Post-Grouted Drilled Shaft Behavior

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Abstract. Using post grouted cells at the tip of the piles form part of recommendations of construction application in several countries. The effect of this practice is valued ranging from a simple construction standard for improving contact between the pile tip and soil support, to the application of coefficients which enhance the load capacity of the pile as a whole. In the city of Córdoba, Argentina there is provided the use of a solution of large diameter piles with the execution of a cell of post grouted for the foundation an important highway viaduct. This foundation system is supported on a sand blanket between clean and silty, performing at the design stage an analytical estimate of the point resistance improvement as a consequence of post grouted execution. While it has international background of improving effects on the overall behavior of the pile through the implementation of these treatments, there is no specific application information in our environment for the case under analysis. This publication shows the prior analyzes conducted to estimate the contribution to the load capacity of the pile for treatment implementation. At the same time the process followed in the design of the testing and validation of the method of construction of the cells is described, and concludes in the description and analysis of load tests on piles made.

Keywords. In situ tests, pile, post grouted

1. Introduction

One of the most commonly alternatives to found large structures are drilled shafts. Although the performance of this type of foundation is limited by the maximum contribution of end bearing capacity and frictional capacity, these values are not achieved completely due to three mechanisms, or combination of them:

1. Incompatible deformations: while the pile develops its maximum frictional resistance for settlement of the order of 0.5% to 1% of the diameter of the pile, the settlement required to reach all of the point resistance ranges from 10% and 15% of the diameter.
2. The disturbance caused by the construction process that produces relaxation of the soil by the overload digging.
3. Weak debris presence in the bottom of the excavation as a result of the construction methods.

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To overcome these shortcomings in some measure, the post grouted by injection of piles point are used. The objectives of this technique can be summarized as:

- Decrease the settlements required by the pile, to get into load, and compatible the deformations between the shaft and the tip.
- Strengthening and repair of alterations below the tip of the future pile that excavation could produce.
- Generating, by compression, a plastic deformation of the base underlying soil while that additional volume is filled with cement grouting, generating a preload at the tip.
- Mobilize the pile shaft capacity due to the upward force generated by the injection, producing a frictional preload (the shaft result in a negative friction).

This technique is highly effective in low or medium density frictional soils, because these are more susceptible to be affected by the three different mechanism described.

The injection of piles point by means of post grouted cells has been widely used worldwide. Design methods currently exist for estimating the increased load capacity of the pile depending on the last peak capacity estimated based on the number of strokes of the SPT and the frictional resistance of the pile [1][2].In general, the injection is carried out in stages by successively increasing the injection pressure and decreasing the water / cement ratio grout. The maximum injection pressure is calculated based on the maximum frictional pile capacity, which must balance the upward force generated at the pile tip.

It was utilized for the first time by Argentine engineers [3] in the 1973 year, in the Project of two big way bridges over the Paraná River. The cell consists, basically, of a basket formed by two metal discs and a wire mesh forming a cylindrical wall. The lower disk has a series of holes to produce a uniform distribution of the cement grouting. Within the cell there are injection pipes and gravel of uniform size this basket are placed uniform particle size gravel and injection pipes with valves. In Cordoba, Argentina, on sandy silt soils, there are several studies [4][5].

The study is based on analysis and evaluation of static load tests performed on two piles located on the Road Interchange named “Tropezón”, in the city of Cordoba. The aim of the static load test on piles is to evaluate experimentally the load-deformation behavior for extrapolating the results in the piles project, in order to validate, or adjust, the geotechnical design made for these foundation elements. Particularly to analyze the influence from the cell arrangement of preload in the pile tip.

2. Test setting

The static load test aims to determine the following aspects of axial behavior of piles:

- Establish the ultimate load capacity (contact pressures at the pile tip) or yield load , through theoretical and experimental test correlations.
- Determine the axial stiffness, to estimate the expected deformations under service loads, in the project pile.
- Identify relationships pressure - settlement for the pile tip.

Test piles have a total length of 6.50 m, ensuring contact with the layer of silt sands, according to geotechnical studies.

The particular characteristics of the test piles are:

Pile PE1. Without load cell at the tip of 0.5m in diameter. Based on the objectives stated in this study, in order to minimize resistance developed along the pile shaft, the construction of the pile was performed using the following methodology:

- Dig to a depth of 5.00 m, with a diameter of 0.70 m. Introduction of a 0.60 m diameter jacket, fixed on the bottom of the excavation. Then fill the annular space, between the jacket and the excavation wall, with a mixture of soil and sand, to improve the local confinement of the shirt, with a low resistance along the shaft.
- Excavation 1.50 m of the remaining pile with a diameter of 0.5 m, placing the drilling equipment inside of the jacket. Installation of reinforcement and concreting the pile.

Pile PE2. With load cell at the tip of 0.50 m in diameter. The scheme of the cell is shown in Figure 1. The construction sequence is:

- The first step is the same that PE1, except that the soil mixture has cement, which seals the dig before the preload injection, in the pile tip.
- The pile reinforcement, has in the tip, the load cell designed with similar characteristics to use in the final project piles.

After three days, that the pile has been concreting, the injection of preload cell is carried out. The injection mixture has the following characteristics: Relationship water - cement = 1, bentonite content = 0.5 Kg / 50Kg cement, expansive additive content = 0.5 Kg / 50Kg Cement.

Figure 2 shows a schematic of the test systems formed.

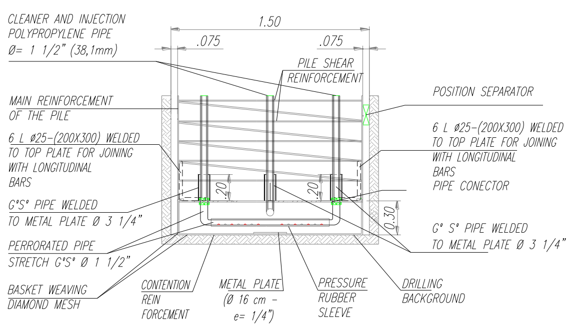


Figure 1.a. Cell sketch

Figure 1.b. Cell picture

3. Tests results

The pile behavior was estimate with the classic geotechnical models, for characterizing relationship between loads and settlement. These relations are shown in t-z curves [6]. The AASHTO, bridge design manuals, recommends this method.

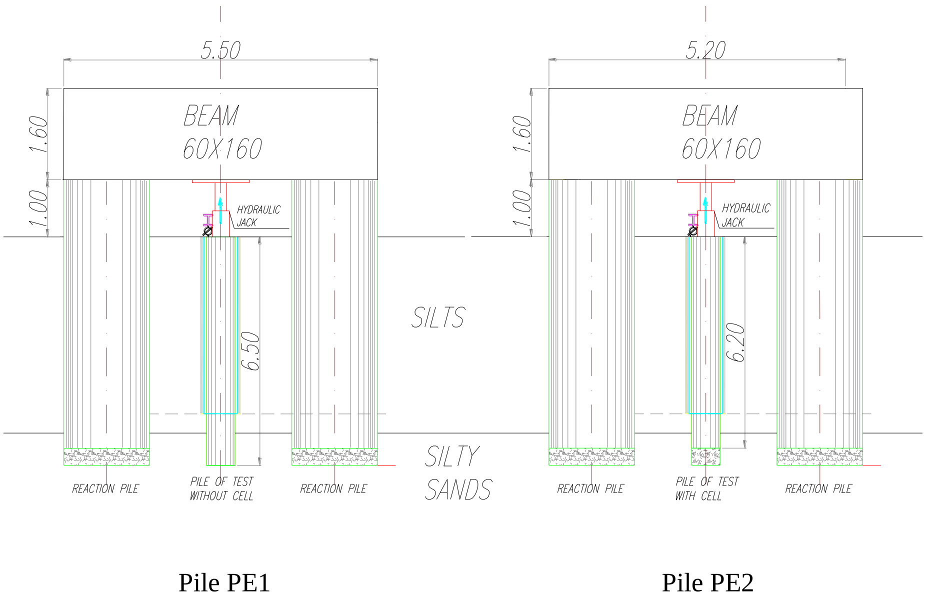


Figure 2. Test setup

Being these relatively short piles, it is considered that this component of the pile structure shortening in negligible compared to shortening dependent of the load transferred by shaft and tip.

The results obtained are shown in Figure 3.

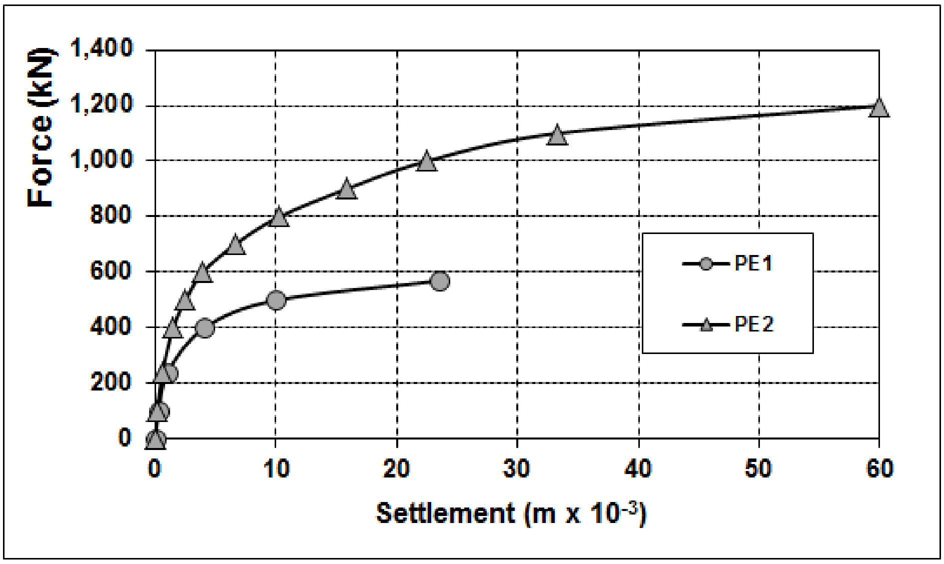


Figure 3. Test Results.

The main features of the tests are:

- It is considered that, depending on the soil that affect the interaction of the pile with the shaft and the tip, the load transfer curves that better adjust are: a) for the shaft the interaction cohesive soils curves , b) in the tip corresponding to non-cohesive soils curves.

- In both cases it can be seen an initial elastic behavior. In the case of transfer curves applied to the shaft, this first section is maintained to a magnitude of deformation of the order of 0.3 to 0.6% of the pile diameter. Transfer curves in the tip, can be extended to values between 2 and 5% of the pile diameter.
- The effects of "isolation" of the shaft have been achieved satisfactorily, maximizing charge into the pile tip.
- The limit of elastic behavior in the pile tip can be interpreted as a diffuse point.

According to previous assumptions, the analysis of the load applied in each sector of the pile was carried out, as indicated below.

3.1. Identifying stresses in each part of the pile

Combined resistance values (friction and cohesion) in the pile shaft contact with the ground have been set as follows:

- Maximum concrete - soil contact stress. 50 kPa.
- Maximum jacket – soil/sand stress. 10 kPa.
- Maximum jacket – soil/sand/cement stress 25 kPa.

With these values and the geometry of the pile in each case, has been estimated maximum load that each element transmitted to the ground by the shaft. The results obtained are shown in Tables 1 and 2.

Table 1. Estimation of force transmitted by the shaft at test pile PE1

Level	Length (m)	Diameter (m)	Shaft Resistance (kPa)	Force (kN)	Material
1	5.00	0.60	10.0	94.2	Jacket and soil-sand
2	1.50	0.50	50.0	117.8	Pile - soil
Total Shaft force				212.1	

Table 2. Estimation of force transmitted by the shaft at test pile PE2

Level	Length (m)	Diameter (m)	Shaft Resistance (kPa)	Force (kN)	Material
1	5.00	0.60	25.0	235.6	Jacket and soil-Ce
2	1.50	0.50	50.0	117.8	Pile – soil
Total Shaft force				353.4	

Following the guidelines of Reese and O'Neill models, the results shown in Figure 4 are achieved.

3.2. Transfer curve (stiffness at the tip) for each type pile.

As shown in the above figures, the settlement - pressure curve in the pile tip has a strong nonlinear behavior. In this regard, it has adopted for representation an equation of hyperbolic type, based on the classic hyperbolic models. Equation has the form of the equation. (1).

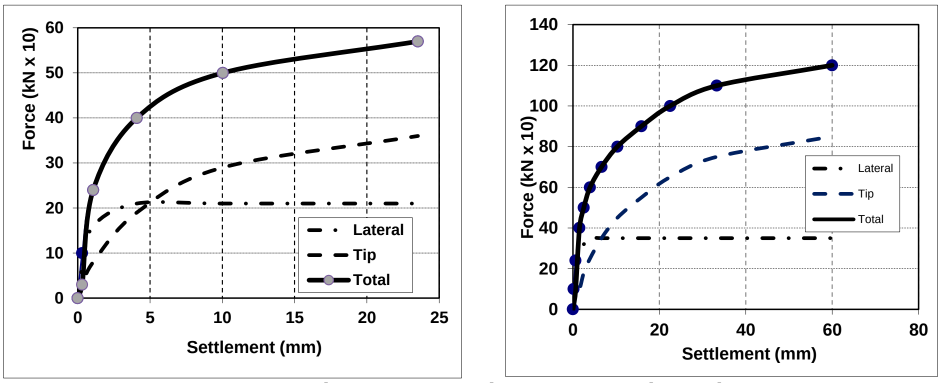


Figure 4. Load components – settlements in PE1 and PE2 piles

$$\sigma_p = \frac{\varepsilon_v}{\frac{1}{E_i} + \frac{1}{\sigma_{rot}} \cdot \varepsilon_v} \qquad (1)$$

Where: σ_p, is the pressure on the pile tip. ε_v, is the deformation in the tip, it has been assumed as a direct proportion to the diameter of the pile, ie is equal to the ratio between the settlement (δ) and pile diameter (Φ). Ei, is the initial modulus, which depends on a initial stiffness parameter (K), the mean confining pressure (σ_3) and an exponential shape coefficient (n). Consequently, the module can be expressed as:

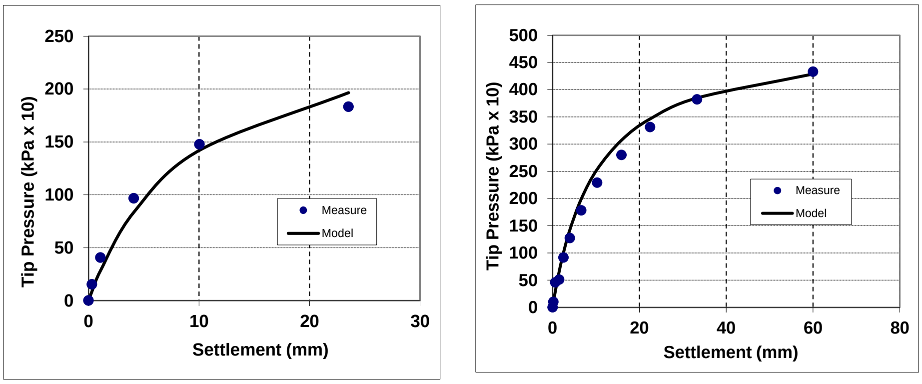
$$E_i = K \cdot p_{atm} \cdot \left(\frac{\sigma_3}{p_{atm}} \right)^n \qquad (2)$$

σ_{rot}, ultimate soil stress, interpreted as the value at which tends to be asymptotic pressure – settlement curve. Have been identified parameters K, n y σ_{rot} that best fit the experimental values. The basic parameters used and the results obtained are shown in Table 3.

Table 3. Application parameters on pressure tip pile - settlement curves

Parameter	PE1 test	PE2 test	Units
Diameter	0,50		m
Area	0,20		m2
Unit W	17,5		kN/m3
Depth	6,50		m
Confining P	59,5		kPa
Reference P	100		kPa
K Module	2.300	3.700	
Exponent	0,70	0,90	
Ultimate resistance	2530	5000	kPa
Module Ei	159.920	231.880	kPa

The adjustment level achieved can be seen in Figures 5.



PE1. Pile

PE2. Pile

Figure 5. Relationship settlement and pile tip pressure. Measured and calculated values.

3.3. Comparison of the allowable stresses for working conditions.

Considering allowable the model of pressure in the pile tip - settlement is possible to draw the corresponding stiffness curves for each of the piles tested. The results are shown in Figure 6.

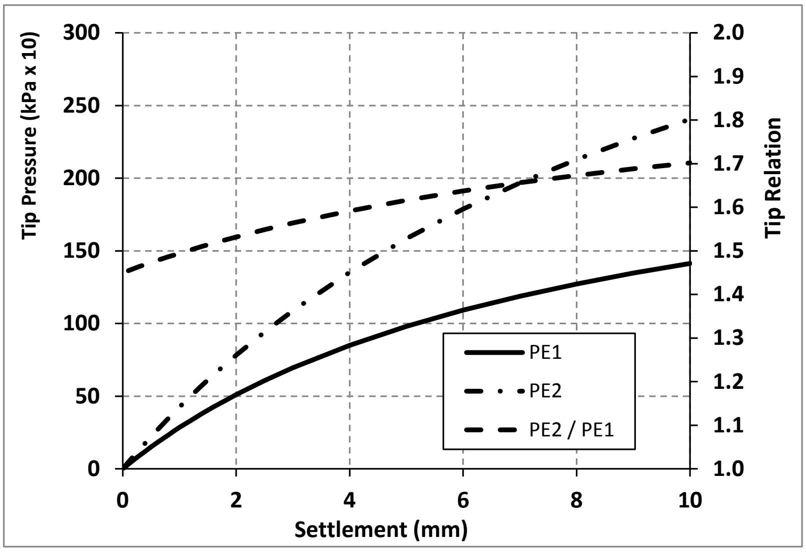


Figure 6. Pressure - settlement curves and pressure curves relationships

4. Conclusions

The results obtained allow the following observations, as conclusions, and in relation to the objectives of the proposed study:

- Through the static load tests conducted on piles, has verified the difference in behavior of these items depending on the implementation of preload injections on the tip.
- Deductions from pressure applied to the pile tip result in significantly different stiffnesses relations, according to the pile tip has been injected or not. For settlements exceeding 1.5 mm, the pressure ratio between the injection case (pile PE2) and one without injection (PE1) shows values higher than 1.50.
- A ultimate level pressures in the soil bearing pile, it is appreciated that the values are of the order of 2.500 kPa in the case of the pile without injection (PE1) and 5.000 kPa in the case of the pile with injection (PE2). Applying safety factors of the order of 3, the "admissible stress" are set to 830 kPa and 1.650 kPa to the pile without injection and with the injected tip respectively. The ratio of allowable stress at the tip to the case with and without injection is 1.99 (165/83), which is greater than the value of 1.50 recommended in the geotechnical report. Although it is possible to apply higher than the recommended values, it is considered that the value of 1.50 is acceptable to contemplate scale effects between the pile test and actual of the work and differences in the soil - pile interaction that could not be captured in this test. At the same time, using the values specified in the geotechnical studies permit the conclusion that the expected settlements are sufficiently restricted, implying values between 2 and 4 mm that are acceptable.

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