30th January 2016

The Bolivian Experimental Site for Testing (B.E.S.T.) Piles

On September 16, 2015, the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) Technical Committee “Deep Foundation” (TC212), decided to instigate an experimental site in Santa Cruz de la Sierra, Bolivia, with the aim of studying piles and associated geotechnical features in reference to the current state of the art and practice, as expressed in the technical literature, standards, guidelines, and codes.

BACKGROUND

According to Randolph (2003), although scientific approaches to pile design have advanced enormously in recent decades, the most fundamental aspect of pile design – that of estimating the axial capacity - still relies heavily upon empirical correlations. In spite of significant improvements have been made in identifying the complex process undergone within the critical zone of soil immediately surrounding the pile, the quantification of the changes in stress and fabric due to different pile installation methods is not straightforward.

The matter is made more and more problematic by the continuous developments of existing types of pile (Drilled Displacement Piles, Helical Piles, Injected Micropiles, etc.) as well as the introduction in the pile market of new devices (Expander Body Piles, Toe Box Piles) aimed to improve pile performance.

The current international practice for the pile design relies primarily on the results of boreholes and penetration tests (SPT and CPT, sometimes CPTU). The use of other in-situ tests, such as dilatometer tests (DMT), geophysical tests (SASW and REMI), and pressuremeter tests (PMT) is rare. The results are then used in empirical correlations whose coefficients are selected in function of pile and soil types.

To all above, it must be added that the behaviour of a single pile is different from that of the same pile in a group because of the interaction effects developing during installation and loading.
As well known, repeated installation effects can significantly alter the state (stress and void ratio) of the soil mass in which piles have been placed, resulting in a different pile response to axial load when comparing the "isolated" pile response to that of the same pile when surrounded by other installed piles. For instance, a displacement pile belonging to a group of displacement piles installed in sandy soil can have a much higher axial capacity ($R_{1,group}$) than that of the same displacement pile when "isolated" ($R_{1,isol}$). The ratio $\eta_{inst} = R_{1,group}/R_{1,isol}$ – that is a measure of the change of axial capacity due to installation effect – has been rarely studied in literature.
Assuming $R_{1,group}$ as known, when a pile group is loaded to failure, its axial capacity R_{group} is typically referred to that of the single pile, thus allowing for an estimation of the so-called group effect at failure by the well known efficiency factor at failure $\eta_f = R_{group}/R_{1,group}$, that is a measure of the change of axial capacity due to pile-pile interaction at failure. Several studies have been carried out on the topic, almost never separating installation effects from failure effects; in other terms, suggested values for η_f are referred to $R_{1,isol}$ instead of $R_{1,group}$, thus generating scatters and in some way confusion.
It is also well known that the effectiveness of a pile is generally reduced by the proximity of other piles, especially with respect to its stiffness. This reduced effectiveness is generally measured by the so-called efficiency in terms of stiffness η_w defined as the ratio of the stiffness of the pile group K_G to the sum of the stiffness of the single pile K_S. In the case of a group made by N identical pile with an axial stiffness K_S: $\eta_w = K_G/(N \cdot K_S)$.
Due to high loads to be applied, full scale experiments on pile groups made by a quite large number of piles are rare. Moreover, the piles are generally of limited size (diameter and length) if failure conditions have to be attained.
Higher loads have to be applied if the experiments concern with piled raft, that is a pile group with a raft in contact with the soil. The experimental evidence collected on this aspect is more and more limited for obvious reasons.

GEOLOGY OF THE PROPOSED B.E.S.T.

The area of Santa Cruz de la Sierra, lies in the southern part of the Amazonas.
The geology is a Paleozoic (250 million years old) sedimentary basin. The soils of interest to civil engineering construction are quaternary with the dominant minerals being calcite, silica, and feldspar. The main agent is the Piray River and its tributaries, which meandering over the area has resulted in a sedimentation-erosion-sedimentation process and a profile dominated by fine to medium sands with intermittent layers of clay or clayey sand.
The upper soils (about 15 to 18 m thick) consists of normally consolidated layers of clay, silt and sands, in various combination and thickness, thus resulting in a spatial variation even within short horizontal distances. At greater depths, the soil is more homogeneous and consists mostly of sand and gravel.
The groundwater table lies typically at a depth of about 6 m in the highest part of the city and at about 1 to 3 m depth in the lowest part of the city.
The geological situation is representative of the entire city of Santa Cruz del la Sierra; it follows that even light buildings need to be supported on piles.

B.E.S.T. PILES – SHORT DESCRIPTION

Compatibly with the available financial budget, the research program will try to increase the knowledge about the aspects listed in Background.
In particular, the geotechnical conditions of the selected site will be investigated using conventional methods (boreholes, SPT) and less common methods (SCPTU, DMT, PMT). Also geophysical tests (SASW and REMI) will be carried out.
After soil investigations will be completed, different full-scale piles (6 types) will be installed, isolated and in a piled raft, for a total of 26 piles (*Table 1*).

<table>
<tr><th>Pile type</th><th>Number</th><th>Description</th><th>Pile length (m)</th><th>Diameter (mm)</th><th>Notes</th></tr>
<tr><td>A</td><td>3</td><td>Bored with retrievable casing</td><td rowspan="2">12 to 15</td><td>620</td><td>1 pile with Toe Box at the base</td></tr>
<tr><td>B</td><td>2</td><td>CFA</td><td rowspan="2">450</td><td></td></tr>
<tr><td>C</td><td>2</td><td>FDP</td><td rowspan="2">12</td><td>1 pile with Expander Body (600 mm) at the base</td></tr>
<tr><td>D</td><td>2</td><td rowspan="2">Vibro-driven</td><td rowspan="2">200</td><td>1 pile with Expander Body (500 mm) at the base</td></tr>
<tr><td>E</td><td>14</td><td>10</td><td>1 single
1 piled raft (13)</td></tr>
<tr><td>F</td><td>2</td><td>Hollow bar</td><td rowspan="2">12</td><td>90</td><td></td></tr>
<tr><td>G</td><td>1</td><td>Helical</td><td>300</td><td></td></tr>
</table>

Table 1. Summary of the experiments

<u>All the piles will be instrumented along the shaft and at the base</u> in order to separately study the mobilisation of the shaft resistance and the base resistance.
After due time, piles will be checked according to *Table 2* and loaded according to *Table 3*.

Type of Check	Description	Piles	Notes
C1	Pile Integrity Testing (PIT)	All piles	
C2	Cross-Hole (CH)	A, B, C	

Table 2. Summary of the pile checks

Type of Test	Description	Piles	Notes
T1	Bi-directional	A, C, D, F	
T2	Static	B, D, G, H	
T3	Dynamic (PDA/CAPWAP)	A, B, C, F, G	
T4	Bi-directional simultaneous	E	1 piled raft (13)

Table 3. Summary of the pile testing

In *Table 4* is reported the details of the instrumentation by which any pile will be equipped.

<table>
<tr><th>Pile type</th><th>Number</th><th>Basic instrumentation</th><th>Additional instrumentation</th></tr>
<tr><td>A</td><td>3</td><td rowspan="7">Sister-bar vibrating wire strain gage every 2.0 m</td><td>Accelerometers at pile base to measure movements during dynamic testing; thermal wires</td></tr>
<tr><td>B</td><td>2</td><td>Accelerometers at pile base to measure movements during dynamic testing</td></tr>
<tr><td>C</td><td>2</td><td>Accelerometers at pile base to measure movements during dynamic testing; thermal wires</td></tr>
<tr><td>D</td><td>2</td><td></td></tr>
<tr><td>E</td><td>14</td><td>Accelerometers at pile base to measure movements during dynamic testing; thermal wires</td></tr>
<tr><td>F</td><td>2</td><td>Accelerometers at pile base to measure movements during dynamic testing</td></tr>
<tr><td>G</td><td>1</td><td>Accelerometers at pile base to measure movements during dynamic testing</td></tr>
</table>

Table 4. Summary of pile instrumentation

Table 5 summarizes the soil investigations.
For sandy soils, laboratory tests will be only aimed to classify the soils (*Unified* S*oil Classification System*, USCS). For clayey soils, oedometer tests will also be performed.

<table>
<tr><th>Pile type</th><th>Number</th><th>Soil investigation</th><th>Additional information</th><th>Notes</th></tr>
<tr><td>A</td><td>3</td><td rowspan="7">SPT
DPSH
SCPTU
DMT
PMT
SASW
REMI</td><td rowspan="7">- SPT and DPSH with instrumented bars to measure the transferred energy
- SPT equipped for torque measurements (SPT-T)</td><td rowspan="4"></td></tr>
<tr><td>B</td><td>2</td></tr>
<tr><td>C</td><td>2</td></tr>
<tr><td>D</td><td>2</td></tr>
<tr><td>E</td><td>14</td><td>For only 2 piles out of 14</td></tr>
<tr><td>F</td><td>2</td><td rowspan="2"></td></tr>
<tr><td>G</td><td>1</td></tr>
</table>

Table 5. Summary of soil investigation

B.E.S.T. PILES – PREDICTION EVENT

One (static) or two (static and bi-directional) single piles and the 13-piled raft will be used in an International Prediction Event. All the pertinent technical information (soil and pile installation data) as well as the established rules to participate will be available for downloading from the BEST site: (www.cfpb.com/best)
People and parties from all over the world will be kindly invited to participate to the Prediction Event.

In addition to above, also a “Pile Integrity Testing Event” will be organized with the aim of checking the reliability of the existing integrity methods of analysis. For that, 4 piles (type yet to be decided on), will be installed with a single intentional defects while one or two piles will be installed without any intentional defects. Also in this case, people and parties in the industry active professionally and commercially will be invited to participate by performing field test aimed to discover and categorize the defects. The planning of the related site activities will be established in conjunction with the invited parties.

B.E.S.T. PILES – DISSEMINATION OF THE RESULTS

All the results of the experimental tests will be presented during the 3rd Bolivian Conference on Deep Foundations and 1st TC212 International Conference to be held in Santa Cruz presumably during the first week of May 2017.