Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering– Rahman and Jaksa (Eds)

Effect of the use of the Expander Body on the stiffness response of piles constructed by different drilling technologies

Effet de l'utilisation du Expander Body sur la réponse en rigidité des pieux construits par différentes technologies de forage

Mario Terceros A.
INCOTEC S.A., Bolivia, mta@incotec.cc

Carlos Medeiros
EMBE S.A, Brazil, carlos@embre.com.br

ABSTRACT: The Expander Body (EB) consists in a folded steel balloon that is installed at the tip of a pile or anchor. Once installed, the device is injected with grout, producing a “balloon” like element. During the expansion process, the device compacts the surrounding soil to its critical state density, and increment the toe size, thus increasing substantially the resistance of each element. Furthermore, during the expansion process, the pressure and volume of the injected grout are recorded, thus allowing the device to function also as a quality control device that enables the evaluation of the soil conditions of all the elements.
During the 3rd Bolivian Conference of Deep Foundations held in Santa Cruz in April 2017, an experimental site for testing piles was created: the Bolivian Experimental Site for Testing Piles (B.E.S.T), in which 28 piles of different technologies were constructed. Some of them were equipped Expander Bodies in order to compare the resistance of each pile with and without Expander Body.
The objectives of the present paper are: to contrast load-movement behavior of piles with and without EB, constructed with different technologies and to compare the stiffness increase produced due to the EB.

RÉSUMÉ : Le Expander Body (EB) consiste en un ballon en acier plié qui est installé à l'extrémité d'une pile ou d'un ancrage. Une fois installé, le dispositif est injecté avec du coulis, produisant un élément de type «ballon». Pendant le processus d'expansion, le dispositif compacte le sol environnant à sa densité d'état critique et augmente la taille des orteils, augmentant ainsi sensiblement la résistance de chaque élément. De plus, pendant le processus d'expansion, la pression et le volume du coulis injecté sont enregistrés, permettant ainsi au dispositif de fonctionner également comme un dispositif de contrôle de qualité qui permet l'évaluation des conditions de sol de tous les éléments. Lors de la 3e Conférence bolivienne des fondations profondes qui s'est tenue à Santa Cruz en avril 2017, un site expérimental de test des pieux a été créé: le site expérimental bolivien de test des pieux (B.E.S.T), dans lequel 28 piles de technologies différentes ont été construites. Certains d'entre eux ont été équipés de corps d'expansion afin de comparer la résistance de chaque pile avec et sans corps d'expansion.Les objectifs du présent article sont les suivants: comparer le comportement charge-mouvement des pieux avec et sans EB, construits avec différentes technologies et comparer l'augmentation de rigidité produite par l'EB.

KEYWORDS: Expander Body, pile stiffness, installation methods for piles, technology

1 INTRODUCTION.

On April 27-29, 2017, the 3rd Bolivian International Conference on Deep Foundations was held in Santa Cruz, Bolivia under the auspices of INCOTEC S.A., the UPSA University, the Bolivian Association of Soil Mechanics and Geotechnical Engineering and the TC 212 of ISSMGE. To coincide with the conference, a research study on construction and static and dynamic testing of 28 instrumented piles was undertaken. An extensive soil investigation program was performed, including SPT, T-SPT, SCPTU, DMT, PMT, MASW, DPSH, and routine laboratory tests. Dynamic, head-down and bidirectional (BD) static loading tests were also performed, including a full-scale group comprising of 13 piles equipped with Expander Body, EB.

The document is based in the abundant information available from the Bolivian Experimental Site for Testing Piles (B.E.S.T.), both of the soil investigations and of the loading tests. The results will show the relative and absolute values of the increase in resistance and stiffness of the analyzed piles thanks to the use of Expander Body Technology, in comparison with the same size and type of pile without the technology.

2 EXPERIMENTAL SITE

As part of the program of the B.E.S.T., a total of 28 piles were constructed, from which 26 were load tested. These piles were constructed with different construction methods in order to compare their behaviors when loads were imposed. Figure 1 presents the pile locations and Table 1 shows a summary of the different piles installed. All piles were installed at a depth of 9.5m, i.e., embedded about 1m into the medium dense sand layer, and about 1.5m above the 1m thick soft clay layer.

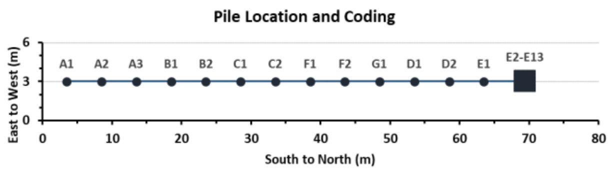

Figure 1. Pile location and coding

Table 1. Constructed piles and test summary

ID	PILE CONSTRUCTION METHOD	PILE DIAMETER (mm)	TOE DEVICE	TEST AND SEQUENCE	GAGE TYPES AND LEVELS	
					VW	RESISTIVE
A-1	Drilled with Slurry	620	EB800 (3)	BD+HD+DT (5,6,7)	L1, L2, L3	L1, L2, L3
A-2			TB (4)	BD+HD+DT	L1, L2, L3	L1, L2, L3
A-3				HD+DT		L1, L2, L3
B-1	CFA (1)	450	EB600	BD+HD+DT	L1, L2, L3	L1, L2, L3
B-2				HD+DT		L1, L2, L3
C-1	FDP (2)	450	EB600	BD+HD+DT	L1, L2, L3	L1, L2, L3
C-2				HD+DT		L1, L2, L3
F-1	Drilled with Slurry	450		BD+HD+DT	L1, L2, L3	L1, L2, L3
F-2		600		BD+HD+DT	L1, L2, L3	L1, L2, L3
G-1	Helical	300				L1, L2, L3
D-1	Self-drilling Micropile	150	EB500	HD	L1, L2, L3	L1, L2, L3
D-2				HD		L1, L2, L3
E-1	FDP	300	EB400	BD+HD	L1, L2, L3	L1, L2, L3
E-2 TO E-14			EB400	BD+HD	L1, L3	L2

(1) CFA: Continous Flight Auger *(4) TB: Toe Box* *(7) DT: Dynamic load test*
(2) FDP: Full Displacement Pile *(5) BD: Bi-directional static load test*
(3) EB: Expander Body *(6) HD: Head Down static load test*

This paper focuses exclusively on the comparison of the behavior of piles with and without EB Technology as a toe enhancement elements, i.e. piles A1 and A3, B1 and B2, C1 and C2 , D1 and D2.

2.1 *Soil Conditions*

CPTU soundings were pushed to 22 m depth at each of test pile types A, B, C, and D. Figure 2 shows the results of the CPTu performed in pile A1. Also, boreholes were drilled to 10 m depth at a few test pile locations. A few PMT and DMT were also performed. Figure 3 shows the SPT performed at Pile A 3 location.

At the time of the field tests, the groundwater table was at a level elevation and the ground elevation ranged from 0.50m through 1.85 m above the water table.

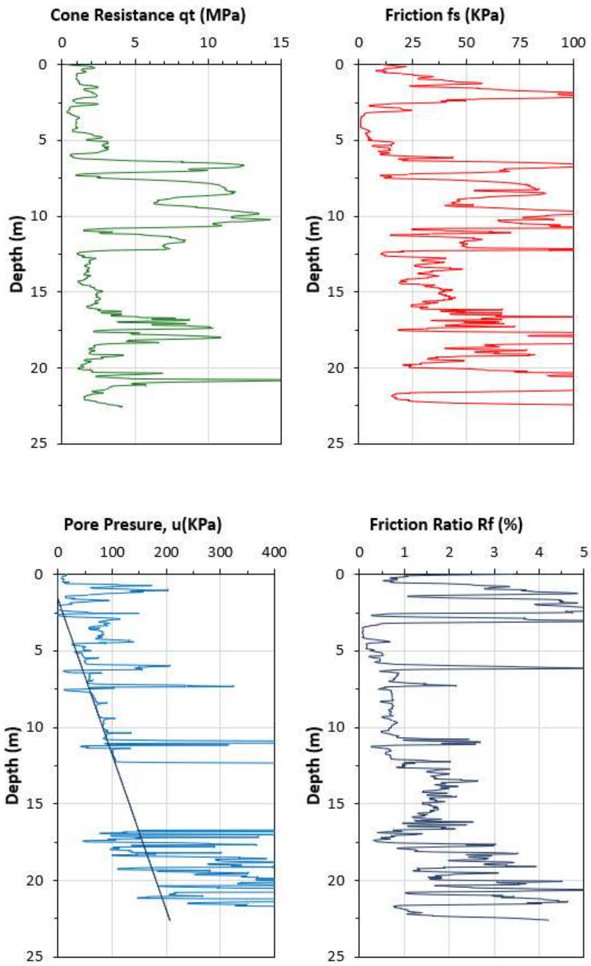

Figure 2. CPTu results – Pile A3

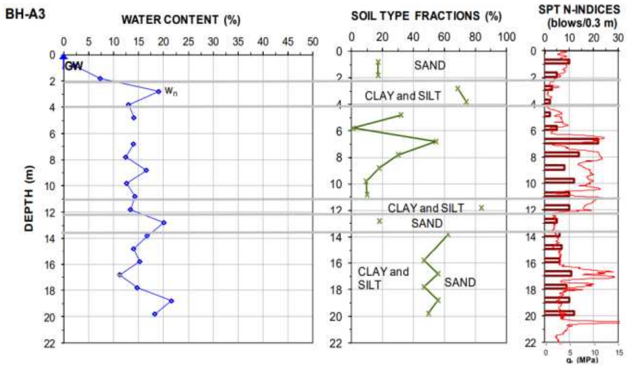

Figure 3. Borehole result on pile A3

Figure 4 presents the superposition of the cone resistances (qt) of the CPTu's performed on the locations of the study piles. From this figure it is possible to notice that the soil layers have a homogeneous horizontal distribution within the experimental site, thus making the load tests results more comparable for their analysis.

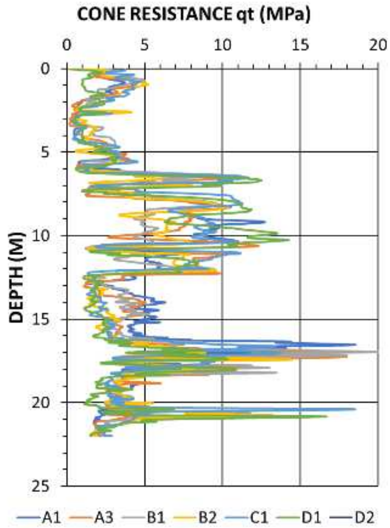

Figure 4. CPTu qt superposition

2.2 *Pile Construction Details*

The construction procedures of the piles used in this paper were as follows. The cylinder strength of concrete and mortar was designed to be 30 MPa (≈4,300 psi). The reinforcement cage consisted of six 12-mm bars with a 6-mm spiral with a 250-mm pitch. All reinforcement cages are instrumented with strain-gages. Piles A1, B1 and C1 had a BD cell above the EB. The specific details are as follow:

A. Two piles 620-mm diameter, bored piles A1, and A3 drilled with slurry. Once the final depth was reached, the 500-mm reinforcement cage was installed. Thereafter, the concrete was pumped into the shaft starting at the toe of the pile and the casing was gradually withdrawn. Pile A1 had an EB800 (800 mm after expansion) placed below the BD. Pile A3 had no EBI.

B. Two 450-mm diameter continuous flight auger (CFA), partial displacement piles, B1 and B2. The central stem of the auger is 250 mm of O.D. Mortar is used instead of concrete in order to allow the subsequent installing the reinforcement cage. Pile B-1 has a bidirectional cell (BD) and an Expander Body (EB800) placed below the BD. Pile B2 is straight (have no EB).

C. Two 450-mm diameter Full Displacement Piles (FDP) with "lost bit", C1 and C2. The equipment consists of a 440-mm O.D. displacement body (pipe) with a 800 mm long bulb attached to a 1.15 m long auger with a 350-mm diameter. The auger rotation pulled down the displacement tool. The auger had a short conical tip that was left in the hole upon completion ("lost bit"). Pile C1 had an Expander Body EB 600 (600 mm after expansion) at the toe and Pile C2 was straight. After placing the reinforcement cage in the casing, concrete was pumped into the shaft starting at the toe of the pile gradually withdrawing the casing. The "lost bit" remained in the ground.

D. Two 150-mm diameter self-boring micropiles, D1 and D2, with a 75-mm diameter drilling pipe and a cutting tool at the pipe end. Fluid grout was injected as the pile penetrated the soil. Pile D1 had an EBI 500 (500 mm after expansion) at the toe and Pile D2 was straight. The reinforcement cage consisted of six 12-mm bars inside a 6-mm spiral with a 250-mm pitch. The drilling pipe remained in the pile. A solid 50-mm diameter bar was placed inside the Pile-D1 drilling pipe to increase the axial stiffness of the shaft.

3 LOADING TESTS

The static loading tests, bidirectional (BD) and head-down (HD) tests, were carried out by applying 20 equal increments of load holding the load level constant for ten minutes. Tests on piles with BD jack and EB device (piles A1, B1 and C1) started with the BD test followed by the HD test. Piles without EB (piles A3, B2, C2 and D2) were only subjected to a HD test. The self-drilling EB pile (Pile D1), was also subjected only to a HD test. In each static loading test—bidirectional as well as head-down—the applied load and movement along with readings of strain at three strain-gage levels (2.0, 5.0 and 7.5 m depth) were recorded.

The figures 5a, 5b, 5c and 5b show the load-movement curves and the stiffnes curve for each pile type. The figures contrast the curves for the pile with EB and without EB in the same chart. From these load-deformation curves presented below, a considerable benefit can be observed when using EB technology in the general behavior of foundations, being able to withstand higher load levels at lower settlement levels. In other words, in general, EB piles present a considerable increase in average stiffness.

Due to the variation in the load-deformation behavior that the piles have presented, the stiffness of the piles will be compared from a secant modulus calculated between the origin (Load = 0 KN) and the point of the curve corresponding to an equivalent settlement of 1% of the final diameter of the injected EB:

$$M_{secante} = \frac{(L_2 - L_1)}{(S_2 - S_1)} \quad (1)$$

where, L1 is the load at the origin (0KN), L2 is the load at the level of settlement (S2) equivalent to 1% of the diameter of the injected EB. S1 is the settlement at the origin (0mm).

For the calculation of the secant modulus Msec, the reference point equivalent to 1% of the diameter of the pile tip has been used, generalizing that said point is within a low settlement level within the curve, even while still in the zone higher rigidity of the pile.

In the following Stiffness-Load curves, the first load steps of piles A1, B1, C1 and D1 had to be cut in order to avoid excessive distortion of stace. The stiffness curves were cut in the first steps of load up to 96 KN, 114 KN, 500 KN and 200 KN in piles A1, B1, C1 and D1 respectively.

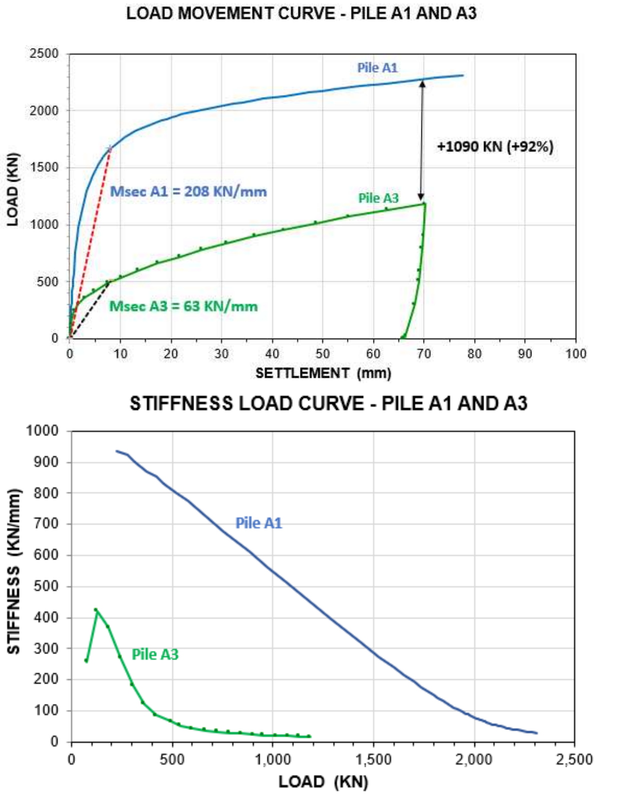

Figure 5.a. Load-movement curve and Sitffness-Load curve for piles A1 and A3

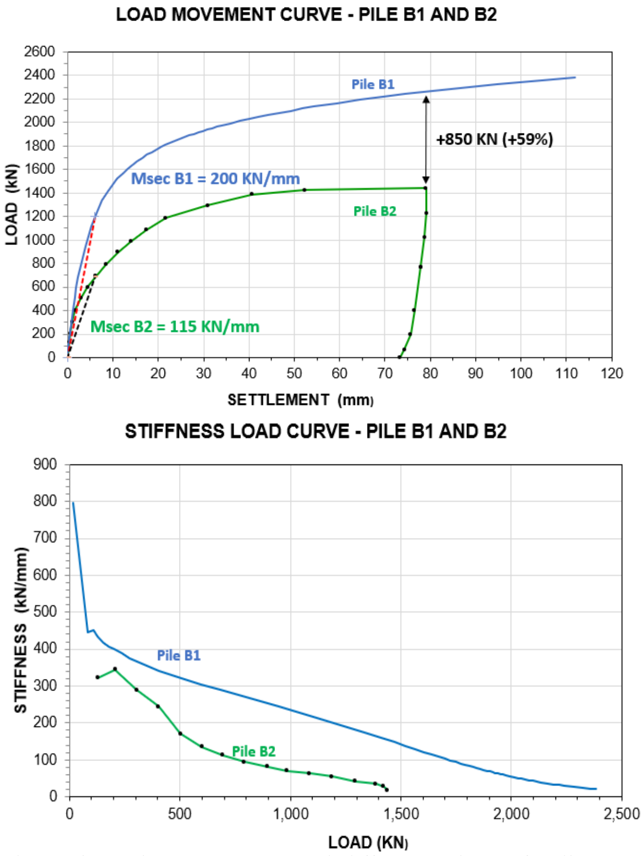

Figure 5.b. Load-movement curve and Sitffness-Load curve for piles B1 and B2

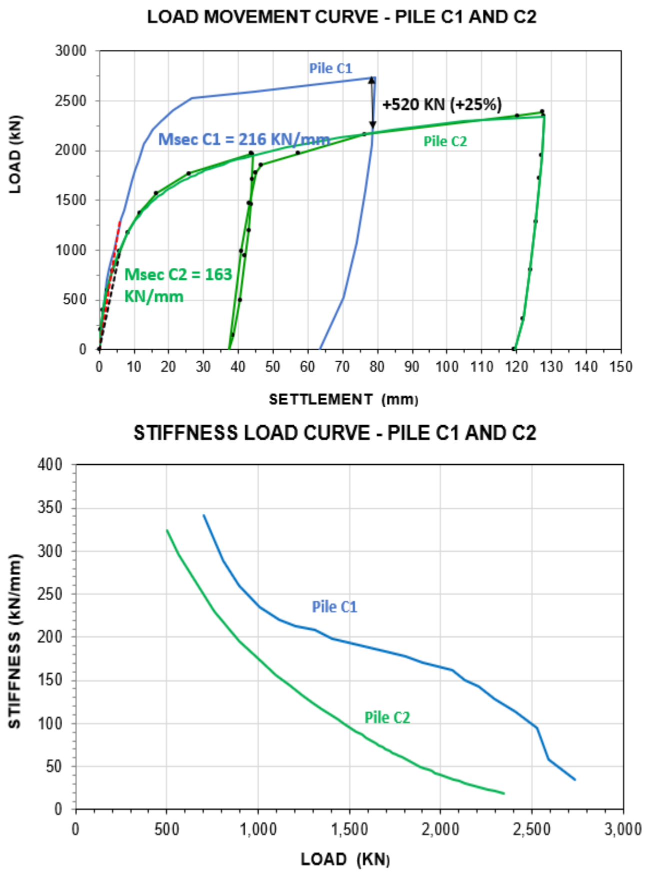

Figure 5.c. Load-movement curve and Stiffness-Load curve for piles C1 and C2

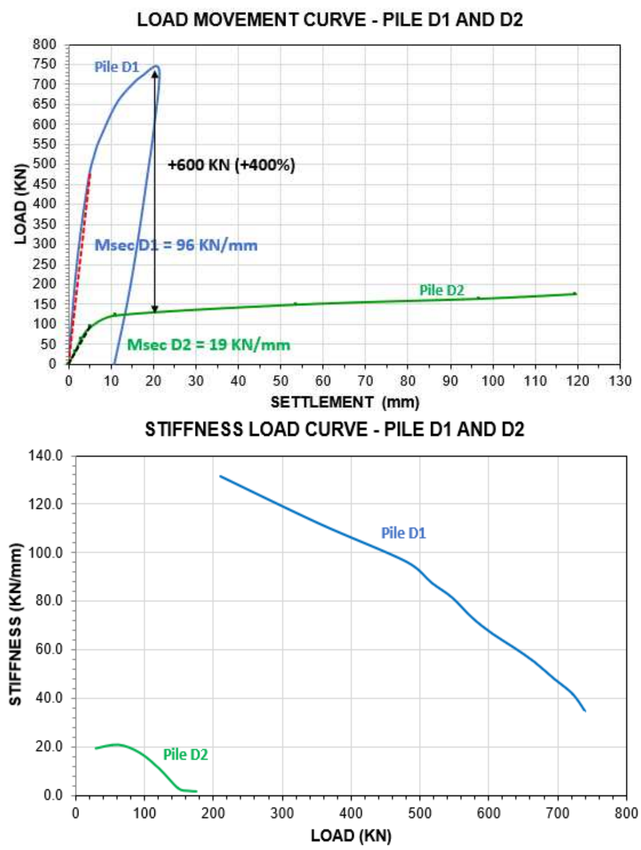

Figure 5.d. Load-movement curve and Sitffness-Load curve for piles D1 and D2

4 CONCLUSIONS

In can be concluded that with the use of the EB, an increase in the initial stiffness of the pile of between 33% and 400% is achieved with respect to the initial stiffness of the same pile but without EB. Similarly, an increase of between 25% and 400% has been observed in the load resistance at the same levels of settlement, due to the simple use of EB technology. From the analysis carried out, it is highlighted that the benefit that EB technology provides to the behavior of the foundations varies depending on the system used for the construction of the piles:

- The piles built using the FDP method, a large displacement system, were those that showed the least incremental benefit from the use of EB both in stiffness and in the maximum applied load. The improvement in the initial stiffness was 33% and in the maximum reference load 25%.
- Material removal / replacement piles, built with CFA-D technology and mud circulation drilling, present a greater incremental benefit when employing EB technology. The piles built with CFA-D technology showed a 74% improvement in the initial stiffness and 59% in the maximum reference load, while the piles drilled with mud had an improvement in the initial stiffness of 227% and in the maximum load of 92% reference.
- Finally, the self-drilling micropile was the one that presented even greater benefits, with an increase in the initial stiffness of the pile of 405% and 400% in the maximum load reached.

Table 2 Results of stiffness and resistance increment obtained from the load tests.

	INITIAL SECANT MODULUS (KN/mm)	LOAD @ desp.= a mm* (KN)
PILOTE A1	209	2270
PILOTE A3	64	1180
INCREASE (%)	227%	92%
PILOTE B1	200	2290
PILOTE B2	115	1440
INCREASE (%)	74%	59%
PILOTE C1	217	2640
PILOTE C2	163	2120
INCREASE (%)	33%	25%
PILOTE D1	96	750
PILOTE D2	19	150
INCREASE (%)	405%	400%

** a for piles A = 70mm* ** a for piles C = 80mm*
** a for piles B = 80mm* ** a for piles D = 20mm*

As a general observation, it can be concluded that, in piles with a higher friction resistance due to the construction process, the relative incremental benefit generated by EB is lower. However, the absolute benefit is significantly higher, which can be observer in Figure 6:

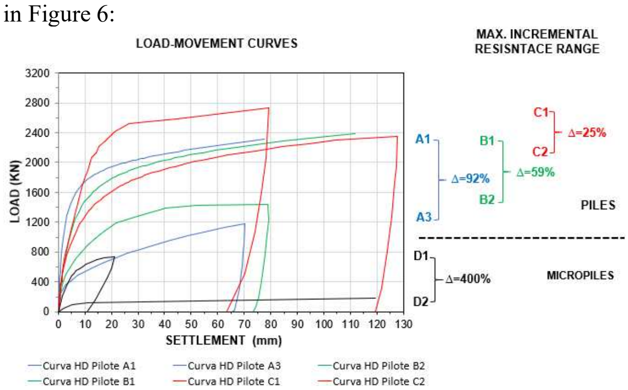

Figure 6. Superposition of Load-movement curves of study piles

Similarly, from the previous figure, a clear border can be defined between the total results obtained between the three tested piles and the micropile. Although the absolute result of the micropile was considerably lower than the other piles, the relative improvement of this micropile due to the use of EB was much bigger.

The increase in initial stiffness in piles with Expander Body technology and its ability to withstand higher load levels for the same settlements, can be due to the following reasons:

- General displacement of the soil produced during the expansion of the Expander Body, which generates a rearrangement of the soil particles, compacting it and increasing its density. This densification of the soil surrounding the Expander Body implies an increase in its resistance to shear and an improvement in its geomechanical properties, which translates into a more rigid behavior of the soil-pile system. In the case of EB implementation in fine soils, the expansion of the element generates an increase in pore pressures, which over time are dissipated, causing the surrounding soil to consolidate and in the same way improve its geomechanical properties. In the case of the implementation of EB in groups of piles, a substantial improvement is generated in the mass of soil located at the tip of the group of piles, thus also improving the behavior of the pile group.
- The increase in the stress state that is generated in the soil during the injection process of the elements and that is part of the mechanism explained in the previous point.
- Increase in the section of the pile tip (contact area), which reduces the stresses transmitted to the ground and thus allows a greater load transfer.

5 REFERENCES

Bauer Maschinen GmbH. (2013). "FDP: Full Displacement Pile System - Process and Equipment." 16 p.

Fellenius, B.H., Massarsch K.R., Terceros M.H., and Terceros, M.A., 2018. A study of the augmenting effect of equipping piles with an Expander Body. Proc. of DFI-EFFC International Conference on Deep Foundations and Ground Improvement, Rome, June 6 - 8, 2018, pp. 114-123

Fellenius, B.H. Terceros H.M., and Massarsch, K.R, 2017. Bolivian experimental site for testing. Presentation of field testing programme. 3rd Bolivian International Conference on Deep Foundations, Santa Cruz de la Sierra, Bolivia, April 27-29, Vol. 2, pp. 3-31.

Terceros Arce, M. (2020). Efecto del uso del Expander Body en la Rigidez de Pilotes Construidos por Distintas Tecnologías de Perforación. Master's Thesis. Universidad Mayor Real y Pontificia de San Francisco Xavier, Chuquisaca, Bolivia.

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, México. pp. 1319-1327.