Case study of using static and dynamic pile load tests as quality assurance of existing piles for SRT Red Line Project, Thailand

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ABSTRACT

This paper discusses a case study of using static and dynamic pile load test method as quality assurance of existing piles in Bangkok subsoil conditions for SRT Red Line Project, Thailand. The SRT Red Line Mass Transit project is a commuter rail system which most of the railway are run alongside of the halted Hopewell Project. The existing piles from Hopewell Project in some location cannot be avoided due to limitation of working area and was decided to be used as part of a foundation of elevated structure of SRT Red Line Project. Therefore, reliable verification procedures have been conducted on two representative existing pile starting from parallel seismic test, dynamic pile load test and static pile load test to ensure quality and load-carrying capacity of existing piles. The comparison of load-settlement curve between static and dynamic load test have been performed. Good agreement between the results obtained from dynamic load test and static load test have been observed. The results indicate the reliability of the dynamic pile load test to be employed as a quality assurance tool for other existing piles to be used in the SRT Red Line Project.

Keywords: Static pile load test, Dynamic pile load test, Quality assurance, Existing pile

1 INTRODUCTION

This paper discusses a case study of using static and dynamic pile load test method as quality assurance (bearing capacity & integrity verification) of existing piles which have been constructed more than 2 decades in Bangkok subsoil conditions for State Railway of Thailand (SRT) Red Line Project, Thailand. Reliable verification procedures have been conducted to ensure quality and load-carrying capacity of existing piles. Two representative existing piles have been tested by parallel seismic test, static pile load test and dynamic pile load test methods. Good agreements between the results obtained from two load test have been observed.

2 BACKGROUND OF THE PROJECT

The Bangkok Elevated Road and Train System (BERTS), commonly known as the “Hopewell Project” after main contractor Hopewell Holdings, was a failed project to build an elevated highway and rail line from central Bangkok to Don Mueang International Airport. Construction began in 1990, but was suspended by the government in 1992. The project ground to a halt amid much legal wrangling in 1997, when it was just only 10-13% completion, and was finally cancelled in 1998.

The Hopewell Project left a numerous concrete pillars standing idle along the SRT Red Line planned routes. According to an Asian Institute of Technology study, the vast majority of the pillars remain structurally sound and in usable condition, and it has therefore been proposed to use some of the existing pile to build a sub-structure of the SRT Red Line.

Fig. 1. SRT Red Line Project Route.

The alignment of SRT Red Line covers the rest of the BERTS north–south line, and the project has been described as a "Hopewell revival". After repeated delays, the SRT Red Line eventually opened for trial operation on August 2021, and full opened for public on November 2021, 31 years after the construction of the Hopewell Project started.

The SRT Red Line Mass Transit project is a commuter rail system running for 26km along North-South from Bang Sue Grand Station to Rangsit as shown in Figure 1. The 26km, 10 station Bang Sue to Rangsit section finally started construction in May 2013 in which comprises of 2 Contracts (Contract 1: Civil Works for Bang Sue Grand Station and Depot and Contract 2: Civil Works for Bang Sue – Rang Sit Railway).

Most of the railway are run alongside of existing on-grade railway tracks and the halted Hopewell Project. The numerous existing piles as shown in Figure 2 which was leaved in-place for more than 2 decades in some location cannot be avoided due to limitation of working area and was decided to be used as part of a foundation of elevated structure of SRT Red Line Project.

Fig. 2. Pillars along the current SRT Red Line.

3 BANGKOK SUBSOIL CONDITIONS

Bangkok is situated on the low-lying Chao Phraya plain area. A typical subsoil profile is relatively consistent in different localities in Bangkok. It consists of alternating layers of clay and sand deposits existing to a great depth. The existing ground elevations lie from 0 to 2 m above mean sea level, with the soil layers being marine deposits. The subsoil profile along the route consists of made-ground up to 3 m thick underlain by well-known Bangkok Soft Clay range from 10 to 15 m thick. About 2 to 4 m thick medium stiff clay can be observed between soft clay and underlying stiff clay. Below that, alternating layers of stiff to hard clay and dense to very dense sand is followed.

Because of the existence of thick soft clay layer, most of the buildings and infrastructures are found on piles. For those infrastructures, deep seated large diameter bored piles are generally employed with its tips extended to the second sand layer (40 to 60m depth). For SRT Red Line Project, it was designed to used large diameter bored pile range from 1.0m to 1.5m embedded to 2nd sand layer with generally range from 50-56m in depth.

4 COMPARISON OF STATIC LOAD TEST AND DYNAMIC LOAD TEST FOR BANGKOK SOIL CONDITIONS

Static pile load test is commonly used for an infrastructure project in Bangkok as it is the most accurate and reliable method to determine capacity and deformation behavior of a pile. In recent decade, high strain dynamic pile load test becomes widely practiced as a quick and cost-effective method. Usually for large scale project, dynamic load test results with signal matching are calibrated against static load test results. The test procedures are generally start with static pile load test followed by dynamic pile load test on the same pile for confirmation of ultimate pile capacity.

The results from static load test and dynamic load test on large piles in Bangkok soil conditions from many projects have been collected and compared by well-known pile testing agency in Thailand, STS Group. It is summarized in Table 1 below which has been extracted from STS Group publication in Thai. (Reliability of evaluating the behavior of large bored piles by dynamic load testing methods).

Table 1. Comparison of ultimate bearing capacity of bored piles and barrette pile.

No.	Project	Pile size	Pile length (m)	Ultimate Load Capacity (tons)		Difference (%)
				Static load test	Dynamic load test	
1	Wat Nakorn-In Bridge, Major Bridge (EW:1, Axis 10)	1.5m dia.	50.7	2657	2674	+0.64
2	Wat Nakorn-In Bridge, Main Bridge (Axis 8 & 9)	1.5m dia.	52.8	3132	3146	+0.45
3	Rama VII Bridge	1.5m dia.	54.1	3393	3158	-6.93
4	MRT Project, Station 12	Barrette 0.80×2.5m	46.3	3140	2734*	-12.92
5	SES Project, Sector D	1.0m dia.	43.0	1347	1302	-3.34
6	Bang Pa In-Pak Kret Expressway, #BPP1	1.0m dia.	43.5	975	928	-4.82
7	Bang Pa In-Pak Kret Expressway, #BPP2	1.0m dia.	43.5	978	982	+0.41
8	Bang Pa In-Pak Kret Expressway, #BPP3	1.0m dia.	46.5	1544	1457	-5.63
9	Bang Pa In-Pak Kret Expressway, #BPP4	1.0m dia.	49.5	1137	1110	-2.37

Note: * Not fully mobilized

Table 1 shows the comparisons of ultimate bearing capacity obtained from static load test and dynamic load test. Mazurkiewiez's Method is employed to obtain the ultimate pile capacity from static load test, while the pile capacity from dynamic load test is calculated by Wave Matching Analysis Program, CAPWAP. Dynamic load test has shown quite close value of ultimate pile capacity compared with static load test with range about -6.93% to +0.64%).

In addition, the comparisons of load-settlement relationships and load distribution along test piles are shown good agreement between the results obtained from both test methods.

However, as the typical test procedures are start with static pile load test followed by dynamic pile load test with wave matching analysis, there could be some doubt on reliability of dynamic load test and wave matching analysis. Hence, for SRT Red Line test programme, it was started with dynamic pile load test and wave matching analysis prior to commencement of static load test to verify the reliability of dynamic load test for quality assurance.

5 QUALITY ASSURANCE OF EXISTING PILE

Conducting load tests on constructed piles has been emphasized in many papers (Matsumoto et al 1995, Hayashi et al 2000 and Matsumoto et al 2006). It has been discussed the roles of load tests in construction sites of pile foundations in terms of construction control or quality assessment of constructed piles, and the use of pile load test results in design of foundation structures (Matsumoto et al 2008).

As mentioned above, the Hopewell Project left a numerous concrete pillar and its sub-structure along the planned route. The existing piles from Hopewell Project in some location cannot be avoided due to limitation of working area and was decided to be used as part of a foundation of elevated structure of SRT Red Line Project. Therefore, verification procedures have been conducted to ensure the load-carrying capacity of the existing pile prior to implementation of the foundation.

5.1 Testing Procedure

Two representative existing piles have been selected to test for quality assurance. The testing procedures are illustrated as shown in Figure 3.

The programme was started with parallel seismic test in order to estimate the existing pile tip depth because the as-built information could not be obtained. Then, dynamic pile load test was conducted to predict ultimate pile capacity by wave matching analysis. The dynamic load test result was submitted prior to static load test. In the last stage, static pile load test was performed on the same pile to obtain the ultimate pile capacity. All the tests have been successfully performed with close supervision of the relevant parties (i.e. Consultants, Engineers and Owners).

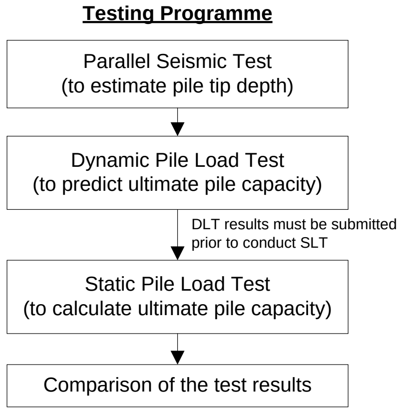


Fig. 3. Testing Programme.

6 PILE LOAD TEST PROGRAMME

As described in Section 5 on the testing procedures for quality assurance of existing pile, pile testing details and its results is explained in this Section. Table 2 summarize two representative test pile details and its designed ultimate pile capacity.

Table 2. Summary of test pile for 2 Contracts

No.	Contract	Pile size	Pile tip depth (m)	Max. Test laod (2.5 times of required allowable load) (tons)
1	Contract 1	1.5m dia.	-54	3000
2	Contract 2	1.5m dia.	-49	3000

6.1 Parallel seismic test

Parallel seismic test is the method of estimating the acoustic length and verification the integrity of a pile by measuring the transit time of a stress-wave travelling down the pile and through the intervening ground to a sensor lowered down a vertical tube alongside the pile. The length of time taken for a stress-wave to travel down is directly related to the pile length. By measuring the transit time of the stress-wave to various levels, it is possible to calculate the depth of continuous concrete material. By implication, once the probe has passed beyond the pile tip, an increasing proportion of the travel path will be through the intervening soil and the transit time will increase correspondingly.

Fig. 4. Parallel seismic test on existing bored pile.

The parallel seismic tester (PST Unit) with low frequency geophone has been used for the test of existing pile. A small diameter hole was formed adjacent to the pile with a depth greater than expected toe level. The tube was then filled with water to provide an acoustic coupler, and a piezoelectric probe is lowered to the bottom. The pile was struck with a hammer as shown in Figure 4. The stress-wave imparted into the structure, the transit time was measured and recorded. A change on the rate of the increase of transit time with depth indicated the pile toe as shown in Figure 5. This pile toe (pile length) is then used for wave matching analysis in dynamic pile load test result calculation.

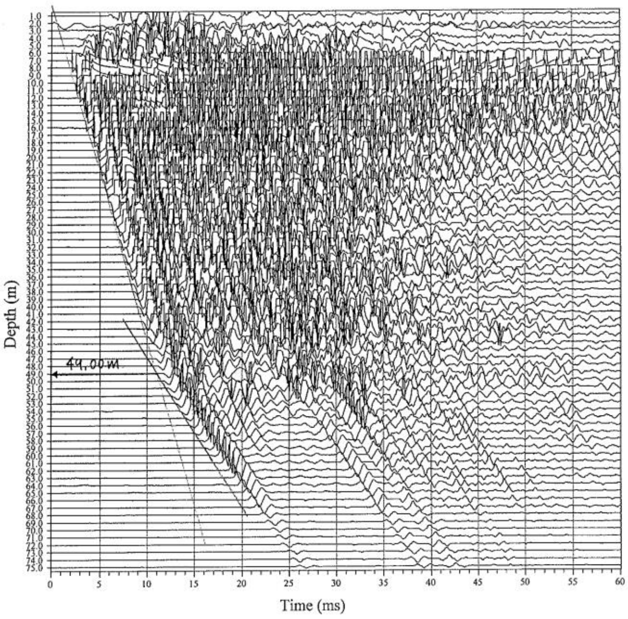


Fig. 5. Parallel seismic test indicated pile toe.

6.2 Dynamic pile load test

Dynamic load testing is quick and cost-effective test method, and unsusceptible to the reaction system. Therefore, dynamic load test is useful to confirm performance of many constructed piles in the site and to assess the safety of the constructed foundation (Matsumoto et al 2008). Dynamic pile load test is today routine application in pile design and used worldwide.

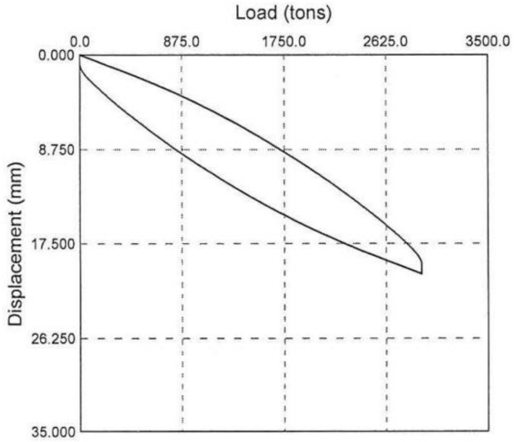
In general, to carry out a dynamic load test, a steel ram of sufficient weight is dropped from appropriate height, on the pile head with a cushion between hammer face and pile head (Figure 6). The impact produced by the steel weight causes a compressive wave which travels down the pile with the certain wave speed depending upon the pile properties. The reflected stress wave recorded is in response to the skin resistance, toe resistance, changes in the pile properties and cross-sectional area. The stress waves, produced by the impact are registered by the strain transducers and accelerometers attached close to the pile top. The signals are converted to force and velocity signals, which are then used to determine the pile capacity. The analysis is carried out using the Pile Driving Analyzer (PDA) testing and includes CAse Pile Wave Analysis Program (CAPWAP) Analysis. It is to be noted that analysis and interpretation of dynamic pile load test would require an experience engineer to assure the accurate and precise result interpretation.

Fig. 6. Dynamic pile load test.

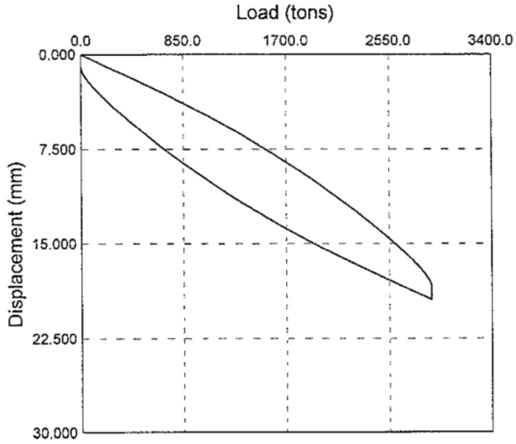
The integrity condition of the pile is interpreted from force and velocity plotting as a function of time. If the pile has a reduction in pile impedance, (cross sectional area) at any depth, it will be reflected as a tensile wave and correspondingly force will be decreased and velocity will be increased.

By applying incremental loads at the pile top and computing the pile top displacements, a graphical plot of the load versus displacement has been simulated as shown in Figure 7. The simulated curve shows that activated ultimate capacity of 2928.4 metric tons occurs at displacement approximately 19.3mm for Contract 1 and ultimate capacity of 2901.3 metric tons occurs at displacement approximately 18.5mm for Contract 2 as shown in Figure 7.

Dynamic pile load test was then employed to test all existing piles that planned to be used as a part of new foundation for SRT Red Line.



(a) Contract 1.



(b) Contract 2.

Fig. 7. Dynamic pile load test results.

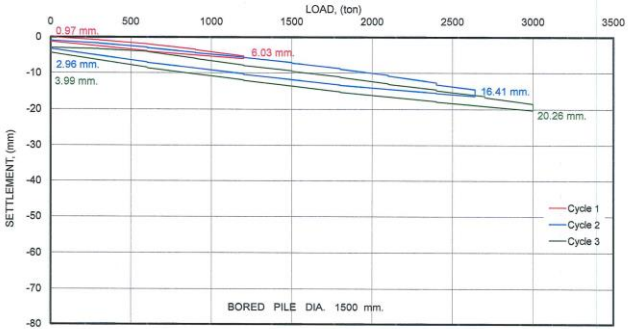
6.3 Static Pile Load Test

Static pile load test is the most common method of testing the capacity of a pile and it is also considered to be the best measure of foundation suitability to resist anticipated design loads. The static load test involves the direct measurement of pile head displacement in the response to a physically applied test load. This test provides very reliable data for pile capacity.

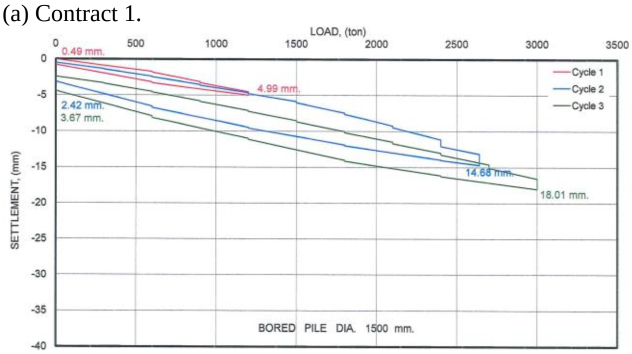
Two representative existing piles have a required allowable load of 1200 tons. The maximum test load was applied up to 2.5 times (3000 tons) of required load to ensure load bearing capacity of existing piles. Load will be applied by hydraulic jacks acting against steel reaction frame supported by anchored piles. Maintained load test method was applied in 3 cycles.

The load-settlement curve shows that the maximum test load at 3000 metric tons (using factor of safety of 2.5) occurs at displacement 20.23mm for Contract 1 and 18.01mm for Contract 2 as shown in Figure 9. By consideration the load-settlement curves, the behavior of test pile under cycle 1, 2 and 3 are found in elastic zone, therefore, it can be concluded that the existing pile can carry the required load.

Fig. 8. Static pile load test.



(a) Contract 1.

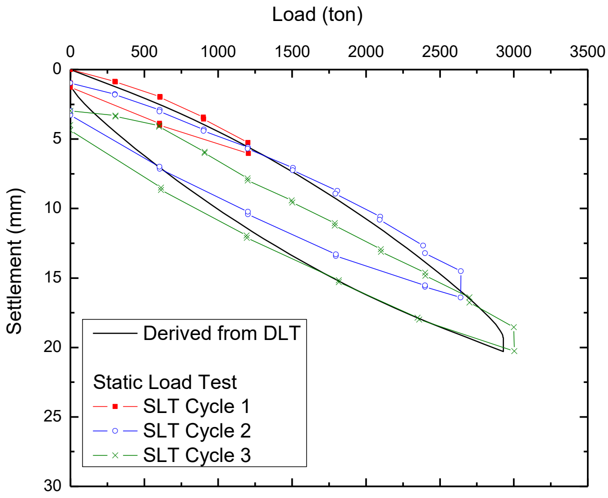


(b) Contract 2.

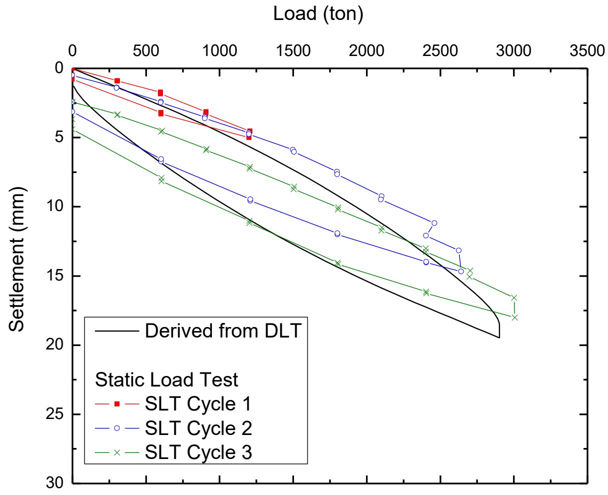
Fig. 9. Static pile load test results.

7 COMPARISON OF TEST RESULTS

For both Contracts, the ultimate capacity obtained from dynamic load test shows a slightly lower value compared with the ultimate capacity obtained from static pile load test. The comparative studies of load-settlement curve have been performed as shown in Figure 10. It can be seen that the graphical plots indicate the same trend line of load-settlement, the ultimate capacity also indicates a very close value from both test methods.



(a) Contract 1.



(b) Contract 2.

Fig. 10. Comparison of test results from both methods.

8 CONCLUSIONS

This paper discussed case study of using static and dynamic pile load tests as quality assurance of existing piles for SRT Red Line Project. The following major conclusion are summarized below:

- The comparison of load-settlement curve between static and dynamic load test indicates a similar trend line and value for the two methods of testing.
- Good agreement between the results obtained from dynamic load test and static load test have been observed on both two representative existing piles.
- The results indicate the reliability of the dynamic pile load test to be employed as a quality assurance tool for other existing piles to be used in the SRT Red Line Project.

Fig. 11. Completion of SRT Red Line (elevated).

ACKNOWLEDGEMENTS

The authors would like to appreciate to State Railway of Thailand (SRT) which owns this project for their kind permission to access the data.

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