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Micropile bearing capacity analysis using fiber optic technology

Analyse de la capacité portante des micropieux en utilisant la technologie de la fibre optique

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ABSTRACT: This paper discusses the bearing capacity of micropiles and the performance of shortening pile measurement using fiber optic technology. Results from a static pile load test on a micropile are presented, along with an analysis of the shortening of the pile shaft based on data obtained from fiber optic measurements. An optical fiber, placed at the center of the micropile, was used to measure deformations along the entire length of the pile. The test involved a 6-meter-long micropile and was conducted until failure. Successive load stages enabled the analysis of the behavior of the entire micropile shaft under load. The ground conditions facilitated the interaction of the pile side with the soil from the surface. The test was conducted on a micropile using rock bolting technology with ARCO steel pipes, which serve as the reinforcement of the micropile. A fiber optic sensor was placed inside the pipe (bar).

RÉSUMÉ: Cet article traite de la capacité portante des micropieux et de la performance de la mesure du raccourcissement des pieux en utilisant la technologie de la fibre optique. Les résultats d'un essai de charge statique sur un micropieu sont présentés, accompagnés d'une analyse du raccourcissement du fût du pieu basée sur les données obtenues par des mesures à fibre optique. Une fibre optique, placée au centre du micropieu, a été utilisée pour mesurer les déformations sur toute la longueur du pieu. L'essai a impliqué un micropieu de 6 mètres de long et a été mené jusqu'à la rupture. Les étapes de charge successives ont permis d'analyser le comportement de l'ensemble du fût du micropieu sous charge. Les conditions du sol ont facilité l'interaction du côté du pieu avec le sol depuis la surface. L'essai a été réalisé sur un micropieu utilisant la technologie de boulonnage de roche avec des tuyaux en acier ARCO, qui servent de renforcement au micropieu. Un capteur à fibre optique a été placé à l'intérieur du tuyau (barre).

Keywords: Mikropile; distributed fiber optic sensing; geotechnical load tests; soil mechanics.

1 INTRODUCTION

The primary characteristic of the micropile installation technique is its effectiveness in high-resistance soils, including rocky terrains, as well as in areas with limited overhead space and uneven surfaces (FHWA, 2005). In this context, tip resistance is often overlooked, with a predominant emphasis on load transfer through skin friction (Allen et al., 2004). Choi & Cho (2010) observed that the injection of neat cement grout can potentially enhance the load capacity of micropiles by over 100% in both soil and rock environments.

For the tested micropile, the ARCO steel pipe anchoring technology was employed. The advantage of this method lies in the integration of corrugated pipes with the ground through a mixture of grout and sand, similar to the reinforcement in concrete structures, thereby ensuring protection against external factors.

Additionally, some researchers (Finno et al., 2002; Holman & Barkauskas, 2007) have highlighted the potential for relative displacement between the steel casing and the neat cement grout. However, the use of stronger grouts and corrugated pipes, as in this study, can mitigate this issue. Żarkiewicz (2023) observed a significant impact of the simultaneous mobilization of skin resistance and resistance under the pile base near its base in his studies, which may also be relevant for loaded micropiles. While the application of micropiles in various solutions is not novel, their comprehensive examination and analysis, particularly in terms of interaction with the ground, are relatively scarce, similar to the situation with the larger market for standard piles, where despite greater accessibility, research is also limited.

In recent years, the use of distributed fiber optic monitoring systems has significantly increased in geotechnical applications. These systems provide the advantage of offering distributed strain and temperature measurements with high accuracy along the entire length of the structure, without any data gaps (Monsberger 2020). Ouyang (2015) and Schilder (2013) have utilized fiber optic instrumentation to monitor load tests, focusing respectively on a large diameter pile in London and on reinforced concrete piles. Esmaeili (2013) presented a case study on the use of micropiles for reinforcing high railway embankments, while Glisic (2002) discussed the application of fiber optic sensors in monitoring pile behavior during axial compression, pullout, and flexure tests.

The primary objective of this study is to introduce a fiber-optic approach to micropiles, to assess their performance in sand-fine gravel soil, and subsequently to determine the causes of the loss of bearing capacity of the tested micropile. Figure 1 presents the schematic and a view of the conducted load test.

2 EXPERIMENTAL SETUP

The micropile used in this study is a result of employing self-drilling anchors, with a diameter of approximately 16 cm and a length of 6 meters. It is drilled by rotation using an R51 steel pipe equipped with a disposable drill bit tip. This pipe is inserted using a drilling machine specifically designed for this task. The choice of drilling fluid, either water-cement or water, depends on the soil type. Upon completion of the drilling process, a substantial injection of water-cement mixture is conducted. The bar, serving as the reinforcement for the perforated micropile, eliminates the need for additional reinforcement insertion. The continuous threading ensures excellent adhesion of the cement mortar.

In addition to the previously described setup, a linear fiber-optic strain sensor, EpsilonRebar, supplied by shmsystem.pl, was installed inside the micropile's steel pipe reinforcement.

The use of a pure water-cement grout facilitated the easy installation of the sensor within the central part of the micropile. EpsilonRebar is capable of providing accurate strain and crack measurements over its entire length.

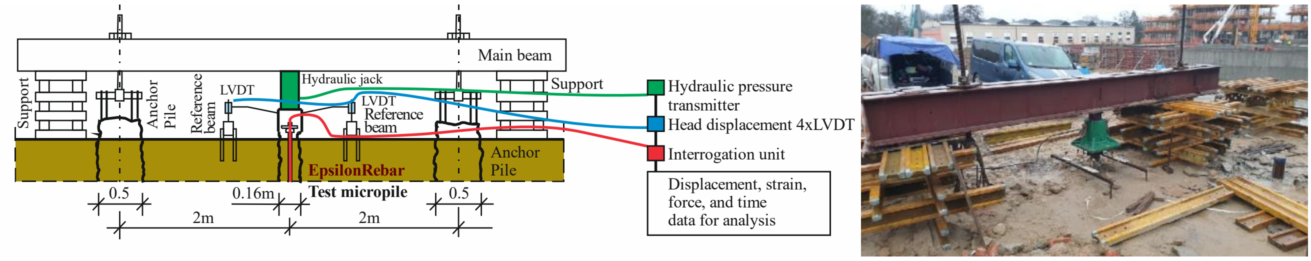

Figure 1. Schematic of the load test and photograph of the test setup.

It is designed as a composite rebar, available in any diameter, with a standard diameter of Ø5 mm. This sensor is suitable for direct embedding into newly-designed structures (such as concrete or soil) or for installation within existing structures (for example, inside grooves in concrete or on the surface of pipelines).

EpsilonRebar's resistance to mechanical loads and environmental conditions makes it ideal for in-situ applications in construction sites or existing infrastructure. The sensor's specifications include a strain measurement resolution of 1.0 με, a strain measurement range of ±2 %, an operating temperature range from -20 to +100 °C, and it is made of glass fiber and epoxide. The sensor utilizes scattering techniques such as Rayleigh, Brillouin, or Raman for its measurements.

3 RESULTS AND ANALYSES

The load test was conducted according to the scheme presented in Figure 2.

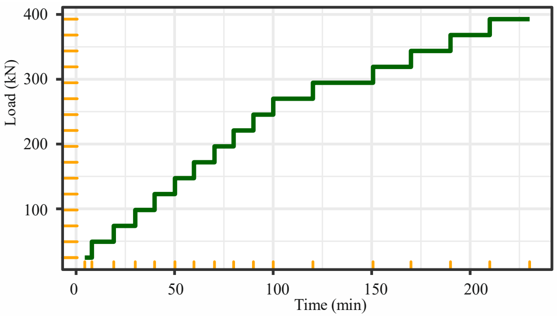

Figure 2. Variation of load over time (hydraulic pressure change of 0.5 MPa).

The study was carried out in 17 stages of loading, with the assumption that the test would continue until the micropile failed. During the test, efforts were made to maintain the condition that the transition to the next loading stage would occur when, after 10 minutes, the average settlement recorded by the displacement sensors at the micropile head was less than 0.05 mm. After 100 minutes, particularly beyond the applied force of 270 kN, stabilization occurred over a period longer than 10 minutes for each load stage.

The displacement of the micropile head is presented in Figure 3 for successive loading stages. The last six stages required stabilization periods longer than 10 minutes. In the final stage, the micropile failed.

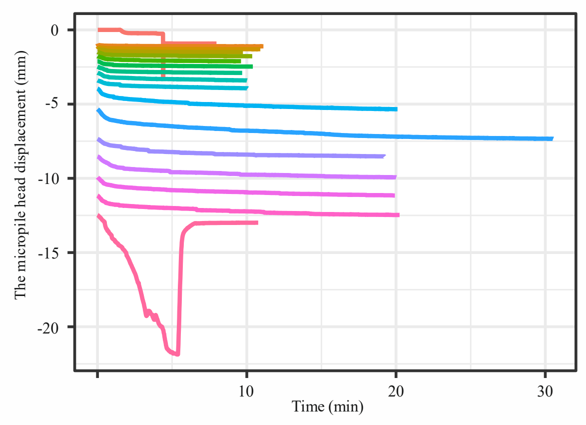

Figure 3. The displacement of the micropile head.

This figure (Figure 4) illustrates the continuous displacement of the micropile head, plotted against the backdrop of the total shaft shortening over time.

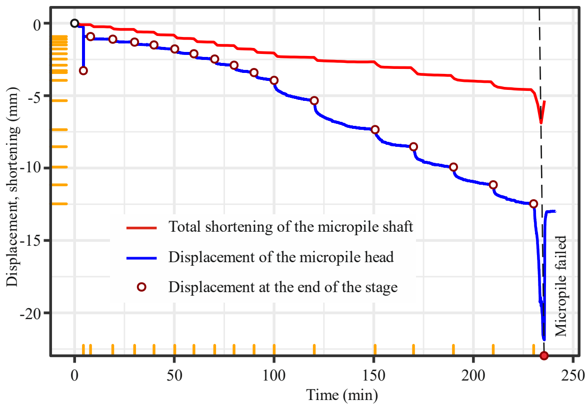

Figure 4. Continuous displacement of the micropile head with total shaft shortening over time and end-of-stage head displacements.

Additionally, it highlights the final displacements of the micropile head at the end of each loading stage, providing a comprehensive view of the micropile's behavior under progressive loading conditions.

Next figure (Figure 5) depicts the correlation between the shortening of the micropile shaft and its depth along the entire length of the micropile, as measured by the high-precision fiber-optic sensor EpsilonRebar. The results, showcasing measurements with an accuracy of 1 cm, are presented for the first ten loading stages, during which the micropile quickly stabilized under the applied load. This detailed analysis illustrates the variations in shaft shortening with depth at each stage, providing crucial insights into the initial structural behavior of the micropile under varying loading conditions.

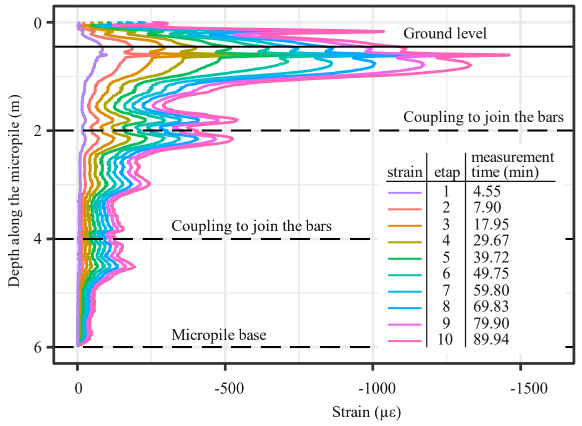

Figure 5. Relationship between the micropile shaft shortening and depth for the first ten loading stages.

Continuing the analysis, the subsequent Figure 6 extends our understanding to the later phases of the load testing.

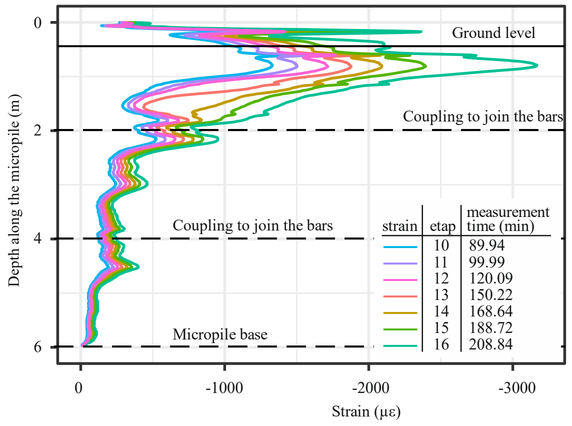

Figure 6. Relationship between the micropile shaft shortening and depth for the next six loading stages.

In this chart (Figure 6), the horizontal axis has been rescaled to twice its original size for clarity. It presents the behavior of the micropile during the following six stages of loading, further elucidating the structural response under increased stress.

The last chart, Figure 7, illustrates the final 5 minutes of the test, during which the micropile shaft failed, rather than a loss of bearing capacity in the soil substrate. This crucial phase highlights the structural limits of the micropile under extreme loading conditions. The determination of the shaft's failure was made possible through the use of a fiber-optic sensor, which unequivocally allowed for the assessment of the nature of the damage.

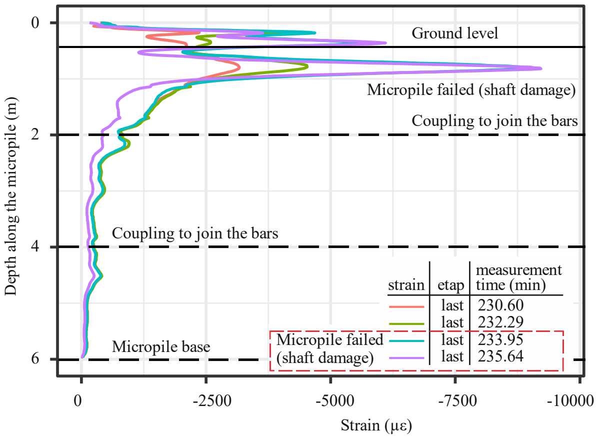

Figure 7. The final 5 minutes leading to micropile shaft failure.

4 CONCLUSIONS AND ACKNOWLEDGEMENTS

This project was an intriguing endeavor that served as a test of our capabilities and prepared us for significantly larger tasks. It required the coordination of numerous variables within a constrained timeframe. Breaking away from conventional solutions and adopting an unconventional approach allowed for the application of one of the most interesting solutions currently available for monitoring piles along their entire length. This solution is not only simple to install but also provides a vast amount of data for analysis. Future plans include correlating the obtained results with theoretical and semi-empirical analyses of the micropile-soil interaction. Further field studies of this nature are also planned.

The project, which involves the micropile tests at the designated test site, is funded privately as part of a collaborative initiative aimed at employing micropiles in regional investments.

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