## WORK INSTRUCTIONS FOR ENGINEERS

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# OP-023. INTERPRETATION OF INSTRUMENTED TEST PILE RESULT

## INTERPRETATION OF INSTRUMENTED TEST PILE RESULT

## 23.1 INTRODUCTION

This procedure presents a brief guideline for planning of instrumented test pile and the interpretation of instrumented test pile results.

## 23.2 REFERENCES

- Chua, T.S (1999), Instrumented pile load test: Some observations on local practice. Field Measurements in Geomechanics, Leung, Tan & Phoon (eds)1999 Balkema, Rotterdam, ISBN 90 5809 0663
- Hayes, J & Simmonds,T. (2000), Interpretating strain measurements from load test in bored pile, 9th International Conference on Piling and Deep Foundation, Nice, June 3-5, 2000.
- BS8110:
- Reynold,C.E & Steedman, J.C. (1988). Reinforced Concrete Designer's Handbook.

## 23.3 GUIDELINE ON INSTRUMENTED TEST PILE

1) Instruments used:
   - strain gauges (preferably sister bars using vibrating wire strain gauge)- to measure strain in concrete or reinforcement and therefore the axial stress on the pile cross section can be computed.
   - extensometers – to measure the pile displacement at designated locations.

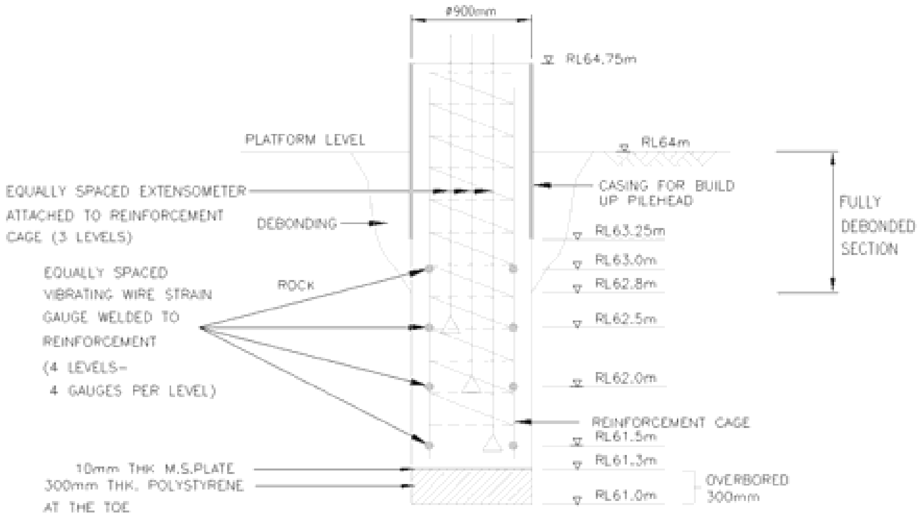
2) Location of instrumented test pile:
   - preferably near S.I borehole for correlation of test results with the subsoil parameters.

3) Location of strain gauges:
   - can be placed at appropriate intervals within the pile and at locations where soil/ rock changes for meaningful load transfer profile.
   - It is recommended to provide 3 to 4 strain gauges equally spaced out per level to detect any strain difference due to eccentric loading.
   - It is recommended to place the 1st level of strain gauge near to the pile head and free from any interaction from the ground as a calibrating strain gauge with the load cell. The calibrating strain gauges will be used to assess the actual pile stiffness, AE values for interpretation.
   - If casing is used to build up the pile head, it is advisable to remove the steel casing before casting or place the 1st level of strain gauges below the casing to avoid interaction from the confining force of the steel casing.
   - The pile section between the pile head and the calibrating level shall be debonded to eliminate interference.
   - To avoid stress concentration or arching, the location of the 1st level strain gauge shall be at least one pile diameter from the pile head (where the load is applied).
   - All strain gauges including the signal wires shall be protected using PVC tubes (or similar) to prevent damaged gauge during pile installation. However, cautions shall be taken to ensure no excessive debonding of the strain gauges due to the protection sleeve or significant change of the sectional properties affecting the interpretation.

4) Location of extensometers:
   - It is recommended to place at the same levels as the strain gauges to establish a relationship between the load transfer behaviour and the pile shaft movement.
   - An extensometer is recommended to be placed at the pile toe to monitor the pile toe settlement.

5) Test Pile
   - For rock socketted pile, artificial soft toe may be used to eliminate the end bearing resistance, and to measure the mobilised socket friction.
   - It is advisable for shallow piles to place Styrofoam (about 300mm thick) at the base of the pile reinforcement to prevent build up of base resistance. (Only applicable if pile design is based on shaft friction or socket friction).

6) A typical instrumentation detail for test pile drawing is shown below:




7) Readings on strain gauges shall be taken before and after attaching them to reinforcement cages, after lowering into borehole and concreting to check the condition of strain gauges in the installation process and to establish potential locked-in stress in pile installation.

## 23.4 STEP BY STEP FOR STRAIN GAUGES INTERPRETATION

### 23.4.1 Step 1: to obtain strain at each level of strain gauge

1. For all strain gauges, the strain, $\varepsilon_z$ shall be computed as follows:

$\boldsymbol{\varepsilon_z} = \boldsymbol{\varepsilon_{zm} - \varepsilon_0}$

$\varepsilon_z$ = strain at the particular strain gauge

$\varepsilon_{zm}$ = strain reading at particular applied loads

$\varepsilon_0$ = initial strain reading taken immediately before testing (ie. Applied top load=0)

2. Average strain for each level of strain gauge,

$\boldsymbol{\varepsilon_{z(average)} = (\varepsilon_{zA} + \varepsilon_{zB} + \varepsilon_{zC} + \varepsilon_{ZD})}$ / numbers of gauge per level

$\varepsilon_{z(average)}$ = Average strain at depth z

$\varepsilon_{zA}$, $\varepsilon_{zB}$, $\varepsilon_{zC}$, $\varepsilon_{ZD}$ = strain at 4 strain gauges of the same level

### 23.4.2 Step 2: to establish pile stiffness (EA)

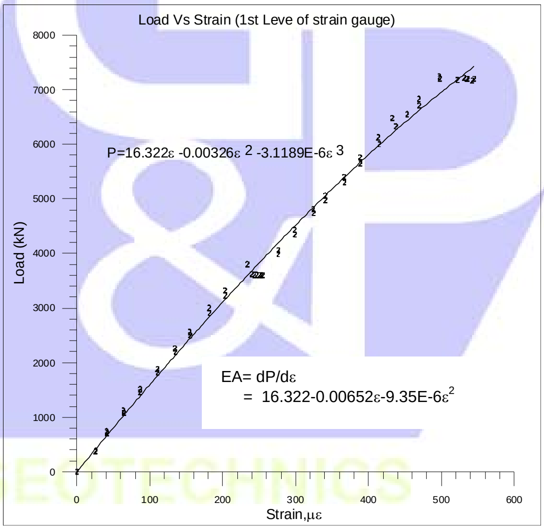
Based on BS8110:Part 1: , the concrete modulus ranges from 21 to 33 GPa for concrete grade 35. However, the research shows that the actual concrete modulus may vary very much from the typical value, and it has direct a impact on the interpretation of test results.

1. **Method 1**

- The concrete modulus can be computed based on BS8110 mean values:
  - o $E_c = 20 + f_{cu}/5$
  - o $E_c$ (ACI) $= 0.043w^{1.5} \times \sqrt{f_c}$ (MPa)
    - w = unit weight of concrete (kg/m$^3$)
    - $f_c$ = unconfined compressive strength of concrete (MPa)
- This method should only be used if Methods 2 & 3 could not be adopted.
  - o $(EA)_{pile} = E_cA_c + E_sA_s$ (composite section)

2. **Method 2 (Recommended)**

- This method is adopted if calibrating level strain gauge is used.
- Steps:
  - o Plot a graph of applied top load against strain at the calibrating level.
  - o Best fit the curve and obtain a polynomial equation of the best fit curve.
  - o Obtain the equation for EA by differentiating the polynomial equation:
    - $(EA)_{pile} = dP/d\varepsilon$ (composite section)



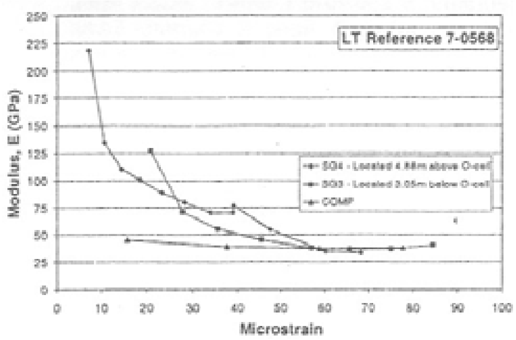

3. **Method 3 (Tangent Modulus Estimates)**

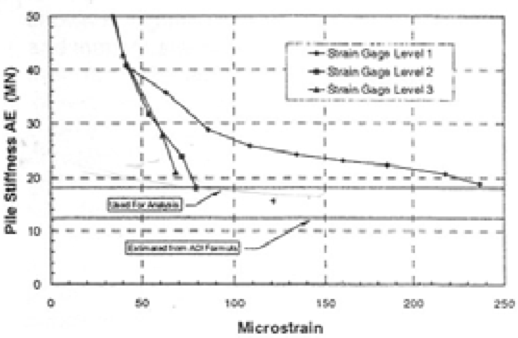
- This method is adopted if calibrating level strain gauge is not provided and at least one of the instrumented pile segment is fully mobilised.
- Limitations:
  - o The ultimate shaft friction above particular level of strain gauge has to be fully mobilised during testing.
  - o Strain at a particular level has to be large enough to stress the concrete section, so that the EA values with loading increment are approaching a constant value.

- Steps:
  - o Compute the assumed EA values for each level by using the following equation:
    - ▪ EA = $P/\varepsilon_{z(average)}$

      Where
      - P = applied top load
      - $\varepsilon_{z(average)}$ = average strain corresponding to the applied top load at a particular level

  - o Plot EA computed in the above step against $\varepsilon_{z(average)}$ curve for all levels of strain gauge in one single graph.
  - o The actual $(EA)_{pile}$ shall be taken as tangent modulus in which the EA value is close to constant even with changes of strain.




### 23.4.3 Step 3: to compute load transfer at subsequent levels

1. If the calibrating level strain gauge is located within the pile section with steel casing (for pile head build up), the EA value computed in Step 2 is composite modulus. Therefore, the pile stiffness (for the subsequent interpretation) shall be computed by:

$$\mathbf{(EA)_{pile} = (EA)_{composite} - E_{steel}\, A_{steel\ casing}}$$

2. Steps:

- For pile with same cross sectional area, load transferred, $P_z$ :
  - o $P_z$ = $(EA)_{pile} \times \varepsilon_{z(average)}$

- For pile with different cross sectional area, load transferred, $P_z$:
  - o $\mathbf{P_z}$ = $\dfrac{(EA)_{pile}}{A_{calibratinglevel}} \times \varepsilon_{z(average)} \times A_z$

    Where
    - $(EA)_{pile}$ = pile stiffness as computed in Step 2.
    - $\varepsilon_{z(average)}$ = Average strain at depth z
    - $A_{calibratinglevel}$ = Cross sectional area at calibrating level
    - $A_z$ = Cross sectional area at depth z

### 23.4.4 Step 4: to compute shaft friction & end bearing

1. The average unit skin friction between any two sections of the pile can be calculated by the changes in load divided by the circumference area between the two sections, as the following equation:

$$\mathbf{F_s} = \frac{\mathbf{P_{z2} - P_{z1}}}{\mathbf{\pi D(z_2 - z_1)}}$$

Where

$F_s$ = average shaft friction between depth $z_1$ and $z_2$
$P_{z1}$ = axial load at the depth $z_1$
$P_{z2}$ = axial load at the depth $z_2$
$z_1$ = depth at $z_1$
$z_2$ = depth at $z_2$
D = as built pile diameter at this section

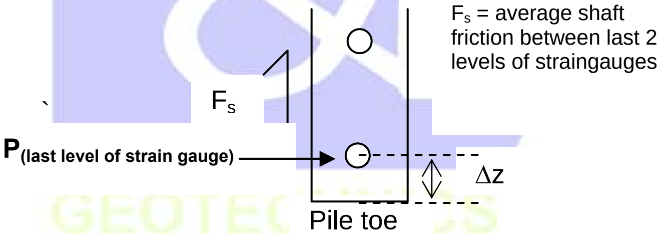
2. The mobilised end bearing of the pile is computed by:

$$\mathbf{F_b} = \frac{\mathbf{P_{toe}}}{\mathbf{\pi D^2/4}}$$

$F_b$ = End bearing
$P_{toe}$ = load at pile toe

- Notes: If strain gauge is not installed at the pile toe, the loads at the pile toe shall be computed by assuming the unit shaft friction near the pile toe is same as that of the shaft friction at upper section.

$$\mathbf{P_{toe} = P_{(last\ level\ of\ strain\ gauge)} - F_s \pi D \Delta z}$$




### 23.4.5 Pile Settlement

1. The pile top settlement can be obtained from the dial gauge readings.
2. The pile settlement at depth of rod extensometer can be obtained by:

$$\mathbf{S_z = S_m - S_O}$$

$S_z$ = displacement at depth z
$S_m$ = measured displacement at depth z
$S_O$ = initial reading for respective extensometer

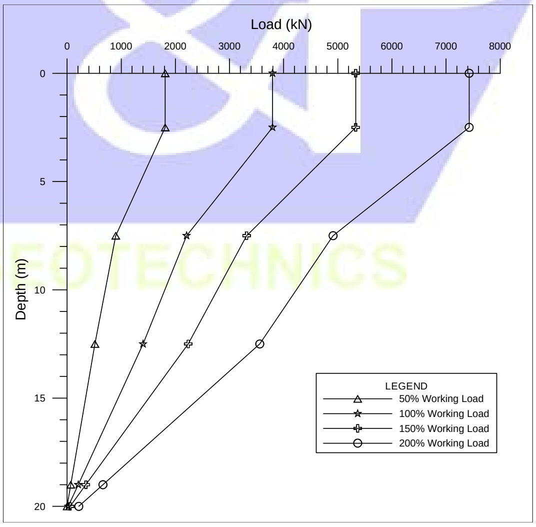
### 23.4.6 Presentation of Table

1. Summary of load distribution

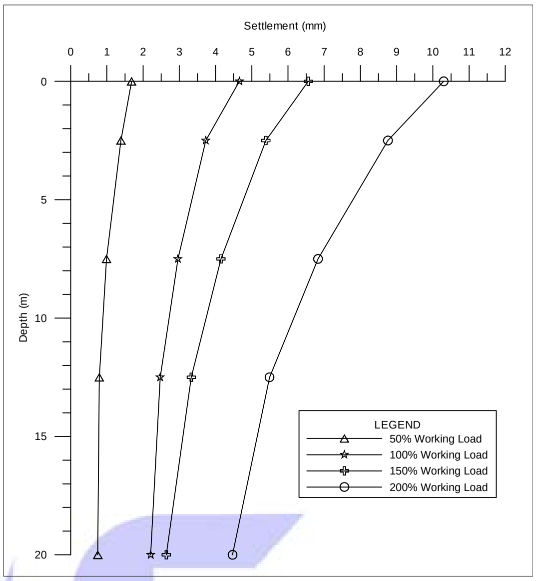
| Depth | Load (kN) | | | | Percentage of Load (%) | | | |
|---|---|---|---|---|---|---|---|---|
| | 50% working load | 100% working load | 150% working load | 200% working load | 50% working load | 100% working load | 150% working load | 200% working load |
| 0 | 1,810 | 3,790 | 5,330 | 7,420 | 100 | 100 | 100 | 100 |
| 2.5 | 1,810 | 3,790 | 5,330 | 7,420 | 100 | 100 | 100 | 100 |
| 7.5 | 900 | 2,200 | 3,320 | 4,910 | 50 | 58 | 62 | 66 |
| 12.5 | 510 | 1,400 | 2,240 | 3,560 | 28 | 37 | 42 | 48 |
| 19 | 70 | 200 | 350 | 660 | 4 | 5 | 7 | 9 |
| 20 | 0 | 20 | 50 | 220 | 0 | 1 | 1 | 3 |

### 23.4.7 Presentation of Graphs (sample)

**1. Depth Vs Load**

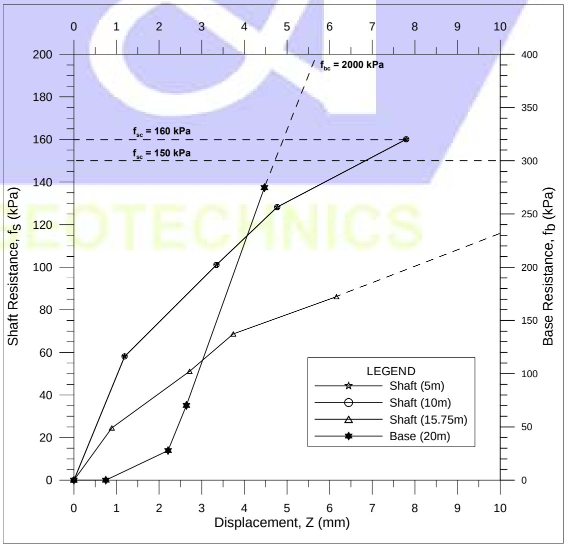


## 2. **Depth Vs Pile Settlement** (sample)




Note: pile settlement at particular level is obtained from the extensometer readings.

## 3. **Load Transfer Curve for Shaft Friction and End Bearing** (sample)



## 4. **Depth Vs Shaft Friction and End Bearing** (sample)