Prediction of pile behavior under static and bi-directional tests and comparison with field results

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ABSTRACT.
This paper includes a comparison between the measured data at the occasion of a campaign of full scale static pile load tests performed for the 3rd Bolivian International Conference on Deep Foundations and the values calculated by means of the software PIVER developed at IFSTTAR and using two kinds of t-z curves: The first one has been developed by Frank and Zhao (1982), and the second one is called AB1 (Abchir and al. 2016). These two kinds of t-z curves are defined by correlations from Ménard pressuremeter tests (PMT) data. The comparison between the measured and the calculated values enables to better estimate the bias and the uncertainty of the two t-z curves used and the method of the calculation of the bearing capacity.

1. INTRODUCTION

Pile design is generally based on the calculation of bearing capacity and application of safety factors. These factors aim to limit the load applied on the pile and ensure small displacements for the supported structures. Nevertheless, in some cases, the structures supported by piles may need high service requirements and pile settlement calculation becomes a major issue for the geotechnical engineer in charge of the design of these piles.

In this context, the comparison between measured and calculated values of pile settlement is very important to provide reliable methods. The understanding of axially loaded piles both in terms of displacements and bearing capacity has attracted important research efforts over the past decades (Poulos, 1989, Randolph, 2003) and many calculation models can be used. The two main approaches are the elastic continuum approach (Poulos and Davis, 1968) and the load transfer approach with t-z curves (Seed and Reese, 1957). This latter method is based on local interaction models between the ground and the pile where the ground is described by a series of independent non linear springs. These springs are distributed along the shaft (mobilisation of the shaft friction), and at the base, only one spring is considered (mobilisation of the base resistance). The shaft friction and the base resistance are progressively mobilised in function of the pile settlement.

This paper includes a comparison between the measured data at the occasion of a campaign of full scale static pile load tests performed for the 3rd Bolivian International Conference on Deep Foundations and the values calculated by means of the software PIVER developed at IFSTTAR and using two kinds of t-z curves: The first one has been developed by Frank and Zhao (1982), and the second one is called AB1 (Abchir and al. 2016). These two kinds of t-z curves are defined by correlations from Ménard pressuremeter tests (PMT) data.

2. SOIL CONDITIONS

The research site is located in Santa Cruz in Bolivia. Different in-situ and laboratory methods have been used in order to investigate the geotechnical conditions of the site. Boreholes with laboratory tests, standard penetration tests (SPT), cone penetration tests (CPTU), Marchetti dilatometer tests (DMT) and pressuremeter tests (PMT) have been performed. In the present research, a particular interest is given to PMT records. Indeed, the calculation methods for the analysis are based on the results of pressuremeter tests. The results presented in this paper are based on the interpretation of PMT data done by Reiffsteck (2017).The results of this interpretation are plotted on Figure 1.

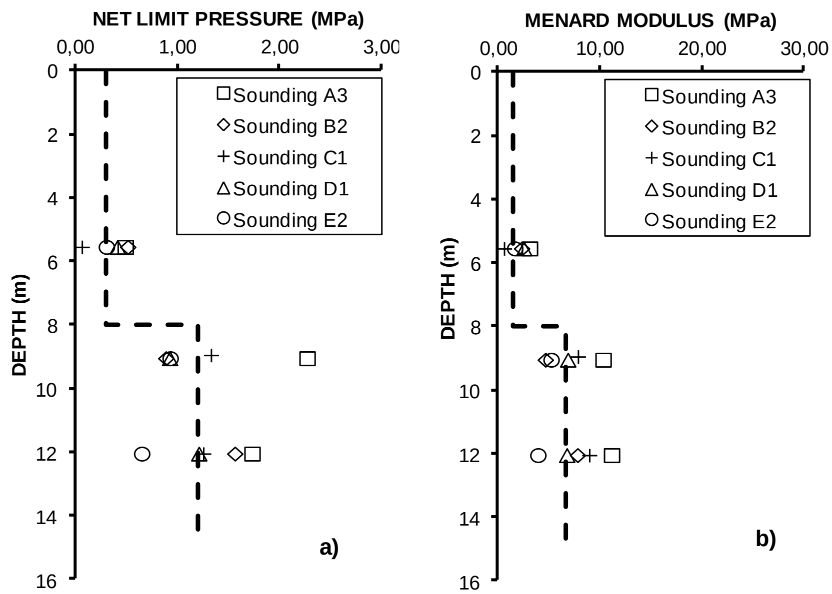

Fig. 1. Evolution of a) the net limit pressure pl* with depth and, b) the Ménard modulus with depth from the interpretation of PMT records (Reiffsteck 2017)

3. PILE PROPERTIES

The prediction event includes four piles called A3, B2, C1 and E1, and a group of piles called E2-E14. The present study focuses on the bored pile A3, the Continuous Flight Auger (CFA) B2, and the two Full-Displacement-Piles (FDP) C1 and E1. A bi-directional test is performed on the pile E1. Thus, a bi-directional cell is installed at 1.2 m from the bottom of the pile as shown on Figure 2. In the present study, E1 is separated into two different piles, in order to predict the upward and downward load-movement response during the bidirectional test. The upper and lower parts are called respectively P1 and P2. Table 1 summarizes the principal properties of the experimental piles.

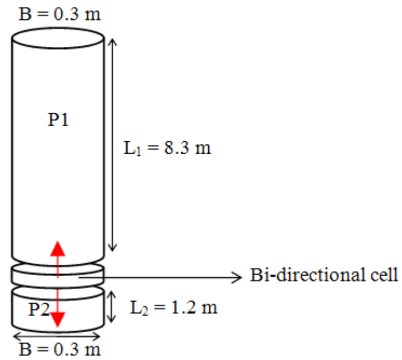

Fig. 2. Description of the pile E1 in which a bi-directional cell is installed

TABLE 1. Properties of the piles called A3, B2, C1 and E1

Pile	Type of pile	Length L	Diameter B	Equivalent Modulus	Bearing capacity
		(m)	(mm)	(MPa)	(kN)
A3	Bored	9.5	620	30991	1273
B2	CFA	9.5	450	31353	1096
C1	FDP	9.5	450	31353	1292
E1_P1	FDP	9.5	300	32.309	
E1_P2	FDP	9.5	300	30588	

According to the description of pile construction and the French standard NF P 94-262 (AFNOR 2012), the piles A3, B2 and C1 are considered respectively as a bored pile with recoverable casing, as a CFA pile and as a screw cast in place pile. P1 and P2 are also considered as screw cast in place piles. The values of the equivalent modulus E_{eq} given in Table 1 are calculated using Eq. 1.

$$E_{eq} = \frac{A_c * E_c + A_s * E_s}{A} \tag{1}$$

where E_c is the concrete Young Modulus, E_s the steel Young Modulus, A_c the concrete cross section area, A_s the steel cross section area and A the pile cross section area.

The bearing capacity R_c assessed in Table 1 is the sum of the shaft resistance R_s, and the base resistance R_b. It is calculated using Eq. 2 according to the French standard (AFNOR 2012).

$$R_c = R_s + R_b = \left(\pi B \int_0^L q_s (p_l *) dz \right) + (q_b * A) \tag{2}$$

where q_s is the limit shaft friction, q_b the limit base pressure, p_l* the net limit pressure and z the depth.

The values q_s and q_b are calculated according to the standard using Eqs. 3 and 4. The French standard gives the details of each term of the following equations. The distribution of limit shaft friction q_s at pile-soil interface with depth is presented in Figure 3.

$$q_s = \alpha_{pile-soil} f_{soil}(p_l *) \quad (3)$$

where $\alpha_{pile-soil}$ is the parameter depending on the type of soil and the pile type and f_{soil} is the function depending on the type of soil and the net limit pressure p_l*

$$q_b = k_p * (p_{Le} *) \quad (4)$$

where k_p is the base factor and p_{Le}* the equivalent net limit pressure.

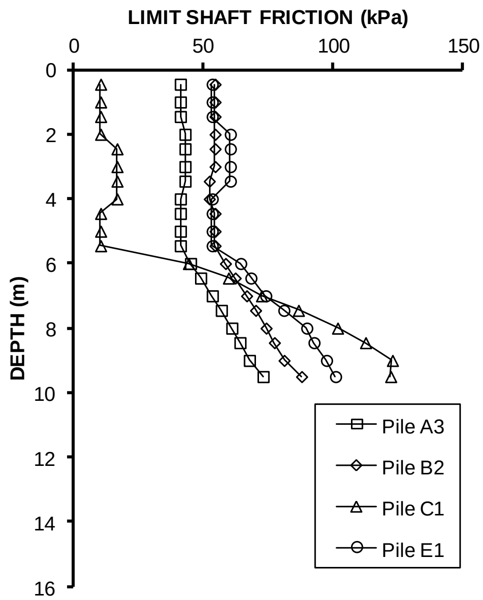

Fig. 3. Distribution of limit shaft friction q_s with depth along piles A3, B2, C1 and E1

4. COMPUTATION METHOD

In order to predict the pile-head load movement curves of the piles presented above, a software called PIVER developed at IFSTTAR (France), based on the load transfer method, is used. The computation using this software requires the pile dimensions, the type of piles, the Young Modulus of the pile, the soil properties and the shape of the t-z curves at different depths. The present work proposes two predictions using two kinds of t-z curves. The first one has been developed by Frank and Zhao (1982), and the second one is called AB1 (Abchir and al. 2016). The software called PIVER gives the load-movement curves, the distribution of axial load versus depth and can be used to predict the behaviour of a pile submitted to a bi-directional test.

5. RESULTS

The following section presents the computed results using the software PIVER and its comparison with field data. A brief analysis and discussion is also presented below.

5.1 Load-movement curves

Figure 4 represents the load movement curves during the static loading tests applied to the piles A3, B2 and C2. The figure shows the computed results calculated using Frank and Zhao (1982) and the AB1 model (Abchir and al., 2016). The computed and experimental results present a clear difference that still remains acceptable for a design. The ratio $\frac{R_{c,cal}}{R_{c,mes}}$ where $R_{c,cal}$ is the computed pile capacity, and $R_{c,mes}$ is the measured pile capacity, can be calculated for each pile. The value of $R_{c,cal}$ corresponds to the load when the displacement is equal to B/10. This ratio is equal to 1.13, 0.72 and 0.57 for the piles A3, B2 and C2 respectively. The ratio $\frac{R_{c,cal}}{R_{c,mes}}$ is not too far from 1 for the bored pile A3 and CFA pile B2, whereas for the FDP (screw) pile C2, this ratio is significantly lower than 1. This difference might be due to a slight underestimation of q_s and q_b for screw piles in the French standard NF P 94-262 (AFNOR 2012). Figure 4 also shows that the two t-z models overestimate the measured displacements for the CFA and FDP piles, and for the bored pile, the calculated displacements underestimate the measurements.

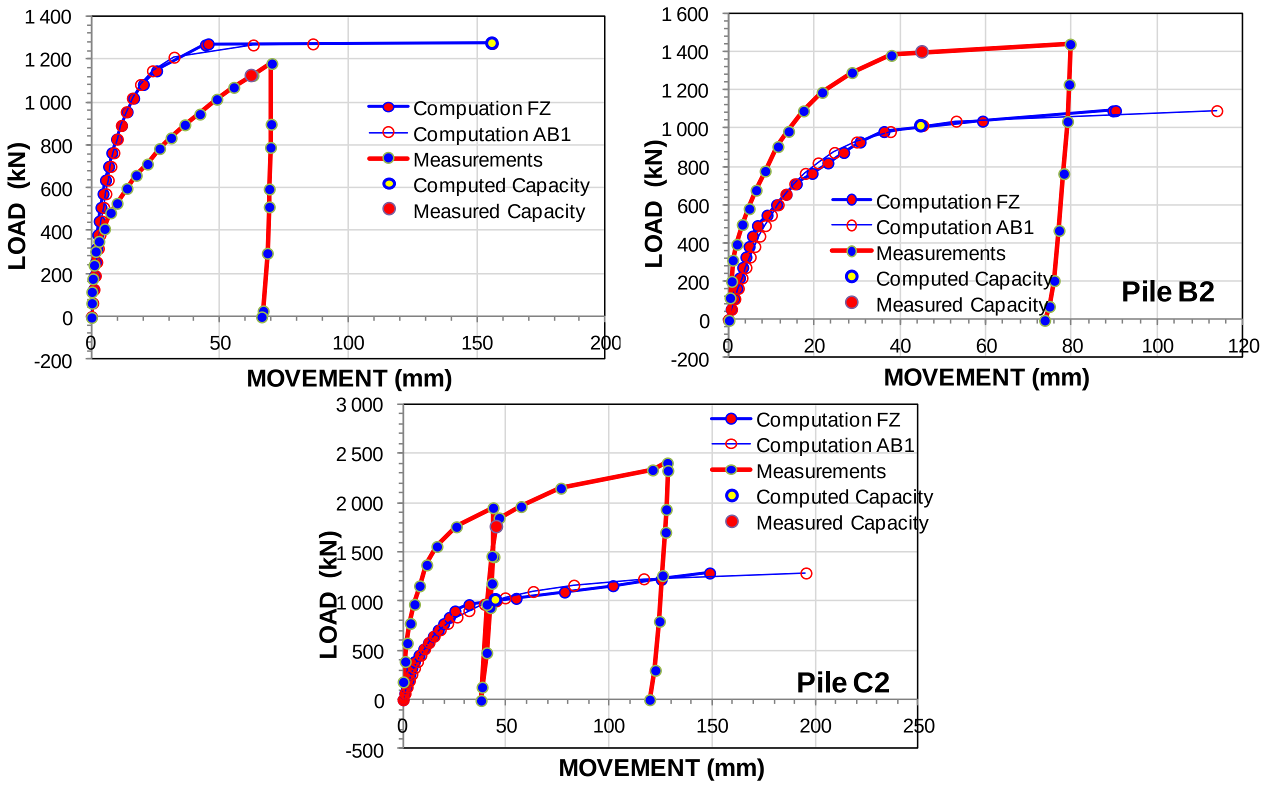

Fig. 4. Load-movement curves measured and computed with the two t-z curves Frand and Zhao (1982) and AB1 (Abchir and al. 2016)

Figure 5 shows the predicted distribution of axial load versus depth using the Frank and Zhao (1982) model. The phenomenon of load transfer from the superficial soil layers to the deep layers is noticed. The predicted pile base capacities R_b are equal to 367 kN, 182 kN and 389 kN for the piles A3, B2 and C2 respectively. Similar results are obtained using AB1 model (Abchir and al. 2016).

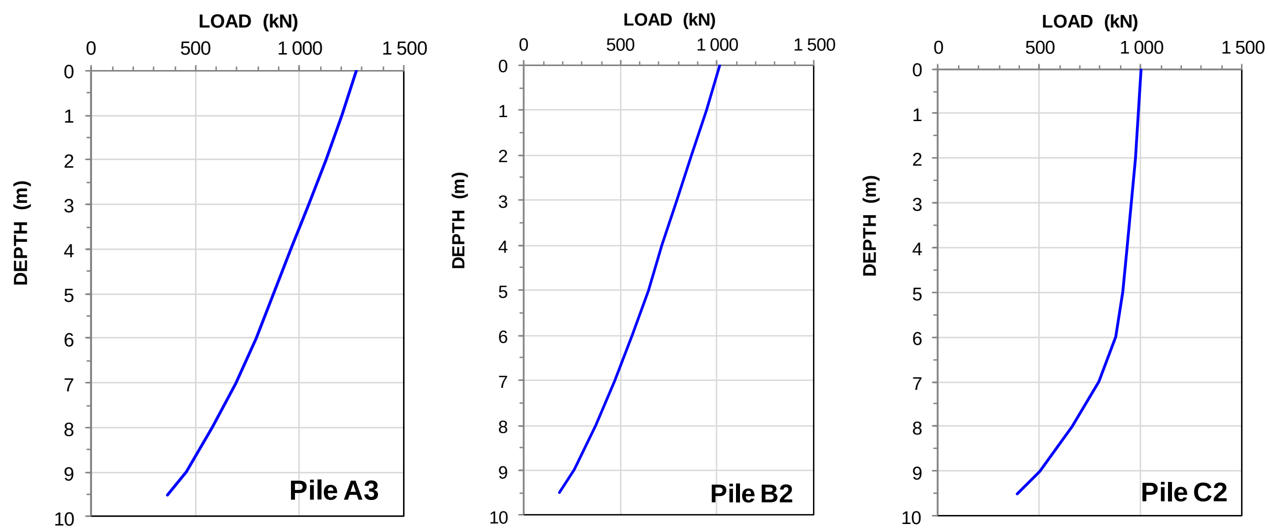

Fig. 5. The predicted distributions of axial load versus depth for a pile head load equal $R_{c,cal}$ using Frank and Zhao (1982) t-z curve

5.2 Results of bi-directional test

To predict the upward and downward load-movement response during the bidirectional static loading on pile E1, two calculations have been done: the first one on the upper part of E1, called P1, with a base resistance equal to 0, and the second one on the lower part of E1 that is considered as a second pile P2 (Figure 2).

The predicted upward and downward movements are plotted on Figure 6. The computations show that the lower part reaches the failure before the upper part. For the model developed by Frank and Zhao (1982), the calculated bearing capacities are equal to 481 kN and 231 kN for the upper and lower parts respectively. For the AB1 model (Abchir and al. 2016), the calculated bearing capacities are equal to 475 kN and 240 kN for respectively the upper and the lower parts. The comparison with field results shows that the prediction using the two t-z curves underestimates slightly the bearing capacity of the upper part of E1. Indeed, the ratio $\frac{R_{c,cal}}{R_{c,mes}}$ of the upper part of E1 is equal to 0.82 and 0.80 for Frank and Zhao (1982) and AB1 models respectively.

5.3 Equivalent head-down load movement

In order to predict the equivalent head-down load movement curve, two steps are required:

1. the estimate of the equivalent settlement at pile head called s_t ;
2. the estimate of the equivalent load at pile head Q_t.

In order to provide these two estimates, several methods have been developed. In the present prediction work, a method called "elastic method" proposed by Lee and Park (2007) is used. The equivalent head-down load movement curve obtained using this method is plotted on Figure 7.

The estimated pile bearing capacity $R_{c,cal}$ is equal to 732 kN and 720 kN for respectively Frank and Zhao (1982) and AB1 (Abchir and al. 2016) models.

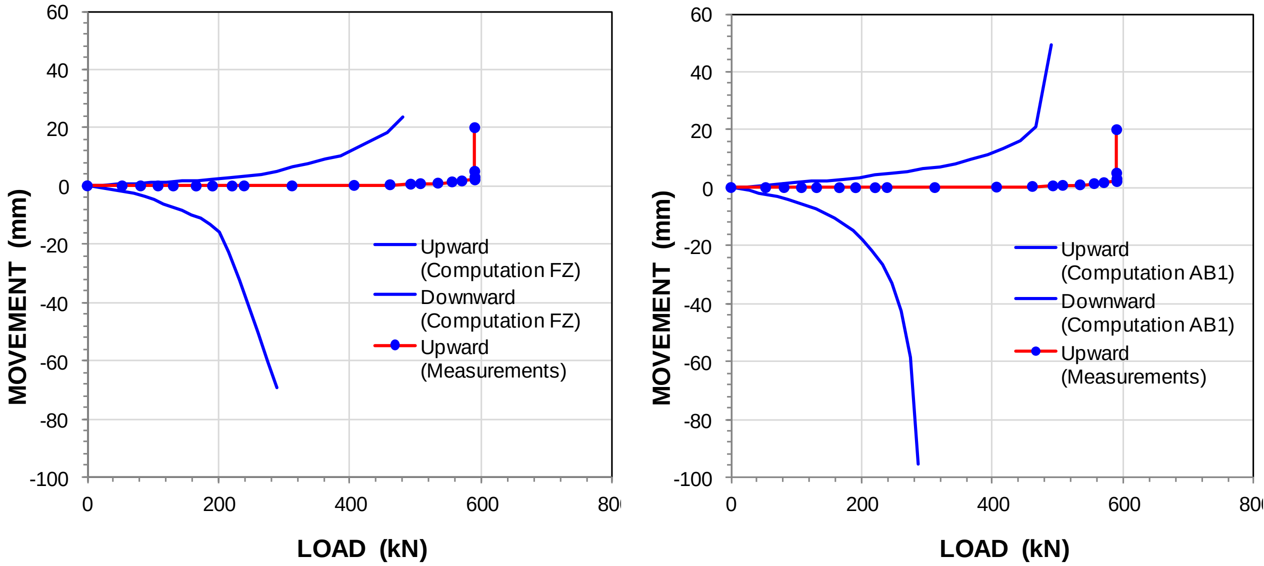

Fig. 6. The Upward and downward movements predicted using Frank and Zhao (1982) model and AB1 model (Abchir and al. 2016), compared to the measured upward movement of the pile E1

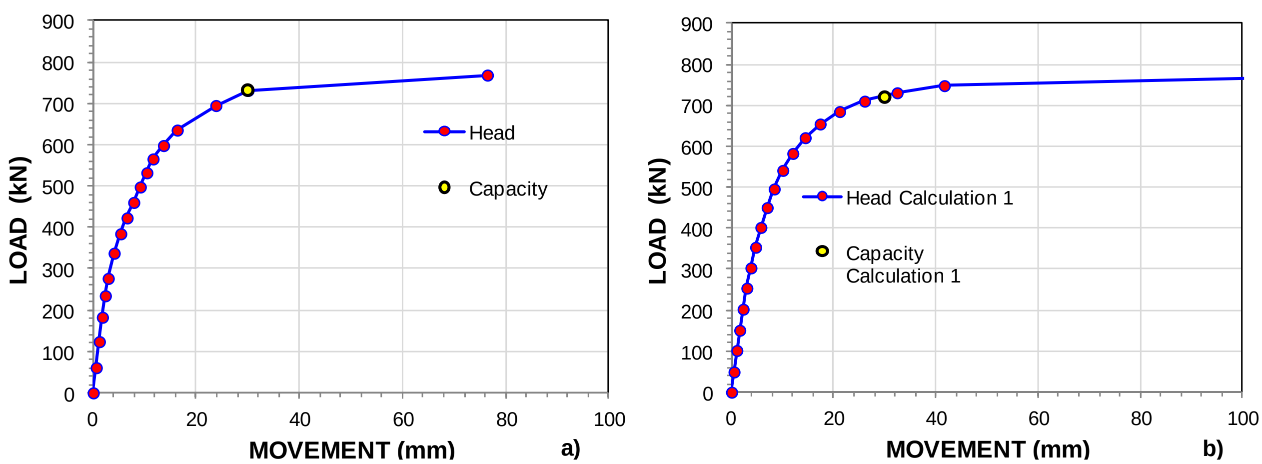

Fig. 7. Equivalent head-down load movement curve predicted for the pile E1 using a) Frank and Zhao (1982) model, and b) AB1 model (Abchir and al. 2016)

6. CONCLUSION

This paper presents a comparison between the measured data at the occasion of a campaign of full scale static pile load tests performed for the 3rd Bolivian International Conference on Deep Foundations and the values calculated by means of the software PIVER developed at IFSTTAR and using two kinds of t-z curves: The first one has been developed by Frank and

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The results allow to estimate the reliability of the two kinds of t-z curves used and the necessity to increase the number of comparisons between measured and calculated values in order to increase the precision of the calculation methods. This comparison underlines the need of high quality in terms of ground investigations since, in this case, both the bearing capacity of the piles and the t-z curves are derived from PMT data.

7. REFERENCES

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