

APPLICATION OF GLOBAL STRAIN EXTENSOMETER (GLOSTREXT) METHOD FOR INSTRUMENTED BORED PILES IN MALAYSIA

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A novel instrumentation and analysis technique, called GLOSTREXT method has recently been introduced for bored pile load tests in Malaysia. This 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.

INTRODUCTION

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 improvements in recent years.

A conventional bored pile instrumentation method for static load testing is shown in Fig.1(a). In general, vibrating wire strain gauges and mechanical tell-tales are 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 toe level.

The constraints with this method includes long lead-time required for instrumentation, instruments have to be pre-assembled and installed onto the steel cage prior to concreting of the pile, information on pile length and instrument locations has to be planned and predetermined before the drilling and installation of the test pile.

Strain gauges give localized strain measurements and are sensitive to variations in pile cross-section. Sleeved rod tell-tales 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.

When instrumentation levels increases for a

particular complex soil strata or geological structure, it is sometimes not practical to put tell-tales at every level due to congestion of the sleeved pipes in the piles, as well as difficulty in monitoring set-up at the pile head.

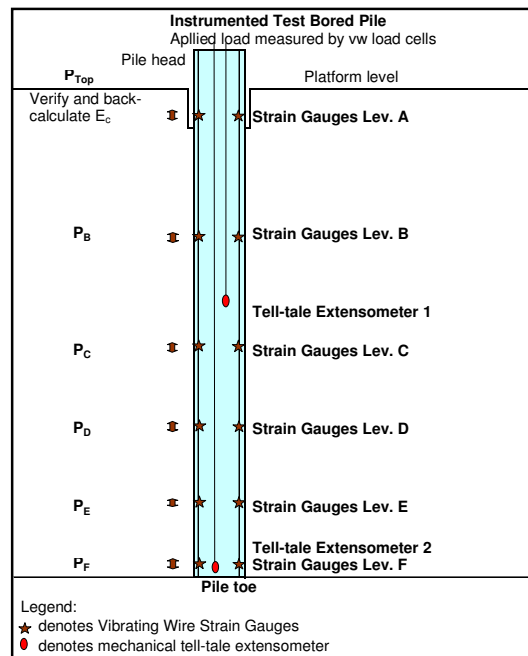


Fig.1(a) : Conventional pile instrumentation

While development of removable extensometers in full scale static load tests (Bustamante et al 1991) had been very successful and unique in Europe for many years now, the advancement had not been

materialized in this part of the world. Thanks to a new generation of pneumatic retrievable extensometer anchors coupled with high-precision spring-loaded vibrating-wire sensors (Geokon, 1995, 2003), highly accurate measurements of the relative deformations of anchored segments across entire pile lengths are now possible to be logged with relative ease during static load testing.

The paper's main focus is to highlight the several advantages of GLOSTREXT method and high correlation between GLOSTREXT method and conventional instrumentation from the results of five case histories involving both instrumentation details placed in within the same instrumented piles.

DESCRIPTION OF GLOSTREXT METHOD

The GLOSTREXT Method for static load testing on bored piles is a deformation monitoring system using advanced pneumatically anchored extensometers and a novel analytical 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 optimizing 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.

Fig.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.

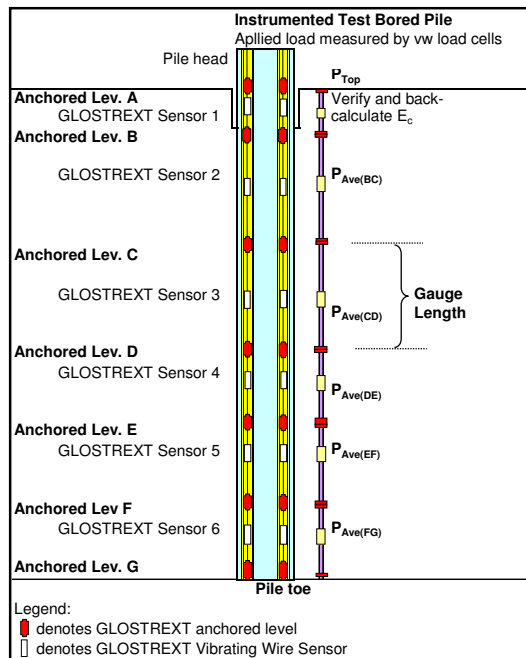


Fig.1(b) : GLOSTREXT pile instrumentation

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 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. Fig.2 gives a typical illustration for instrumentation and monitoring set-up.



Fig.2: Typical pile test instrumentation and monitoring set-up

Subsurface Conditions and Piles Instrumentation Scheme

The location of the site [Figure 3(a)] 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.

Standard penetration tests (SPT N values in blows/30cm) from borehole result at each test



Fig.3(a): Site location plan

pile location and pile instrumentation details are graphically represented in Figure 3(b).

For each of the sacrificial bored piles, two types of instruments, namely, the vibrating wire strain gauges and retrievable 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 retrievable 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.

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:

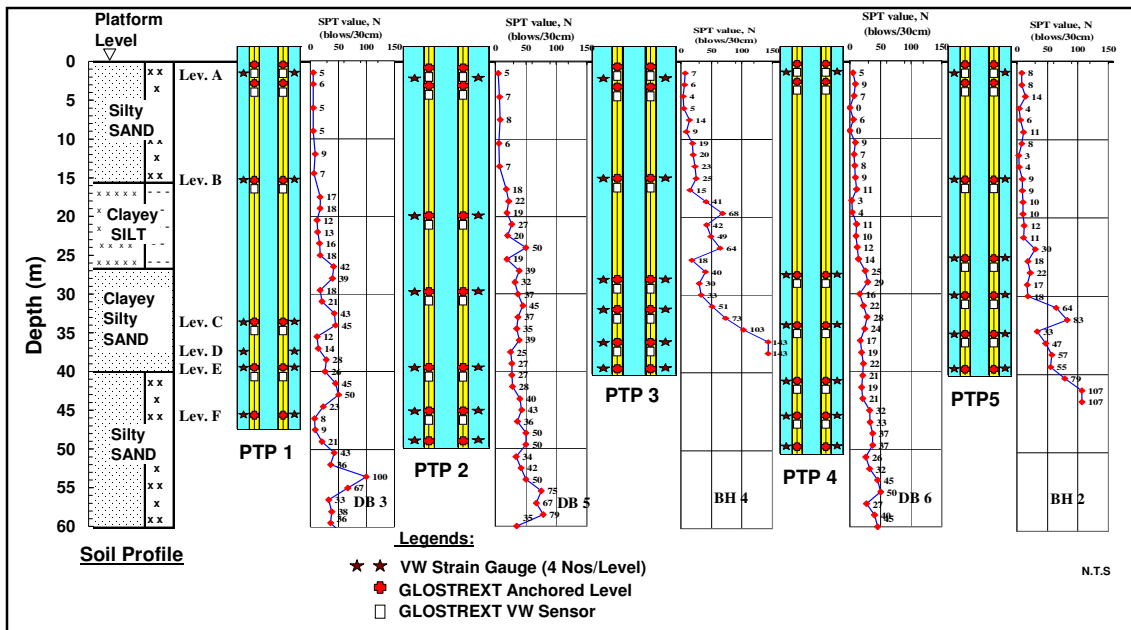


Fig.3(b) : SPT N values and pile instrumentation scheme for PTP1 to PTP5

Table 1: Structural Properties of Piles

Test Pile No.	Pile Diameter (mm)	Pile Length (m)	Main Reinforcement	Concrete Over-break
PTP1	750	47.0	12T20	<9%
PTP2	1000	50.5	40T20	<14%
PTP3	1000	40.0	40T20	<9%
PTP4	750	55.7	12T32	<8%
PTP5	750	40.1	20T20	<15%

Procedures for Installation of Test Piles

The bored cast-in-place test piles were excavated with a Bauer BG22 heavy-duty rotary drilling rig using an 12m length temporary casing with bentonite slurry as a stabilizing fluid. Steel reinforcement cage was lowered after base cleaning using cleaning bucket and desanding of bentonite, followed by placing of Grade 40 concrete using tremie method.

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 calibrated vibrating wire load cells. Static load tests commenced typically 3 weeks after pile installation, with cube strength exceeded specified concrete cube strength of 40 N/mm².

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

Table 2 : Test Programs

Pile No.	Date Installed	Total Loading Period	Maximum Test Load
PTP1	15/09/03	102 hours	6,237 kN
PTP2	22/09/03	61 hours	11,056 kN
PTP3	25/09/03	83 hours	12,500 kN
PTP4	27/09/03	85 hours	8,125 kN
PTP5	09/10/03	85 hours	8,125 kN

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.

RESULTS AND ASSESSMENT OF PILES PERFORMANCE

Load Movement Behaviour Of The Piles

The measured pile head load-pile head settlement behaviours, pile head load versus pile toe settlement and the measured pile head load-total shortening behaviours are presented in Figure 4 for PTP1 to PTP5.

Shortening readings acquired from measurements of the relative movement of anchored segments across entire pile lengths seemed highly consistent, giving highly reliable pile toe settlement behaviours (derived by subtracting the structural shortening from the pile head settlement).

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 concrete modulus) based on as-built details (including concreting record) known from the construction record.

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

$$P = \varepsilon (E_c \cdot A_c + E_s \cdot A_s)$$

where

- ε = average change in strain gauge readings
- A_c = cross-sectional area of concrete
- E_c = Concrete Modulus
- A_s = cross-sectional area of steel reinforcement
- E_s = Young's Modulus of Elasticity in steel (= 200 kN/mm²)

The modulus of concrete, E_c was back-calculated with the aid of the strain gauge results at level A and the pile top loads. For each stage of loading, E_c is back-calculated by assuming that the load at the strain gauge level A was equal to the applied load at the pile top. Load distribution curves acquired from

VW Strain Gauges test results for the test cycle for PTP1 to PTP5 are presented in Fig.5.

Axial Load Distribution From Retrievable VW Extensometers

In the GLOSTRET method, the modulus of concrete, E_c was back-calculated by measuring the strains in the top 2.0m of the pile using the GLOSTREXT vw sensors and the pile top loads. For each stage of loading, E_c 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.

Load distribution curves acquired from GLOSTREXT test results for the test cycle for PTP1 to PTP5 are plotted and presented in Fig.6. It is worthy to note that Fig.5 and Fig.6 show very similar characteristics.

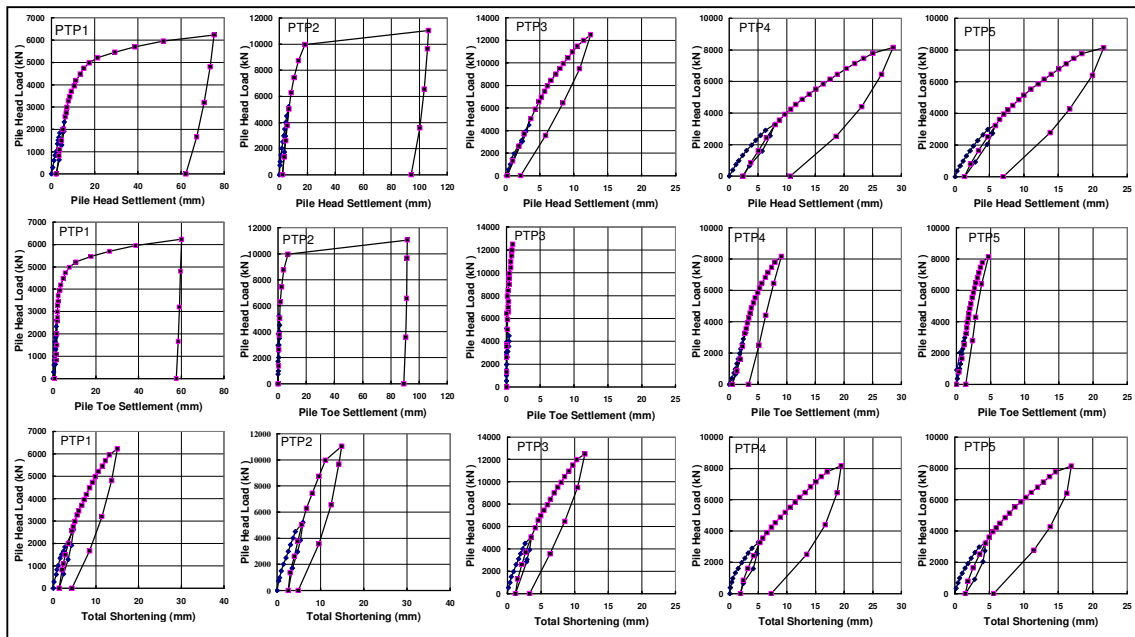


Fig.4: Pile Head Settlement, Pile Toe Settlement and Total Shortening behaviour, PTP1 to PTP5

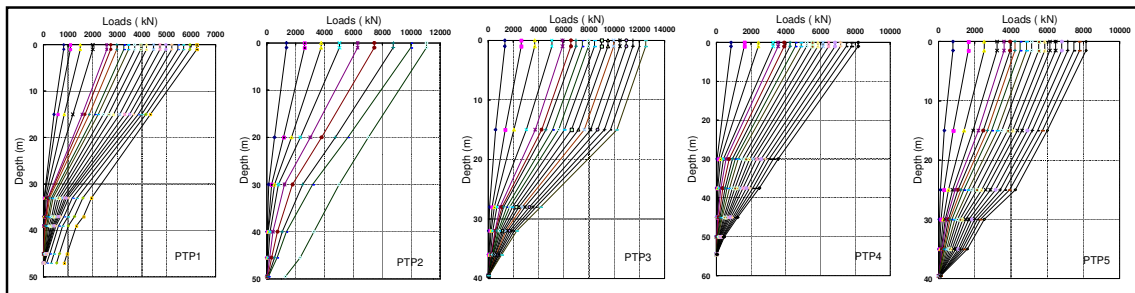


Fig.5: Load Distribution Curves computed from vw strain gauges test results for PTP1 to PTP5

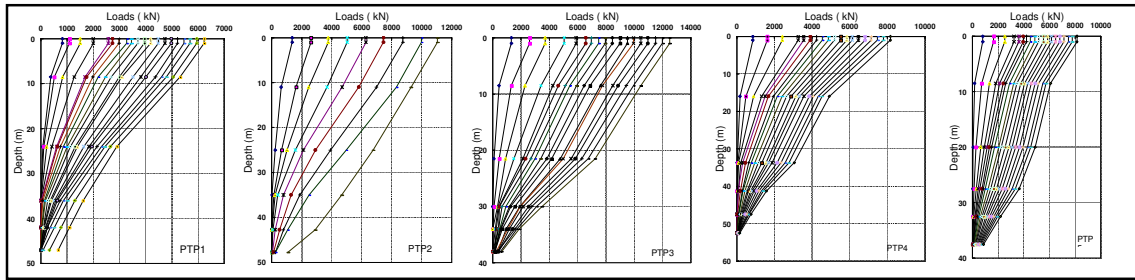


Fig.6: Load Distribution Curves computed from GLOSTREXT test results for PTP1 to PTP5

COMPARISON OF RESULTS FROM CONVENTIONAL AND GLOSTREXT METHOD

Comparison Of Back Calculated Concrete Modulus Values

The plots of back-calculated concrete modulus values, E_c , versus measured axial strain at level A from both conventional strain gauges (at 1.0m depth) and Global Strain Extensometers (from 0.0m to 2.0m depth) for the test cycles for 5 piles are plotted and presented in Fig.7 (a) to Fig.7 (e) respectively.

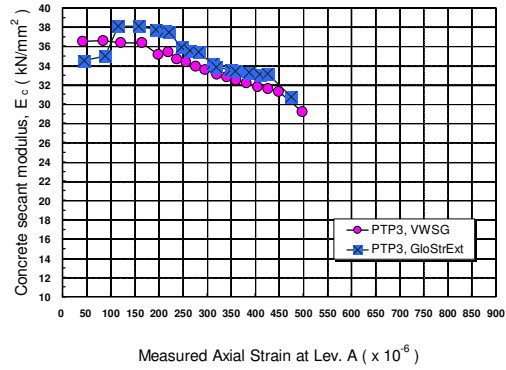


Fig. 7(c): E_c vs Measured Axial Strain for Test Pile PTP 3

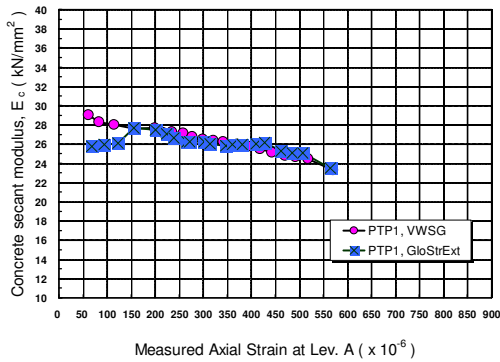


Fig. 7(a): E_c vs Measured Axial Strain for Test Pile PTP 1

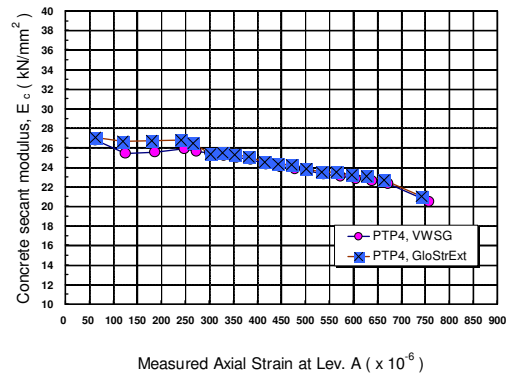


Fig. 7(d): E_c vs Measured Axial Strain for Test Pile PTP 4

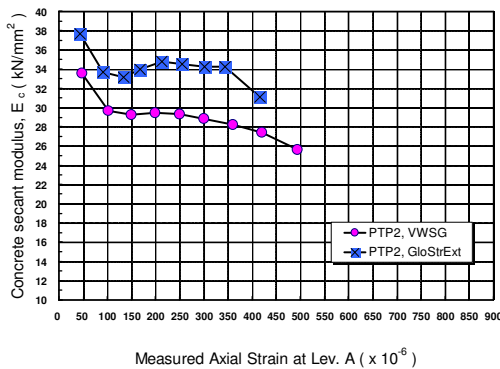


Fig. 7(b): E_c vs Measured Axial Strain for Test Pile PTP 2

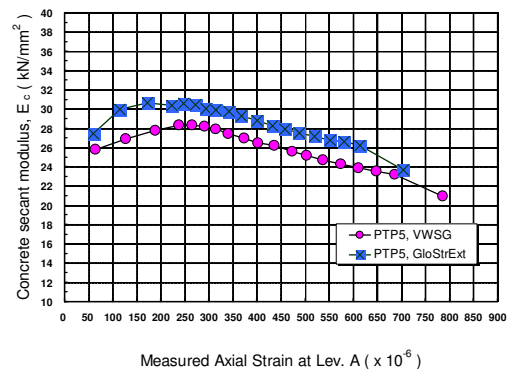


Fig. 7(e): E_c vs Measured Axial Strain for Test Pile PTP 5

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 axial load distribution computation using back-calculated E_c .

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 Fig.8(a) to Fig.8(e) respectively.

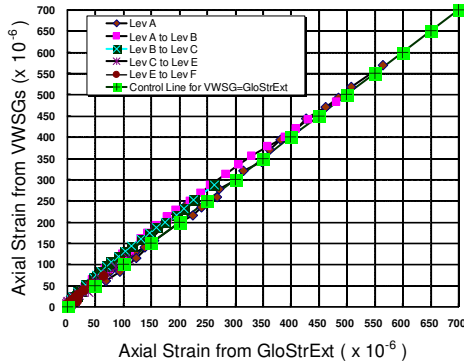


Fig. 8(a) : Measured Axial Strain from VWSG vs Axial Strain from GloStrExt for PTP 1

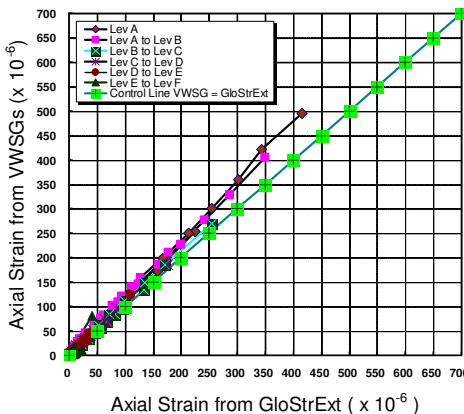


Fig. 8(b) : Measured Axial Strain from VWSG vs Axial Strain from GloStrExt for PTP 2

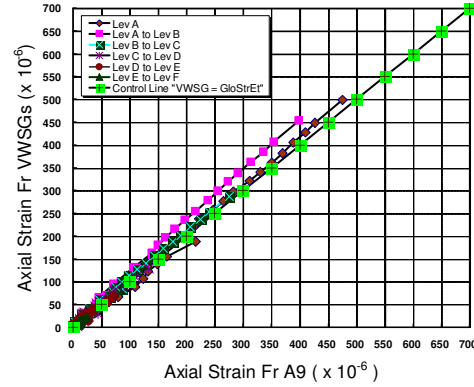


Fig. 8(c) : Measured Axial Strain from VWSG vs Axial Strain from GloStrExt for PTP 3

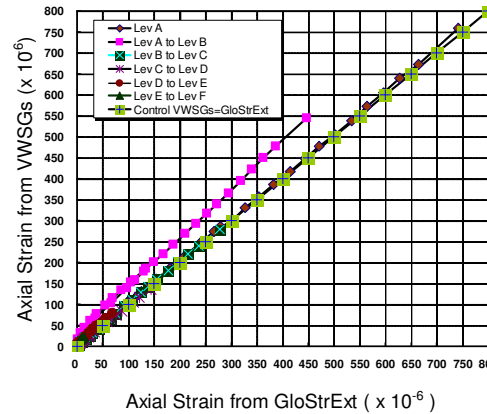


Fig. 8(d) : Measured Axial Strain from VWSG vs Axial Strain from GloStrExt for PTP 4

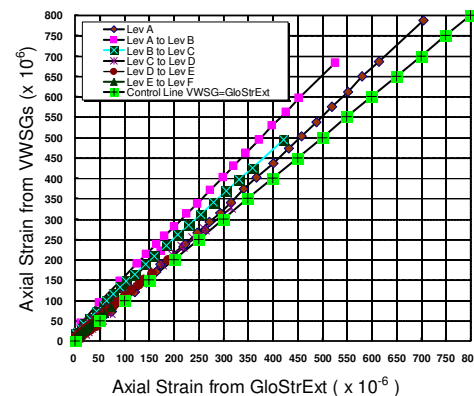


Fig. 8(e) : Measured Axial Strain from VWSG vs Axial Strain from GloStrExt for PTP 5

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.

CONCLUSIONS

The results of five instrumented bored test piles involving full-scale static load tests with both GLOSTREXT method 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.
- iii) 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 minimizes the risk of instruments being damaged during the concreting process.

Acknowledgement

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