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New Pile Instrumentation Technique for Driven and Jacked –In Prestressed Spun Concrete Piles

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NEW PILE INSTRUMENTION TECHNIQUE FOR DRIVEN AND JACKED – IN PRESTRESSED SPUN CONCRETE PILES

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ABSTRACT

Currently, strain gauges are normally used to monitor the shortening or compression of pile during static pile load test. For concrete spun pile, the technique used either by incorporating high temperature-resistant strain gauges into the heat-cured production process of the spun piles or by installing an instrumented steel pipe into the hollow core of the spun piles followed by cement grout infilling. The former is extremely unpopular due to high cost of these gauges and the uncertainty over their ability to survive the pile production and driving processes. The shortcoming of the other technique is the infilling of cement grout substantially alters the structural properties of the piles, thus rendering their load-response behaviour significantly different from that of the actual working piles. This paper highlights the application of a method, recently developed by the authors, which uses retrieval sensors instead of strain gauges which have to be sacrificed in every test. The method also has the ability to monitor loads and displacements at various levels along the pile shaft and toe of instrumented piles. Results of field tests show high quality, reliable and consistent data, clearly far exceeding the capability of both conventional methods of using strain gauges.

INTRODUCTION

The high strength prestressed spun concrete piles, commonly driven with hydraulic impact hammers or preferably installed with jacked-in rigs when considering the stricter regulations with respect to noise and vibrations in more urban areas, often offer a competitive choice of foundation system for projects with medium and high loadings. They are widely used in foundations for schools, high-rise buildings, factories, ports, bridges and power plants in this region.

In early years, the main construction control for driven piles was mostly based on the measurement of set of each pile coupled with a selected small number of non-instrumented static load tests to verify the specified load-settlement requirements.

In recent years, with critical evolution in the understanding of the load transfer and bearing behaviour of piles (mainly through analysis of instrumented full-scale load tests), many engineers can now appreciate that the pile performance is not simply a matter of ultimate load value alone [Chan, S.F. & Lee, C.S.P. ,1990; Chan, S.F., 2004]. According to Fleming [1996] some of the basic parameters required for forecasting pile deformation under loads include (a) Ultimate shaft load and its characteristics of transformation to the ground; (b) Ultimate base load; (c) Stiffness of the soil below the pile base; (d) Pile dimensions; and (e) Stiffness of the pile material.

Conventional Instrumentation Method

A conventional instrumentation scheme for spun pile static load testing is shown in Figure 1. The method involves incorporating high temperature-resistant strain gauges into the heat-cured production process of prestressed spun concrete piles.

This method is extremely unpopular and difficult to be routinely applied in project sites due to the following constraints:

(a) High cost of these temperature-resistant strain gauges;
(b) Tremendous difficulties involved in coordinating the installation of the strain gauges into pile segments;
(c) Long lead-time is normally required for instrumentation works, as the instruments have to be pre-assembled and installed onto the high strength prestressing bar cage prior to heat-cured 'spin-cast' production process of the piles; and
(d) Great uncertainty over the ability of the delicate instruments to withstand the stresses arising from pile production and driving processes.

Approximate Instrumentation Method

Due to the difficulties of using the conventional method, the engineering community for spun pile industry has been using an approximate instrumentation method for the past few decades, by installing either an instrumented reinforcement cage or an instrumented pipe, into the hollow core of spun piles followed by cement grout infilling (Figure 2).

Figure 3 shows typical sequence of spun pile installation by jack-in method, commonly used vibrating wire strain gauges mounted to steel pipe, lowering of instrumented pipe into the annular space of the test pile followed by cement grout infilling.

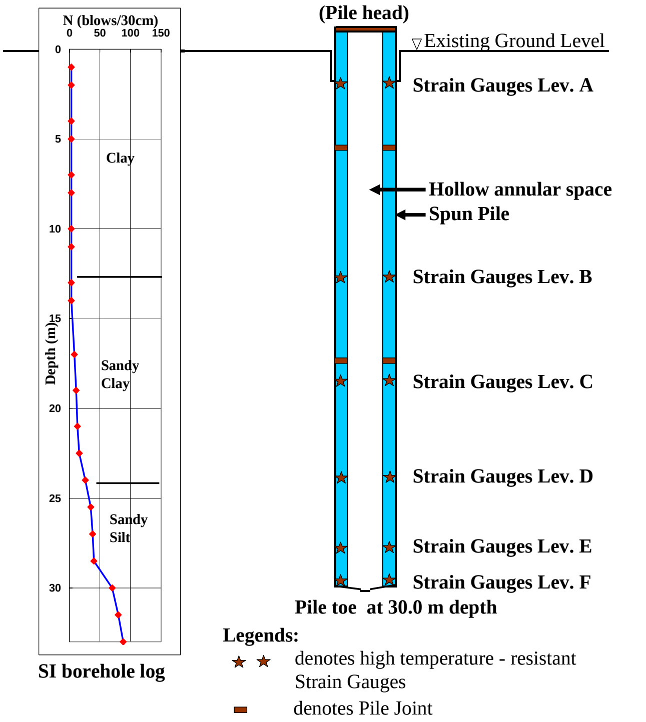

Fig. 1. Diagrammatic illustration of conventional spun pile instrumentation scheme

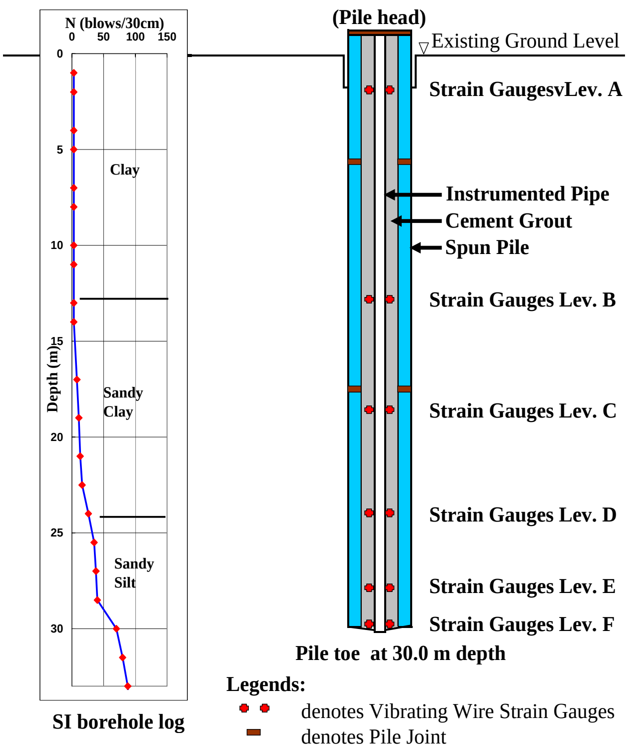

Fig. 2. Diagrammatic illustration of approximate spun pile

As this approximate method is comparatively more "convenient" to be implemented than the conventional method, it was widely practiced in this region for the past few decades.

Some contract specifications also ask for the inclusion of conventional sleeved rod extensometers (depending on the space available) to monitor the pile shortening reading during the static load tests. Either using an instrumented reinforcement cage or an instrumented pipe, with or without the added-in sleeved rod extensometers, the end product after the cement grout infilling is more towards a solid pile.

Fig. 3. Typical installation process of spun pile instrumentation in approximate method

Therefore the obvious shortcomings of this approximate method include:

(a) The infilling of cement grout substantially alters the structural properties of the piles, thus rendering them significantly different from the actual working spun piles, which are usually not grouted internally;
(b) The change in strain in the post-grouted core under the applied loading may not be the same as the change in strain in the prestressed concrete wall of the pile because of the different stiffness of the two materials of different mix, strength and age;
(c) Structural shortening measurement of the test piles are not representative of the actual working piles;
(d) Structural integrity of the original pile cannot be reliably ascertained, particularly performance of pile joints, during the static load test; and
(e) Significant time loss due to grout infilling and curing process, beside the environmental unfriendly nature of this method.

RECENTLY DEVELOPED INSTRUMENTATION METHODS

To address the challenges and difficulties posed by the conventional and approximate methods, retrieval sensors hereby named as global strain extensometers for spun piles had been developed, improved and field tested, by the authors.

<u>Description of the Global Strain Extensometer</u>

The technology consists of a deformation monitoring system that uses advanced pneumatically- or hydraulically-anchored extensometers coupled with high-precision spring-loaded transducers, and a novel analytical technique to monitor loads and displacements down the shaft and at the toe of foundation piles. This method is particularly useful for monitoring pile performance and optimizing pile foundation design.

To appreciate the innovation contained in the technology, the basic deformation measurement in the pile by strain gauges and tell-tale extensometers are reviewed. Normally, strain gauges (typically short gauge length) are used for strain measurement at a particular level or spot, while tell-tale extensometers (typically long sleeved rod length) are used purely for shortening measurement over an interval (over a length between two levels). From a 'strain measurement' point of view, the strain gauge gives strain measurement over a very short gauge length while the tell-tale extensometer gives strain measurement over a very long gauge length. Tell-tale extensometer that measure strain over a very long gauge length may be viewed as a very large strain gauge or simply called global strain extensometer. With recent advancement in the manufacturing of high-precision spring-loaded vibrating-wire sensors, it is now possible to measure strain deformation over the entire length of piles in segments with ease during static load testing.

Figure 4 shows a schematic spun pile instrumentation diagram using the global strain extensometer. This system is equivalent to the conventional method of using 24 no. strain gauges and 6 no. sleeved rod extensometers, which might not be possible to be installed satisfactorily due to congestion in the spun piles.

For the analysis of test data for spun piles using the global strain extensometer, the load distribution can be computed from the measured changes in global strain gauge readings and pile properties (cross-section area of spun pile and concrete modulus). Load transferred (P_{Ave}) at mid-point of each anchored interval can be calculated as:

$$P = \varepsilon(E_c A_c) \qquad (2)$$

where,

ε = average change in global strain gauge readings;
A_c = cross-sectional area of spun pile section;
E_c = concrete secant modulus in pile section.

With the instrumentation set-up as described in Figure 4, the global strain extensometers system is able to measure shortening and strains over an entire section of the test pile during each loading steps of a typical static pile load test, thus it integrates the strain over a larger and more representative sample.

<u>Advantages of Using the Global Strain Extensometer</u>

Due to the significant difference in the methodology evolution, from conventional sacrificial cast-in method to a new retrievable post-install approach, the global strain extensometer technology has been proven via a large number of full-scale load tests to be a reliable and powerful pile load testing and data interpretation tool.

Some of the obvious benefits of using global strain extensometer technology are as follow:

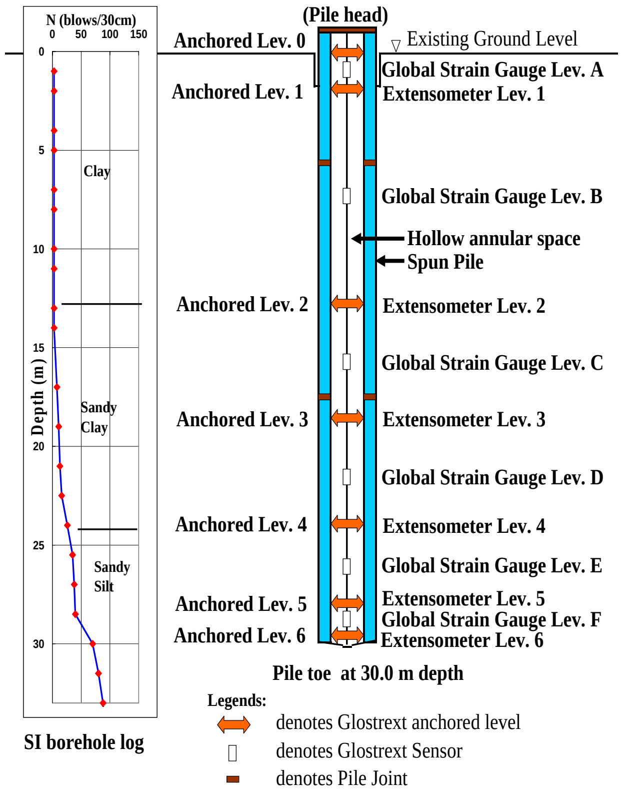

Fig. 4. Schematic diagram of typical instrumented spun pile using global strain extensometer technology

(i) The technology enables installation of instrumentation after pile-driving and thus virtually eliminates the risk of instrument damage during pile production and installation;
(ii) The post-install nature of the method empowers engineers to select instrumentation levels along the as-built depth of foundation piles using pile driving/installation records and site investigation data as guides;
(iii) The technology reliably measures segmental shortening/elongation and strain over an entire section of the test pile during each loading step of a typical static load test. Unlike the conventional strain gauges that make just localized strain measurements, the new technology integrates individual measurements over a larger and more representative sample;
(iv) Significant cost and time saving, as the additional and cement grout infilling are not required;
(v) The technology is extremely environmental friendly, as the sensors are retrievable, and no messing around with cement grouts; and
(vi) Mass implementation of spun piles instrumentation is now made viable with this technology, to capture

representative and reliable data in large quantities to assist engineers to build up a reliable databank for better design and safety.

FIELD TESTS RESULTS AND DISCUSSION

The technology has been recently used to fully instrument a 500 mm diameter (with 90 mm wall thickness) jacked in prestressed spun concrete pile for a commercial building project in the state of Melaka, Malaysia. The test pile instrumentation details along with nearby borehole SPT N-values plot are graphically represented in Figure 5. The pile was jacked-in to 30m penetration length when the jack-in force reached approximately two times working load or 4000kN. The jack-in frame was also used for subsequent static load test (Figure 6).

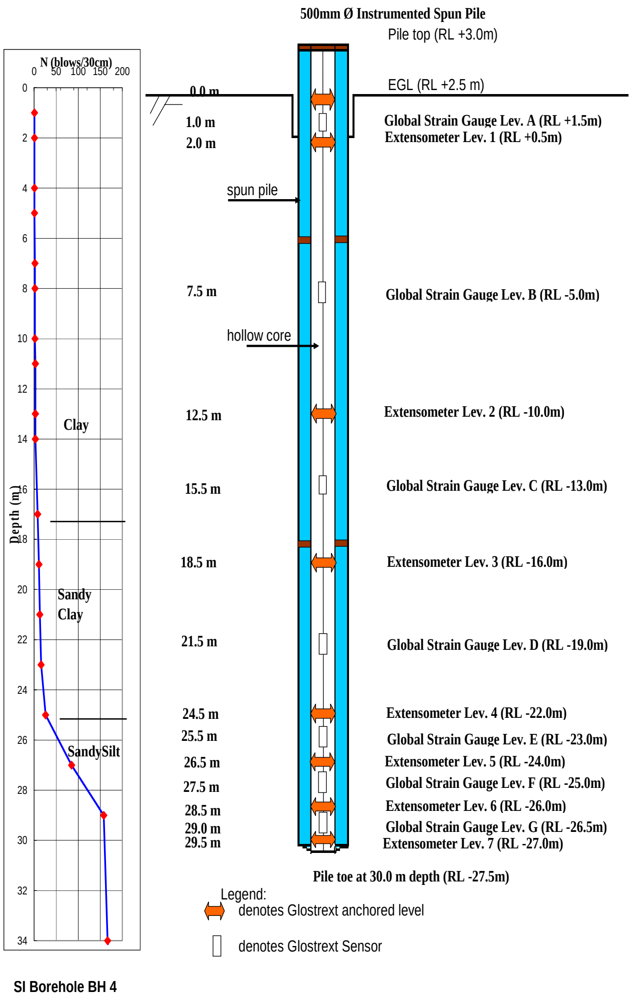

Fig. 5. Test Pile 1 instrumentation using global strain

Fig. 6. Static axial compression load test set-up for Test Pile 1 at Melaka site, Malaysia

Fig. 7. Instrumentation and monitoring test set-up for Test Pile 1 at Melaka site, Malaysia

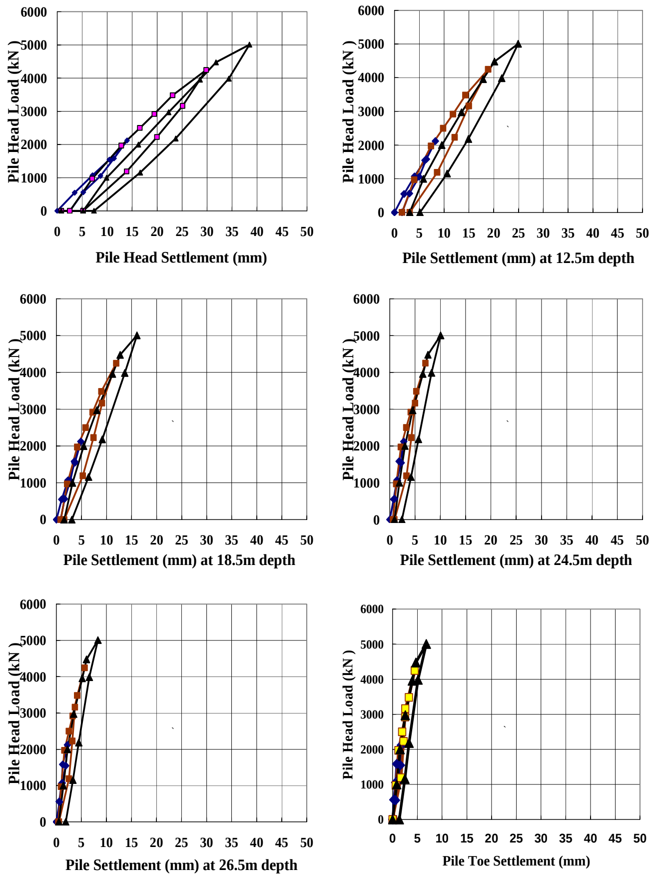

Fig. 8. Pile head settlement and pile settlement at various depths including pile toe for Test Pile 1 at Melaka site, Malaysia

Pile head movement was monitored using both Linear Variation Displacement Transducers (LVDTs) and by affixing pile tops with vertical scale rules that could then be sighted by precise level instruments. Vertical scales were similarly provided on the reference frame to monitor frame movements during load testing. The applied loads were measured by calibrated vibrating-wire load cell. The vibrating-wire load cell, global strain extensometers and LVDTs were all logged automatically using a Micro-10x datalogger system (Figure 7).

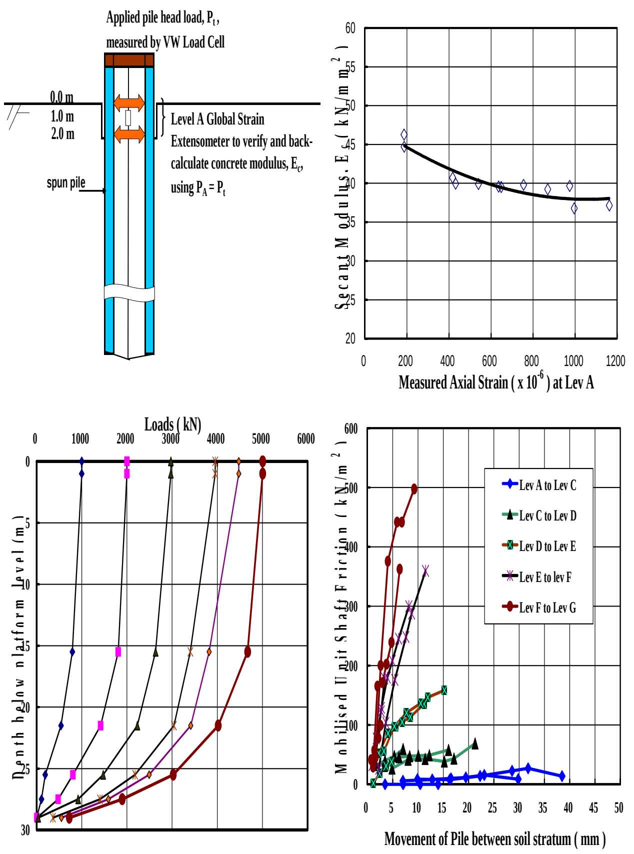

Fig. 9. Level A sensor arrangement for verifying and back-calculate E_c values, modulus-strain curve, load distribution curve and mobilized unit shaft friction versus average movement of pile between soil stratum measured using global strain extensometer for Test Pile 1

Pile head settlement and pile settlement at various depths including pile toe (derived by subtracting the structural shortening at corresponding depth from the pile head settlement) are presented in Figure 8.

In the pile test analysis, it is highly recommended in practical terms to obtain the pile concrete modulus, E_c value directly from the material of the pile Fleming, K. [1992] . Global strain extensometer technology appeared to provide an excellent answer to this recommendation (Figure 9), giving a reliable site-specific calibration of strain-dependent modulus to be ascertained before converting strains into axial loads.

A conspicuous benefit which can be derived from the plots shown in Figure 8 and Figure 9 is that they enable engineers and researchers nowadays to have an opportunity to have an insight understanding on the relationship between the pile settlement along the pile depth and the corresponding load transfer characteristics.

CONCLUSIONS

Considering the inherent shortcomings of conventional and approximate instrumentation method for spun piles, the global strain extensometer technology appeared to be a more superior and logical evolution due to its revolutionary difference in the methodology approach, from conventional sacrificial cast-in method to a new retrievable post-install nature. Field tests using this technology on both driven and jacked-in spun piles showed high quality, reliable and consistent data, clearly far exceeding the capability of both conventional and approximate methods.

The advanced features and novel nature of the global strain extensometer technology also made it an improved alternative of instrumentation approach to the following research areas, where it could be too cumbersome and sometimes economically not viable if using conventional and approximate methods:

(a) Fully instrumented piles for long term load transfer characteristic study, including both positive and negative skin friction development with time;
(b) Study of locked-in stresses in piles due to handling and installation process, particular suitable for jacked-in piles;
(c) Fully instrumented piles for study of influence due to installation process of adjacent piles;
(d) Study of pile joints performance under loadings;
(e) Mass implementation of spun piles instrumentation in fast- track projects.

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