THE USE OF THE EXPANDER BODY WITH CAST IN SITU PILES IN SANDY SOILS

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ABSTRACT

The Expander Body (EB) technology has been used successfully to increase the pile toe capacity of bored piles in loose to medium dense soil. An important advantage of the EB system is the ability to monitor 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 of the soil below the expanded pile toe. This improvement measure provides additional strength and stiffness to the pile toe and reduces pile settlement.

The shaft bearing capacity of bored piles can be increased by using a soil displacement auger, which avoids soil decompression and increases lateral soil stress. This paper describes the principle of the EB system. During the past 20 years, a large number of EB piles have been installed in Bolivia and elsewhere, providing a sound database. Results from field loading tests are presented. A comprehensive study of test piles with and without EB base has been carried out which demonstrates the improvement effects that can be achieved by the EB pile system and the combination with the displacement auger pile method. A design concept for the EB pile system with the full displacement auger pile is presented. A high degree of quality control can be achieved by monitoring the entire pile installation process, including the displacement pile and the Expander Body.

1. Introduction

In many regions of South America, soil deposits consist often of predominantly loose to medium dense sands and silts, often with high groundwater table. In the Santa Cruz area in central Bolivia, such soils are frequently quaternary sediments, deposited by the river Piray. The city of Santa Cruz is located at the right bank of the river.

The most common deep foundation method during the last 30 years has been cast in situ piles, augered and concreted under support of bentonite slurry. The design of such piles has been based on SPT results. However, SPT is often performed without quality control and the reliability of geotechnical data is therefore often poor. Traditional methods of pile installation with simple well drilling equipment of insufficient capacity are frequently used. Such methods lack basic requirements of quality control. Such piles have usually low toe resistance and work mainly by shaft resistance . Although the construction process and materials are cheap, the final product has variable and limited capacity. However, the most serious deficiency is that actually achieved pile capacity and pile settlement can be erratic and difficult to predict, leading to uncertainties with regard to actual foundation performance.

In order to eliminate uncertainty with respect to pile quality and to increase pile capacity, a new foundation concept was introduced, which combines the auger pile method with an expanded, pressure-grouted base, the Expander Body (EB). The 1 to 2 m long EB consists of a folded steel tube, which can be expanded from 0.12 m to a diameter of approximately 0.6 m. Pressure and volume of grout during inflation of the Expander Body are continuously recorded. Due to the controlled expansion process, horizontal soil stress, soil strength and stiffness of the soil around the EB can be improved significantly. In fact, the EB functions as a large-scale pressuremeter, as it provides information about stress-strain characteristics of the soil adjacent to the pile toe. This information is used to verify that the anticipated toe bearing capacity has been achieved. During inflation of the EB

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and with increasing diameter, the EB shortens in length. Therefore, after inflation of the Expander Body, the soil below the EB base can be post-grouted during a second, controlled grouting phase. This process further increases the stiffness of the soil and the toe bearing capacity of the pile. In this way, the capacity of each pile can be tested and verified. The innovative combination of the Expander Body system with the traditional auger pile method has resulted in the increase of service load, cost reductions and safety of the foundations. An additional benefit is the unprecedented level of quality control, which is important for the design. Extensive experience has been accumulated from different parts of the world regarding the practical application of the EB system for different types of piles and as soil anchors, (Berggren et al. 1988, Broms 1985, Broms et al. 1985, Massarsch and Wetterling 1993, Massarsch 1994, Terceros Herrera et al. 1995, Terceros Herrera 2008).

In loose to medium-dense and silty sands, displacement auger piles are an efficient pile foundation method, which increases, in particular, the shaft bearing capacity. Combining displacement auger piles with the Expander Body concept results in a pile with high shaft capacity as well as high toe bearing capacity. This solution is particularly suitable for high capacity piles in sandy and silty soils. Particular emphasis in this paper is on the combination of the EB system with the full displacement auger pile system, where during the installation of the pile shaft, the soil is compressed and moved laterally, thereby increasing horizontal soil stress and stiffness.

The paper presents the monitoring of all phases of the pile installation process. Particular emphasis is on the determination of pile capacity based on monitoring parameters during installation of the displacement auger pile and EB inflation. The efficiency of the pile system has been documented by load tests. Several case histories are used to illustrate the application of this novel foundation system.

2. Development of the Expander Body System

The Expander Body (EB) concept was developed by the Swedish engineer Bo Skogberg during the 1980's and its initial application was the "Swellex" rock anchor. Thereafter, the Expander Body soil anchor was developed. It consists of a folded steel tube with a square cross section. By injection of grout the EB can be inflated, thereby creating a water-tight steel balloon of high strength. Gradually, new applications of the EB system were developed, such as for soil anchors, driven, and vibrated and bored piles, Broms and Nord (1985). Extensive field tests were carried out to verify the bearing capacity of piles with EB base, on which the Swedish Commission on Pile Research published design and installation recommendations and monitoring procedures (Berggren et al. 1988). Initially, the most common application of the EB system, at the beginning, was for underpinning of structures and for use as soil anchors. Experience from a large number of EB applications has been documented in the geotechnical literature (Broms 1985, Massarsch and Wetterling 1993, Massarsch 1994, Terceros et al. 1995). The EB pile system is also included in Eurocode CEN 2000 "*Execution of special geotechnical work - Displacement piles*". During the past decade, the design and construction of the EB was further improved in Bolivia. The present EB system has a cylindrical shape, instead of the square cross section used originally. Also, a new post grouting system has been implemented, which makes it possible to inject grout through the inflated body into the soil below. This feature can increase significantly the performance of the EB pile.

Since the start of its introduction to South America, the EB system was used as exclusively in combination with piles. The performance of the EB system has been very successful. In the Santa Cruz region, more than 10,000 EB piles have been installed for a variety of projects, from high-rise buildings and hotels to industries, bridges, and silos.

As the EB cross section before expansion is very small, installation of EB piles can be by conventional drilling, driving, jacking, or vibration methods or by placement in a preformed hole.

3. How the Expander Body Works

The EB can be manufactured in different sizes. The geometry of different EB types after inflation are shown in Table 1. The EB diameter prior to expansion is approximately 120 mm and increases during the inflation process to between 600 to 800 mm, resulting in an increase of the diameter by about

500 % to 600%. The increase in EB diameter is directly related to the injected grout volume. Lateral expansion is one of the main reasons for the high ground improvement effect, which takes place in the soil adjacent to the EB.

Table 1. Geometric parameters of different EB sizes after expansion, Expander Body Incotec (EBI).

Type	Length[1)]	Length[2)]	Diameter	Toe Area	Skin Area	Volume
	m	m	m	m^2	m^2	m^3
EB 610	1.0	0.76	0.6	0.28	1.43	0.21
EB 612	1.2	0.96	0.6	0.28	1.83	0.27
EB 615	1.5	1.26	0.6	0.28	2.38	0.36
EB 815	1.5	1.26	0.6	0.50	3.17	0.63
EB 820	2.0	1.76	0.8	0.50	4.42	0.88

[1)] Prior to expansion [2)] After expansion

The expansion steps of an EB 600 are shown in Figure 1. The grouting process of the liquid-tight EB takes place under controlled conditions without leakage. Thus, it is possible to measure the gradual increase in EB volume and the required pressure. All relevant parameters, such as flow rate, pressure, and volume of grout are recorded by a computer-controlled data acquisition system, which is an integral part of the quality control. The applied grouting pressure reflects the soil resistance during expansion of the EB and is a measure of soil stiffness and soil strength. The grouting record is obtained for each pile and offers in this way a unique method of quality documentation.

Fig. 1. Expansion steps of the EB Incotec (EBI) with field monitoring by data acquisition system.

The pressure-grouting of the EB can be done right after concreting the pile or at an appropriate later time depending on the hydration progress of the concrete. In one case, EBs have been injected up to four months after installation of the pile without affecting the bearing capacity of adjacent piles. As the concrete layer (shell) surrounding the unexpanded EB is thin the tension forces induced during the EB expansion easily fracture the shell. The expansion forces the concrete shell into the soil.

It is possible that leakage of grout could occur before the full EB diameter has been reached. The typical reasons for leakage to occur before the full volume has been reached are: a) damages to EB during installation (punctures) b) excessively stiff soils that do not allow full expansion. As the injection process is recorded, it is possible to determine the actual EB volume from the calibration curve, which exists for each EB model. Figure 2 shows a typical calibration curve of volume vs. diameter. By knowing the pressure and the volume, it is possible to calculate de effective cross section of the EB, and to take into account a reduced EB diameter in the design. In any case, when leakage occurs, is a minor loss of grout, and is instantaneously measured and recorded.

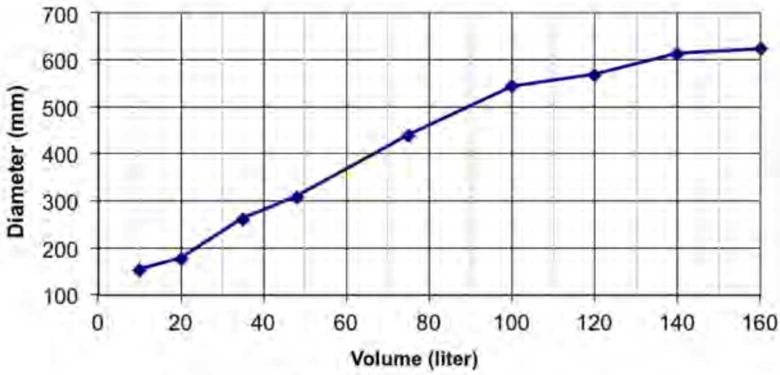


Fig. 2. Calibration curve of volume vs. diameter for EBI 600.

Figure 3 shows the grout pressure vs. grout volume as recorded during expansion of the EB. As the EB functions similar to a pressuremeter, monitoring of the EB inflation process is in fact an in situ soil test. The initial part of the pressure-volume curve provides information regarding the initial soil conditions prior to EB inflation. The shape of the curve depends on the geotechnical conditions (in situ stress, strength and stiffness) of the soil. Extensive experience has been accumulated from a large number of projects, which makes it possible to understand the geotechnical conditions at the pile toe.

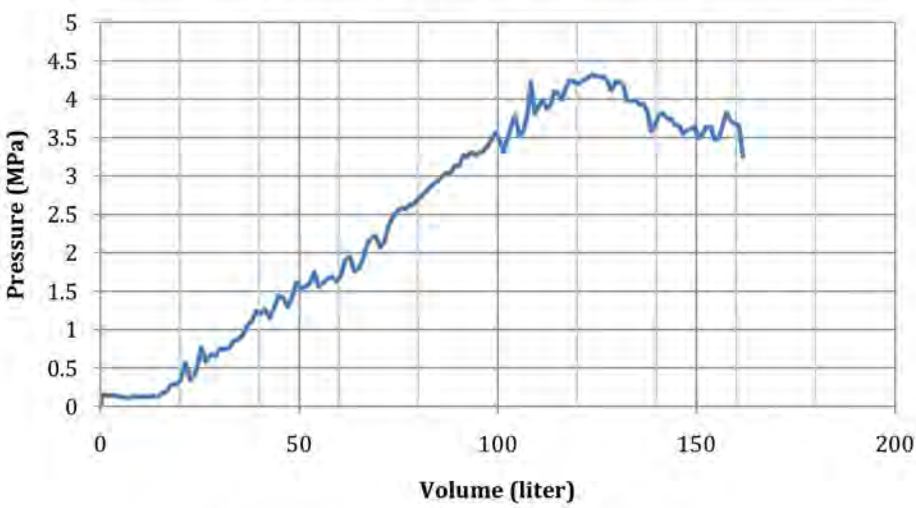


Fig. 3 – Typical grouting curve in medium dense sandy soil

In loose granular soil, the shape of the grouting curve looks different. Figure 4 shows an initial slow increase in grout pressure, indicating a low soil resistance. After injection of a volume of approximately 130 liter, the soil surrounding the EB has been compacted and passive earth pressure start developing.

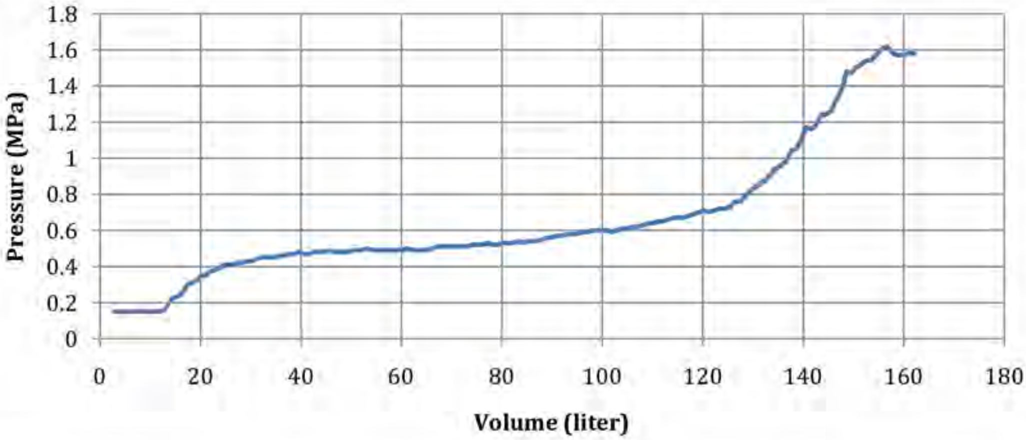


Fig. 4. Typical grouting curve in loose sandy soil. Note that the maximum pressure is significantly lower than in a medium dense sand, cf. Fig. 3.

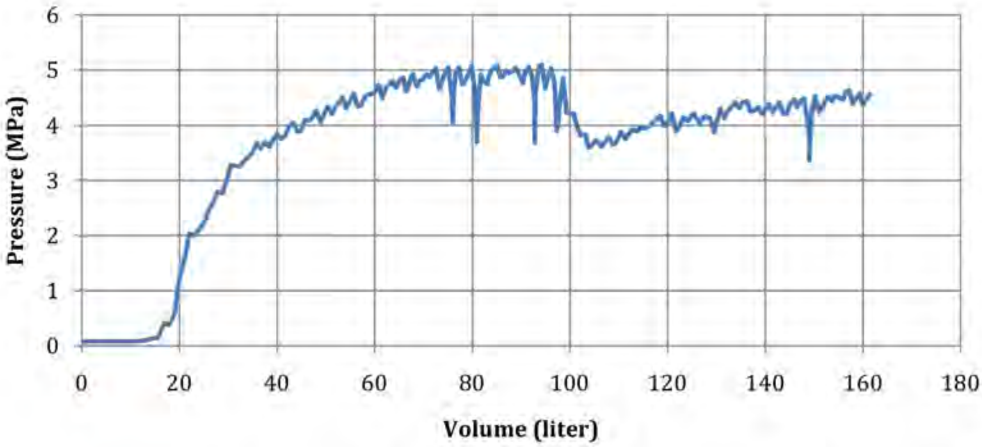
Comparison of Figure 3 and 4 clearly shows the different behavior of EB inflation in loose and medium dense soil, which is reflected by the shape of the pressure curve and the maximum grout pressure.

An important advantage of the EB monitoring system is that the actual condition of each EB pile toe can be monitored and evaluated. Any leakage of the EB due to damage during installation or inflation can be noted from the grout pressure – volume curve. The maximum pressure during EB inflation does not necessarily correspond to the final expansion pressure. This is illustrated by two cases shown in Fig. 5. Figure 5a) shows a grouting curve where - after having reached the peak – the grout pressure drops slightly and then stabilizes at a slightly lower value. This is an indication that some grout leakage has occurred but that this effect does not affect pile toe capacity. Figure 5b shows a sudden drop in grout pressure, indicating leakage of grout pressure. During continued inflation, the pressure recovers only slightly. This type of grout pressure curve is generally considered unreliable and suggests a reduced EB resistance.

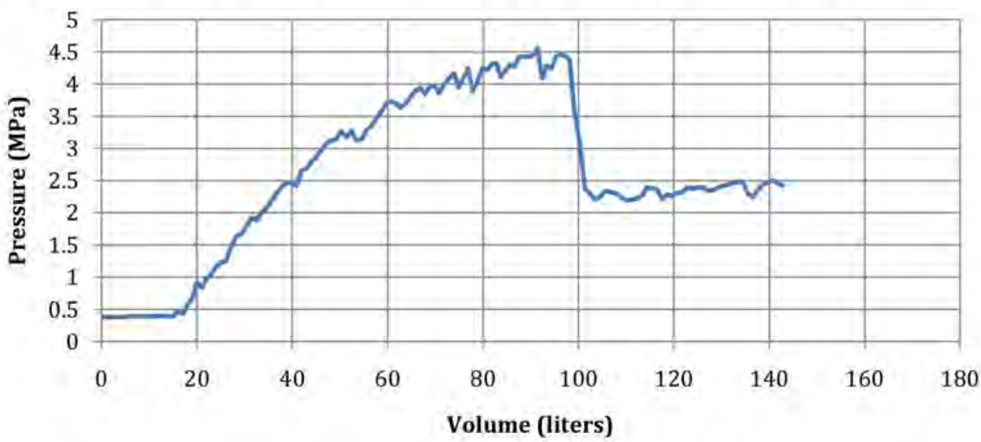
In cases the full EB volume is not achieved, it is possible to estimate the actual toe diameter from a calibration graphic showing grout volume vs. diameter, cf. Fig. 2. In the case of the Fig. 5a, the volume used for calculation of pile toe capacity was 99 liters at a pressure of 4.85 MPa. In the case shown in Fig. 5b, the volume used for calculation of pile capacity was 77 liter at a pressure of 4.05 MPa.

In many cases, the maximum grout pressure is achieved before the full EB volume has been reached. The EB diameter is then smaller than the maximum value given in Table 1, and the records will be used to estimate the actual pile toe diameter needed for calculating the pile toe response.

The ability to monitor the inflation process is an important part of the EB pile system. No other known pile system can provide information regarding the in-situ strength and stiffness properties at the pile toe. Any observed deviations from the design assumptions can be taken into account by adjusting the design to the actually achieved pile toe response.



a) Temporary leakage and gradual recovery of grout pressure – assumed EB volume: 97 l



b) Permanent leakage and unreliable recovery of grout pressure – assumed EB volume: 96L

Fig. 5. Two examples of anomalies of grout pressure during EB expansion, indicating reduced pile toe capacity.

During the expansion, the EB diameter increases but at the same time, its length is reduced. The risk of soil decompression below the pile toe due to the shortening of the EB is in most cases not significant. It is possible to increase the stiffness and strength of the soil below the pile toe in order to reduce pile settlement. An important new development is the possibility to grout the soil immediately below the EB after its expansion, ensuring the strength and stiffness of the pile toe response. By measuring the grouting pressure, valuable information is obtained regarding the improvement effect below the pile toe. The EB pile with post-grouting is known as the EB Incotec (EBI) system.

The Expander Body is especially suitable for foundations in deep soil deposits, consisting of loose to medium dense sands and silts, which occur in the Santa Cruz region.

4. Use of CFA Piles

The most common pile in Santa Cruz is the bored pile where the auger borehole is temporarily supported by bentonite slurry. The loose to medium dense sands and silts, prevailing in the Santa Cruz region, are not suitable for conventional CFA piles. One of the most serious problems is soil decompression, which occurs when the speed of auger penetration is slower than the critical speed, v_{crit} below which the auger starts to transport soil up to the ground surface, (Massarsch et al. 1988). The critical penetration speed depends on the equipment parameters, which are identified in Figure 6.

$$v_{crit} = n\, l \left(1 - \frac{d^2}{D^2}\right) \tag{1}$$

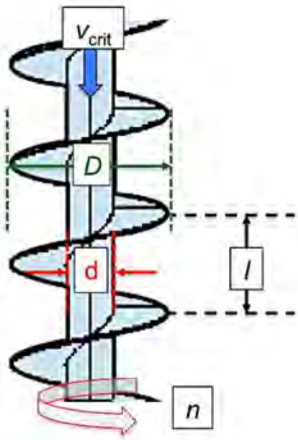


Fig. 6. CFA pile installation parameters, defining the critical penetration speed according to Eq. (1).

Based on Eq. (1) it is possible to determine the minimum auger penetration speed required to avoid soil decompression and movement of the soil up to the ground surface, Figure 7. The risk of soil decompression can be avoided by assuring that the thrust and torque of the auger equipment is sufficient to exceed the critical penetration speed.

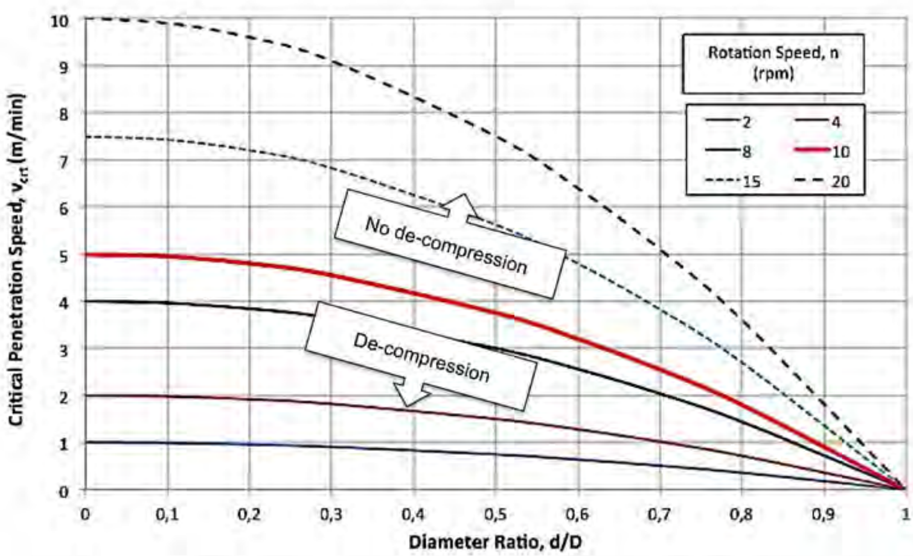


Fig. 7. Determination of critical auger penetration speed, v_{crit} as function of auger rotation, n and auger diameter ratio d/D, cf. Fig. 5. A typical value of the auger pitch l = 0.5 m has been assumed.

As the shaft capacity of conventional bored and CFA piles is usually low, the EB system provides a reliable pile toe resistance. In spite of the more sophisticated manufacturing and installation process compared to traditional methods, EB and EBI piles are competitive due to the significantly higher bearing capacity, and the quality control features of he system. The EB system has several important, beneficial effects on pile bearing capacity:

- The pile has an enlarged pile toe with known shape and cross section, which can be verified by field monitoring.
- The inflation of the EB is similar to a Pressuremeter test, where monitoring of the expansion process provides information regarding soil stiffness and strength.
- The soil strength and stiffness of granular soils increases adjacent to the expanded pile toe due to compaction and increase in lateral stress.
  In soft, cohesive soils, the shear strength increases as a result of consolidation.

Thanks to the information from the EB expansion process, it is possible to develop design concepts, which can be based on the measured expansion pressure.

5. EBI with Full Displacement Auger Pile (FDP)

An important improvement of the auger pile method was the introduction of a specially designed displacement auger, the full displacement auger pile (FDP) cf. Figure 8. Figure 8a shows the specially designed drilling tool, which during penetration displaces the soil laterally. Due to the high torque and crowd (down-ward force), the lateral soil stress along the pile shaft is increased significantly. The typical shaft diameter of the FDP, used in Bolivia, ranges from 360 mm or 440 mm. Another important advantage of the FDP method, compared to conventional bored and auger piles is, that the installation process can be monitored and documented in great detail, cf. Fig. 8b.

a) Displacement auger pile tool (FDP) *b) Monitoring of auger FDP installation*

Fig. 8. Example of displacement auger pile (FDP) tool and electronic monitoring of pile installation process.

Different parameters can be recorded during pile installation, such as crowd, torque, probe penetration, and extraction speed, grout volume and grout pressure. These parameters provide valuable information to the machine operator who can adjust the installation and pile construction process to the prevailing soil conditions. Also, interpretation of the measured parameters provides valuable information regarding the soil conditions along the pile shaft during installation. In many ways, the FDP system is an ideal complement to the EBI pile system. The pile installation concept of the FDP method is similar to that of the EB, as it increases lateral soil stress, thereby enhancing soil stiffness and strength along the pile shaft. Combination of the EBI with the FDP results in an efficient foundation solution especially in loose and medium dense soils. The FDP provides high pile shaft resistance and the enlarged toe of the EBI significantly increases pile toe resistance.

Lateral soil compression achieved by the FDP is also beneficial for the performance of the EBI at the pile toe. This effect is reflected by the grout pressure vs. volume curve registered during EBI inflation shown in Figure 8. The initial slope of the pressure-volume curve is much steeper, indicating high soil resistance. Recent load tests on instrumented piles show that the addition of the EBI greatly enhances the stiffness response of the pile toe.

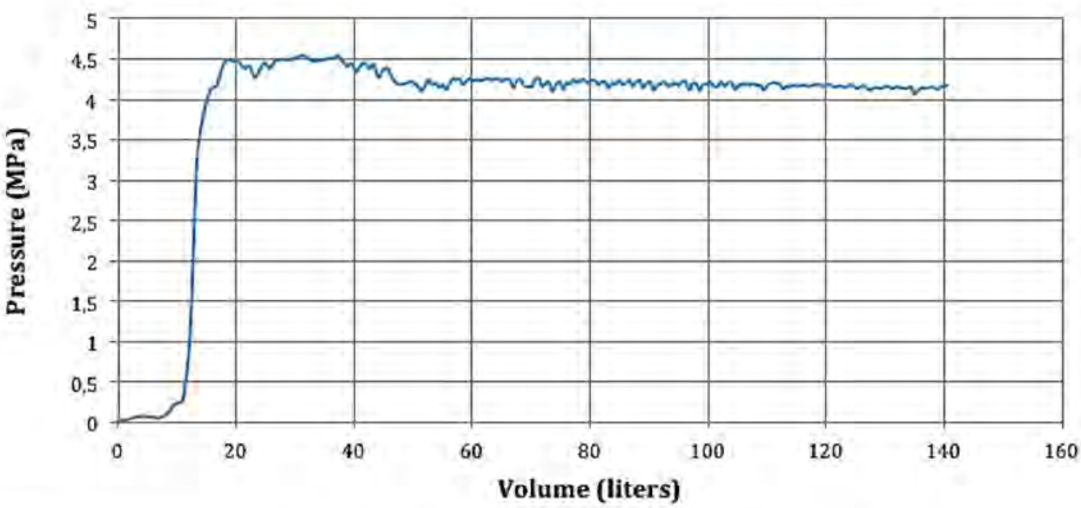


Fig. 9. Grout pressure vs. volume curve showing the high initial stiffness of an EBI installed at the toe of an FDP, cf. Fig. 3 and 4.

6. Application of EB Piles in Bolivia

A large number of mainly bored piles with EB base have been installed in Bolivia. At each project, the grouting process was documented and detailed information of inflation parameters was compiled. An example of the compiled information for each EB pile is shown in Table 2.

Table 3 presents a summary of information from more than 1,000 EB installations from 20 projects implemented during 2012. In those projects, the SPT N-values at the level of the Expander Bodies varied between 19 and 35. From Table 3, which compiles the installation information of a large number of EB projects, a relationship can be obtained between the average SPT *N*-value and the maximum EB-expansion pressure, σ_{max} and the minimum expansion pressure σ_{min}.

$$\sigma_{max} = 0.18\,N \tag{2a}$$

$$\sigma_{min} = 0.06\,N \tag{2b}$$

For instance, in a soil with an SPT N-value of 30, the expected maximum expansion pressure will be about 5.4 MPa, and the minimum expansion pressure 1.8 MPa.

The use of loading test as design tool has increased locally in the recent times. Until the beginning of 2012, all tests performed were static loading test. Those test were according with ASTM D 1143, quick test.

Table 2. Typical compilation of grouting process during EB inflation.

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REPORT ABOUT PILES SERVICE LOAD

PROJECT: EDIFICIO ALAS

CAP N°	PILE N°	DRILLED DEPTH (m)	LENGTH OF THE SHAFT (m)	AVERAGE SHAFT DIAMETER (m)						POST GROUTING		SERVICE CAPACITY (Ton)			EQUIVALENT DIAMETER (mm)	TOE AREA (m²)	PROJECTED SERVICE LOAD (Ton)
					DATE	VOL. (m³)	DATE	PRESSURE (Mpa)	VOL. (liters)	PRESSURE (Mpa)	VOL. (liters)	SHAFT	EBI	TOTAL			
C-10	1	15	14,00	0,41	2012-08-13	1,88	2012-09-01	36,00	127,62	23,00	32,00	40,02	88,22	128,24	600,00	0,29	81,00
C-10	2	15	14,00	0,40	2012-08-13	1,80	2012-09-01	32,00	127,34	31,00	15,00	39,36	78,41	117,77	600,00	0,29	81,00
C-10	3	15	14,00	0,40	2012-08-13	1,79	2012-09-01	30,00	128,67	21,00	18,00	39,05	73,51	112,56	600,00	0,28	81,00
C-10	4	15	14,00	0,41	2012-08-13	1,87	2012-09-01	34,00	128,18	24,00	25,00	39,91	83,32	123,23	600,00	0,29	81,00
C-10	5	15	14,00	0,42	2012-08-13	1,90	2012-09-01	36,00	126,74			40,23	88,22	128,45	600,00	0,28	81,00
C-10	6	15	14,00	0,42	2012-08-17	1,91	2012-09-01	36,00	126,08	25,00	21,00	39,81	88,22	128,03	600,00	0,29	81,00
C-10	7	15	14,00	0,41	2012-08-17	1,86	2012-09-01	34,00	129,40	32,00	20,00	39,16	83,32	122,48	600,00	0,29	81,00
C-10	8	15	14,00	0,40	2012-08-17	1,80	2012-09-01	40,00	127,75			37,94	98,02	135,96	600,00	0,29	81,00
C-10	9	15	14,00	0,39	2012-08-17	1,73	2012-09-01	30,00	128,74	18,00	29,00	40,02	73,51	113,53	600,00	0,29	81,00
C-10	10	15	14,00	0,40	2012-08-17	1,79	2012-09-01	30,00	126,10	19,00	32,00	38,70	73,51	112,22	600,00	0,29	81,00
														1.222,45			810,00

Table 3. Results of EB expansion monitoring during grouting, with soil strength indication by SPT N-values.

Project	Average Injection Pressure	Average Volume	Maximum Pressure	Minimum Pressure	Standard Deviation	Nº of Registra -tions	SPT N-value at EB Level
		liter	MPa	MPa			
Dresco	37.30	124.76	4.90	1.00	7.23	59	35
Silos Sofia	19.73	159.78	2.80	0.40	4.04	45	21
Tres Carabelas	45.37	120.47	5.30	3.10	5.30	19	25
Santa Elena	40.63	124.53	6.00	1.00	10.67	87	28
Florencia	38.13	117.56	4.90	1.70	5.94	32	33
Itaguazú	44.43	137.03	5.40	1.50	7.76	37	32
Uagram	38.09	150.91	6.00	2.70	9.64	11	35
Parqueo Alas	36.30	124.82	6.20	2.00	7.63	95	28
Itati	49.51	137.11	6.20	2.00	7.62	92	28
Ferrotodo	45.33	128.22	5.90	2.50	11.90	9	25
Platino	48.91	108.76	6.60	2.00	11.86	55	34
Domani	36.68	135.77	7.00	1.40	8.87	133	32
Clinica Nuclear	17.6	117.65	2.89	0.64	6.2	38	19
Torres Duo	33.0	132.96	5.85	1.02	10.0	167	30
Zurita (1)	24.8	124.82	4.54	1.20	9.7	38	23

Equipetrol Norte	52.2	125.17	3.80	0.97	14.65	6	36
Alianza	29.91	130.00	4.90	2.10	6.58	47	27
Artemisa	31.48	117.77	4.33	2.16	4.45	94	24
Torre Salto	34.26	124.45	5.80	2.20	8.25	73	26
Equipetrol Norte 4	33.31	121.73	4.50	2.30	5.79	34	32

7. Design Methods

Different design methods can be used for the EB pile system. The method used in Sweden is based on results of the cone penetration test (CPT) and has been described by Massarsch and Wetterling (1993). The design method presented below is based on pressuremeter theory and consists, in its simplified form, of the following expression is used for the total bearing capacity. Q_T:

$$Q_T = Q_B + Q_S \tag{3}$$

where Q_B is the pile toe resistance of the Expander Body

$$Q_B = k \ \sigma_l \tag{4}$$

and Q_S is the shaft resistance

$$Q_S = A\,\sigma_1 \tan\phi_1 \tag{5}$$

with

k: Pressuremeter coefficient, typically 1,95

σ_l: Limit pressure from grout-volume curve

A: Side area of the Expander Body

$Ø_1$: Steel-soil friction angle, with a typical values of 10º.

Equations (3) though (5) are used for design purpose in medium dense to dense soils with $N_{SPT} > 18$. Based on extensive experience from EBI projects, an average value of $\sigma_l = 2$ MPa is used.

Determination of the pile shaft resistance of FDP piles, the method proposed by NeSmith (2002) can be used. Good correlation has been obtained between results from loading test and predicted values of shaft friction.

In both cases, EB and FDP, the recent incorporation of SCPTu in the local market, will improve the quality of the data used for the design.

8. Summary and Conclusions

Extensive experience from different parts of the world, and in particular from many applications in Bolivia, demonstrate that the Expander Body provides an efficient, enlarged-base cast in situ pile. A high degree of quality control can be achieved, as the expansion process of each EB pile toe can be recorded and documented. An important new development has been the introduction of post-grouting below the expanded pile toe, which further increases soil strength and stiffness.

When installed at the toe of bored piles, the EB system increases the pile toe resistance in a wide range of soils, from very loose, silty sands to medium dense sands and stiff clays. Although the EB requires a more sophisticated installation process, the increased pile capacity makes the EBI pile a cost-efficient deep foundation solution, compared with low-cost, less reliable pile types.

EB installation by the full displacement methods (EB + FDP) further increases pile shaft capacity. Recent field tests demonstrate that pile capacity can be increased at least four times compared to conventional, bored piles.

9. References

Berggren, B., Sellgren, E. and Wetterling, S. 1988. Expanderkroppar. Anvisningar för dimensionering, utförande och kontroll (Expander Body. Instructions for design, installation and control). Swedish Commission on Pile Reseach, Report 79, 54 p.

Broms, B.B. 1985. Expander Bodies – A new concept for underpinning of structures. Proceedings XI ICSMGE San Francisco. Vol. 3, pp. 1531 – 1534.

Broms, B.B. and Nord, B. 1985. Axial bearing capacity of the expander body pile. Soils and Foundations 25(2) pp. 31-44.

CEN 2000. Execution of special geotechnical work - Displacement piles. European Committee for Standardization (CEN). ICS 93.200. December 2000, 46 p.

Coutand, S.C. 2007. Ajuste de parámetros presiométricos en la estimación de la capacidad de carga última de pilotes con tecnología Expander Body en arenas sedimentarias. Tesis de grado. Ed. Universidad Federico Santa María. Valparaíso, Chile. 99 p.

Fellenius, B.H. and Terceros, Herrera.M. 2014. Response to Load for four different types of piles. Proceedings, International Conference on Piling and Deep Foundations. 2014, Stockholm, submitted for publication.

Massarsch, K.R., Brieke, W. and Tancré, E. 1988. Displacement auger piles with compacted base. Proceedings, Deep Foundations on Bored and Auger Piles. Balkema, Rotterdam, pp. 333 – 342.

Massarsch, K. R. and Wetterling, S. 1993. Improvement of augercast pile performance by expander body system. 2nd International Seminar on Deep Foundations on Bored and Auger Piles, Ghent, June 1 - 4, 1993, pp. 417 - 428.

Massarsch, K. R. 1994. Execution, supervision and quality control of anchors. Panel Discussion, Section 3.3, Construction, Instrumentation and Real Time Management, XIII. Proceedings, International Conference on Soil Mechanics and Foundation Engineering, New Delhi, India, Vol. 5, pp. 317 - 319.

NeSmith, W. 2002. Static capacity analysis of augered, pressure-injected displacement piles. Deep Foundations Journal 2002: pp. 1174-1186.

Terceros Herrera, M. 2008. El uso de la tecnología Expander Body en fundaciones profundas en suelos sedimentarios de Santa Cruz, Bolivia (Use of Expander Body technology for deep foundations in sedimented soil of Santa Cruz, Bolivia). Proc. of 19th Congreso Argentino de Mecánica de Suelos e Ingeniería Geotécnica, La Plata, Argentina, 8 p.

Terceros Herrera M., Wetterling, S., and Massarsch K. R. 1995. Application of the Soilex Pile System with Expander Body in Bolivia. X. Congreso Panamericano de Mecanica de Suelos e Ingenieria de Cimentaciones, Mexico. pp. 1319 - 1327.