6th SC7 Working Group Meeting WG3/TG3 Introduction to Discussions on Pile Design and PT4 Drafting Work

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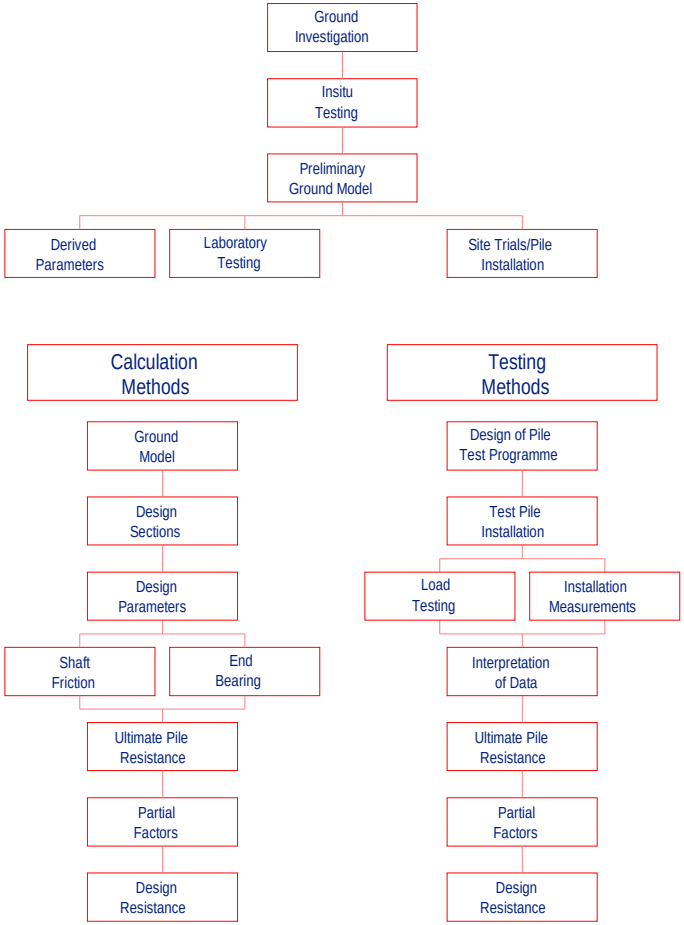
What am I going to talk about?

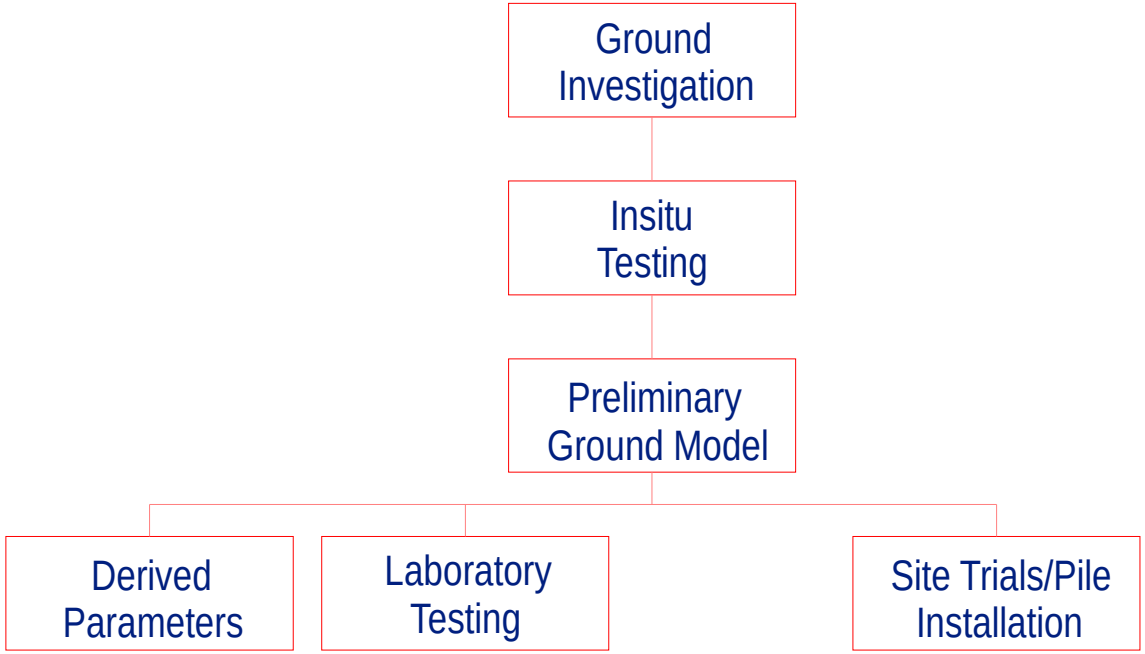
- Taken over Chair of WG3/TG3
- Hand Over from EG7 to PT4
- Pile Design - Bearing Capacity
  - Focus not on the differences across Europe
  - Highlight the similarities
- Interface between WG3/TG3 and PT4
- Key topics that need to be included in new draft
- Some possible discussion topics

Flow Chart – Pile Bearing Capacity



Ground Investigation

- All pile design starts with site investigation, insitu testing and laboratory testing to a greater or lesser extent



Ground Investigation

- Site investigation is used to establish:
  - Geometrical constraints
  - Soil layering
  - Soil and rock types
  - Variations
  - Groundwater conditions
- Also used to determine basic soil parameters

Ground Investigation

- Site investigation is used to establish geometrical constraints, soil layering, variations and groundwater conditions

Boreholes	CPT	Rotary Drilling	Trial Pits	Geophysics
Soil/Rock Layering	Soil/Rock Type	Variations	Descriptions	Groundwater

- But also a preliminary Ground Model

Soil/Rock Layers	Variations	Soil/Rock Type

Ground Investigation

- But site investigation could also include:
  - Site trials and prototype pile installation
  - Installation of piles for testing
  - Observation of pile spoil from bored piles
  - Drive blows for driven piles
  - Drive energy [wave analysis] for driven piles
  - Dynamic load testing
  - Static load testing

Ground Investigation

- Insitu testing is used to determine basic soil parameters

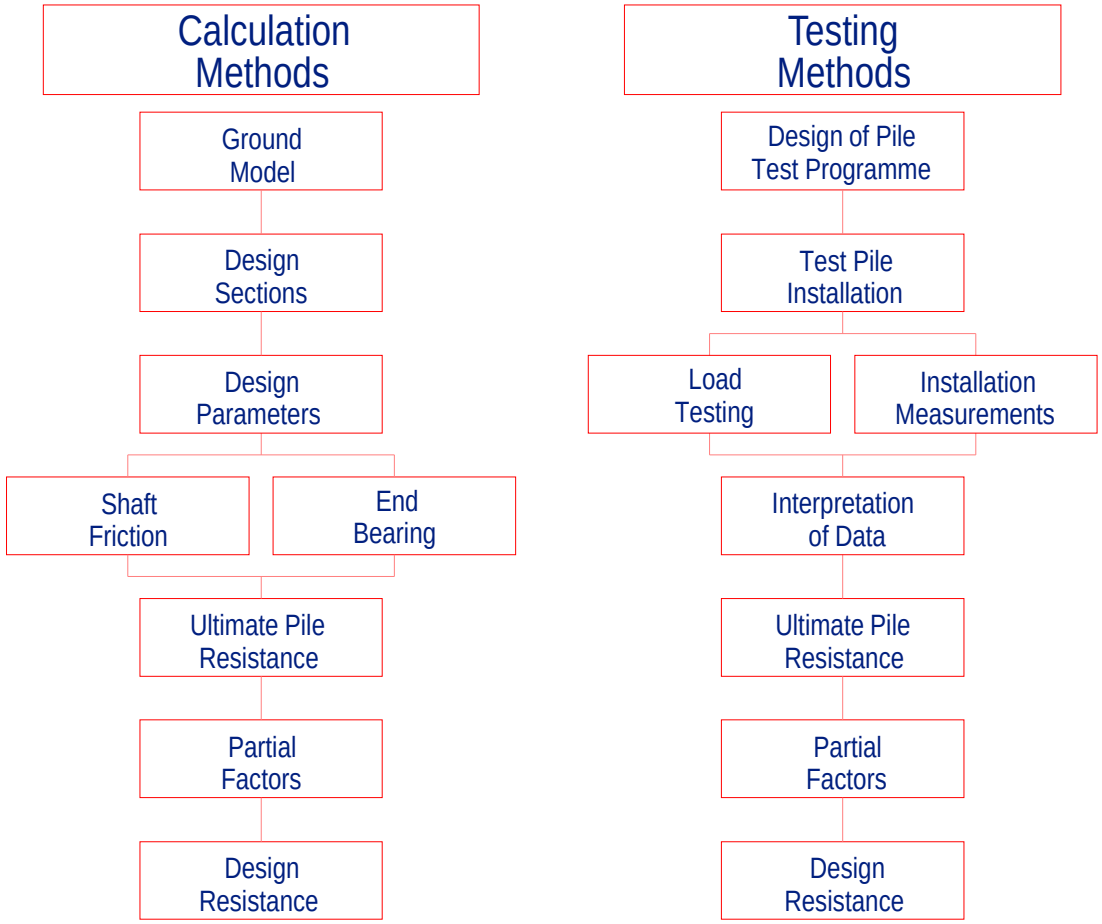
CPT q_c	SPT N_{60}	PMT p_L

- There are differences across Europe on what we do with the basic soil parameters and other test data
- But all approaches are being used successfully somewhere
- PT4 need to remain inclusive and not rule out any particular approach as being better or worse

Pile Design

- Pile design can broadly be divided into two methods:
  - Calculation based on insitu or laboratory test results
  - Design based on pile load testing
- Both options are legitimate and acceptable
- Both methods are being used successfully across Europe
- But PT4 must not show preference for either option

Pile Design By Calculation or Testing



Pile Design By Calculation

- All design methods require a ground model

Soil/Rock Layers	Variations	Soil/Rock Type

- These are simplified to provide representative design sections or multiple profiles [Borehole or CPT profiles]

Simplified Sections	Assumed Soil Properties	Groundwater Conditions

Pile Design By Calculation

- The differences in the design methods in use across Europe relate mainly to how insitu or laboratory test data is used
- But they all have in common the derivation of pile shaft stress f_s and end bearing pressure q_b
- These can be via derived soil properties c', φ', Cu or UCS
- Or by direct correlation from CPT q_c, SPT N_{60} or PMT p_L
- Or by using experience [tables related to q_c or Cu]

Pile Design By Calculation

Shaft Friction f_s	α Cu	$\sigma_v' K_s \tan \delta$	Tables	Direct
End Bearing q_b	N_c Cu	$\sigma_v' N_q$	Tables	Direct

- The similarity is that all methods end up with f_s and q_b, whether this is the German EA-Pfähle, UK φ' and Cu methods, the French PMT methods or other methods in use elsewhere in Europe

Pile Design By Calculation

- The resulting f_s and q_b are used to **calculate** the ultimate pile shaft R_s and end bearing R_b resistances
- A model factor is often applied to derive the characteristic values of the shaft $R_{s,k}$ and end bearing $R_{b,k}$ resistances

Shaft Resistance	$\sum f_{s,k,} A_s$
Base Resistance	$q_{b,k} A_b$

Pile Design By Calculation

- The characteristic resistance is taken equal to the sum of the characteristic pile shaft $R_{s,k}$ and end bearing $R_{b,k}$ resistances

Pile Resistance	$R_{ult} = R_{s,k} + R_{b,k}$

- The calculation method is common in many European countries
- PT4 need to recognise that the calculation method is possibly the most common pile design approach in Europe

Pile Design By Testing

- The other main design methods are based on pile installation measurements or pile load testing
- All methods requires a preliminary ground model from the GI

Design of Test Pile Programme	Pile Type	Loading Variations	Pile Length & Diameter/Size	Probable Foundation
Test Pile Installation	Observations	Confirmation of Ground Model	Construction Measurements	Instrumentation Measurements

Pile Design By Testing

- Pile load testing

Static	Dynamic	Wave Analysis	Drive Blows
Instrumentation	Load Cells	Strain Gauges	Extensometers

- Testing can be static or dynamic load tests, or wave analysis of the energy measurements during installation, or analysis of the measured drive blows
- Load tests can also be instrumented to provide more data

Pile Design By Testing

- Pile load testing requires interpretation

CAPWAP	CASE	CEMSET	Instrumentation and Monitoring
Shaft Resistance	Base Resistance	Total Resistance	Settlement

- Instrumented load tests can provide more data including separation of the shaft and end bearing components
- Most interpretation will just give a single total resistance

Pile Design By Testing

- There are also difficulties in determining the ultimate pile resistance from the test data
- Some options:

$R_{ult} = R_{test,\ max}$	$R_{ult} = R_{test,\ \Delta = 10\%\ Dia}$	$R_{ult} = R_{extrapolation\ to\ \infty}$

- This is an area that PT4 may need some guidance from WG3/TG3

Pile Design By Testing

- Design by pile testing is reliable under certain circumstances
- BUT difficulties can arise due to:
  - Large variations in ground geometry
  - Variations in pile loads
  - Changes in vertical effective stress after testing
  - Ground heave or negative shaft friction

- To deal with these, the Designer needs to revert to **calculation**

Design Approach and Factors

- Currently, there are very big differences across Europe in the choice of Design Approach, model, correlation and resistance factors adopted for pile design
- PT4 have a major difficulty here in meeting the requirement to harmonise and simplify
- Recommendations from PT1/PT2 are to adopt the resistance factor approach [RFA] for pile design
- Whatever PT4 recommend, they must be inclusive of all methods currently being used

Pile Design By Calculation

- The design resistances $R_{c;d}$ or $R_{t;d}$ are obtained from the characteristic end bearing and shaft friction by using partial resistance factors

$$R_{c;d} = \left[\frac{R_{b;k}}{\gamma_b} + \frac{R_{s;k}}{\gamma_s}\right] \text{ or } \left[\frac{R_{c;k}}{\gamma_t}\right] \qquad R_{c;k} = R_{b;k} + R_{s;k}$$

- PT4 need guidance on values for γ
- Can values be simplified, or extended?
- UK use different values dependent on amount of load testing

Pile Design From Static Load Tests

- The characteristic resistance is obtained directly from static load testing by applying correlation factors ξ using the following

$$R_{c;k} = \text{Min}\left[\frac{\text{Mean } R_{c;m}}{\xi_1}\right] \text{ or } \left[\frac{\text{Minimum } R_{c;m}}{\xi_2}\right]$$

- The design resistance $R_{c;d}$ can then be obtained using partial resistance factors

$$R_{c;d} = \left[\frac{R_{c;k}}{\gamma_t}\right]$$

- PT4 need guidance on values for ξ

Pile Design From Dynamic Impact Tests

- The characteristic resistance can also be obtained from dynamic impact test data using the following similar relationship:

$$R_{c;k} = \text{Min}\left[\frac{\text{Mean } R_{c;m}}{\xi_5}\right] \text{ or } \left[\frac{\text{Minimum } R_{c;m}}{\xi_6}\right]$$

- An additional model factor γ_{Rd} is also required:
  - 0.85 when using signal matching (CAPWAP)
  - 1.10 when the test includes pile head displacement
  - 1.20 if no measurement of pile head displacement
- PT4 need guidance on values for ξ and γ_{Rd}

Pile Design From Ground Test Results

- The characteristic resistance can also be obtained from empirical relationships with ground test results (such as CPT) using the following similar relationship:

$$R_{c;k} = \text{Min}\left[\frac{\text{Mean } R_{c;cal}}{\xi_3}\right] \text{ or } \left[\frac{\text{Minimum } R_{c;cal}}{\xi_4}\right]$$

- Values for ξ_3 and ξ_4 depend on the number of ground test results with values decreasing as the number of profiles increases
- PT4 need guidance on values for ξ

Interface between WG3/TG3 and PT4

- PT4 can essentially ignore anything that WG3/TG3 says or recommends as there is no contractual linkage between the two
- BUT PT4 need to convince WG3/TG3 to accept any draft at the end of the process
- What I hope is that PT4 will work with WG3/TG3 [and the other task groups] and maintain some liaison throughout the process
- There are a large number of areas where WG3/TG3 could provide support to PT4

Key Issues to be included in the PT4 Draft

- Pile design by calculation as the primary pile design method
- Guidance on model factors
- Confirm values for resistance factors
  - But maintain different factors for different pile types
  - Different factors for different load test validation
  - Factors to consider settlement control
- Confirm values for correlation factors
- Recommendations must be inclusive of all current methods

Some Possible Discussion Topics 1

- Is it necessary to include derivation of shaft friction f_s and end bearing pressure q_b as informative annexes to EN 1997?
  - These can be via derived soil properties c', φ', Cu or UCS
  - Or by direct correlation from CPT q_c, SPT N_{60} or PMT p_L
  - Or by using experience [tables related to q_c or Cu]

- Surely these are well covered by text books, guidance documents, research papers and other NCCI

Some Possible Discussion Topics 2

- Should interpretation of static and dynamic pile load testing be included?
- Are simple rules such as load corresponding to a pile settlement equal to 10% of the diameter/size a reasonable definition?
- Or should we extrapolate to infinite movement as this is more mathematically correct?

Some Possible Discussion Topics 3

- Should horizontal loads on piles be designed using partial load and resistance factors, or is it better to treat as a serviceability problem using unfactored loads and parameters?
- Load factors would be applied to the effect of the actions

Some Possible Discussion Topics 4

- Should pile groups be designed using partial load and resistance factors, or is it better to treat large pile groups as a serviceability problem using unfactored loads and parameters?

- What are the difficulties in designing combined raft and pile foundations?

Some Possible Discussion Topics 5

- Should structural resistance of piles be covered by EN 1997 as this is not adequately dealt with by EN 1992?

- What are the difficulties in designing long slender piles to avoid buckling and bending problems in very soft ground?
- Do we need to adopt the MFA rather than RFA in this case?