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Field Verification Study on Micropiles Underpinning for Ground Improvement

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ABSTRACT

Micropiles are mostly employed to resist static and seismic stresses and as an in-situ stabilizing device for slopes and excavations. A micropiles testing facility was designed to support the Light Rail Transit 3 (LRT3) project. A borehole of 150mm in diameter was used to install three micropiles that ranged in length from 3, 5, and 7 meters. This article explores the more detailed techniques used to complete foundation retrofits, with a focus on micropiles as a ground improvement method. The comparative analysis discussed the data obtained with the static load test and piles driving analyzer (PDA). This study found that the bearing capacity of Ru 177 tonnes and 111 tonnes are more than the load, which is calculated at 60.9 tonnes. Finally, several recommendations for further research were presented after evaluation to prevent micropiles damage was performed.

Keywords: Micropiles; Ground improvement; Piles driving analyzer; Static load test; Bearing capacity

INTRODUCTION

Micropiles are well-known in Malaysia as a preferred alternative to traditional foundations and a frequent ground improvement method with problematic soil issues. This is due to difficulties with the ground conditions, such as natural or man-made obstacles and regional geological variables (Sun et al., 2013). Several researchers have previously explicitly reviewed the performance and behaviour of this improved method (Howe, 2010; Mamat et al., 2019). The primary function of micropiles is to provide support for structures, either by resisting static and seismic stresses or by stabilizing excavation sites and slopes. Micropiles are small-diameter (less than 300 mm) non-displacement piles that are usually reinforced. The micropiles installation process consists of drilling a borehole, adding steel reinforcement and grouting the hole. Micropiles are an excellent foundation solution for reinforcing damaged foundations and improving existing damaged foundations in Malaysia (Wang et al., 2019).

Small-scale, shallow-diameter micropiles are built using processes that produce the least disruption to buildings, soil and the surrounding environment. They may be installed anywhere, regardless of ground conditions or soil type. In order to be installed at any angle below the horizontal, micropiles may utilize the same kind of equipment used for installing ground anchors and for grouting projects. The installed micropiles can bear external loads or stresses at essential locations like stations or long piers (Budi et al., 2015). Although these issues are a problem, they are worsening the micro-pile issues during pile cap excavation. The backhoe bucket impacted the micropile case, causing it to crack or get chipped.

This paper provided an overview of a field study on micropiles improvement for deep foundation applications in expanding soils. Also, this study presented a chance to improve our knowledge of the construction technique and its effect on micropiles resistance. The accuracy of the pile foundation bearing capacity predicted using the PDA test compared to that determined from the static load test was analyzed.

CONCEPTUAL DESCRIPTION OF MICROPILES

Nowadays, dynamic pile tests are often used to verify that pile capacity complies with the specification during pile driving and monitor the installation process to avoid pile damage caused by hammer impact. According to Hannigan et al. (2006), the number of piles that need to be dynamically tested on a project is dependent on the project's size, the diversity of the subsurface conditions, the availability of static load test data, and the purpose for performing the dynamic tests. When a modest project is being done, at least two dynamic pile tests should be conducted. Large and small projects with anticipated installation problems or severe time-dependent capacity concerns should conduct more dynamic pile testing. On more extensive projects, CAPWAP analysis generally employs dynamic test data gathered from first driving and restrike dynamic tests, typically around 20 to 40 per cent of the total (Simanjuntak & Suita, 2017). In order to compensate for less-than-ideal testing loads, the design load must be lowered, or more piles or pile lengths must be placed.

For all types of piles (bored, cast-in-place and CAF), it is crucial to use CAPWAP to ensure the accuracy of PDA findings. For every site being monitored for pile end of driving and all re-strike tests, CAPWAP should be utilized at least for the first few driven heaps. The CAPWAP software uses integrated field data and wave equation type methods to estimate a pile's static bearing capacity and soil resistance distribution (Simanjuntak & Suita, 2017). Force and velocity data are taken directly by the PDA. The software calculates the velocity data required to impose a certain velocity, depending on the applied force.

In order to monitor Dynamic Pile Case method piles, a PDA is used to evaluate pile power, hammer energy transfer, driving stresses and pile integrity, which is done in real-time for each impact (Misra & Chen, 2002). CAPWAP analysis employs field data gathered using a PDA and wave equation method analytical technique to estimate pile performance, such as static load power, pile-soil load transfer characteristics, soil resistance distribution, soil damping and earthquake values (Cadden et al., 2004). Technical expertise and a grasp of the pile, soil and hammer behaviour are needed to implement CAPWAP. PDA testing results may only be adequately interpreted and evaluated with its use. Skin friction, bearing strength, pile integrity and top pile displacement allow the designer to come to fast and informed conclusions. A good match means that the match quality number for bored piles is less than 5, and for driven piles, it's usually less than 3 (Esmaeili et al., 2013).

FIELD INSTALLATION AND LOAD TEST SETUP

Pile load test conducted at project LRT 3 GS07- 08 on 17 February 2020 (Figure 1). In this test, two numbers of 300mm diameter micropiles, which are labelled as MC23 and MC35, is required to perform a dynamic pile load test to evaluate its geotechnical capacity and pile integrity. The site was challenged with 379 caisson piles, which ranged in diameter from 2.5 to 3.0 metres and in depth from 15 to 23 metres, all situated on slopes and along existing slip roads with a restricted working area for heavy and big equipment.

FIGURE 1. Structural model of learning approaches and employability

PREPARATION AND API PIPE IMPROVEMENT WORK

Micropiles will be excavated to the level where the grout is still intact to the micropiles. 300mm diameter PVC pipe was installed around the micropiles. The joint between the PVC pipe and the existing micropiles will be boxed (cover using timber and timber secured by rebar to support PVC pipe before grouting) and sealed using cement mortar before grouting works. A bonding agent layer shall be applied to the existing grout cover surface, ready to receive the new grout. Method of application for approved bonding agent shall as per mentioned in MSA product datasheet (brush for into bond).

In bent micropile, the section of bent API pipe shall be cut using a mechanical disc cutter and replaced with a new American Petroleum Institute (API) pipe. The joint between the existing straight API pipe and the new API pipe will be tapered and connected/joined by butt welding, followed by grouting works. During the installation of the new API, a crane shall hold the short piece in a position and check for verticality. Temporary mild steel plates might be tag welded externally to secure the new API into place during full butt weld is carried out. After completion, the butt weld joint shall be tested using the Magnetic Particle Imaging (MPI) method, conducted by qualified personnel to ensure the weld quality is acceptable.

GROUTING WORK PREPARATION

The micropiles and PVC pipe cover shall be maintained using a suitable metal spacer with tack welding or space block. Spacer needs to be fitted into the gap between 300mm diameter PVC pipe and 177.8mm diameter API, securing the PVC pipe and API before grouting as shown in Figure 2. Grouting work will be carried out using the tremie method as shown in Figure 3. Evenly mechanically mixed cement grout consists of Ordinary Portland Cement (OPC) Plus Water (WC ratio: 1: 0.4 - 0.5) shall be used as grout. Cube samples will be collected for testing.

FIGURE 2. Installation of casing pipe

FIGURE 3. Grouting work

After all affected micropiles are fully grouted/repaired, backfill the area using suitable materials. The method of backfilling is similar to backfilling for pile cap works (Figure 4). The PVC pipe will be permanently left installed with the micropiles. Concerning the energy transmitted to the pile during testing, the accuracy degree of PDA data is subjected to uncertainties. The data were processed using CAPWAP software and the CASE method.

FIGURE 4. Backfilling work

DYNAMIC LOAD TEST

The dynamic load test equipment of Geonamics (M) Sdn. Bhd. consists of three parts: (a) a specially designed hammer with a housing frame, (b) several pairs of "strain" transducers and "acceleration" transducers and (c) a PDA computer. PDA computer is manufactured by Pile Dynamics Inc. (POI), used to read and record the "strain" and "acceleration" transducers. As a mobile data collection device and an on-site data evaluation computer, PDA systems can provide real-time, on-site data assessment outputs such as:

i. The CASE method-based capacity for static loads mobilized.
ii. The pile's integrity, which is the location and degree of the damage.
iii. Stresses in pile (maximum compression forces).
iv. Maximum energy transmission to the pile using the hammer.

The field-measured data will be utilized with chosen representative data for post-processing to determine the pile capacity and integrity. This post-processing of signal data requires a proprietary software called CAPWAP, which is an office-based facility to do simulation and signal matching with the measured data. The CAPWAP analysis applies as a boundary condition for a pile that is modelled as continuous segments. Each pile segment is surrounded by soil which is modelled as a lumped mass, spring and damper. For a uniform pile, the cross-sectional area (or diameter) of each segment in the pile model shall be consistent and constant over the depth. For a nonuniform pile, the cross-sectional (or diameter) area of each segment in the pile model required careful judgement, and concreting record is always a good reference to estimate the pile shape.

This section presents the setup details of the dynamic load test for the test pile in this project. In order to prepare the dynamic load test, the setting-up of the hammer and its housing frame and installation of transducers are depicted as below:

a) The setting-up of hammer and housing frame.

The client carries out all the site preparation work near the pile head. It is followed by some excavation work within the test pile to facilitate installing "strain" and "acceleration" transducers. Upon completing excavation work, the hammer and housing frame is set up on the pile top. The hammer and housing frame are positioned on the pile head such that the applied impact force would be concentric with the long axis of the pile.

b) The installation of strain and acceleration transducers.

Four sets of strain and acceleration transducers are installed at about 1D - 1.5D from the pile top. These transducers are placed in a plane perpendicular to the pile axis, symmetrically opposed and equidistant from the pile centre. After installing transducers on the pile head, a monitoring station is set up safely from the hammer with the PDA computer connected to these transducers, as shown in Figure 5.

The dynamic load test is performed by lifting the hammer to the designated height and subsequently drop on the pile top to induce the shock pulse in a pile. The designated drop height is derived from the hammer weight, hammer efficiency and pile set requirements. Upon the dynamic impact of the hammer, the measured signal data at the pile top is processed by the PDA computer, which can produce the graphs of Force versus Time and Velocity x Impedance versus time. The lifting and dropping of the hammer may involve several blows/impacts to obtain a good signal data quality. After getting a good quality of signal data, the lifting and dropping of the hammer are stopped. The post-processing work with CAPWAP analysis follows it.

FIGURE 5. PDA setup for MC 23

RESULTS AND DISCUSSION

CASE METHOD

The on-site geotechnical capacity of the tested pile could be estimated by adopting the CASE Method. Case Method is a closed-fon solution of wave propagation to evaluate the pile capacity and integrity on-site. All the piles show good pile condition due to the curve in Figure 6. The velocity curve is always below the force curve within the 2L/c box. Further analysis showed that the WU curve was consistently above baseline within the 2L/c box.

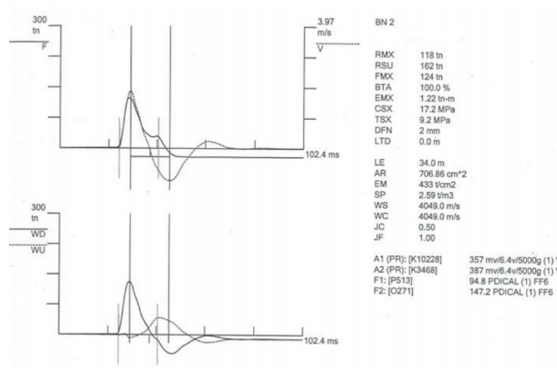

FIGURE 6. Velocity curve

THE BTA VALUES FOR A BORED PILE

BTA (beta) is an output quantity that represents an assessment of the severity of the pile damage. In general, a BTA value of less than 100 indicated pile damage (Budi et al., 2015). The PDA cannot check for damage if the pile is small or the climb is extremely lengthy, and the value 200 for this condition is assigned. It has been observed that BTA is meant to gauge the integrity of uniform pile material. Applying BTA to a non-uniform bored pile requires careful consideration. Compute a BTA using a cross-sectional area of the pile.

Piles that are longer with high friction spread down the shaft may see their velocity turn negative at a distance of 2L/c before the topsoil layers empty and the lower soil layers load. If this situation is in place, the BTA calculation may suggest that the gear is damaged. A possible sign of damage is a noticeable drop in the wave-up curve. In the early unloading instances, just the early unloading likely took place, and there was no further damage.

As Table 1 from the PDA test results indicates, all the piles were perfectly structurally sound with zero BTA values. How bad the damage of the pile depends on the building and its use, the circumstances under which it was built and damaged, and the construction materials and locations (Capatti et al., 2016). As a result, a thorough investigation should be undertaken to identify any damage.

CAPWAP ANALYSIS

The capability of both micropiles and blows, in addition to PDA testing, was validated using CAPWAP tests. The quality of signal force and velocity data will be evaluated in each hammer blow and the best hammer strike will be chosen. Force and velocity are measured at the pile's summit and then fed into CAPWAP software. The algorithm searches by comparing signals until it finds an adequate match. As shown in Table 2, the results of the CAPWAP analysis showed that the accuracy of matching a pile with its mobilized capacity was good and accurate, based on a matching quality rating of 3 to 5 (Rausche & Robinson, 2010). These values were confirmed by measuring skin friction and load-bearing capacity, each greater than 15 tonnes, for piles used as the deep foundation system.

TABLE 1. BTA values

Pile No.	BTA Value (%)	Depth to BTA (m)	Remarks
MC23	100%	--	Acceptable
MC35	100%	--	Acceptable

TABLE 2. Matching quality values

Pile No	Matching Quality (MQ)	Mobilized Skin Friction (Tons)	Mobilized Total Loads (Tons)
MC23	4.60	112.2	118.3
MC35	4.14	193.2	194.6

DISCUSSION

In addition to PDA testing, a CAPWAP analysis was performed on some piles to acquire more information on their load-bearing properties and validate the load capacity found by PDA testing. As seen in Table 3, CAPWAP testing yielded these results. As demonstrated in Table 3, the ultimate capacity values of Micropiles MC-23 and MC-35 were identical to those found using PDA measurements. Micropiles MC-23 and MC-35 showed similar static load capacities, with a 21 kips difference in Micropiles MC-35 compared to a 2 kips difference in Micropiles MC-23. It is noted that the ultimate capacity given by PDA and CAPWAP on micropiles is comparable with the authors' experience using micropiles to construct micropiles into clay soil (Gómez et al., 2004). As noted in the test comparison, it was discovered that with the current dynamic testing method, the estimated capacities of the input micropiles are fairly accurate. Overall, improvements to micropiles no deeper than 3 meters below ground level are widely acceptable (Budi et al., 2015). It is also cheaper and faster than the extraction of the entire micropile structure.

TABLE 3. Summary of Results from PDA Testing, CAPWAP analyses and static load testing

Test Point	Length (m)	PDA (Tons)	CAPWAP (Tons)	Static Load Test (Tons)
MC23	34.0	118	112	118
MC35	34.0	172	193	172

CONCLUSION

The constrained location and limited access environment were well-supported by micropiles for the foundation placement. With their use, new columns might be installed next to the old buildings with little disruption to the existing weak foundations. Some micropiles work was neglected due to the fact that it was simply an additional structure to support loads. Some recommendations can be provided to assist with the construction or improvement of damaged micropiles:

- Need a specific way to repair damaged micropiles.
- Need review and update the standard operating procedure from time to time to synchronize with current site conditions.
- Specific procedures need to be displayed on the site office notice board.
- Identify the exact personnel involved in every step or stage outlined in the standard operating procedure for a better and clearer understanding.

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DECLARATION OF COMPETING INTEREST

None.

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