). Typical grading of the granular material is normally from 40 to 75 mm. Stone column diameters from 400 to 700 mm will depend upon the strength of the soils and size/power of the vibrator.

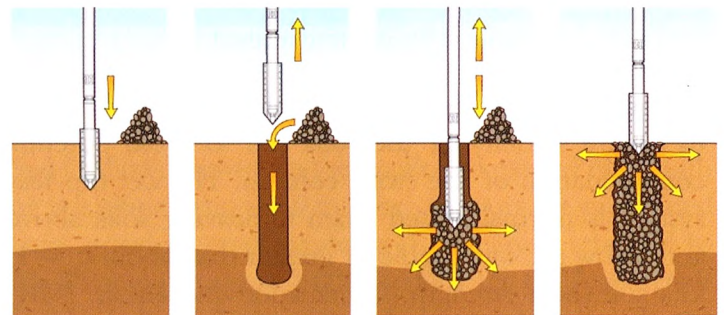


Figure 3: Dry top feed system

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 effective system for marine works. The wet top-feed system known also as blanket feed method (Figure 4) can be used for the improvement of soft soils below the water table where larger column diameters are required.

The penetration of the vibrator is assisted by water flushing. On attaining the required depth the vibrator can be partially withdrawn before then surging and flushing 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 is then placed around the top of the bore at ground 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 in similar manner to the top-feed system.

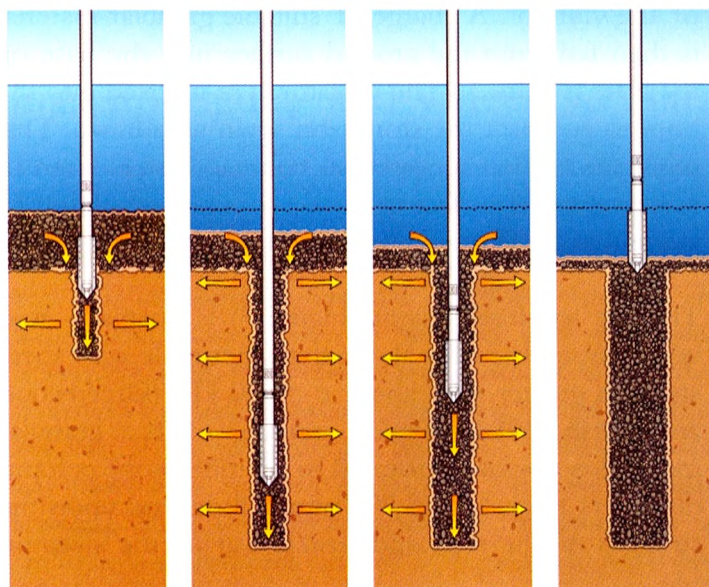


Figure 4: Blanket feed method

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 $c_u = 15$ kPa soil shear strength (Greenwood and Kirsh, 1984). Typical grading of the granular material is between 20 and 75 mm with stone column diameters of from 600 to 1000 mm being constructed.

Marine deep vibratory compaction

Vibro compaction is an established technique for stabilising fine granular soils prevalent in marine environments and is especially effective for sand compaction (Figure 5). The method is highly effective for land reclamation projects and mitigating the risk of liquefaction in areas of the world subject to seismic activity.

Shock waves and subsequent oscillation cause these saturated 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 particles (Moseley and Priebe, 1993) as shown in Figure 6.



Figure 5: Vibro compaction - Palm Island, Dubai

Mitchell (1982) identified suitable soil types according to grain size distribution and indicated that most coarse-grained soils with a fines content (amount of particles smaller than 0.06 mm, Sieve #200) below 10% can be compacted by vibratory method.

The vibroflot is deployed to the required design depth. This is achieved by using water jetting to assist penetration through the sands with the horizontal vibratory action and water jetting compacting loose soils into a denser condition to significantly improve the bearing capacity of the treated ground.

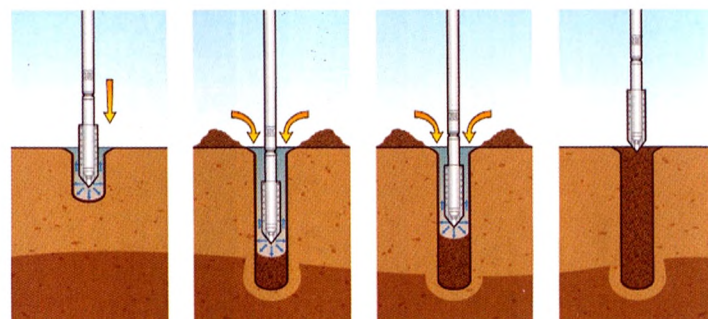


Figure 6: Deep vibratory compaction

Wet bottom-feed system (aquacaster)

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 and 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.

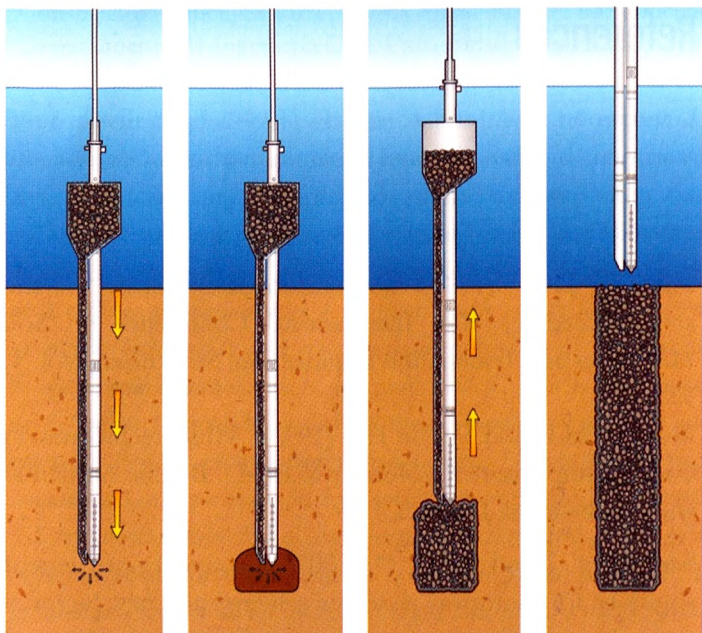


Figure 7: Aquacaster system

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 1 m 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 in Figure 7.

Equipment

All four systems can be performed using similar types of hydraulically driven depth vibrator (Figures 8 and 9). 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 of Figures 8 and 9.

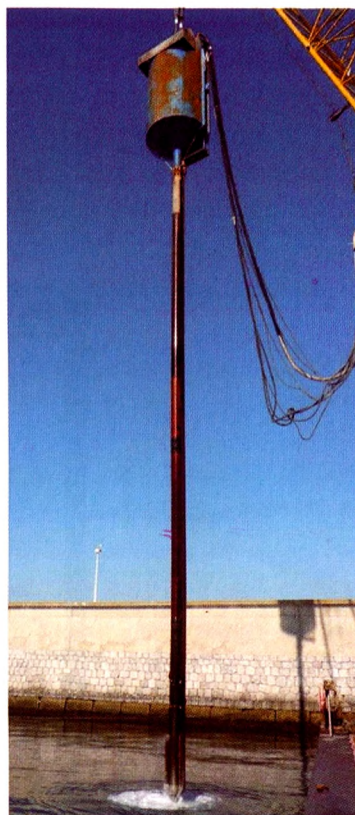


Figure 8: Aquacaster Vibro

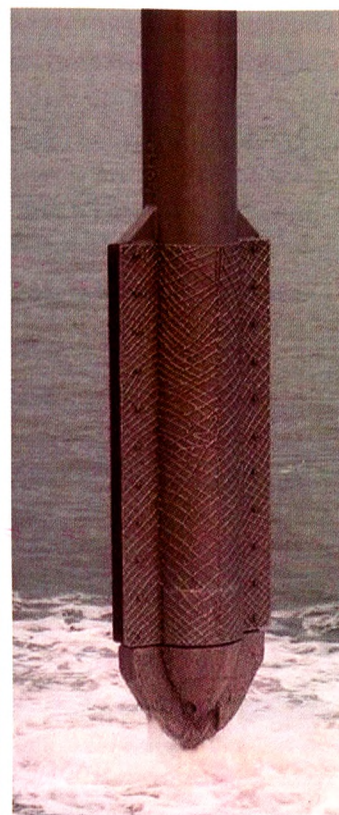


Figure 9: Series DB400

Steel follower tubes are then added to extend the length of the vibrator up to 60 m. The vibrators are suspended from crawler cranes working from barges attached to the Pennine purpose built Stratacaster or Terraformer crawler rigs. All the rigs can be equipped with the Pennine data logger computer to monitor each column installation (Figure 10).



Figure 10: Pennine data logger system

The data logger captures depth and hydraulic pressures. This data is processed in a local PVA database (PVA stands for Pennine Vibropiling Analysis) 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 (Figure 11).

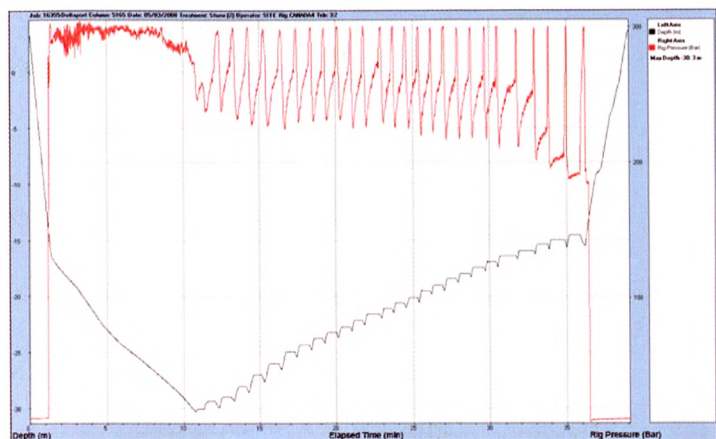


Figure 11: Columns installation graphs

Testing

The densification can be readily checked using a standard penetration test SPT or a cone penetration test CPT (Moseley and Priebe, 1993). Pennine can undertake cone penetration testing as a fast and safe method to verify design accuracy.

As with all construction projects, a good site investigation is of paramount importance, with information on compressibility and strength of the soils being particularly crucial for ground improvement design.

Good supervision and experienced site personnel are essential to ensure that ground improvement design is implemented correctly in the field (Serridge and Synac, 2007).

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