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Dear Sir / Madam

JOINT BCA / IES / ACES / GEOSS CIRCULAR 2022

PERFORMANCE-BASED PILE DESIGN FOR BORED PILES: STREAMLINED APPROVAL PROCESS

BACKGROUND

1. The current practice of bored pile design involves the Design Qualified Person ("**QP(D)**") submitting one set of pile design prepared based on a set of assumed pile design parameters, for approval by the Commissioner of Building Control ("**CBC**"). The set of assumed pile design parameters will subsequently be verified by the performance of the Ultimate Load Tests ("**ULT**") conducted on site. Where the actual pile parameters obtained from the ULT are better than those used in the original approved design, project parties may optimise the pile design by submitting an amendment submission to adopt the better pile parameters. In such cases, the installation of working piles based on optimised pile parameters may proceed only after the amendment submission for the optimised parameters has been approved. Hence, the optimisation of pile design will only be applicable to the piles that have yet to be installed at the time the amendment submission is approved, and the full benefits of optimisation could not be reaped.

2. To maximise the optimisation of pile construction and to streamline the process for pile design approval, the Building and Construction Authority ("**BCA**") has taken initiative to form an industry working group comprising academia, government agencies, practitioners and members from *Institution of Engineers Singapore (IES)*, *Association of Consulting Engineers Singapore (ACES)* and *Geotechnical Society of Singapore (GeoSS),* to jointly develop guidelines on **Performance-Based Pile Design For Bored Piles**.

STREAMLINE PILING PLAN APPROVAL PROCESS

3. Under performance-based pile design, BCA allows the flexibility for QP(D) to submit more than one set of pile design and pile design parameters in a single submission for approval, for

projects adopting bored pile foundation, subject to verification by instrumented maintained ULT. **Appendix A** sets out the streamlined procedure for performance-based pile design.

4. For performance-based pile design approved by the CBC, QP(D) shall use the method of interpretation of pile load test results in **Appendix B** to verify the pile design parameters. QP(D) will then decide on the Design Set adopted, with concurrence of the Accredited Checker, and inform CBC through the form **Pile_PB_Annex B1.** After obtaining written approval from the CBC of the adopted design and pile design parameters, installation of working piles can commence on site. Under the performance-based pile design, pile optimization can be carried out on site without the need to wait for the approval to the amendment plan.

5. **Notwithstanding this Circular, all qualified persons must continue to exercise their engineering judgment and evaluation and take all reasonable steps and due diligence to ensure that the adoption of Performance-based pile design method will fulfil the objectives and performance requirements as stipulated in the *Fifth Schedule of the Building Control Regulations 2003* and comply with all relevant standards and codes of practice.**

6. Please disseminate the contents of this circular to your members. If you need any clarification, please contact us at tel. 1800 3425 222 or submit your enquiry through BCA's Online Feedback Form at https://www.bca.gov.sg/feedbackform/. Thank you.

Yours faithfully

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DIRECTOR, BUILDING ENGINEERING GROUP
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APPENDIX A – PROCEDURE OF PERFORMANCE-BASED PILE DESIGN FOR BORED PILES

The procedure for obtaining CBC's approval for performance-based pile design is summarized in the six stages in **Table A.1**. A comparison of the workflow of piling works between normal pile design and performance-based pile design is shown in **Fig. A.1**.

Table A.1: Procedure of performance-based pile design

Stage	Description
Stage 1: Submit pile design parameters and piling plan for approval	• QP(D) adopting the performance-based pile design for their projects can propose **more than one set** of probable pile design parameters, i.e., unit shaft friction, f_s and unit end bearing resistance, q_b, taking into consideration the ground condition, specified pile installation method, and workmanship of the proposed specialist builder. • QP(D) should arrange Design Set 1 as the most conservative design set, followed by less conservative set(s), with the last set being the most optimistic. • For each set of the proposed pile design parameters, QP(D) shall carry out the geotechnical design, prepare and submit the design calculations and drawings for approval in compliance with the requirements as stipulated under code or practices and Building Control Regulations 2003. QP(D) could use a separate sheet of drawing for each set of pile design parameters. • **QP(D) will be required to add the following note on the piling plan:** *"QP(D) shall verify the adopted pile design parameters by performing an ultimate load test ("**ULT**"). QP(D) shall submit the interpretation of the ULT results, administratively mark up on the drawings the adopted pile design based on the verified pile design parameters and obtain CBC's written approval before commencing the installation of working piles."* • A sample of the pile schedule format with more than one design sets is as shown in **Fig A.2**.

Stage	Description
Stage 2: Carry out ULT	• QP(D) should plan and design the ULT diligently to achieve the desired outcome of fully mobilizing both the pile shaft and base resistances for the purpose of substantiating the pile design parameters. • The ULT is recommended to be conducted based on the **most optimistic** set of pile design parameters, i.e., the shortest pile depth of all the design sets. *Refer to **Appendix C** on conducting the ULT effectively.* • If more than one ULT are carried out for a project, QP(D) must clearly identify in drawings the building works for which each ULT is performed. For example, identify that ULT No. 1 is performed for Zone No. 1, and ULT No. 2 is performed for Zone No. 2, at the project site.
Stage 3: Verify pile design parameters	• QP(D) shall: a) review the instrumented ULT results. b) prepare an interpretation report for the ULT using ONLY the pile load test interpretation approach detailed in Appendix B; and c) select the most appropriate set of design parameters that satisfy the allowable pile head settlements as stipulated in the Joint BCA / IES / ACES / GeoSS Circular on "Requirements on Ground Investigation, Load Test and Quality Control Test for Foundations" issued on 22 September 2016 ("**Piling Circular – 2016**"). • QP(D) shall strictly adopt only **one set** of pile design parameters for pile construction without mixing the values across different design sets. • Amendment ST submission will be required when: a) All the approved sets of pile design parameters are not verified by the ULT; or b) Further optimization of pile design is pursued (e.g., actual pile parameters verified by ULT are better than the most optimistic design set approved).
Stage 4: Obtain CBC's written approval to commence working pile installation	• Once the set of pile design parameters to be adopted for construction has been verified and subsequently selected by QP(D) with concurrence of AC, QP(D) shall submit the following to BCA via correspondence in respect of the approved piling ST submission and email to the BCA's officer: a) Form **Pile_PB_Annex B1** appending the ULT interpretation report, Form **Pile_PB_Annex B2** and ULT factual report; and b) Administratively mark-up drawings clearly showing the adopted pile design set for construction (See **Fig A.3** for sample).

Stage	Description
	• Written approval from CBC shall be obtained before the installation of working piles can commence on site. *Refer to **Appendix D** for the additions to the conditions of the Permit, which are applicable to projects adopting performance-based pile design.*
Stage 5: Working pile installation on site	QP(D) shall issue to the builder the documents listed in **Stage 4** to ensure that there is no miscommunication. Builder shall install the working piles according to the documents listed in **Stage 4**, under the supervision of Supervising Qualified Person ("QP(S)").
Stage 6: Submit as-built piling record plan	Within 28 days upon completion of piling works, QP(S) shall submit the as-built pile record plans together with the administratively mark-up drawings issued by QP(D) clearly showing the adopted pile design set for construction.

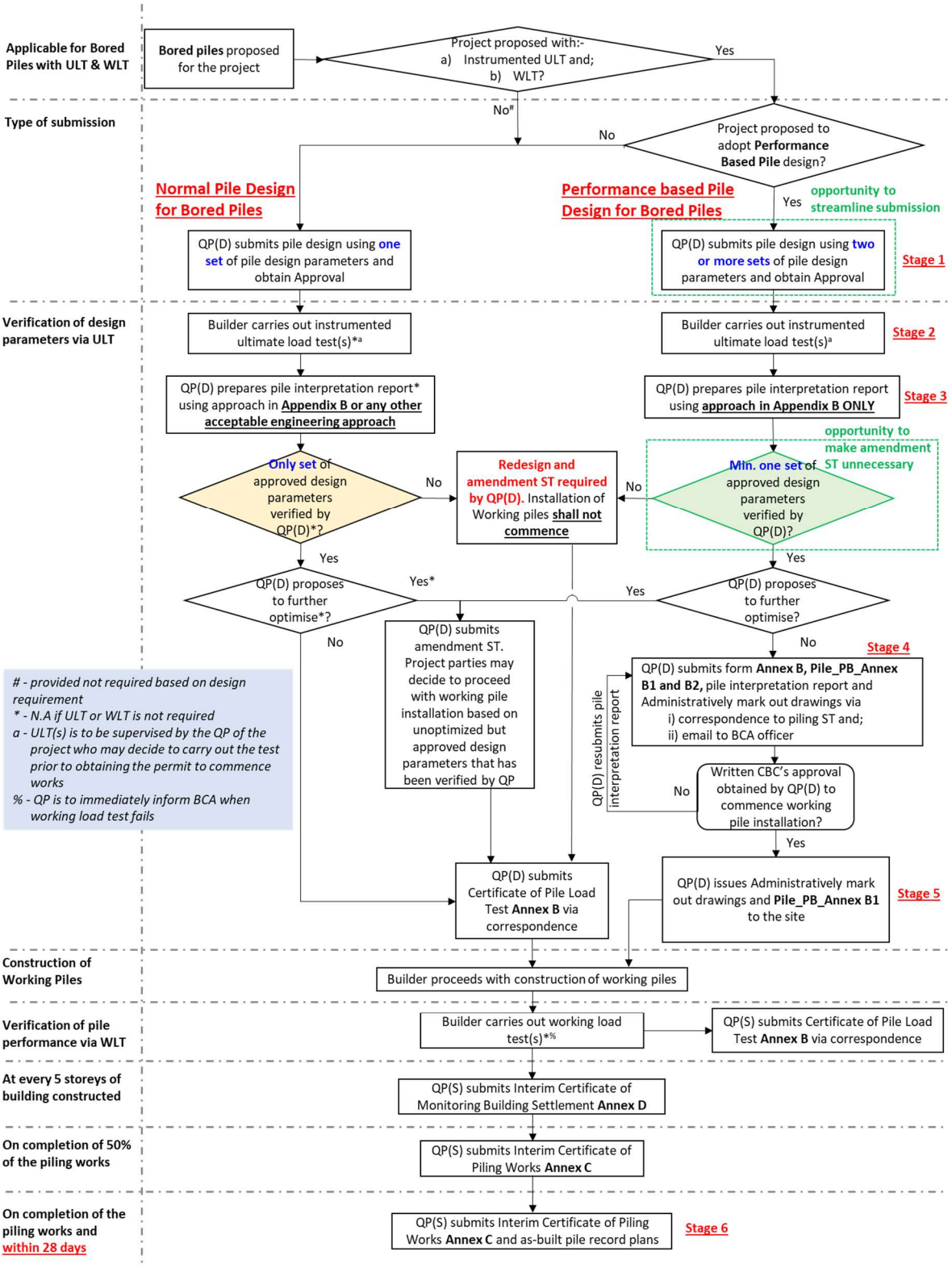

Fig A.1 *– Comparison of workflow of piling works between normal pile design and performance-based pile design*

Fig A.2 *– Sample of pile schedule showing 3 sets of pile design and parameters for project adopting performance-based pile design, submitted by QP(D)* ***for ST approval***

Fig A.3 *– Sample of administratively mark-up drawing showing the adopted set of pile design for i)* ***issuance to the site for construction*** *and ii) for* ***as-built piling record submission***

APPROVAL RECORDS FOR PERFORMANCE-BASED PILING WORKS

Project Ref: _____ **Structural Plan No.(s):** _____

Project Name: _____

This form is to be prepared, completed, and certified by QP(D) and QP(Geo)(D) (where applicable) for performance-based piling works. This form is to be submitted together with the ultimate load test ("**ULT**") interpretation report to the Commissioner of Building Control ("**CBC**") for review via 1) email and 2) correspondence in respect of the approved piling ST plans. Written approval from CBC via correspondence will be required before the installation of working piles on site can commence. The QP(S) and QP(Geo)(S) (where applicable) are required to keep a copy of the completed form and relevant supporting documents on site.

Section A: To be completed and certified by QP(D) and QP(Geo)(D) (where applicable)**, with interpretation report of ULT appended**

I / We# have assessed and reviewed the performance of the ultimate pile load test(s) adopting the method described in **Appendix B** of BCA's circular entitled **"Performance-Based Pile Design for Bored Piles"** dated 1 September 2022, and declare that: -

i) The ULT results have verified one set of the pile design parameters approved in the above listed structural plan(s) ("**Adopted Pile Design Parameters**");

ii) The Adopted Pile Design Parameters comply with the allowable pile head settlement as stipulated in BCA's circular "Requirements on Ground Investigation, load test and quality control test for foundations" dated 22 Sep 2016.

iii) I / We have clearly shown the Adopted Pile Design Parameters on the administratively mark-up piling plans, which will be issued to the builder appointed for the project; ***and***

iv) Working piles based on the Adopted Pile design Parameters can be constructed for the project, and such working piles are designed in compliance with all relevant performance requirements in the Fifth Schedule to the Building Control Regulations 2003.

Adopted Pile Design Parameters *(To type or paste part print below)*

_____ _____

Name, stamp & signature of QP(D)
Date: _____

Name, stamp & signature of QP(Geo)(D) (where applicable)
Date: _____

Section B: To be completed and certified by AC and AC(Geo) (where applicable)

I / We# have reviewed the ULT result(s), QP(D)'s / QP(Geo)(D)'s# interpretation report of the ULT and concur with the declarations set out in Section A above. Working piles based on the Adopted Pile Design Parameters can be constructed for the project, and such working piles are designed in compliance with all relevant performance requirements in the Fifth Schedule to the Building Control Regulations 2003.

_____ _____

Name, stamp & signature of AC
Date: _____

Name, stamp & signature of AC(Geo) (where applicable)
Date: _____

To delete as appropriate

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APPENDIX B – METHOD OF INTERPRETATION OF ULTIMATE PILE LOAD TEST RESULTS

1. Introduction

This Appendix presents an engineering interpretation method using the measured pile load settlement response of an instrumented maintained ULT to derive the appropriate unit shaft resistance f_s and unit end bearing resistance q_b for pile design. QP(D) can consider using this method for ULT that is carried out by static maintained load test, or calibrated rapid load tests. For ULT conducted using bi-directional load tests, QP(D) is to exercise caution so as not to use the extrapolated portion of the equivalent load settlement curve generated at pile head, and with proper consideration of the elastic compression of the pile.

The salient principles considered when adopting this interpretation method are : (1) Load settlement response of a pile shall not be extrapolated due to its nonlinear nature, which means that the maximum test load of the ULT should be large enough to generate the required pile settlement performance; and (2) The f_s and q_b values that have been mobilised in pile load test may have to be reduced for adoption in design to satisfy the allowable pile head settlement as stipulated in the **Piling Circular – 2016**.

2. An engineering method to interpret pile design parameters

2.1 The objective of this interpretation method is to determine a set of appropriate f_s and q_b values, from the instrumented ULT, that meets the serviceability limit criteria for the design of working piles. It is to be based on the measured load-settlement curve of ULT, without any extrapolation.

2.2 The serviceability limit requirement on allowable pile head settlement as stipulated in the **Piling Circular – 2016** shall be complied.

2.3 The ultimate test pile needs to be fully instrumented with strain gauges along the pile shaft as well as near the pile toe to enable the measurement of strain at various pile depth intervals for derivation of f_s and q_b values.

2.4 The ultimate test pile depth is calculated in accordance with Eurocode 7 based on the initially assumed f_s and q_b values ("f_{s1}", "q_{b1}") and its originally assumed working load ("*WL1*"). The working load ("*WL*") is the sum of characteristic permanent action G_k and characteristic variable action Q_k. The installed ULT pile depth should not be larger than this calculated pile depth. Otherwise, the chance to mobilise the initially assumed f_s and q_b values is greatly reduced, diminishing the usefulness of the ULT test. If the ULT results show that the serviceability limit requirements in clause 2.2 are satisfactory, QP(D) can consider adopting the initially assumed value of f_{s1}, q_{b1} for working pile design.

2.5 In this proposed interpretation method, when larger values of f_s and q_b ("f_{s2}", "q_{b2}") than the initially assumed f_s and q_b are mobilised in the ULT test, then a larger magnitude of working load ("*WL2*") than *WL1* can be back calculated based on Eurocode 7. If the settlement at 1.5 x *WL2* or 2 x *WL2* is within the acceptable limit, it is considered that f_{s2} and q_{b2} are verified and can be adopted for working pile design.

2.6 On the other hand, when smaller values of f_s or q_b ("f_{s3}", "q_{b3}") than the initially assumed f_s and q_b are mobilised in the ULT test, then a smaller magnitude of working load ("*WL3*") than *WL1* will be back calculated based on Eurocode 7. If the settlement at 1.5 x *WL3* or 2 x *WL3* is within the acceptable limit, it is considered that f_{s3} and q_{b3} are verified and can be adopted for working pile design.

2.7 The proposed interpretation method of pile load test involves 4 steps, that are described in Table B.1 below. To standardize the procedure of the interpretation of ULT, QP(D) is to fill **Pile_PB_Annex B2** form which documents the interpretation process to determine the appropriate f_s and q_b values for pile design and submit it together with the ULT interpretation report.

2.8 Limitation of applicability of the interpreted pile design parameters.
Although the interpreted f_s and q_b values from the steps above have taken into consideration the serviceability limit of that ULT pile, the application of these interpreted parameters to the design of working piles may still be affected by factors such as pile size, magnitude of working load, etc. Therefore, QP(D) should exercise caution with the f_s and q_b values to be adopted in design especially when the working piles are of different size, shape, or depth from the ULT pile.

Table B.1: Procedure to interpret pile design parameters from ULT results

Step 1: Extract representative mobilized f_s and q_b values from ULT test and calculate total shaft friction ("F_s") *and total end bearing resistance ("Q_b")*

QP(D) should assess the data in the ULT test report and verify (a) the representative f_s for each layer of soil; and (b) the mobilized q_b. For the first trial, QP(D) can choose the f_s and q_b values mobilised at the maximum applied test load point. Based on these f_s and q_b values, QP(D) will compute F_s and Q_b, and verify that the sum of F_s and Q_b is equal to the test load applied for this point.

When correlating representative unit skin friction f_s to SPT N value for each type of soil using empirical relationship $f_s = K_s$ N, conservative value should be adopted for the coefficient K_s, unless weighted average value is justifiable.

Step 2: Calculate the *WL* based on F_s and Q_b obtained in Step 1

Based on the calculated F_s and Q_b in step 1, the corresponding *WL* (*WL* = G_k+Q_k) that the test pile can take, can be calculated, using the two equations (1) and (2) below, and the same partial resistance factors (γ_s and γ_b) and model factor (γ_m) to be used for the working pile design.

G_k+1.3Q_k = (F_s/γ_s+Q_b/ γ_b)/ γ_m (1)

Project specific ratio between G_k and Q_k (2)

Equations (1) & (2) are in accordance with geotechnical design of Eurocode 7.

Step 3: Review pile head settlement at $1.5 \times WL$ or $2.0 \times WL$

Check the magnitude pile head settlement at $1.5 \times WL$ and/or $2.0 \times WL$ based on load settlement curve measured at pile head from the ultimate load test.

Step 4: Iteration of steps 1 to 3 using f_s and q_b extracted at a smaller test load

If pile head settlement is within the limit stipulated in **Piling Circular – 2016**, the verified f_s and q_b in step 1 can be used as pile design parameters. Otherwise, a lower set of f_s and q_b values which will correspond to a lower *WL* shall be considered such that the serviceability limit can be met. This is done by repeating Step 1 to Step 3 using a lower set of f_s and q_b values which are mobilised at a lower applied test load in ULT.

Figure B.1 gives an illustration of the steps in the interpretation of ultimate load test. Step 1 to Step 3 should be repeated until a suitable set of f_s and q_b are determined.

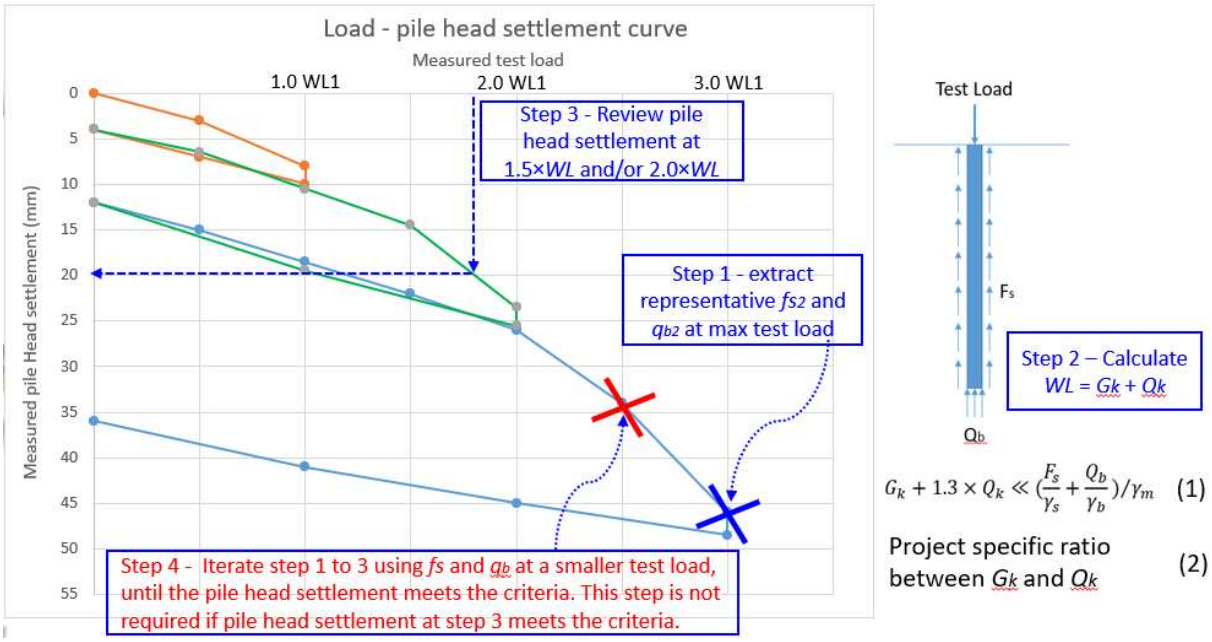

Figure B.1 Steps in interpretation of ultimate load test results

3. Caution on adoption of q_b value that is not mobilised in ULT test

3.1 If an ULT is properly planned, designed, and implemented, it should be able to mobilise the initially assumed f_s and q_b values. If the initially assumed f_s and q_b values are conservative, there is a chance of achieving design optimisation after the test. On the other hand, if the initially assumed f_s and q_b values are too optimistic, there is a possibility that the initially assumed f_s and q_b values need to be downgraded.

3.2 In principle, only mobilized f_s and q_b from ULT should be adopted when optimization of pile design is proposed. Nevertheless, considering that end bearing may not be adequately mobilized in ULT when the test pile is over designed that resulted in very small pile settlement, QP(D) may consider a reasonable but still conservative q_b value based on industry norm when the following minimum conditions are satisfied:

(i) the pile head settlement is checked to comply with the allowable limits at both $1.5 \times WL$ and $2.0 \times WL$ based on measured load-settlement curve of ULT.
(ii) the computed $2.0 \times WL$ is within the measured load-settlement curve of ULT.
(iii) ULT test results show that the mobilised q_b value has not reached ultimate limit state yet.

If QP(D) decides to adopt the assumed q_b which is not mobilised in the ULT test, the validity of the assumed q_b value is to be carefully assessed with sound engineering judgement, supported by past experience of similar piles in similar ground conditions.

INTEPRETATION OF ULTIMATE LOAD TEST — Pile_PB_Annex B2

This form is to be prepared and submitted by QP(D) and QP(Geo)(D) (where applicable) and included in the ultimate load test ("**ULT**") interpretation report of each ULT carried out for a project. It should be submitted together with Annex B form "Certificate of Supervision on Pile Load Test" in Piling Advice Letter.

Project Ref:		**Structural Plan No.(s):**	
Project Name:			

Test Pile Details

Pile Diameter (mm)	Designed *WL1* (kN)	Max Test Load (kN)	Design Pile Length (m)	Constructed Pile Length (m)

Step 1: Extract representative mobilized f_s and q_b values from ULT test and calculate F_s and Q_b

a) Refer to clause 2.4 of Appendix B, if initially assumed f_{s1} and q_{b1} are adopted.
b) Refer to clause 3.2 of Appendix B, if adopted q_b is not mobilized in ULT.
c) For other cases, either mobilized f_s and q_b at max test load, or intermediate test load should be adopted.
d) QP(D) may attach separate calculation of F_s and Q_b.

Soil Layer	Soil Type	Top Level (SHD)	Thickness (m)	SPT N value	Initially assumed f_s & q_b		Mobilized f_s & q_b		Adopted f_s & q_b	
					f_{s1}	q_{b1}	f_s	q_b	f_s	q_b
1										
2										
3										
4										
5										
6										
7										
			Total end bearing (kN)	Q_b =						
			Total shaft friction (kN)	F_s =						
			Total geo resistance (kN)	$F_s + Q_b$ =						

Step 2: Calculate the *WL* based on F_s and Q_b obtained in Step 1

				Initially assumed f_s & q_b	Mobilized f_s & q_b	Adopted f_s & q_b
Equations (1) and (2)			G_k =			
(1) $G_k + 1.3Q_k = (F_s/\gamma_s + Q_b/\gamma_b)/MF$			Q_k =			
γ_s	γ_b	*MF*	$WL = G_k + Q_k$ =			
e.g. 1.4	e.g. 1.7	e.g. 1.35	$1.5 \times WL$ =			
(2) G_k/Q_k =			$2.0 \times WL$ =			

Steps 3: Review pile head settlement at 1.5 × *WL* and/or 2.0 × *WL* for adopted f_s & q_b, based on measured load settlement curve

Plot measured pile-load settlement curve here

For the adopted f_s and q_b,

(1) If both f_s and q_b are mobilized, is pile head settlement at $1.5 \times WL \leq 15$ mm, **OR** at $2.0 \times WL \leq 25$ mm?
(Yes / No / Not Applicable) *

(2) If adopted q_b is not mobilized, is pile head settlement **BOTH** at $1.5 \times WL \leq 15$ mm, **AND** at $2.0 \times WL \leq 25$ mm?
(Yes / No / Not Applicable) *

* To delete as appropriate

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THE INSTITUTION OF ENGINEERS SINGAPORE

APPENDIX C – CONDUCTING ULTIMATE LOAD TEST TO ACHIEVE DESIGN VERIFICATION AND OPTIMISATION

1. Importance of planning and designing of ULT

In order to reap the maximum benefits from the conduct of ultimate pile load test, pile designers should plan and design the test in such a way that the test:

a) can adequately mobilise the shaft resistance of every soil layer along the pile shaft and the base resistance in either competent soil or bedrock, depending on the socketing criteria of the project, and

b) enables the pile head settlement performance to be investigated at a load large enough to enable the potential optimisation of pile design parameters using the deem to satisfy method as described in **Appendix B** of this circular.

2. Tips on conduct of ULT

Over-conservative estimation of f_s and q_b prevents the shaft and end bearing resistances of the pile from being adequately mobilised in the test. In such circumstance, the ultimate load test will not be able to substantiate the parameters assumed for the design and therefore does not serve its original purpose.

On the other hand, over-optimistic estimate of f_s and q_b values may lead to shorter test pile depth, thus not validating the design parameters of the deeper layer of soil that the working piles will be socketed into.

The following aspects could be considered in the planning and design of ultimate pile load test with consideration of the workmanship expected and installation method adopted for the project:

a) Design the test pile based on the upper bound best estimates of f_s and q_b values to enable the mobilisation of shaft and base resistances. Doing so will result in a shorter ULT pile depth, and hence boosting the chance of mobilising larger values of shaft and base resistances.

b) Increase the test load as much as possible as long as it is within the structural capacity of the test pile. Clause 7.5.2.1(1) of Eurocode 7 requires that for trial piles, loading shall be such that conclusions can be drawn about the ultimate failure load. Clause A.3.3.2 of Singapore National Annex to Eurocode 7 requires the resistance to be verified by a maintained load test taken to the calculated, unfactored ultimate resistance. In any case, the ULT test load should be minimally $F_s + Q_b$.

c) Shorten the socketing depth within similar rock layer to achieve a higher mobilisation of rock friction and end bearing resistance in rock.

d) Debond the upper portion of the pile to enable the maximum mobilisation of pile resistance at lower soil layers, which normally contributes to the majority of pile geotechnical capacity.

e) Consider to purposely create a “very soft” pile toe to enable the maximum mobilisation of shaft resistance, if useful.

f) Review the design of subsequent ultimate pile load tests, if any, to validate the proposed changes in pile design parameters based on the interpreted results of the earlier ULT test.

g) Avoid installing the ULT test pile longer than the designed depth, as this will (i) lead to a smaller mobilised shaft and end bearing resistances in the test, and (ii) make the installed pile not representative of the original ULT pile design.

Building and Construction Authority

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APPENDIX D – Amendments to Conditions of Permit (For Information)

1.1 Project parties shall take note of the following amendments to the Conditions of Permit that are underlined, which are applicable to projects adopting Performance-Based Pile Design for Bored Pile:

Piling

2. The Builder shall install adequate vibration monitoring devices before starting any piling works. In carrying out the piling works, the Builder shall implement precautionary measures to prevent excessive vibrations or damage to neighbouring properties.

2A. Where building works in the Project are carried out adopting performance-based pile design for bored piles:

the Design QP:

a) shall submit the interpretation report of the ultimate load test carried out for the project and the required documents as specified in the Circular "PERFORMANCE-BASED PILE DESIGN FOR BORED PILES" confirming a set of the approved pile design parameters has been verified, to obtain a written approval from the Commissioner of Building Control before starting any piling works.

the Builder and Supervising QP:

b) shall ensure that piling works do not commence until a written confirmation from the Commissioner of Building Control has been obtained.