Innovation in Instrumented Test Piles in Malaysia: Application of Global Strain Extensometer (GloStrExt) Method for Bored Piles

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ABSTRACT

A new instrumentation and analysis technique, called GloStrExt method has recently been introduced for bored pile load tests. This new technique provides an innovative and improved alternative for conventional bored pile instrumentation methods commonly practiced for the past few decades. Results for five case histories involving full scale static load tests for high capacity bored piles with both new and conventional instrumentation details placed in within the same instrumented piles are presented to demonstrate the advantages of this novel technique. Results show good agreement between the new and conventional instrumentation.

Keywords : Static load tests, strain gauges, tell-tale extensometers, global strain extensometers.

1. INTRODUCTION

Static load test remains to be unsurpassed as the engineer's favorite choice in determining the geotechnical capacity of a pile for optimising design and providing verification of suitability and constructability in the foundation industry. However, over the past few decades, there is an obvious lack of innovation in the area of instrumentation and monitoring for the classical static load tests, while other indirect or alternative pile test methods such as Dynamic Load Tests, Statnamic Load Tests and Bi-Directional O-Cell Load Testing had undergone significant improvement in recent years.

Commonly practiced conventional bored pile instrumentation method for static load testing, see Figure 1(a), normally uses vibrating wire strain gauges and mechanical tell-tale extensometers installed and cast within the pile to allow for monitoring of axial loads and movements at various levels down the pile shaft including the pile base level.

Due to lack of innovation in this area, coupled with the following constraints and shortcomings, this instrumentation method had been limited to very few selected high profile bored pile projects, and rarely used in driven piles application.

a) Long lead-time and great care are required, as instrumentation has to be pre-assembled and installed to steel cage prior to concreting of pile. Information on pile length,

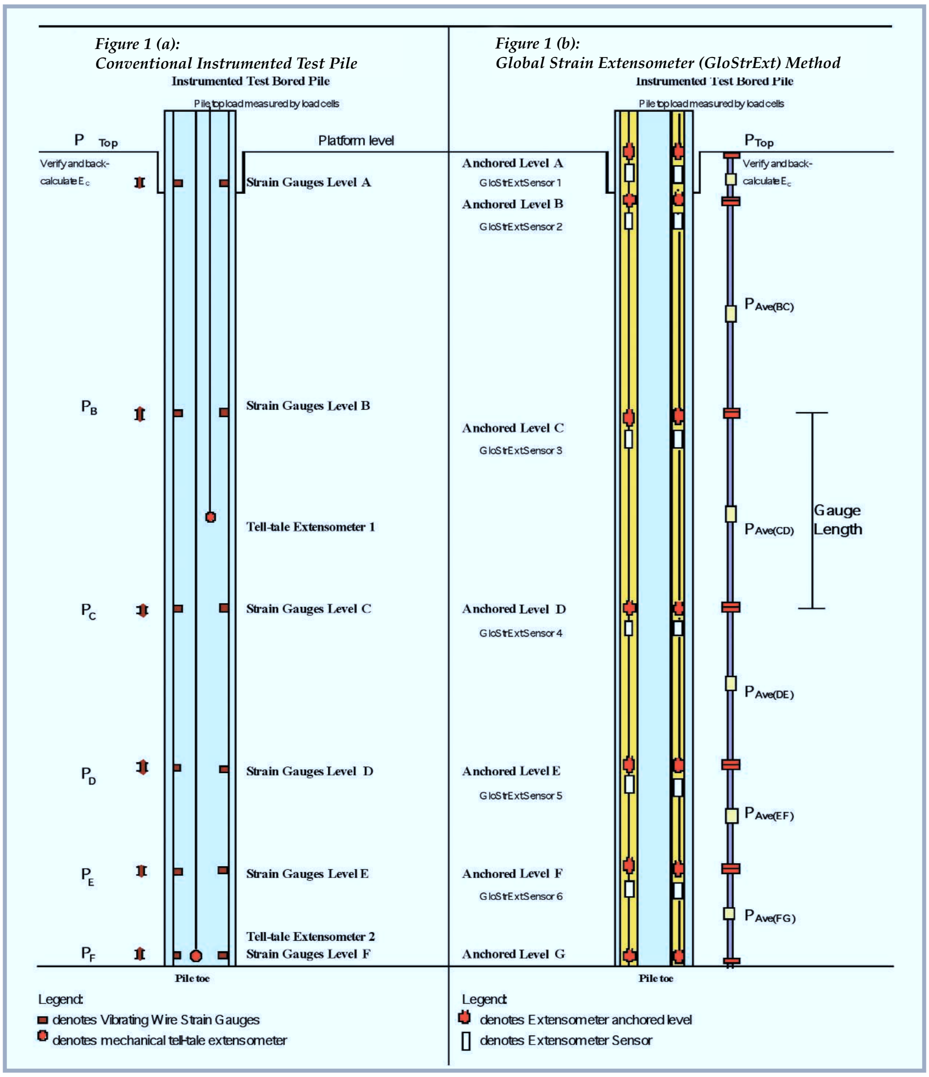

Figure 1: Description of Global Strain Extensometer (GloStrExt) method versus conventional method for bored pile instrumentation for static load tests

long before the boring and installation of test pile.

b) Strain Gauge gives localised strain measurement, sensitive to variation in pile cross-section.

c) Sleeved rod tell-tale extensometer often gives unsatisfactory results due to rod friction, bowing, eccentricity of loading and reference beam movement. The movement for lower portions of pile shaft is particularly difficult to be reliably measured most of the time.

d) When instrumentation levels increases for particular complex soil strata or geological structures, it is sometimes not practical to put tell-tale extensometers at every levels due to congestion of sleeved pipes in the piles, as well as difficulty in monitoring set-up at pile top.

2. DESCRIPTION OF GloStrExt METHOD

The GloStrExt Method for static load testing is a deformation monitoring system using extensometers with a new analysis technique for determining axial loads and movements at various levels down the pile shaft including the pile base level. This method is particularly useful for monitoring pile performance and optimising pile foundation design.

To appreciate the basic innovation contained in the GloStrExt Method, the 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 retrievable extensometers such as state-of-the-art vibrating wire extensometers, it is now possible to measure strain deformation over the entire length of piles in segments with ease during static load testing.

Figure 1(b) illustrates typical arrangement of retrievable vibrating wire extensometers in test pile, permitting improved monitoring of axial loads and movements at various levels down the pile shaft including the pile base level using GloStrExt Method. Generally two strings of retrievable vibrating wire extensometers with 6 or 7 anchors are adequate to yield improved results for instrumented static load tests. This system is equivalent to the conventional method of using 24 no. VW Strain Gauges and 6 no. sleeved rod extensometers, which might not be possible to be installed satisfactorily due to congestion in small-sized piles.

3. CASE HISTORIES

The results of five instrumented sacrificial bored test piles namely PTP1, PTP2, PTP3, PTP4 and PTP5, involving full scale static load tests with both new and conventional instrumentation details placed within the same piles are presented. The load tests were

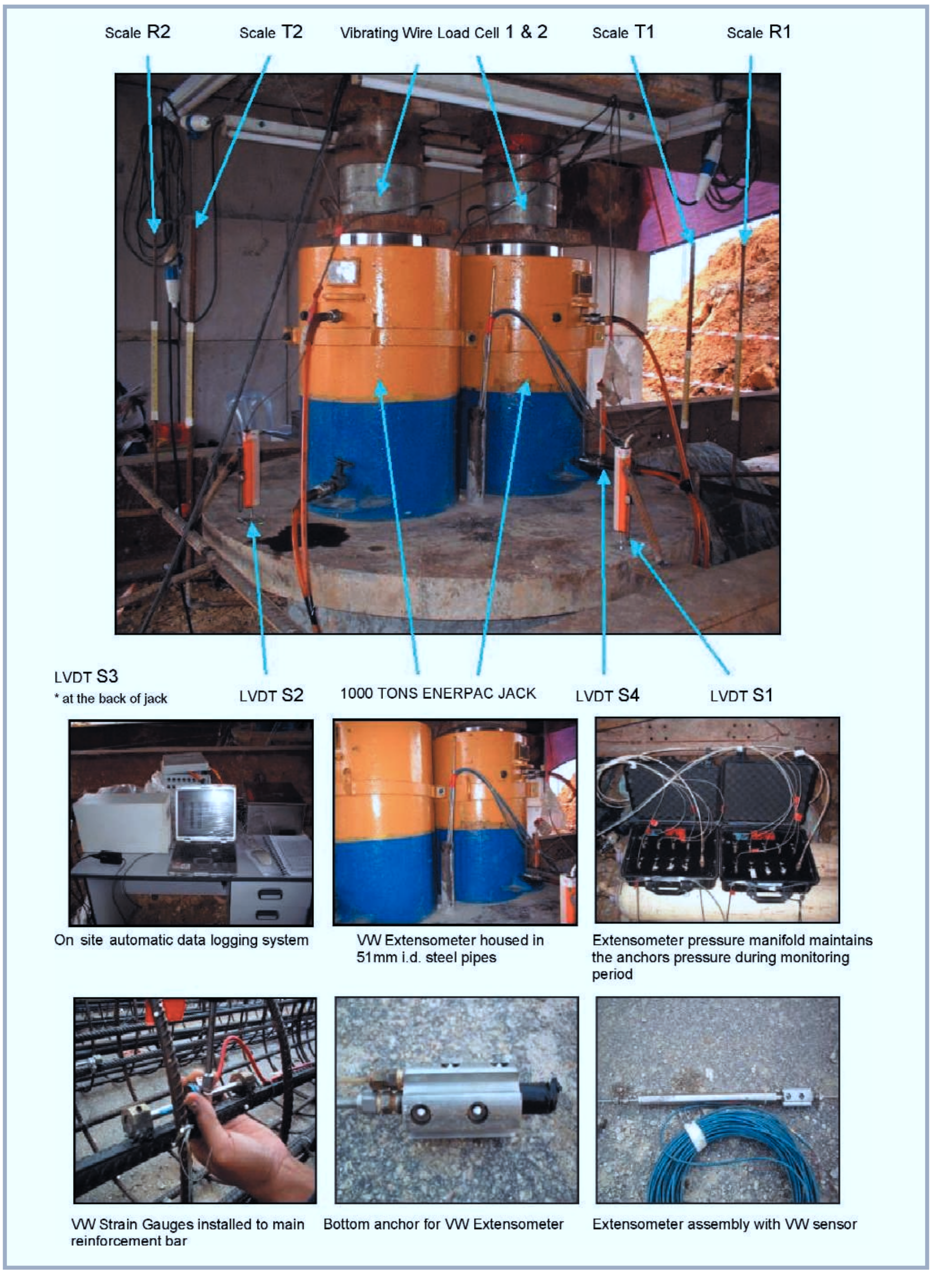

Figure 2: Typical pile test instrumentation and monitoring set-up

conducted with great care and control as described in following subsections. All the monitoring instruments were measured automatically during the loading and unloading cycles using a data-logger system. Figure 2 gives a typical illustration for instrumentation and monitoring set-up.

For the project requirements, instrumented load tests are conducted to establish and verify the following for the use in the design of working piles which are to be constructed in similar soil strata and using similar construction methods: -

(i) To determine the bearing capacity of the pile and its apportionment into shaft friction and end bearing;

(ii) To evaluate the design parameters in relation to the ultimate skin friction and end bearing, and

(iii) To study the behaviour of pile settlement and structural shortening under the applied loads.

3.1 DESCRIPTION OF TEST PILES

3.1.1 Location Of Site And Subsurface Conditions

The location of the site is at Interchange No.1 (ICW01), part of Southern Integrated Gate Project located at Johor Bahru, Johor, Malaysia. The site is underlain predominantly by weathered residual soils, which consist mainly of silty sand. A typical borehole result is shown in Figure 3.

3.1.2 Piles Instrumentation

For each of the sacrificial bored piles, two types of instruments, namely, the Vibrating Wire Strain Gauges and Vibrating Wire Extensometers were installed internally in the pile. The strain gauges were installed at six levels with four strain gauges at each level. The Geokon A-9 Vibrating Wire Extensometers sensors, housed in a 51mm internal diameter sonic logging pipe was installed at six levels at corresponding strain gauges levels, with 2 sets per level.

Figure 3 gives a typical arrangement of instrumentation along the pile depth, covering both new and conventional instrumentation details placed in within the same pile.

3.1.3 Piles Structural Properties

The instrumented test piles PTP1, PTP2, PTP3, PTP4 and PTP5 constructed were all bored cast-in-situ reinforced concrete piles having structural properties as listed in Table 1.

3.1.4 Procedures for Installation of Test Piles

The test piles were installed with 12m length temporary casing with bentonite as a stabilising fluid. The boring of soil was carried out with a Bauer BG22 rig.

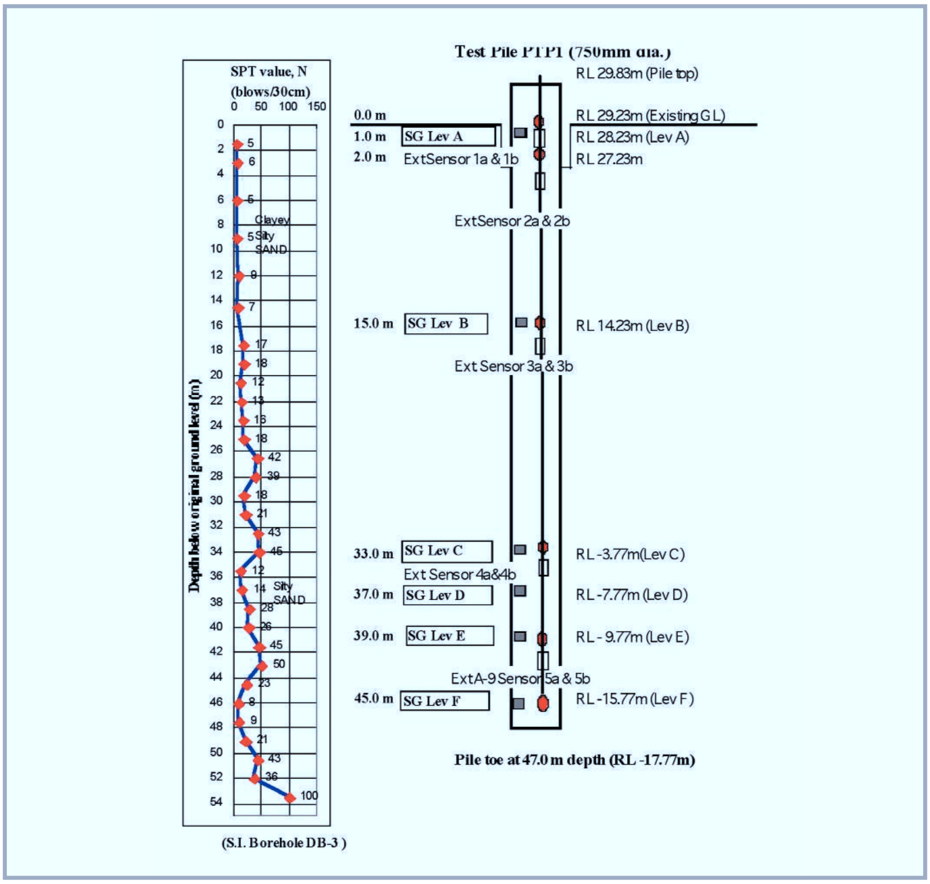

Figure 3: Instrumentation levels for test pile PTP 1 (750mm dia.) As-built Pile Length = 47.0m

Table 1: Structural properties of piles

Test Pile No.	Pile Diameter (mm)	Pile Length (mm)	Main Reinforcement	Circular Links	Concrete Grade	Concrete Over-consumption
PTP1	750	47.0	12T20	T12 at 200mm c/c	G40/T2	<9%
PTP2	1000	50.5	40T20	T16 at 200mm c/c	G40/T2	<14%
PTP3	1000	40.0	40T20	T16 at 200mm c/c	G40/T2	<9%
PTP4	750	55.7	12T32	T12 at 200mm c/c	G40/T2	<8%
PTP5	750	40.1	20T20	T12 at 200mm c/c	G40/T2	<15%

Table 2: Test programs

Test Pile No.	Pile Diameter (mm)	Date Installed	Date of Load Testing	Total Loading Period	Maximum Test Load
PTP1	750	15 Sep 2003	8 to 12 Oct 03	102 hours	6,237 kN
PTP2	1000	22 Sep 2003	16 to 19 Oct 03	61 hours	11,056 kN
PTP3	1000	25 Sep 2003	6 to 10 Nov 03	83 hours	12,500 kN
PTP4	750	27 Sep 2003	29 Nov to 2 Dec 03	85 hours	8,125 kN
PTP5	750	9 Oct 2003	11 to 15 Dec 03	85 hours	8,125 kN

3.1.5 Loading Arrangement And Test Programmes

The instrumented piles were tested by the Maintained Load Test (MLT) using a kentledge reaction system. In the set-up used, the test loads were applied using two 1,000 tonne capacity hydraulic jacks acting against the main reaction beam. The jacks were operated by an electric pump. The applied loads were measured by cali-brated vibrating wire load cells.

To obtain good quality data, small load increments were chosen. Typically, increments of 10% of the working load were applied prog-ressively in two loading cycles to a maximum test load of two and a half times the working load or failure, whichever occurs first.

3.1.6 Pile Movement And Instruments Monitoring System

The pile top settlement was monitored using the following instruments:

(i) Four Linear Variation Displacement Transducers (LVDTs) mounted to the reference beams with its plungers placed vertically against glass plates fixed on the pile top.

(ii) Vertical scale rules fixed to pile top sighted by a precise level instrument. Vertical scales were also provided on the reference beams to monitor any movement during load testing.

The vibrating wire load cells, strain gauges, retrievable extensometers and LVDTs were logged automatically using a Micro-10x Datalogger and Multilogger software, at 3 minutes intervals for close monitoring during loading and unloading steps. Only precise level readings were taken manually.

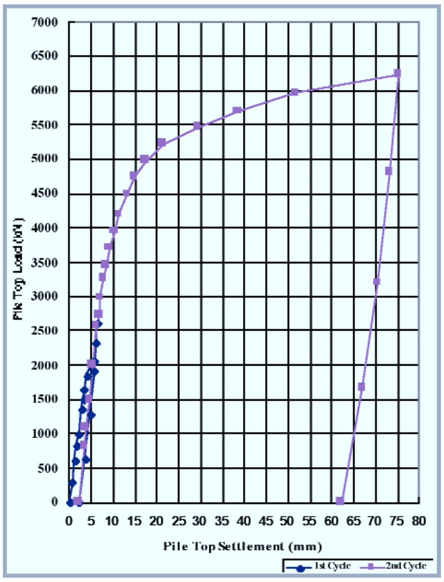

Figure 4: Plot of pile top loads (kN) vs pile top settlement (mm) for 1st and 2nd cycle of maintained load testing, PTP 1

3.2 RESULTS AND ASSESSMENT OF PILES PERFORMANCE

3.2.1 Load Movement Behaviour Of The Piles

Measured load movement behaviour of piles are summarised in Table 3(a) and Table 3(b).

Typical plots for pile top load versus pile top settlement, pile top load versus

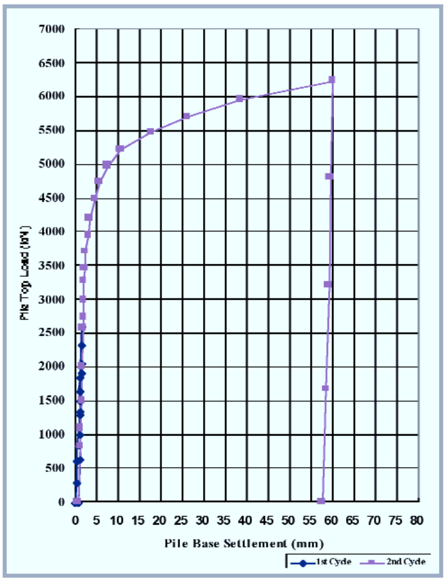

Figure 5: Plot of pile top loads (kN) vs pile base settlement (mm) for 1st and 2nd cycle of maintained load testing, PTP 1

Table 3(a): Summary of measured pile settlements and shortening at working load (Cycle 1)

Test Pile No.	Applied Pile Top Load (1xWL) (kN)	Pile Top Settlement (mm)	Pile Base Settlement (mm)	Total Pile Shortening (mm)	Residual Pile Top Settlement (mm)
PTP1	2,500	6.34	1.55	4.78	2.16
PTP2	5,000	6.57	0.62	5.95	2.42
PTP3	5,000	3.60	0.02	3.58	0.19
PTP4	3,250	7.89	2.85	5.04	2.40
PTP5	3,250	5.81	1.40	4.41	1.36

Table 3(b): Summary of measured pile settlements and shortening at maximum test load (Cycle 2)

Test Pile No.	Maximum Applied Pile Top Loan (kN)	Total Pile Top Settlement (mm)	Total Pile Base Settlement (mm)	Total Pile Shortening (mm)	Residual Pile Top Settlement (mm)
PTP1	6,237	75.20	60.18	15.02	62.12
PTP2	11,056	106.46	91.54	14.91	94.04
PTP3	12,500	12.46	0.92	11.54	2.17
PTP4	8,125	28.56	9.10	19.46	10.61
PTP5	8,125	21.59	4.70	16.89	7.01

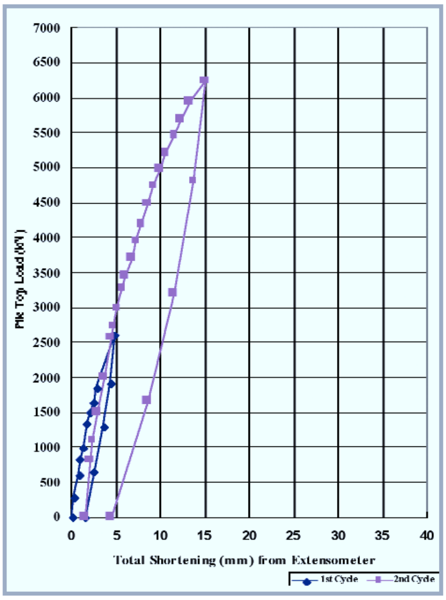

Figure 6: Plot of pile top loads (kN) vs shortening (mm) of whole pile for 1st and 2nd cycle of maintained load testing, PTP 1

pile base settlement and shortening readings for PTP1 are presented in Figures 4, 5 and 6 respectively.

3.2.2 Axial Load Distribution From VW Strain Gauges

The load distribution curves indicating the load distribution along the shaft and at the base were derived from computations based on the measured changes in strain gauge readings and pile properties (steel content, cross-sectional areas and modulus of elasticity) based on as-built details (including concreting record) known from the construction record.

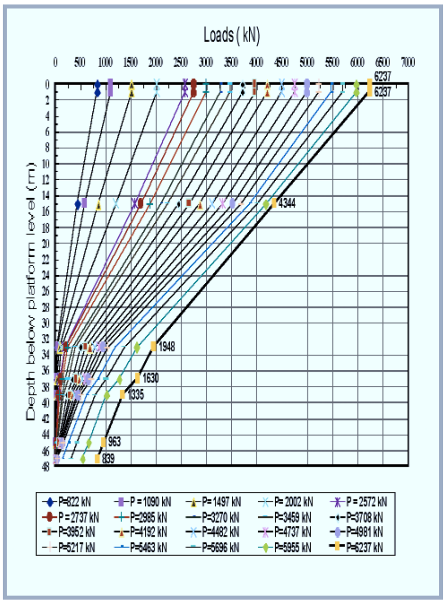

Figure 7: Load distribution curve computed from VW strain gauges test result, PTP

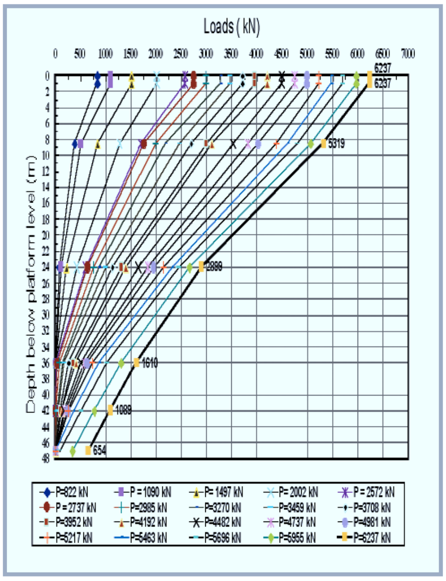

Figure 8: Load distribution curve computed from Global Strain Extensometer test result, PTP 1

Load transferred (P) at each level is calculated as follows:

$P = \varepsilon\,(E_c{*}A_c + E_s{*}A_s)$

where

ε = average change in strain gauge readings

A_c = cross-sectional area of concrete

E_c = Young's Modulus of Elasticity in concrete

A_s = cross-sectional area of steel reinforcement

E_s = Young's Modulus of Elasticity in steel = 200 kN/mm^2

The Young's Modulus of Elasticity in concrete, Ec was back-calculated with the aid of the strain gauge results at level A and the pile top loads. For each stage of loading, Ec is back-calculated by assuming that the load at the strain gauge level A was equal to the applied load at the pile top.

Typical load distribution curves from VW Strain Gauges test results for the test cycle for PTP1 are presented in Figure 7.

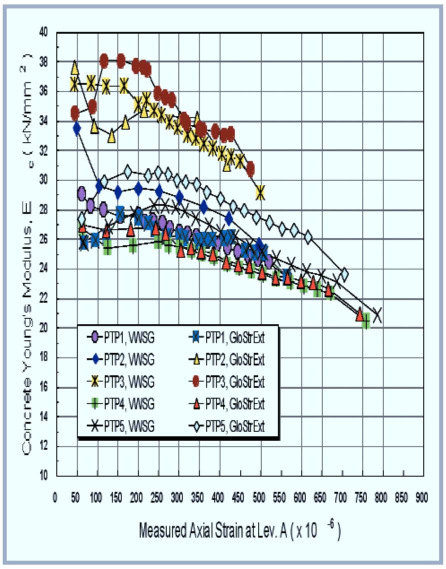

Figure 9: Plot of back-calculated concrete modulus values, Ec vs measured strain from VW Strain Gauges at level A (at 1.0m depth) and GloStrExt (0.0m to 2.0m) for PTP 1, PTP 2, PTP 3, PTP 4 and PTP 5

3.2.3 Axial Load Distribution From Retrievable VW Extensometers

In the GloStrExt method, the Young's Modulus of Elasticity in concrete, Ec was back-calculated by measuring the strains in the top 2.0m of debonded length of the pile using the VW Extensometers and the pile top loads. For each stage of loading, Ec is back-calculated by assuming that the load at the mid-point of the 2.0m debonded length level was equal to the applied load at the pile top.

Typical load distribution curves from GloStrExt test results for the test cycle for PTP1 are plotted and presented in Figure 8. It is worthy to note that Figures 7 and 8 show very similar characteristics.

3.3 COMPARISON OF RESULTS FROM CONVENTIONAL AND GloStrExt METHOD

3.3.1 Comparison Of Back Calculated Concrete Modulus Values

The plots of back-calculated concrete modulus values versus measured axial strain at level A from both conventional strain gauges and Global Strain Extensometers for the test cycles for 5 piles are plotted and presented in Figure 9. As a practical guide, reference is made to BS8110 Part 2 (1985) Table 7.2 (for f_{cu} = 40 N/mm^2, $E_{c,28}$ typical range = 22 to 34 N/mm^2) as a comparison to the measured value.

From the plots presented, it is clear that the back-calculated concrete modulus values measured by two independent systems (conventional Strain Gauges and Global Strain Extensometers) agree reasonably well.

These plots are also extremely useful to study the correction of E_c according to variation of strain level with pile depth, which can further improve the accuracy of the present method of axial load distribution computation using back-calculated E_c.

3.3.2 Comparison Of Measured Axial Strain Along Pile Shaft

The plots of measured axial strain at various levels along pile shaft from both conventional strain gauges and Global Strain Extensometers for 5 piles are presented in Figures 10 (a) to 10 (e) respectively.

From the plots presented, it is shown that the axial strains measured by the two independent systems are in good agreement. Considering that the Global Strain Extensometers measure strains over an entire section of a pile, thus it integrates the strains over a larger and more representative sample than the conventional strain gauges.

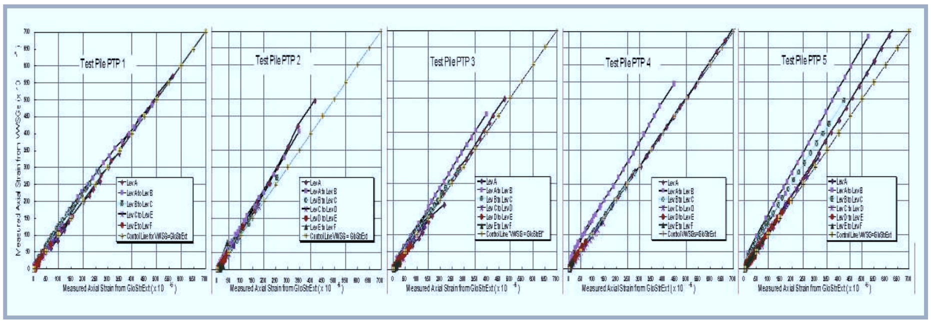

Figure 10: Plot of Measured Axial Strain from VW Strain Gauges Vs Global Strain Extensometers for PTP 1, PTP 2, PTP 3, PTP 4 and PTP 5

4. CONCLUSION

The results of five instrumented bored test piles involving full-scale static load tests with both new and conventional instrumentation show the following behavior:

(i) the back-calculated concrete modulus values measured by two independent systems (conventional Strain Gauges and Global Strain Extensometers) agree reasonably well.

(ii) the axial strains measured by the two independent systems are in good agreement. The Global Strain Extensometers measure strains over an entire section of a pile, thus it integrates the strains over a larger and more representative sample than the conventional strain gauges.

Using the global strain extensometers, measurement of the pile shortening over the whole pile length can now be reliably measured in segments. This enables the movement of the pile and strains at various levels down the pile shaft to be determined accurately, thus permitting an improved load transfer distribution of piles in static load tests.

The GloStrExt method significantly simplifies the instrumentation effort by enabling the sensors to be post-installed after casting of pile. It also minimises the risk of instruments being damaged due to concreting process. ■

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