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Static Load Testing of Piles in Restricted Access - An Opportunity for Change

PART 2- Micropile Testing and Eurocode 7

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ISM International Society for Micropiles

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Static Load Testing of Piles in Restricted Access- Catalysts for Change

Current situation implies only dynamic testing is possible due to access constraints.

Dynamic testing for micropiles not universally accepted without cross reference to static load (refer EN 14199:2005, cl.9.3.3 and EN1997-1:2004, cl. 7.5.3).

Design optimisation by reduction of factor of safety not acceptable with dynamic testing alone (refer EN1997-1:2004, cl. 7.4.1).

Restricted access piling has typically lower production rates than conventional large rig piling = comparatively high **COST**(£, $, €) per Kilonewton.

Economics, sustainability and technology advances calls for greater micropile capacities year on year = **RISK.**

Static Load Testing of Piles in Restricted Access- Catalysts for Change

EC7 Clause 7.5.3(1) “Dynamic load tests may be used to estimate the compressive resistance provided an adequate site investigation has been carried out and the method has been calibrated against static load tests on the same pile type, of similar length and cross section, and in comparable soil conditions”. See also 7.6.2.4

EC7 Clause 7.6.2.6(2)P ”Where wave equation analysis is used to assess the resistance of individual compression piles, the validity of the analysis shall have been demonstrated by previous evidence of acceptable performance in static load tests on the same pile type, of similar length and cross section, and in similar ground conditions”.

Static Load Testing of Piles in Restricted Access- Catalysts for Change

These two clauses present a fundamental change for restricted access micropiling given that hitherto, dynamic testing has often been relied upon for verification of pile capacity without recourse to static load tests

Static Load Testing of Piles in Restricted Access- Reasons for Load Testing Micropiles

Key benefits:

- Design optimisation = shorter piles
- Significant cost savings – materials and programme
- Reduction in material wastage
- Lower carbon emissions
- Reduced material transfer to landfill
- Reduced design risk
- Under EC7 piles will be longer than BS8004 for no testing where live loads >10% of applied overall loads

Static Load Testing of Piles in Restricted Access- Current UK Practice vs Eurocode 7

Both current UK practice (BS8004) and EC7, include clauses which favour static load testing, EC7 suggests that dynamic testing can only be relied upon when calibrated against static load tests from similar pile types within the same geological stratum.

Current UK Practice allows a reduced factor of safety to be employed in cases where load testing has been carried out. Table 1 shows the LDSA guidelines which have been generally accepted into UK piling practice.

Factor of Safety[b]	Required Testing Regime
3.0	No pile testing
2.5	Test 1%[a] of working piles
2.0 / 2.25	Undertake preliminary pile tests on non-contract piles
Notes:	a) Often specified but seldom strictly adhered to. b) Global factors of safety after BS 8004.

Table 1 Extracts from Table 1 of LDSA Guidelines

Static Load Testing of Piles in Restricted Access- Eurocode 7 Correlation Factors

Eurocode 7 uses correlation factors (ξ) to derive characteristic values for compressive resistance from static load tests (Table 2).

$$R_{c;k} = \mathrm{Min}\left\{\frac{(R_{c;m})_{mean}}{\xi_1};\frac{(R_{c;m})_{min}}{\xi_2}\right\}$$

Where:

$R_{c;k}$ = Characteristic value of the compressive resistance (R_c) of the ground against a pile at ULS.

$(R_{c;m})_{mean}$ = Mean measured value of R_c in one or more pile tests.

$(R_{c;m})_{min}$ = Lowest measured value of R_c in one or more pile tests.

ξ_1 and ξ_2 = Correlation factors related to the no. of piles tested (Table 2).

Static Load Testing of Piles in Restricted Access- Eurocode 7 Correlation Factors

It can be seen that the greater the number of tests (n) the lower the correlation factor (ξ).

i.e. Increased testing provides more certainty to the parameters and thereby reduces the effective partial factor to be applied.

ξ for	$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n \geq 5$
ξ_1	1.55	1.47	1.42	1.38	1.35
ξ_2	1.55	1.35	1.23	1.15	1.08
ξ_1 on the mean values of the measured resistances in static load tests ξ_2 on the minimum values of the measured resistances in static load tests					

Table 2 Correlation factors ξ to derive characteristic values of the resistance of axially loaded piles from static pile load tests (n = number of tested piles)

Static Load Testing of Piles in Restricted Access- Eurocode 7- Static vs Dynamic

As stated previously EC7 gives more credence to the results of Static Load Testing than those of Dynamic Load Tests.

Compare Tables 2 and 3.

It can be seen that more favourable correlation factors may be applied in calculations when results from Static Load Tests are used.

It appears that EC7 places more value on a single static load test than on 20 or more Dynamic Impact Tests.

ξ for	n = 1	n = 2	n = 3	n = 4	n ≥ 5
ξ_1	1.55	1.47	1.42	1.38	1.35
ξ_2	1.55	1.35	1.23	1.15	1.08

ξ_1 on the mean values of the measured resistances in static load tests
ξ_2 on the minimum values of the measured resistances in static load tests

Table 2 Correlation factors ξ to derive characteristic values of the resistance of axially loaded piles from static pile load tests (n = number of tested piles)

ξ for	n ≥ 2	n ≥ 5	n ≥10	n ≥15	n ≥ 20
ξ_5	1.94	1.85	1.83	1.82	1.81
ξ_6	1.90	1.76	1.70	1.67	1.66

ξ_5 on the mean values of the measured resistances in dynamic load tests
ξ_6 on the minimum values of the measured resistances in dynamic load tests

Table 3 Correlation factors ξ to derive characteristic values of the resistance of axially loaded piles from dynamic impact tests (n = number of tested piles)

Static Load Testing of Piles in Restricted Access- Eurocode 7- Selecting Parameter Values

Under clause 7.4.1.2, EC7 advocates the use of static load testing for **'selecting parameter values'**, in other words **optimising pile design.**

Parameters can be derived by back analysing pile test results using for example a 'Chin Analysis' such an approach can provide a range of actual skin friction parameters mobilised under test.

Mean and minimum values of derived skin friction parameters are used to derive the characteristic pile resistance $R_{c;k,}$ thus:

$$R_{c;k} = \text{Min}\left\{\frac{(R_{c;m})_{mean}}{\xi_1}; \frac{(R_{c;m})_{min}}{\xi_2}\right\}$$

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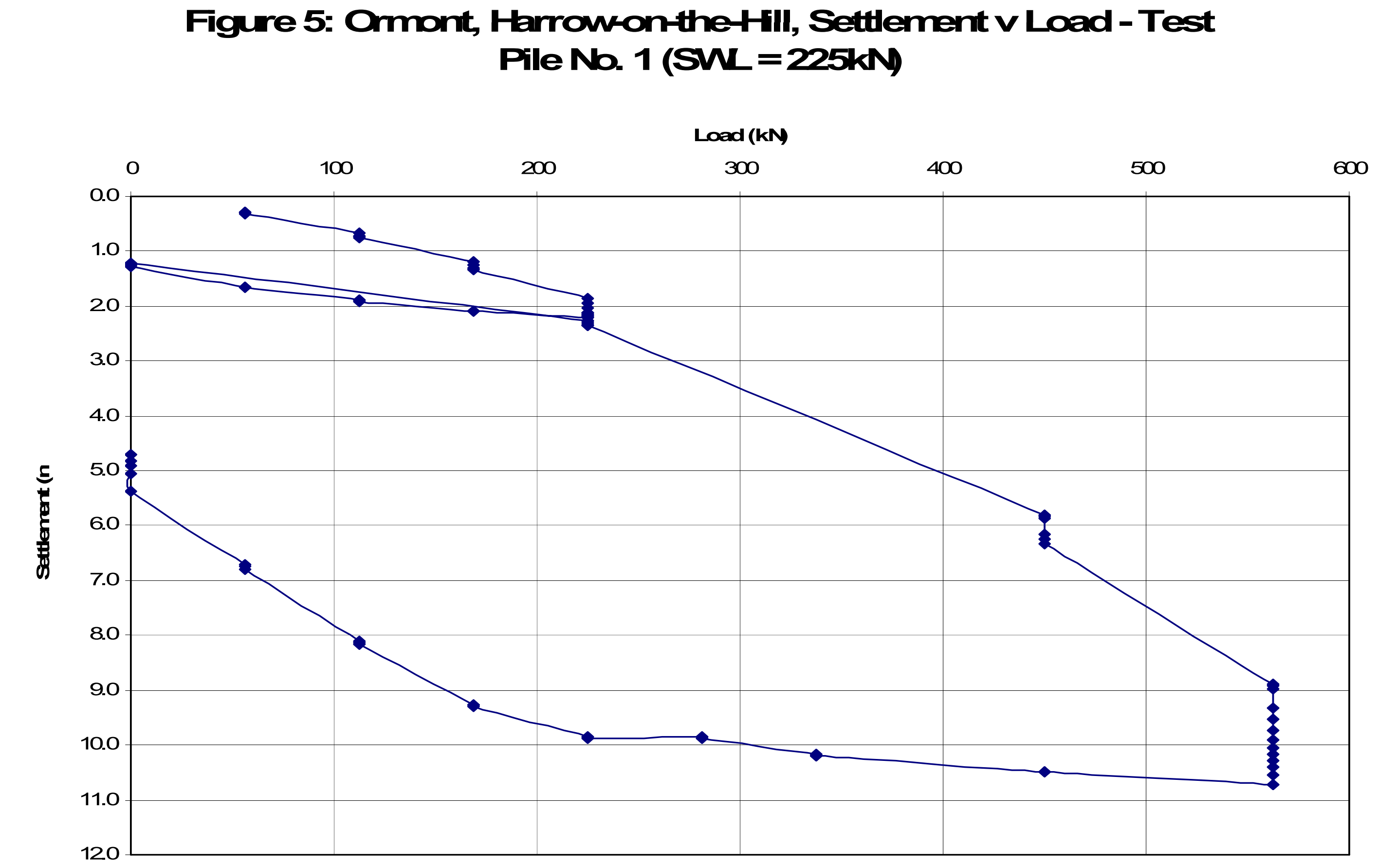
tricted Access-
he Hill, London

This example will demon
derive design parameters

Static Load Testing of Piles in Restricted Access Eurocode 7- Example; Harrow on the Hill, London

Pile Test Results- Test Pile 1



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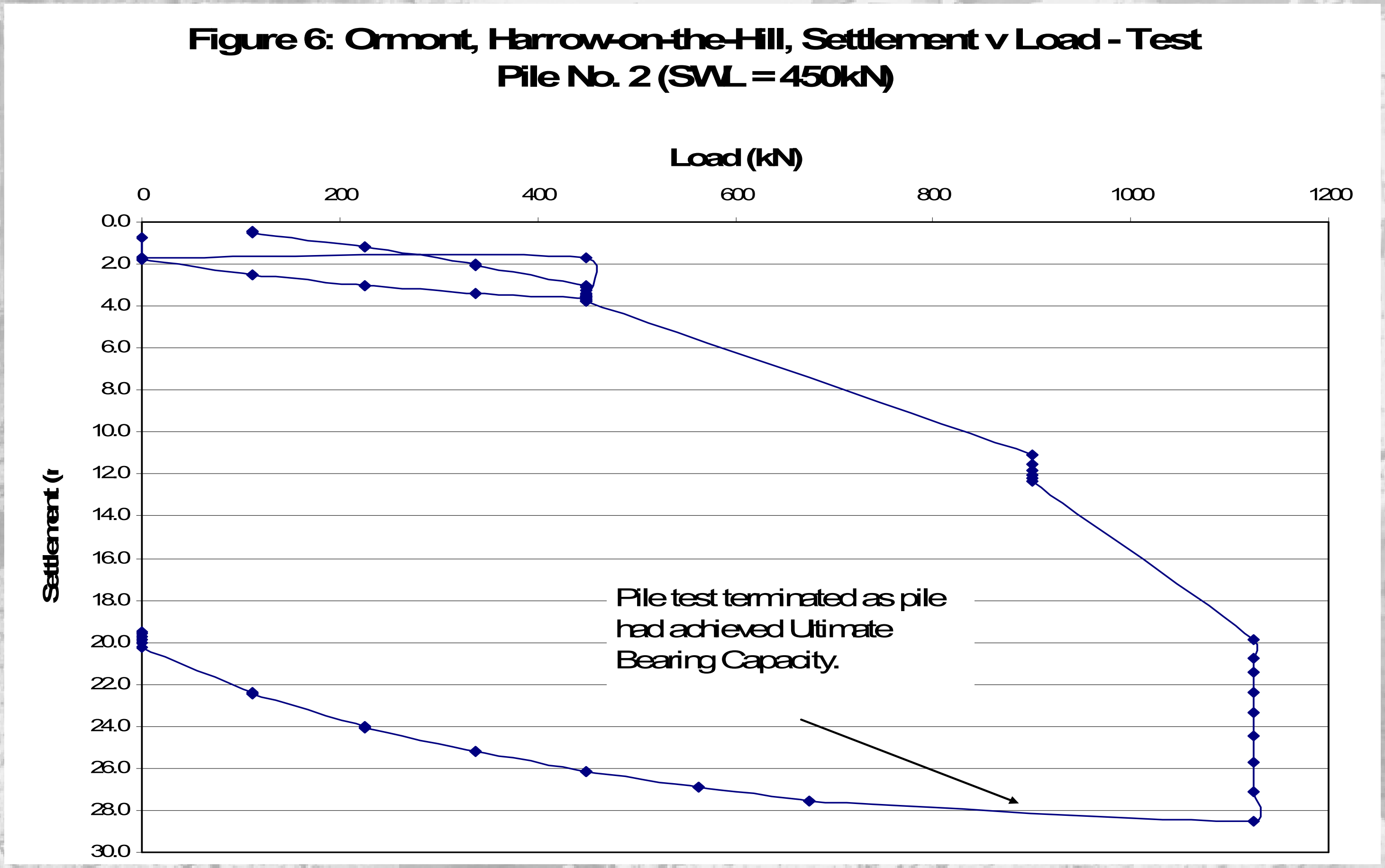
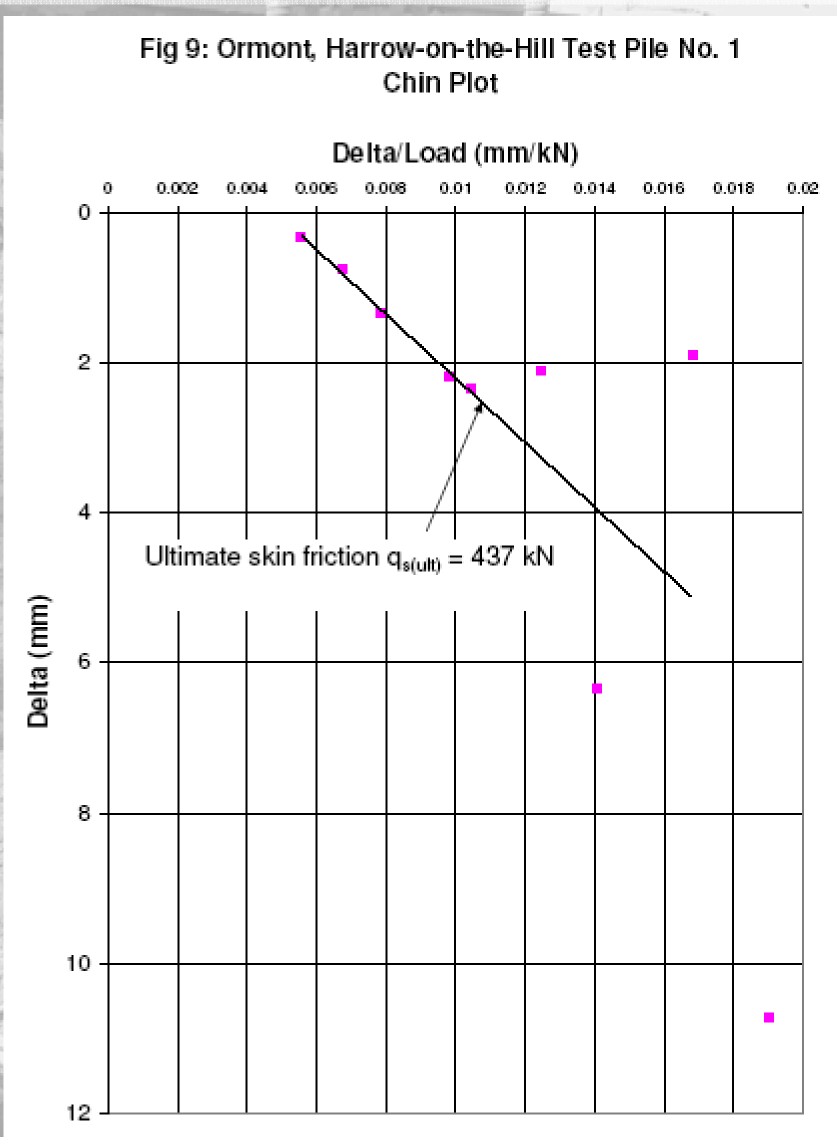
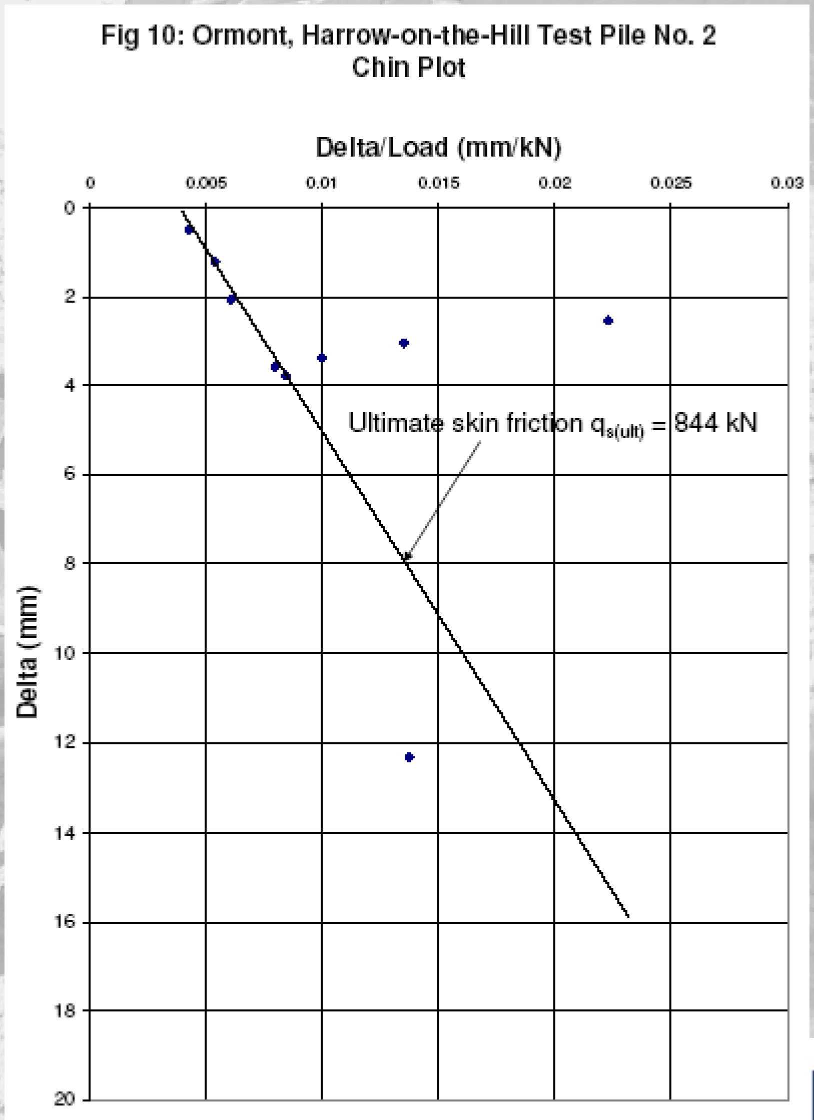
Static Load Testing of Piles in Restricted Access Eurocode 7- Example; Harrow on the Hill, London

Pile Test Results- Test Pile 2



Static Load Testing of Piles in Restricted Access Eurocode 7- Example; Harrow on the Hill, London





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ξ for	n = 1	n = 2	n = 3	n = 4	n ≥ 5
ξ_1	1.55	1.47	1.42	1.38	1.35
ξ_2	1.55	1.35	1.23	1.15	1.08
ξ_1 on the mean values of the measured resistances in static load tests ξ_2 on the minimum values of the measured resistances in static load tests					

Table 2 Correlation factors ξ to derive characteristic values of the resistance of axially loaded piles from static pile load tests (n = number of tested piles)

The correlation factor for 2 tests is then used in the equation:

$$R_{c;k} = \mathrm{Min}\left\{ \frac{(R_{c;m})_{mean}}{1.47} ; \frac{(R_{c;m})_{min}}{1.35} \right\}$$

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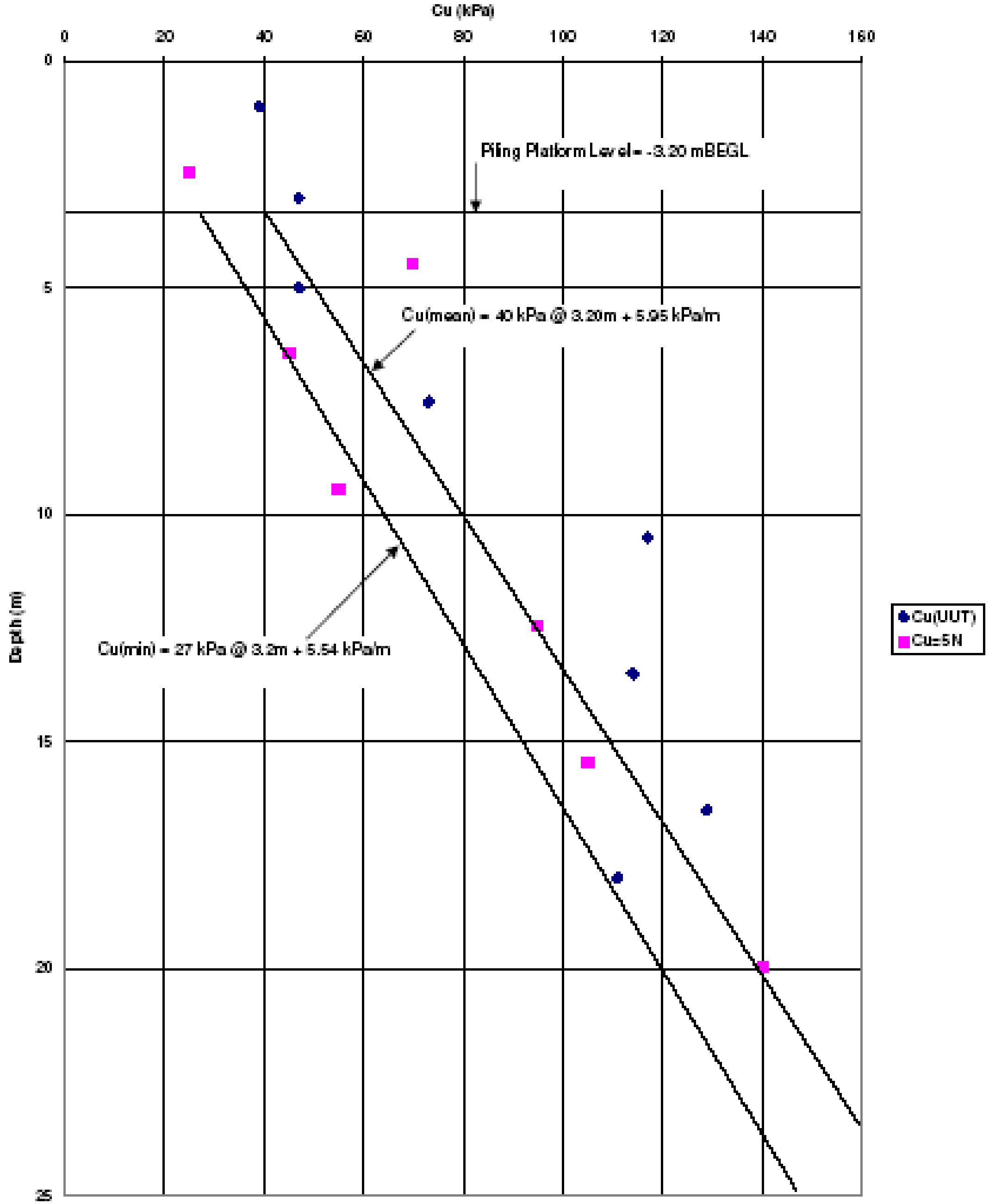
Static Load Testing c
Eurocode 7- Example

Soil Strength Data

Figure 9: Soil Strength Data, Ormont, Harrow-on-the-Hill
Undrained Shear Strength (Cu) v Depth



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EC7 cl. 7.6.2.3(8), Equation 7.9

Actions:

Permanent $G_k = 270$ kN

Variable $Q_k = 180$ kN

Pile Properties

Bored Pile, d = 280mm

$C_{u(mean)} = 40 \text{ kPa} + 5.95 \text{ kPa/m}$

$\alpha = 0.6$

$R_{s;k} = \Sigma_i \{ A_{s;i} \times q_{s;i;k} \}$

Try L = 24.1

$R_{s;k} = 1421$ kN

$\gamma_b = 2.00$

$\gamma_s = 1.60$

$\gamma_t = 2.00$

$\gamma_{Rd} = 1.40$ (model factor)

Design Approach 1 Combination 2
A2 "+" (M1 or M2) "+" R4

$$R_{c;d} = \text{Min}\left\{ \frac{\left(\frac{R_{b;k}}{\gamma_b} + \frac{R_{s;k}}{\gamma_s}\right)}{\gamma_{Rd}} ; \frac{\left(\frac{R_{b;k} + R_{s;k}}{\gamma_t}\right)}{\gamma_{Rd}} \right\}$$

$R_{c;d} = 507$ kN

Table A3:

$\gamma_G = 1.00$

$\gamma_Q = 1.30$

$F_{c;d} = 504$ kN

$F_{c;d} < R_{c;d}$ **OK**

L = 24.1 m

Lumped factor = (504/450) x 1.4 x 2 = 3.136

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EC7 cl. 7.6.2.3(5)P Equation 7.2

$$R_{c;k} = \text{Min}\left\{\frac{(R_{c;m})_{mean}}{\xi_1};\frac{(R_{c;m})_{min}}{\xi_2}\right\}$$

$$(R_{c;m})_{mean} = \frac{437}{\pi \times 0.175 \times 8.5} + \frac{844}{\pi \times 0.28 \times 10.5}$$

$$(R_{c;m})_{mean} = \frac{93.5 + 91.4}{2} = 92.5 \text{ kPa}$$

$$(R_{c;m})_{min} = 91.4 \text{ kPa}$$

$$R_{c;k} = \text{Min}\left\{\frac{92.5}{1.47};\frac{91.4}{1.35}\right\}$$

$$R_{c;k} = 62.9 \text{ kPa}$$

γ_b = 1.70 (end bearing ignored)

γ_s = 1.40

γ_t = 1.70

Design Approach 1 Combination 2

A2 ”+” (M1 or M2) “+” R4

Try L = 15.5m

$R_{c;d} = R_{c;k} / \gamma_t$

$= (62.9 \times \pi \times 0.28 \times 15.5)/1.7$

$R_{c;d}$ = 505 kN

γ_G = 1.00

γ_Q = 1.30

$F_{c;d}$ = 504 kN

$F_{c;d} < R_{c;d}$ **OK**

L = 15.5 m

SAVING= **9.4m** = **39%**

Static Load Testing of Piles in Restricted Access Eurocode 7- Example; Harrow on the Hill, London

		Required Bored Length (m)					
SWL (kN)	Dia. (mm)	EC7 cl. 7.6.2.3[1]	EC7 cl. 7.6.2.2[2]	% saving	BS8004[5]	BS8004[6]	% saving
225	175	21.0	12.4	41.0	20.4	8.8	56.9
450	280	24.1	15.5	35.7	23.4	11.1	52.6

Notes

1) Adopting correlation and partial resistance factors from NA to BS EN 1997-1:2004[5].

2) Adopting correlation and partial resistance factors from NA to BS EN 1997-1:2004[5].

3) Adopting a factor of safety of 3.0 and an adhesion factor of 0.6 after Part B, LDSA Guidelines, Table 1[3] for no pile testing.

4) Adopting a factor of safety of 2.0 and an adhesion factor of 0.5 after Part B, LDSA Guidelines, Table 1[3] using back calculated strength parameters from preliminary maintained load tests.

Table 8: Results summary

Static Load Testing of Piles in Restricted Areas- Eurocode 7- Example; Harrow on the Hill, London

		Required Bored Length (m)			(£) - 000's		
SWL (kN)	Dia. (mm)	EC7 cl. 7.6.2.3(1)	EC7 cl. 7.6.2.2(2)	% saving	EC7 cl. 7.6.2.3(1)	EC7 cl. 7.6.2.2(2)	Saving
225	175	21.0	12.4	41.0	30 - 35	20 - 25	10
375 / 400	280	22.0	13.7	37.7	100 - 120	70 - 90	30
450	280	24.1	15.5	35.7	45 - 55	30 - 40	15
							55

Notes

1) Adopting correlation and partial resistance factors from NA to BS EN 1997-1:2004(5).

2) Adopting correlation and partial resistance factors from NA to BS EN 1997-1:2004(5).

Table 9: Cost savings

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Static Load Testing of Piles in Restricted Areas- Eurocode 7- Example; Harrow on the Hill, London

		EC7 cl. 7.6.2.3[1]				EC7 cl. 7.6.2.2[2]						Embodied Energy Saved[3]				CO_2 Saved[4]	
SWL (kN)	Dia. (mm)	Required Bored Length	Required Vol. of grout	Cement Used	Steel Used	Required Bored Length (m)	Required Vol. of grout	Cement Used	Steel Used	Cement Saved	Steel Saved	Cement	Steel	Cement	Steel	Cement	Steel
				A	B			C	D	A - C	B - D						
		(m)	(m^3)	(kg)	(kg)	(m)	(m^3)	(kg)	(kg)	(kg)	(kg)	MJ/kg	MJ/kg	kwh	kwh	(kg)	(kg)
225	175	21.0	9.3	8389	2793	12.4	5.5	4954	1649	3436	1144	26798	40033	7444	11120	2754	4115
375 / 400	280	22.0	57.3	51531	9460	13.7	35.7	32090	5891	19441	3569	151642	124915	42123	34699	15586	12838
450	280	24.1	21.8	19617	4446	15.5	14.0	12617	2860	7000	1587	54601	55535	15167	15426	5612	5706
			88.4	79537	16699		55.2	49660	10400	29877	6300	233042	220483	64734	61245	23952	22661

Total CO_2 saved **46612** kg

Notes

1) Adopting correlation and partial resistance factors from NA to BS EN 1997-1:2004[5].

2) Adopting correlation and partial resistance factors from NA to BS EN 1997-1:2004[5].

3) Embodied energy in building materials taken from Baird[10], 7.8 MJ/kg for cement and 35 MJ/kg for imported steel.

4) Carbon emission factors for coke are used given as 0.37 kg CO_2/kwh from Energy and Carbon Conversions[11].

Table 10: Environmental savings

Static Load Testing of Piles in Restricted Access- Conclusions

- EC7 makes it mandatory for the results of static load tests to form the basis of all design
- Results of dynamic load tests cannot be used without correlation with the results of static load tests
- Under the old factor of safety of 3.0 approach, the EC7 equivalent method will result in increased pile lengths where live loads are more than 10% of the overall applied loads
- The results of static load tests can be used to engineer micropile lengths
- There are key benefits for all parties if static load testing in restricted access is undertaken
- Finally, the development of this test beam and the introduction of EC7 offers an opportunity for change (arguably for the better) for the micropiling industry

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The End

Thanks for Listening

Any Questions???

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