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In-situ test campaign on innovative resin grouted micropiles

Campagne d'essai in situ sur de nouveaux micropieux en résine

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ABSTRACT: An in-situ test campaign was recently performed in the facilities of the BBRI to study the geotechnical behavior of innovative resin grouted micropiles, consisting of hollow steel anchor bars covered by hardened resin. After the installation of hollow steel bars into the ground by dry drilling, expanding and curing synthetic resins are injected, throughout the hollow steel bars and they penetrate, at several depths via openings, into the surrounding soil to form, after chemical reaction, hardened resin bodies around the steel bars. These new grouting type micropiles can be used for ground improvement works or for stabilizing existing foundations by soil consolidation generally up to a depth of five meter. In the case of underpinning projects, the individual resin grouted micropiles and the existing foundation are then fastened together.

The purpose of the present experimental test campaign was first to study the feasibility of the installation process of these resin grouted micropiles. Static load tests (SLT's) were then performed on six individual resin grouted micropiles to analyze their load-settlement behavior and to determine their bearing capacity when subjected to compressive loads.

RÉSUMÉ: Une campagne d'essais in situ a été réalisée au sein des installations du CSTC afin d'étudier le comportement géotechnique de nouveaux micropieux en résine. Ces derniers consistent en des barres d'ancrage creuses, en acier, recouvertes d'une résine durcie. Ces barres d'acier sont initialement forées à sec dans le sol. Ensuite, des résines expensives et durcissantes sont injectées à travers les barres et pénètrent, à différentes profondeurs, dans le sol via des ouvertures réalisées dans les barres pour former, après réaction chimique, un manteau de résine durcie autour des barres en acier. Ce nouveau type de micropieu peut être utilisé dans des travaux d'amélioration de sol ou pour stabiliser des fondations existantes par renforcement du sol généralement jusqu'à une profondeur de cinq mètres. Dans le cas de reprises en sous-oeuvre, les micropieux en résine sont connectés à la fondation existante.

Le but de la présente campagne expérimentale est d'abord d'étudier la faisabilité du processus d'installation de ces micropieux en résine. Des essais de chargement statique ont ensuite été réalisés sur six micropieux individuels afin d'analyser leur comportement charge-tassement et pour déterminer leur capacité portante lorsque ceux-ci étaient soumis à un chargement en compression.

Keywords: Micropiles, Injection, Resin, bearing capacity, SLT

1 INTRODUCTION

In October 2017, the company GCP APPLIED TECHNOLOGIES has made an appeal to the Belgian Building Research Institute (BBRI) in order to organize and to perform a geotechnical testing campaign on innovative resin grouted micropiles installed on the test site of the BBRI in Limelette (Belgium). The purpose of the in-situ test campaign was to study the geotechnical behavior of resin grouted micropiles, consisting of hollow steel anchor bars covered by hardened resin.

After the installation of hollow steel bars into the ground by dry drilling, expanding and curing synthetic resins are injected, through the hollow steel bars and they penetrate, at several depths via openings, into the surrounding soil to form, after chemical reaction, hardened resin bodies around the steel bars.

These new grouting type micropiles can be used for ground improvement works or for stabilizing existing foundations by soil consolidation generally up to a depth of five meter. In the case of underpinning projects, the individual resin grouted micropiles and the existing foundation are then fastened together.

The yield load of the hollow steel bars used within the framework of this test campaign, the DE NEEF® AXI Anchor Bars, is equal to 228 kN. The length of the steel bars, installed on the test site of the BBRI, was equal to 5 m. The external diameter of the bars was equal to 32 mm and their area to 430 mm².

Within the framework of the present test campaign, three kinds of resin were studied:

- the resin DE NEEF® AXI G1 (resin + catalyst),
- the resin DE NEEF® AXI G3 (two-component resin),
- and the resin DE NEEF® AXI G4 (two-component resin).

The installation depth of the bars was equal to 4.5 m.

2 GEOTECHNICAL CONTEXT

Before the beginning of the test campaign, several types of soil, present on the test site of the BBRI in Limelette, were tested in the laboratory facilities of GCP APPLIED TECHNOLGIES in Belgium. On the basis of several lab tests, it was decided to install the resin grouted micropiles in an artificial testing well of 5.5 m deep, previously installed on the test site of the BBRI, and filled with Brusselian sand coming from the sand quarry of Mont-St-Guibert (Belgium) where it is extracted for its use in the construction industry.

The purpose of this choice was to assess the geotechnical behavior of the resin grouted micropiles in a soil consisting in a loose sandy layer of about 5 m deep.

More information with regard to the geological background of the Brusselian sand can be found in Vanden Berghe (2001). The analysis performed on a sand sample taken in the well highlighted the fact that it is a poorly-graded medium sand (d_{50} around 0.35 mm and Cu of 1.58) characterized by irregular shaped grains with round or angular edges.

In order to fulfill the purposes of the test campaign, it was decided to install eight resin grouted micropiles in the artificial sand well of the BBRI facilities.

Figure 1 provides the definition of the installation plan. As illustrated in Figure 1, the distance between each resin grouted micropile is 2.2 m to avoid mutual influence of the static load test (SLT) on neihgboring piles.

For the geomechanical characterization, eight variable energy lightweight dynamic cone penetrometer tests (also called PANDA® tests) and six electric cone penetrometer tests (CPT’s) were performed.

Before installing the steel bars into the ground, eight PANDA® tests were executed in the axis of the eight future resin grouted micropiles.

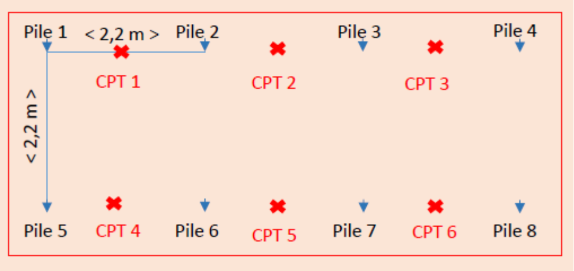

Figure 1. Installation plan of the micropiles

The PANDA® tests were executed according to the NF P 94-105 with a cone presenting a surface area of 2 cm². The six CPT's were executed according to the ISSMGE TC16 procedure (1999) with an electrical cone of 10 cm². The positions of the CPT's are indicated in Figure 1. Figure 2 presents the results of the Panda® tests. As illustrated in Figure 2, it seems that there are two "trends" in terms of cone resistance. Two different soil profiles can be highlighted on the basis of the PANDA® tests. The cone resistances seem to present comparable values for the locations 1, 2, 3 and 4 and for the locations 5, 6, 7 and 8 respectively. Figure 3 provides an oversight of the results of the six CPT's. As illustrated in Figure 3, the two "trends", previously observed in the Panda® test results, are also identified.

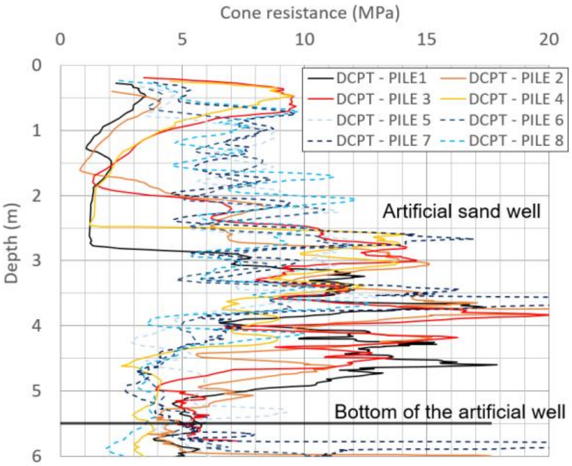

Figure 2. Results of the eight Panda® tests

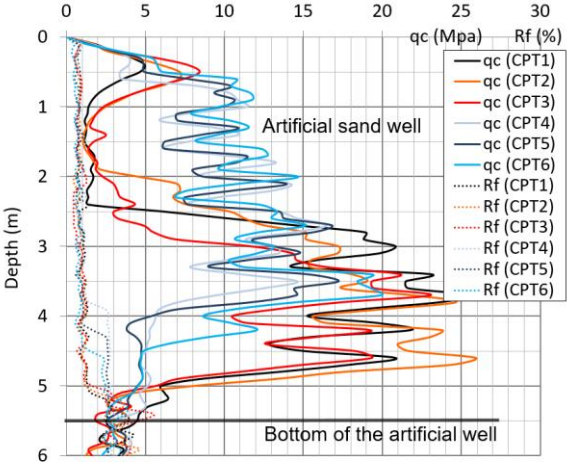

Figure 3. Results of the six CPT's with electrical cone

On the basis of the in-situ geomechanical characterization of the sand layer present in the artificial well of the test location, it was decided to inject at least the three different resins in the two different soil profiles. With that configuration, each type of resin grouted micropile (made with a specific resin) will be subjected to a SLT in the two different soil profiles.

3 INSTRUMENTATION OF THE STEEL BARS WITH OPTICAL FIBERS

Before installation into the ground, the hollow steel bars were instrumented in the laboratory facilities of the BBRI. The instrumentation consisted in an optical fiber integrated into the body of the steel bar to follow the deformations of the steel material during the future SLT's.

The optical fiber technology used within the framework of the present test campaign is the Fiber Bragg Gratings technique (FBG). With that technology, a multitude of sensor points are available on one single optical fiber.

The working principle of the Fiber Bragg Gratings technology (FBG) can be described as follows. One single continuous optical fiber is at several well-defined positions provided with a Bragg grating that serves as a sensor. At the position of such a Bragg grating an incident spectrum from a light source is reflected at a specific (predetermined) wavelength. By providing Bragg gratings at several positions on the optical fiber and at the condition that each Bragg grating reflects the incident spectrum at a different wavelength, a multi-point sensor can be obtained. With this technology, variations of parameters such as the temperature or the deformation at the location of the Bragg grating shift in a linear way the reflected wavelength, reason why this technology can be used as sensor device e.g. to measure the deformation at the location of the grating (Huybrechts et al., 2016).

For the present project, five sensing areas or sensors are provided on each continuous optical fiber. That means that, during the SLT's, the deformation of the steel bars will be measured at five different locations. The five locations of measurement have been defined as follows. The first sensor is installed 10 cm above the micropile base (= 10 cm above the underside of the steel bar to be installed into the ground). The spacing between all the sensors is 90 cm. This configuration should allow a reliable measurement of the base resistance of the resin grouted micropile, as the first sensor is located very close to the micropile base, and a good discretization of the shaft resistance with a distance of 90 cm between each measurement zone.

4 REALIZATION OF THE RESIN GROUTED MICROPILES

The eight DE NEEF® AXI anchor bars were first drilled into the ground with a dry process (see Figure 4). During the process, neither water, nor drilling grout/liquid were used. Five meter long steel bars were installed in one operation (installation depth of 4.5 m). No coupling sleeves were used. Just after installation of the steel bars into the ground, the staff of GCP APPLIED TECHNOLOGIES has cleaned and installed the injection tubes inside the hollow steel bars (see Figure 5).

Figure 4. Dry drilling of the steel bars into the ground

Figure 5. Installation of the injection tube inside the hollow steel bar

After the installation of the steel bars into the ground, eight reinforced concrete slabs were installed around the bars in order to simulate the presence of a building slab at the surface of the soil (as for underpinning projects) and to provide the proper containment for the injection material.

For the purpose of isolating the steel bar from the concrete slab, at the level of the future concrete slab, the steel bar was covered with a classical PU foam injected inside a PVC tube (see Figure 6). During the SLT's, the concrete slabs were removed. Figure 7 presents the test location after concreting of the eight slabs.

The injection process was performed one week after the installation of the concrete slabs. The micropiles ID 1, 2 and 5 were injected with the resin DE NEEF® AXI G1, the micropiles ID 3, 6 and 7 with the resin DE NEEF® AXI G4 and the micropiles ID 4 and 8 with the resin DE NEEF® AXI G3. Figure 8 illustrates the injection phase.

Figure 6. Isolation of the steel bar with the PU foam

Figure 7. Test location after concreting the eight slabs

Figure 8. Injection phase

5 REALIZATION OF THE STATIC LOAD TESTS IN COMPRESSION

The reaction device for the SLT's consists in a partially buried ballast system (see Figure 9).

With regard to the innovative character of the resin grouted micropile (related to the nature of the micropile body and to its unknown dimensions and shape), a preliminary SLT was firstly performed on the micropile ID 5 to have a first idea of the load-settlement behavior and of the bearing capacity of that kind of micropile.

The six final SLT's were then performed according to the French standard NF P 94-150-1 including two loading cycles and one intermediate unloading cycle.

Figure 9. Different views of the reaction device and the measurement set-up used for the SLT's

The first day of the test, five constant loading steps of 60 minutes are applied until the load reaches a value corresponding to 50% of the estimated ultimate load Q_{max}. The micropile is then unloaded. The second day of the test, the five initial loading steps (until 50%Q_{max}) are reproduced but with a duration of 30 minutes. Afterwards, constant loading steps of 60 minutes are applied until failure is reached or until the yield strength is reached in the steel bars. If there is no structural and geotechnical failure of the resin grouted micropile, a final unloading procedure is applied.

For the six final SLT's, on the basis of the results and observations of the preliminary SLT, constant loading steps of 18 kN are considered.

6 MAIN RESULTS OF THE SLT'S

During the test campaign (i.e. the six SLT's), the geotechnical bearing capacity of the micropiles was never reached. Either a structural failure of the steel bar was observed (by buckling) or the deformation level, reached in the steel bar, was close to its yield strength and an unloading procedure was applied. A comparison of the load-settlement curves obtained for the six tested micropiles is given in Figure 10.

Within the framework of this geotechnical test campaign, a sudden structural failure of the micropile by buckling of the steel bar was observed for the micropiles ID 2 (failure at 111 kN during the increase of the load), ID 7 (after 10 minutes of loading at 180 kN) and ID 8 (at 138 kN during the increase of the load). In Figure 10, the dotted lines indicate the last measurements taken just before failure.

A level of deformation close to the yield strength of the steel bar was observed for the micropiles ID 1 and 4 (see indications in Figure 10). The analyse of the deformations in these micropiles and the evolution of the forces inside the anchor bars (deduced with the help of the Fellenius method) highlight the progressive buckling of these steel bars. An unloading procedure was thus applied for the two SLT's performed on micropiles ID 1 and 4.

For the micropile ID 3, no measurement of the deformation was available. Comparing the settlement of the micropile head with the measurement available for the micropile ID 7 (same resin), it was decided to unload the micropile to avoid a structural failure of the bar.

As a result of the structural failures or of the high level of deformation close to the yield strength of the steel bar, it was not possible to go further with the loading of the micropiles. The geotechnical bearing capacity of the different resin grouted micropiles are thus, in the given soil conditions, larger than their structural resistance. Considering the limited settlements measured for all the SLT's (see Figure 10), extrapolation methods (e.g. the Chin method) do not allow to provide reliable values of the geotechnical bearing capacity of the different micropiles.

Finally, it can be noted that the resin grouted micropiles obviously present a high capacity of mobilization of friction forces along their shaft. As illustrated in Figure 11, in the six final SLT's, the base resistance of the six tested micropiles was only mobilized in a limited way due to the efficient mobilization of the friction forces. Hence, significant friction forces developed during the SLT's considering the soil resistance given in Figures 2 and 3. For the sake of illustration, the friction mobilization curves of the SLT performed on the micropile ID 7 are given in Figure 12.

7 CONCLUSIONS AND PERSPECTIVES

During the test campaign, the geotechnical bearing capacity of the resin grouted micropiles was never reached. Either a structural failure of the steel bar was observed (by buckling) or a high level of deformation was reached in the steel bar. That means that, in the given soil conditions, the capacity of such micropiles is limited by the steel strength, what is very positive for the micropile concept, as the steel strength can be adapted by the customer in function of the design requirements. Hence, a perspective could be the use of stronger steel bars to increase the structural limit of the system. That result also demonstrates the effective geotechnical behavior of the resin body of the micropile with a significant level of friction mobilization at the interface resin-soil. Considering the results presented in Section 6, there is still “reserve” in terms of friction mobilization but also in terms of base resistance.

Geotechnical tensile tests are currently performed on the micropiles ID 1, 6 and 4. The test results will be later published.

In the near future, the eight resin grouted micropiles will be excavated in order to measure their dimensions. Core samples will also be taken to obtain the mechanical characteristics (compressive strength, modulus of elasticity and tensile strength) of the different resins as installed in-situ.

8 ACKNOWLEDGEMENTS

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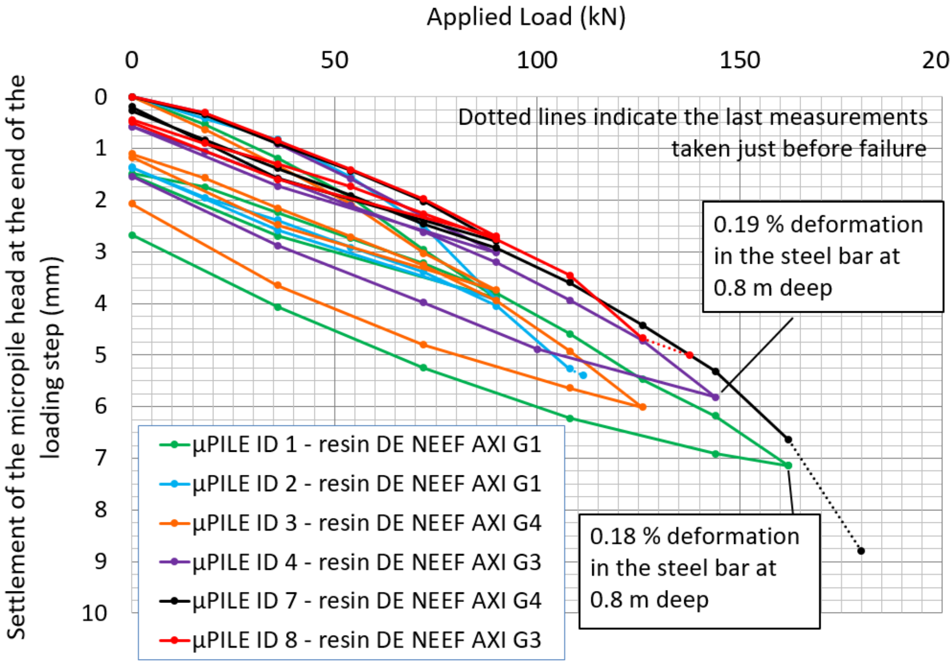

Figure 10. Results of the six final SLT's performed on the resin grouted micropiles - Settlement at the end of the loading step as a function of the applied load

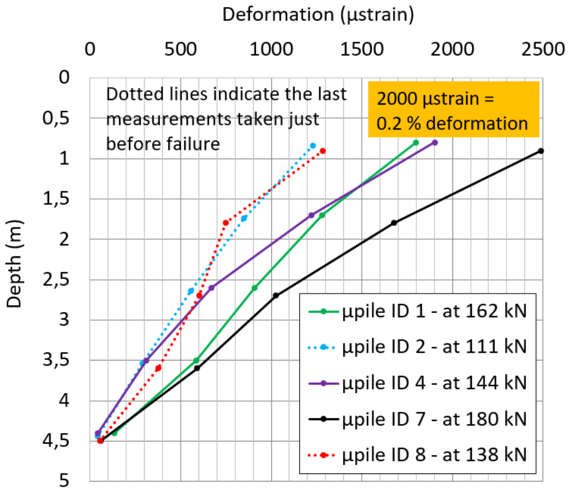

Figure 11. Last deformation levels measured during the SLT's as a function of the depth

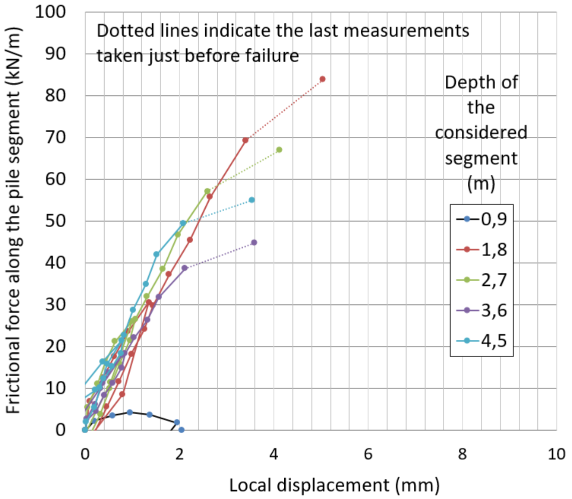

Figure 12. Example of friction mobilization curves given for the SLT performed on the micropile ID 7