Soil Improvement Using Vibro Replacement Technique

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ABSTRACT

If the properties of the existing soil cannot fulfill the requirements set by the proposed loading conditions, bearing capacity, lateral stability and earthquake induced liquefaction potential, various techniques propose an economical solution for the ground improvement. Soil improvement methods should be determined only after development and analysis of the complete geotechnical record. This record includes groundwater depth, subsoil stratification, soil strength and type, consolidation and compaction characteristics, permeability, liquefaction strength, and dynamic deformation characteristics. Additional testing for bearing capacity or slope stability may also be required for determination of appropriate remediation techniques. As there are many soil improvement techniques and minor variations often occur in the industry; therefore, it is important to work closely with the contractor to fully understand the effect or influence of each variation. In this paper, popular techniques, Deep Vibro Techniques especially Vibro Stone Columns will be explained. Finally the case study having done in the north of Iran is described.

Key words: Soil improvement, Deep Vibro Techniques, Vibro Compaction Technique, Vibro Stone Columns

Introduction

The ground improvement techniques being used today have significantly shortened the timeframe for preparing the new land for use and therefore secured the economic viability of many projects. The consolidation phase has become an essential part of soil improvement and several techniques have been developed to stabilize the new ground.

The main goal of most soil improvement techniques used for reducing liquefaction hazards is to avoid large increases in pore water pressure during earthquake shaking. This can be achieved by densification of the soil and/or improvement of its drainage capacity. Soil improvement is also applied to improve the mechanical characteristics of impure soft soil.

When building on many sites with poor ground conditions the most economical approach to the foundations is to improve the bearing pressure rather than attempt to bypass the weaker soils with piled foundations. Ground Improvement systems can typically be 50% of the costs of a piling scheme but, more importantly, further cost benefits are provided by adopting simpler sub structures and in most cases the lack of spoil generation.

Vibro Flotation is a collective term for forms of ground improvement brought about by inserting a vibrating poker into the ground, and includes Vibro Compaction and Vibro Replacement. The latter process is often referred to as Vibro Stone Columns.

The Vibro Compaction Technique compacts granular soils with negligible fines content by rearrangement of the soil particles into a denser state. The Vibro Replacement Technique builds load bearing columns made from gravel or crushed stone in cohesive soils and granular soils with high fines content (Figure 1).

For all techniques the Vibro process starts with the penetration of the oscillating vibrator into the ground to the required improvement depth. The soil treatment is carried out on extraction by either compacting the soil or by building a stone column or structural element from the bottom up.

The deep Vibro Techniques provide a highly versatile ground improvement method that can be adjusted to a wide variety of ground conditions and foundation requirements. Its execution is comparatively fast even if large volumes of soil are to be improved and subsequent structural works can follow quickly. The soil improvement enables the contractor to utilize standard shallow footings or ground bearing slabs which, in turn, leads to additional savings compared to suspended floor options. Another advantage is its environmental friendliness of the deep Vibro Techniques, as natural and in situ materials are used and a comparatively small quantity of soil is removed in the process.
Fig. 1: Particle size distribution illustrating applicability of Vibro-Compaction and Vibro-Replacement.

Vibro Replacement Columns:

Cohesive, mixed, and layered soils generally do not densify easily when subjected to vibration alone. Vibro Replacement extends the range of soil types that can be improved with a deep vibratory process. Vibro Replacement is similar to Vibro Compaction except that rather than sand; a gravel backfill is used, with the columns providing both a minimal degree of reinforcement to the soil and an effective means of additional drainage. Vibro Replacement is appropriate for soft, cohesive soils, and with saturated soils having fines greater than 12%.

The Vibro Replacement method is also used in granular soils with high fines contents and in cohesive soils. For the construction of Vibro Replacement columns the bottom or top feed processes can be employed to optimize the performance of this process and to accommodate the specialized equipment, the Vibrocat base unit has been developed which guides the vibrator on its leader and allows the exertion of an additional pull- down pressure during penetration and compaction.

The Vibro Replacement process consists of alternating steps. During the retraction step, gravel runs from the vibrator tip into the annular space created and is then compacted and pressed into the surrounding soil during the following re-penetration step. In this manner stone columns are created from the bottom up, which act as a composite with the surrounding soil under load (Figure 2).

The Vibro Replacement process, does not assume any compaction in the surrounding soil. The improvement relies on the higher stiffness and higher shear strength of the stone column. While the compaction of the surrounding soil can be easily verified by surroundings, the improvement effect of the Vibro Replacement can best be checked by in situ load tests.

The effectiveness of Vibro Replacement depends to a large extent on the soil type, column installation technique, relative spacing of columns and column diameter. During installation, the uncased Vibroflot penetrates to the desired depth, stone is added, and the vibroflot is plunged until the desired level of compaction is obtained. Typical columns vary from 30 to 42 inches in diameter, with depths to 100 feet. Stone columns greatly increase bearing capacity, settlement properties, and shear strength of soft clay soils. The critical depth for effectiveness with respect to increased bearing capacity is typically four column diameters.

For the foundation design, the improved ground is treated as normal subsoil. The allowable bearing pressure that is achieved after the improvement is typically in the range of 150 to 400 kPa. Mixed grained and fine grained soils frequently do not possess a sufficient bearing capacity. For fines content in excess of 10% to 15% the soils cannot be effectively compacted without the introduction of additional material. For these cases the Vibro Replacement Technique is a viable option. This technique is also suitable for the treatment of coarse fills such as rubble, building debris and slag heaps.

Case Study:

Case study is about three oil tanks of 150 thousand barrel, located in the town of Neka (northern of Iran); will be constructed to increase the storage capacity of imported oil.

Based on geotechnical investigation, having done by Irankhak consulting engineering company in 2008, because of high groundwater table and existing sandy soil with medium dense (resulting from SPT test), liquefaction risk of soil underneath the oil tanks to upper 15 meter depth is definite during earthquake. In the other hand, according to the mechanical parameters of soil around the case, obtained from the result of in-site and laboratory test, bearing capacity will not be satisfied. So it is needed to solve these two problems by improving the soil underneath the oil tank. Based on Geotechnical studies and compared the cost and the time of the soil improvement methods, the correct selected option was Vibro Replacement Columns. Because of different methods to execute Vibro Replacement Columns the use of contractors experienced in the use of this method lies in the strict recommendations.
Understanding the underground layers, based on field studies of a borehole drilled (depth 30 m) from the geotechnical studies have been done. The soil profile is divided into three layers as follows:

- **First layer**: This layer of the surface to a depth of 4 classified to poorly sandy soil (SP) with layers of sand with silt (SM), from the results of the standard penetration test lies in the dense class.
- **Second layer**: This layer depth of 4 to 16.5 m from the classified to fine clay and silt (CL, CL-ML) with layers of sand with clay and silt (SM, SC).
- **The third layer**: including the depth of 16.5 m to the end of the drilling depth consists of the alluvial sand with clay and sand with silt (SM, SC) lies in the medium density class.

Groundwater level in the project is located at a depth of 2 m from the surface.

In Figure 3 the execution phases of the Drilling and arm vibration in the sand columns are shown. During constructing stone columns with Vibro Replacement, 15 to 35 percent of poor soil volume is replaced with suitable dense materials. Diameter of stone columns is about 70 to 120 cm. The effective radius of this type of soil improvement, that is functions of grain size and the amount of incoming vibration energy and the fine grained percent, is normally about 0.60 to 1.5 meter (from the column center). Therefore it is necessary to act in a regular grid with distances of about 1.5 to 3.5 m in whole.

To select the grain size it is necessary to consider parameters such as shear strength, ability of vibration compressibility and capability of proper drainage.
columns, three experimental patterns are run. What will change in these patterns is the distance of the grid points, which is equal to 1.6, 1.8 and 2 m that is considered in the triangular form. However, the company proposed to eliminate the pattern of 1.6 m (due to difficulty of executing columns in the form of triangular at intervals of less than 1.8 m) and adding a test pattern 2.2 meter. Finally it is observed that the distance of 1.6 meter is away from the optimal minimum distance and the distance of 2 m does not provide the desired density at all depth. Thus pattern of 1.8 meter provides better alignment with considering operational projects and technical issues.

**Conclusion:**

Reviewing many trials and tests, the conclusion must be drawn that many options exist which can successfully accelerate the consolidation of soils to develop newly reclaimed land or compaction methods to stabilize subsoil in vulnerable seismic areas. Each technique has its own advantages and disadvantages in relation to time, cost and performance. The best method is always to consider the specific needs of a project and contact specialist contractors to evaluate the needs of the project. The conclusions are as following:

1. The Deep Vibro Techniques provide a highly adaptable ground improvement method that can be adjusted to a wide variety of ground conditions and foundation requirements. Its execution is comparatively fast even if large volumes of soil are to be improved and subsequent structural works can follow quickly.

2. The Vibro Replacement method is used in granular soils with high fines contents and in cohesive soils.

3. The Vibro Stone Column technique is one of the most widely-used ground improvement processes in the world. Historically the system has been used to densify loose granular soils, but over the past 35 years, the system has been used increasingly to reinforce soft cohesive soils and mixed fills.

4. Vibro Replacement is also appropriate for soft, cohesive soils, and with saturated soils having fines greater than 12%.

5. The stone column is possibly the most “natural” foundation system in existence. Stone columns consist entirely of gravel, a substance that is found naturally in the subsoil. No additives are mixed into the stone columns. They are therefore not only environmentally neutral but also more durable than any other foundation system that would involve the use of cement or steel.

6. Based on Geotechnical studies in Neka (northern of Iran) and compared the cost and the time of the soil improvement methods, the correct selected option was Vibro Replacement Columns. Because of different methods to execute Vibro Replacement Columns the use of contractors experienced in the use of this method lies in the strict recommendations.

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