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Non-destructive integrity testing on piles founded in Bangkok subsoil

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Non-Destructive integrity testing on piles founded in Bangkok subsoil

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ABSTRACT: Pile foundation is compulsory in Bangkok, Thailand, to support almost all types of structure due to prevailing subsoil condition. Large bored piles of 600mm to 1800mm in diameter and barrettes (0.8mx2.7m-1.5mx3.0m) with toe level up to 60m depth are commonly used to support heavy structures covering high-rise buildings, subway stations, elevated highways, etc. In order to test or check the quality of such high load carrying foundation piles constructed in multi-layered soil conditions, three main types of non-destructive integrity tests such as sonic integrity, sonic logging and high strain dynamic load tests are usually employed. Sonic integrity test is the most common method in integrity testing on both driven and bored piles. Sonic logging test is occasionally employed as a part of pre-planned site quality control system. High strain dynamic load test is commonly used for pile capacity evaluation. This paper presents an overview of these three commonly used non-destructive tests on piles in Bangkok subsoil. Some findings from the author's involvement in research works are also presented.

1 INTRODUCTION

Three techniques namely sonic integrity, sonic logging and high strain dynamic load tests are the commonly used non-destructive integrity tests applied in Bangkok, Thailand. The effectiveness and suitability in terms of both cost and method of application itself are the primary reasons of the greatest growth in use of these tests. An overview of sonic integrity, sonic logging and high strain dynamic load tests conducted on piles particularly bored piles founded in Bangkok subsoil is presented in this paper.

2 TYPICAL SUBSOIL CONDITION IN BANGKOK

Subsoil profile is relatively consistent at different localities in Bangkok. A typical subsoil profile is characterized by the alternating layers of clay and sand deposits as soil succession shown in Figure 1. Weathered Crust of 1m to 3m thick occurs as upper most layer underlain by Very Soft to Soft Clay commonly known as Bangkok Soft Clay (BSC). Thickness of Soft Clay layer varies from 12m to 18m depending on the location. Underneath Soft Clay, lies Medium to Stiff Clay. Dense to Very Dense Sand layer also known as First Sand layer is found below Stiff Clay layer at depths about 25m to

38m. Second Dense to Very Dense Sand layer occurs at about 46m depth. Between these sand layers, Hard Clay layer is present.

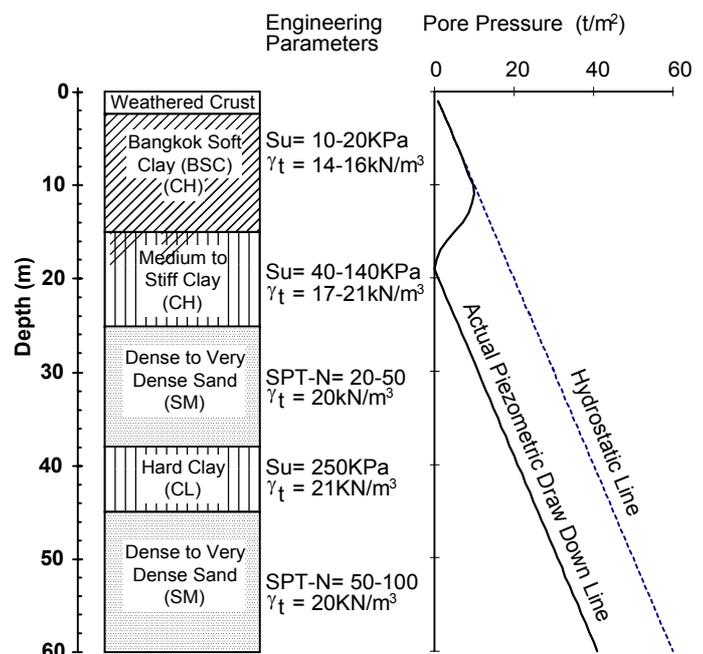


Figure 1. Typical soil profile of Bangkok plain with piezometric draw down conditions (after Thasnanipan et al., 1998a).

The depth of bedrock is not well determined in the Bangkok area but has been reported to be at least

550m deep (Balasubramaniam, 1991). Existing pore water pressure conditions in upper part of BSC are hydrostatic from nearly 1m below the ground level. Then the hydrostatic conditions change to piezometric draw down near bottom level of BSC.

3 COMMON CONSTRUCTION METHOD

The common practice of bored pile construction method in Bangkok can be divided into wet and dry processes.

For the wet process, bored piles are constructed using bentonite or polymer slurry as drilling fluid over the full length of the piles, to ensure the stability of the excavation at all stages. Top 15m-thick soft clay was temporarily cased. Drilling for the piles was done with a conventional drilling auger or auger bucket. To clean the sediments at the borehole base the airlift technique or cleaning bucket is applied. After lowering the rebar cage, concrete is poured with tremie method.

Generally the dry process is employed for small piles (0.35m to 0.6m in diameter and 25m in length). This method uses a steel temporary casing of about 15m in length to protect the soft clay from caving in. Boring is carried out by rotary drilling or percussion tripod rig.

Bored piles are commonly constructed with reinforcement of 0.5-1.2% of sectional area of pile.

4 COMMON DEFECTS CAUSED IN BORED PILES

Common pile defects such as size reduction/necking, discontinuity, soil/slurry inclusions, etc. may be caused during pile construction. Most of the cracks in bored piles caused at post construction stage are usually induced by construction activities associated with basement excavation and improper trimming of pile head to design cut-off level. Causes of defects in bored piles during construction are;

- Inadequate length to protect the soft clay layer
- Delayed feeding of slurry and improper slurry level maintenance for wet process
- Long time duration of maintaining open borehole
- Non continuous concrete pouring or disruption in concreting
- Lifting up of insufficient workable concrete or hardened concrete upon extracting the temporary casing
- Contamination of concrete with drilling slurry or soil
- Soft pile toe due to improper base cleaning

5 THE SELECTION OF SUITABLE METHOD

In general, non-destructive tests are conducted to verify the quality of the pile. Turner (1997) highlighted the factors in selection of pile testing in CIRIA Report 144 as follows;

- The perceived nature of possible features or defects within the pile
- The ability of the test method to detect the feature or defect under investigation
- The cost of testing and examination
- The ease of use and interpretation

Like other indirect measurement of pile integrity, sonic integrity and sonic logging tests are only capable of identifying structurally significant features. Rejection or acceptance of individual piles should not rely only on the results of these tests. Further investigation, engineering evaluation and judgement are highly recommended to confirm the defect detected by these indirect techniques. Both methods however are very useful for cost-effective screening test to identify piles with potential defect.

Sonic integrity test is usually selected for both quality check (control test) and retrospective investigation. It is the cheapest in terms of cost and the simplest in terms of testing process. The main advantage of this test is that since no particular measures/preparation is necessary during the pile construction phase it is more flexible to select which pile is to be tested. However, interpretation of sonic integrity testing needs considerable experience and knowledge in testing, subsoil condition and construction method.

Sonic logging test is relatively expensive. It is mainly employed as a pre-planned site quality control testing. The major advantage of this method is that test can be carried out shortly after the pile construction. Hence, rectification measures can be implemented while the foundation contractor is on site. However, this method is generally not applicable if pile integrity is in question due to post construction activities as access tubes are usually grouted after completion of the test.

High strain dynamic load test is usually selected to verify the load carrying capacity of piles. Pile integrity can also be determined by high strain dynamic load test. The major advantages of this test in comparison with static pile load test are those of cost, time and space requirement. In some projects, dynamic load test was applied to justify the capacity of pile after rectifying its defect detected by other integrity tests. Table 1 shows the suitability of test method for different type of common defects.

Table 1. The suitability of test method for different type of defects.

Type of defects	Test method and suitability for defect detection		
	Sonic integrity	Sonic logging	High strain dynamic load test
Crack	Suitable	Possible	Suitable
Pile size change	Suitable	Possible	Suitable (if severe defect)
Poor quality concrete or Contaminated concrete	Possible	Suitable	Suitable (if severe defect)
Soft pile toe	-	Not usually	Suitable

6 SONIC INTEGRITY TEST

6.1 Overview of the test in Bangkok

Sonic integrity test, also known seismic test is the most common method of integrity testing for both driven and bored piles in Bangkok. In many projects it is a part of the contractual requirement to conduct sonic integrity test. Minimum 10 % to maximum 100 % of production piles are commonly tested. It is also a reasonably acceptable method for applying as a retrospective investigation in determining integrity of the pile.

6.2 Interpretation of the test results

As has been reported in various literatures, it is to be emphasized that sonic integrity test is highly dependent on the experience in both field testing and interpretation. The signal characteristics and their interpretations of sonic integrity test on piles founded in Bangkok subsoil were reported by Thasnanipan et al. (1998b). The authors presented the interpretation of various features of sonic integrity test signals in comparison with soil investigation data and construction records.

6.3 Some findings from sonic integrity test in Bangkok

Toe reflections are generally clear for the piles with length to diameter ratio (L/D) within 40, but toe reflection was hardly detected for piles founded at depth deeper than 30-35m as reported by Thasnanipan (1998b). However, it was found that toe reflection is detectable for some deep-seated bored piles of about 50m in length if pile was tested at early age. Figure 2 shows the significant toe reflection of 52.0m-long pile tested few days after concreting. This is considered mainly due to the fact that at early stage the bonding between soil and pile has not yet

fully developed so that damping effect or attenuation of the sonic signal by shaft friction is relatively low.

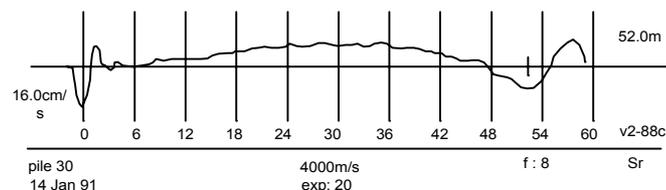


Figure 2. Sonic signal showing a toe reflection of bored pile at 52.0m tested few days after concreting.

Use of temporary casing usually causes larger size at the top portion (from pile top to casing bottom) for completed piles in Bangkok subsoil. This is caused by the size difference between casing and the drilling tool (bucket/auger) as the top section of pile formed by the outside diameter of the casing is usually 5-10cm larger than the lower section of pile with nominal diameter formed in the borehole made by drilling tool (Figure 3). Test signal shown in Figure 3 indicates a clear reflection at approximate 11m from pile top (about 15m below ground level) with a repeat or multiple reflection at about 2 times of that distance (approximate 22m from pile top). As the polarity of the reflection is negative, the first interpretation is that this pile has decrease in cross section or crack at 15m below ground level. However, with the consideration of pile construction method, it is concluded that negative reflection is caused by variation in pile cross section at the bottom end of 15m long temporary casing. The sonic signals with anomaly acquired on those piles are often misinterpreted as indicative of defect piles, leading to an argument.

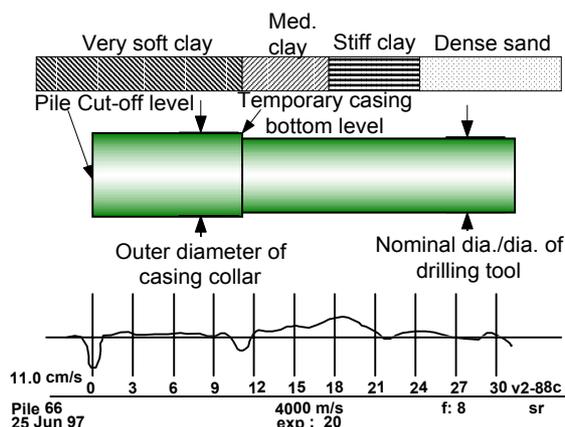


Figure 3. A typical pile shape constructed in Bangkok soil and resulted sonic integrity test signal profile.

For the analysis of sonic integrity test, velocity of sonic wave in pile material (concrete) is typically assumed 4000m/s in most cases. Basically, lower strength of concrete gives lower wave propagation velocity. The trend of sonic wave velocity increment with pile age derived from a number of 600mm diameter bored piles with known lengths is presented in Figure 4.

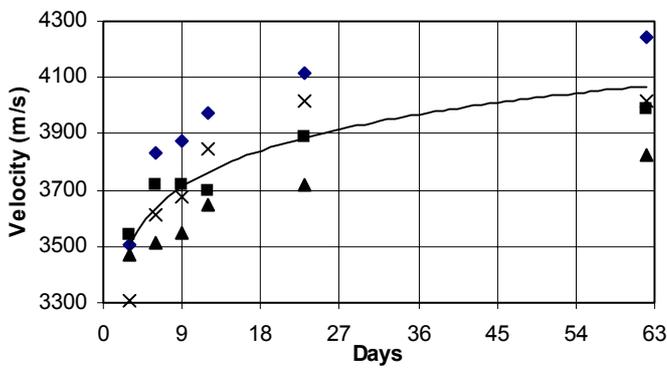


Figure 4. A curve of sonic wave velocity vs. pile age in Bangkok sub soil ($f_c' \approx 35$ MPa).

7 SONIC LOGGING TEST

7.1 Overview of the test in Bangkok

Use of Sonic logging test for checking pile integrity has increased in Thailand in recent years. It is used for cast-in-place foundation elements such as bored piles, barrettes, diaphragm walls and caissons. Both PVC and steel tubes can be used as access tubes. Though cost of steel tube is higher than that of PVC, steel tubes are considered more suitable than PVC tubes for two reasons; (1) less potential for bending and damage especially for deep-seated bored piles and barrettes with heavy steel reinforcement and (2) better bonding with concrete. These access tubes are sometimes also used for pile base grouting. The access tubes are attached to the reinforcement cage, which is installed prior to concreting as a normal practice for cast-in-place piling.

Two access tubes are required as a minimum for sonic logging test. For a good coverage of the test pile, recommended number of tubes for different sizes of bored piles is shown in Table 2.

Table 2. Recommended number of tubes for different pile size

Pile Diameter (mm)	Minimum No. of tubes	Tube spacing (degree)
$D \leq 750$	2	180
$750 < D \leq 1000$	3	120
$1000 < D \leq 1500$	4	90
$1500 < D \leq 2500$	6	60
$2500 < D$	8	45

A typical problem encountered in sonic logging test is the access tube blockage which often comes to know only at the time sonic testing is conducted one week or more after pile construction. The blockage of access tube is mainly caused by intrusion of concrete from leakage at either bottom cap or tube connection and intrusion of soil or other material from the top cap of the tube. Sonic test instruments (transducer and receiver) sometimes may not be able to insert down to the bottom of the access tubes due to the bend of the tube itself. Though the problem associated with the access tube blockage can be

overcome by drilling through the obstruction in the worst case (but not possible if tube is bent), it should be eliminated in the first place by careful fabrication, installation and protection of the tubes.

7.2 Interpretation of test results

The results of a series of laboratory tests to determine the effects of various defects or inhomogeneities within a concrete section were reported by Stain and Williams (1991). The test results were carried out on small panels constructed to model various pile construction defects and anomalies. The results from these panels were related to tests on control panels formed from homogeneous concrete.

Faiella and Superbo (1998) reported the analysis of the sonic logging test results of over 6800 piles collected from 37 sites in Italy. Based on the results of analyses, the authors presented the defect classification criteria for piles monitored by different number of tubes as illustrated in Tables 3 (a) and 3 (b).

Table 3 (a). Defect classification criteria monitored by means of 2 tubes (Faiella and Superbo, 1998)

T_a/T_s	T_k/D	Type of defect
<1.15	-	Non-homogeneous concrete
1.15-1.45	<3	Light
	>3	Probably serious
1.45-2.0	<1	Light
	>1	Probably serious
>2.0	<0.5	Probably serious
	>0.5	Light

Table 3 (b). Defect classification criteria monitored by means of 3 and 4 tubes (Faiella and Superbo, 1998).

T_a/T_s	P_a/P_t	T_k/D	Type of defect
<1.15	$\frac{P_a < P_t}{P_a = P_t}$	-	Non-homogeneous concrete
	$P_a < P_t$	<3	Non-homogeneous concrete
1.15-1.45	$P_a < P_t$	>3	Light
	$P_a = P_t$	<3	Light
1.45-2.0	$P_a < P_t$	>3	Serious
	$P_a < P_t$	<1	Non-homogeneous concrete
1.45-2.0	$P_a < P_t$	1-3	Light
	$P_a = P_t$	>3	Serious
>2.0	$P_a < P_t$	<1	Light
	$P_a = P_t$	>1	Serious
>2.0	$P_a < P_t$	<0.5	Light
	$P_a < P_t$	0.5-3	Serious
>2.0	$P_a = P_t$	>3	Serious
	$P_a = P_t$	<0.5	Light
>2.0	$P_a = P_t$	>0.5	Serious

where:

T_a = Travel time of sonic waves in the anomalous zone

T_s = Travel time of sonic waves in the sound concrete

T_k = Thickness of the anomalous zone

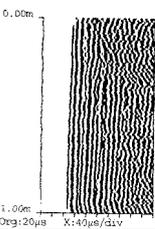
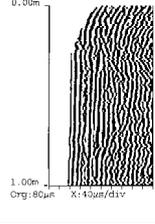
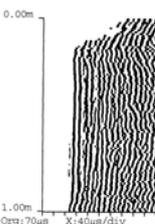
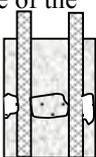
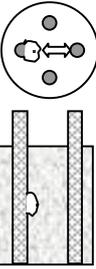
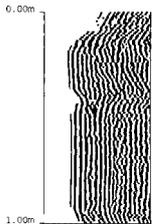
P_a = Number of measurement paths affected by sonic anomalies

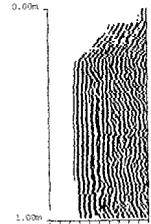
P_t = Total number of travel paths for each pile

D = Pile diameter

Srivanavit et al. (1999) reported the interpretation of test signals in comparison with the actual integrity of 9 model tests conducted in Bangkok. Model piles are of 800mm diameter with 1m length. The summary of the model test results including the description of model piles as well as discussions by authors are illustrated in Table 4.

Table 4. The summary of sonic logging model test results

Case	Concrete & material properties	Profile	Discussion of signal
1	Standard good concrete pile with clean tubes and clean water.		Sonic logging profile shows continuous signal, no anomaly.
2	Good concrete pile with dirty tubes and clean water.		Sonic logging profile shows defect at pile head due to bleeding of concrete.
3	Good concrete pile with dirty tubes and dirty water (contaminated with bentonite slurry) filled.		Sonic logging profile shows defect at pile head due to bleeding of concrete, similar to case 2.
4	Good concrete with Layer of bentonite slurry, sand, gravel fill (30cm.Thickness whole Section) at middle of the pile. 		Sonic logging profile shows signal loss from 0.4m to 0.7m due to delay of sonic wave.
5	Good concrete with Clay on surface of one tube (50 cm. from top of concrete). 		Sonic logging profile shows signal delay at 0.5m depth.

Case	Concrete & material properties	Profile	Discussion of signal
6	Concrete mixed with bentonite slurry.		Sonic logging profile shows non-uniform signal, not clear signal due to poor concrete and inhomogeneous concrete.
7	Thin smear of 2mm. bentonite slurry on tubes (50 cm. from top of concrete).		Sonic logging profile shows signal loss from depth 0-0.5m (more travel time).
8	Thick smear of 5mm. bentonite slurry on tubes (50 cm. from top of concrete).		Sonic logging profile shows continuous signal loss and signal delay at depth 0-0.5m, similar to case 7.
9	Weak concrete (high w/c ratio).		Though weak (low strength) concrete is used, sonic logging profile shows continuous signal, because of homogeneity of the tested media.

7.3 Factors to be considered in interpretation of sonic logging test

Turner (1997) pointed out the need of both theoretical knowledge and practical experience in interpretation of the test results in CIRIA Report 144. Suggestion is also made in this report that the anomaly shown in sonic test signals can be caused not only by changing in physical properties of the materials, but also by factors within the measuring system itself. These factors are;

- Free movement of the probes within access tubes
- Mismatched probe positions especially at pile toe
- Measurement resolution
- Incorrect position of access tube
- Air gaps or different material around access tubes
- Aggregate variation (in the case of base grouting)

It is to be noted from the author's suggestion based on the above factors that only variations of transmit time more than 15 to 20% of the norm should be regarded as warranting further investigation.

8 HIGH STRAIN DYNAMIC LOAD TEST

8.1 Overview of the test in Bangkok

High strain dynamic integrity test has become a well-accepted method especially for evaluating the pile capacity in the foundation industry today. A large number of related technical papers and case histories of the test have been published and it is a part of standards and specifications such as ASTM D4945-89 (Standard Method for High-strain Dynamic Testing of Piles). In Bangkok, dynamic load test is applied for both driven and bored piles. A summary of the number of dynamic load test carried out during 1991 to 1997 is shown in Table 5. It is to be noted that quantities shown are collected from the available sources and the actual tested numbers are likely to be slightly more than those indicated in the table. As can be seen in the table, application of dynamic load test increases year by year in Thailand.

The pile driving analyzer (PDA) with computer software by Pile Dynamic INC, USA is mainly used in Bangkok.

Table 5. Yearly minimum quantity of dynamic load test conducted in Thailand during 1991 to 1997

Year	No. of dynamic load test done
1991	84
1992	134
1993	242
1994	369
1995	464
1996	473
1997	695

For driven pile it is usually performed at two stages, during driving (initial driving monitoring) and some period after installation of pile (restrike test). For bored piles, a specially designed pile cap is normally required as an integral part of the pile head to avoid pile head damage. Ram weights of 4 ton to 20 ton are commonly used in Bangkok. The common ram weights used for different pile sizes are shown in Table 6.

Table 6. Common ram weights used for different size of piles

Pile size (m)	Ram weight (ton)
≤ 0.50	4.00
0.50 – 0.80	8.00
1.00 – 1.50	20.00

The dynamic load test is also occasionally used as an additional investigation when pile is found with

defect by other integrity tests. Figure 5 shows the photo of dynamic load test carried out on barrette of size (1.0x2.7m) with toe depth 48.94m located at the bank of water supply canal. A 20 ton hammer was used to activate the 2050 ton test load in this project.



Figure 5. Dynamic load test carried out on a barrette (1.0m x 2.7m x 48.94m).

8.2 Comparison and correlation of dynamic and static pile load test

A comparison between dynamic and static load test results has been reported by various researchers. Seidel and Rausche (1984) reported the results of dynamic and static load tests performed on drilled shafts of the West Gate Freeway in Melbourne, Australia. A 20 ton hammer with drop heights between 1.6 and 2.5m was used for the dynamic tests of 12 shafts ranging from 1100mm and 1500mm in diameter and 35m to 64m in length. The authors reported that dynamic activation of static pile resistance forces exceeded 3000 ton for some 1500mm diameter shafts. Skin friction predictions from dynamic load tests and values obtained from instrumented shafts under static load tests were remarkably similar and pile head load-movement relationships obtained from both test methods were comparable as reported by the authors.

Prebaharan et al. (1990) reported the results of dynamic and static tests conducted on bored piles at the Marina Bay Station of the Singapore Rapid Transit System. According to the report, dynamic load tests were carried out for bored piles of 1000mm diameter and 25m to 50m length founded in Old Alluvium of Singapore Island. Agreement between dynamic and static load tests results permitted replacement of 44 out of 51 tests with dynamic load test from originally planned static load tests as stated by the authors.

Vasinvarthana and Kampananon (1997) presented the efficiency and reliability of dynamic load test carried out in Bangkok. Figures 6 (a) and 6 (b) show the load settlement curves of dynamic and static load tests conducted in Bangkok on large and small di-

iameter piles respectively. As can be seen in the figures, load-settlement characteristics obtained from dynamic load test agree well with those of static load test for both large and small diameter bored piles.

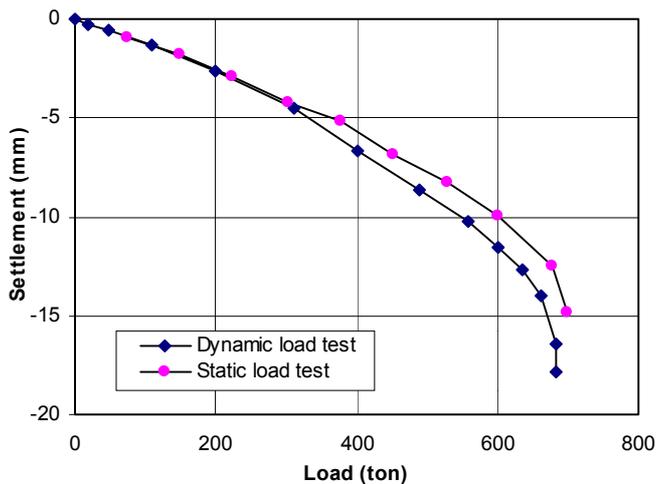


Figure 6 (a). Load-settlement curves of dynamic and static load tests on large diameter piles (ϕ 0.80m x 50.0m).

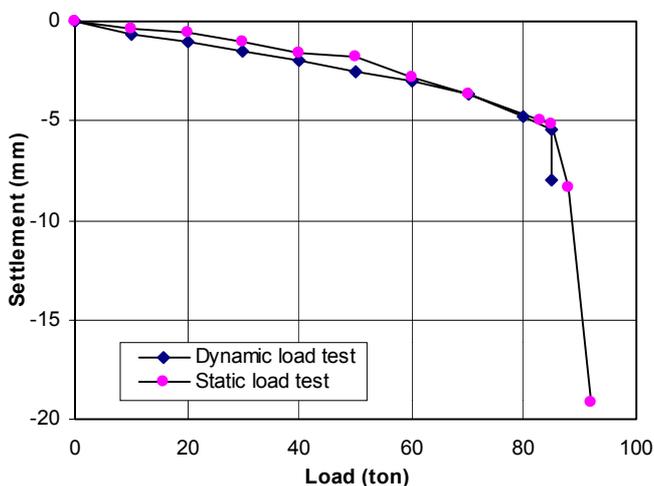


Figure 6 (b). Load-settlement curves of dynamic and static load tests on small diameter piles (ϕ 0.35m x 18.91m).

9 CONCLUSIONS

Use of sonic integrity, sonic logging and high strain dynamic tests in Bangkok has been presented.

Though sonic integrity test is a simple and cost effective method, the reliability of the test results is highly dependent on the experience of the person in both field-testing and interpretation.

The results from sonic logging test conducted on model piles in Bangkok helps to extend the knowledge of the signal characteristics and interpretation.

High strain dynamic test has become a well-accepted method especially for load testing of piles. Agreement between static and dynamic load test results enhances the confidence in using the dynamic load test as shown by rapid increment in number of tests conducted in seven years in Thailand, mainly in Bangkok.

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