BASICS OF DESIGN OF PILED FOUNDATIONS

Bengt H. Fellenius

Load Transfer and Capacity of Piles

Brisbane November 28, 2008

Driving closed-toe pipe piles into fine sand about 2.5 m above the groundwater table

Driving 12-inch precast concrete pile into clay for Sidbec in 1974

Head measured in aquifer
below the clay layer

GW

Svärta River 1969

What really is Capacity?

Capacity is what we

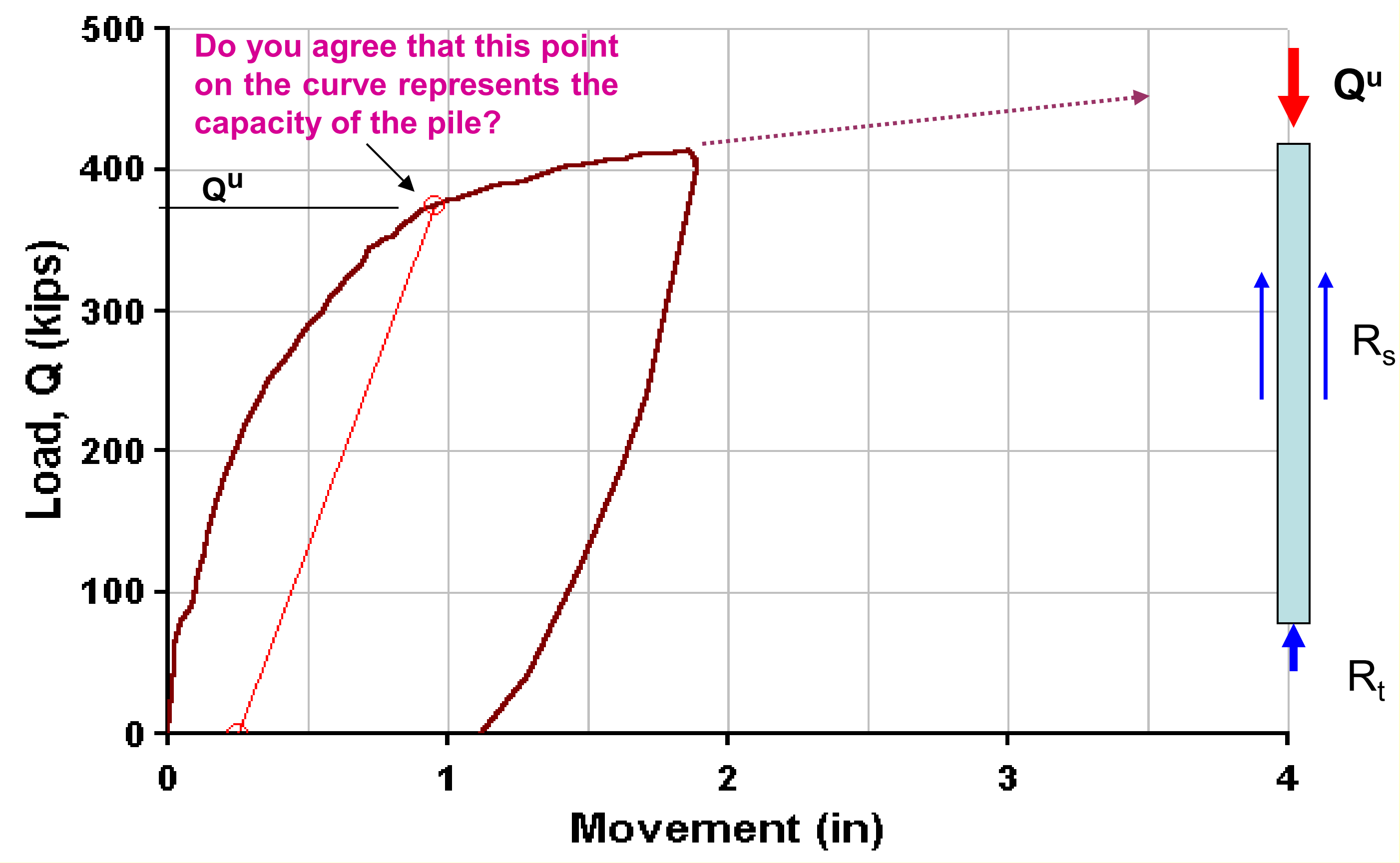
determine in

— **define from** —

a loading test

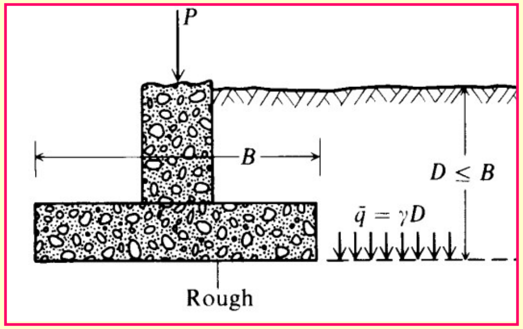
?

e.g.: The Offset Limit Load (Davisson, 1972)



The Bearing Capacity Formula

$$r_u = c' N_c + q' N_q + 0.5 b \gamma' N_\gamma$$



where r_u = ultimate unit resistance of the footing

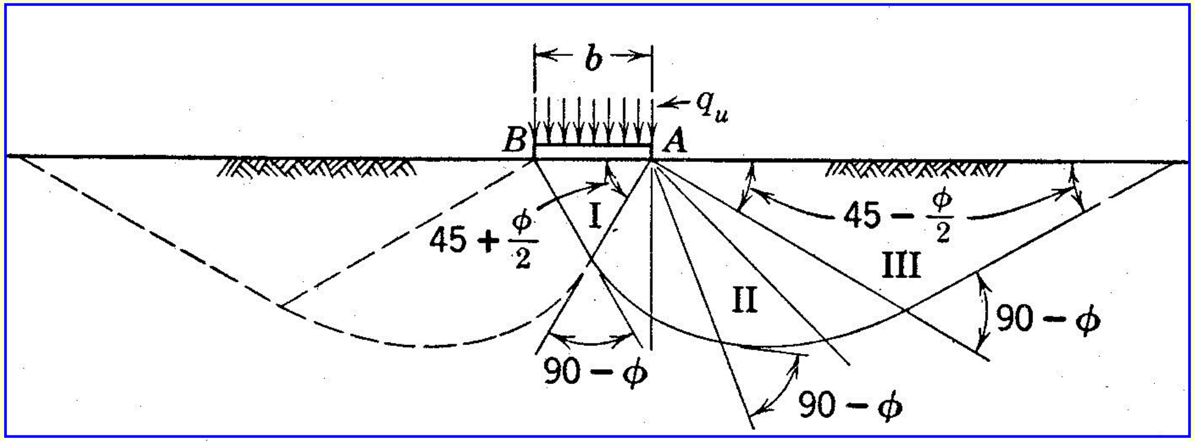
c' = effective cohesion intercept

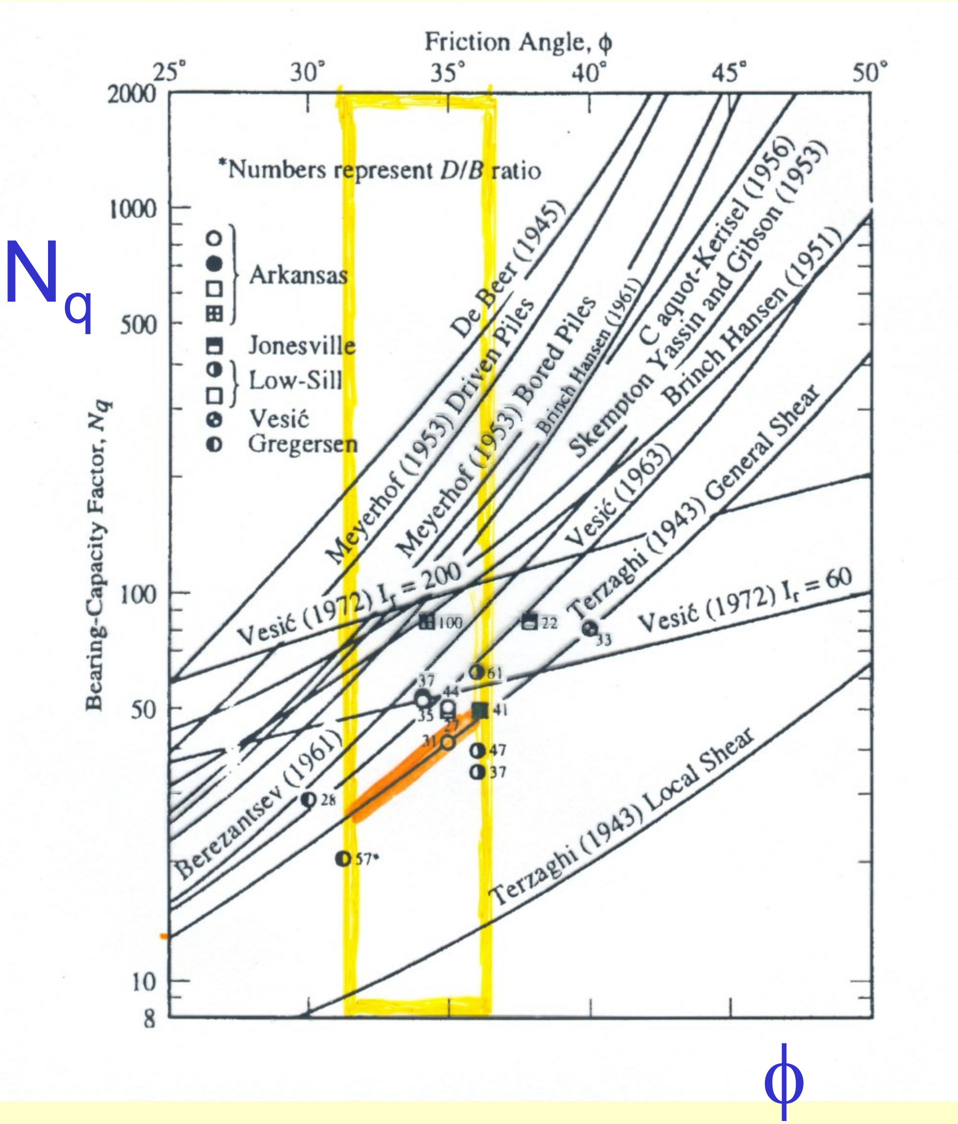
B = footing width

q' = overburden effective stress at the foundation level

γ' = average effective unit weight of the soil below the foundation

N_c, N_q, N_γ = non-dimensional bearing capacity factors



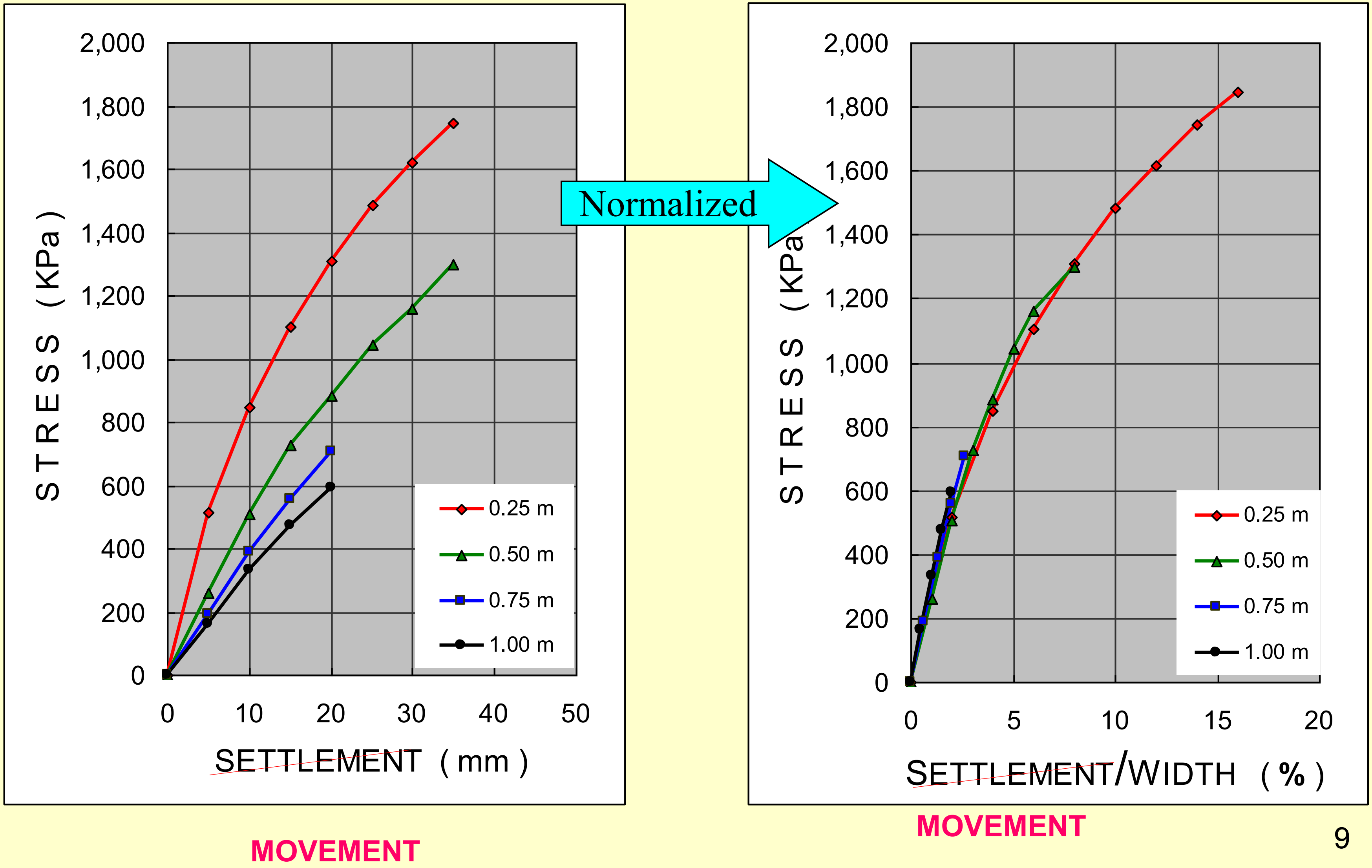


The main factor is the

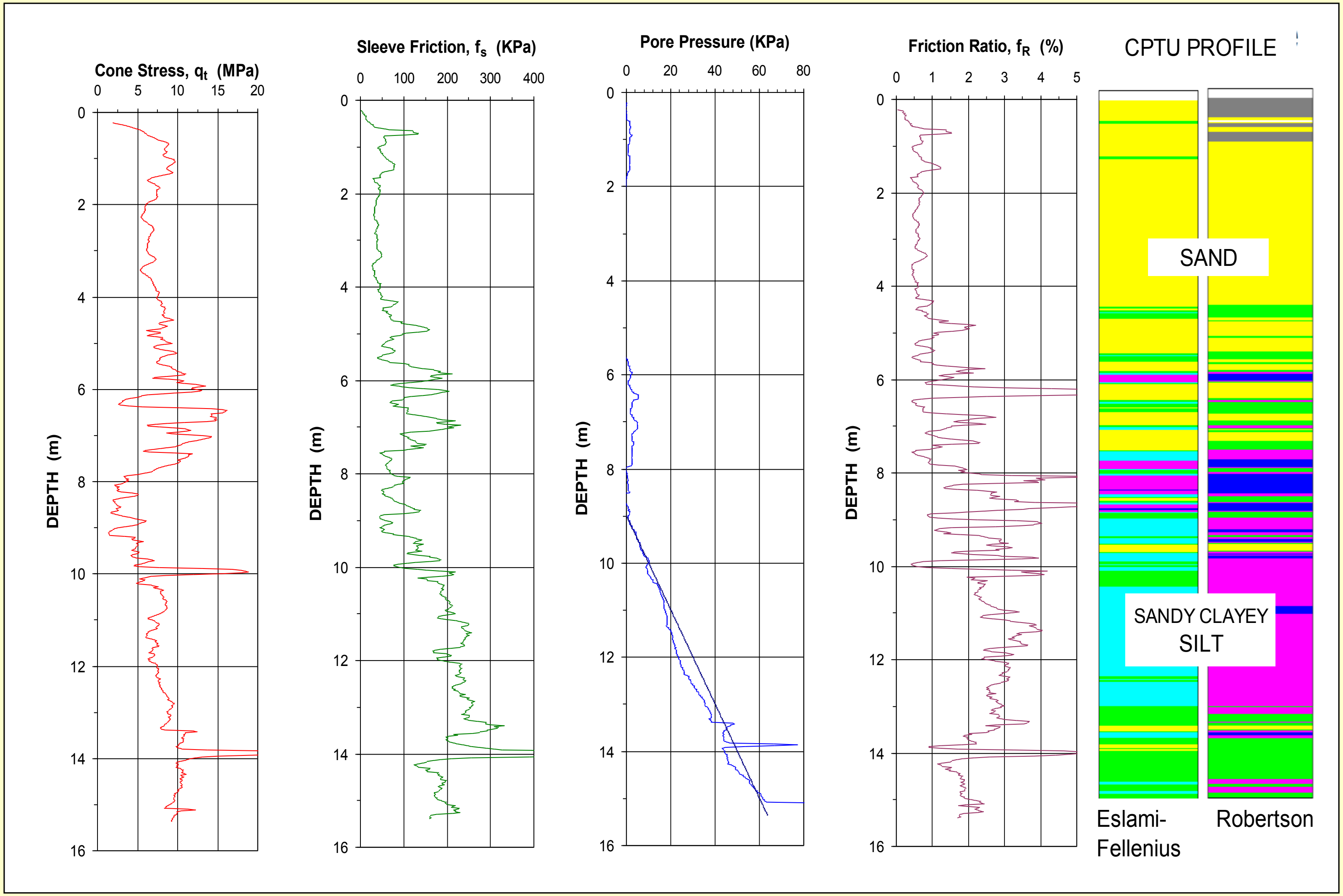
“N_q”

But what is the reality?

Results of static loading tests on **0.25 m to 0.75 m** square **footings** in well graded sand (Data from Ismael, 1985)`

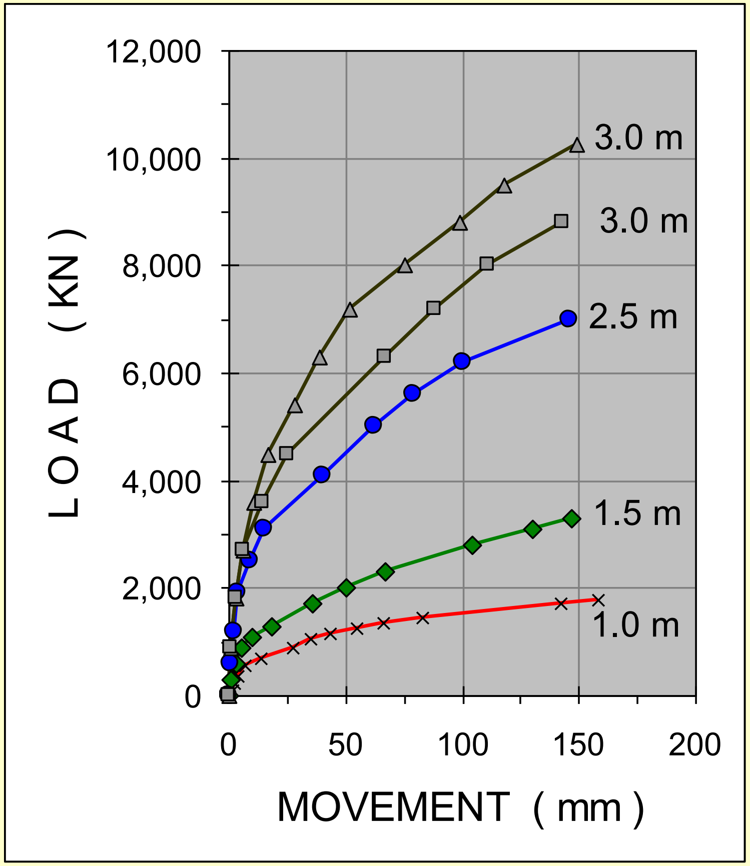


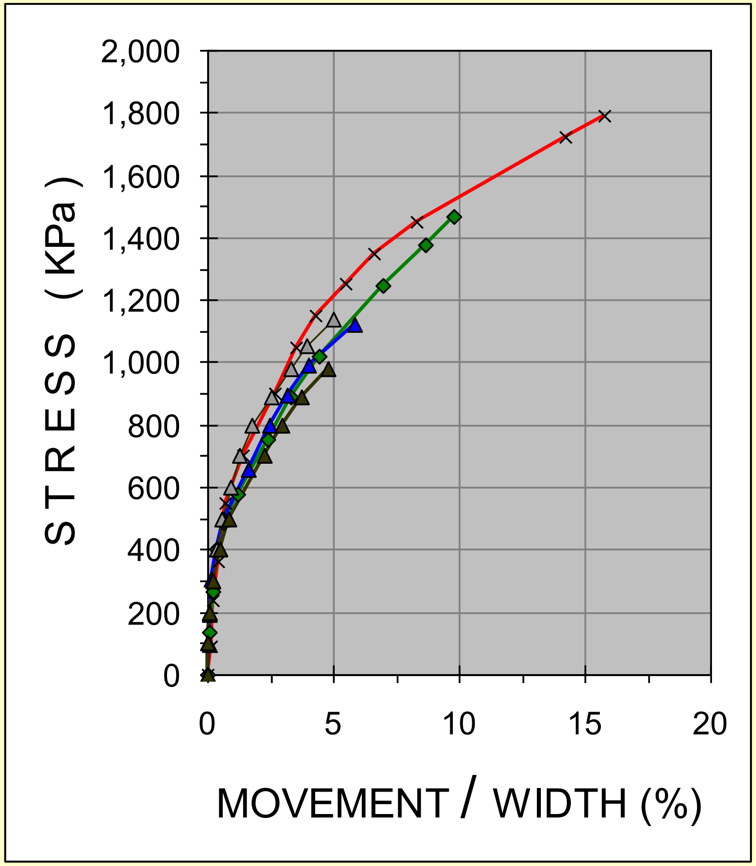
"Prediction of Load-Movement for Five Footings on Sand"
Texas A&M University Experimental Site
ASCE GSP 41, J-L Briaud and R.M. Gibbens 1994



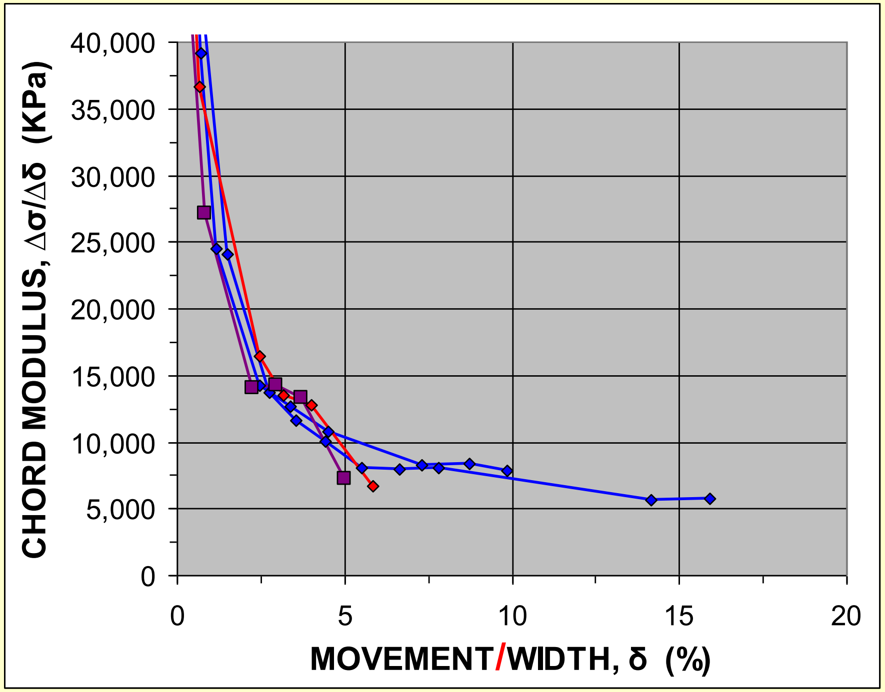
Load-Movement of Four Footings on Sand
Texas A&M University Experimental Site
ASCE GSP 41, J-L Briaud and R.M. Gibbens 1994

The data will tell us more, if we divide the load with the footing area (to get stress) and divide the movement with the footing width, as follows.

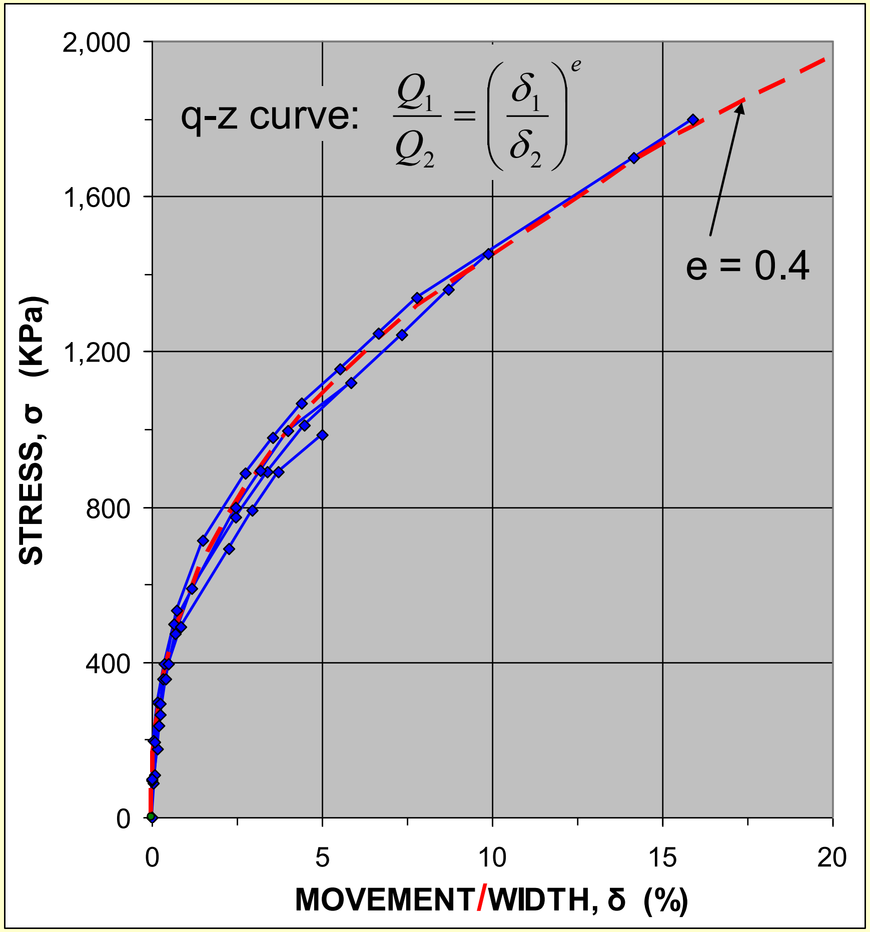




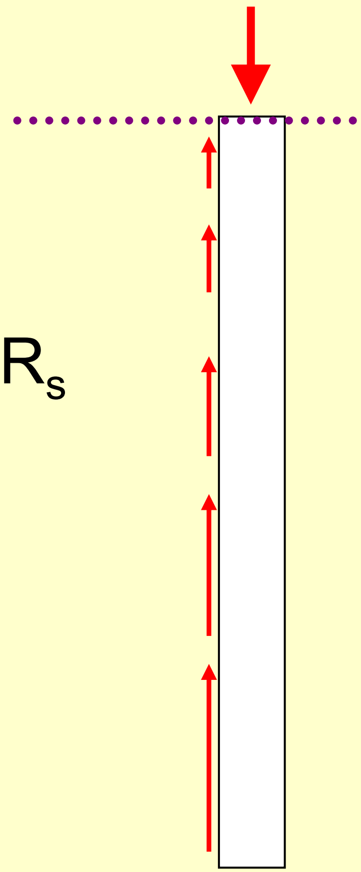
Plotting the "Chord Modulus" ("Tangent Modulus") vs. the Normalized Movement ("strain") makes it clear that using a constant compressibility (modulus) in calculating the footing movement is not suitable (It is "movement" not "settlement" because the affected volume keeps changing).

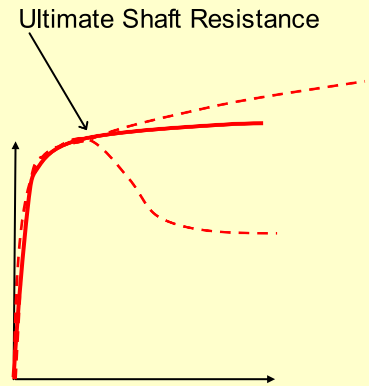


We can also borrow from pile analysis (Pile toe response) and apply a q-z function to the stress-movement data.

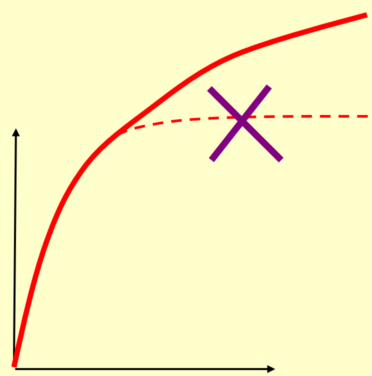


r_s, R_s





Ultimate Shaft Resistance is a reality



Ultimate Toe Resistance does not exist other than as a definition of load at a certain movement

Ultimate Toe Resistance is not

- Pile capacity is the combined effect of shaft resistance and toe resistance.
- Shaft resistance is governed by shear strength, which has an ultimate value. That is, **shaft capacity is reality**.
- In contrast, toe resistance is governed by compression, which does not have an ultimate value. As the load is increased, a larger and larger soil volume is stressed to a level that produces significant compression, but no specific failure or peak value: **Toe capacity is a delusion**.

Analysis Methods

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The Total Stress Method

The Lambda Method

The SPT Method

The CPT and CPTU Methods

The Pressuremeter Method

The **Beta Method**

Piles in Clay

Total Stress Method

$$r_s = \tau_u$$

where r_s = unit shaft resistance

τ_u = undrained shear strength

The undrained shear strength can be obtained from unconfined compression tests, field vane shear tests, or, to be fancy, from consolidated, undrained triaxial tests. Or, better, back-calculated from the results of instrumented static loading tests. **However, if those tests indicate that the unit shaft resistance is constant with depth in a homogeneous soil, don't trust the analysis!**

Clay adhering to extracted piles

Photo courtesy of K.R. Massarsch

Piles in Clay

The Lambda Method

Vijayvergia and Focht (1972)

$$\bar{r}_s = \lambda(\sigma'_m + 2c_m)$$

where $\bar{r}_m$ = mean shaft resistance along the pile

λ = the 'lambda' correlation coefficient

σ'_m = mean overburden effective stress

c_m = mean undrained shear strength

Approximate Values of λ

Embedment (Feet)	Embedment (m)	λ (-)
0	0	0.50
10	3	0.36
25	7	0.27
50	15	0.22
75	23	0.17
100	30	0.15
200	60	0.12

The Lambda method was developed for long piles in clay deposits (offshore conditions)

Piles in Clay

$$r_s = 0.8\{2.2 + 0.016(OCR) - 0.87\,\lg(S_t)\}(OCR)^{0.42}(2h/b)^{-0.2}\,\sigma'_z \tan\delta'$$

where

r_s	=	unit shaft resistance
OCR	=	overconsolidation ratio
S_t	=	sensitivity
h	=	height of point above pile toe ; $h \leq 4b$
b	=	pile diameter
δ’	=	interface friction angle

ICP

Jardine, Chow, Overy, and Standing (2005)

Shaft Resistance in Sand

$$r_s = \underline{M \tan\phi' K_s} \sigma'_v$$

$$r_s = \beta \sigma'_v$$

where	r_s	=	unit shaft resistance
	M	=	tan δ' / tan φ'
	K_s	=	earth stress ratio = σ'_h / σ'_v
	σ'_v	=	effective overburden stress

The SPT Method

Meyerhof (1976)

$$R = R_t + R_s = mNA_t + nNA_sD$$

where m = a toe coefficient

n = a shaft coefficient

N = N-index at the pile toe (taken as a pure number)

N = average N-index along the pile shaft (taken as a pure number)

A_t = pile toe area

A_s = unit shaft area; circumferential area

D = embedment depth

m = $400 \cdot 10^3$ for driven piles and $120 \cdot 10^3$ for bored piles (N/m^2)

m = 4 for driven piles and 1.2 for bored piles (t/ft^2)

n = $2 \cdot 10^3$ for driven piles and $1 \cdot 10^3$ for bored piles (N/m^3)

n = 0.02 for driven piles and 0.01 for bored piles (t/ft^3)

CPT and CPTU Methods for Calculating the Ultimate Resistance (Capacity) of a Pile

Schmertmann and Nottingham (1975 and 1978)

deRuiter and Beringen (1979)

Meyerhof (1976)

LCPC, Bustamante and Gianeselli (1982)

ICP, Jardine, Chow, Overy, and Standing (2005)

Eslami and Fellenius (1997)

The CPT and CPTU Methods

Schmertmann and Nottingham
(1975 and 1978)

$$r_t = C_{OCR}\, q_{ca}$$

$$r_s = K_f\, f_s \qquad \text{CLAY and SAND}$$

$$r_s = K_c\, q_c \qquad \text{SAND (alternative)}$$

where r_t = pile unit toe resistance (**<15 MPa**)

C_{OCR} = correlation coefficient governed by the overconsolidation ratio, OCR, of the soil

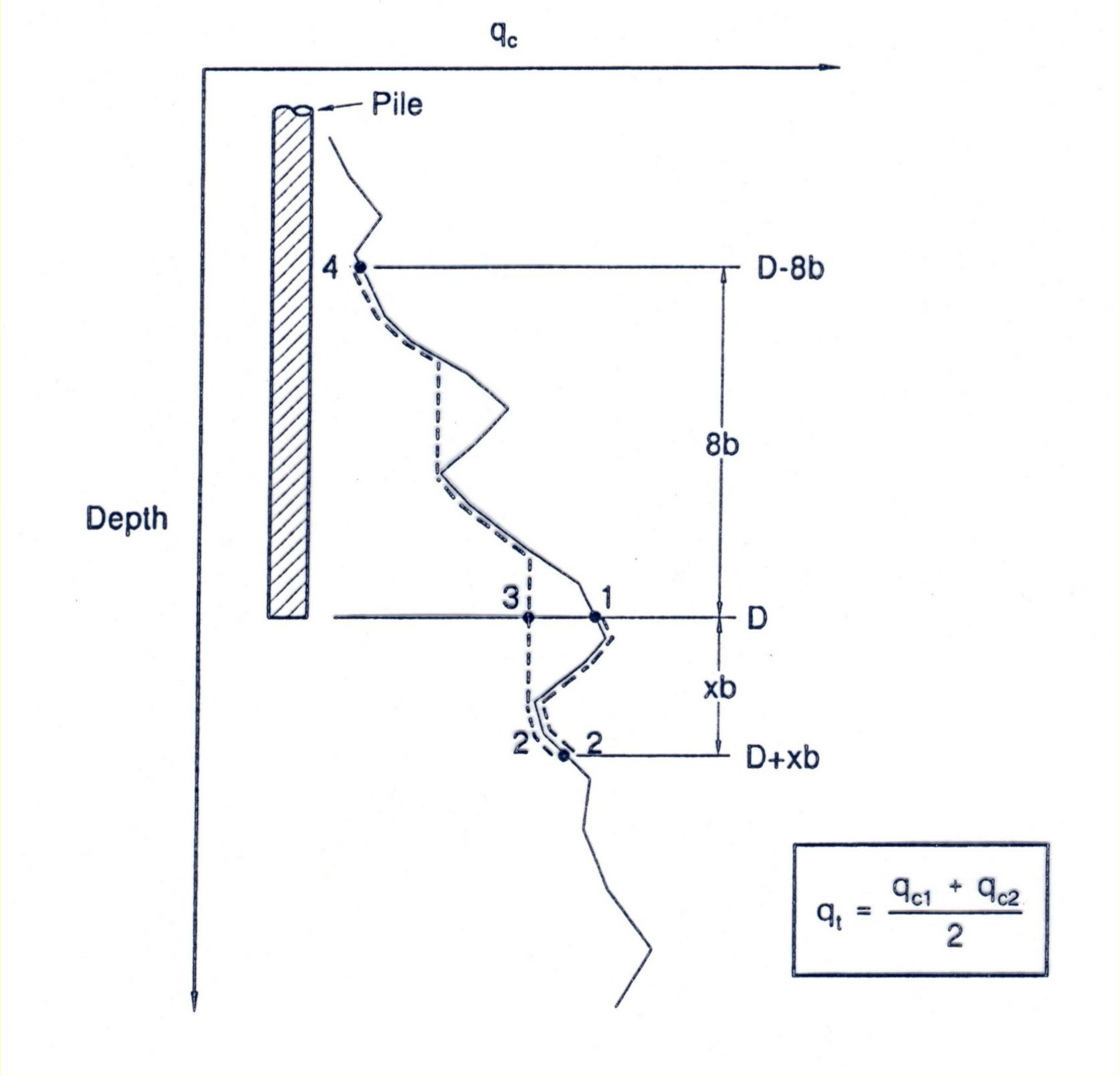
q_{ca} = arithmetic average of q_c in an influence zone*)

K_f = a coefficient depends on pile shape and material, cone type, and embedment ratio. In sand, the coefficient ranges from 0.8 through 2.0, and, in clay, it ranges from 0.2 through 1.25.

K_c = a dimensionless coefficient; a function of the pile type, ranging from 0.8 % through 1.8 %

q_c = cone resistance (total; uncorrected for pore pressure on cone shoulder)

*) The Influence zone is 8b above and 4b below pile toe



Filtering of q_c-values and determining pile toe resistance (Schmertmann method)

deRuiter and Beringen

(1979)

$$r_t = N_c \, S_u$$

$$r_s = \alpha \, S_u$$

where r_t = pile unit toe resistance

N_c = conventional bearing capacity factor

S_u = undrained shear strength — — — — —> $S_u = \dfrac{q_c}{N_k}$

N_K = a dimensionless coefficient, ranging from 15 through 20, reflecting local experience

α = adhesion factor equal to 1.0 and 0.5 for normally consolidated and overconsolidated clays, respectively

An upper limit of 15 MPa is imposed for r_t

Meyerhof
(1976)

$$r_t = C_1 \, C_2 \, q_{ca}$$

$$r_s = K_f \, f_s$$ CLAY and SAND

$$r_s = K_c \, q_c$$ SAND (alternative)

r_t	=	unit toe resistance
q_{ca}	=	arithmetic average of qc in a zone ranging from "1b" below through "4b" above pile toe
C_1	=	[(b + 0.5)/2b]n; modification factor for scale effect when b > 0.5, otherwise C_1 = 1
C_2	=	D/10b; modification for penetration into dense strata when D< 10b, otherwise C_2 = 1
n	=	an exponent equal to: 1 for loose sand 2 for medium dense sand 3 for dense sand
b	=	pile diameter
D	=	embedment of pile in dense sand strata
K_f	=	1.0
K_c	=	0.005

LCPC

Bustamante and Gianeselli (1982)

$$r_t = C\, q_{ca}$$

$$r_s = K\, q_c$$

C	=	toe coefficient ranging from 0.40 through 0.55
q_{ca}	=	cone stress averaged in a zone 1.5 b above and 1.5 b below the pile toe plus filtering
r_t	=	pile unit toe resistance < 15 KPa, <35 KPa, or <120 KPa, depending on soil type, pile type, and pile installation method
K	=	a dimensionless coefficient; a function of pile type, ranging from 0.5 % through 3.0 % (Compare: Schmertmann proposes 0.8 % through 1.8 %)

ICP

Jardine, Chow, Overy, and Standing (2005)

$$r_t = (1 - 0.5\frac{b}{d_c})\, q_{ca}$$

$$r_s = K_J\, q_c$$

$$K_J = (0.0145 q_c (\frac{\sigma'_z}{\sigma_r})^{0.13} (\frac{b}{h_t})^{0.38} + \Delta\sigma'_m)\tan\delta$$

$$\Delta\sigma'_m = [2q_c(0.0203 + 0.00125 q_c(\sigma'_z\,\sigma_r)^{-0.5} - 1.216 * 10^{-6}(\frac{q_c^2}{\sigma'_z\,\sigma_r})]^{-1}\,\frac{0.01}{b}$$

Eslami and Fellenius
(1997)

$$r_t = C_t \; q_{Eg}$$

$$r_s = C_s \; q_E$$

$$C_t = \frac{1}{3b}$$ b in metre

$$C_t = \frac{12}{b}$$ b in inch

r_t = pile unit toe resistance

C_t = toe correlation coefficient (toe adjustment factor)—equal to unity in most cases

q_{Eg} = **geometric** average of the cone point resistance over the influence*) zone after correction for pore pressure on shoulder and adjustment to "effective" stress

r_s = pile unit shaft resistance

C_s = shaft correlation coefficient, which is a function of soil type determined **from the soil profiling chart**

q_E = cone point resistance after correction for pore pressure on the cone shoulder and adjustment to "effective" stress

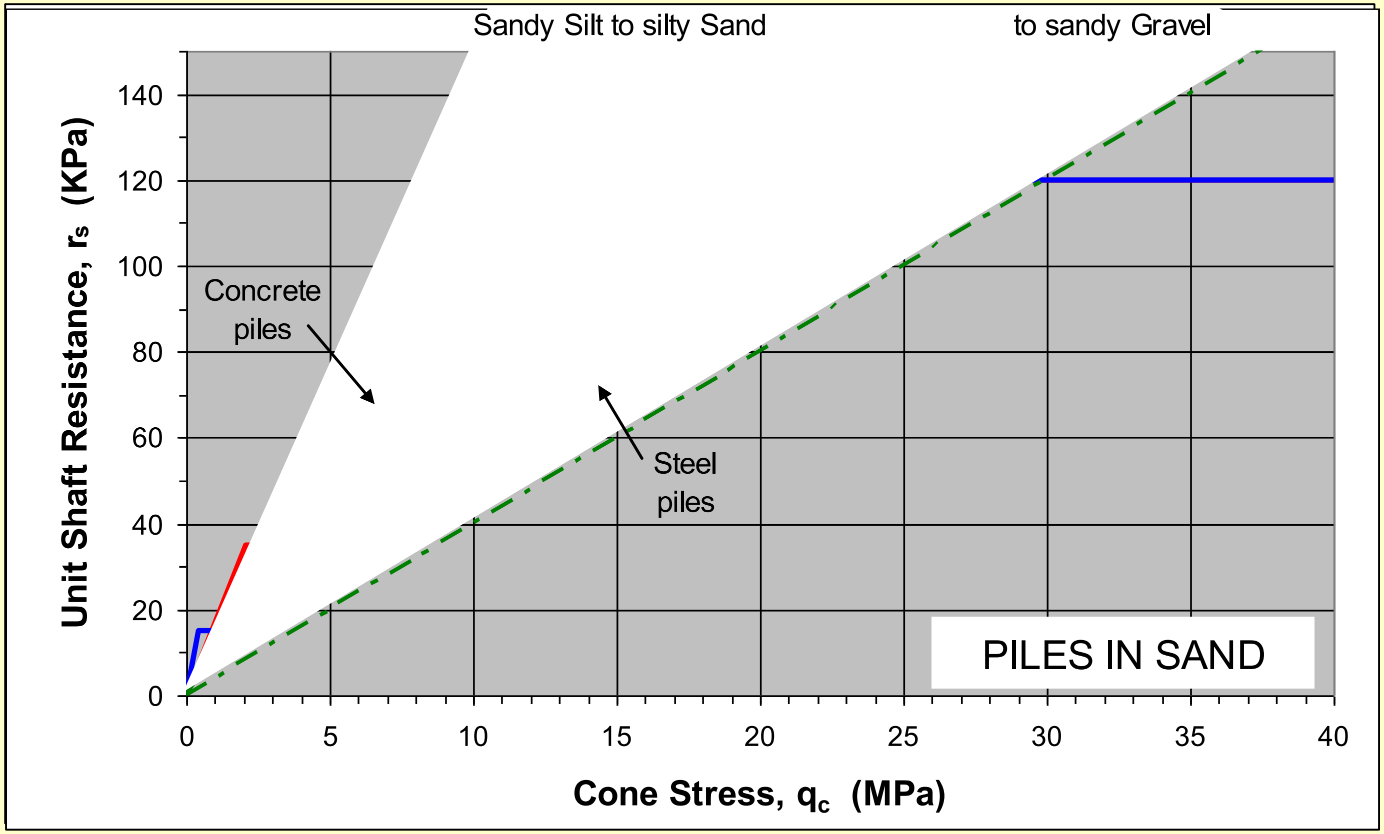
*) The Influence zone is 8b above and 4b below pile toe

Shaft Correlation Coefficient

Soil Type *)	**C_s**
Soft sensitive soils	8.0 %
Clay	5.0 %
Stiff clay and	
Clay and silt mixture	2.5 %
Sandy silt and silt	1.5 %
Fine Sand and silty Sand	1.0 %
Sand to sandy gravel	0.4 %

*) **determined directly from the CPTU soil profiling**

Unit shaft resistance as a function of cone stress, q_c in Sand according to the LCPC method and compared to the Eslami-Fellenius method



Pile Capacity or, rather, **Load-Transfer** follows principles of effective stress and is best analyzed using the **Beta method**

the **Beta method**

Unit Shaft Resistance, r_s

$$r_s = c' + \beta\sigma'_z$$

where c' = effective cohesion intercept

β = Bjerrum-Burland coefficient

σ'_z = effective overburden stress

Total Shaft Resistance, R_s

$$R_s = \int A_s r_s dz = \int A_s (c' + \beta\sigma'_z) dz$$

where A_s = circumferential area of the pile at Depth z (surface area over a unit length of the pile)

Only using β is **Effective Stress Analysis** (Beta-analysis)

→ Including c' is rarely worthwhile (other than for bored piles in some clays and silts).

Only using c' is **Total Stress Analysis** (Alpha analysis)

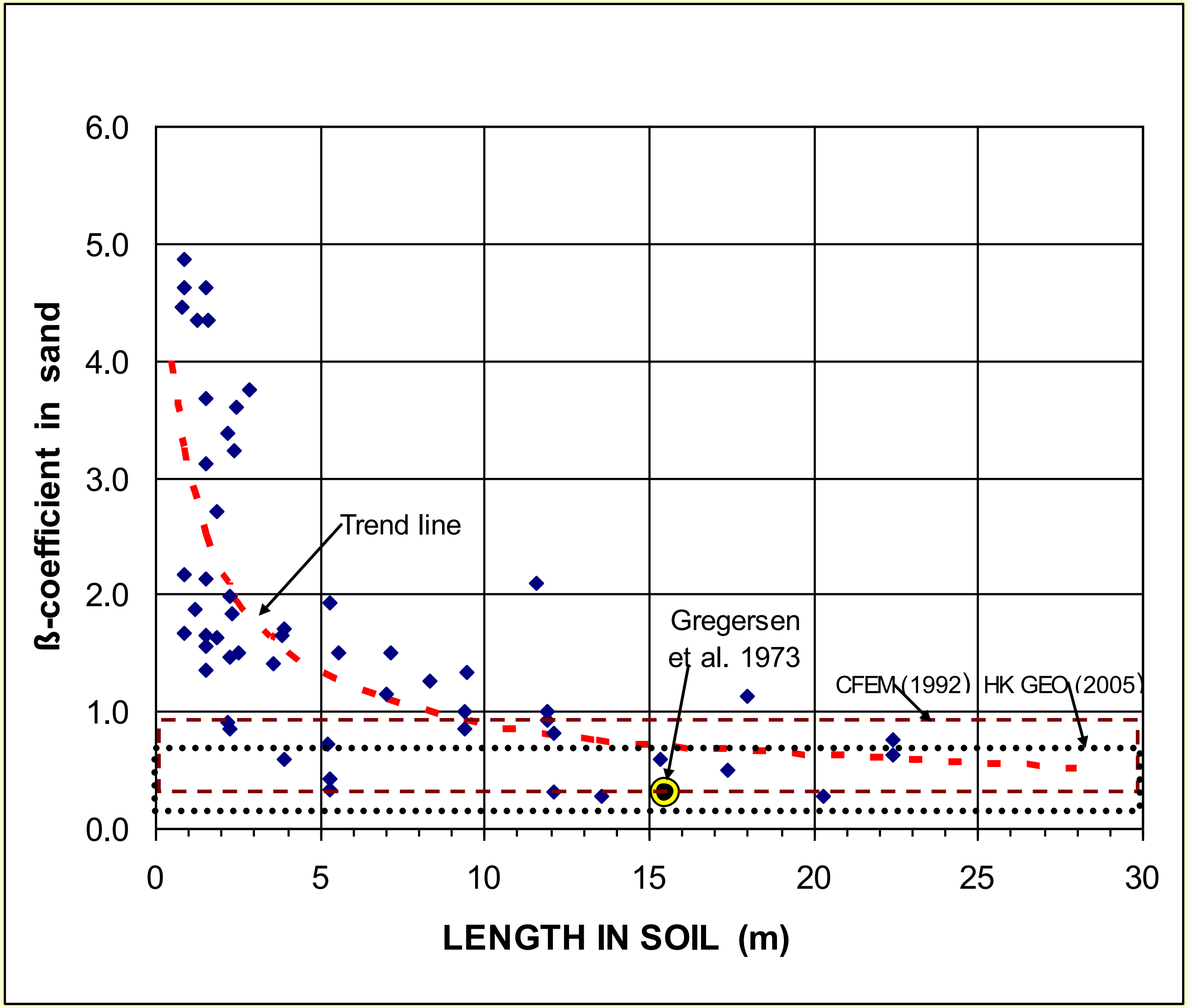
Approximate Range of Beta-coefficients

SOIL TYPE	Phi	Beta
Clay	25 - 30	0.20 - 0.35
Silt	28 - 34	0.25 - 0.50
Sand	32 - 40	0.30 - 0.90
Gravel	35 - 45	0.35 - 0.80

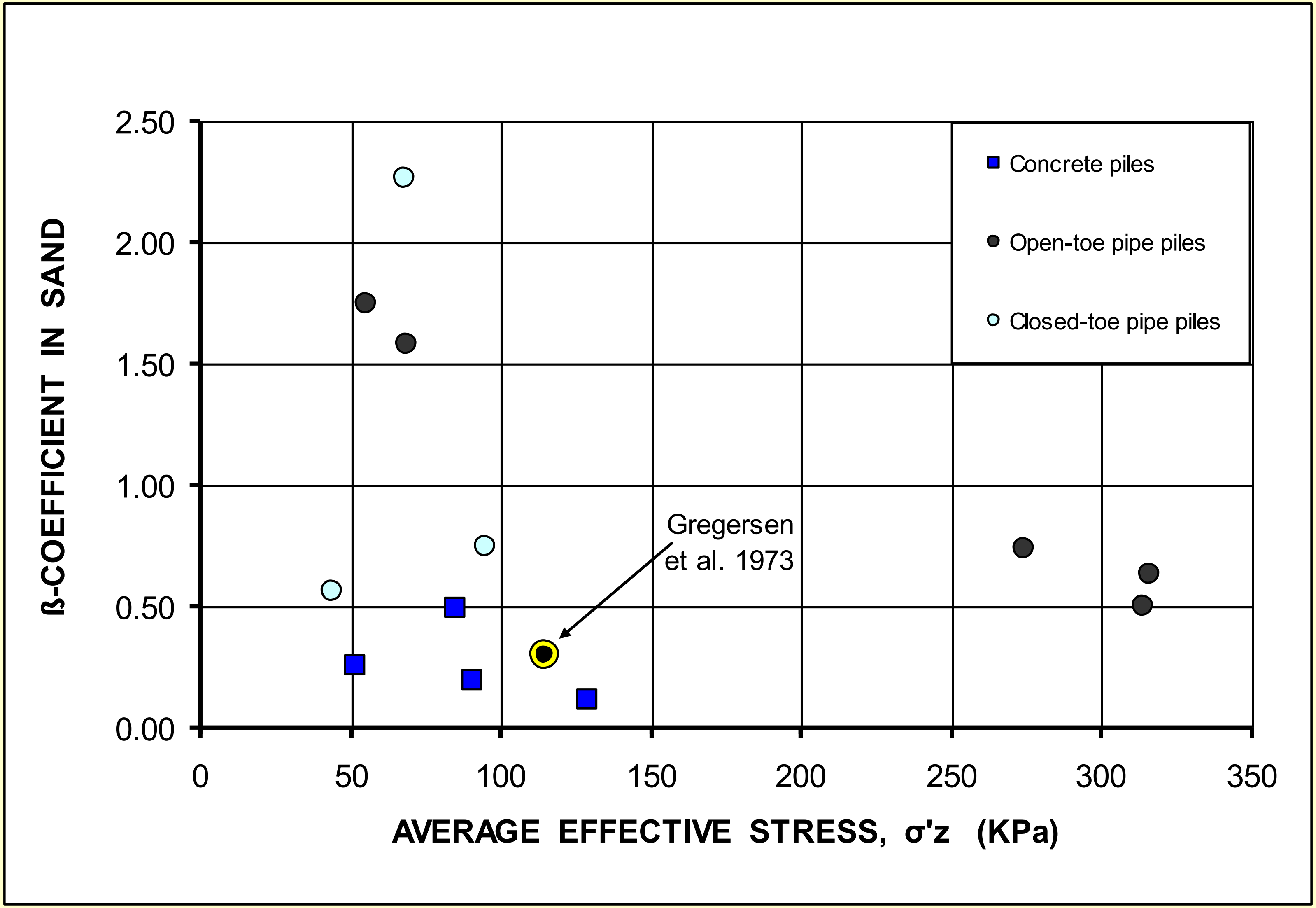
0.05 - 0.80 !

These ranges are typical values found in some cases. In any given case, actual values may deviate considerably from those in the table.

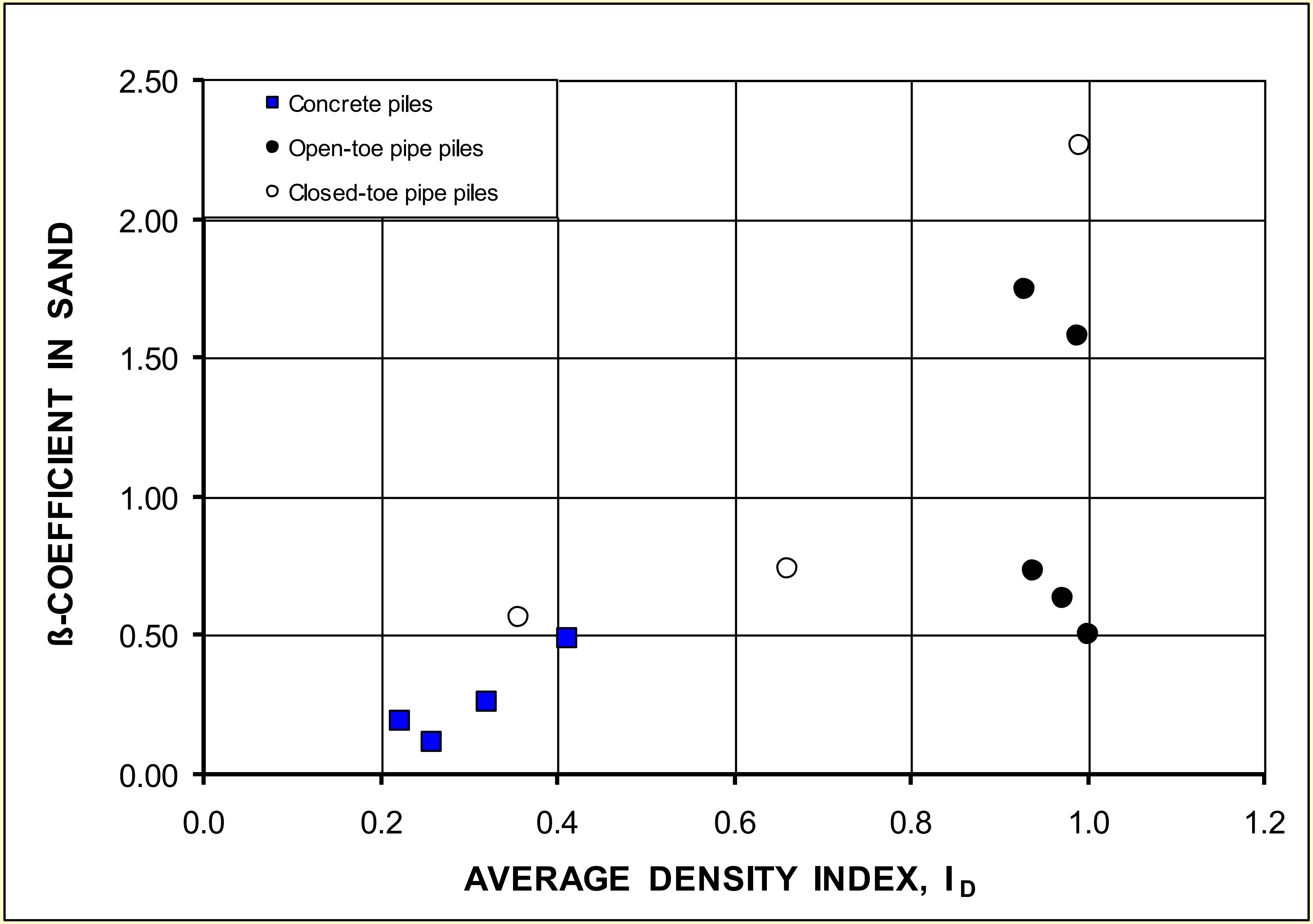
Practice is to apply different values to driven as opposed to bored piles, but ....



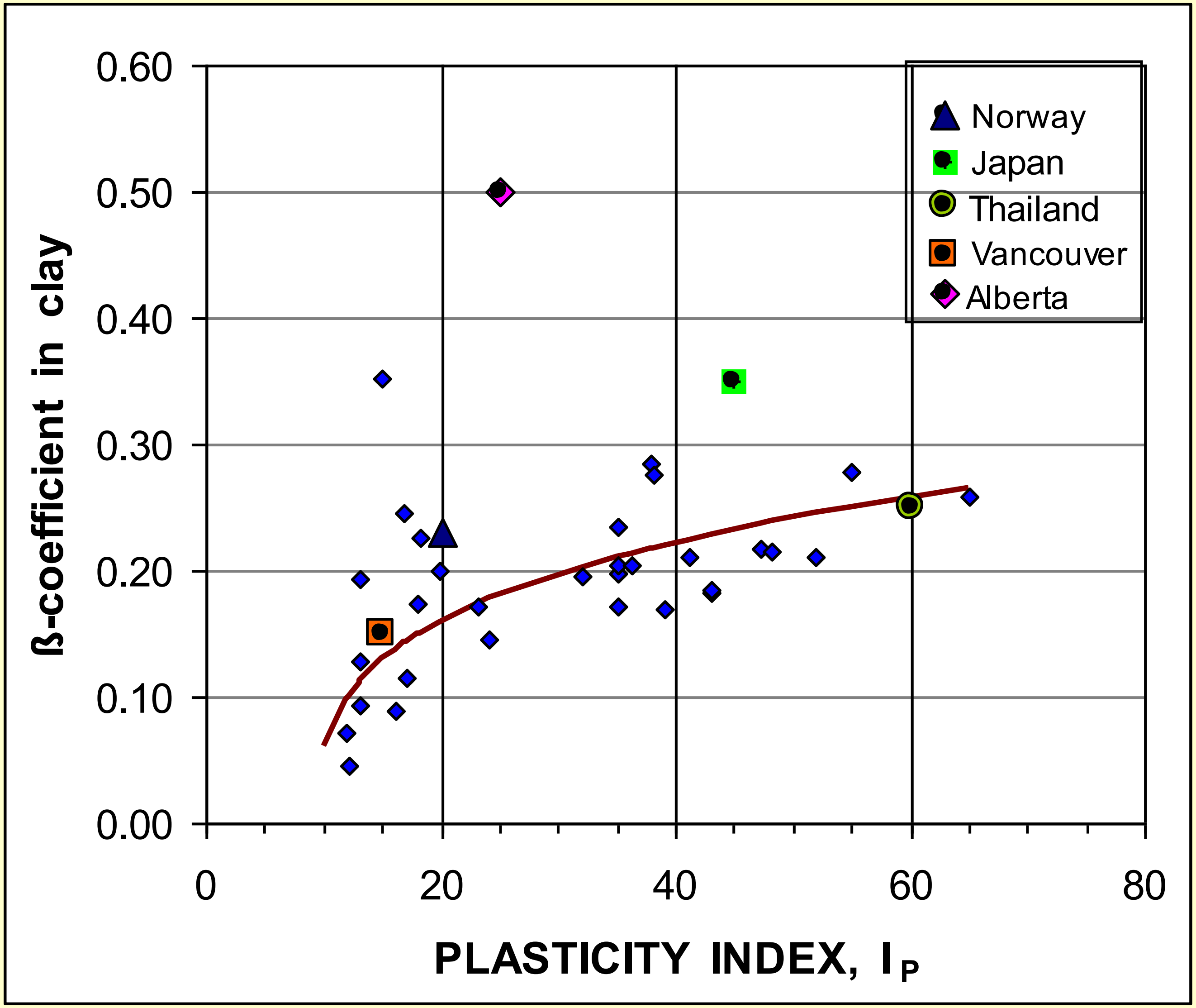
Beta-coefficient versus embedment length for piles in sand (Data from Rollins et al. 2005). Ranges suggested by CFEM (1993), Gregersen et al 1973, and Hong Kong Geo (2005) have been added.



Beta-coefficient versus average σ’ for piles in sand. (Data from Clausen et al. 2005).



Beta-coefficient versus average I_D for piles in sand. (Data from Karlsrud et al. 2005).



Beta-coefficient versus average I_P for piles in clay. (Data from Karlsrud et al. 2005 with values added from five case histories).

Unit Toe Resistance, r_t

$$r_t = N_t \, \sigma'_{z=D}$$

where N_t = toe "bearing capacity" coefficient

D = depth to pile toe

$\sigma'_{z=D}$ = effective overburden stress at the pile toe

Total Toe Resistance, R_t

$$R_t = A_t r_t = A_t \, N_t \, \sigma'_{z=D}$$

where A_t = toe area (normally, the cross sectional area of the pile)

Approximate Range of N_t-coefficients

SOIL TYPE	Phi	N_t
Clay	25 - 30	3 - 30
Silt	28 - 34	20 - 40
Sand	32 - 40	30 - 150
Gravel	35 - 45	60 - 300

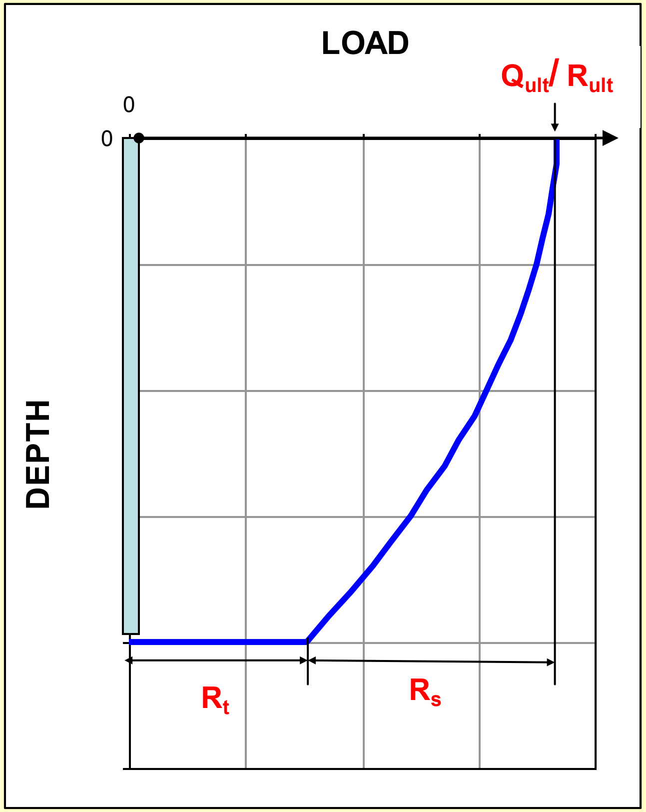
The Toe Resistance, R_t, while not really an “ultimate” resistance, is usually considered as such in design. It should be thought of as the toe resistance mobilized in a static loading test at the maximum acceptable movement usually considered applicable to the foundation supported by the pile(s).

Total Resistance ("Capacity")

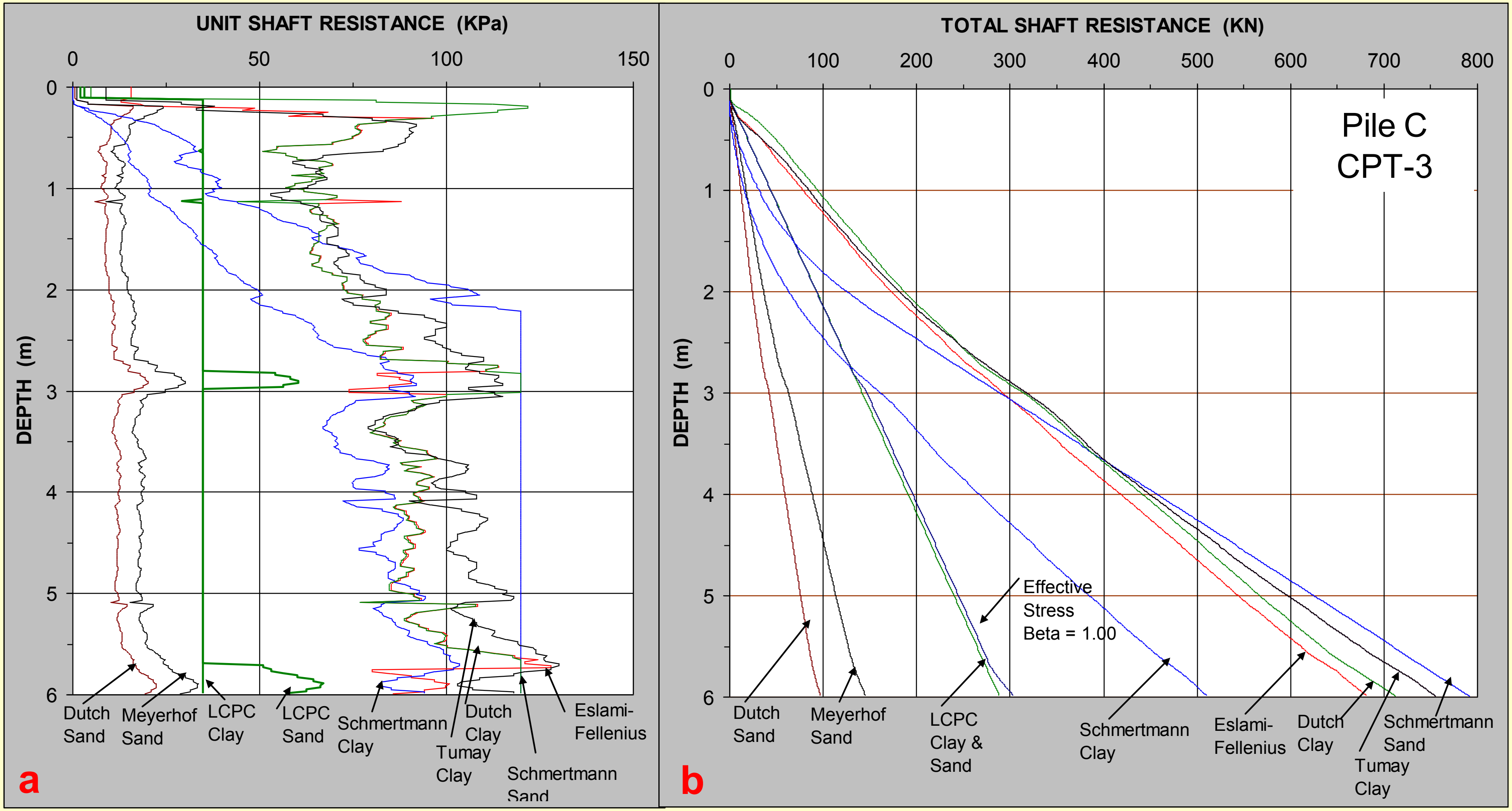
$$Q_{ult} = R_s + R_t$$

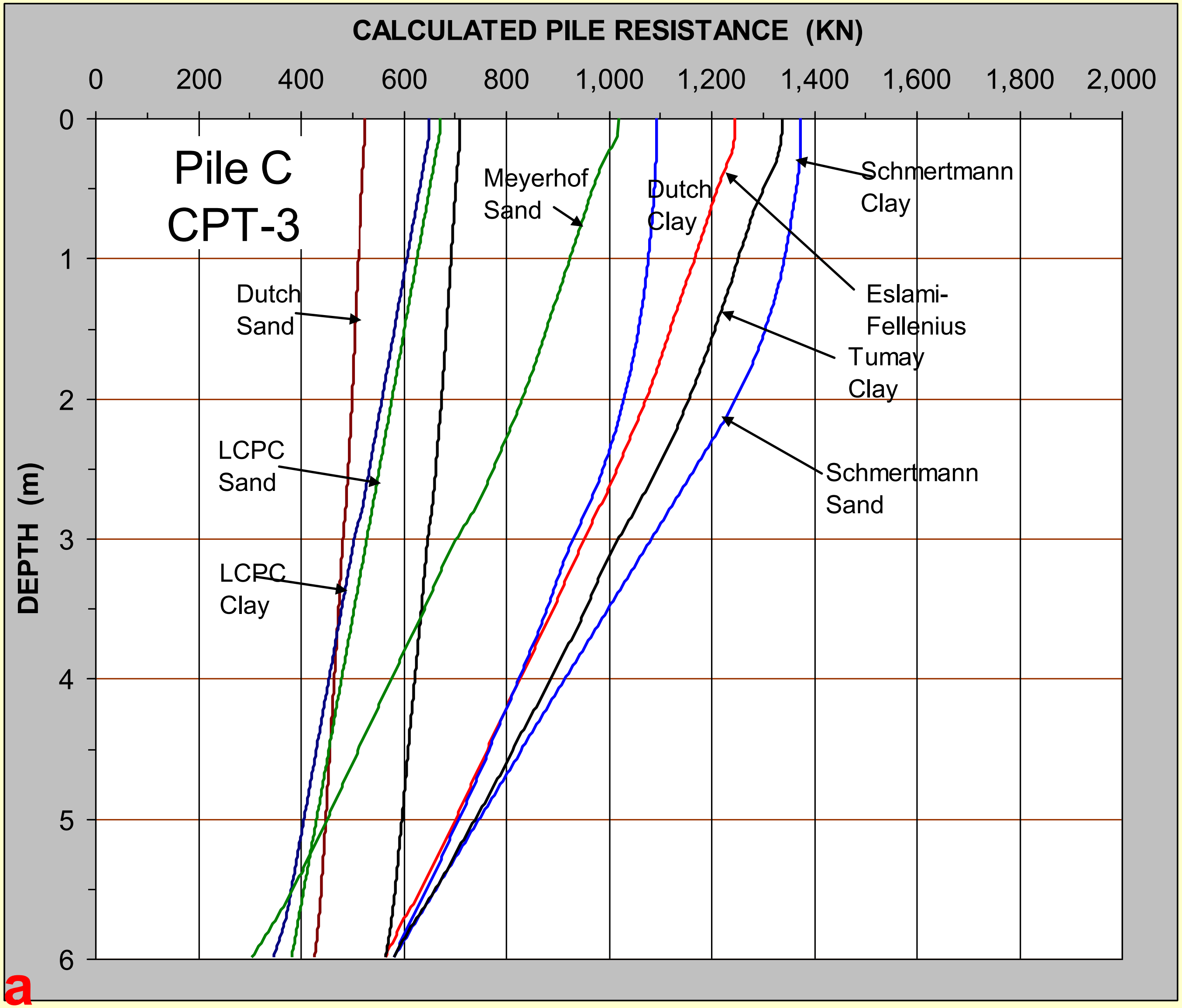
$$Q_z = Q_u - \int A_s \beta \sigma_z' \, dz = Q_u - R_s$$

Effective stress — Beta — analysis is the method closest to the real response of a pile to an imposed load



Calculations of unit and total shaft resistances for a pile driven into a saprolite (residual soil) in Porto, Portugal. The soil can be classified both as a clay type and sand type.





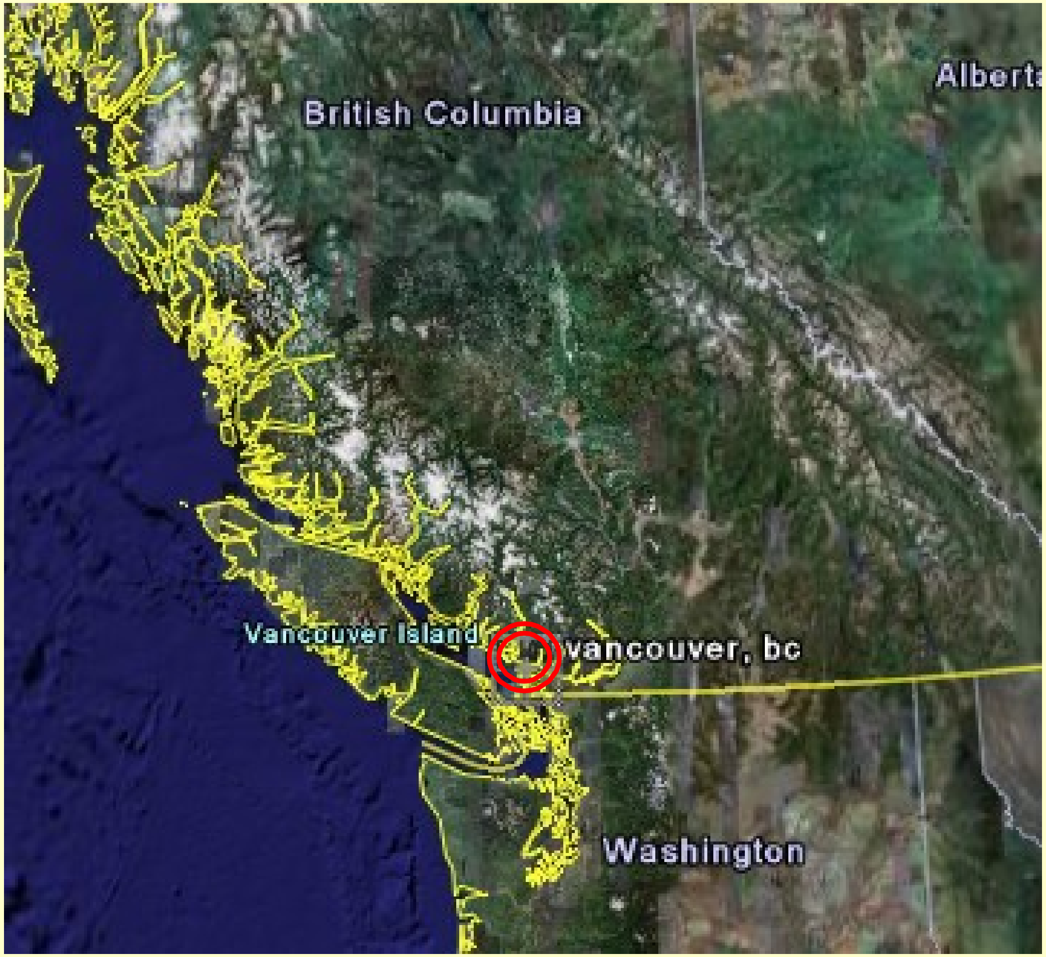
CALCULATED PILE RESISTANCE (KN)
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
DEPTH (m)
0
1
2
3
4
5
6
Pile C
CPT-3
Meyerhof
Sand
Dutch
Clay
Schmertmann
Clay
Dutch
Sand
Eslami-
Fellenius
Tumay
Clay
LCPC
Sand
Schmertmann
Sand
LCPC
Clay
a

Let's look at a few case studies

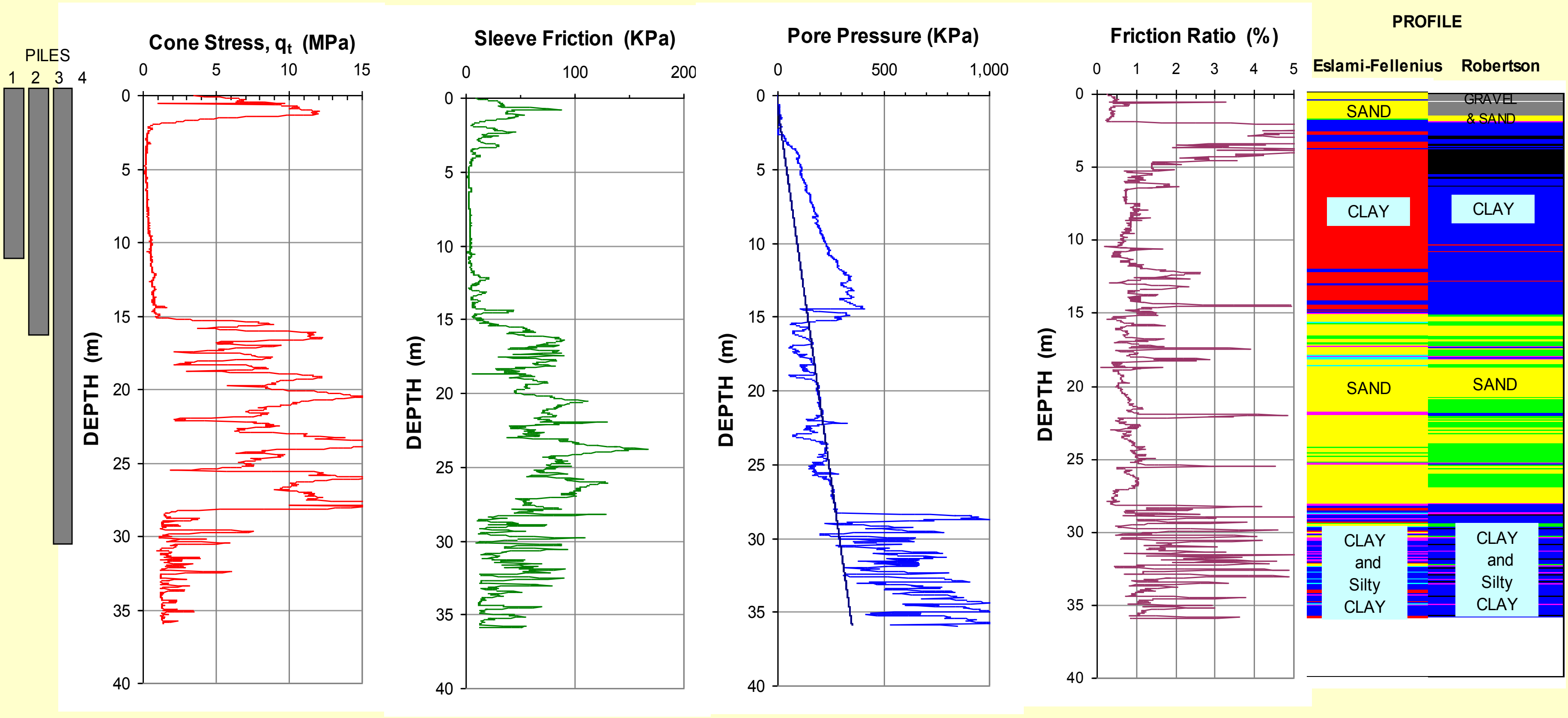
Annacis/Lulu Island Tests, Vancouver, BC

by UBC 1985

Static loading tests on three 324 mm diameter pipe piles driven to depths of 14 m, 17 m, and 31 m into the Fraser River deltaic soils

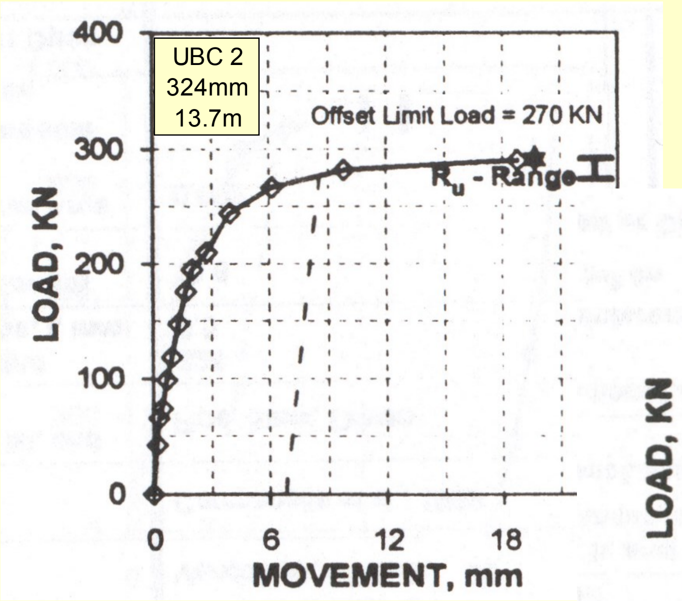


CPT and CPTU analysis for capacity

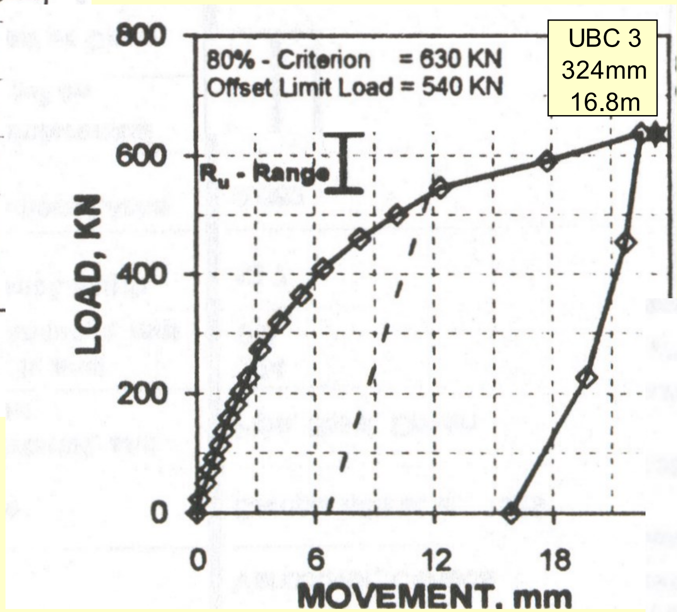


Annacis/Lulu Island Tests
by UBC 1985

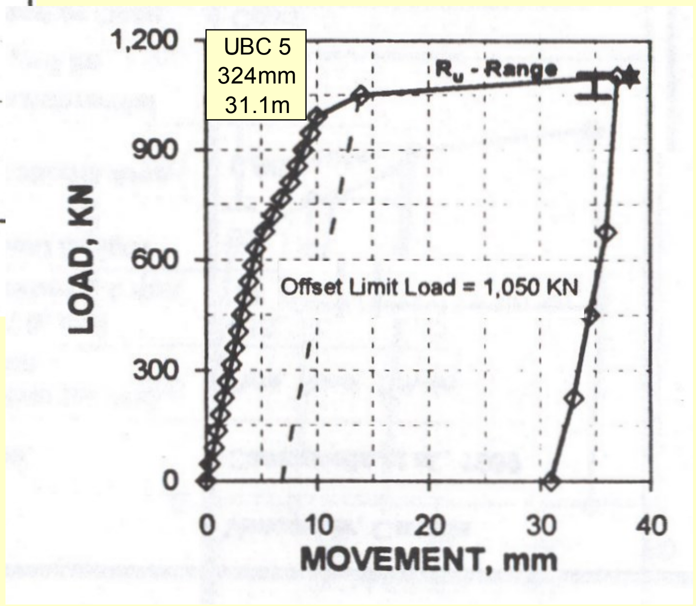
Load-Movement Results from Static Loading Tests



10 weeks after EOID



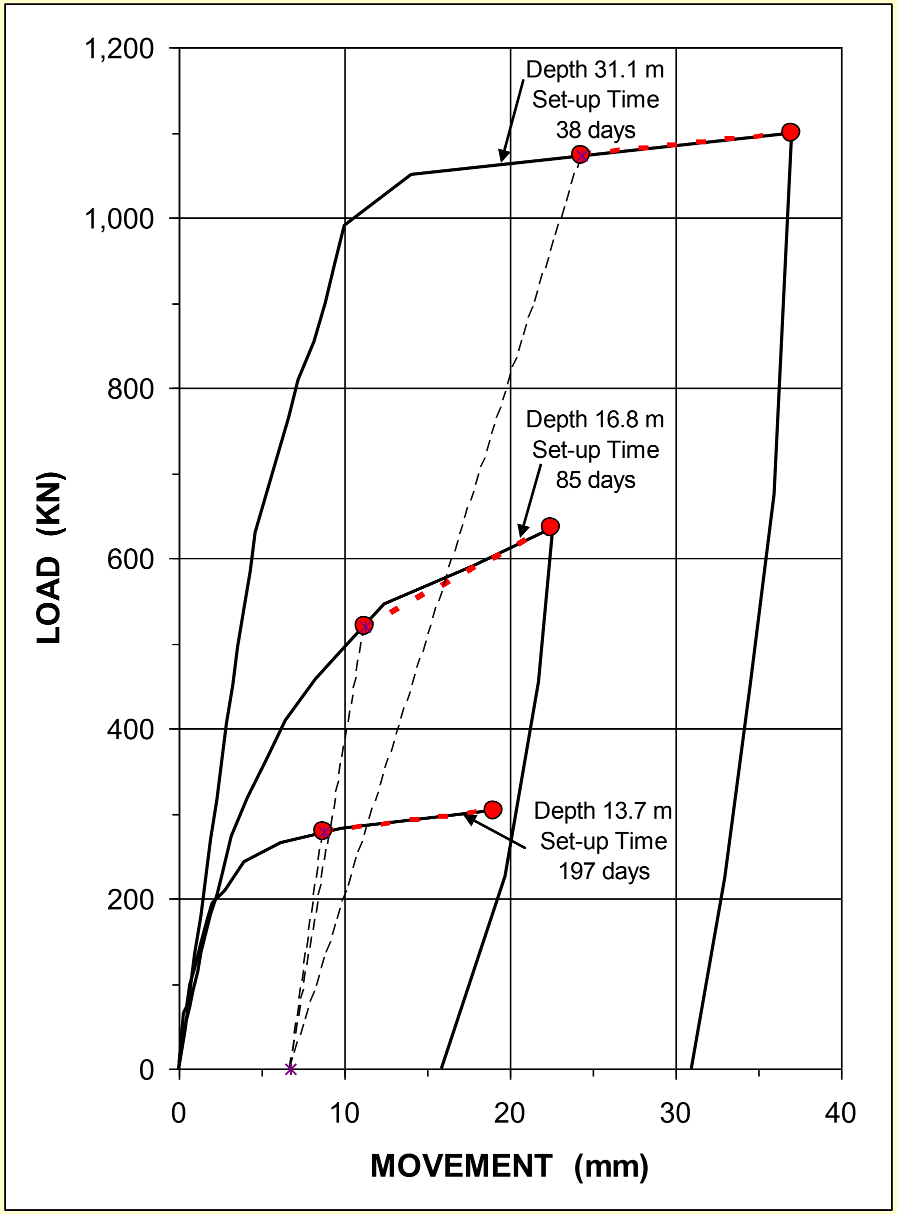
10 weeks after EOID



3 weeks after EOID

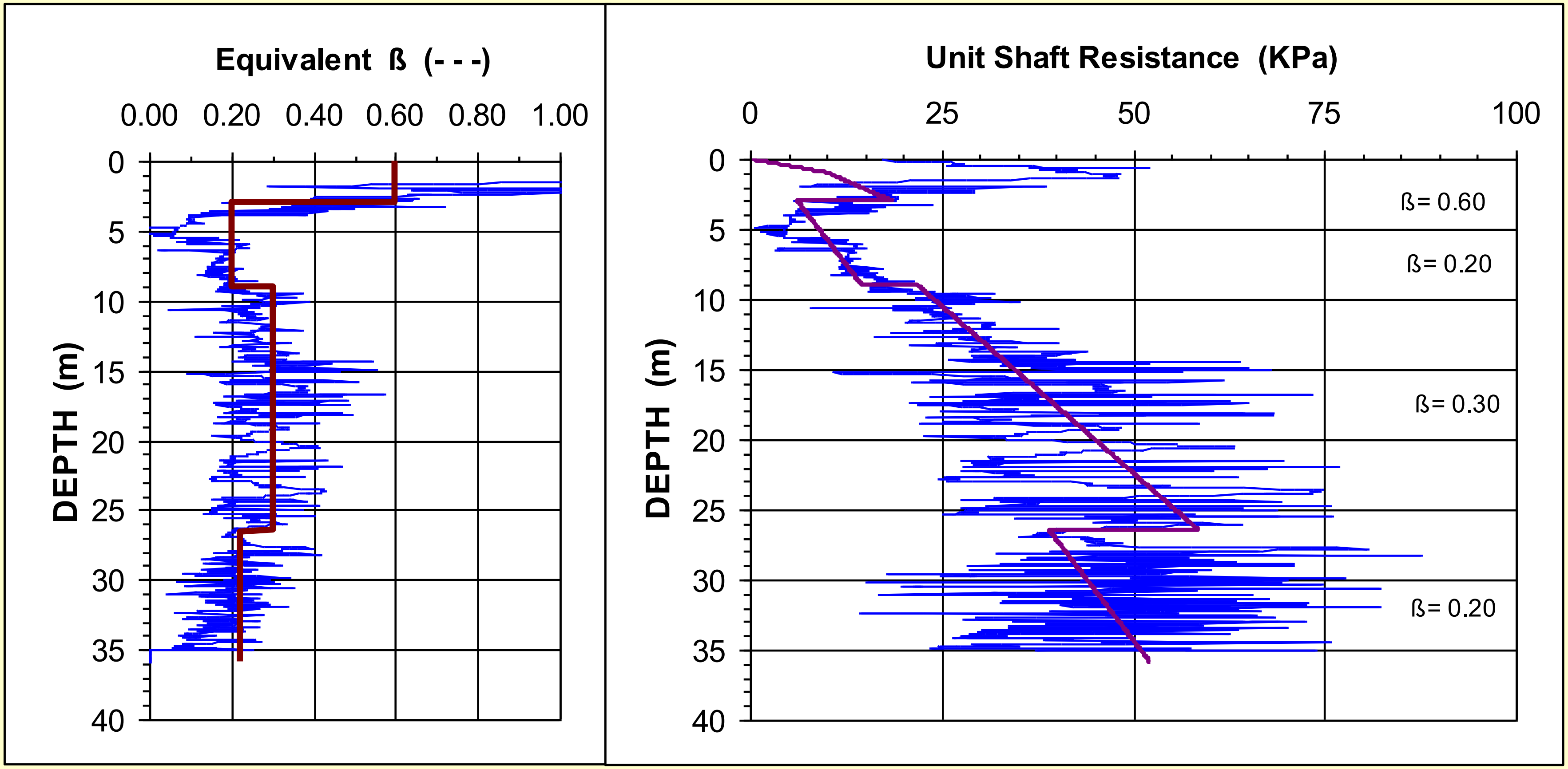
Annacis/Lulu Island Tests
by UBC 1985

The results of the load-movement curves from all three tests combined in one graph. (With offset limit lines and maximum load in the tests).



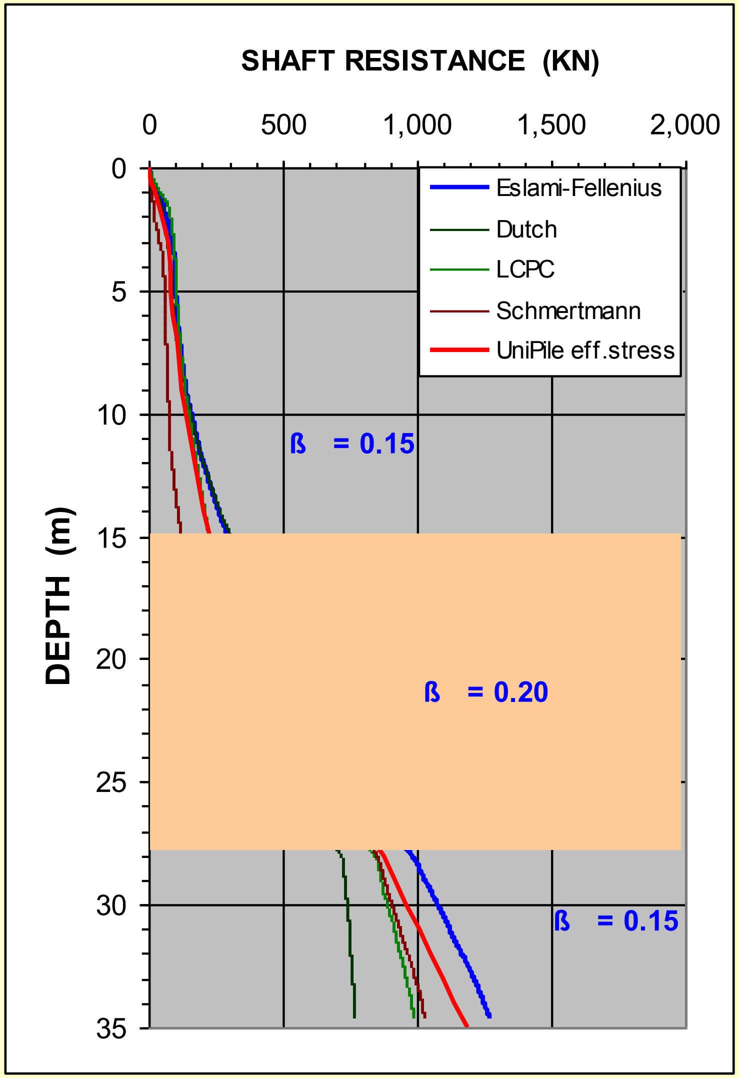
Data from Lulu Island Tests
by UBC 1985

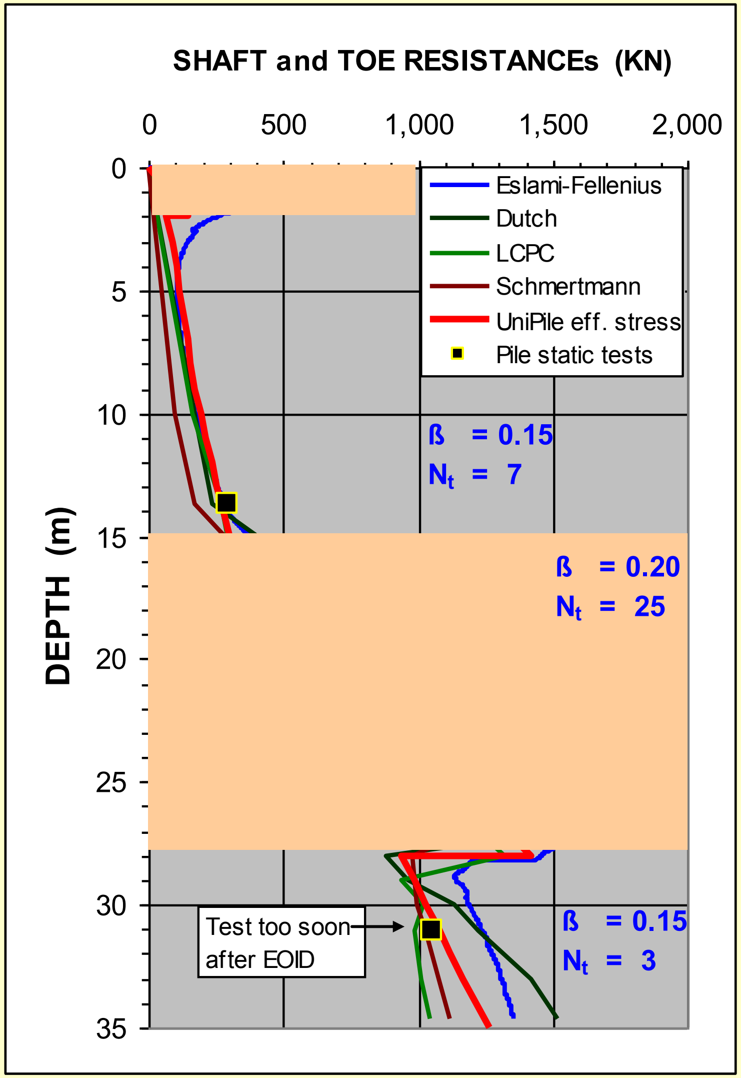
Beta-analysis fitted to CPTU analysis



Data from Lulu Island Tests
by UBC 1985

Results of CPTand CPTU analysis compared to capacity from the static loading tests



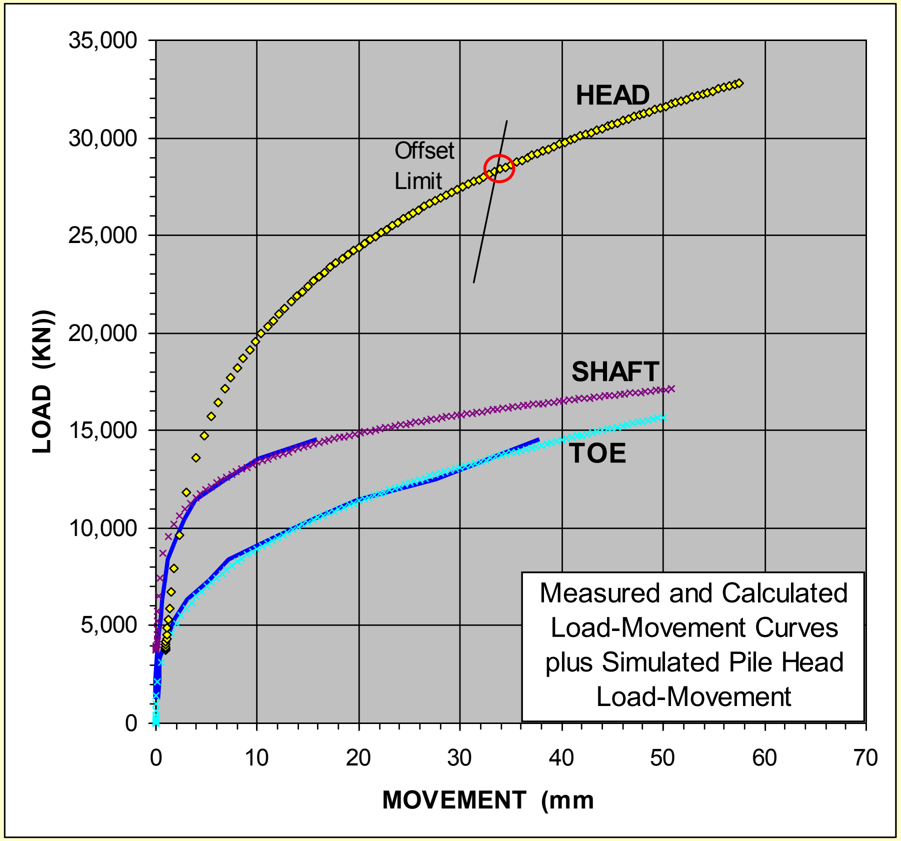


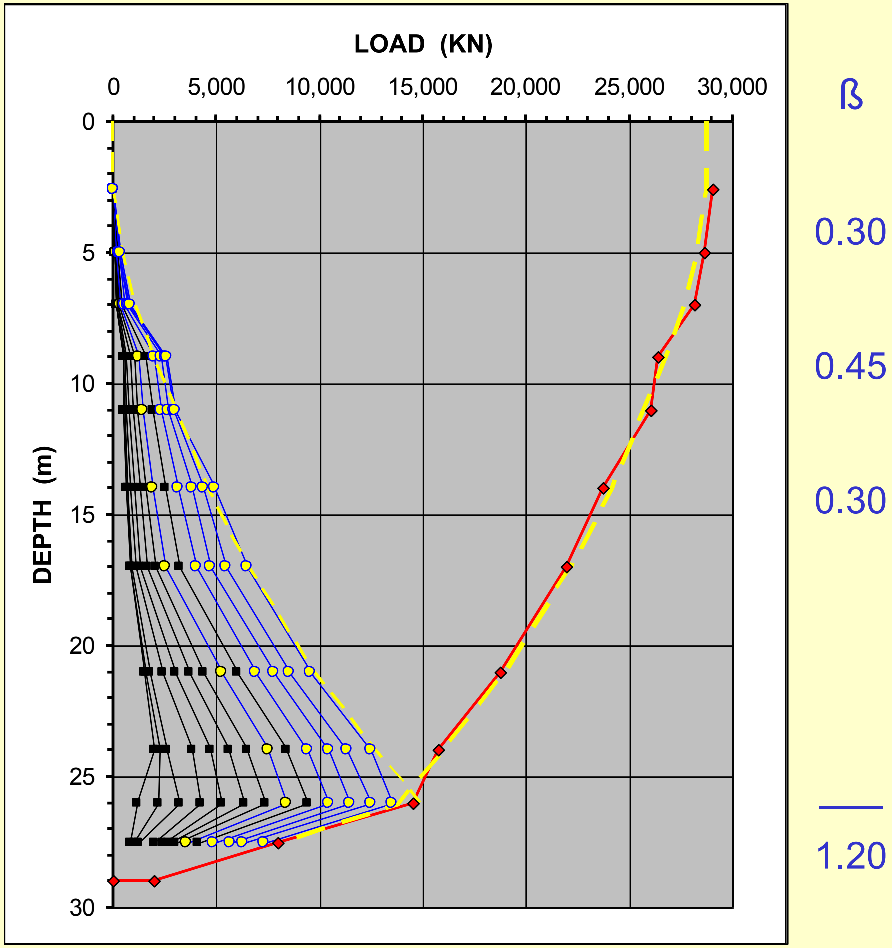
“UniPile” is effective stress analysis matched to results of static tests

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.

Test Results Processed for Design Analysis





The foregoing analysis results are quite good predictions

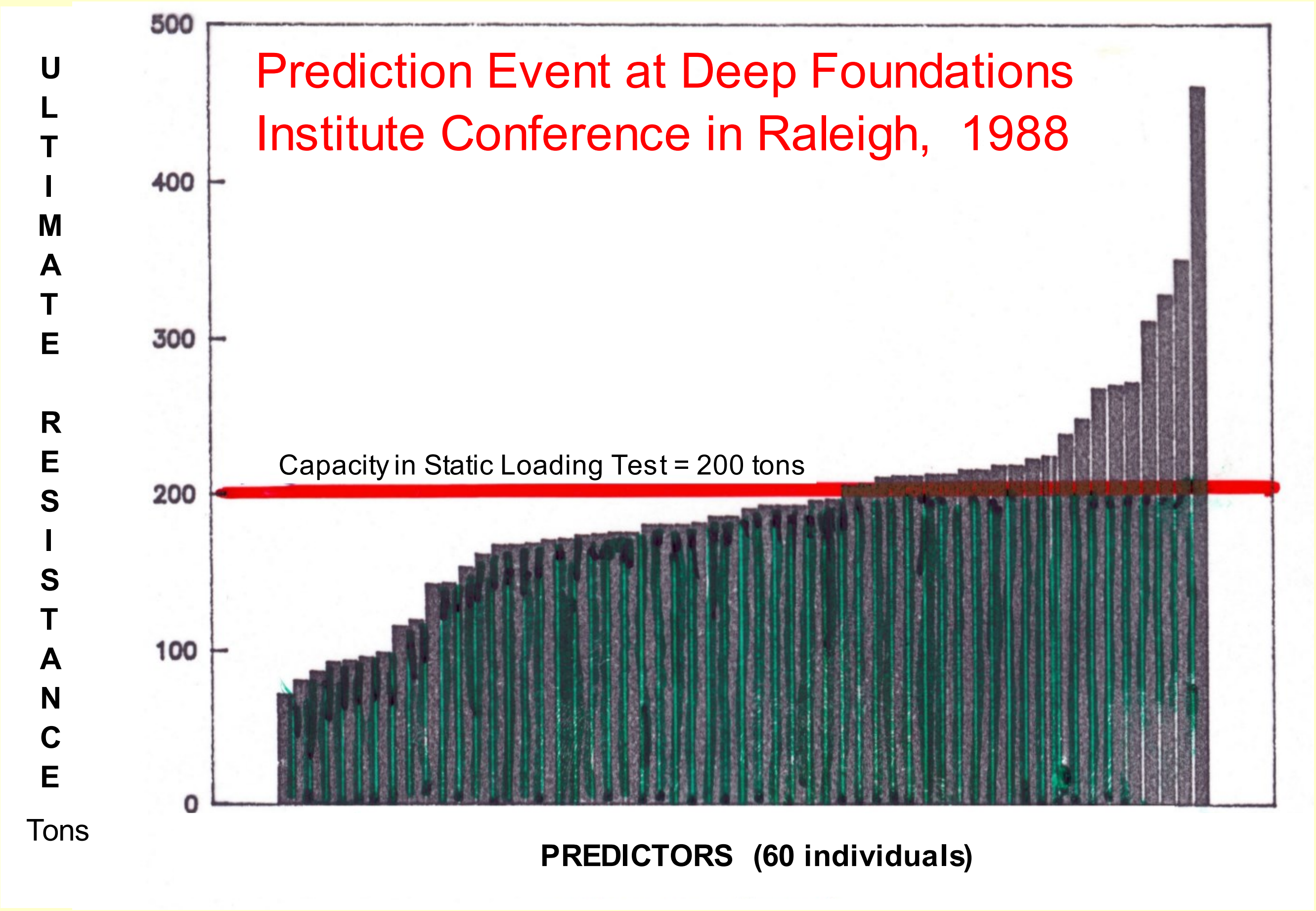
They were performed after the test results were known

Such “predictions” are always the best!

So, what about true predictions?

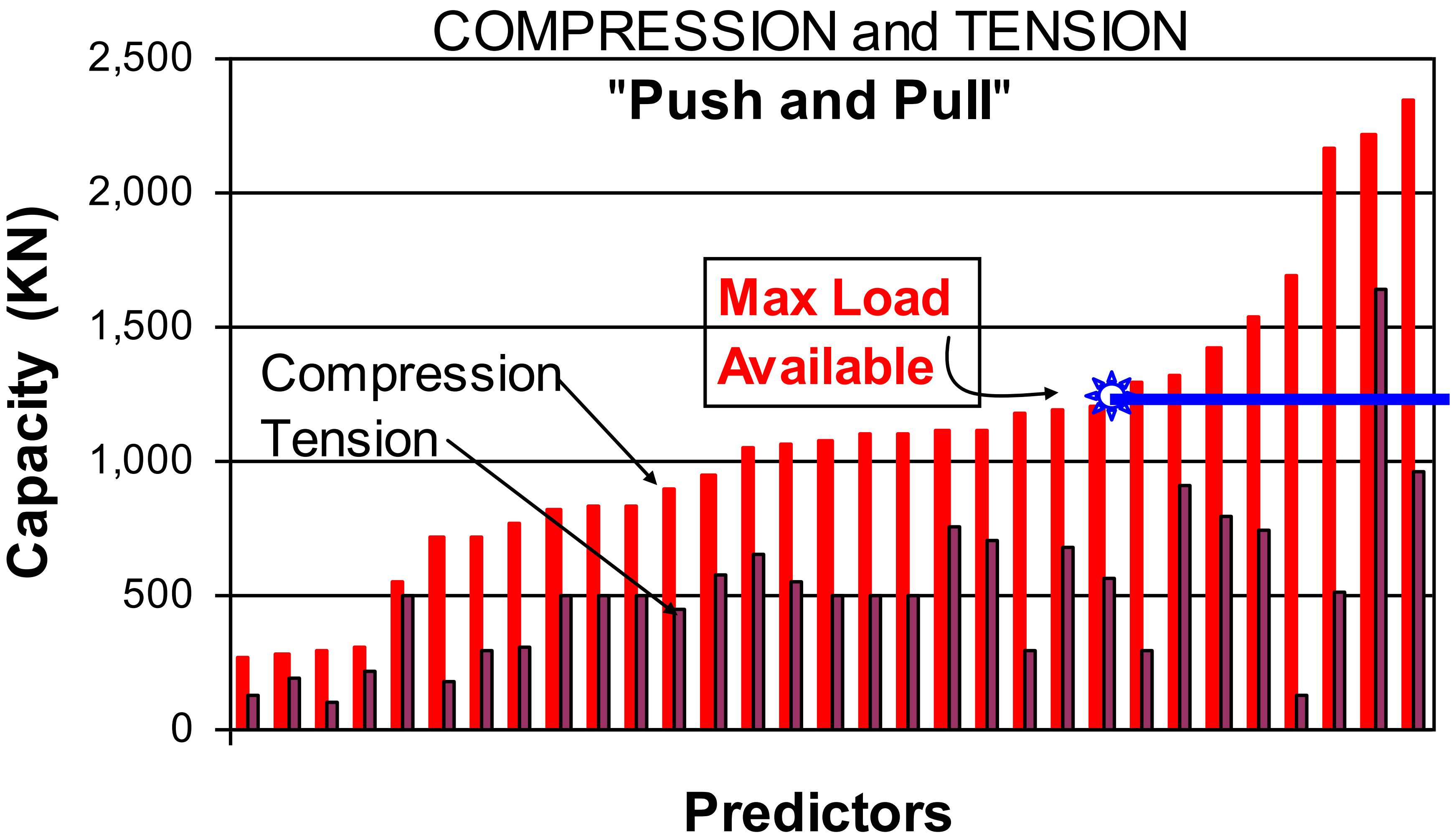
Let’s see the results of a couple of

Prediction Events

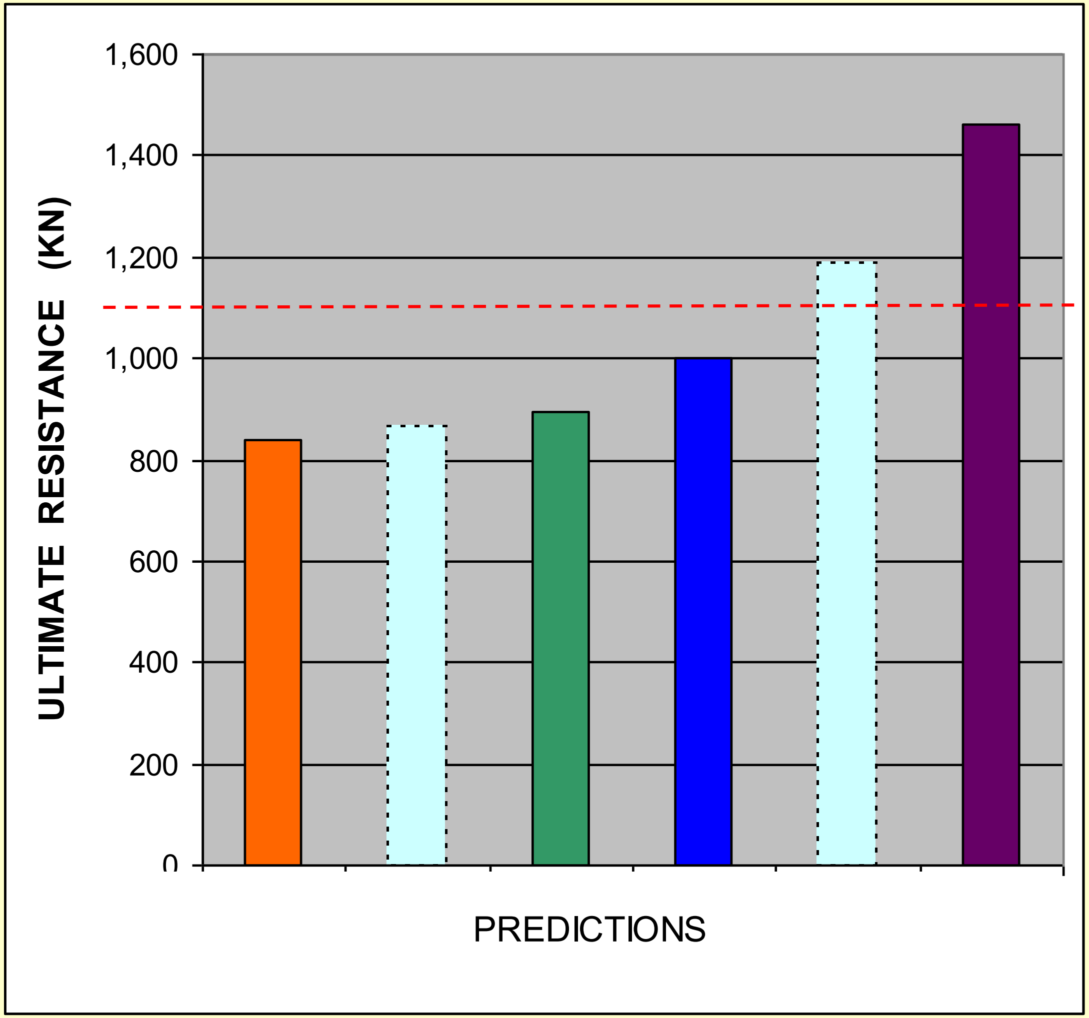


44 ft embedment, 12.5 inch square precast concrete driven through compact silt and into dense sand

Orlando 2002 Predictions



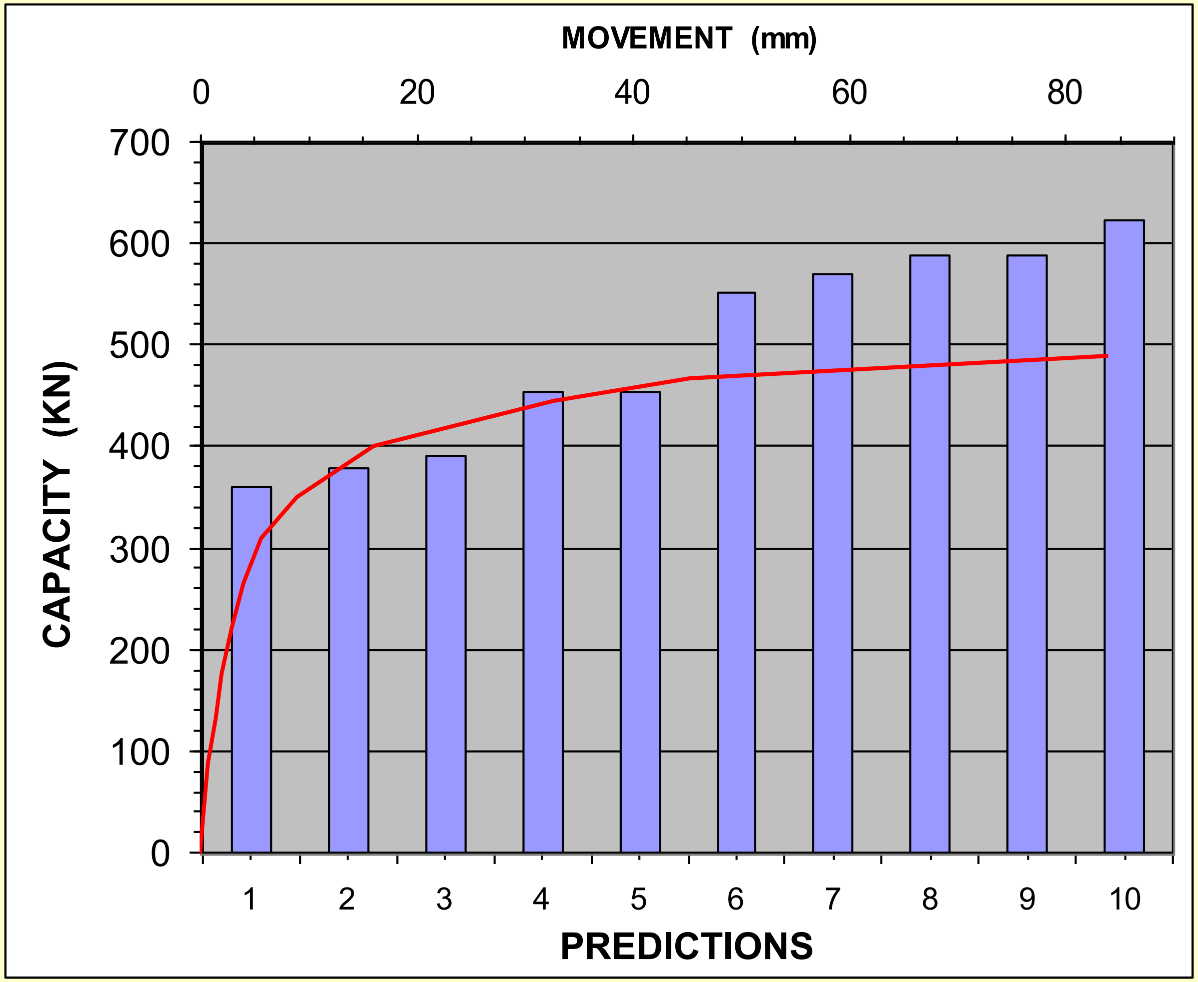
Flanders, Merville, France, 2003



508 mm (20") pipe pile (t = 0.6") driven to 9.4 m embedment in “Flandrian Clay”

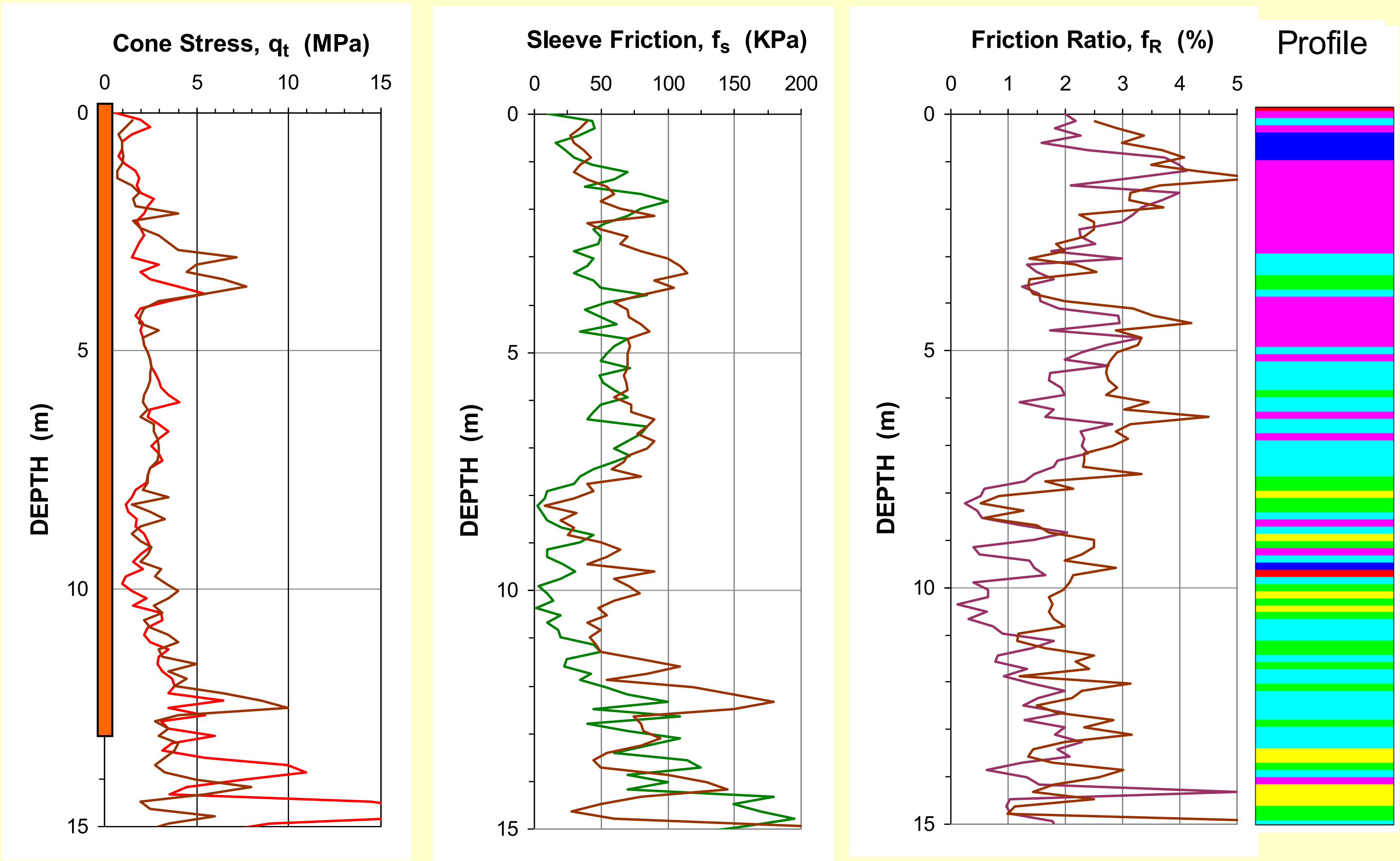
FHWA Washington, DC, 1986

273 mm diam. closed-toe pipe pile driven 9.1 m into hydraulic sand fill

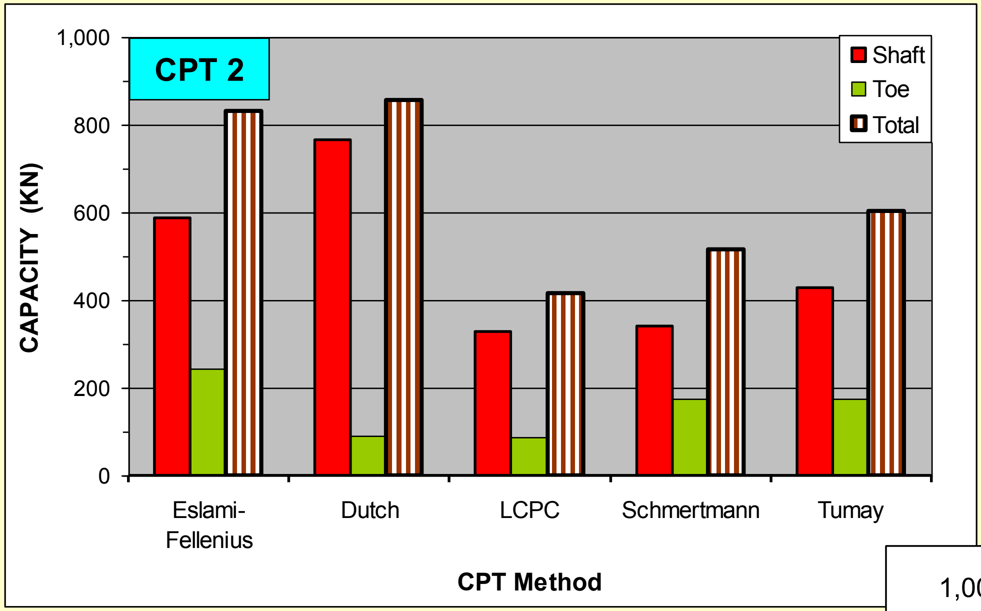


FHWA Baltimore, MD, 1980

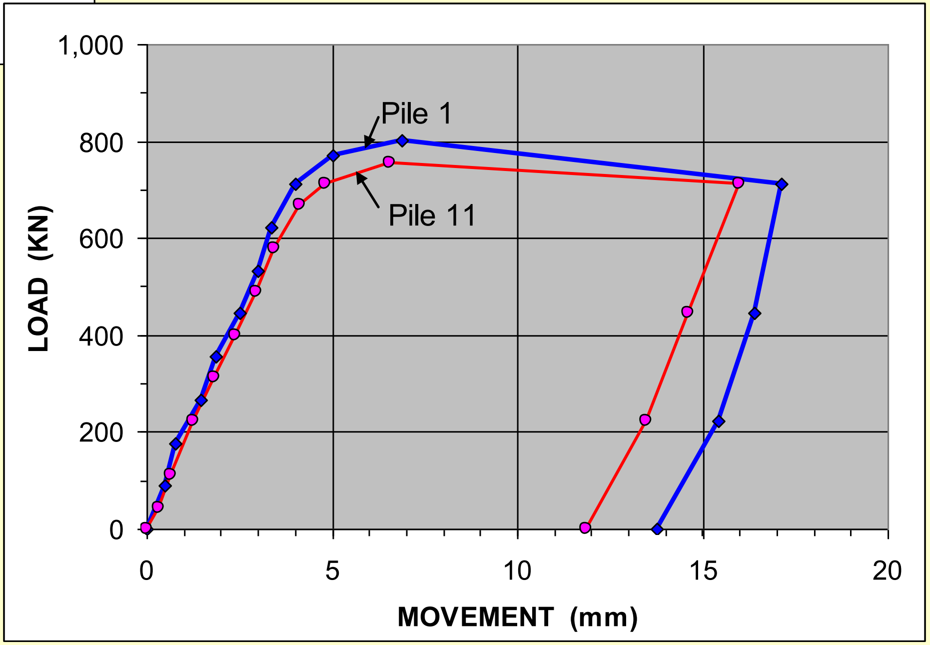
273 mm diam. closed-toe pipe pile driven 13.1 m into Beaumont clay



Data from Yamane and Wu 1979, and Vesic 1980, and O'Neill 2000

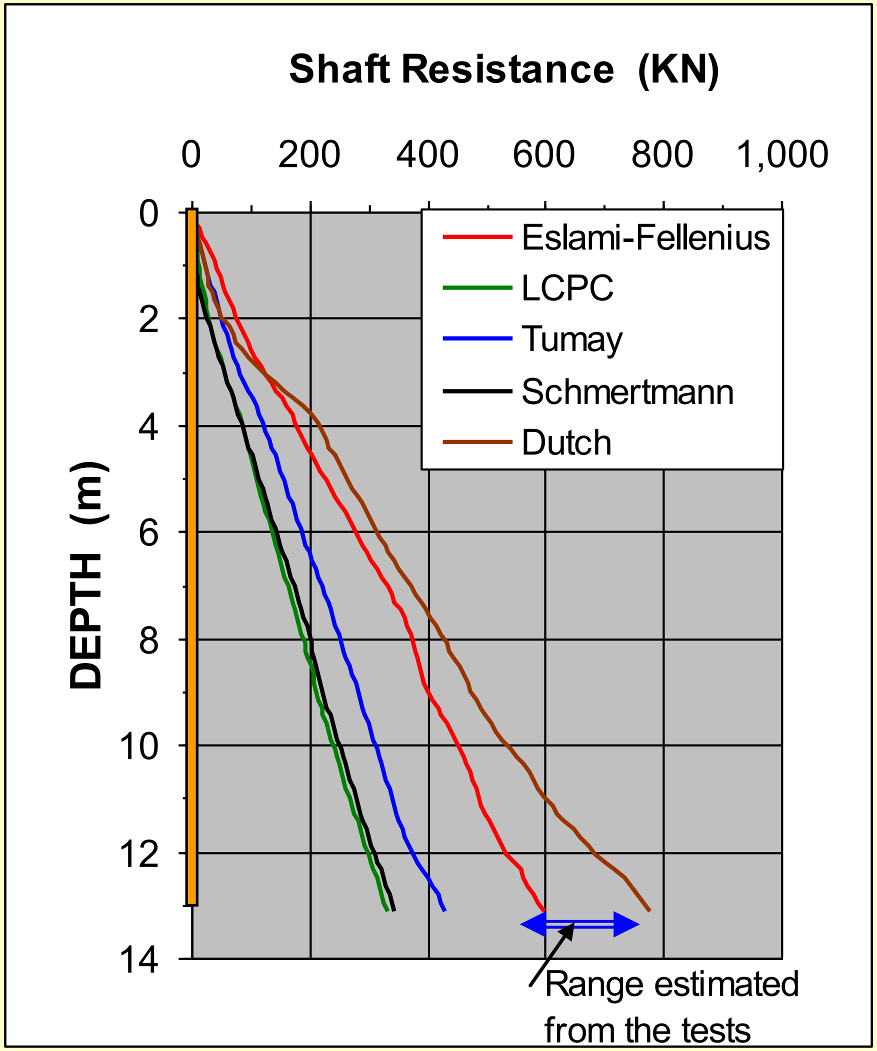


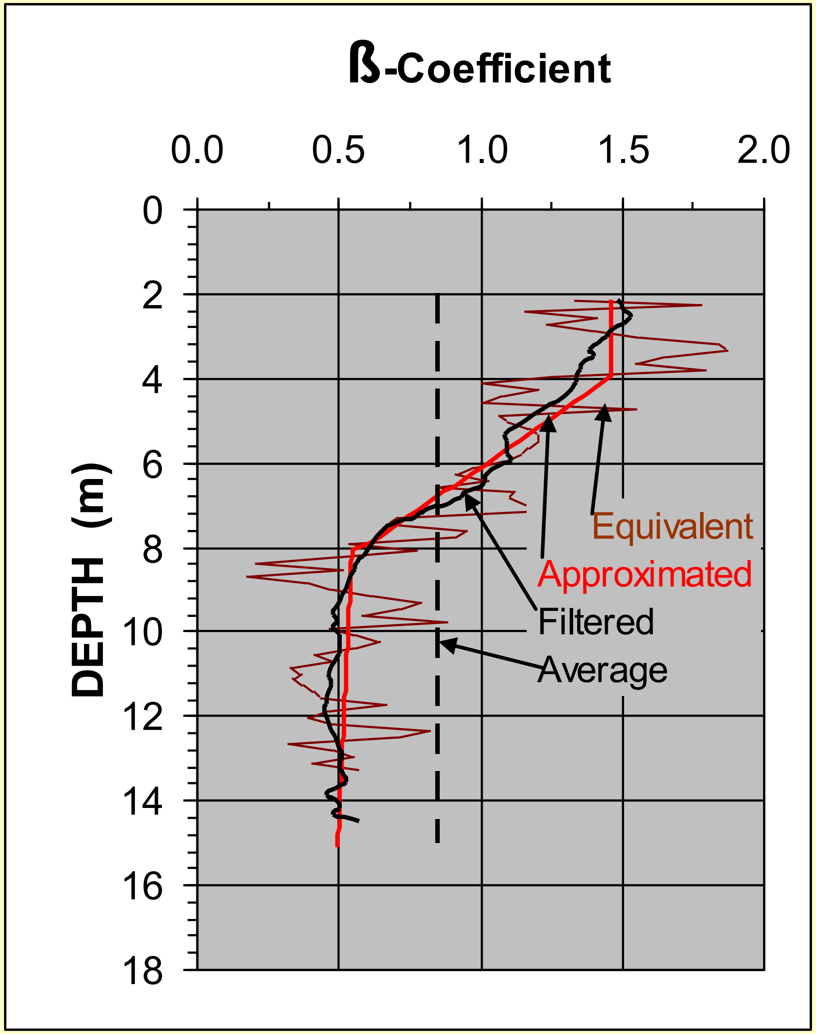
Results of static loading tests on the two single piles



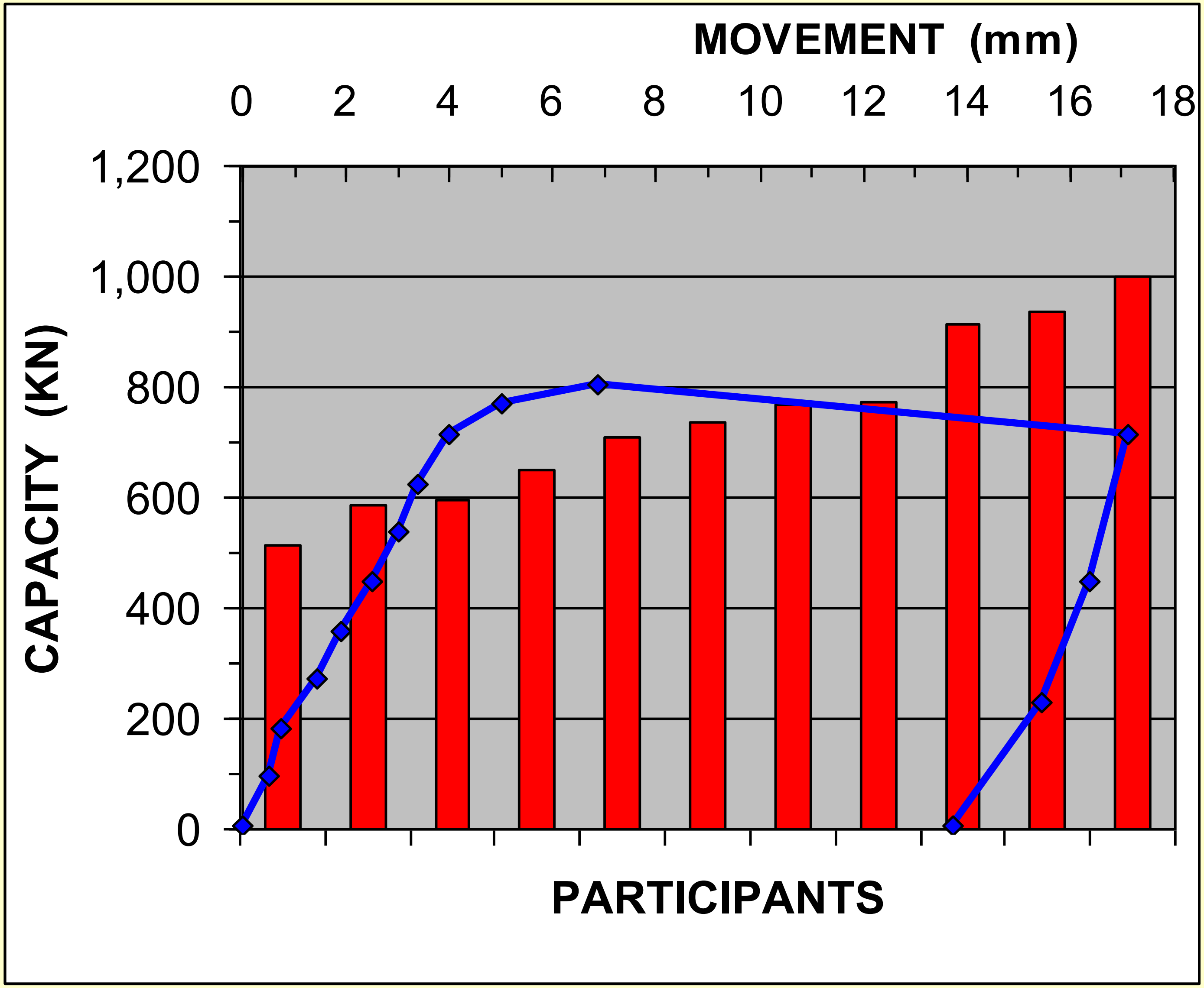
Total shaft resistance can be estimated to be about 600 KN. Of course, the actual value can differ quite a bit from this.

A shaft resistance of 600 KN corresponds to an average unit shaft resistance of 50 KPa.

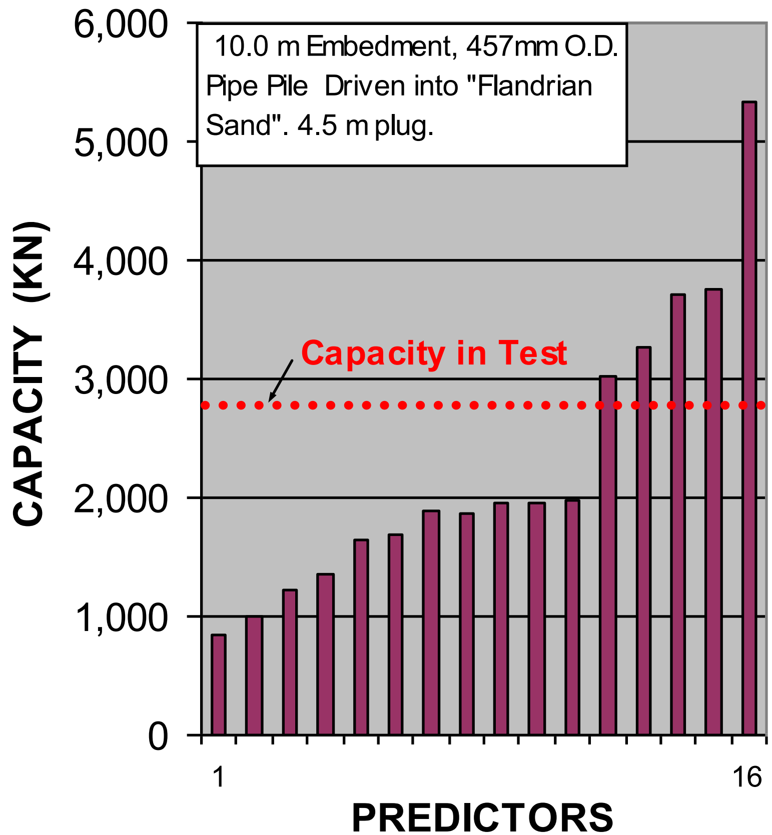


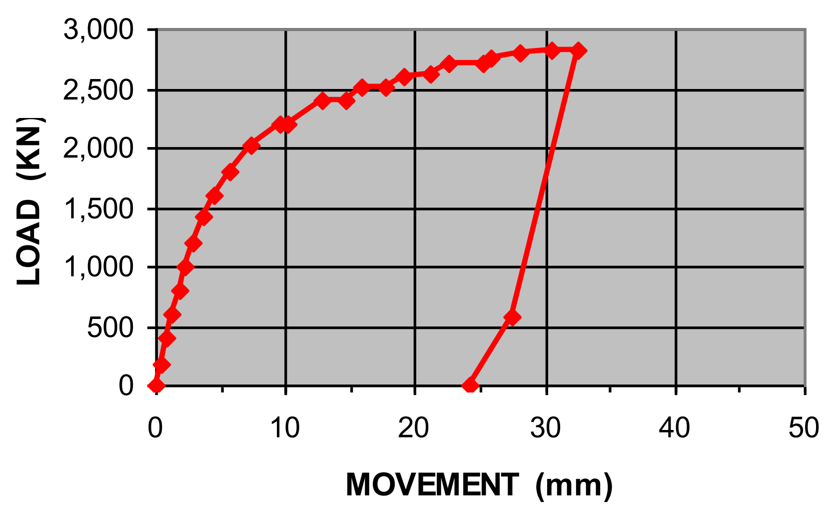


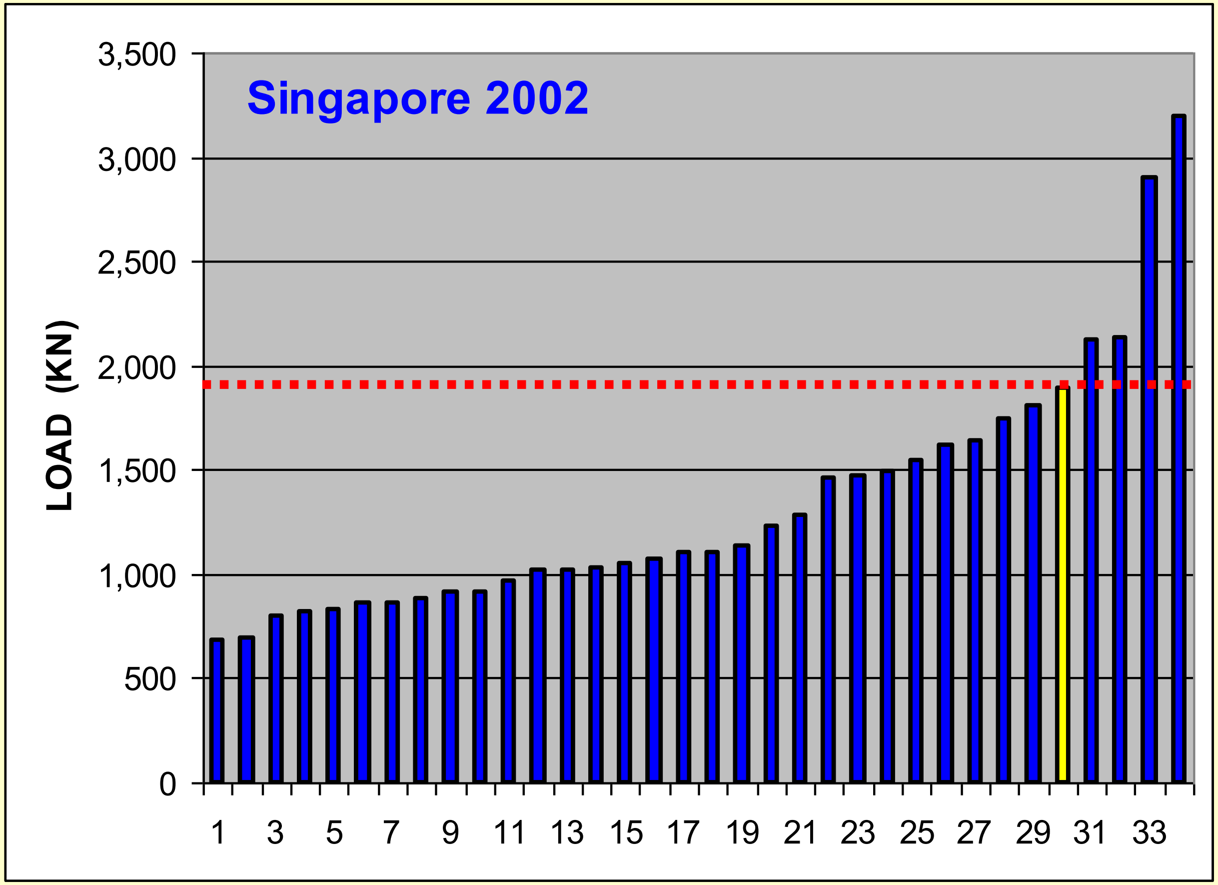
Calculations from the CPT soundings

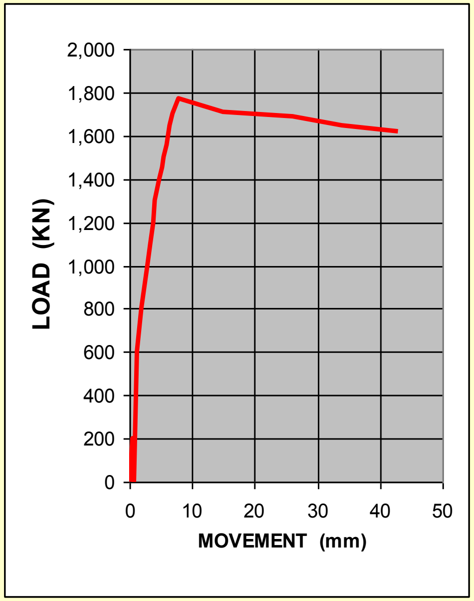

MOVEMENT (mm)
0
2
4
6
8
10
12
14
16
18
1,200
1,000
800
600
400
200
0
CAPACITY (KN)
PARTICIPANTS

Imperial College Prediction Event 1999

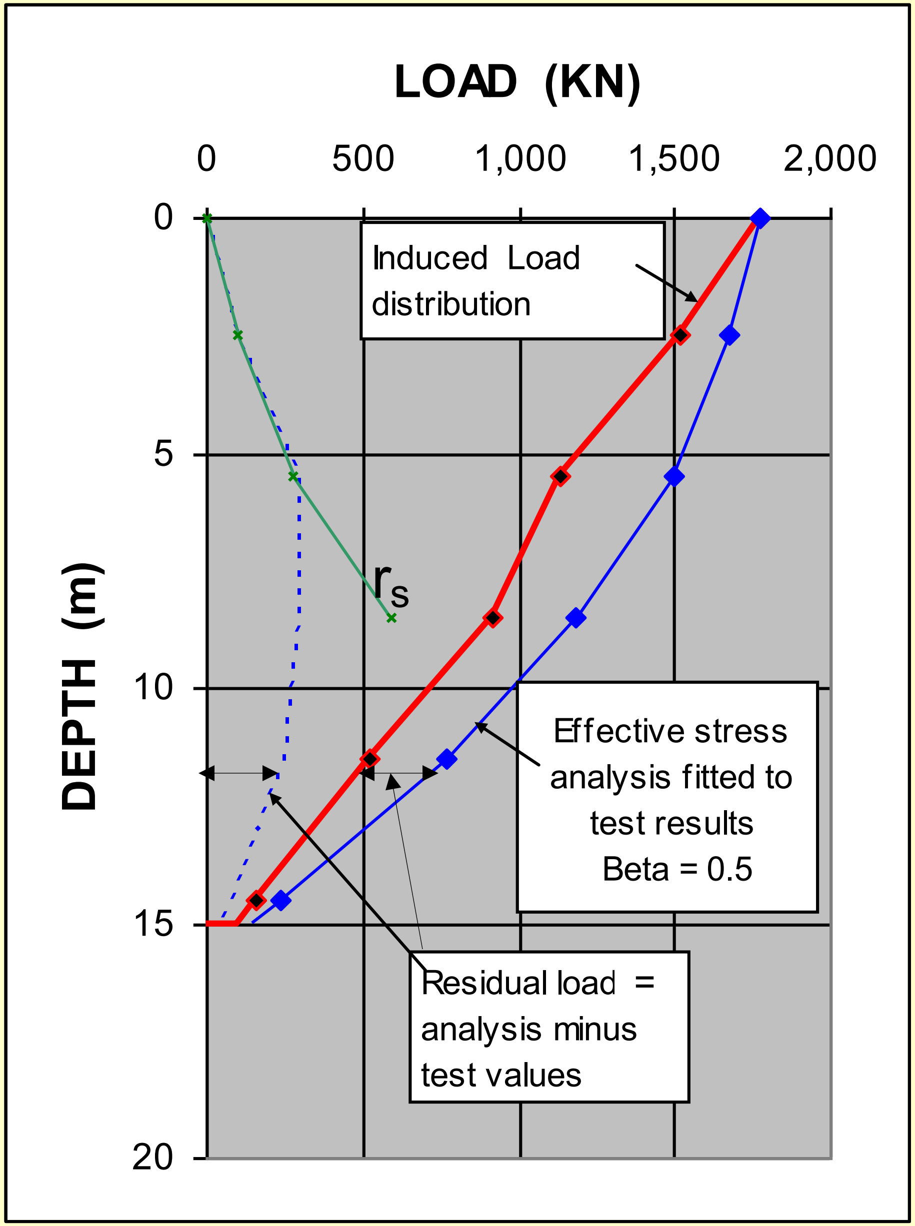








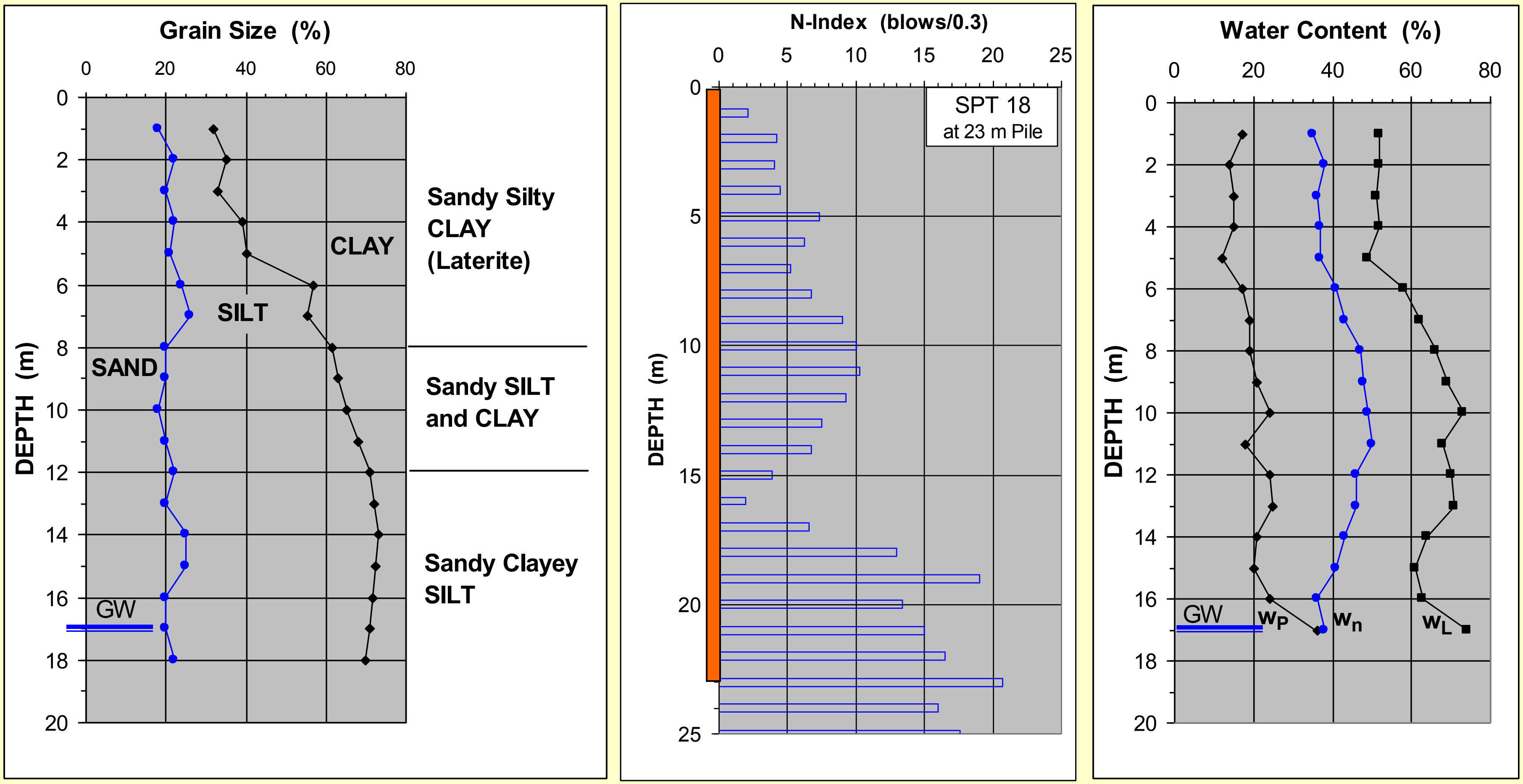
400 mm H-Pile (168 kg/m) driven through sandy clay to a 15 m embedment



SINGAPORE

Measured and Calculated Load Distributions

Brazil 2004: Bored pile (Omega screw pile) 23 m long, 310 mm diameter

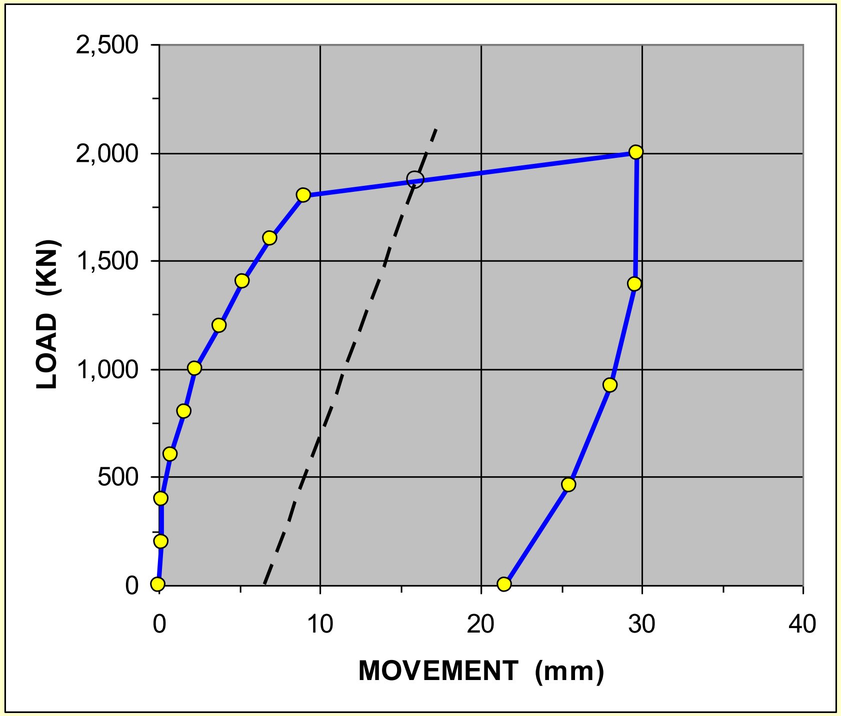


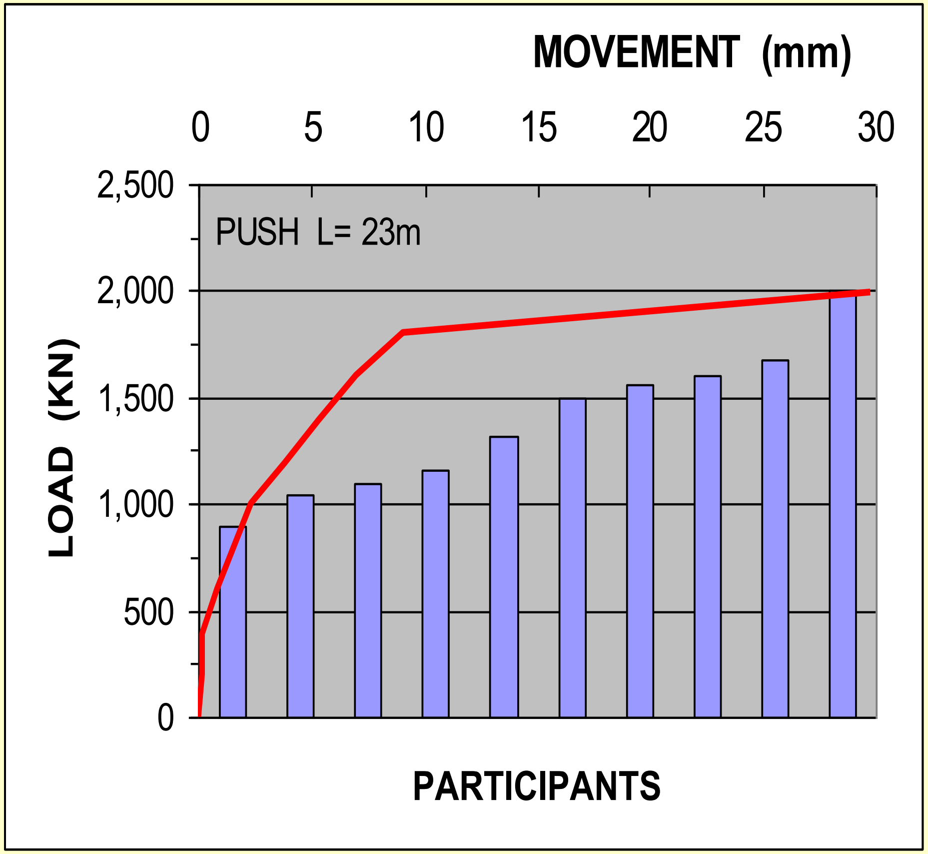
Prediction Compilation

Static Loading Test

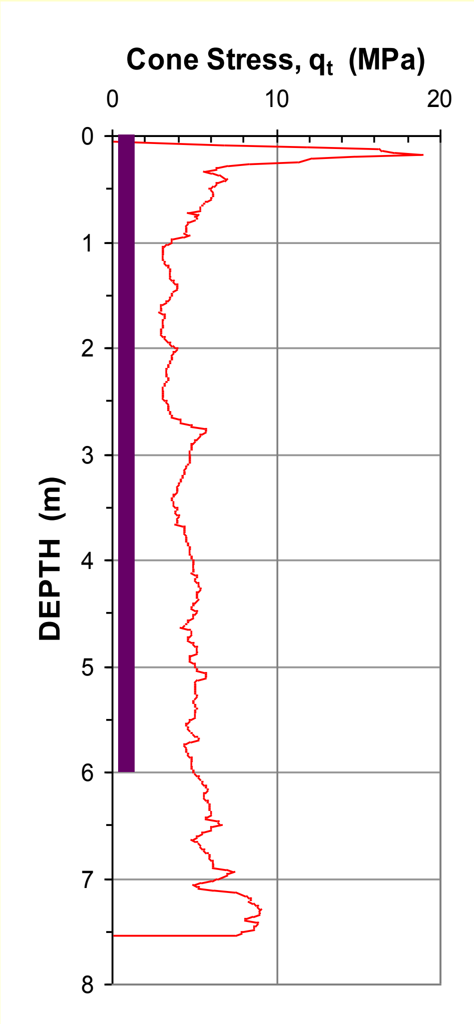
on a 23 m 310 mm bored pile

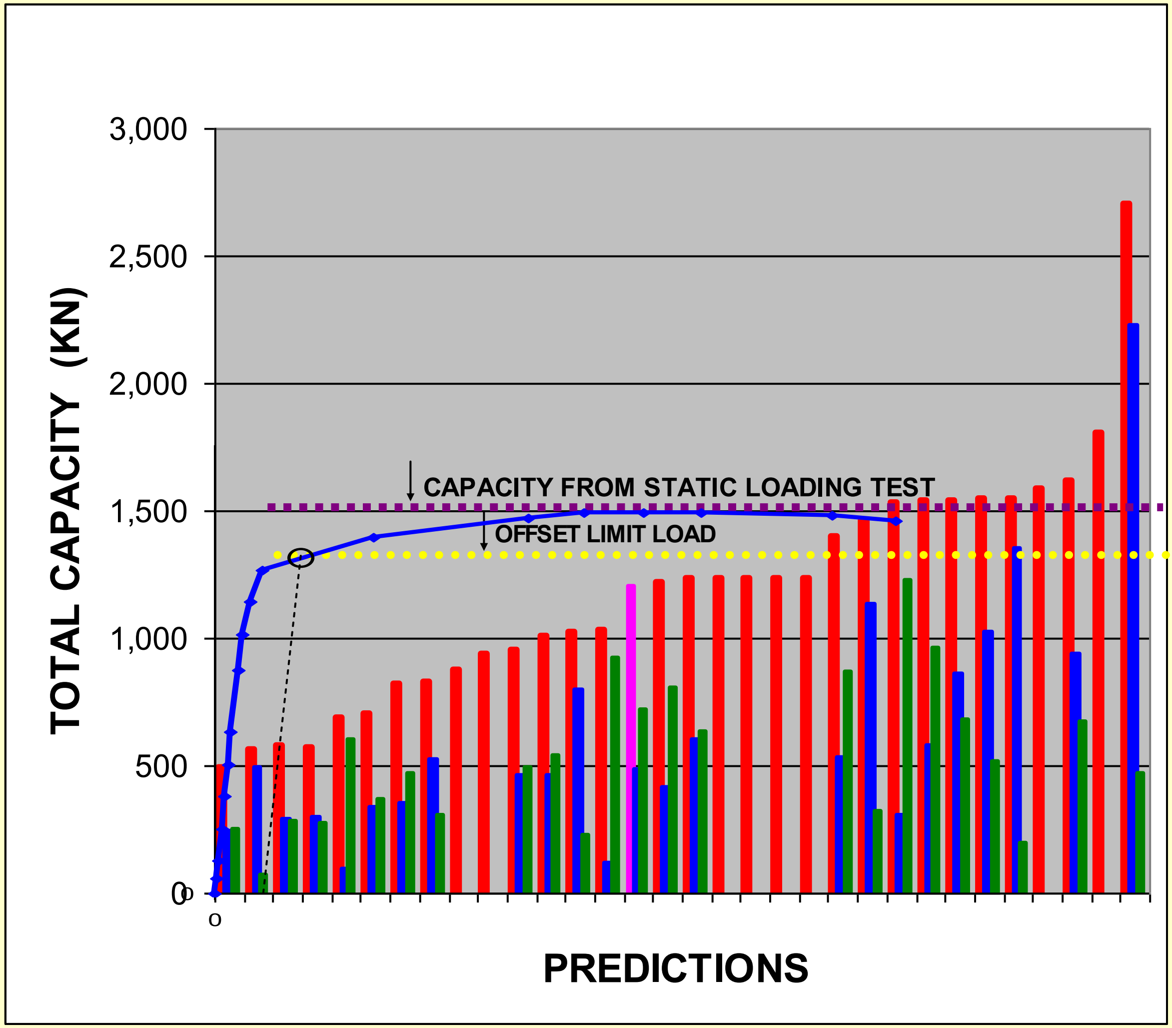
Load-Movement Response



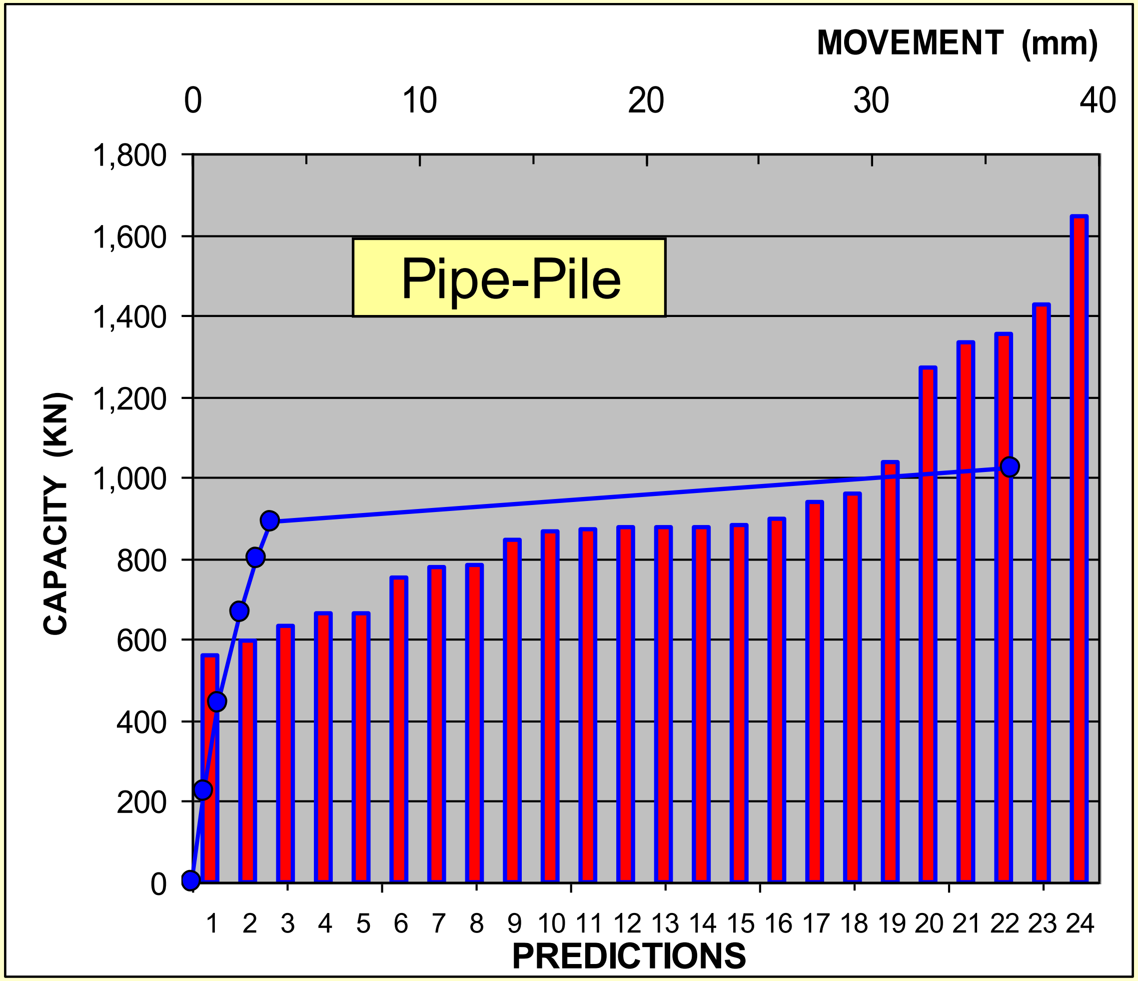


Portugal 2004. Precast 350 mm diameter pile driven to 6 m depth in a saprolite, a residual soil consisting of silty clayey sand.



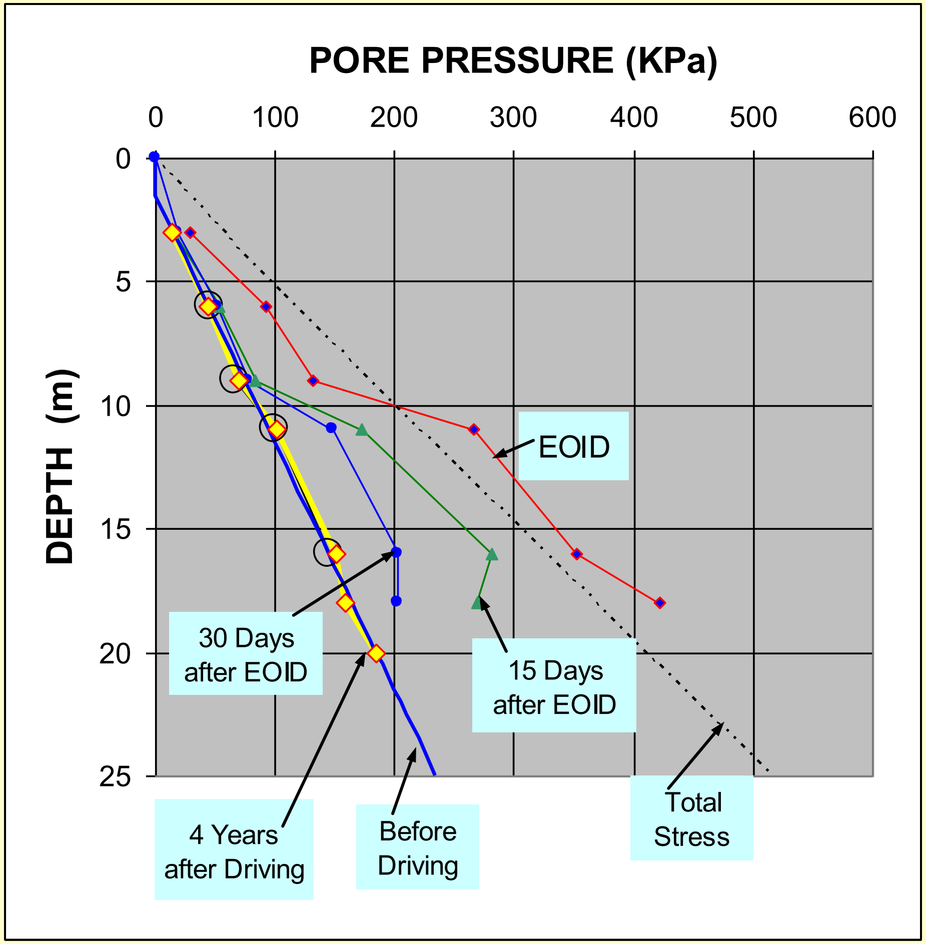


Northwestern University, Evanston, Illinois, 1989.
15 m embedment, 457 mm diameter closed-toe pipe piles driven in sand on clay.



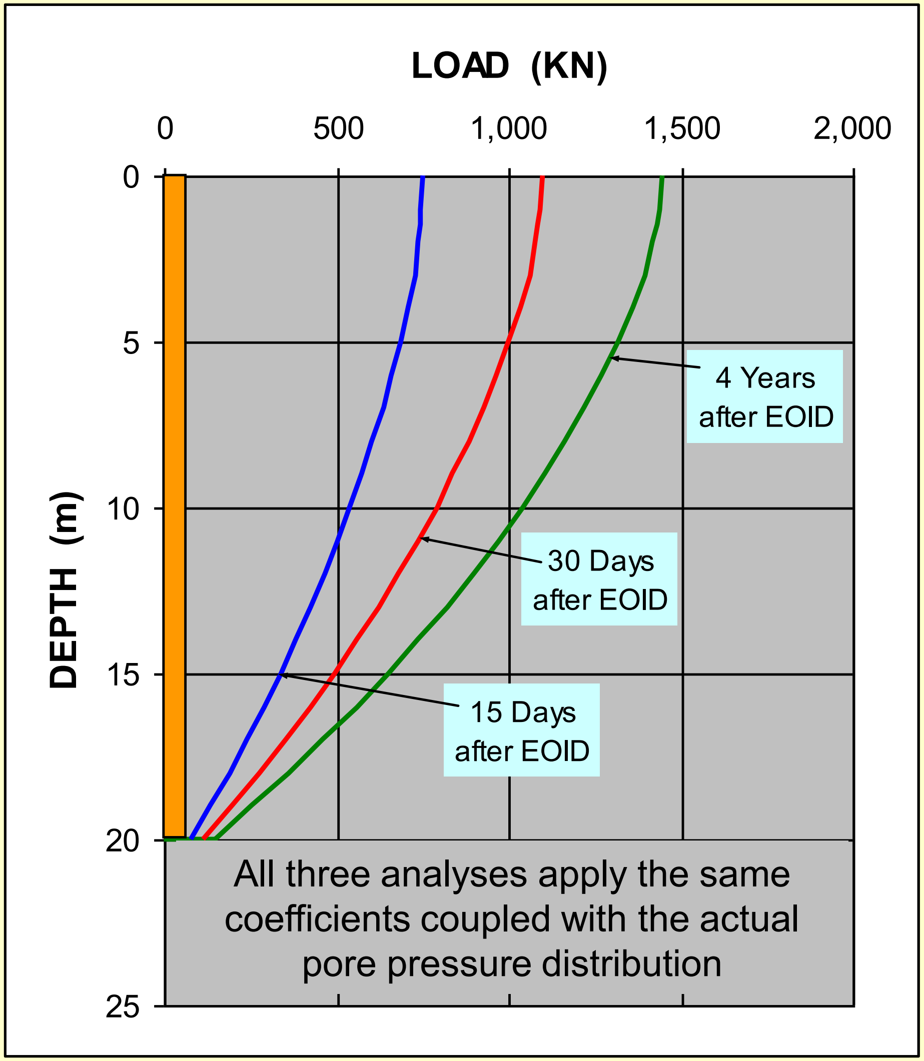
Finno 1989

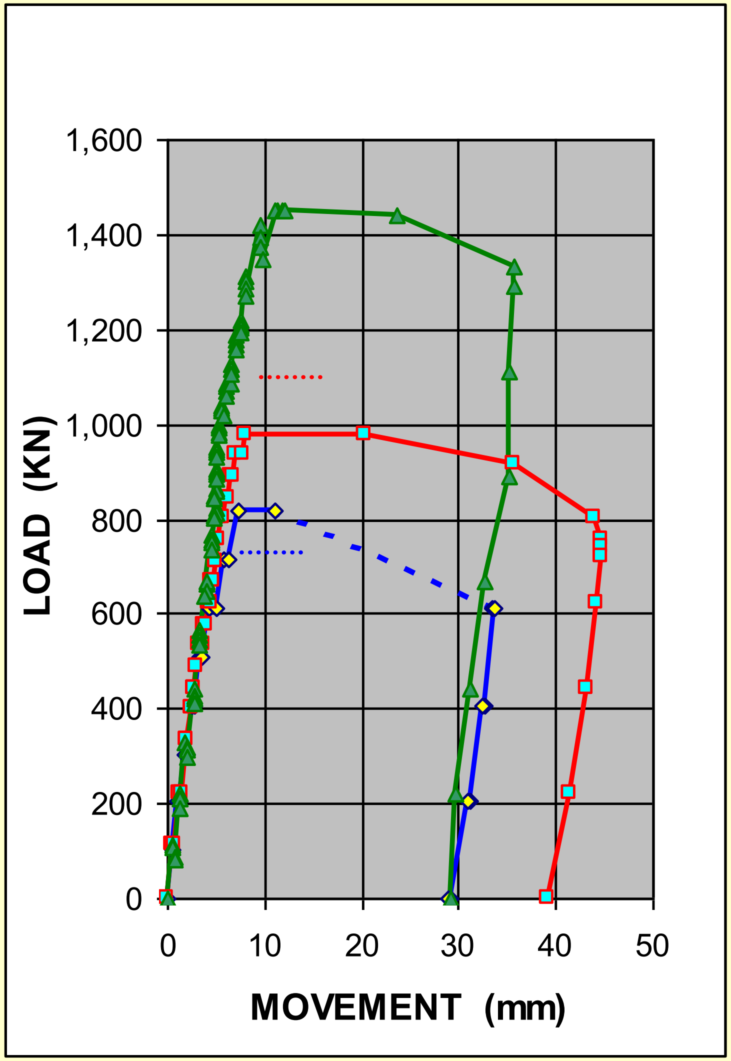
Pore Pressure Dissipation



Paddle River, Alberta, Canada

Effective Stress Analysis Matching 4-Year Capacity





Paddle River, Alberta, Canada

Miscellaneous Details

Open vs. Closed Toe

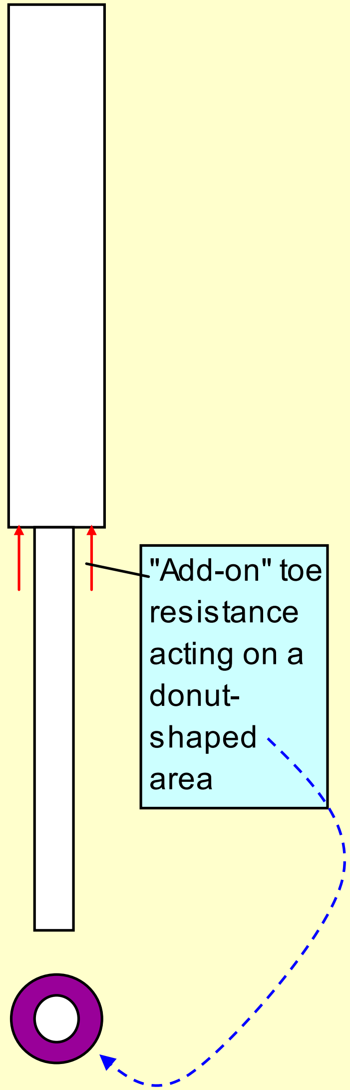
Tapered section

H-section

. . . .

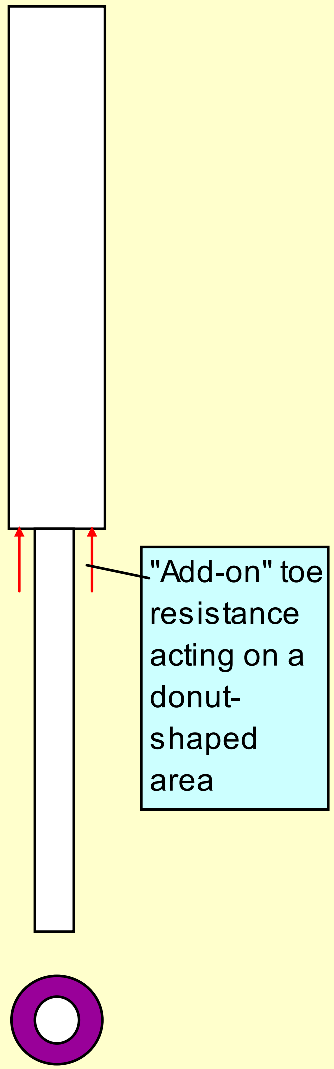
Special Conditions

Step-tapered pile



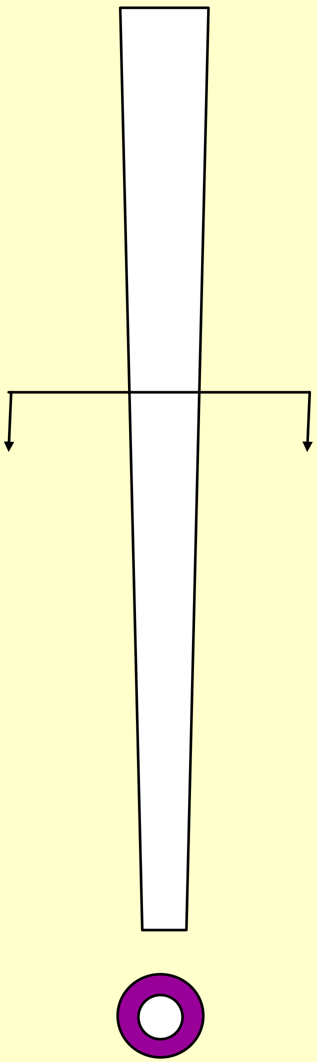
Special Conditions

Step-tapered pile



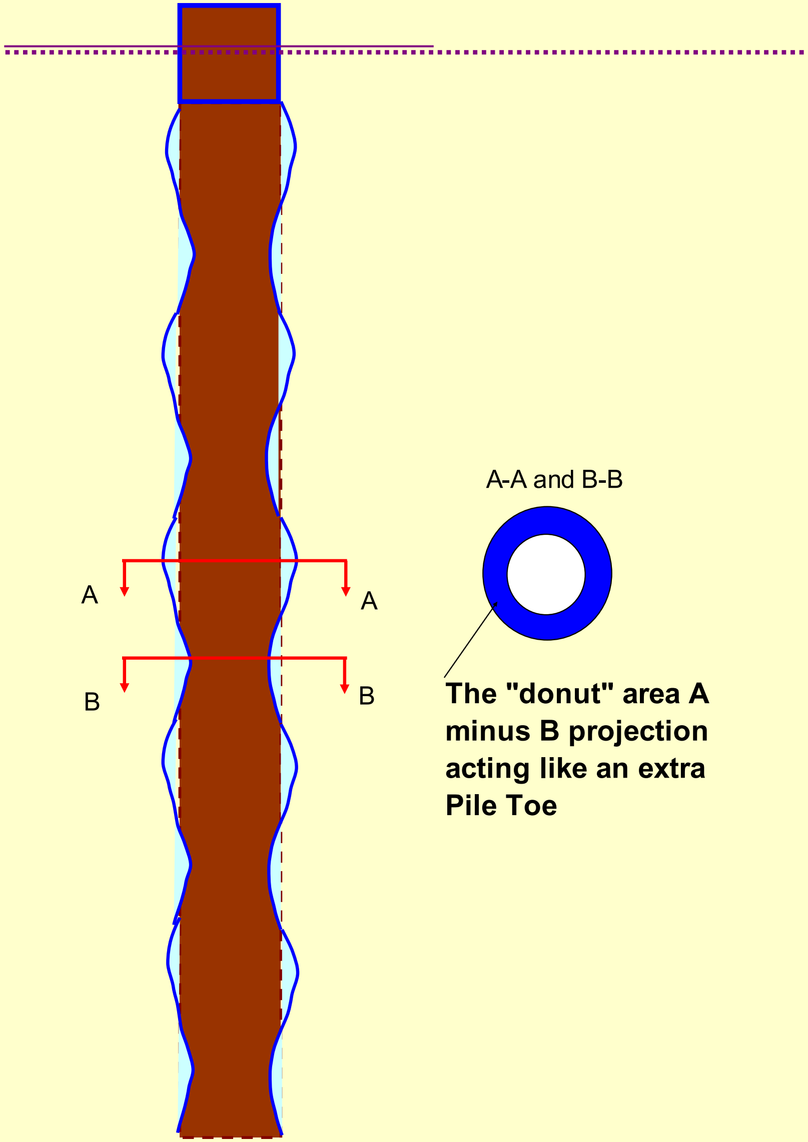
Smooth-tapered pile

Conical pile (wood pile)



Calculate in elements (increments) at every metre or so the shaft resistance acting along the pile and toe resistance for the "donut" of each element

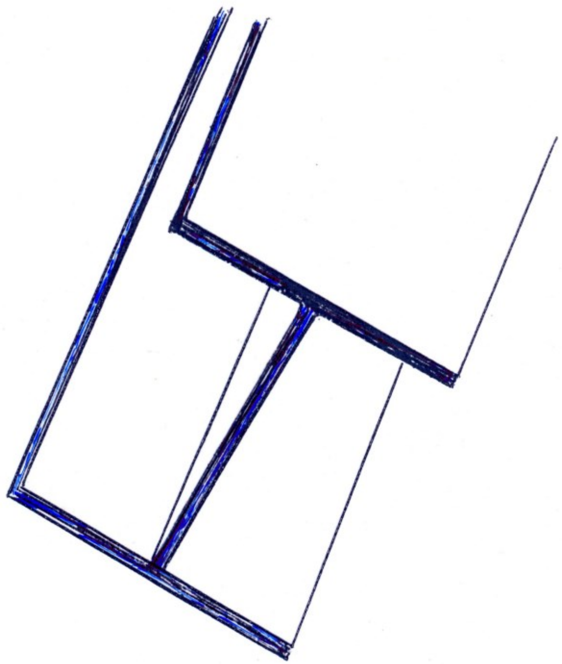
Just because the design assumes that the pile shaft is smooth and straight with parallel sides does not mean it is.

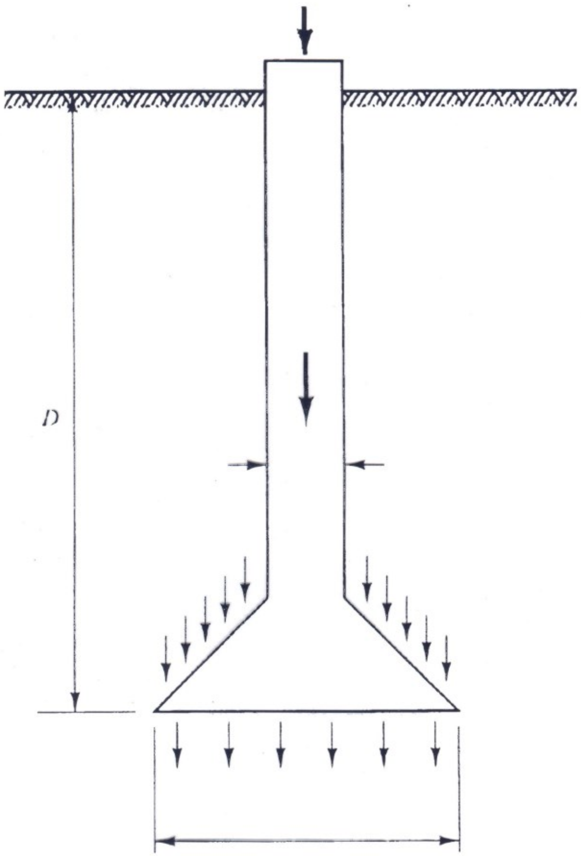


An unintentional effect for many bored piles and intentional for “multi-underreamed” piles

THE H-PILE

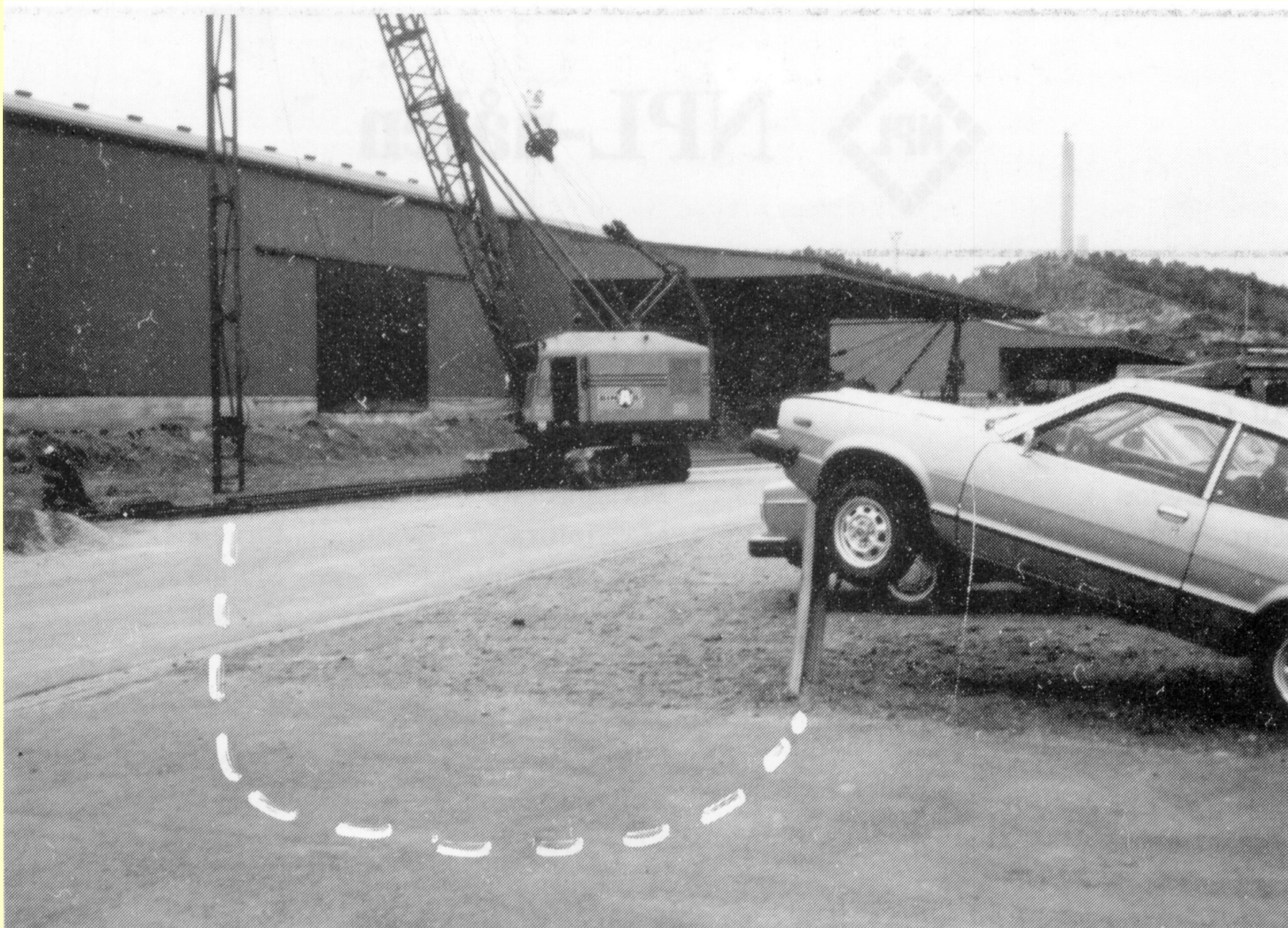
SHOULD WE USE THE SQUARE OR THE CROSS SECTION?

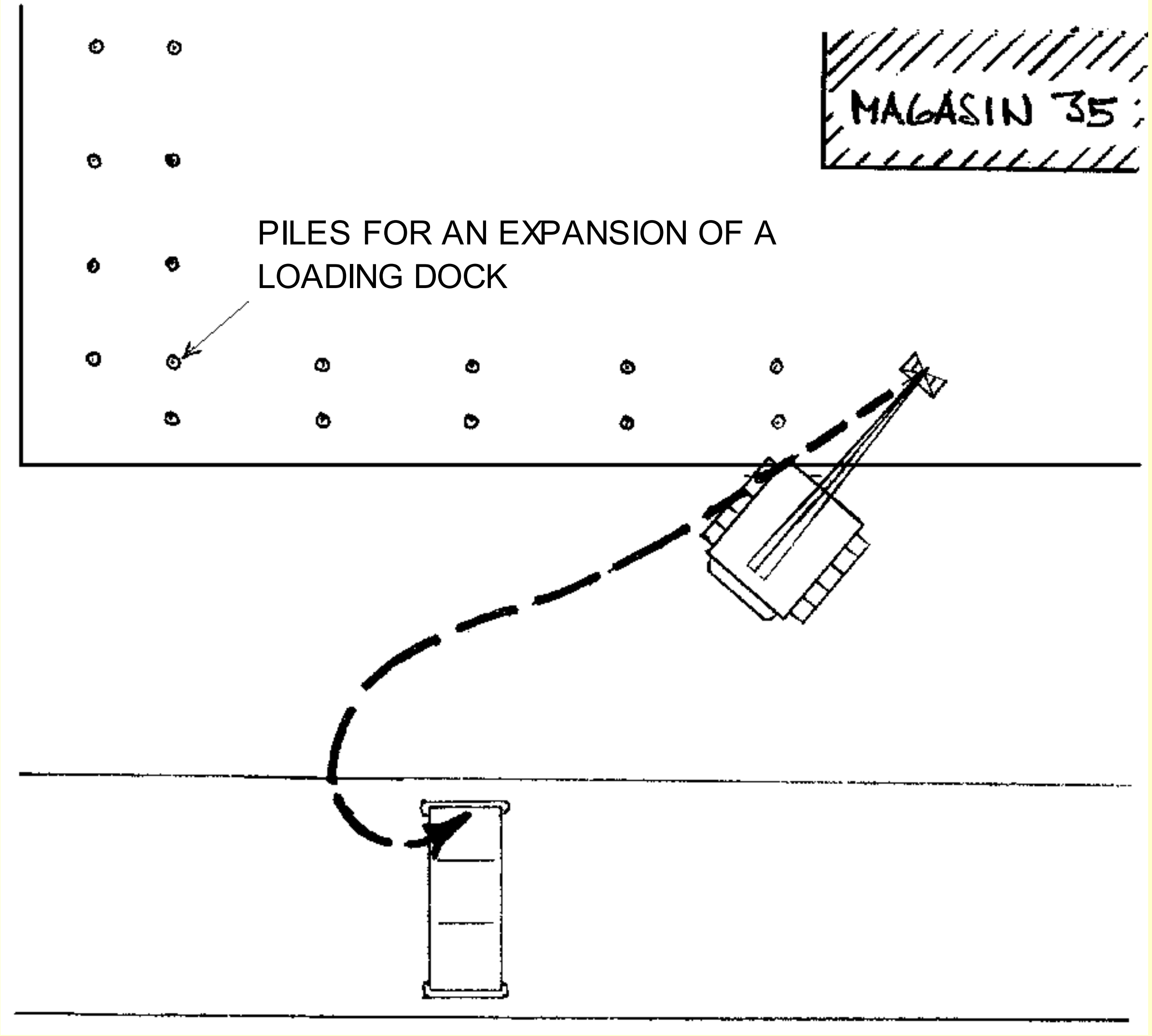




Belled Caisson — “Chicago” style


EJD 798




MAGASIN 35
PILES FOR AN EXPANSION OF A LOADING DOCK

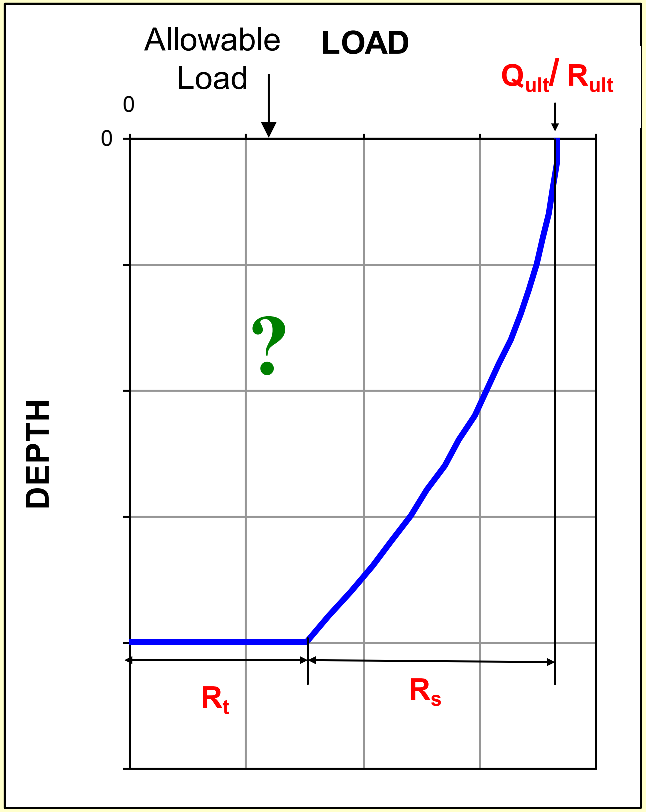

EJD 798
MOUND

Well, we have calculated the pile capacity (by one or more of the analysis methods presented in the foregoing) and we have established the load-transfer curve.

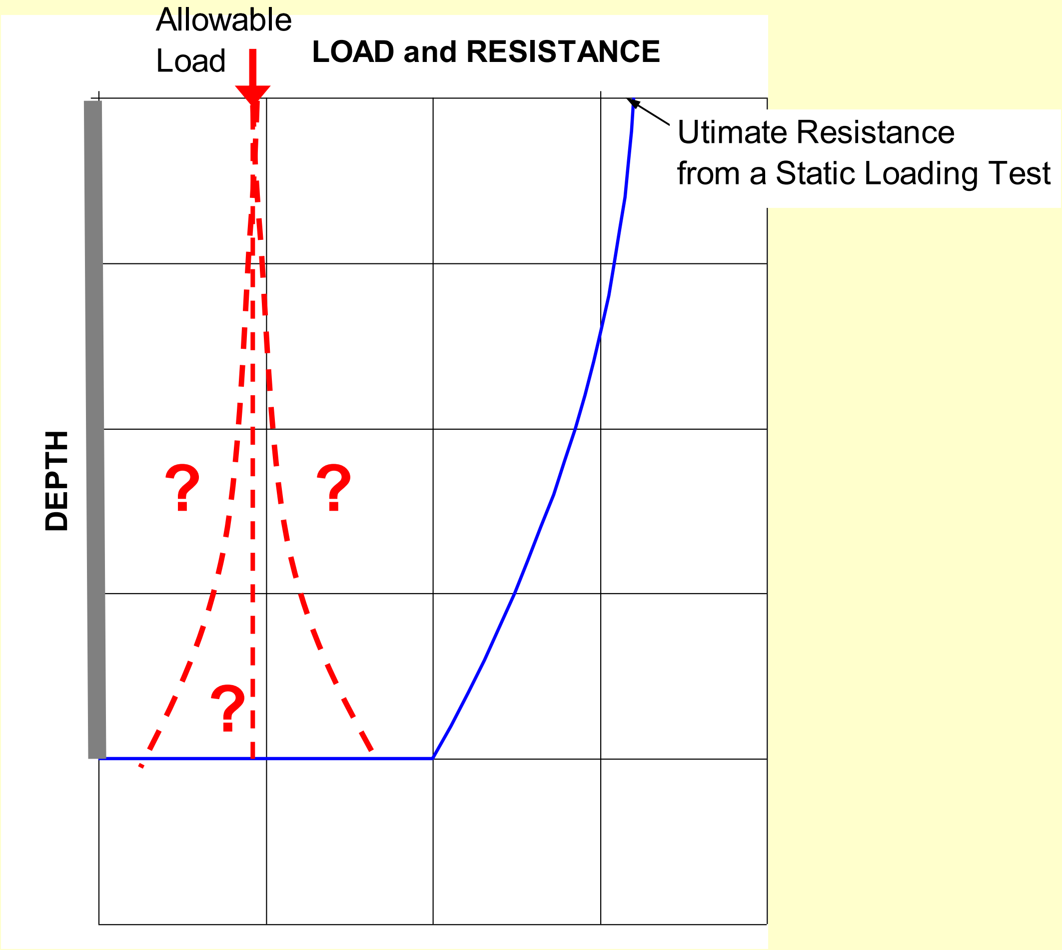
Note, the calculations are based on the ultimate conditions: ultimate shaft resistance and ”ultimate toe resistance”. Therefore, our next step is to divide the total capacity with a Factor-of-Safety, which gives us the allowable load on the pile(s).

Then what?

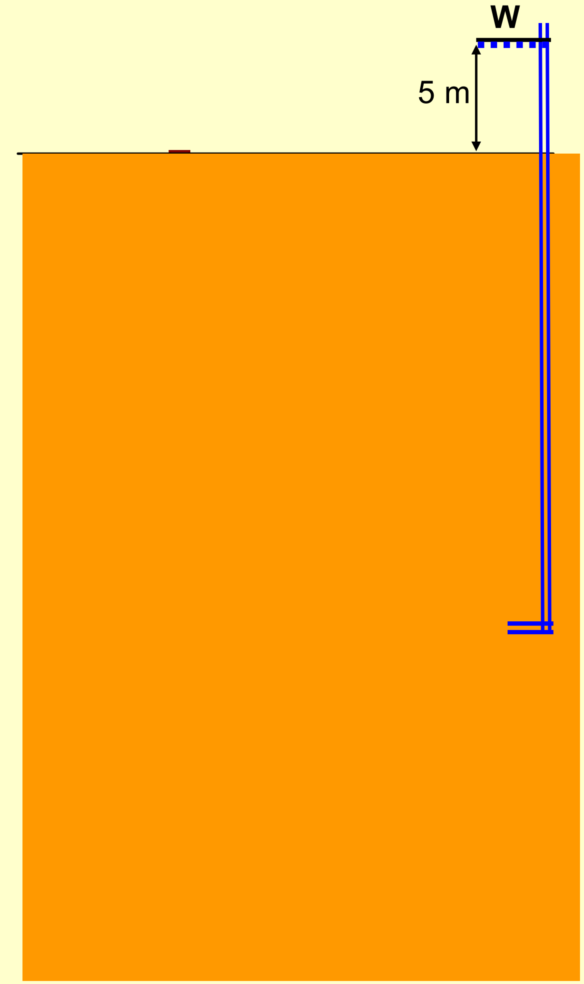
If this is the distribution of load in a pile loaded to its ultimate resistance, what is then the distribution when the pile is only loaded to its allowable load?



If this is the distribution of load in a pile loaded to its ultimate resistance, what is then the distribution when the pile is only loaded to its allowable load?



CALCULATION OF PILE CAPACITY
and
LOAD-TRANSFER CURVES



355 mm diameter closed-toe pipe pile to 32 m embedment

Area, A_s = 1.115 m^2/m Live Load, Q_l = 200 KN

Area, A_t = 0.099 m^2 Dead Load, Q_d = 800 KN

LAYER 1 Sandy Silt ρ = 2,000 kg/m β = 0.40

LAYER 2 Soft Clay ρ = 1,700 kg/m^3 β = 0.30

LAYER 3 Silty sand ρ = 2,100 kg/m^3 β = 0.50
With artesian head of 5 m

LAYER 4 Ablation Till ρ = 2,200 kg/m^3 β = 0.55
N_t = 50

CALCULATION OF PILE CAPACITY

Area, A_s = 1.115 m^2/m

Area, A_t = 0.099 m^2

Live Load, Q_l = 200 KN

Dead Load, Q_d = 800 KN

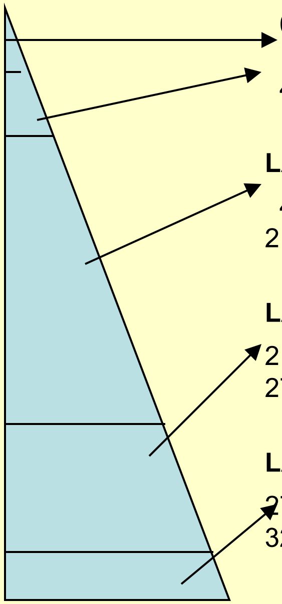
Total Load, Q_a = **1,000 KN**

Shaft Resistance, R_s = 1,817 KN

Toe Resistance, R_t = 1,205 KN

Total Resistance, R_u = **3,021** KN

F.S. = 3.02



DEPTH (m)	**TOTAL STRESS** (KPa)	**PORE PRES.** (KPa)	**EFFECTIVE STRESS** (KPa)	**INCR. R_s** (KN)	
LAYER 1 Sandy Silt	**ρ = 2,000 kg/m³**	**β = 0.40**			
0.00	30.00	0.00	30.00	0	
1.00(GWT)	48.40	0.00	48.40	18	
4.00	104.30	30.00	74.30	82	
LAYER 2 Soft Clay	**ρ = 1,700 kg/m³**	**β = 0.30**			
4.00	104.30	**30.00**	74.30		
21.00	380.97	**260.00**	120.97	549	
LAYER 3 Silty sand	**ρ = 2,100 kg/m³**	**β = 0.50**			
21.00	380.97	260.00	120.97		
27.00	504.80	320.00	184.80	511	
LAYER 4 Ablation Till	**ρ = 2,200 kg/m³**	**β = 0.55**			
27.00	504.80	320.00	184.80		
32.00	613.41	370.00	243.41	657 ➔	1,817 KN
				N_t = 50 ➔	1,205 KN
					3,021 KN

CALCULATION OF LOAD TRANSFER

Area, A_s = 1.115 m^2/m Live Load, Q_l = 200 KN Shaft Resistance, R_s = 1,817 KN
Area, A_t = 0.099 m^2 Dead Load, Q_d = 800 KN Toe Resistance, R_t = 1,205 KN
Total Load, Q_a = 1,000 KN Total Resistance, R_u = 3,021 KN
F.S. = 3.02 Depth to N. P. = 26.51 m Load at N. P., Q_{max} = 1,911 KN

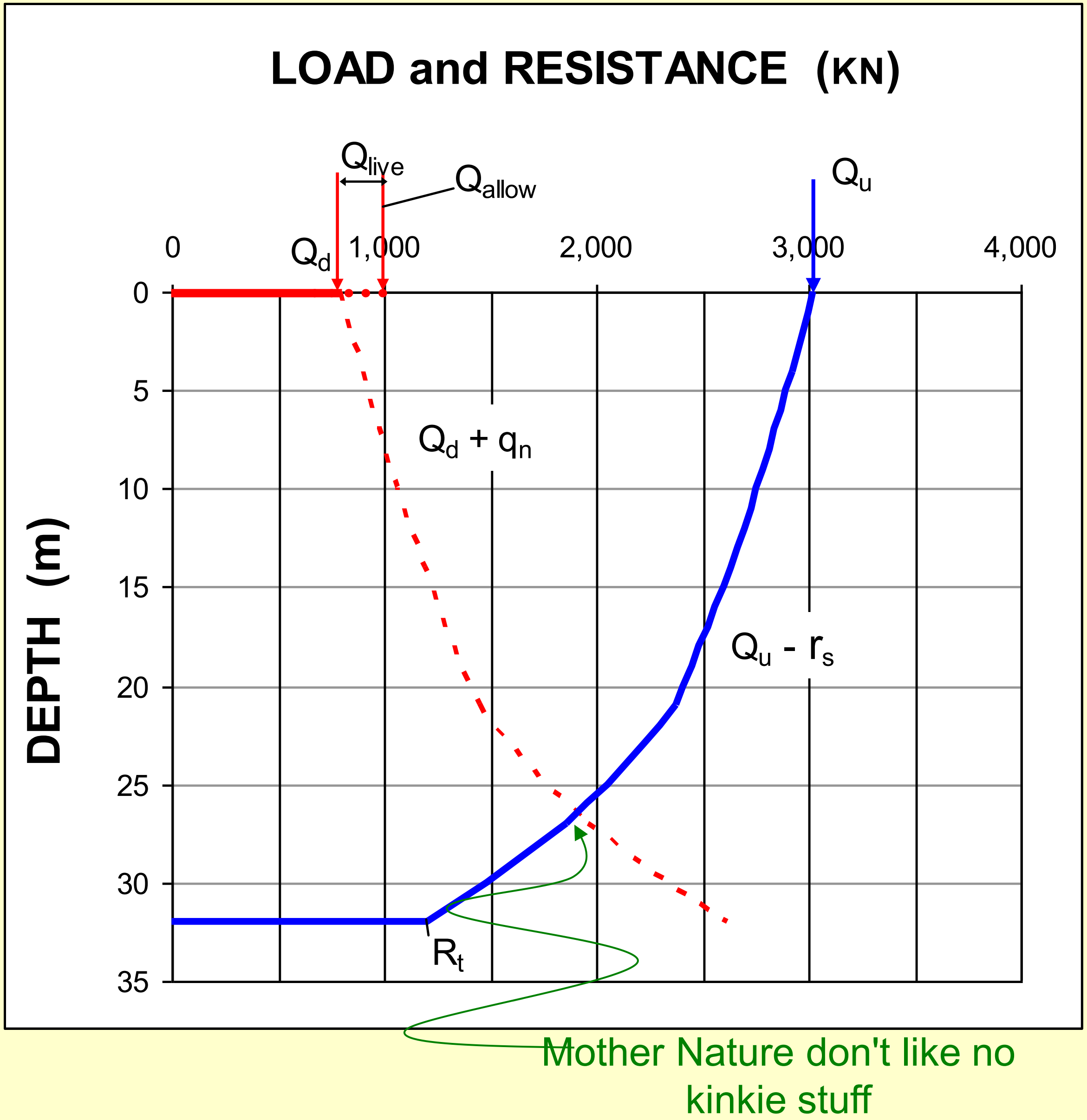
DEPTH (m)	TOTAL STRESS (KPa)	PORE PRES. (KPa)	EFFECTIVE STRESS (KPa)	INCR. R_s (KN)	Q_d+Q_n (KN)	Q_u-R_s (KN)
LAYER 1 Sandy Silt		**ρ = 2,000 kg/m³**	**β = 0.40**			
0.00	30.00	0.00	30.00	0.0	800	**3,021**
1.00(GWT)	48.40	0.00	48.40	17.5	817	3,004
4.00	104.30	30.00	74.30	82.1	900	2,922
LAYER 2 Soft Clay		**ρ = 1,700 kg/m³**	**β = 0.30**			
4.00	104.30	30.00	74.30		900	2,922
5.00	120.13	43.53	76.60	25.2	925	2896
6.00	136.04	57.06	78.98	26.0	951	2870
7.00	152.03	70.59	81.44	26.8	978	2844
8.00	168.08	84.12	83.96	27.7	1005	2816
9.00	184.20	97.65	86.55	28.5	1034	2787
10.00	200.37	111.18	89.20	29.4	1063	2758
11.00	216.60	124.71	91.89	30.3	1094	2728
12.00	232.88	138.24	94.64	31.2	1125	2697
13.00	249.19	151.76	97.43	32.1	1157	2664
14.00	265.55	165.29	100.26	33.1	1190	2631
15.00	281.95	178.82	103.12	34.0	1224	2597
16.00	298.38	192.35	106.03	35.0	1259	2562
17.00	314.84	205.88	108.96	36.0	1295	2526
18.00	331.33	219.41	111.92	37.0	1332	2489
19.00	347.85	232.94	114.91	37.9	1370	2451
20.00	364.40	246.47	117.93	39.0	1409	2413
21.00	380.97	260.00	120.97	40.0	1449	2373
LAYER 3	**Silty sand**		**= 2,100 kg/m³**		**β = 0.50**	

CONTINUED

DEPTH (m)	TOTAL STRESS (KPa)	PORE PRES. (KPa)	EFFECTIVE STRESS (KPa)	INCR. R_s (KN)	Q_d+Q_n (KN)	Q_u-R_s (KN)
21.00	*380.97*	*260.00*	*120.97*	*40.0*	*1449*	*2373*
LAYER 3	**Silty sand**		**= 2,100 kg/m^3**		**β = 0.50**	
21.00	380.97	260.00	120.97		1449	2373
22.00	401.56	270.00	131.56	70.4	1519	2302
23.00	422.17	280.00	142.17	76.3	1596	2226
24.00	442.80	290.00	152.80	82.2	1678	2144
25.00	463.45	300.00	163.45	88.2	1766	2055
26.00	484.11	310.00	174.11	94.1	1860	1961
27.00	504.80	320.00	184.80	100.1	1960	1861
LAYER 4	**Ablation Till**		**= 2,200 kg/m^3**		**β = 0.55**	
27.00	504.80	320.00	184.80		1960	1861
30.00	569.93	350.00	219.93	372.4	2332	1489
32.00	613.41	370.00	243.41	285.1	2617	**1205**

N_t = 50

Plot of the Calculated Values



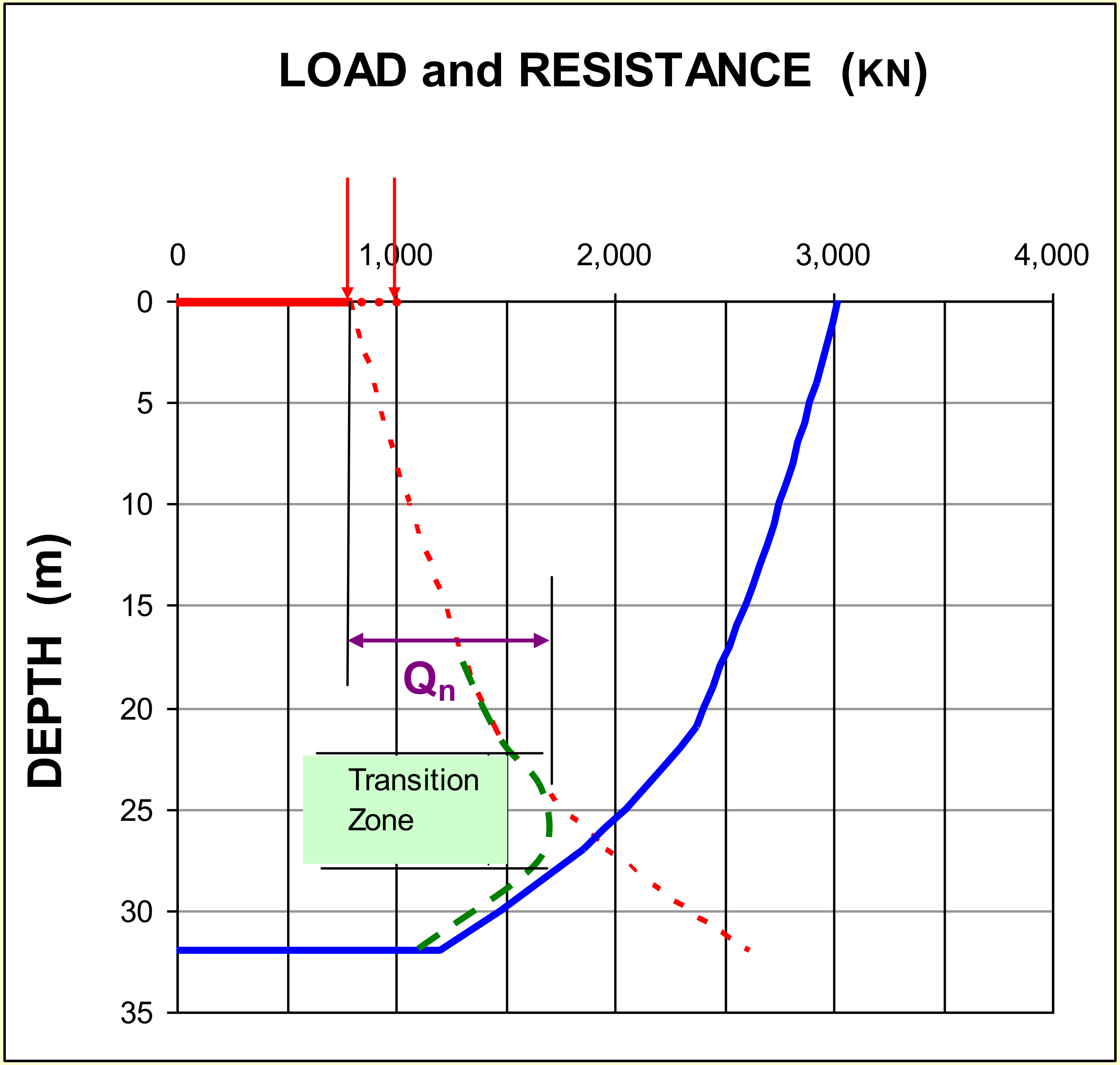
Calculation of shaft and toe resistance per the effective stress method

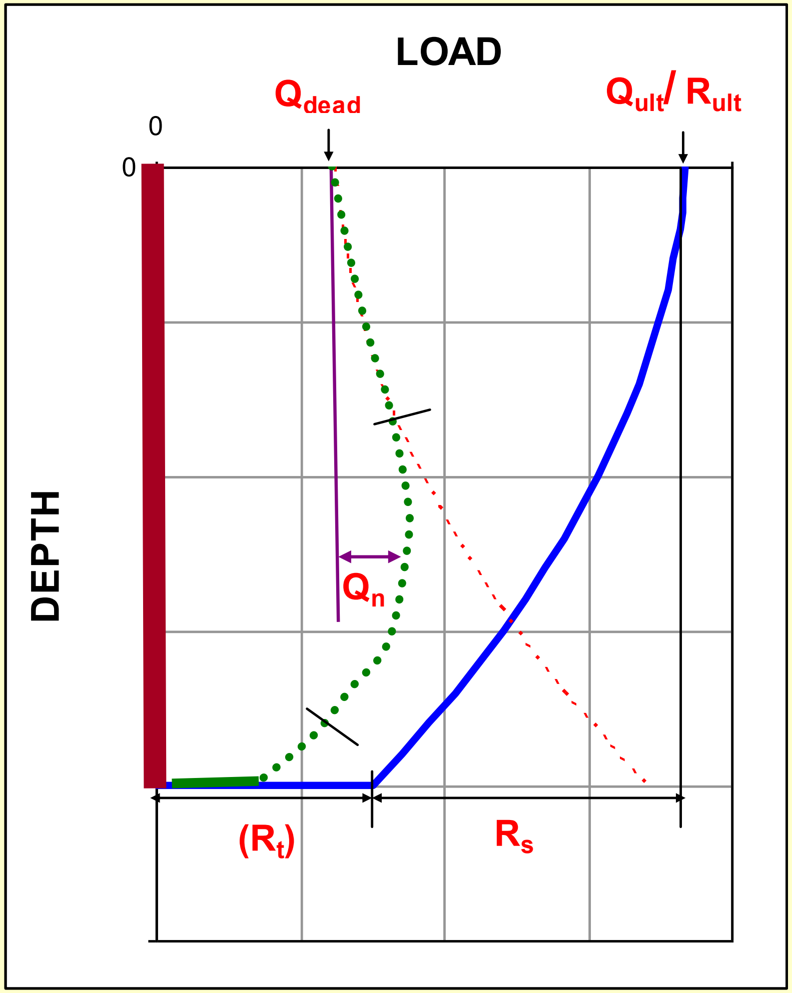
$$r_s = c' + \beta\sigma'_z$$

$$r_t = N_t\, \sigma'_{z=D}$$

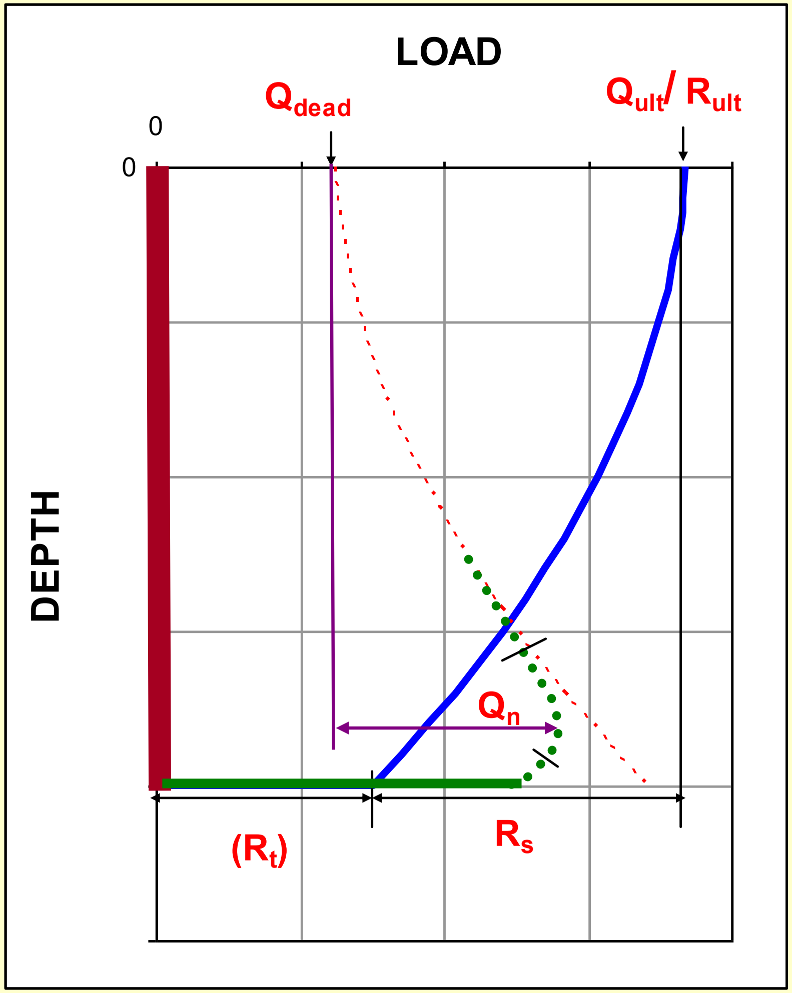
$$R_s = \int A_s r_s dz = \int A_s (c' + \beta\sigma'_z) dz$$

$$R_t = A_t r_t = A_t\, N_t\, \sigma'_{z=D}$$


LOAD and RESISTANCE (KN)
0
1,000
2,000
3,000
4,000
DEPTH (m)
0
5
10
15
20
25
30
35
Q_n
Transition Zone



A) **Small** settlement only in the surrounding soils

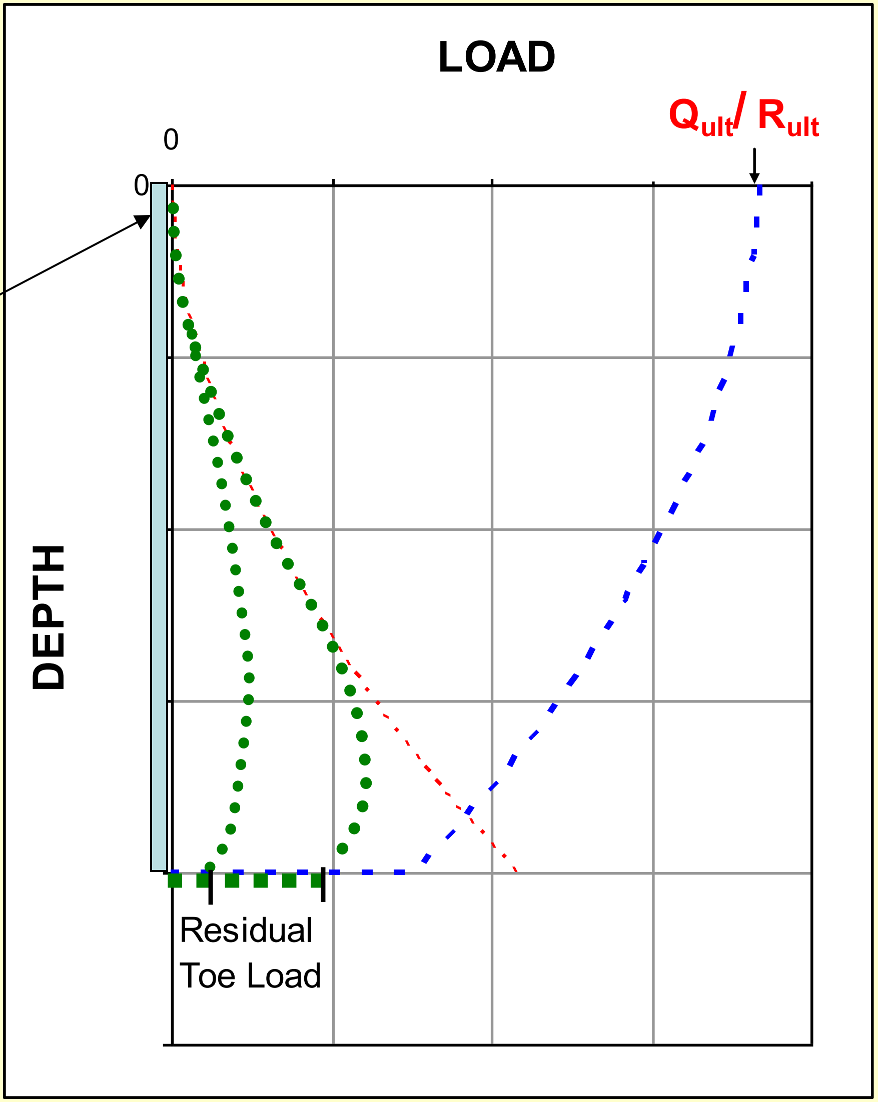


B) **Large** settlement in the surrounding soils

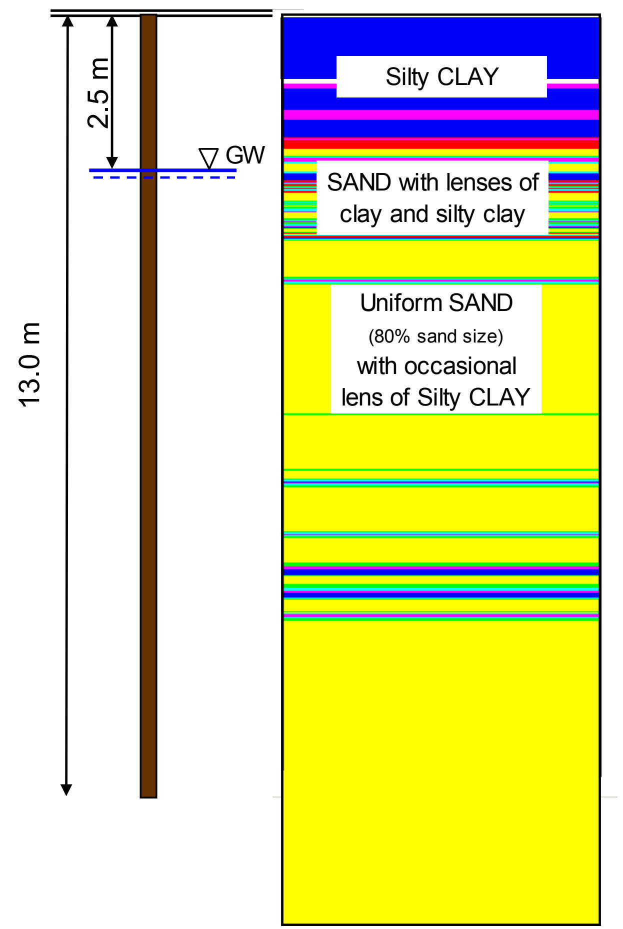
RESIDUAL LOAD

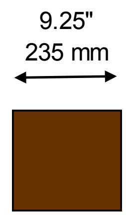
A test pile.

Before the start of the test there is no load on the pile head



A Case history of evaluation of static and dynamic tests on a 300 mm, 12 m long pile driven in sand. Data from Axelsson (2000).





TESTS

Static loading test 5 days after driving at Depth 12.8 m

Restrike after static test to final depth 13.0 m with PDA/CAPWAP

Redrive to 13.0 m depth

Static loading test 1 day after redrive

Static loading test 8 days after redrive

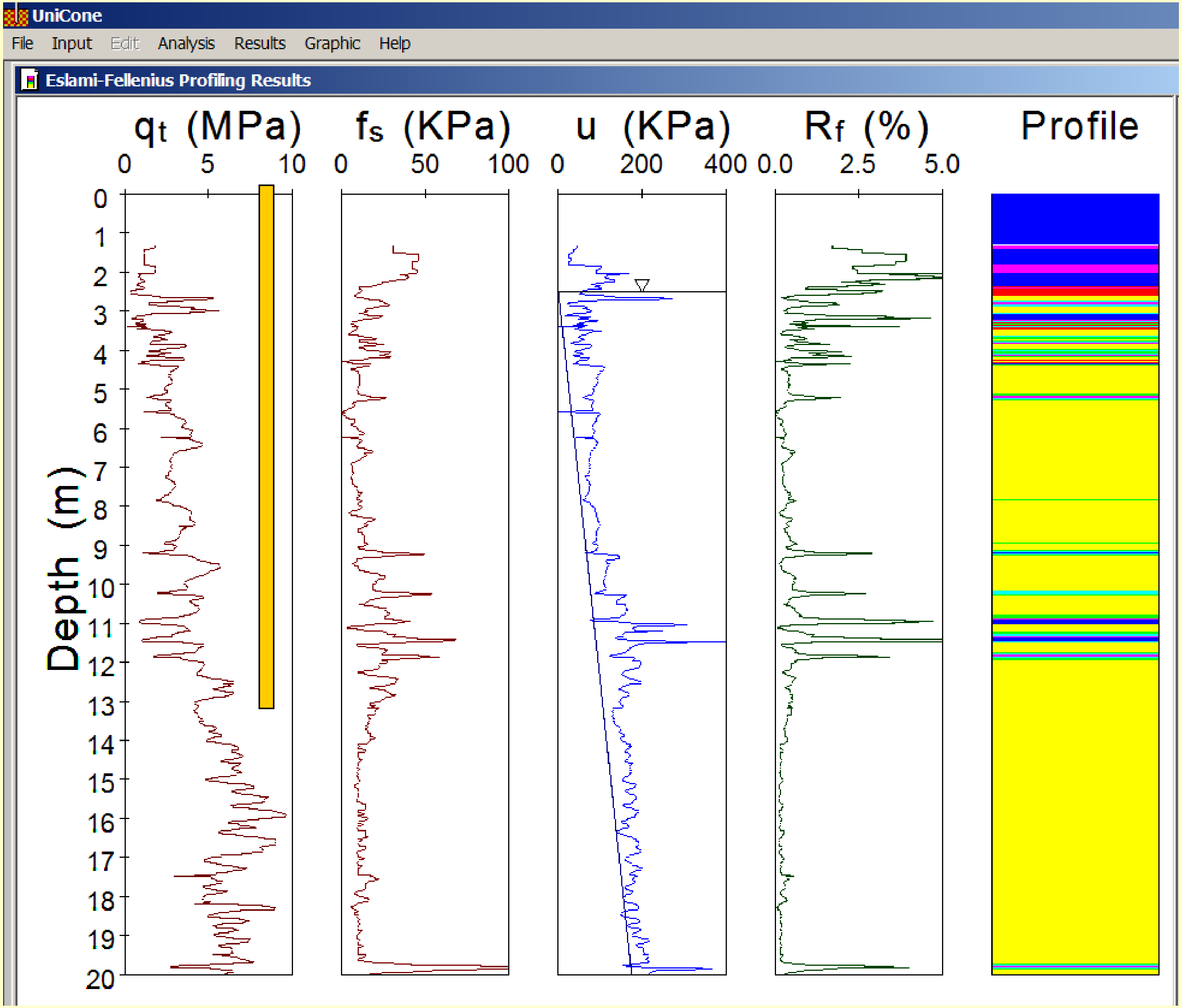
Static loading test 120 days (4 months) after redrive

Static loading test 670 days (22 months) after redrive

Total unit weight 0 m - 2.5 m = 18 KN/m^3
Total unit weight 2.5 m - 13.0 m = 19 KN/m^3

Hydrostatic pore pressure distribution

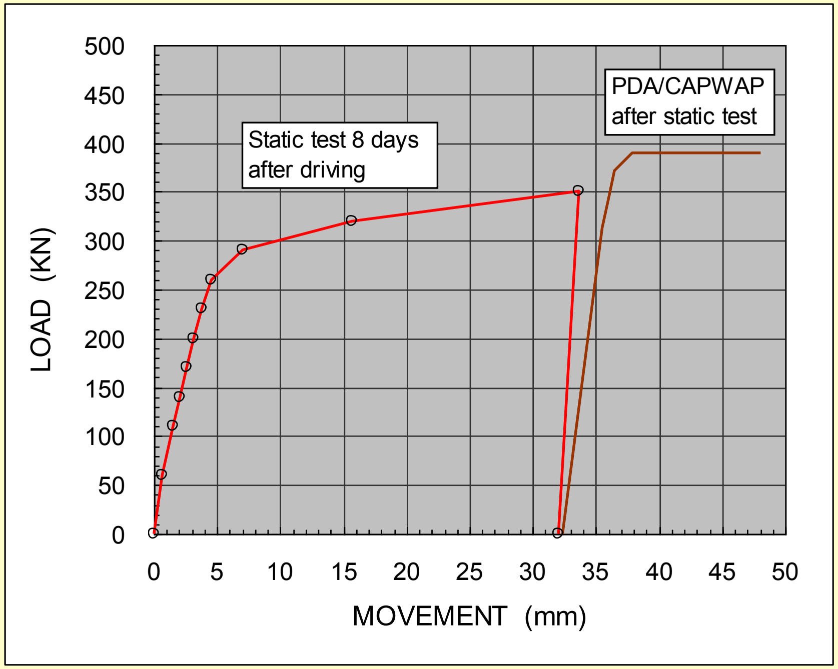
cnt.



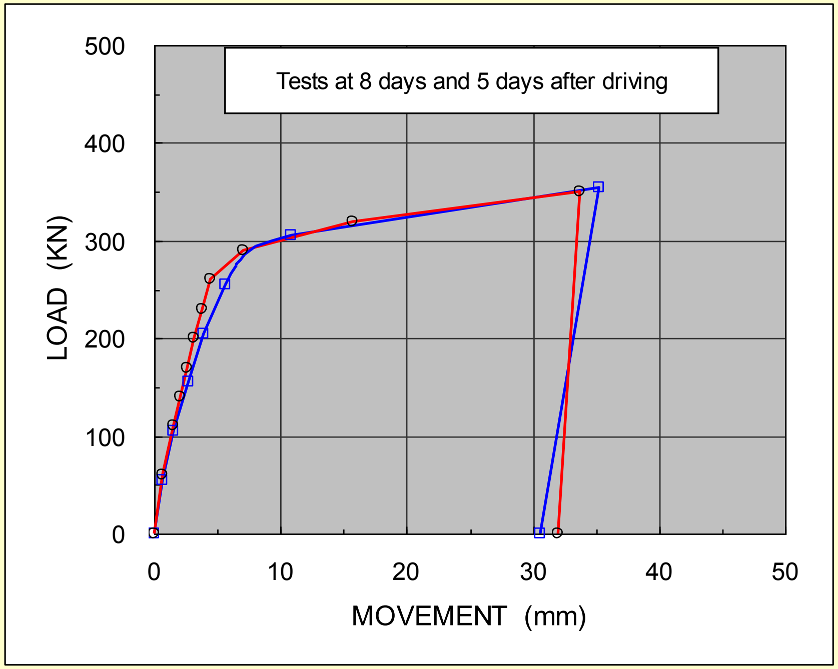
UniCone
File Input Edit Analysis Results Graphic Help
Eslami-Fellenius Profiling Results
qt (MPa)
0 5 10
fs (KPa)
0 50 100
u (KPa)
0 200 400
Rf (%)
0.0 2.5 5.0
Profile
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

cnt.

Results of static loading test and a subsequent CAPWAP analysis

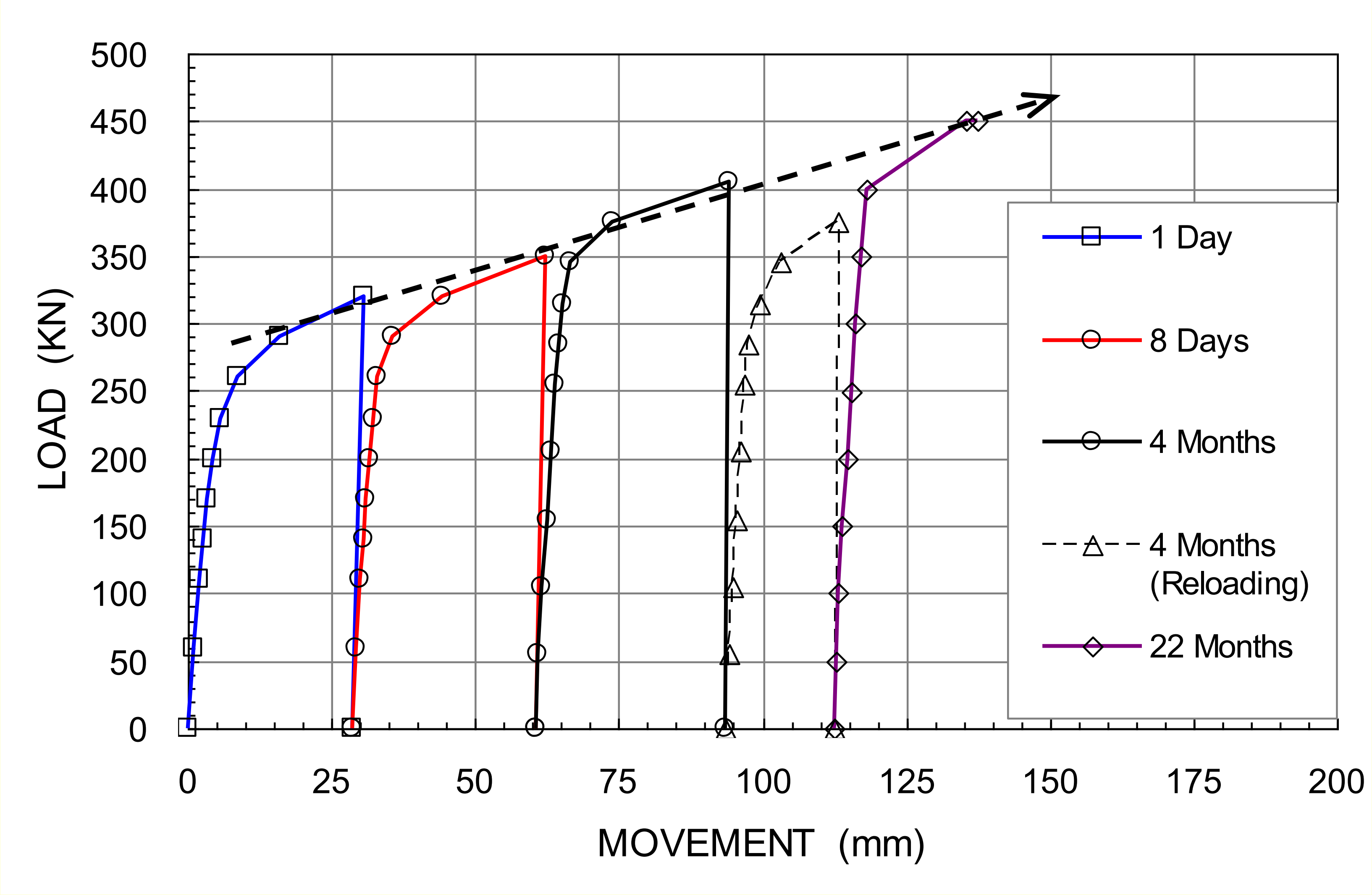


Static loading tests after 8 days and 5 days later after a 0.20 m **restrike and redrive**

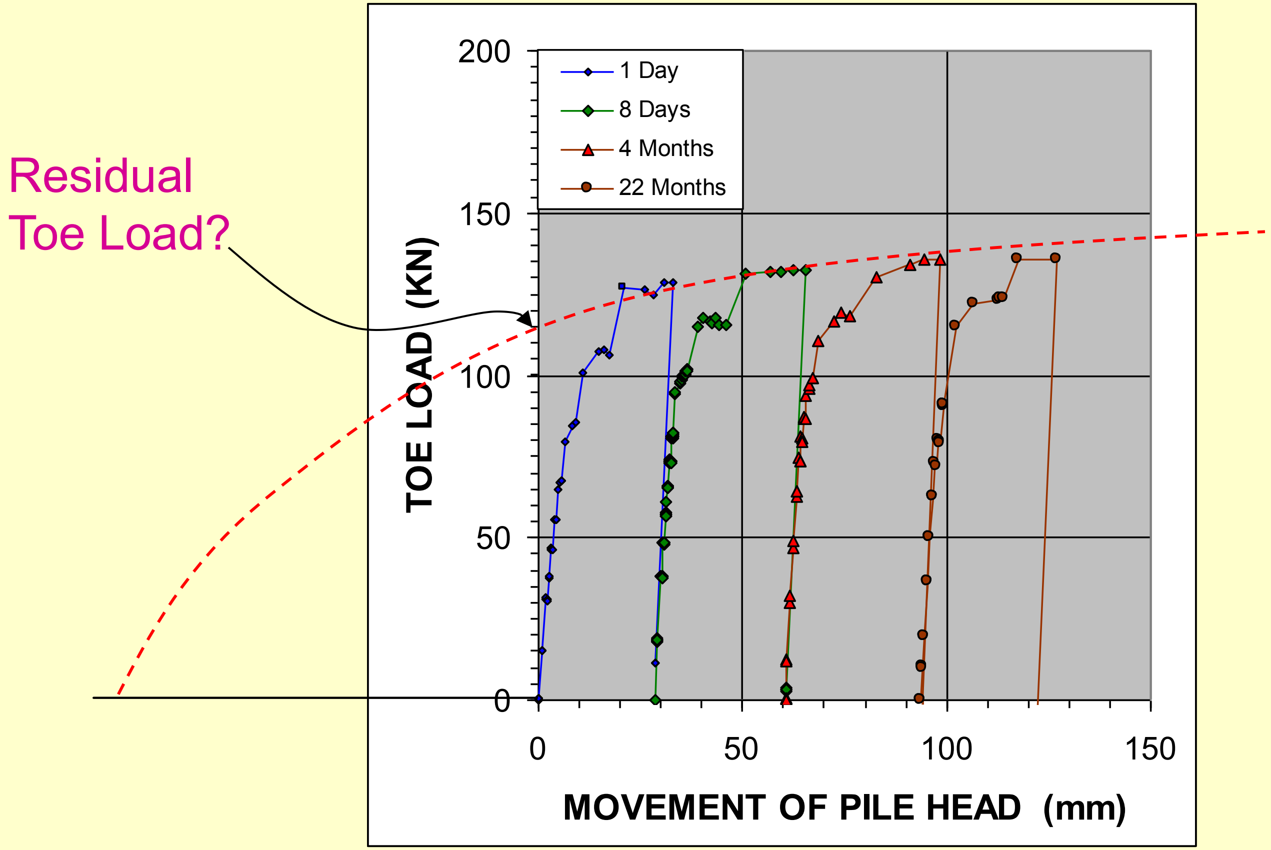


cnt.

Load-Movement Curves for the Tests after the Redrive

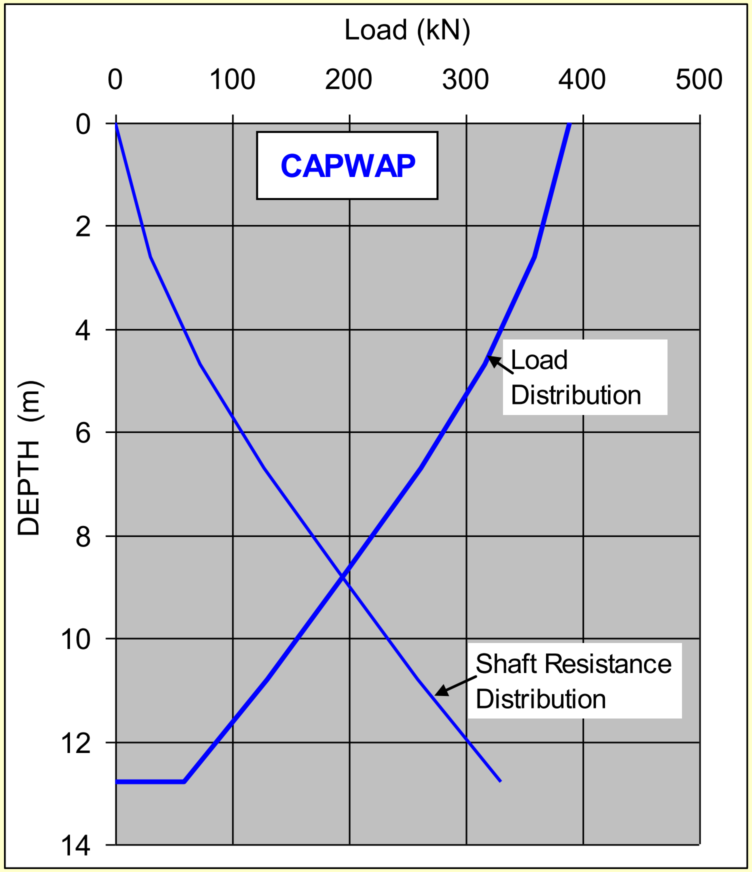


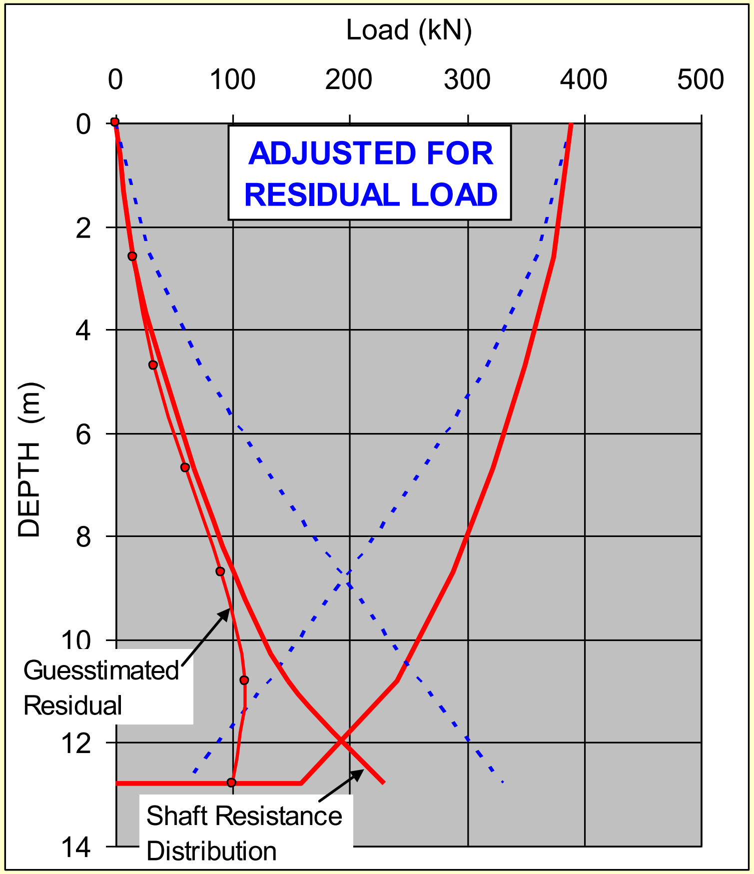
Toe load from earth stress cell at pile toe



cnt.

Distributions from CAPWAP analysis

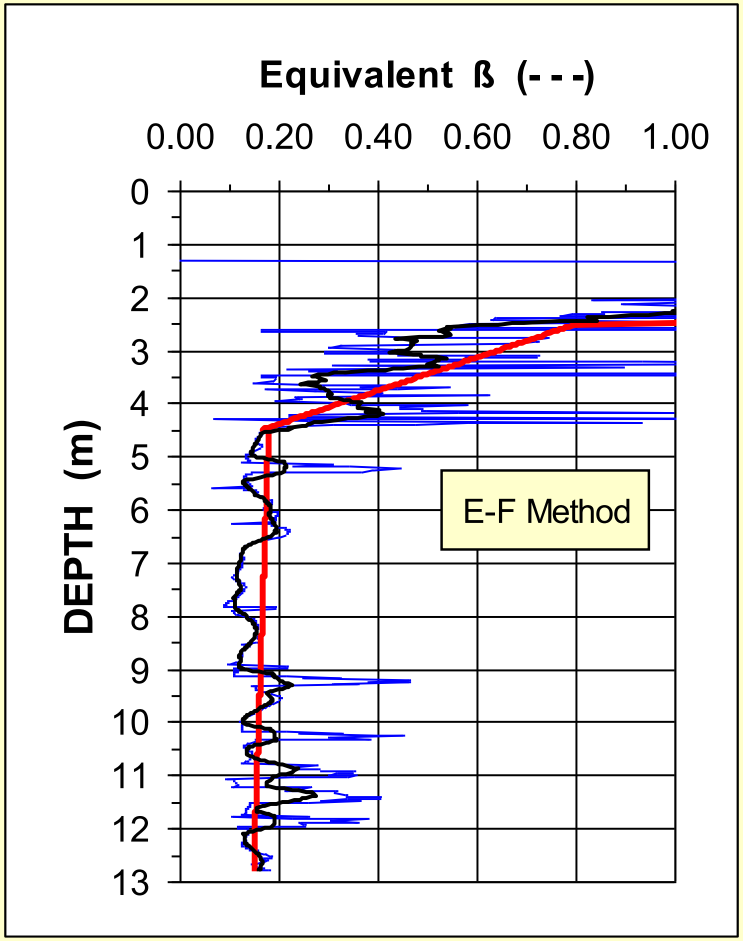




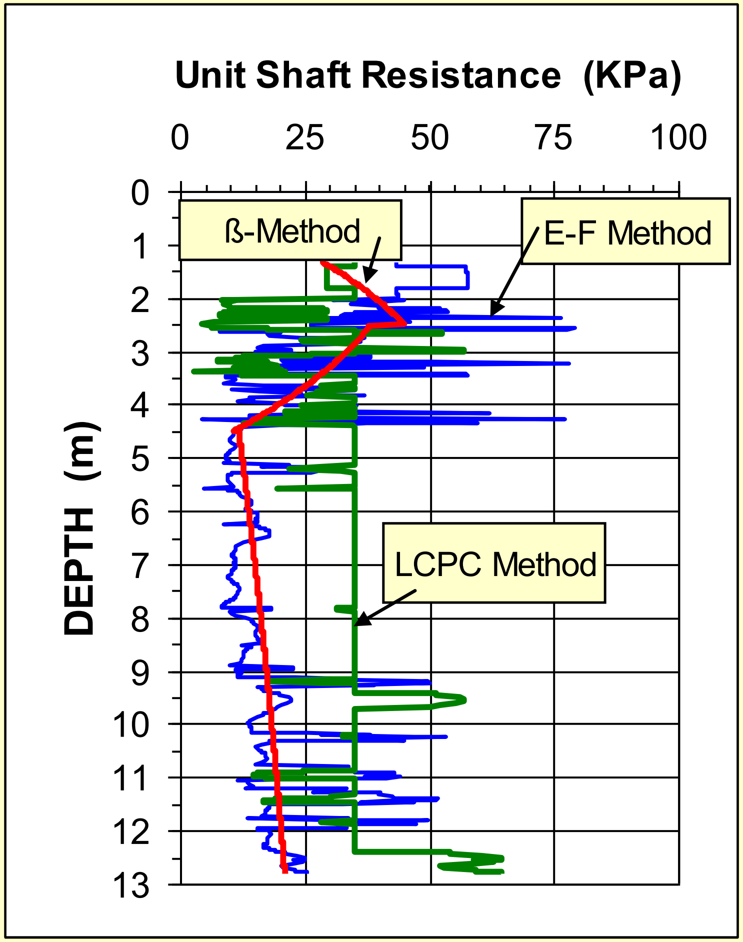
The residual load distribution is speculative, but . . .

cnt.

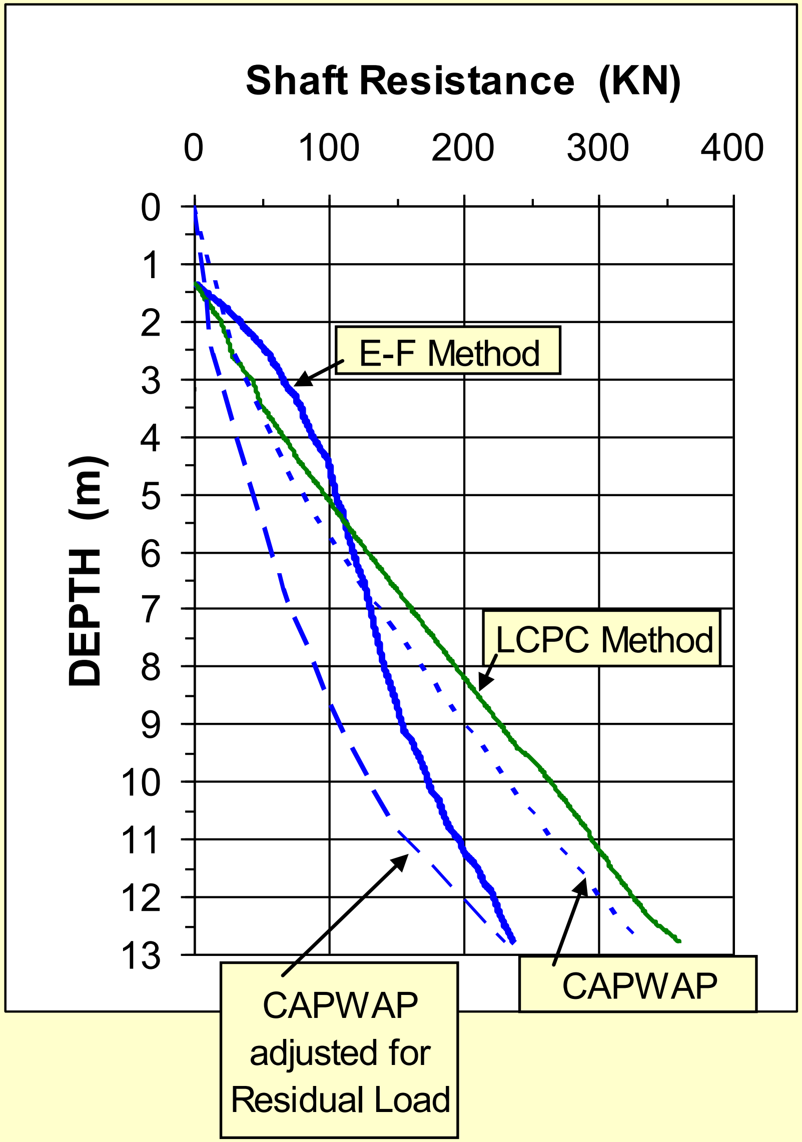
Equivalent ß-coefficient from CPTU sounding and Eslami-Fellenius Method



Unit Shaft Resistance from Equivalent ß-coefficient and CPTU Method plus LCPC-Method



cnt.



Few published case histories measure up to the quality, details, and value of this test. Yet, significant uncertainty remains as to the actual shaft and toe resistances. Had an uplift static loading test been included, it would have resolved much of the uncertainty.

Tests should be planned to positively determine the distribution of residual load and to separate shaft and toe resistance values.

Most O-cell tests will include these aspects.


化粧室は後方へ
For Restrooms,
Go back toward your behind.
14

Vaughani Shores,