Piling Practice in Sedimentary Soils-- Some Experiences

by

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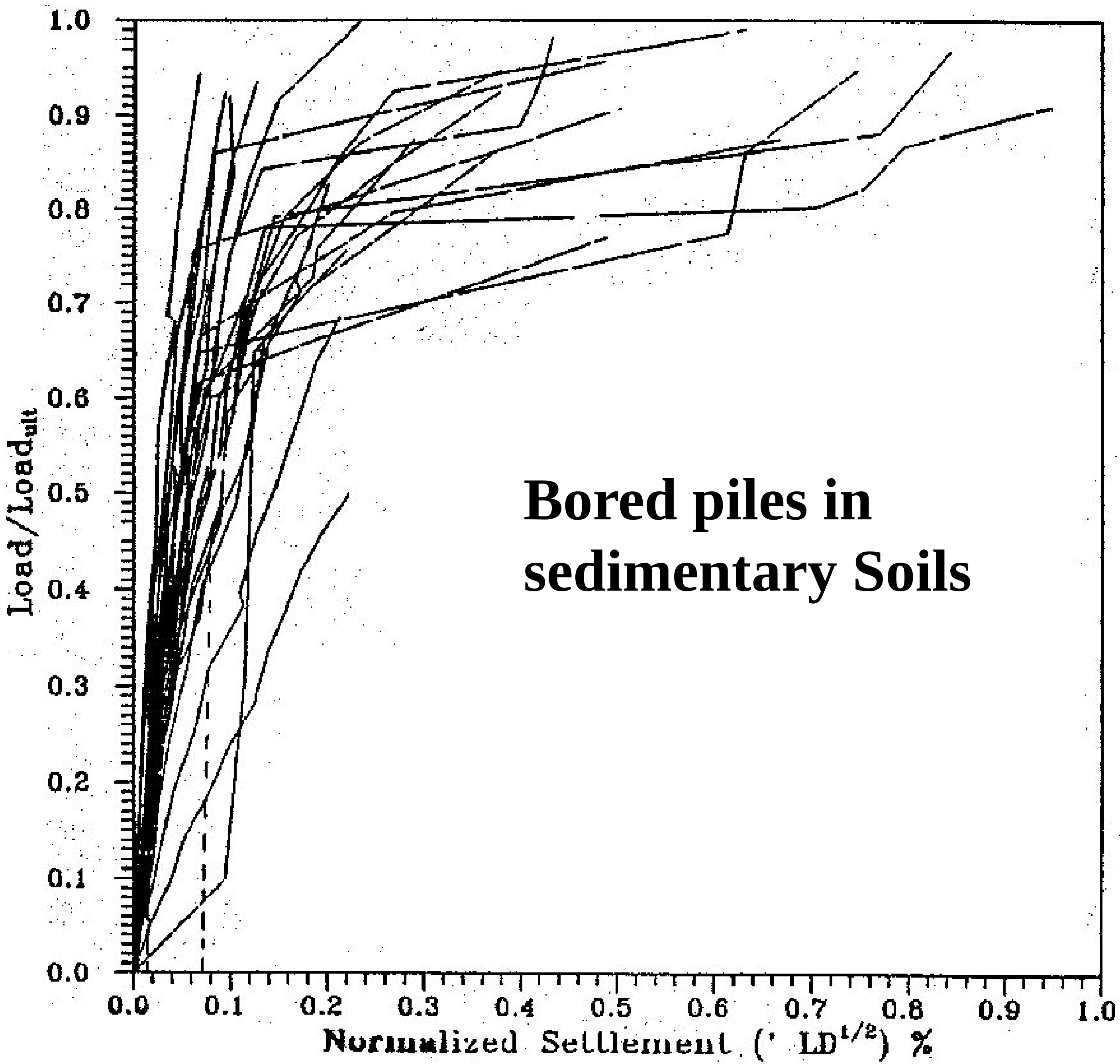


Bored piles in sedimentary Soils
Load/Load$_{ult}$
Normalized Settlement (' LD$^{1/2}$) %
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Factor of safety

1. Code of practice normally do not specify a value.

2. Code says that the factor of safety be chosen having regard to the nature of the soil, its variability over the site and the reliability of the method by which the ultimate bearing capacity is determined.

3. An appropriate factor for a single pile would be between 2 and 3.

4. The lower values would be justified by pile tests or local experience; the higher values when there is less certainty of the ultimate failure load

Background

1. Over a twenty five year period foundation requirements have demanded higher working loads and as such piling works need to accommodate

    a. Larger cross section of piles

    b. Longer lengths

    c. Switch from driven piles to bored piles

2. Carrying capacity of of friction piles arise from a combination of shaft load and end bearing

3. In the case of driven piles, spun piles have larger section and higher capacity than the ordinary driven piles of varying cross section. Large diameter bored piles can achieve much larger carrying capacity than even the largest driven spun pipe piles.

4. In heavily over-consolidated London clay an enlarged base is used with the bored pile. Such enlargement is not adopted for bored piles in sedimentary soils alternating as clay and sand layers and when the piles bear in a water bearing sand stratum.

5. In the case of driven piles, the pile set is taken as a rough guide to determine the founding level even in clayey soils.

6. In the case of closely driven piles in soft clays substantial excess pore pressure can develop due to pile driving and the piles already driven can undergo substantial heave and lateral movements.

7. The shaft friction load in clays is estimated by the total stress method in using an adhesive coefficient α and this method of calculation is referred to as the α method. An effective stress approach called the β method is also adopted lately in estimating the skin friction of piles in clays. For offshore works a combination of the total stress and the effective stress called the λ method is popularly adopted for large diameter open ended steel pipe piles driven to great depths.

8. **In the case of sand, the skin friction is estimated with the use of a lateral earth pressure coefficient K_s, the effective overburden pressure and a friction angle of the soil -pile interface taken as a function of the angle of internal friction of the sand layer.**

9. **The end bearing of both driven and bored piles can be determined using the bearing capacity formula for deep foundations. The bearing capacity factors of Meyerhof is popular, but for clays the N_c value is taken as nine and the N_q value for sand is obtained from the work of Berezantsev.**

10. **In the case of soft clays, in-situ test such as the vane test is used to obtain the undrained shear strength in the α method. For medium stiff and stiff clays, unconfined compression tests can be used while the UU triaxial tests are preferred.**

11. **In the case of heavily overconsolidated clay such as the London clay, plate loading tests are done to estimate the end bearing as well as the undrained shear strength.**

12. **Cone penetration tests can be done to estimate the skin friction and end bearing loads in clays and sands.**

13. **Correlations exist with the Standard penetration tests to estimate the undrained strength in stiff clays and the angle of internal friction in sand; alternatively the skin friction and end bearing values of the piles can also be correlated.**

14. **Pile testing is of two types. One to determine the load-settlement characteristic and the other to determine the integrity of the piles. For all major projects load tests are more or less compulsory and these are divided into maintained load test (both slow and quick) and constant rate of penetration tests. The integrity tests range from pile coring to vibration and sonic testing as well as radiometric logging.**

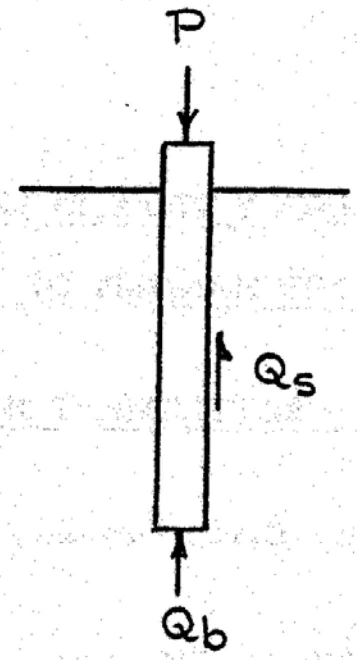
15. **Chin method can be used to check the integrity of driven piles as well as to obtain the ultimate load from load tests terminated at loads lower than the ultimate one. It is also possible to separate the end bearing and shaft friction components.**

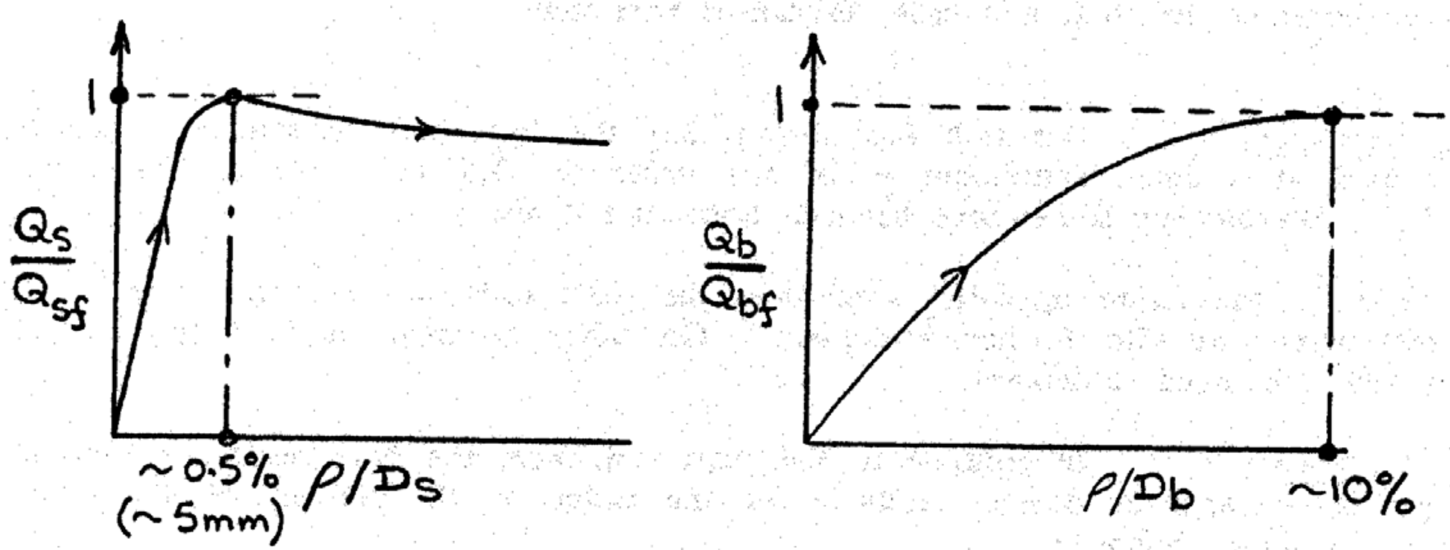
16. **Fellenius list a number of methods which can be used to estimate the ultimate loads in driven piles.**

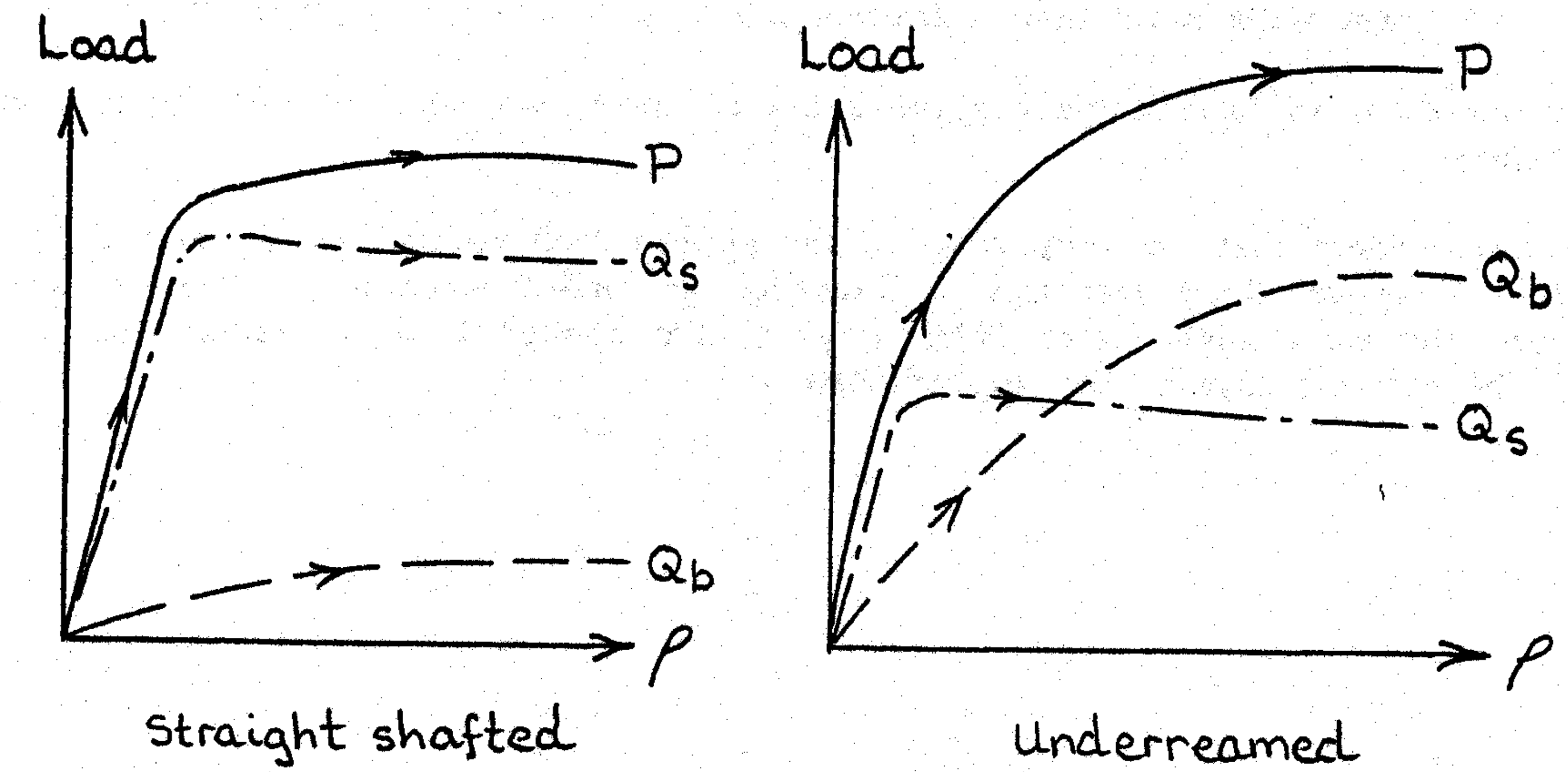
15. **In the case of bored piles in stiff overconsolidated London clay smooth development of shaft friction and end bearing with pile displacement was noted and this was used to establish simple load settlement graph for skin friction and end bearing and hence the overall load load settlement characteristics. However in the case of sedimentary soils, all types of curves are obtained due to poor construction methods. Nevertheless it is possible to determine the load transfer characteristics from instrumented piles and establish how the skin friction develops in each layer as well as the end bearing.**

16. **Base grouting is used in bored piles to strengthen both the end bearing as well as the skin friction in sandy formations. However the method calls for very careful grouting techniques.**

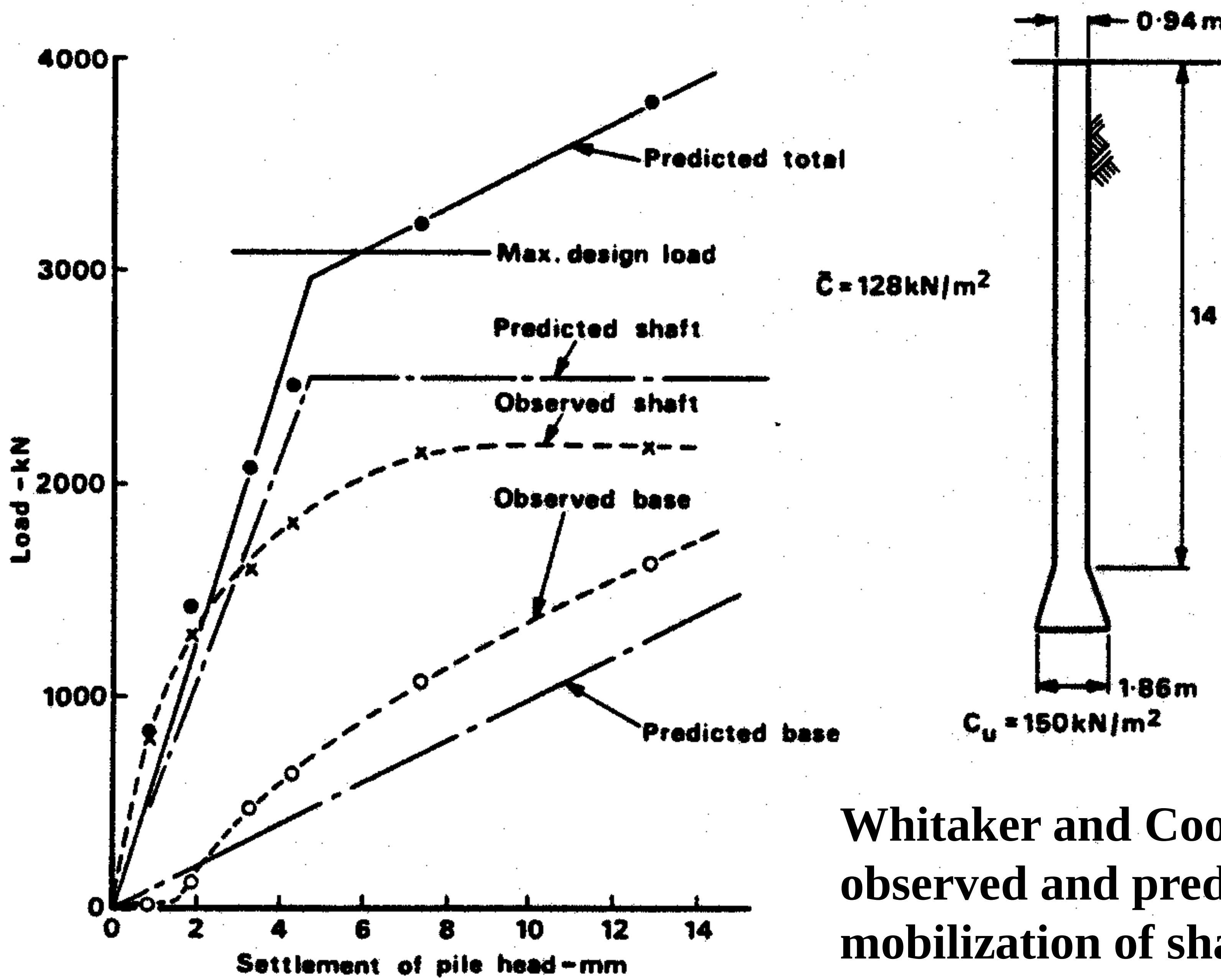
Mobilization of shaft load load and end bearing with pile settlement





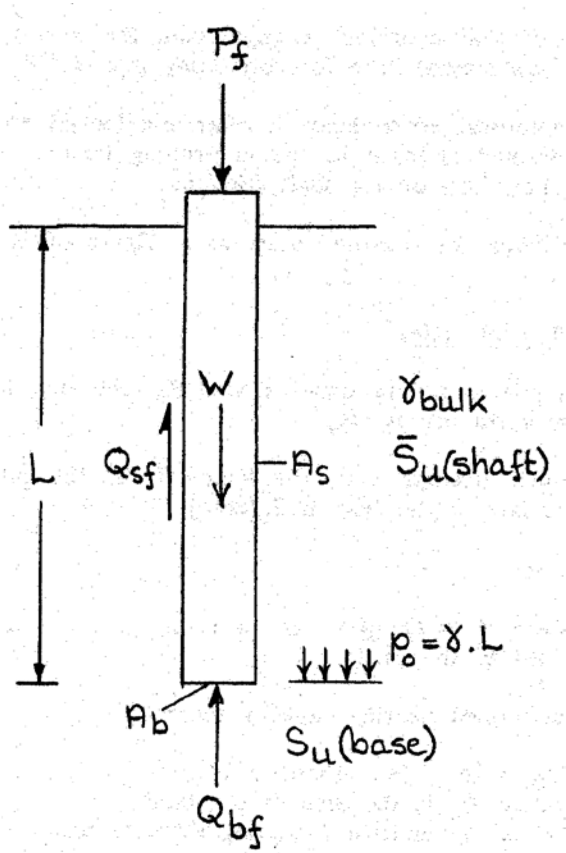


Load Mobilization in straight shafted and under-reamed piles



Whitaker and Cooke's observed and predicted mobilization of shaft and base loads

Total stress analysis -α method



$Q_{sf} = A_s \tau_{sf}$ ------- Shaft Load

$Q_{bf} = A_b (s_u)_{base} N_c$ ---- Base Load

$$P_f = Q_{sf} + Q_{bf}$$

$$\tau_{sf} = \alpha\, s_u$$

Undrained strength

1. **Stress path --strength in plane strain or triaxial extension is lower than triaxial compression**

2. **Orientation-- depends on the orientation of the principal stresses; anisotropy**

3. **Size --- In stiff fissured clays, depend on the fissure pattern and amount**

4. **Rate --- usually slower rate gives lower strength**

5. **Sample disturbance-- it can operate both ways; some time reducing and some time increasing.**

Undrained strength

1. Different type of tests and different size of samples can give different values. In particular the values of s_u from in situ tests such as vane, cone pressuremeter etc will frequently differ from values measured in say triaxial apparatus.

2. So in the α method a clear understanding of how s_u were measured is important, when α values are selected.
   For soft clays the s_u come from field vane tests and for stiff clays from 38 mm diameter samples and from UU tests or more usually from unconfined compression tests.

Values of α

1. The values of α vary from 1.5 for soft sensitive clays to as low as 0.2 for very stiff clays.

2. α reduces with s_u and thus when s_u depends on so many factors; the choice of α is rather difficult to be very precise. Tomlinson goes on to say that α depends on pile length and the overlying materials through which it has been driven. The sand dragged down increase the value where as soft clay dragged down reduce the value.

3. It has been reported that α values can vary very widely even in one site. For soft clay the variation is reported as 0.4 to 1.0 and in stiff clay from 0.25 to 0.45.

Effective stress approach-- the β method

1. For most buildings and also for pile testing, the piles are installed long before the subsequent activity. Thus the excess pore pressure during installation would have dissipated. Thus a drained condition prevails.

2. The shaft friction at failure is

$$\tau_{sf} = \sigma_{hs}{}' \tan\delta + c_s{}'$$

where is the effective angle of interface friction

$c_s{}'$ is the effective interface cohesion

is the effective horizontal stress

Dividing by the overburden pressure σ_v'

$$\frac{\tau_{sf}}{\sigma_v'} = K_s \tan\delta + \frac{c_s'}{\sigma_v'} = \beta$$

In the β method

$$\tau_{sf} = \beta\sigma_v'$$

In the α method

$$\tau_{sf} = \alpha s_u$$

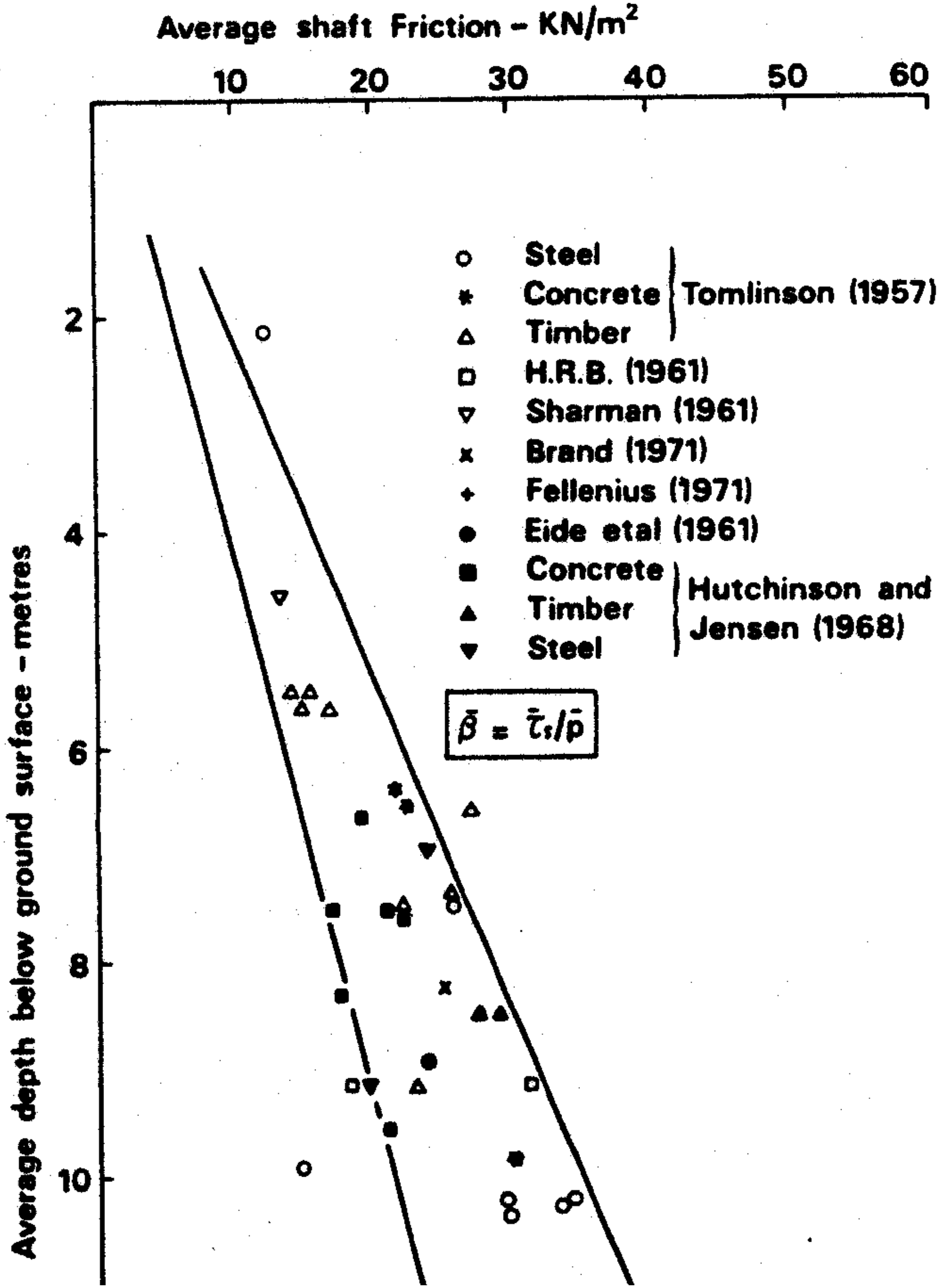
For normally consolidated clay

$K_0 = 1 - \sin\phi_{cv}'$ If $\delta = \phi_{cv}'$

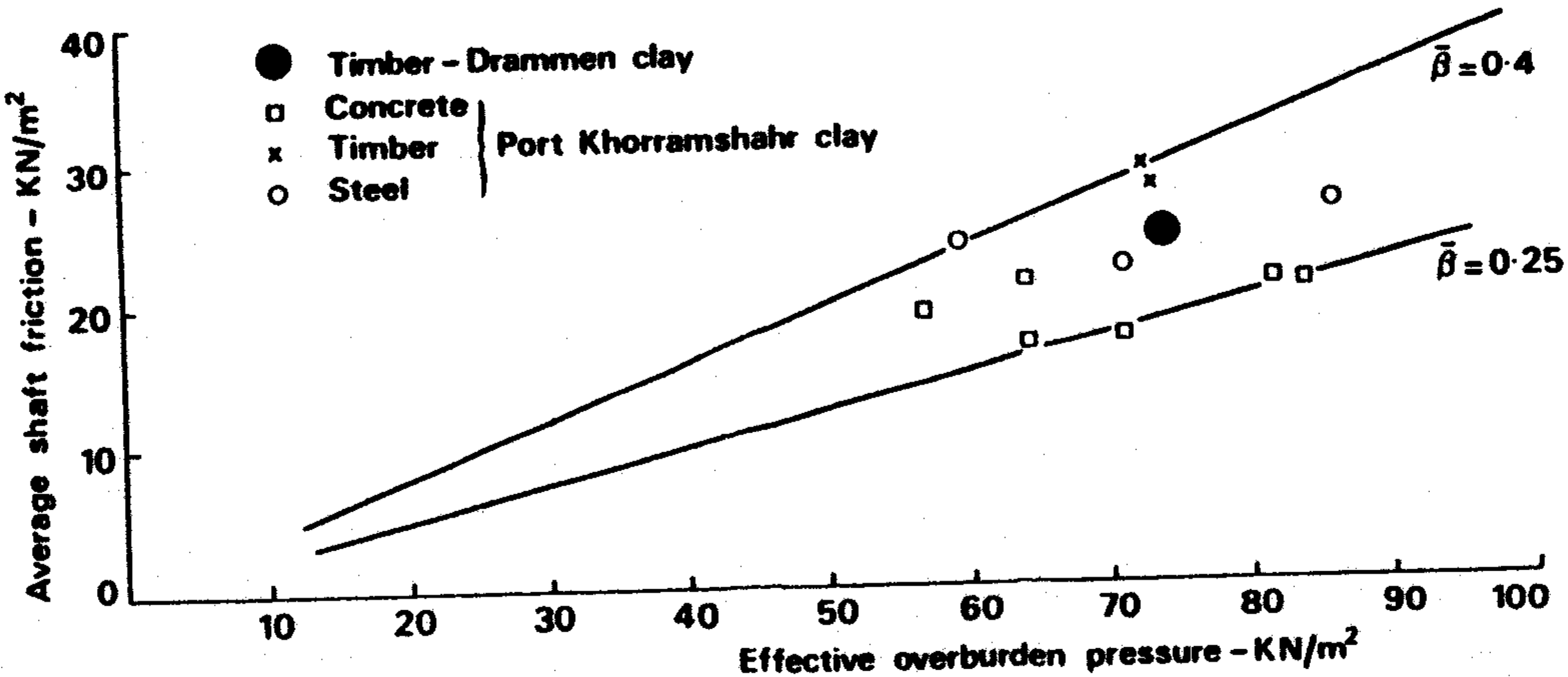
then $\beta = \left(1 - \sin\phi_{cv}'\right)\tan\phi_{cv}'$

For ϕ_{cv} varying from 20^0 to 40^0
β varies from 0.25 to 0.3. Surprisingly within small range

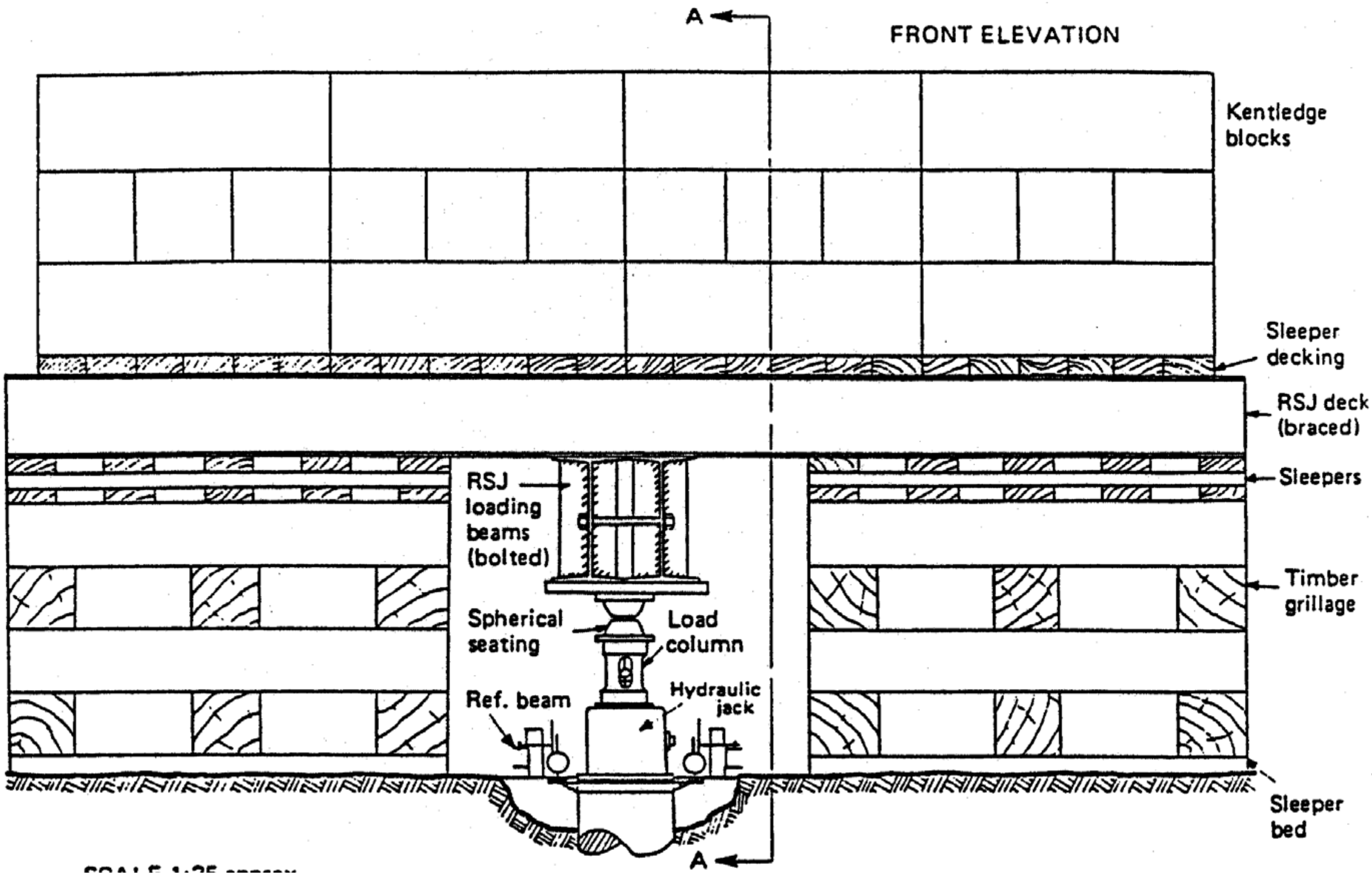
Burland's β values from full scale pile load tests from various sites



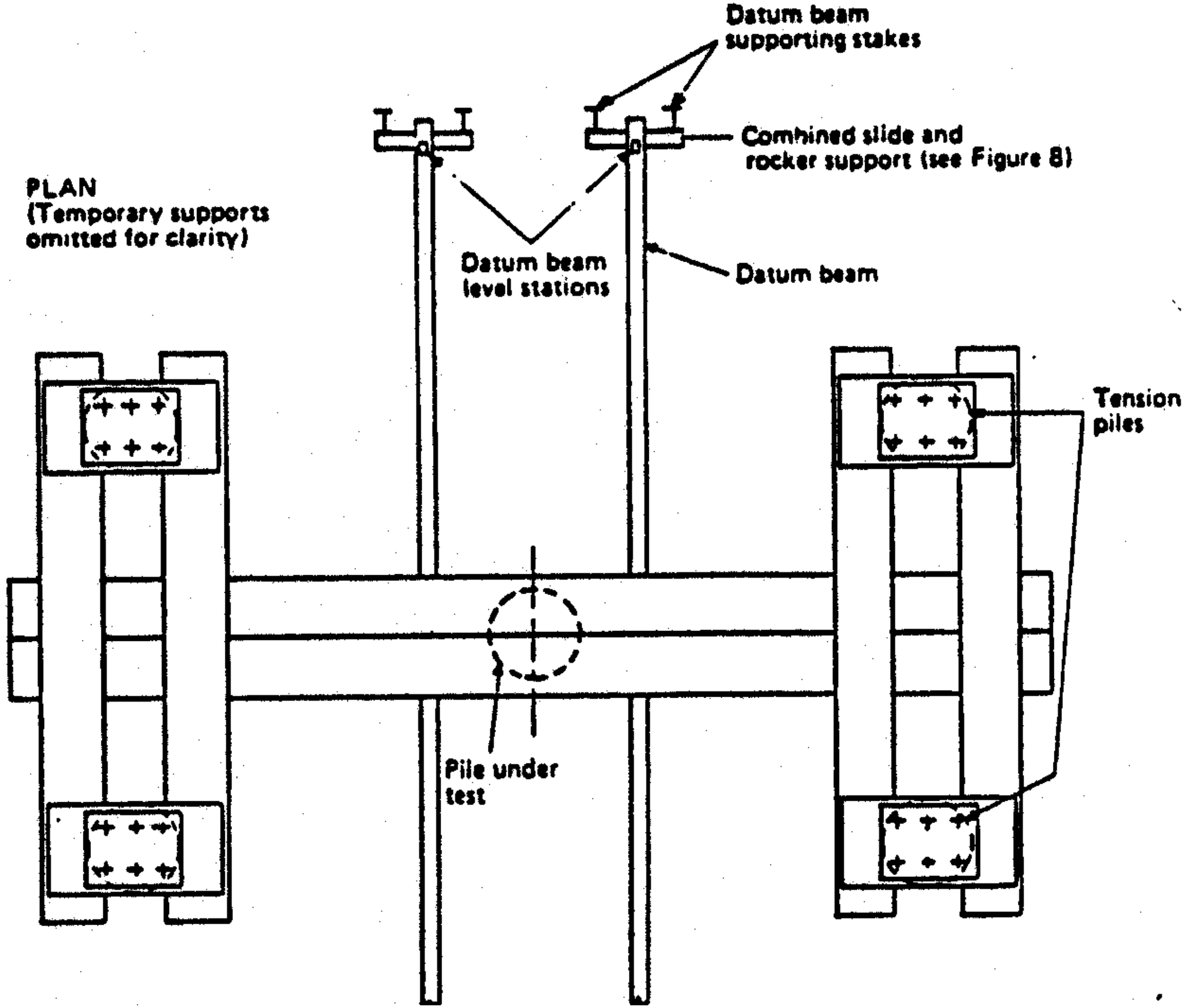
β values from 0.25 to 0.4



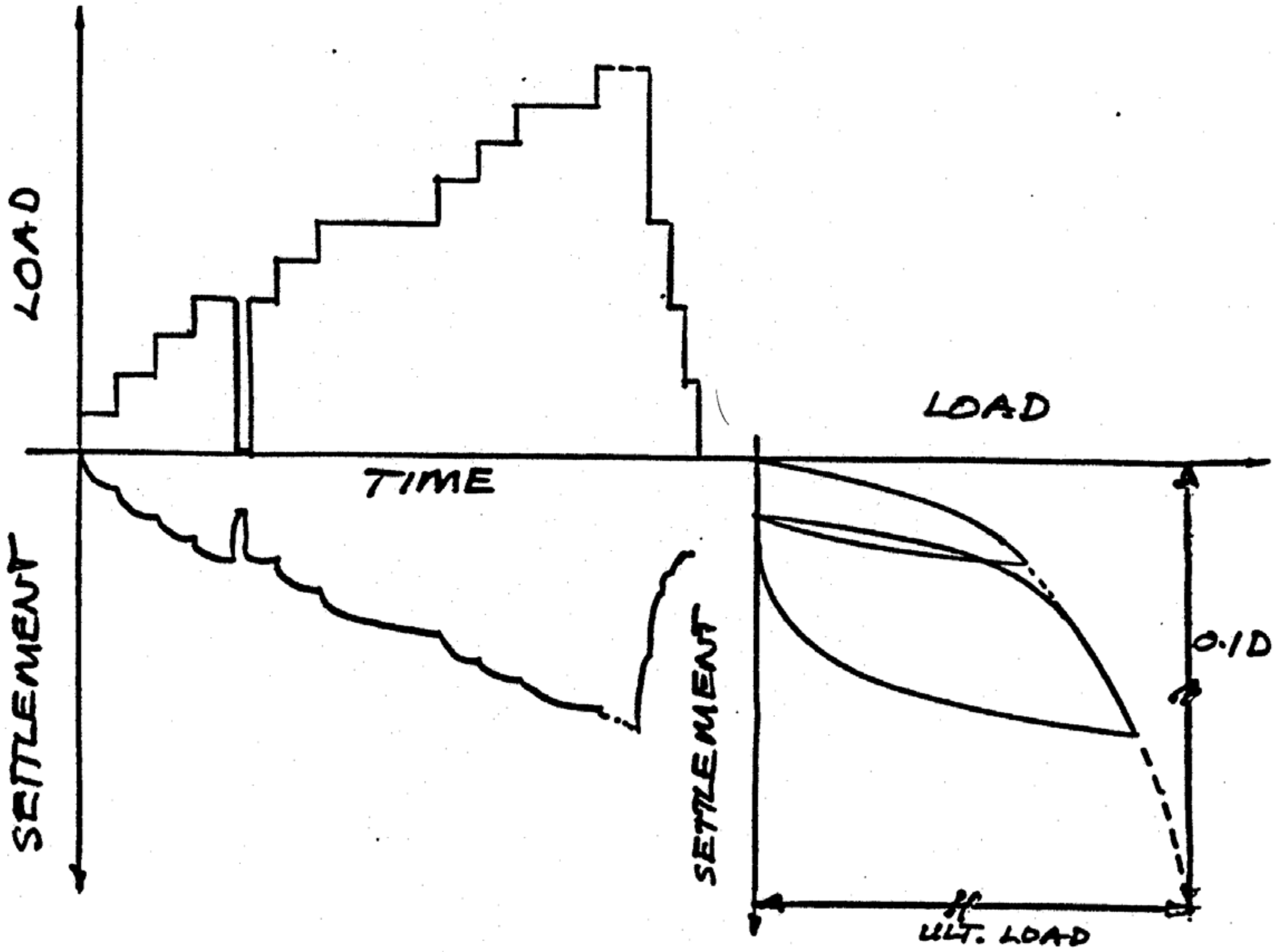
β values from 0.25 to 0.4



Kentledge pile test set up



Four tension pile reaction system



Plotting load settlement curve

Ultimate load from graphical methods

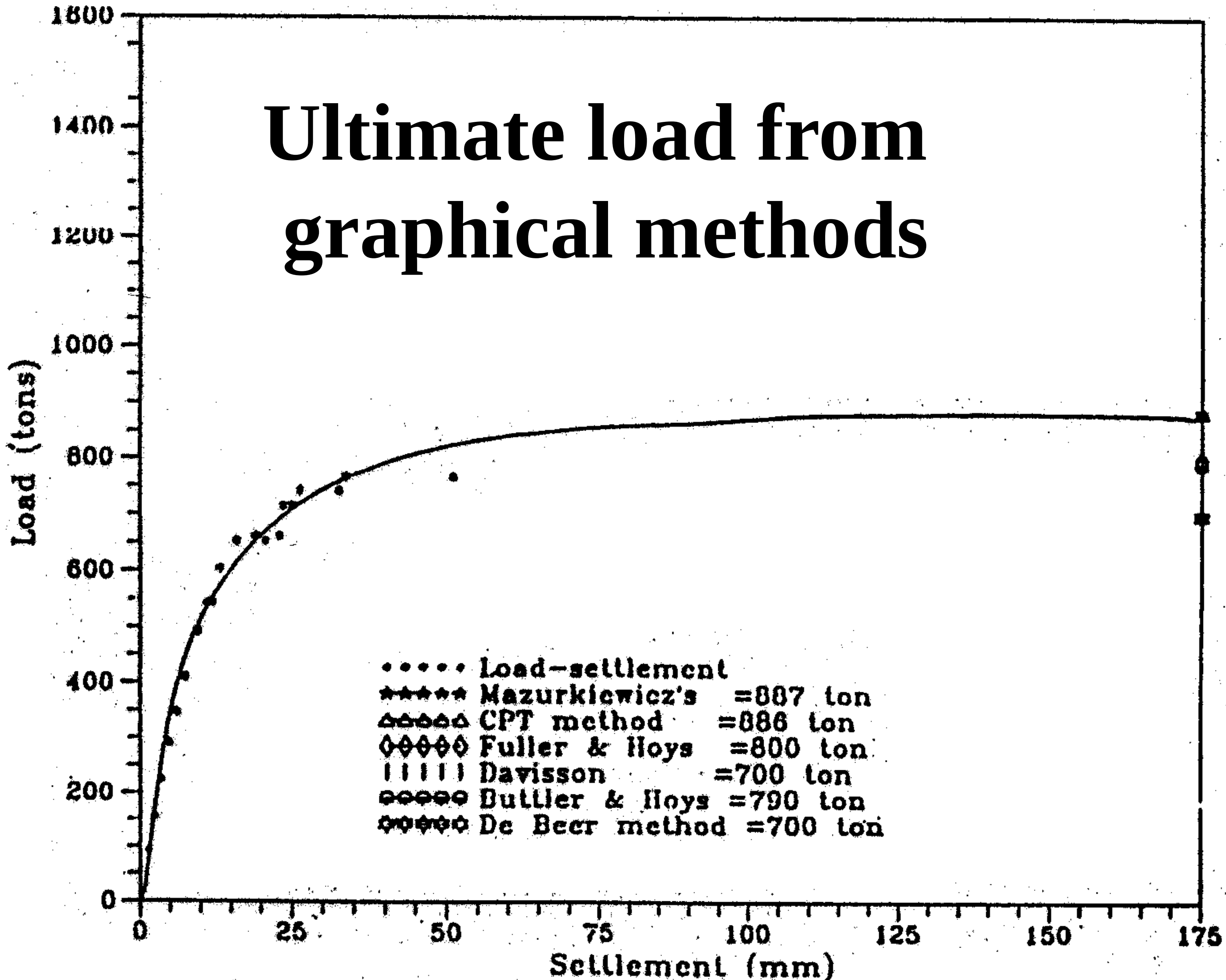


FIG. F.14 Test Pile at km 16 + 035 (0.8 m x 24.6 m)

Ultimate load from graphical methods

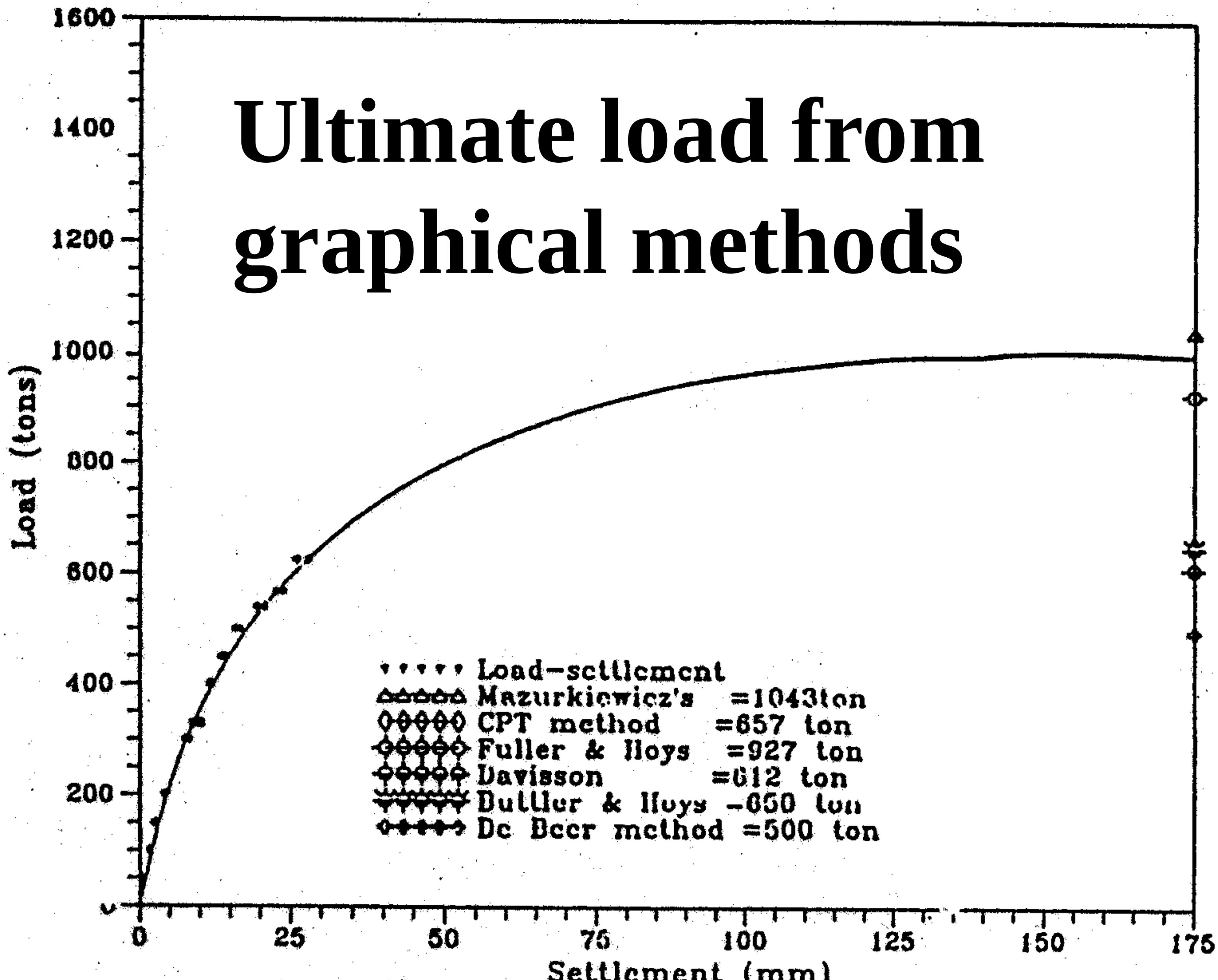


FIG. F.13 Test Pile at km. 16 + 035 (0.6 m x 37.5 m)

Ultimate loads by graphical methods

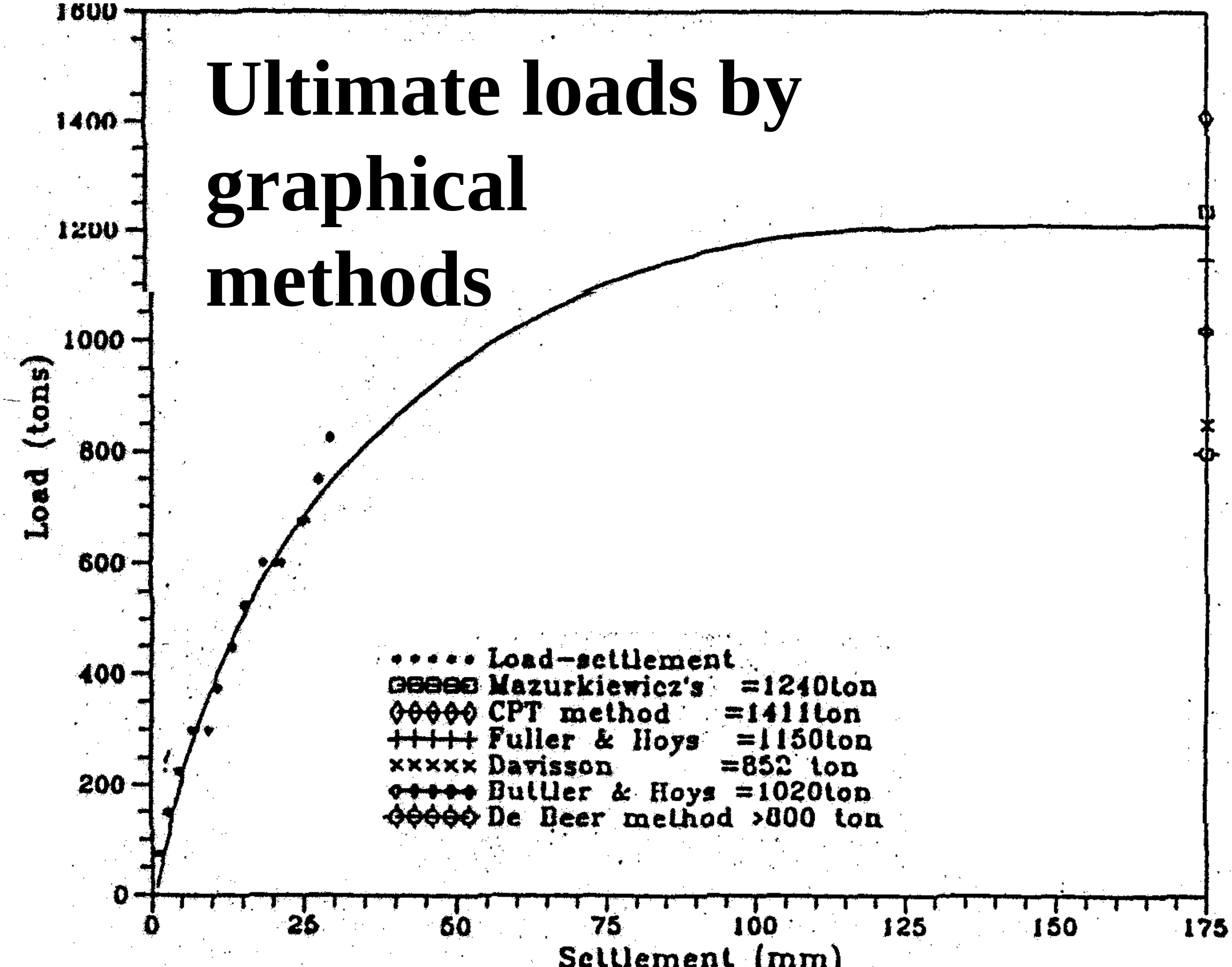
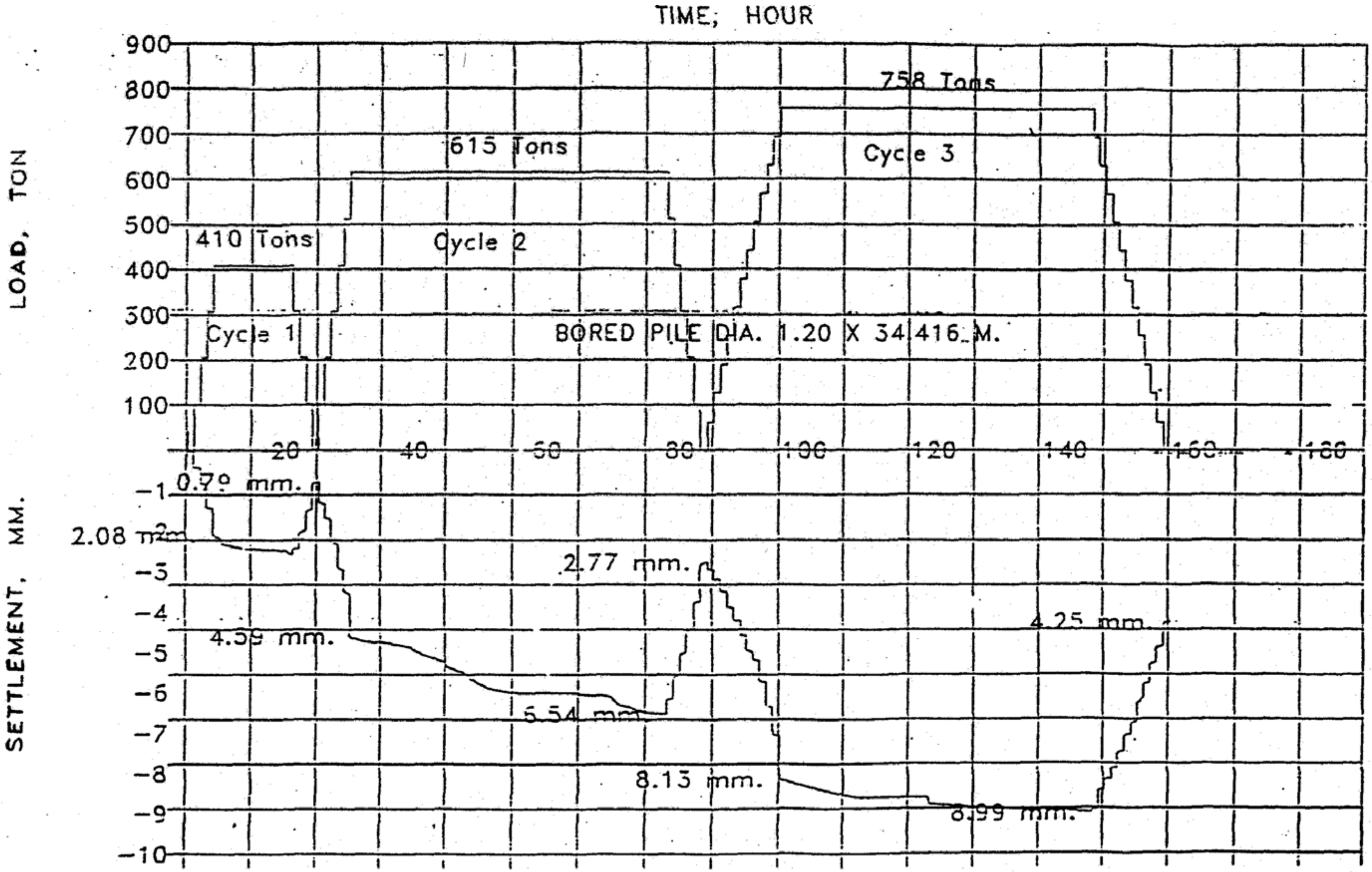
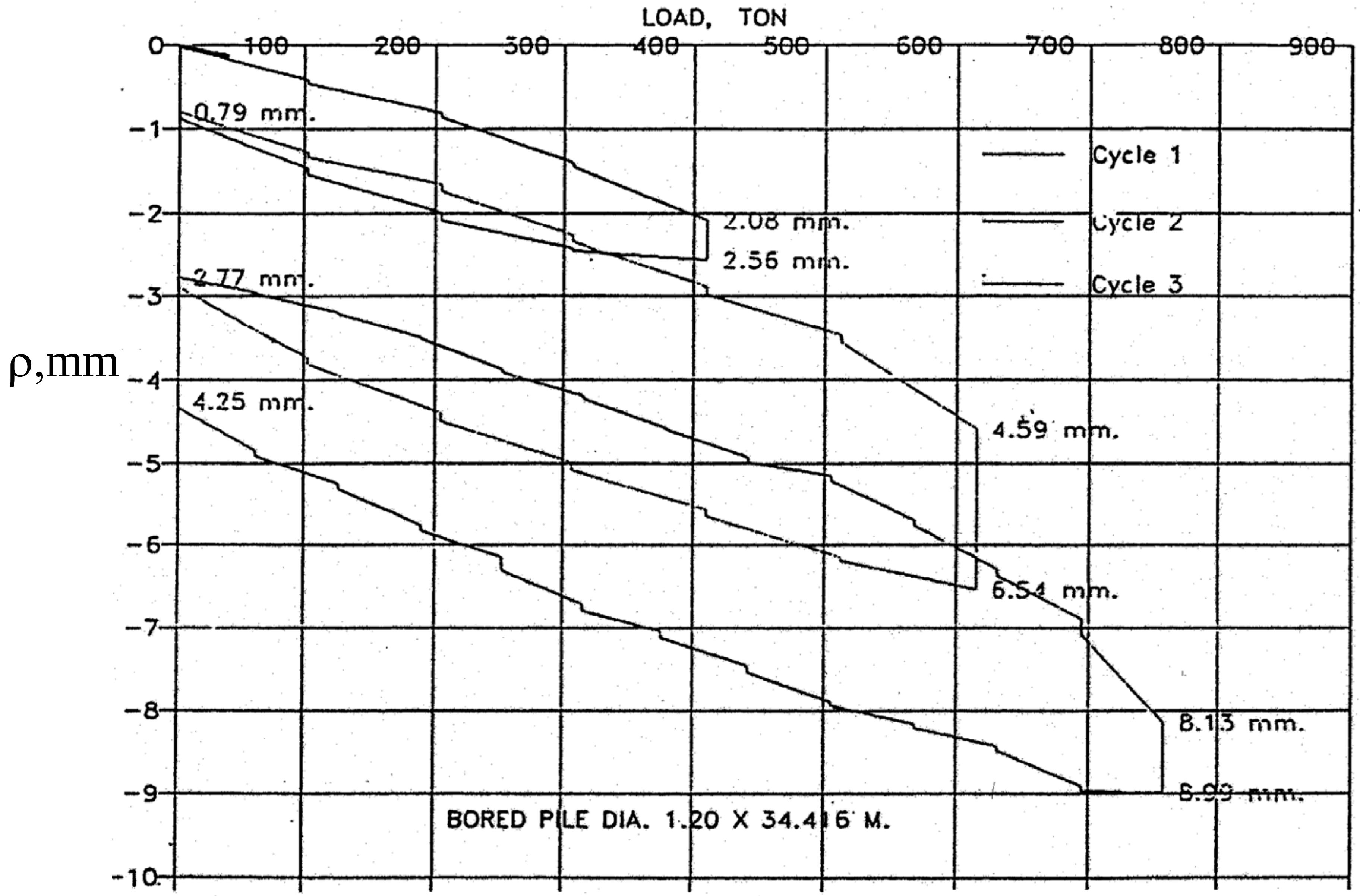


FIG. F.16 Pile at Don Muang (TP2)
Don Muang Project (0.8 m X 26 m)

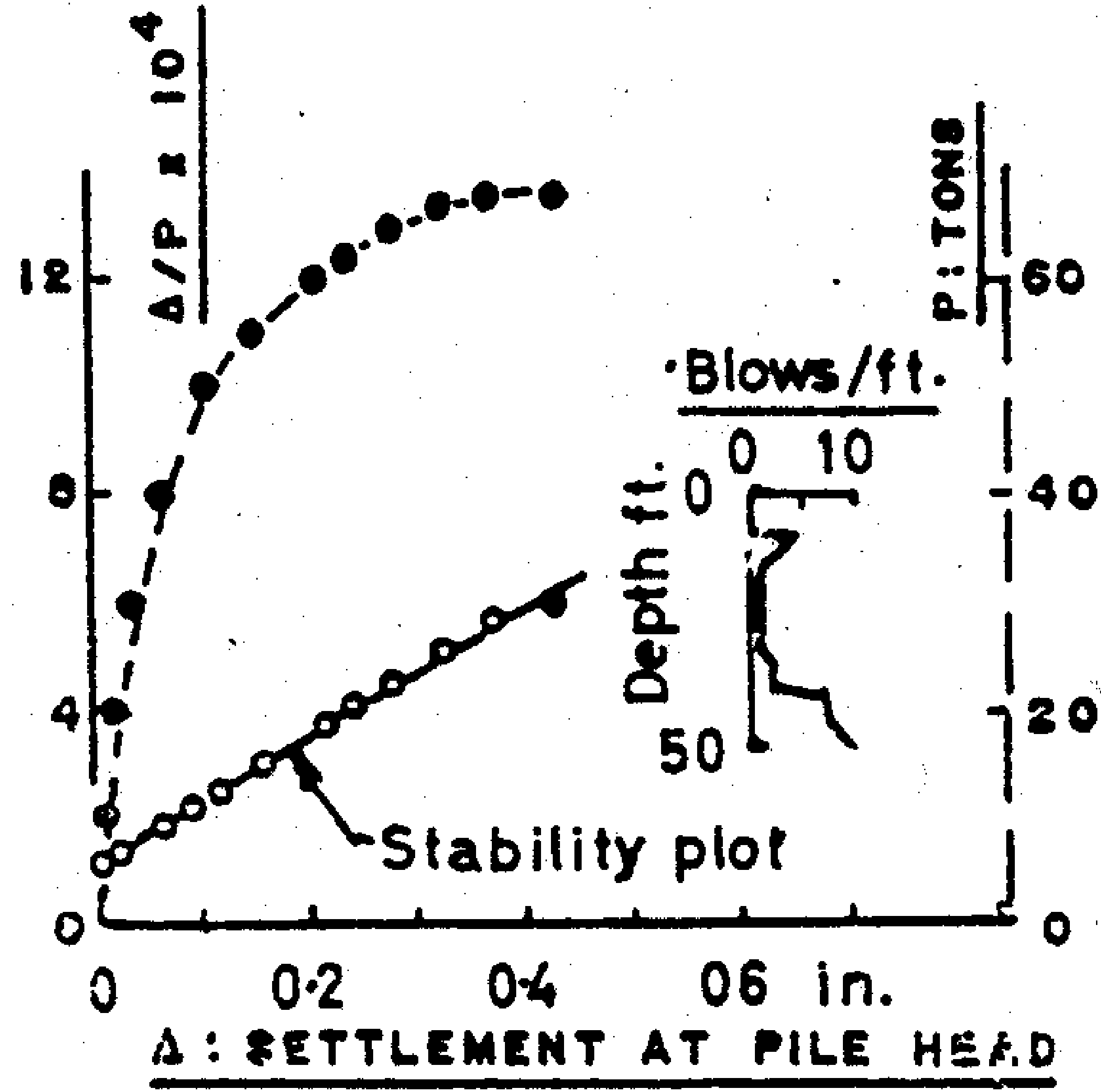


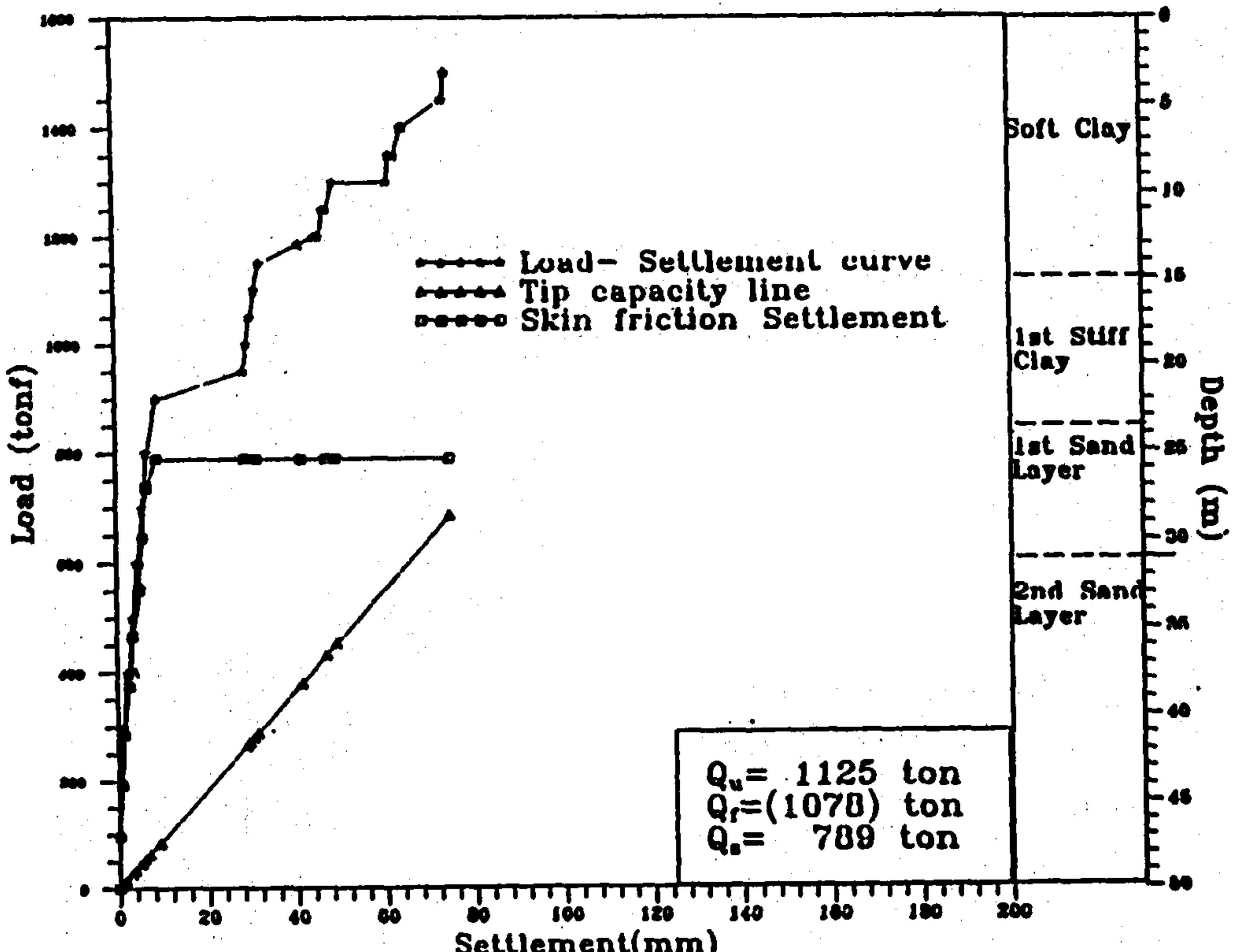
Second stage expressway-- pile load test data
Load -settlement Details



Load-settlement data

Chin's Stability Plot





DF 21 (1.0 m X 47.2 m)

Table 1.2 **Summary of Piling Practice in Bangkok Area**

Unit : piles

Tip Level	Driven Ple		Bored Pile		Auger Pressed Pile	
	Building	Bridge	Building	Bridge	Building	Bridge
Soft Clay	18	-	-	-	-	-
Stiff Clay	35	10	17	-	9	-
1st Sand Layer	1	3	33	4	8	-
2nd Stiff Clay	-	-	17	-	1	-
2nd Sand layer	-	-	46	14	-	-
Subtotal	54	13	113	18	18	-
Total	67		131		18	

Chin's method for ultimate load

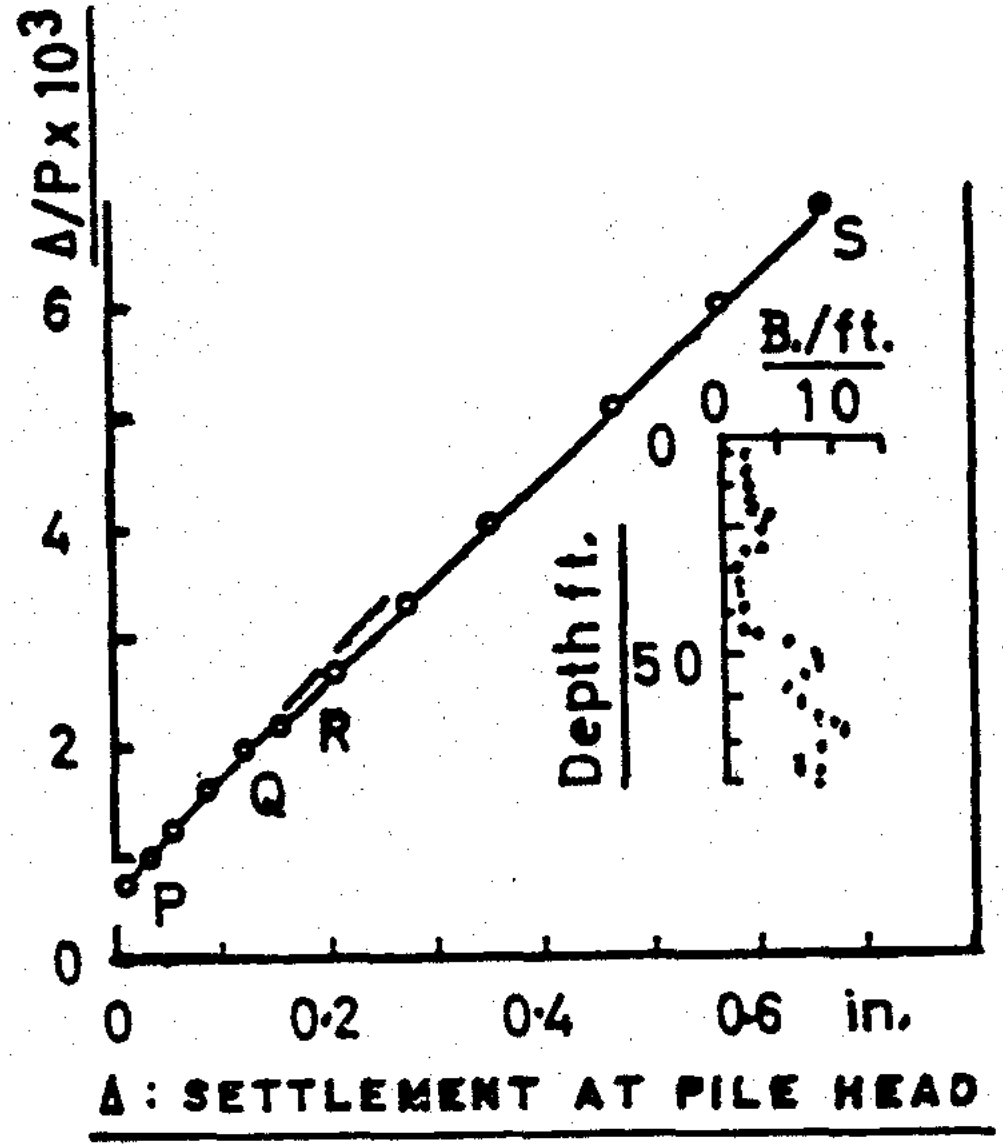
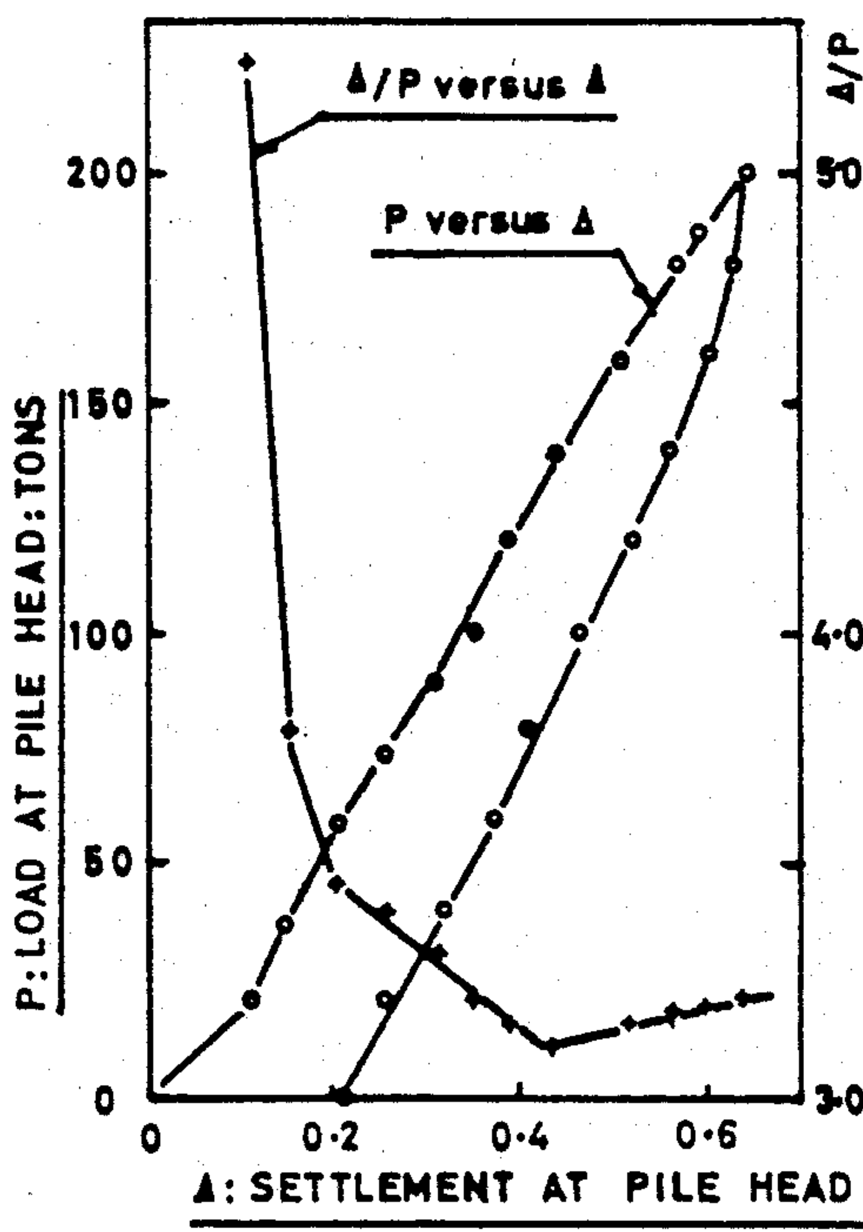


Fig. 2. Stability plot - the bearing capacity of pile is skin friction plus end bearing.

Chin's method for damaged reinforced concrete pile



Stability plot; reinforced concrete pile damaged at joint.

Chin's method for pile diagnosis; steel pile with toe badly crushed

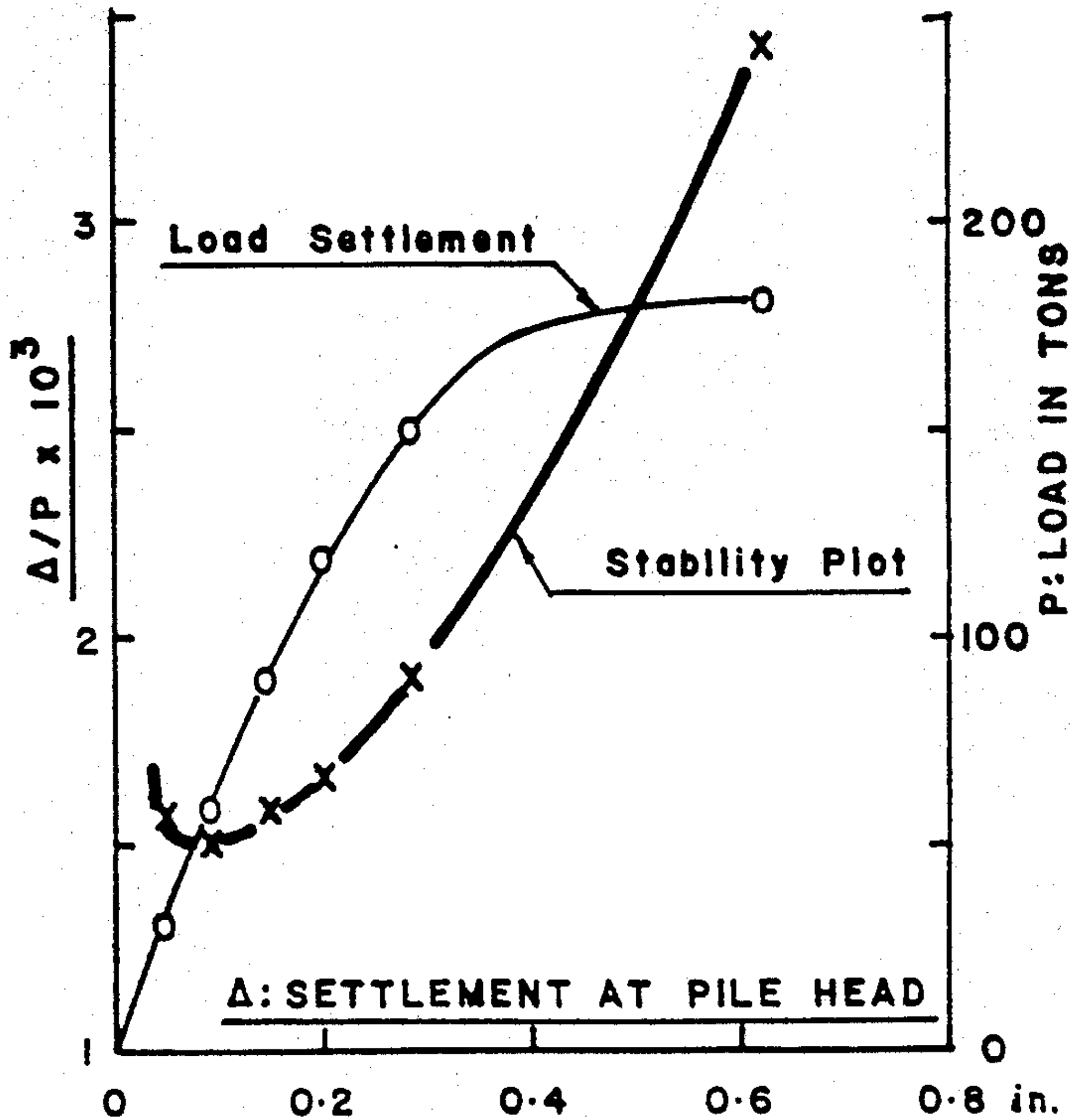


Fig. 4. Stability plot; steel pile toe badly crushed.

Fellenius paper on interpretation of load settlement curves

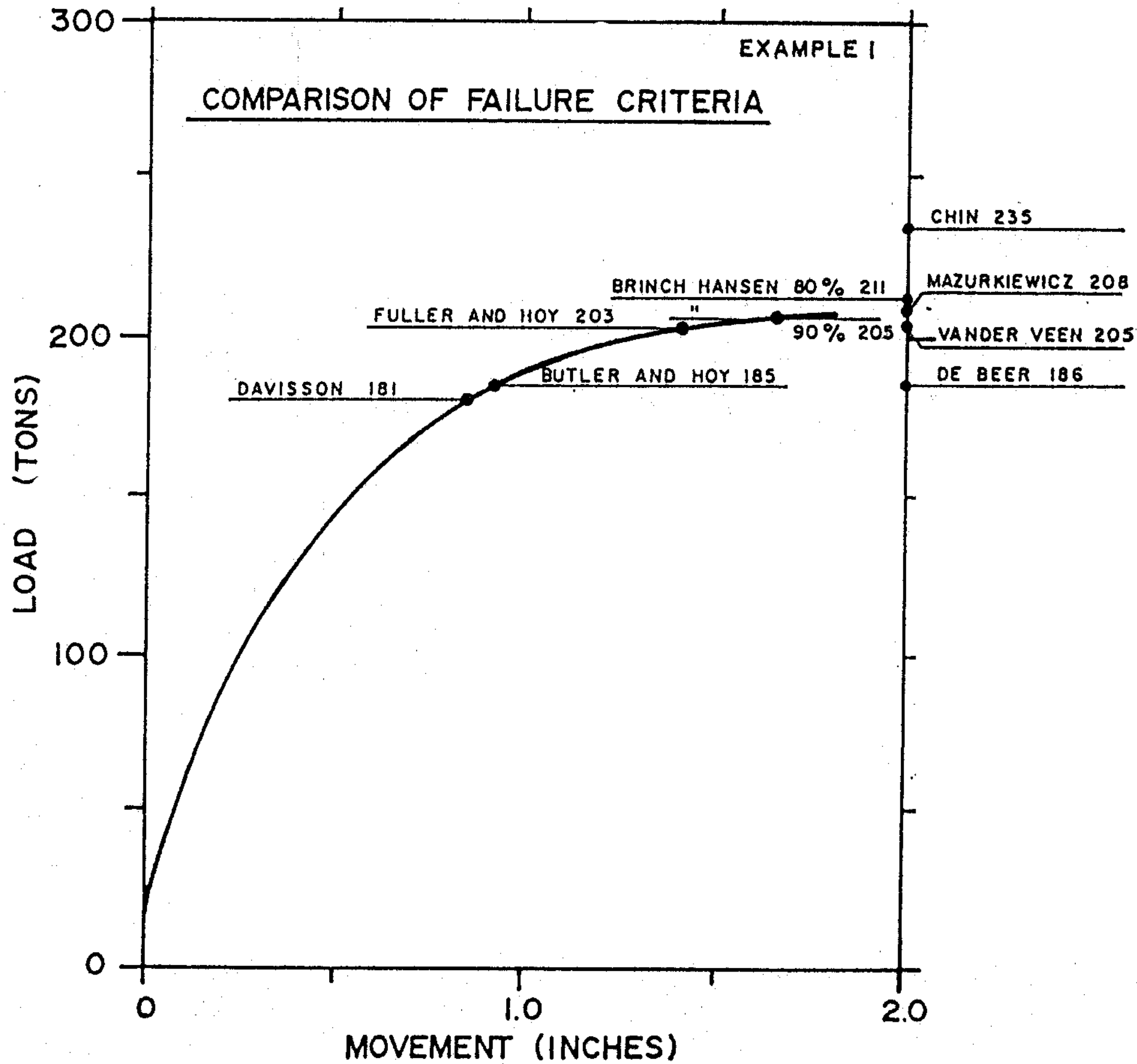
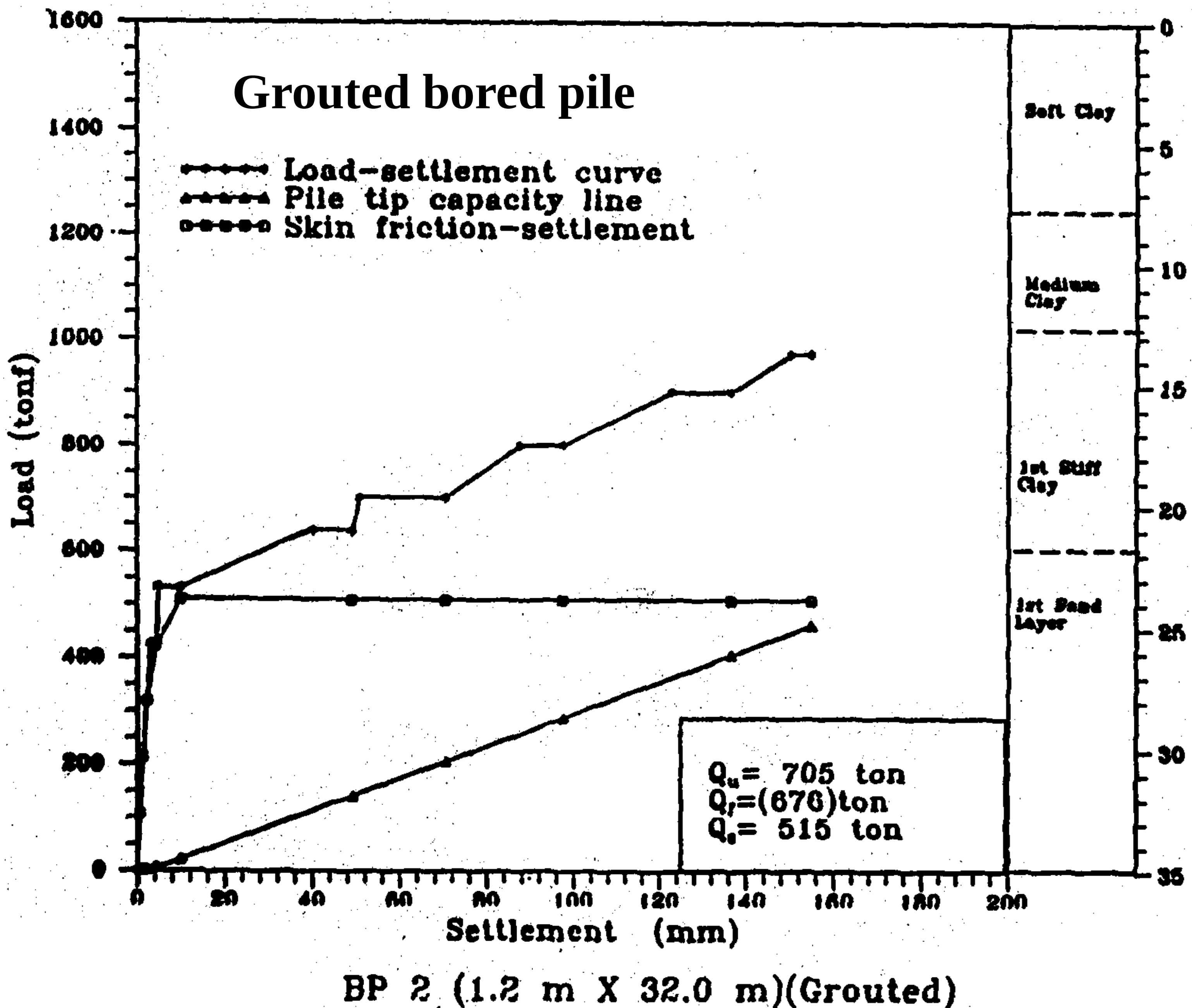
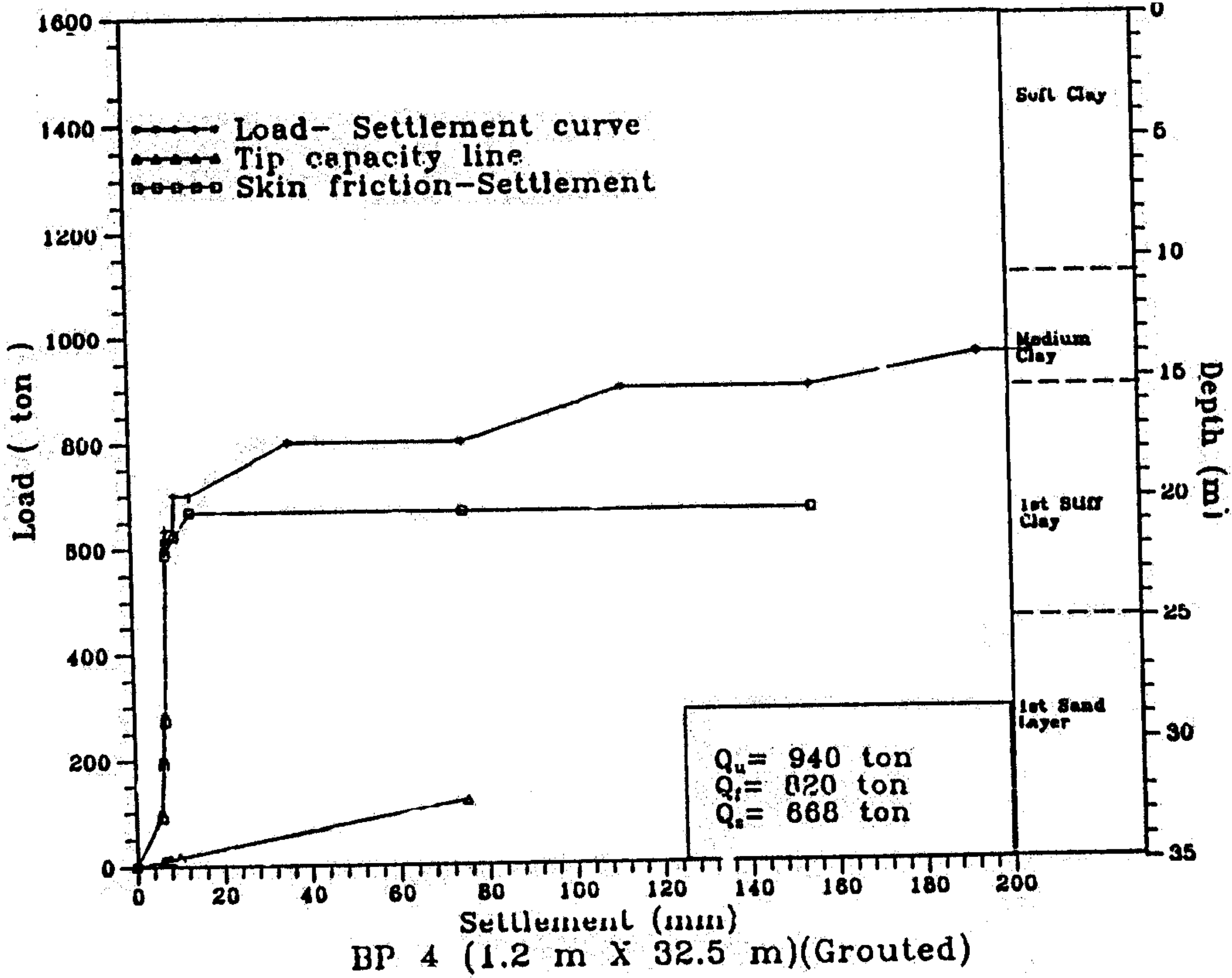


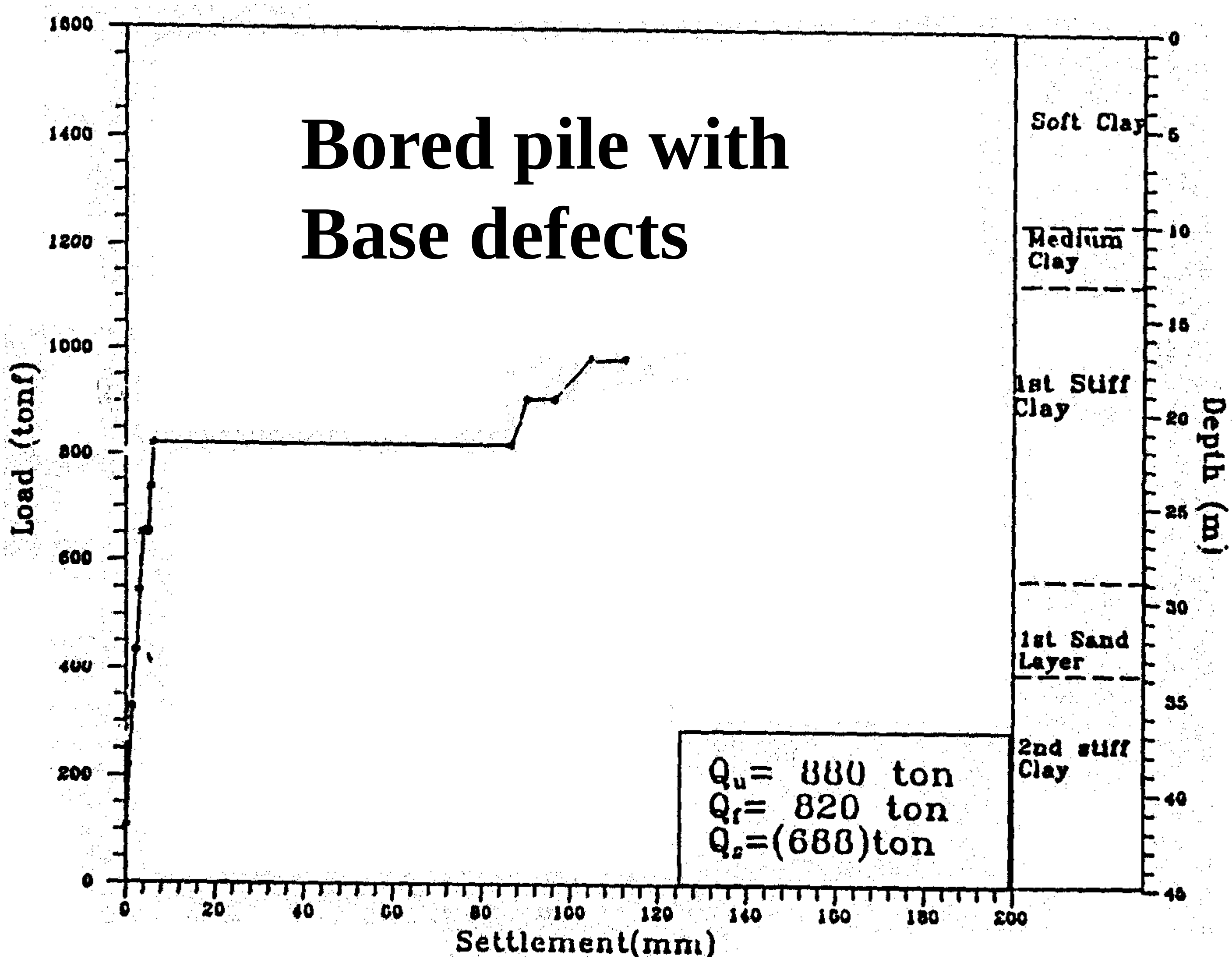
Fig. 10. Comparison of nine failure criteria


Grouted bored pile
Load-settlement curve
Pile tip capacity line
Skin friction-settlement
Load (tonf)
Settlement (mm)
Depth (m)
Soft Clay
Medium Clay
1st Stiff Clay
1st Sand Layer
Q_u = 705 ton
Q_f =(676)ton
Q_s = 515 ton
BP 2 (1.2 m X 32.0 m)(Grouted)



Grouted pile with low performance in end bearing

Bored pile with Base defects



BP 8 (1.2 m X 42.5 m)

K_s tan δ

for skin

friction in Bored piles

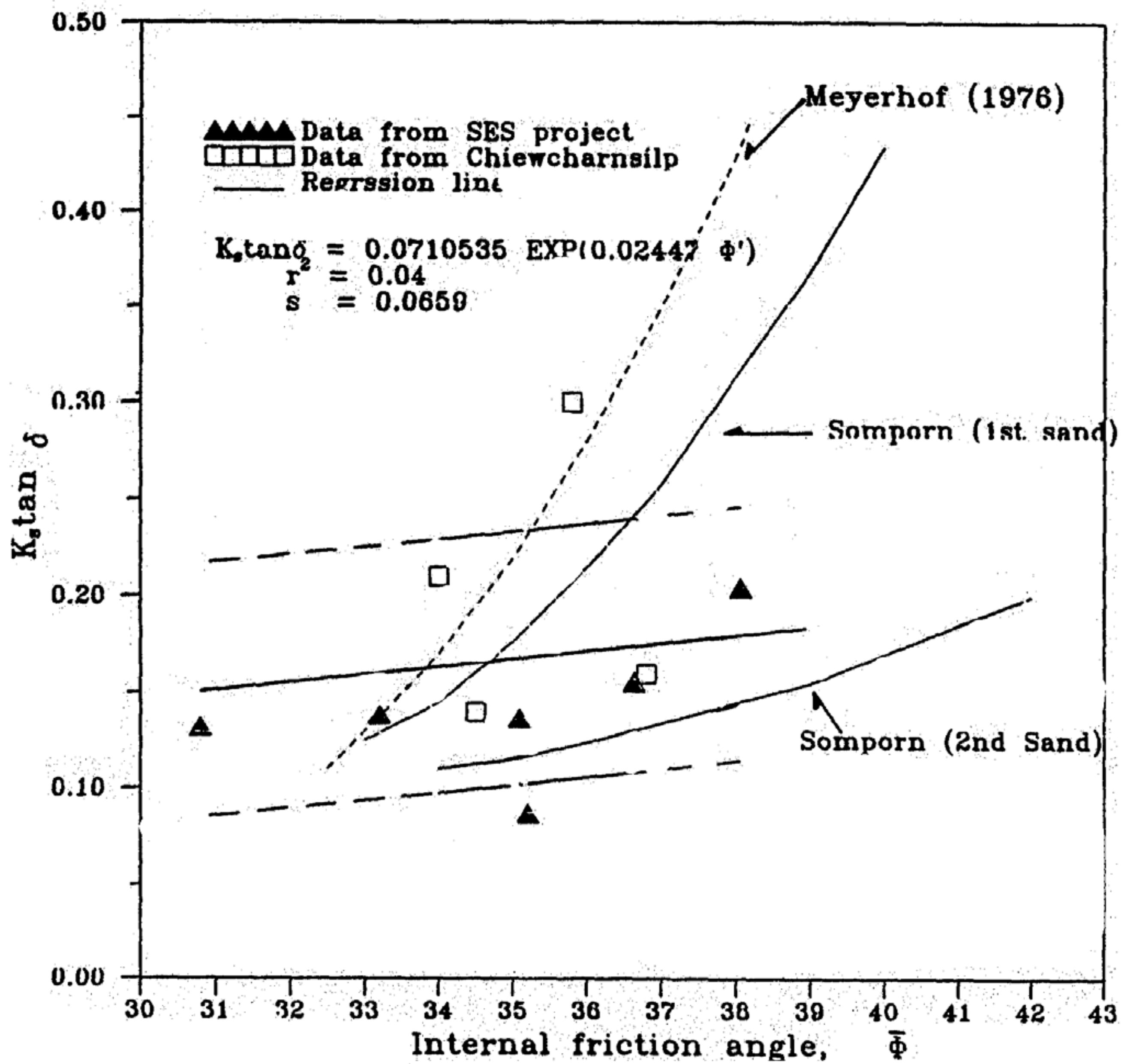


Fig 4.17– Relation between $K_s\tan\delta$ & internal friction angle Φ̄ in SES project

Bearing capacity factor N_q in end bearing

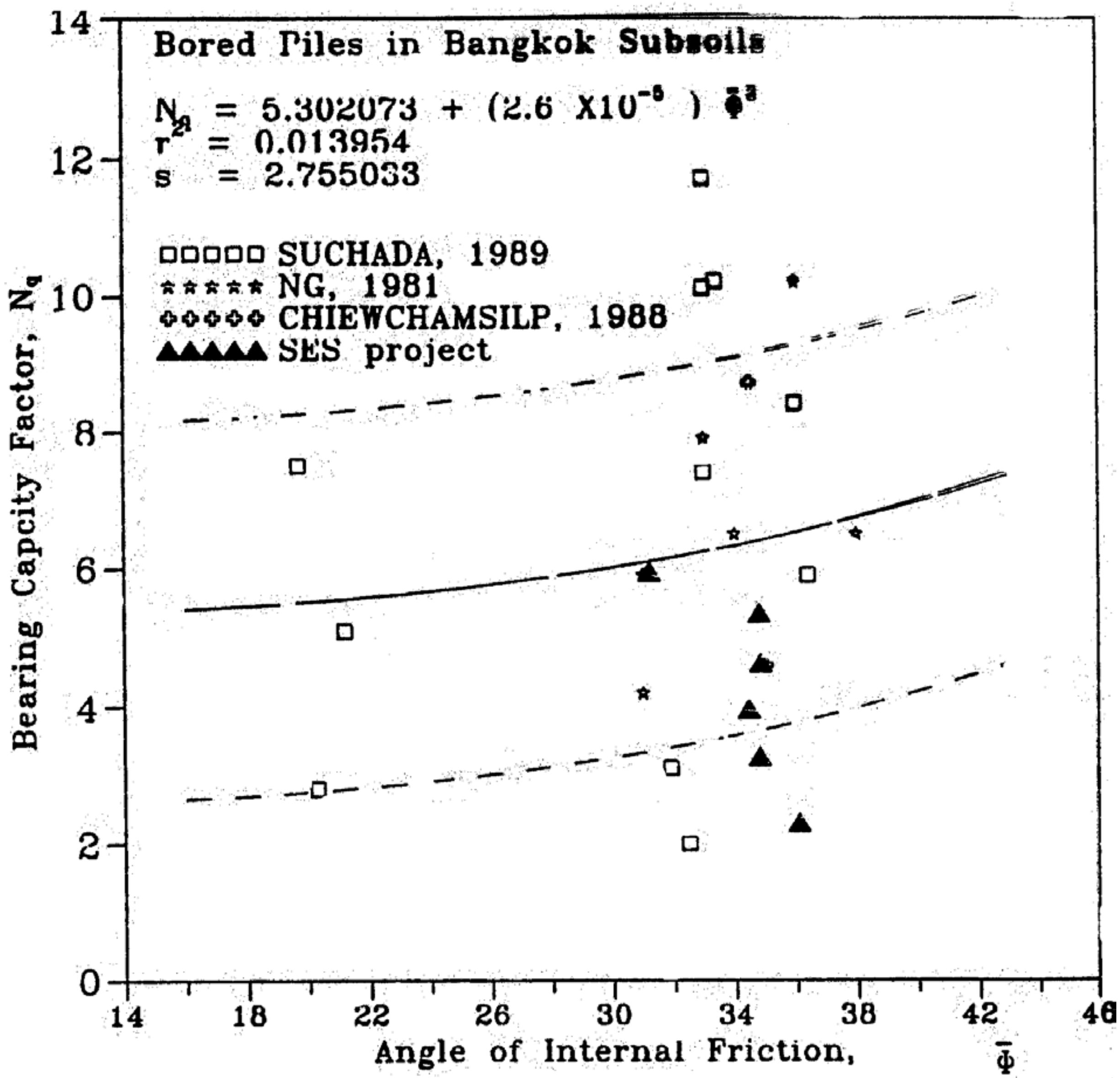
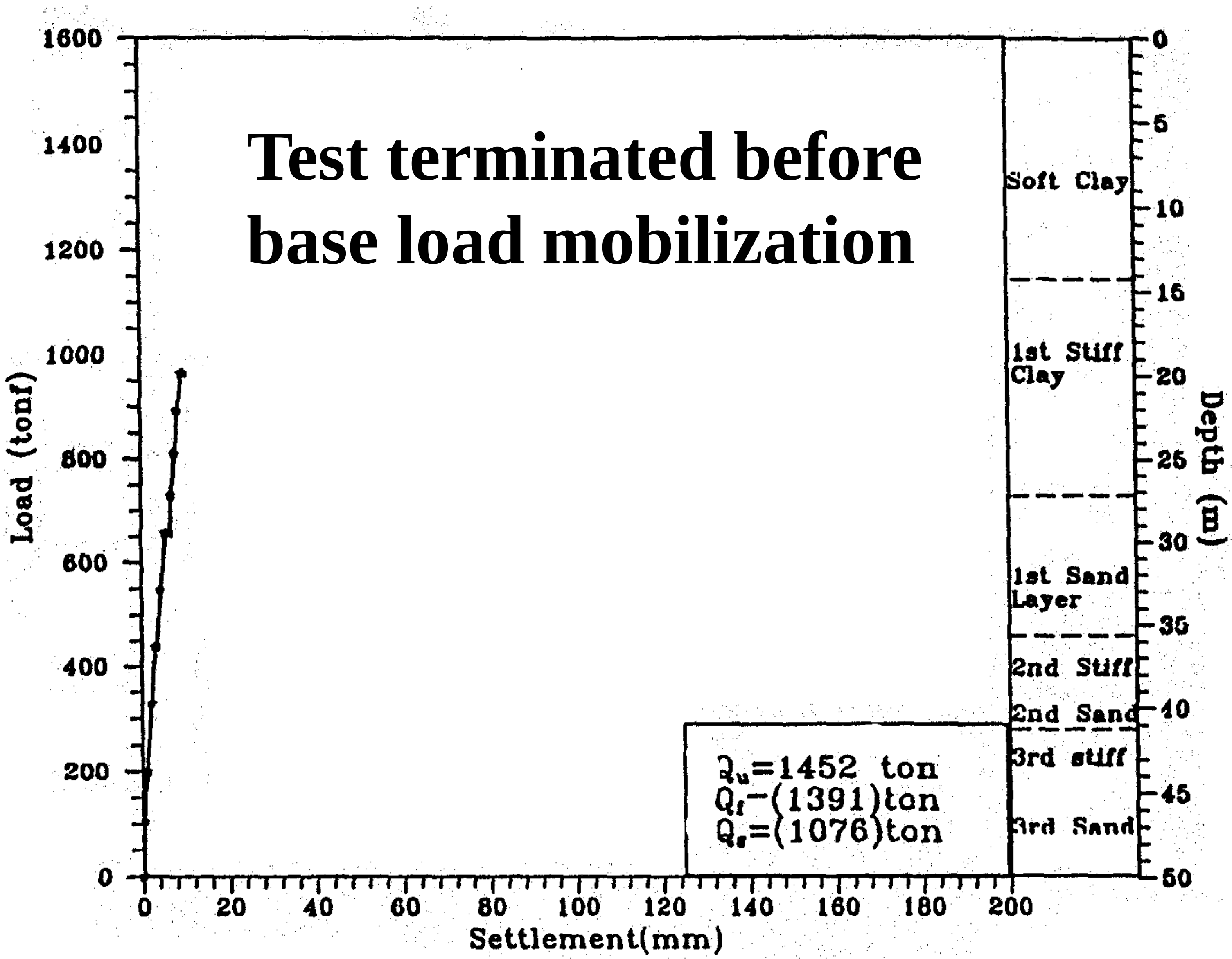


Fig.4.18– Relationship between Bearing Capacity Factor, N_q, and Angle of Internal Friction, $\bar{\Phi}$, of Bored Piles

Test terminated before base load mobilization



BP 17A (1.2 m X 47.25 m)

Table 3.1(b) **Summary of Pile Load Tests in The Second Stage Expressway System Project**

Pile No.	Location	Dia. (m)	Depth (m)	T.L. (ton)	Tip Layer	Remarks
BP# 1	P401/2-P401/3	0.6	26.04	335	1st sand	Toe grouting
BP# 2	P401/3-P401/4	1.2	32.32	980	1st sand	G & I
BP# 3	P401/4-P401/5	1.0	30.50	727	1st sand	G & I
BP# 4	PN400/2	1.2	32.50	1004	1st sand	Toe grouting &
BP# 5	km(10+404)	1.2	30.00	914	1st sand	Toe grouting &
BP# 6	PN/329	0.8	30.00	510	1st sand	
BP# 7	P463/13-P462/14	1.0	31.50	730	1st sand	
BP# 8	PE/56-P453/11	1.2	42.50	966	2nd Stiff	Instrumented
BP# 9	PE/87-PW/88	0.8	31.90	587	1st sand	
BP#12	EW2(Km 0+71)	1.0	46.50	1170	2nd sand	Instrumented
BP#13	EW2(Km 0+114)	1.2	41.60	971	2nd Stiff	Instrumented
BP#14	P373/2-P372/16	1.2	32.45	959	2nd sand	Instrumented
BP#15	EW2(Km 1+010)	1.2	44.17	942	2nd Stiff	Instrumented
BP#16	P450/4-P450/A	0.6	32.04	375	1st sand	
BP#17	PE/22-PE/23	1.0	47.25	963	3rd sand	
BP#18	PN/403-PN/404	1.2	30.50	1000	1st sand	
BP#19	PN/423-PN/424	1.2	34.50	1000	1st sand	
BP#21	NS3(Km 15+100)	1.0	47.00	1500	1st sand	
BP#22	NS3(Km 16+542)	1.0	40.56	1150	1st sand	Instrumented
BP#23	NS3(Km 16+800)	1.2	45.10	1500	2nd Stiff	Instrumented
BP#25	PS/610	1.2	30.00	930	2nd sand	
BP#26	PS/639-PS/640	1.2	31.50	960	1st sand	
BP#28	PN/642-PN/643	1.2	39.00	900	3rd sand	
BP#29	PN/656-PN/657	1.2	33.00	1240	2nd sand	
BP#31	PN440/14-440/15	1.2	34.50	1575	2nd sand	
BP#32	PS/628	1.0	38.92	986	2nd sand	

(Remarks) I : Instrumented
G : Toe Grouting

Adhesion factor for Bored piles

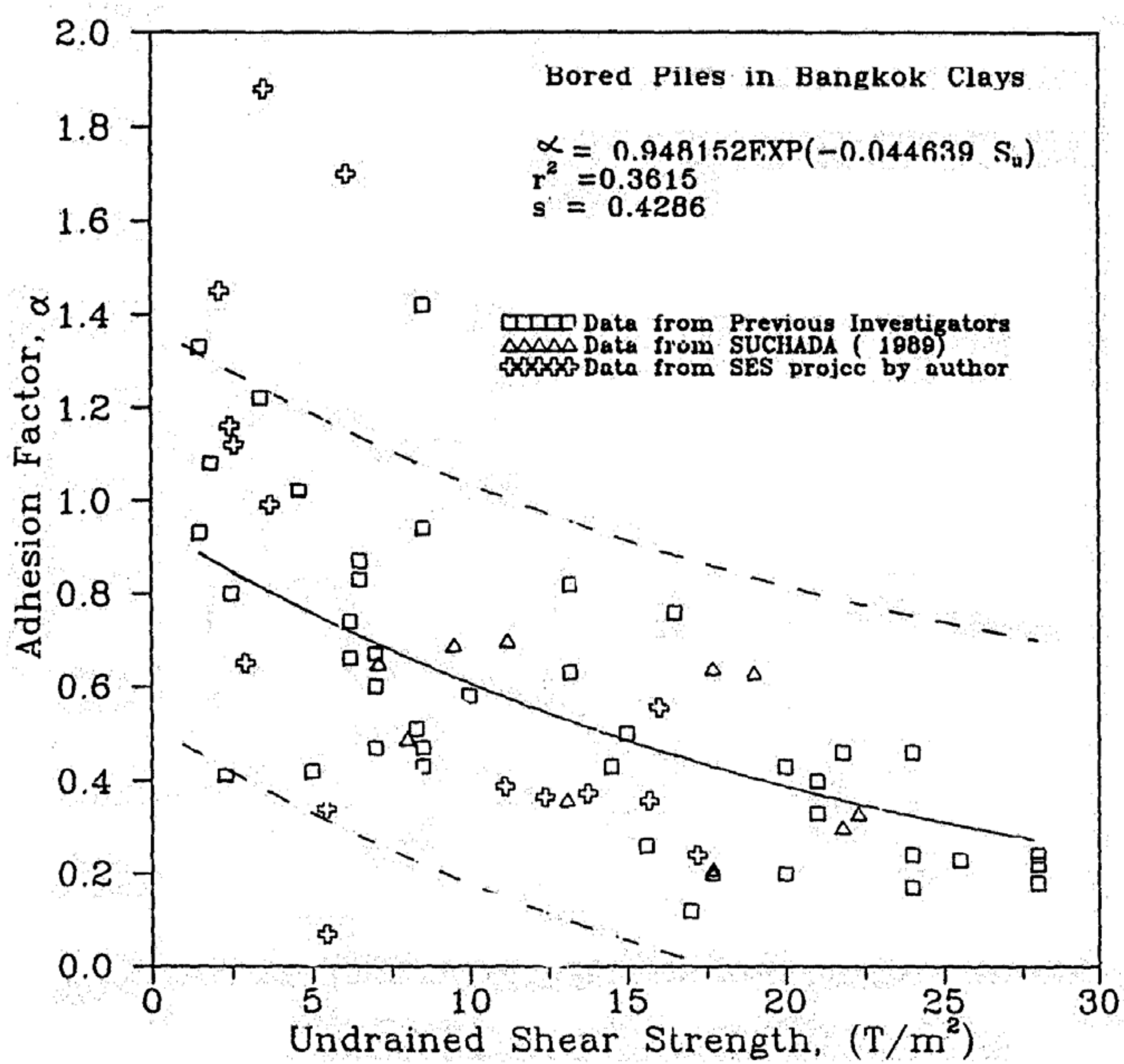
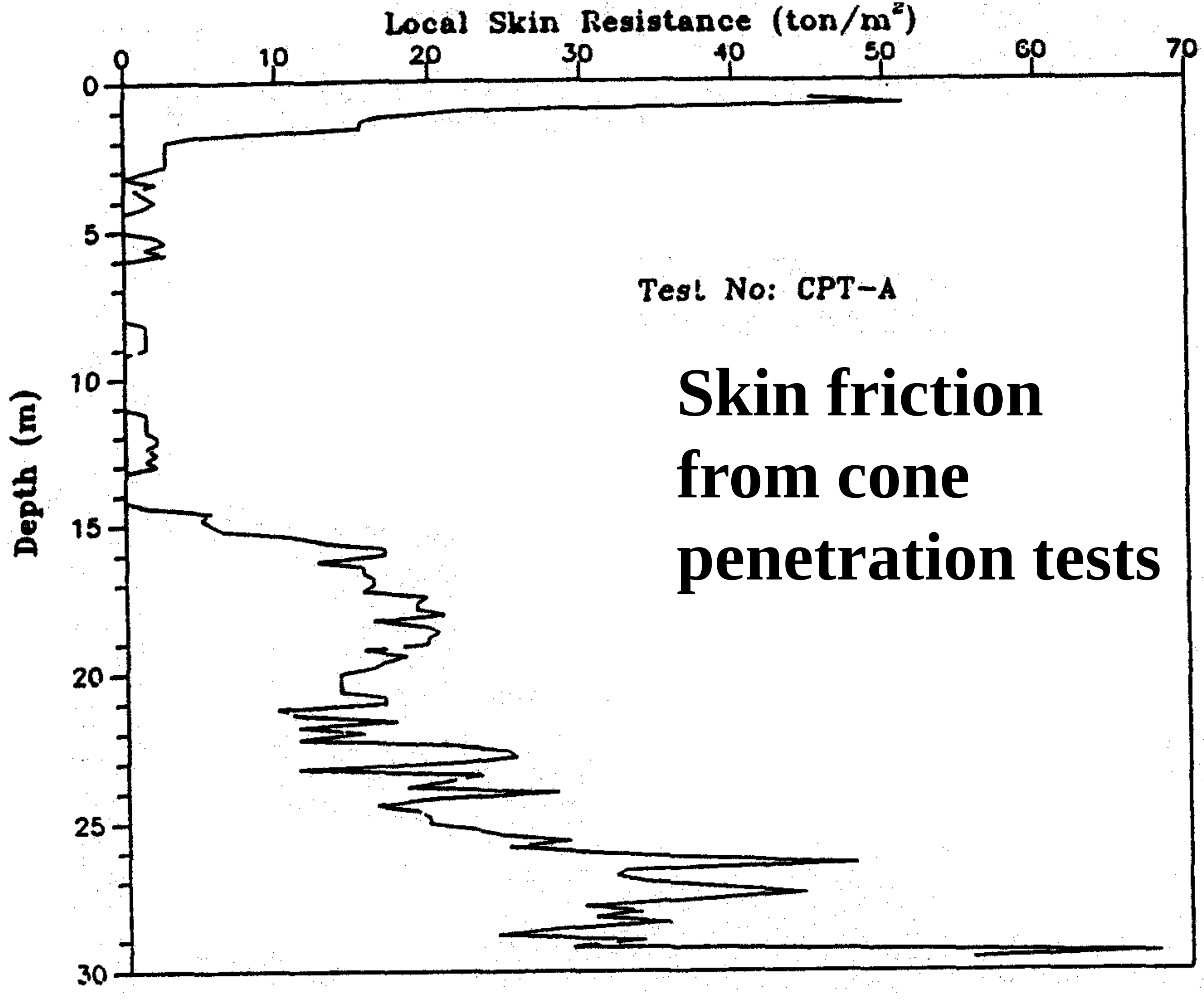


Fig.4.15− Relation between Adhesion Factor (α) & Undrained Shear Strength for Bored Piles



Skin friction from cone penetration tests

Base resistance from cone penetration tests

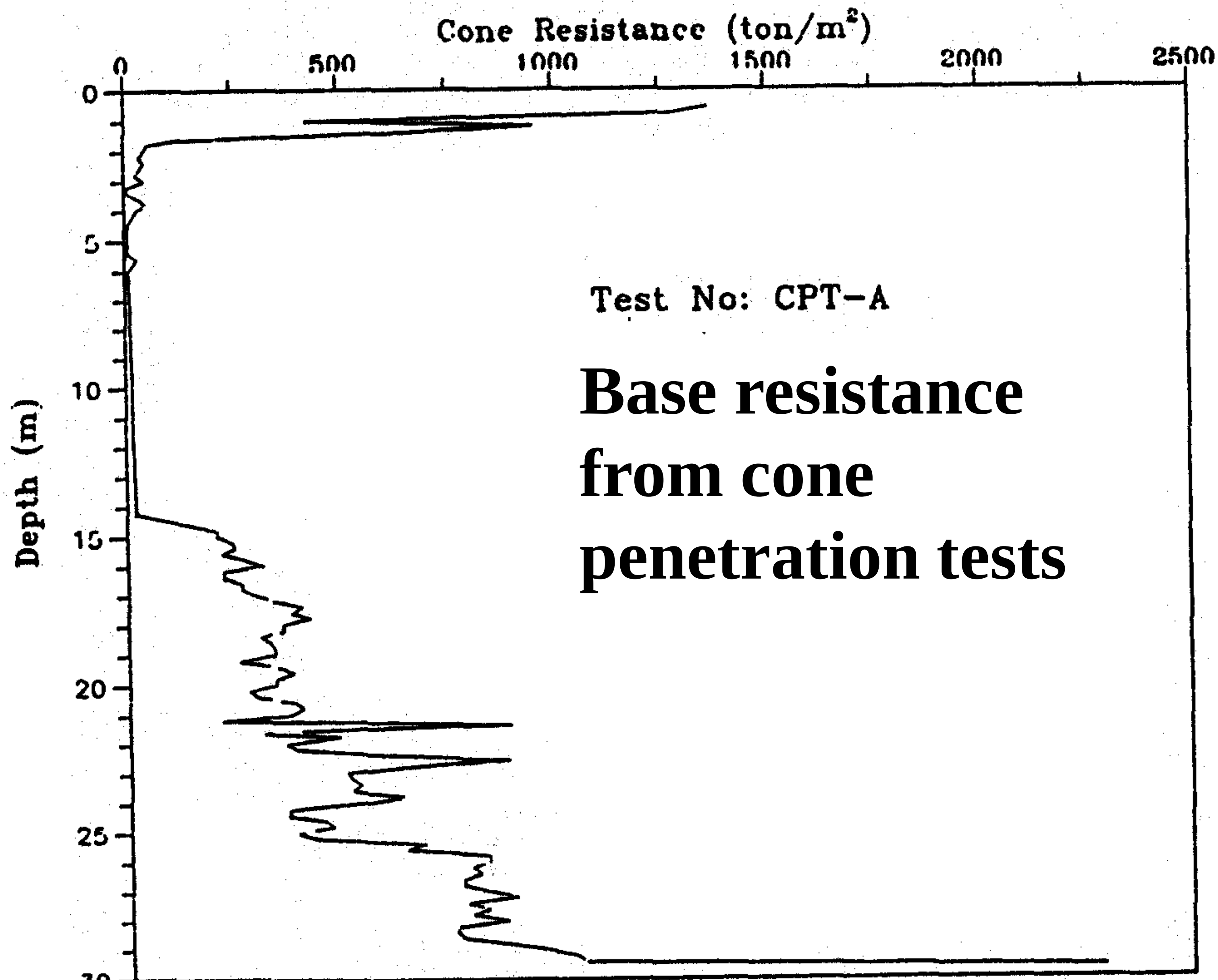
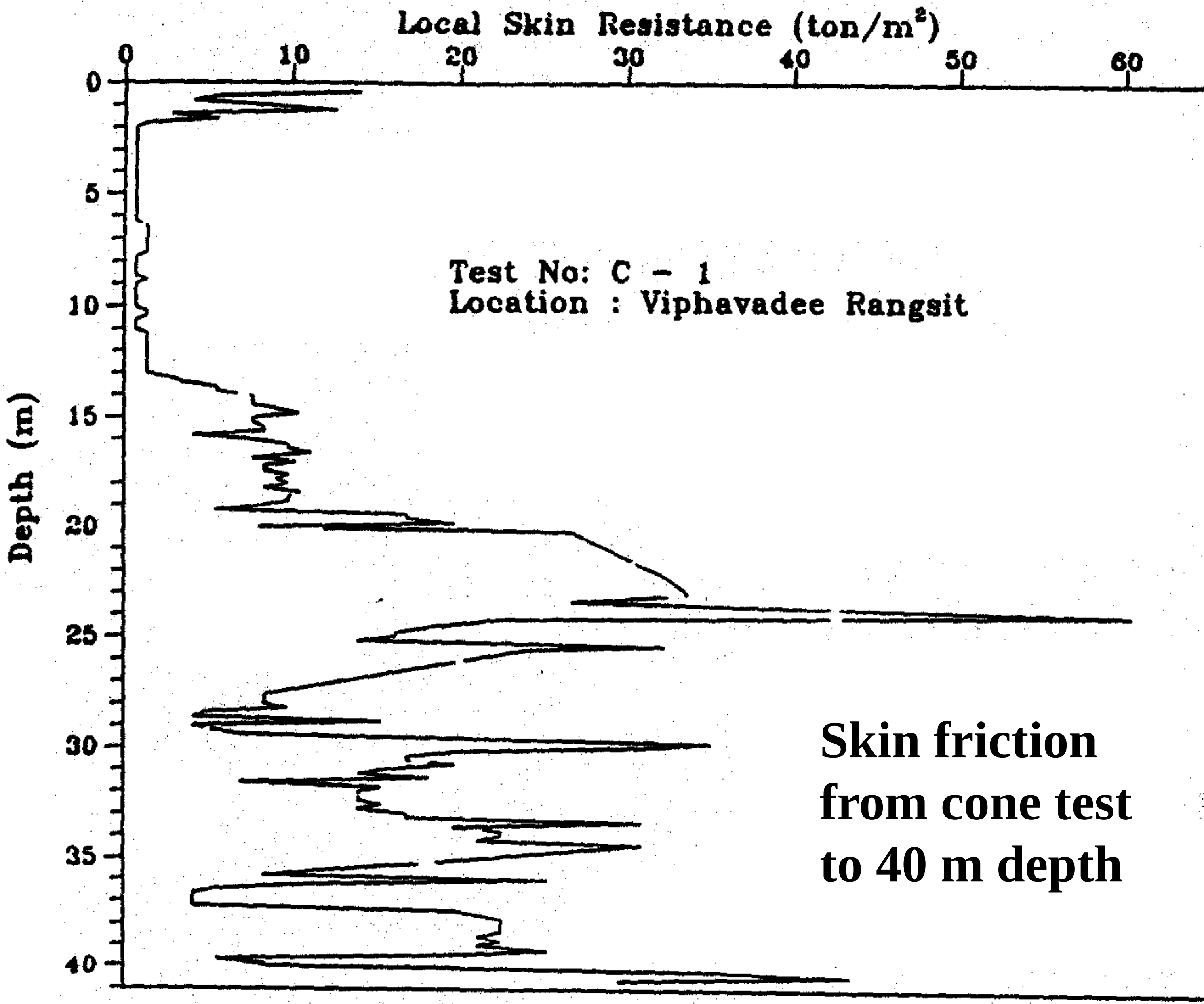


Fig.3.3 CPT Profile for TP10 at Chatuchak Park
Don Muang Project (0.8 m X 30 m)



Skin friction from cone test to 40 m depth

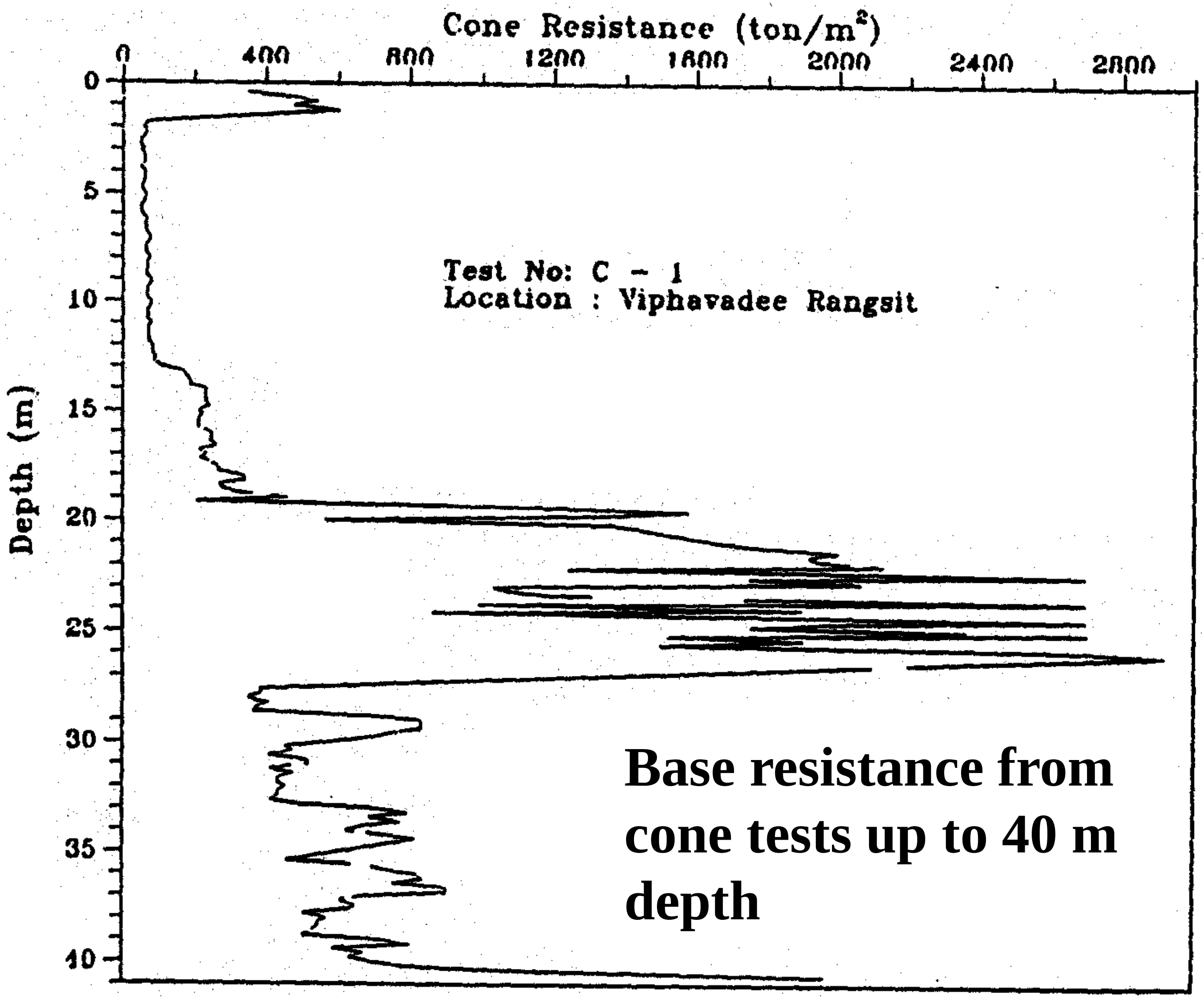


Fig. 3.5 CPT Profile for pile at 16+035
Don Muang Project (0.8 m X 37.5 & 24.6 m)

0.8m diameter spun piles

Skin friction per linear meter in medium stiff to stiff clay

N Value (Measured)	Qs (CH) (tonf/m)	Qs (CL) (tonf/m)
8	15.7	12.9
10	18.1	15.1
12	20.4	17.0
14	22.3	18.8
16	24.2	20.4
18	25.8	21.9
20	27.3	23.3
22	28.7	24.7
24	29.9	25.9
26	31.0	27.0
28	32.1	28.1
30	33.0	29.1

Depth of Pile Tip (m)	Skin Friction (tonf/m) Penetration Thickness in sand layer (m)						
	2	4	6	8	10	12	14
20	32.1	31.2	30.3	29.4	28.4	27.5	26.6
22	33.9	33.0	32.1	31.2	30.3	29.4	28.4
24	35.7	34.8	33.9	33.0	32.1	31.2	30.3
26	37.5	36.3	35.7	34.8	33.9	33.0	32.1
28	39.3	38.4	37.5	36.3	35.7	34.8	33.9
30	41.1	40.2	39.3	38.4	37.5	36.3	35.7
32	42.8	42.0	41.1	40.2	39.3	38.4	37.5
34	44.6	43.7	42.8	42.0	41.1	40.2	39.3
36	46.4	45.5	44.6	43.7	42.8	42.0	41.1
38	48.2	47.3	46.4	45.5	44.6	43.7	42.8
40	50.0	49.1	48.2	47.3	46.4	45.5	44.6

Skin friction per linear meter in first sand layer for 0.8 m spun piles

Base resistance of 0.8m diameter spun piles with tips in the first sand layer

N Value (Measured)	End Resistance (tonf)							
	Depth of Pile Tip (m)							
	15	16	17	18	19	20	21	22
20	241	244	258	267	269	277	285	290
22	247	255	262	272	278	283	291	300
24	255	265	269	279	287	289	296	303
26	262	272	276	286	292	296	304	310
28	275	281	284	294	296	303	312	321
30	281	287	296	303	304	315	319	330
32	294	301	301	306	316	323	331	337
34	302	309	315	319	324	329	338	341
36	312	322	326	339	341	344	350	360
38	326	338	336	358	347	359	365	374
40	347	357	357	375	368	373	377	387
42	366	370	376	394	382	396	394	406
44	378	385	389	399	398	410	414	422
46	385	391	403	410	420	424	428	433
48	408	419	418	422	427	438	452	456
50	425	445	442	458	444	450	460	464
52	472	467	477	468	478	482	478	491
54	493	498	503	497	499	501	507	512
56	539	533	525	537	530	522	540	546
58	561	559	550	568	560	554	583	561
60	582	586	575	592	590	580	596	605

Table 2.2 Recommended Ks Values by BROMS (1966)

Pile Types	Low Relative Density	High Relative Density
Steel piles	0.5	1.0
Concrete piles	1.0	2.0
Wood Piles	1.5	4.0

Table 2.3 - The Angle of Friction (δ) between Pile and Soil (AAS, 1966)

Pile Types	Angle of Friction
Steel Piles	20 degree
Concrete Piles	3/4 Φ'
Wood Piles	2/3 Φ'

Recommended values of K_s and δ

Table 2.4- Bearing Capacity Factor, N_q of bored piles in sand under Bangkok Subsurface Condition

Investigators	Pile No.	σ'_v ton/m^2	Φ'	N_q
NG (1983)	B8	36.9	34	6.5
	B9	38.0	31	5.9
	B11	45.9	31	4.2
	B12	47.5	33	7.9
	B13	44.9	36	10.2
	B14	44.9	38	6.5
CHIEWCHARNSILP (1988)	TP1	54.3	35	4.6
	TP3	49.1	34.5	8.7

Recommended values of N_q for bored piles bearing in sand

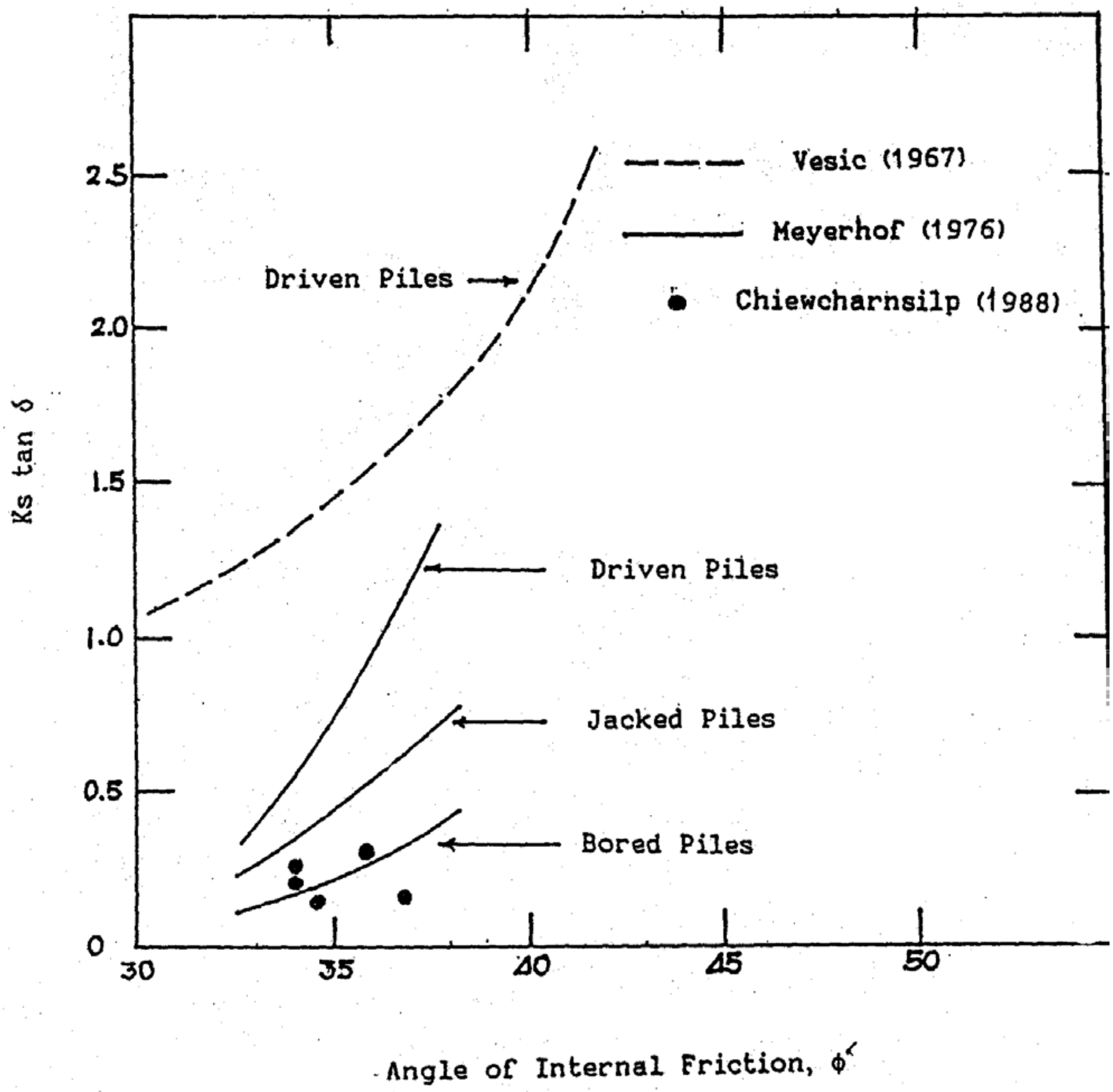
Investigator	α				λ	
	Soft Clay	Medium Stiff Clay	Stiff Clay	Sand	Clay	sand
Pham, 1972	1.4	1.4	0.7	-	0.33	1.0
Juta-Sirivongse 1972	1.0	1.0	1.0	1.0	0.33	1.0
Chotivittaya-thanin, 1977	1.1	0.7	0.5	0.5	0.33	0.5
Phota-Yanuvat	1.0	0.7	0.5	0.8	0.33	0.5
Chukiat Phota-Yanuvat, 1979	1.0	0.7	0.5	0.8	0.33	0.5

Friction and end bearing factors for driven piles to be used with cone penetration test data

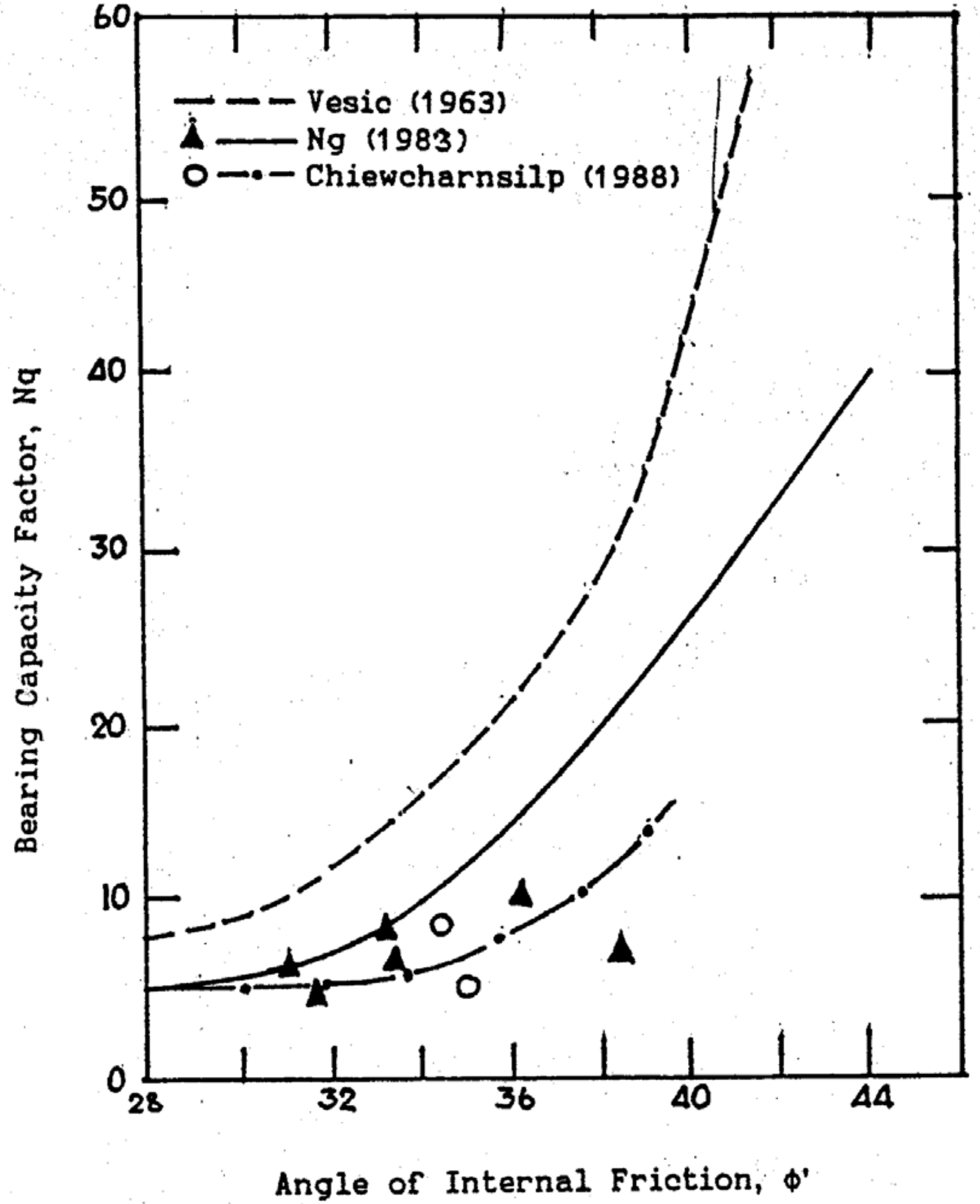
Pile No.	Type	Location (km)	Dia. (m)	Length (m)	T.L. (tonf)	Tip Layer	Remarks
-	Driven	km 16+035	0.8	24.6	840	1st sand	
	Driven	km 16+035	0.8	37.5	872	2nd Stif	Lot 6
TP2	Driven	km 21+100	0.8	26.0	900	1st sand	Dong Muang
	Driven	km 12+400	0.8	28.1	900	1st sand	Lad Prao
TP10	Driven	Chatuchak	0.8	30.0	872	1st sand	
	Driven	km 16+035	0.6	37.5		2nd stiff	
TP3	Driven	km 12+400	0.6	30.0	690	1st sand	
TP1	Driven	km 21+100	0.6	36.0	600	1st sand	Dong Muang

Details of pile load tests data for driven piles from Ding Daeng - Dong Muang Tollway Project

K_s tan δ for bored piles in estimating skin friction in sand

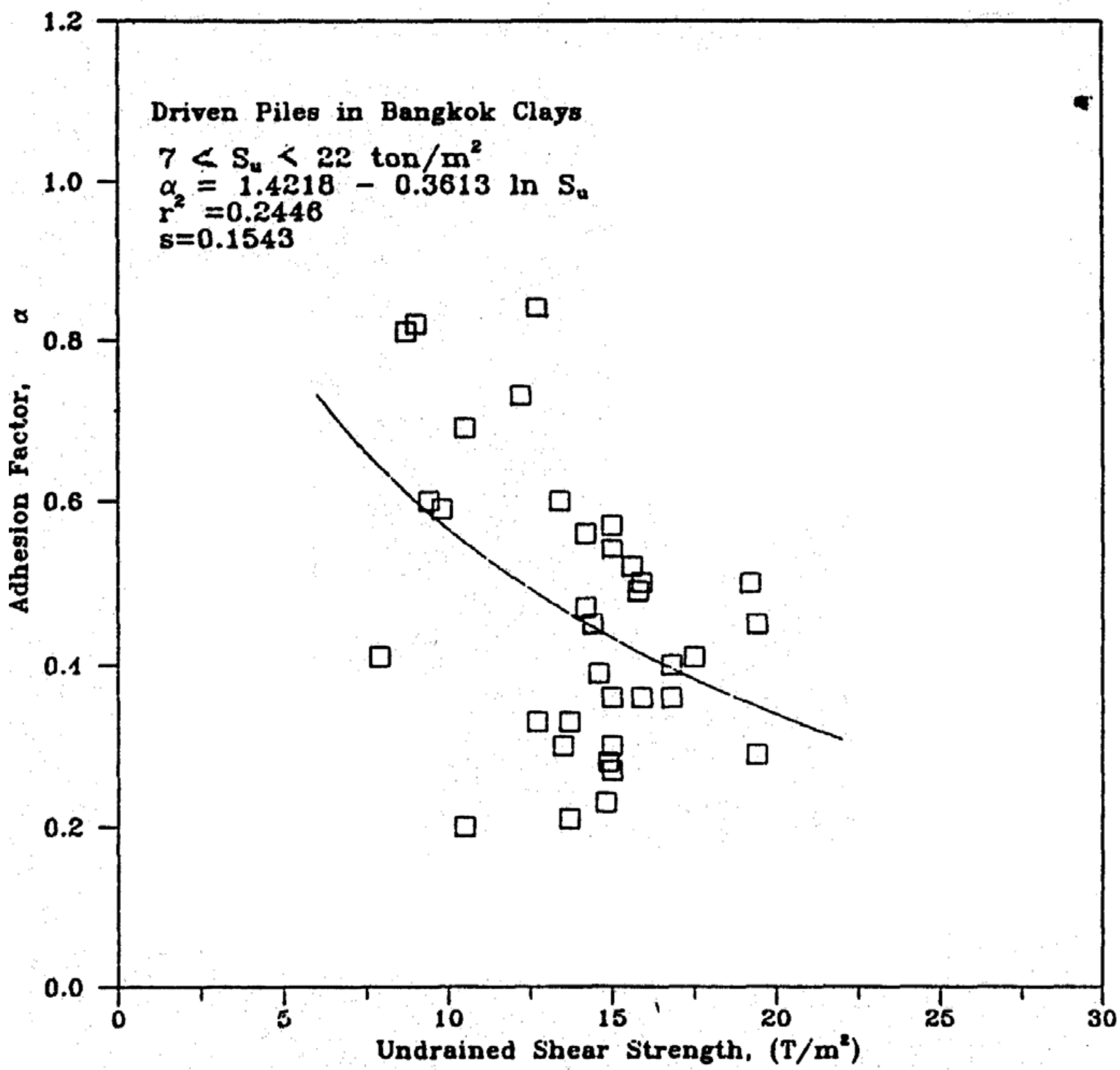


Bearing capacity factor N_q for bored piles bearing in sand layer



Skin friction in bored piles mobilized in small pile movements of 1 to 13 mm

Name of Investigators	Pile No	Depth m	Skin Load Transfer ton/m²	Average Su ton/m²	Adhesion Factor α	Mobilized Displacement mm
CHIRUPPAPA (1968)	-	-	-	2.3	0.41	-
SUWANAKUL (1969)	-	-	-	3.4	1.22	-
BANDEKAR (1980)	B5	2.6	2.00	1.85	1.08	-
		7.8	9.80	3.2	3.06	-
		13.0	4.20	7.0	0.60	-
		18.2	4.00	8.5	0.47	-
		23.4	4.10	15.6	0.26	-
	B6	7.95	4.73	1.85	2.56	-
		13.25	4.70	7.0	0.67	-
		18.55	12.10	8.5	1.42	-
		23.95	4.00	15.6	0.26	-
	B9	2.55	2.00	1.5	1.33	-
		7.65	2.00	1.5	1.33	-
		12.75	2.10	5.0	0.42	-
		17.85	4.20	8.3	0.51	-
		22.95	12.50	16.5	0.76	-
PROMBOON (1981)	-	-	-	2.5	0.80	4-8
	-	-	-	15.0	0.50	10
NG (1983)	BP2	11.0	6.23	14.5	0.43	2.20
		28.00	5.81	25.5	0.23	2.00
	BP3	14.80	8.40	21.0	0.40	3.60
		19.80	5.80	24.0	0.24	4.00
	BP4	15.75	11.00	24.0	0.46	4.50
		40.00	4.90	28.0	0.18	2.20
	BP5	14.80	6.90	21.0	0.33	2.20
		19.8	4.10	24.0	0.17	1.10
		38.00	6.20	28.0	0.22	1.30
	BP6	37.50	6.80	28.0	0.24	3.00
	BP8	37.50	6.20	28.0	0.22	1.00
	BP10	20.60	8.00	8.5	0.94	1.10
		39.50	8.50	20.0	0.43	2.30
	BP11	22.50	5.80	10.0	0.58	2.00
		38.50	2.00	17.0	0.12	1.20
CHIEWCHARNSILP	TP1	-	1.40	1.5	0.93	5.10
		-	4.60	6.2	0.74	12.90
		-	8.30	13.2	0.63	10.20
	TP2	-	4.10	6.20	0.66	5.50
		-	10.80	13.20	0.82	11.00
	TP3	-	4.70	4.60	1.02	4.50
		-	5.40	6.50	0.83	4.50
	TP5	-	5.70	6.50	0.87	6.20
		-	3.30	7.00	0.47	4.10
		-	10.10	21.80	0.46	10.10



Adhesion factor for bored piles in stiff clay layer

Franki piles in Penang

Defects in enlarged Pile base

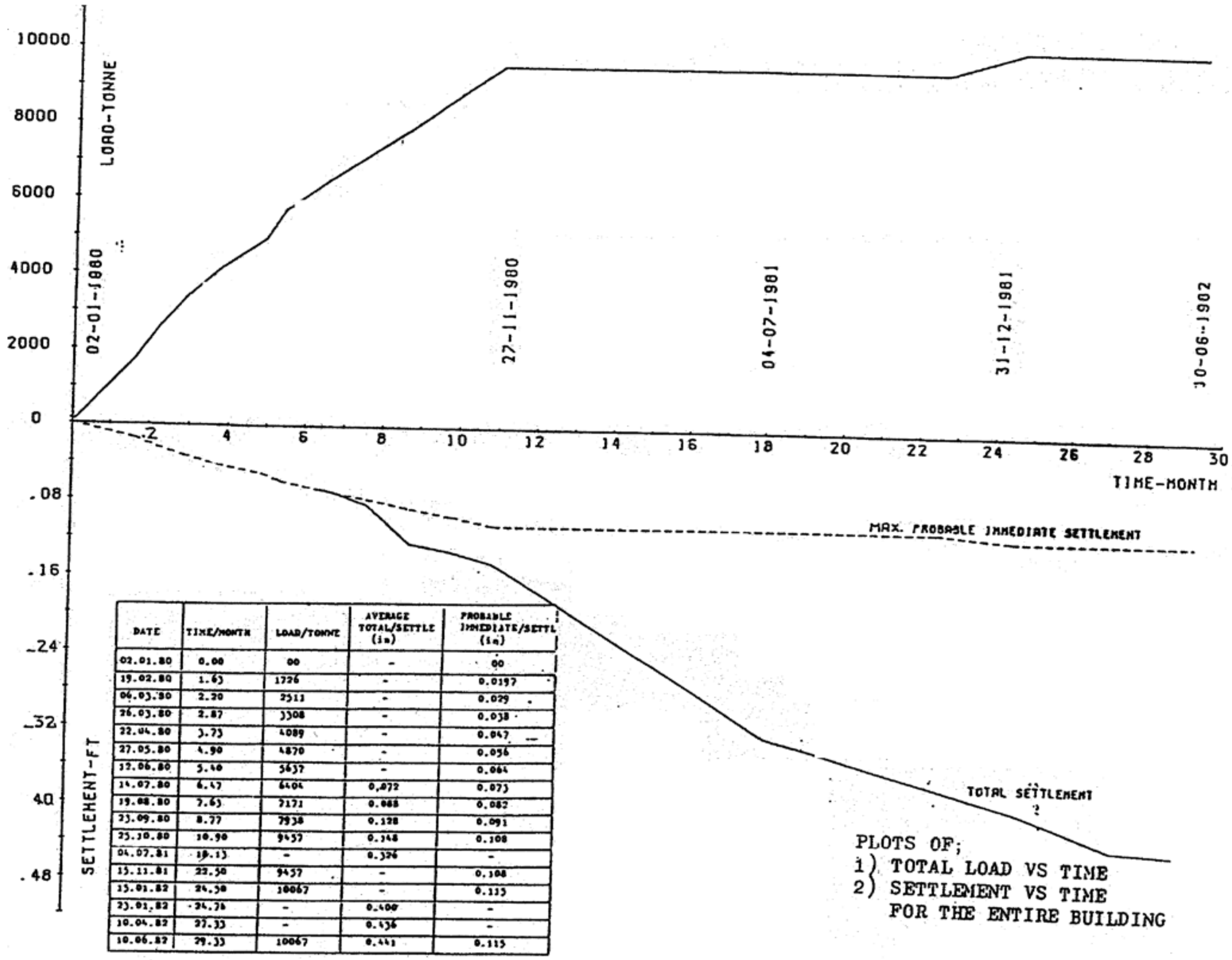
7. Number of Piles Required

For Solution A we assumed 50, 30 and 20% of the working load on rows M, K and J respectively. The analysis performed gave the results for Solution B :-

Column	Working Load	Allowable Load on Existing Piles	Number of Micropiles each with 50 t Working Load
J3	566	360	4 x 50 t
J5	525	320	4 x 50 t
J7 + J8	1123	670	9 x 50 t
J10 + J11	1124	670	9 x 50 t
J12	521	320	4 x 50 t
J13	567	360	4 x 50 t
K3	666	450	4 x 50 t
K5	534	320	4 x 50 t
K7	546	340	4 x 50 t
K8 + K10	1919	1260	12 x 50 t
K11	526	320	4 x 50 t
K12	529	320	4 x 50 t
K13	668	450	4 x 5' t
M3	512	360	4 x 50 t
M5	503	320	4 x 50 t
M7 + M8	764	450	6 x 50 t
M10 + M11	751	450	6 x 50 t
M12	497	320	4 x 50 t
M13	543	360	4 x 50 t

Shaft load and end bearing calculated as straight shafted pile. ***Balance load to be carried by micro-piles***

Building underpinned with micro-piles in Penang



DATE	TIME/MONTH	LOAD/TONNE	AVERAGE TOTAL/SETTLE (in)	PROBABLE IMMEDIATE/SETTL (in)
02.01.80	0.00	00	-	00
19.02.80	1.63	1726	-	0.0197
06.03.80	2.20	2511	-	0.029
26.03.80	2.87	3308	-	0.038
22.04.80	3.73	4089	-	0.047
27.05.80	4.90	4870	-	0.056
12.06.80	5.40	5637	-	0.064
14.07.80	6.47	6404	0,072	0.073
19.08.80	7.63	7171	0.088	0.082
23.09.80	8.77	7938	0.128	0.091
25.10.80	10.90	9457	0.148	0.108
04.07.81	18.13	-	0.326	-
15.11.81	22.50	9457	-	0.108
15.01.82	24.50	10067	-	0.115
23.01.82	24.76	-	0.400	-
10.04.82	27.33	-	0.436	-
10.06.82	29.33	10067	0.441	0.115

Excessive column settlement 150 mm

Case history with Y.S. Lau in Penang

Structural defects due to foundation failure

Defects in enlarged pile base

(1) 1st Floor: Vertical hair cracks in beams J12-J13, K12-K13.

(2) 2nd Floor: Vertical hair cracks in beams K3-K5, J12-J13.

(3) 3rd Floor: Vertical hair cracks in beams M3-M5, J12-J13, K12-K13.
Diagonal hair crack in beam K7-K8.

(4) 4th Floor: Veritcal hair cracks in beams M3-M5, K11-K12, J12-J13, K12-K13, M12-M13

(5) 5th Floor: Vertical hair cracks in beams J3-J5, M3-M5, K7-K8, K8-M8, J12-J13, J13-K13, M12-M13.

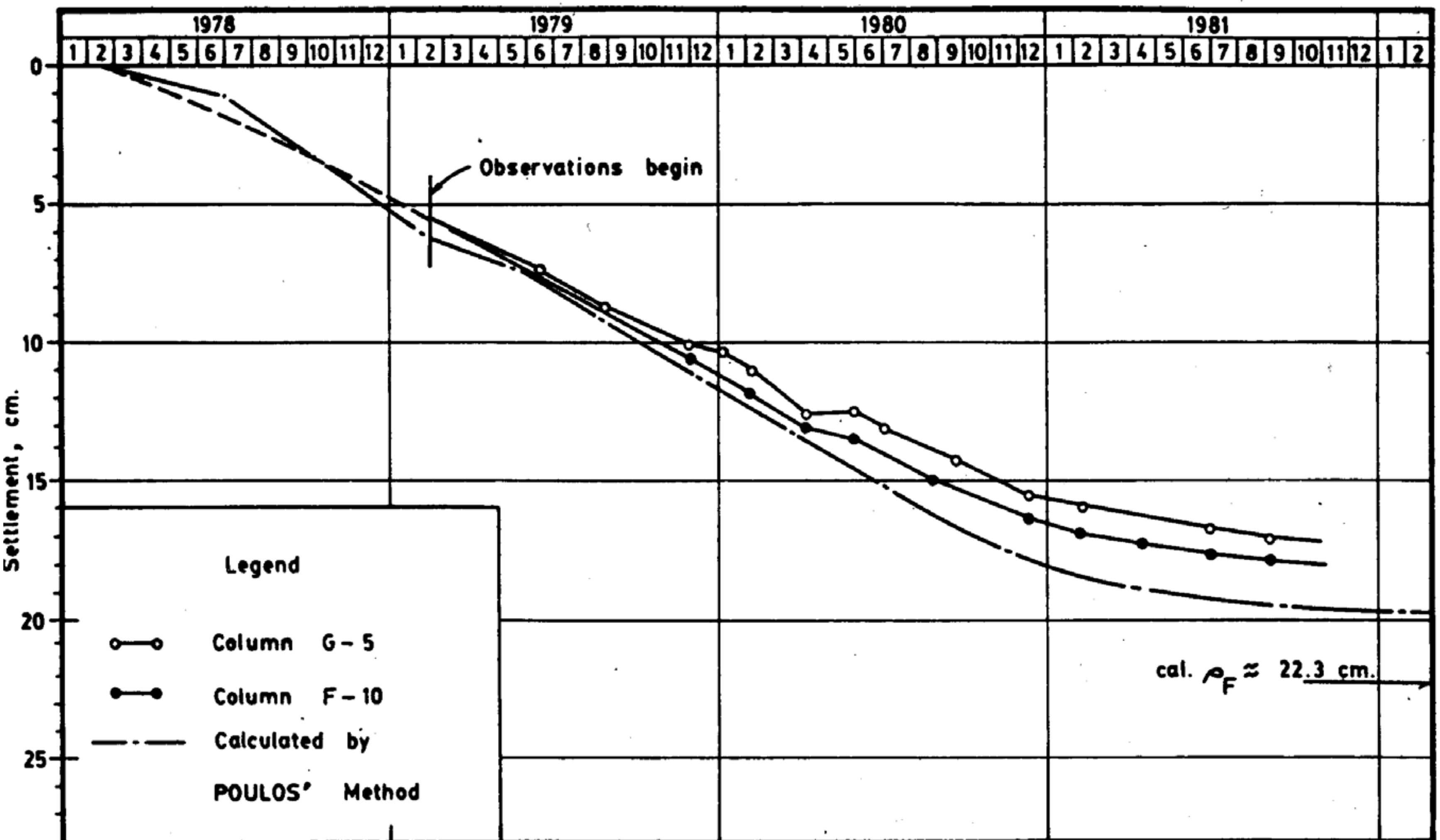
(6) 6th Floor: Vertical hair cracks in beams J3-J5, K3-K5, M3-M5, J5-K5, M5-M7, J12-K12, K12-M13, J12-J13, J13-K13.
Near vertical hair crack near K8 in beam K8-M8.
Near vertical crack up to 0.7 mm wide in beam M5-M7 (at a "cold joint").

(7) 7th Floor: Vertical hair cracks in beams K3-M3, J3-J5, M3-M5, M5-M7, J12-K12, J12-J13
Diagonal crack up to 0.4 mm wide starting from slab soffit near K8 in beam K8-M8.

(7) 8th Floor: Vertical hair cracks in beams K3-M3, J3-J5, K3-K5, M3-M5, M5-M7, J11-J12, K11-K12, J12-K12, J12-J13, M12-M13.

(8) 9th Floor: Vertical hair cracks in beams J3-J5, K3-K5, J5-K5, K5-M5, K11-K12, J12-J13, K12-K13.

(9) 10th Floor: Vertical hair cracks in beams J3-K3, K3-M3, K3-K5, M3-M5, J5-K5, J12-J13.



Observed settlement of columns 180 mm

Bored piled Foundation bearing in sand with clay layer below

Correcting tilt and raising a building by 500 mm with underpinning techniques.

In-adequate pile capacity

Building on hydraulic jacks and being raised, while the staff are busy working inside

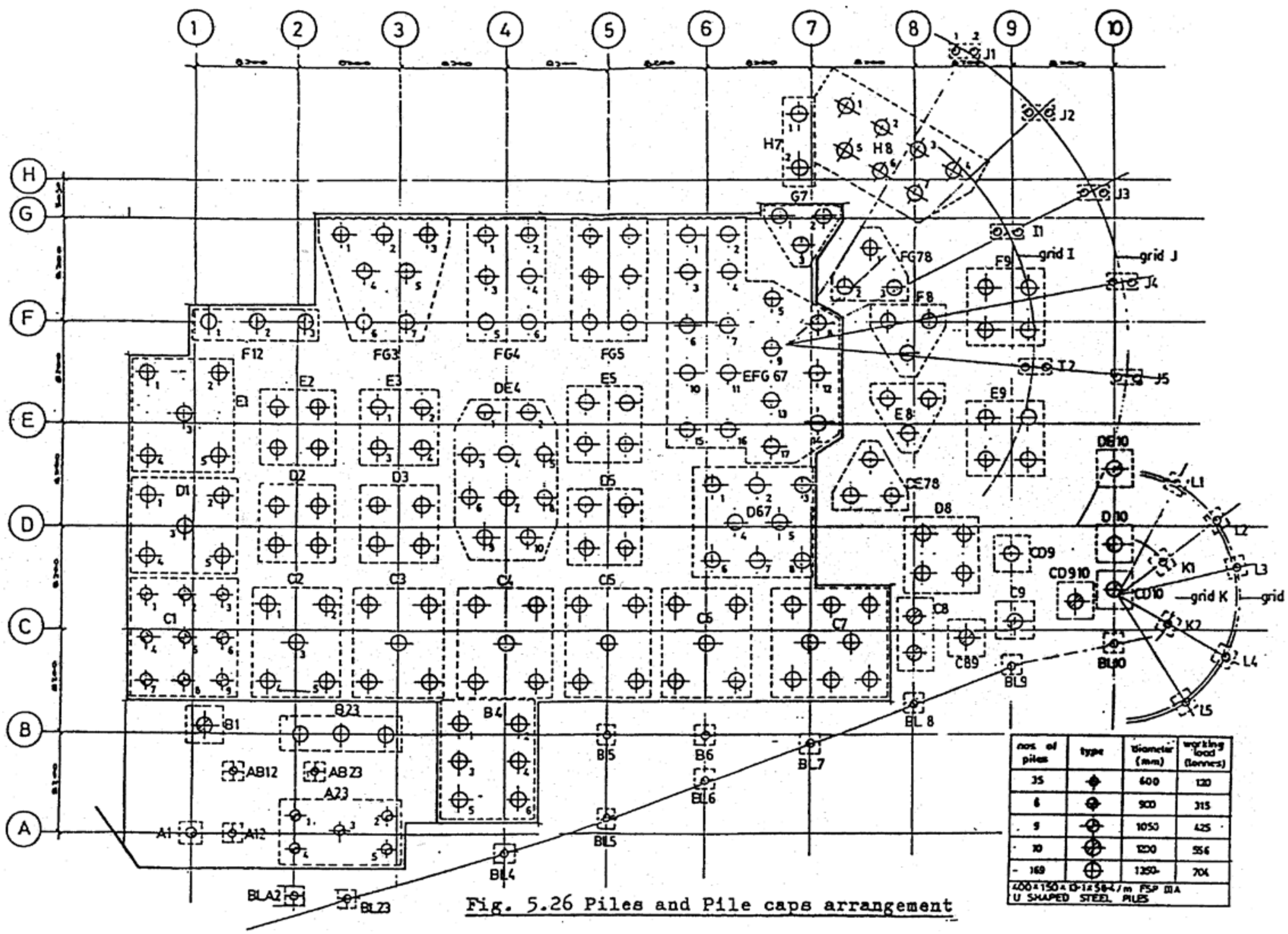
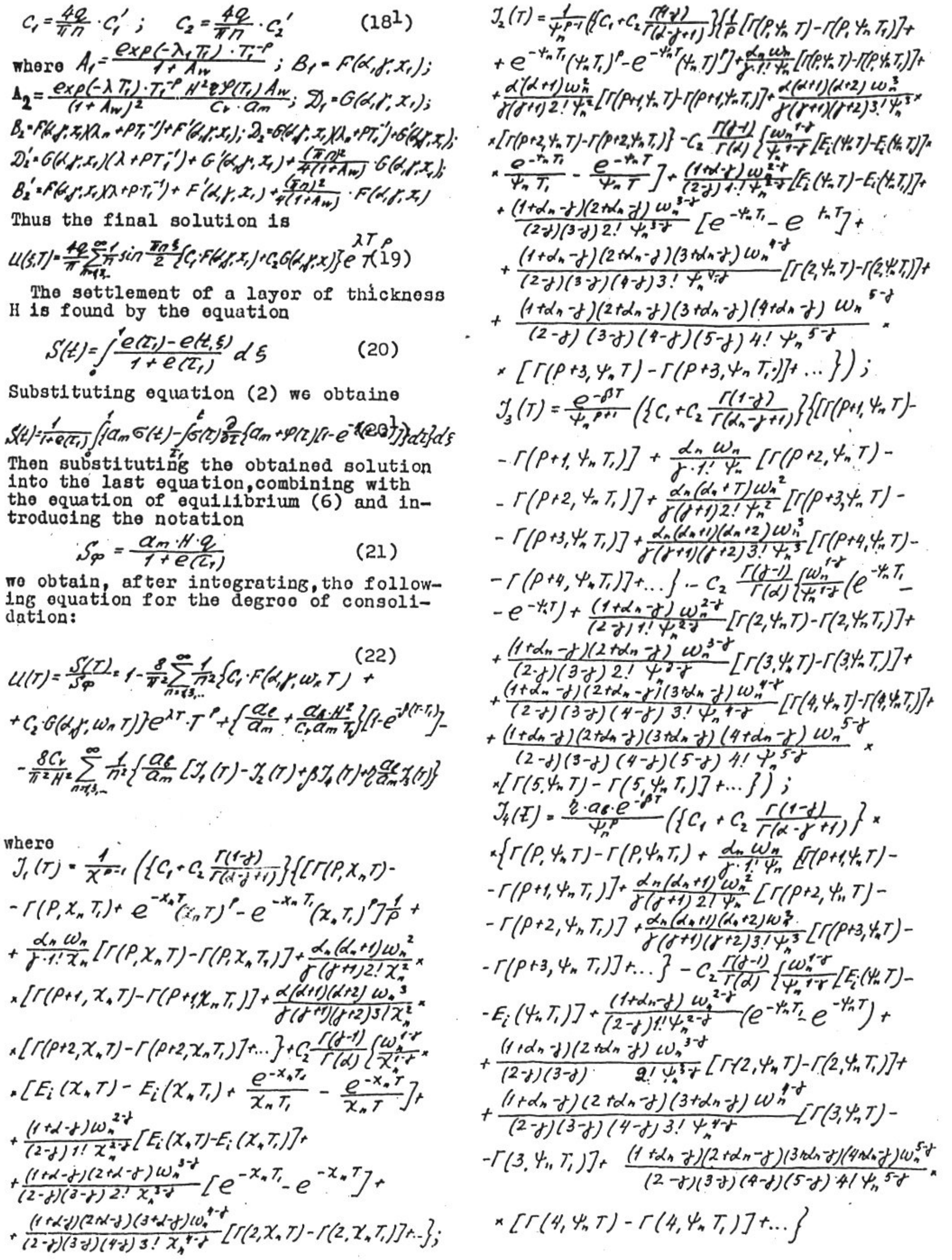


Fig. 5.26 Piles and Pile caps arrangement

Bored piles and pile caps arrangement

Sophistication must go hand in hand

Theory while Standard penetration test is used to obtain soil parameters


$$C_1=\frac{4q}{\pi n}\cdot C_1' ;\quad C_2=\frac{4q}{\pi n}\cdot C_2' \qquad (18^1)$$

where $A_1=\frac{exp(-\lambda_1 T_1)\cdot T_1^{-\rho}}{1+A_w}$; $B_1=F(\alpha,\gamma,x_1)$;

$A_2=\frac{exp(-\lambda T_1)\cdot T_1^{-\rho}}{(1+A_w)^2}\cdot\frac{H^2\varphi(T_1)A_w}{C_v\cdot a_m}$; $D_1=G(\alpha,\gamma,x_1)$;

Thus the final solution is

$$U(\xi,T)=\frac{4q}{\pi}\sum_{n=1,3,\ldots}^{\infty}\frac{1}{n}\sin\frac{\pi n\xi}{2}\{C_1F(\alpha,\gamma,x)+C_2G(\alpha,\gamma,x)\}e^{\lambda T}T^{\rho} \qquad (19)$$

The settlement of a layer of thickness H is found by the equation

$$S(t)=\int\frac{e(\tau_1)-e(t,\xi)}{1+e(\tau_1)}d\xi \qquad (20)$$

Substituting equation (2) we obtaine

Then substituting the obtained solution into the last equation, combining with the equation of equilibrium (6) and introducing the notation

$$S_\varphi=\frac{a_m\cdot H\cdot q}{1+e(\tau_1)} \qquad (21)$$

we obtain, after integrating, the following equation for the degree of consolidation:

$$U(T)=\frac{S(T)}{S_\varphi}=1-\frac{8}{\pi^2}\sum_{n=1,3,\ldots}^{\infty}\frac{1}{n^2}\{C_1\cdot F(\alpha,\gamma,\omega_n T)+C_2G(\alpha,\gamma,\omega_n T)\}e^{\lambda T}\cdot T^{\rho}+\ldots \qquad (22)$$

where

Soil profile

1. Upper clay
2. First sand
3. Second clay
4. Second sand

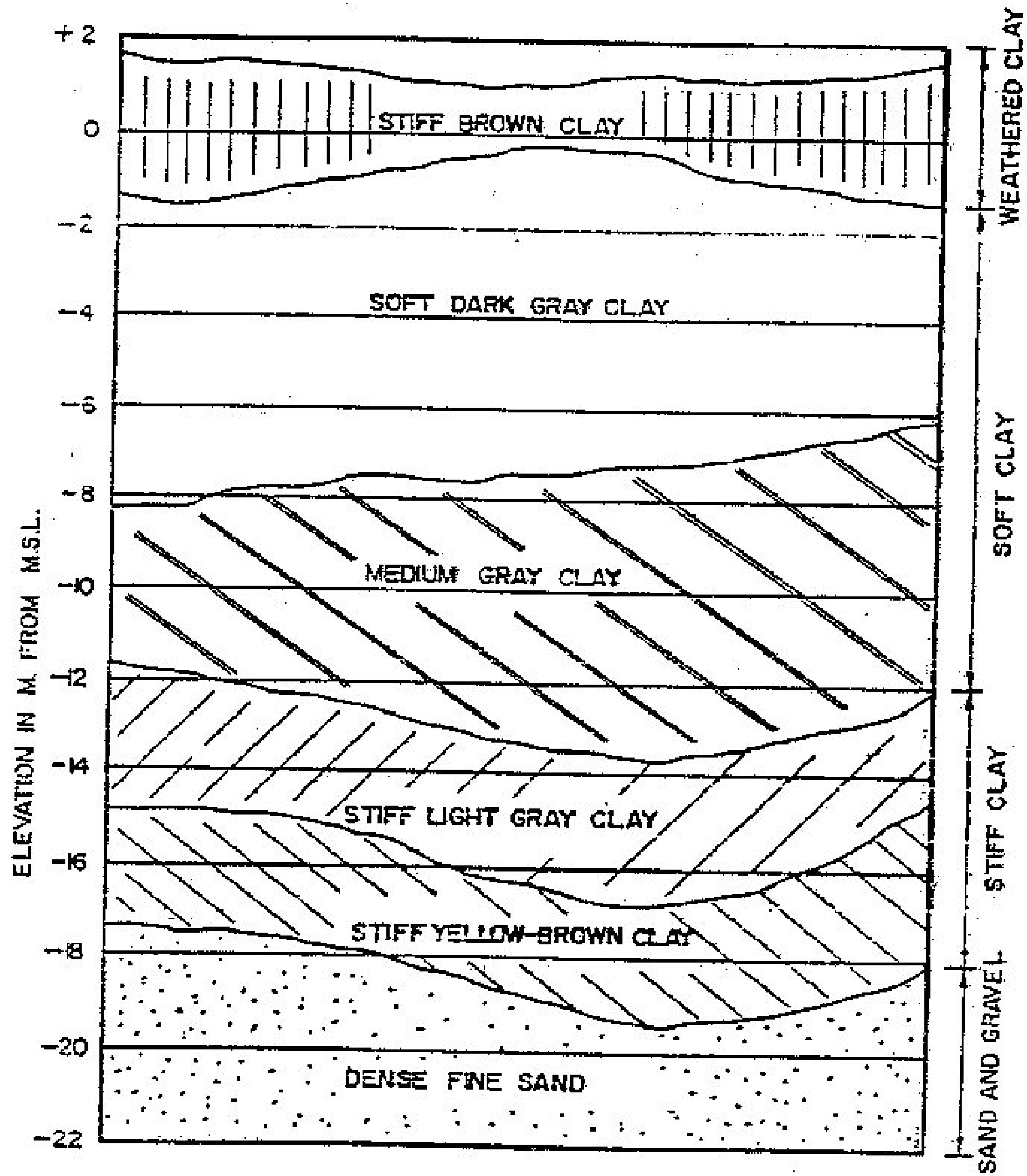
Maximum load reached in each founding level

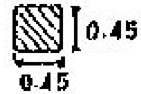
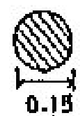
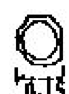
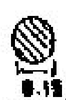
Tip Elevation	Driven Pile Building	Driven Pile Expressway	Bored Pile Building	Bored Pile Expressway	Auger Pressed Pile Building	Auger Pressed Pile Expressway
Soft Clay	12	–	–	–	–	–
Stiff Clay	358	316	720	–	434	–
1st Sand Layer	387	360	1125	1073	443	–
2nd Stif Clay	–	–	1522	–	300	–
2nd Sand Layer	–	–	2855	2080	–	–
Qmax (tons)	387	360	2855	2000	443	–

Founding level before 1973

1. First stiff clay

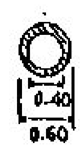
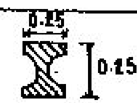
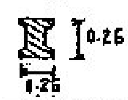
2. First sand layer

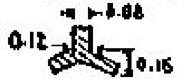
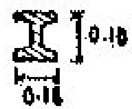
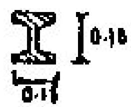
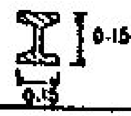
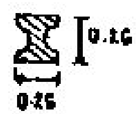


	Type of Pile	Size and Shape (m)	Length (m)	X-sectional area (m^2)	Perimeter (m)	L
Short piles founded in soft and medium stiff clay layer	Prestressed concrete pile		26.7	0.2025	1.80	
	Steel H-Pile		26.7	0.0106	1.46	
			30.7	0.0106		
	Steel Pipe Pile		6.05	-	1.445	
			12.10	-	1.445	
Longer piles founded in stiff clay and sand layers	Wooden Piles		6.0	0.018	0.471	
			6.0	0.018	0.471	
			6.0	0.018	0.471	
			6.0	0.018	0.471	
			6.0	0.018	0.471	
	Reinforced concrete pile		6.0	0.019	0.497	
	Wooden pile		6.0	0.018	0.471	

*Wooden piles
*Reinforced concrete piles
*Pre-stressed concrete piles
*Steel piles

Length up to 30 m

Type of Pile	Size and Shape (m)	Length (m)	X-sectional area (m^2)	Perimeter (m)
Reinforced concrete pile	 0.15	6.0	0.019	0.497
wooden pile	 0.15	6.0	0.018	0.471
wooden pile	 0.17	7.8	0.022	0.523
		7.8	0.022	0.523
Prestressed concrete pile	 0.40, 0.60	28	0.157	1.885
		29	0.157	1.88
		29	0.157	1.885
Prestressed concrete pile	 0.25, 0.25	21	0.0404	1.190
Prestressed concrete pile	 0.26, 0.26	21	0.048	1.36
Prestressed concrete pile	 0.26, 0.26	21	0.0414	1.29
Prestressed concrete pile	 0.26, 0.26	21	0.0414	1.29

Type of Piles	Size and Shape (m)	Length (m)	X-sectional area (m^2)	Perimeter (m)
Prestressed concrete pile		10	0.0193	0.72
Prestressed concrete pile		10	0.0176	0.92
Prestressed concrete pile		11	0.0176	0.92
Prestressed concrete pile		13	0.0147	0.70
Prestressed concrete pile		11	0.0225	0.85
Prestressed concrete pile		21	0.049	1.21

Pre-stressed concrete piles

Full Record

1. Type of test
2. Driven date
3. Date tested
4. Max. Load

PILE	Depth of pile tip (m)	Type of Test	Date Driven	Date of Test	Resting time (days)	Measured Ultimate Load(tons)
TP21	20.025	ML & Quick-ML	11/ 7/77	24-28/7/77	44	80
TP22	18.50	ML & Quick-ML	19/10/77	2-6/11/77	14	78
TP23	20.50	ML & Quick-Ml	15/11/77	3-7/12/77	18	82.5
TP24	9.90	ML	30/4/78	1-2/5/78	1	9.0
TP25	9.60	ML	30/4/78	3-4/5/78	2	9.0
TP26	10.60	ML & Quick-Ml	2/ 4/77	29-31/4/77	27	14.3
TP27	12.65	ML	8/ 3/78	27/ 3/78	19	12.0
TP28	10.70	ML	8/ 3/78	14-15/4/78	37	12.0
TP29	20.70	Quick-Ml	26/ 6/76	9/ 7/76	13	67.0

* **Cone resistance**

* **Driving Resistance**

* **Ultimate Load measured**

PILE	Depth of Pile Tip (m)	Average cone Resistance q_c; (t/m^2)	Driving Resistance Qo; (t-m/m)	Measured Ultimate Pile Loads Qu; (tons)
TP1	25.26	545	330	210
TP2	25.32	525	280	165
TP3	29.33	518	430	210
TP17	27.55	780	840	360
TP18	26.95	689	1,110	360
TP19	27.05	615	1,050	360
TP20	22.40	430	117	90
TP21	28.025	402	385	180
TP22	18.50	415	183	78
TP23	20.50	535	293	82.5
TP29	20.70	366	66	67
TP30	25.00	759	1,250	270
TP31	22.30	403	350	143
TP32	18.20	265	260	71
TP33	18.30	275	280	86
TP34	18.40	260	240	67
TP35	24.40	403	470	122

PILE	Pile Weight (t)	Section area (m^2)	Pile length (m)	Hammer weight (t)	Hammer drop (m)	Hammer Coefficient (k)	Efficiency of the blow (η)		Temporary Elastic Compression (mm)		Final Set(s) (mm)
							Hiley	Janbu	Cp+Cq (mm)	C_c (mm)	
TP1	12.64	0.2026	26.7	6.0	0.50	0.9	0.38	0.70	7.5	6.3	9.09
TP2	3.36	0.0106	26.7	6.0	0.50	0.9	0.69	0.70	11.5	5.0	10.7
TP3	3.87	0.0106	30.7	6.0	0.50	0.9	0.67	0.70	13.0	5.0	6.98
TP17	10.55	0.157	28	4.3	1.955	0.9	0.33	0.70	9.5	6.3	10.0
TP18	10.92	0.157	29	4.3	1.985	0.9	0.33	0.70	12.0	6.3	7.7
TP19	10.92	0.157	29	4.3	1.985	0.9	0.33	0.70	9.0	6.3	8.06
TP20	2.04	0.0404	21	4.5	0.30	0.8	0.69	0.70	7.5	5.0	11.60
TP21	2.42	0.048	21	3.5	0.30	0.8	0.62	0.70	10.5	5.0	2.73
TP22	2.09	0.0414	21	4.7	0.20	0.8	0.69	0.70	8.0	5.0	7.69
TP23	2.09	0.0414	21	3.0	0.30	0.8	0.62	0.70	9.5	5.0	3.05
TP29	2.61	0.049	2	3.0	0.30	0.8	0.57	0.70	6.0	5.0	13.6

Pile driving details

PILE	Predicted Ultimate Loads, tons			Measured Ultimate Loads (tons)
	Hiley	Janbu	Danish	
TP1	64	83	146	210
TP2	98	81	114	165
TP3	113	92	130	210
TP17	139	155	267	360
TP18	150	170	289	360
TP19	161	167	285	360
TP20	42	36	46	90
TP21	50	52	68	80
TP22	55	45	57	78
TP23	43	43	57	82.5
TP29	22	23	32	67

Use of pile driving Formulae

Pile Driving Resistance

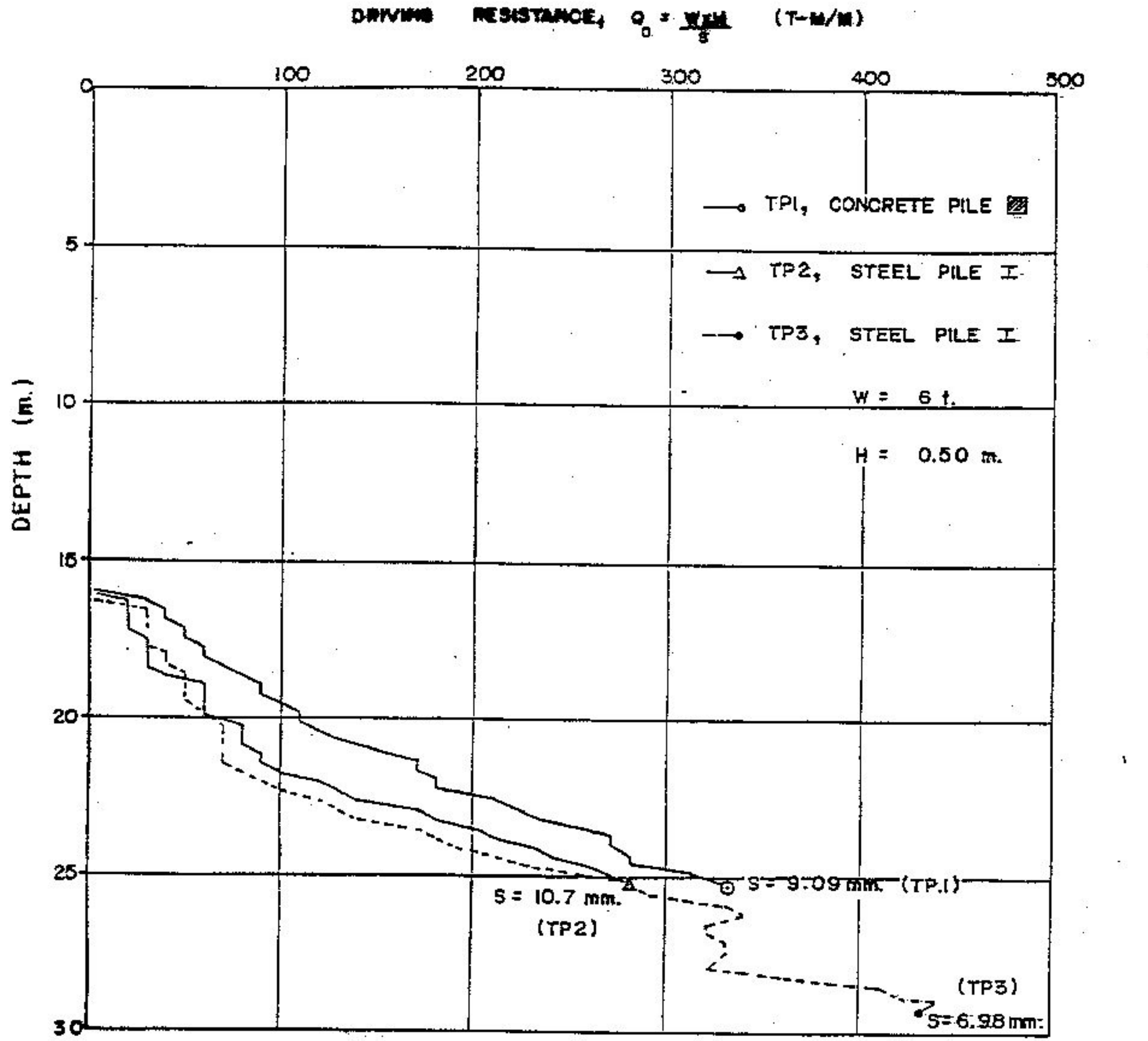
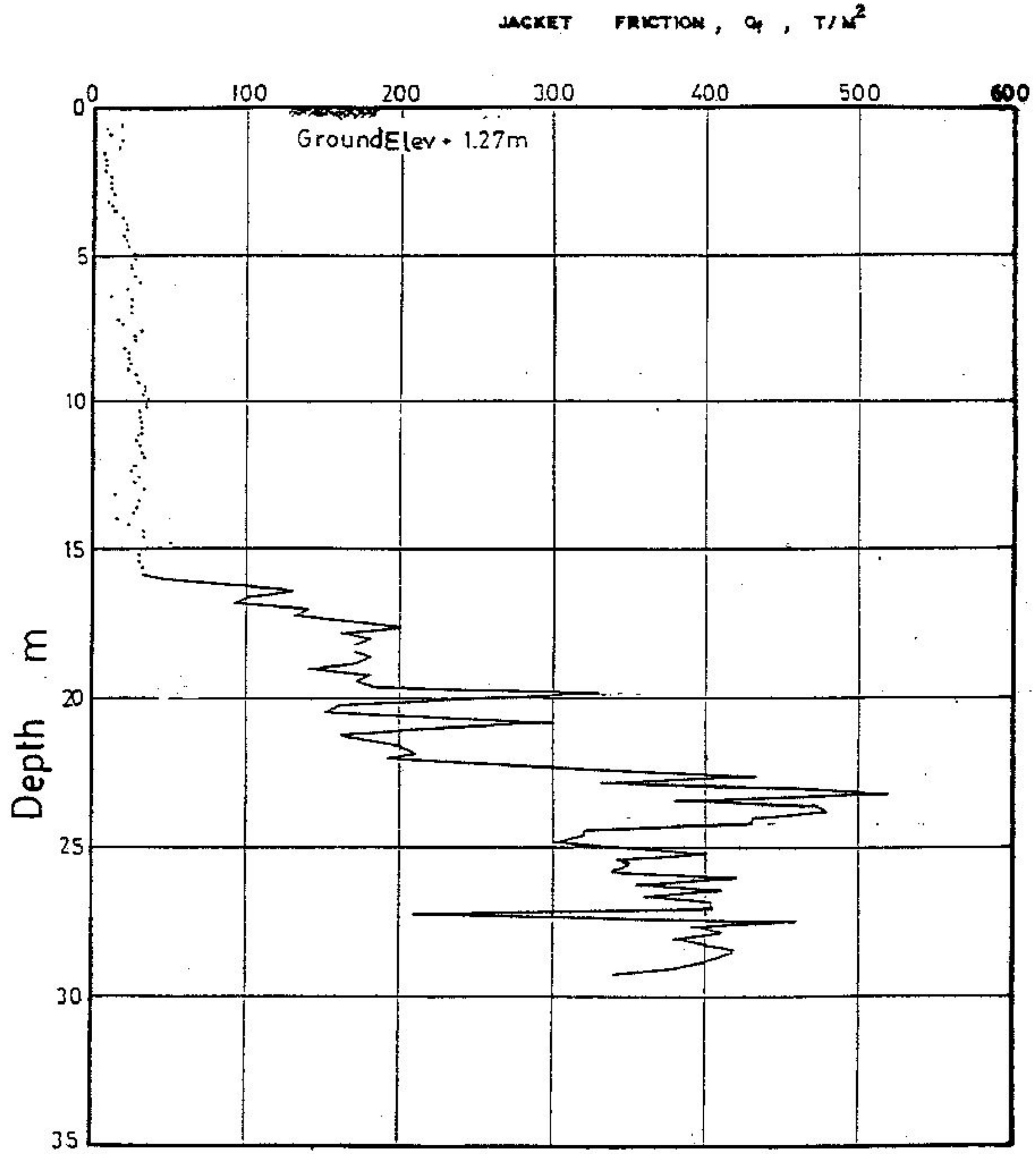


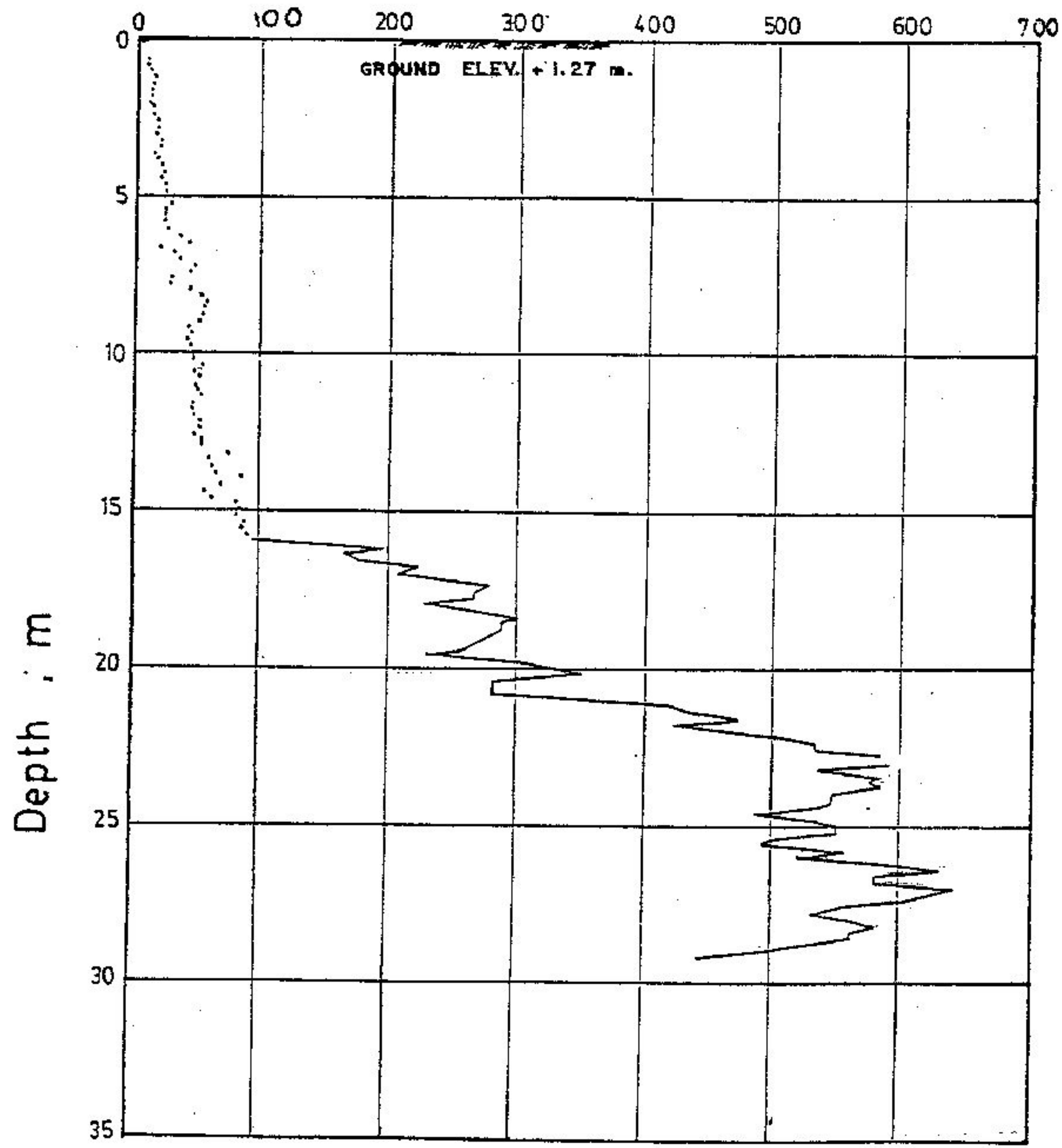
FIG. F.3 DRIVING RESISTANCE V.S. DEPTH OF TEST PILES AT POM PRACHUL

(TP1, TP2, TP3)

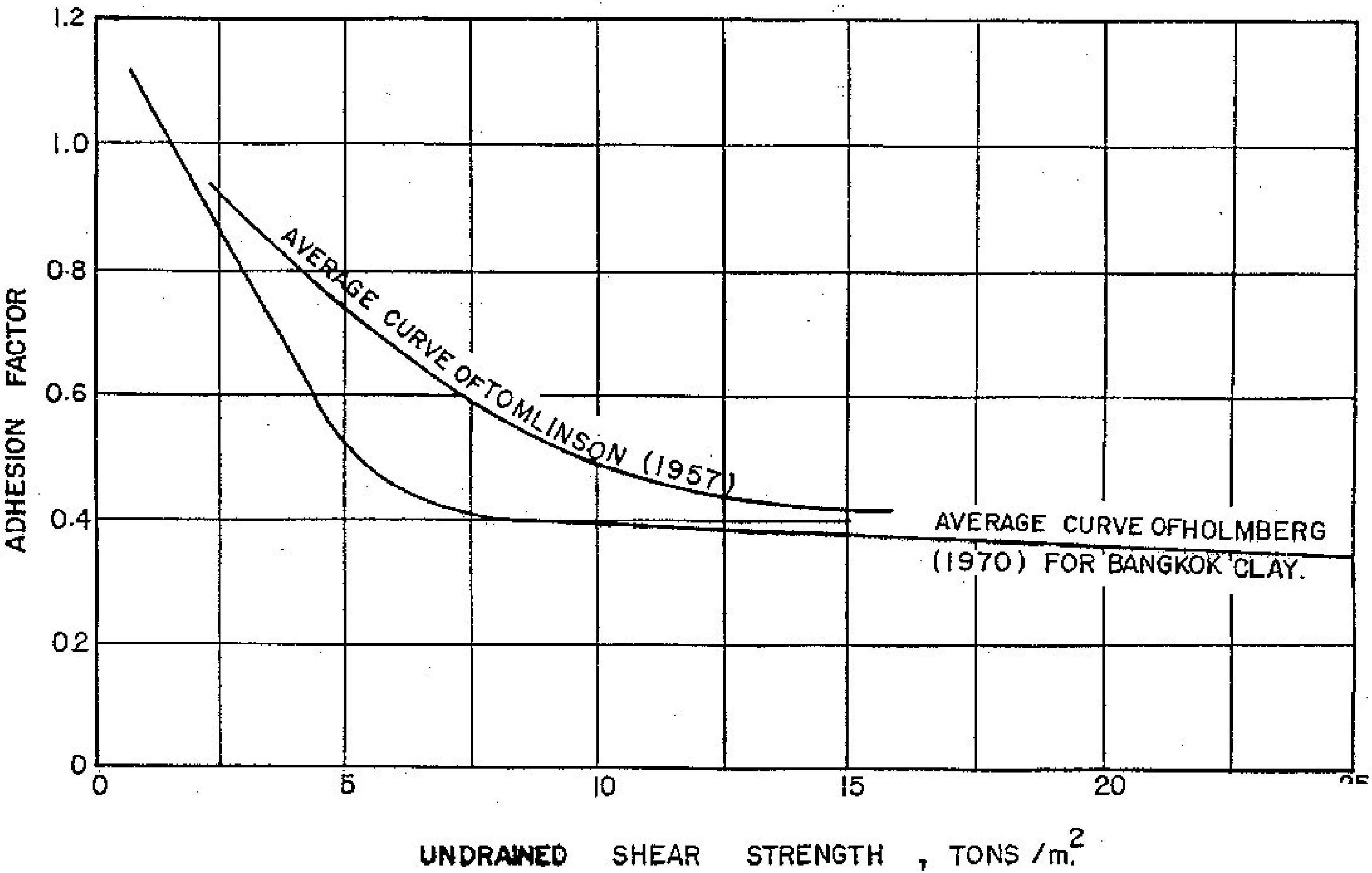
Jacket friction in Cone penetration test



Cone resistance in t/m^2



Cone Resistance



Adhesion factor α

Vane strength used

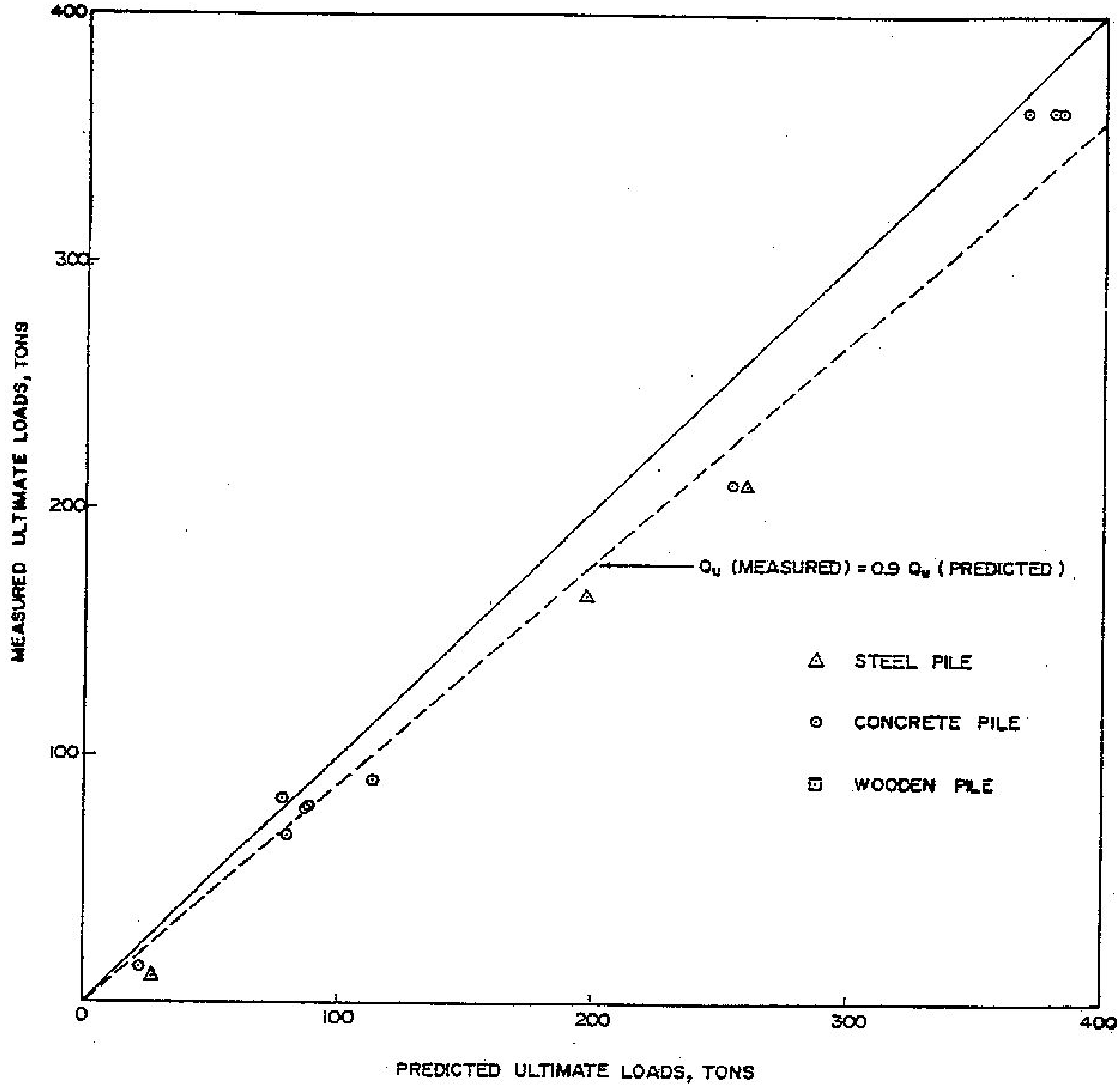
α Method short piles

PILE	Ap (m^2)	C (t/m^2) Vane	Nc	Qp (t)	P (m)	Embedded length (m)	α	Su (t/m^2)	Qs (t)	Qu (t)	Qu Load Tests (t)
TP4	-	-	-	-/	1.445	5.33	1.0	1.20	9.2	9.2	4.7
TP5	-	-	-	-	1.445	11.3	0.97	1.73	27.4	27.4	10.3
TP6	0.018	2.65	10	0.47	0.471	6.0	0.88	2.42	6.0	6.47	3.5
TP7	0.018	2.65	10	0.47	0.471	6.0	0.88	2.42	6.0	6.47	3.5
TP8	0.108	2.65	10	0.47	0.471	6.0	0.88	2.42	6.0	6.47	4.5
TP9	0.018	2.65	10	0.47	0.471	6.0	0.88	2.42	6.0	6.47	4.5
TP10	0.018	2.65	10	0.47	0.471	6.0	0.88	2.42	6.0	6.47	4.5
TP11	0.019	2.60	10	0.49	0.497	4.0	0.89	2.31	4.1	5.59	2.24
TP12	0.018	2.60	10	0.49	0.471	4.0	0.89	2.31	3.9	4.39	2.10
TP13	0.019	2.60	10	0.48	0.497	4.0	0.89	2.31	4.1	4.59	2.16
TP14	0.018	2.60	10	0.49	0.471	4.0	0.89	2.31	3.9	4.39	2.10
TP15	0.022	2.65	10	0.58	0.523	7.5	0.85	2.56	8.5	9.08	6.5
TP16	0.022	2.65	10	0.58	0.523	6.0	0.88	2.42	6.7	7.28	5.5
TP24	0.0193	2.0	10	0.40	0.72	9.9	1.0	1.30	9.3	9.70	9.0
TP25	0.0324	2.0	10	0.65	0.92	9.6	1.0	1.25	11.0	11.65	9.0
TP26	0.0324	3.9	10	1.26	0.92	10.6	0.87	2.46	20.9	22.16	14.3
TP27	0.0225	2.2	10	0.50	0.70	12.65	0.95	1.95	16.4	16.90	12.0
TP28	0.0324	2.15	10	0.70	0.85	10.7	0.96	1.90	16.6	17.30	12.0

PILE	Depth of Pile Tip (m)	BASE Ap (m^2)	N_c	C (t/m^2)		Qp (t)	SHAFT p (m)	Soft Clay Su (t/m^2)	α	L (m)	Qs (t)	Medium Stiff Clay Su (t/m^2)	α	L (m)	Qs (t)	Stiff Clay Su (t/m^2)	α	L (m)	Qs (t)	Sand K	Avg. $\bar{\sigma}_v$ (t/m^2)	δ (deg)	L (m)	Qs (t)	Total Qs (t)	Qu (t)	Qu (t) Load Tests
TP1	25.26	.2025	10	38		77	1.80	1.6	0.98	8.6	24.8	3.0	0.80	7.5	33.2	20.9	0.35	9.16	120.6	-	-	-	-	-	178	256	210
TP2	25.32	.133	10	38		51	1.46	1.6	0.98	8.6	20.1	3.0	0.80	7.5	27	20.9	0.35	9.22	98.5	-	-	-	-	-	146	197	165
TP3	29.33	.133	10	42		56	1.46	1.6	0.98	8.6	20.1	3.0	0.80	7.5	27	24.0	0.34	13.2	157.3	-	-	-	-	-	204	260	210
TP21	20.025	.0676	10	18.6		12.5	1.36	2.1	0.92	13.6	36	5.5	0.48	3.0	11	15.5	0.39	3.43	28	-	-	-	-	-	76	88	80
TP22	18.50	.0676	10	16.8		11.4	1.29	3.2	0.76	10	31	4.5	0.57	5.0	17	16.8	0.37	3.5	28	-	-	-	-	-	76	87	78
TP23	20.50	.0676	10	18.4		12.4	1.29	1.25	1.0	13	21	5.4	0.49	4.0	14	18.4	0.37	3.5	31	-	-	-	-	-	66	78	82.5
TP29	20.70	.0676	10	15.0		10.0	1.21	2.4	0.87	13	33	5.0	0.53	4.5	14	15.0	0.38	3.2	22	-	-	-	-	-	69	79	67
			$\bar{\sigma}_v$ (t/m^2)	ϕ (deg)	N_q																						
TP17	27.55	.157	23.0	34	45	162	1.885	2.16	0.[illegible]	11.0	40.	.8	0.54	4.0	19.5	15.8	0.38	10.2	116	1.0	22.0	25.5	2/35	46	221	383	360
TP18	26.95	.157	11.5	34	46	169	1.805	2.16	0.91	11.0	40.8	4.8	0.54	4.0	19.5	15.8	0.38	10.2	115	1.0	22.0	25.5	1.75	35	210	369	360
TP19	27.05	.157	19.0	36	56	167	1.885	2.6	0.85	11.5	48	5.1	0.53	1.5	7.6	10.2	0.40	8.2	63	1.0	16.5	27.0	5.85	93	212	379	360
TP20	22.40	.0404	15.5	35	43	27	1.19	2.7	0.84	15.0	41	-	-	-	-	7.1	0.42	3.8	14	1.0	14.5	26.3	3.6	31	86	113	90

Total stress method-- long piles

Total stress method long piles



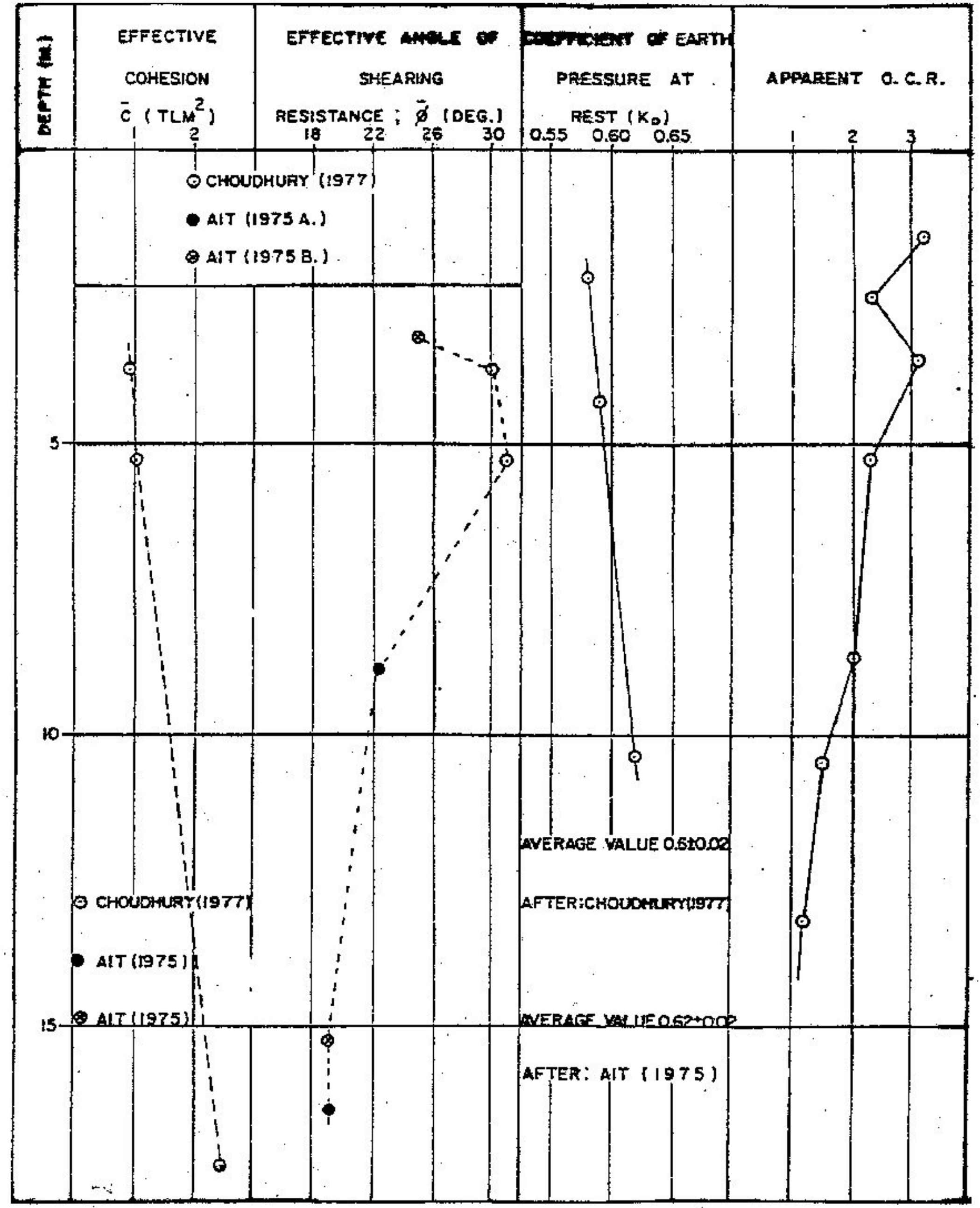
PILE	Depth of Pile Tip	BASE				SHAFT																		Weight of Pile	Qu	Qu Load Test
							Soft Clay				Medium Stiff Clay				Stiff Clay				Sand							
		Ap	q_c	λ	Q_p	P	L	q_{TF}	α	Qs	L	q_{TF}	α	Qs	L	q_{TF}	α	Qs	L	q_{TF}	α	Qs	Qs			
	(m)	(m^2)	(t/m^2)		(t)	(m)	(m)	(t/m)		(t)	(m)	(t/m)		(t)	(m)	(t/m)		(t)	(m)	(t/m)		(t)	(t)	(t)	(t)	(t)
TP1	25.26	.2025	545	0.33	36.4	1.80	8.6	10	1.0	18	7.5	15	0.7	18.9	9.16	164	0.5	147.6	-	-	-	-	184.5	12.64	208	210
TP2	25.32	.133	525	0.33	23.0	1.46	8.6	11	1.0	16	7.5	20.5	0.7	21	9.22	144	0.5	105	-	-	-	-	142	3.36	162	165
TP3	29.33	.133	518	0.33	22.7	1.46	8.6	11	1.0	16	7.5	17	0.7	17.4	13.2	242	0.5	176.6	-	-	-	-	210	3.87	229	210
TP21	20.025	.0676	402	0.33	8.9	1.36	13.5	19.5	1.0	26.5	3.0	14.5	0.7	13.8	3.43	50	0.5	34	-	-	-	-	74.3	2.42	81	80
TP22	18.50	.0676	415	0.33	9.3	1.29	10	16	1.0	20.6	5.0	18	0.7	16.3	3.5	52	0.5	33.5	-	-	-	-	70.4	2.09	78	78
TP23	20.50	.0676	535	0.33	11.9	1.29	13	15	1.0	19.4	4.0	9	0.7	8.1	3.5	71	0.5	45.8	-	-	-	-	73.3	2.09	83	82.5
TP29	20.70	.0676	366	0.33	8.2	1.21	13	18	1.0	21.8	4.5	32	0.7	27.1	3.2	26	0.5	15.7	-	-	-	-	64.6	2.61	70	67
TP17	27.55	.157	780	0.5	61	1.885	11	16	1.0	30.1	4.0	9	0.7	11.9	10.2	159	0.5	150	2.35	72	0.8	108.6	300.6	10.55	351	360
TP18	26.95	.157	689	0.5	54	1.885	11	12	1.0	22.6	4.0	31	0.7	40.9	10.2	190	0.5	179	1.75	53	0.8	80	322.5	10.92	366	360
TP19	27.05	.157	615	0.5	48	1.885	11.5	15	1.0	28.3	1.5	2.5	0.7	3.3	6.2	100.5	0.5	94.7	5.85	132	0.8	199	325.3	10.92	362	360
TP20	22.40	.0404	430	0.5	8.7	1.19	15	24.5	1.0	29.2	-	-	-	-	3.8	30.5	0.5	18.1	3.6	40	0.8	38.1	85.4	2.04	92	90

Dutch cone test used in pile capacity determination

Only few sets of c' and ϕ'

No definite pattern of variation

β method Effective stress analysis



Effective stress analysis
β –method

Type of Tests	Stress history	Average depth (m)	Effective Strength Parameter			
			at$(\sigma_1' - \sigma_3')_{max}$		at$(\bar{\sigma}_1 / \bar{\sigma}_3)_{max}$	
			$\bar{c}$ (t/m^2)	$\bar{\phi}$ (deg)	$\bar{c}$ (t/m^2)	$\bar{\phi}$ (deg)
CID	NC	8.9	0	22.4	-	-
CID	NC	16.4	0	19.3	-	-
CID	NC	3.2	0	24.9	-	-
CID	NC	15.2	0	19.2	-	-
$\overline{CK_oU}$	NC	8.1	0	28.7	0	32.7
$\overline{CK_oU}$	NC	4.6	0	27.8	0	31.0
CK_oU	NC	3.75	0	29.9	0	32.4
	NC	5.25	0	30.9	0	30.0

Very few test data for c’ and ϕ’

Effective stress analysis

Type of Tests	Stress history	Average depth (m)	Effective Strength Parameters at $(\sigma'_1 - \sigma'_3)_{max}$ $\bar{c}$ (t/m^2)	$\bar{\phi}$ (deg)	at $(\bar{\sigma}_1/\bar{\sigma}_3)_{max}$ $\bar{c}$ (t/m^2)	$\bar{\phi}$ (deg)
$\overline{CU}$	NC	5.4	0	22.6	0	23.9
$\overline{CIU}$	NC	7.5	0	21.4	0	22.6
$\overline{CIOU}$	NC	7.5	0	21.4	0	22.6
$\overline{CIU}$	NC	11.4	0	22.5	0	22.5
$\overline{CIU}$	NC	1.05	0	20.2	0	20.2
	NC	2.45	0	21.9	0	21.9
	NC	3.90	0	20.2	0	20.2
	NC	5.25	0	21.4	0	23.2
$\overline{CAU}$	NC	1.5	0	24.8	0	26.2
$\overline{CU}$	NC	9.0	0	22.0	-	-
$\overline{CAU}$-V	NC	5.25	0	23.2	0	24.4
$\overline{CIU}$	NC	9.25	0	23.0	-	

More c's and ϕ's at AIT Campus but unfortunately no pile test data to analyze

Cluster of values around 0.33 for β

Back calculated β values from full scale pile load tests

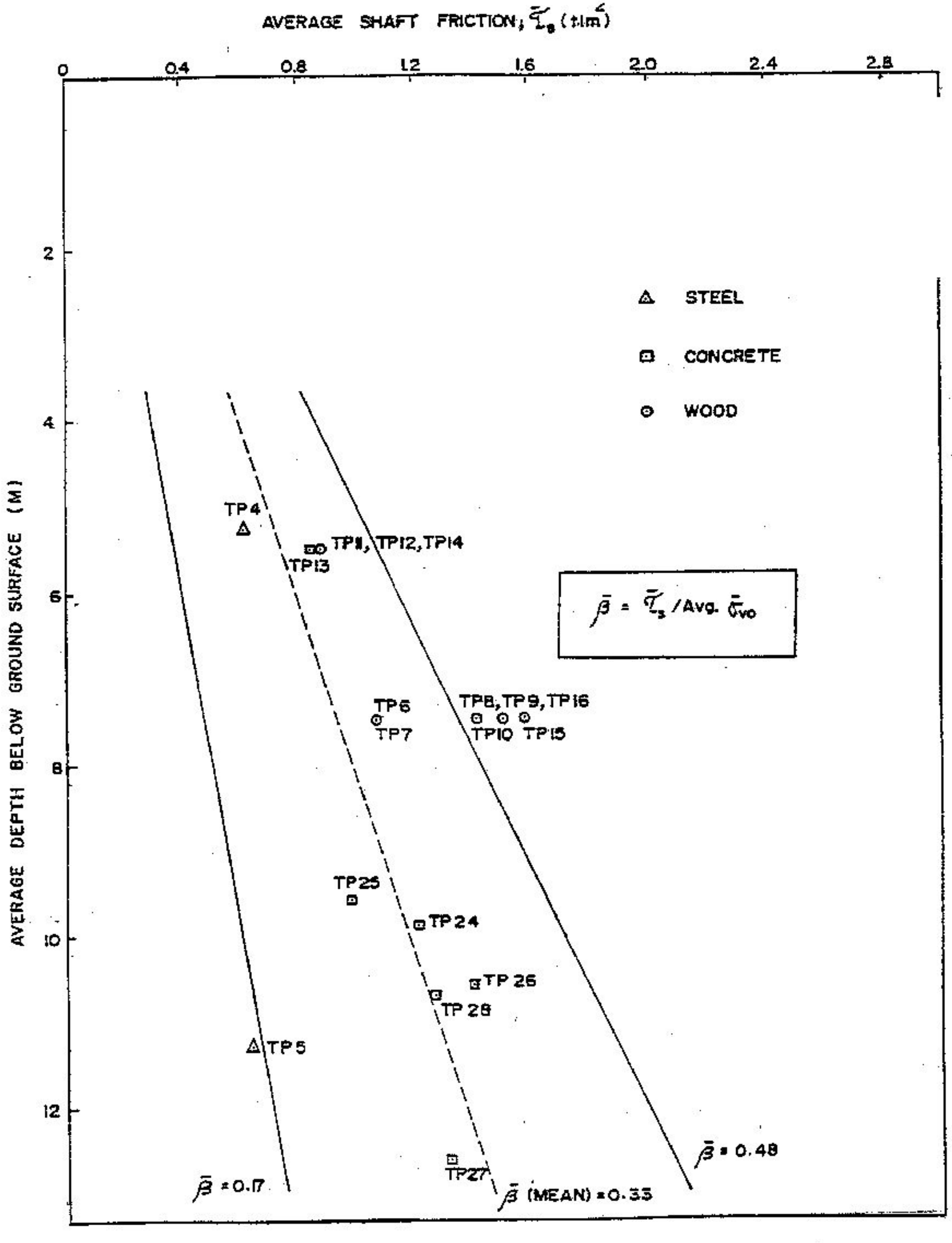


FIG F.10 RELATIONSHIP BETWEEN AVERAGE SHAFT FRICTION ($\bar{\tau}_s$) AND

Effective stress analysis- β method

Pile	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12	TP13	TP14	TP15	TP16	TP24	TP25	TP26	TP27	TP28
$\bar{\tau}_s$ (t/m²)	0.61	0.63	1.07	1.07	1.42	1.42	1.42	0.88	0.87	0.84	0.87	1.51	1.58	1.21	0.98	1.40	1.32	1.27
Avg. $\bar{\sigma}_{vo}$ (t/m²)	1.80	3.70	3.37	3.37	3.37	3.37	3.37	3.05	3.05	3.05	3.05	3.20	3.37	4.02	3.66	3.97	5.05	4.67
Avg. depth (m)	5.33	11.3	7.5	7.5	7.5	7.5	7.5	5.5	5.5	5.5	5.5	7.5	7.5	9.9	9.6	10.6	12.65	10.7

Estimated β values from full scale pile load tests

Effective stress analysis short piles

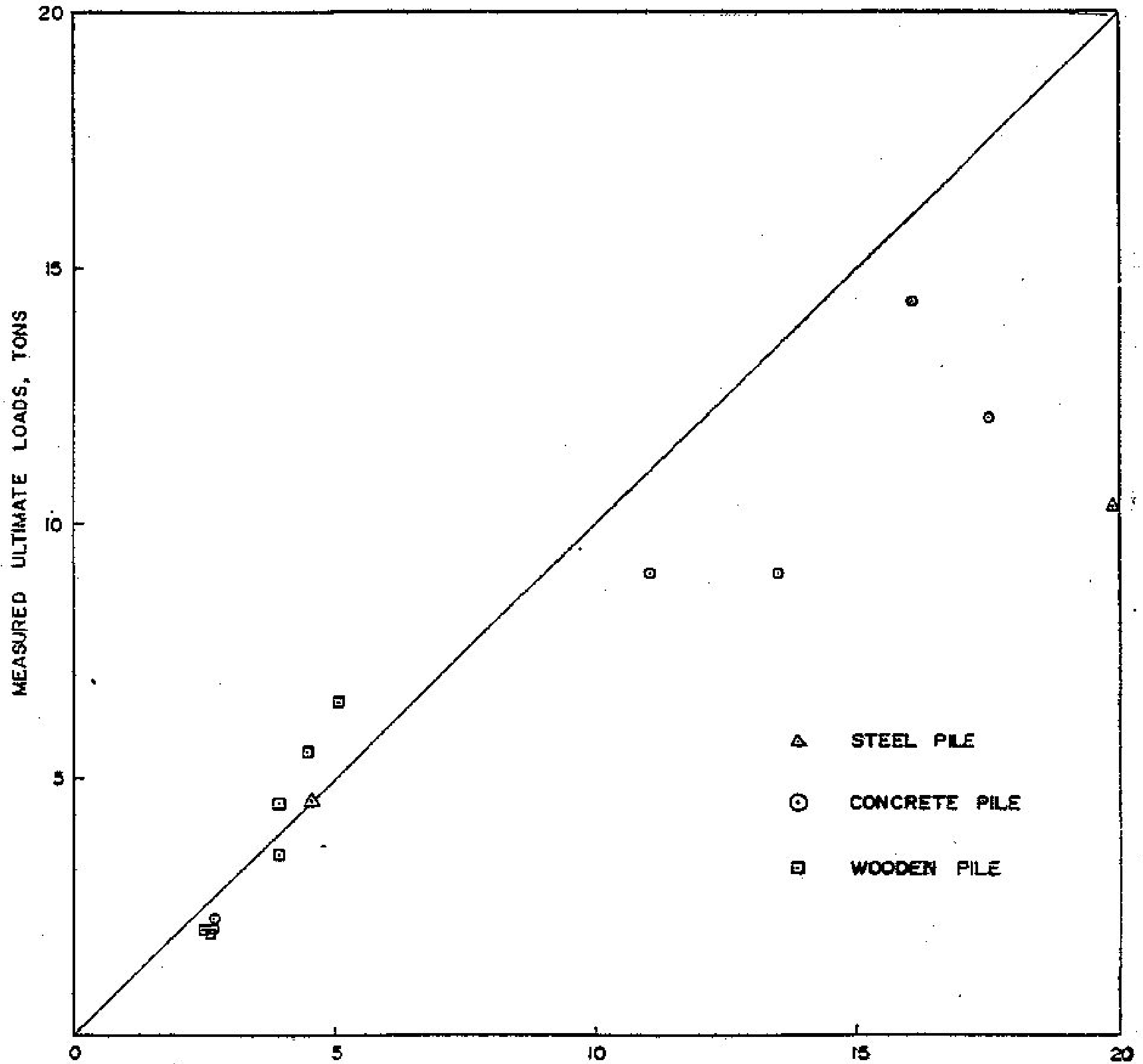
β method

PILE	Depth of pile tip (m)	Ap (m^2)	$\bar{\phi}$ deg	Nq	$\bar{\sigma}_{vo}$ t/m^2	Qp (t)	P (m)	Embedded length (m)	Avg $\bar{\sigma}_{vo}$ (t/m^2)	Qs (t)	Qu (t)	Qu load tests (t)
TP4	5.33	-	-	-	-	-	1.445	5.33	1.80	4.6	4.6	4.7
TP5	11.3	-	-	-	-	-	1.445	11.3	3.70	19.9	19.9	10.3
TP6	7.5	.018	21.5	9	4.8	.78	.471	6.0	3.37	3.14	3.92	3.5
TP7	7.5	.018	21.5	9	4.8	.78	.471	6.0	3.37	3.14	3.92	3.5
TP8	7.5	.018	21.5	9	4.8	.78	.471	6.0	3.37	3.14	3.92	4.5
TP9	7.5	.018	21.5	9	4.8	.78	.417	6.0	3.37	3.14	3.92	4.5
TP10	7.5	.018	21.5	9	4.8	.78	.047	6.0	3.37	3.14	3.92	4.5
TP11	5.5	.019	22.5	9.5	3.9	.70	.497	4.0	3.05	2.0	2.7	2.24
TP12	5.5	.018	22.5	9.5	3.9	.67	.471	4.0	3.05	1.9	2.57	2.10
TP13	5.5	.019	22.5	9.5	3.9	.70	.497	4.0	3.05	2.0	2.7	2.16
TP14	5.5	.018	22.5	9.5	3.9	.67	.471	4.0	3.05	1.9	2.57	2.10
TP15	7.5	.022	21.5	9.0	4.8	.95	.523	7.5	3.20	4.15	5.10	6.5
TP16	7.5	.022	21.5	9.0	4.8	.95	.523	6.0	3.37	3.5	4.45	5.5
TP24	9.9	.019	25	15	6.0	1.74	.72	9.9	4.02	9.4	11.1	9.0
TP25	9.6	.032	25	15	5.8	2.8	.92	9.6	3.66	10.7	13.5	9.0
TP26	10.6	.032	25	15	6.8	3.3	.92	10.6	3.97	12.8	16.1	14.3
TP27	12.65	.022	25	15	8.2	2.8	.70	12.65	5.05	14.8	17.6	12.0
TP28	10.7	.032	25	15	7.4	3.5	.85	10.7	4.67	14.0	17.5	12.0

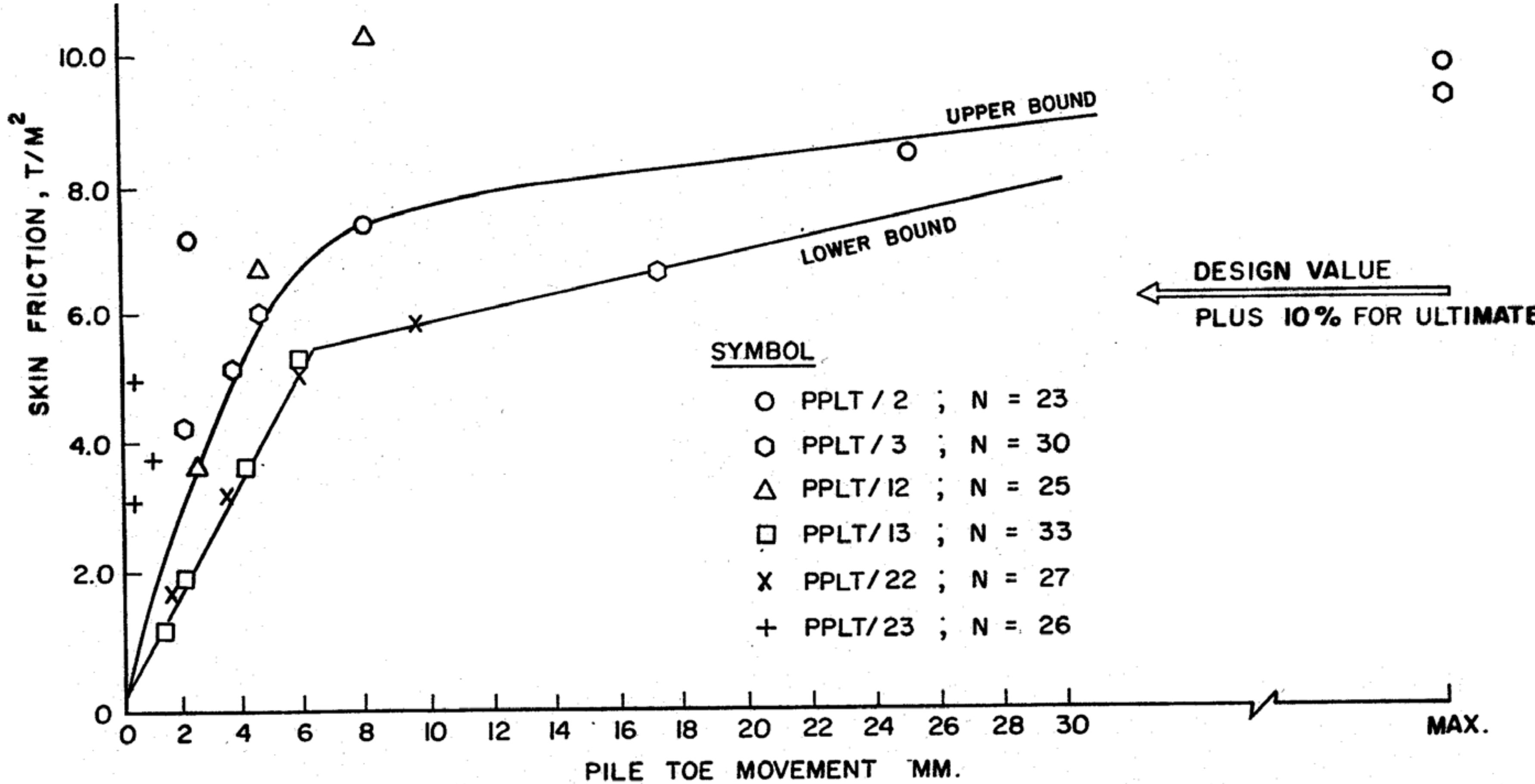
PILE	Depth of Pile Tip (m)	BASE					SHAFT																	Qu (t)	Qu(s) Load Tests
								Soft Clay				Stiff Clay					Sand					Qs (t)		
		Ap (m^2)	$\bar{\phi}$ (deg)	Nq	$\bar{\sigma}_{vo}$ (t/m^2)	Qp (t)	p (m)	$\bar{\beta}$	L (m)	Avg. $\bar{\sigma}_{vo}$ (t/m^2)	Qs (t)	Ko	$\bar{\phi}$ (deg)	Avg. $\bar{\sigma}_{vo}$ (t/m^2)	L (m)	Qs (t)	K	Avg. $\bar{\sigma}_{vo}$ (t/m^2)	δ (deg)	L (m)	Qs (t)			
TP1	25.26	.2025	19.25	7.5	31.0	47	1.80	0.33	16.1	6.96	67	0.72	19.25	23	9.16	96	-	-	-	-	-	162	209	210
TP2	25.32	.133	19.25	7.5	31.0	31	1.46	0.33	16.1	6.96	54	0.72	19.25	23	9.22	78	-	-	-	-	-	132	163	168
TP3	29.33	.133	19.25	7.5	38.0	38	1.46	0.33	16.1	6.96	54	0.72	19.25	26.6	13.2	128	-	-	-	-	-	182	220	210
TP21	20.025	.0676	21	8.5	15.0	8.6	1.36	0.33	13.6	5.4	33	0.72	21	12.2	6.43	29	-	-	-	-	-	62	71	[illegible]
TP22	18.80	.0676	21	8.5	13.6	7.8	1.29	0.33	10.0	3.9	17	0.72	21	9.6	8.6	29	-	-	-	-	-	46	54	78
TP23	20.50	.0676	21	8.5	14.5	8.3	1.29	0.33	13.0	5.1	28	0.72	21	11.5	7.6	31	-	-	-	-	-	59	67	[illegible]
TP17	27.56	.157	34	4	23.0	162	1.805	0.33	15.0	7.4	69	0.72	21	15.8	10.2	84	1.0	22.0	25.5	2.35	46	199	361	[illegible]
TP18	26.96	.157	34	5	22.6	159	1.805	0.33	15.0	7.4	69	0.72	21	15.8	10.2	84	1.0	22.0	25.5	1.76	35	188	347	[illegible]
TP19	27.05	.157	36	[illegible]	19.0	167	1.805	0.33	13.0	4.26	34	0.72	21	10.1	8.2	43	1.0	16.5	27	5.85	93	170	337	[illegible]
TP20	22.40	.0404	35	[illegible]	16.5	27	1.19	0.33	15	5.7	34	0.72	21	11.5	8.8	14	1.0	14.5	26.3	3.6	31	78	106	[illegible]

Effective stress analysis on long piles- β method

Effective stress analysis on long piles



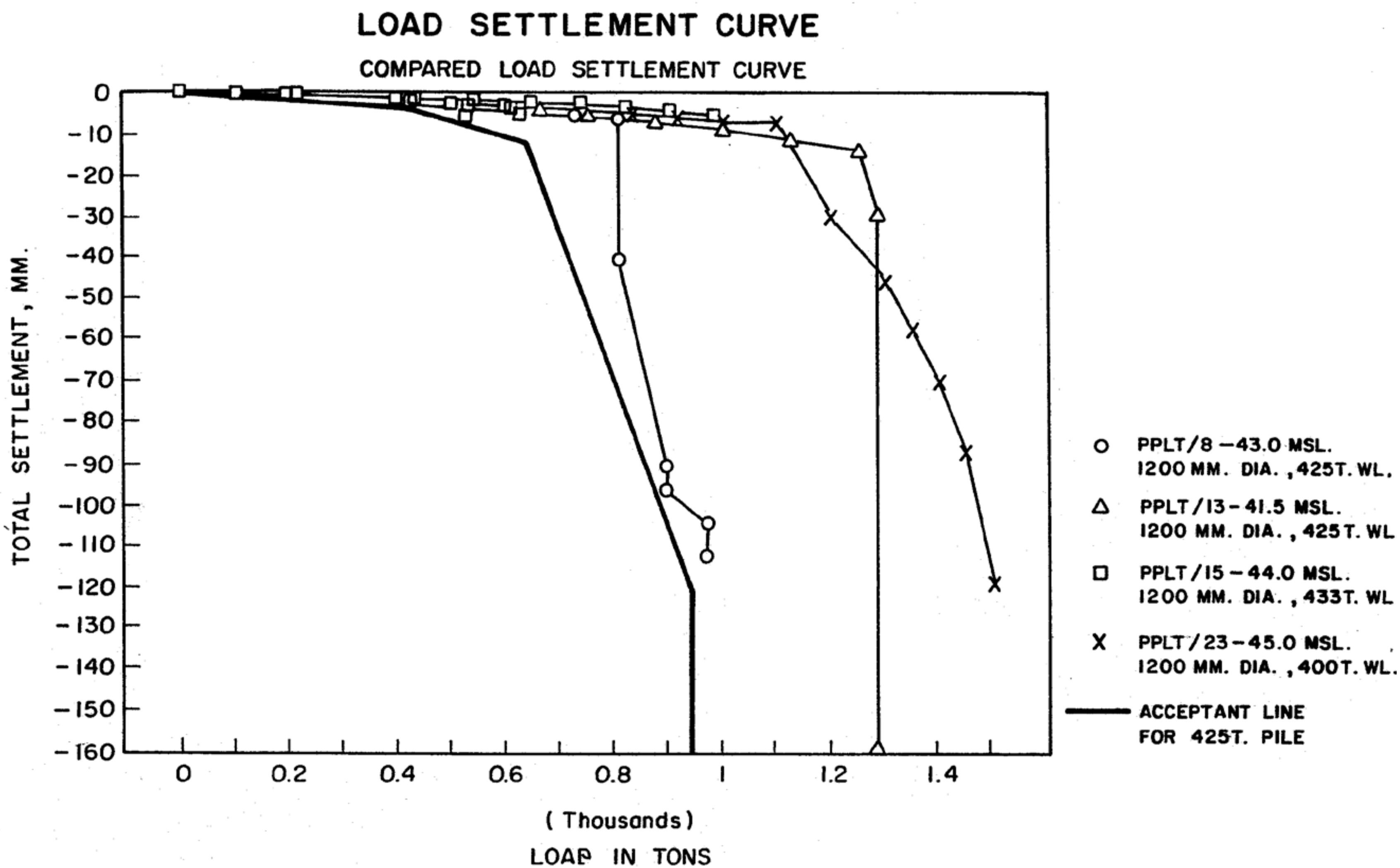
Calculated load, tonf



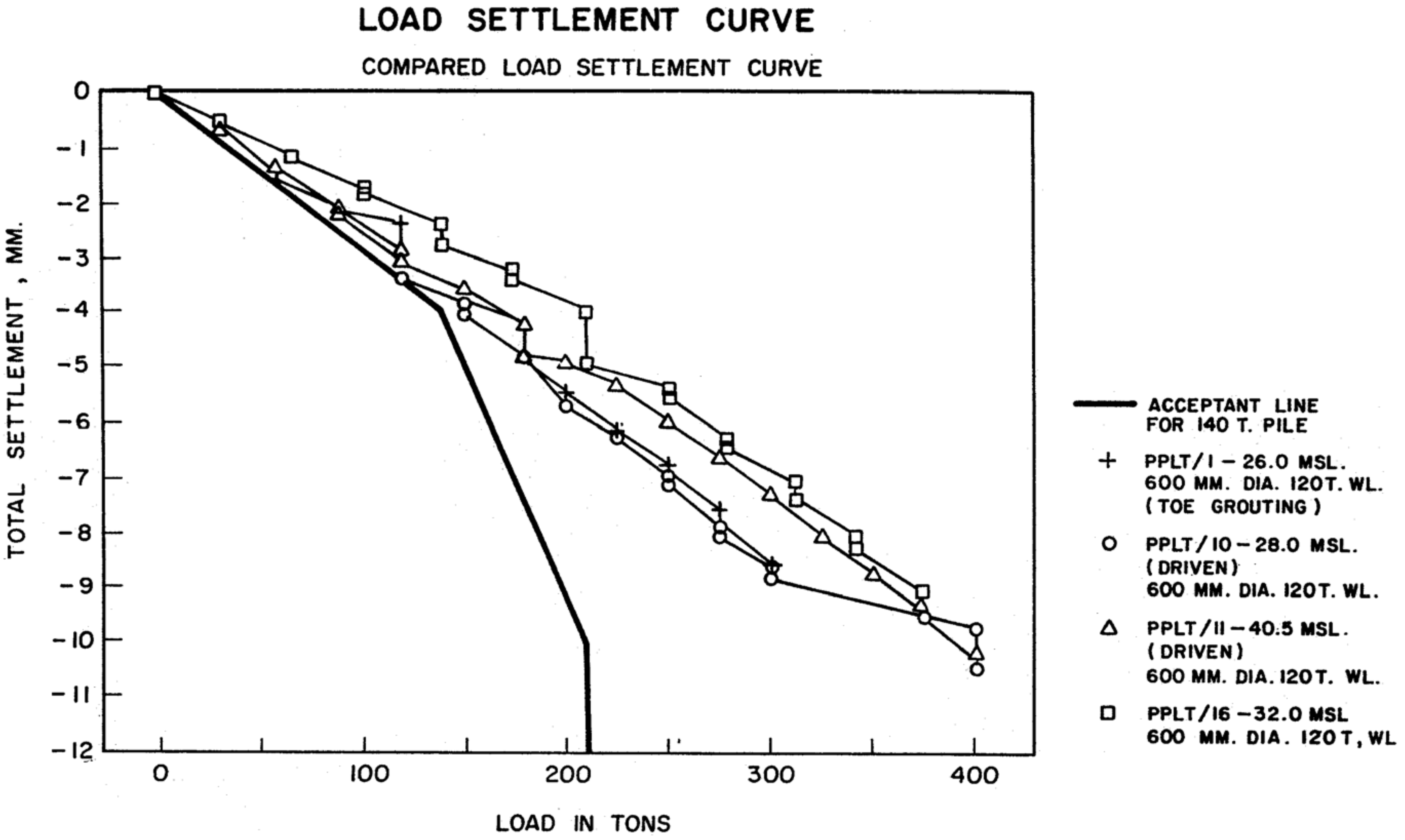
Mobilization of skin friction in stiff clay

No.	Contact	Piling Contractor	Type	Design Pile Dia. (mm.)	Avg. Actual Pile Dia. (mm.)	Actual P.F.L. (MSL.)	Working Load (tons)	Calc. Ultimate Load (tons)	Load at 10%D (tons)	Max. Carrying Load	Instru-mentation	Acceptance Criteria	Remark
PPLT#1	NS1	THAI BAUER	Bored	600	618	-26.04	120	335	>>320	>>320	X	/	Toe Grouting - Max before Yield
PPLT#2	NS1	THAI BAUER	Bored	1200	1180	-32.32	425	917	900	980	/	X	Toe Grouling
PPLT#3	NS1	THAI BAUER	Bored	1000	"	(-30.5)	325	727	916	1000	/	/	Toe Grouting
PPLT#4	NS1	THAI BAUER	Bored	1200	"	(-32.5)	425	1004	891	960	/	X	Toe Grouting - Retest
PPLT#5	NS1	THAI BAUER	Bored	1200	"	(-30.0)	(425)	914	"	"	/	X	Toe Grouting
PPLT#6	NS1	THAI BAUER	Bored	800	"	(-30.0)	225	510	520	545	X	/	
PPLT#7	EW1	KIN SUN	Bored	1000	"	(-31.5)	321	730	600	721	X	X	
PPLT#8	EW1	KIN SUN	Bored	1200	"	(-42.5)	425	966	971	971	/	/	
PPLT#9	EW1	KIN SUN	Bored	800	893	-31.90	225	524	530	582	X	/	
PPLT#10	EW1	KIN SUN	Driven	600	600	-27.75	120	381	>400	>400	X	/	Max before Yield
PPLT#11	EW1		Driven	600	600	-40.50							
PPLT#12	EW2	KIN SUN	Bored	1000	1057	-46.50	425	1170	1425	1425	/	/	
PPLT#13	EW2	KIN SUN	Bored	1200	1247	-41.60	425	971	1250	1250	/	/	
PPLT#14	EW2	KIN SUN	Bored	1200	1220	-32.45	433	959	>953	953	/	X	Max befor 10% Pile Dia. Sett.
PPLT#15A	EW2	KIN SUN	Bored	1200	1224	-44.17	433	942	>>1130	>1130	/	/	Retest - Max befor Yield
PPLT#16	EW2	KIN SUN	Bored	600	667	-32.04	120	354	>327	>>327	X	/	Max before Yield
PPLT#17	EW2		Bored	1200		(-30.0)	(410)	940					
PPLT#17A	EW2	KIN SUN	Bored	1000	1084	-47.25	433	1209	>963	>>963	X	/	Max before Yield
PPLT#18	NS3	THAI BAUER	Bored	1200		(-30.5)	406	934	>983	983	X	/	Max before 10% Pile Dia. Sett.
PPLT#19	NS3	THAI BAUER	Bored	1200		(-34.5)	388	1094	985	985	X	/	
PPLT#20	NS3		Driven	600	600	"							
PPLT#21	NS3	ITALTHAI TREVI	Bored	1000	1029	-49.60	400	1273	>1500	1500	X	/	Max before 10% Pile Dia. Sett.
PPLT#22	NS3	ITALTHAI TREVI	Bored	1000	1052	-40.56	405	1041	>1150	1150	/	/	Max before 10% Pile Dia. Sett.
PPLT#23	NS3	ITALTHAI TREVI	Bored	1200	1266	-45.10	400	928	>1500	1500	/	/	Max before 10% Pile Dia. S
PPLT#24	NS3	MPAC ENG.	Auger Press Driven	800	800	-29.30	225	660	>>600	>600	X	/?	Max before Yield
PPLT#25	NS5/6												
PPLT#26	NS5/6												
PPLT#27	NS5/6												
PPLT#28	NS5/6												
PPLT#29	NS5/6												
PPLT#30	NS5/6												
PPLT#31													

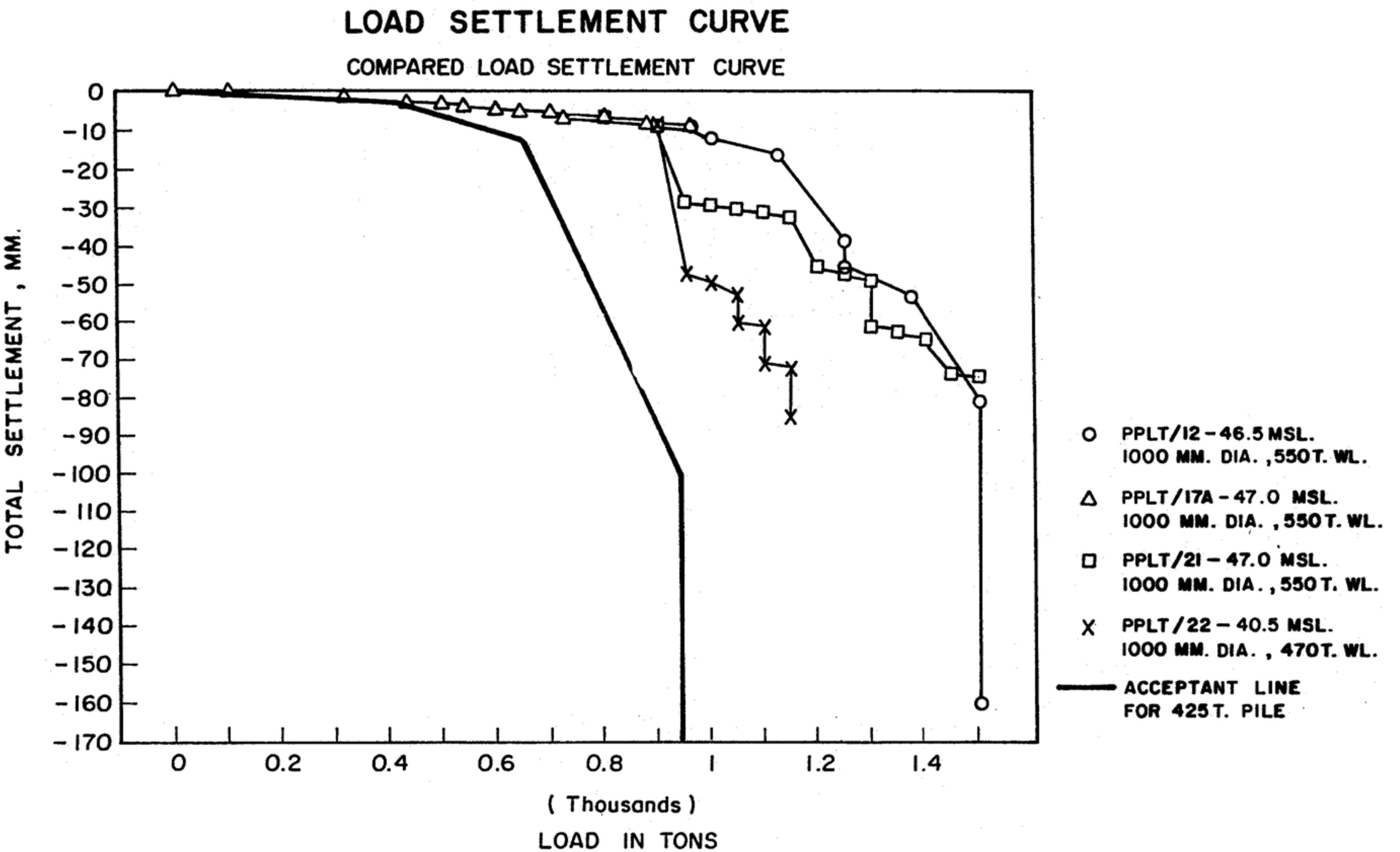
Instrumented pile load test program



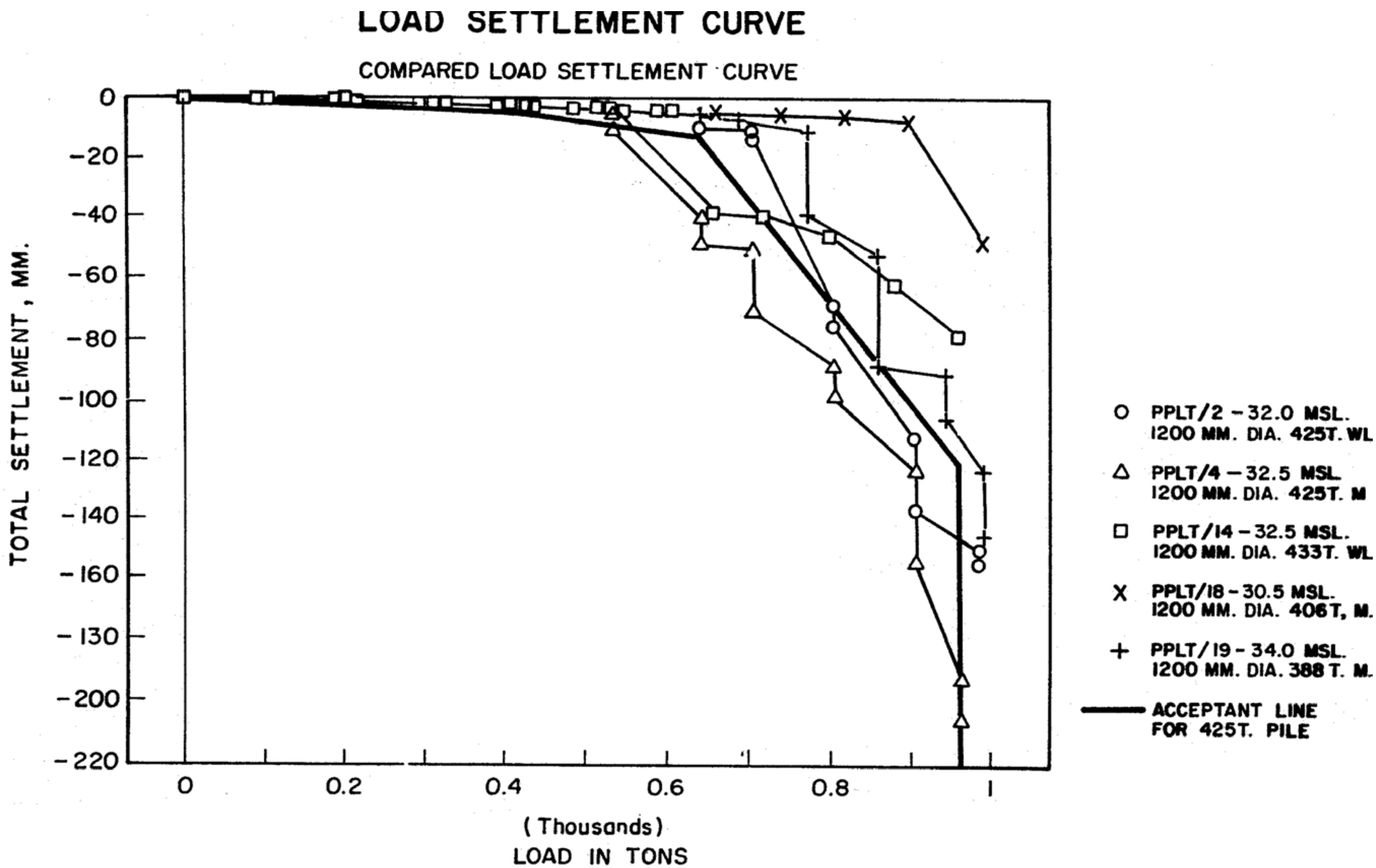
Acceptable load settlement graph



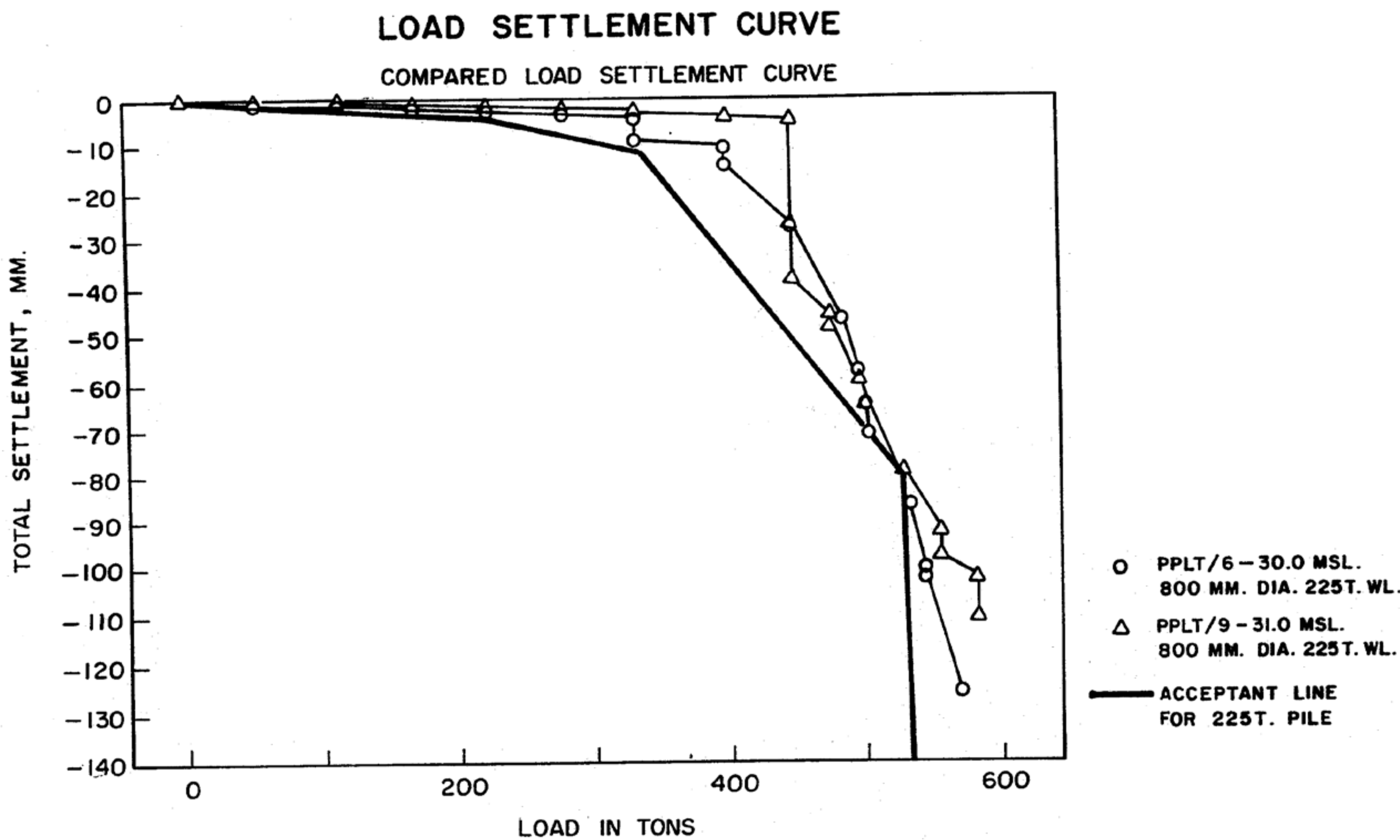
Acceptable load settlement graph



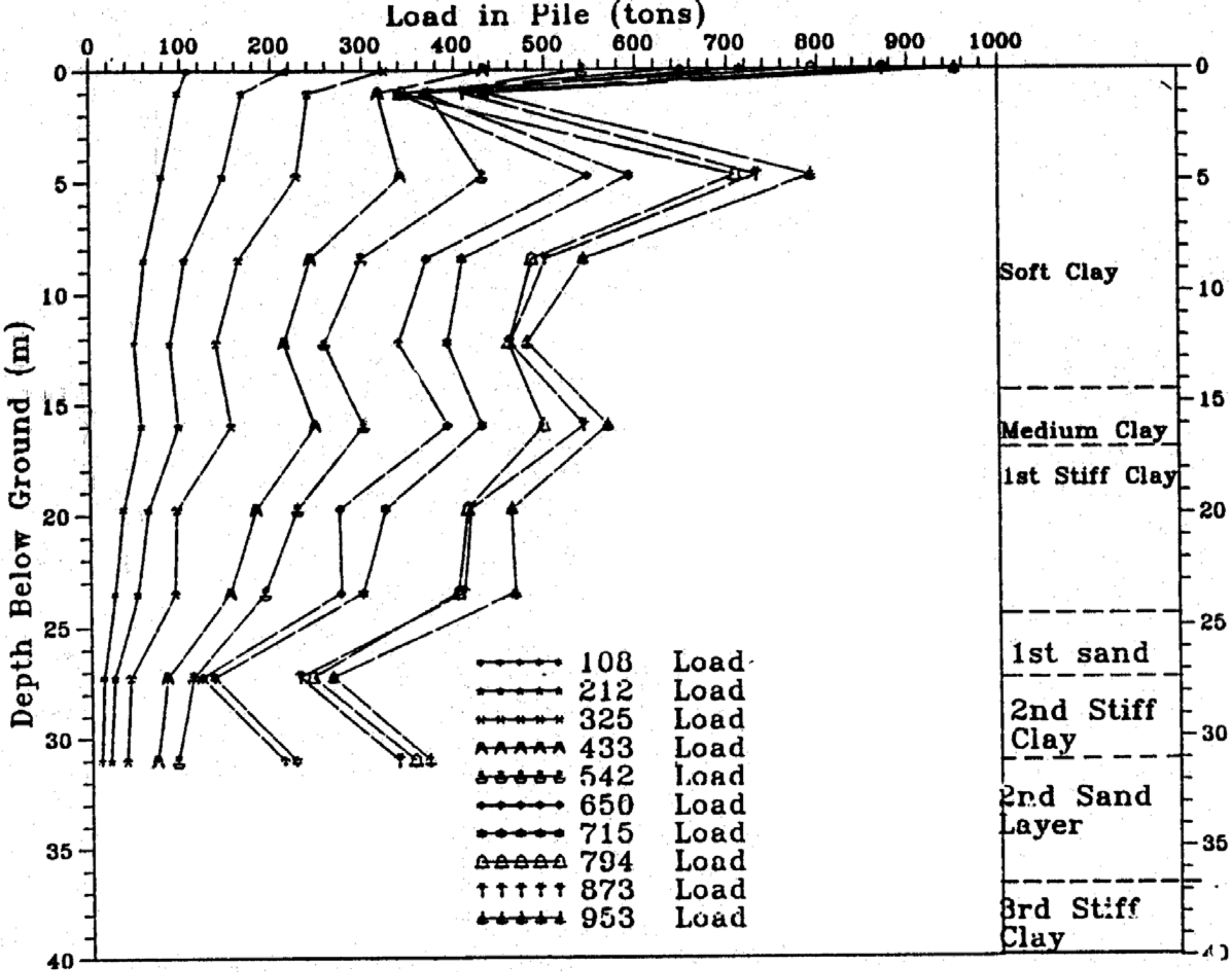
Acceptable boundary for load settlement graph



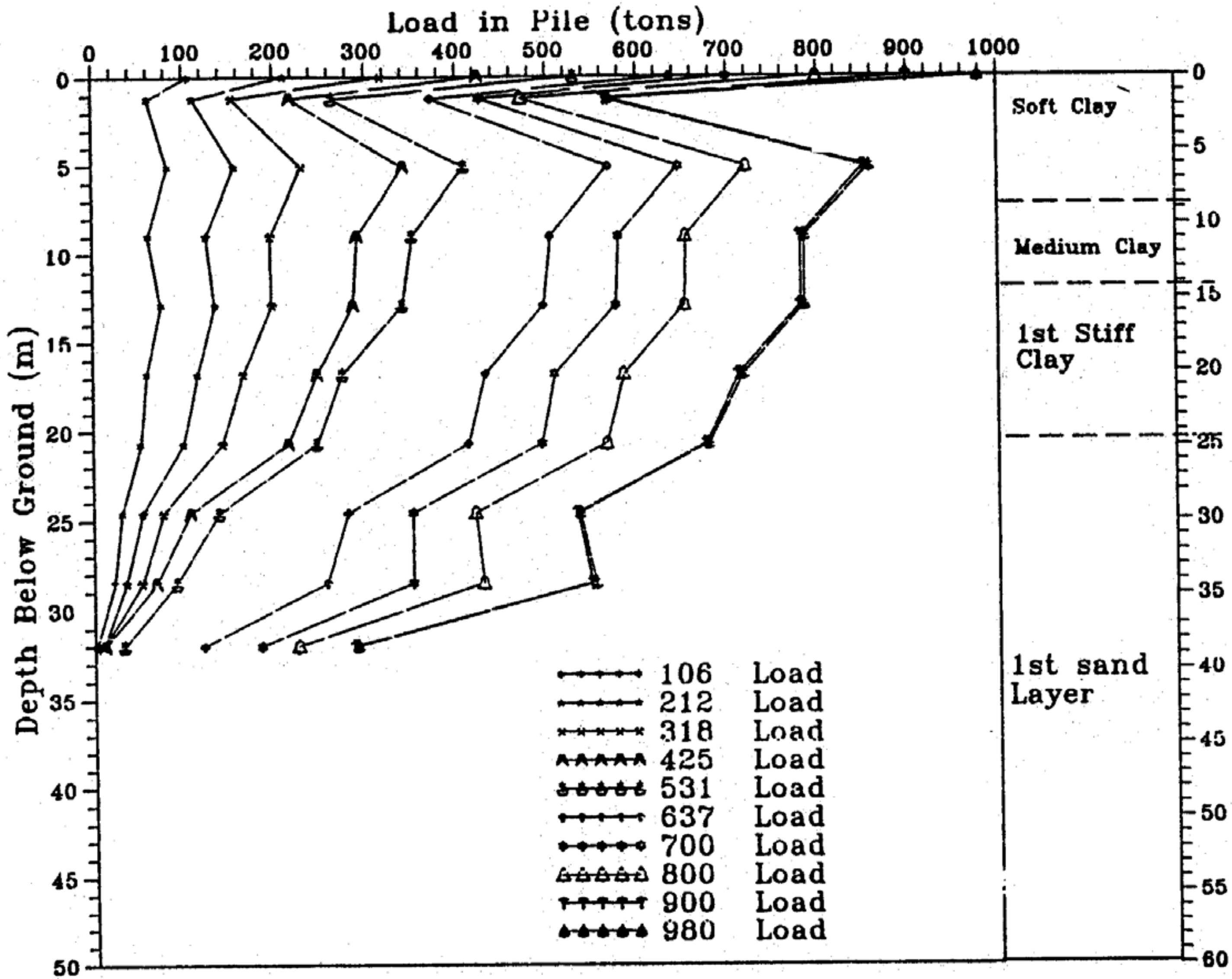
Acceptable boundary for load settlement graph



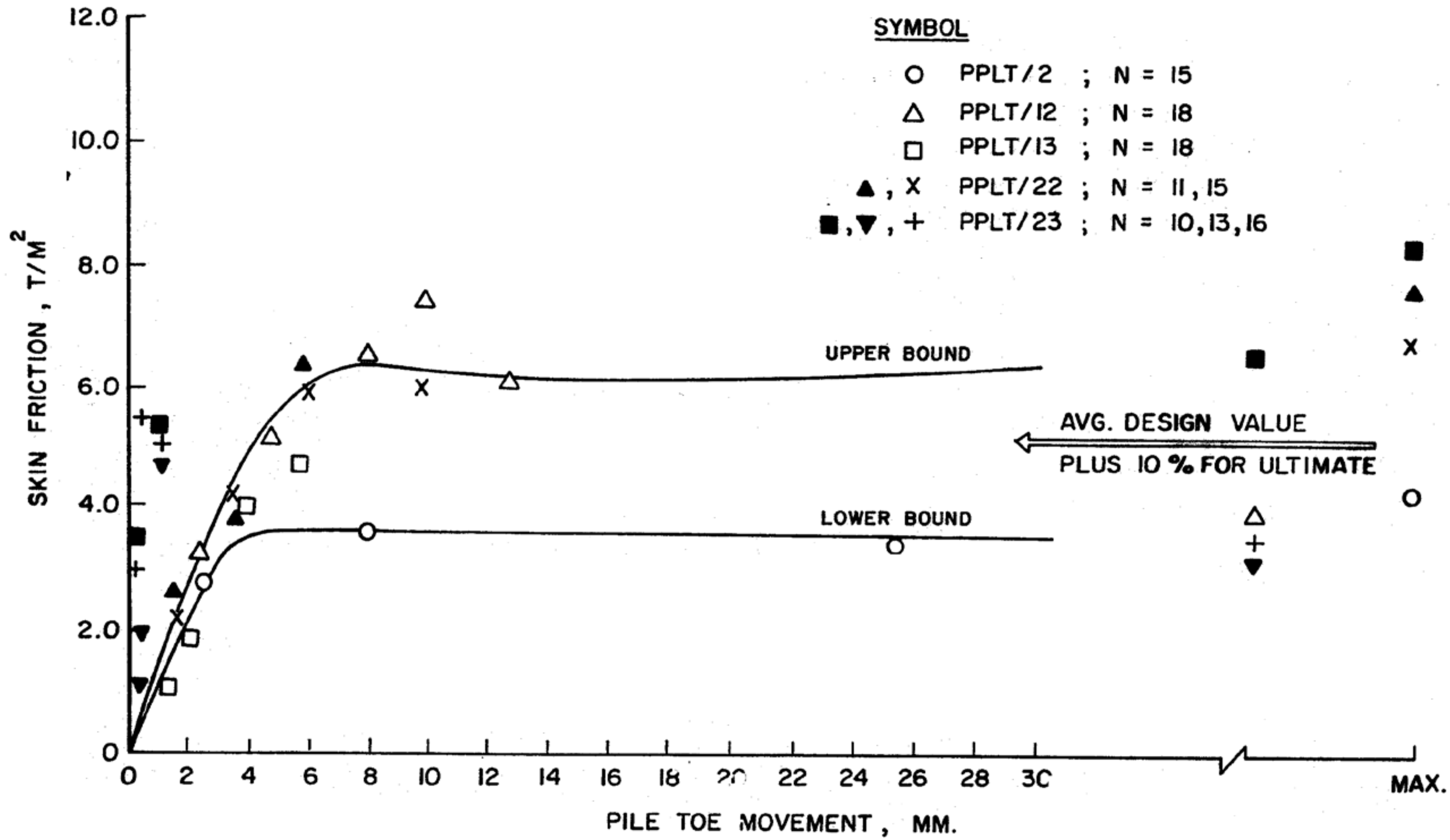
Acceptable boundary for load settlement graph



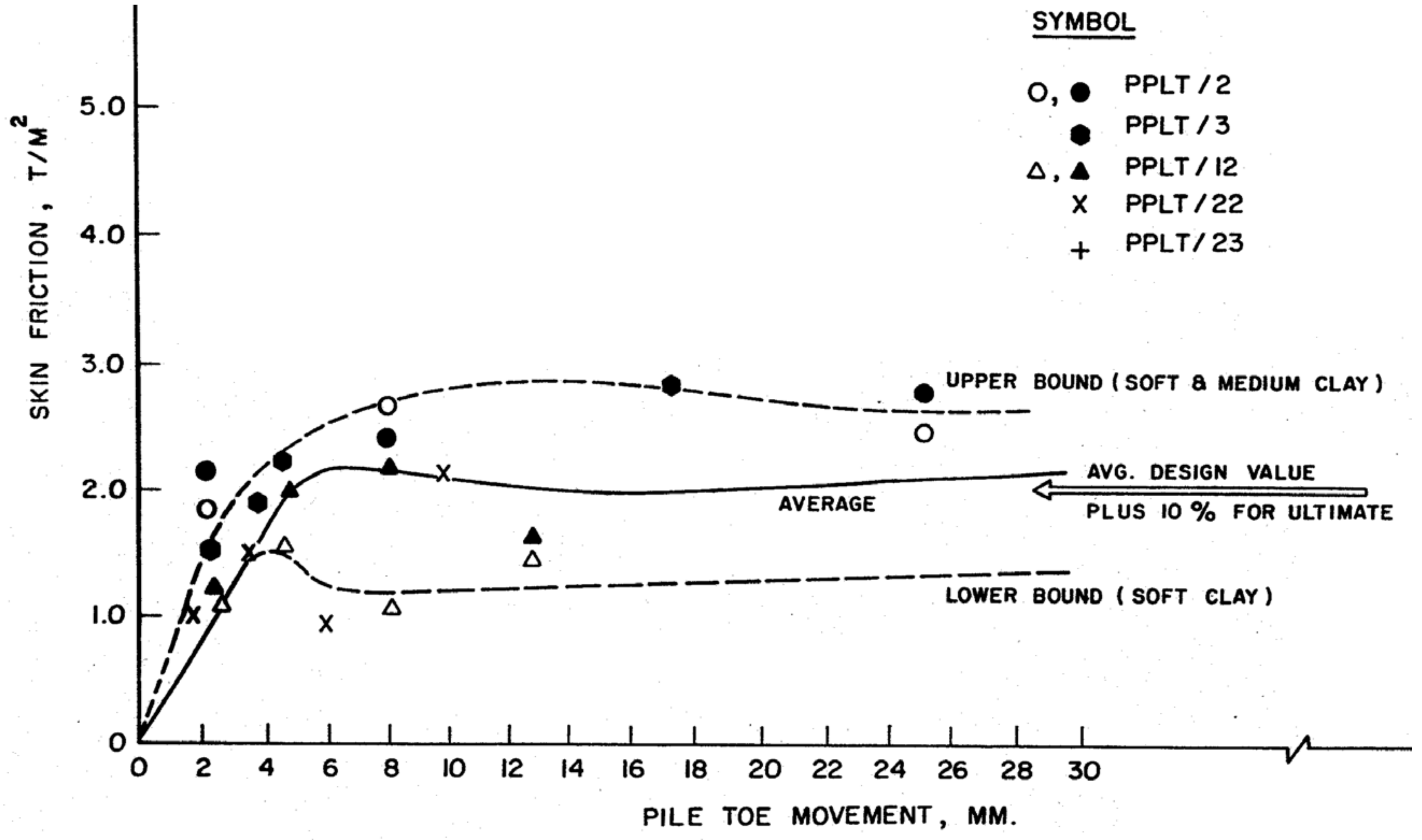
Load transfer graph for BP 14



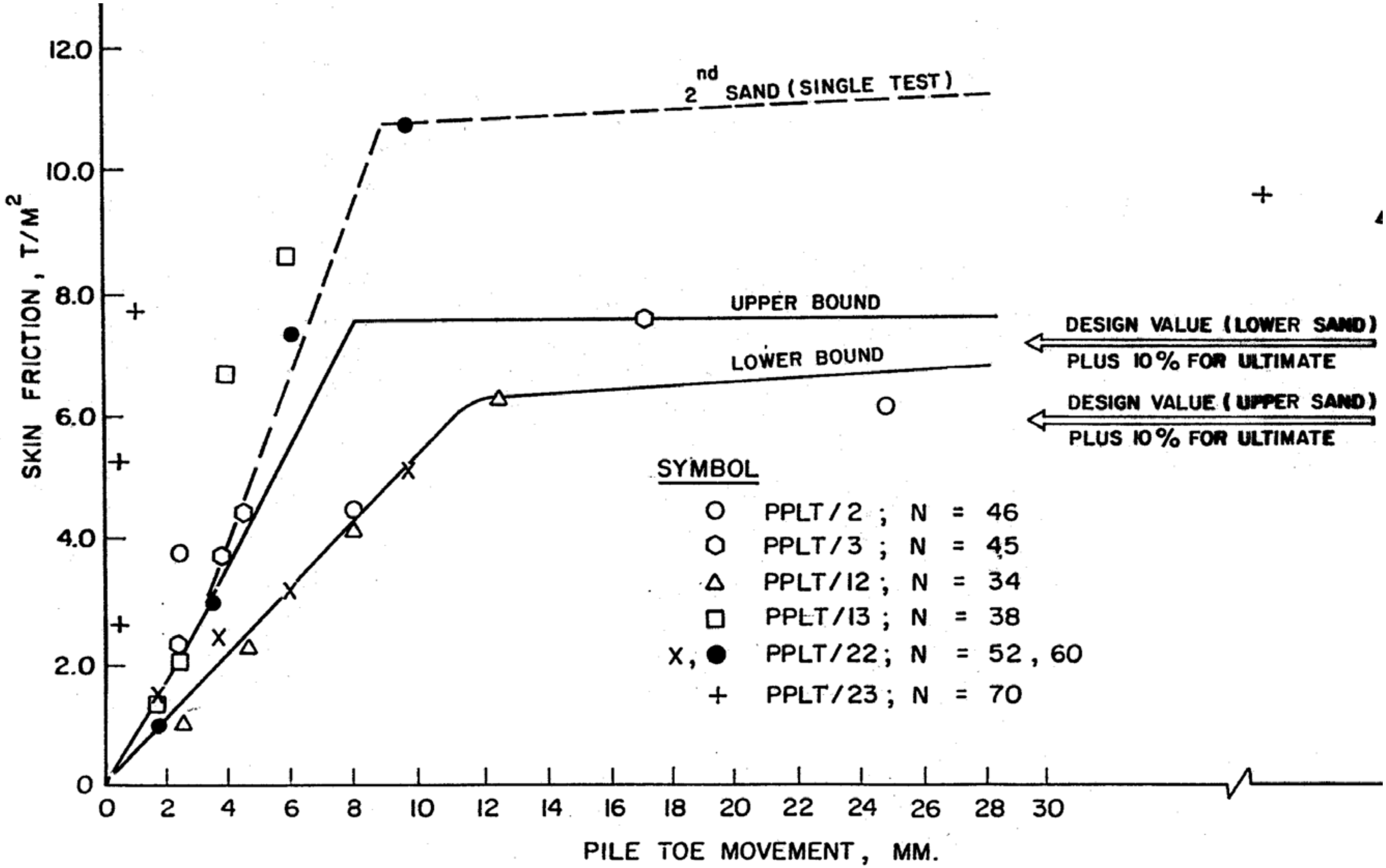
Load transfer graph for BP2



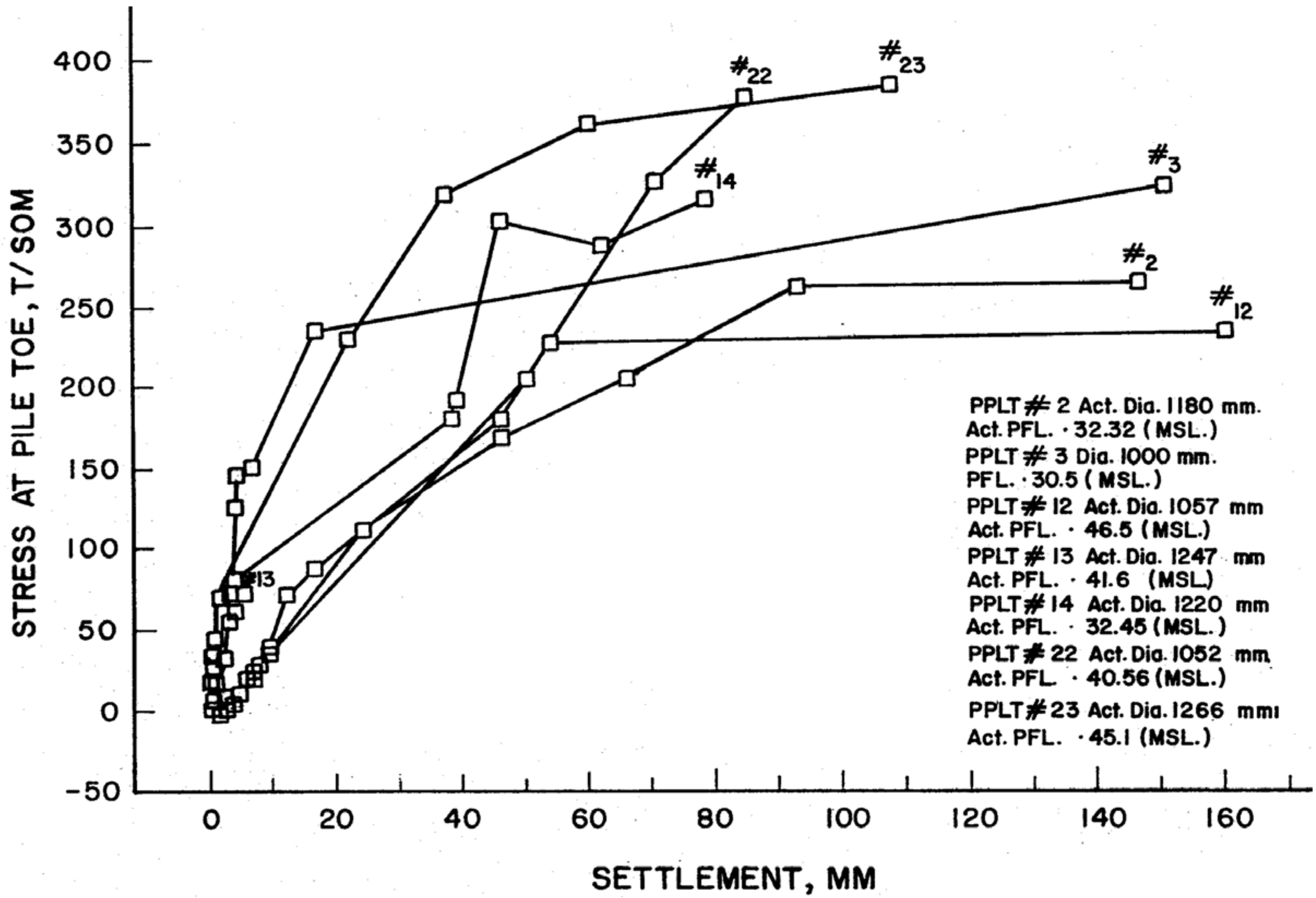
Skin friction mobilization in stiff clay



Skin friction in soft and medium stiff clay layer

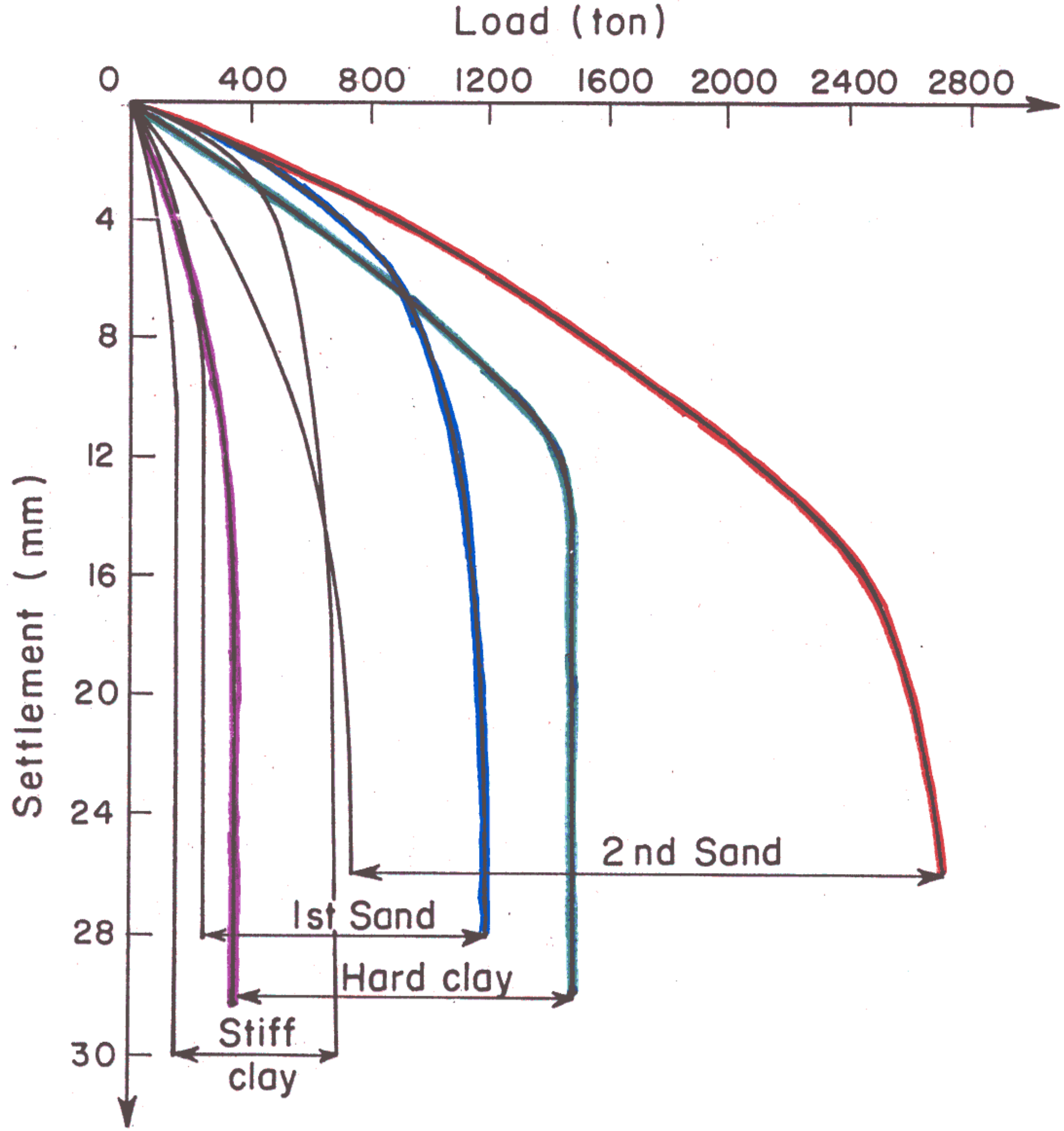


Skin friction parameter first sand layer

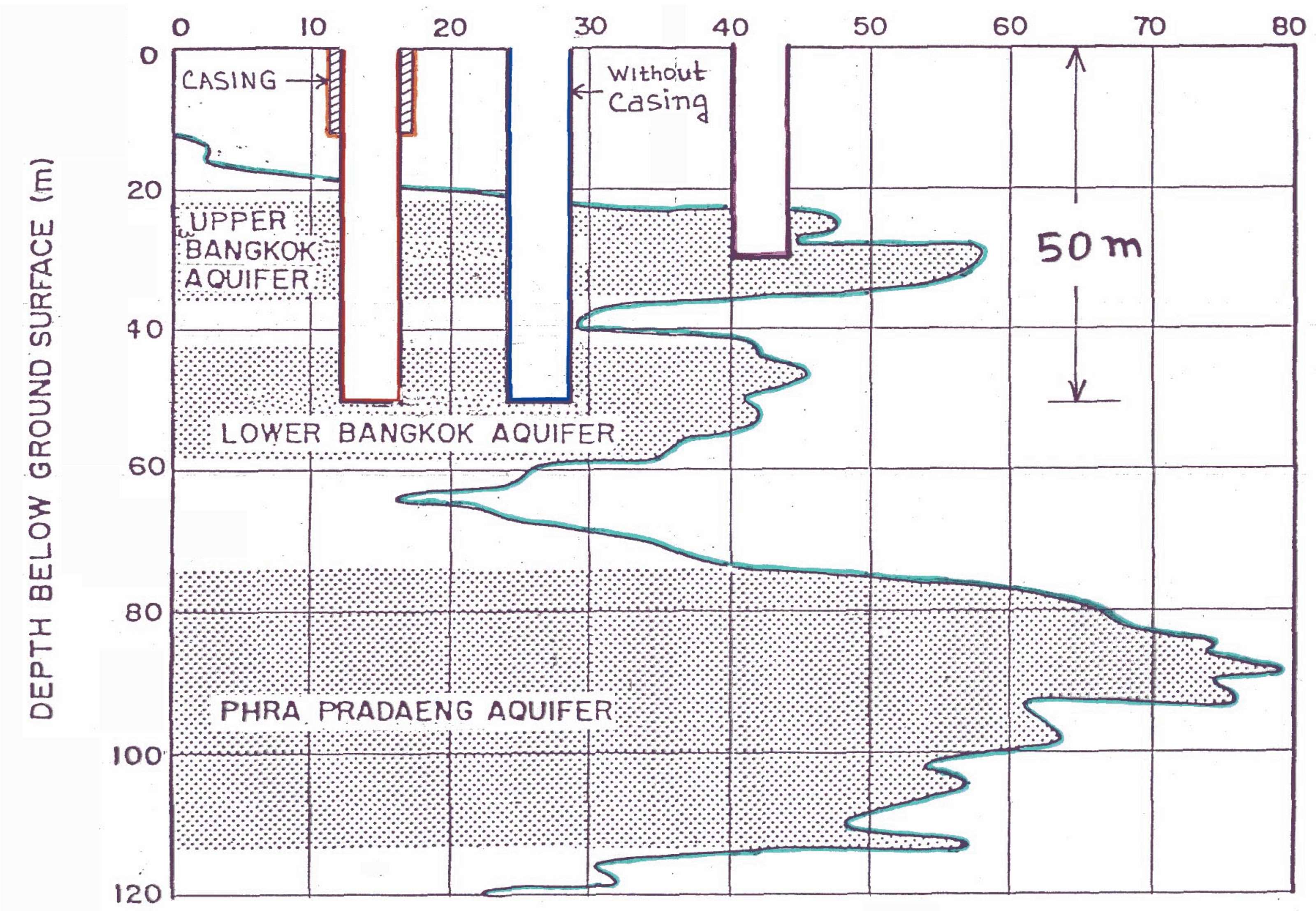


Development of bearing capacity at pile toe

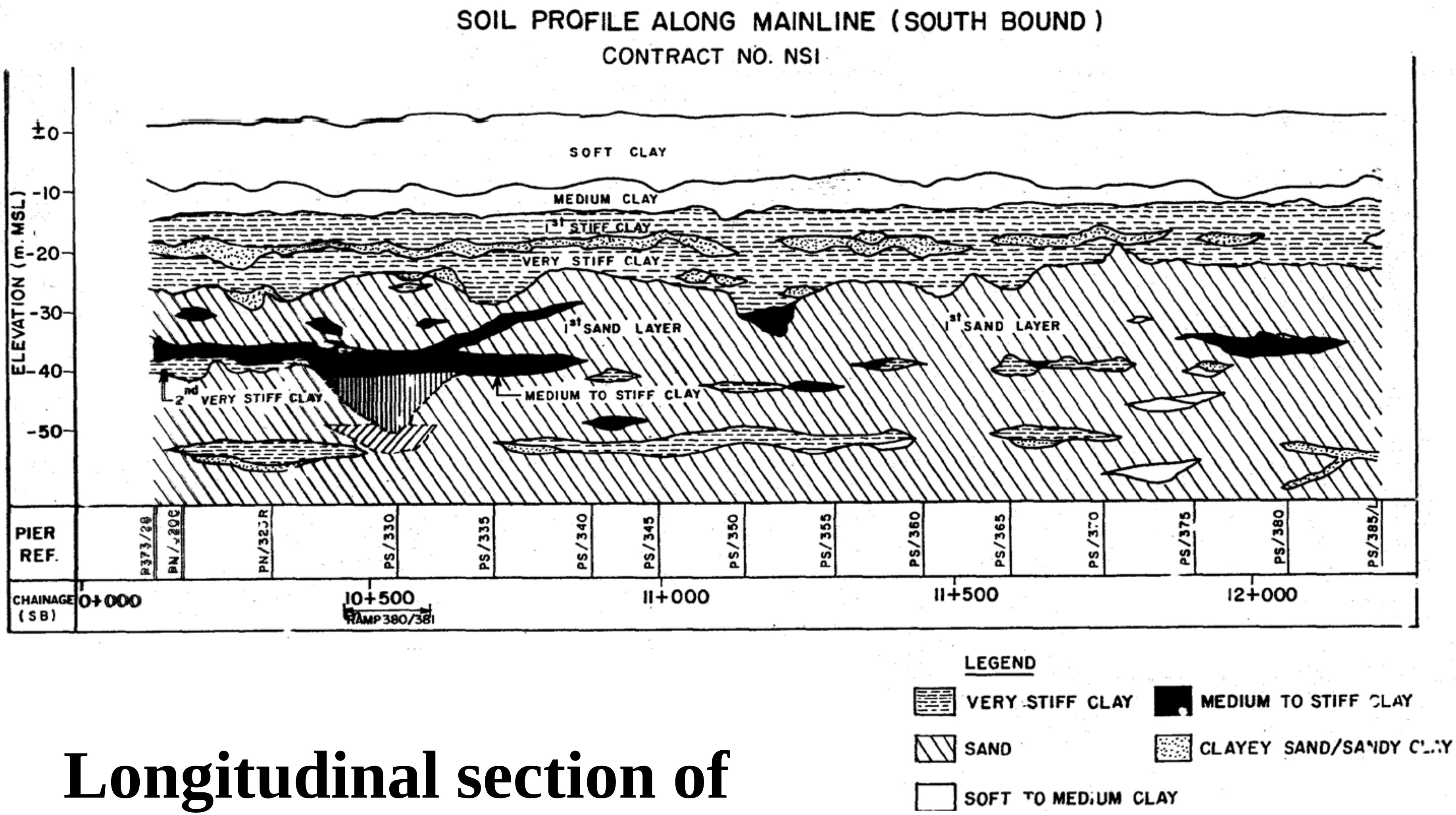
Higher load capacity with large diameter piles founded in deeper stiff layers



Load capacity of piles founded in different layers



Bored piles founded in second sand layer



Longitudinal section of soil profile in the second stage expressway project