Displacement rigid inclusions

Inclusions rigides refoulées

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ABSTRACT: In soils with poor mechanical properties and in areas where the generation of excavation debris is an issue, given the restrictions regarding its disposal, the solutions of massive soil improvement with displacement rigid inclusions solve both needs. In this paper we describe the basis of the constructive procedure of displacement rigid inclusions. We explain the concept of improvement with this kind of inclusions; we itemize the bases of their design, and describe their construction sequence, highlighting the controls during the execution to ensure quality.

RÉSUMÉ: Dans les sols ayant des propriétés mécaniques faibles comme dans les zones où l'élimination des matériaux produits des travaux représente un problème, les Inclusions Rigides avec refoulement de sol donnent des solutions à ces deux situations. L'article explique le concept des solutions d'amélioration des sols en utilisant la technique des Inclusions Rigides, donne les bases du dimensionnement, et décrit la séquence de construction des inclusions Rigides en insistant sur les contrôles utilisés pour assurer la qualité finale.

KEYWORDS: soft soil, rigid inclusion, displacement of soil, excavation debris.

1 INTRODUCTION

When studying what type of foundation is best suited to withstand the shock that a new building (structure) will impose on the soil, it is necessary to check not only the limit conditions for failure, but also the limit conditions of service, including total and differential settlements.

Being successful in the choice and design of the type of foundation to be built largely depends on the control of two variables: load and settlement. Nevertheless, there are additional parameters that also play an important role in the decision process, such as the cost of the foundation with respect to the total cost of the project, construction time and —increasingly— the impact on the environment.

The foundations based on rigid inclusions (system structure massive soils improvement) have experienced a boom in recent years, especially in works on large areas subjected to uniform vertical loads. While this is not a new concept (wooden inclusions were used since prehispanic times in Mexico —see Auvinet, G., 2006—), there is now specialized equipment capable of building concrete rigid inclusions following special procedures that not only achieve higher production results, but also greater depths and better loadbearing capacities. They also respect strict quality controls. This gives us the possibility to propose foundations based on the installation of grids of rigid inclusions made of poor concrete that meet specific technical requirements regarding load bearing capacities and the reduction of settlements. They are also attractive: economically and for their constructive feasibility, as well as for their reduced construction times and the quality of their execution.

Displacement inclusions in particular have the great advantage of not generating construction debris, which benefits the environment and reduces or eliminates the cost of its removal. In soils with a large frictional component, the ratio of voids surrounding the inclusion is reduced by the incorporation of the concrete so that the relative compactness of the material increases, as well as the perimeter friction of the inclusion-ground. The construction process of the displacement rigid inclusion guarantees quality control in the execution, so the concrete is placed continually and safe from contamination.

2 BASES OF DESIGN

The goal is to install a set of inclusions in soils with low bearing capacity and/or highly compressibility to create a layer of compound soil-inclusions material that has better mechanical properties.

The improvement or reinforcement of soils with rigid inclusions is commonly used to ensure bearing capacity and/or reduce settlements in the following types of work:

- Slabs,
- Superficial footings (isolated or continuous),
- Embankments, landfills,
- Work or storage yards.

The solution is characterized by the fact that the traditional mechanical link between the pile and the structure in deep or mixed foundations does not exist. A distribution layer, also called a Load Transfer Platform (LTP), is usually placed between the inclusions and the structure to be supported, and this is what marks the difference between piles and inclusions.

The distribution layer spreads the acting loads on the slab or other covering surface towards the underlying soil-inclusions setup. The system described is configured as shown in Figure 1. If there are concentrated vertical loads from one column, isolated or continuous footings can be used to directly transmit the loads to the soil-inclusions setup.

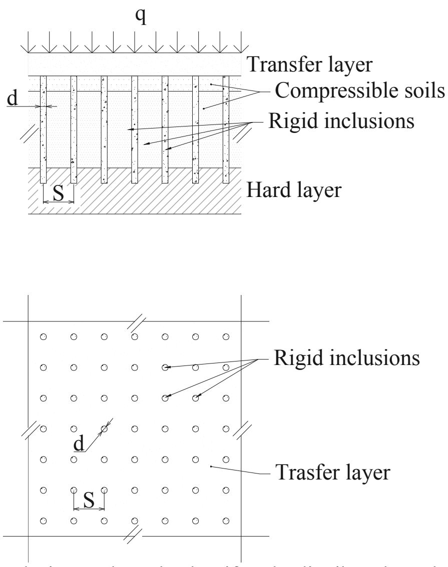


Figure 1. Inclusion under a load uniformly distributed on the surface. Side and top views.

In this case the LTP may not be required and a significant portion of the load from the superstructure will be supported by the grid of inclusions and the remainder will be supported by the soil surrounding the inclusions —see Figure 2—.

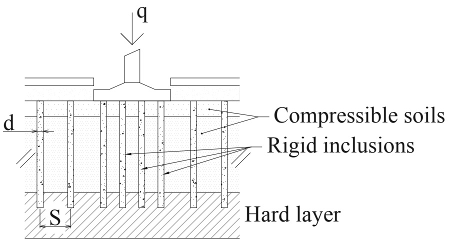


Figure 2. Model setup of inclusions under an acting strut load on a footing. Side view.

In the same way that the inclusion-soil system supports vertical loads —uniformly distributed or concentrated— from buildings, this application can be extended to the case of embankments and landfills in which the system will receive the weight of the material that forms the embankments or landfills. A particular case occurs when the embankment or landfill is significantly high and the soil reinforced with inclusions participates in its stabilization —see Figure 3—.

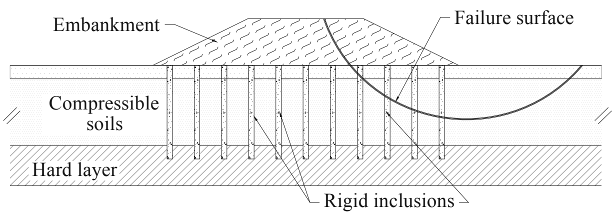


Figure 3. Inclusions that help stabilize an embankment or landfill constructed on the surface.

The inclusions will generally be subjected to the action of vertical forces caused by discharges from the building or due to the weight of the embankment or landfill. However, in cases where the inclusions participate in the stabilization of embankments or landfills, or when they are subjected to the action of seismic forces, the generation of lateral forces will also have to be taken into account in the design.

Several approaches and ways of analyzing and designing inclusions have been developed. Some of them have been recently brought together in the ASIRI (*Amélioration des Sols par Inclusions Rigides*—see ASIRI National Project, 2012—).

3 CONSTRUCTIVE SEQUENCE

The equipment used for the construction of displacement rigid inclusions kind must circulate over a flat working platform, drained and stable, generally constructed of granular material. The inclusions are built from this platform.

The drilling equipment consists of a crane supported on caterpillars with a cab for the operator and a mast that supports a cylindrical auger of a defined length. The auger is hollow and has a special geometry —see Figures 4a, 4b—, capable of displacing soil laterally when drilling. This is the most important feature of displacement rigid inclusions because the surrounding soil becomes laterally compressed. Lateral friction increases in the case of mainly granular soils or soils with a large content of sand.

At the bottom part of the tip there is a hinged lid that remains closed during the drilling phase to prevent the entry of material into the inner tube and which opens to allow the exit of the concrete to form the inclusions.

Besides the necessary drilling equipment there has to be a concrete pump which feeds the upper side of the drilling tool through flexible hoses.

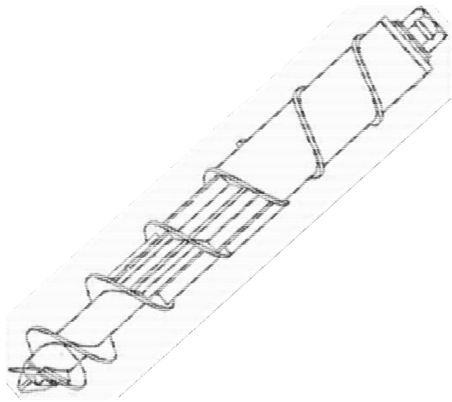
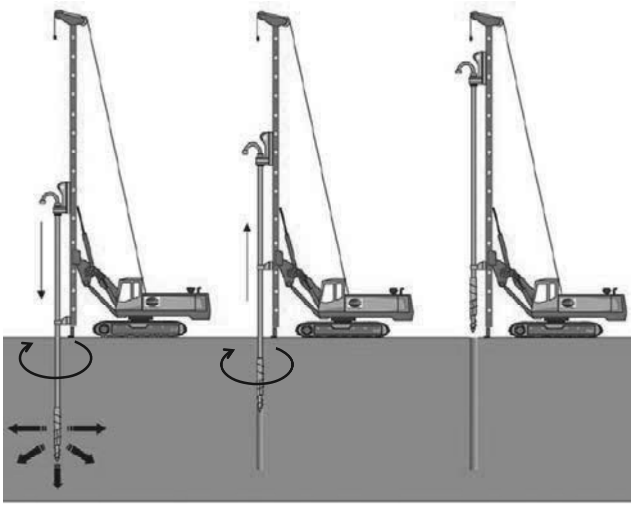


Figure 4a. Diagram of the typical point of the hollow auger for displacement rigid inclusions.

Figure 4b. Point of the hollow auger for displacement rigid inclusions developed for Soletanche-Bachy, RefSol system.

With the topographic location of the inclusion to be built, the process begins by placing the mast of the crane upright and lowering the auger into the ground. A rotor torque and a descending vertical force are applied to the auger to cut, penetrate and displace the soil laterally. This action is performed continuously until the drill reaches the specified depth —see Figure 5A—.

At this point, the concrete is pumped from the tank of the pump through a flexible hose to the upper part of the hollow auger to fill it completely and to generate sufficient pressure on the concrete.



(A) (B) (C)

Figure 5. Execution sequence of a displacement rigid inclusion.

Then the auger is lifted a few centimeters from the soil at the bottom of the perforation, which causes the lid at the lower end of the auger to open. The concrete, subject to pressure, pours into the bottom of the hole, filling it. While still pouring concrete and controlling the pressure, at this point the operator lifts the auger continuously by means of a rotor torque and a vertical pulling force —see Figure 5B—. This process continues until the auger is fully above ground —see Figure 5C—. The concrete is poured continuously from the bottom of the perforation until it reaches the level defined as the head of inclusion, which can be between the working platform level and a few dozen centimeters below it.

Throughout the process of building an inclusion (Figures 5A, 5B and 5C) real time and continuous monitoring of the parameters that intervene in its execution are done with electronic devices located in the cab of the crane. They detect the signals sent by various sensors installed at strategic points of the construction equipment. Through this monitoring, the operator has control of the different construction parameters and can ensure the quality of the construction of the inclusion at all times and along its entire height. Among the parameters controlled are: the drilling depth, the pressure and the volume of the concrete, the upward and downward speeds, rotation and the auger's torque.

The equipment is also able to store the record of the controls for each inclusion, to be processed later on a personal computer. Continuous records are obtained along the depth(see Figure 6).

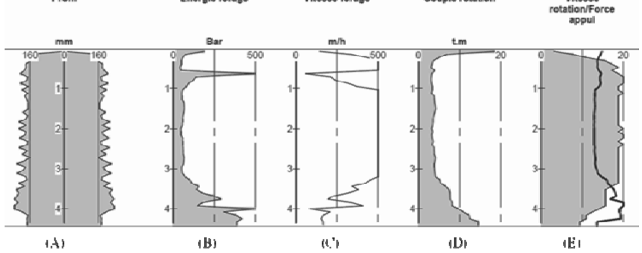


Figure 6. Record of monitoring in continuous real time: (A) Inclusion profile (mm), (B) Perforation energy (bar), (C) Perforation speed (m/h), (D) Rotation torque (t.m), (E) Rotation speed / Bearing force.

The start and stop of the concrete pump is wirelessly controlled by the crane operator from the cab. The speed at which the auger advances, the rotor torque, the rotation speed and down force or extracting force of the auger is controlled manually through the hydraulic system of the crane.

The procedure described is a clean process that leaves practically no perforation debris on the work platform. There are also no vibrations or damage to the surface layers, which makes working in areas adjacent to sensitive structures possible. Additionally, the method is capable of achieving high industrial production compared with traditional methods of pile construction.

For quality control, it is also necessary to carry out strength tests on samples of the concrete used. There will be as many tests as are needed or as required by local regulations. The common values of resistance to compressive strength of the concrete used for the construction of displacement rigid inclusion range from 10 to 15 MPa at 28 days, with modules of elasticity usually set between 5,000 and 10,000 MPa, although higher resistance and rigidity levels can be used according to the needs of each project.

The commercial diameters of displacement rigid inclusion construction range between 250 and 500 mm and can reach depths of up to 30 m.

To guarantee the quality of the implementation and the design criteria, this construction procedure has been certified by the international bureau of control and certification Bureau Veritas.

4 CONCLUSIONS

Soil improvement and reinforcement with displacement rigid inclusions kind solves a great number of foundations in which not only increasing bearing capacity, reducing settlements or ensuring slope stability play an important role, but where also cost and execution times are factors to be considered.

Given the type of auger used in the construction these inclusions are defined as displacement inclusions where the surrounding soil is displaced and laterally compressed at the moment of drilling, which increases the compactness of soils whose frictional component is significant.

During construction of displacement rigid inclusion there is real-time monitoring of parameters such as drilling depth, pressure and volume of the poured concrete, advancement speed and auger rotation, downward force of the rotor torque of the auger, which ensures a high quality control of the construction. Due to the advantages provided by the design of soil improvement systems with rigid inclusions, plus the geotechnical and environmental benefits of displacement rigid inclusions, numerous projects worldwide are being approached with this technique.

5 REFERENCES

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