Piling & Deep Foundations Asia 2009

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Views on Accuracy of Tests and Analyses

Bengt H. Fellenius

9658 First Street
Sidney, BC, Canada
V8L 3C6

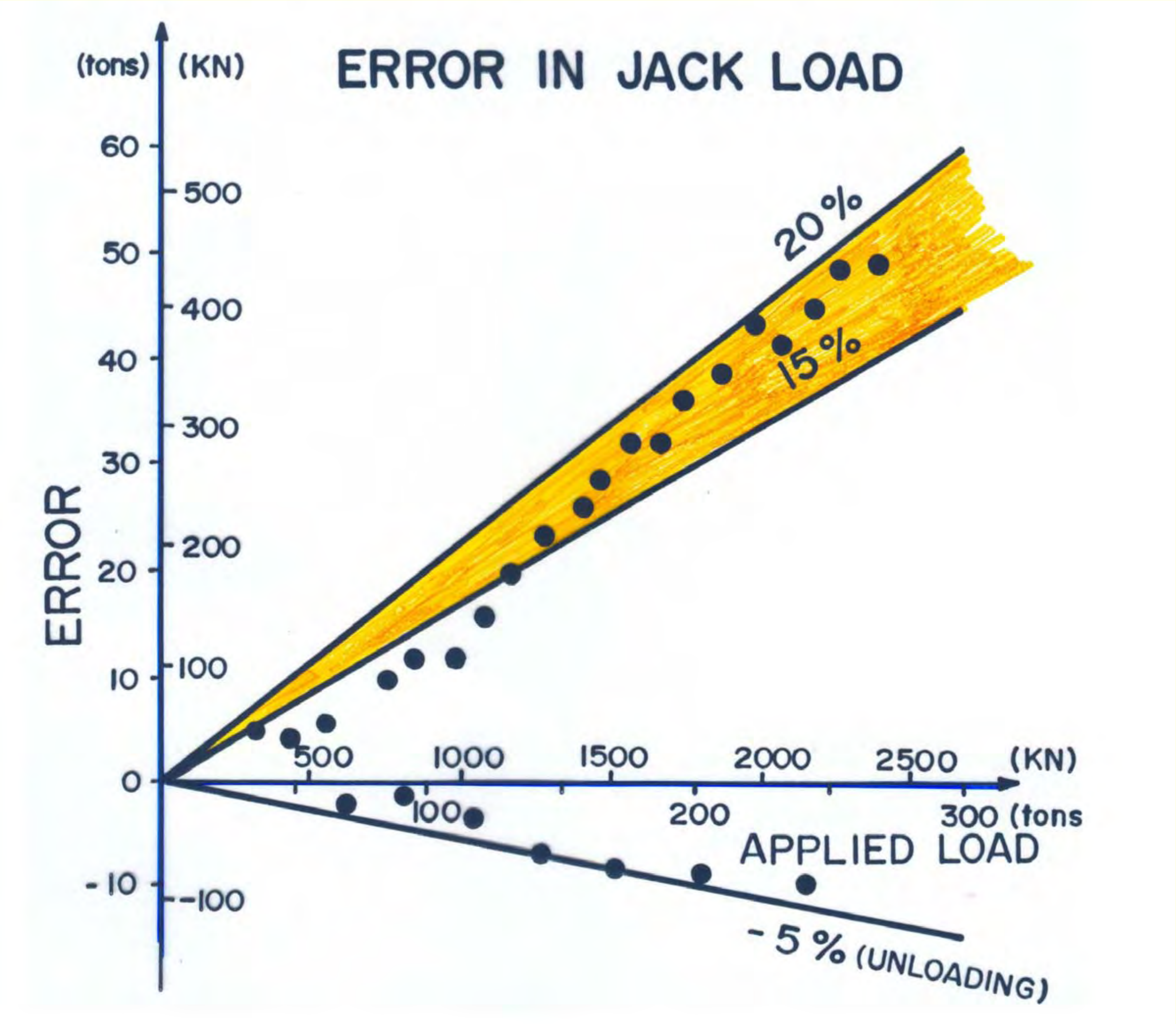
Tel.: (778) 426-0775
e-address: <Bengt@Fellenius.net>
Web site: [www.Fellenius.net]

Don't connect the reference beams to each other. A foot up on one beam and both references are disturbed!

See?

Make sure the support stakes of the reference beams are far enough away from the support of the kentledge load and the latter far enough from the pile. The distances are prescribed in the ASTM Guidelines.

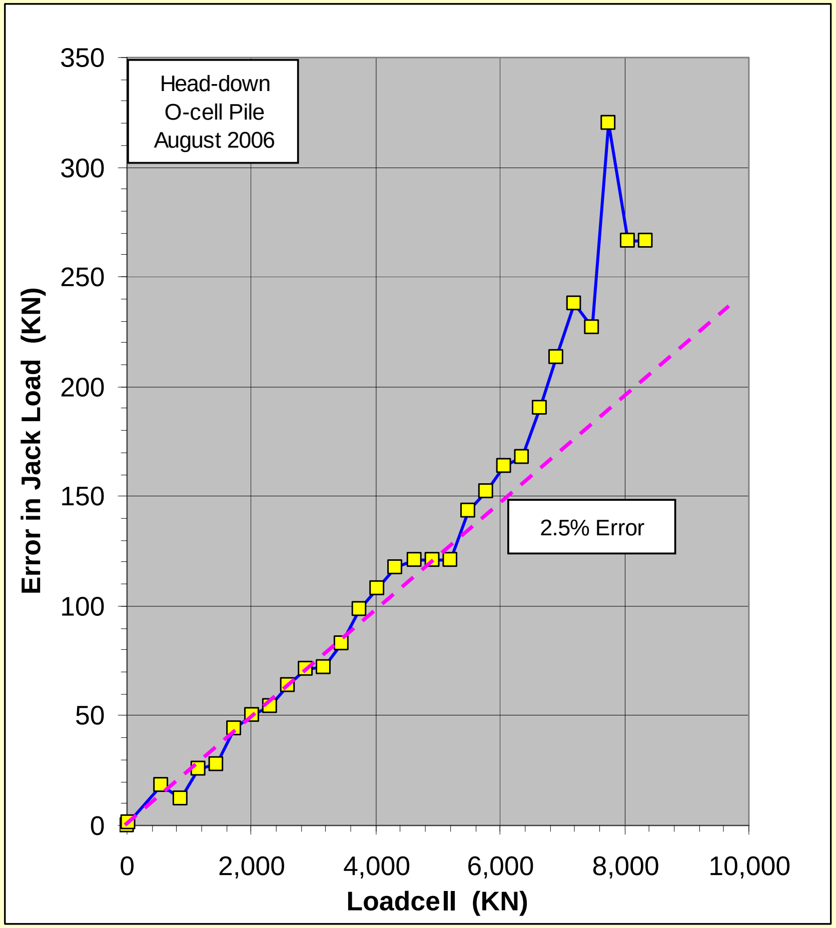
Most piles are installed slightly inclined. Consider this when arranging the reaction structure — and always use a swivel plate to avoid edge loading.

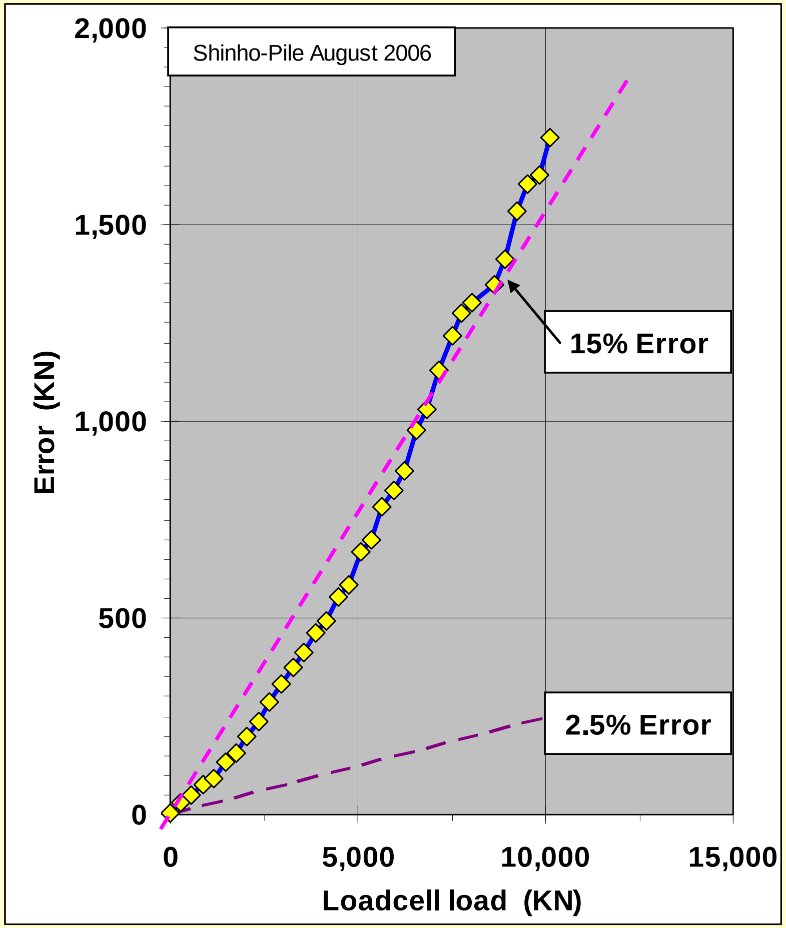


Fellenius 1984

The error can be small or it can be large.

Results from two tests at the same site using the same equipment testing two adjacent piles, one after the other.

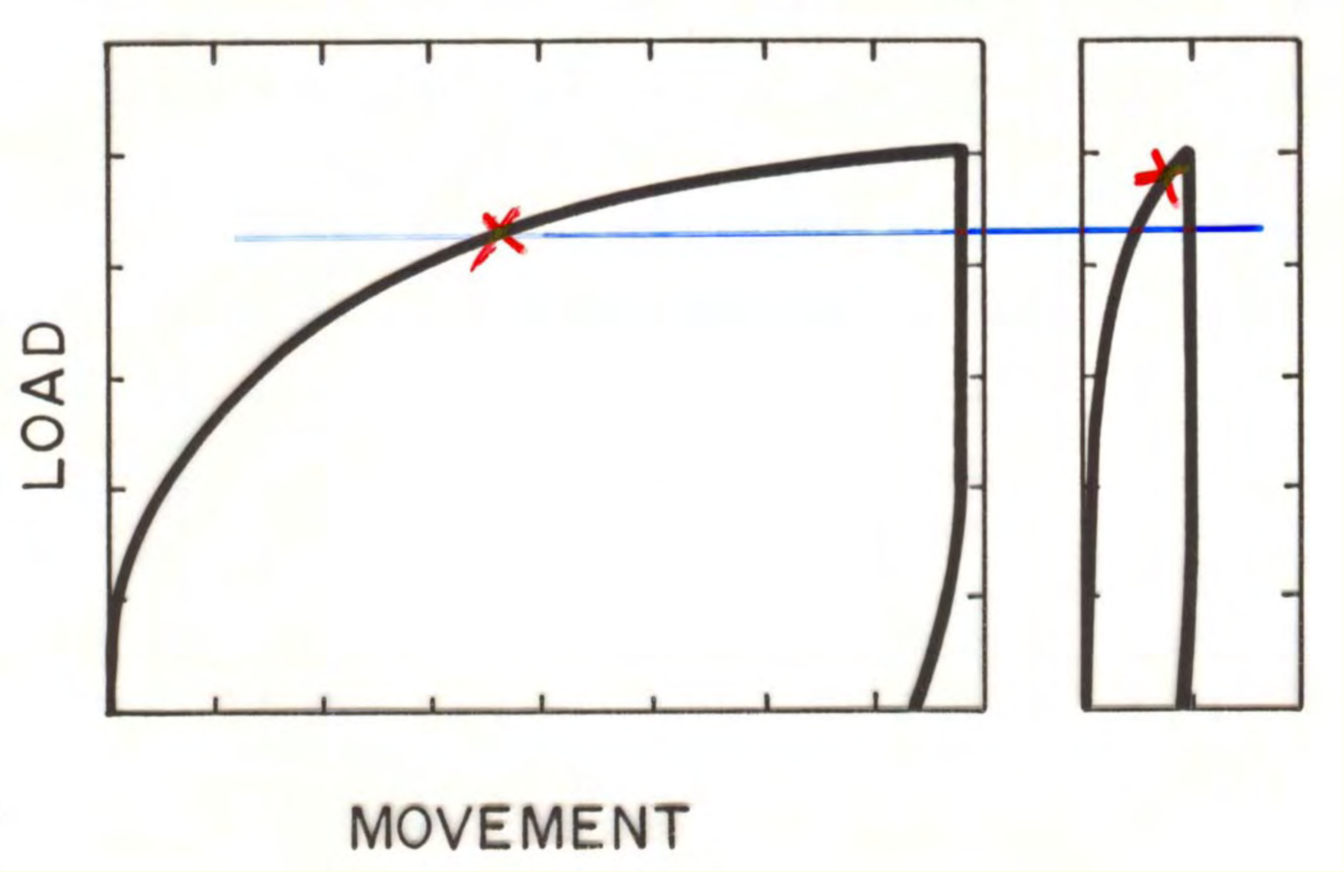


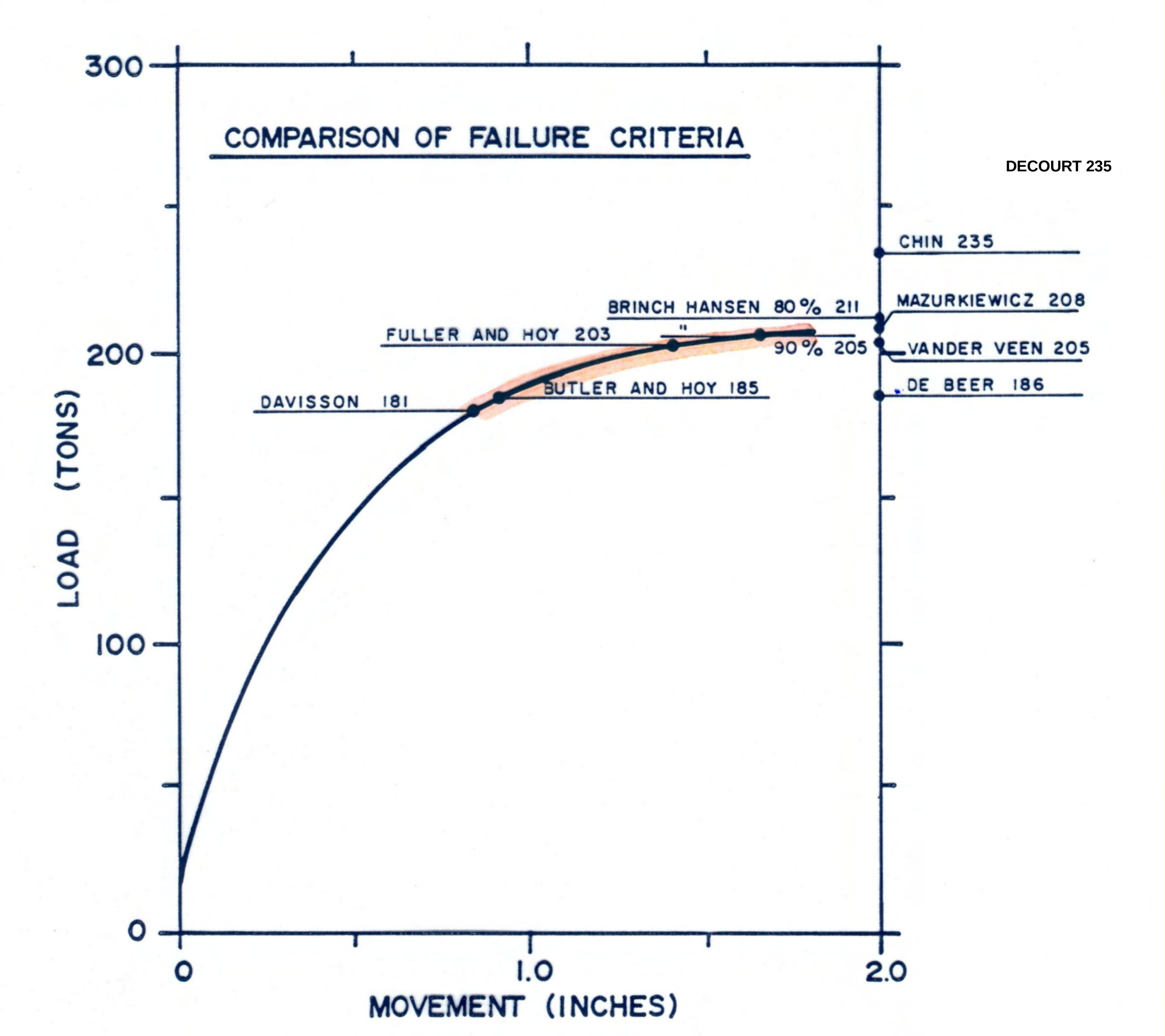


Note, the test on the pile called "O-cell pile" is a head-down test after a preceding O-cell test.

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

and the pile capacity?



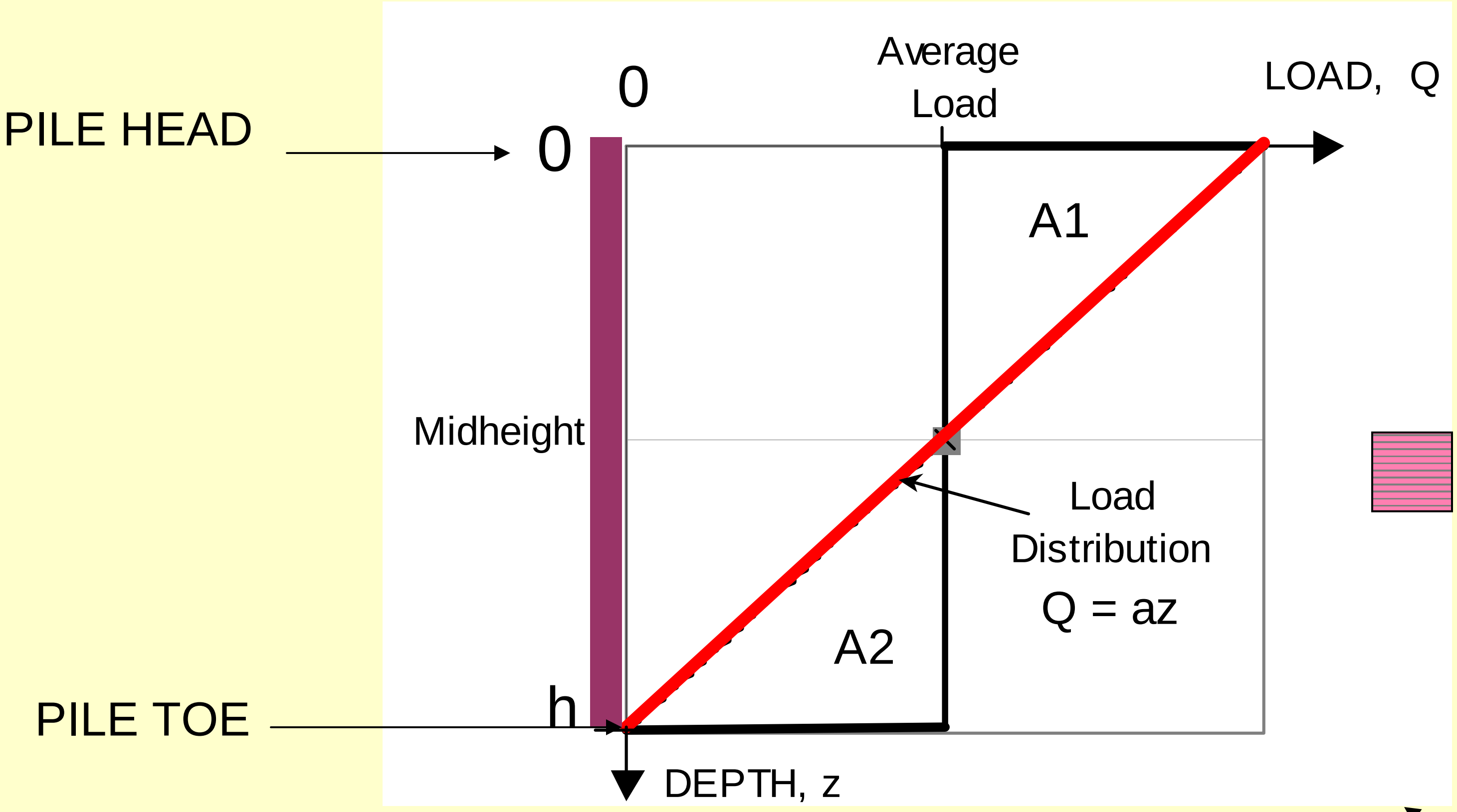

COMPARISON OF FAILURE CRITERIA
DECOURT 235
CHIN 235
MAZURKIEWICZ 208
BRINCH HANSEN 80% 211
"
90% 205
FULLER AND HOY 203
VANDER VEEN 205
BUTLER AND HOY 185
DE BEER 186
DAVISSON 181
300
200
100
0
LOAD (TONS)
0
1.0
2.0
MOVEMENT (INCHES)

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.

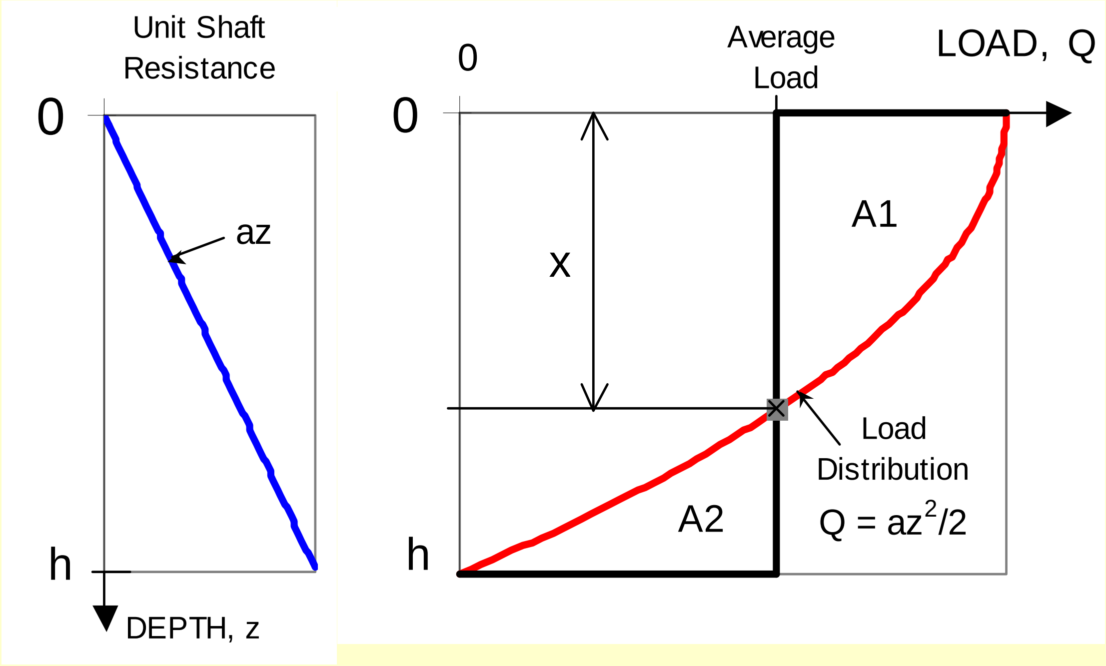
- **To plot a load distribution, where should the load value be plotted? Midway of the length or above or below?**

Load distribution for **constant** unit shaft resistance



$r_s = a$

Linearly increasing unit shaft resistance and its load distribution



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

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

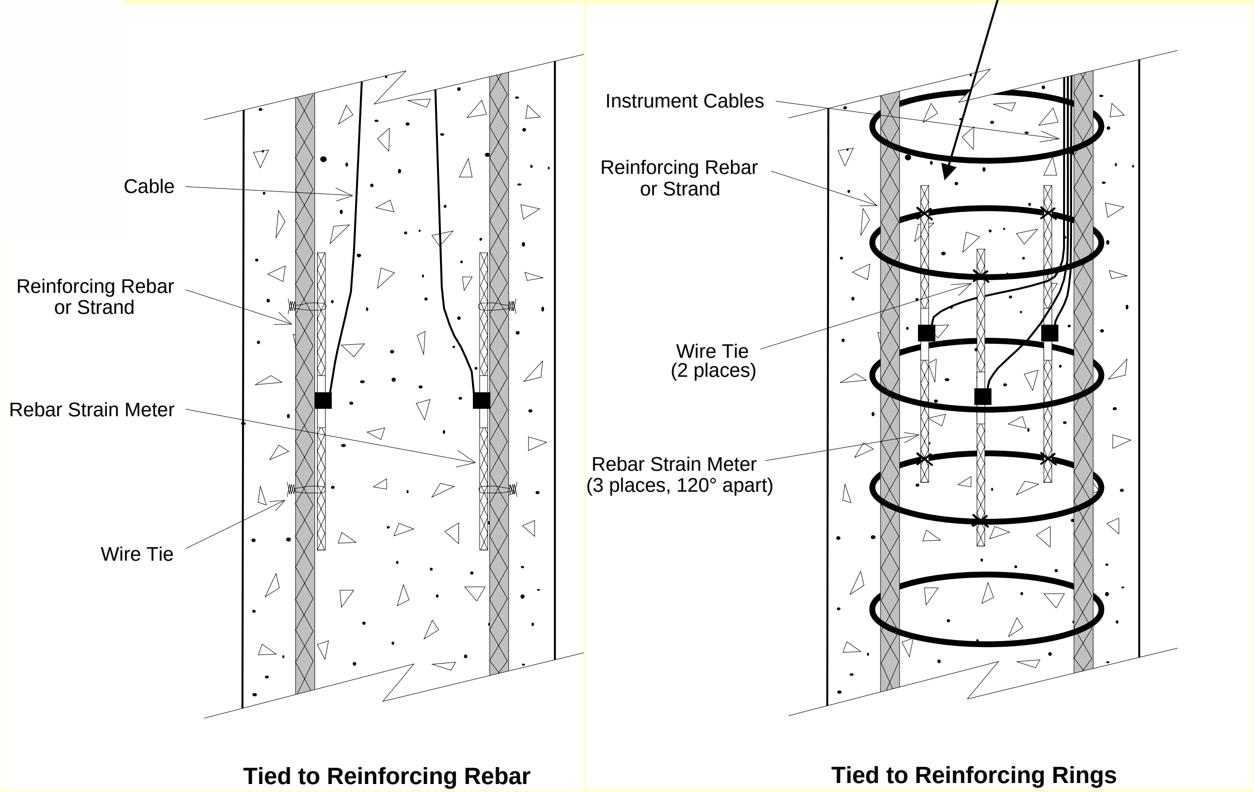
$$A1 = A2$$

"X" is where the average load should be plotted

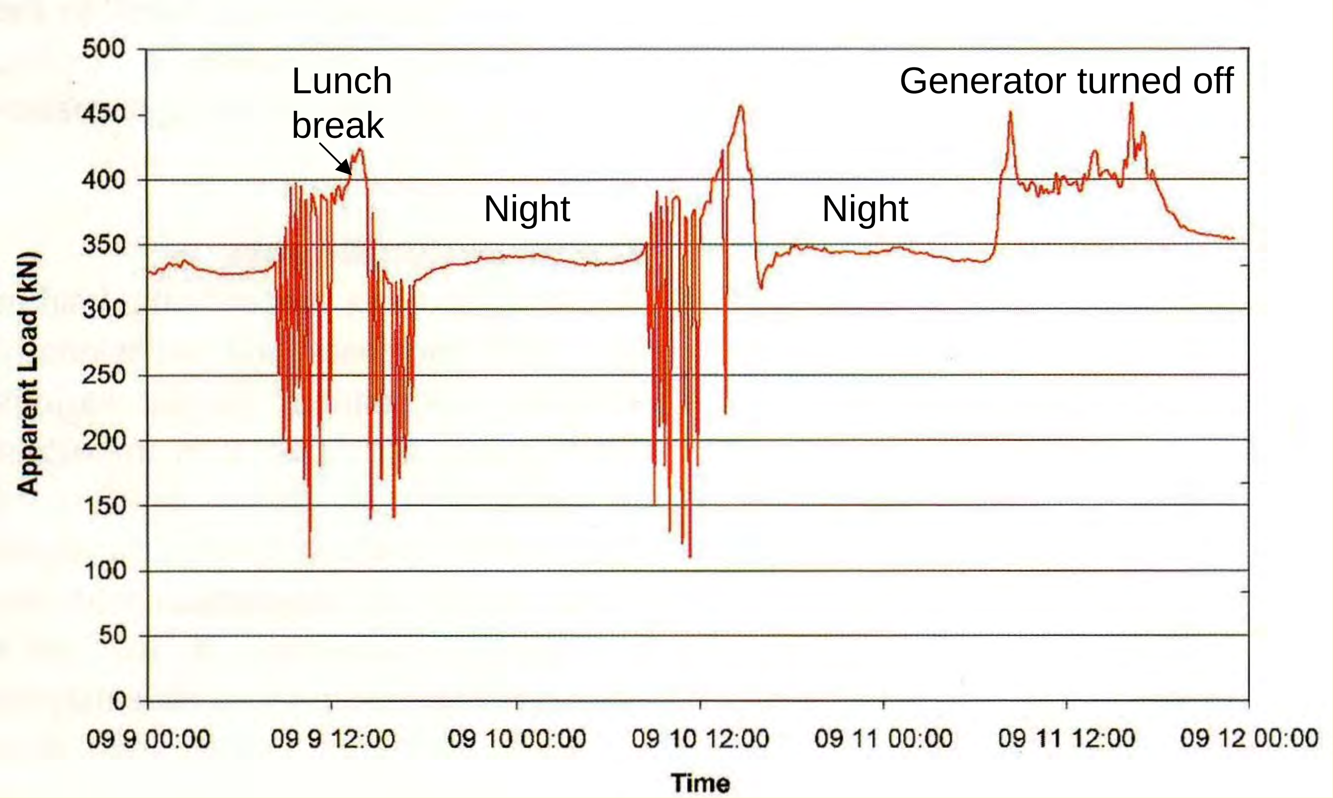
$$X = \frac{h}{\sqrt{3}} = 0.58h$$

- 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.

Rebar Strain Meter — “Sister Bar”



Three
bars?!



Example of Electromagnetic Interference (EMI) — noise — from a generator and power cable affecting vibrating wire strain gages

Sources of noise are for example arc welding, machinery ignition, power generators, and power cables, etc.

Continual noise will impart a general trend of overall accuracy of data by increasing its spread between data points. Sudden noise, for example, when starting up a machine, the ignition may cause a spike in the readings. Electronic noise tends to result in a reduction in strain gage values, whereas magnetic noise increases the strain gage values.

Osborne, N. and Tan, G.H., 2009. Factors influencing the performance of strain-gage instrumented Monitoring systems. Geotechnical News, (27)2 34-37.

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.

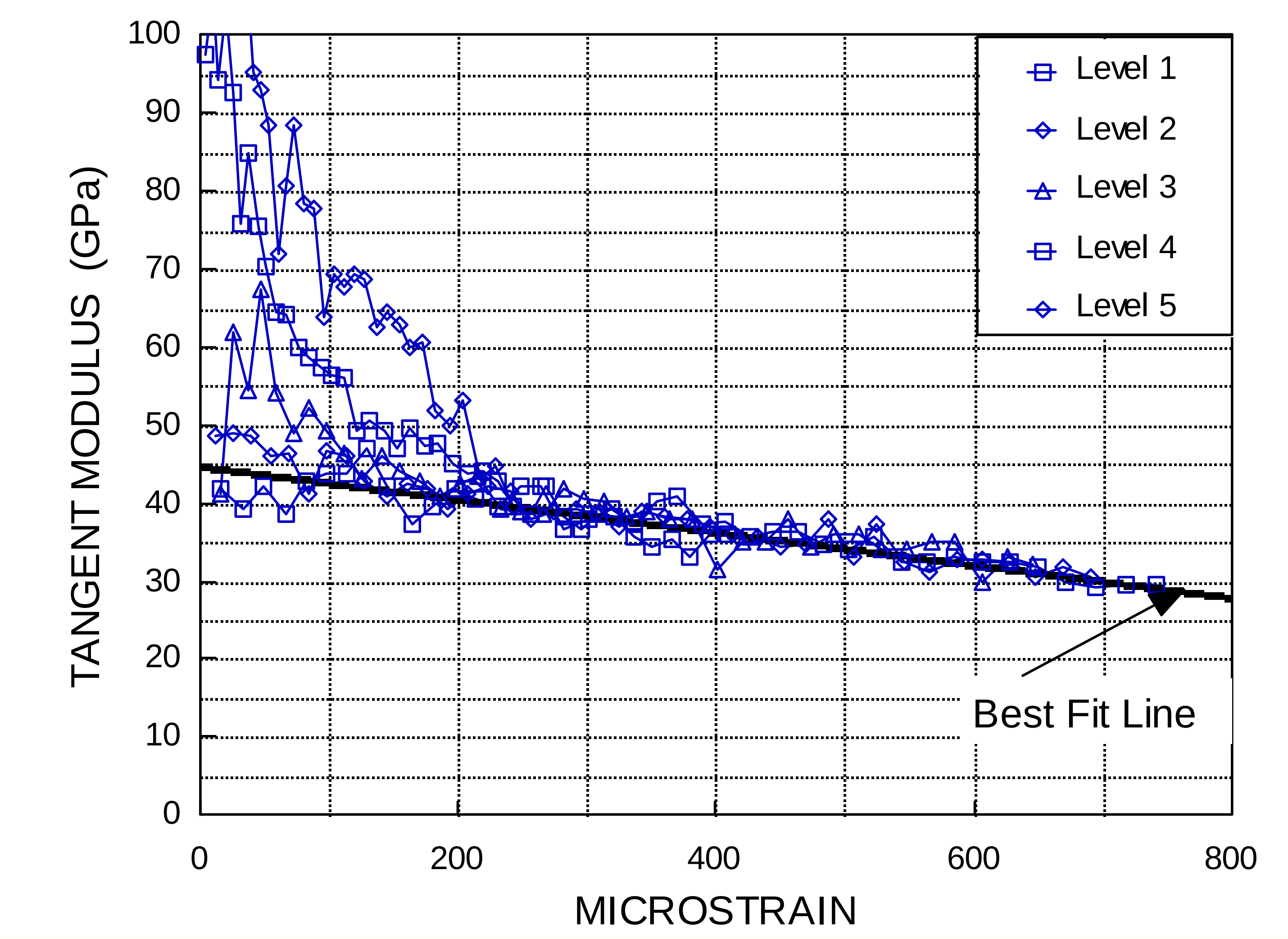
The modulus can be determined from the strain measurements.

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:

$$\sigma = E_s\ \varepsilon$$

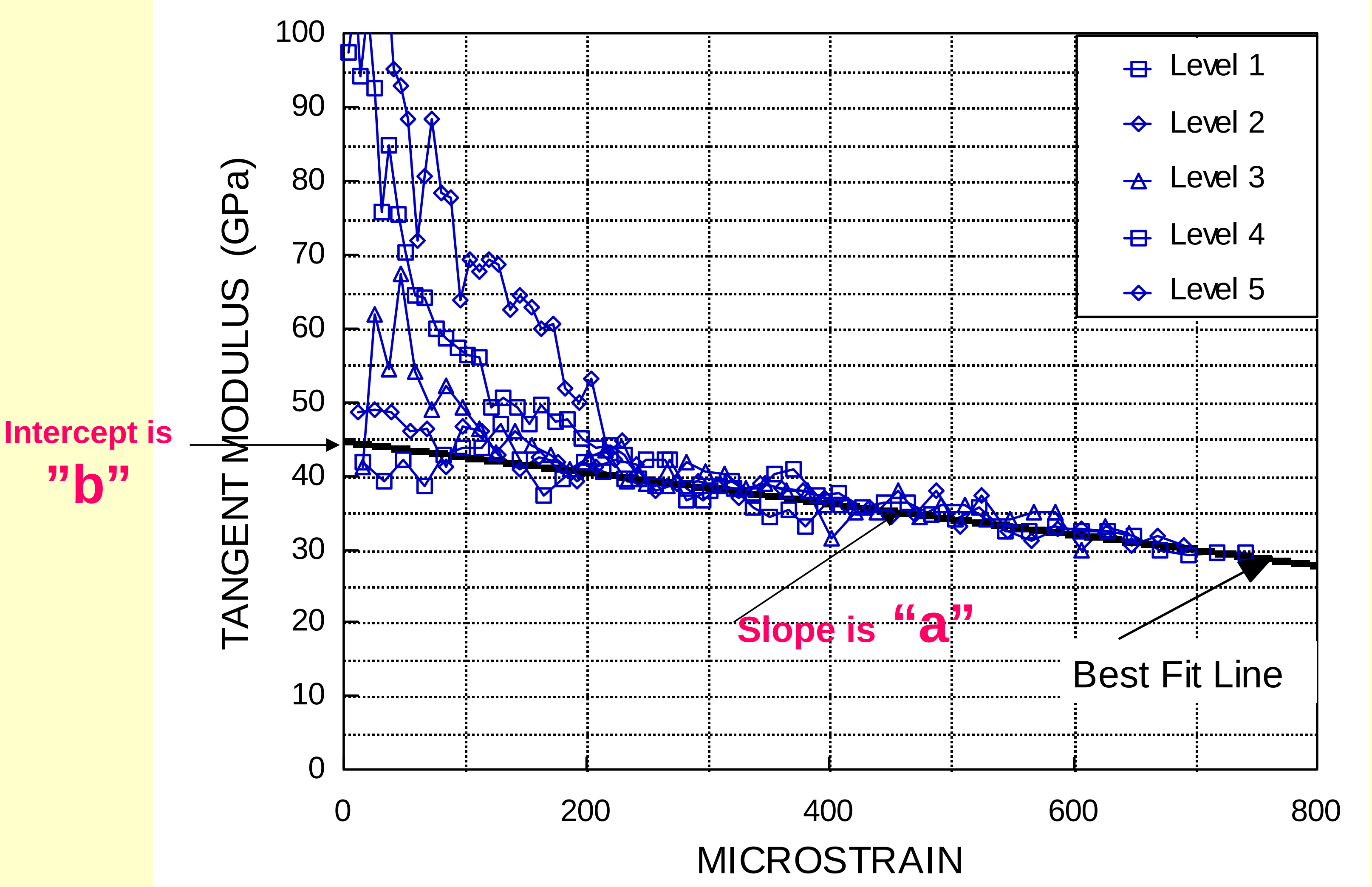
Combined, we get a useful relation:

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

and

$$Q = A\ E_s\ \varepsilon$$

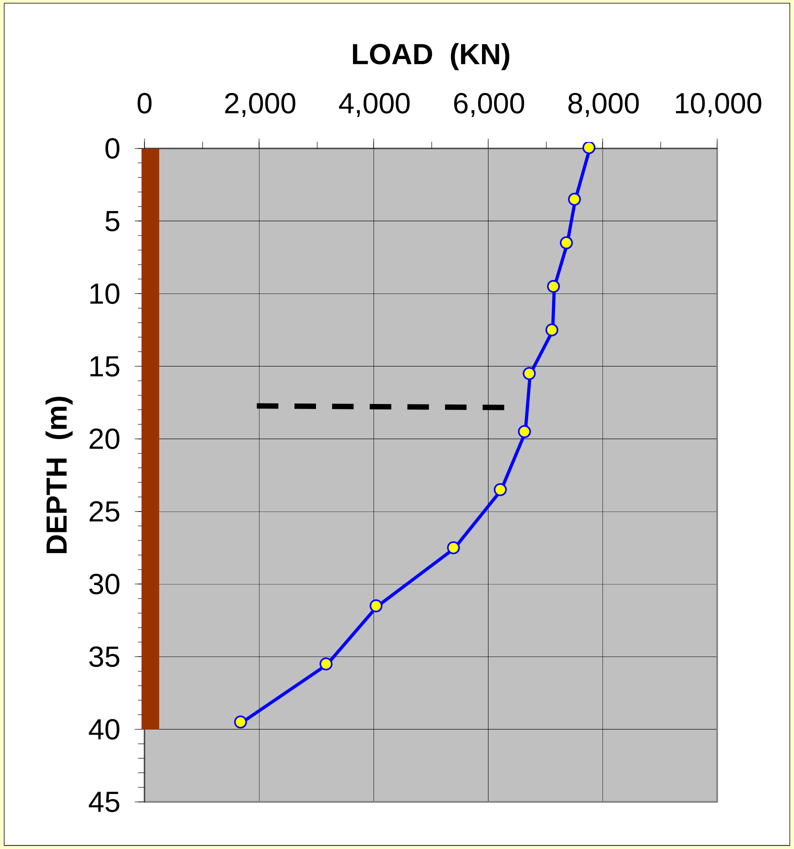
Example of "Tangent Modulus Plot"

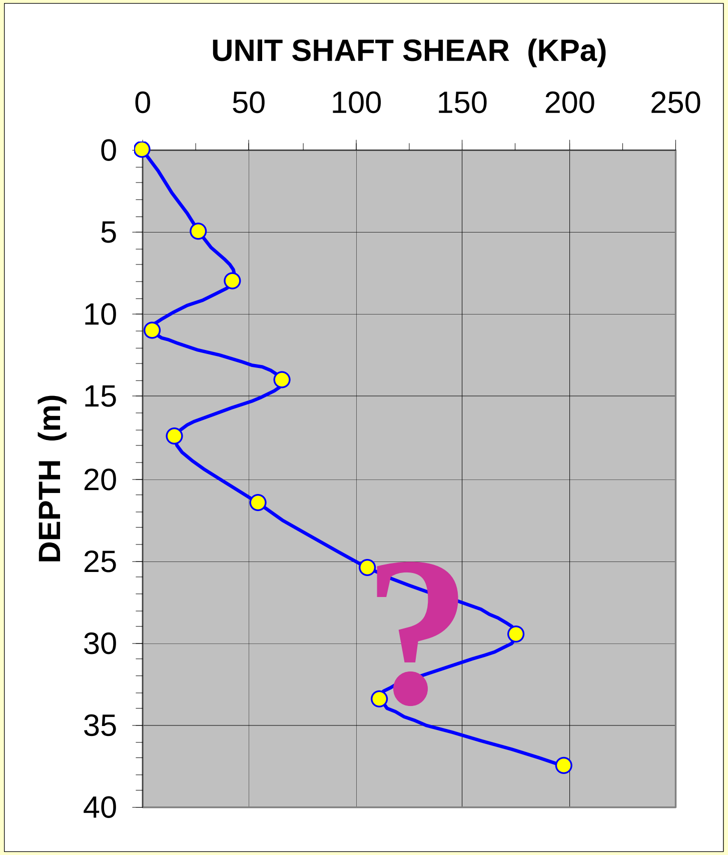


Note, just because a strain-gage has registered some strain values during a test does not guarantee that the data are useful. Strains unrelated to force can develop due to variations in the pile material and temperature and amount to as much as about 50± microstrain. Therefore, the test must be designed to achieve strains due to imposed force of ideally about 500 microstrain and beyond. If the imposed strains 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.

Moreover, each gage reading must be assessed as to it being true to the actual strain and free from interference.

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



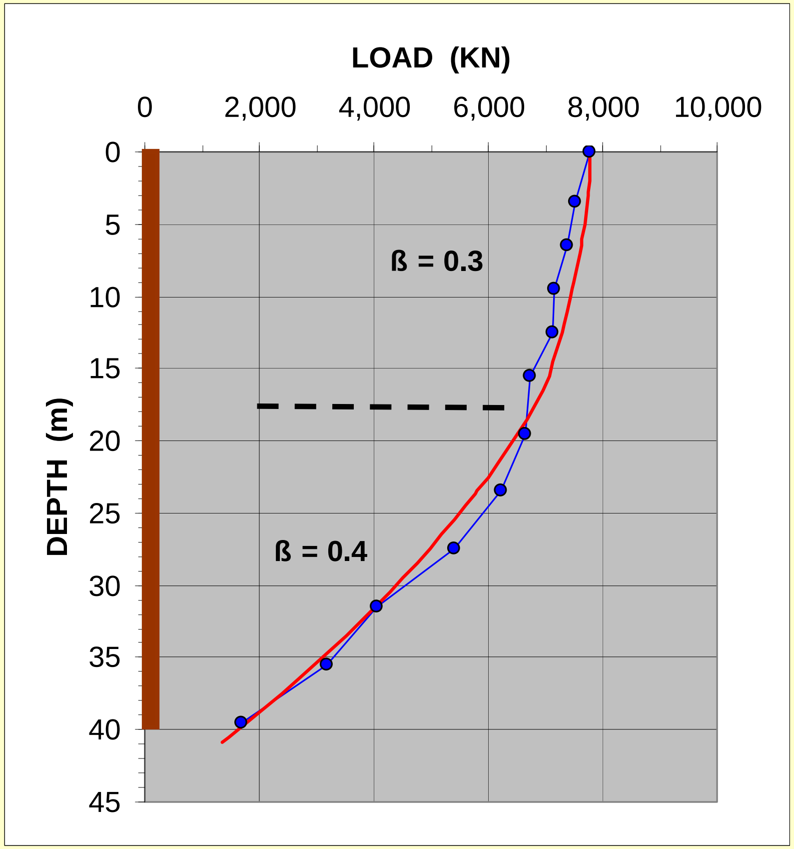


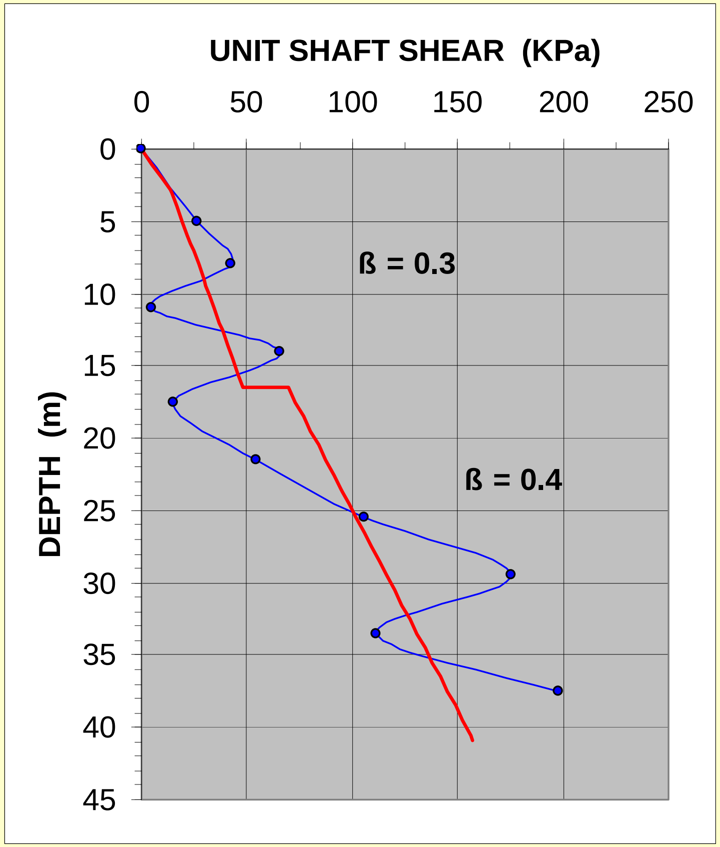
Each gage reading provides a load value. The treatment of the values has to be with understanding of the accuracy/error of each.

The unit shaft resistance is calculated as the difference in evaluated loads for adjacent gage levels divided with shaft area (= distance between gage levels times pile circumference).

The load difference is about the same magnitude as the error in each load value!

A more thoughtful analysis of the data





Could there be load in the pile before we start the loading test?

and, if so,

Could such load have any significant effect on the data evaluation?

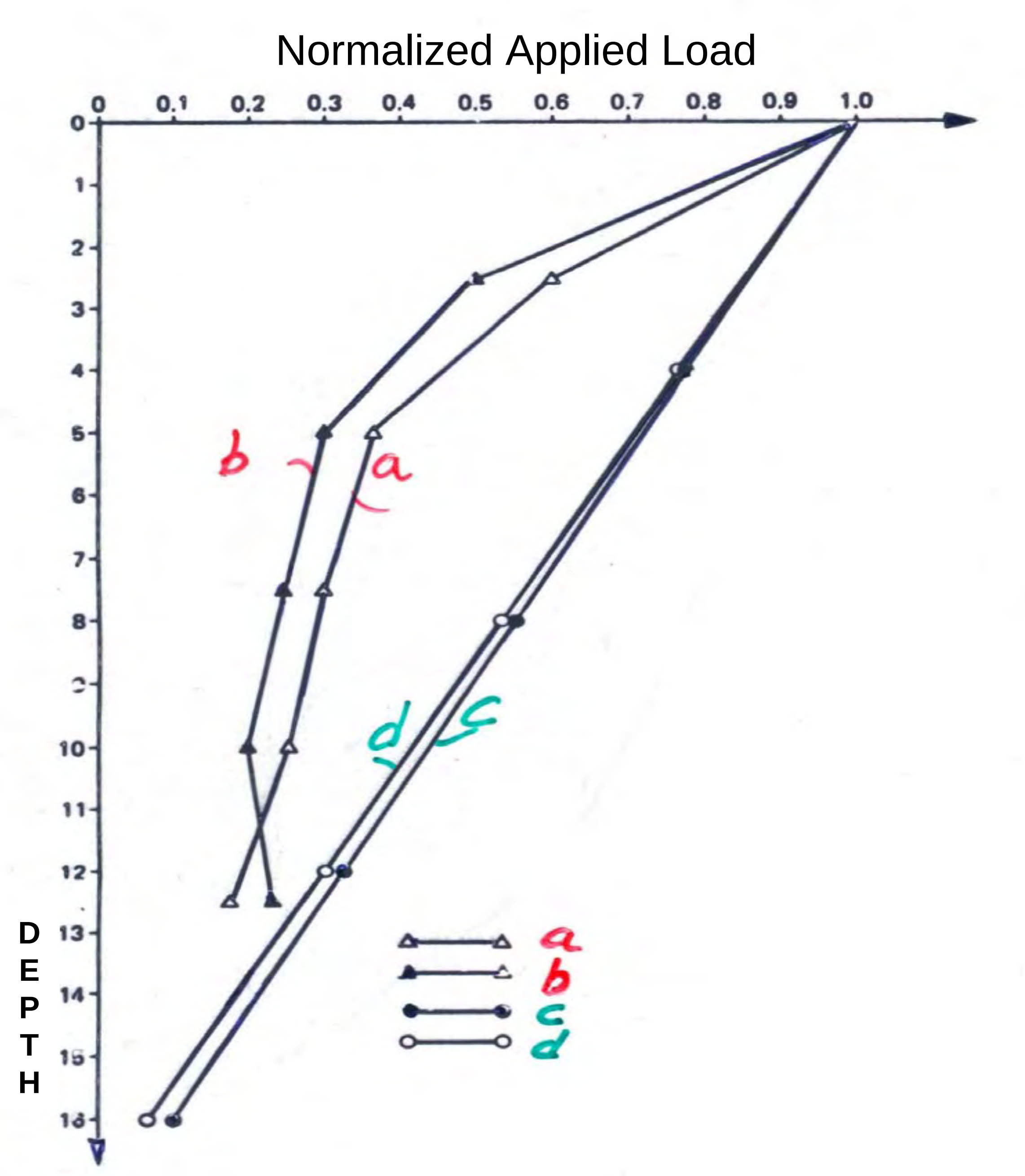
Determining load from strain-gage measurements in the pile

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?

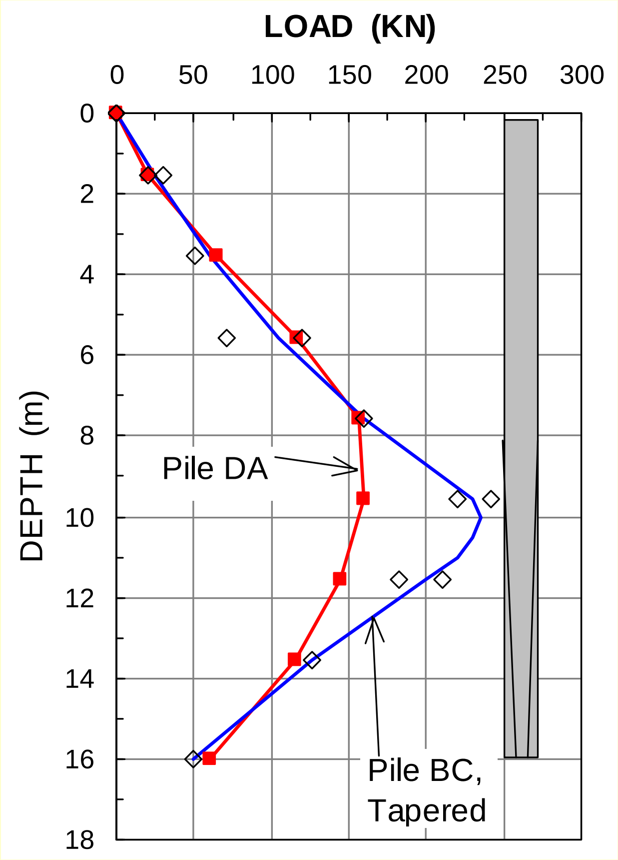
- We often assume – somewhat optimistically or naively – that the reading before the start of the test represents the “no-load” condition.
- However, at the time of the start of the loading test, loads do exist in the pile and they are often large.
- For a grouted pipe pile or a concrete cylinder pile, 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 the pile will impose additional loads on the pile.

What we measure is the increase of load in the pile due to the load applied to the pile head. The external-origin load in the pile that was there before we started the test is called "Residual Load".

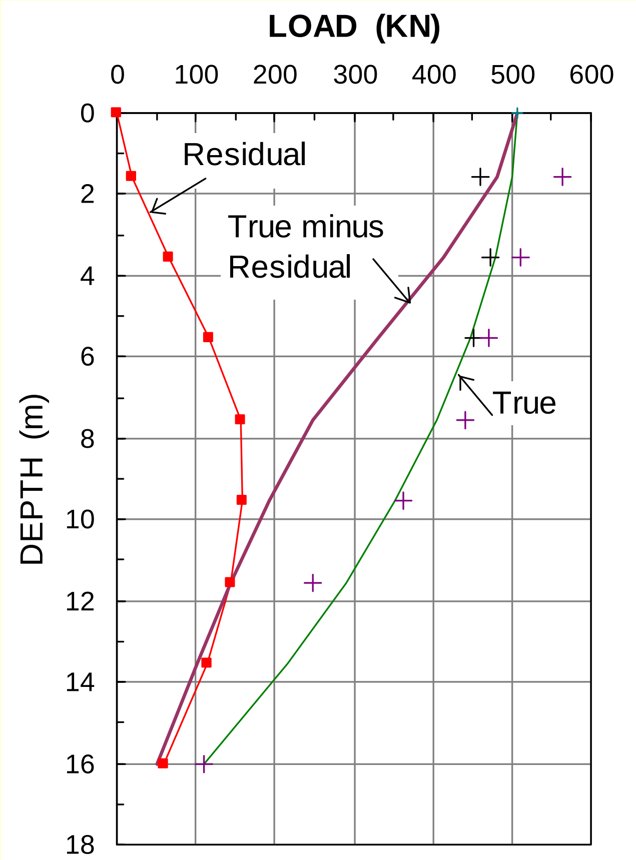


Load distributions in static loading tests on four instrumented piles in clay

Example from Gregersen et al., 1973



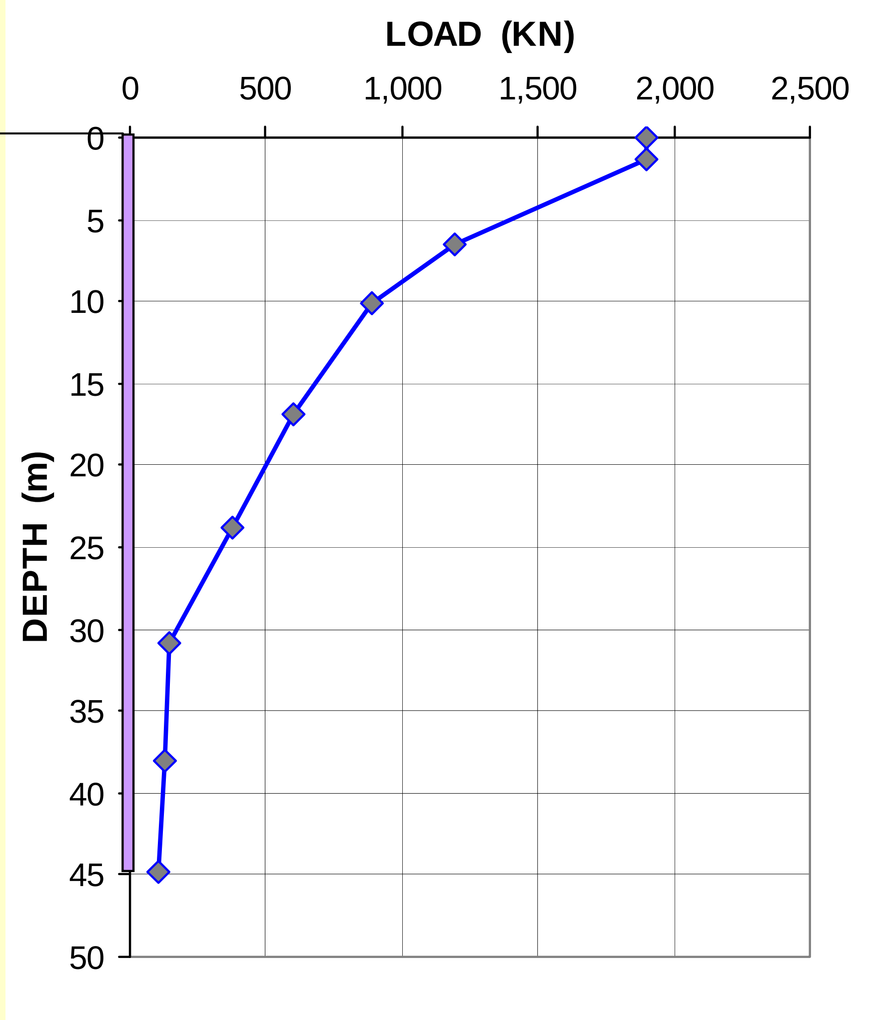
Sand



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

Clay



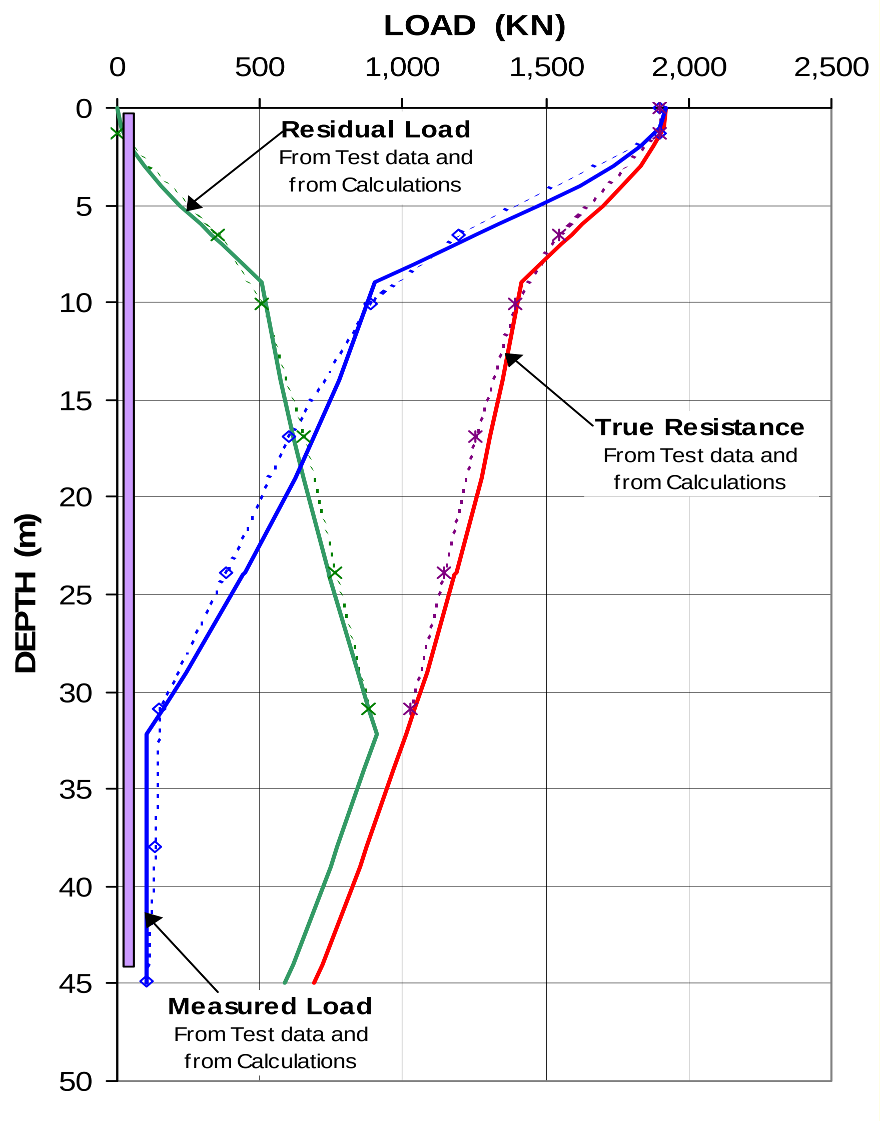
200+ m

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

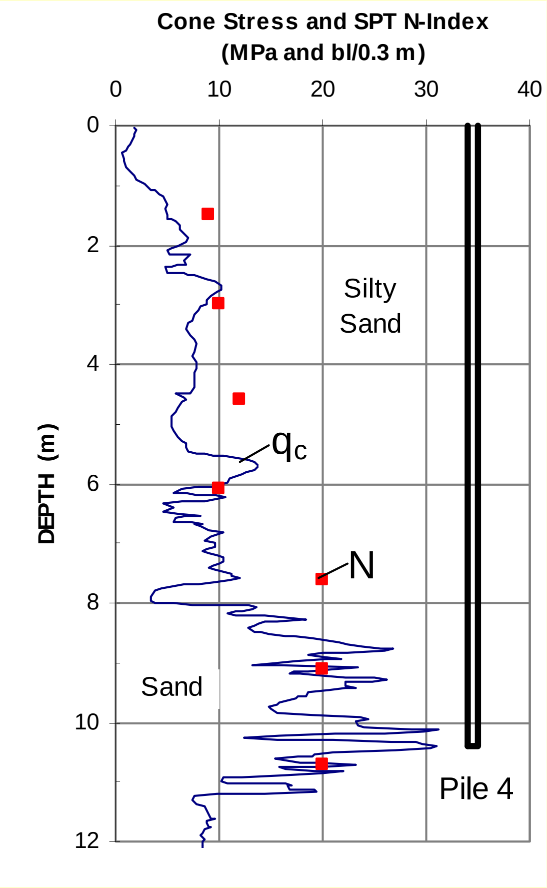


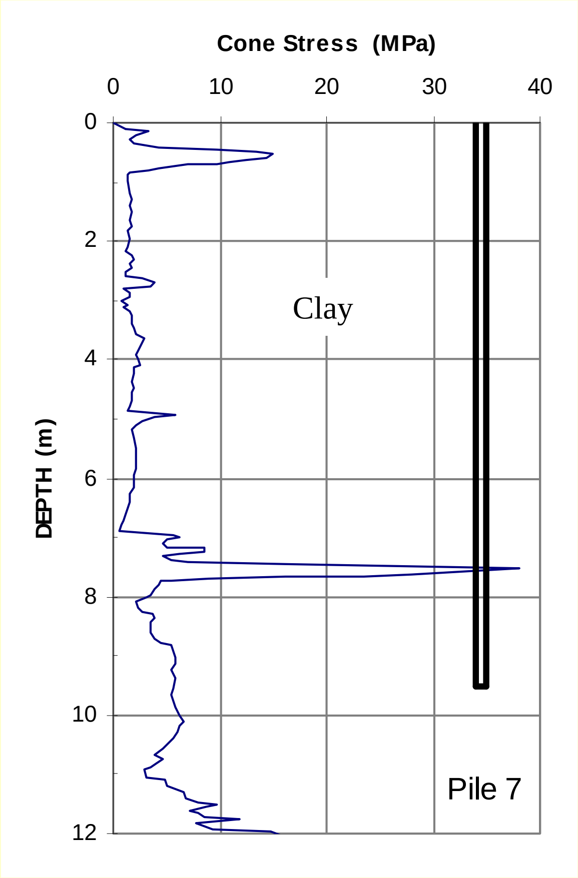
Fellenius et al. 2004

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

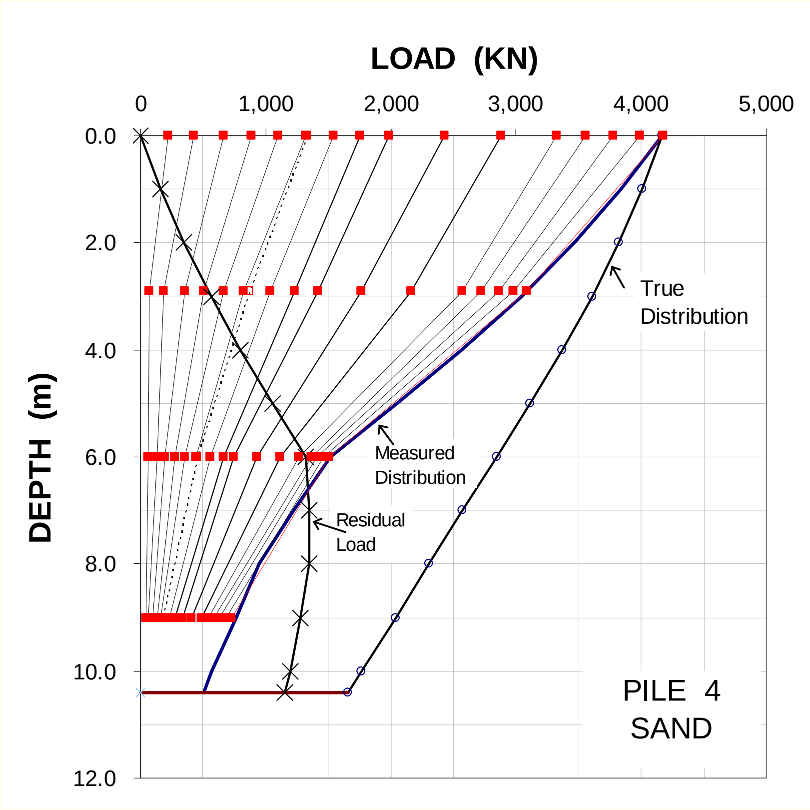
Sand

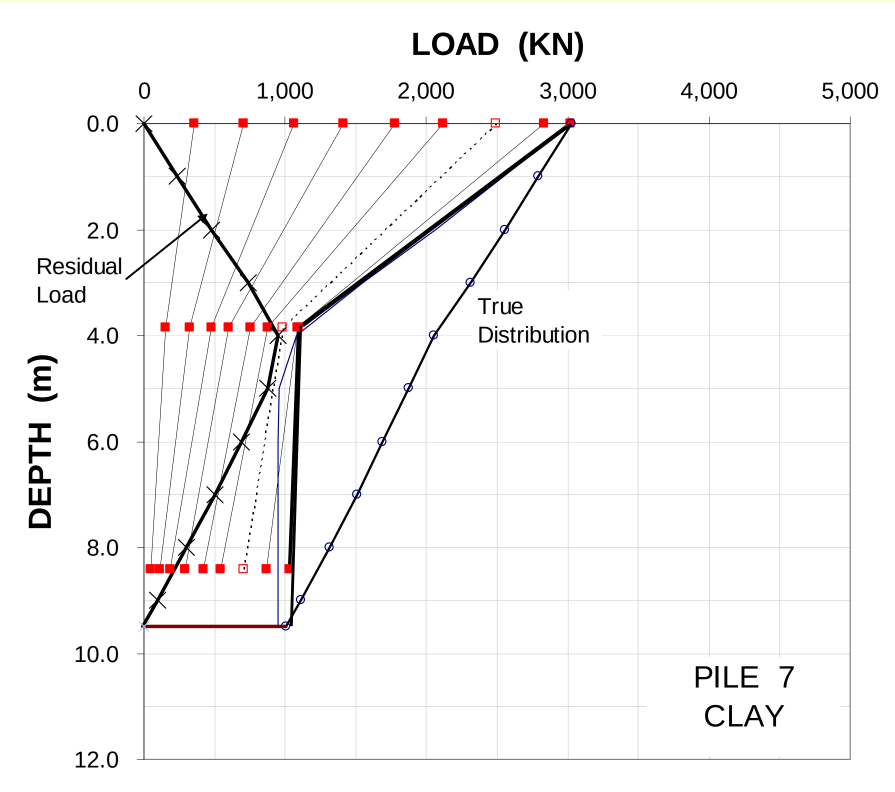




Clay

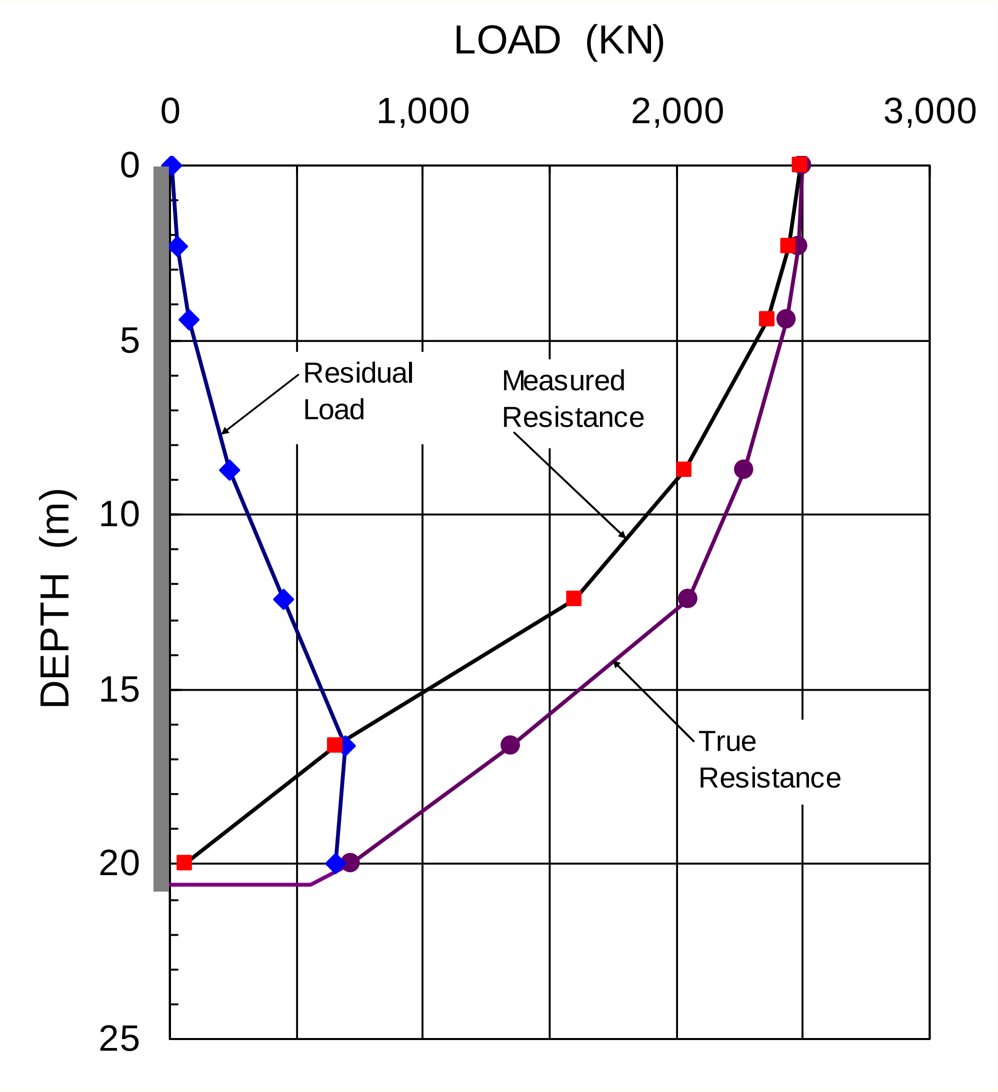
ANALYSIS RESULTS: Load-transfer curves



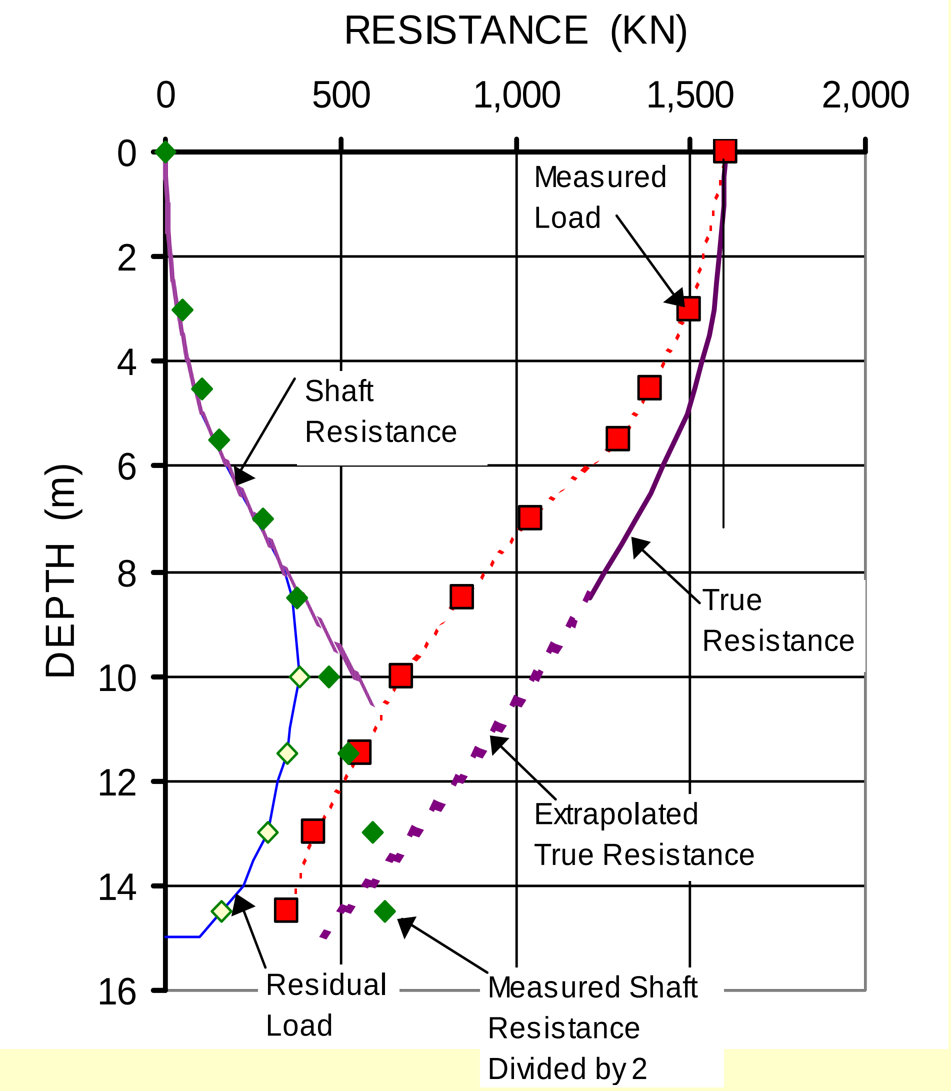


Results of analysis of a Monotube pile in sand

(Fellenius et al., 2000)

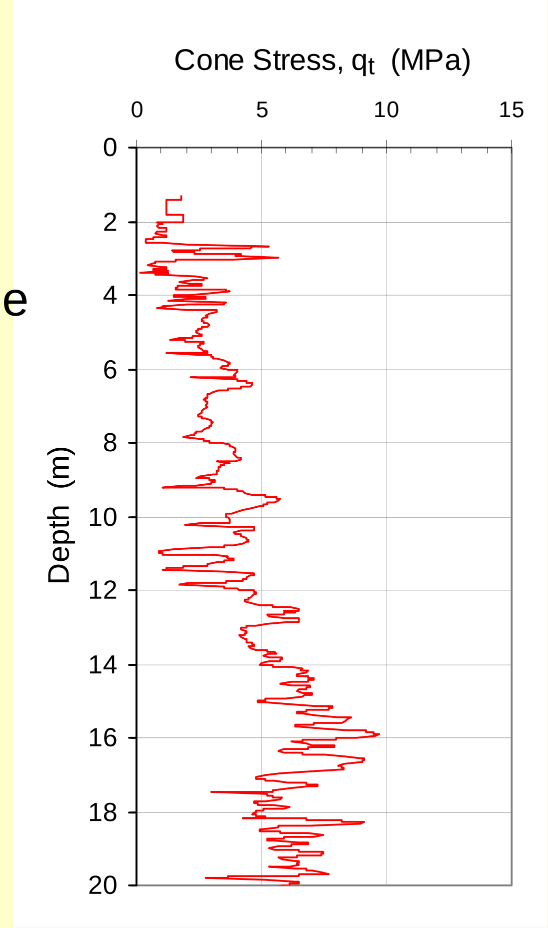


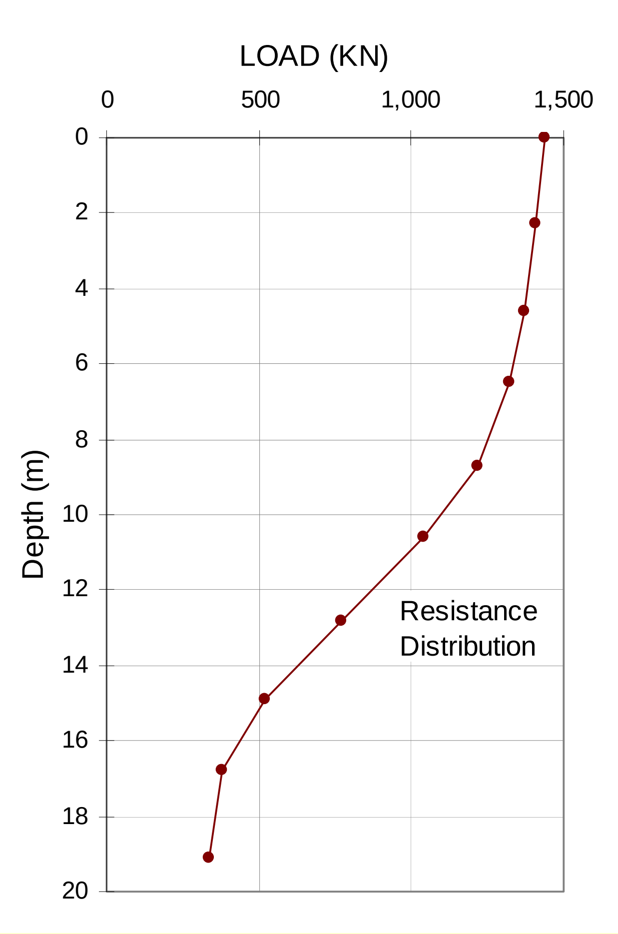
Method for evaluating the residual load distribution



The approach can be applied also to dynamic tests

CPT Profile

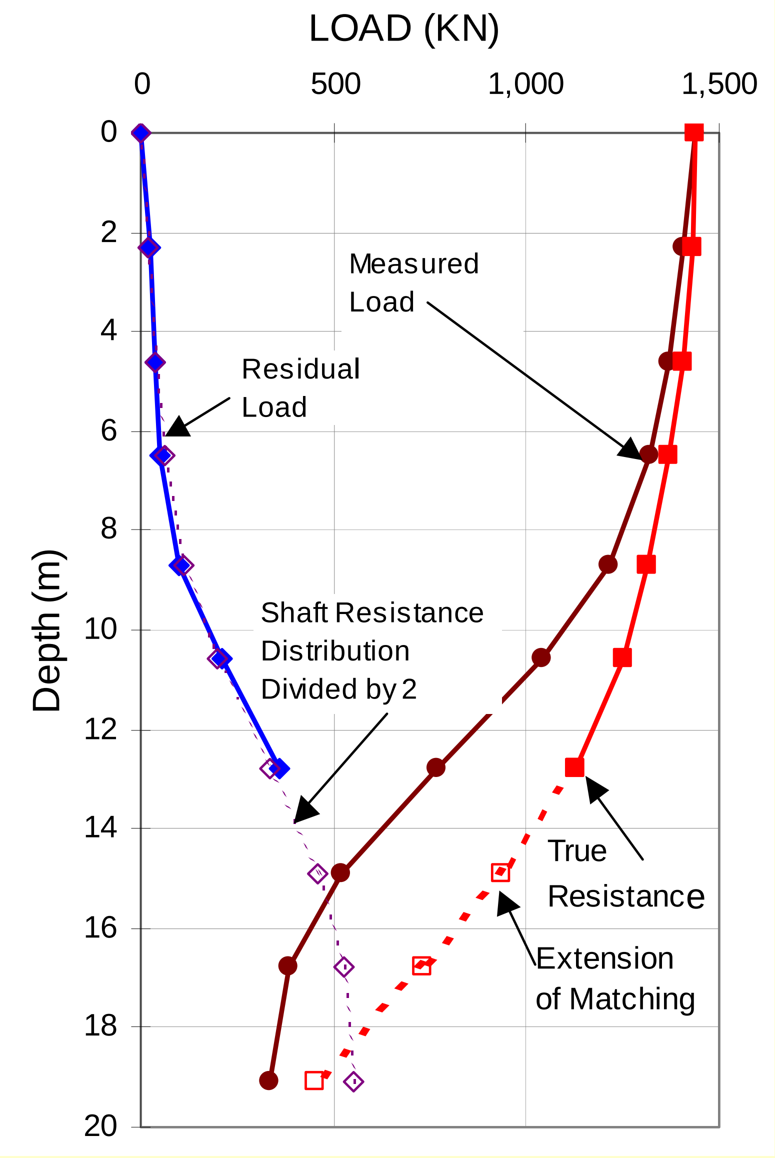




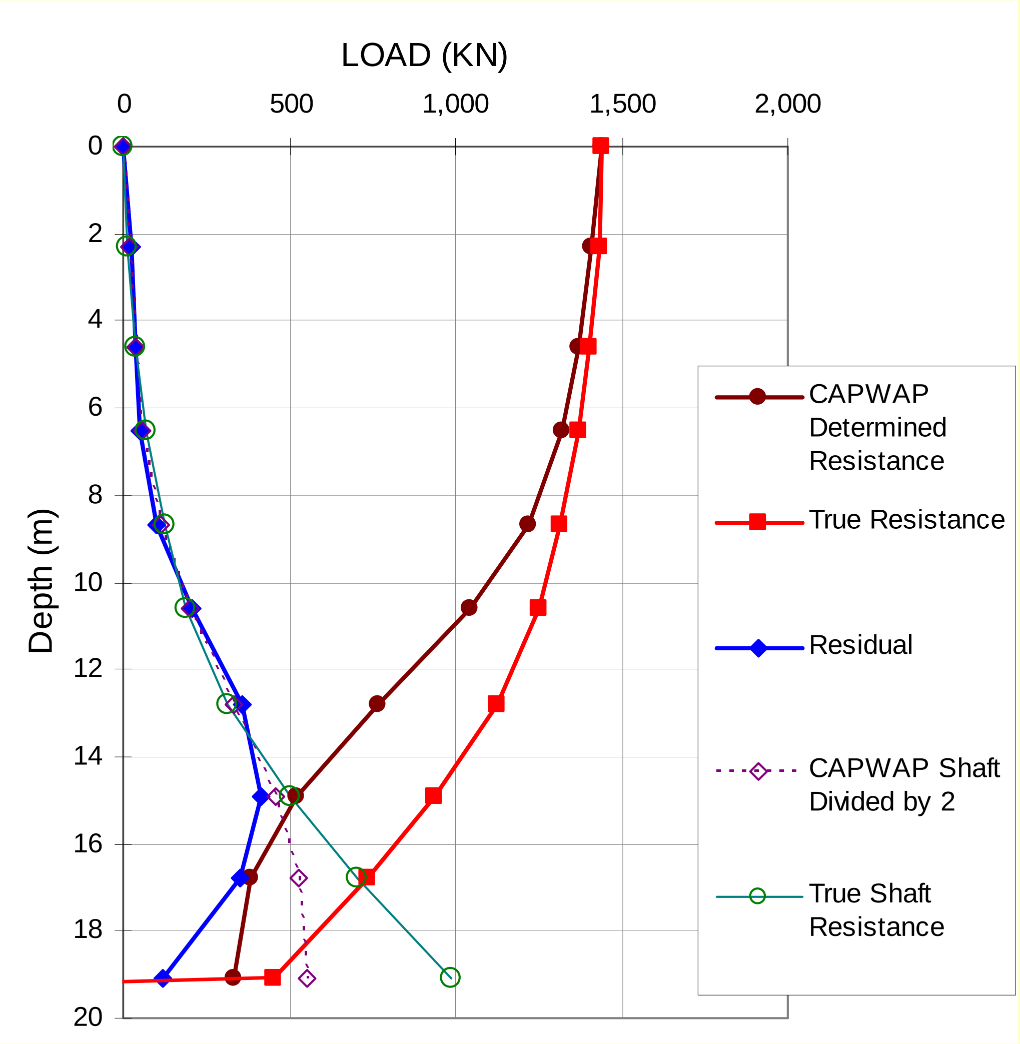
CAPWAP Determined Resistance Distribution

(Data from Axelsson 1998)

Analysis Procedure



Results



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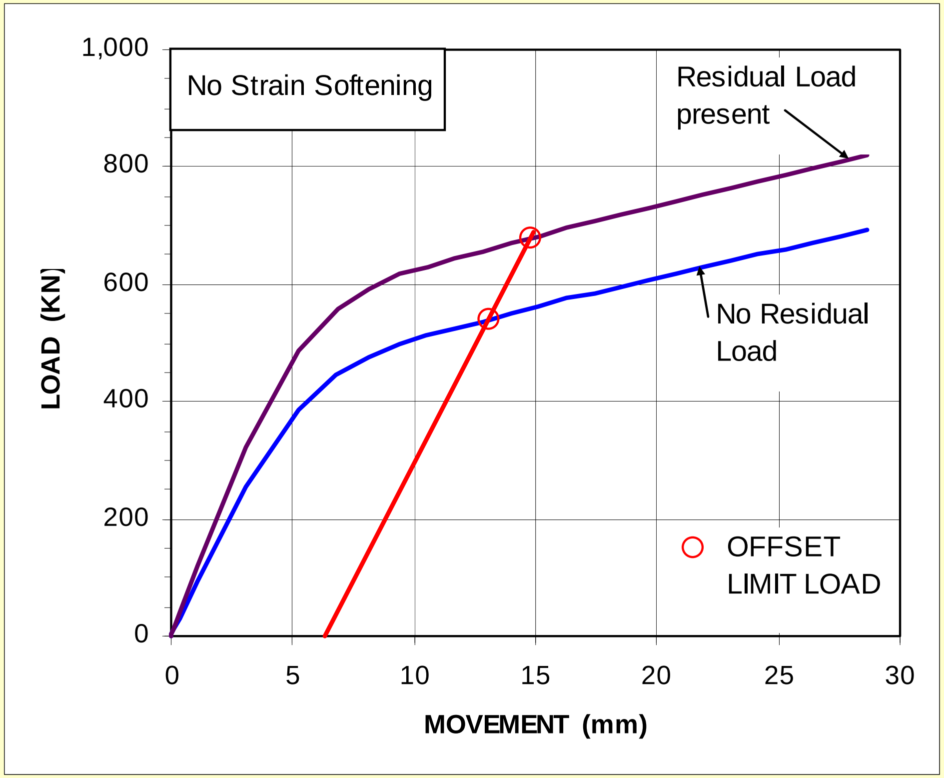
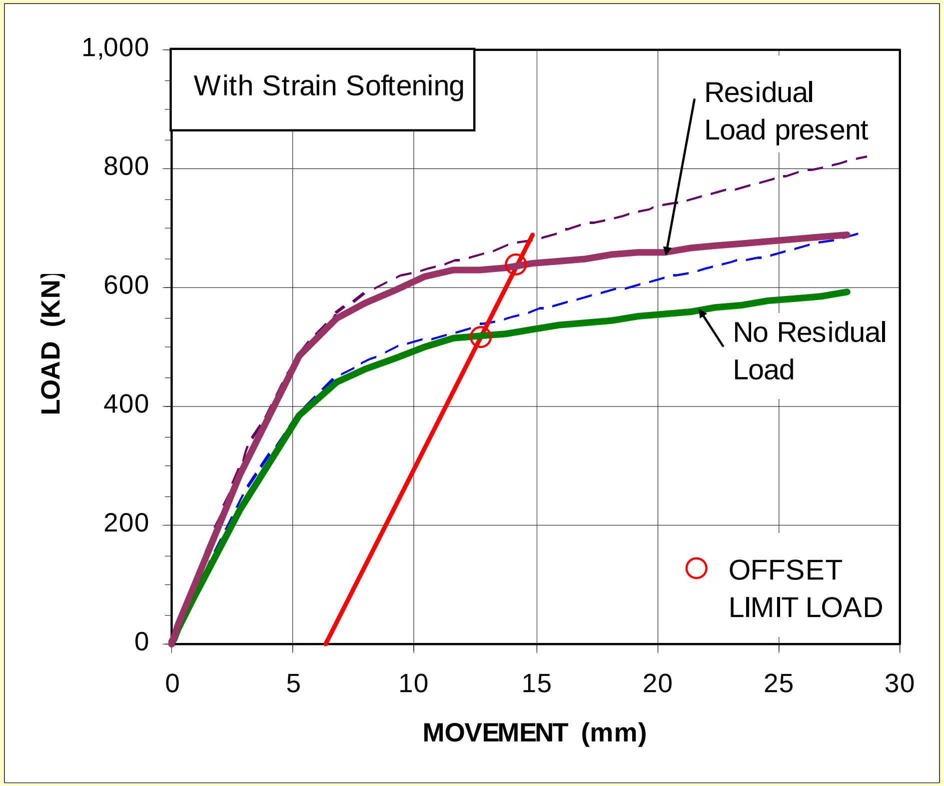
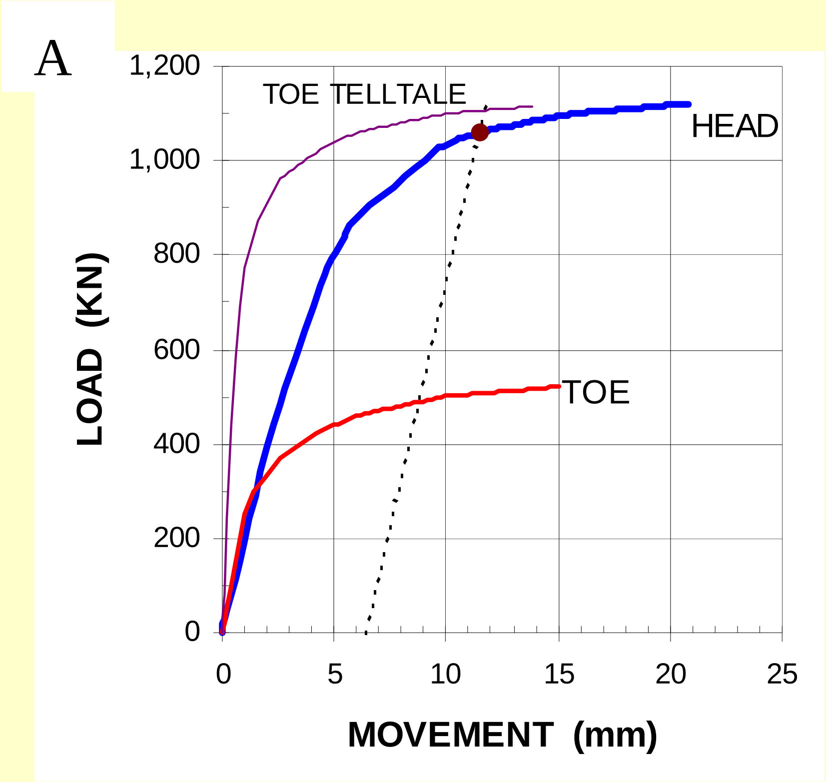
Presence of residual load is not just of academic interest

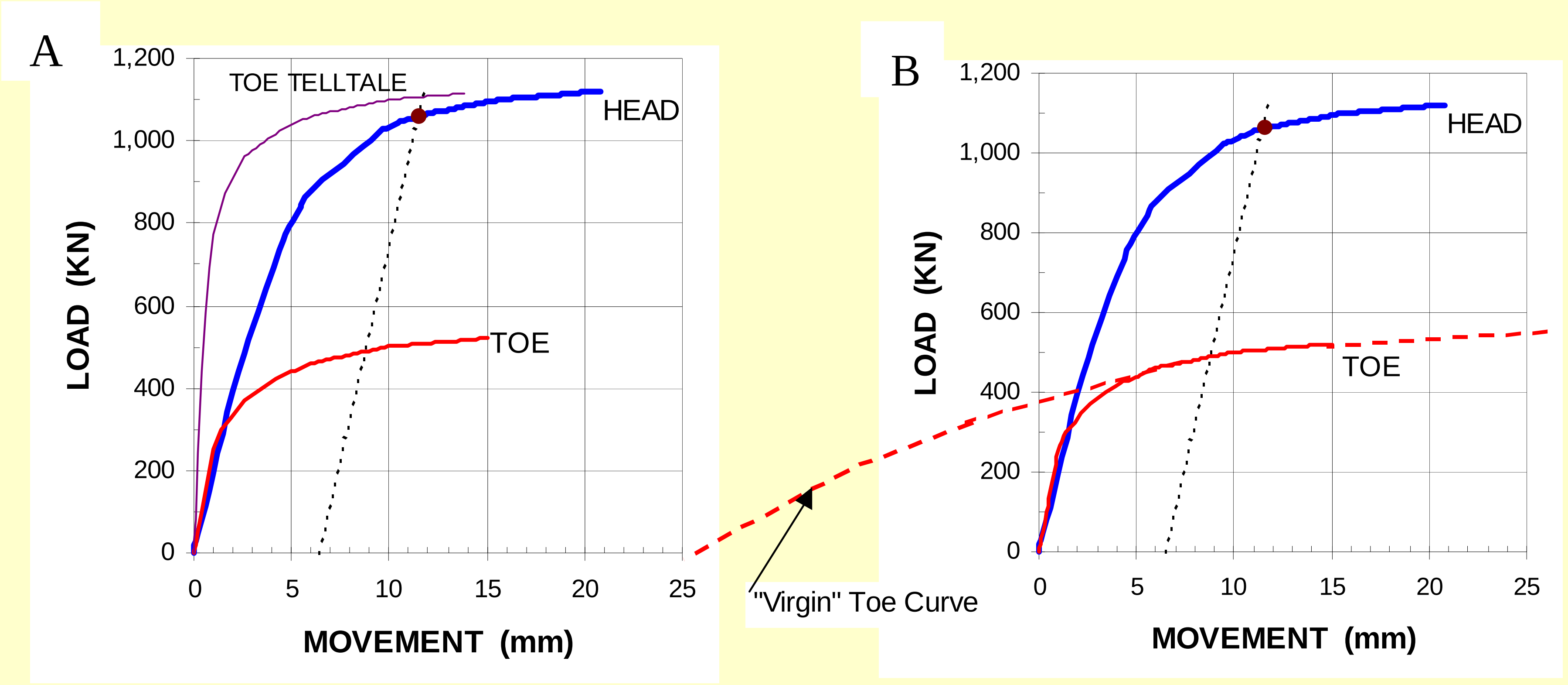




Toe Resistance



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

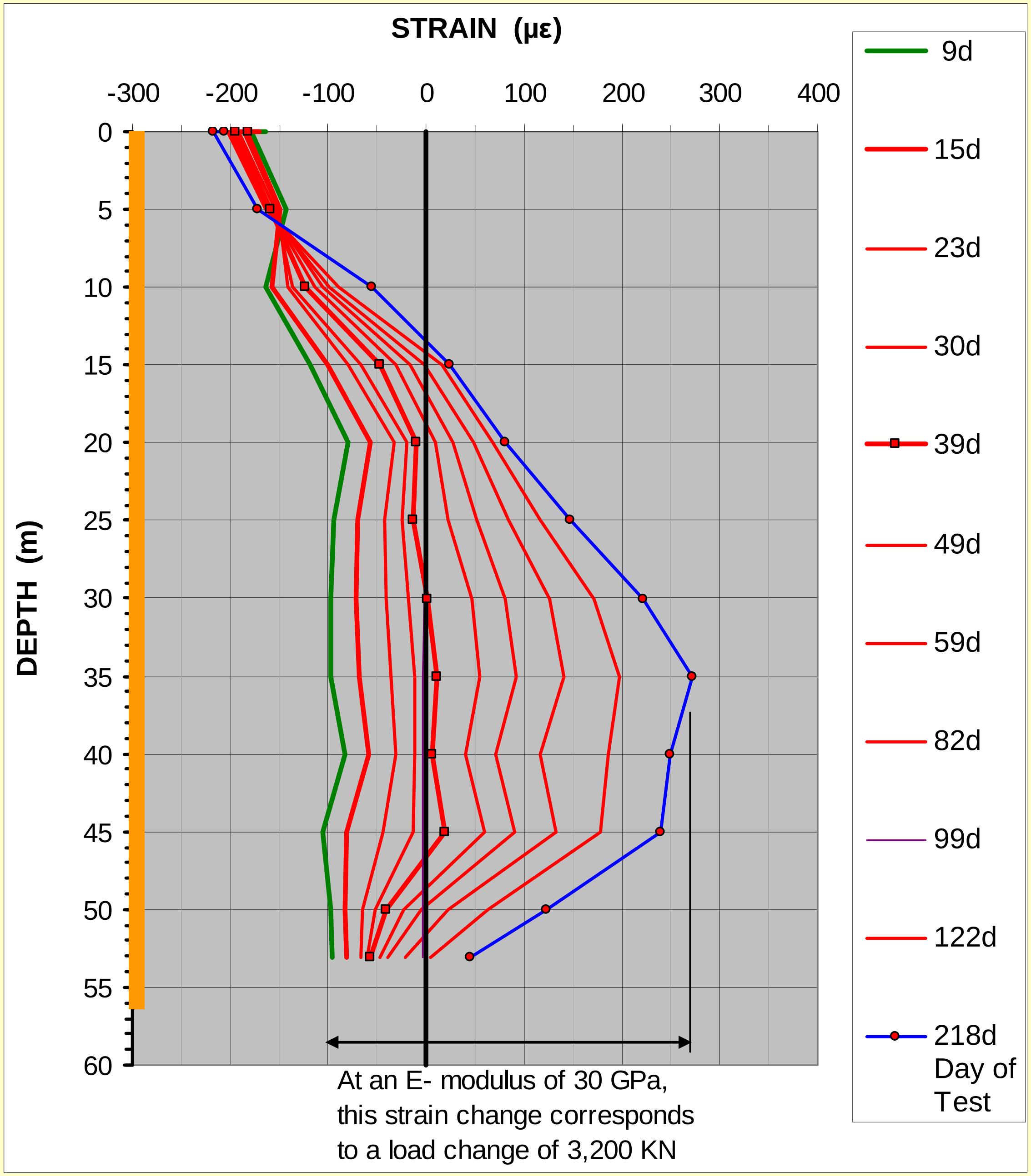


No, it only appears that way when we forget to consider the residual toe load (also called the initial, or “virgin” toe movement)

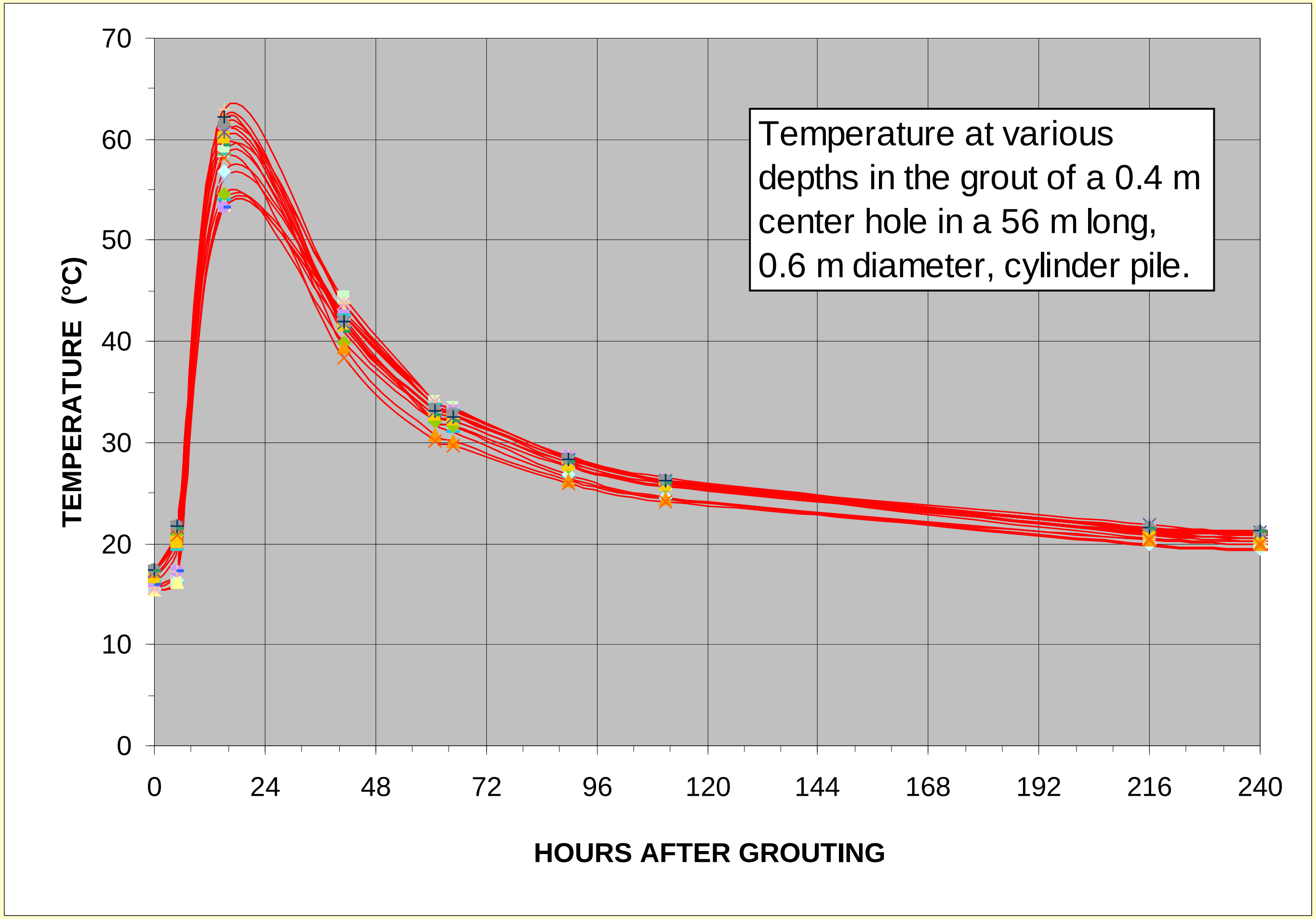
Residual load and other influences on evaluated load distribution

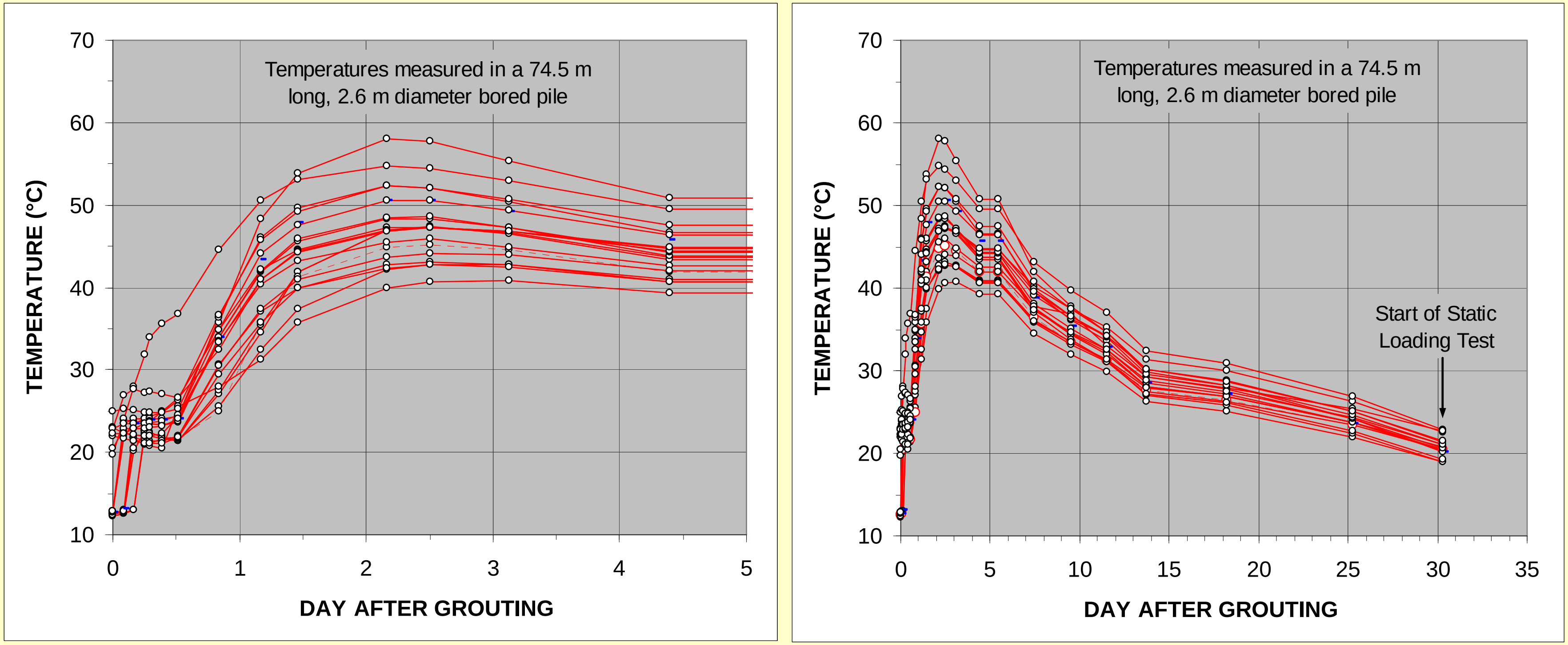
Strain measured during the 218-day wait-period between driving (grouting) and testing.

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

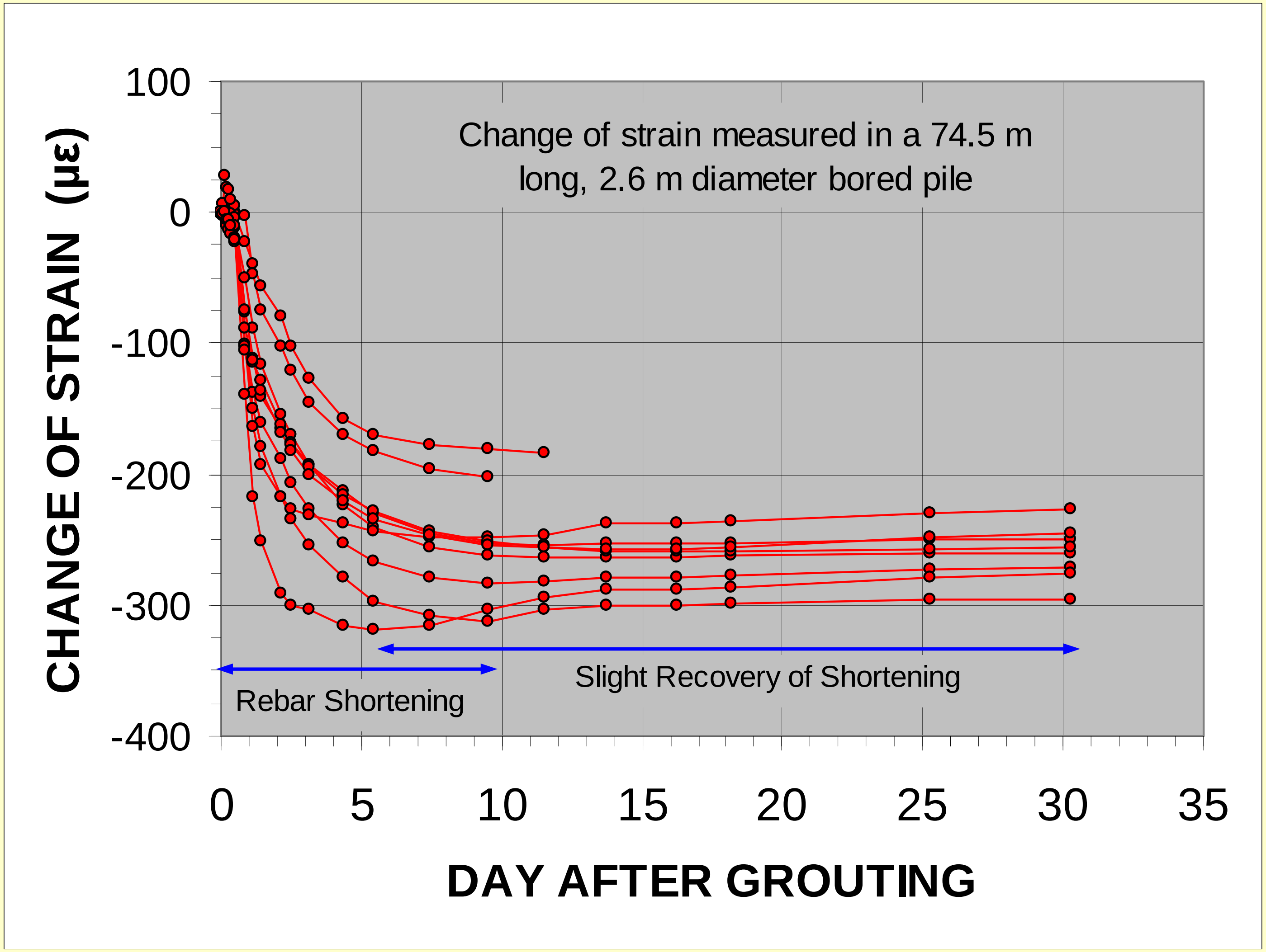


Concrete hydration temperature measured in a grouted concrete cylinder pile





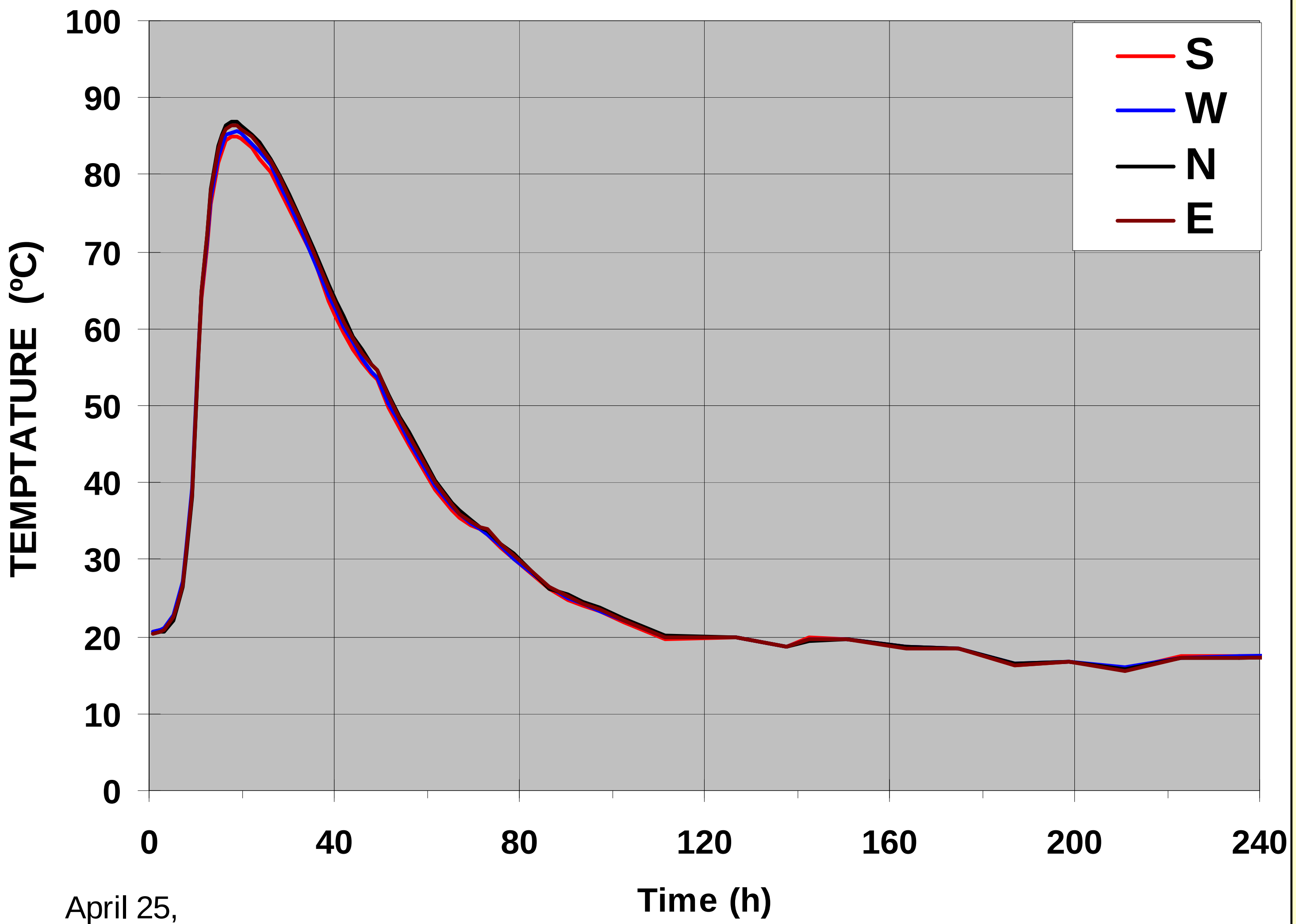
Temperature records during curing of grout in the Golden Ears Bridge test pile, Vancouver, BC. Data courtesy of Trow Engineering Inc. and Amec Inc.



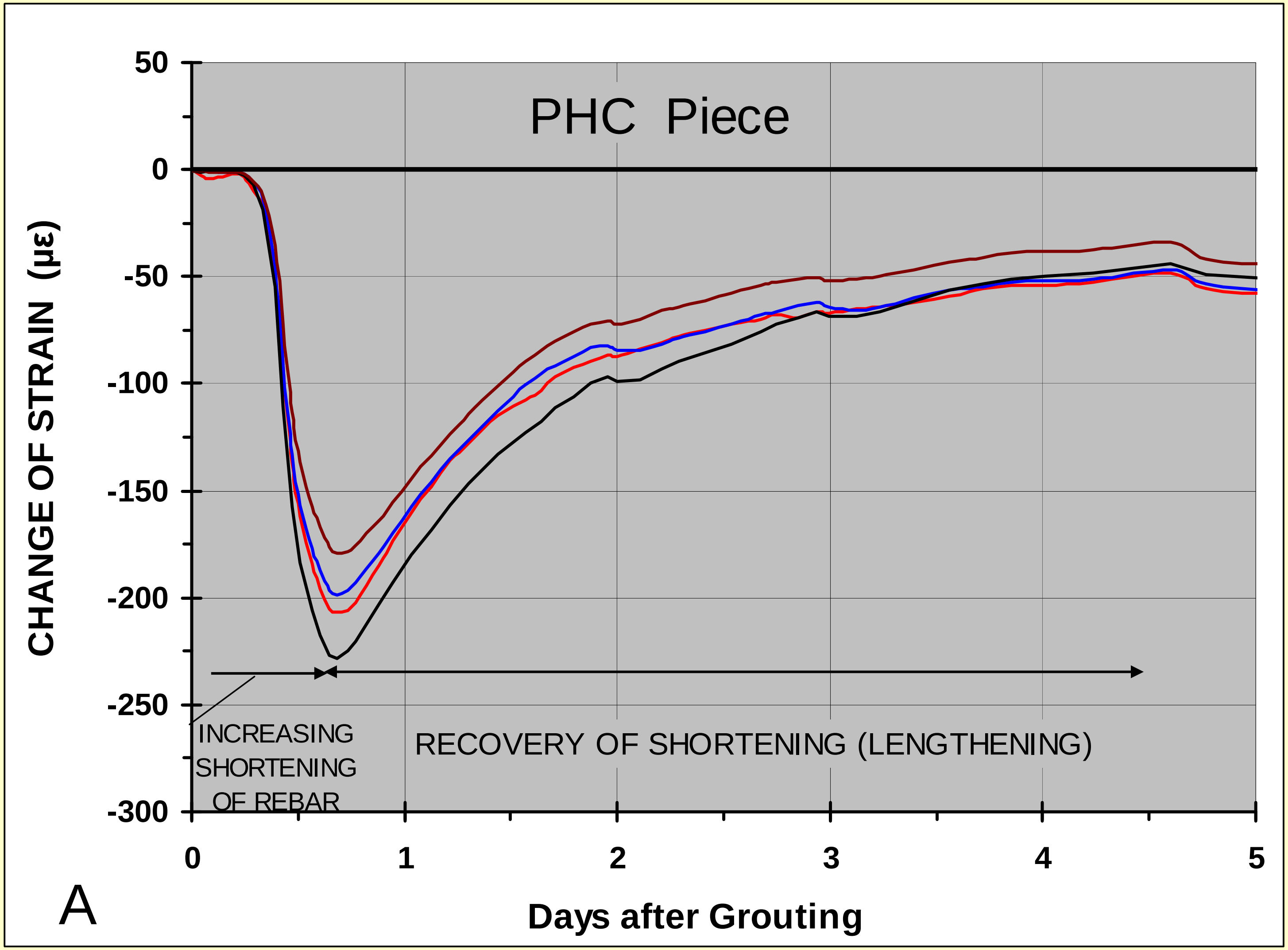
Change of strain during the hydration of the grout in the Golden Ears Bridge test pile

Photo of short (2 m) pieces with plastic tube enabling them to be submerged

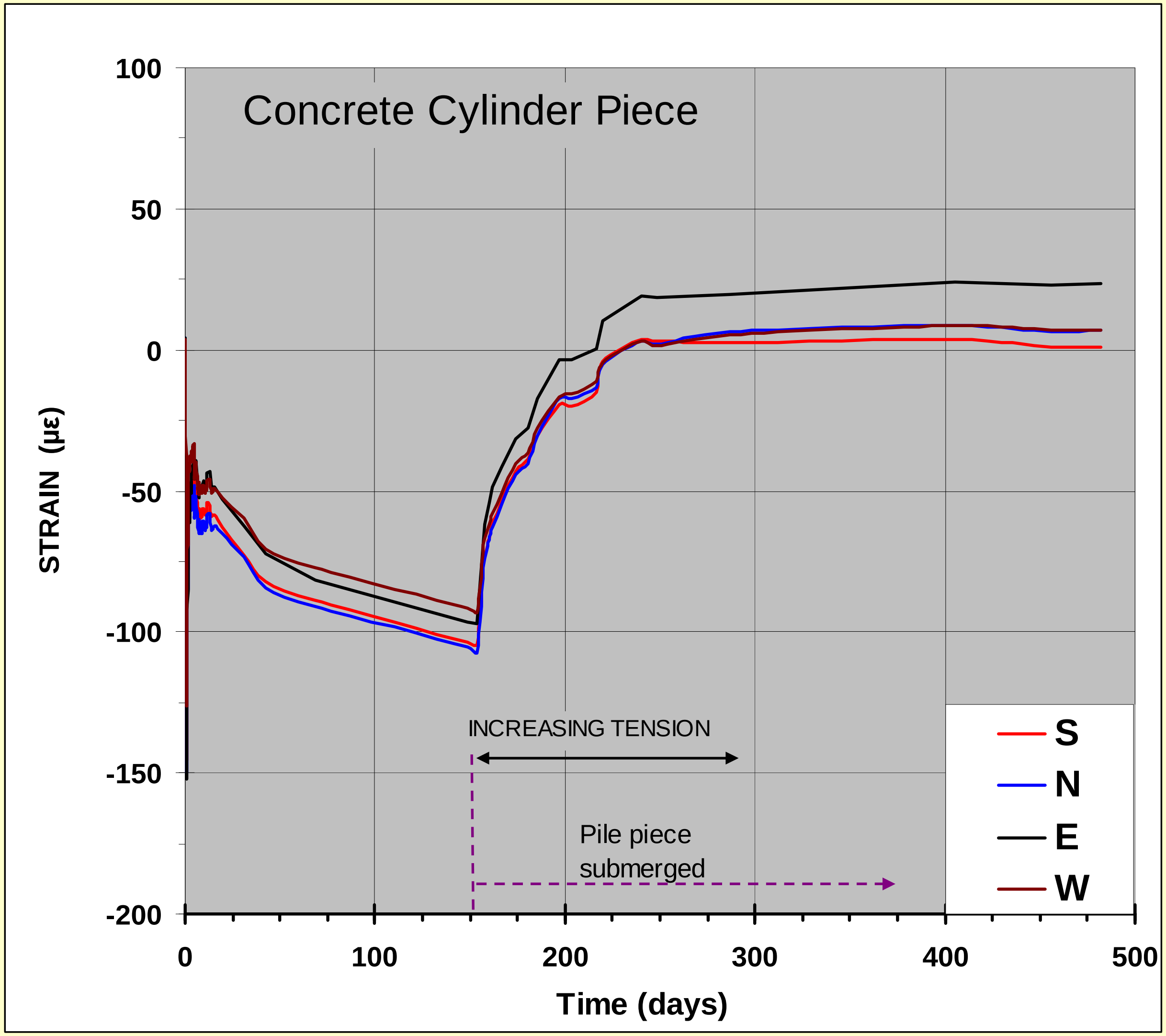
Temperature During Curing of a 2m Lab Specimen



Strain History During Curing of a 2 m Lab Specimen



Submerging the short piece, letting it swell from absorption of water



The strain gages themselves ar not are temperature sensitive, but the records 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, 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

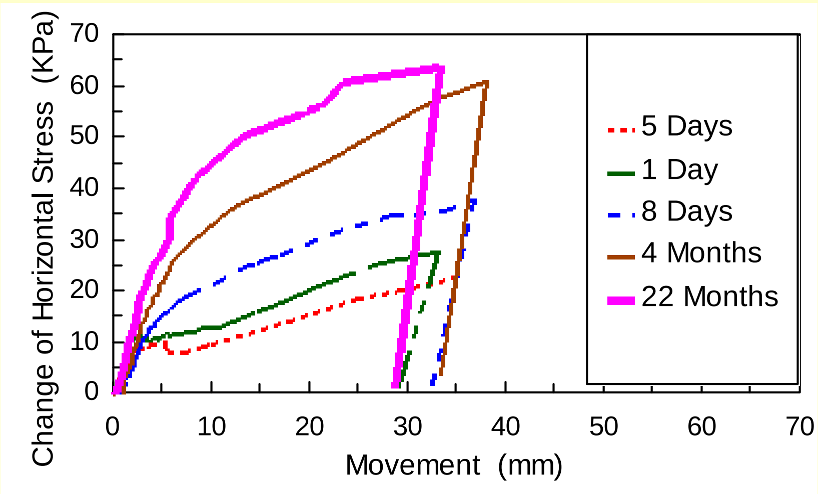
- The No-Load Readings will tell what happened to the gage before the start of the test and will be helpful in assessing the possibility of a shift in the reading value representing the no-load condition

- **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

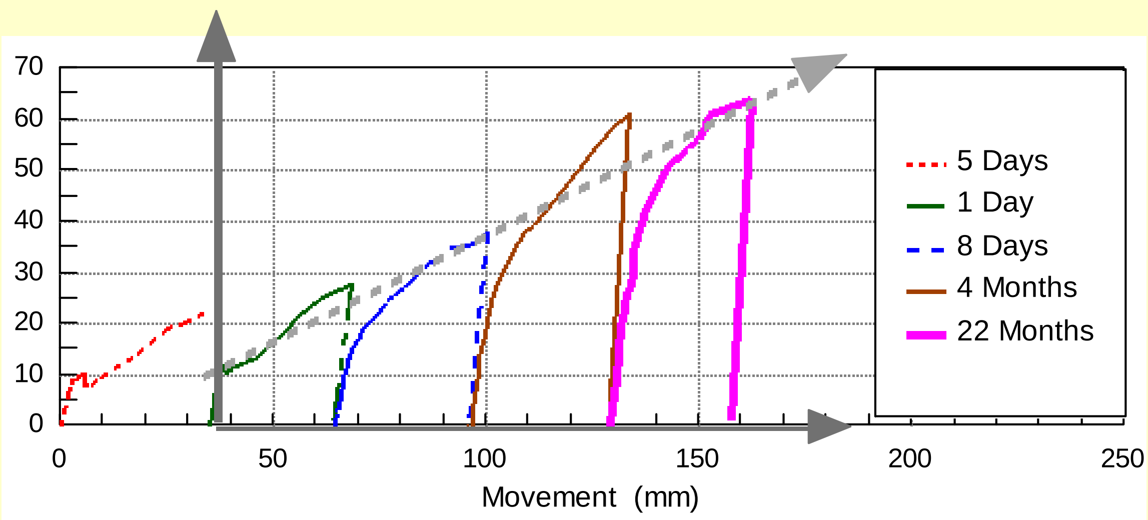
Of course,

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

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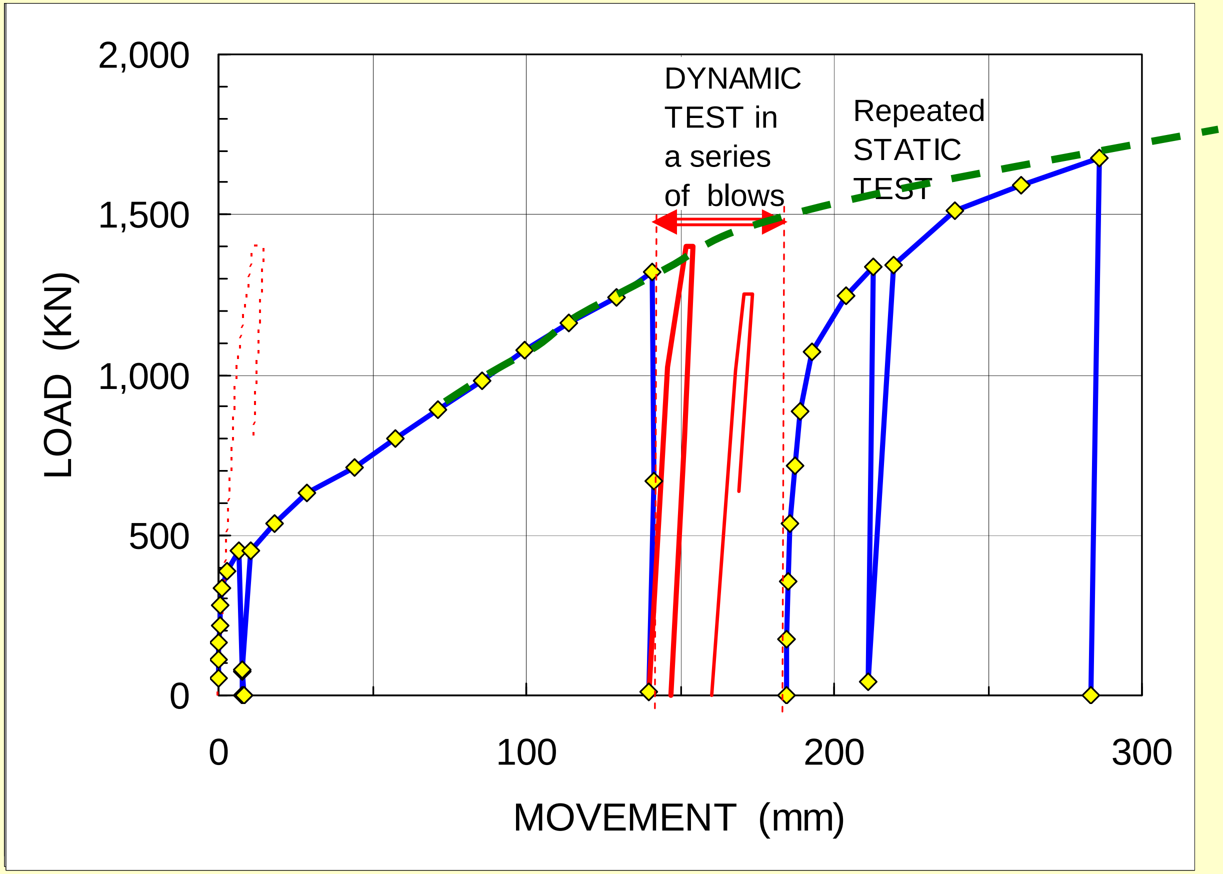
Also the best field work can get messed up if the analysis and conclusion effort loses sight of the history of the data



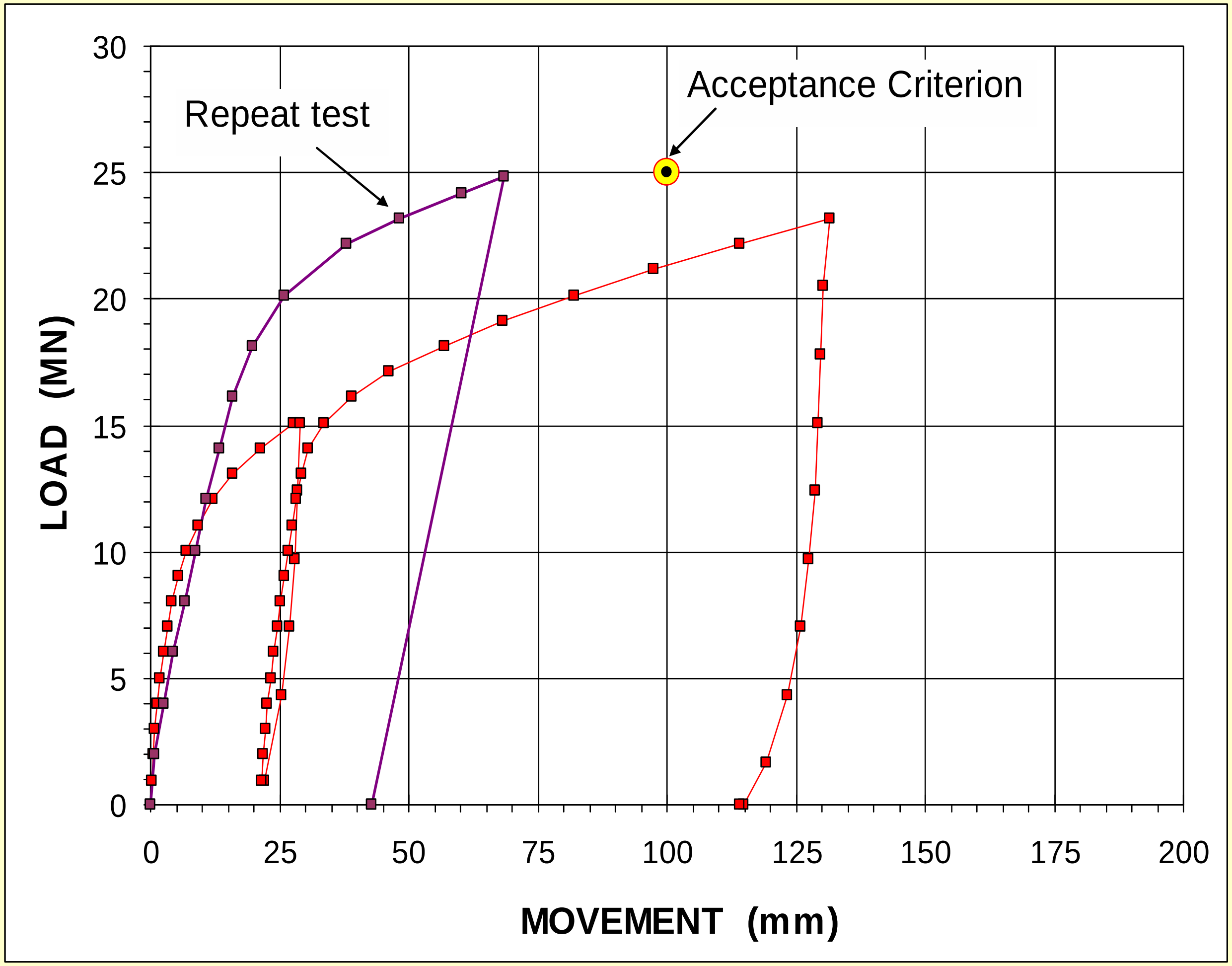
The dynamic test (CAPWAP) was performed after the static test.

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

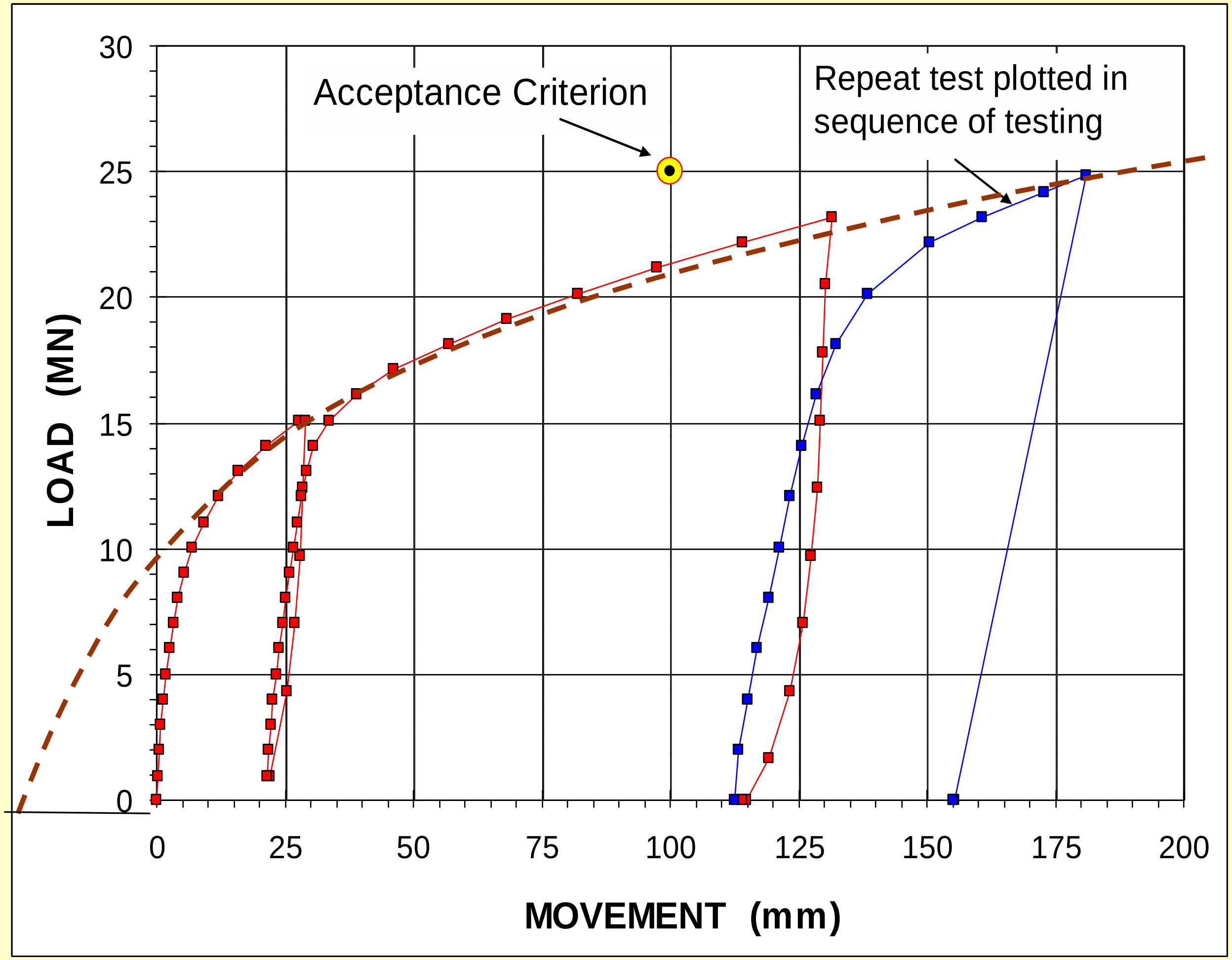
Often the past routines are nothing but jog trotting along with the humdrum past. For example, incorporating unloading/reloading cycles is useless and actually impairs a test.

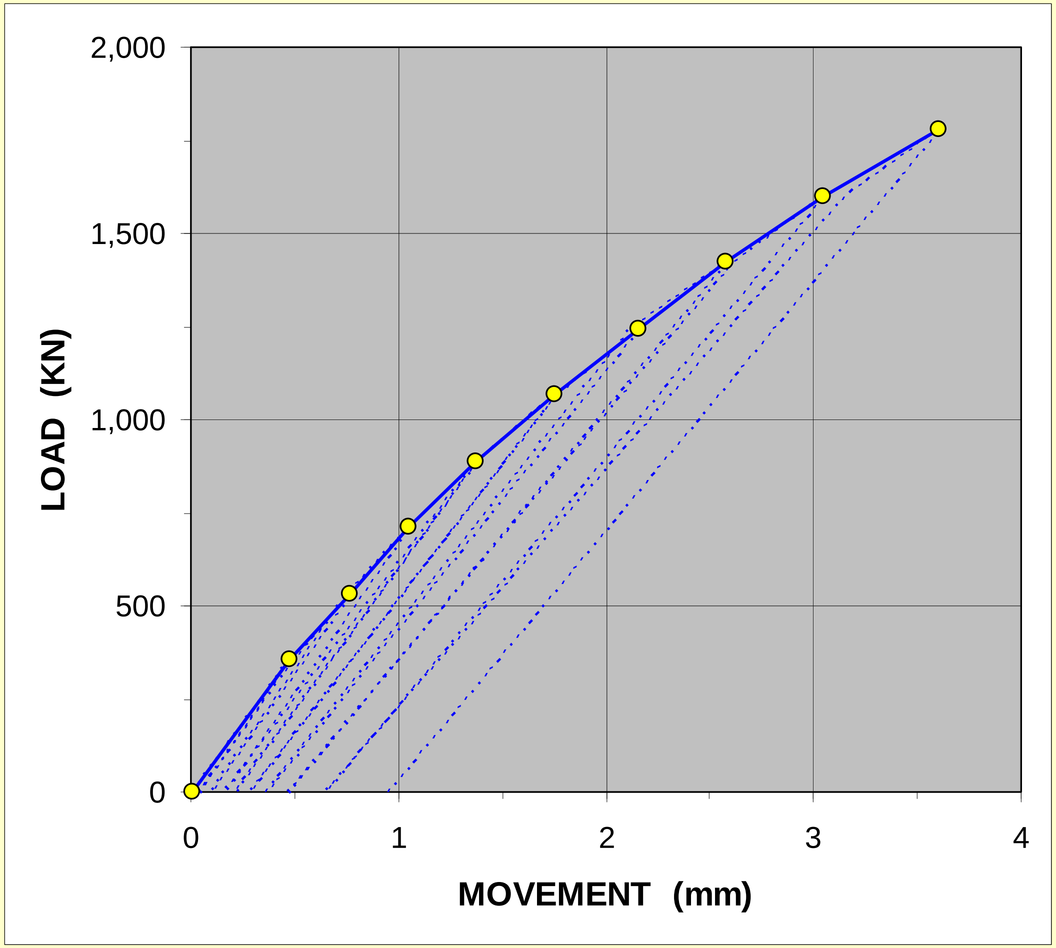
Does unloading/reloading add anything of value to a test?

Result on a test on a 2.5 m diameter, 85.5 m long bored pile



Plotting the repeat test in proper sequence





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


Thank you for your attention