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EVALUATION OF MAINTAINED LOAD TEST (MLT) AND PILE DRIVING ANALYZER (PDA) IN MEASURING BEARING CAPACITY OF DRIVEN REINFORCED CONCRETE PILES

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Results of several full scale RC (reinforced concrete) pile load tests were studied and analyzed to create a comparison between the MLT (maintained load test) and PDA (pile driving analyzer) methods. The ultimate pile capacities derived from analysis of PDA were consistently higher than results from the MLT. A coefficient of 0.9 or a 10% reduction is suggested to be applied to values derived from PDA. It is also observed that the longer the time interval, the greater the shaft friction contribution is towards the pile capacity.

Introduction

Construction of foundations using reinforced concrete (RC) piles is popular and widespread in Malaysia, especially for buildings that are of limited height.

The driven reinforced concrete (RC) piles are usually manufactured with a square or octagonal cross section, 250 mm to 450 mm in diameter and 12 to 30 m in length, although RC piles in other shapes can also be produced. They are able to carry working axial loads of 450 to 3500 kN [1]. The RC pile is a type of displacement pile that transmits loads from above structures into the soil stratum through shaft friction and end bearing capacity of the pile [2-4].

Set criteria for driven RC piles are predetermined by calculation before pile-driving activity begins. If the set criterion for a certain pile is not achieved, excessive settlement of the particular pile may be encountered, and this will eventually affect the stability and integrity of the supported structure or building.

In order to mitigate and prevent such occurrences, a comprehensive pile-testing program must be incorporated into every project. Loading tests can be carried out on preliminary piles to confirm the pile design or on working piles as a proof loading tests. Although pile load tests add to the cost of the foundation, the savings can be substantial.

An example of static testing is the maintained load test (MLT) (Fig. 1), while the pile driving analyzer (PDA) is a type of dynamic test. If the procedures for MLT are strictly followed, the settlement of driven RC piles can be accurately determined. However, the MLT is a very costly and requires a long time for testing, which makes it undesirable.

Testing using PDA has gained popularity in recent years because it is relatively cost-efficient, time saving, and easy to perform [5-9]. Dynamic testing on piles require measuring of the pile's force and velocity during hammer impact. Due to its cost, which is much less compared to MLT, PDA can be performed on more driven RC piles, thus providing a bigger sample of tested piles. However, the accu-

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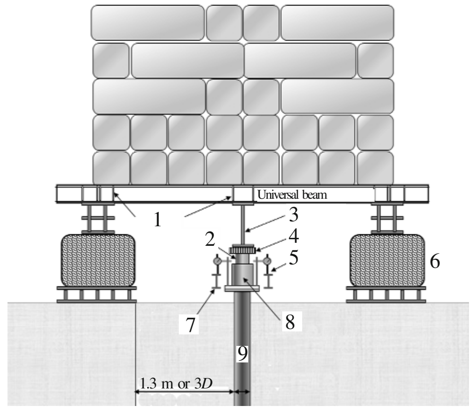

Fig. 1. Typical arrangement for a Maintained Load Test (MLT): 1) stiffeners; 2) load cell; 3) girder; 4) steel cleat; 5) dial gauge; 6) concrete block; 7) reference beam; 8) hydraulic jack; 9) test pile.

TABLE 1

Pile reference	Pile size, mm	Height of drop hammer, mm	Pile penetration, m	Working load, tons
A	250 × 250	300	16.8	70
B	300 × 300	400	18.2	100
C	300 × 300	400	14.7	100
D	350 × 350	600	18.6	140
E	350 × 350	600	17.4	140

racy of data from PDA testing is sometimes doubtful. As both methods have their own advantages and disadvantages, a combination of data obtained from MLT and PDA testing is proposed to provide a clear picture of the driven RC pile bearing capacity and expected settlement.

Likins and Rausche [10] have also investigated the correlation between the CAPWAP and static load tests. After a statistical evaluation of previous studies (reviewing a database containing 303 case histories) the results of CAPWAP analysis for dynamic pile testing data were found to be very reliable in the determination of ultimate capacity of both cast-in-situ and driven piles. Similar results were obtained for torque-driven helical piles in cohesive soils [11]. Rajagopal et al. [12] has also compared the static and dynamic load test of bored pile. After running three full-scale static and dynamic tests, each one on the same bored pile, they observed that the dynamic load test could play an important role for predicting the pile capacity.

Numerous studies have attempted to explain a similar achievement [13-17].

The main objective of this research is to determine and calibrate the ultimate capacity of driven RC piles in cohesive soil utilizing data from the MLT and PDA tests. At present, not many comparisons have been made between PDA and MLT testing for driven RC piles, specifically for cohesive soil in Malaysia.

Material and Methods

The testing program for the driven piles consisted of both static (MLT) and dynamic (PDA) test methods. Piling (Table 1) was carried out using 7-ton hydraulic hammers.

Sub-surface exploration was carried out using a multispeed wash boring rig. Standard penetration test (SPT) was carried out at 1.5 m intervals until the termination of the borehole. Termination was determined by either achieving seven consecutive SPT-N values of 50 or by coring through 2 m of rock. Disturbed soil samples were extruded from the split-spoon sampler. Undisturbed samples were obtained

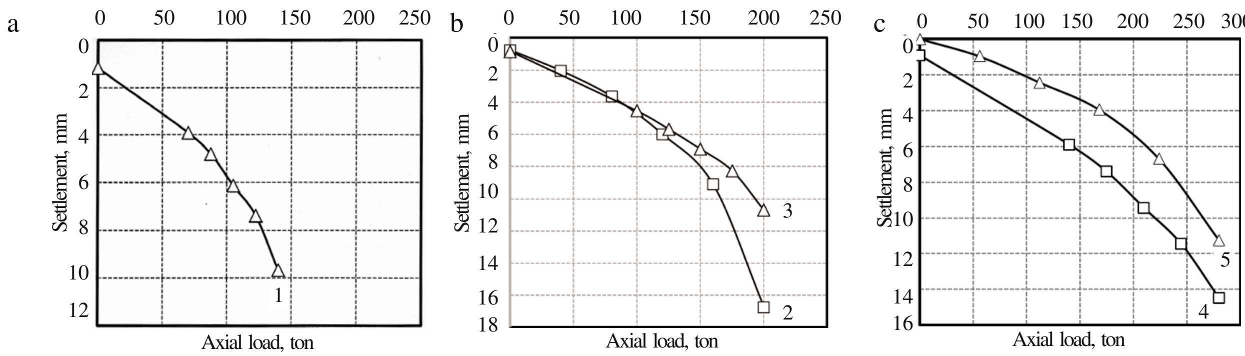

Fig. 2. The variation of settlement (mm) versus axial load for a working load of (a) 70 ton, (b) 100 tons, and (c) 140 tons: 1) pile À, 2) pile B, 3) pile C, 4) pile D, 5) pile E.

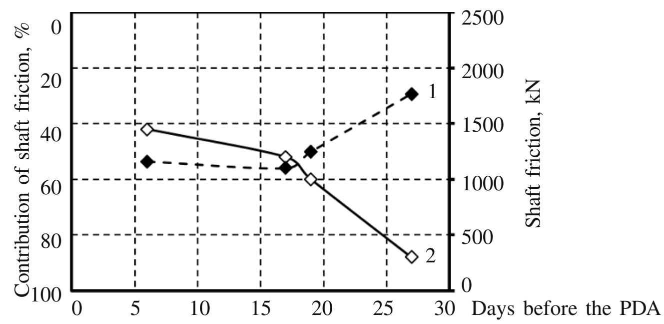

Fig. 3. The effect of time interval between EOD and testing day on shaft friction contribution: 1) shaft friction; 2) portion of pile capacity.

by jacking thin-walled tubes into soft cohesive layers, and the Mazier sampler was used for stiffer soil layers (SPT-*N* values more than 15). The penetration depths of the driven piles are 14-19 m from the ground level. Analysis results from the soil profile show that the soil layers corresponding to the pile penetration depths consist mainly of cohesive soils; there are only traces of sandy soils and gravel in a limited number of boreholes. Generally, the SPT-*N* values for soil layers corresponding to pile penetration depths were observed to range between 11 and 50. Based on the system of classification presented by Bowles [18], the soil strata for the analyzed pile locations in the case study is mainly made up of stiff, very stiff, and hard cohesive soils.

Case Pile Wave Analysis Program (CAPWAP) software was used for the analysis of data from PDA field tests; through CAPWAP, the pile mobilized capacity, skin friction, end bearing, and settlement data at working and test loads were obtained. Pile capacity obtained from the CAPWAP analysis on the PDA test results is considered to be fully mobilized if only the net set of 3 mm is achieved at the time of testing. All of the five piles in the case study had achieved the mobilized capacity and the required test load at the time of testing. During the analysis, adjustments and reasonable judgments had to be made for certain parameters, such as the soil resistance distribution, quake, and damping factors.

Results and Discussion

Data from MLT tests for working loads of 70, 100, and 140 tons are presented in Fig. 2. Many researchers highlight the importance of time interval between end of driving (EOD) and testing day [10, 15, 19-21], as the longer the time interval, the greater the shaft friction contribution is towards the pile capacity (Fig. 3). The percentage of shaft distribution through the length of the pile in regards to the total capacity obtained was also measured and calculated through CAPWAP. The contribution of the

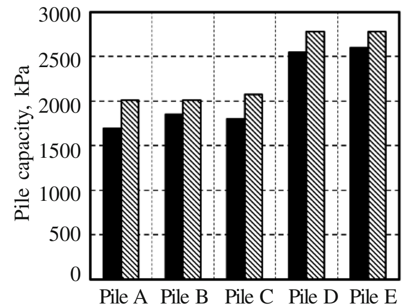

Fig. 4. The ultimate pile capacities obtained through MLT (■) and PDA (▧).

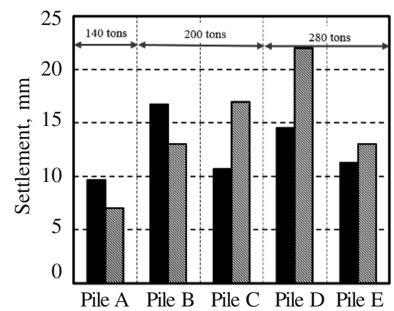

Fig. 5. Pile settlement based on MLT (■) and PDA (▧).

shaft friction to the total pile capacity for pile D and pile A were 88% and 42%, corresponding to the 6 days and 27 days' time interval before the EOD, respectively (cf. Fig. 3).

For all analyzed piles, the ultimate pile capacity derived from the PDA testing method is higher compared to the capacity derived through MLT testing (Fig. 4). The consistency of results based on the analysis can be deemed satisfactory. For piles A, B, C, D, and E, the constant division rate of MLT over PDA were 0.84, 0.92, 0.87, 0.92, and 0.93 respectively. The calculated average value from full-scale piles to define the difference between the MLT and PDA results was 0.89.

However, analysis results from the static and dynamic tests for pile settlement does not indicate consistency. The difference in settlement measured by MLT and PDA was up to 30%, and for piles A and B, pile settlement from MLT was higher compared to settlement derived through PDA, while for the rest of the RC piles the observed results from the PDA test were higher (Fig. 5).

Conclusions

A comparison of the ultimate bearing capacity results derived from MLT and PDA tests is presented. It was observed that ultimate pile bearing capacity obtained from PDA were higher than results derived from MLT for all analyzed piles. A coefficient of 0.9 or 10% reduction was obtained from the study to be applied to the results from PDA tests. It is noted that there are numerous limitations to the application of the coefficient due to the huge number of variables involved in load tests and due to differing site conditions. The number of MLT tests may be reduced and replaced by more PDA tests.

MLT can be used for design purposes and must be carried out in order to provide accuracy and consistency of results.

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