BASICS OF DESIGN OF PILED FOUNDATIONS

Bengt H. Fellenius

Brisbane November 28, 2008

SCHEDULE

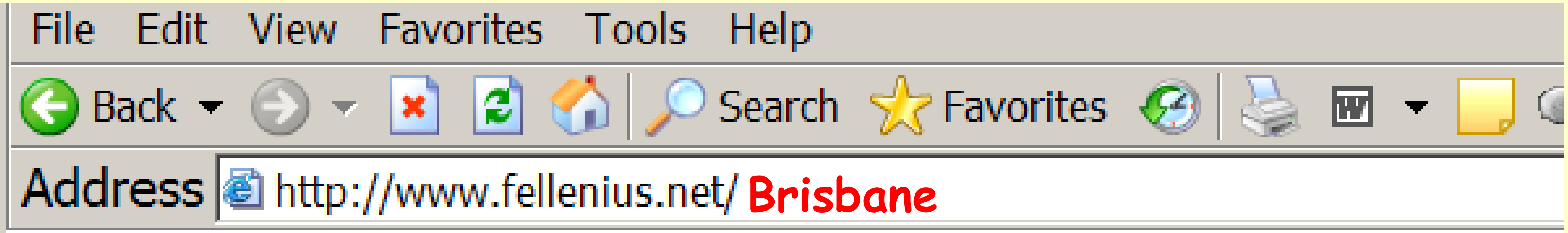
Morning

08:00h	Registration
08:30h	The Static Loading Test and Other Testing Methods
09:40h	Break
10.00h	The Bi-directional Test — the O-cell
11:00h	Brief Background to Basic Principles Applicable to Piled Foundations
12.00h	LUNCH

Afternoon

13:00h	Piles and Pile Groups—Long-term Behavior and How We Know What We Know
14:10h	Break
14:30h	Analysis of Load Transfer and Capacity of Piles
15:40h	Unified Design of Piles and Pile Groups
16.45h	Questions and Discussions
17:30h	End of Day

www.Fellenius.net



Power Point Slides

1-Static_Test.pdf
2-Background.pdf
3-Case_Histories.pdf
5-Analysis.pdf
6-Unified_Method.pdf

UniSoft Programs

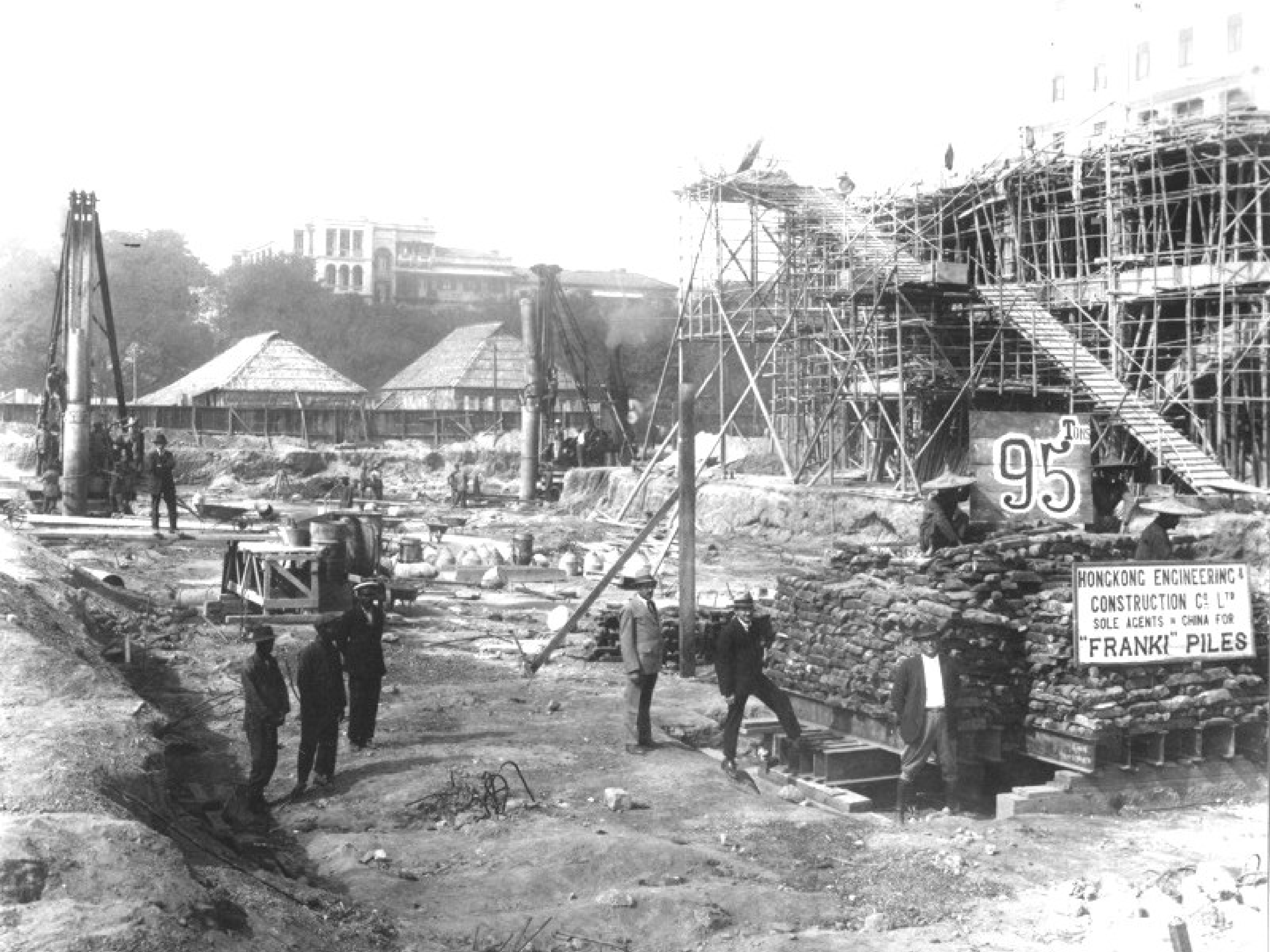
Information and Order Form
UniBear.zip
UniCone.zip
UniPhase.zip
UniPile.zip
UniSettle.zip

BASICS OF DESIGN OF PILED FOUNDATIONS

Bengt H. Fellenius

The Static Loading Test

Performance, Instrumentation, Interpretation



95 TONS
HONGKONG ENGINEERING &
CONSTRUCTION Co. Ltd
SOLE AGENTS IN CHINA FOR
"FRANKI" PILES

Candidates for Darwin Award, First Class

Testing piles is a risky business.

! ! !

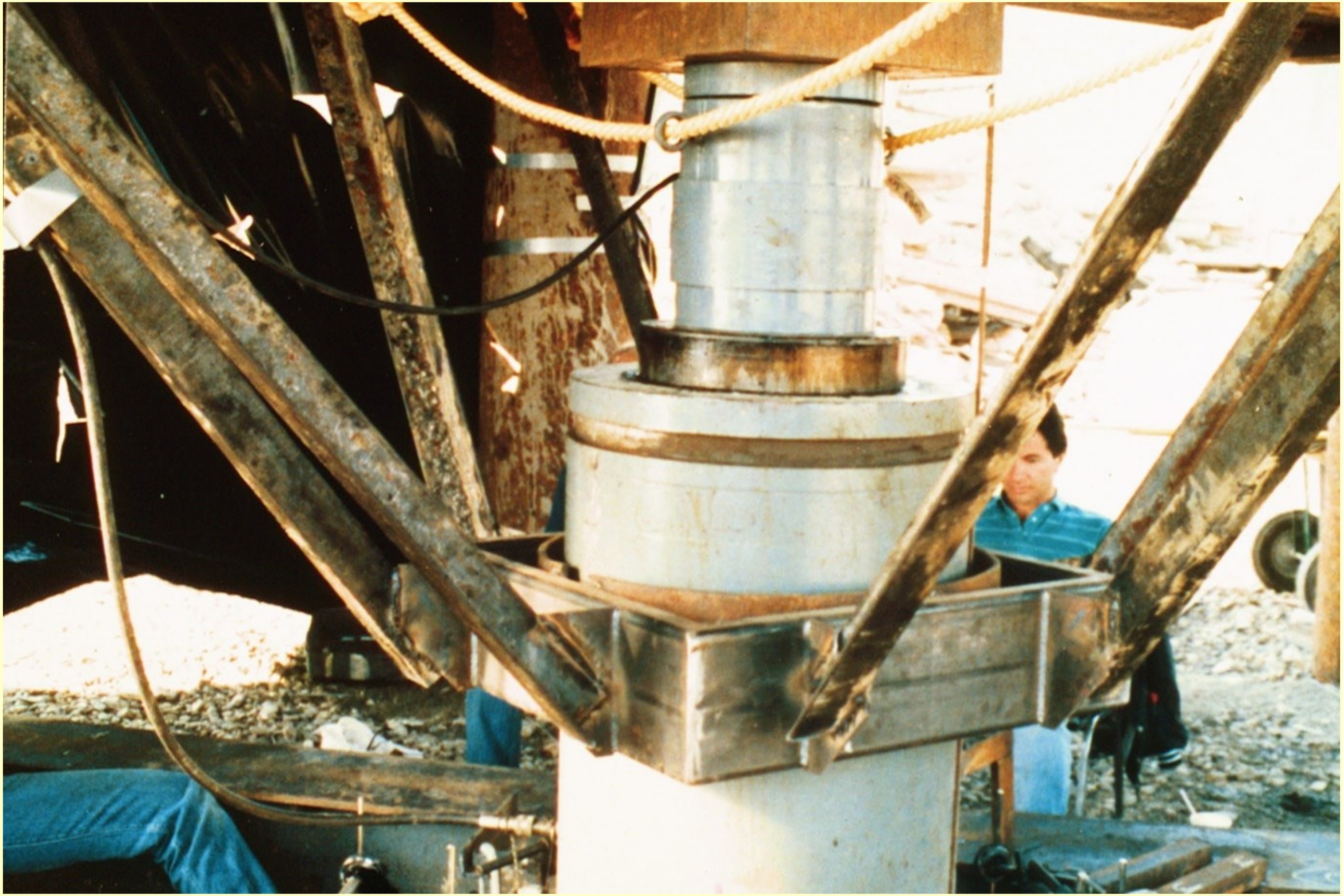
1. SWIVEL PLATE

2. SPACER

3. LOAD CELL

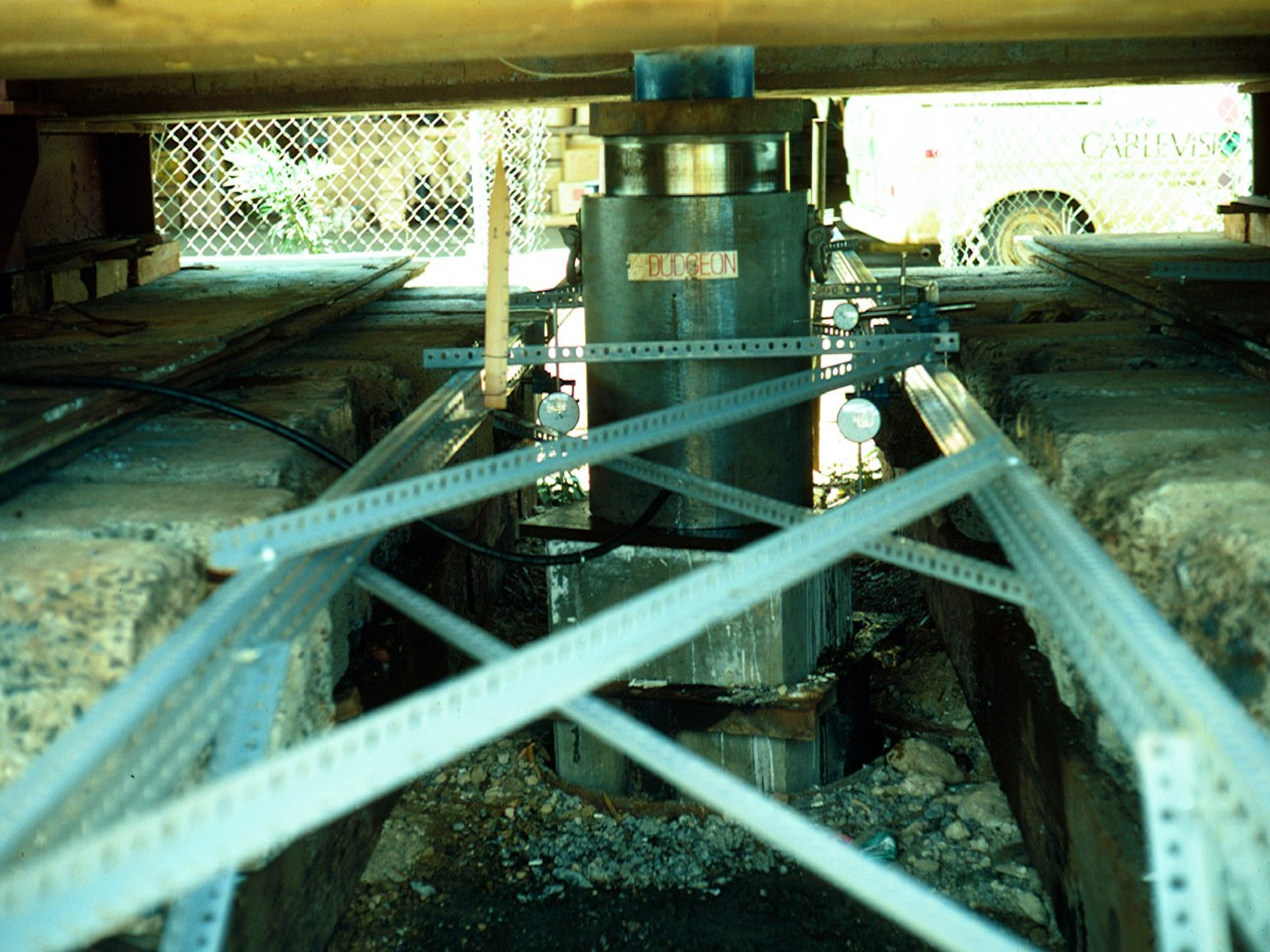
4. JACK

What do you think could happen to the stack of four pieces on the pile head when the load is applied? And, therefore, to the three oblivious persons next to the pile?

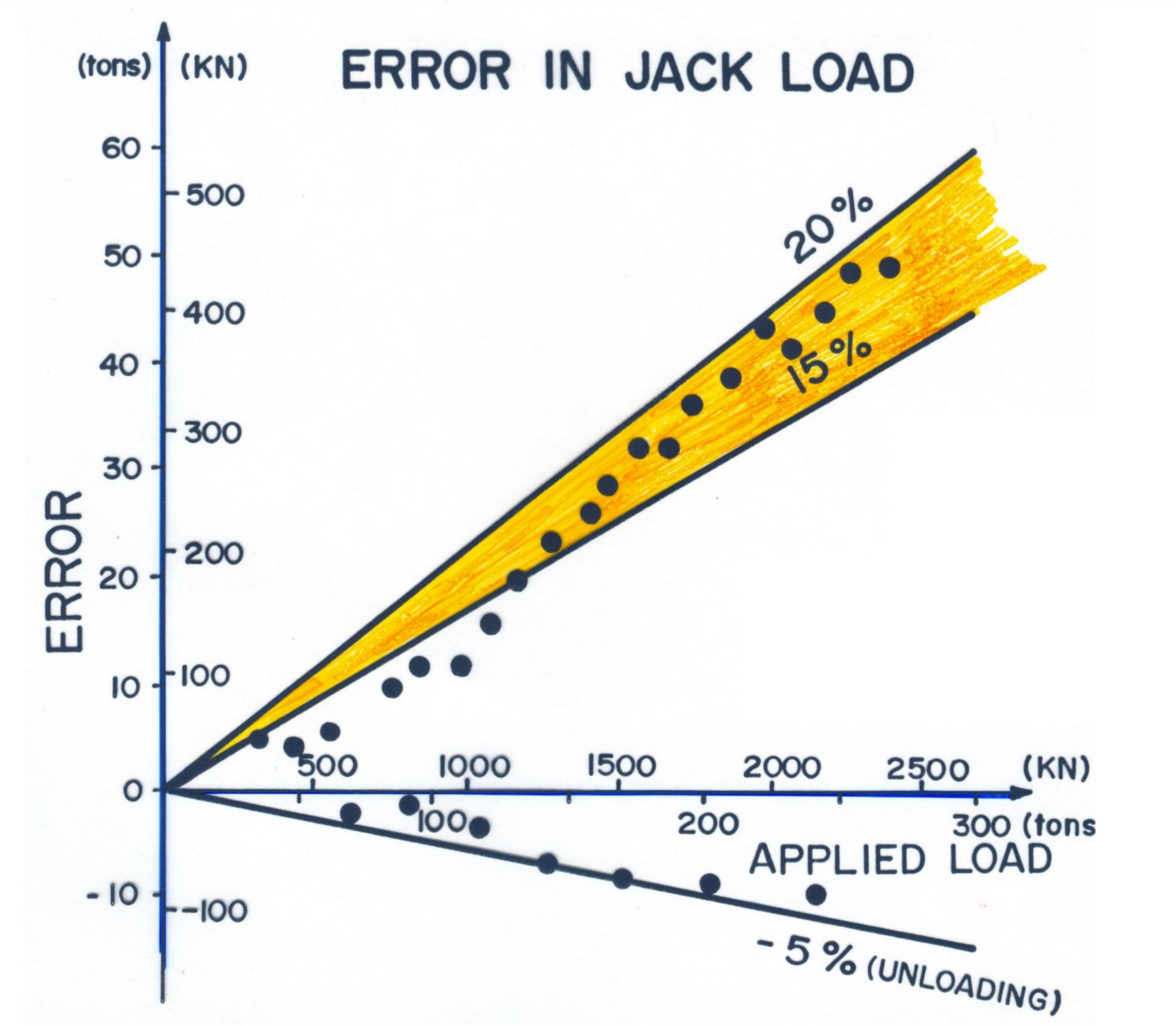


This is how experience taught the three, and others, to arrange the units on the pile head

Better safe than sorry!

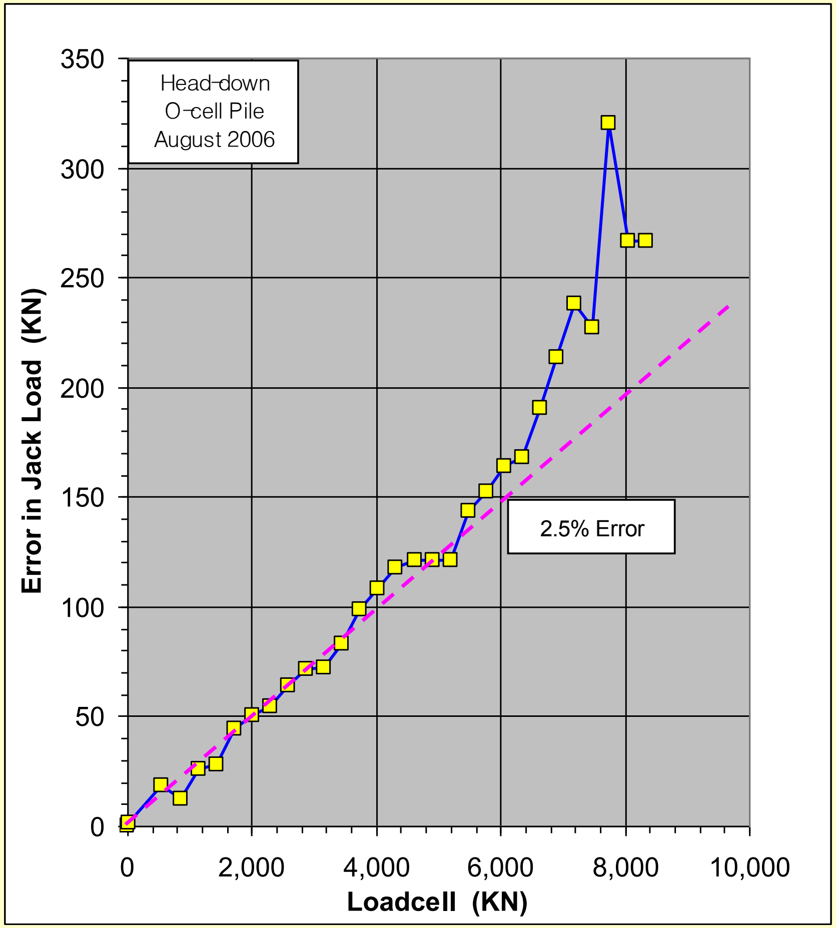

DUDGEON
CABLEVISI

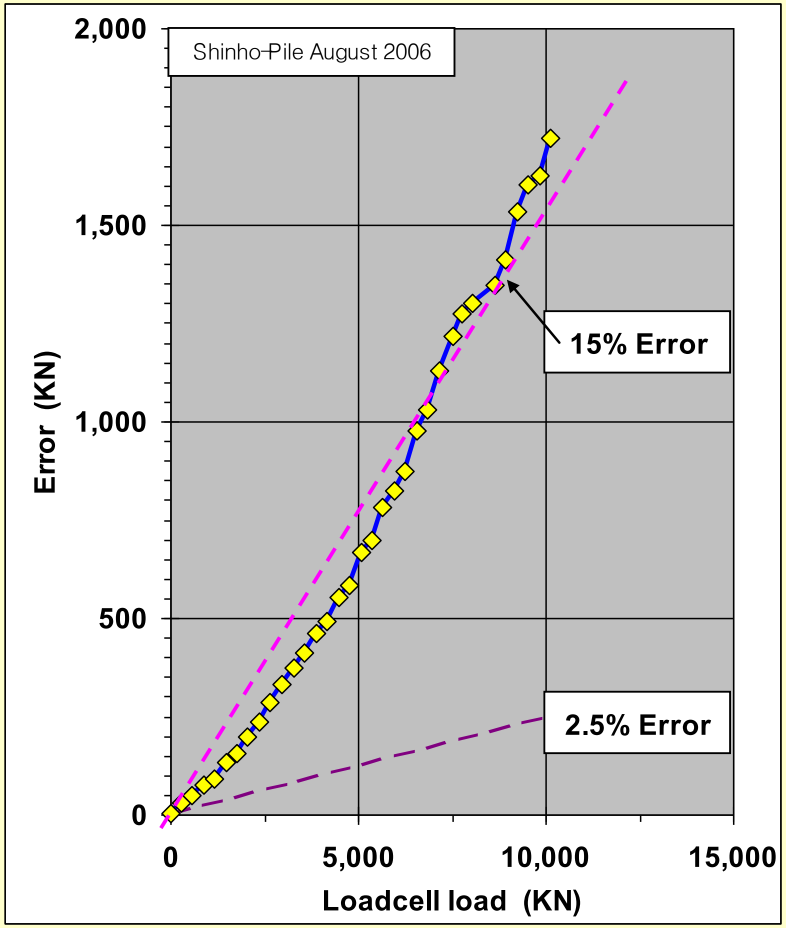

ABLEVISION



Fellenius 1984

The error can be small or it can be large. Here are results from two tests at the same site using the same equipment testing two adjacent piles, one after the other.

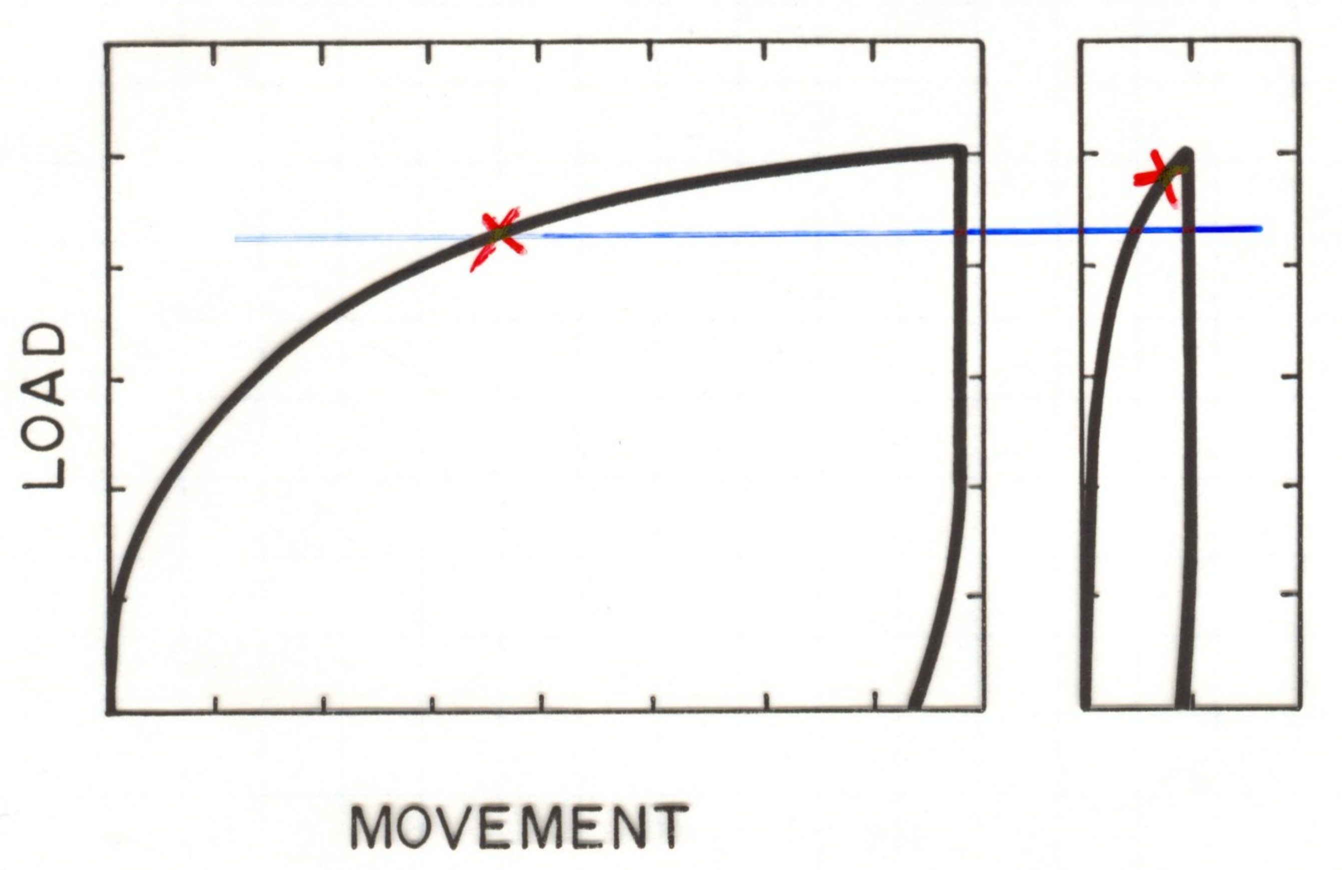




Note, the test on the pile called "O-cell pile" is a head -down test after a preceding O-cell test.

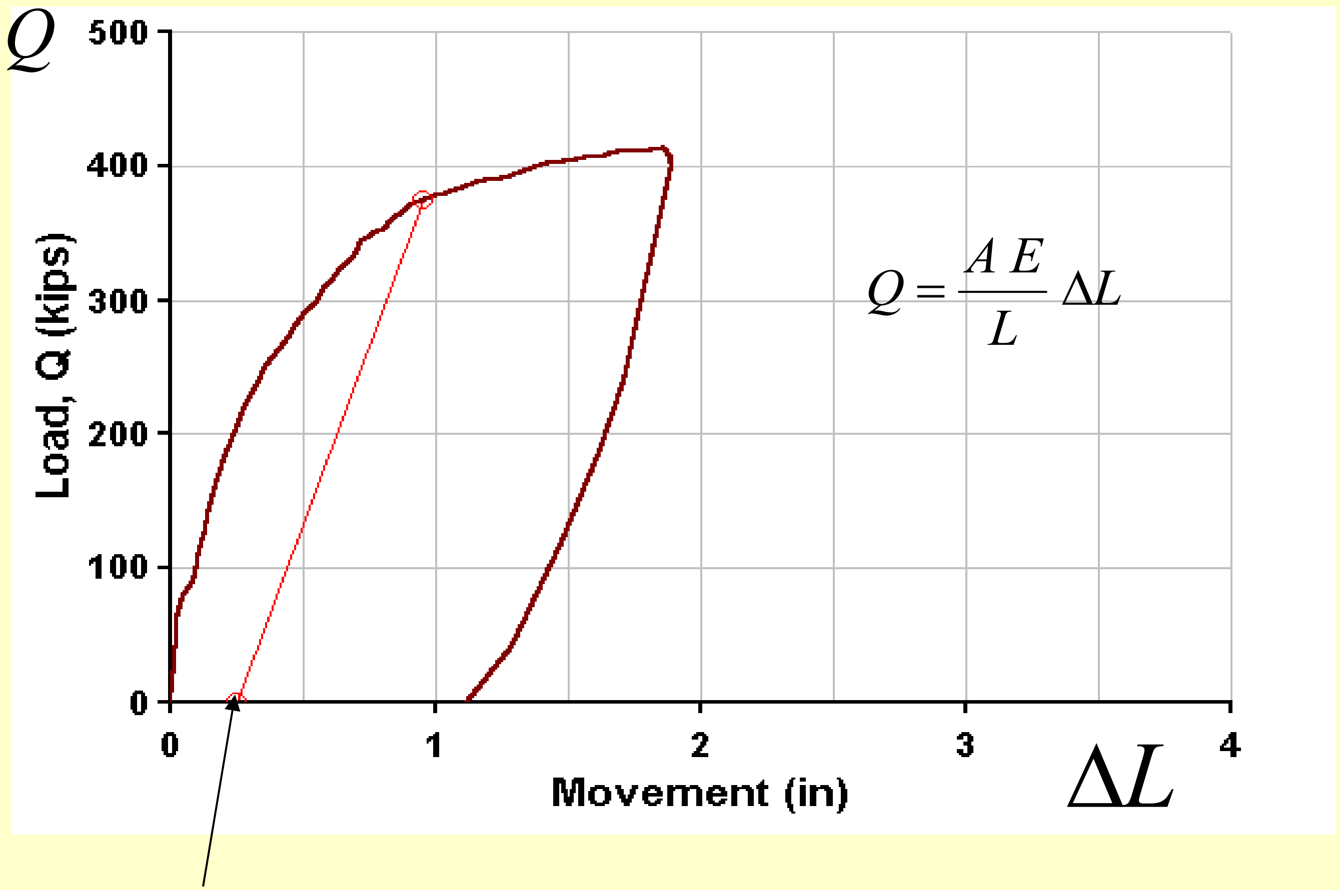
A routine static loading test provides the load-movement of the pile head...

and the pile capacity?



The Offset Limit Method

Davisson (1972)



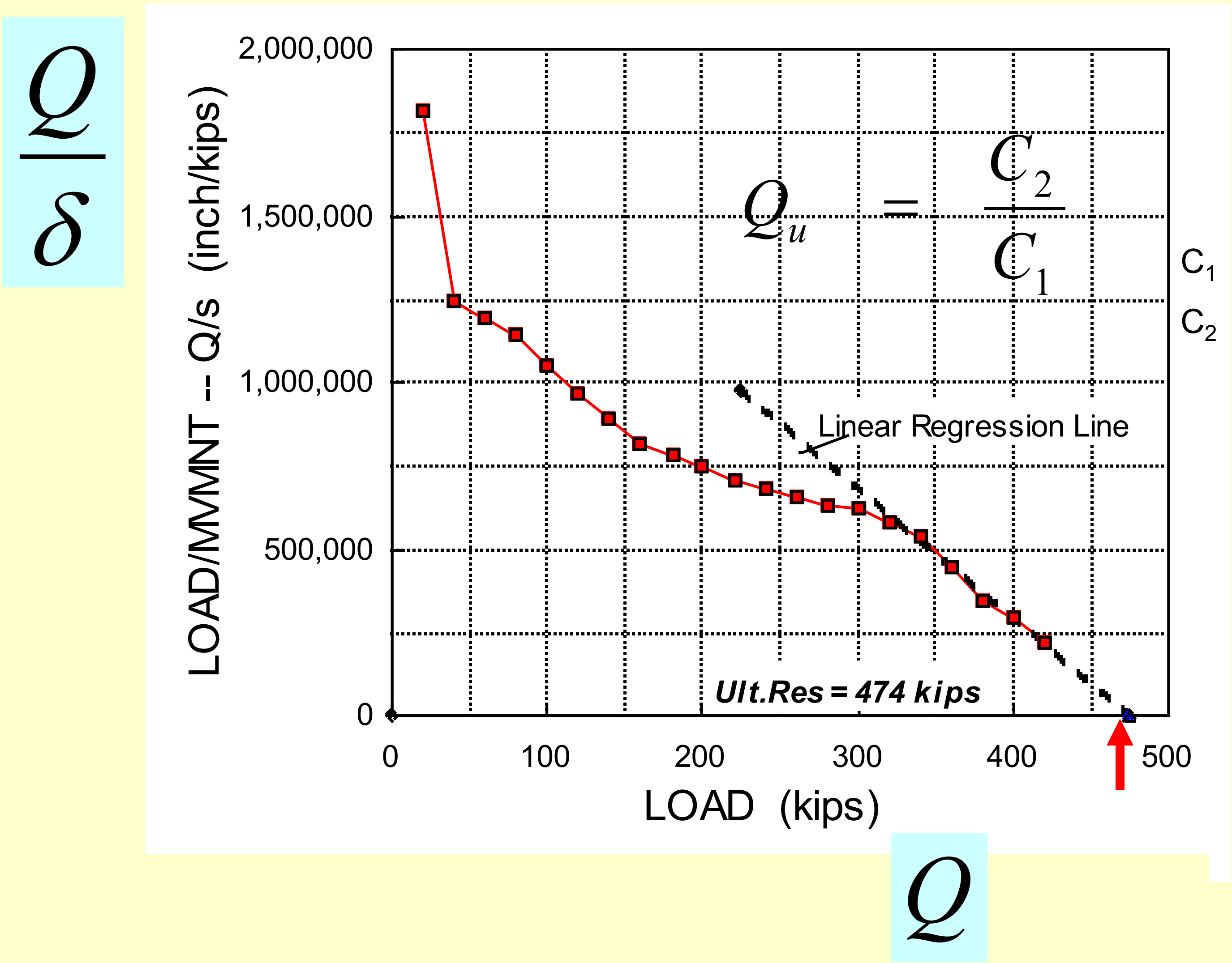
OFFSET (inches) = 0.15 + b/120

OFFSET (SI-units—mm) = 4 + b/120

b = pile diameter (inch or mm)

The Decourt Extrapolation

Decourt (1999)



C_1 = Slope

C_2 = Y-intercept

Other methods are:

The Load at Maximum Curvature

Mazurkiewicz Extrapolation

Chin-Kondner Extrapolation

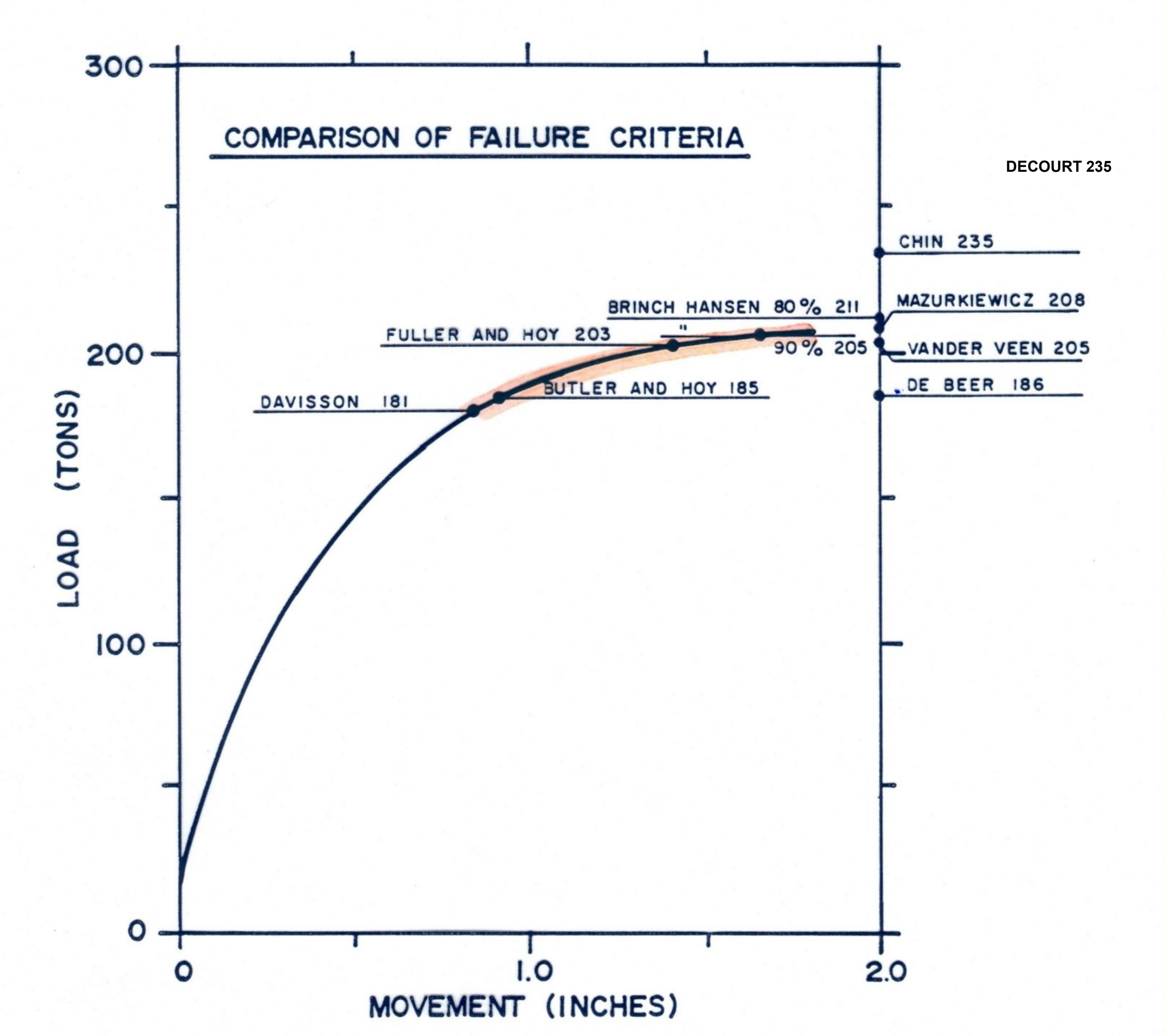
DeBeer double-log intersection

Fuller-Hoy Curve Slope

The Creep Method

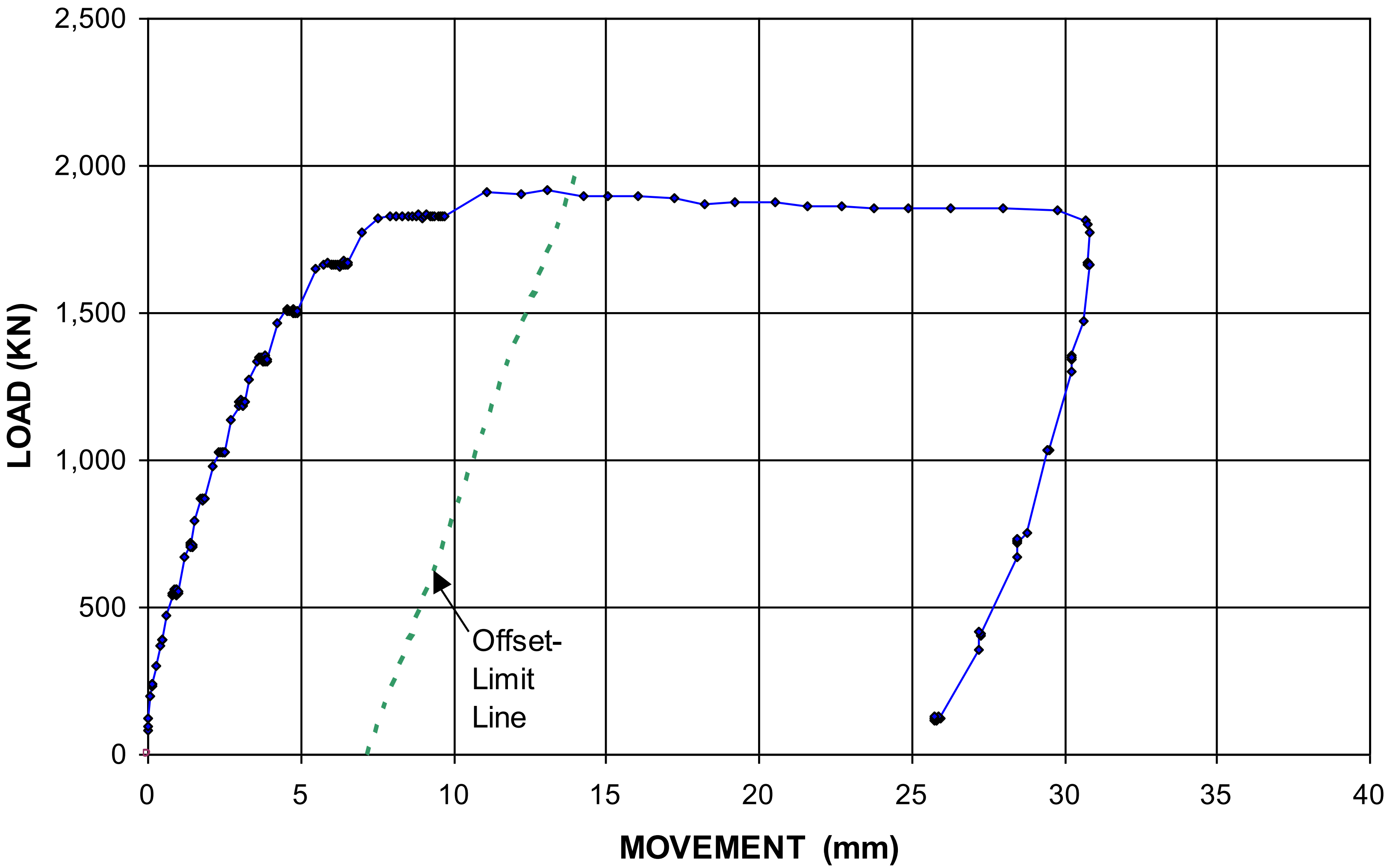
Yield limit in a cyclic test

For details, see Fellenius (1975, 1980)

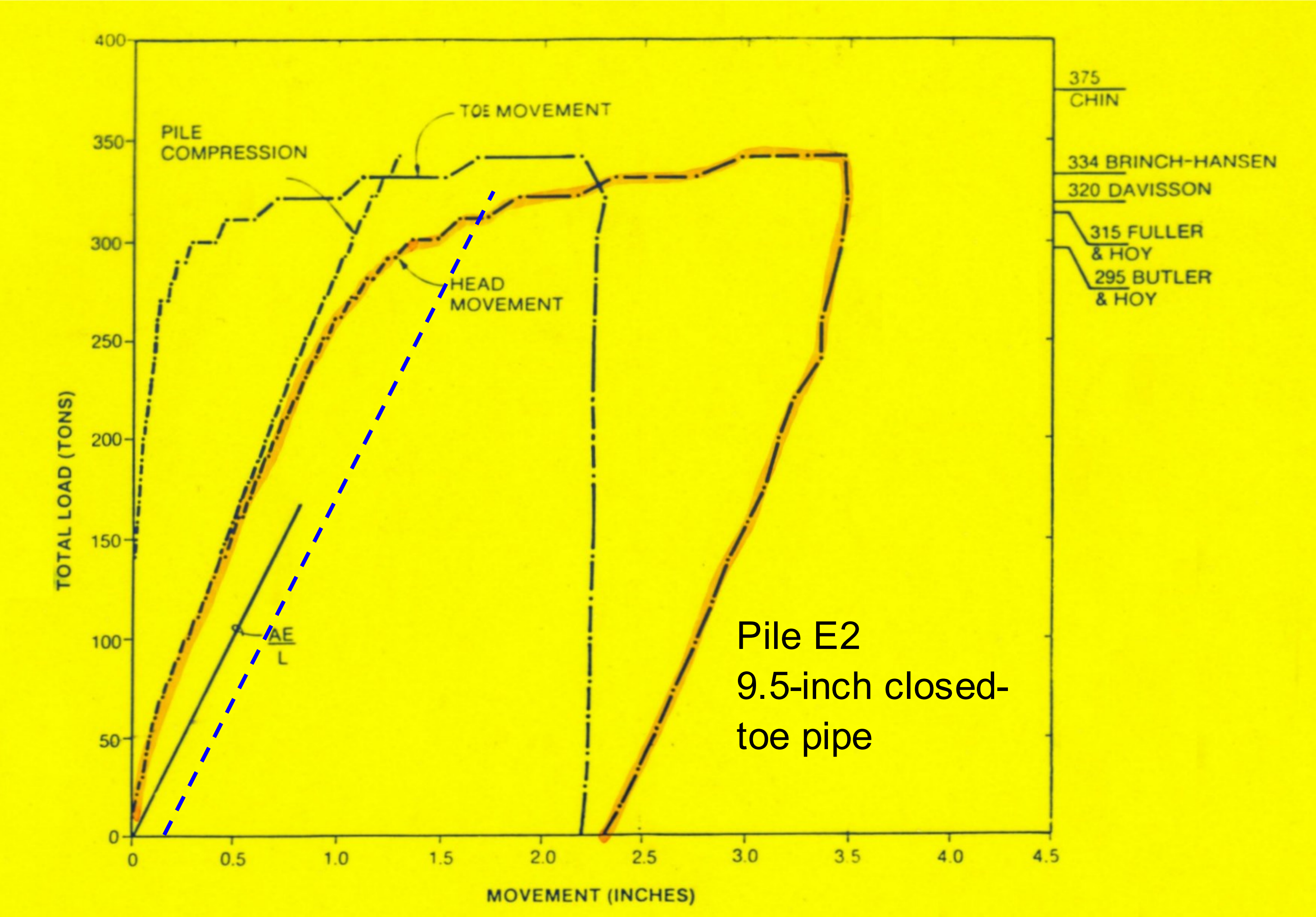


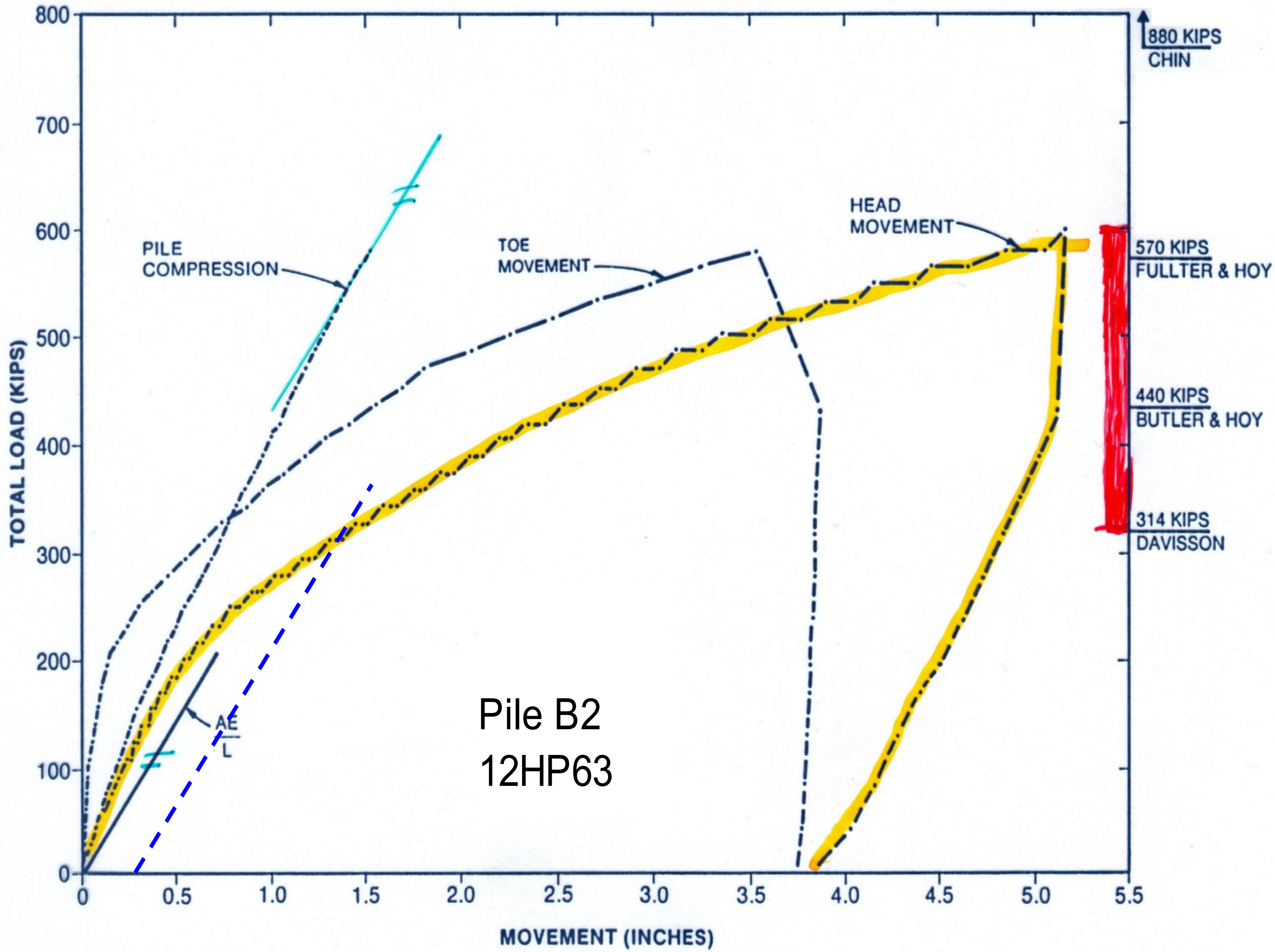
COMPARISON OF FAILURE CRITERIA
DECOURT 235
300
200
100
0
LOAD (TONS)
CHIN 235
BRINCH HANSEN 80% 211
MAZURKIEWICZ 208
FULLER AND HOY 203
"
90% 205
VANDER VEEN 205
DE BEER 186
BUTLER AND HOY 185
DAVISSON 181
0
1.0
2.0
MOVEMENT (INCHES)

Definition of capacity (ultimate resistance) is only needed when the actual value is not obvious from the load-movement curve



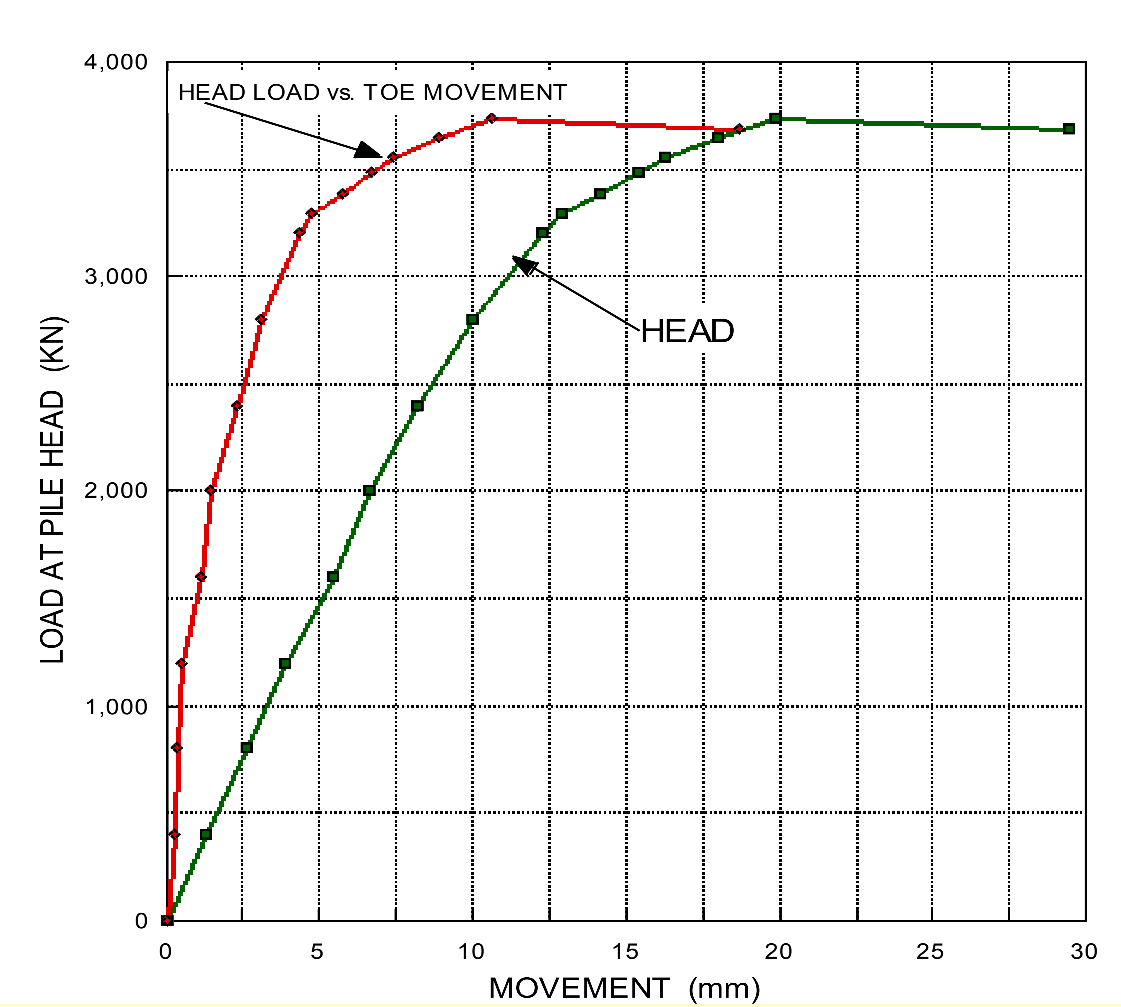
Some results from Jones Island, Milwaukee on 30 m to 50 m long driven piles (Fellenius et al., 1983)





800
700
600
500
400
300
200
100
0
TOTAL LOAD (KIPS)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
MOVEMENT (INCHES)
PILE COMPRESSION
TOE MOVEMENT
HEAD MOVEMENT
AE/L
880 KIPS CHIN
570 KIPS FULLTER & HOY
440 KIPS BUTLER & HOY
314 KIPS DAVISSON
Pile B2
12HP63

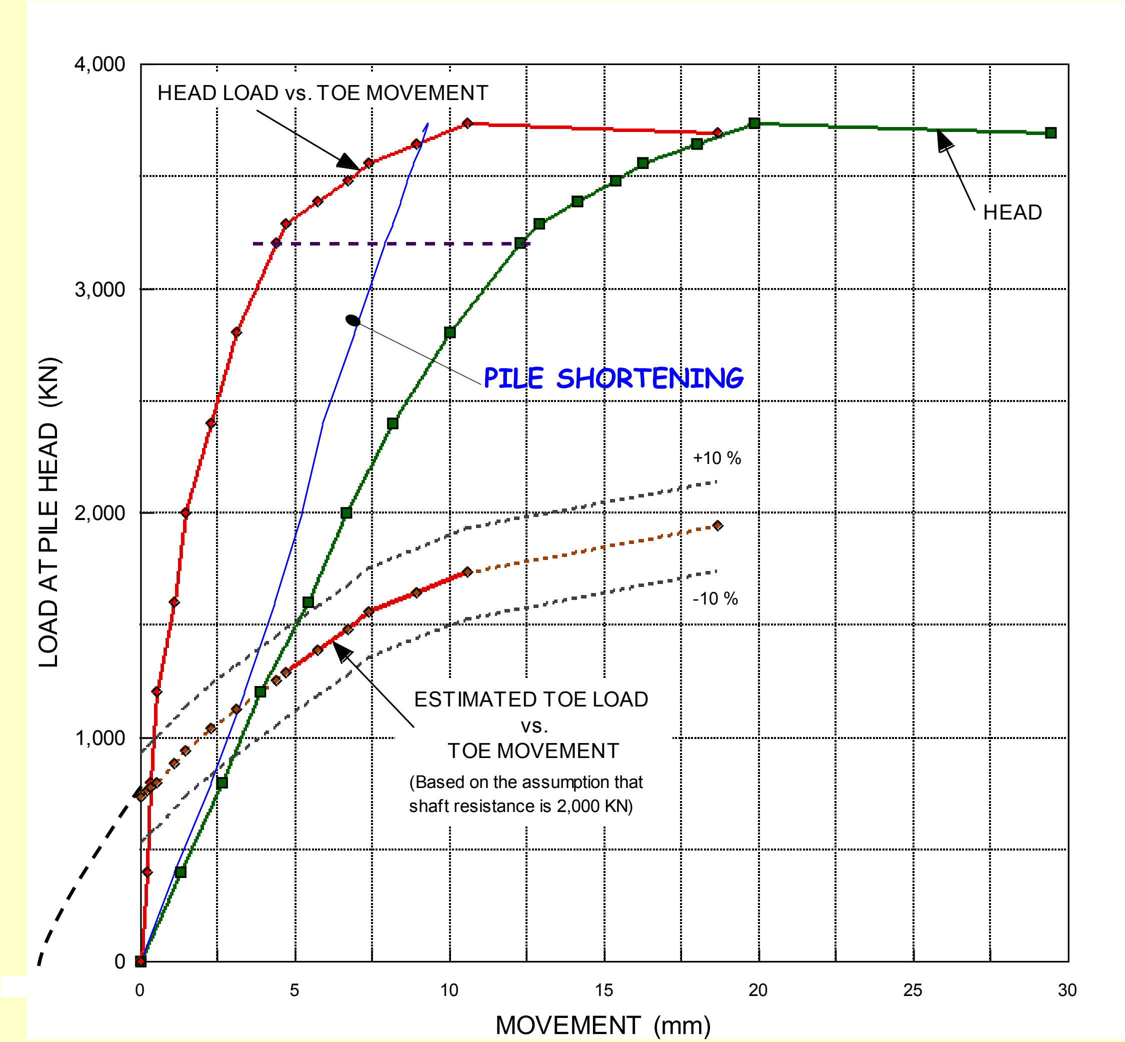
Pile Toe Movement



65 ft long, 14 inch pipe pile.

With a telltale to the toe arranged to determine **pile shortening**. Don't have it measure toe movement directly.

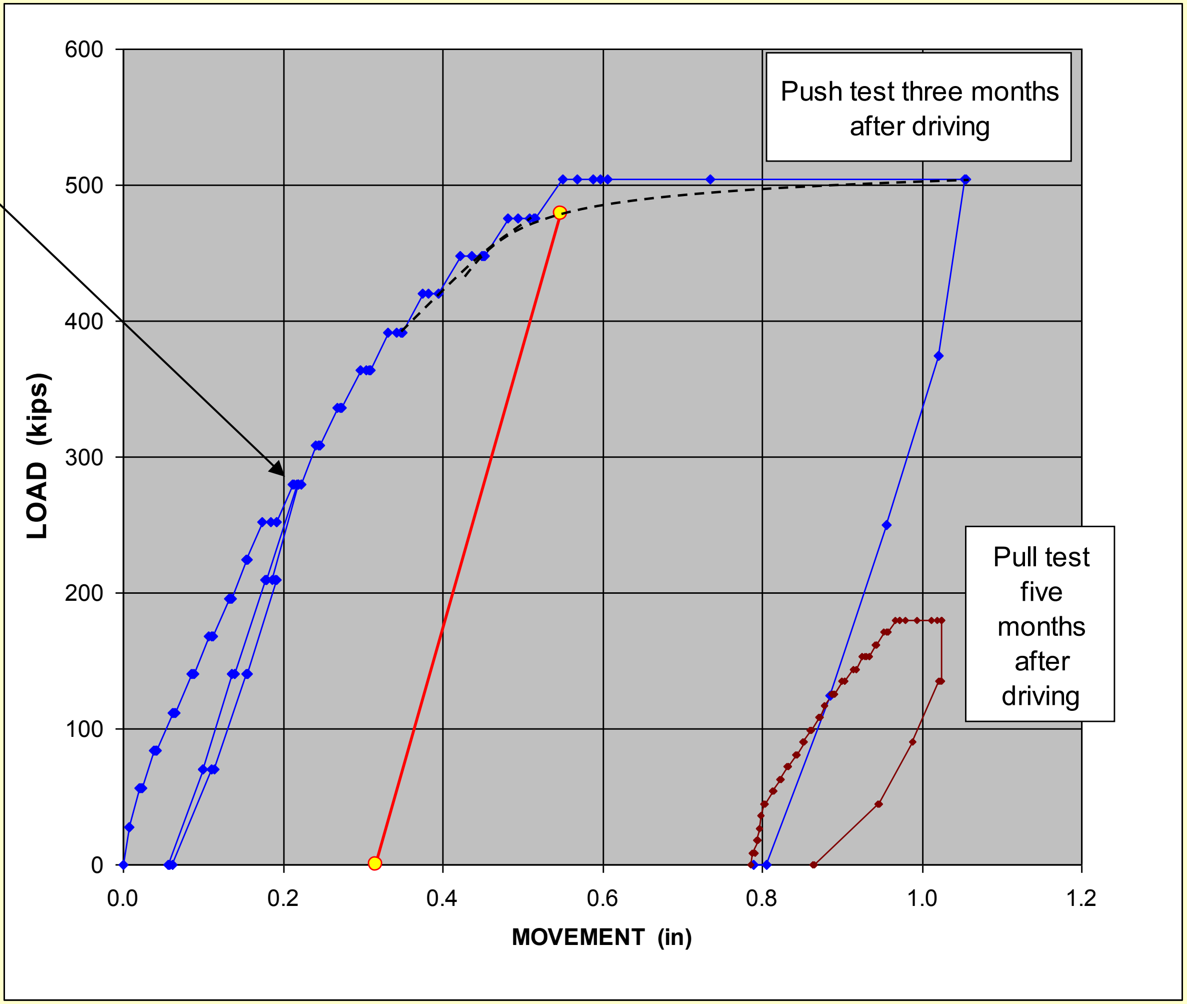
Analysis of toe resistance



An adjacent pull test on a similar instrumented pile established that the pile shaft resistance is about 2,000 KN approximately fully mobilized just short of 5-mm toe movement. The thereafter applied load in the push test goes to toe resistance, only.

20 inch square diameter, prestressed concrete pile driven to 58 ft embedment, through about 45 ft of soft silt and clay, 5 ft of sand, and to bearing 6 ft into hard clay

Unloading-reloading once or a couple of times "on the way up" serves no purpose and may result in distorted analysis results

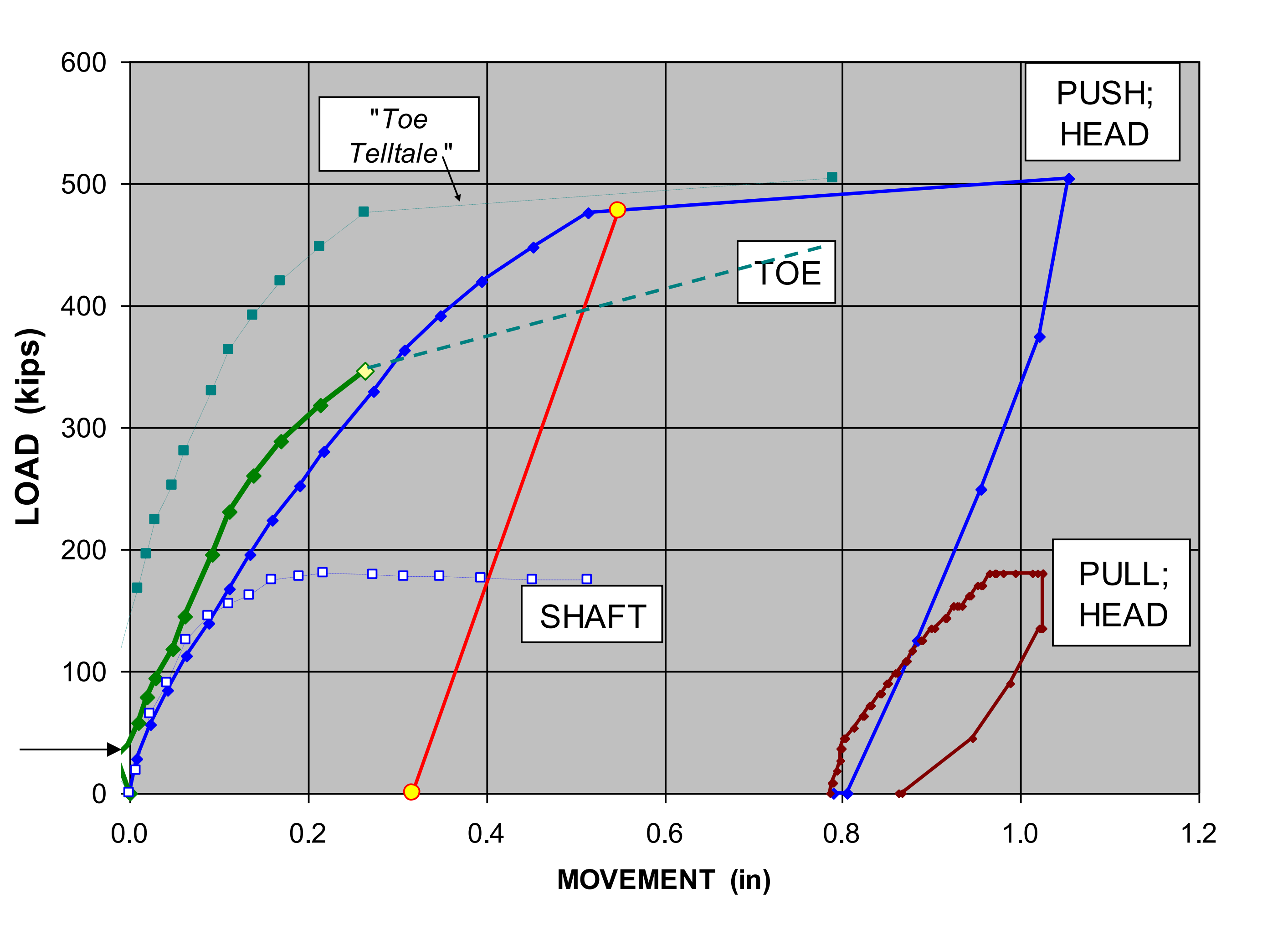


PUSH and PULL

To separate shaft and toe resistances. The pile is equipped with a toe telltale.

Data from AATech Scientific Inc.

Combining the push and pull test results with the telltale measurements to calculate the load-movement for the pile toe



Data from AATech Scientific Inc.

Suggestions for Routine Testing

It is not possible to interpret more than very approximately from the load-movement curve how much of the pile capacity that is toe resistance and how much is shaft resistance.

Adding occasional unloading and re-loading “cycles” only distorts the figure. Cyclic loading requires a multitude of identical cycles — maybe cycle 100 times at each load and unload magnitude, and cycle at several load levels. This is not practical for routine tests, but anything less is waste of effort.

The “standard” method of eight increments up to a maximum load is probably the worst method of the lot. Instead of applying one increment each hour (as a shock to the pile), use one a quarter of the increment size and apply one every 15 minutes — a much more gentle approach. Or, one small increment every 10 minutes — aim for a total of about 30 increments; a five-hour test duration.

On reaching the maximum load and holding it (say, for 10 minutes), unload in, say five or six decrements.

The routine static loading test with load applied to the pile head and movement measured only at the pile head provides very limited information — Good enough for proof testing. However, if more information is desired, instrument the test pile, or run an O-cell test.

Instrumentation

and

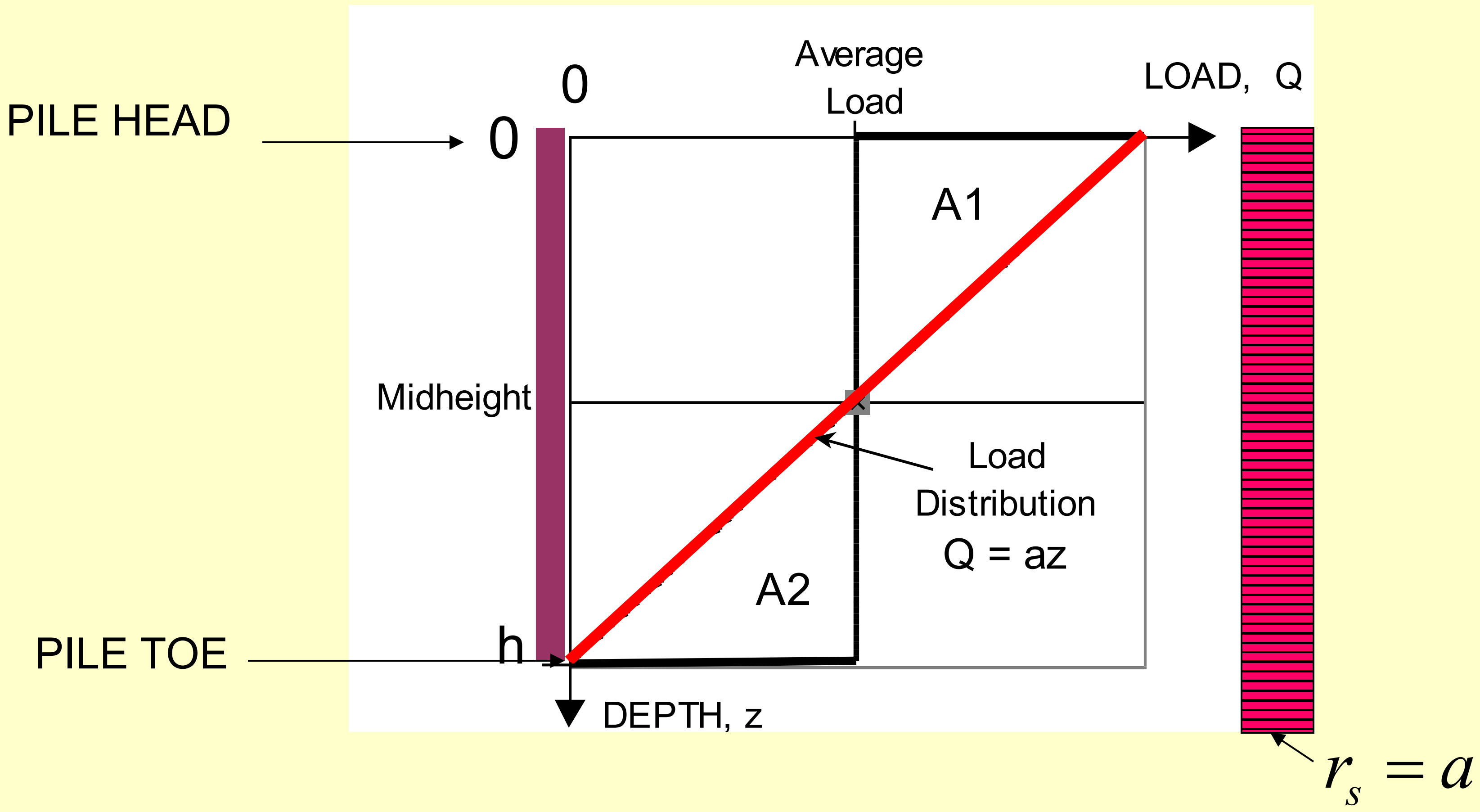
Interpretation

T e l l t a l e s

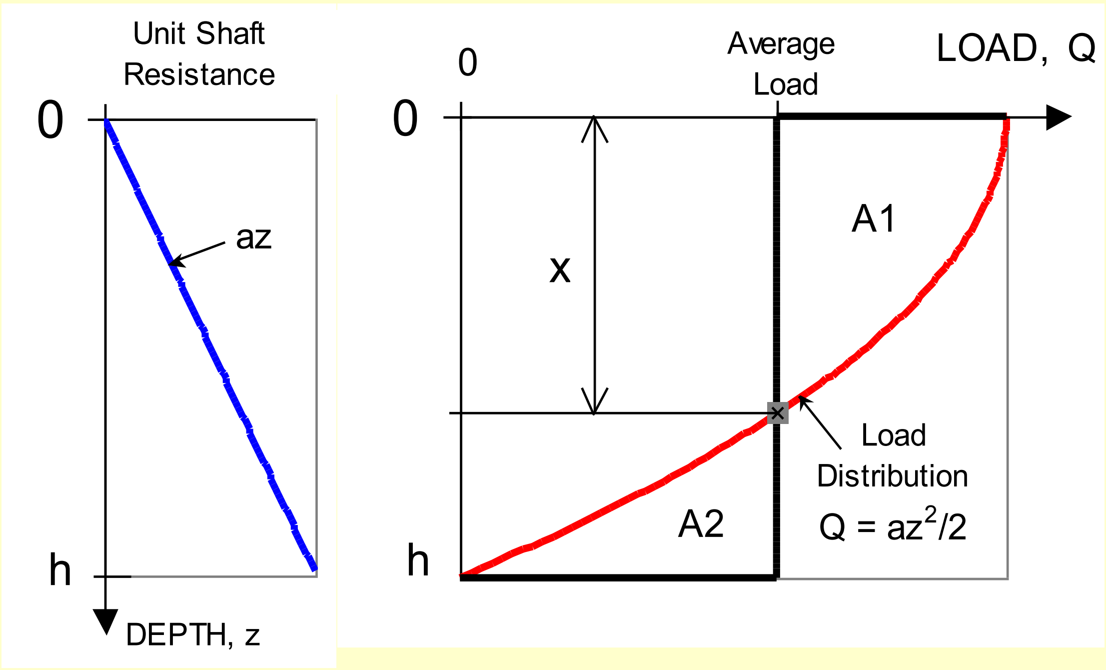
- A telltale measures shortening of a pile and must never be arranged to measure movement.
- Let toe movement be the pile head movement minus the pile shortening.
- For a single telltale, the **shortening** divided by the distance between the pile head and the telltale toe is the **average strain** over that length.
- For two telltales, the distance to use is that between the telltale tips.
- The **strain** times the cross section area of the pile times the pile material E-modulus is the average **load** in the pile.

- **To plot a load distribution, where should the load value be plotted? Midway of the length or above or below?**

Load distribution for **constant** unit shaft resistance



Linearly increasing unit shaft resistance and its load distribution



$$A1 = \frac{ax^3}{3}$$

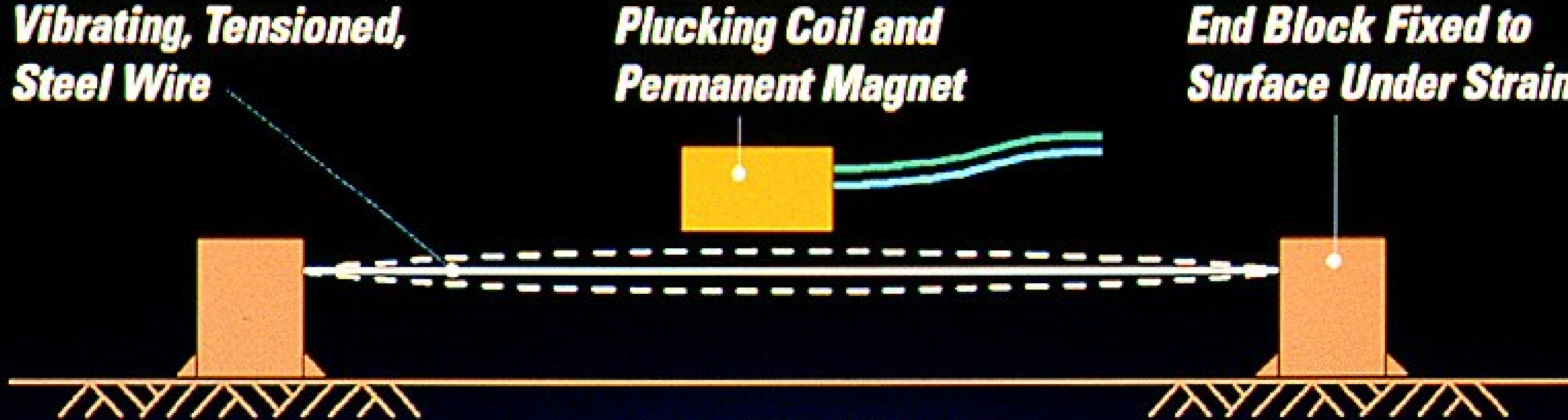
$$A2 = \frac{a(h^3 - 3x^2h + 2x^3)}{6}$$

$$A1 = A2$$

"X" is where the average load should be plotted

$$X = \frac{h}{\sqrt{3}} = 0.58h$$

- Today, telltales are not used for determining strain (load) in a pile because using strain gages is a more assured, more accurate, and cheaper means of instrumentation.
- However, it is good policy to include a toe-telltale to measure toe movement. If arranged to measure shortening of the pile, it can also be used as an <u>approximate</u> back-up for the average load in the pile.
- The use of vibratory strain gages (sometimes, electrical resistance gages) is a well-established, accurate, and reliable means for determining loads imposed in the test pile.
- It is very unwise to cut corners by field-attaching single strain gages to the re-bar cage. Always install factory assembled “sister bar” gages.



f = Frequency of Vibration
L = Wire Length
T = Tension
m = Wire Mass per Unit Length

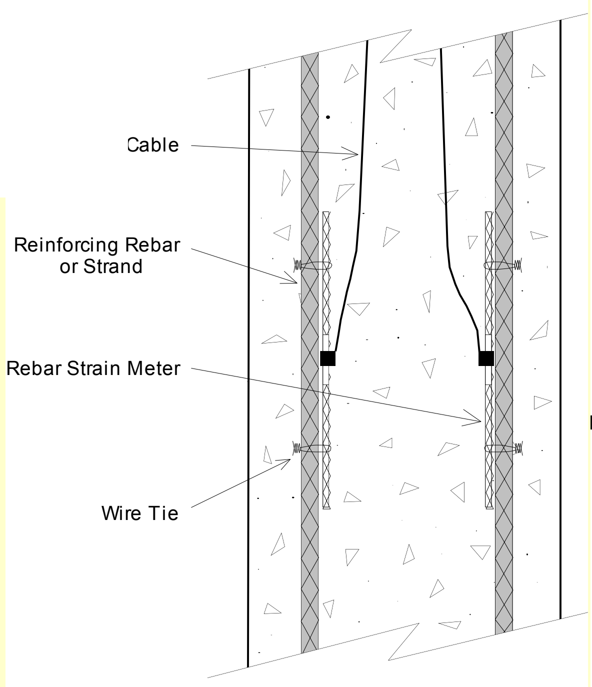
$$f = \frac{1}{2L}\sqrt{\frac{T}{m}} \quad \text{or } f = K_1\sqrt{\varepsilon} \quad \text{where } K_1 = \frac{1}{2L}\sqrt{\frac{AE}{m}}$$

$$\Delta\varepsilon = K_2\left(f^2 - f_0^2\right)$$

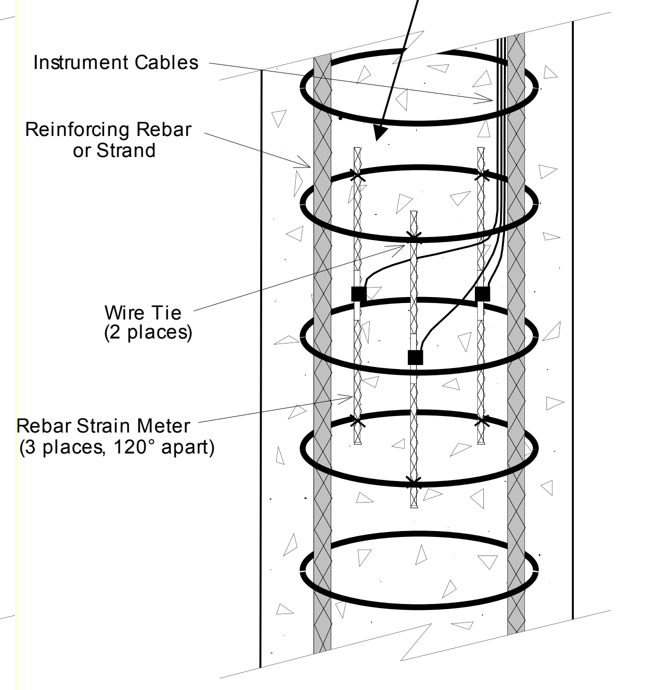
Vibrating Wire Transducer

Rebar Strain Meter — “Sister Bar”

Three bars?!



Tied to Reinforcing Rebar



Tied to Reinforcing Rings

We have got the strain. How to we get the load?

- Load is stress times area
- Stress is Modulus (E) times strain

$$\sigma = E\,\varepsilon$$

- The modulus is the key

For a concrete pile or a concrete-filled bored pile, the modulus to use is the combined modulus of concrete, reinforcement , and steel casing

$$E_{comb} = \frac{E_s A_s + E_c A_c}{A_s + A_c}$$

E_{comb}	=	combined modulus
E_s	=	modulus for steel
A_s	=	area of steel
E_c	=	modulus for concrete
A_c	=	area of concrete

- **The modulus of steel is 200 GPa (207 GPa for those weak at heart)**

- **The modulus of concrete is. . . . ?**

Hard to answer. There is a sort of relation to the cylinder strength and the modulus usually appears as a value around 30 GPa, or perhaps 20 GPa or so, perhaps more.

This is not good enough answer but being vague is not necessary.

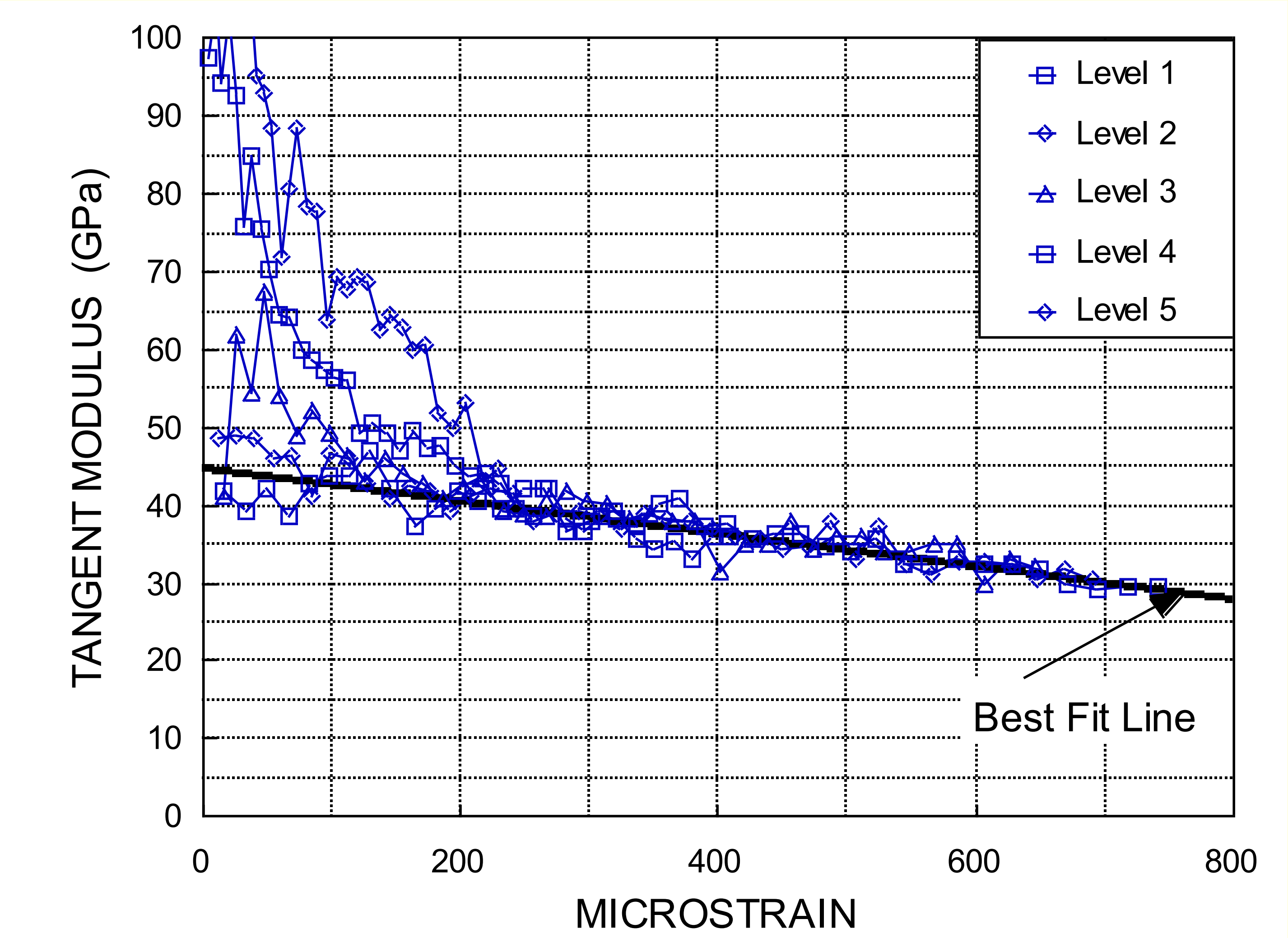
The modulus can be determined from the strain measurements.

Calculate first the *change of strain for a change of load* and plot the values against the strain.

$$E_t = \frac{\Delta\sigma}{\Delta\varepsilon}$$

Values are known

Example of “Tangent Modulus Plot”



In the stress range of the static loading test, modulus of concrete is not constant, but a more or less linear relation to the strain

$$E_t = \left(\frac{d\sigma}{d\varepsilon} \right) = a\varepsilon + b$$

Which can be integrated to:

$$\sigma = \left(\frac{a}{2} \right) \varepsilon^2 + b\varepsilon$$

But stress is also a function of secant modulus and strain:

$$\sigma = E_s \ \varepsilon$$

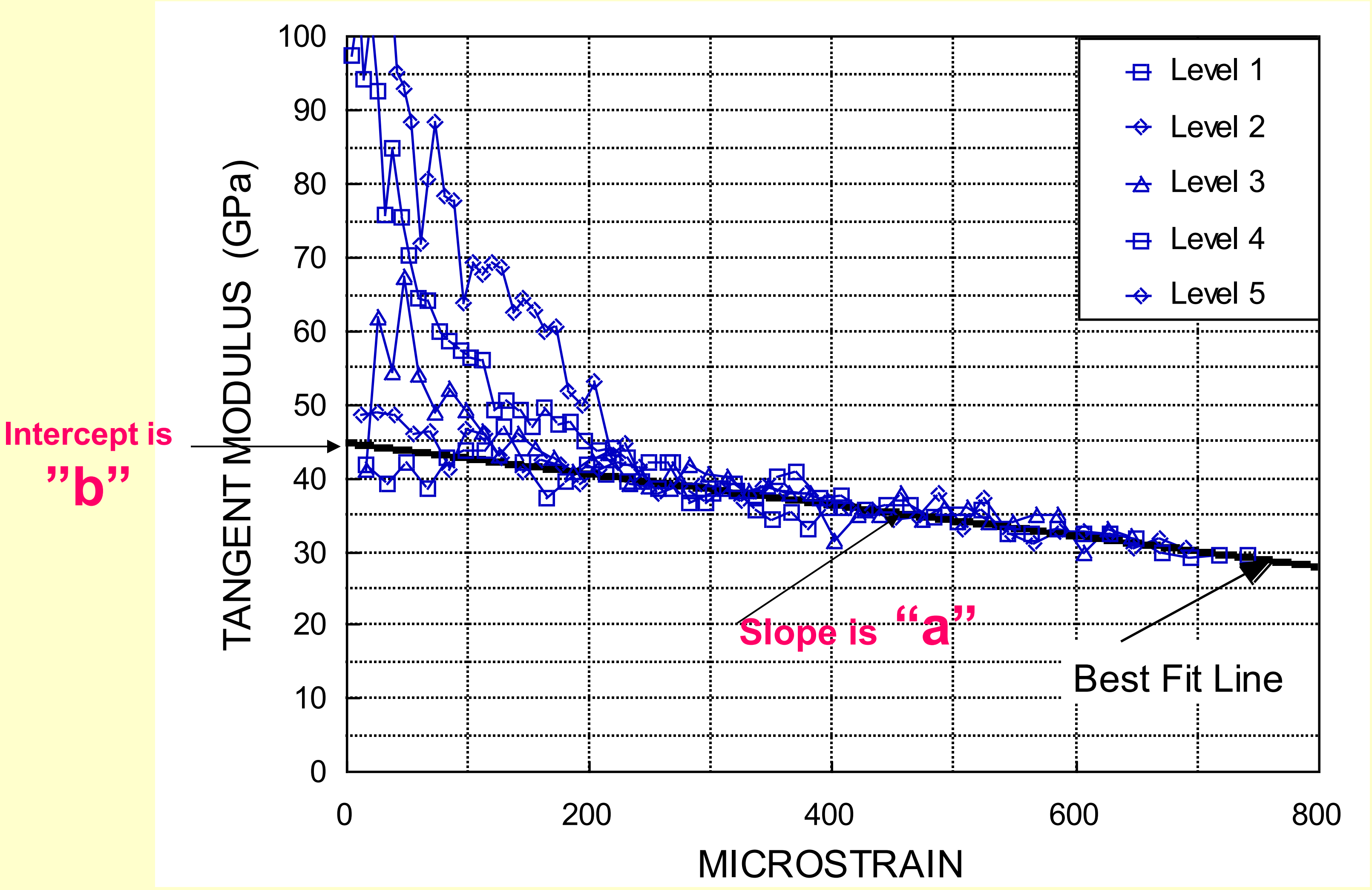
Combined, we get a useful relation:

$$E_s = 0.5 a \varepsilon + b$$

and

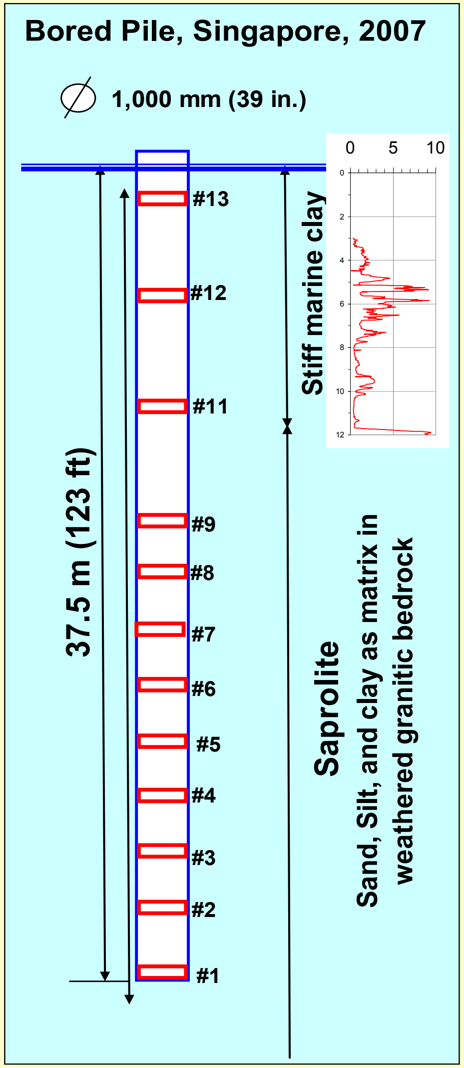
$$\mathrm{Q = A\ E_s\ \varepsilon}$$

Example of “Tangent Modulus Plot”

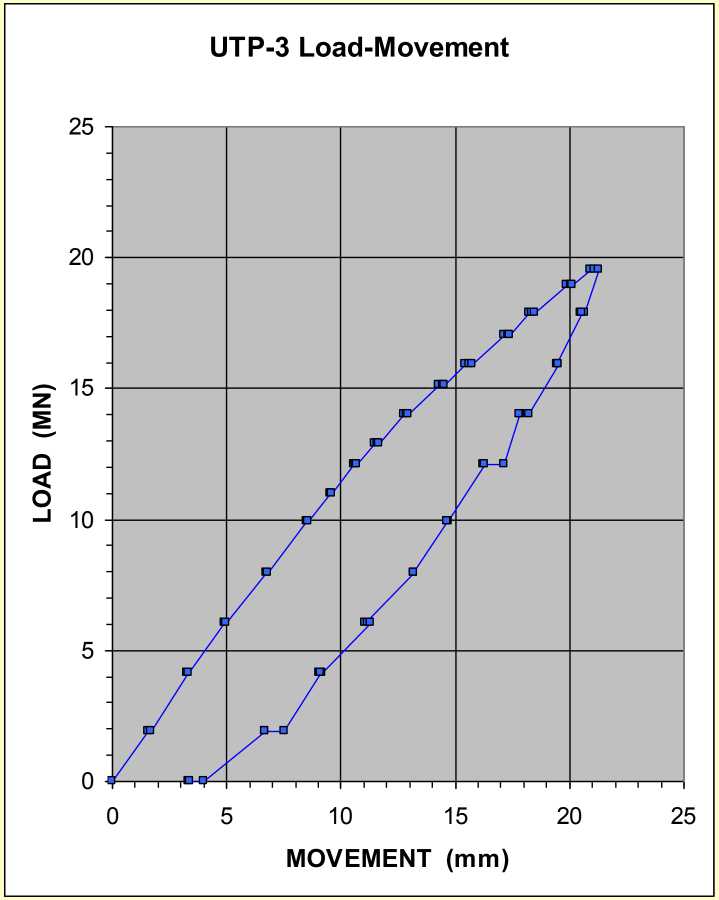


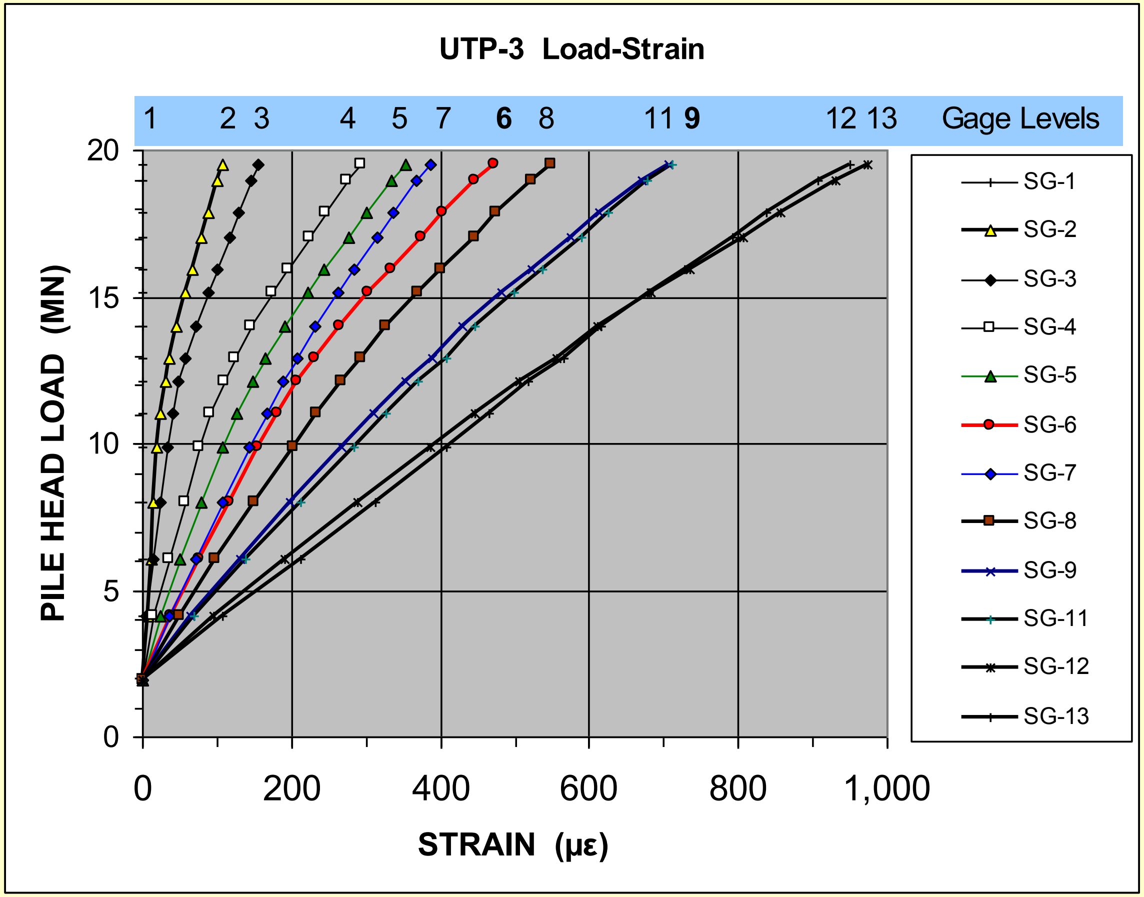
Note, just because a strain-gage has registered some strain values during a test does not guarantee that the data are useful. Unavoidable errors and natural variations amount to about 50 microstrain to 100 microstrain. Therefore, the test must be designed to achieve strain values at least of about 500 microstrain and beyond. If the imposed strain are smaller, the relative errors and imprecision will be large, and interpretation of the test data becomes uncertain, causing the investment in instrumentation to be less than meaningful. The test should engage the pile material up to at least half the strength. Preferably, aim for reaching close to the strength.

Example of evaluation and assessment of strain-gage values



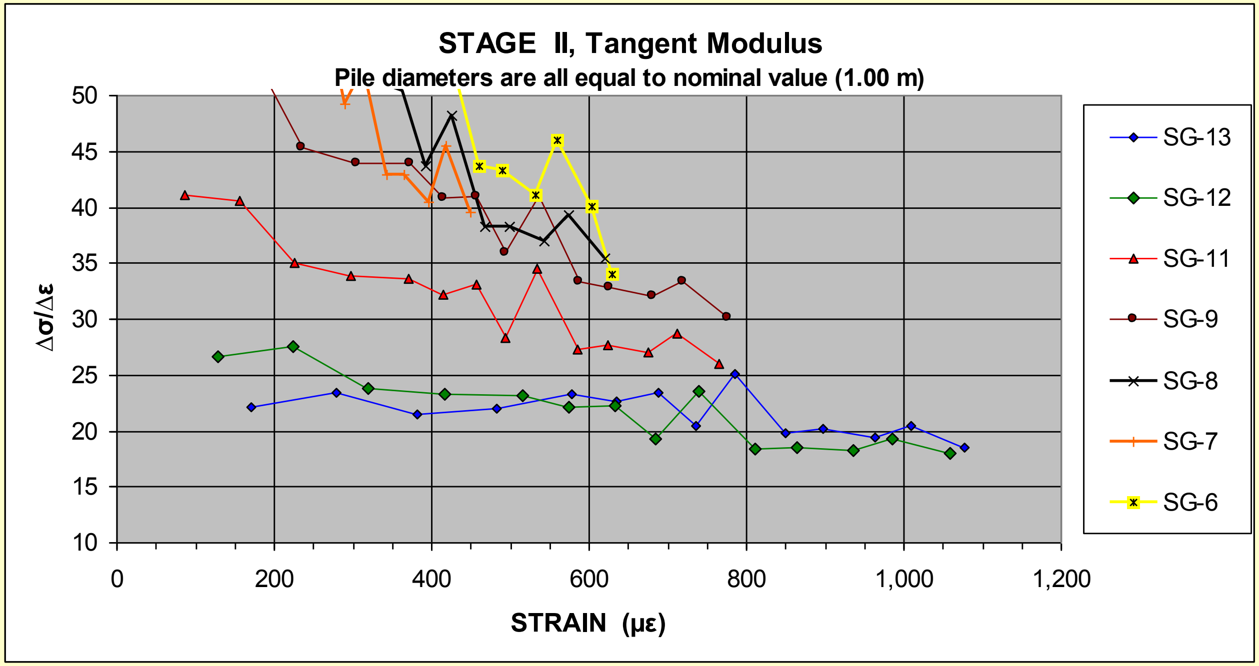
Pair of Vibrating-Wire Strain Gages (Sister Bars)


UTP-3 Load-Movement
LOAD (MN)
MOVEMENT (mm)
0
5
10
15
20
25

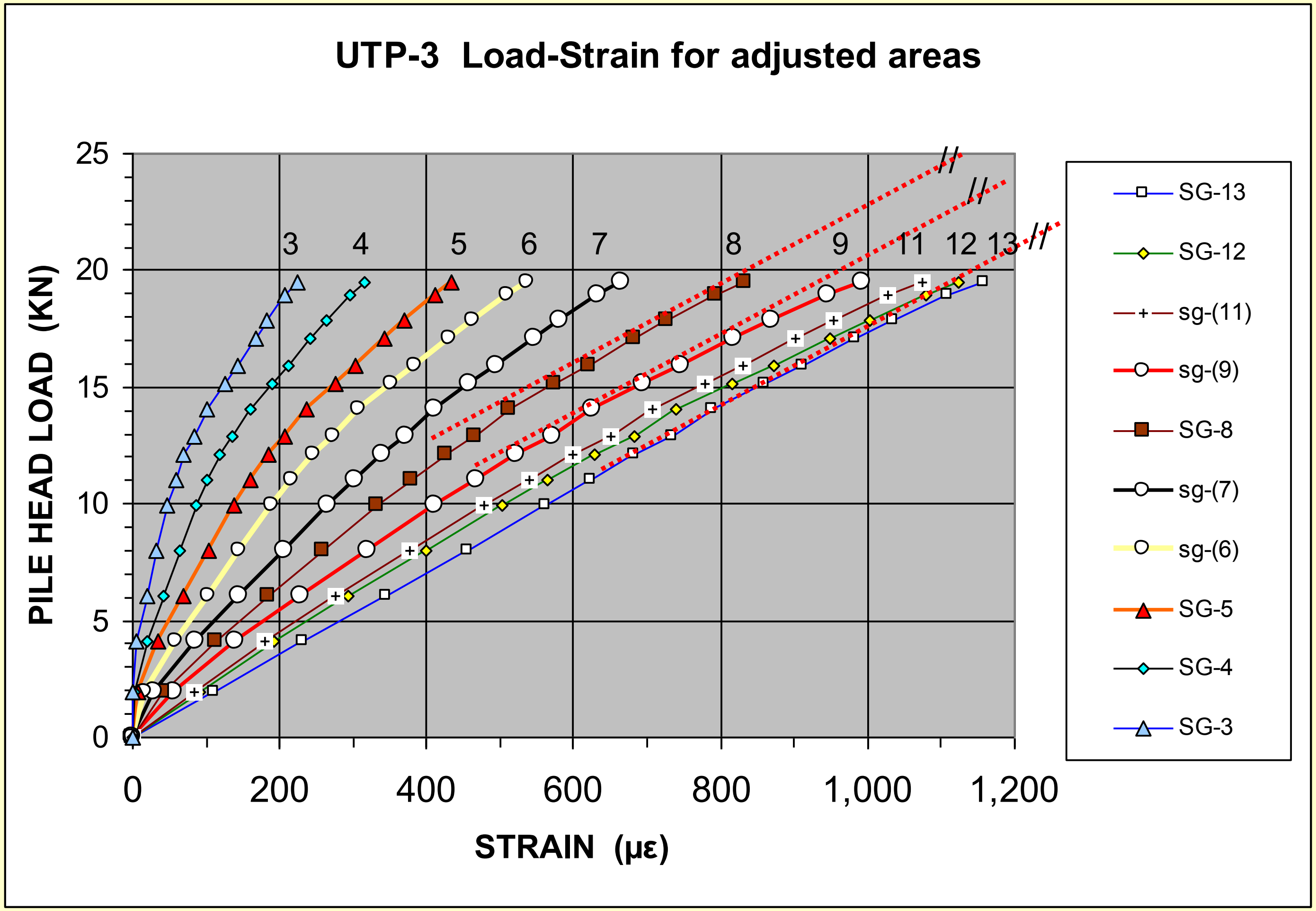

UTP-3 Load-Strain
1 2 3 4 5 7 6 8 11 9 12 13 Gage Levels
PILE HEAD LOAD (MN)
STRAIN (με)
0
200
400
600
800
1,000
0
5
10
15
20
SG-1
SG-2
SG-3
SG-4
SG-5
SG-6
SG-7
SG-8
SG-9
SG-11
SG-12
SG-13

Tangent Modulus Lines

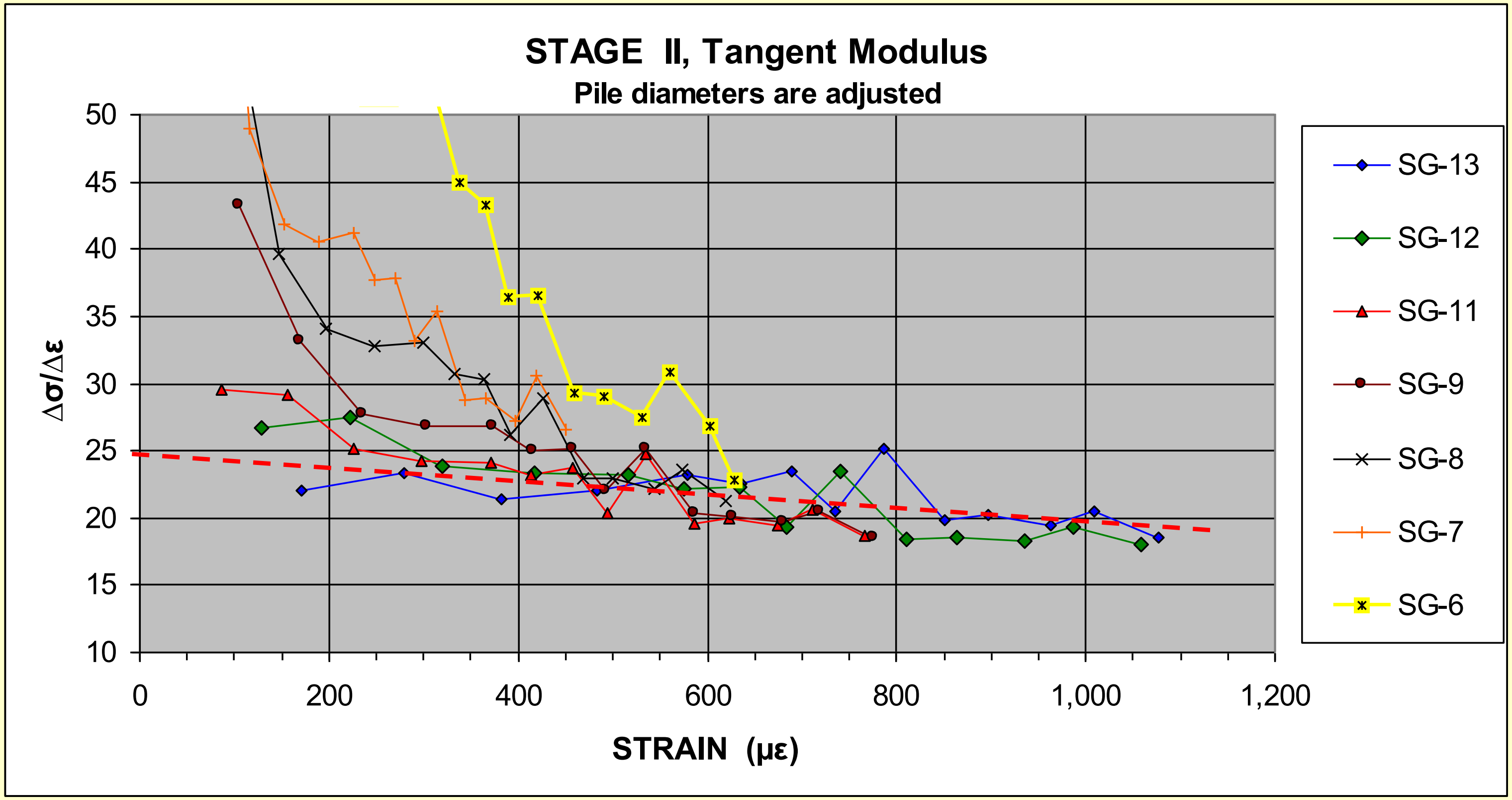
Strains are as measured; all pile diameters are assumed to be equal to the nominal area



In a trial-and-error approach, the piles diameters (pile areas) were adjusted, and the strains were proportioned to the adjusted pile areas to ensure parallel slope of load-strain curves and equal tangent modulus lines.

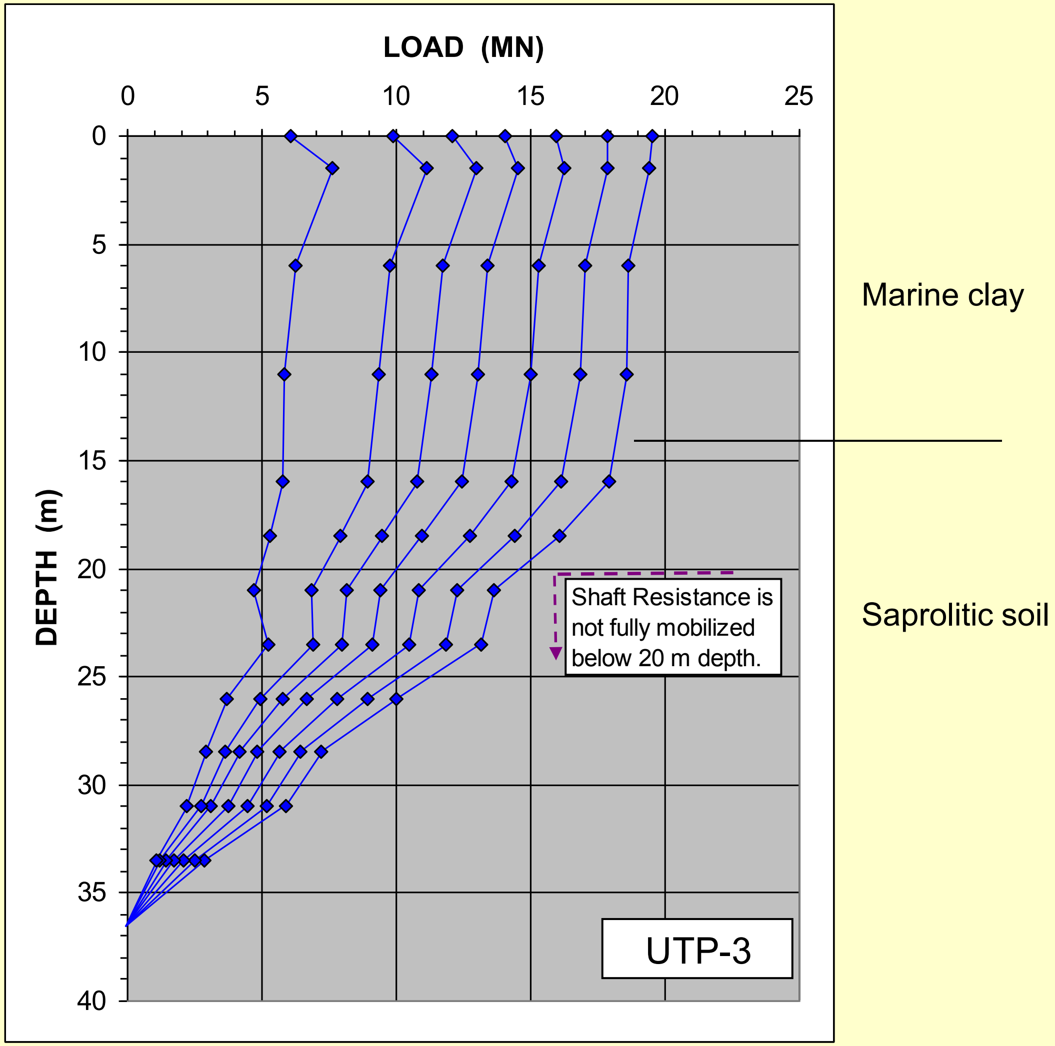


Adjustments ranged from increasing the diameter by 110 mm (#6) through 280 mm (#7)



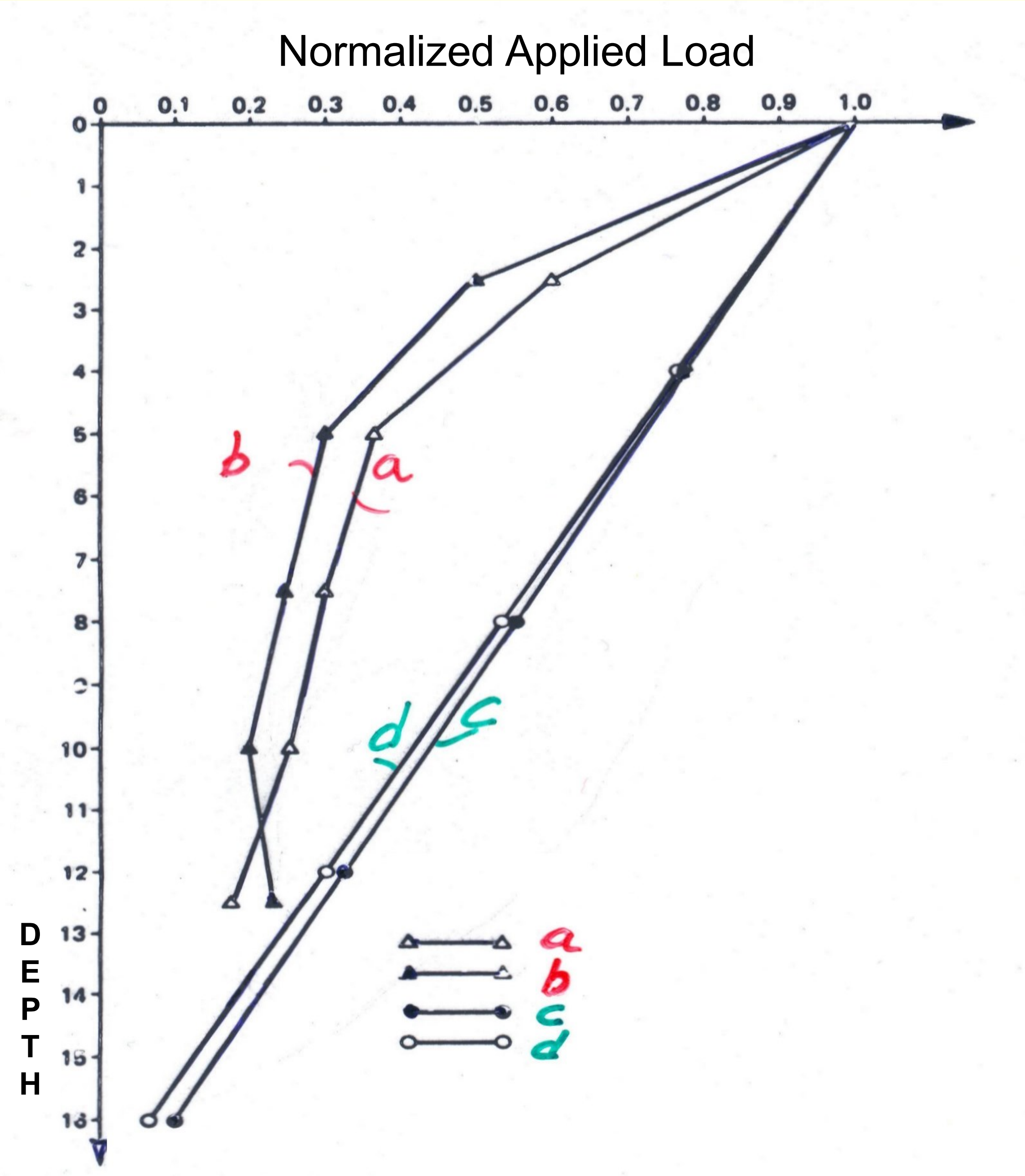
Note, you can also plot the tangent-modulus lines as tangent-stiffness (AE) lines, i.e., plot change of **load** over change of strain as opposed to change of **stress** over change of strain. Then, use the AE-values directly in the load calculation. However, this does give you less reference to what the actual differences are along the pile.

Now, having determined the relation between strain and secant modulus (from knowing the tangent-modulus), we are ready to convert measured strain to ”measured” load in the pile: **The load distribution**.



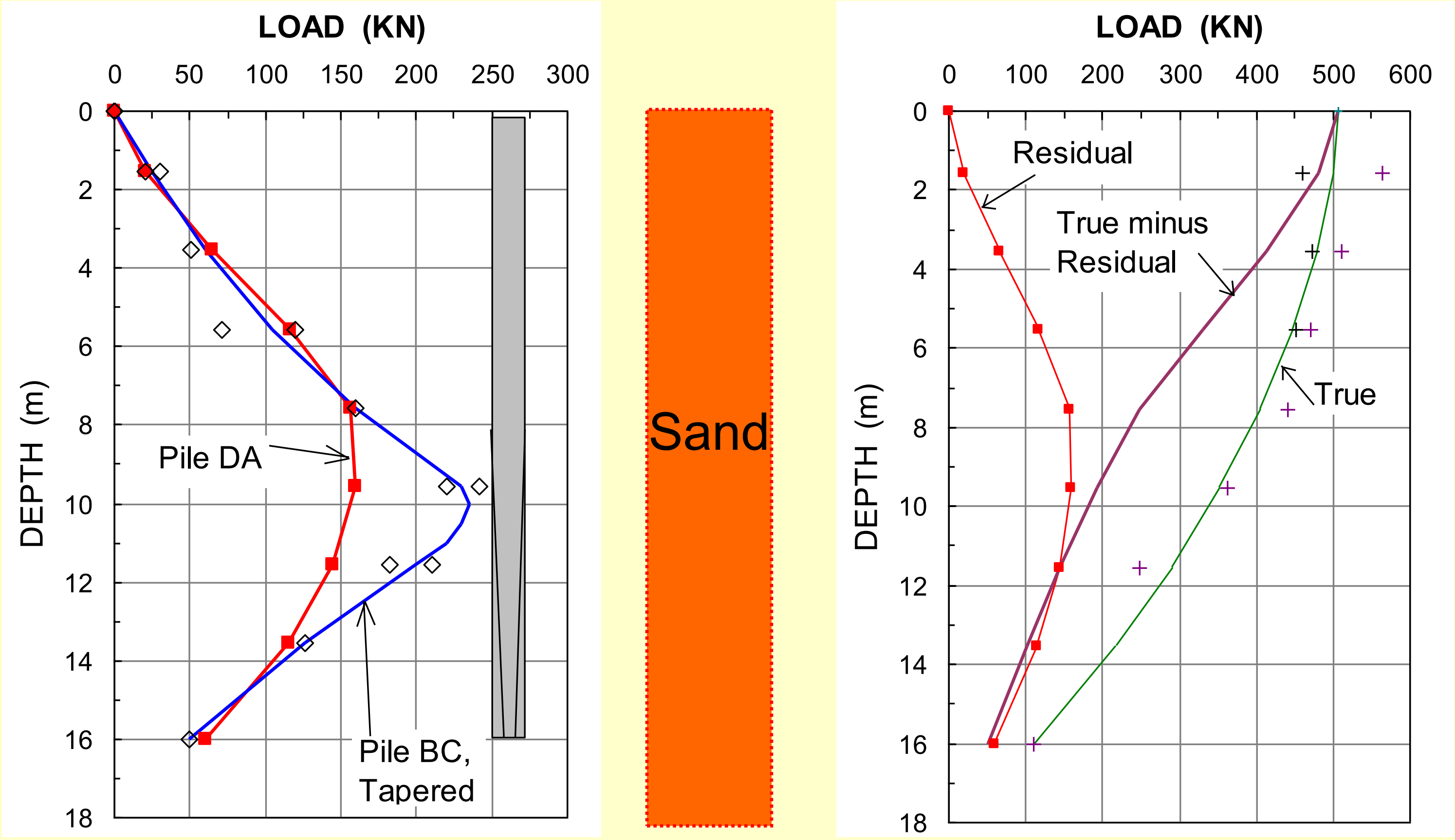
What we measure is the increase of load in the pile due to the load applied to the pile head. What about the external-origin load in the pile that was there before we started the test?

That is, the Residual load.



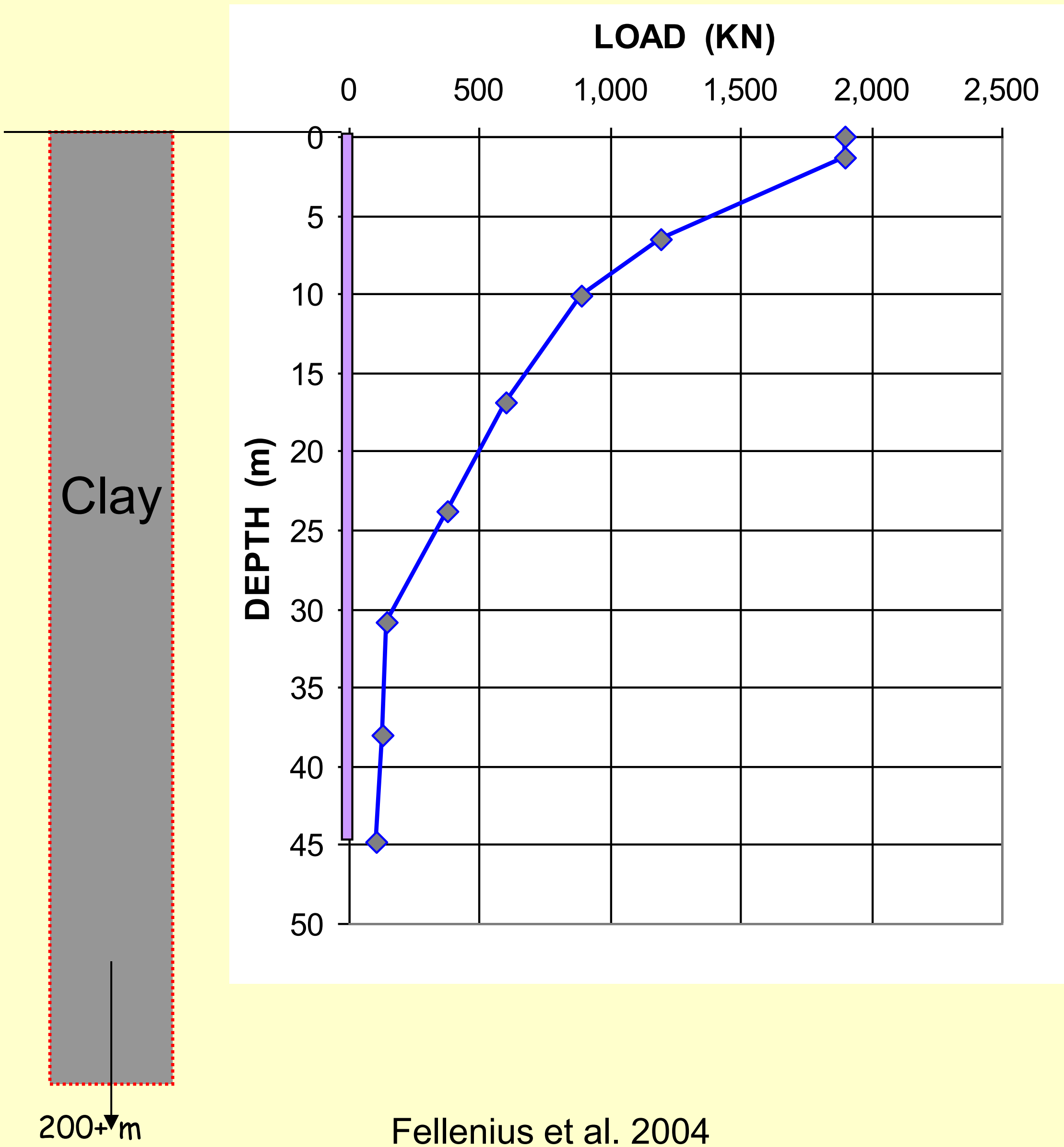
Load distributions in static loading tests on four instrumented piles in clay

Example from Gregersen et al., 1973



A. Distribution of residual load in DA and BC before start of the loading test

B. Load and resistance in DA for the ultimate load applied

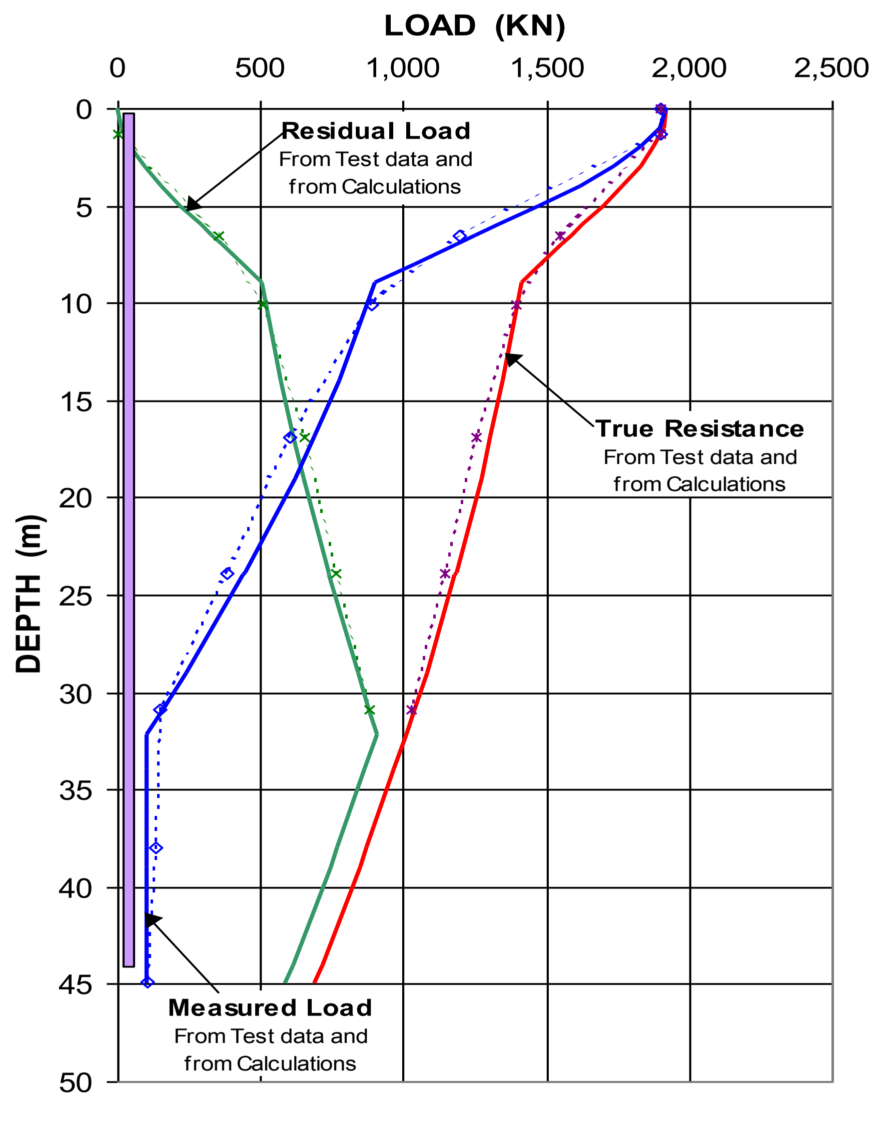


Fellenius et al. 2004

Static Loading Test at Pend Oreille, Sandpoint, Idaho, for the realignment of US95

406 m diameter, 45 m embedment, closed-toe pipe pile driven in soft clay

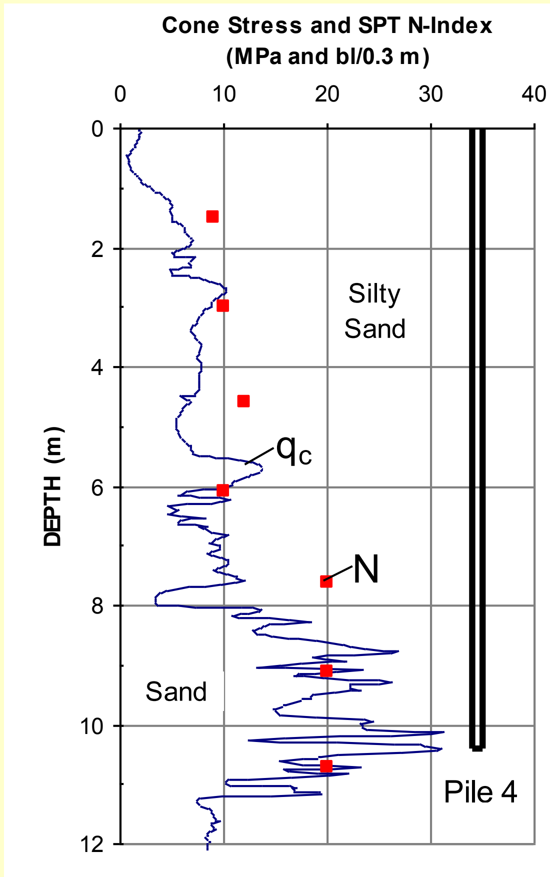
Distribution of Measured Loads (“False Resistance”) and “True Resistance

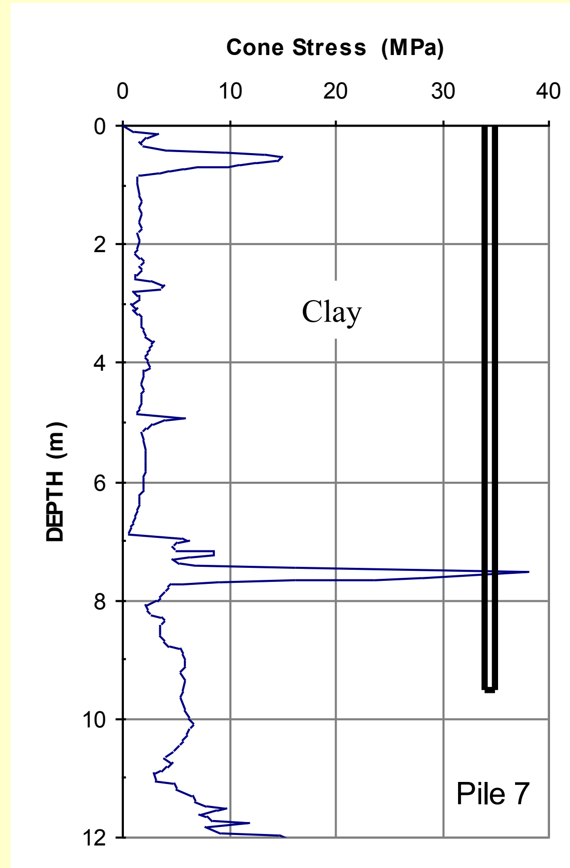


Fellenius et al. 2004

FHWA tests on 0.9 m diameter bored piles
One in sand and one in clay
(Baker et al., 1990 and Briaud et al., 2000)

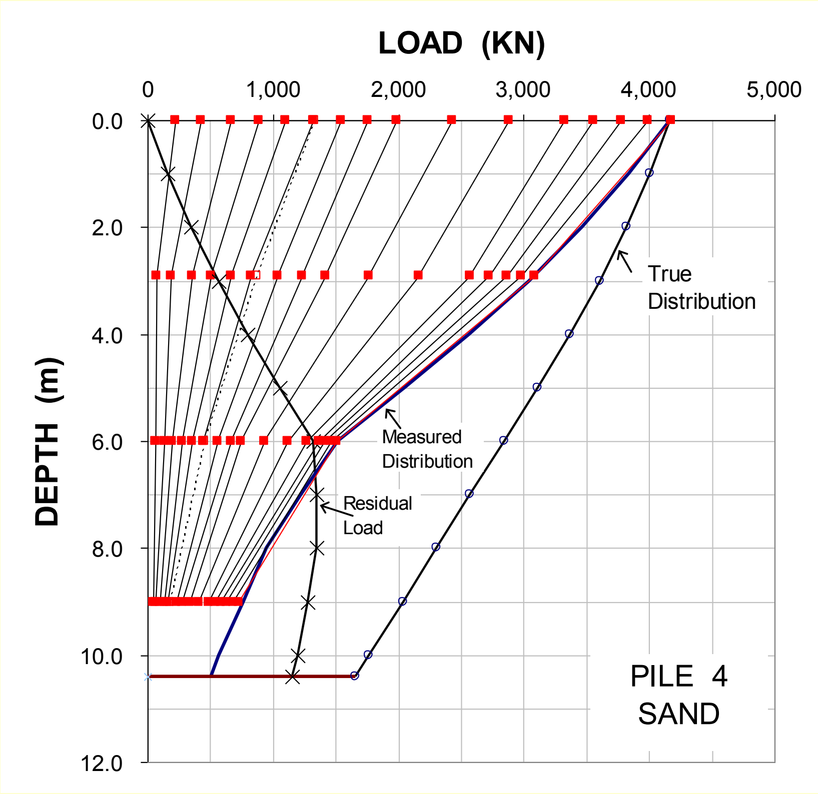
Silty Sand

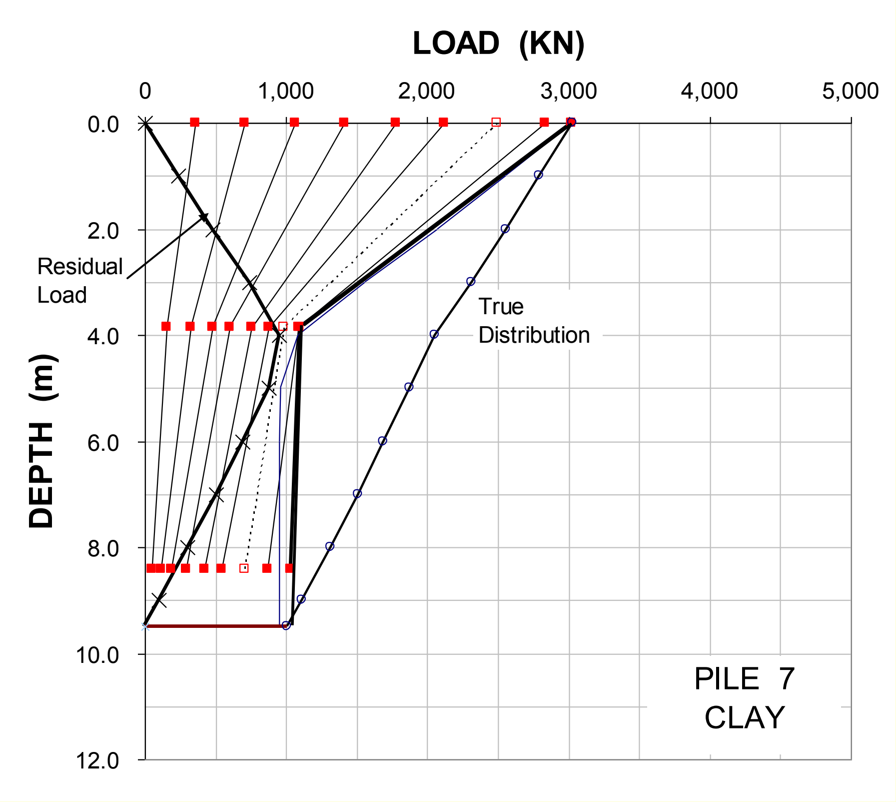




Clay

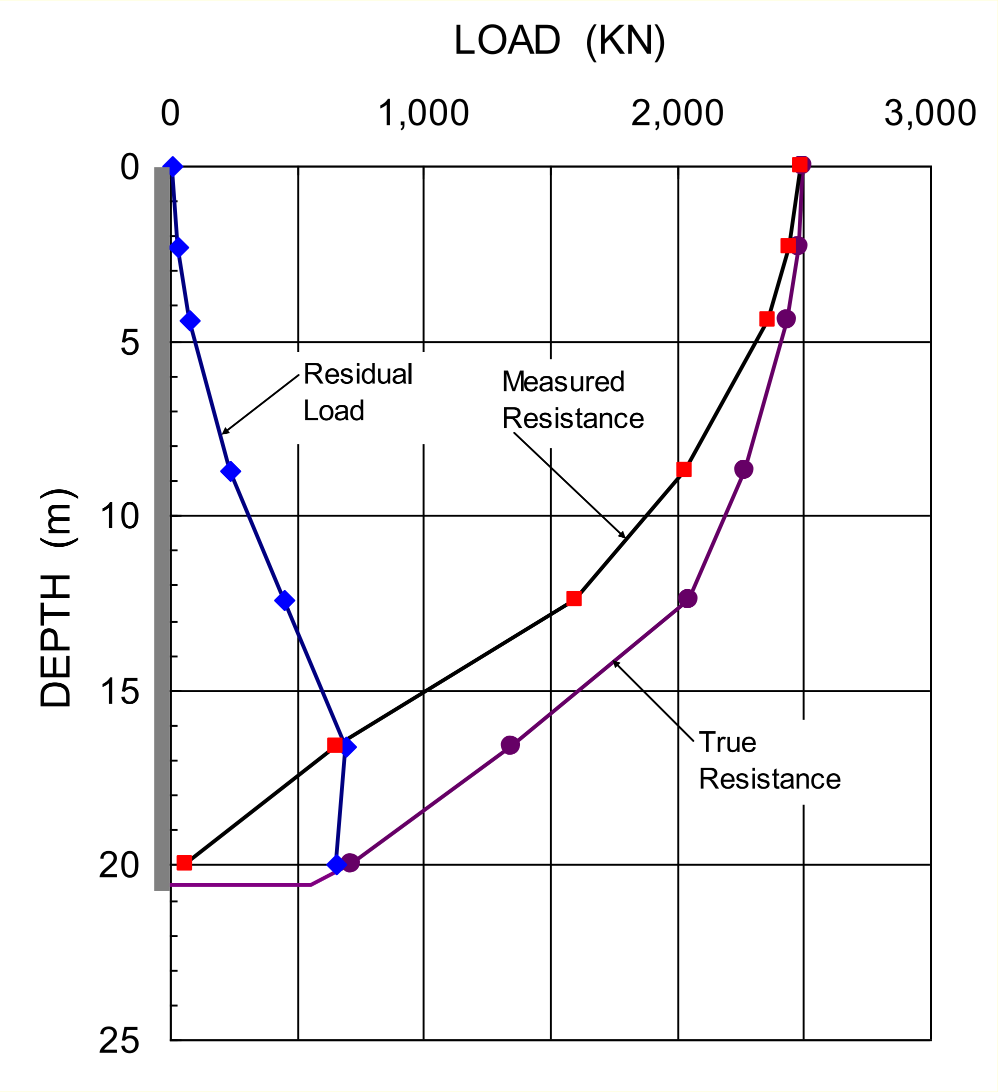
RESULTS: Load-transfer curves



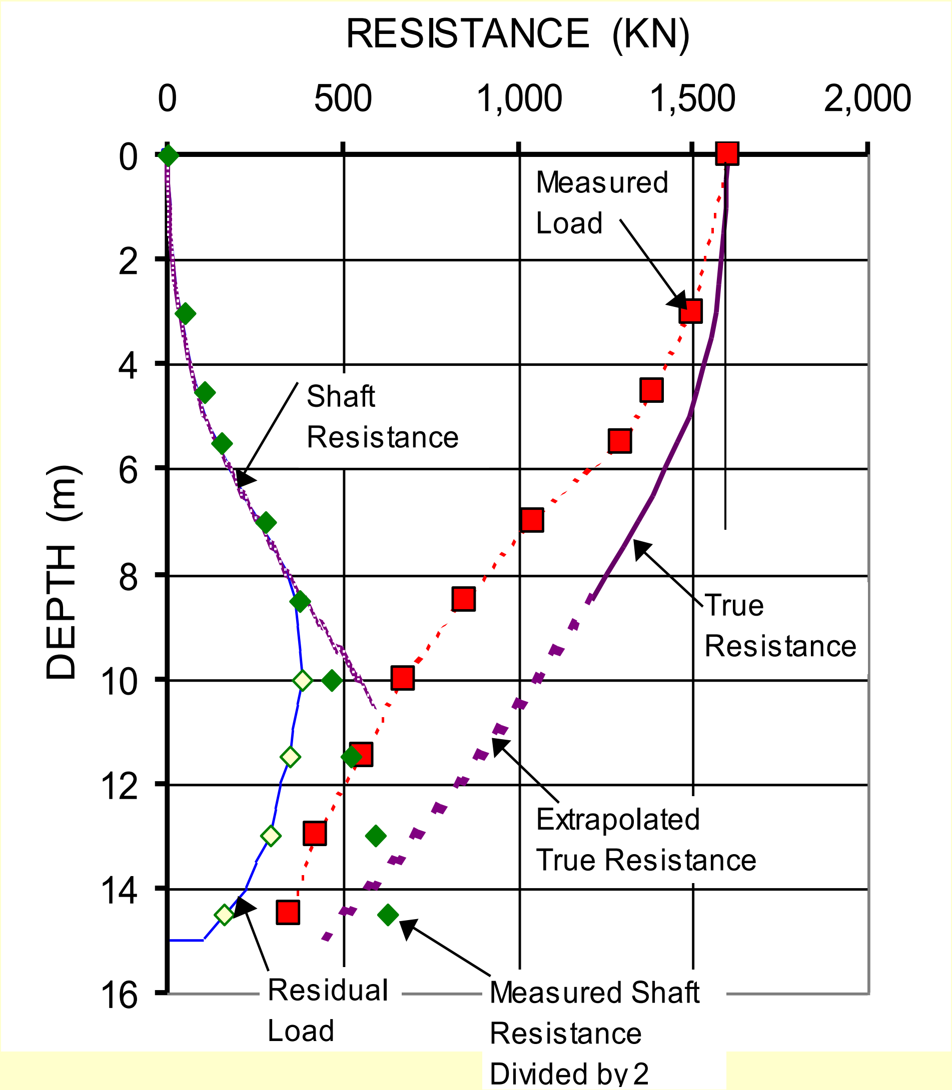


Results of analysis of a Monotube pile in sand

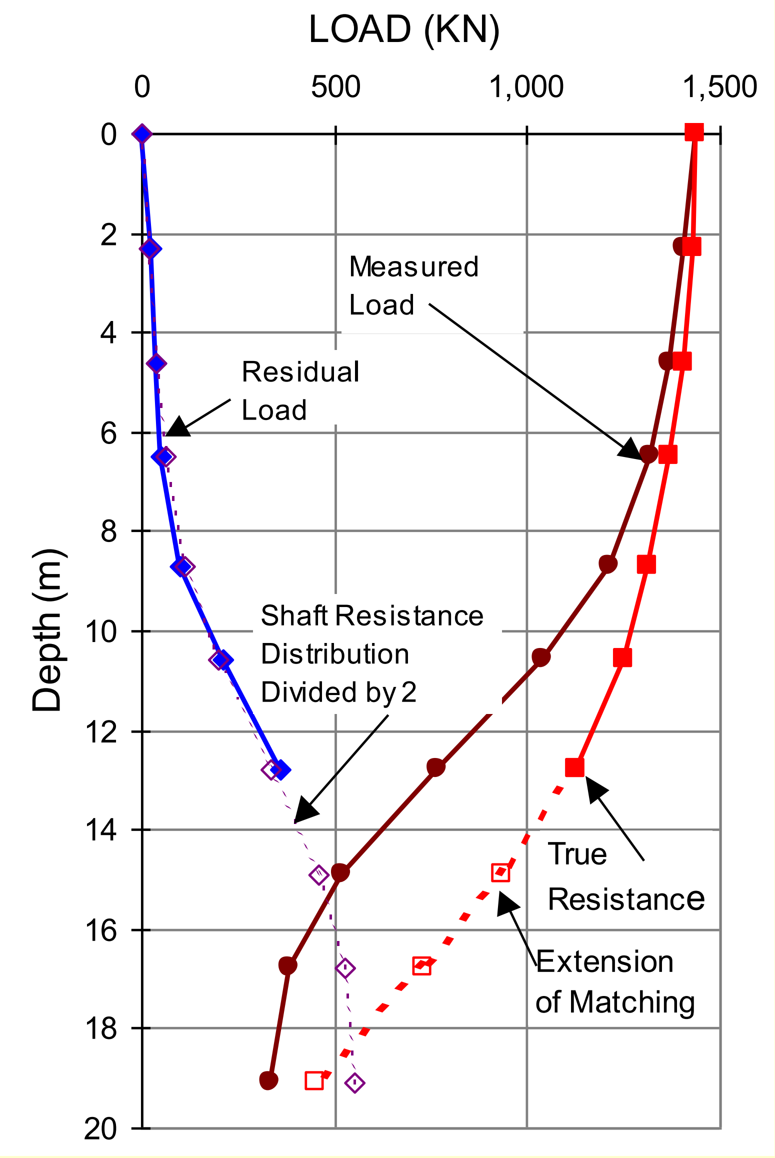
(Fellenius et al., 2000)



Method for evaluating the residual load distribution

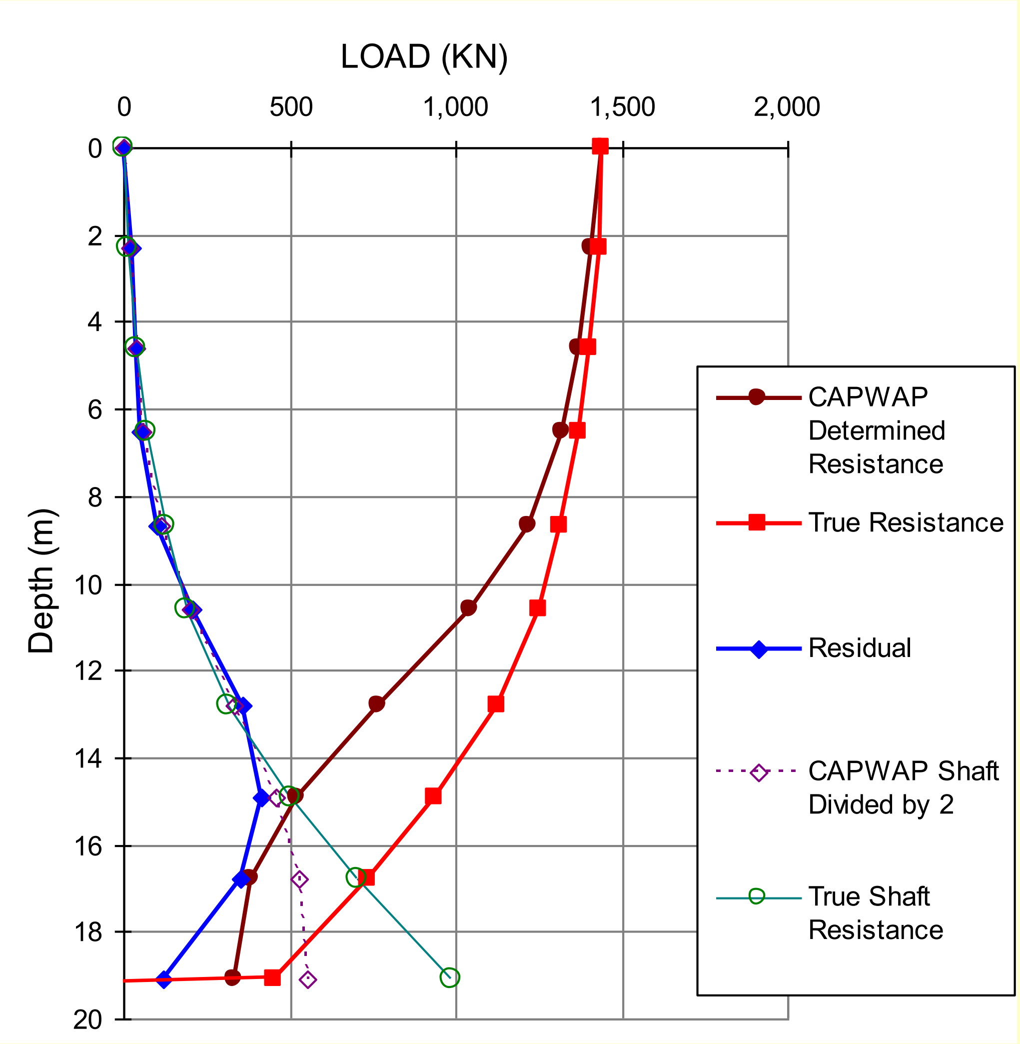


Analysis Procedure



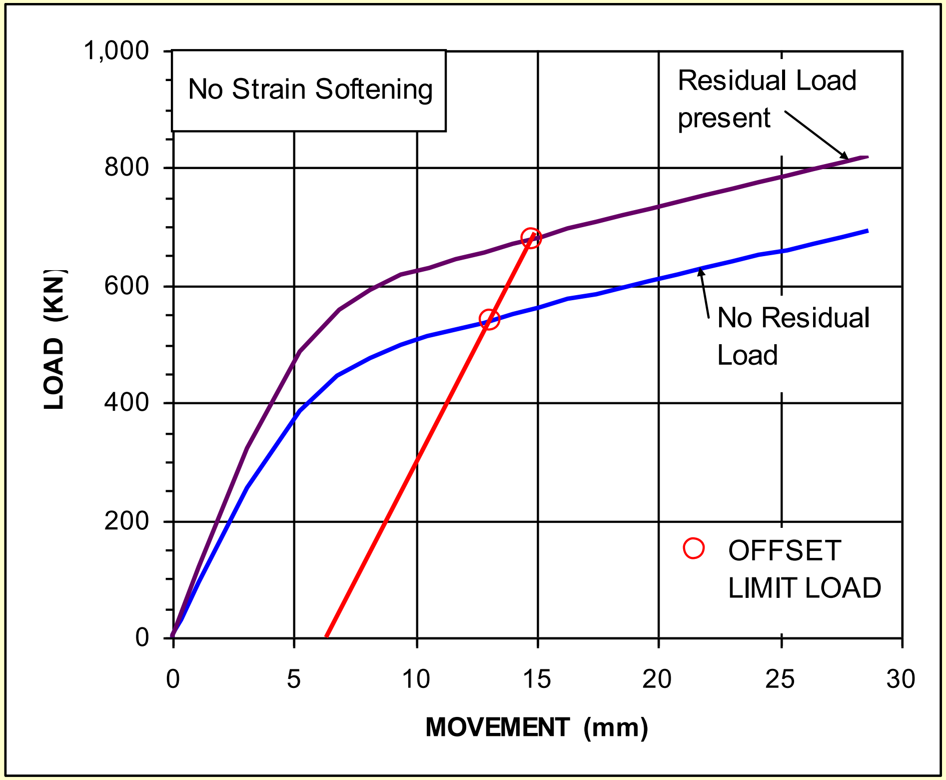
Fellenius 2002

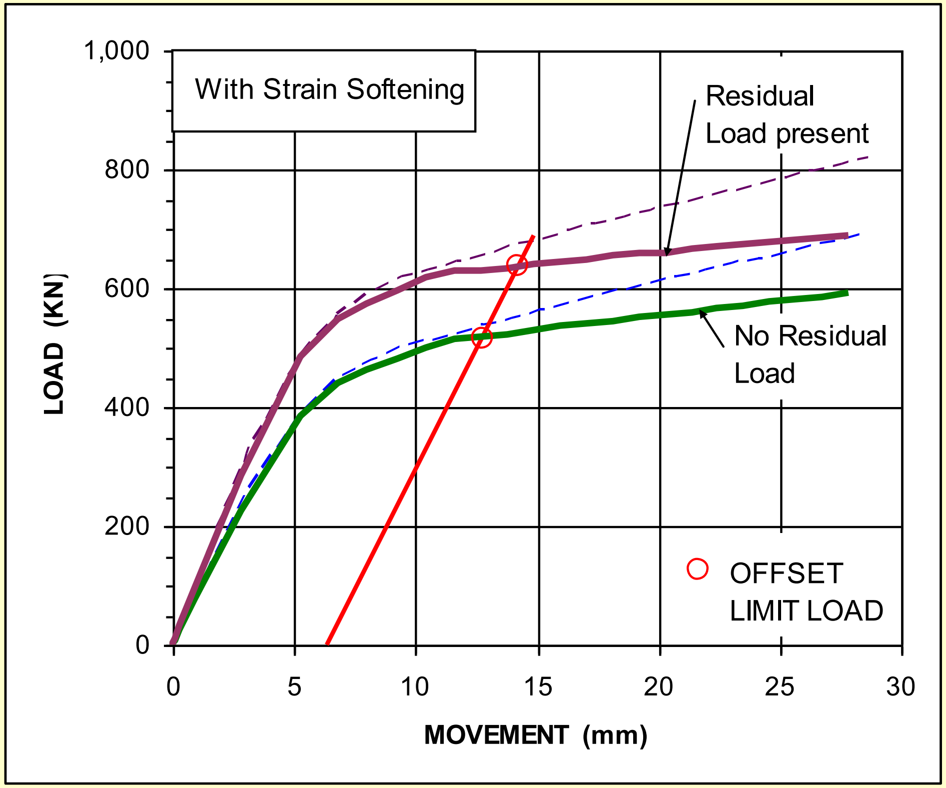
Results



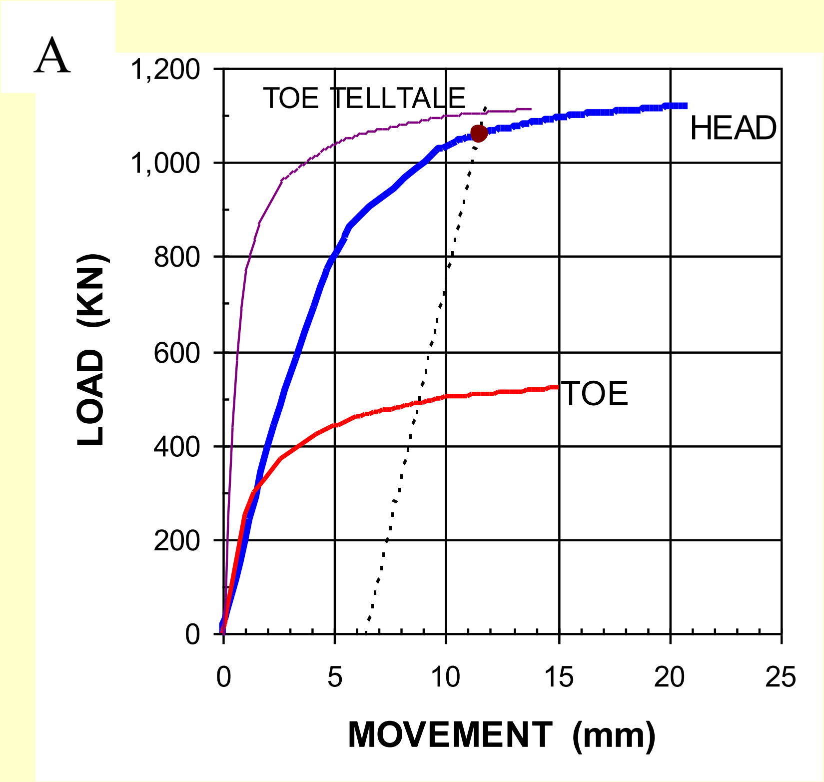
LOAD (KN)
0
500
1,000
1,500
2,000
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
CAPWAP Determined Resistance
True Resistance
Residual
CAPWAP Shaft Divided by 2
True Shaft Resistance

Presence of residual load is not just of academic interest

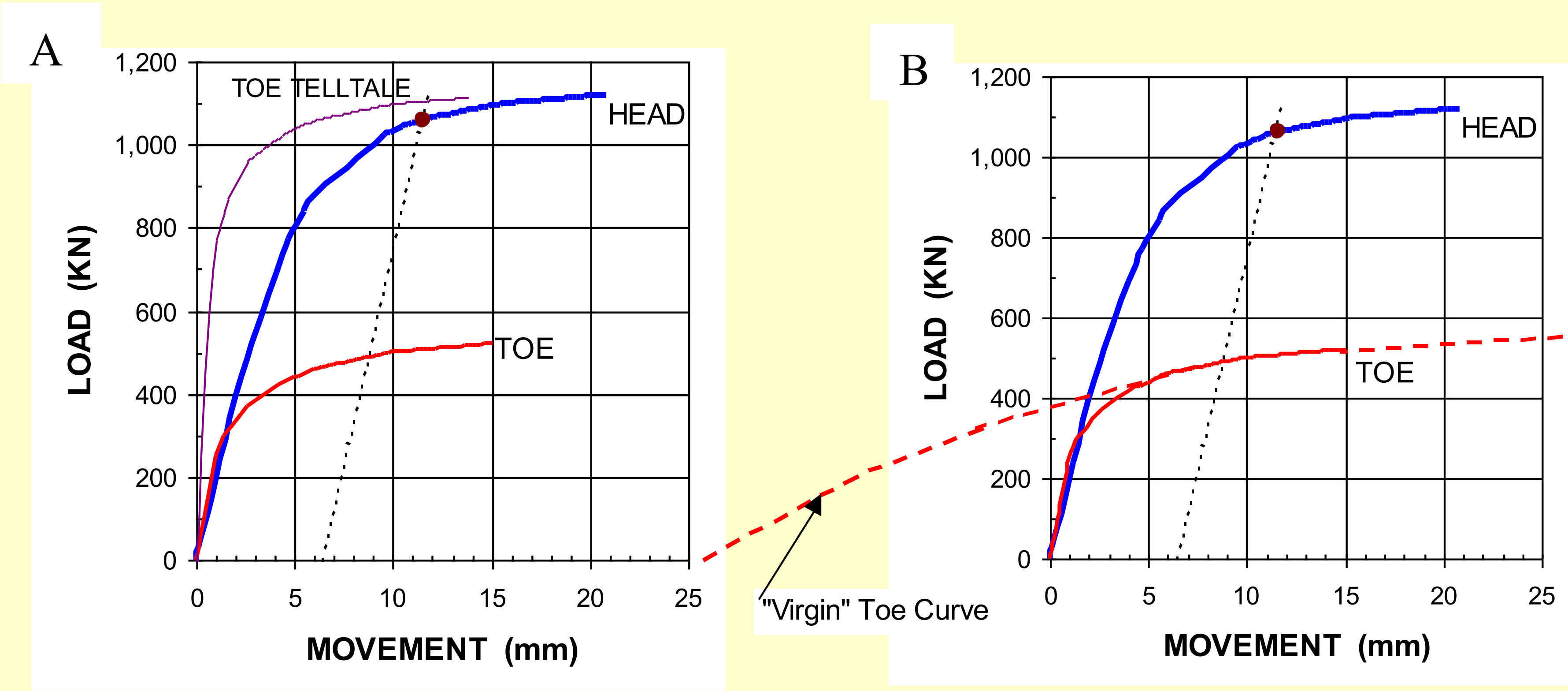




Toe Resistance



Does not this shape of measured toe movement suggest that there is a distinct toe capacity?



No, it only appears that way when we forget to consider the residual toe load (also called the initial, or "virgin" toe movement)

Residual load

- **"Residual Load"** is the same as "**Drag Load**". The distinction made is that by ***residual load*** we mean the locked-in load present in the pile immediately before we start a static loading test. By ***drag load*** we mean the load present in the pile in the long-term
- Residual load as well as drag load can develop in coarse-grained soil just as it does in clay soil
- Both residual load and dragload develop at very small movements between the pile and the soil

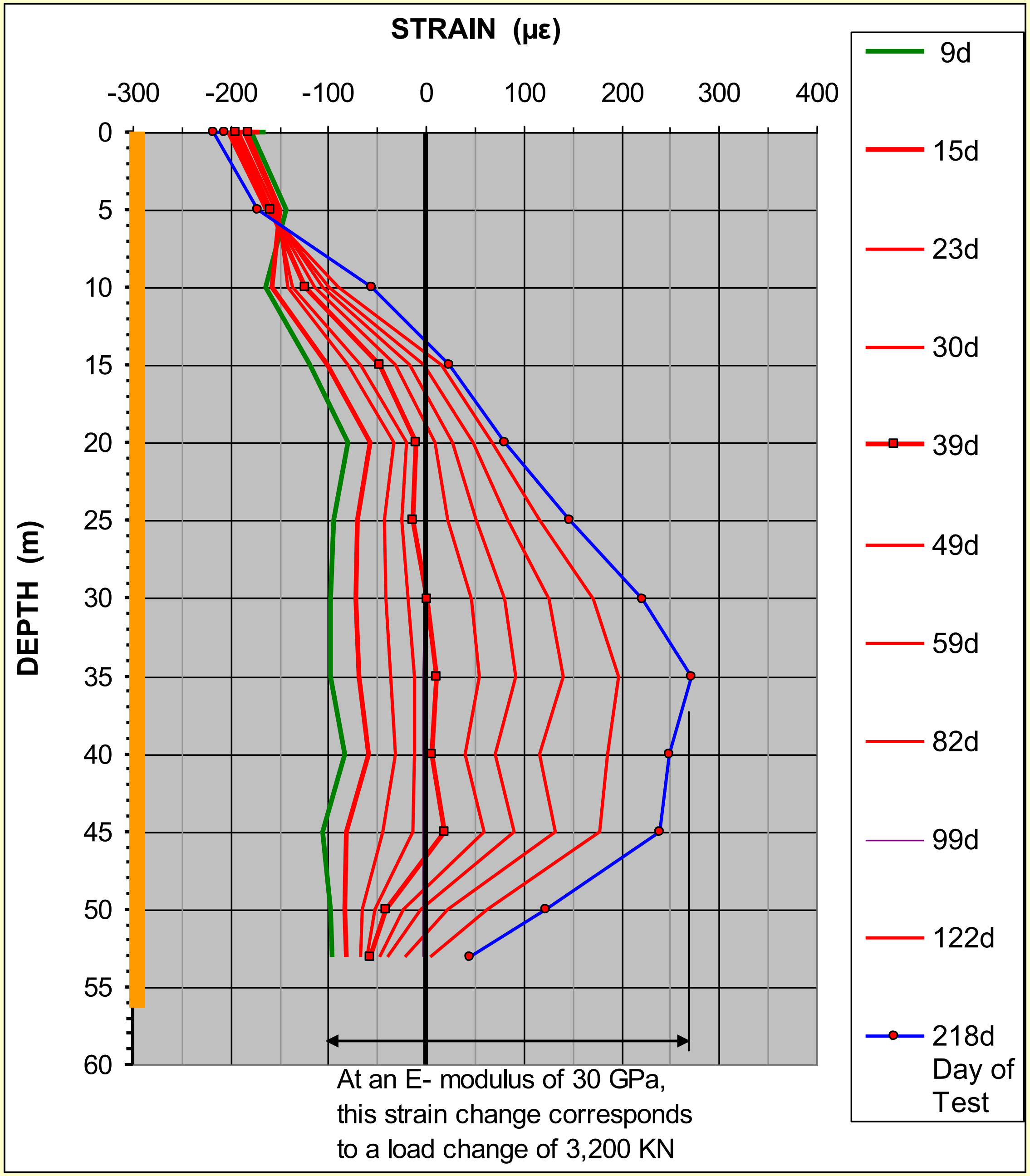
The strain-gage measurement is supposed to be the change of strain relative the “no-load” situation (i.e., when no external load acts at the gage location).

But, is the “no-load” situation really the reading taken at the beginning of the test? What is the true “zero-reading” to use?

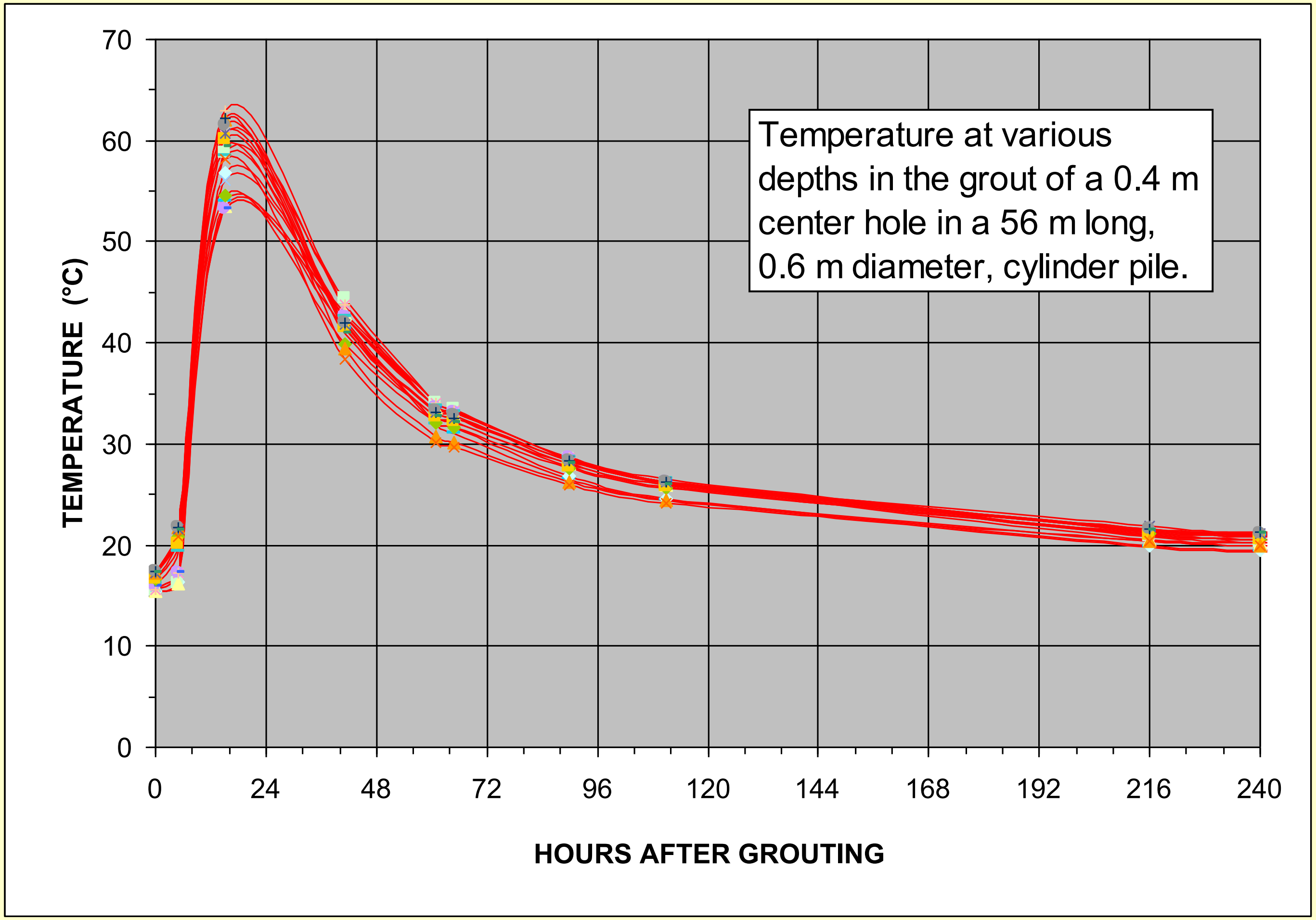
- We often assume – somewhat optimistically or naively – that the reading before the start of the test represents the “no-load” condition.
- However, at the time of the start of the loading test, loads do exist in the pile and they are often large.
- For a grouted pipe pile or a concrete cylinder pile, these loads are to a part the effect of the temperature generated during the curing of the grout.
- Then, the re-consolidation (set-up) of the soil after the driving or construction of hte pile will impose loads on the pile.

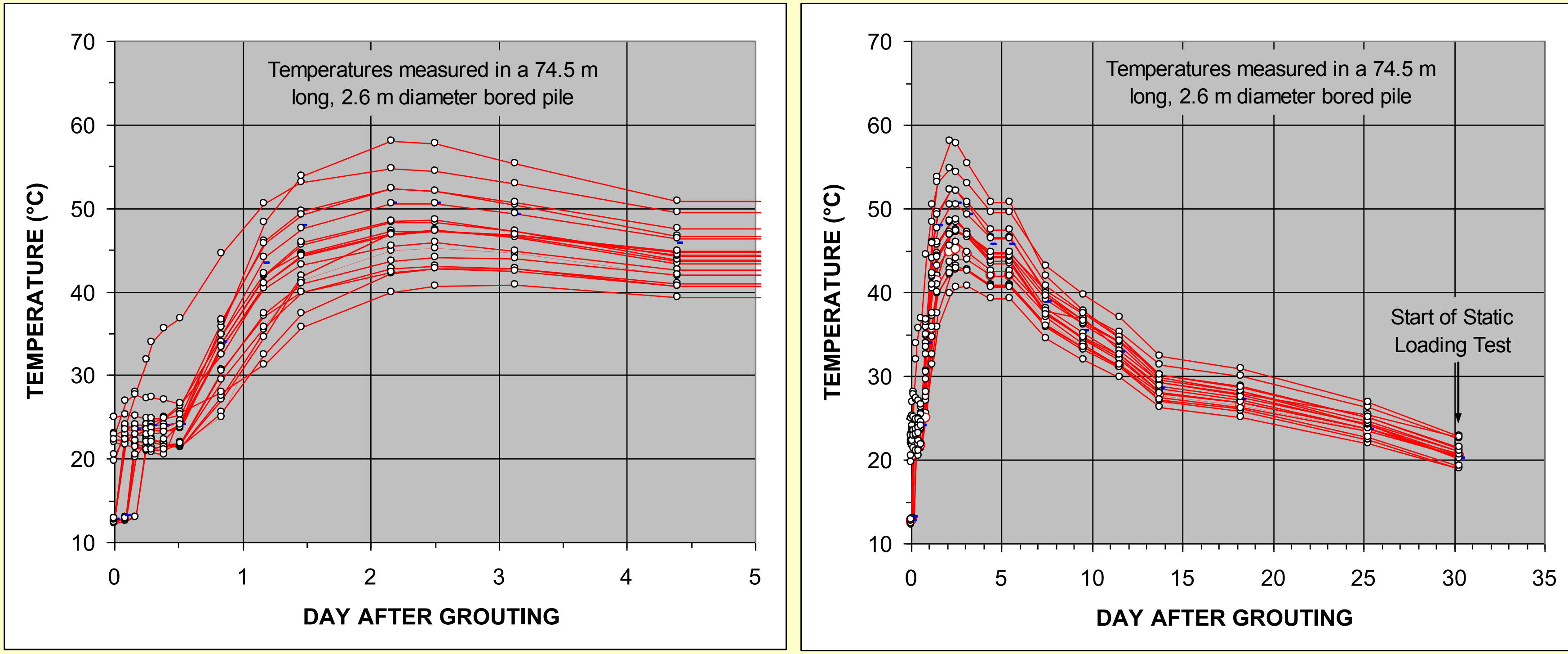
Strain measured during the 218-day wait-period between driving (grouting) and testing.

Do these strains really represent load in the pile, as present before the start of the static loading test?

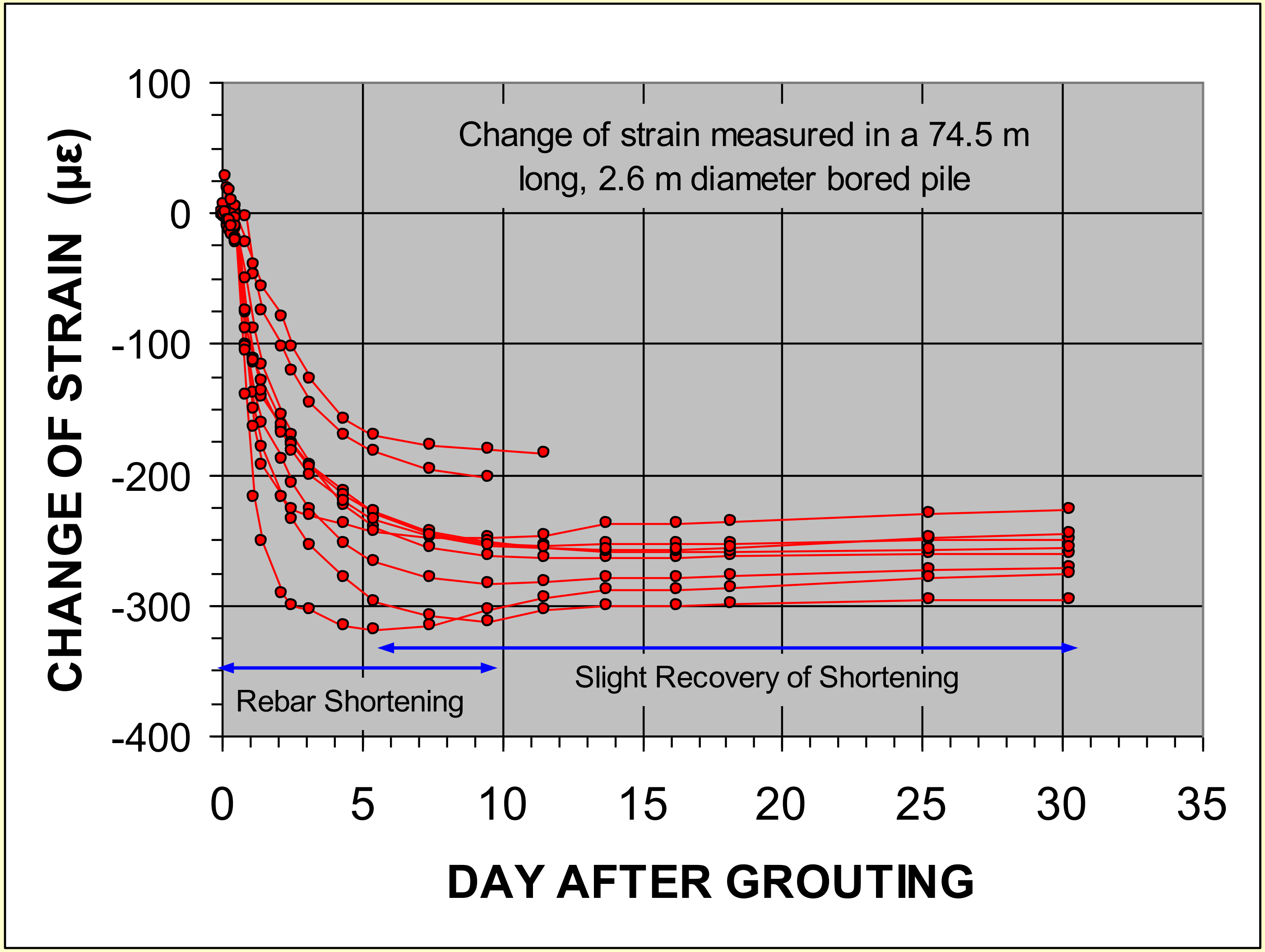


Concrete curing temperature measured in a grouted concrete cylinder pile



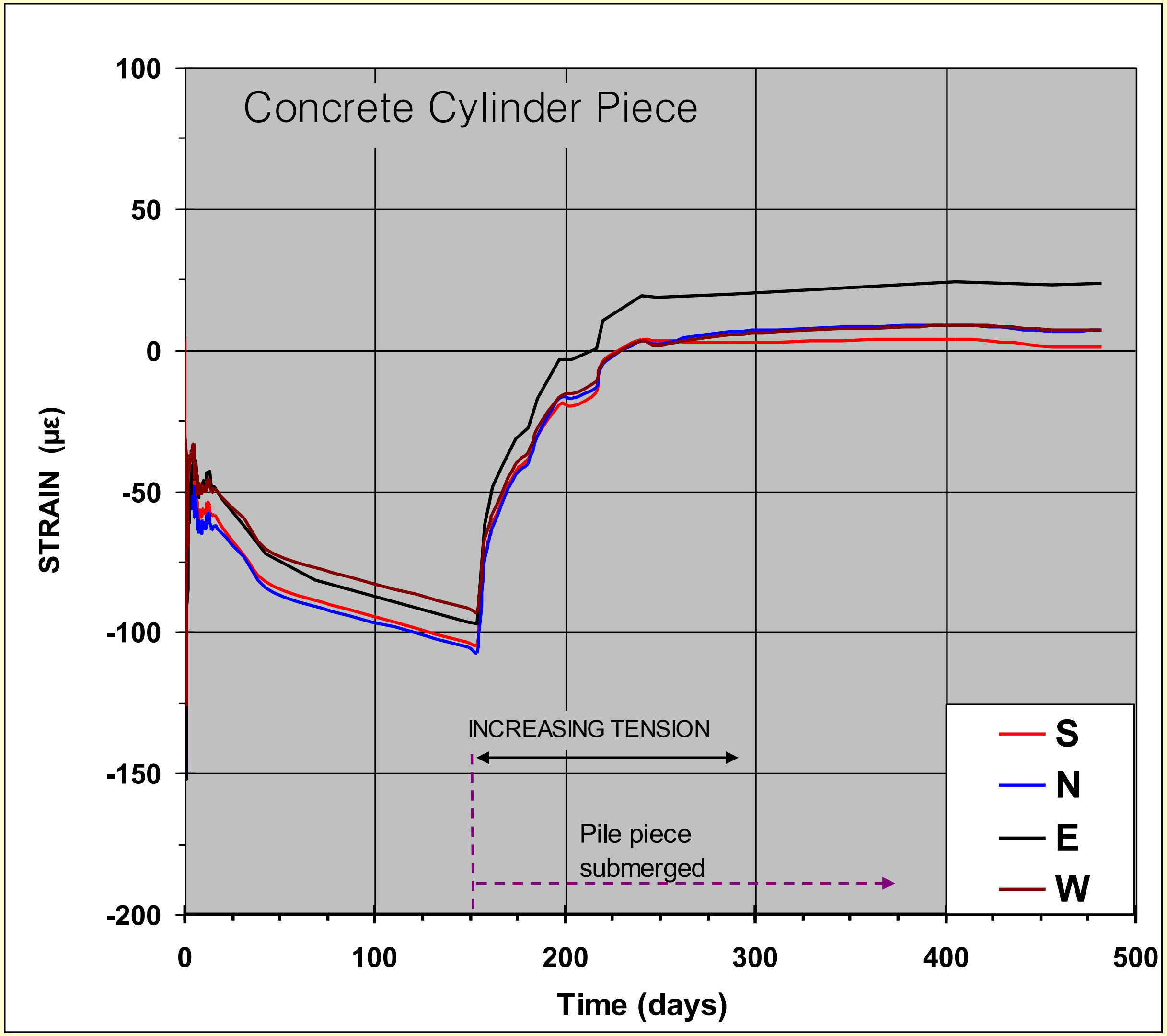


Temperature records during curing of grout in the Golden Ears Bridge test pile, Vancouver, BC. Data courtesy of Trow Engineering Inc. and Amec Inc.



Change of strain during the curing of grout in the Golden Ears Bridge test pile

Submerging the short pile segment, letting it swell from absorption of water



The strain gages are not temperature sensitive, but the strain measurements may be!

The vibrating wire and the rebar have almost the same temperature coefficient. However, the coefficients of steel and concrete are slightly different. This will influence the strains during the cooling of the grout. More important, for lower quality vibrating wire gages, the rise of temperature in the grout could affect the zero reading of the wire and its strain calibration. It is necessary to “heat-cycle” (anneal) the gage before calibration. (A routine measure of Geokon, US manufacturer of vibrating wire gages).

- Readings should be taken immediately before (and after) every event of the piling work and not just during the actual loading test

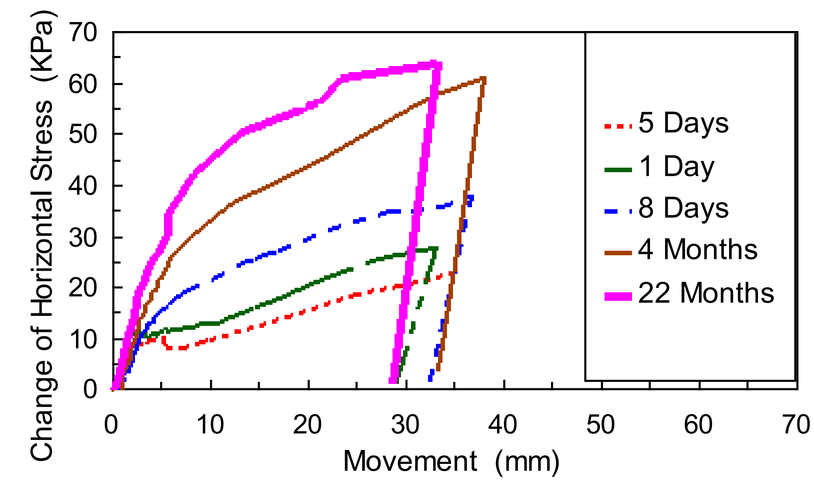
- A series of No-Load Readings will tell what happened to the gage before the start of the test and will be helpful in assessing the possibility of a shift in the reading value representing the no-load condition

- **If** the importance of the No-Load Readings is recognized, and **if** those readings are reviewed and evaluated, then, we are ready to consider the actual readings during the test

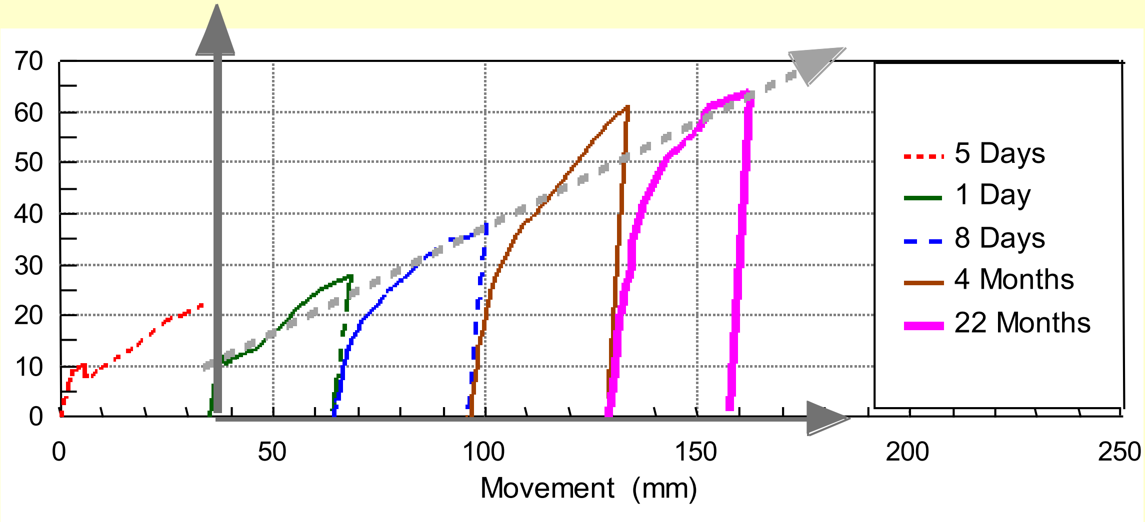
Of course,

we must consider also other aspects:

Interpretation of a series of tests performed at different times



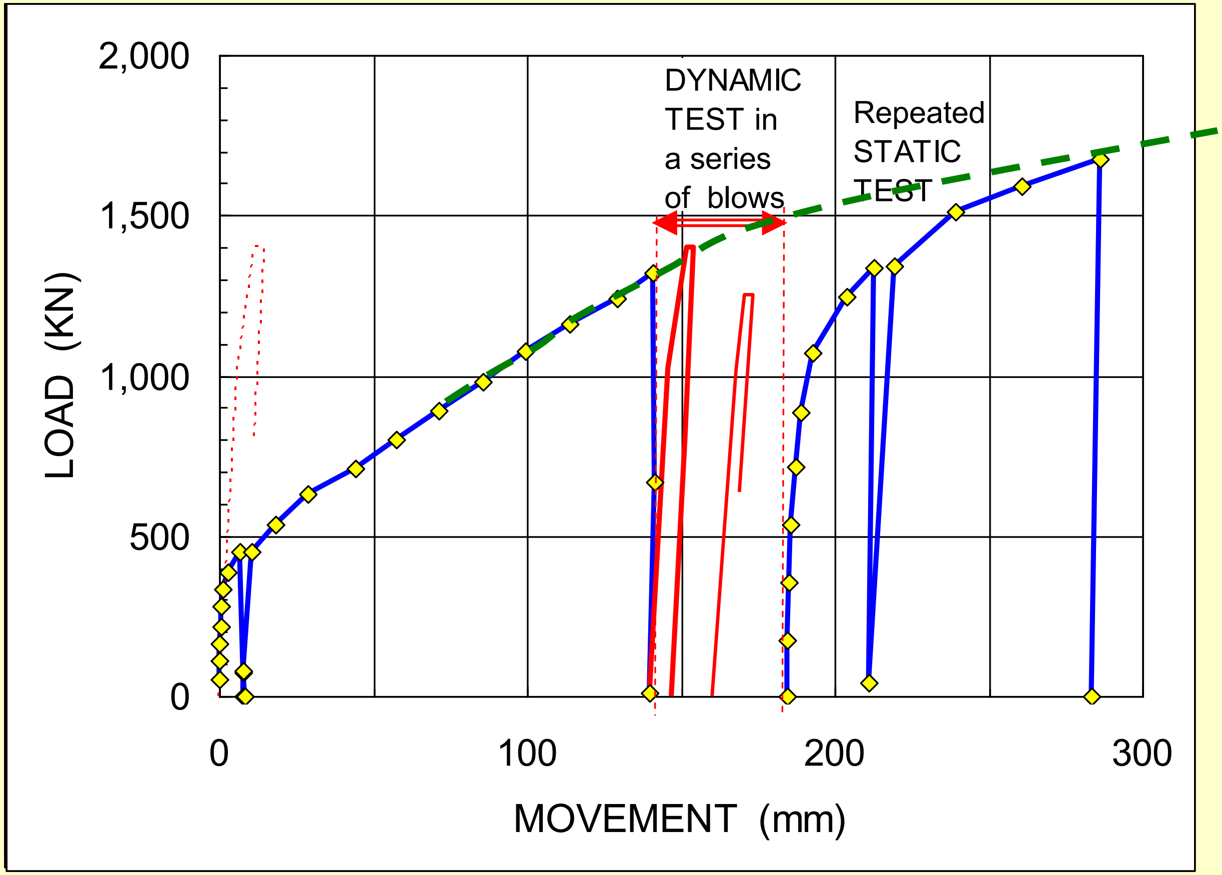
Results thought due to set-up and explained as “Increase in Horizontal Effective Stress”



Results plotted According to Movement Path

Fellenius 2002

Also the best field work can get messed up if the analysis and conclusion effort loses sight of the history of the data

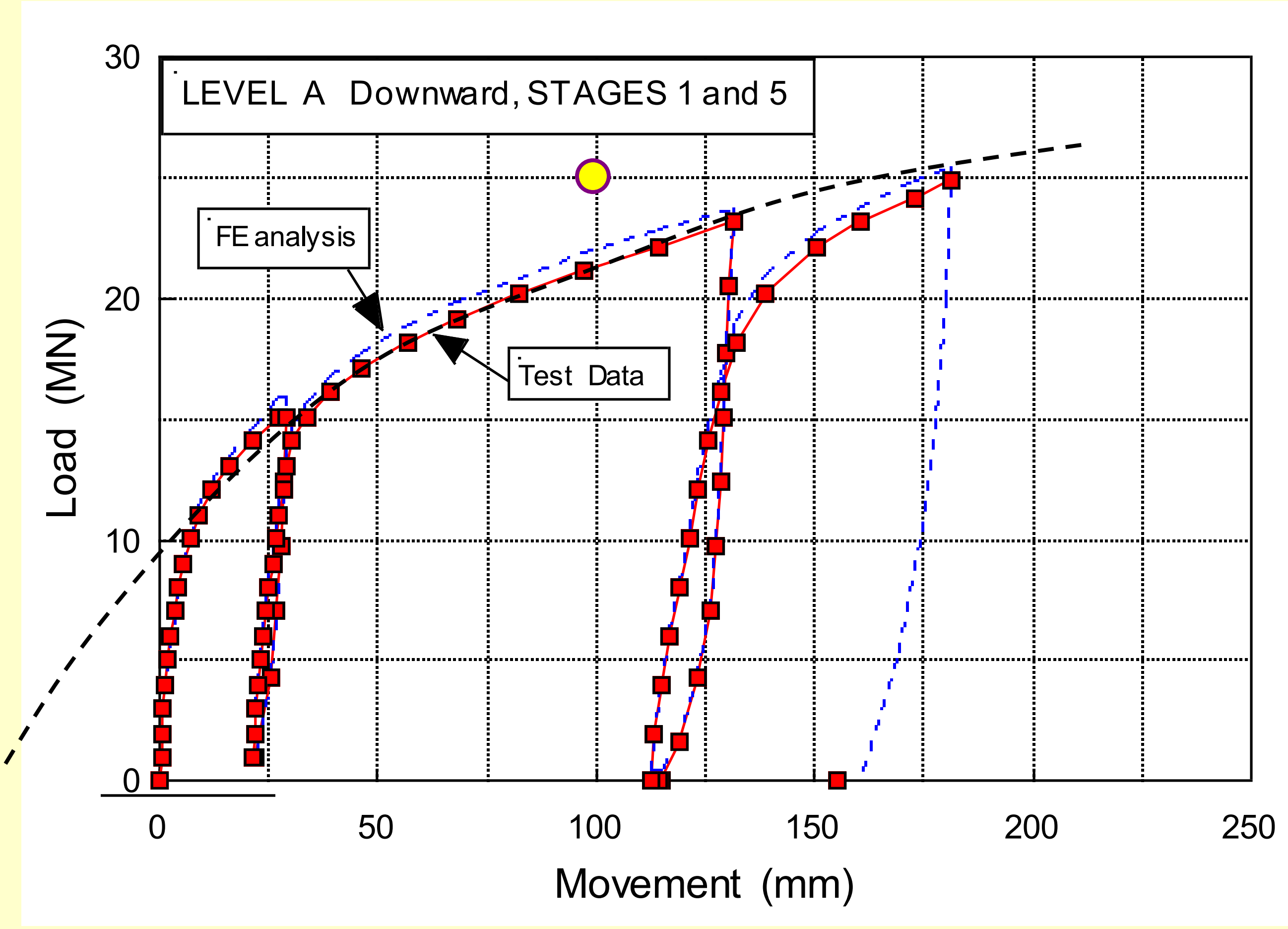


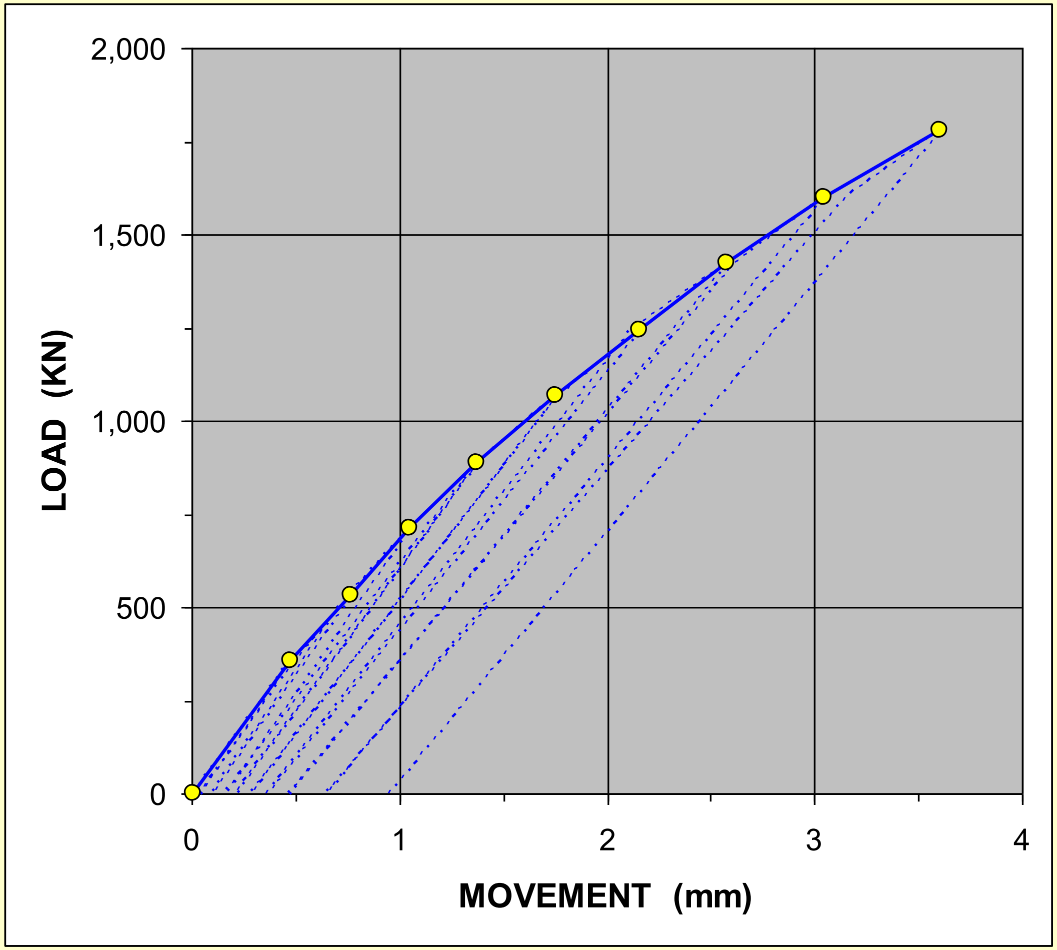
The dynamic test (CAPWAP) was performed after the static test.

The redriving (ten blows) forced the pile down additionally about 45 mm.

Does unloading/reloading add anything of value to a test?

Result on a test on a 2.5 m diameter, 85 m long bored pile



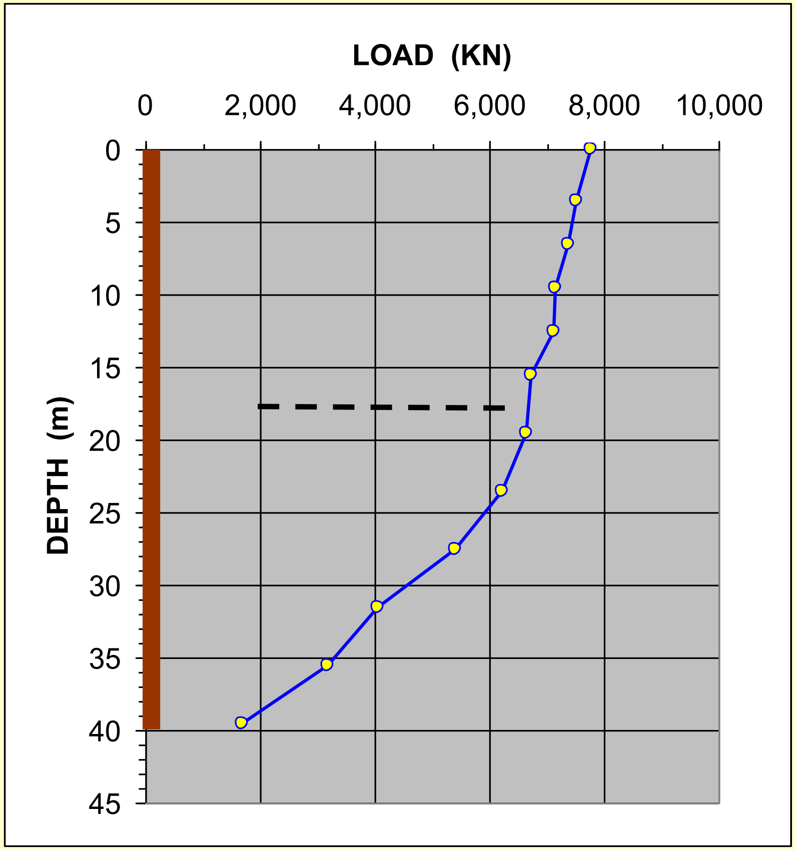


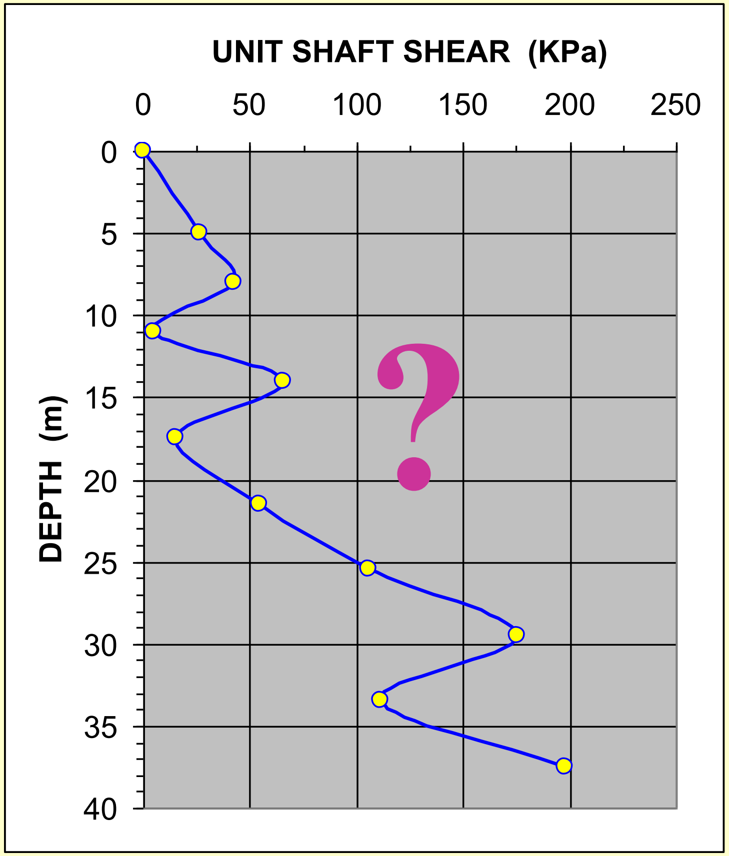
The above series of unloading/reloading has added nothing but cost the client a lot of money.

Good measurements do not guarantee good conclusions!

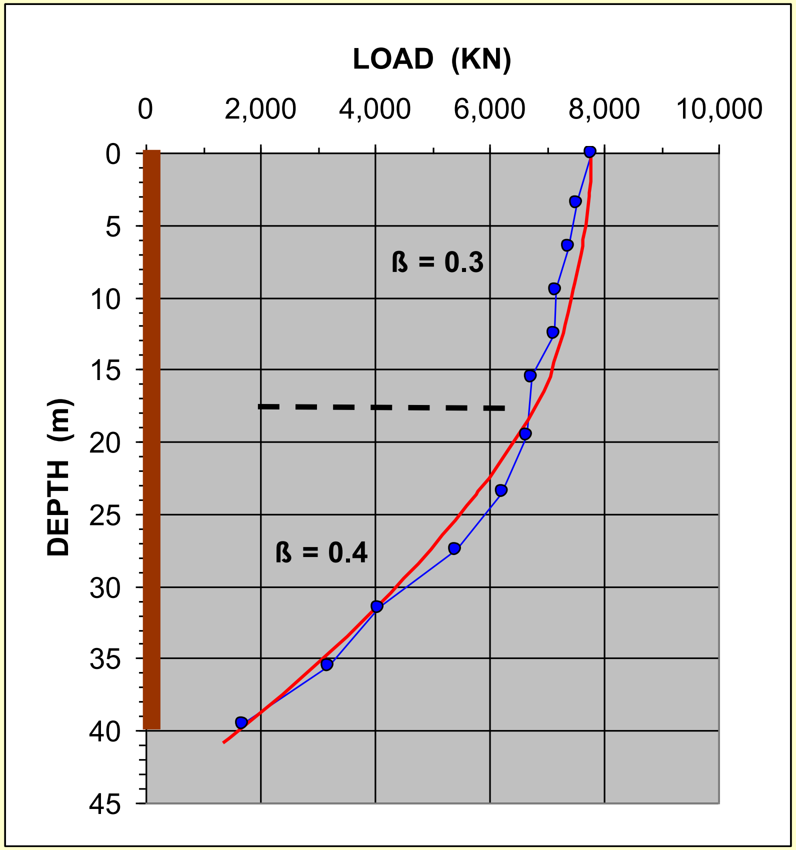
A good deal of good thinking is necessary, too

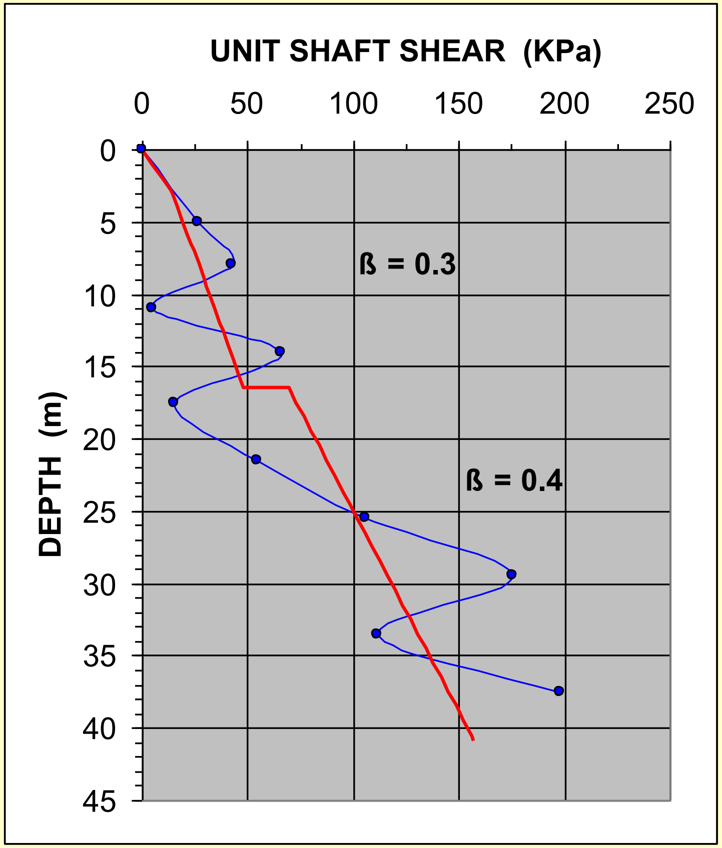
Results of loading tests on 40 m long, instrumented steel piles in a saprolite soil



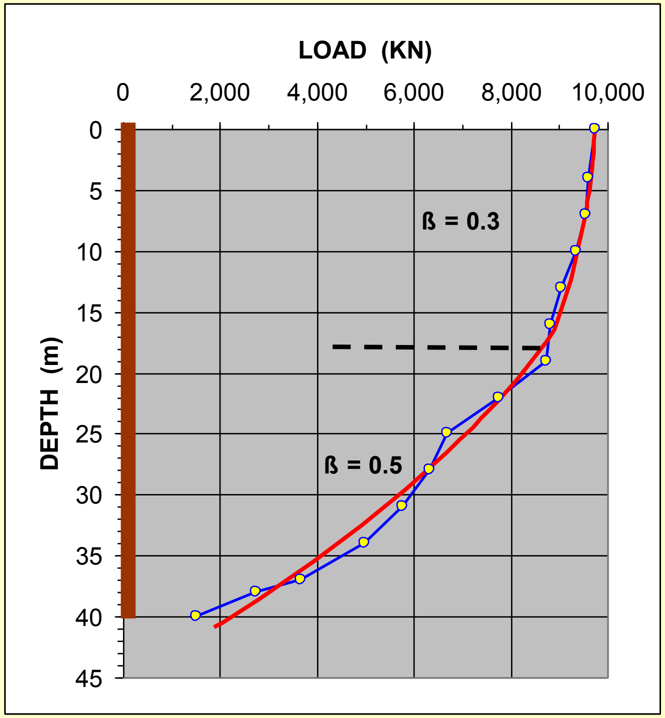


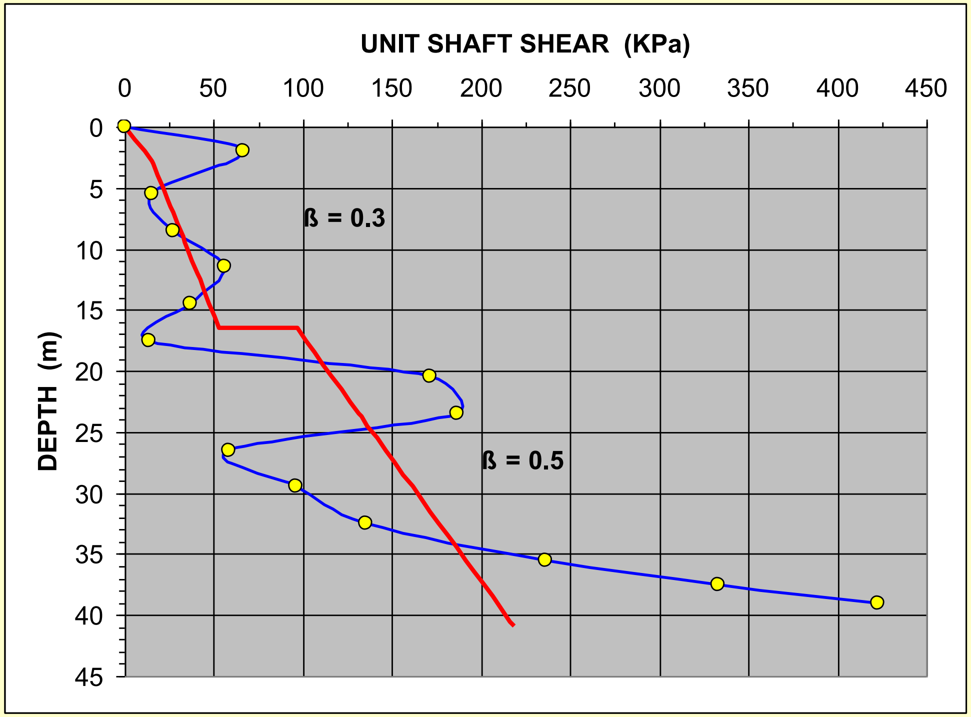
A more thoughtful analysis of the data





And a second pile:





Jorj Osterberg 2001

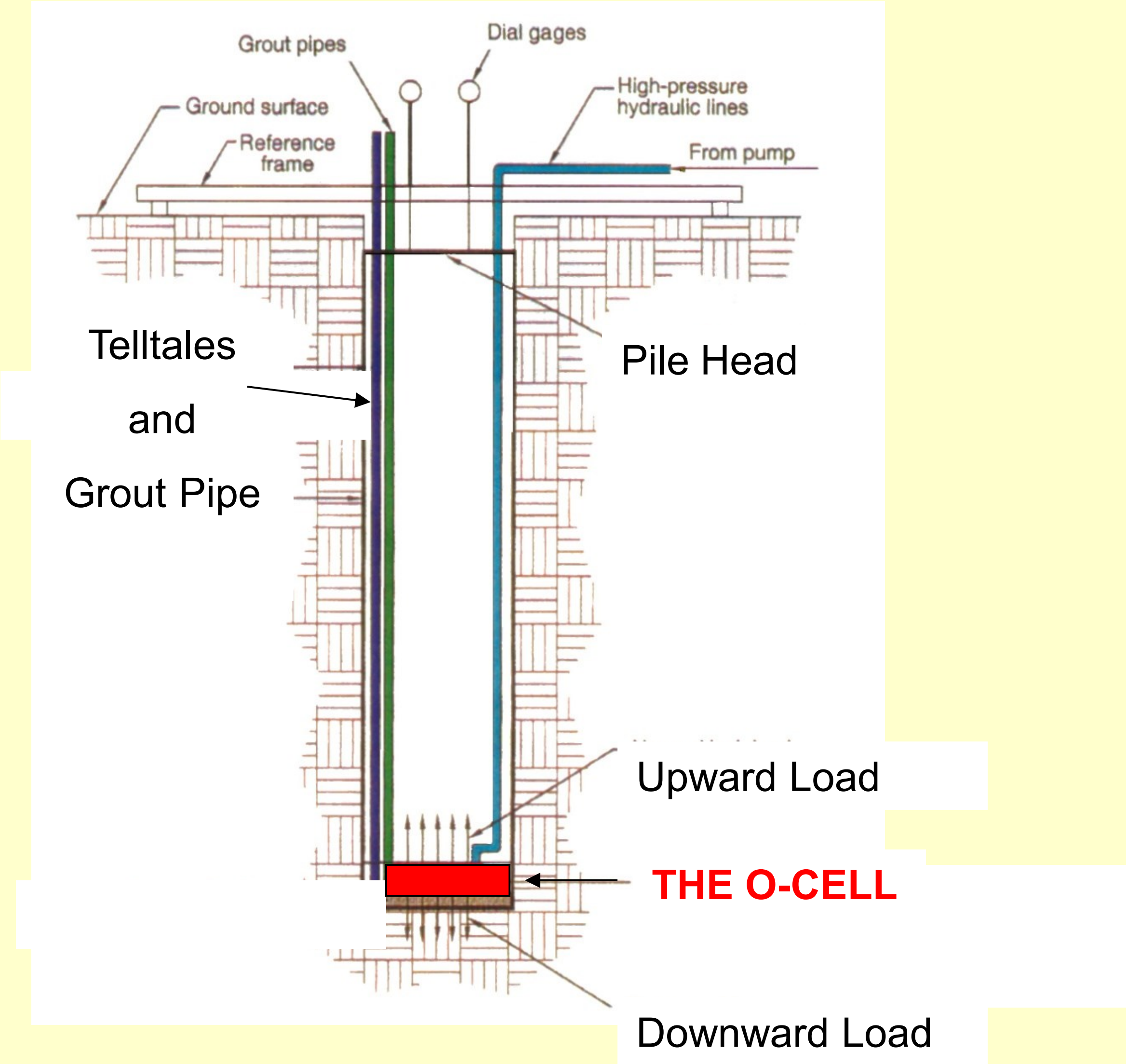
The **Bi-Directional**

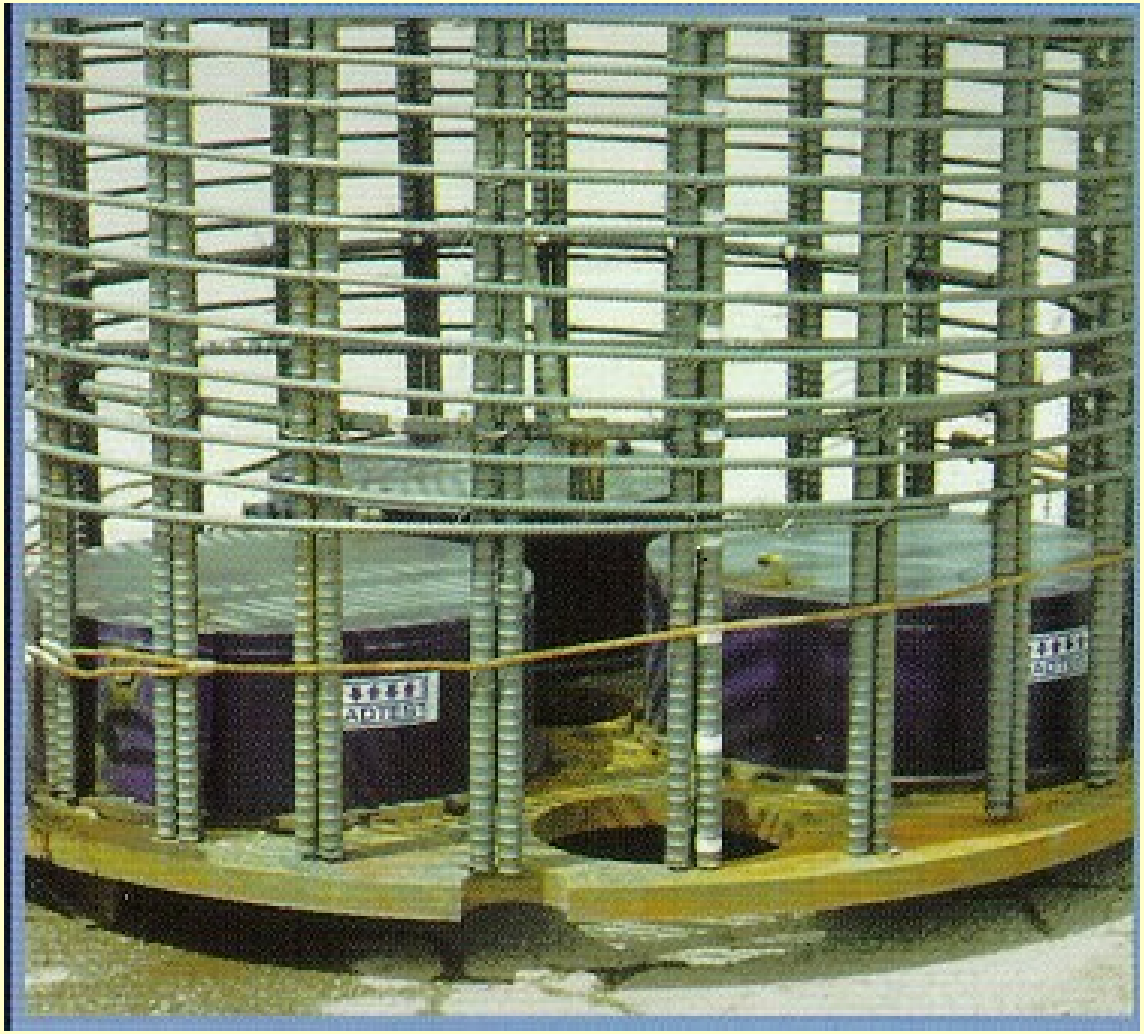
Static Loading Test

The "O-cell Test"

Schematics of the Osterberg O-Cell Test

(Meyer and Schade 1995)





Three O-Cells inside the reinforcing cage

(My Thuan Bridge, Vietnam)

The O-cell can also be installed in a driven pile (after the driving). Here in a 600 mm cylinder pile with a 400 mm central void.

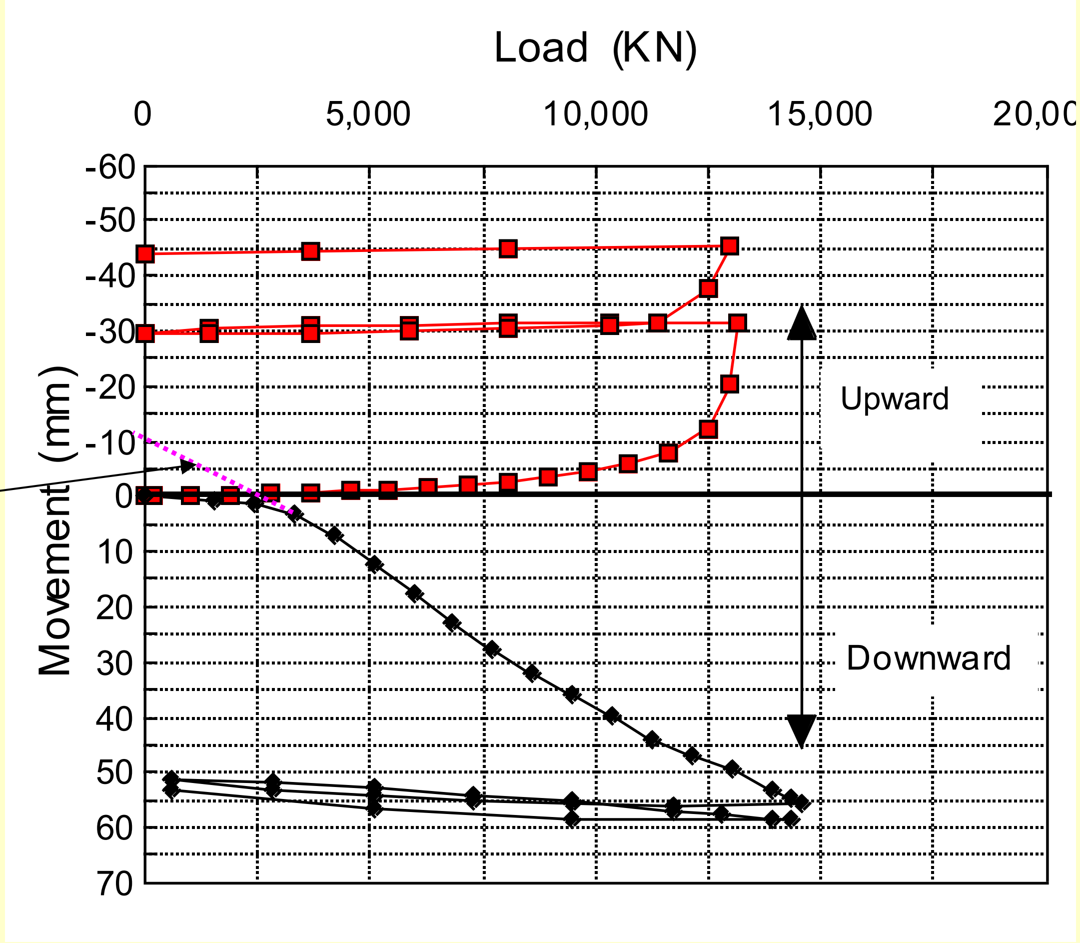
O-cell in a pipe pile inserted in a augercast pile after grouting.

Inchon, Korea

LOADTEST

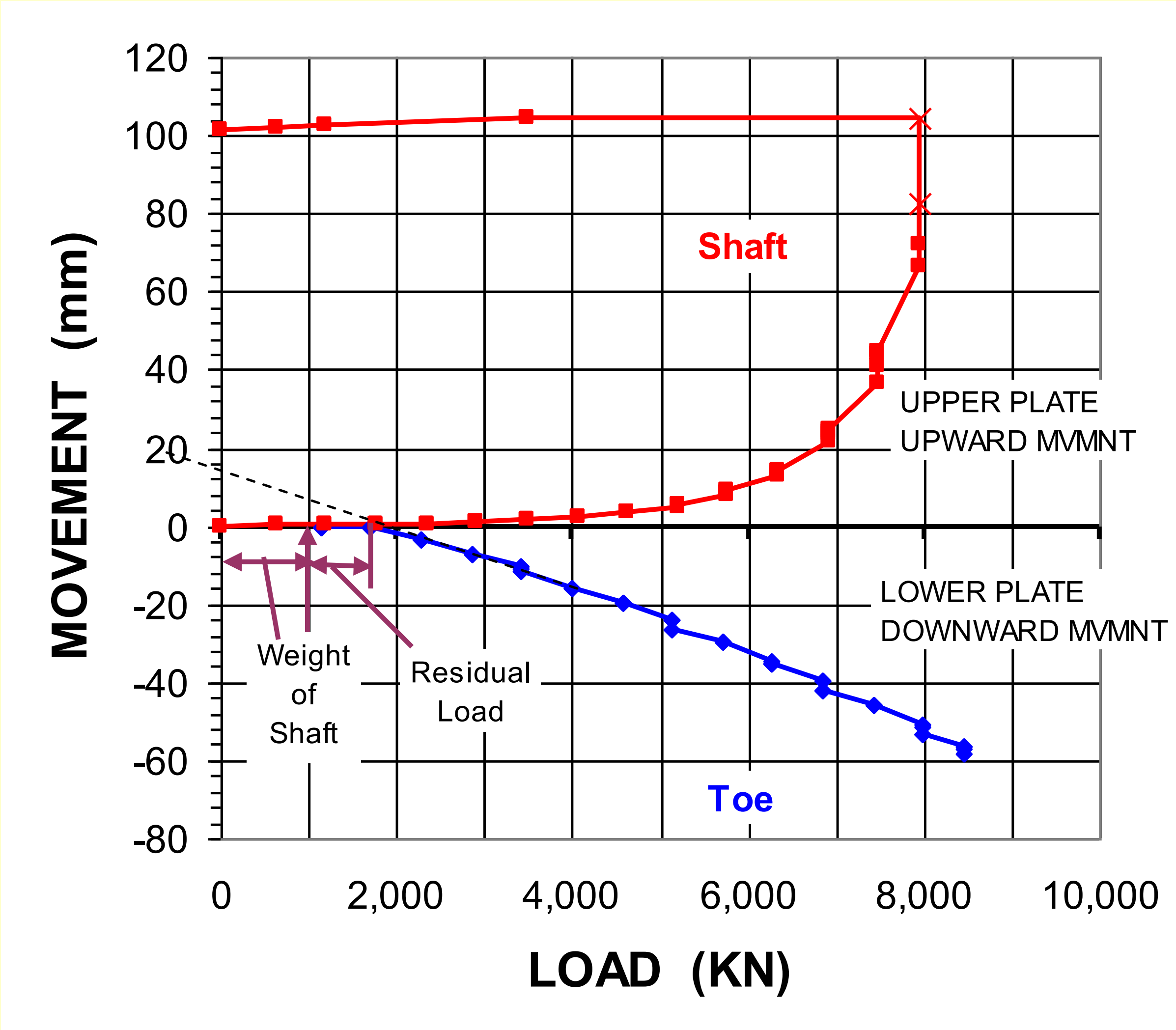
EXAMPLE 1

Results of an O-cell test on a 2.8 m by 0.8 m, 4 m deep barrette in Manila, Philippines



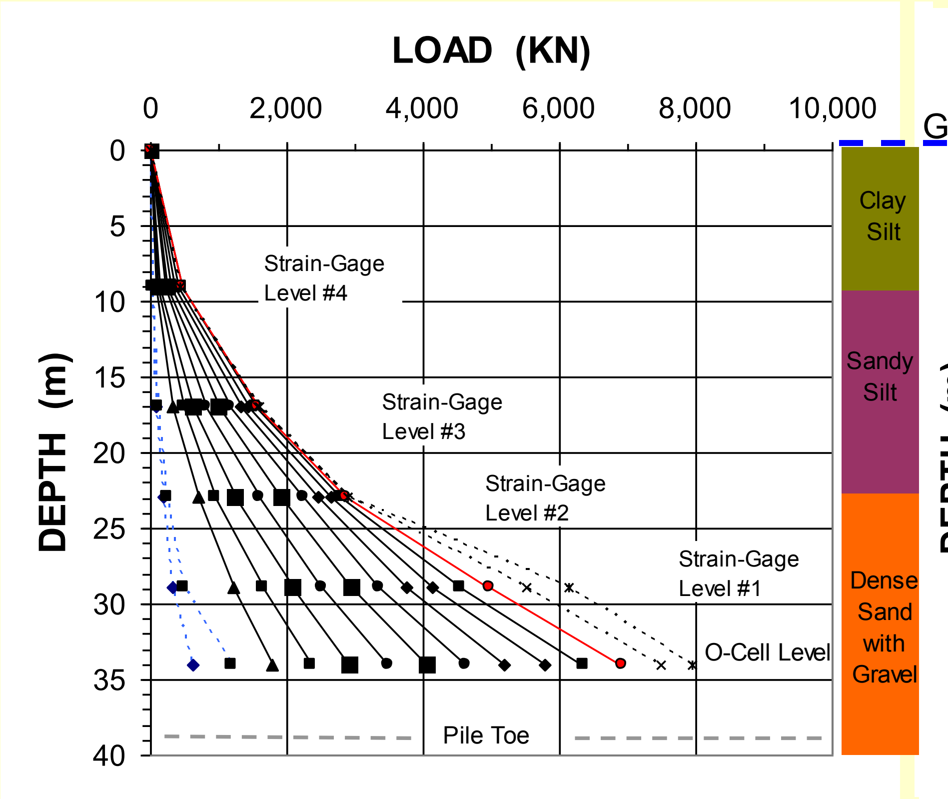
Approximate extension of the toe movement to the zero conditions

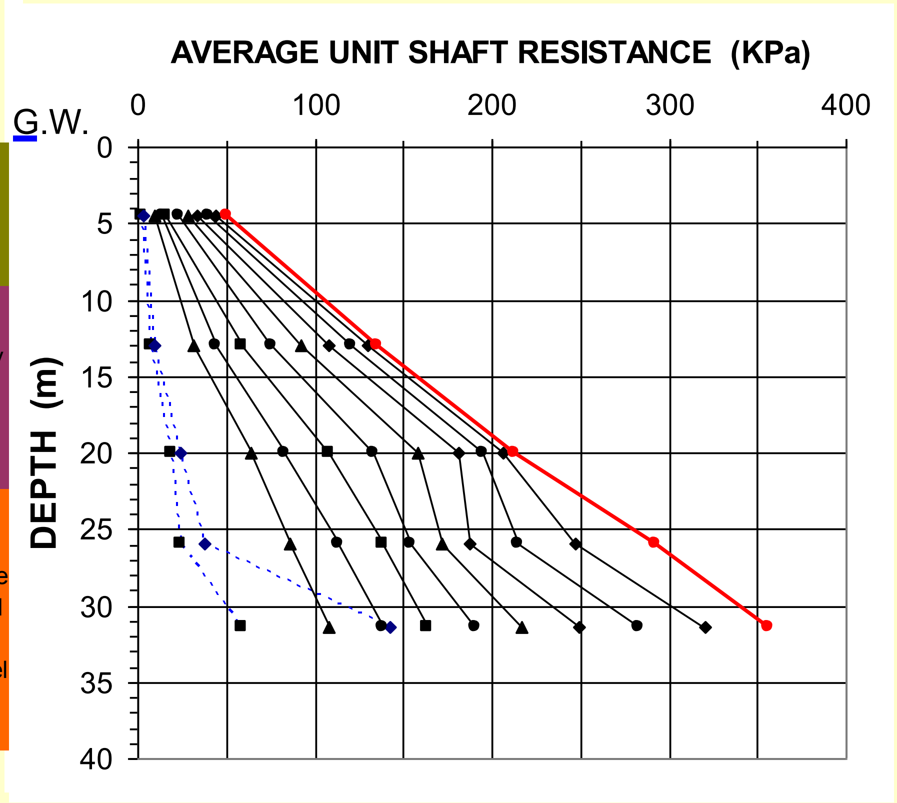
EXAMPLE 2



O-Cell test on a 1,250 mm diameter, 40 m long, bored pile at US82 Bridge in Washington, Mississippi installed into dense sand

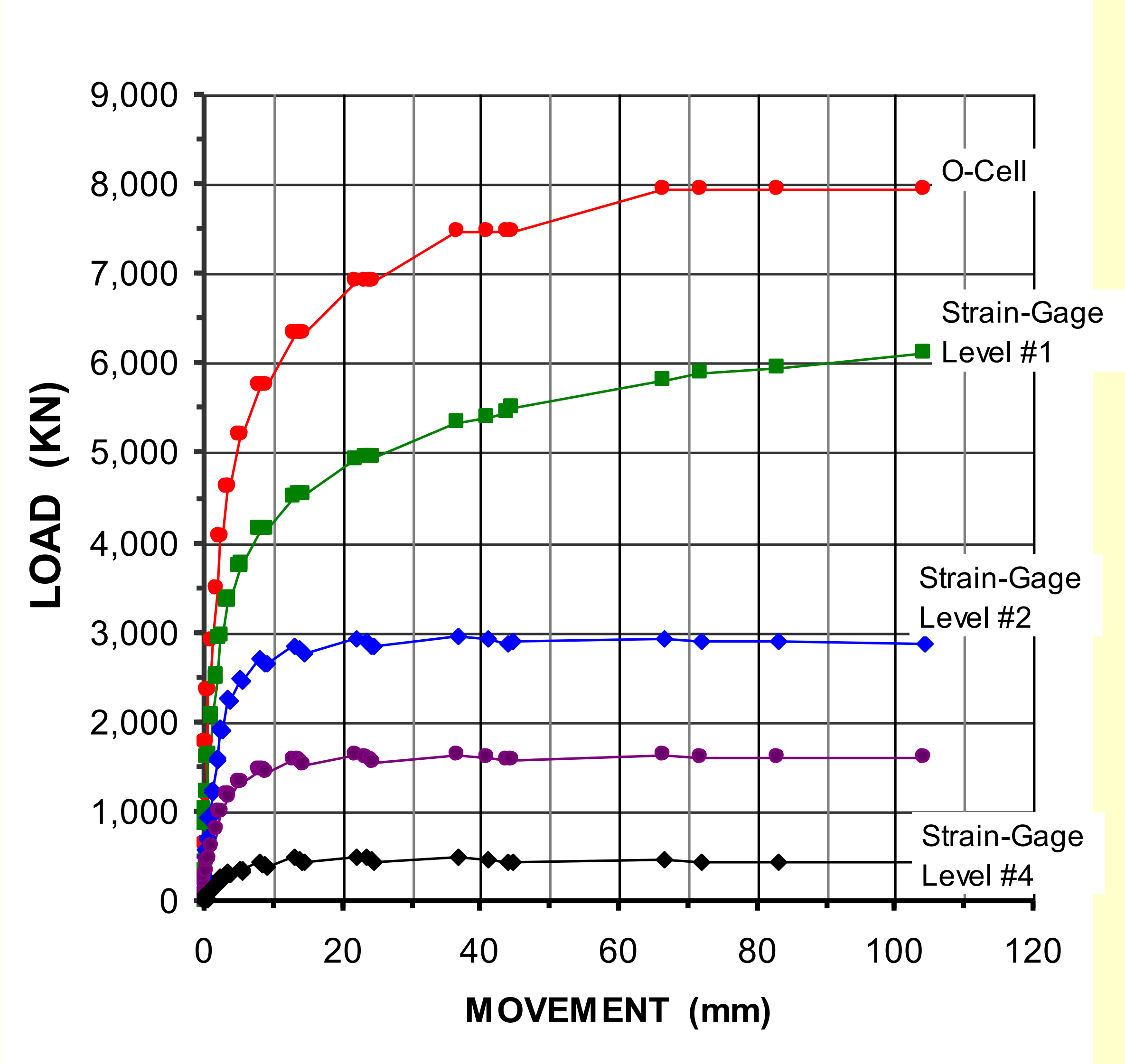
Resistance Distribution



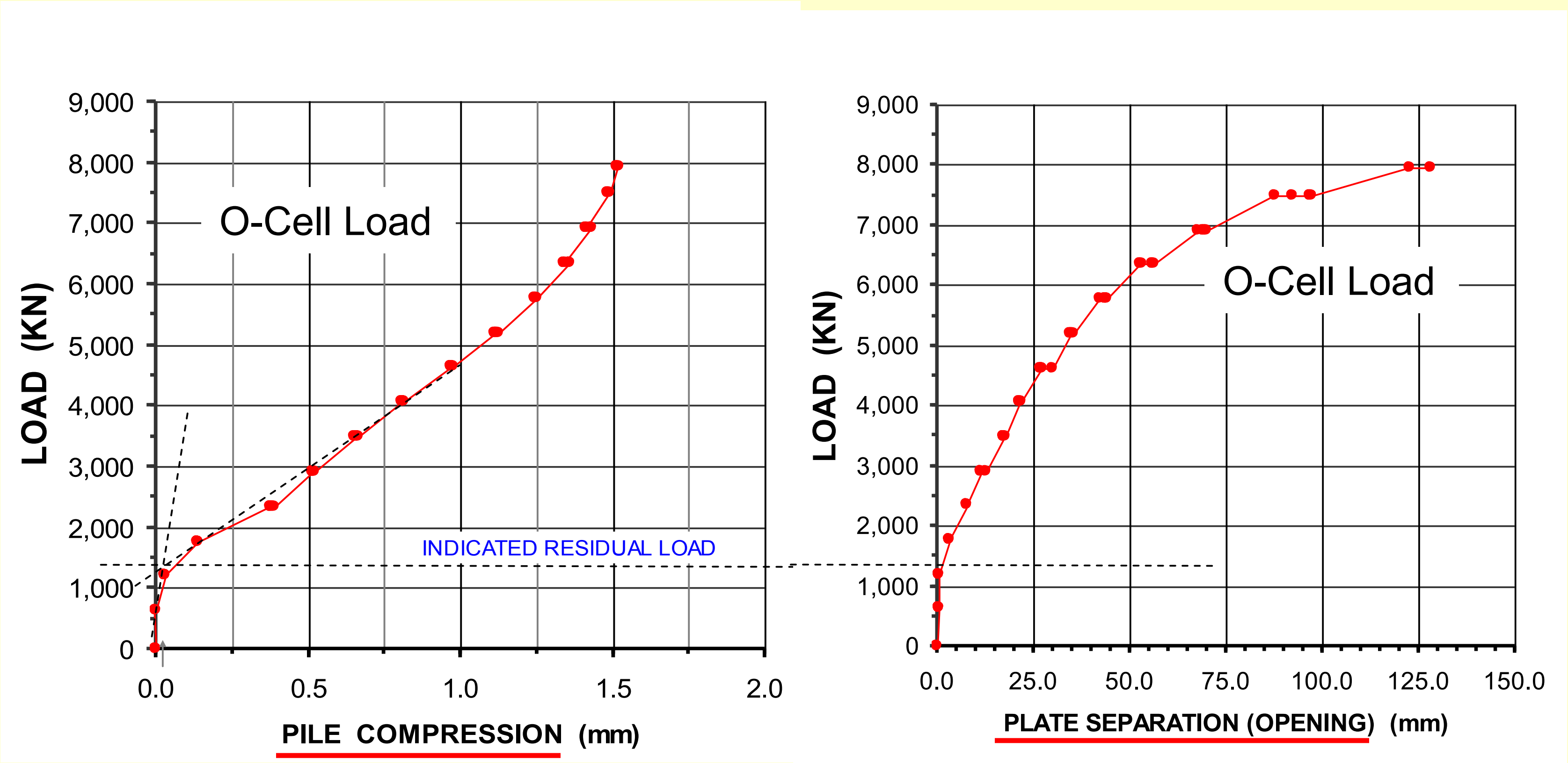


The unit shear resistance at shaft "failure" corresponds to a beta coefficient of about 1.0.

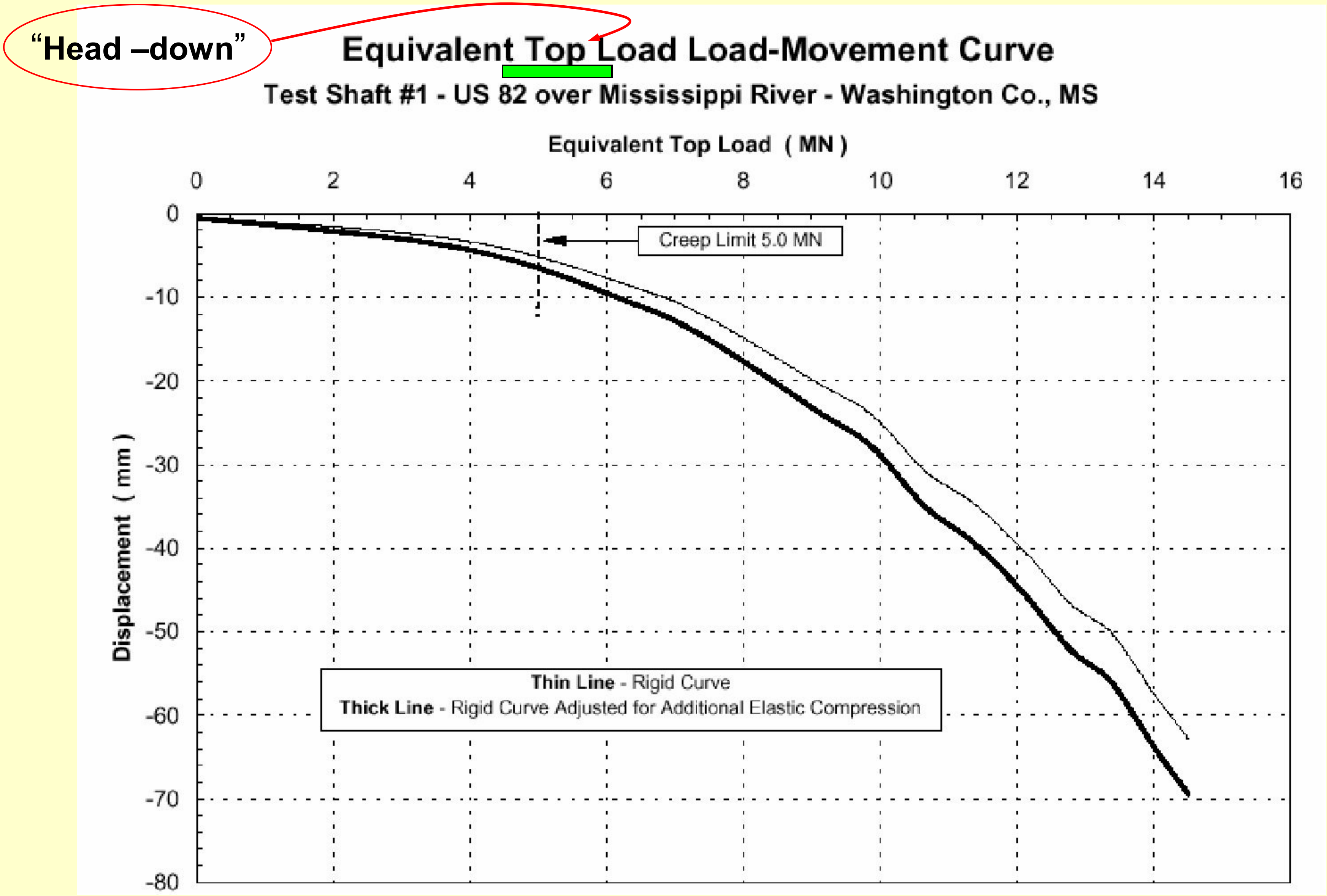
Load-Movement Curves

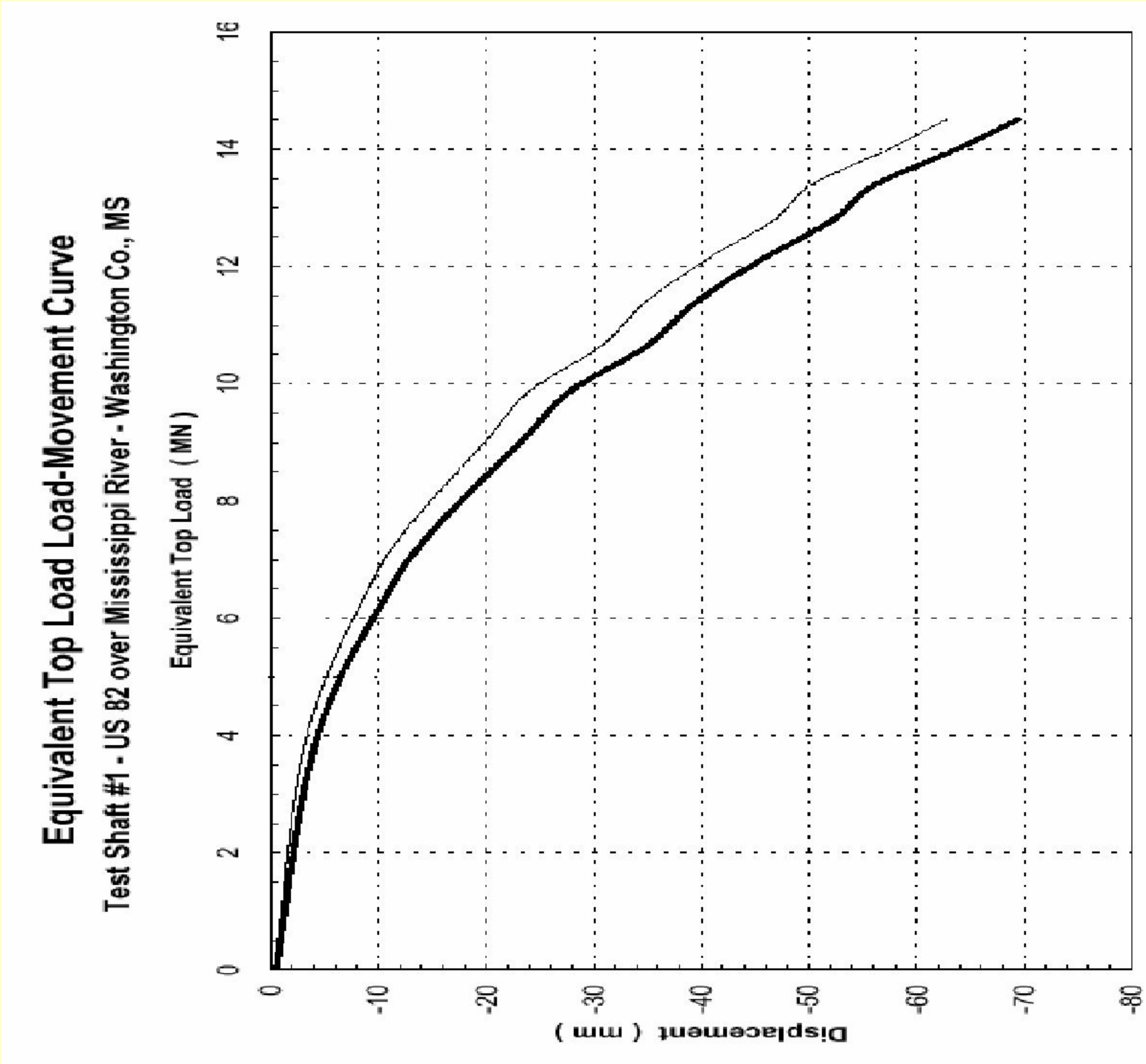


Searching for the Residual Load

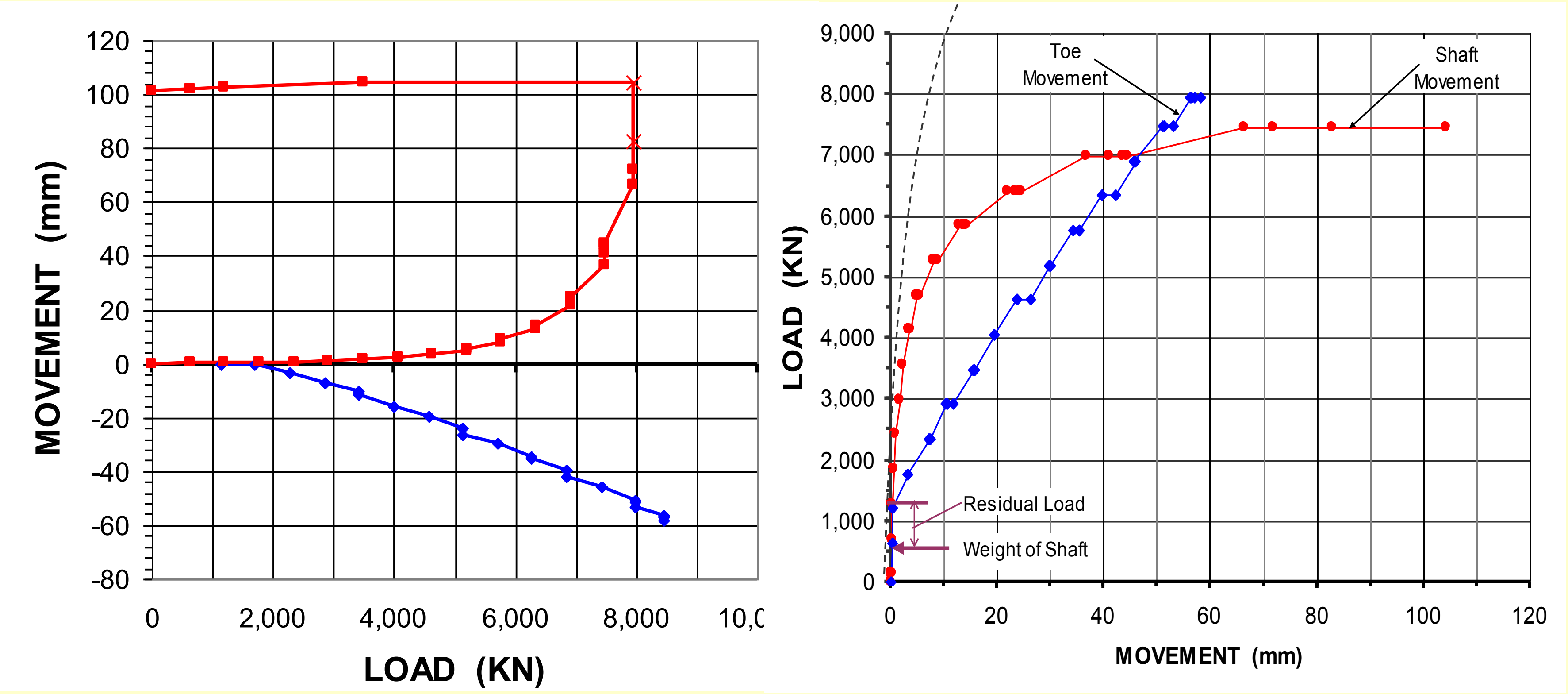


From the O-Cell results, one can produce the load-movement curve that one would have obtained in a routine "Head-Down Test"

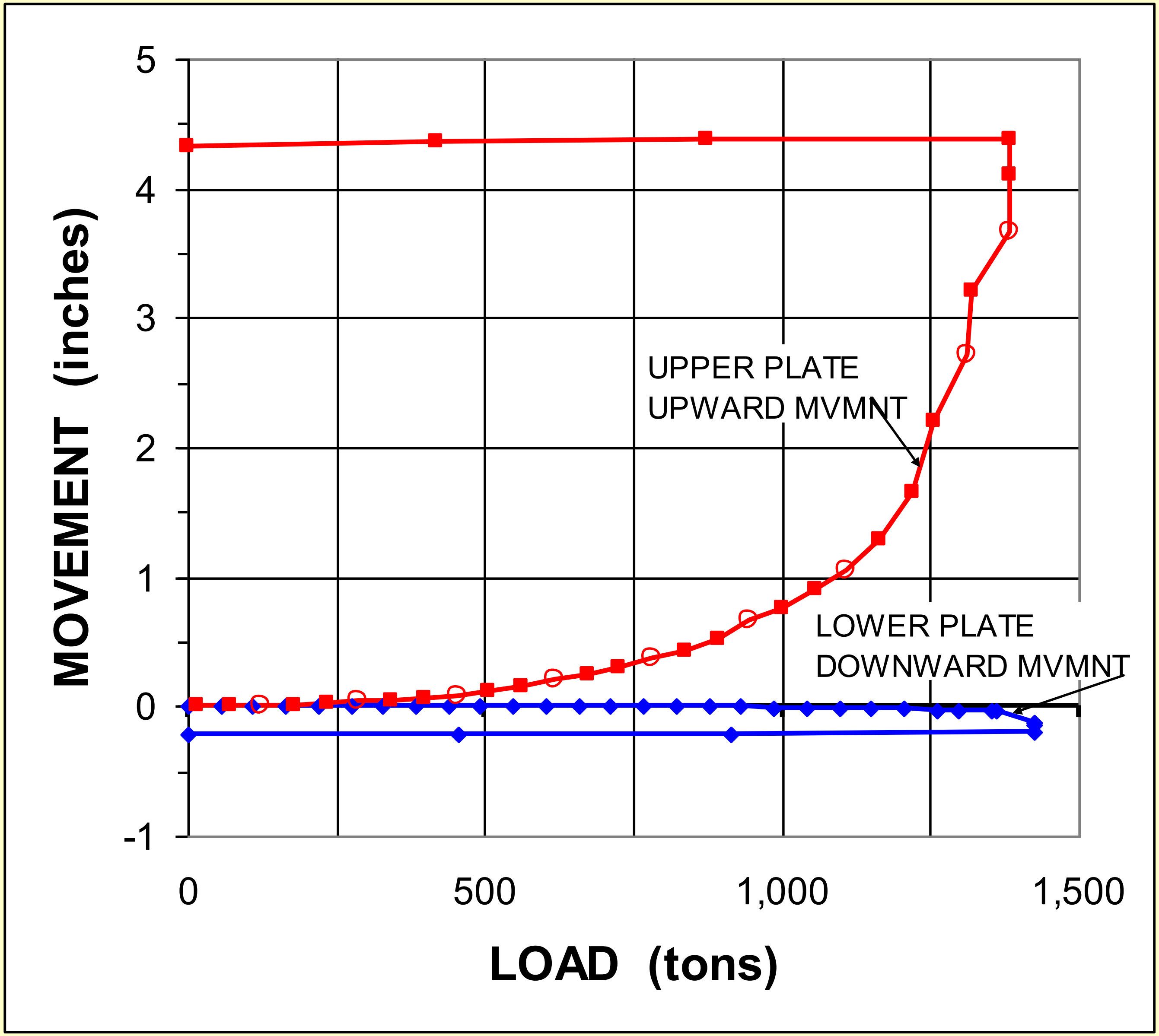



Equivalent Top Load Load-Movement Curve
Test Shaft #1 - US 82 over Mississippi River - Washington Co., MS
Equivalent Top Load (MN)
0
2
4
6
8
10
12
14
16
Displacement (mm)
0
-10
-20
-30
-40
-50
-60
-70
-80

O-Cell Results Shown Two Ways

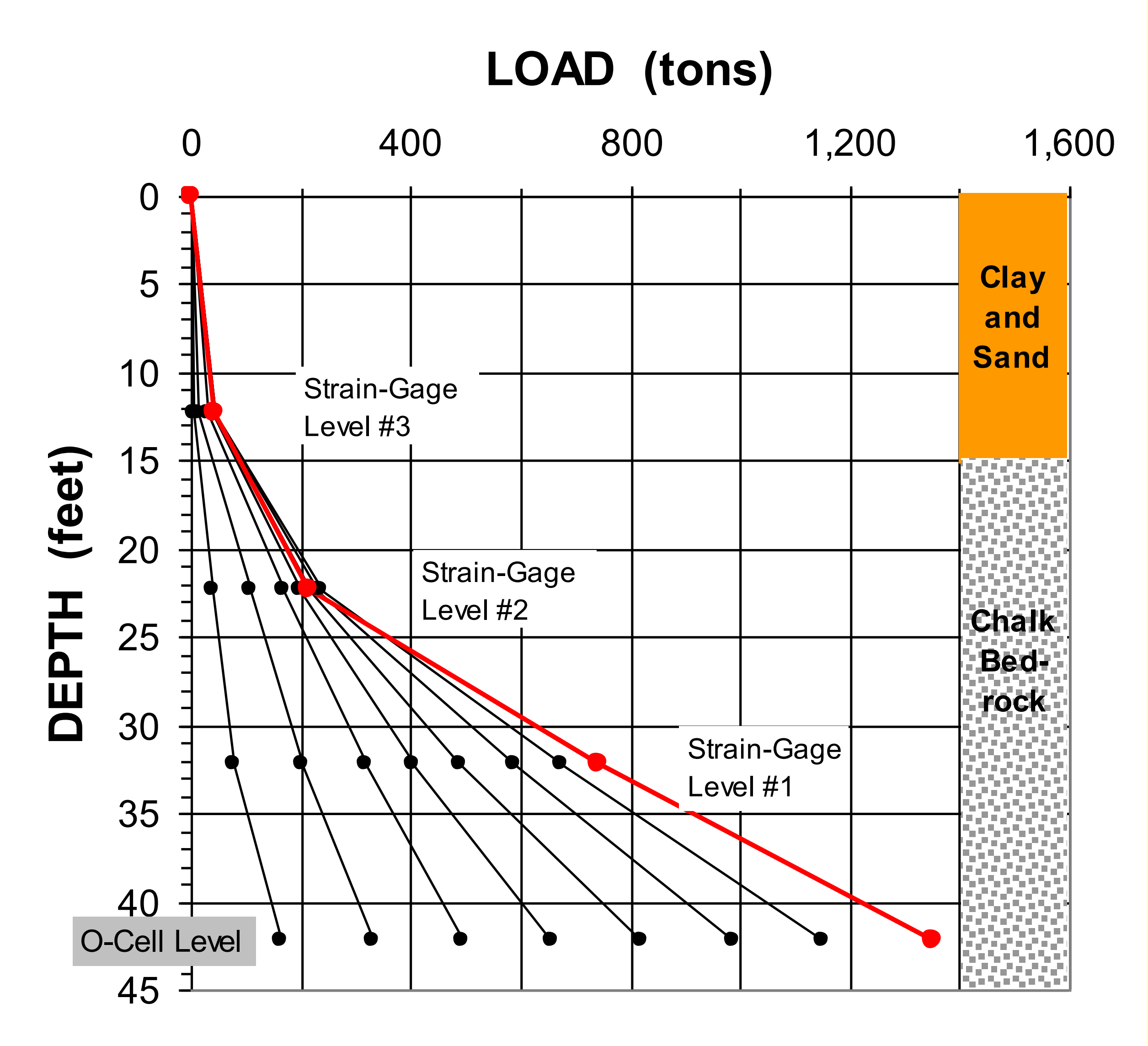


EXAMPLE 3

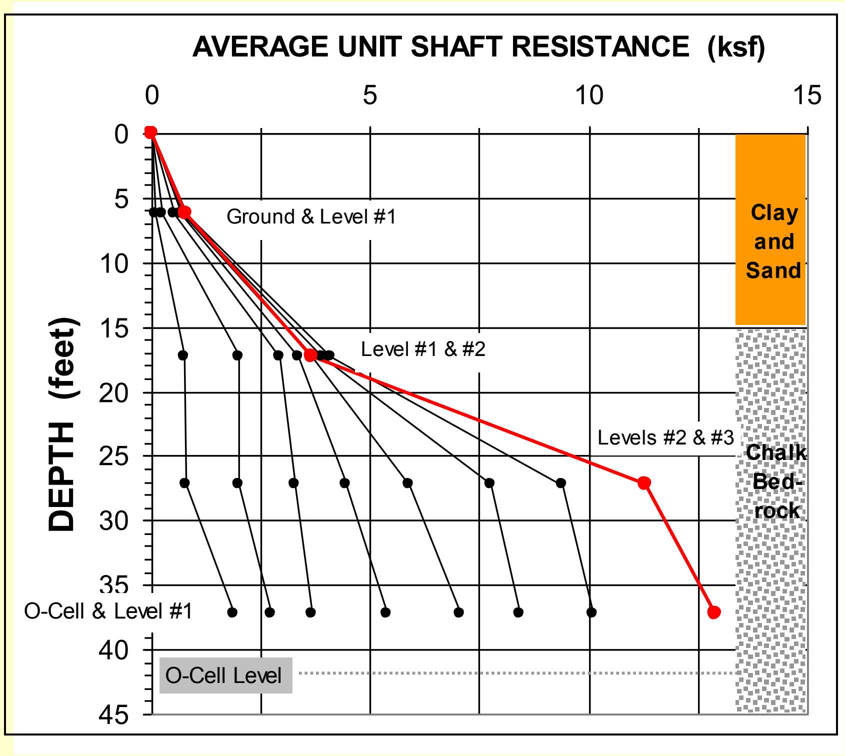


O-Cell test on a 43 ft long pile socketed into chalk bedrock at US82, Bridge at Oktebbeha, MS

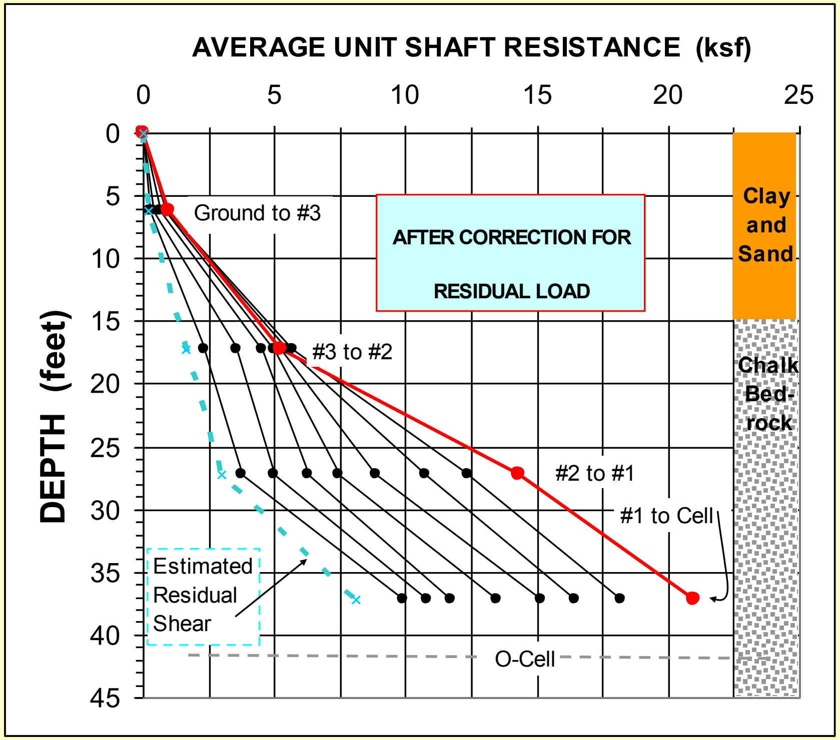
Measured Resistance Distribution



Shaft Shear Distribution



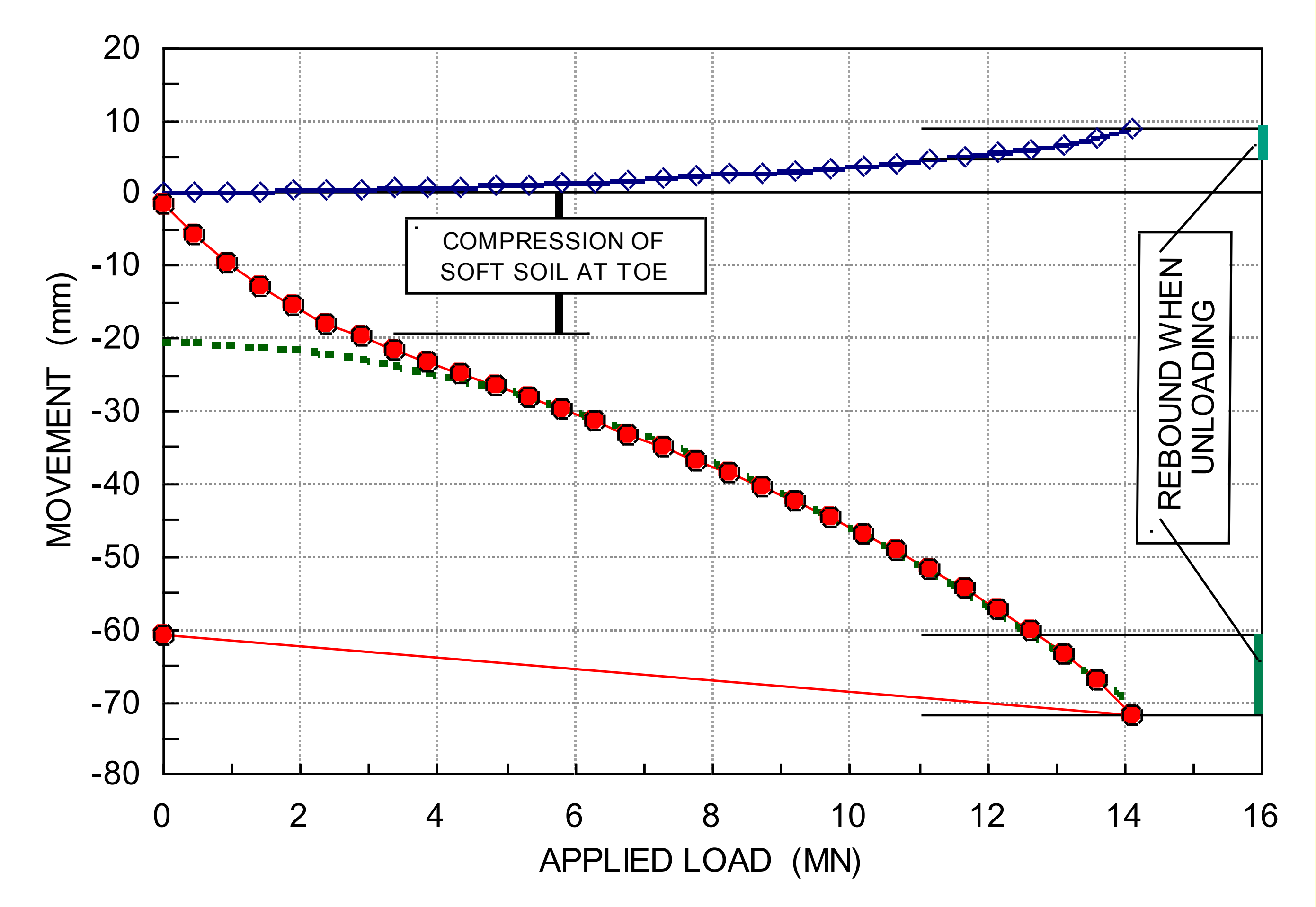
Residual Load not considered



Corrected for Residual Load

Example 4

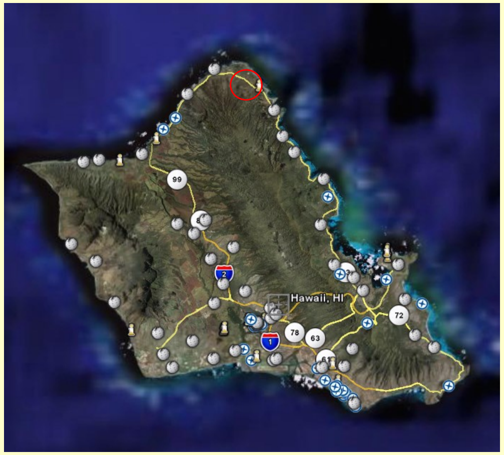
Finding a "soft" toe

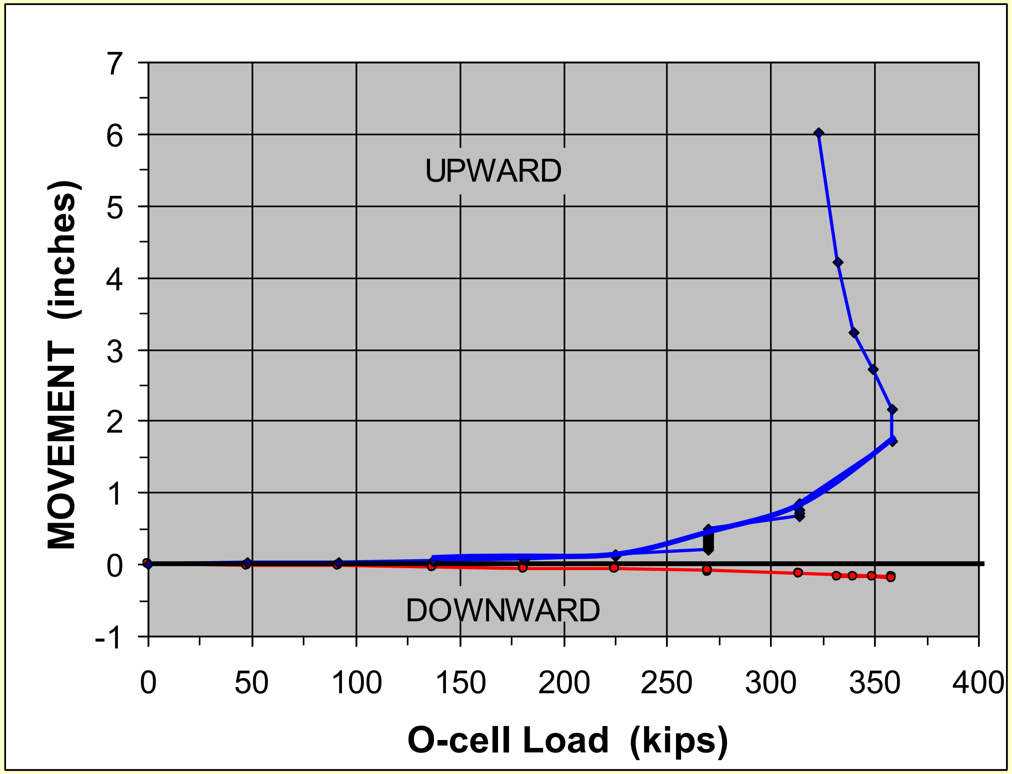


Toe load-movement for a pile with a soft toe at Albuquerque, New Mexico
(Data from Osterberg and Hayes, 1999)

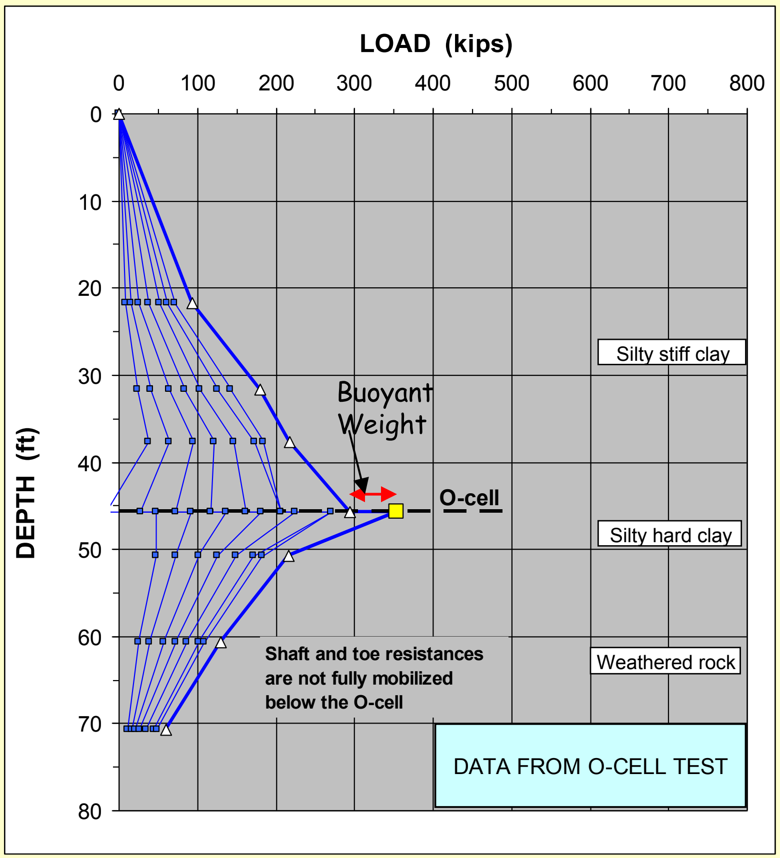
EXAMPLE 5

Kahuku Bridge across
Kamehameha Highway, Hawaii
Test on 600 mm, 17 m long, bored pile
in hard clay and weathered rock

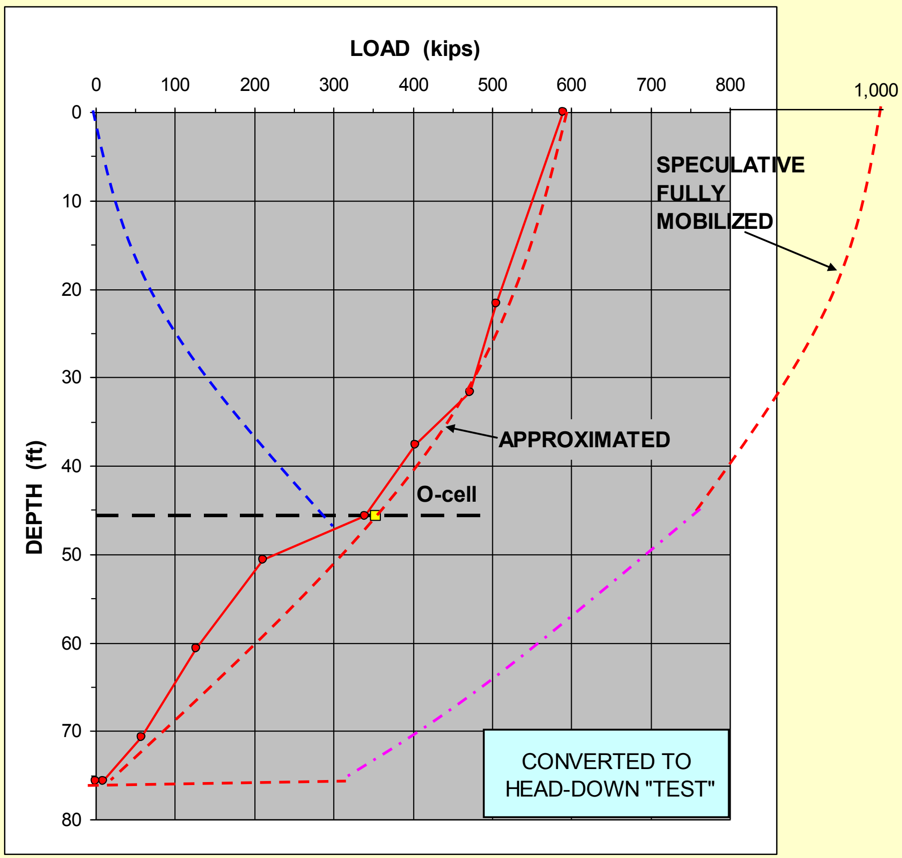




The load distribution after tangent-modulus evaluation of pile stiffness

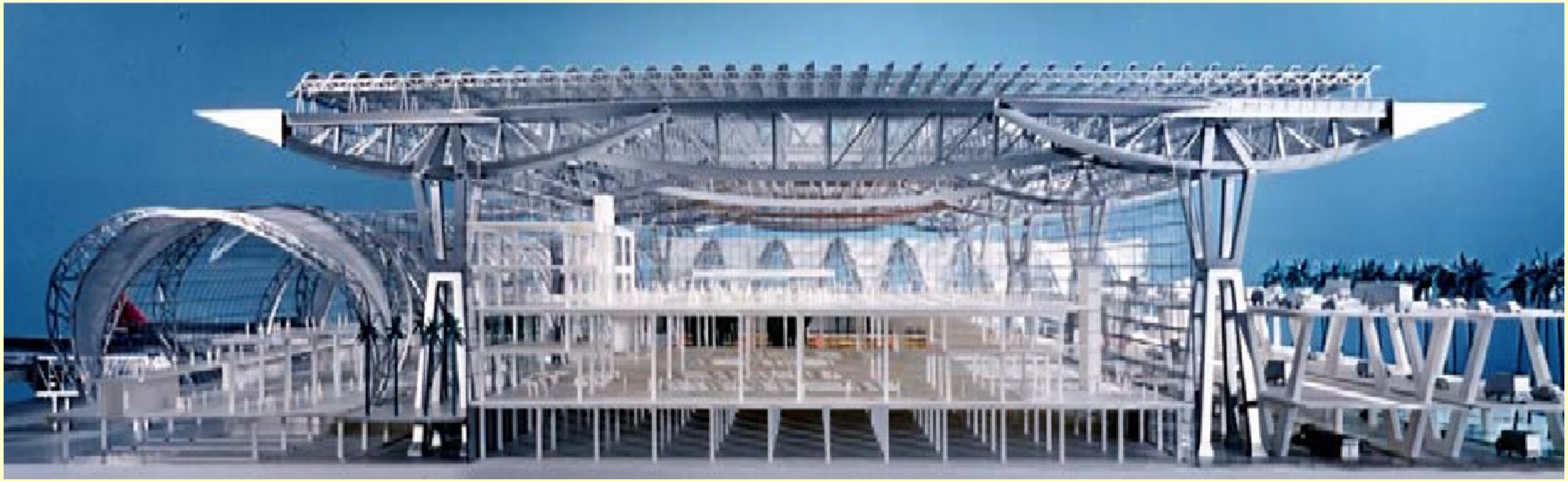


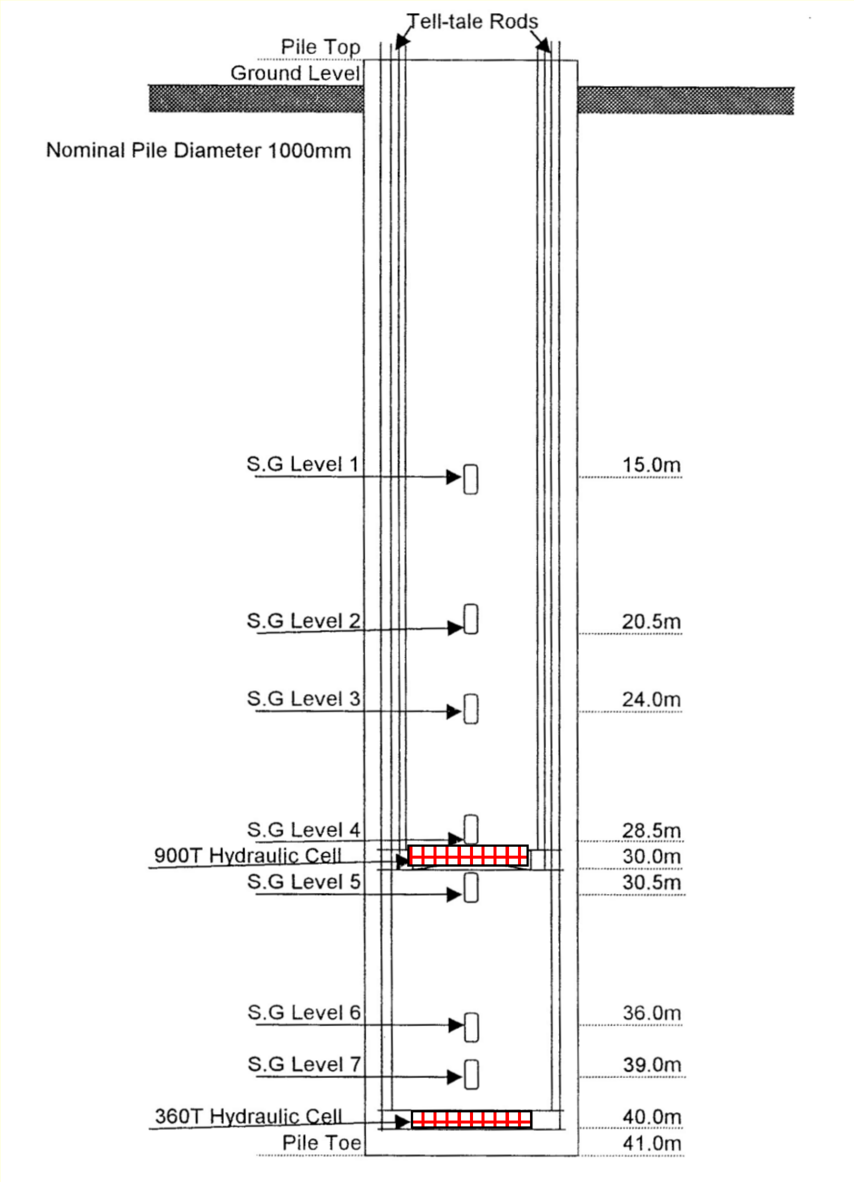
The "head-down" load distribution and speculative fully mobilized resistance



EXAMPLE 6

Test at Bangkok Airport





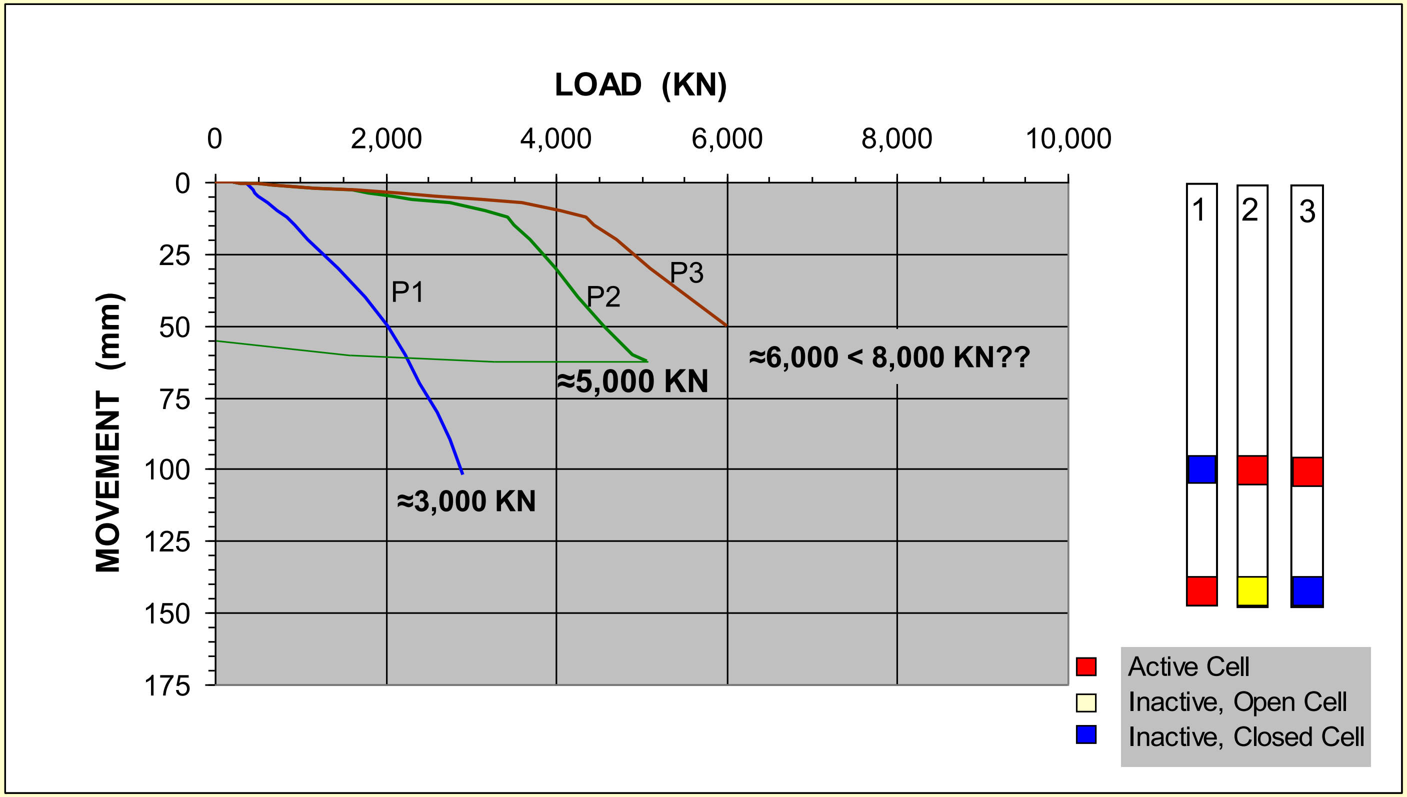
Stage 1
Lower Cell activated
Upper cell closed

Stage 2
Lower Cell open
Upper Cell activated

Stage 2
Lower Cell closed
Upper Cell activated

Data from
Fox, I., Du, M. and Buttling,S. (2004)
Buttling, S. (2006)

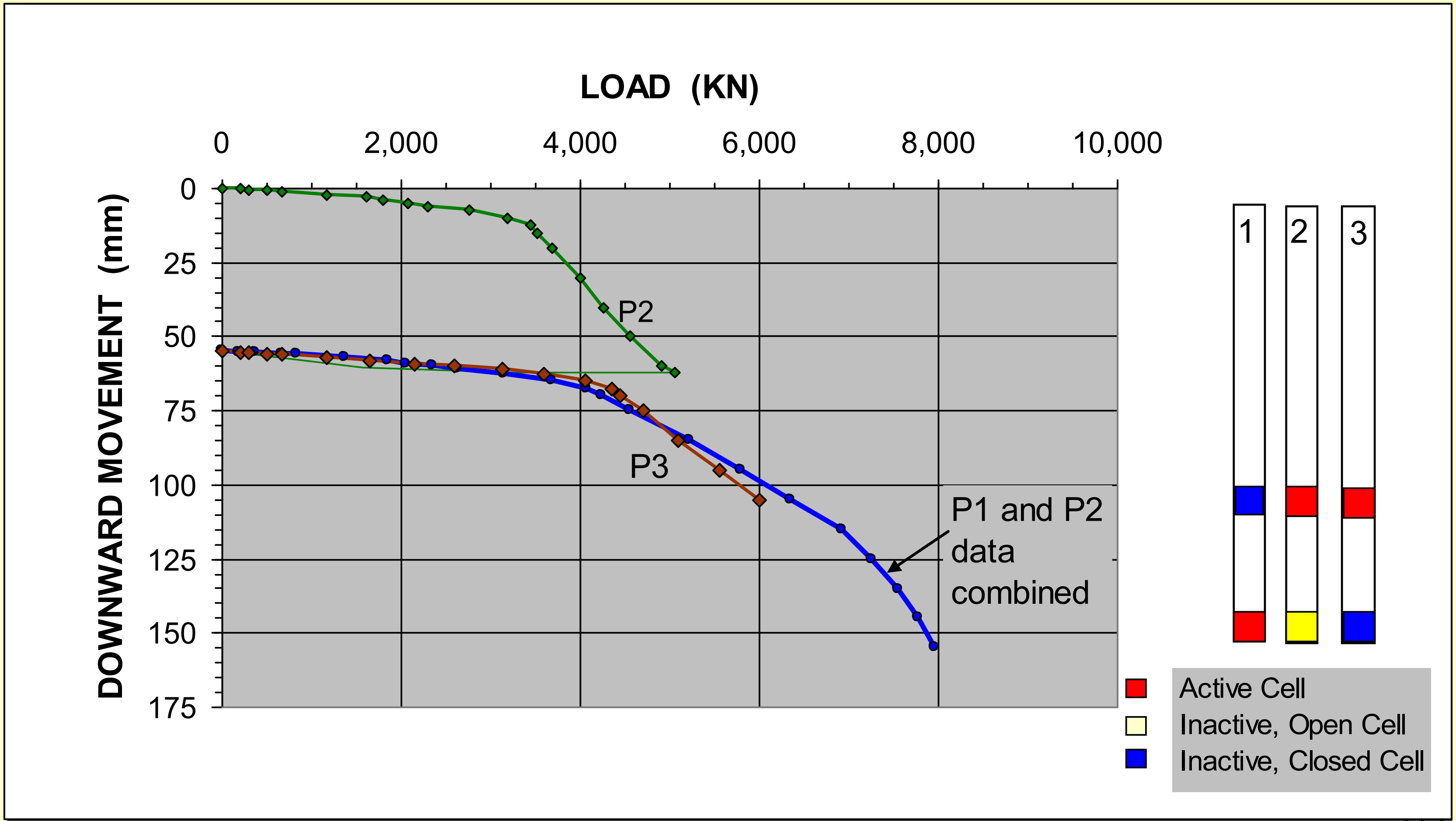
Downward load-movements during test phases 1, 2, and 3.



Concern was expressed (Buttling 2006) that the toe resistance (Phase 1) was ≈3,000 KN and the shaft resistance for the lower segment was ≈5,000 KN (Phase 2), while in Phase 3 the combined shaft and toe resistances were only ≈6,000 KN. Should not the Phase 3 resistance be ≈8,000 KN rather than ≈6,000 KN (i.e., the sum of the values ≈5,000 KN and ≈3,000)?

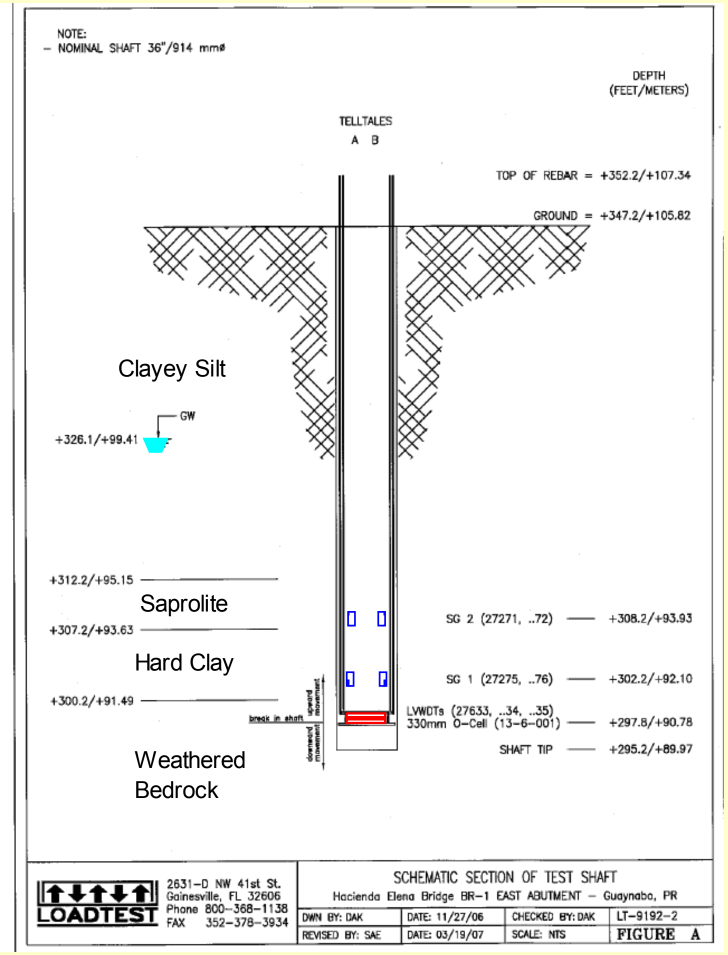
Downward toe movements

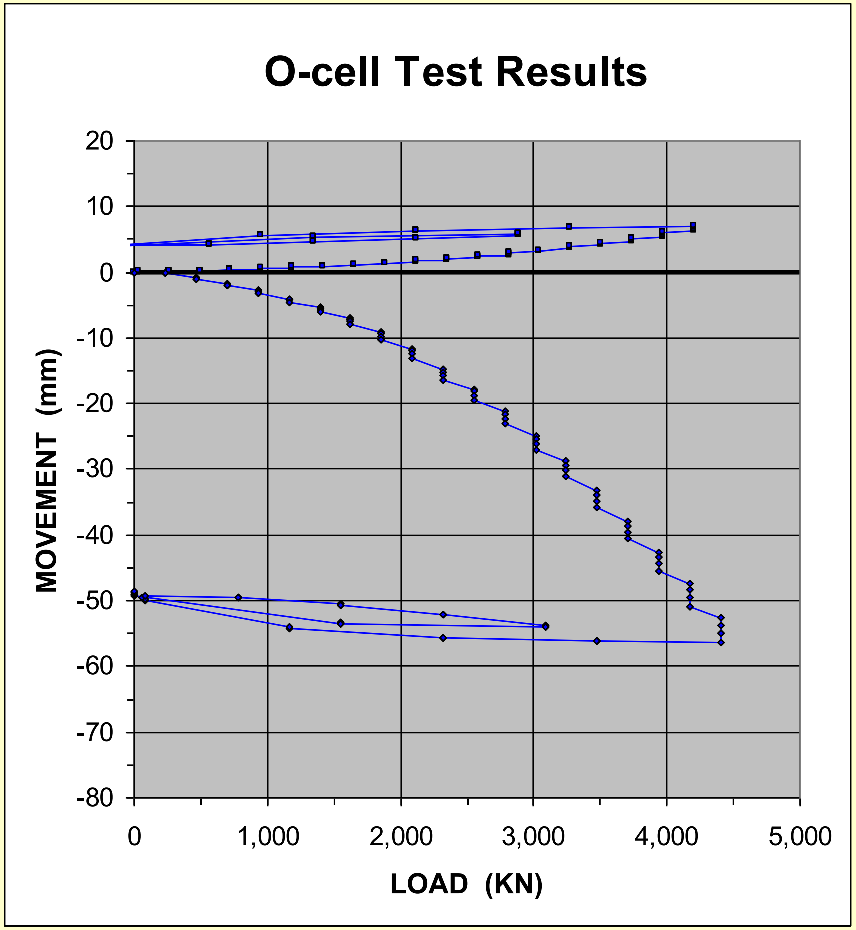
are best plotted per sequence of testing. Particularly when considering the example toe resistance, one must evaluate the load-movement response in comparing Phase 1 + Phase 2 to Phase 3 (i.e., P2 shaft below cell plus P1 toe).



EXAMPLE 7

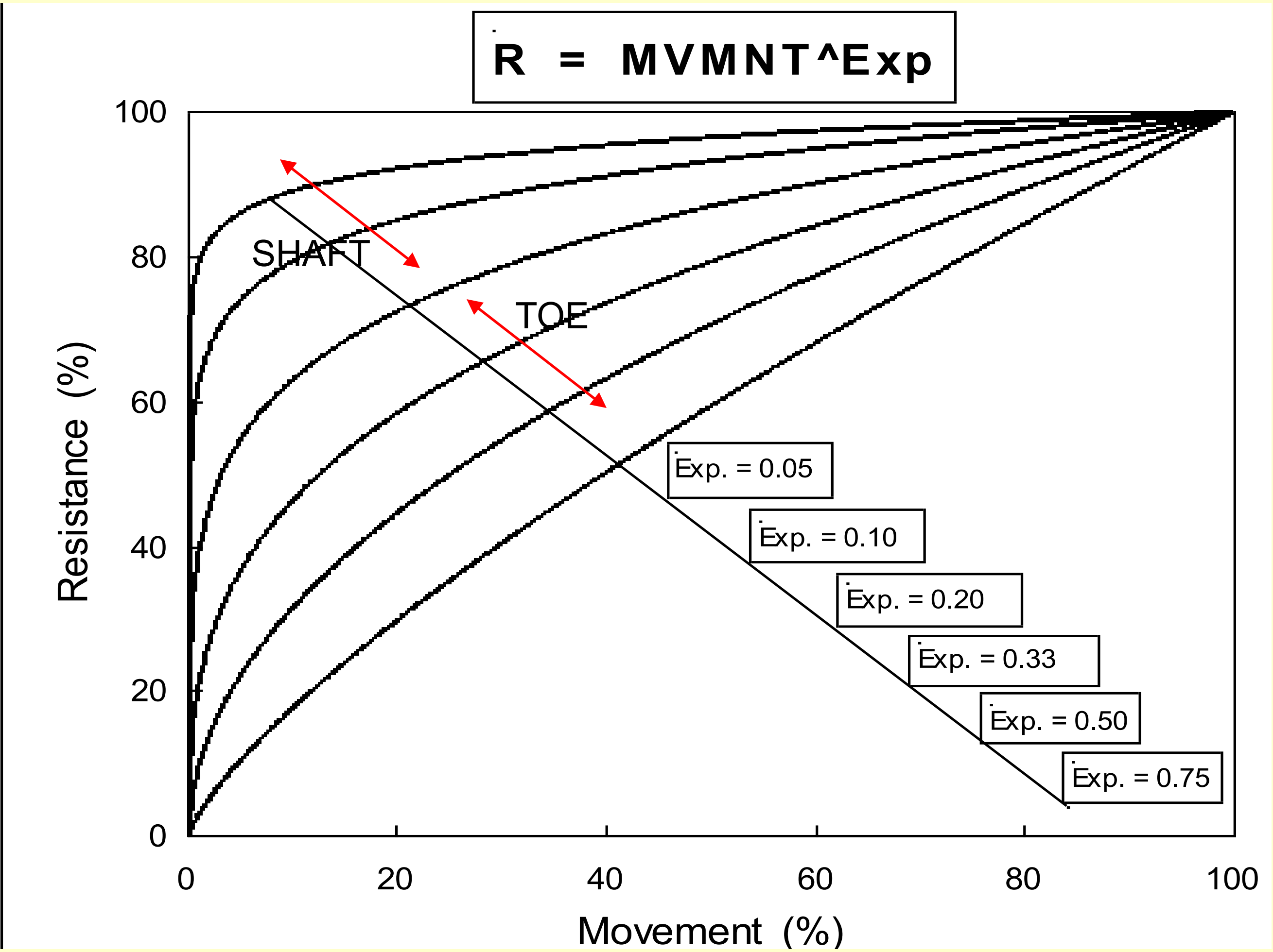
O-Cell tests for Hacienda Elena Development, Guaynabo, Puerto Rico


NOTE:
– NOMINAL SHAFT 36"/914 mmø
DEPTH (FEET/METERS)
TELLTALES
A B
TOP OF REBAR = +352.2/+107.34
GROUND = +347.2/+105.82
Clayey Silt
GW
+326.1/+99.41
+312.2/+95.15
Saprolite
+307.2/+93.63
Hard Clay
+300.2/+91.49
Weathered Bedrock
SG 2 (27271, ..72) +308.2/+93.93
SG 1 (27275, ..76) +302.2/+92.10
LVWDTs (27633, ..34, ..35)
330mm O-Cell (13-6-001) +297.8/+90.78
SHAFT TIP +295.2/+89.97
break in shaft
upward movement
downward movement
LOADTEST
2631-D NW 41st St.
Gainesville, FL 32606
Phone 800-368-1138
FAX 352-378-3934
SCHEMATIC SECTION OF TEST SHAFT
Hacienda Elena Bridge BR-1 EAST ABUTMENT – Guaynabo, PR
DWN BY: DAK
DATE: 11/27/06
CHECKED BY: DAK
LT-9192-2
REVISED BY: SAE
DATE: 03/19/07
SCALE: NTS
FIGURE A


O-cell Test Results
MOVEMENT (mm)
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
1,000
2,000
3,000
4,000
5,000
LOAD (KN)

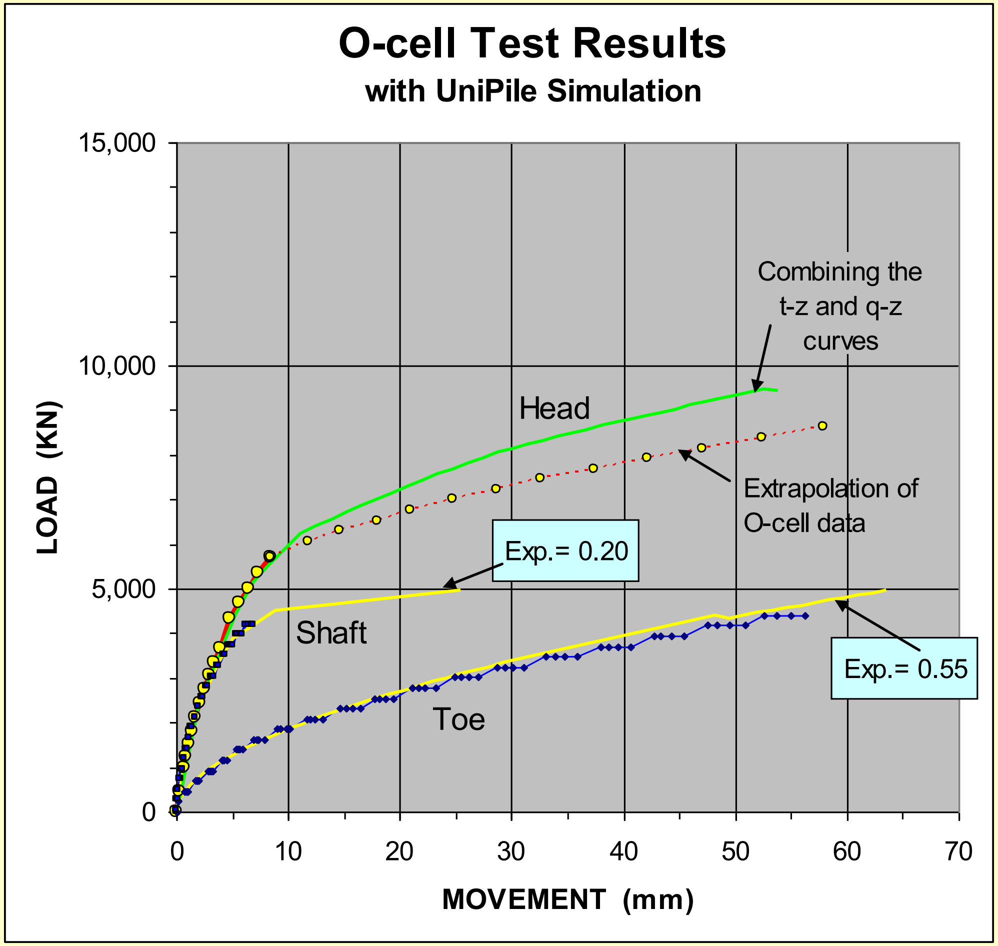
Measured load-movements can be simulated (fitting) to t-z and q-z relations

Pile shaft by t-z relation; Pile toe by q-z relation



$$\frac{R_1}{R_2} = \left(\frac{\delta_1}{\delta_2}\right)^{\exp}$$

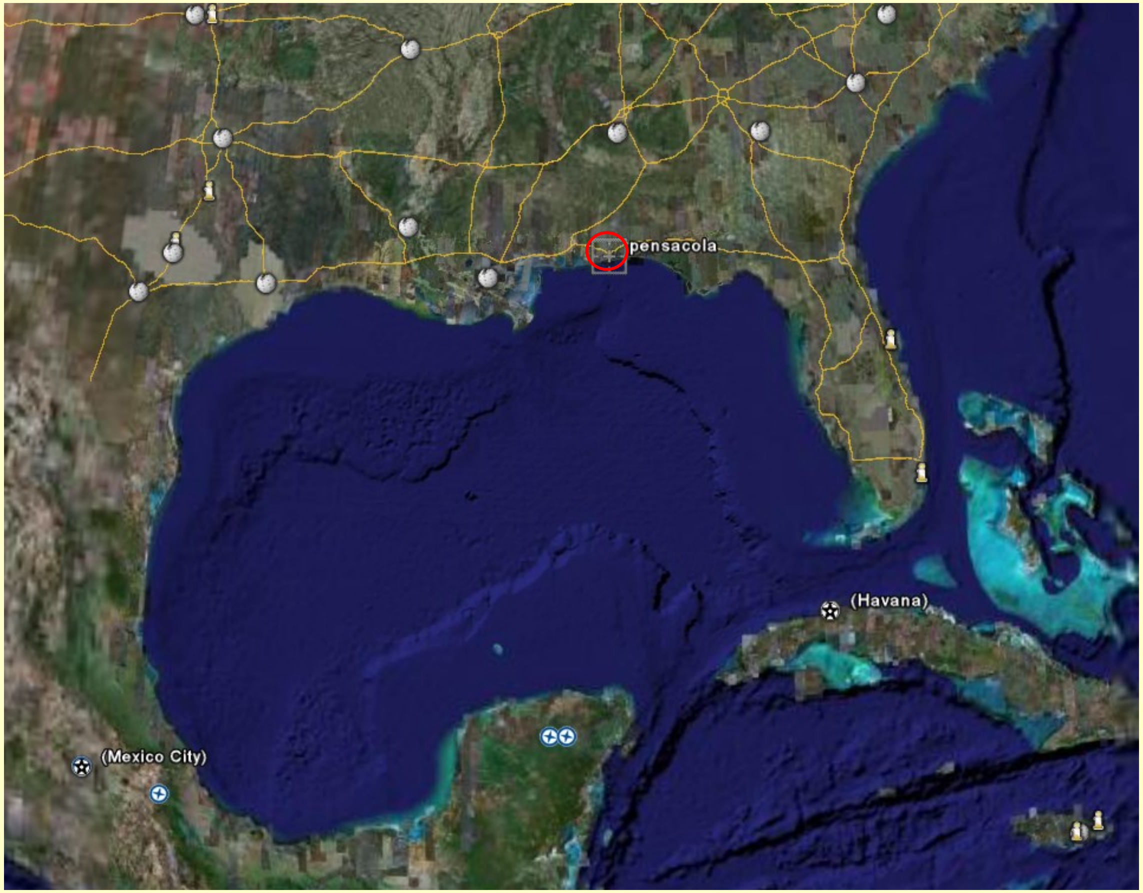
Fitting Results



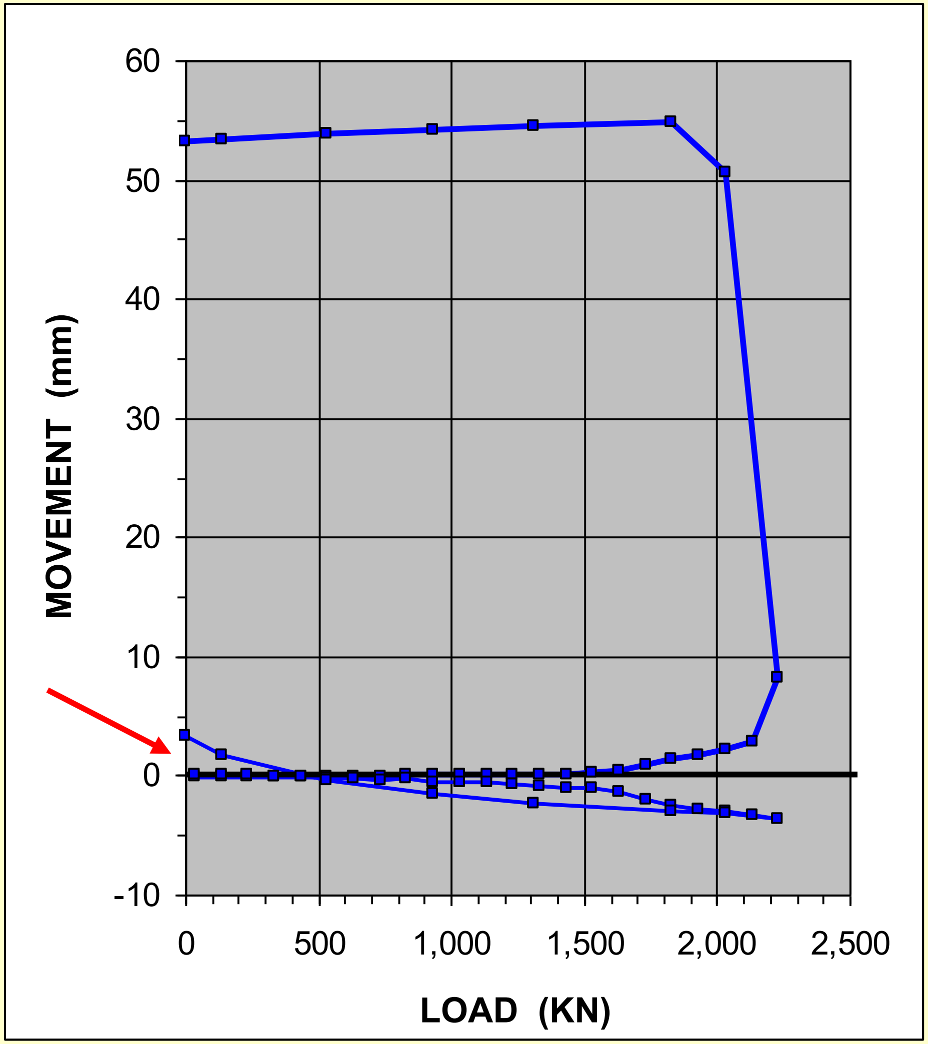
EXAMPLE 8

Pensacola, Florida

410 mm diameter, 22 m long, precast concrete pile driven into silty sand



Pensacola, Florida, USA

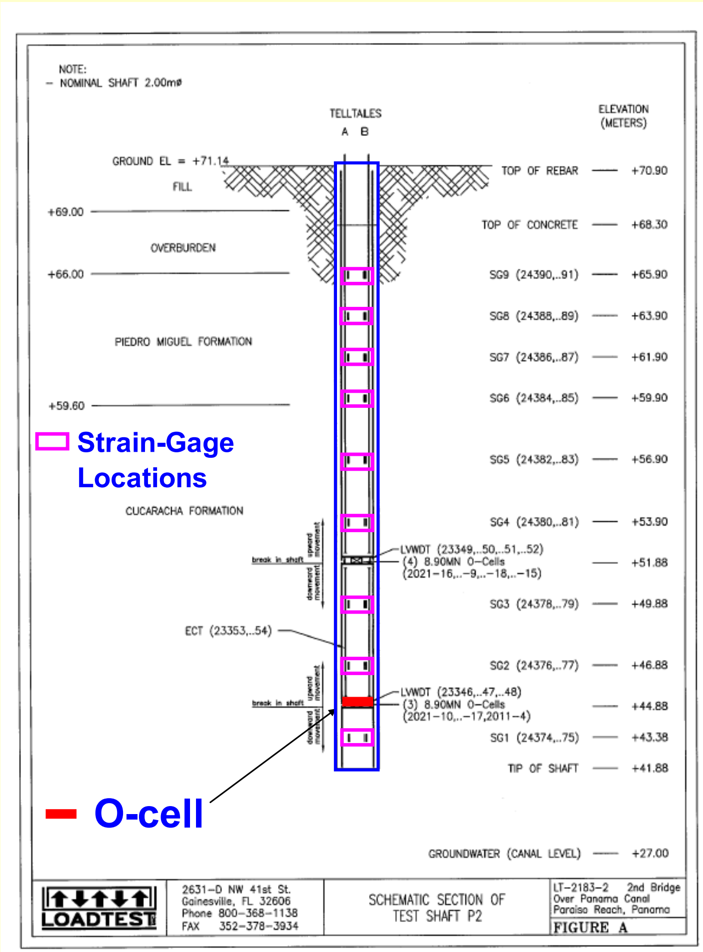


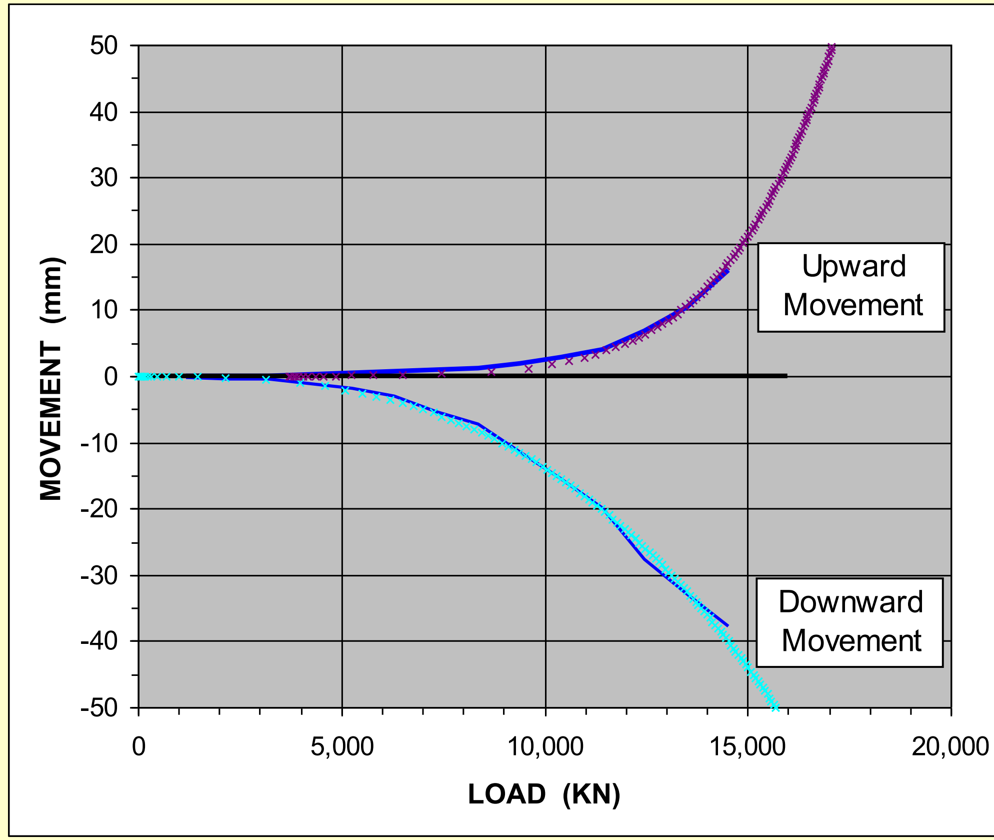
EXAMPLE 9

Bridge over Panama Canal, Paraiso Reach, Republic of Panama

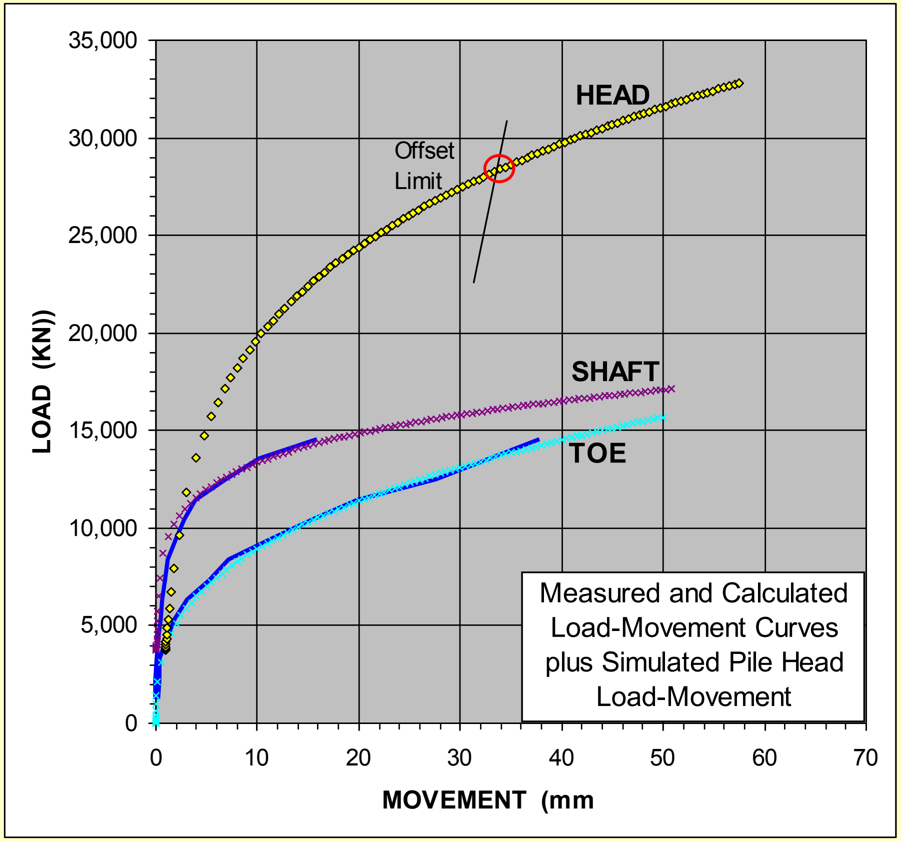
O-cell test on a 2.0 m (80 inches) diameter, 30 m (100 ft) deep shaft drilled into the Pedro Miguel and Cucaracha formations, February 2003.

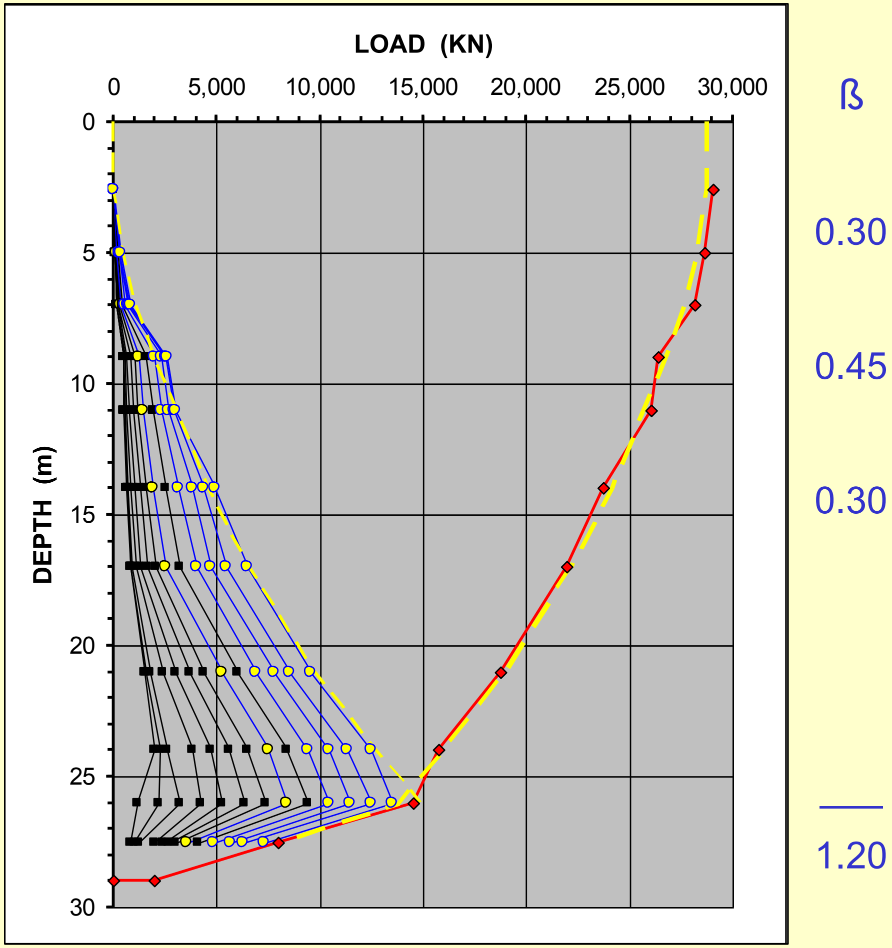
Load-Movements. Measured and Fitted to UniPile Calculation.





Test Results Processed for Design Analysis





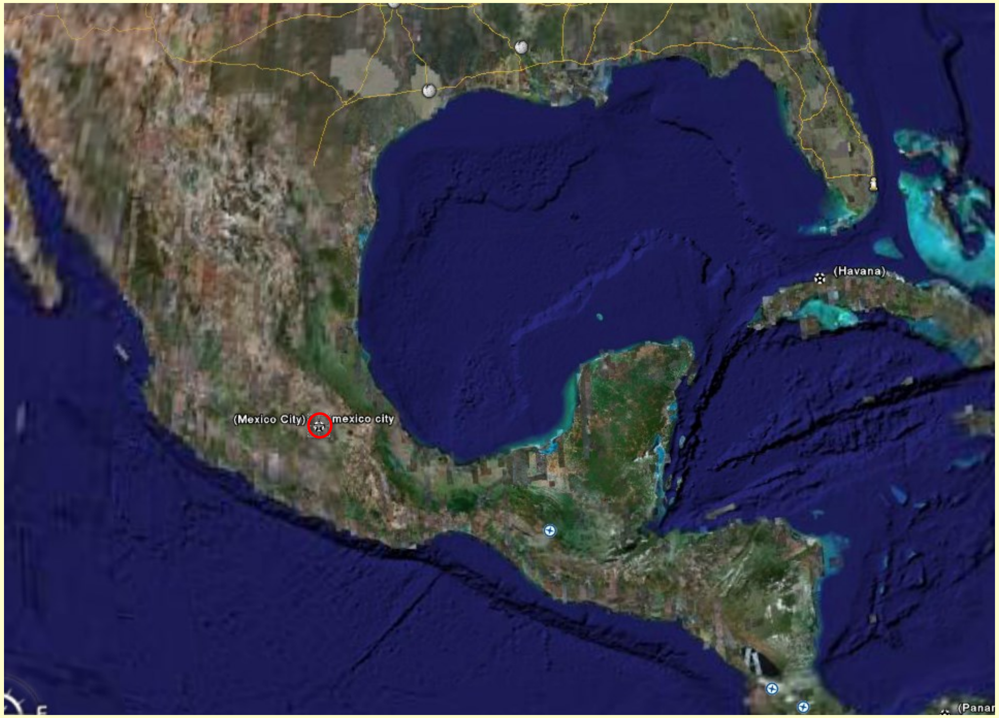
EXAMPLE 10

Torre Chapultepec, Mexico City, Mexico

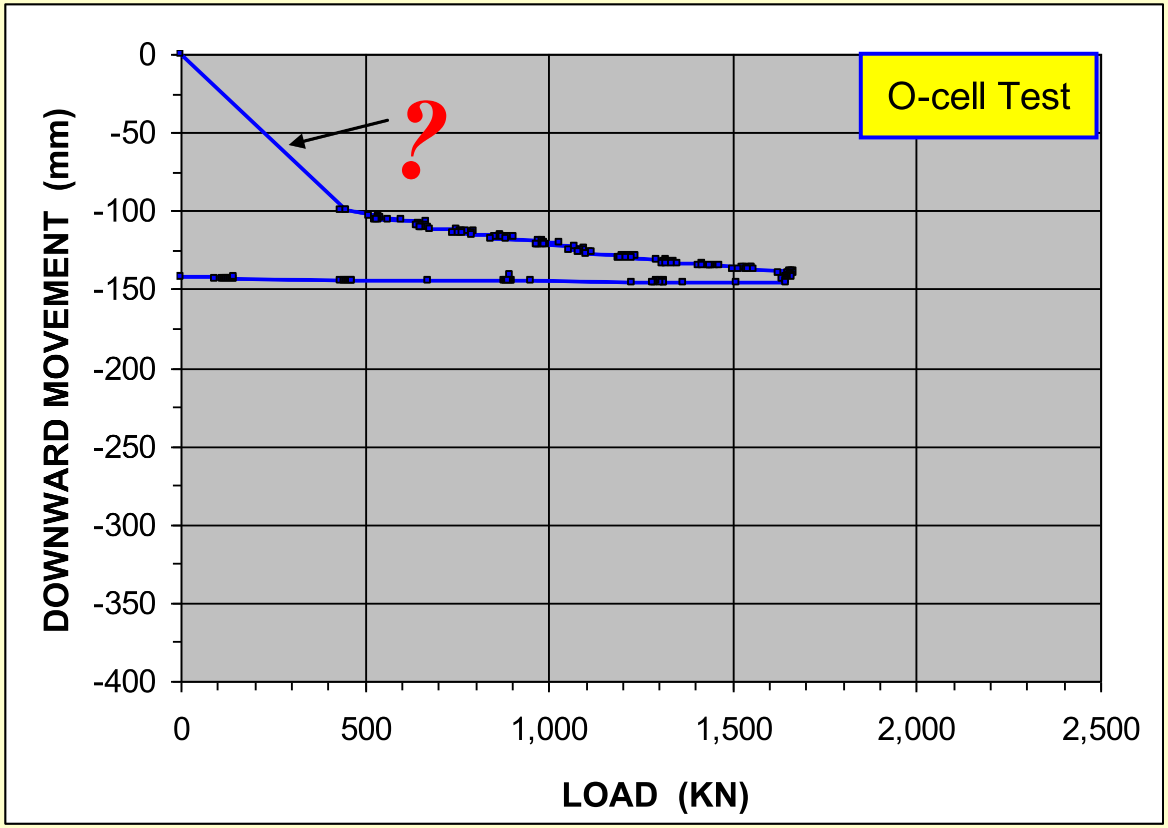
O-cell Test on a 700 mm diameter 34 m deep bored pile

0 m - 26 m desiccated clayey silt

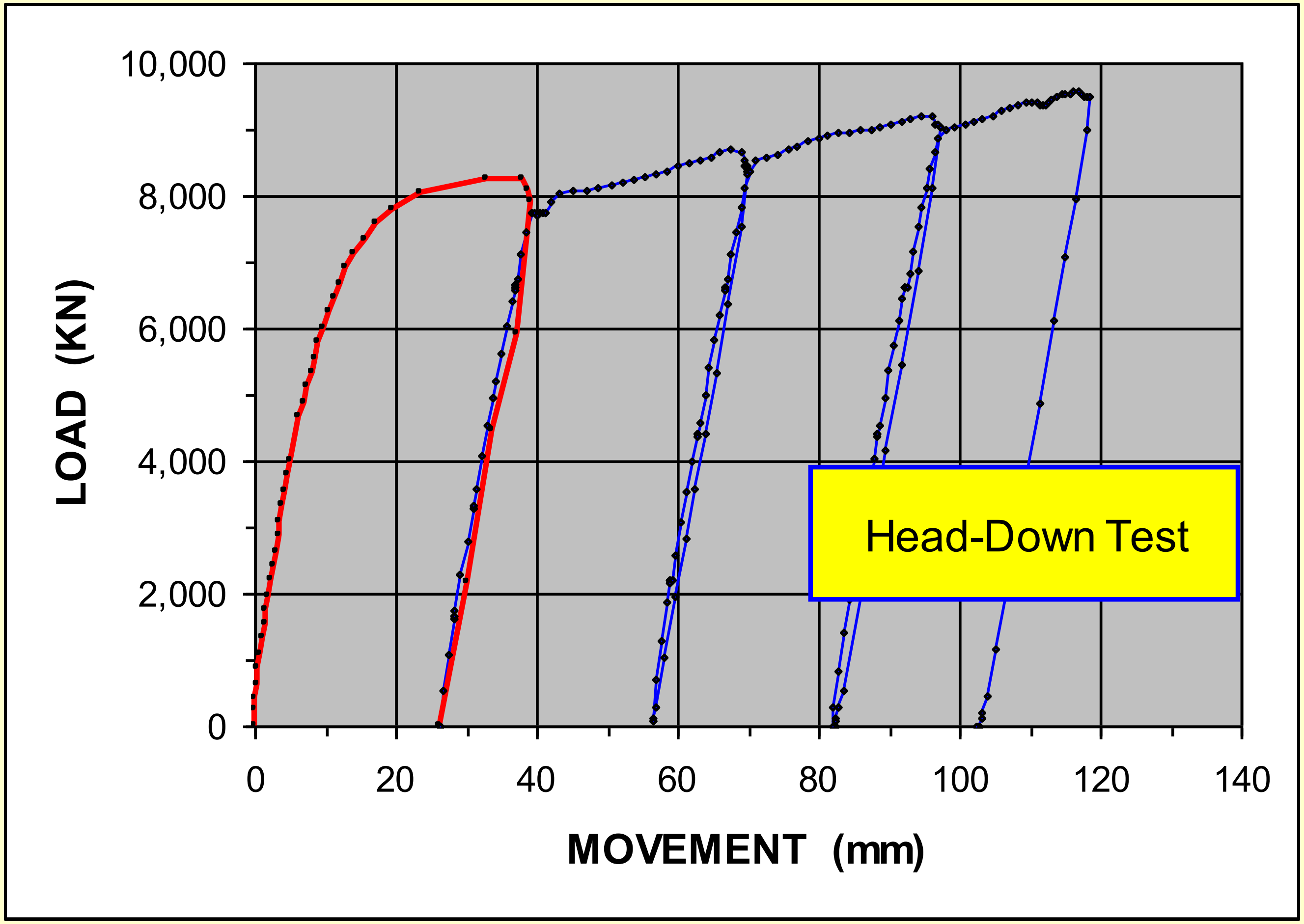
5 m – 34+ m dense sand and silt



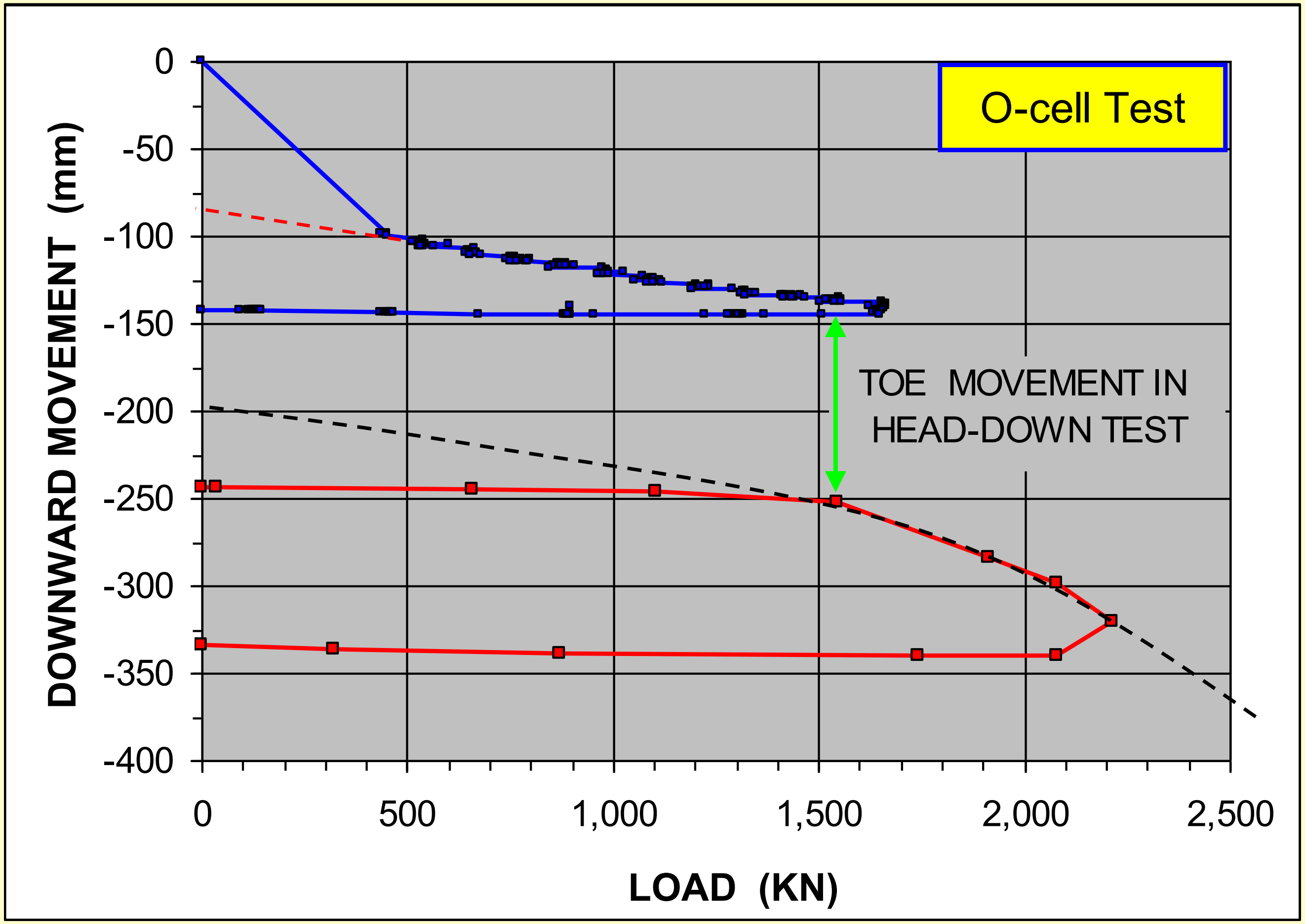
Torre Chapultepec, Mexico City, Mexico



Torre Chapultepec, Mexico City, Mexico



Torre Chapultepec, Mexico City, Mexico

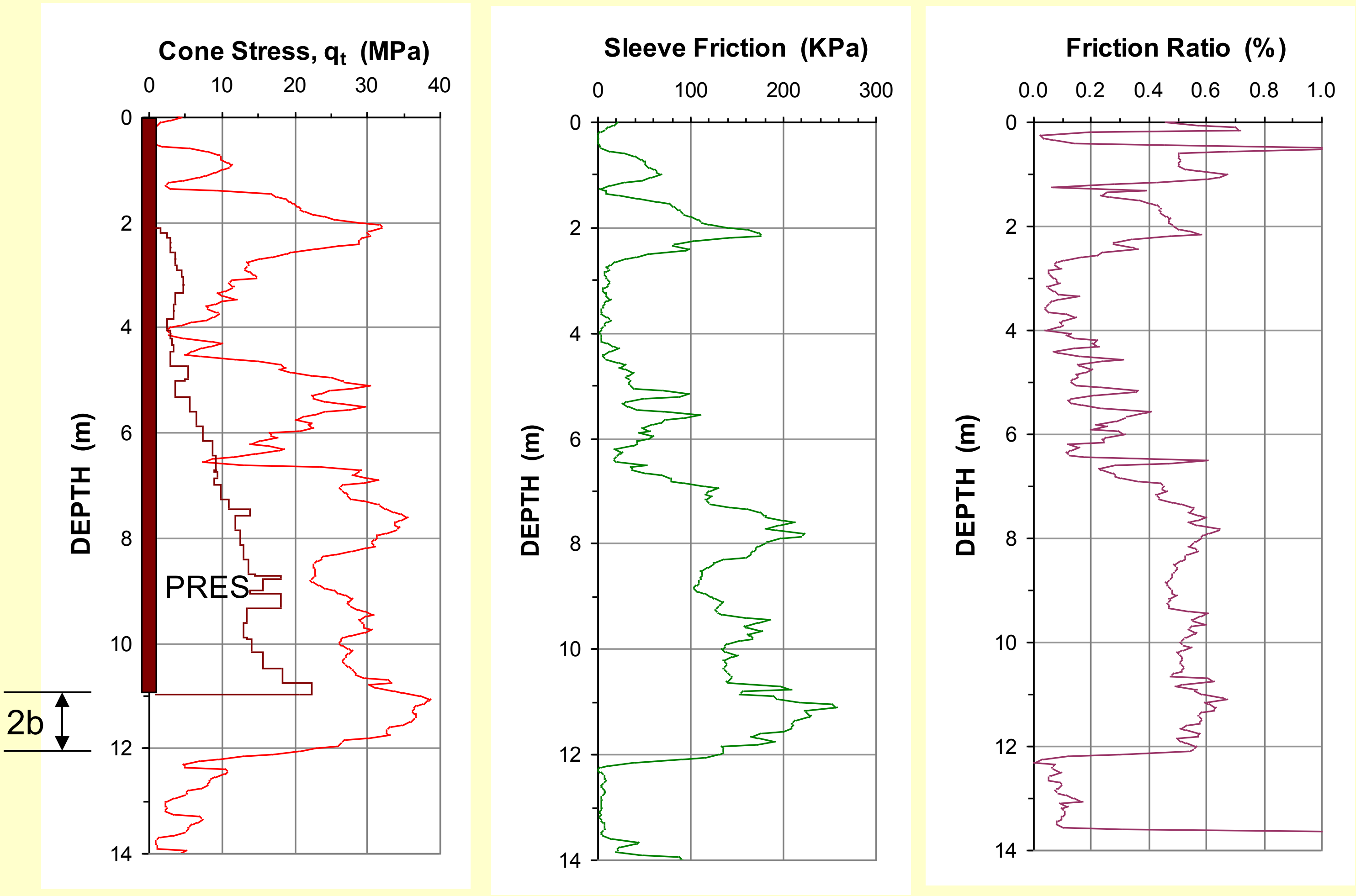


EXAMPLE 11

O-cell Tests on an 11 m long, 460 mm square precast concrete pile driven in silica sand in North-East Florida

(Data from Data from Bullock et al. 2005)

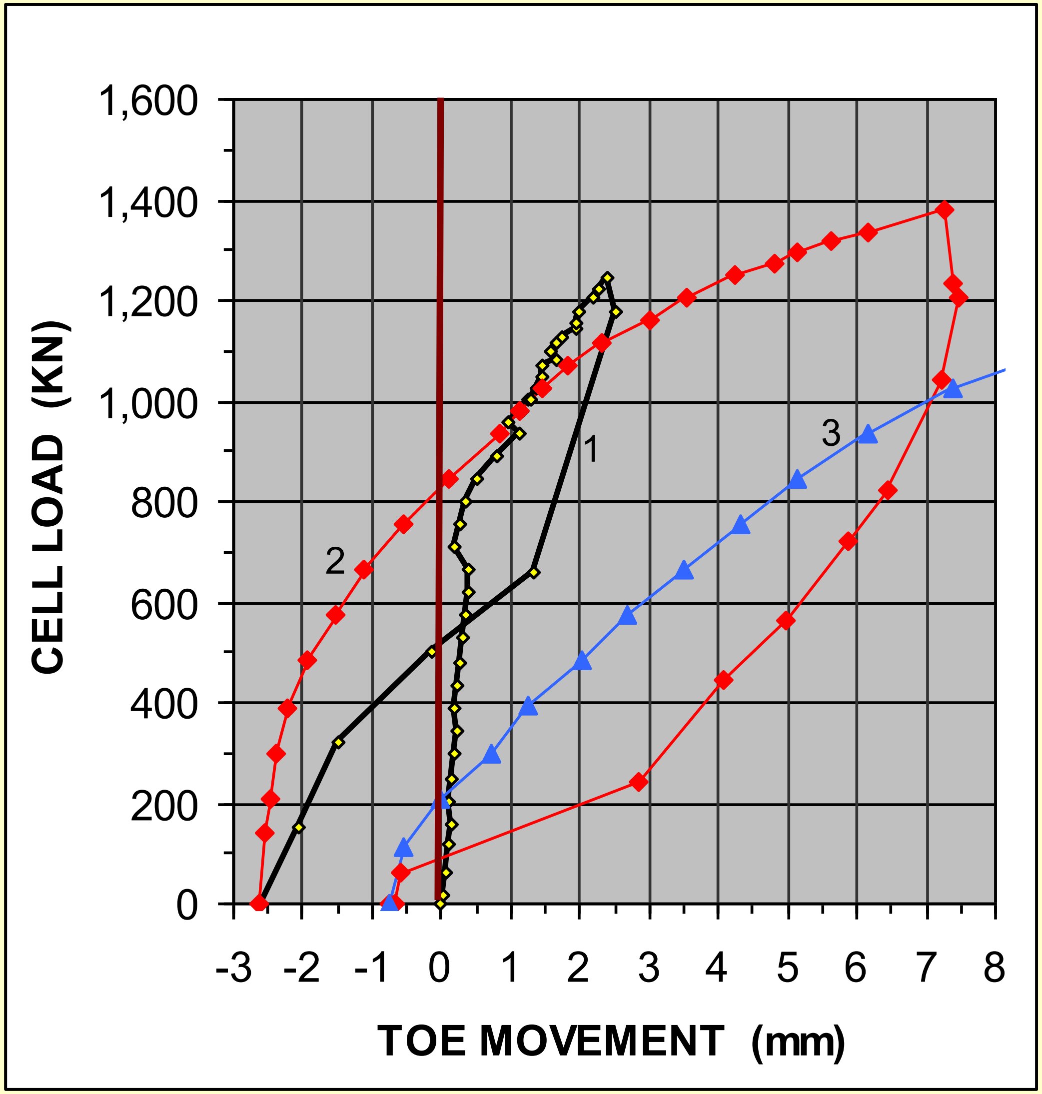
A study of Toe and Shaft Resistance Response to Loading



CPT sounding next to an 11 m long, 460 mm square precast concrete pile driven in silica sand in North-East Florida

Data from Bullock et al. 2005

Toe Resistance Response

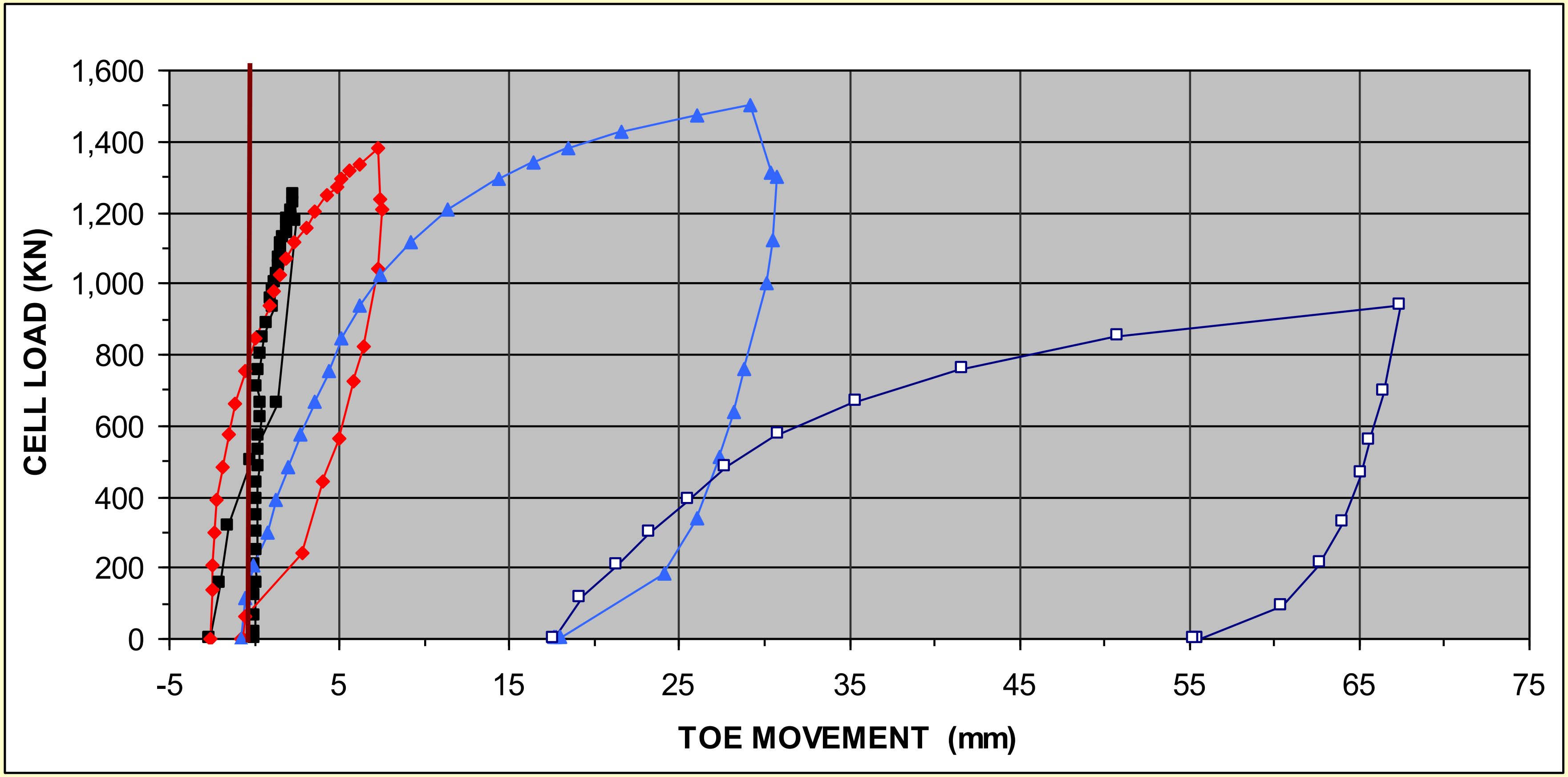


Load-movement curves for the pile toe.

<u>The two first cycles and beginning of the third cycle</u>

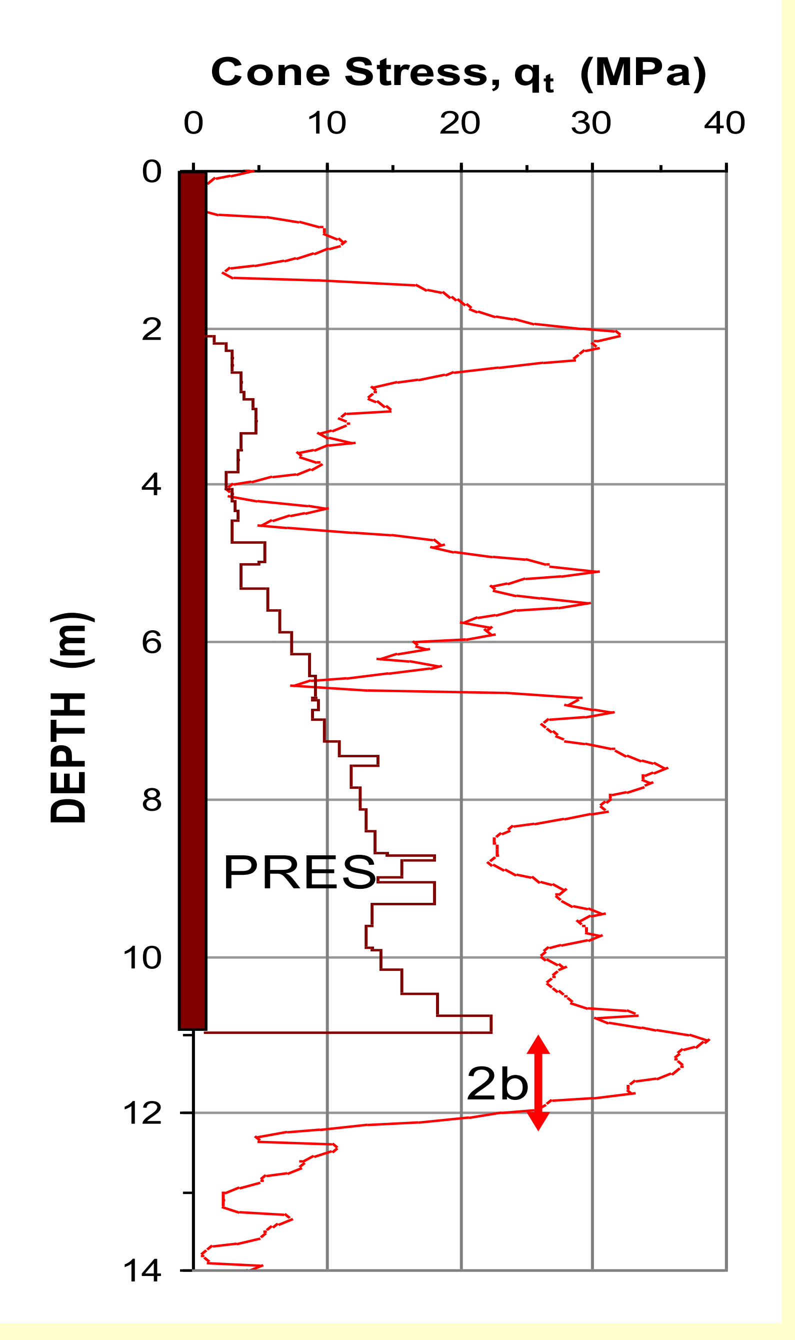
Data from

Bullock et al. 2005



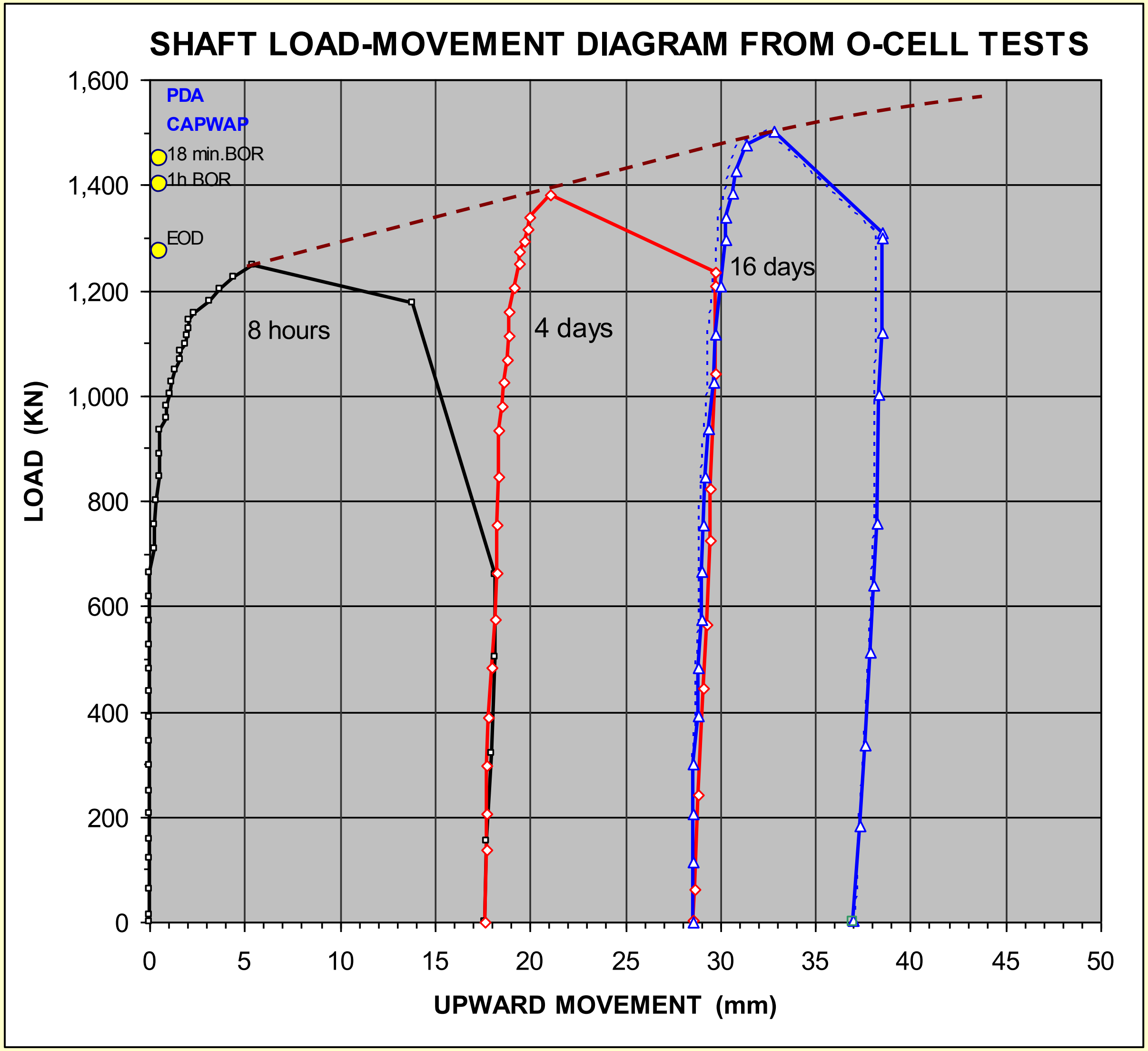
Load-movement curves
for the pile toe during all four load cycles

Data from Bullock et al. 2005



Data from Bullock et al. 2005

Shaft Resistance Response



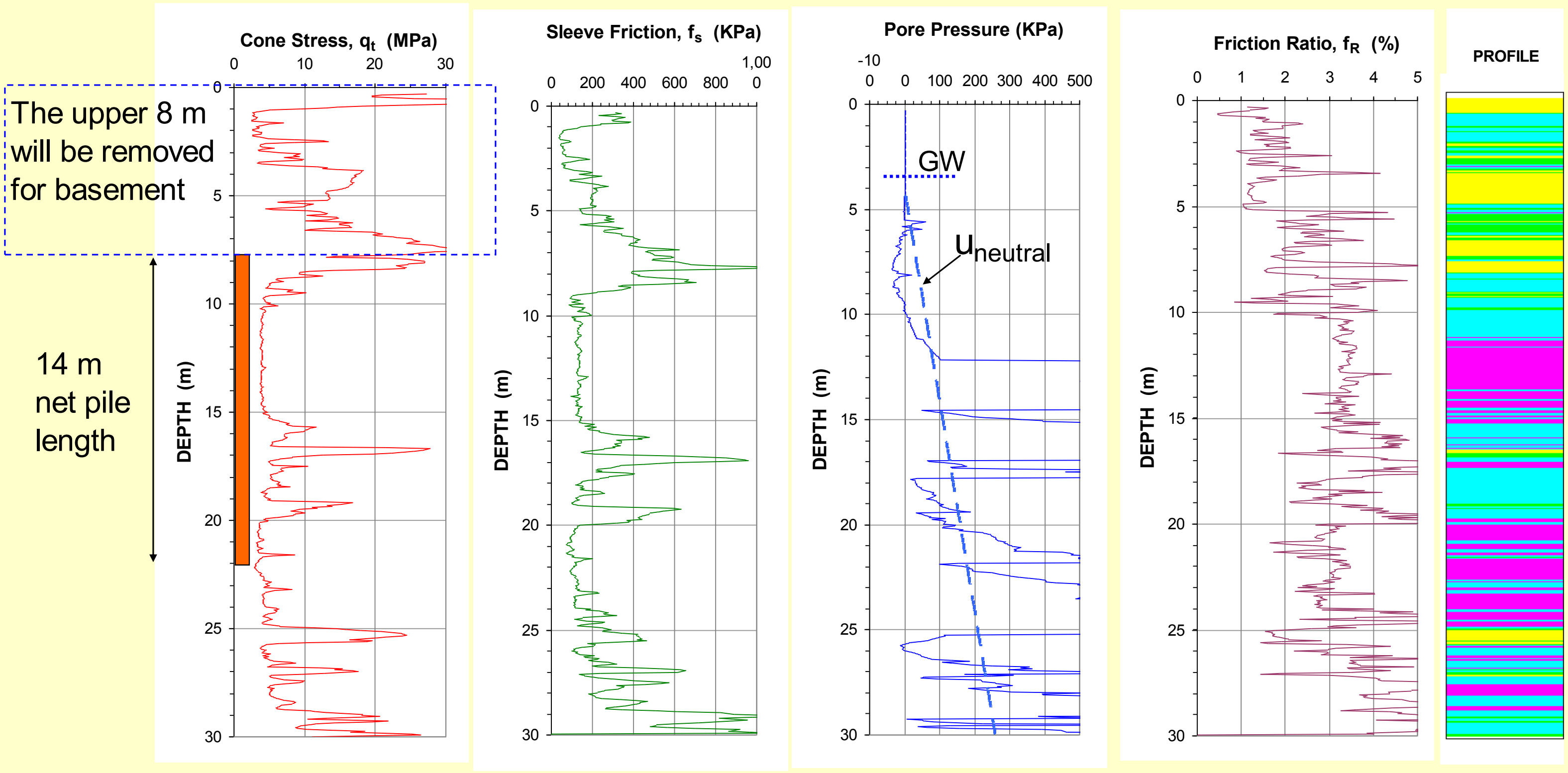
Data from Bullock et al. 2005

EXAMPLE 12

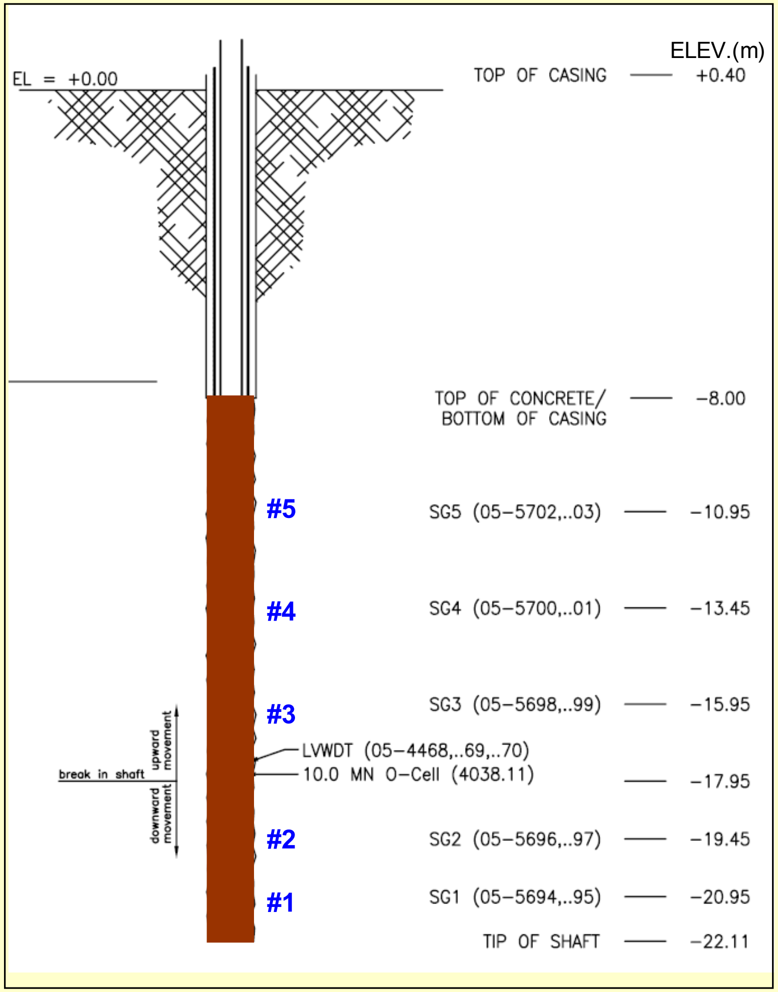
O-cell Tests on a 1.4 m diameter bored pile in North-West Calgary constructed in silty glacial clay till

A study of Toe and Shaft Resistance Response to Loading and correlation to CPTU calculation of capacity

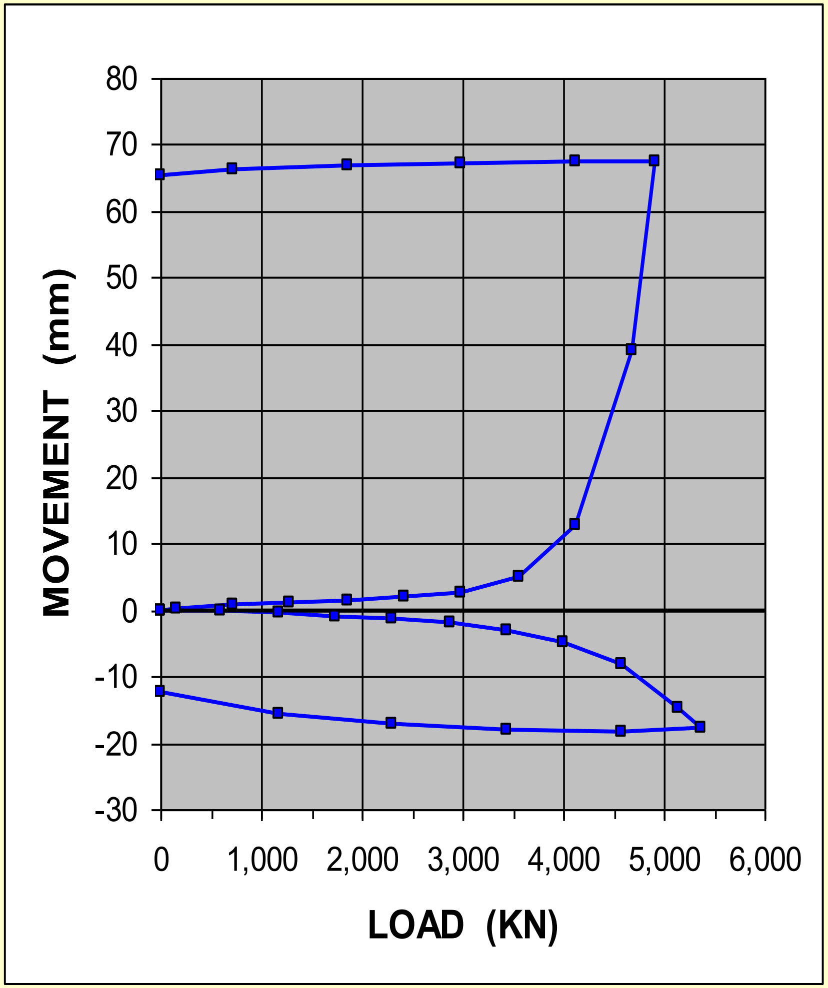
Cone Penetration Test with Location of Test Pile



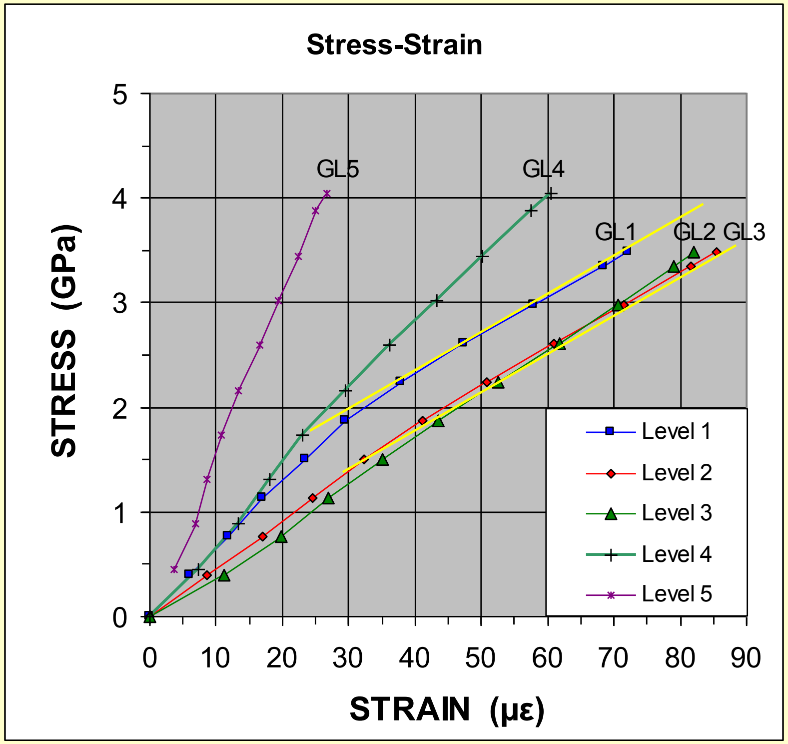
Pile Profile and O-cell Location

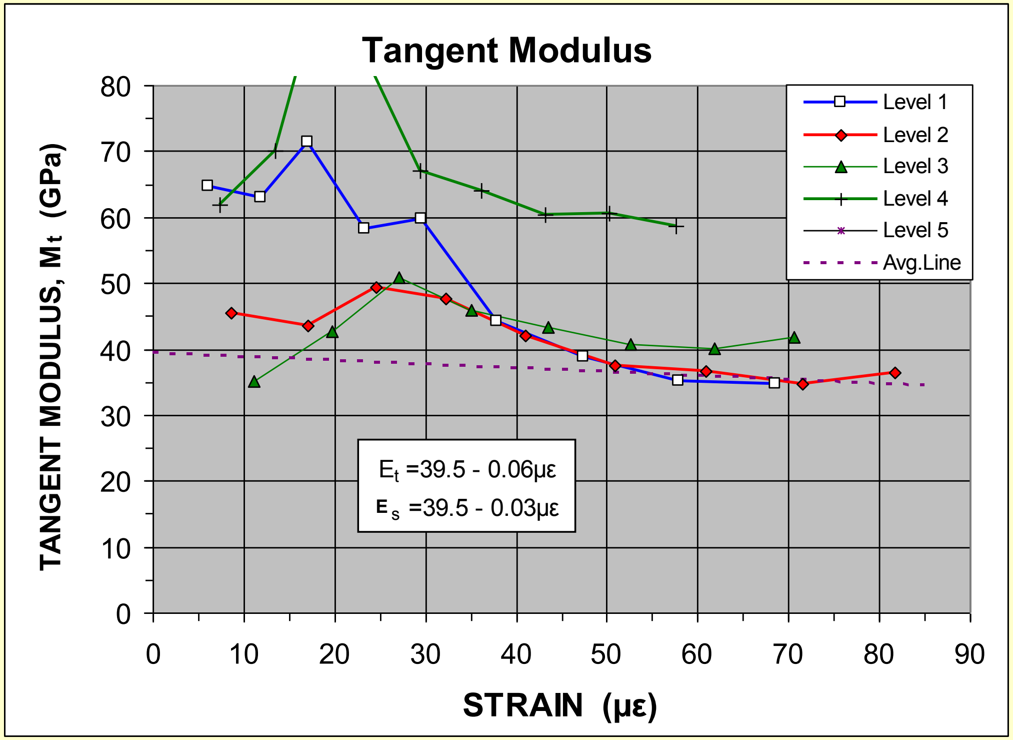


O-cell Load-movement Up and Down

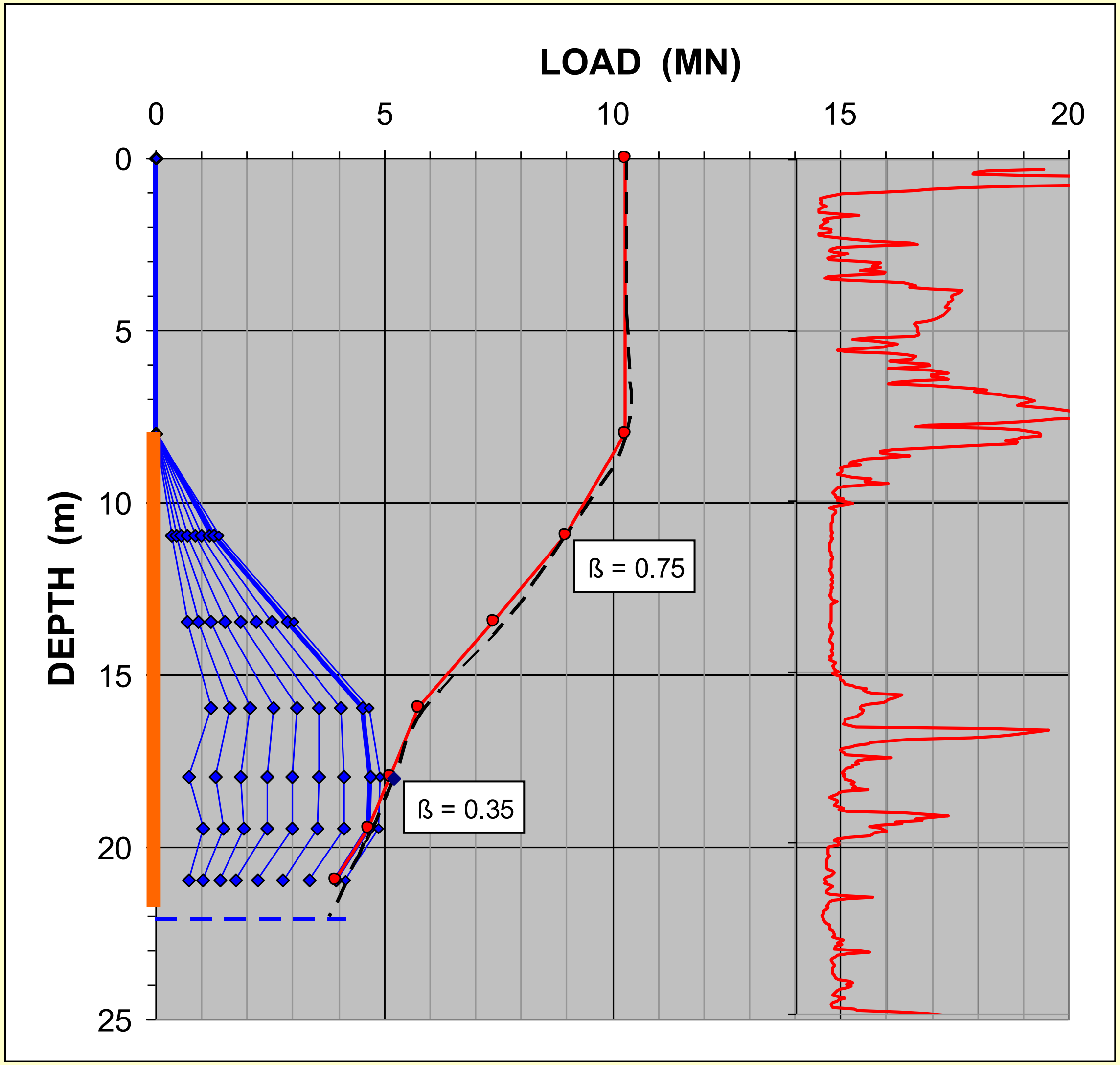


Results from Strain-gage Levels 1 through 5



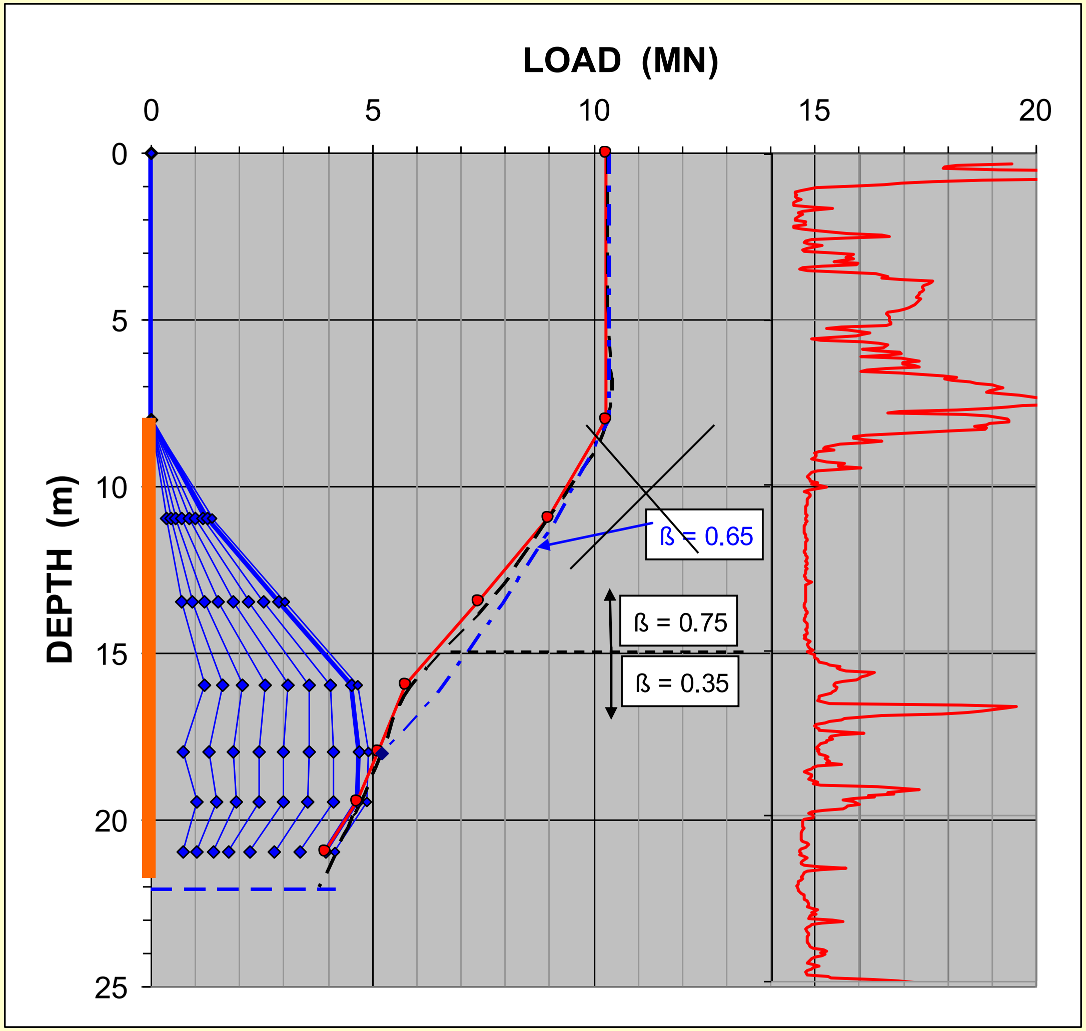


Load Distribution

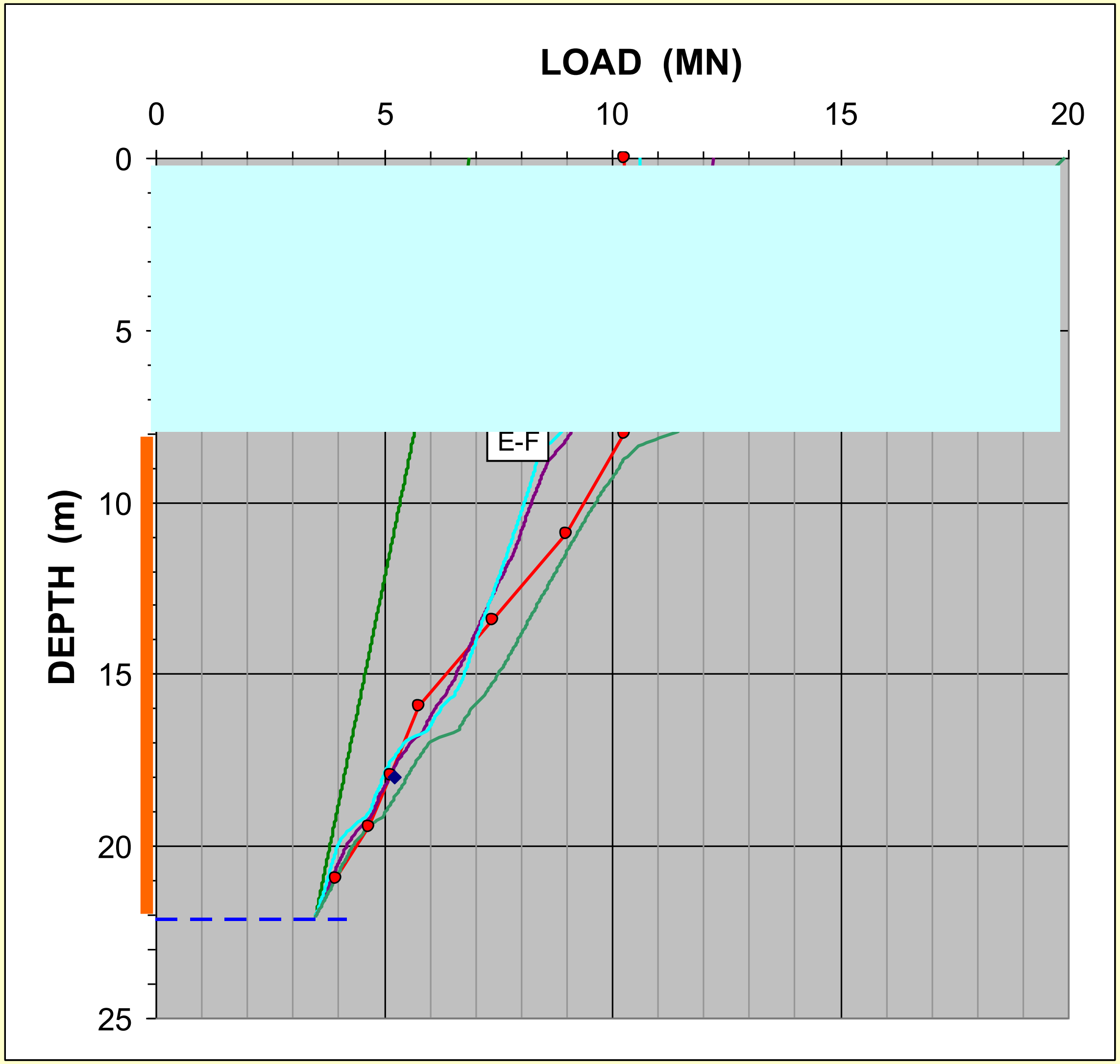


After consideration of potential presence of residual load and applying judgment

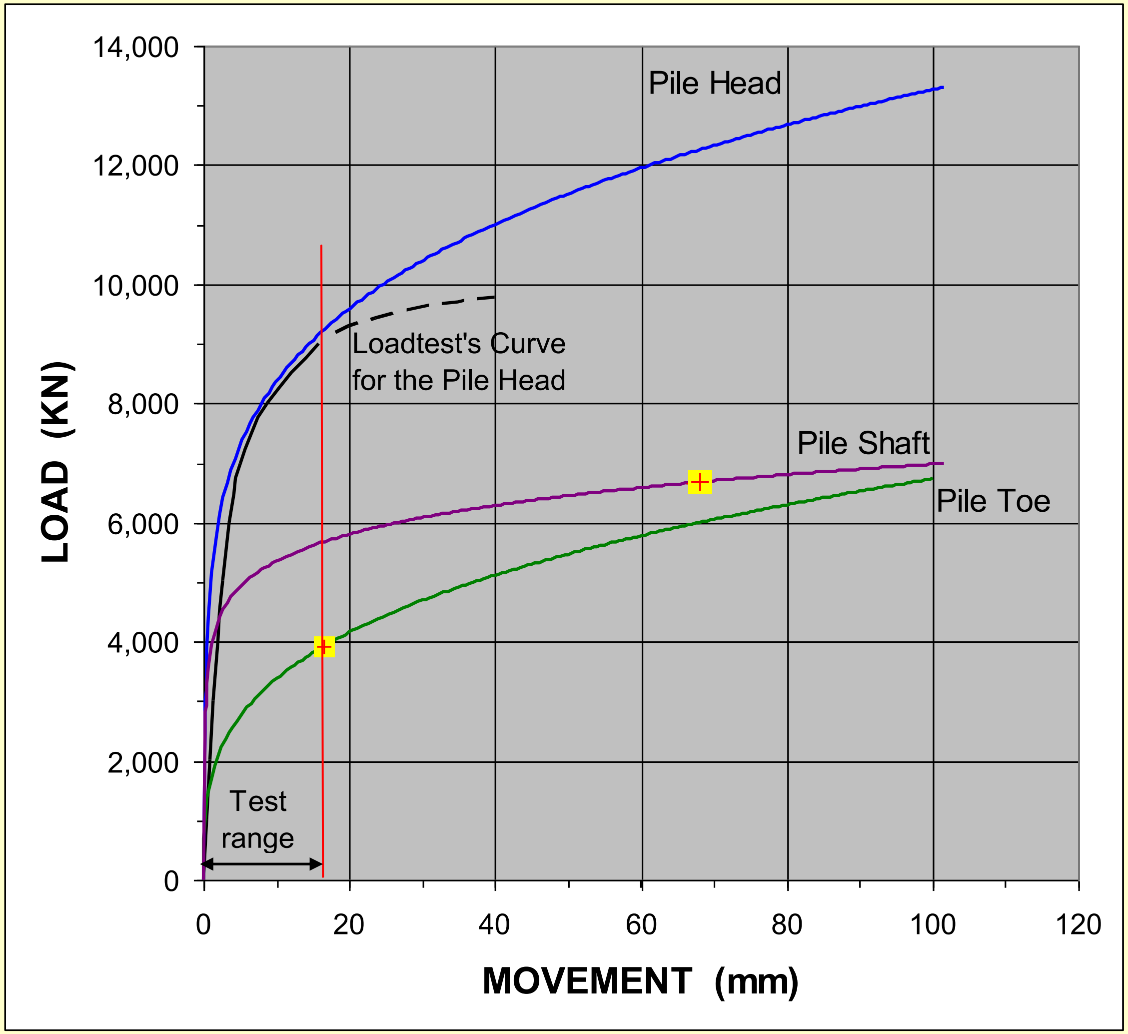
Load Distribution



Load Measured Distribution Compared to Distributions Calculated from the CPTU Soundings



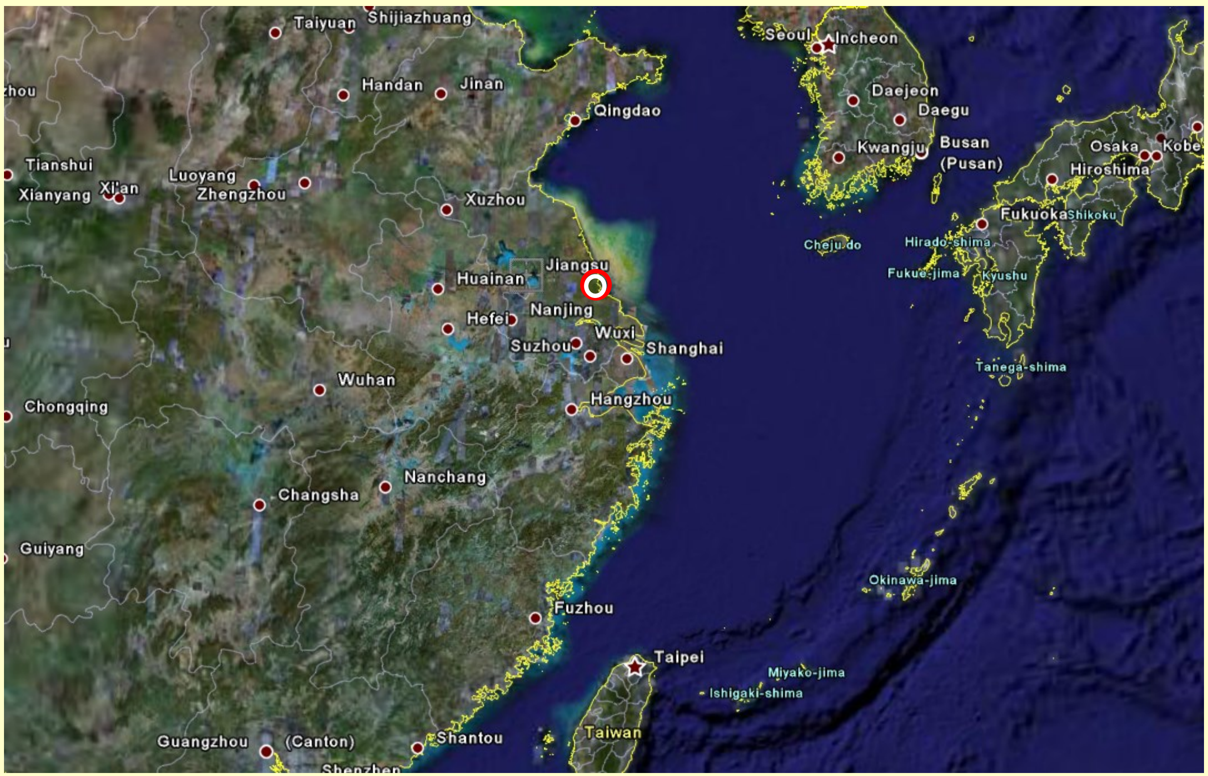
The Test Data for Shaft and Toe and Evaluation of Head-down Movement Using t-z and q-z evaluations

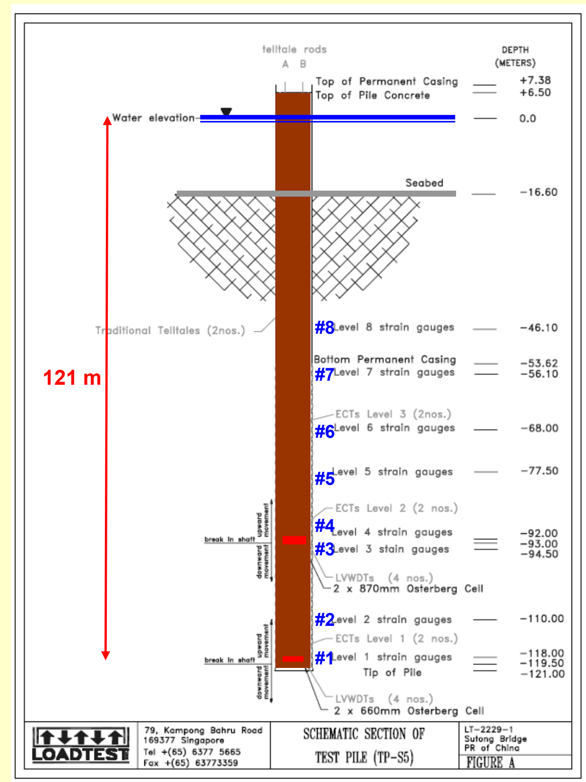


EXAMPLE 13

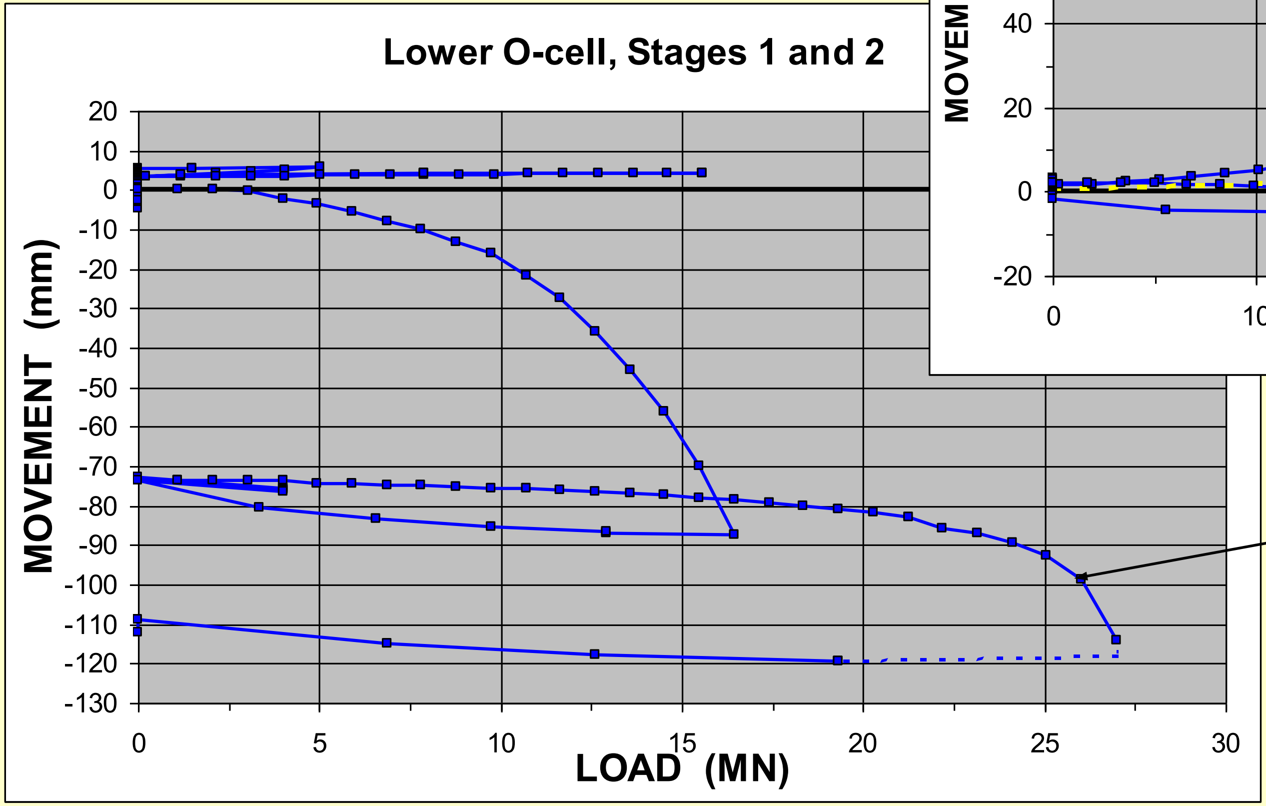
O-cell Tests on a 2.5 m diameter, 121 m deep bored pile for the Sutong Bridge Project - Jiangsu Province, China, constructed in compact to dense to very dense sand.

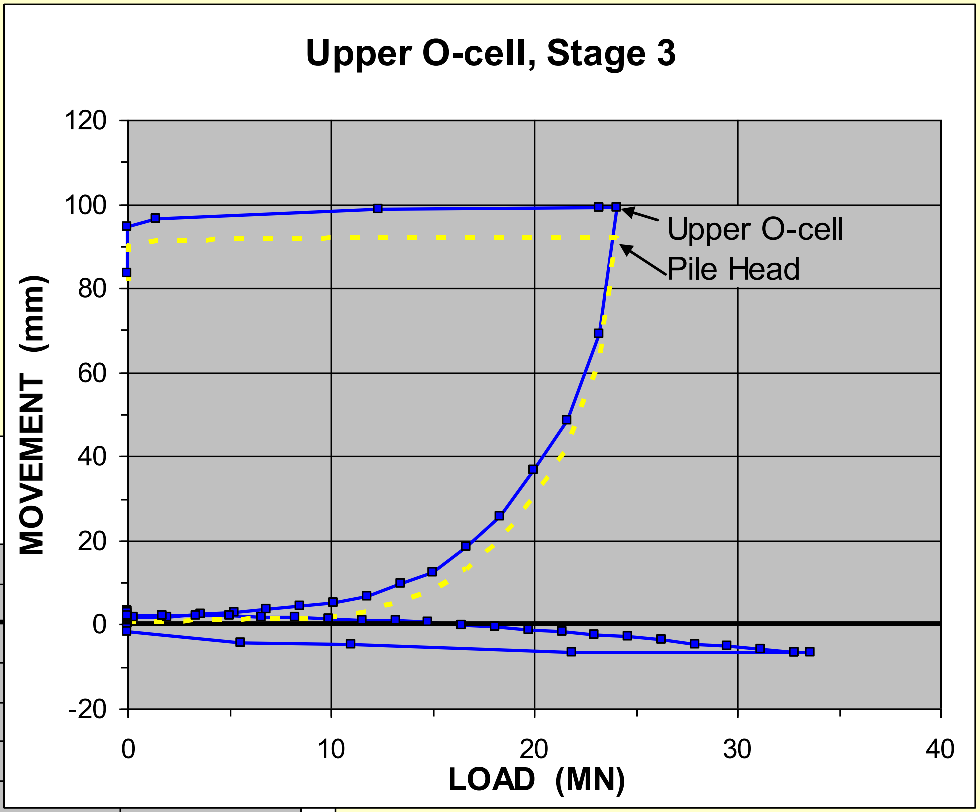
Note, two-level O-cell test





TEST RESULTS

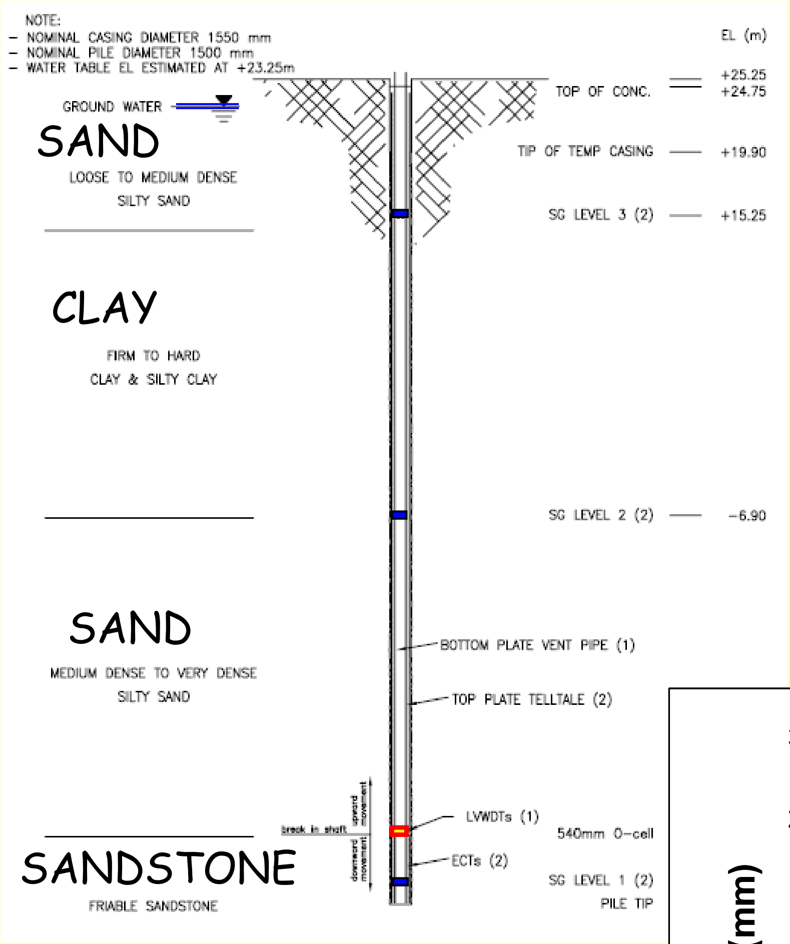




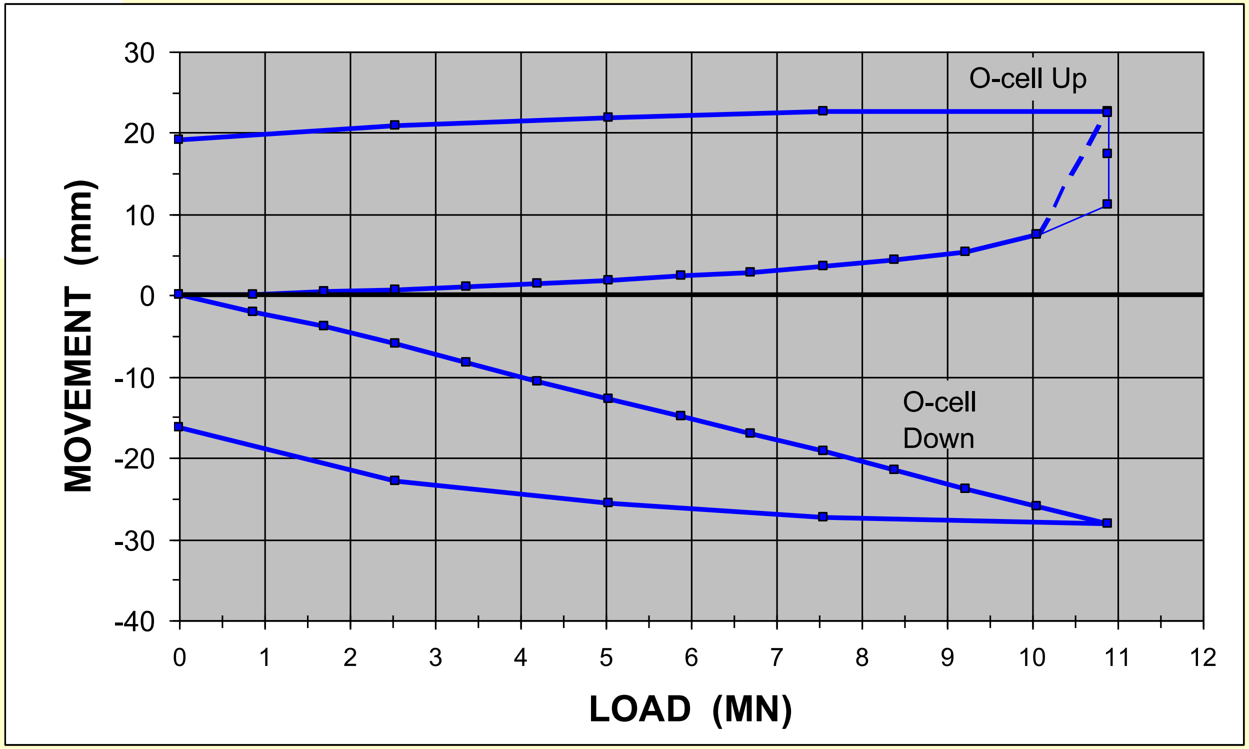
EXAMPLE 14

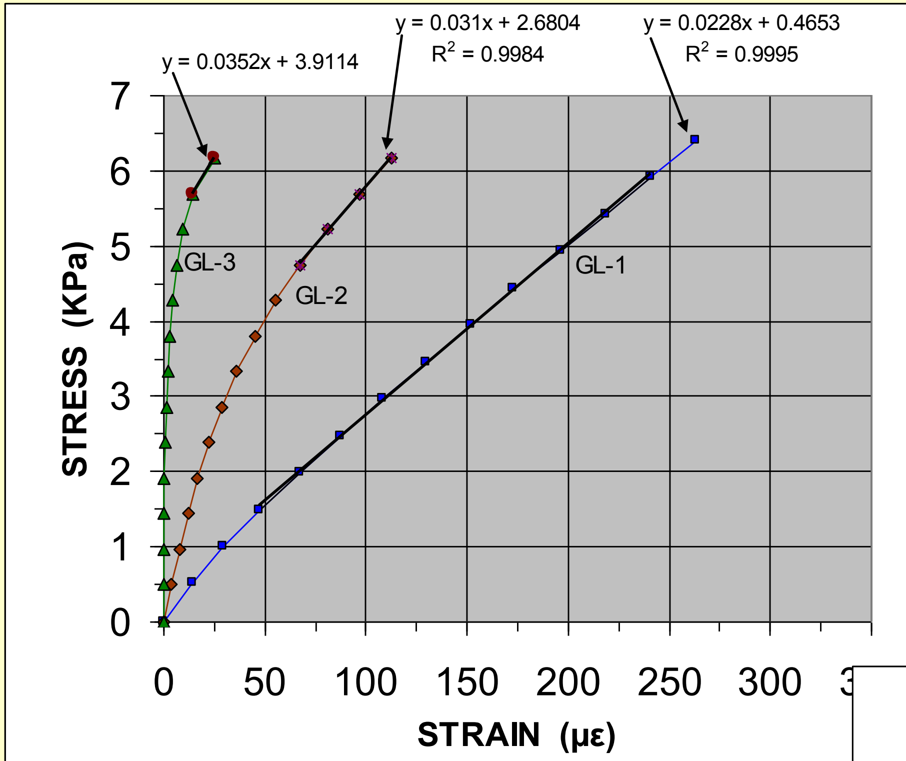
Zambezi River Bridge, Caia, Mozambique

1.5 m diameter
60 m embedment
Bored Pile



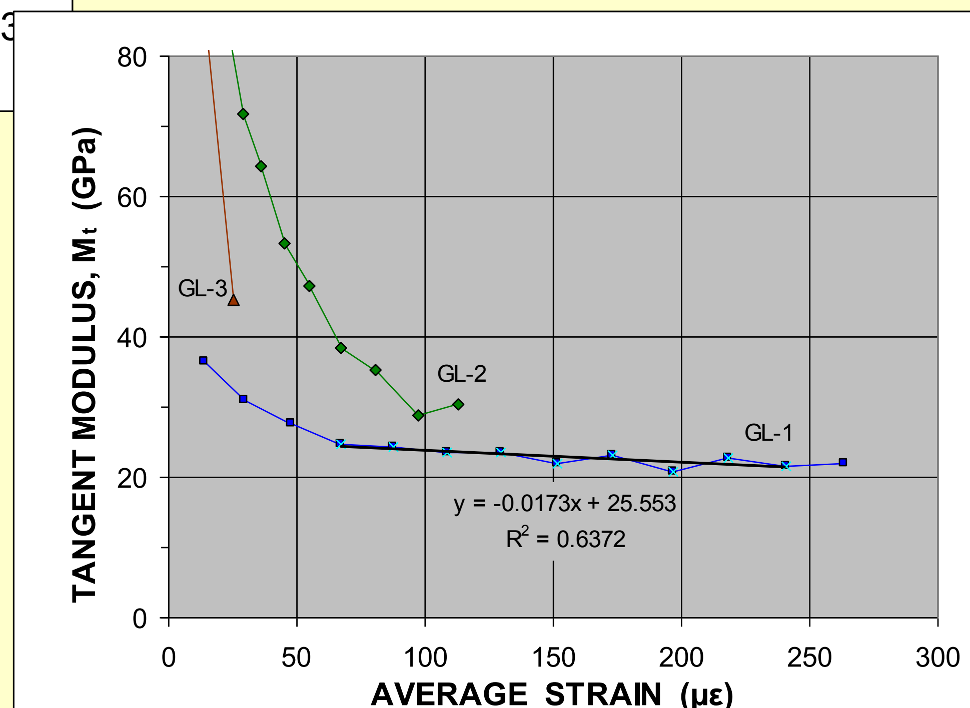
Test Results



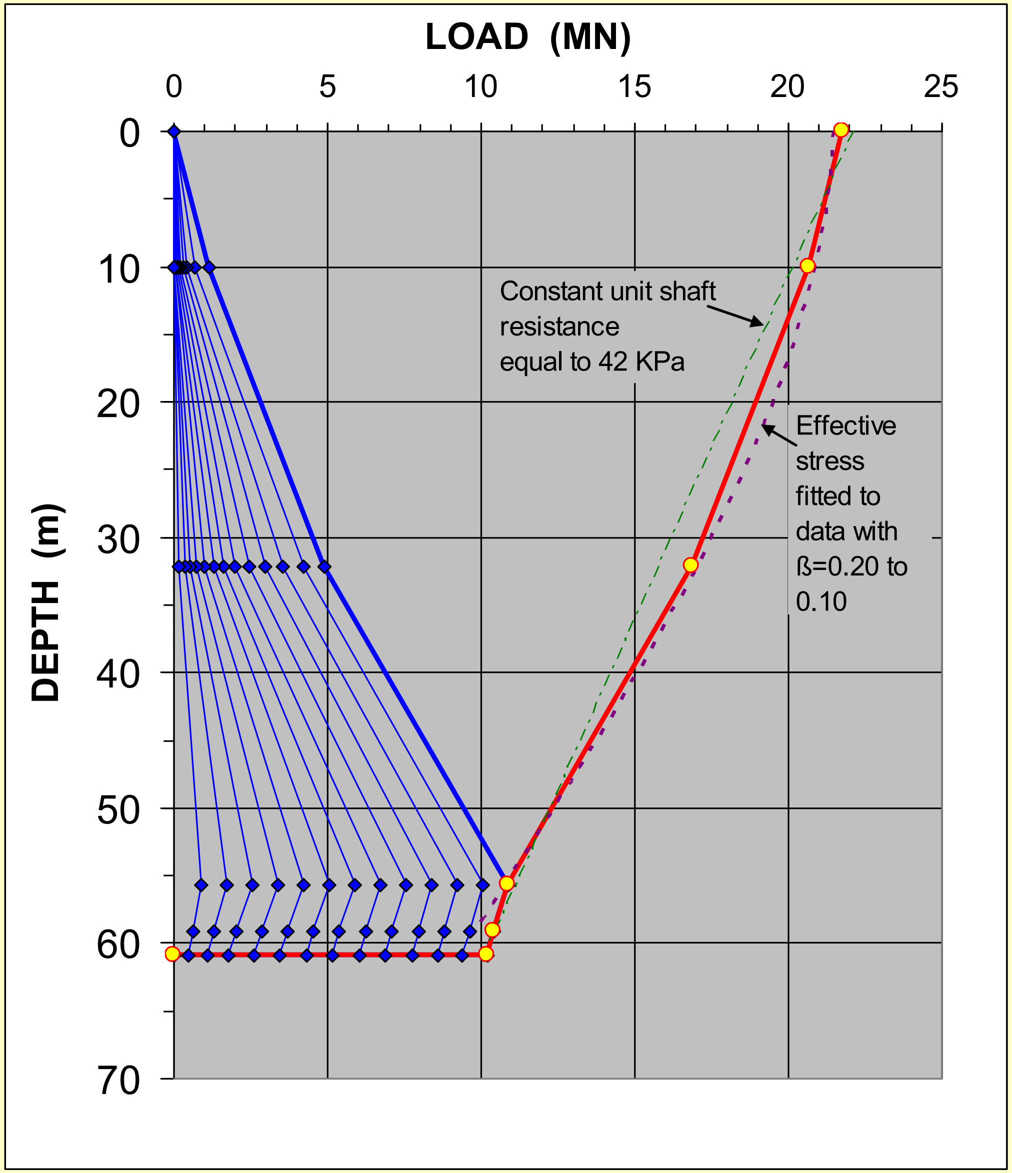


E-Modulus

Tangent Modulus



Load Distribution



The O-Cell test with a couple of strain gages, judiciously placed, will provide:

1. Separate values of shaft and toe resistances
2. Estimate of residual load
3. Load-transfer for the pile
4. Pile-toe load-movement curves (q-z function)
5. Results that can be extrapolated to other piles
6. Data necessary for settlement analysis

Closing remarks

- Not recognizing that test data can be affected by residual load is the reason for delusive concepts such as the Critical Depth.
- It is unfortunate that this fact is still not generally recognized. As should be obvious, this means that poorly thought-through results keep confusing the practice.
- The E-modulus is an important factor in the evaluation of the O-cell data that must not be left to chance.
- The analysis is not completed before the test data have been processed in an effective stress calculations and the t-z and q-z relations have been evaluated.
- Instrumentation and taking the readings must be planned, executed, and evaluated by persons who are experienced in all the various phases.

The Absolute and Ultimate Bi-direction


Vaughani Shores, Vanuatu
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