Research Topic

Analysis of Instrumented Pile Load Test Results

2005

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Overview

- Routine Static Load Test
  - Load- Settlement at Pile Head
  - Shaft Friction in Different Layers
  - Shaft Friction and End Bearing
  - Optimise Pile Lengths & Behaviour

- Pile Instrumentation
  - Strain Gauges
  - Extensometers
  - Pressure Cells

Objective

- Pile Instrumentation Scheme
- Review Interpretation procedures
- Review Analysis Methodology
- Load-Transfer Method
- Analyse Instrumented Test Results
- Derive Design Parameters & Load-transfer Curves – Kenny Hill, Old Alluvium

Pile Instrumentation

- Strain Gauges
  - Vibrating Wire – reliable, effective tool
  - Sensor output – frequency
  - Types – Concrete embedment type, Sister bar strain gauge (robust)
- Extensometers
  - Mechanical Rod Type, Retrievable Extensometers




Instrumented Pile Load Test Data

Projects –

- Gerbang Selatan Bersepadu – 13 nos.
- Kompleks Makamah – 3 nos.
- Jalan Kelang Lama – 1 no.

Geology

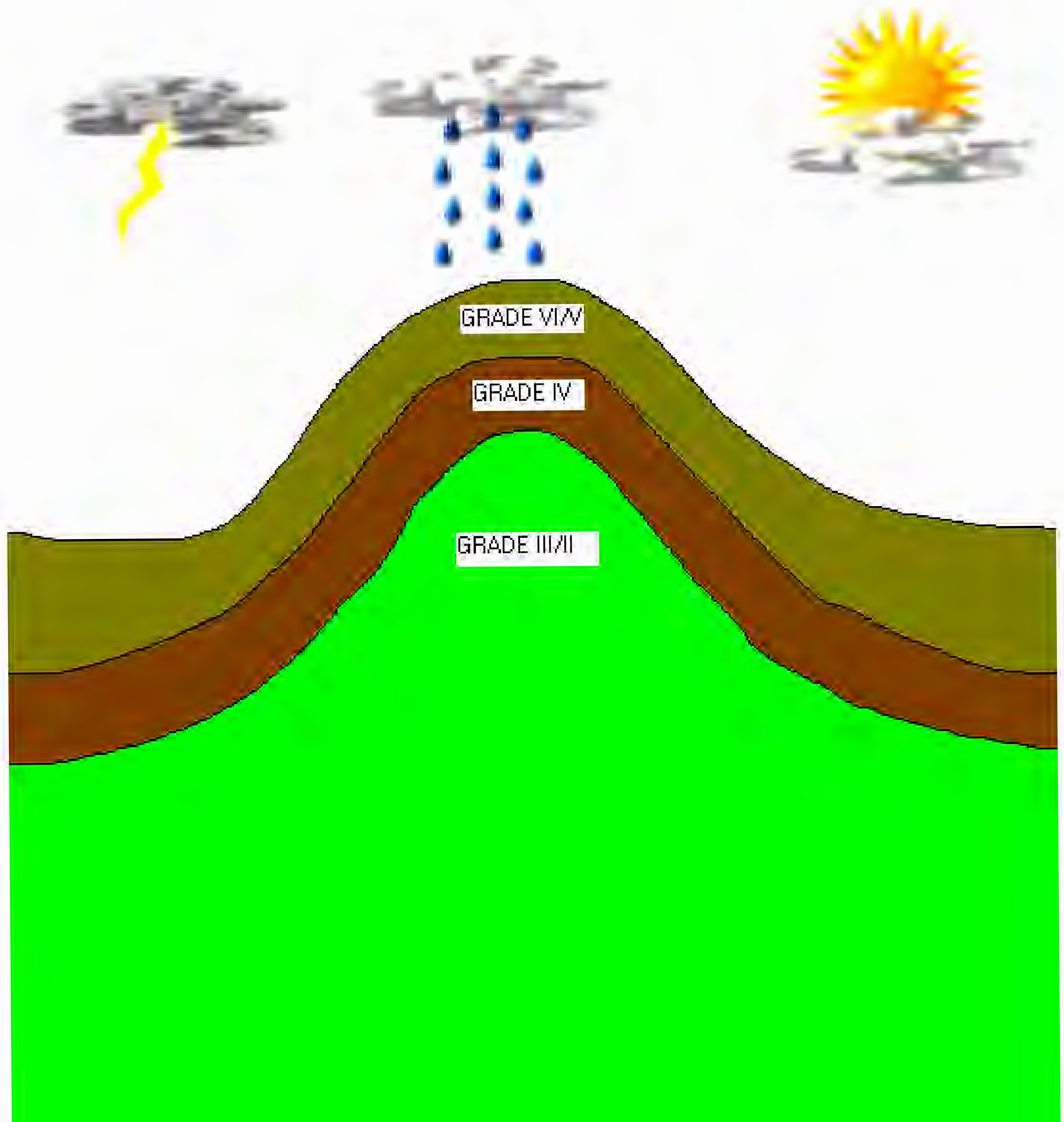
- Kenny Hill – Kompleks Makamah & Jln. Kelang Lama
- Old Alluvium – Gerbang Selatan Bersepadu

Instrumented Pile Load Test Data

No.	SITE LOCATION	INSTRUMENTED PILE NUMBER
1	Gerbang	ICW-01, Pile PTP1 (750mm dia)
2		ICW-01, Pile PTP2 (1000mm dia)
3		ICW-01, Pile PTP3 (1000mm dia)
4		ICW-01, Pile PTP4 (750mm dia)
5		ICW-01, Pile PTP5 (750mm dia)
6		Land Approach, Pile PC3/4 (1200 mm dia)
7		CIQ Main Office, Pile PTP1 (1000 mm dia)
8		CIQ Main Office, Pile PTP2 (900 mm dia)
9		CIQ Main Office, Pile GTP3 (1000 mm dia)
10		CIQ Main office, Pile GTP 5 (1200 mm dia)
11		JB Sentral, Pile PTP1 (1200 mm)
12		Cable Stayed Bridge, Pile 31/W (1500 mm dia)
13		Cable Stayed Bridge, Pile 23/E (1500 mm dia)
14	Kompleks Makamah	Pile ITP1 (750 mm)
15		Pile ITP2 (750 mm)
16		Pile ITP3 (750 mm)
17	Jalan Kelang Lama	Pile PTP2 (1000 mm dia)

Kenny Hill Formation

- Meta-sedimentary
- Interbedded sandstones, shale/mudstone, quartzite & phyllite
- Undergone intense weathering – thickness varies – parent material, geomorphology


GRADE VI/V
GRADE IV
GRADE III/II

GRADE VI

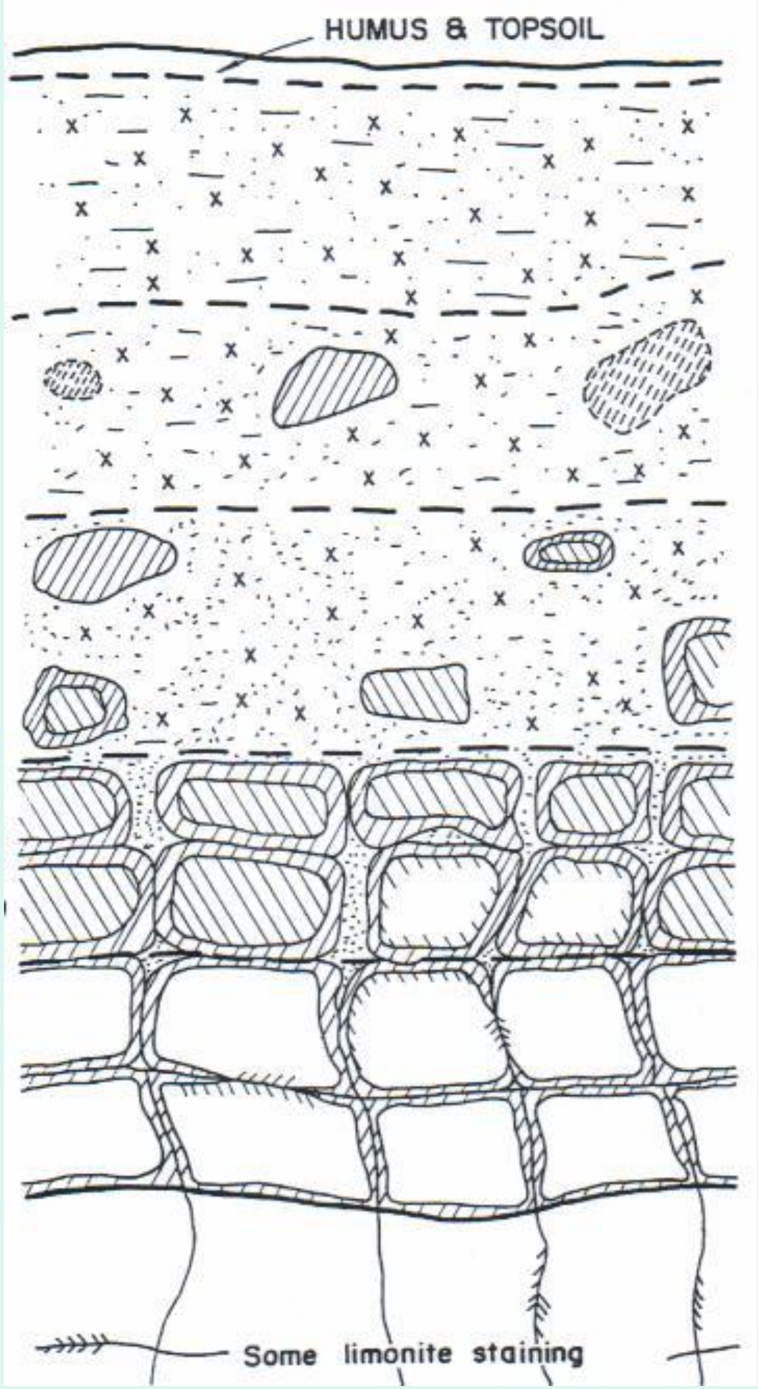
GRADE V

GRADE IV

GRADE III

GRADE II

GRADE I



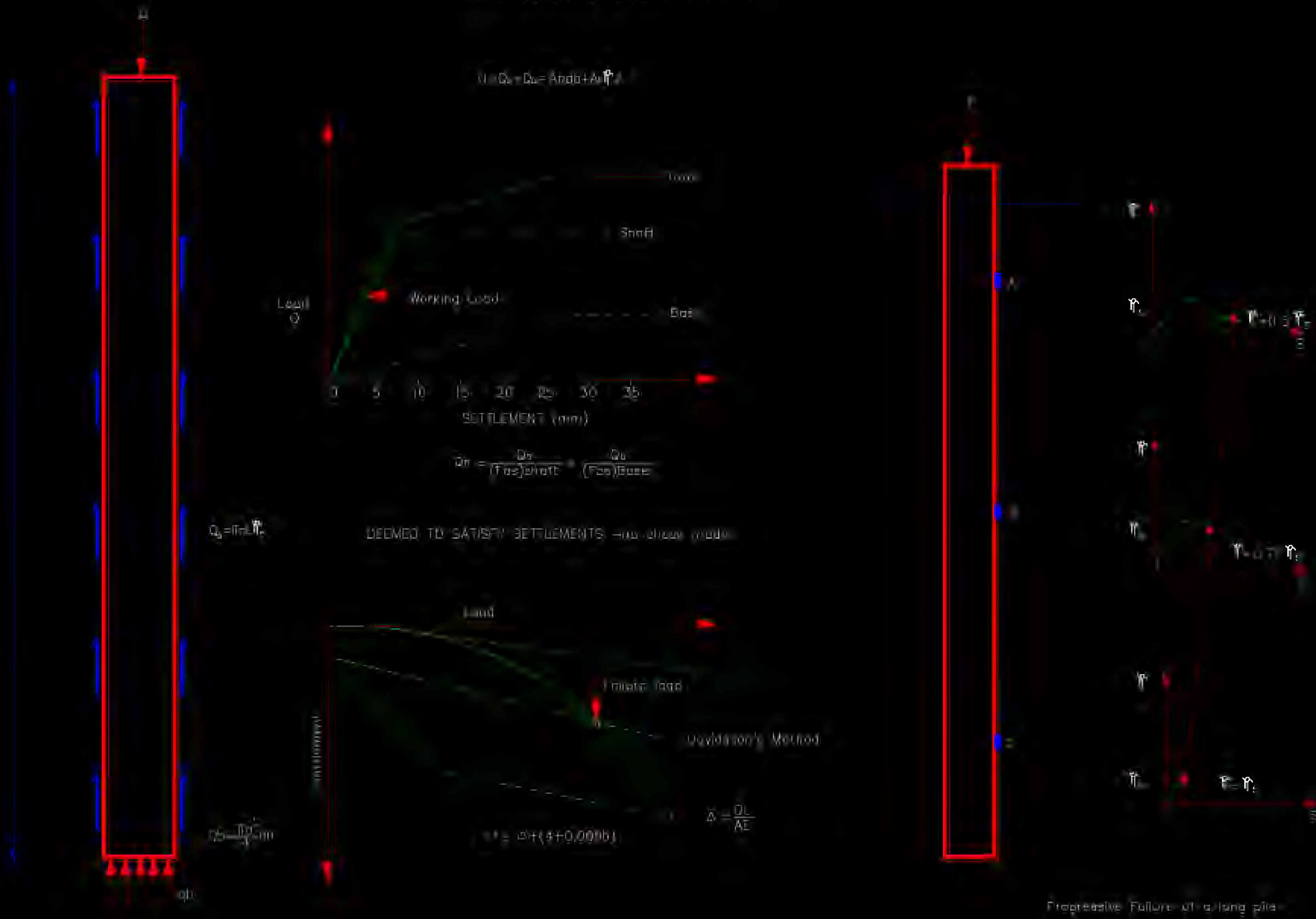
Old Alluvium

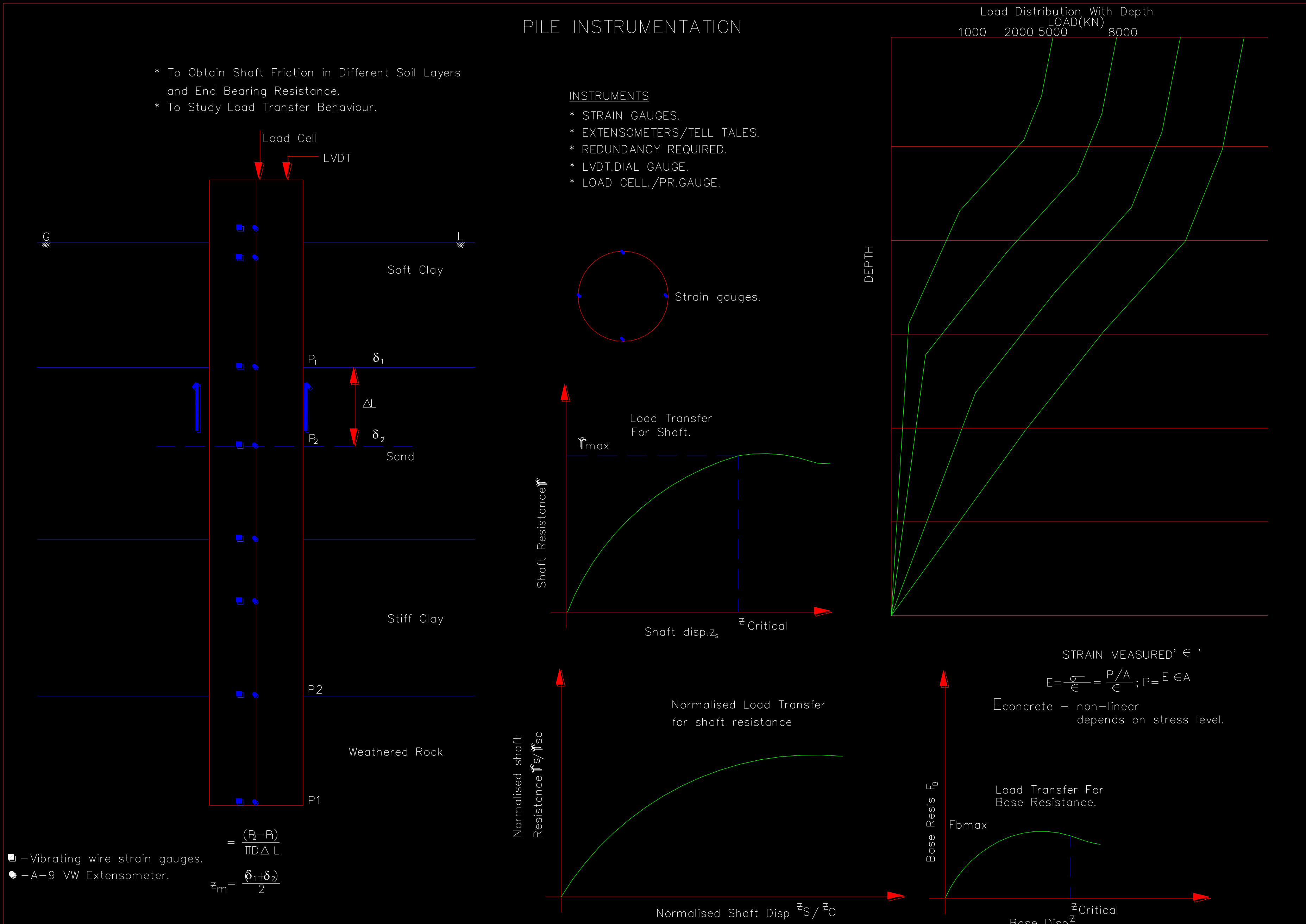
- Continental deposits of SAND, CLAY & Boulder Beds of fluviate and shallow marine origin.
- Base of this formation – 100m and 145m below sea level.

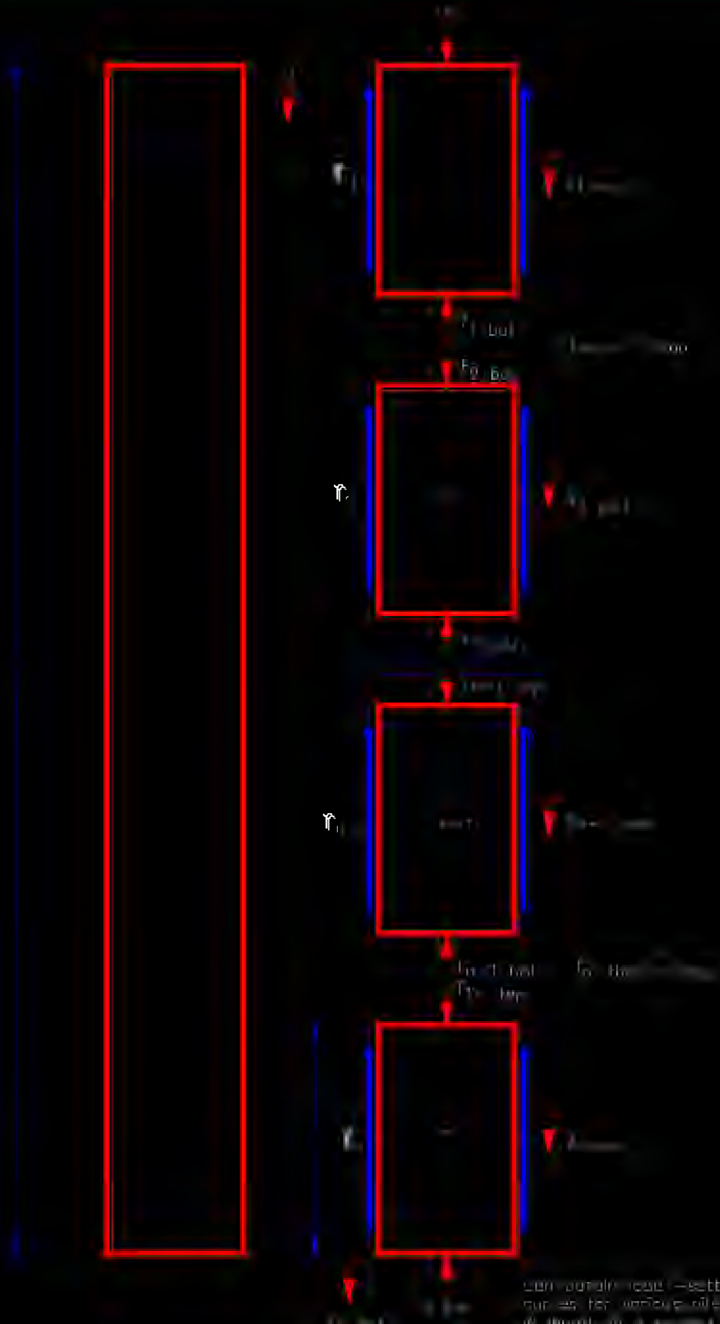
Load Deformation Analysis

- Elastic Analytical Methods
  - Mindlin's equations – Poluos and Davis
  - Randolph and Wroth – closed form soln.
- Numerical Methods – relatively complex
  - Finite Element Method
  - Boundary Element Method
- Load Transfer Method
  - Load transfer characteristics should be known
  - Can be obtained from instrumented pile load tests

PILE DESIGN & BEHAVIOUR




PILE INSTRUMENTATION
* To Obtain Shaft Friction in Different Soil Layers and End Bearing Resistance.
* To Study Load Transfer Behaviour.
Load Cell
LVDT
G
L
Soft Clay
P1
δ1
ΔL
P2
δ2
Sand
Stiff Clay
P2
Weathered Rock
P1
= (P2−P1) / ΠDΔL
zm = (δ1+δ2) / 2
−Vibrating wire strain gauges.
−A−9 VW Extensometer.
INSTRUMENTS
* STRAIN GAUGES.
* EXTENSOMETERS/TELL TALES.
* REDUNDANCY REQUIRED.
* LVDT.DIAL GAUGE.
* LOAD CELL./PR.GAUGE.
Strain gauges.
Load Transfer For Shaft.
fmax
Shaft Resistance f
Shaft disp.zs
z Critical
Normalised Load Transfer for shaft resistance
Normalised shaft Resistance fs/fsc
Normalised Shaft Disp zS/zC
Load Distribution With Depth
LOAD(KN)
1000
2000 5000
8000
DEPTH
STRAIN MEASURED' ∈ '
E = σ/∈ = (P/A)/∈ ; P = E∈A
Econcrete − non−linear depends on stress level.
Load Transfer For Base Resistance.
Base Resis FB
Fbmax
z Critical
Base Disp z



Computed load – settlement curves for various pile diameter & length in a layered

LOAD TRANSFER METHOD

ANALYSIS METHODOLOGY

1. [illegible] the pile into number of segments.
2. Consider the bottom segment "n". Assume a small displacement.
3. [illegible] load P_{bot} [elastic analysis] $= \frac{\pi D E s_{bot}}{1-\nu}$
4. [illegible] assume $\delta_{mid} = \delta_{bot}$
5. Using [illegible] curve for δ_{mid} find corresponding τ_{mid}
6. Compute the load $P_{top} = P_{bot} + (\tau_{mid} \cdot \pi D L)$
7. Assuming linear variation of load distribution along length, segment load at mid point of segment $P_{mid} = \frac{P_{top} + P_{bot}}{2}$
8. Calculate elastic deformation of lower half of segment

$$\Delta \delta = \frac{\frac{P_{bot} + P_{mid}}{2} \times \frac{L}{2}}{AE}$$

9. Calculate displacement of segment mid $\delta_{mid} = \delta_{bot} + \Delta\delta_{bot}$
10. Compare δ_{mid} assumed value in step(4). If outside certain tolerance, assume δ_{mid} as calculated in step(9) & repeat until tolerance is satisfied.
11. Proceed to segment (n-1). Repeat steps (3) to (10) with the following load & displacement values at bottom of segment (n-1)

$P_{(n-1)bot} = P_{ntop}$; $\delta_{(n-1)bot} = \delta_{nmid} + \Delta\delta_{ntop}$; $\left[\Delta \delta_{ntop} = \frac{\frac{P_{top} + P_{mid}}{2} \times \frac{L}{2}}{AE}\right]$

12. Continue in this manner up through segments until load and displacement at pile head is obtained.
13. Steps (1) to (11) repeated for different values of displacement to get load displacement curve.

Generation of Load Transfer Curves

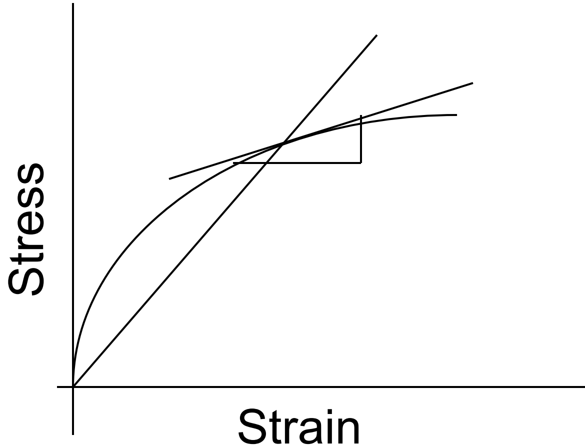
- Usage of Instrumented Pile Load Test result
- Assumption – Strain in steel = strain in concrete.
- P = strain x Area x E
- fsm = (Ptop – P bot)/pi x dia x length
- Mid-shaft movement – linearly interpolated.
- Process repeated for each head load.

Modulus Estimates

- Fellenius (1989, 2001) proposed a method of first determining the tangent modulus from strain gauge measurements and then using it to determine the secant modulus. The stress at a plane is then equal to the secant modulus multiplied by the strain.
- The procedure is based on the fact that, after the side shear on a shaft is fully mobilized and no longer changes with loading, the changes in stress and strain at the plane of the strain gauges reflect the composite modulus of the shaft at that loading.
- One of the limitation of the method is the need to reach or exceed ultimate side shear values during the test. A second limitation is that the total strain at the plane of interest must reach at least 50 micro-strain and preferably more then 200 micro-strain (Hayes J and Simmonds T, 2003).

Modulus Estimates

- The equation of the tangent line is:
  $M = (d\sigma/d\varepsilon) = A\varepsilon + B$ (1)
  which can be integrated to:
  $\sigma = (A/2)\varepsilon 2 + B\varepsilon$ (2)
  However, $\sigma = Es\ \varepsilon$ (3)
  Therefore, $Es = 0.5A\varepsilon + B$



where M = tangent modulus of composite material
Es = secant modulus of composite material
σ = stress (load divided by cross section area)
ε = measured strain
dσ = change of stress from one load increment to the next
dε = change of strain from one load increment to the next
A = slope of tangent modulus
B = y-intercept of tangent modulus line

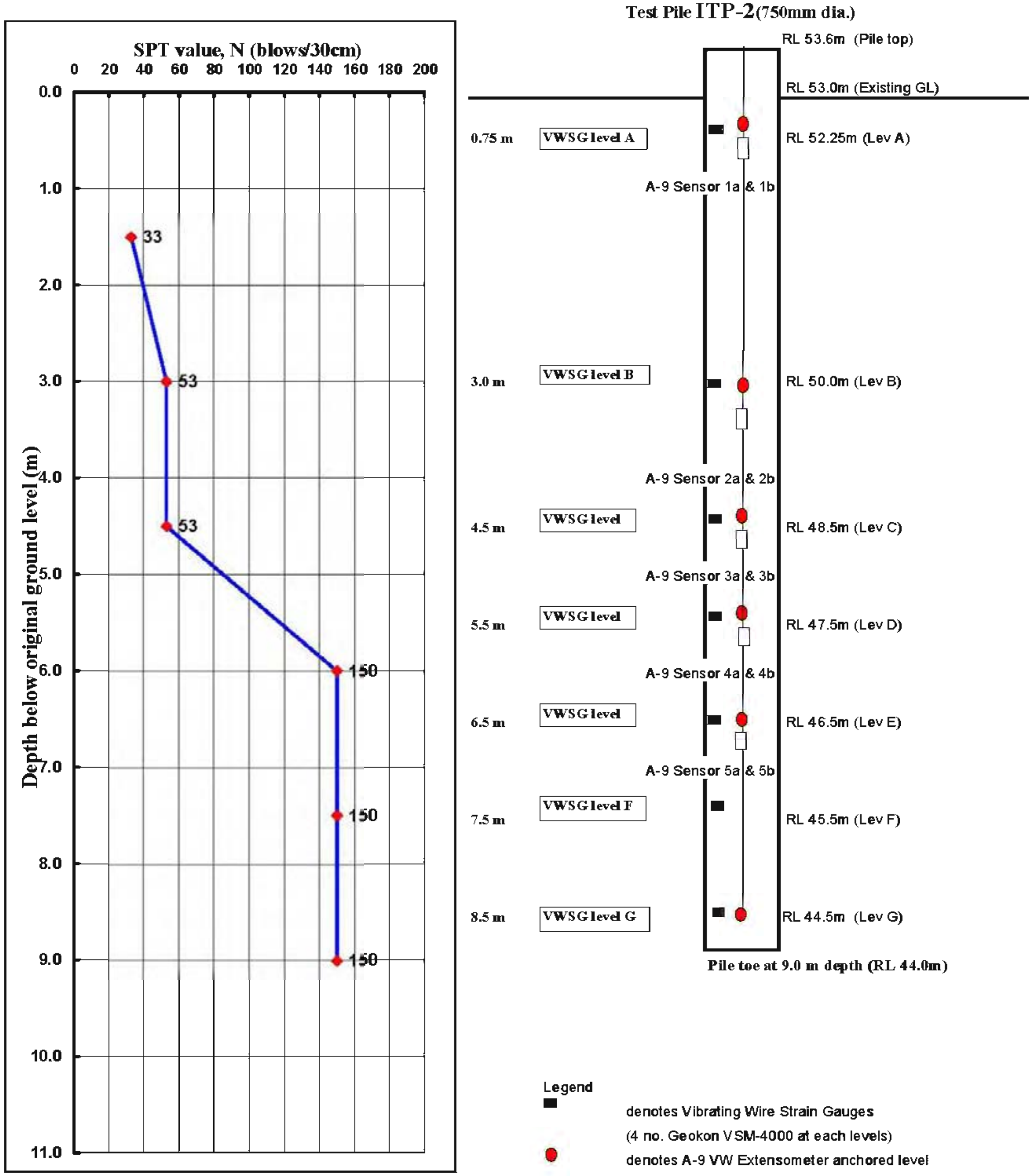
Normalised Load Transfer Curves

- Full mobilisation of the shaft resistance
- fsc, Zsc selected
- The shaft resistance and shaft displacement were normalised with fsc and Zsc and plotted.

Typical Results In Kenny Hill Formation

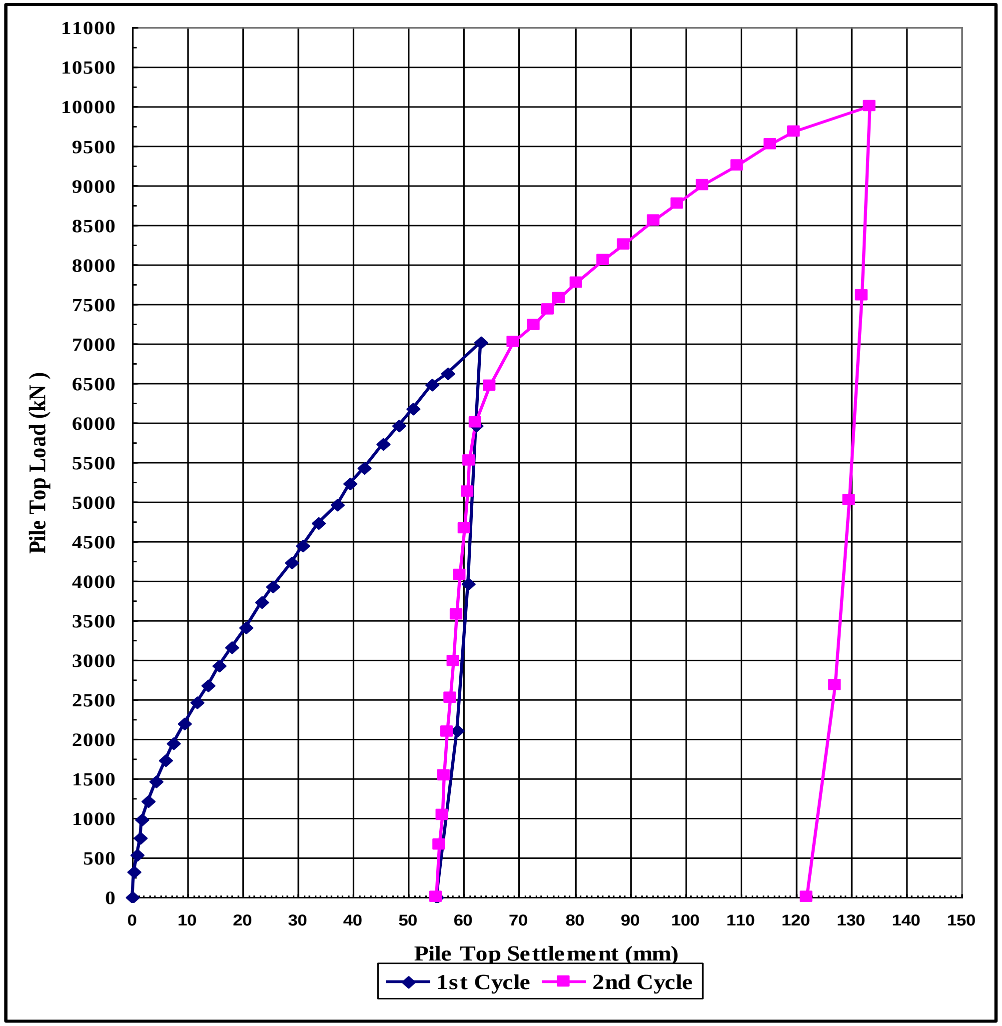
Project : Kompleks Mahkamah, Jalan Duta, Kuala Lumpur.

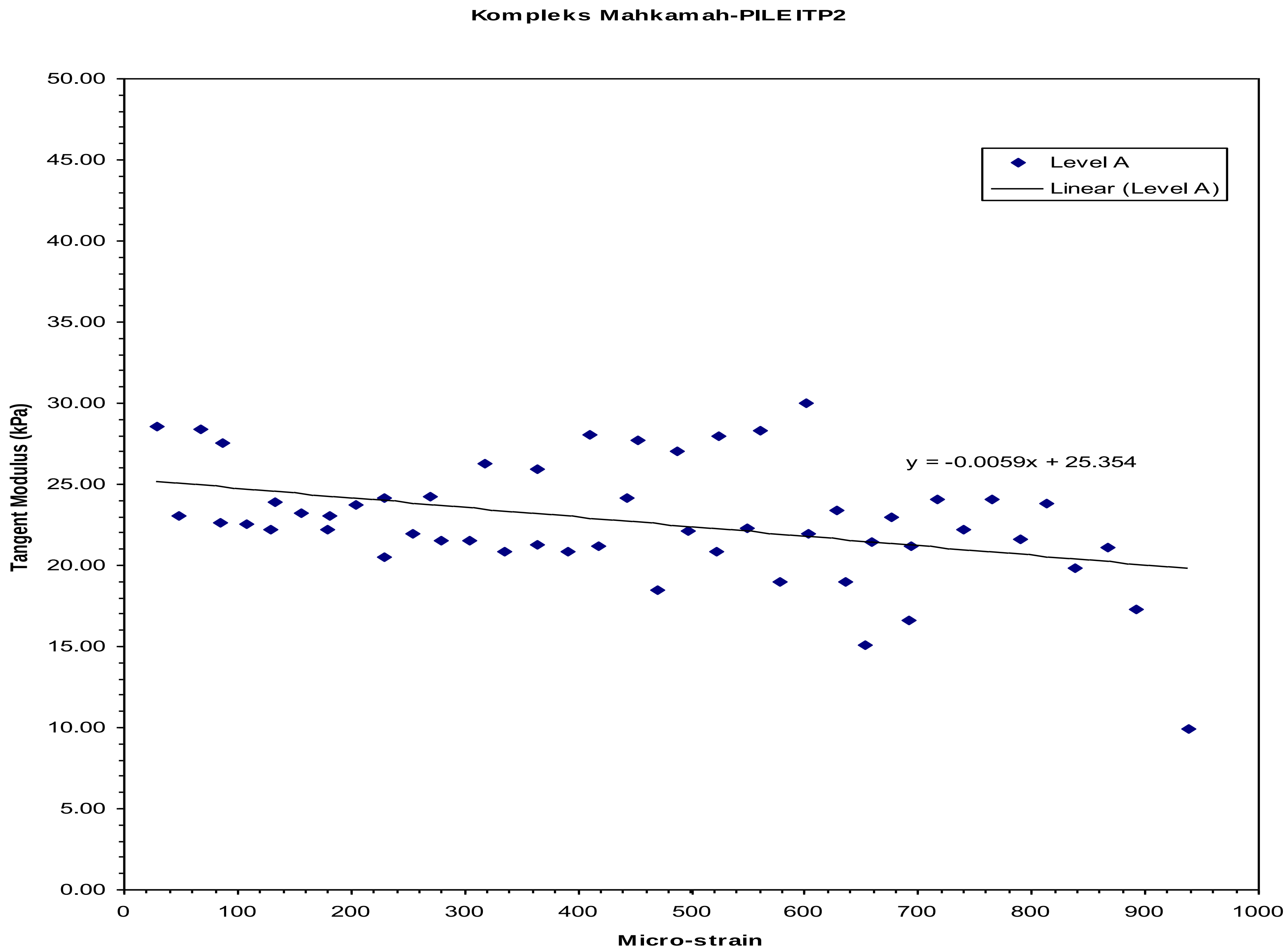
Instrumentation levels for Preliminary Test Pile ITP-2 (750mm dia.) @ G/L 14/C-D, Zone C (Left).
Pile length given = 9.0m from Existing Ground.



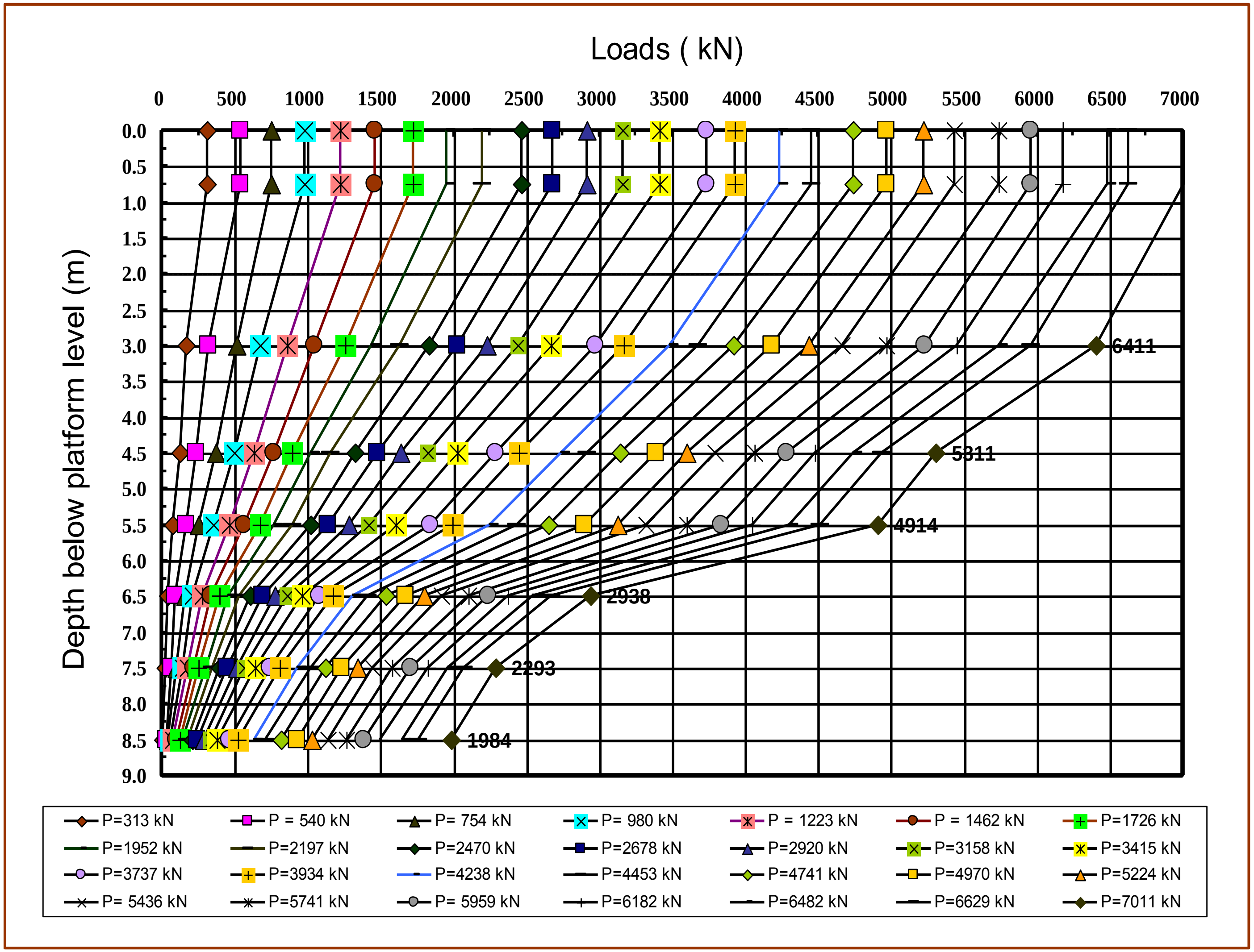
(S.I. Borehole NBH 1)

PLOT OF PILE TOP LOADS (kN) VS PILE TOP SETTLEMENT (mm) FOR 1st & 2nd CYCLE OF MAINTAINED LOAD TESTING

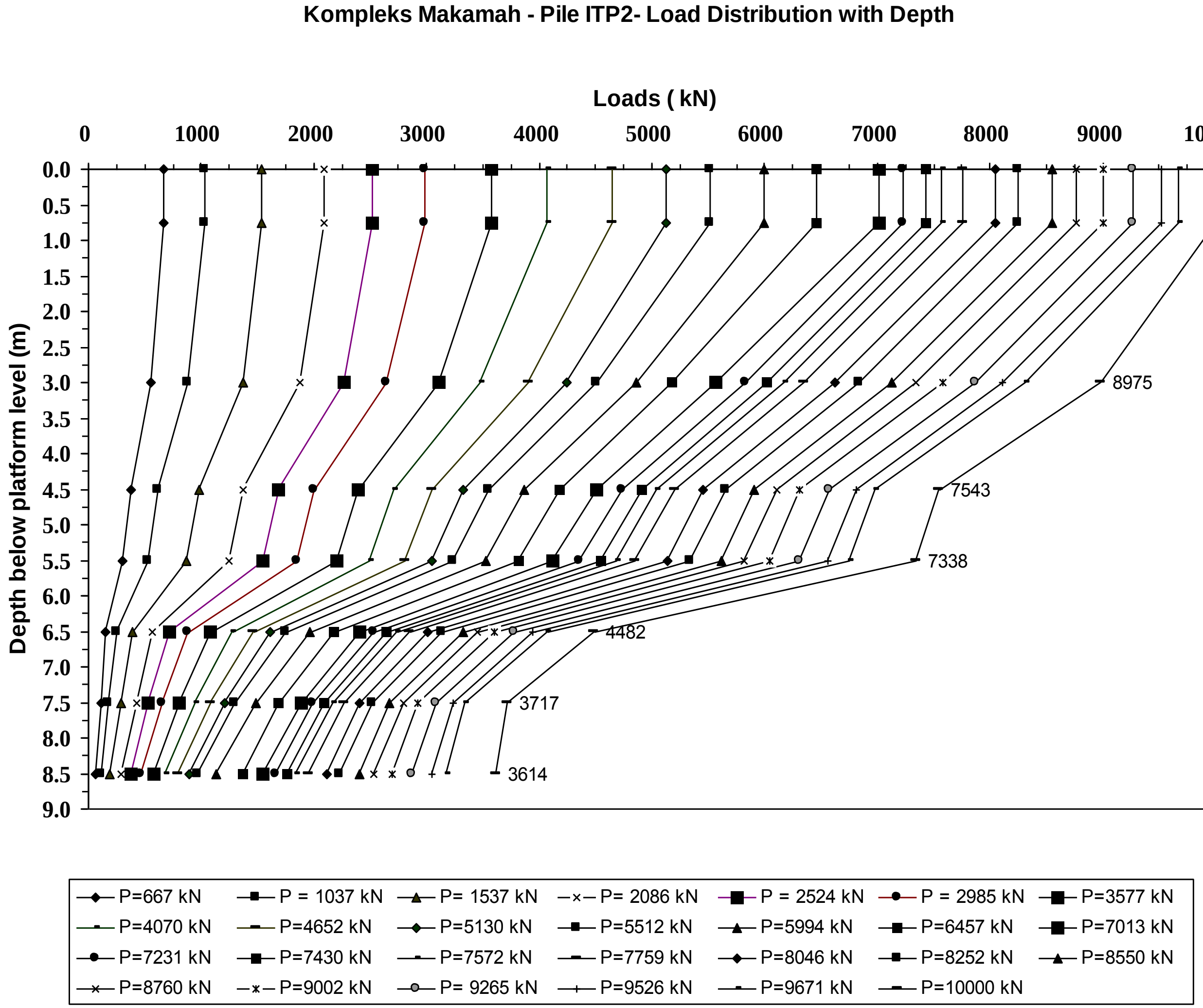


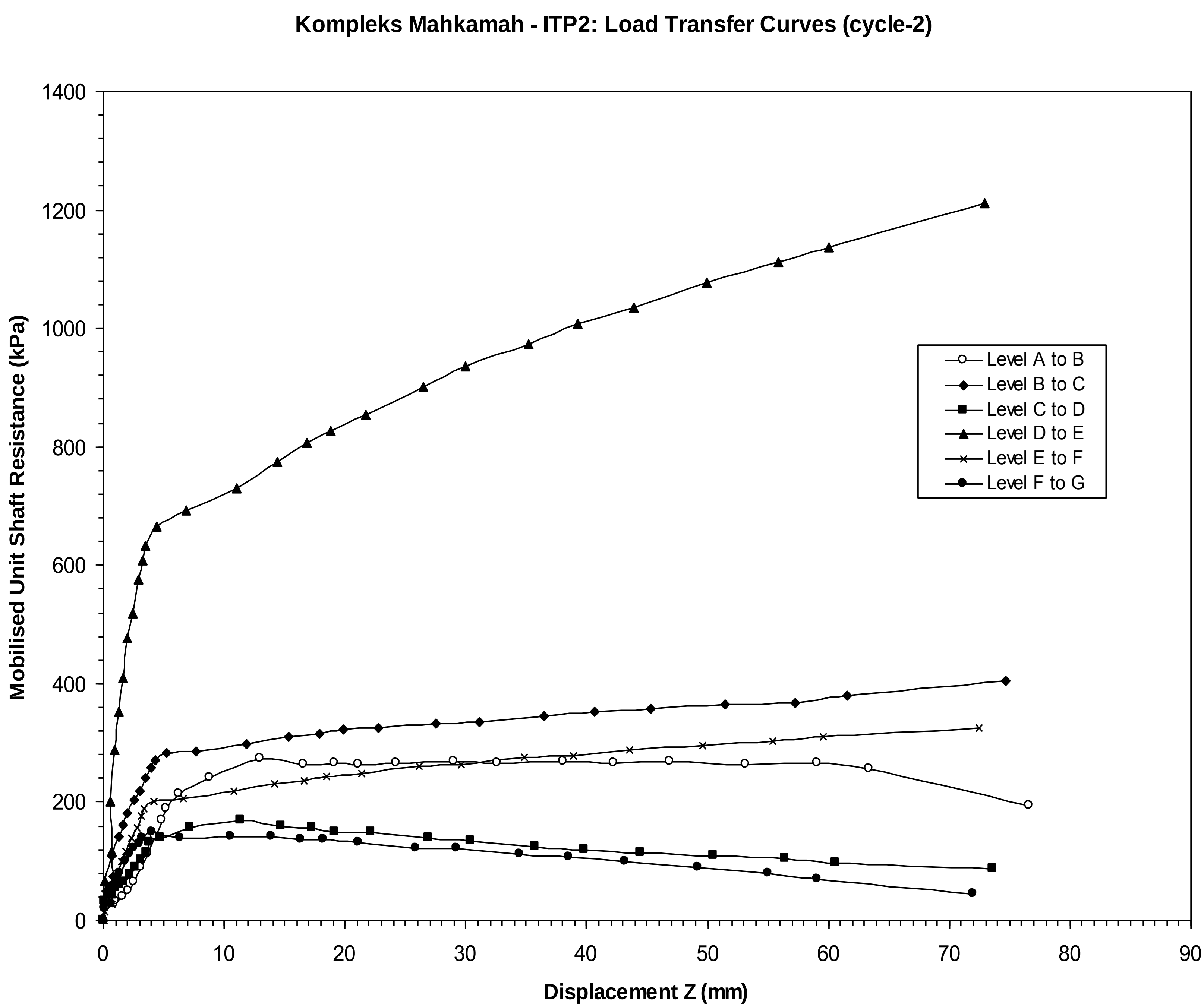

Kompleks Mahkamah-PILE ITP2
Tangent Modulus (kPa)
Micro-strain
Level A
Linear (Level A)
y = -0.0059x + 25.354
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
100
200
300
400
500
600
700
800
900
1000

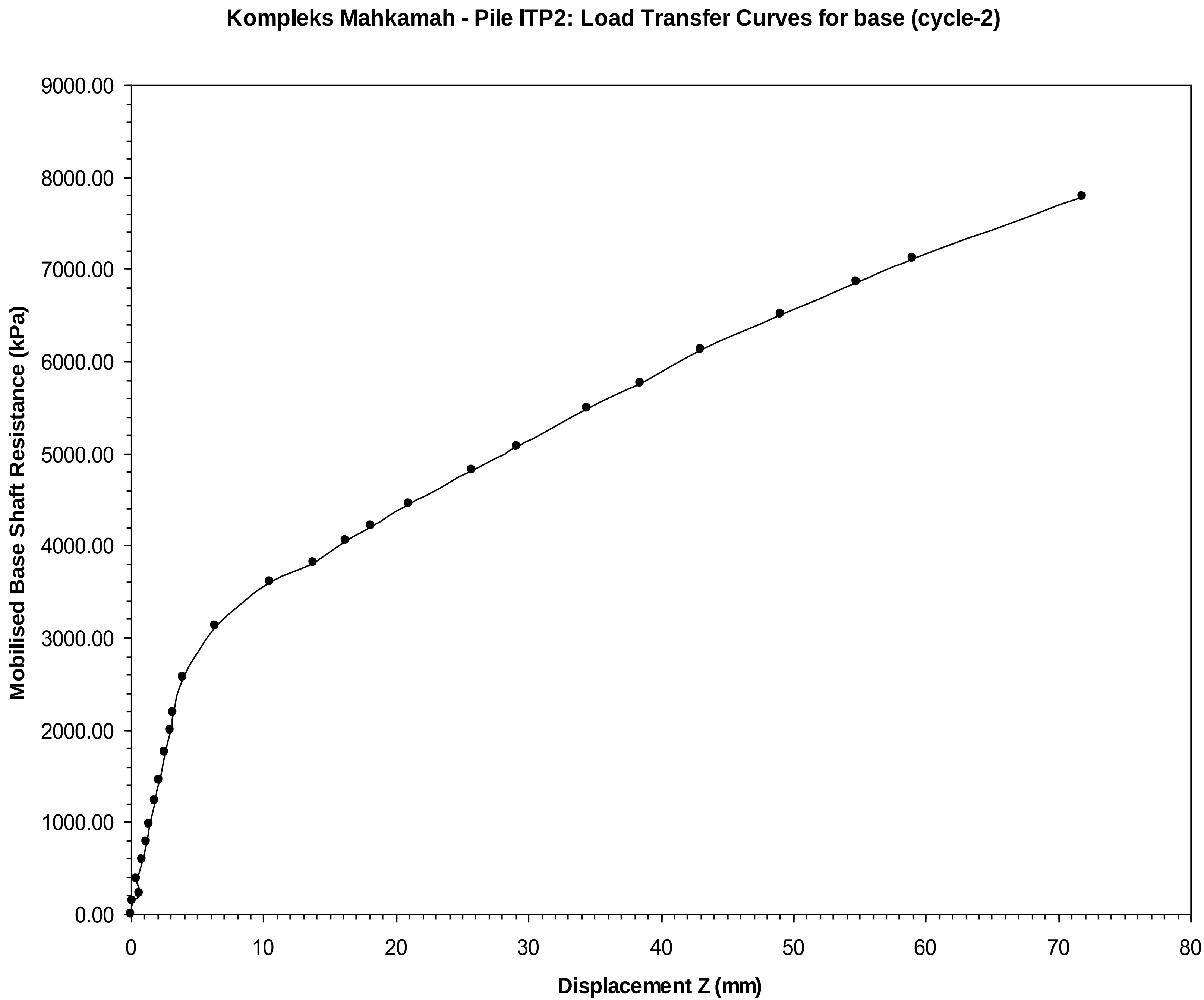
LOAD DISTRIBUTION CURVE FOR 1st CYCLE COMPUTED FROM VWSGs TEST RESULTS



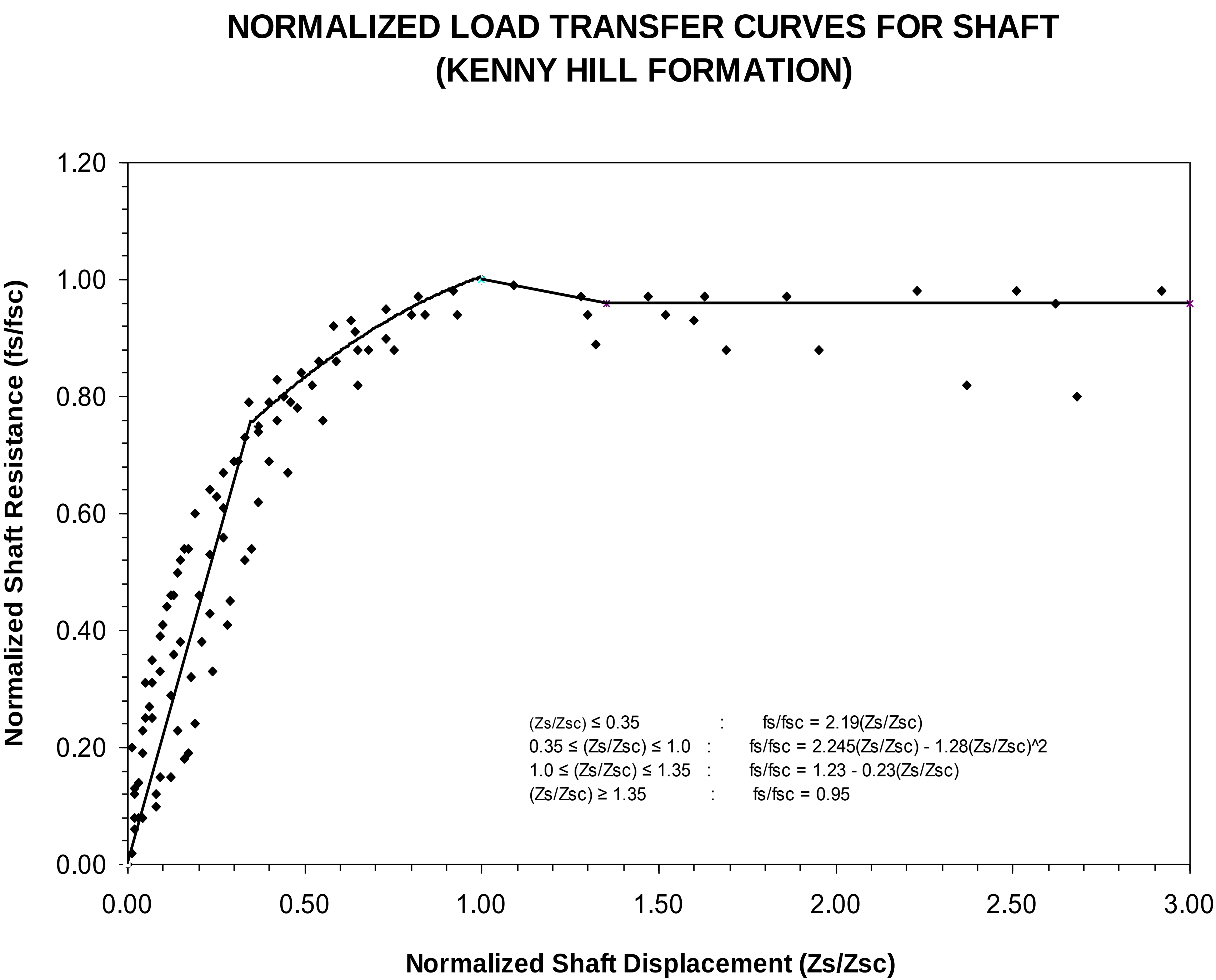
LOAD DISTRIBUTION CURVE FOR 2nd CYCLE COMPUTED FROM VWSGs TEST RESULTS




Kompleks Mahkamah - ITP2: Load Transfer Curves (cycle-2)
Mobilised Unit Shaft Resistance (kPa)
Displacement Z (mm)
Level A to B
Level B to C
Level C to D
Level D to E
Level E to F
Level F to G
0
200
400
600
800
1000
1200
1400
0
10
20
30
40
50
60
70
80
90

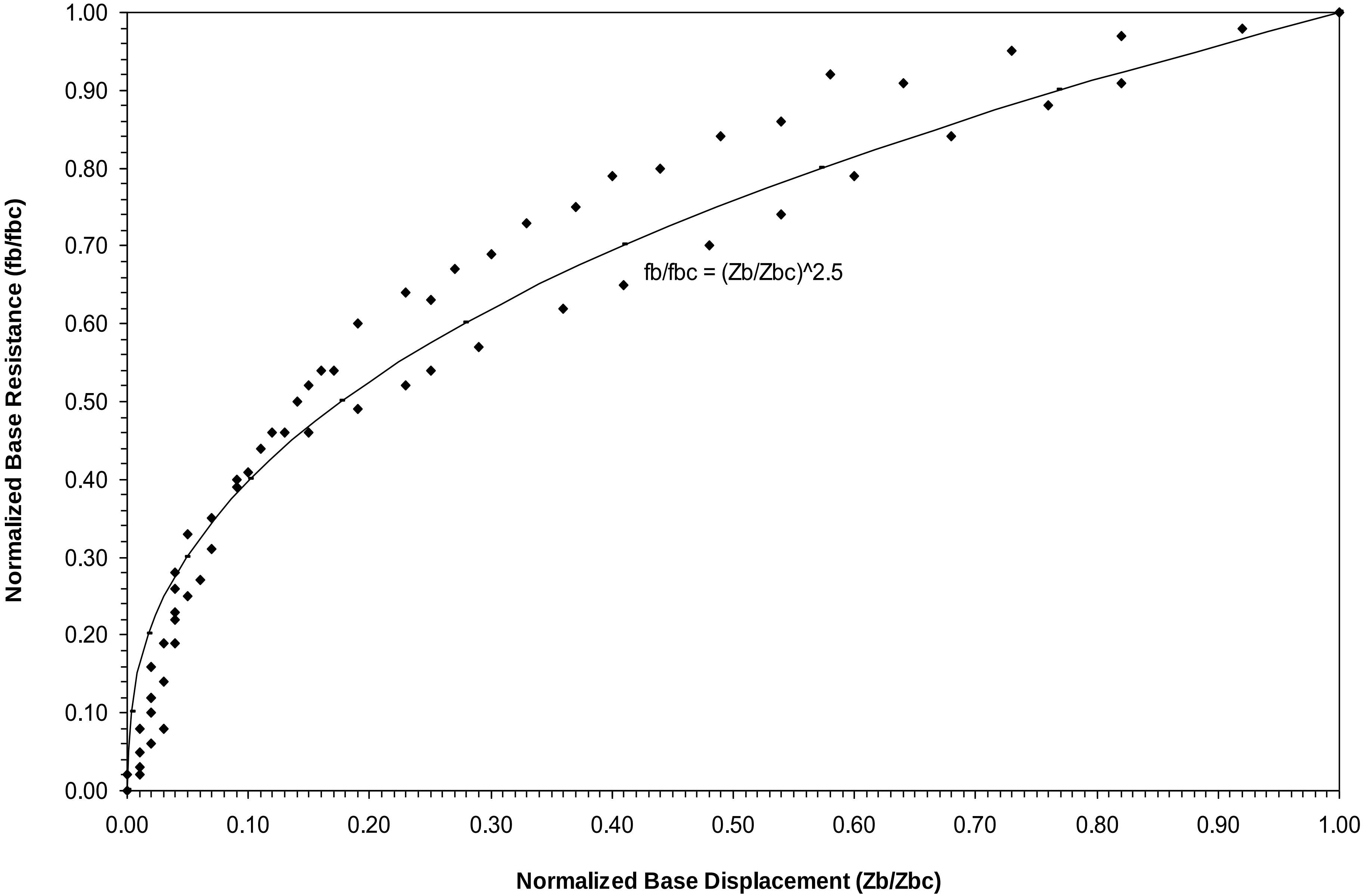

Kompleks Mahkamah - Pile ITP2: Load Transfer Curves for base (cycle-2)
Mobilised Base Shaft Resistance (kPa)
Displacement Z (mm)
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0
10
20
30
40
50
60
70
80

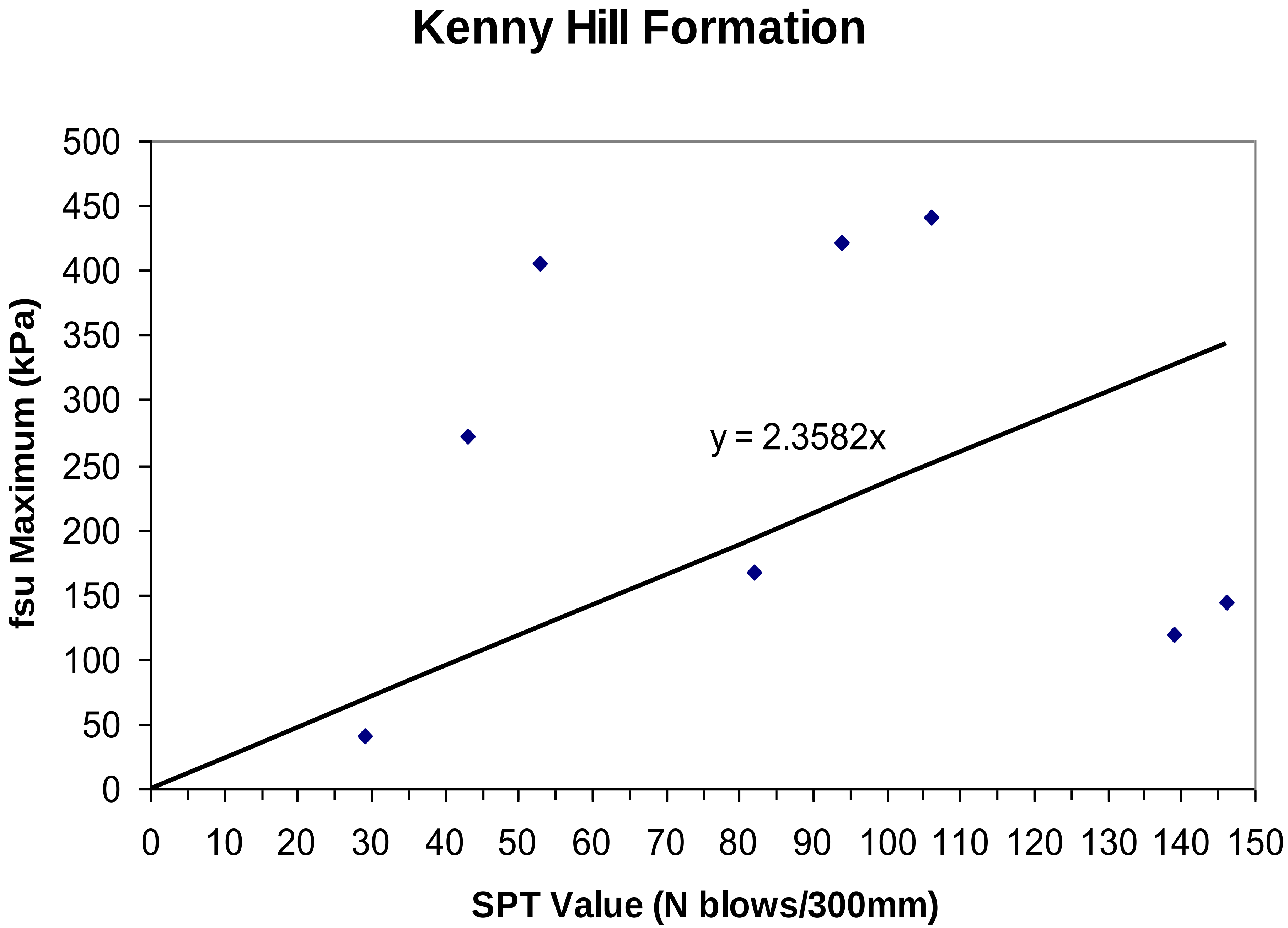
Normalised Load Transfer Curves for Kenny Hill Formation



NORMALIZED LOAD TRANSFER CURVES FOR SHAFT
(KENNY HILL FORMATION)
Normalized Shaft Resistance (fs/fsc)
Normalized Shaft Displacement (Zs/Zsc)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
(Zs/Zsc) ≤ 0.35 : fs/fsc = 2.19(Zs/Zsc)
0.35 ≤ (Zs/Zsc) ≤ 1.0 : fs/fsc = 2.245(Zs/Zsc) - 1.28(Zs/Zsc)^2
1.0 ≤ (Zs/Zsc) ≤ 1.35 : fs/fsc = 1.23 - 0.23(Zs/Zsc)
(Zs/Zsc) ≥ 1.35 : fs/fsc = 0.95

NORMALIZED LOAD TRANSFER CURVES FOR BASE
(KENNY HILL FORMATION)

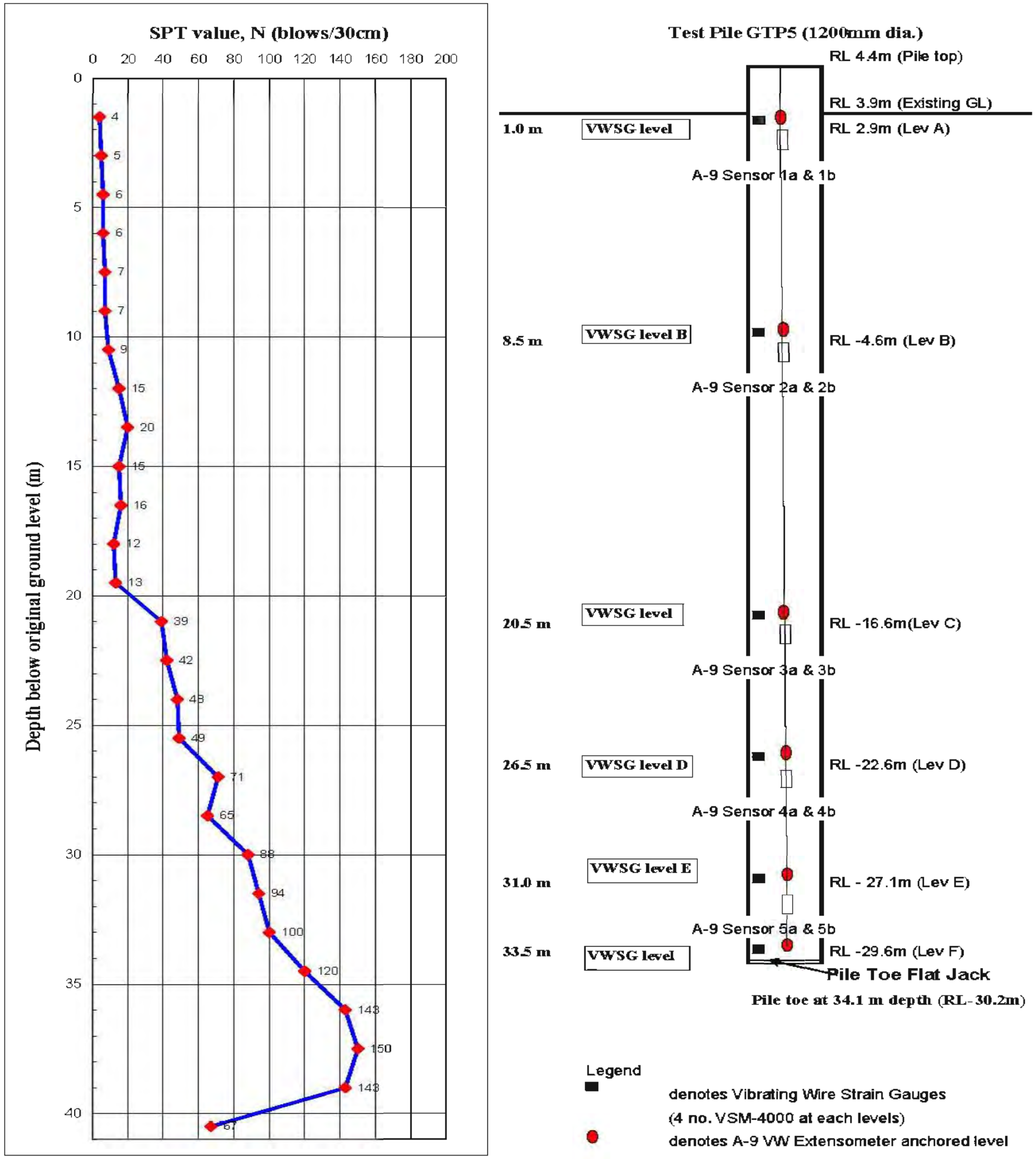



Kenny Hill Formation
fsu Maximum (kPa)
500
450
400
350
300
250
200
150
100
50
0
y = 2.3582x
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
SPT Value (N blows/300mm)

Typical Results in Old Alluvium

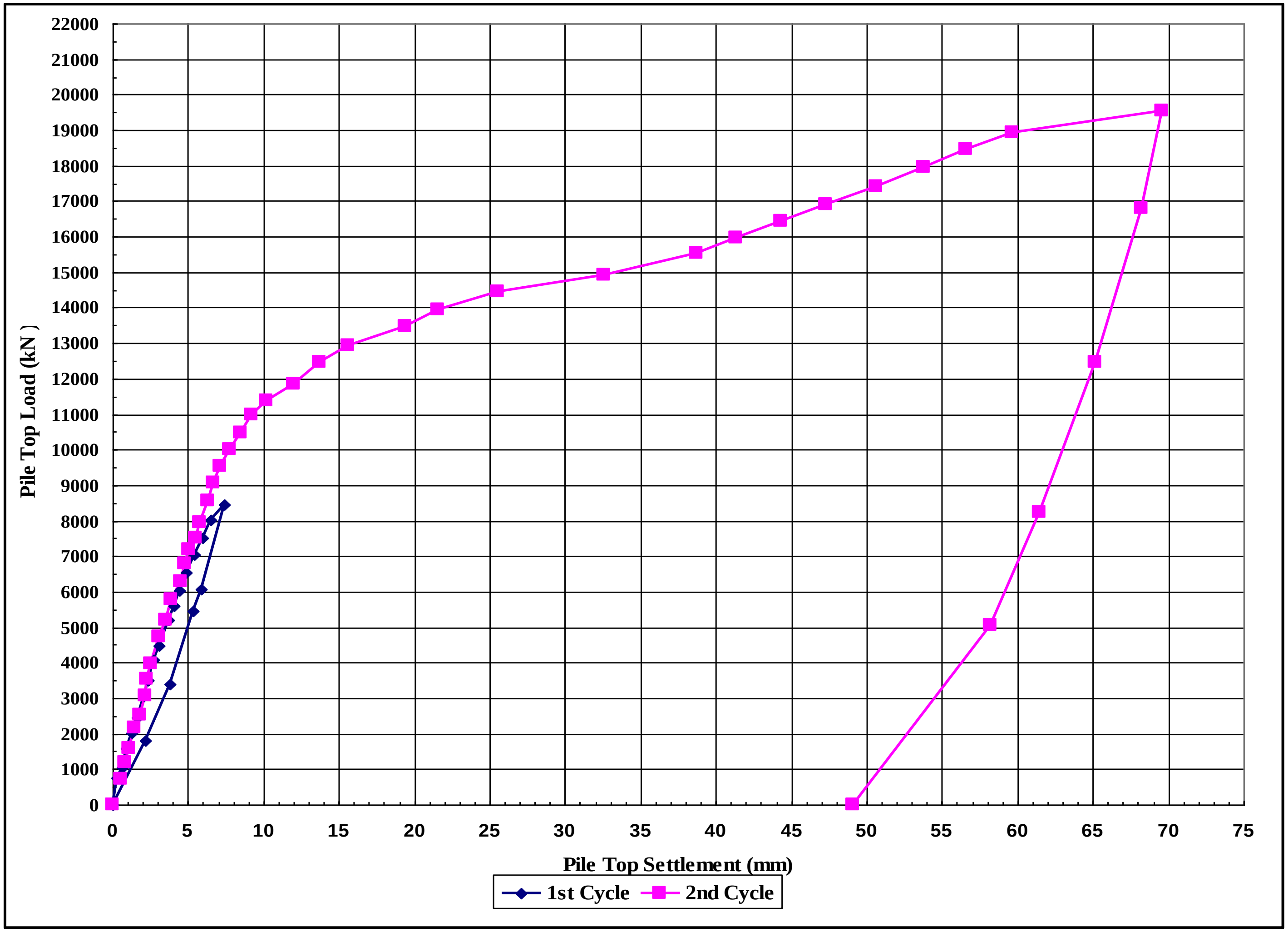
Gerbang Selatan Bersepadu:
CIQ Piling Works At Bukit Cagar, Johor Bahru.

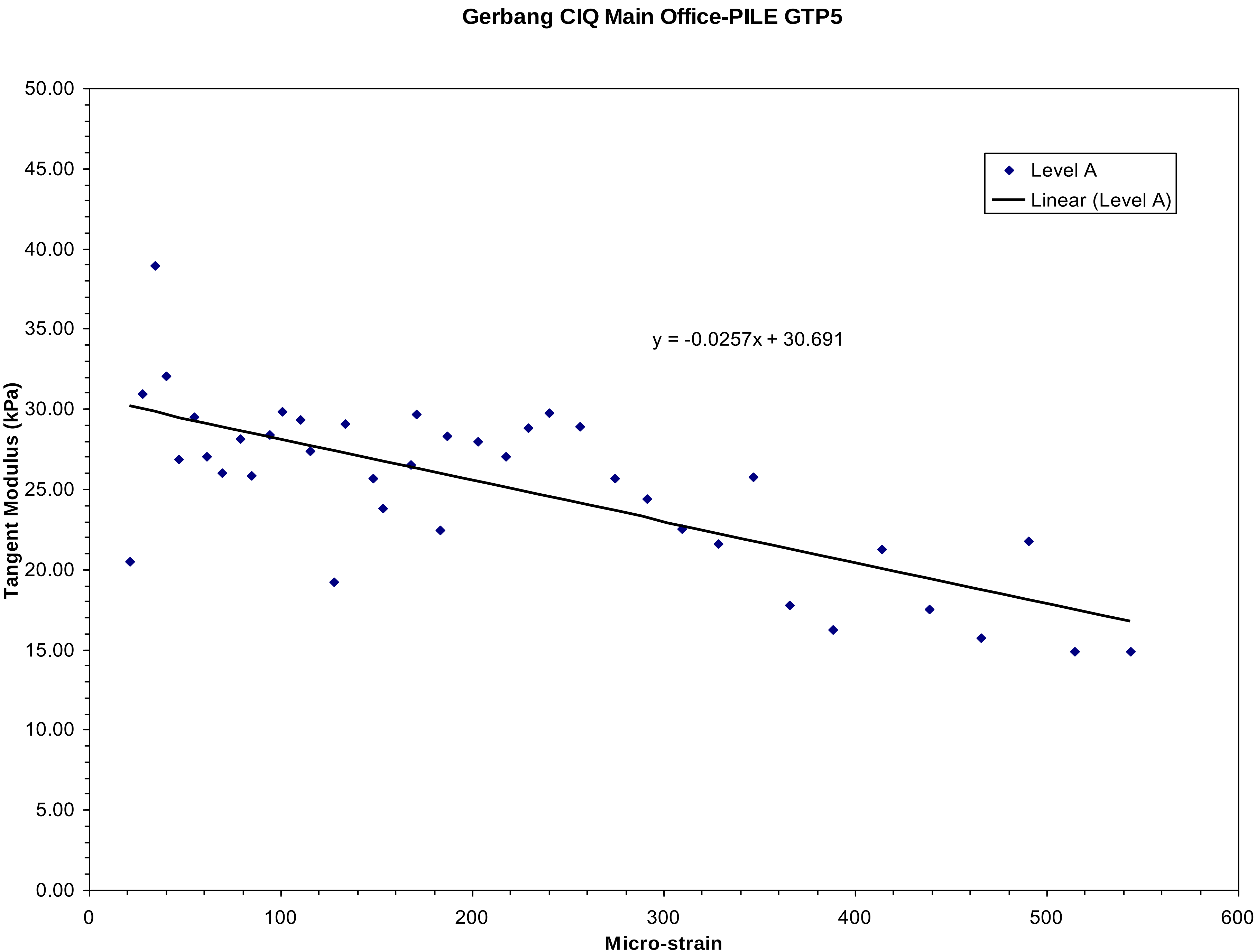
Instrumentation levels for test pile GTP5 (1200mm dia.)
As-built Pile length = 34.1 from Existing Ground Level of RL 3.9m



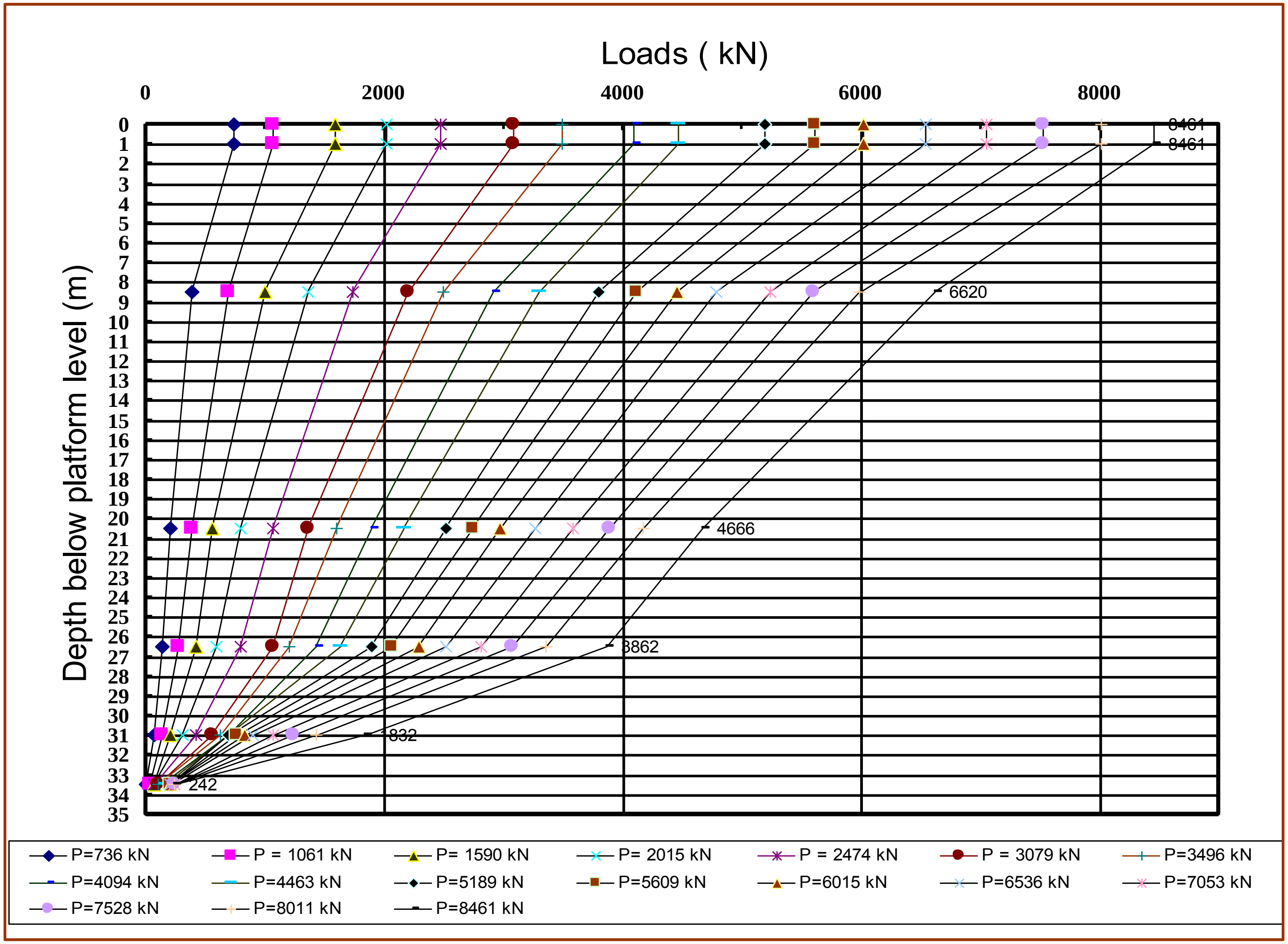
(S.I. Borehole ABH1)

PLOT OF PILE TOP LOADS (kN) VS PILE TOP SETTLEMENT (mm) FOR 1st & 2nd CYCLE OF MAINTAINED LOAD TESTING

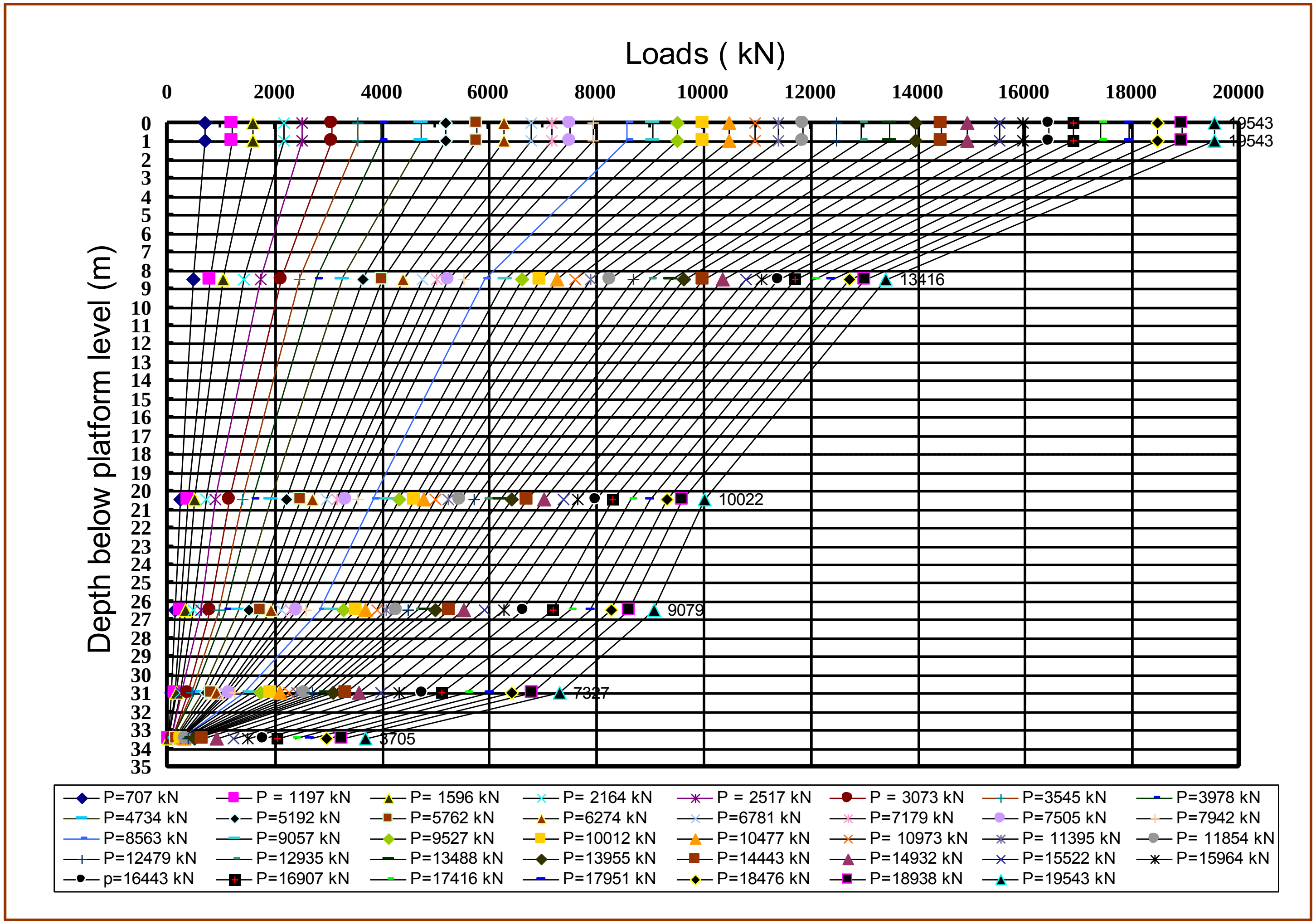


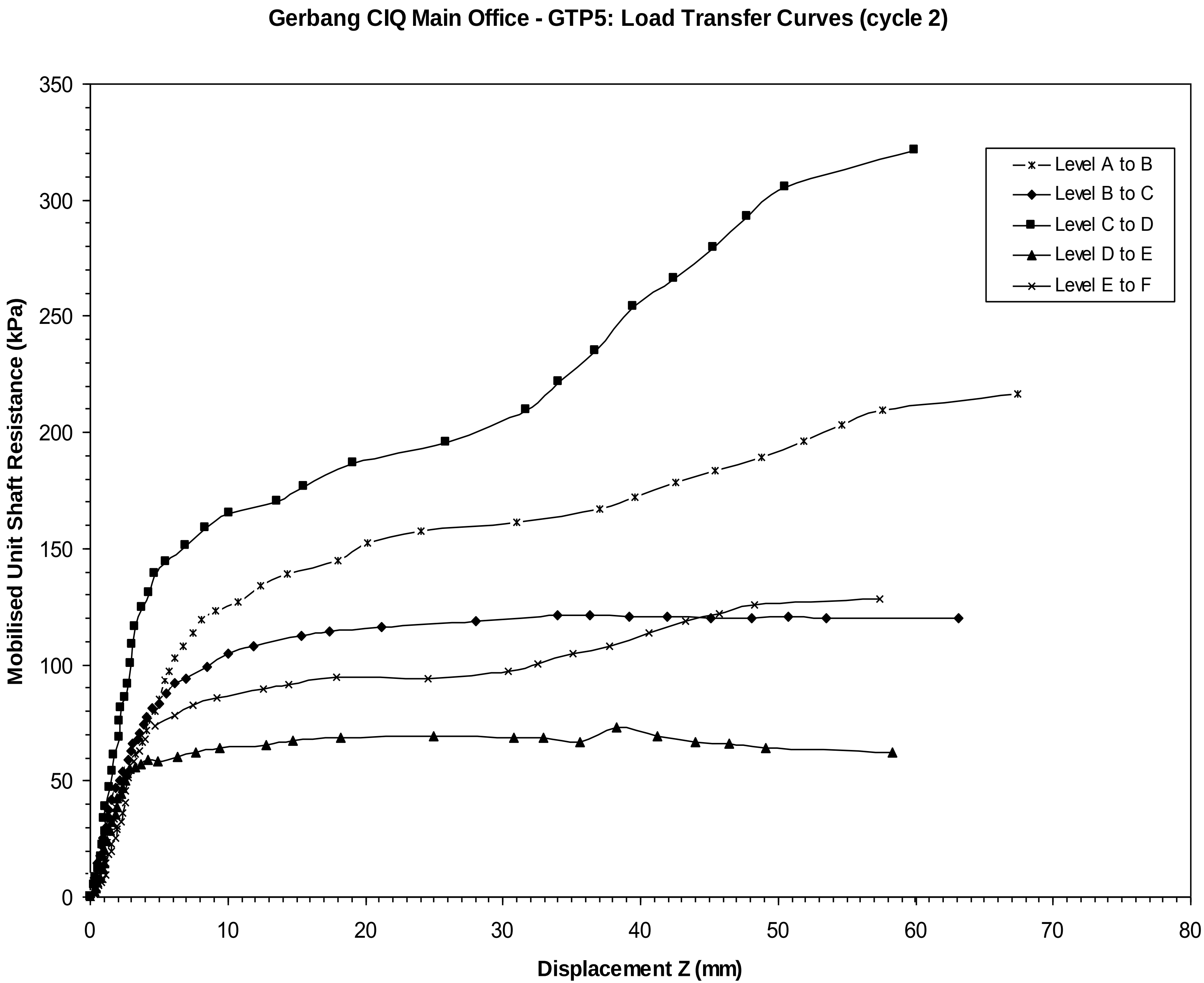

Gerbang CIQ Main Office-PILE GTP5
Tangent Modulus (kPa)
Micro-strain
Level A
Linear (Level A)
y = -0.0257x + 30.691
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
100
200
300
400
500
600

LOAD DISTRIBUTION CURVE FOR 1st CYCLE COMPUTED FROM VWSGs TEST RESULTS



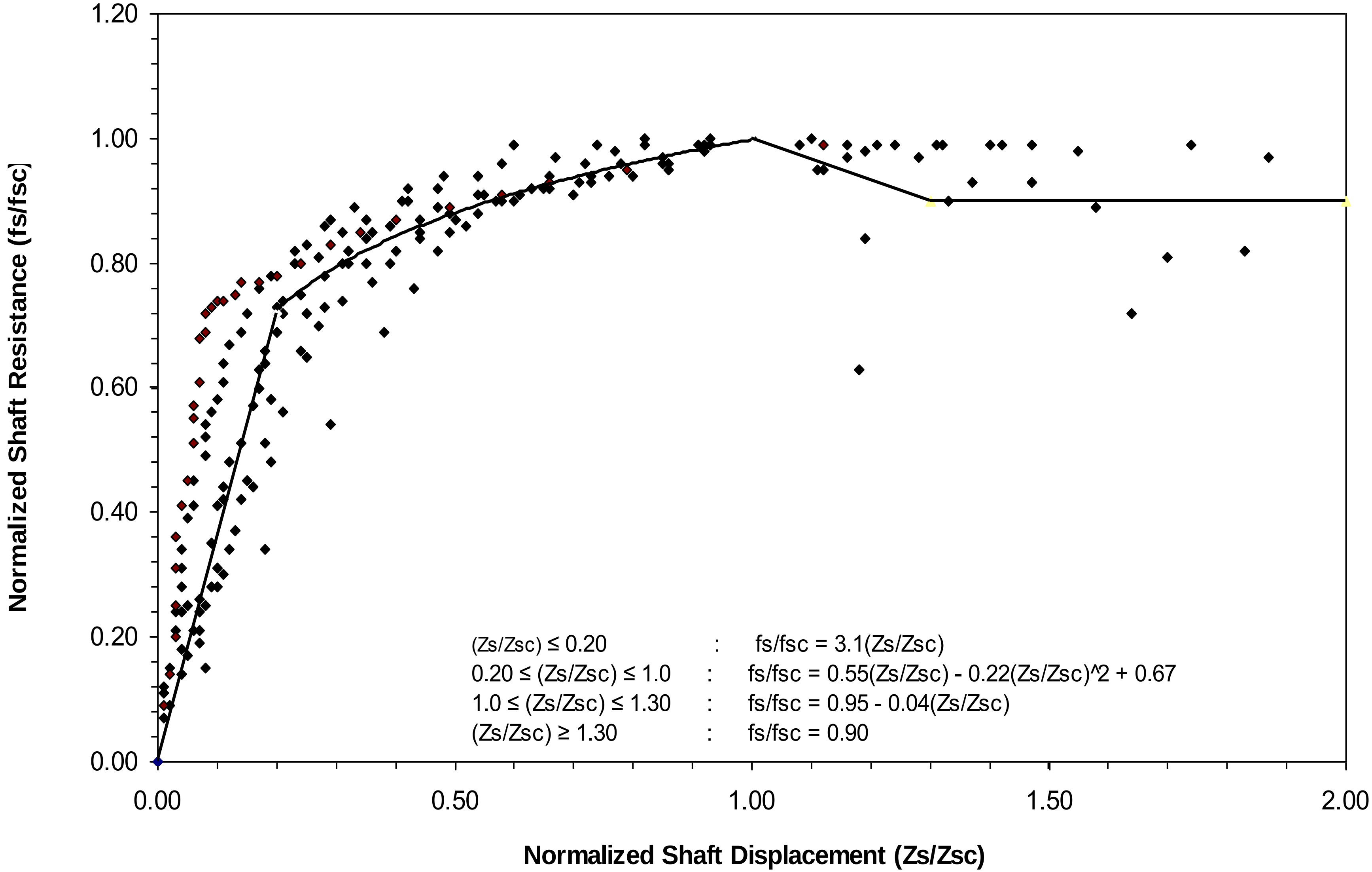
LOAD DISTRIBUTION CURVE FOR 2nd CYCLE COMPUTED FROM VWSGs TEST RESULTS

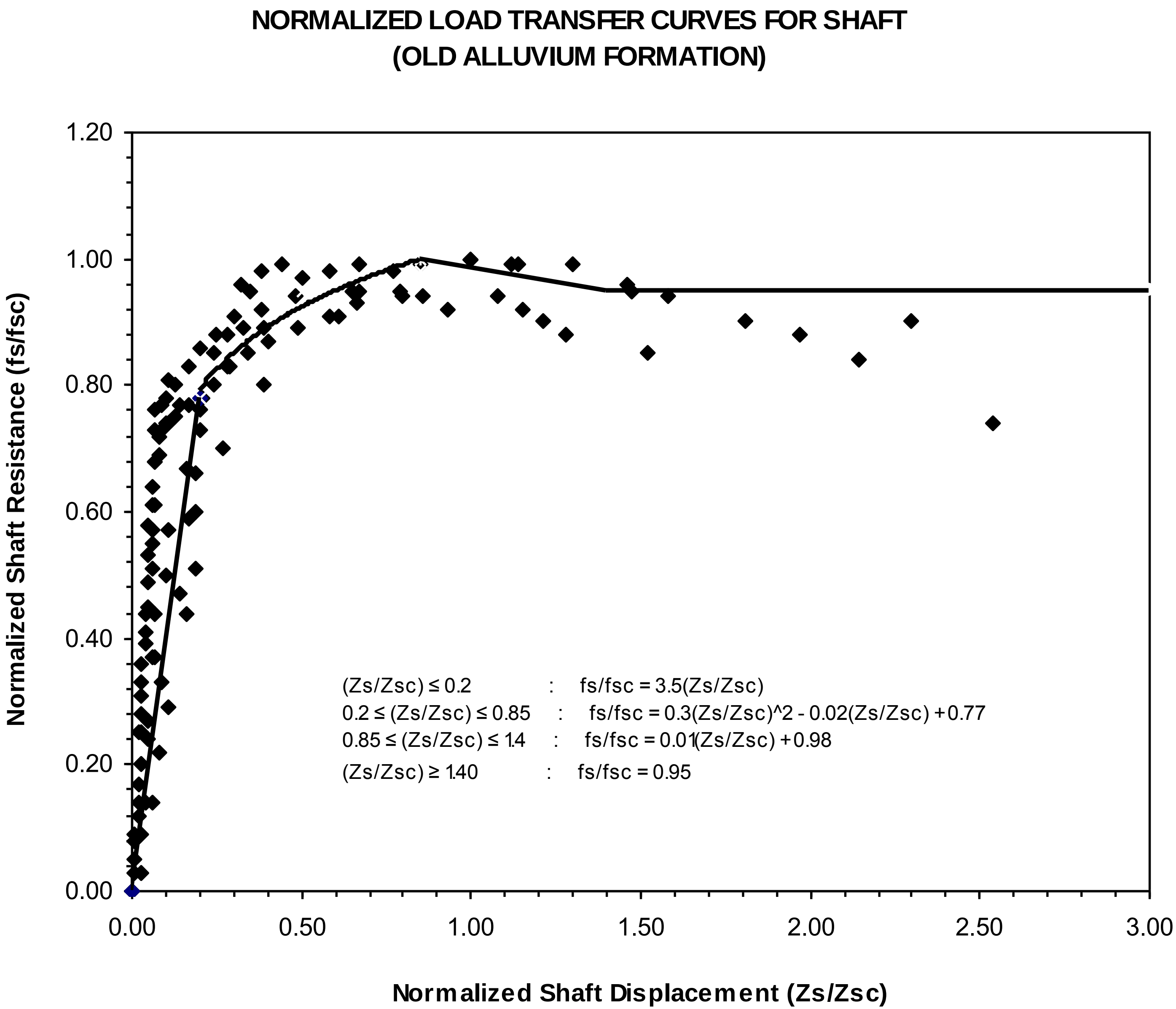



Gerbang CIQ Main Office - GTP5: Load Transfer Curves (cycle 2)
Mobilised Unit Shaft Resistance (kPa)
Displacement Z (mm)
Level A to B
Level B to C
Level C to D
Level D to E
Level E to F
0
50
100
150
200
250
300
350
0
10
20
30
40
50
60
70
80

Normalised Load Transfer Curves

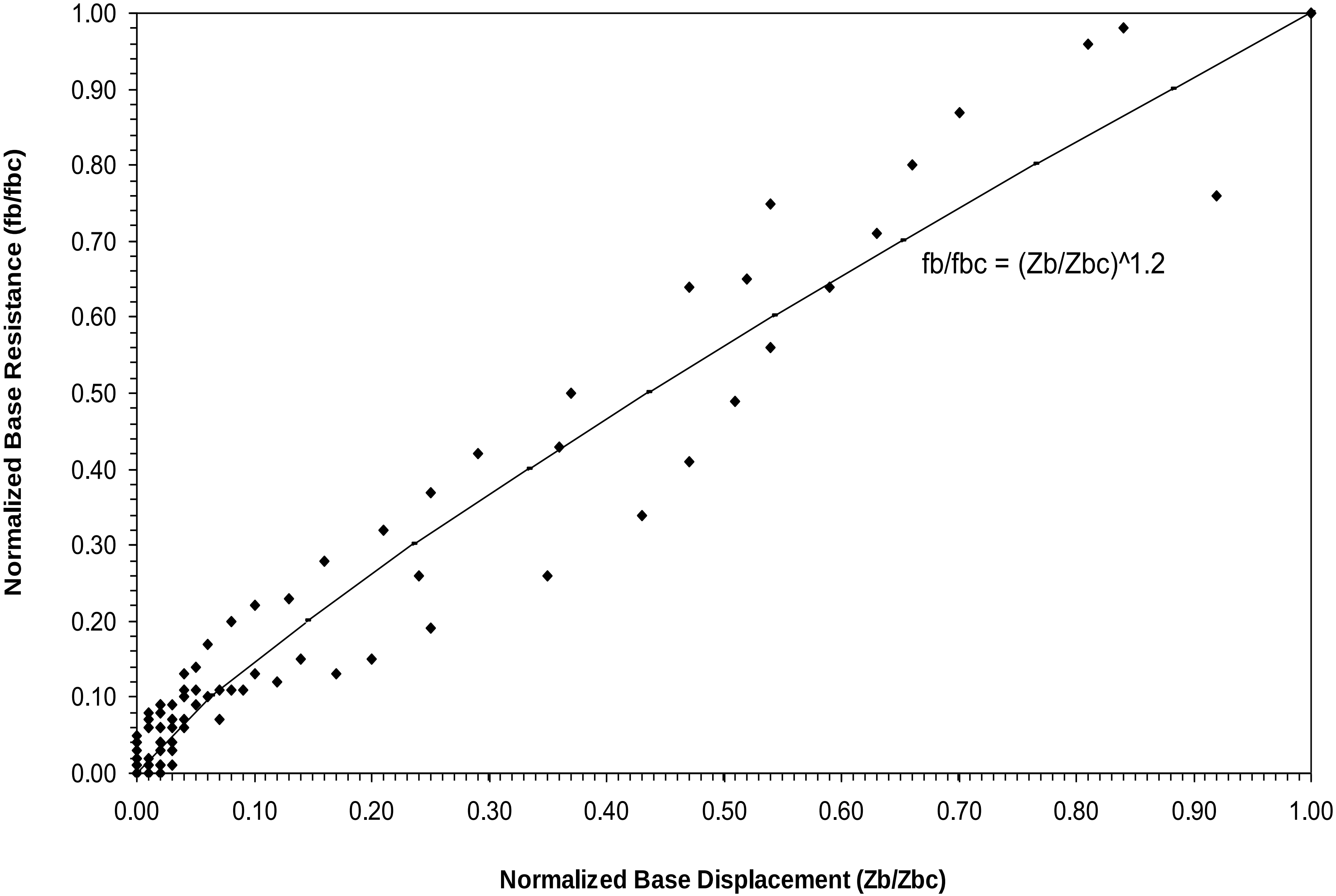
NORMALIZED LOAD TRANSFER CURVES FOR SHAFT
(YOUNG ALLUVIUM FORMATION)

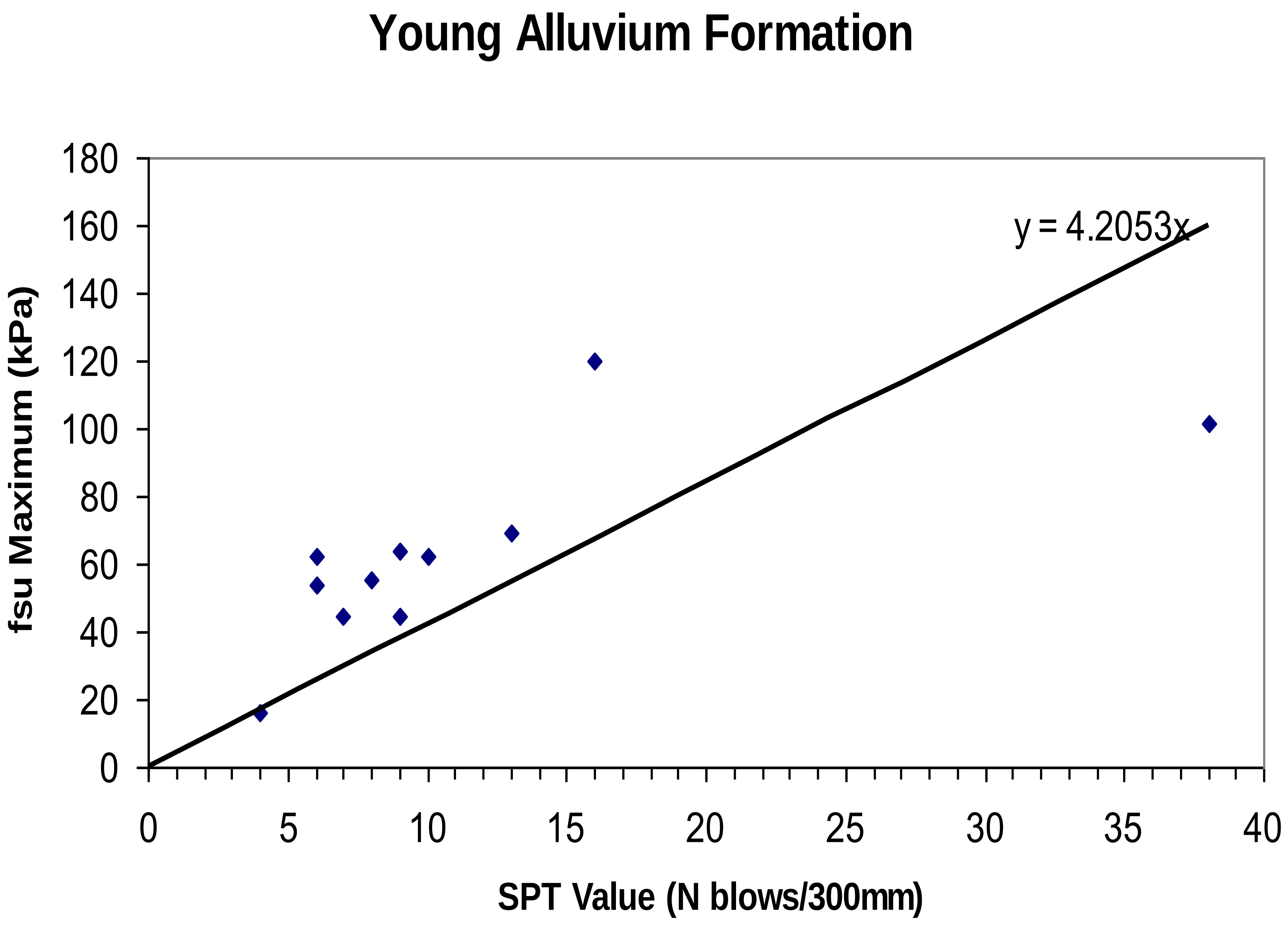


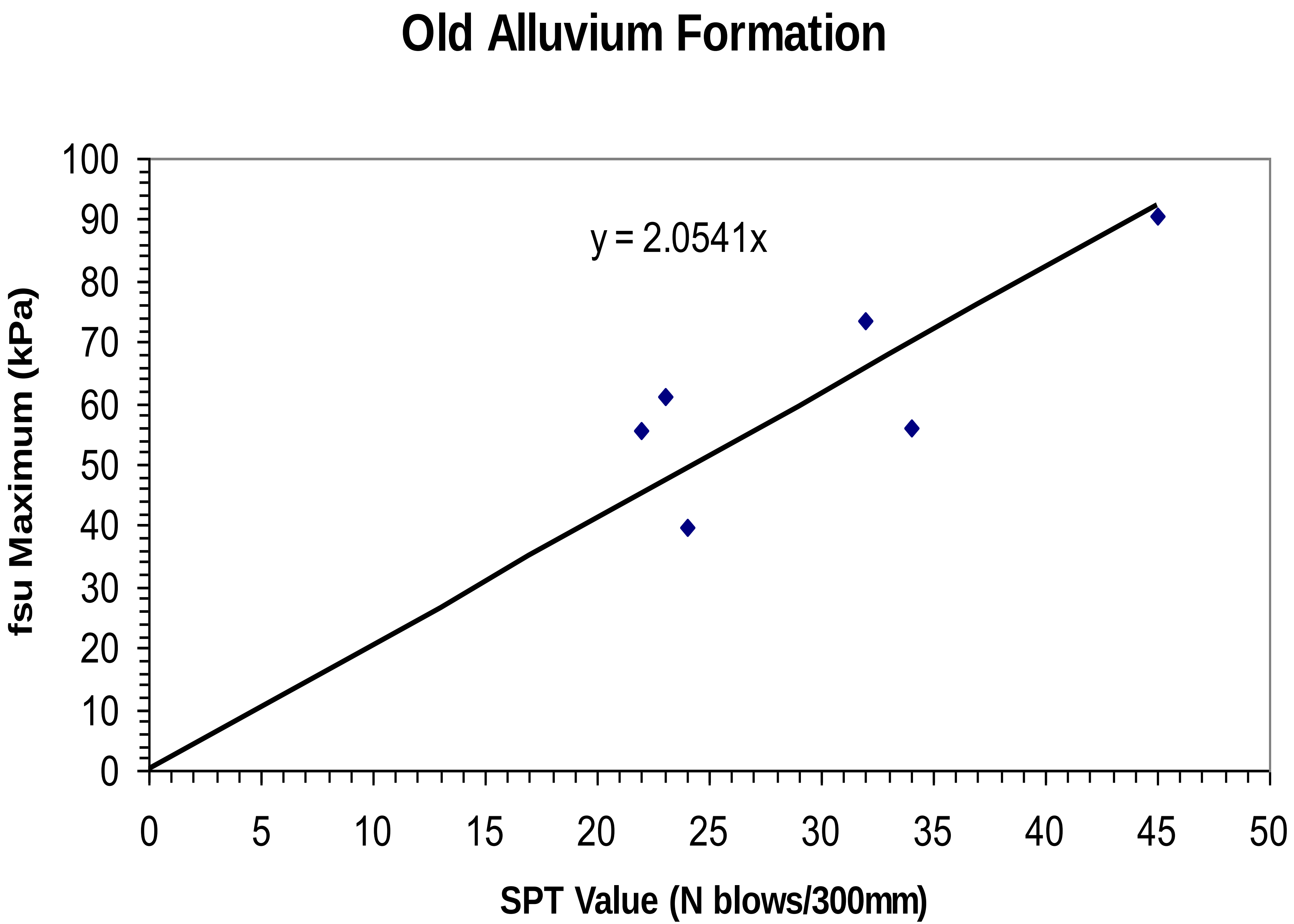


NORMALIZED LOAD TRANSFER CURVES FOR SHAFT
(OLD ALLUVIUM FORMATION)
Normalized Shaft Resistance (fs/fsc)
Normalized Shaft Displacement (Zs/Zsc)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
(Zs/Zsc) ≤ 0.2 : fs/fsc = 3.5(Zs/Zsc)
0.2 ≤ (Zs/Zsc) ≤ 0.85 : fs/fsc = 0.3(Zs/Zsc)^2 - 0.02(Zs/Zsc) + 0.77
0.85 ≤ (Zs/Zsc) ≤ 1.4 : fs/fsc = 0.01(Zs/Zsc) + 0.98
(Zs/Zsc) ≥ 1.40 : fs/fsc = 0.95

NORMALIZED LOAD TRANSFER CURVES FOR BASE (OLD ALLUVIUM FORMATION)




Young Alluvium Formation
y = 4.2053x
fsu Maximum (kPa)
SPT Value (N blows/300mm)
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
40


Old Alluvium Formation
y = 2.0541x
fsu Maximum (kPa)
SPT Value (N blows/300mm)
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35
40
45
50

Results and Discussion

- Test Pile Results
  - Gerbang Selatan Bersepadu
    - Yound Alluvium (N<15) – fsm = 40 kPa to 100 kPa
    - Old Alluvium (N = 20 to 100) – fsm = 50 to 200 kPa
  - Kompleks Makamah
    - Grade IV (N>50) – fsm = 150 to 700 kPa
  - Jalan Kelang Lama
    - Grade VI/V (N<50) – fsm = 40 kPa
    - Garde IV (N>50) – fsm = 100 to 440 kPa

- Results
  - For piles in Old alluvium, end bearing – 0.01% to 2.33% of total capacity – end bearing negligble (34m to 60m long piles)
  - For short piles in KH (7m to 12m) – end bearing – 21% and 57% of total capacity.
  - For long pile in KH (24m), end bearing negligble.

- Results
  - Correlation between SPT N Value and Maximum shaft resistance

  - Young Alluvium – fsu = 4.2N kPa
  - Old Alluvium – fsu = 2.0 N kPa
  - Kenny Hill – fsu = 2.3 N kPa (N < 150)

    fsu = 16 $N^{1/2}$ (N > 150)

Normalised Load Transfer Curves

- Kenny Hill Formation
- For $Zs/Zsc \le 0.35$:$fs/fsc = 2.19\ (Zs/Zsc)$
- For $0.35 \le Zs/Zsc \le 1.0$: $fs/fsc = 2.245\ (Zs/Zsc) - 1.28\ (Zs/Zc)2$
- For $1.0 \le Zs/Zsc \le 1.35$: $fs/fsc = 1.23 - 0.23\ (Zs/Zsc)$
- For $Zs/Zc \ge 1.35$: $fs/fsc = 0.95$
- For Base $fb/fbc = (Zb/Zbc)^{2.5}$

Normalised Load Transfer Curves

- Young Alluvium
- For $Zs/Zsc \leq 0.20$:$fs/fsc = 3.1\ (Zs/Zsc)$
- For $0.2 \leq Zs/Zsc \leq 1.0$:$fs/fsc = 0.55\ (Zs/Zsc) - 0.22\ (Zs/Zc)^2 + 0.67$
- For $1.0 \leq Zs/Zsc \leq 1.30$:$fs/fsc = 0.95 - 0.04\ (Zs/Zsc)$
- For $Zs/Zc \geq 1.30$:$fs/fsc = 0.90$

Normalised Load Transfer Curves

- Old Alluvium
- For $Zs/Zsc \leq 0.2$:$fs/fsc = 3.5 (Zs/Zsc)$
- For $0.2 \leq Zs/Zsc \leq 0.85$:$fs/fsc = 0.3 (Zs/Zc)^2 - 0.02 (Zs/Zsc) + 0.77$
- For $0.85 \leq Zs/Zsc \leq 1.4$:$fs/fsc = 0.98 – 0.01 (Zs/Zsc)$
- For $Zs/Zc \geq 1.4$:$fs/fsc = 0.95$
- For Base $fb/fbc = (Zb/Zbc)^{1.2}$

Recommendations

- To develop a computer code to predict load settlement based on derived load transfer curves
- Instrumented load test on other geological formations
- 1 cycle tests – if piles instrumented
- Geological description included in SI.

THANK YOU