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Recent Advances In The Expander Body Technology

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SUMMARY: The Expander Body (EB) technology has been used successfully to increase the pile toe capacity of bored piles in loose to dense soils. An important advantage of the EB system is the ability to examine the EB expansion process, which provides important information regarding soil strength and soil stiffness. This information, obtained for each installed pile, can be used to determine the actual shape and pile toe area. The expansion pressure can be used to design the pile base capacity. The Expander Body system has been recently improved by incorporating the possibility of post-grouting the soil below the expanded pile toe. This improvement provides additional strength and stiffness to the pile toe and reduces pile settlement. In other hand, the shaft bearing capacity of the traditional bored piles can be increased significantly replacing the bored shaft by using a soil displacement auger, which evades soil decompression and increases lateral soil stress. This paper describes the principle of the EB system and its combination with the full displacement system for the shaft and presents new experiences in different soils. A high degree of quality control can be achieved by monitoring the entire pile installation process, including the displacement pile and the Expander Body. For the case history included, a statistical analysis is presented in order to show how the EB system can be a very valuable tool for risk analysis, seeing that a histogram of the resistance is obtained after the installation of all piles; fact that gives the possibility of a better understanding about soil heterogeneity which is a very common problem in the foundations industry. The use as anchor also gives several advantages in comparison with traditional anchors, due to the extraction cone created by the Expander Body.The quality control of the 100% of the Expander Bodies provide a sound information about the condition of the soils at the toe level, which allows, when properly correlated with loading tests, to have a high level of reliability. The installation process does not imply longer times than in traditional piles and the capacity increment is significantly important. In some cases has been up to 4 times higher than the bored pile.Finally, the EBs are also used as test device in each pile toe because is possible to estimate soil parameters during expansion process during the expansion.

KEYWORDS: Expander Body, Full Displacement Piles, QA/QC

1 INTRODUCTION

As explained in the abstract, the main characteristic of the EB technology consists in the high QC/QA of the system, which provides not only a clear improvement of the toe capacity but also measures this improvement by monitoring the pressure and volume of the injection. In fact, the system is not only a foundation device but also a testing device for 100% of the pile toes. (Terceros et al., 1995,2008, 2014)

The EB can be installed in a wide variety of soils, from very stiff clays to gravel, although the most common soil has been the sandy-silty soil. The experience in other type of soils has shown that the system has a high reliability because of its behaviour as a cylindrical cavity expansion, thus different models already proven for this theoretical approach can be used considering the specific soil parameters.

The EB system consists in a folded steel balloon attached to the toe of a pile, installed with the reinforcement cage or attached to a pipe shaft. Once the pile is installed and concreted, the EB is expanded by grout injection, as shown in the Figure 1.

All the process is electronically monitored in order to measure the injection pressure and injection volume. The injection curve, see Figure 2, obtained from this process allows the interpretation of the capacity of each EB

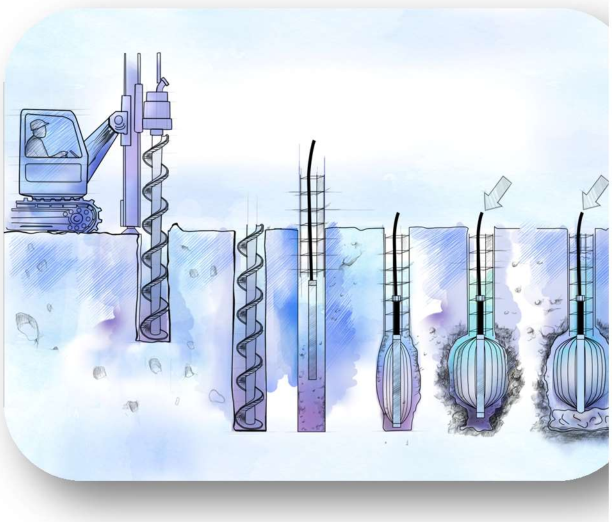

Figure 1. Installation, expansion process and post grouting

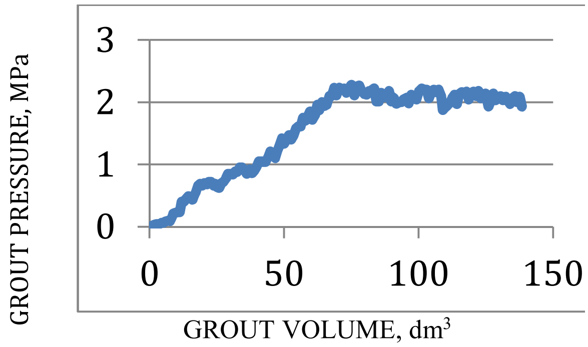

Figure 2. Pressure-volume curve for each EB

2 RECENT ADVANCES

Two recent advances have improved furthermore the capacity and reliability of the EB piles: the post grouting and the use of the EB in the toe of Full Displacement Piles.

2.1. The post grouting, mainly in soft soils, provides an additional improvement of the underlying soil, because the grout increases the pressure bellow the EB, which increase the stiffness of the soil resulting in lower settlements. In Figure 3 is shown the process and the injection curve obtained from a post grouted EB. According with the available data, the post grouting pressure is similar to the injection pressure of the EB.

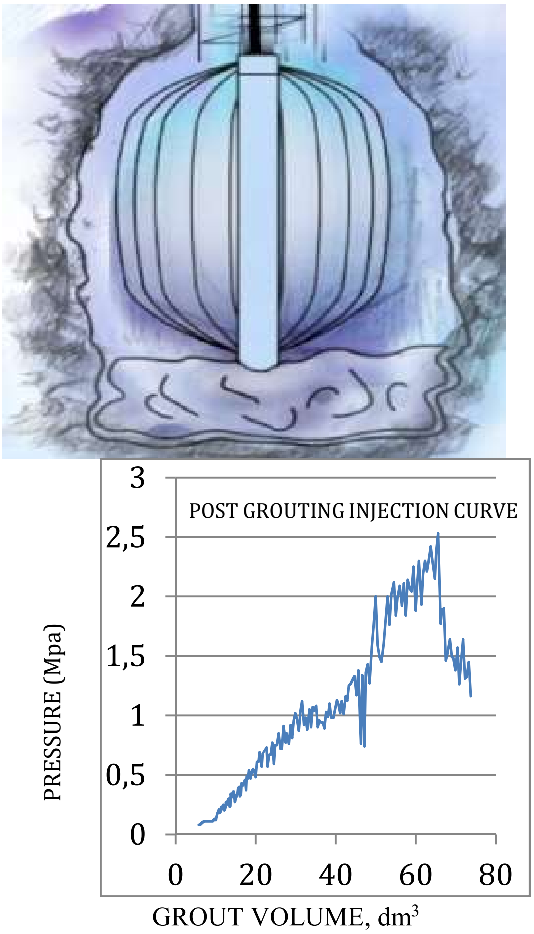

Figure 3. post-grouting process and its typical injection curve

2.2. The combination of FDP shaft with EB gives a very important increase in capacity. According to Fellenius et al., in a test site, four strain-gauges were installed for bored piles instrumentation for sedimentary dense to very dense, fine to medium sand in Santa Cruz, dense to very dense, fine to medium sand in Santa Cruz, Bolivia. Two of the test piles were standard bored piles constructed with bentonite slurry, and two piles were Bauer Full Displacement Piles (FDP). One of each pair was equipped with Expander Body that on pressure-grouting provides an enlarged pile toe. Three of the piles were tested using a head-down static loading test and the fourth pile, a standard pile with Expander Body and an O-cell placed immediately above the EB, was tested in 3 phases. During these tests, the difference in shaft friction between drilled and displacement piles and the toe response in drilled, FDP and piles with EB at the toe were measured. The Figure 4 shows the vertical view of the test site. The EB units (Piles TP3 and TP4) were expanded using pressure grouting immediately after the pile had been concreted. To offset shortening of the height of the expander, which occurs during expansion, also the soil below the EB was pressure grouted. To further increase soil stiffness and strength, pressure grouting was implemented at the bottom of the EB. It is also important to point out that the installation speed is very high, typically sorts between 12 and 25 piles per day. This is an important factor from the economical point of view.

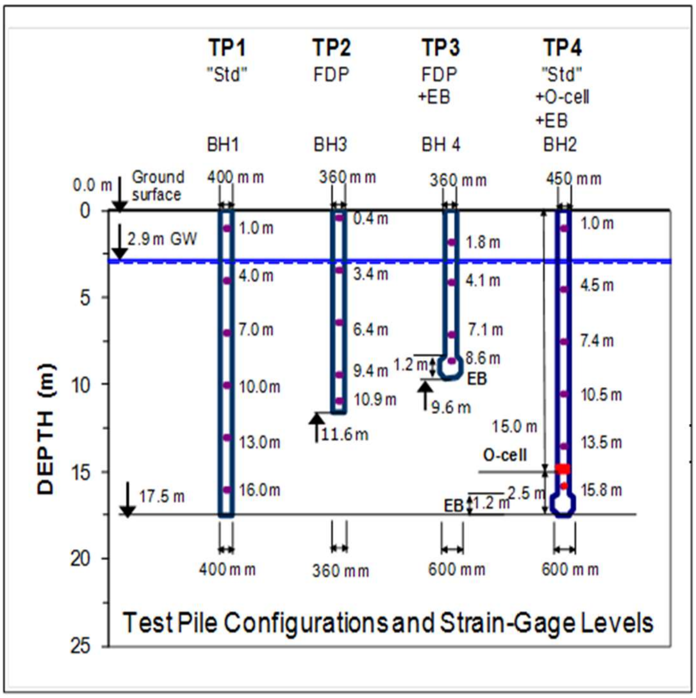

Figure 4. Vertical view of the test site (Fellenius et al., 2013)

During the injection of the EBs at TP3 and TP4, the influence of the construction process was clearly noticed. As shown in Figure 5, the injection curve of TP3 shows a higher initial stiffness than TP4, because of the initial expansion produced by the FDP tool.

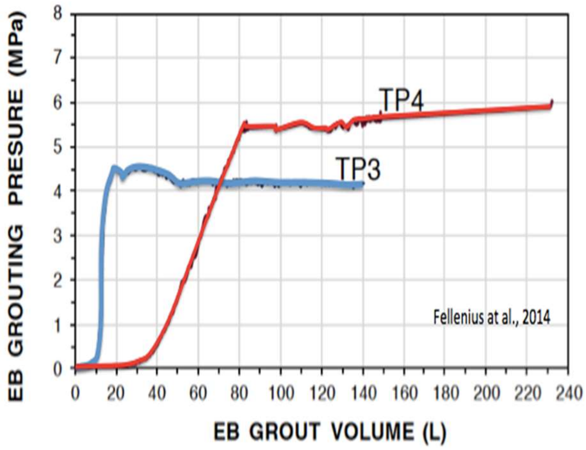

Figure 5. EB grout pressure and grout volume for TP3 and TP4 (Fellenius et al.)

During the referred tests, the beta-coefficients of 0.5 and 0.6 evaluated from the results on the standard bored pile showed the local soils to be quite competent for a compact silty sandy soil. However, the displacement compaction achieved by the Full Displacement Pile, FDP, showed to improve the shaft resistance considerably, increasing the beta coefficient from 2 to 3 times that of the standard pile.

The addition of the EB showed to have greatly enhanced the stiffness response of the pile toe.

The measured response of the EBs was above 2.000 kN for 10 mm movement. (cf. Response To Load For Four Different Types Of Bored Piles, Fellenius, B.H et al., 2014)

3 CASE HISTORY

A high-rise building of 23 stories is being built in Santa Cruz, Bolivia.

The foundation is already finished. The adopted solution was with FDP+EB piles, each pile with a working load of 150 ton.

The characteristic of the piles is:

Shaft diameter: 440 mm
Expander Body: 600 mm
Length of piles: Between 9,50 m and 12,00 m
Level of the pile head: -5,50
Level of the pile toe: Between -15,00 and -17,50
Average daily production: 16 piles per day (2.400 ton of service load installed per day)

As the FDP system measures several parameters during the penetration in soil and pouring concrete (like torque, penetration force, extraction force, rotation speed, penetration speed, alpha value, concrete distribution, etc.) the final depth of each pile can vary depending on the soil in each point. In the following figures, this aspect is shown.

The soil is a medium dense to dense sand with some fine gravel. In Figure 6 is shown the typical CPTU record of the site.

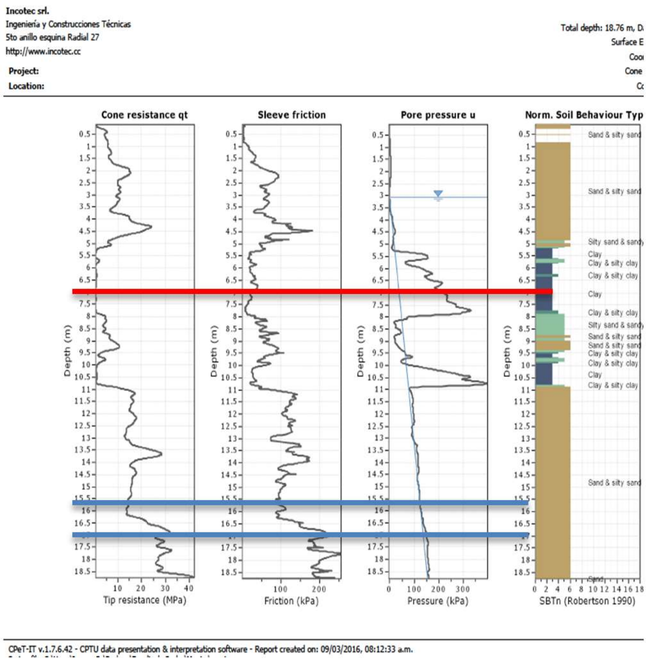

Figure 6. CPTU record. The red line shows the level of the piles heads. The blue lines show the range of levels of the piles toes

Because of the high heterogeneity both horizontally and vertically, the geo seismic tests most used in the region are the surface waves (MASW, SASW, REMI). Because of the layered conditions with soft soils between hard soils, the seismic refraction is not used. Figure 7 shows the 2D profile obtained from the MASW study. The profile shows clearly the increment of V_s with depth.

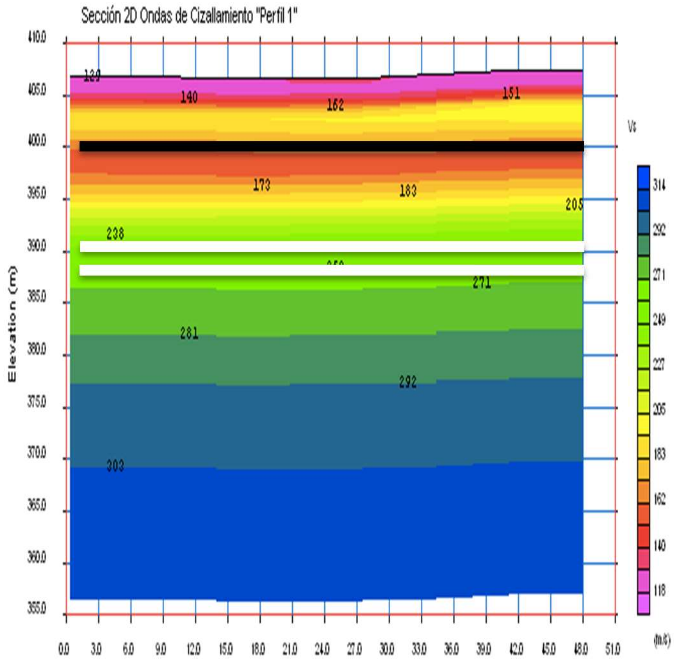

Figure 7. MASW 2D profile. The black line shows the level of the piles heads. The white lines show the range of levels of the piles toes

The Figure 8 shows the type of FDP tool used for the job.

The tool, also named FDP Lost Bit tool, has a lost tip, which allows introducing the EB and the reinforcement prior to concreting. This is a very functional tool because it avoids the problem of introducing the elements into fresh concrete, which is usually complicated.

Figure 8. FDP Lost Bit tool, 440 mm in diameter

The figure 9 shows the load-movement curve of two dynamic loading tests performed at the site. In both cases the behaviour of the piles show a low movement for the required service load, around 5 mm for 150 ton in the first test and 2,5 mm for 150 ton in the second test. The values are congruent with other tests in similar soils.

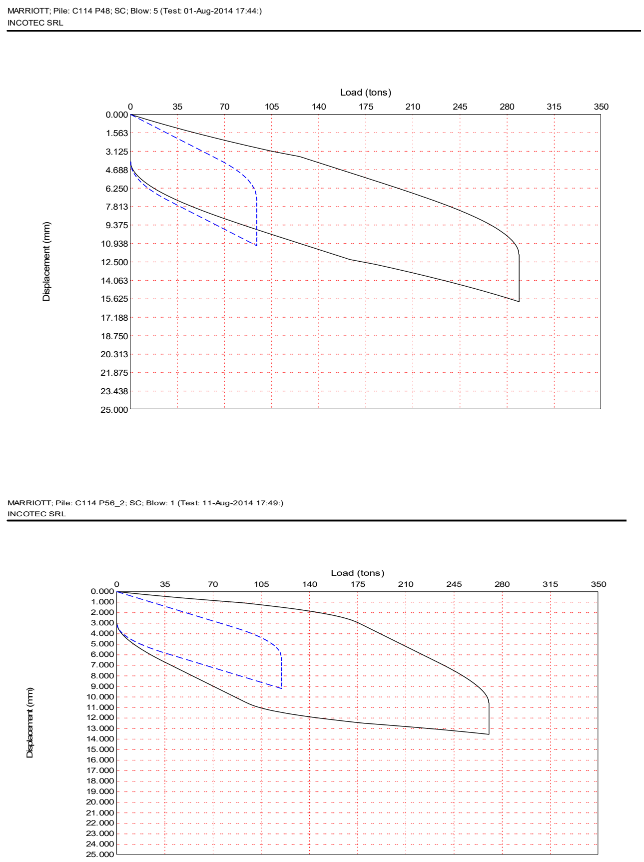

Figure 9. Load-movement curve of two dynamic loading tests in the project

The figure 10 shows the histogram of the final injection pressures of the EBs (similar to the limit pressure in PMT). In the distribution is important to see the wide range of injection pressures, which is consistent with the typical heterogeneity of the local sedimentary soils. It also demonstrates that any pile system without a reliable control of the construction process can derivate in high risks or unnecessary costs because of the implicit uncertainties of the soil characteristics; Moreover, if typical soil investigations are not complete enough.

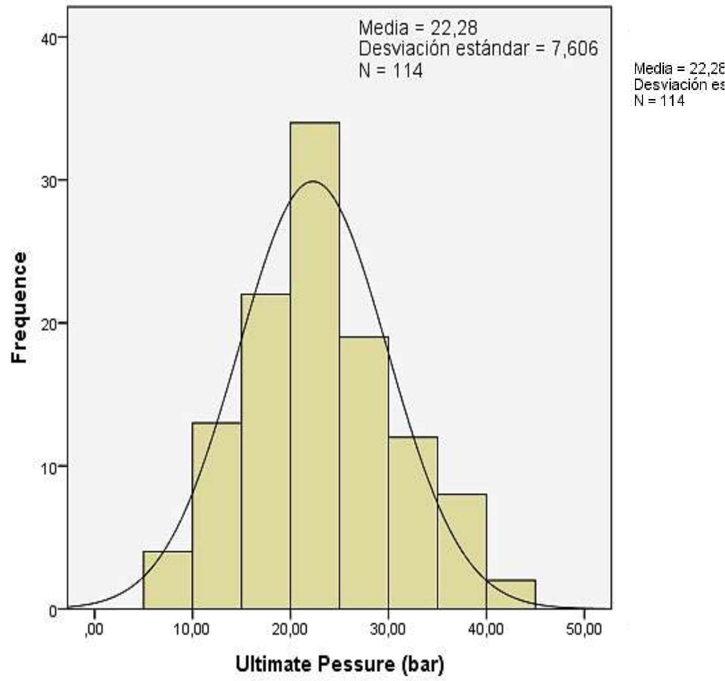

Figure 10. histogram of final injection pressures (limit pressure)

Figure 11 shows the typical electronic registers provided by the equipment for each EB injection. This type of register was made in the 100% of the piles.

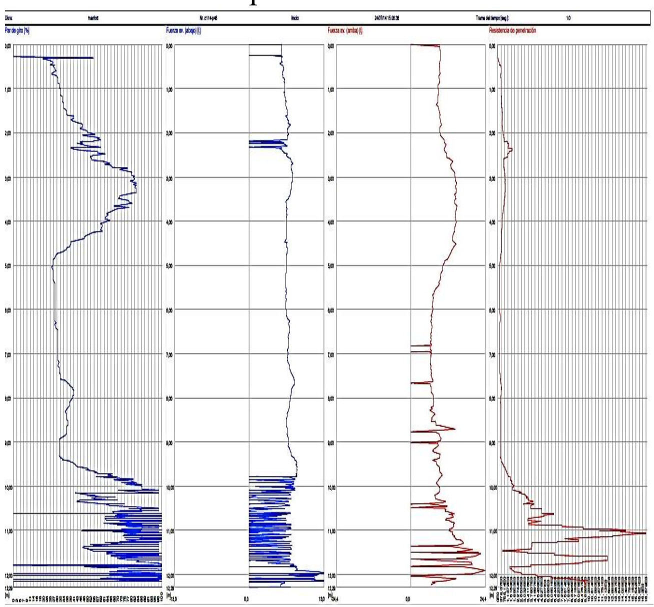

Figure 11. Typical register of torque, downward force, upward force and alpha value

4 CONCLUSIONS

According with the information presented, and using the case history as a typical example of the FDP+EB pile type, it can be concluded:

1.- The QA/QC systems is in the 100% of the installed piles

2.- The FDP+EB pile also works as a soil investigation device for the 100% piles

3.- The installation process, the installation speed and the total service load installed per day implies an important economical fact for the project. In this case the price was of 13,45 $us/ton of service load.

4.- With the 100% control is possible to create histograms of capacities or service loads, once the loading test are performed thanks to the correlation of the loading tests with the different measured parameters (EB injection pressure, alpha value, torque, etc.). With this information, the risk analysis becomes easier and with very small uncertainties.

5.- Even with poor geotechnical information, at the end of pile installation process, is possible to know in detail the soil stress conditions at the foundation level. It does not mean that proper soil investigation should be avoided to know the soil parameters below the toe level and performing adequate settlements analysis. Indeed, the better the soil investigation, the more accurate the pile design.

6.- According with several instrumented loading tests, the FDP system provides friction values between 2 and 4 times higher than in drilled piles in sandy soils.

7.- The EB is the only available system in the industry that provides measurement of resistance parameters for each pile toe.

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