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A new type of pile: the shaft grouted driven concrete pile.

Un nouveau type de pieu: le pieu battu en béton préfabriqué, injecté au fût.

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ABSTRACT: The work presented in this paper focuses on a new type of pile; the shaft grouted driven concrete pile, protected under an international patent. The pile has a square cross section with a hollow tube along its longitudinal axis, connected to a network of secondary lateral tubes. Each lateral tube, perpendicular to the pile axis, directly connects the main axial hollow tube with the pile shaft, and is fitted with one-way valve. Following the driving process, the pile skin is pressure grouted to increase its shaft capacity, achieving a greater friction than in a conventional driven concrete pile. As a consequence, several advantages have been identified: the total pile length in a deep foundation can be reduced, cutting down on construction period and reducing foundation cost. The first practical application is also presented herein, explaining the geotechnical problem, the pile design, the on-site works and discussing the results. With the aim of assessing the increase in pile shaft capacity, dynamic load tests were conducted before and after the injection process. These tests showed how the shaft capacity was significantly increased due to the pressure grouting, with shaft capacities between two and six times greater than the ones registered before the injection process.

RÉSUMÉ: L'article présente un nouveau type de pieu: le pieu battu en béton préfabriqué, injecté au fût, qui a été protégé par un brevet international. Le pieu a une section transversale carrée avec un tube creux le long de son axe longitudinal, connecté à un réseau de tubes latéraux secondaires. Chaque tube latéral, perpendiculaire à l'axe, directement relie le tube axial avec la surface latérale du pieu et est équipé d'une valve à sens unique. À la suite du battage, la surface latérale du pieu est injectée pour augmenter sa résistance au cisaillement. En conséquence, plusieurs avantages ont été identifiés : la longueur totale des pieux peut être réduite, réduisant le délai de construction et le coût de la fondation. La première application concrète de ce nouveau type de pieu est également présentée dans l'article, expliquant les problèmes géotechniques, la conception des pieux, les travaux sur place et enfin discutant les résultats. Pour évaluer l'augmentation de la capacité des pieux, des essais de charge dynamique ont été réalisés avant et après le processus d'injection, montrant que la capacité des pieux a augmenté à valeurs entre deux et six fois supérieurs à ceux enregistrés avant le processus d'injection.

Keywords: driven pile; shaft grouting; one-way valve; shaft capacity; dynamic load test.

1 INTRODUCTION

Piles are usually classified on the basis of their behaviour, construction procedure, materials used and cross-sectional shape.

According to the construction methodology, piles can be classified as in situ piles and driven piles. In situ drilled and grouted piles have been extensively used in carbonated soils, where only very low shaft capacities can be developed. There is a sound understanding of the performance of this pile type, thanks to the extensive experimental research conducted so far, the existence of numerous field tests (both at full and reduced scales), as well as laboratory tests (at reduced scale).

Due to the high installation costs associated to the construction of drilled and grouted piles, alternatively grouted driven piles with circular hollow sections were developed. For this particular pile type, there is a limited number of field tests; both at full and reduced scales; and a relatively large number of laboratory tests. Nevertheless, due to the uncertainty associated to grout cover thickness, the difficulties for measuring thickness and estimating grout shrinkage, grouted driven piles with circular hollow sections have never been used for practical applications.

In order to improve the driving process, both for steel and concrete piles, several alternatives have been considered and studied so far. Shaft grouting has been used in these piles either filling in the pile-soil gap generated during the driving, or filling in lateral membranes attached to the pile surface. So far, for practical applications, only the first system has been used for driven steel piles with open cross-sections.

The work presented in this paper focuses on a new type of pile: the shaft grouted driven concrete pile. This new pile type has been protected under an international patent (Ruiz Terán, P., Arcos Álvarez, J.L., Gil Lablanca, R., Cano Barreiro, C. 2016).

2 SHAFT GROUTED DRIVEN PILES. PREVIOUS EXPERIENCE

2.1 Ideas to facilitate pile driving

The idea of shaft grouted drive pile was first presented by the company Raymond International (Phares, L. 1974).

The intention was to use a tubular steel driven pile with an ovesized shoe, in order to reduce the shaft friction during the driving process. At the same time, the annular space around the pile would be filled with cement grout (Figure 1).

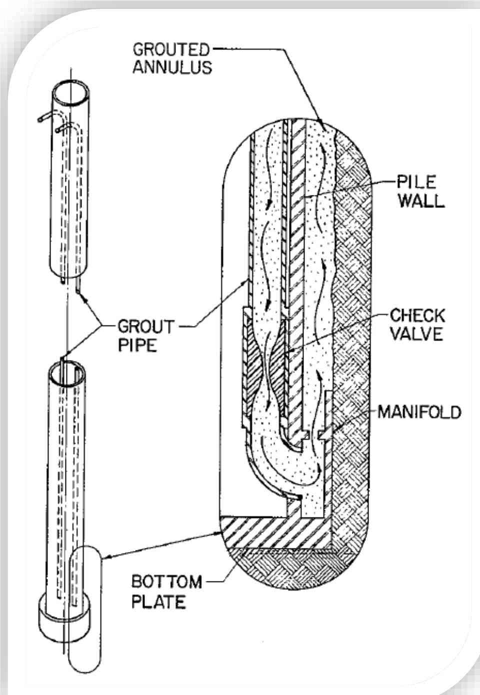

Figure 1. Grouted tubular steel driven pile presented by Raymond International Co. (Phares, 1974)

This concept was supported by full scale field tests. Even it was perfomed in real construction scenarios but only using I-section steel profiles (Richwien, A., Vollstedt, W., Woltering, S. 2008).

McVay, M., Bloomquist, D., Forbes, H., Johnson, J. (2009) used a driven concrete pile jetting water in the base in order to assist the pile driving and later on, injected the side membranes attached to the pile and the pile tip with cement grout (Figure 2).

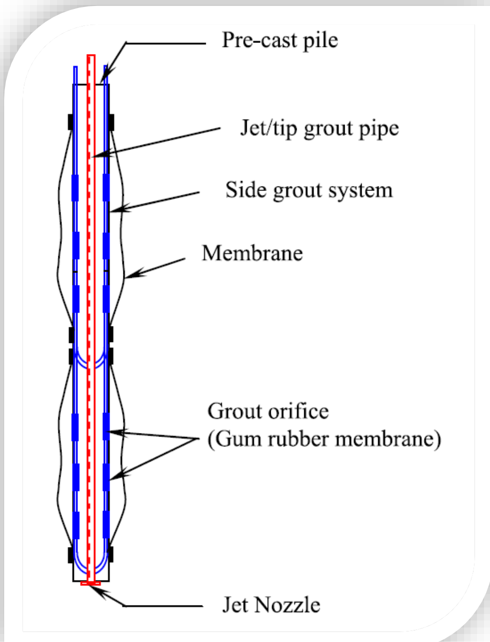

Figure 2. Driven concrete pile with side membranes

Thiyyakkandi, S., McVay, M., Bloomquist, D., Lai, P. (2013) justify the use of membranes through two reasons: first, to confine the grout zone, to improve radial expansion during pile grouting and also, to prevent the mixing of the grout with the soil, which improves bonding between the grout and the pile. This idea was supported by reduced scale tests.

2.2 *Ideas to increase the strength of the pile-soil interface*

The company Solmarine -the offshore branch of Soletanche- developed also the idea of grouted concrete driven pile to increase the shaft resistance.

Barthelemy, H., Bustamante, M., Gouvenot, D., Martin, R. (1986) set out that, similarly to the use of the grouting techniques in on-shore applications of piles, micropiles or anchorages, it would be possible to put them in use in offshore applications but with tubular steel driven piles instead of the procedures based on driven or grouted drilled piles.

Barthelemy, H., Geffriaud, J.P., Legendre, Y. (1987) suggested that throught the grouting it could be possible to increase the shaft resistance, because the pile diameter would be increased and so the horizontal effective stress to vertical effective stress ratio and the pile-soil friction angle.

Once the pile would be driven and grouted, it could be grouted achieving a shaft resistance equal to or higher than that of a grouted drilled pile. Then, the tubular steel grouted driven piles are born to combine the lower cost of the conventional driven piles with the higher shaft capacity of the grouted drilled piles (Barthelemy, H., Martin, R., Nauroy, J.F., Le Tirant, P., Cipriano de Meideros, J.Jr. 1988).

These authors proposed to use injections of both IGU (from the French term “Injection Globale Unitaire”) and IRS (“Injection Répétitive et Sélective”) types. In any case, they indicated the necessity of a thorough control of the grouting pressure, the injected volume, the discharge and the grout properties.

Barthelemy, H., Martin, R., Le Tirant, P., Nauroy, J.F., Cipriano de Meideros, J.Jr. (1987) proposed that the system must accomplish with the following limitations: it must not alter the driving process conditions, it must allow the possibility of boring in the cross-section central part of the pile, it must be capable of supporting the inherent conditions of the driving, to be simple to use and without needing a large number of people and/or auxiliary means. Finally, it must be safe.

Taking into account the above comments, the company finally chose a system with the following configuration: one or several injection tubes next to the pile shaft inner side, T-connections outside the pile, holes in the shaft surface fitted with one-way valves, protected tubes at the pile tip and injection lines with double packers (Rickman, J.P., Barthelemy, H. 1988).

2.3 *Field tests at full scale*

The company Solmarine initially validated the idea through five field tests at 1:1 scale (Barthelemy, H., Bustamante, M., Gouvenot, D., Martin, R. 1986).

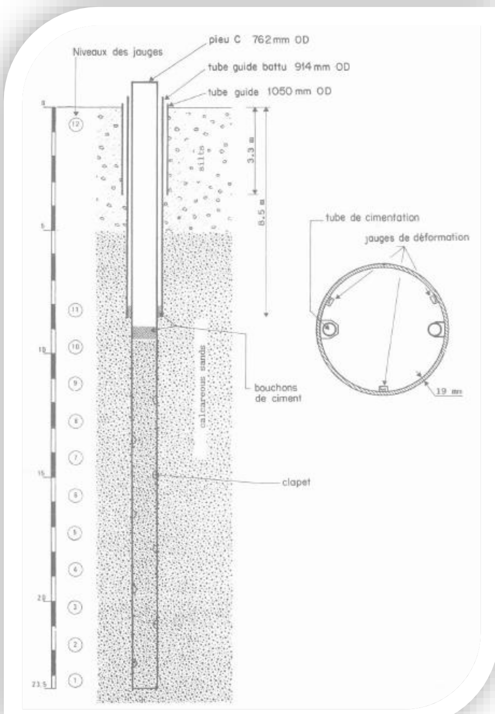

Figure 3. Shaft grouted tubular steel driven pile layout

Later, the same company carried out a new test at full scale (Figure 3), with financial support from the joint venture ARGEMA and the firm Petrobras. Solmarine made three new similar field tests, now for the company Esso Australia, confirming again the reliability of this type of pile (Le Tirant, P., Nauroy, J.F., Brucy, F., Barthelemy, H., Kervadec, J.P. 1989).

Randolph, M.F., Joer, H.A., Khorshid, M.S., Hyden, A.M. (1996) presented the results of three steel driven piles with closed tip, grouted along the shaft. The piles were equipped with two inner tubes diametrically oposed, following the system described by Solmarine.

2.4 *Field tests at reduced scale*

The joint venture ARGEMA performed also tests with grouted driven piles of 75 mm diameter and 2 m long (Nauroy, J.F., Brucy, F., Le Tirant, P. 1988).

2.5 *Laboratory tests at reduced scale*

The École Nationale Supérieure de Mécanique of Nantes (France) carried out an experimental program with laboratory tests on piles from 20 to 40 mm diameter, in order to study the peak shear strength and the shape of the sealing bulb (Levacher, D. 1988; Levacher, D., Bennabi, A. 1990; Bennabi, A., Levacher, D. 1994, 1996).

The University of Western Australia made also a similar experimental study, on piles from 20 to 50 mm diameter, in order to study the peak shear strength, the residual shear strenght, the grout coverage and the behaviour under cyclic loading (Joer, H.A., Randolph, M.F. 1994; Joer, H.A., Randolph, M.F., Gunasena, U. 1994; Gunasena, U., Joer, H.A., Randolph, M.F. 1995; Randolph, M.F., Joer, H.A., Khorshid, M.S., Hyden, A.M. 1996; Gunasena, U. 1998; Joer, H.A., Randolph, M.F. 1998; Joer, H.A., Randolph, M.F., Gunasena, U. 1998).

2.6 *Pros and cons weigh-up. Present situation*

The main advantages of the shaft grouted tubular steel driven pile are: the reduction of the length of the pile, the reduction of the piles execution times, the reduction of the cost of the foundation and the possibility of performing dynamic loading tests.

The main shortcomings are: the lack of coverage that could lead to possible corrosion problems, probles related to quality control and possibility of the grout shrinkage.

The final conclusion is that the shaft grouted tubular steel driven pile has never been used before in a real construction scenario.

3 THE SHAFT GROUTED DRIVEN CONCRETE PILE

3.1 Introduction

Shaft grouted driven concrete pile has been born taking advantage of some concepts raised within the field of offshore foundations. It solves each and every disadvantage for which the shaft grouted tubular steel driven pile has never been applied on site to date.

While generally in this type of in-situ piles there exists a decompression of the ground during their drilling, in the driven piles the ground is displaced radially as the pile penetrates into the ground. For this reason, the shaft resistance of a driven pile is equal to or greater than that of a in-situ pile.

On the other hand, the shaft resistance of a pressure-grouted micropile is higher than that of a in-situ pile; since, by means of injection, it is possible to displace the ground radially.

Taking into account also that if a pile can be driven, it can be injected, then, it is possible to drive a concrete pile and later to inject its shaft with a pressured grout, so that this pile has a shaft resistance greater than that of a conventional driven concrete pile (Ruiz Terán, P. 2016).

The goals that have been pursued when increasing the shaft resistance are the following: to reduce the length of the piles, to reduce the execution time and to reduce the cost of the foundation.

3.2 Shaft grouted concrete driven pile

The pile has a square cross section with a hollow tube along its longitudinal axis, which is connected to a network of secondary lateral tubes. Each lateral tube, placed in perpendicular direction to the pile axis, directly connects the main axial hollow tube with the pile surface, and is fitted with one-way valve (figure 4 and 5).

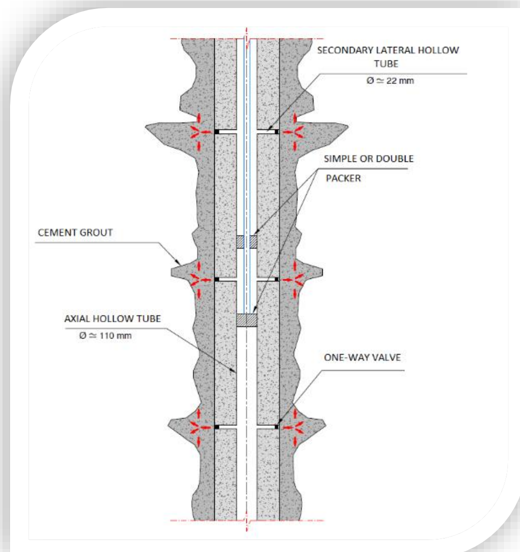

Figure 4. Longitudinal section of the shaft grouted driven concrete pile.

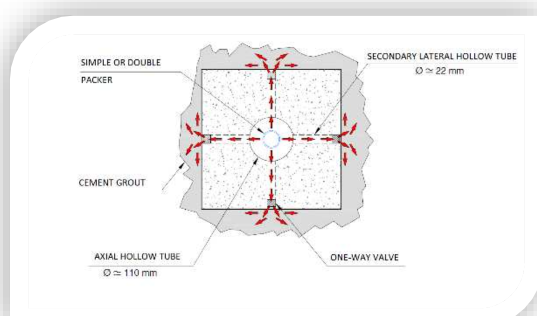

Figure 5. Cross section of the shaft grouted driven concrete pile.

In this way, the pile shaft resistance can be increased by means of the injection of cement grout with expansive additive or a pre-dosed compensated shrinkage product along the pile shaft, through one-way valves. To grout the pile shaft under pressure conditions it is possible to choose between a single or a double packer.

The injection is controlled by a real-time parameter recording, verifying that it is carried out according to the established criteria. A pressure-volume injection limit established, which is programmable, so is possible to take real-time decisions without penalizing the execution times. The recording of injection parameters also allows for a further analysis of results and the verification of suitability of the established prescriptions.

3.3 First case story.

3.3.1 Characteristics of the soil

The soil was constituted by limestone wind sands, well classified and more or less cemented by carbonates. They presented a large-scale and wide-angle cross-stratification, with interbeded red clay levels from decalcification and calcareous crusts. The level of compactness was not constant, with significant variations horizontaly and presented in vertical with multi-episodic character.

3.3.2 Geotechnical difficulties. Proposed foundation.

Carbonated soils are known for having a significantly lower shaft friction resistance value than expected through the conventional calculation methods.

The current trend of deep foundations in carbonated soils is to move away from the driven piles, being the preferred alternative the grouted drilled piles. Due to the their high installation costs, the shaft grouted driven concrete pile was proposed as an alternative foundation system.

Taking into account the characteristics of the different ground geotecnical levels and the injection pressures, an average characteristic shaft resistance of 130 kPa and a characteristic toe resistance of 920 kPa were considered.

3.3.3 Analysis of the results of the load tests

In order to verify the piles load capacity and the increase of the shaft resistance as a result of the injection, dynamic load tests were performed both before and after grouting. The shaft resistance reached values from 18 to 123 kPa before the injection, with an average value of 61 kPa, while after the injection reached values of 71 to 213 kPa, with an average value of 136 kPa (Figure 6).

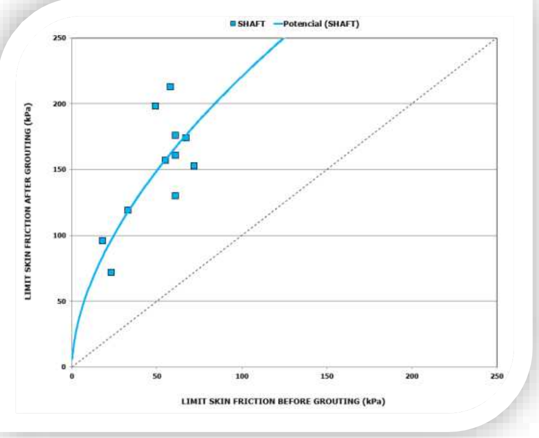

Figure 6. Shaft resistance before and after grout injection.

When comparing the results before and after the injection, the shaft capacity was multiplied by two to six times (Figure 7).

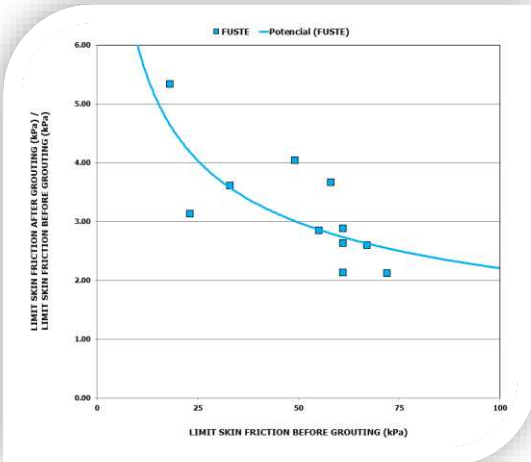

Figure 7. Shaft resistance increase.

The curves proposed by Bustamante, M., Gambin, F., Gianeselli, L. (2009), used for single global or multiple repeatable post grouting piles calculation, can be used in order to perform a pre-design for this type of piles. Since the pile shaft resistance is above these curves, it can be considered that the design remain on the safe side.

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