REINFORCEMENT AND GROUND IMPROVEMENT GEOPIER® SOLUTIONS

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EXTENDED ABSTRACT

1.- GEOPIER® SYSTEM DESCRIPTION

GEOPIER® System for reinforcement and ground improvement consist in of the execution of rammed aggregate piers or rigid inclusions, to increase the bearing capacity of the soil and reduce the seating of the supported structures, as well as to increase the shear strength in the overall stability of embankments and retaining walls, and for the mitigation of liquefaction in soils of seismicity areas.

These are intermediate foundation solutions, alternatives to traditional excavation and ground substitution solutions, structural fillers, foundation wells and preloads, for the support of structures, footings, foundation slabs, tanks, wind turbines, embankments, etc.

They are constructed by replacing and/or displacing the soil in columns made up of successive layers of compacted gravel aggregates, using specially patented tools to apply high vertical compaction energy, with high frequency and low impact amplitude,¿ thus? achieving high internal friction angles, which vary between 48-52º, while the elasticity modules of the column reach values vary between 150 and 250 MPa, higher than those reached with gravel columns performed by means of vibro-substitution.

The vertical compaction action increases the lateral pressure and improves the capacity and resistance of the surrounding soils resulting in an over-consolidation of the soil around the column which, together with the high rigidity of the constructed element, allows the reduction and control of the seats in a very effective way. It can be applied in loose soils, soft cohesive or compressible soils: soft clays and silts, loose sands, in uncontrolled landfills, rigid clays and silts and sands of medium to dense density, which require improvement to reduce or avoid differential seating.

For very soft and stiff soils, where the lateral tension is not enough to contain and confine the column of rammed aggregates, a very high stiffness modulus may be executed by adding a cement slurry during the rammed of the gravel or by constructing a concrete column, compacted and enlarged at the tip in potentially upgradeable soils, in order to increase the geotechnical capacity of the column.

Rammed Aggregate Piers (RAP) were developed in the United States in the 1980s and have since been used in countless projects around the world.

2.- GEOPIER® SOLUTIONS

These are techniques that cover practically the entire spectrum of foundation solutions where ground improvement is required to increase bearing capacity, reduce seats or limit differential seats, as alternative solutions technically and economically to deep foundations (See Figure 1).

The rammed aggregates piers are:

- ***Geopier System (GP3)*****:** up to 5-7 m deep, where the bearing capacity of the soil requires a previous perforation, for its later filling and compaction with the aggregate of gravel for the conformation of the column.
- ***X1 System (X1):*** up to 15-17 m deep, as in the previous case, in soils where bearing capacity requires prior drilling and filling and compaction of the column with the addition of gravel.
- ***Geopier Impact (IMPACT)*****:** up to 25-27 m deep in saturated or cohesive sandy, potentially cavity soil, where the column is constructed by displacing the soil and compacting the gravel aggregate.

In very weak and compressible soils, GEOPIER® solutions include rigid inclusions:

- ***Grouted Impact Pier (GIP)*:** is the same solution as ***IMPACT*** but introducing a cement slurry which is mixed with the rammed aggregate, resulting in a column with a high stiffness modulus.
- ***Geo-Concrete Columns (GCC*):** is a concrete column up to 25-27 m deep, with a high stiffness modulus, which is constructed by displacing the ground by installing a base or tip with a larger diameter than the shaft of the column, by compacting the concrete and by lateral displacement and deformation of the surrounding ground. In this way, the geotechnical resistance of the column is increased, growing the bearing capacity in soft and very deformable soils, transferring the loads to the immediately lower layer that has been improved during the construction of the column.

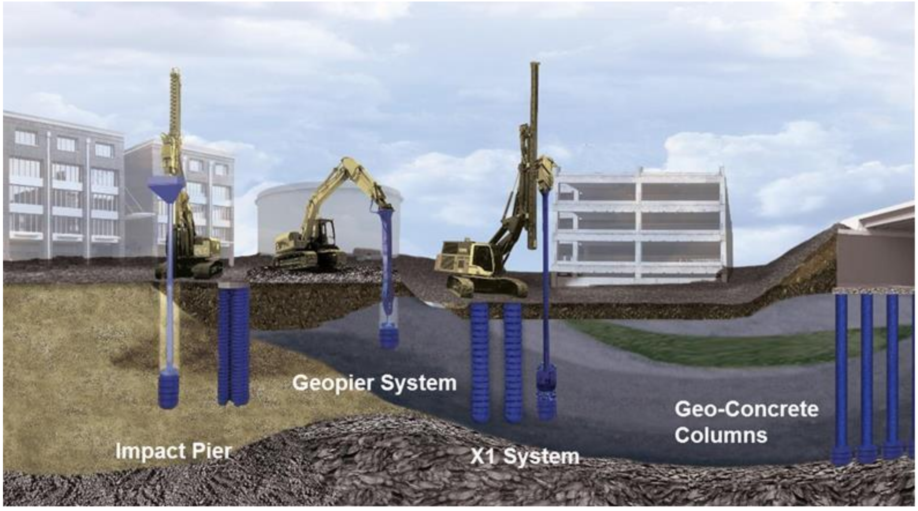

Figure 1. GEOPIER® System Intermediate Soils Foundations

In all cases, GEOPIER® systems make it possible to reduce execution times; these are fast and safe solutions, with high quality control, the results of which are verified with static load tests to check the stiffness modulus of the column and guarantee the estimated seats.

The design of the rammed aggregate piers is based on the classical principles of soil mechanics and geotechnical analysis techniques. The settlement calculation is performed by subdividing the stratigraphic soil profile into two layers. The first, called upper zone, involves the reinforced strata with the rammed aggregated piers, while the second, called lower zone, refers to the strata below the reinforced zone, but is located at a depth where the effort received is greater than 10% of the total effort applied at the level of the superficial foundation.

The settlement in the upper zone (SZS) or reinforced zone, will depend on three factors: (a) the stiffness of the rammed aggregated piers, (b) the original stiffness of the original soil, and (c) the replacement area occupied by the rammed aggregated piers under the foundation slab or footing.

The settlement in the lower zone (SZi) or the unreinforced zone can be estimated using classical soil mechanics techniques, including the analysis and selection of the compressibility parameters of the lower zone strata and the concept of stress distribution under foundations, using conventional theories of soil elasticity.

As these are elements of high rigidity compared to the surrounding soils, a concentration of loads on the head of the columns will occur, which can be improved by installing a load transfer layer with or without reinforcement geogrids. Therefore, the design must consider the magnitude and means of transfer of loads and the level of admissible seats, according to the tolerances of the structure, and depending on this, the number, the spacing of the mesh and the dimensioning of the columns will be established.

3.- PERFORMANCE PROCESS

The traditional method (***Geopier System - GP3***) involves drilling boreholes from 60 to 90 cm in diameter, in soils with a certain bearing capacity, free of phreatic level, where once the design depth of the column has been reached, the installation and compaction of successive layers of gravel aggregates with a thickness of approximately 30 cm is carried out by means of a tool specially beveled, a *Tamper*, to which a high vertical compaction energy is applied by means of a hydraulic hammer.

During the construction of the element, the high energy applied with the Tamper, in combination with its beveled shape, leads to the vertical densification of the gravel aggregate, causing a lateral displacement of the gravel, pre-stressing and pre-deforming the surrounding soils, resulting in an increase in lateral pressures soil matrix leading it to the mobilization of its passive.

The ***GEOPIER IMPACT®*** system is used in soils with less rigidity, in soft or granular soils without cohesion, or under the water table; in soils susceptible to collapse during pre-drilling of the column. The mandrel includes a sacrificial cap or the provision of internal flow restrictors to prevent soil from entering the tamper foot and mandrel during driving.

The process displaces soils laterally, resulting in densification and reinforcement, driven by a vibrating hammer located in the head of the element to the maximum depth of design to go in withdrawal, gradually, pouring and compacting the gravel inside the cavity, in layers of about 30 cm thick, until the total conformation of the column.

During the driving of the mandrel, a first improvement of the ground occurs due to the driving process and displacement of the surrounding ground. A second process of reinforcement of the soil matrix takes place during the process of pouring and compacting the gravel. The process densifies aggregate laterally into cavity sidewalls, increasing the diameter of the column and pre-stressing and pre-deforming the surrounding soils. This results in excellent coupling with surrounding soils and reliable settlement control with superior strength and stiffness, therefore an increase in the resistance to the stresses applied by the acting loads of the surface foundation.

Rammed aggregated piers are typically designed to cover the area under the footprint of the foundations, with a 25-40% substitution surface for replacement systems and 10-15% for displacement systems. Foundations supported on soils reinforced with rammed aggregated piers can withstand stresses of 200 to 450 kN/m^2. The permissible bearing capacity will depend on the rigidity of the compacted aggregate columns, the consistency of the matrix soil and the percentage of coverage of the columns, the ratio of the area of the columns (Ac) versus the area of the footing (As), reaching a load per column between 200 and 750 kN.

Rammed aggregated piers are used to improve and stiffen the most superficial layers of the ground to comply with the design criteria, and not to support the loads directly as independent rigid or structural elements. Therefore, they are not considered elements that transmit their loads to the tip, as is the case with piles, but rather that the loads are adsorbed by the shaft, for which reason it is not necessary for them to reach a layer of soil competent for use as a foundation element.

In seismic events, as rammed aggregated piers are considerably stiffer than the surrounding soil, they will take a higher percentage of shear strength, thus reducing the load on the ground. Additionally, due to the high permeability of the element, they will provide a radial drainage to dissipate the excess pore pressure that could be generated during the earthquake.

In the case of very soft and compressible cohesive soils, even with organic material contents, GEOPIER® systems offer a rigid inclusion by means of concrete columns: ***GEO-CONCRETE COLUMNS® (GCC®)***. The construction process is like the ***IMPACT®*** system, by driving a casing pipe or mandrel driven by a vibrator installed at the head, while pumping concrete into the ground, which results in lateral displacement of the ground without any removal of detritus.

At the end of the drive, once the practical rejection has been reached, an enlarged tip is constructed, with a larger diameter than the column shaft, which allows greater resistance to be exploited from a geotechnical point of view. Not only because of the larger diameter of the tip, but also for the reduction in the comprehensibility of the ground matrix at the tip, by lateral deformation carried out by compacting the concrete, creating a bottom bulb.

Subsequently, the tool is removed while simultaneously pumping the concrete, controlling the injection pressure in the column shaft, to avoid cuts in the concreting and ensure the continuity of the column.

Therefore, ***GEO-CONCRETE COLUMNS®*** are an intermediate solution between surface foundation and deep foundation (piles), where soil improvement is performed at the base or tip of the column. Due to the high stiffness ratio between the column and the soil, there will be a concentration of load on the column, transmitting much of it to the deepest substrate, so that there is a discharge of the compressible soil reducing the magnitude of the seats.

The loads supported by the column will depend on its diameter and the characteristic strength of the concrete; while the strength of the column will depend fundamentally on the diameter of the tip and the contribution of the underlying layers improved during the construction of the bulb, so the loads per column can vary between 400 and 1,500 kN.

4.- CONCLUSIONS

GEOPIER® reinforcement and ground improvement solutions are used to increase bearing capacity or foundation in loose soils, soft cohesive or compressible soils, soft clays and silts, loose sands, in uncontrolled landfills, rigid clays and silts and medium to dense sands, requiring improvement to reduce or avoid differential seating.

They are the result of continuous development and research to offer foundation and seat control solutions, providing significant increases in the permissible bearing capacity of the soils or limiting the seating of supported structures according to the requirements of the project. In a seismic event, the gravel aggregate piers will take a greater percentage of the shear stresses, since they are considerably stiffer than the surrounding soil, and will help radially drain excess interstitial pressures. Improved soils around the enlarged tip of the Geo-Concrete Columns allow to increase the loads received by the column while its seat is reduced.

These technologies are fully proven, presenting advantages due to their cost-effectiveness and savings in construction times.

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