Building and Construction Authority
An MND Statutory Board

In Collaboration With

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Dear Sir / Madam

JOINT BCA / IES / ACES / GEOSS CIRCULAR 2024

REQUIREMENTS AND GUIDELINES FOR DESIGN AND CONSTRUCTION OF RAFT AND PILED-RAFT FOUNDATION

Objective

This circular is to inform the industry on the requirements for the design and construction of raft or piled-raft as foundation system for building works in Singapore. The circular aims to provide a framework based on risk-based approach in stipulating the requirements for the design and construction of raft and piled-raft foundation, after a thorough feasibility study and impact assessment conducted by the Engineers to ascertain the suitability for their projects, in order to achieve safe and robust foundation system for the buildings.

Background

2. Raft or piled-raft founded on competent ground can provide cost effective solution for high-rise buildings or infrastructures when properly designed and constructed. Before adopting these foundation systems, proper characterisation of the subsurface geological conditions is of critical importance and has to be thoroughly carried out to ascertain their feasibility. The current provisions in codes and guideline caters mainly for conventional foundation using piles but there is limited guidance on the soil investigation, design, construction control and monitoring of foundation using raft or piled-raft system.

3. To supplement EC7's coverage on this subject matter customised to local condition to enable their safe adoption, the Building and Construction Authority ("**BCA**") has taken the 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 this circular on **Requirements and Guidelines For Design And Construction Of Raft And Piled-Raft Foundation**.

4. The joint industry workgroup has reviewed overseas practices, existing literatures, past projects in local ground conditions and consulted industry practitioners before finalising the requirements and guidelines in **Annex A** and **Annex B**. Annex A describes the classification of buildings into high, medium and low risk categories. Annex B stipulates the design and construction requirements for the various risk categories.

5. These requirements and guidelines on the use of raft or piled raft foundation shall be complied with when making structural plan submissions to the Commissioner of Building Control. This will take effect for a project with the first structural plan submitted on or after the date of this circular.

6. **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 use of Raft or Piled-Raft foundation 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. Where applicable, QPs are expected to incorporate more stringent and/or additional requirements when the circumstances at hand is complicated or the ground condition is highly variable and complex geologically.**

7. Please disseminate the contents of this circular to your members. If you need any clarification, please contact us at tel. 1800-3425222 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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Professionals in charge of each project are strictly advised to do an independent assessment and verification to determine if the information provided in this guide is adequate and sufficient for the needs of their project.

Nothing contained in this guide is meant to replace or negate the need to comply with the provisions of the Building Control Act and building regulations in all aspects. QPs are to note that they have duties under the Building Control Act, amongst others, to take all reasonable steps and exercise due diligence to ensure that building works are designed in accordance with the provisions of the Building Control Act and building regulations.

JOINT BCA / IES / ACES / GEOSS CIRCULAR **ANNEX A**

REQUIREMENTS AND GUIDELINES FOR DESIGN AND CONSTRUCTION OF RAFT AND PILED-RAFT FOUNDATION

Building and Construction Authority

In Collaboration With

DATE OF ISSUANCE: 02 SEPTEMBER 2024

ANNEX A – CLASSIFICATION OF BUILDINGS SUPPORTED ON RAFT AND PILED-RAFT FOUNDATION

Risk Category		
Low	**Medium**	**High**
• Projects classified under Geotechnical Class 1 [Note 1] (e.g. Landed projects on shallow foundation in firm residual soil, single storey sheds, minor road side drains, linkway, etc); or • All buildings that are 3 storeys or less (excluding basement) founded on competent ground	• Projects classified under Geotechnical Class 2 [Note 1]; or • All buildings that are 4 to 9 storeys inclusive (excluding basement); or • Underground structures satisfying criterion in Note 2	• Projects classified under Geotechnical Class 3 [Note 1]; or • All buildings that are 10 storeys or more (excluding basement); or • Major infrastructure projects, like viaduct and bridges

Note 1: Guide on Ground Investigation And Geotechnical Characteristics Values To Eurocode 7 Published By GeoSS (2015)

Note 2: Underground structures where sum of its weight and imposed loads is less than or equal to the weight of soil removed for its construction at founding level may be classified as Medium risk.

Note 3: All buildings with piles are classified as Geotechnical Class 2 [Note 1] or higher.

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ANNEX B – REQUIREMENTS AND GUIDELINES FOR DESIGN AND CONSTRUCTION OF RAFT AND PILED-RAFT FOUNDATION

1.1 Definition of Raft and Piled-Raft

1.1.1 Raft foundation, also called mat foundation, is essentially a continuous slab resting on the soil that extends over the entire footprint of the building, to distribute the building load evenly over a large area of the supporting ground, such that the ground has adequate geotechnical bearing resistance to resist building loads with acceptable settlement and differential settlement limits.

1.1.2 Piled raft is a hybrid foundation comprising both a raft and piles, and allows for load sharing between the raft and piles. In piled-raft foundation, the applied loads are transferred to the supporting ground through the raft as well as the piles via the complex interactions between piles, raft and soil. Geotechnical bearing resistance of piled-raft foundation is contributed by both the raft and the connected piles; with the load sharing between the raft and piles required to be evaluated and established by the Qualified Person. For an effective application of piled-raft foundation, the raft of a piled-raft foundation should be founded on competent ground.

1.1.3 The requirements presented in the following sections shall be considered in design and construction of raft and piled-raft foundation.

1.2 Suitability of Ground for Raft and Piled-Raft

1.2.1 Raft and piled-raft should be founded on competent ground which can provide adequate resistances and stiffness in satisfying both ultimate (e.g. bearing, sliding, overturning resistances etc.) and serviceability (e.g. settlement, differential settlement and tilt) limit state requirements prescribed in prevailing codes of practices and BCA's circulars.

1.2.2 The following ground types are NOT suitable for raft or piled-raft foundation:

a) Soil profiles consisting soft compressible layers or loose sand of the Jalan Besar, Rochor Clay, Tanjong Rhu Clay or Kranji Formations, etc. existing beneath or within pressure bulb of the raft or piled-raft. If unsuitable ground types are present within the pressure bulb, the piles should generally be designed to support the full structural load without considering the raft. Depth of this pressure bulb is normally taken as minimum 3 times the width of the raft below its founding level.

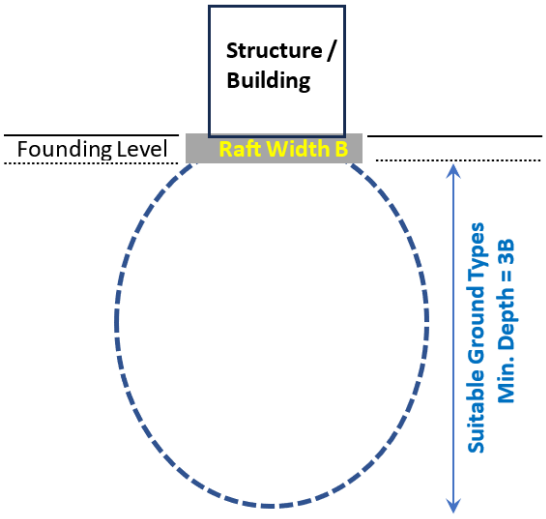
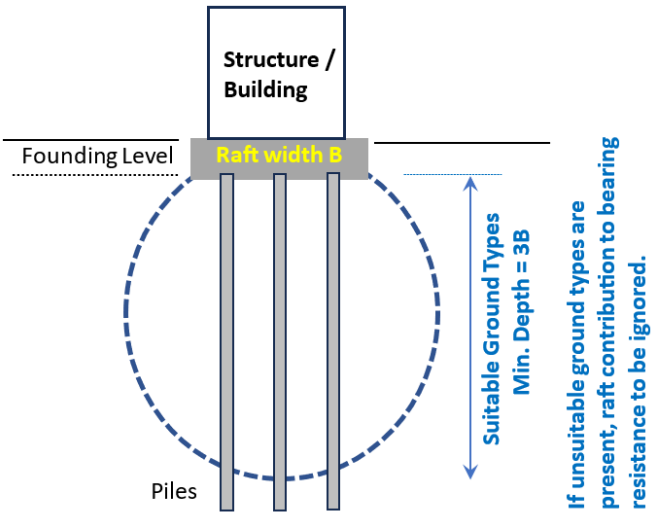
b) Soil profiles that are likely to undergo primary and secondary consolidation settlements due to dewatering and topping up of ground level by backfilling that leads to change in effective stress or shrinking of active clay soil.

1.2.3 Ground types suitable for raft and piled-raft foundation for building of 10 storey or higher shall minimally be hard soil below the founding level. See reference (d) in Section 1.8 for definition of hard soil.

1.2.4 Where localized pockets of soft soils are found to be present, the exact extent need to be accurately explored and mapped out, modelled using three-dimensional Finite Element Method (FEM) and analysed using advanced soil model to have negligible impact on the required performance of the foundation throughout its design life.

Figure 1 gives an illustration of the pressure bulb to determine the suitability of ground for raft and piled raft.

Figure 1 Determination of Suitability of Ground types

Suitable ground type for Raft	Suitable ground type for Piled-Raft
	

1.3 Feasibility Study and Impact Assessment

1.3.1 Raft and piled-raft foundation increases both vertical and lateral stresses in the underlying ground, and causes ground movement both in the vertical and lateral directions below and around its footprint. Under 5th Schedule of Building Control Regulation, the proposed foundation system shall be designed and constructed such that it will not cause ground movement, during construction and during its entire service life, that will impair the stability of or cause damage to adjacent buildings, structures, property, building works, slopes, etc.

1.3.2 In this regard, QP shall evaluate the feasibility of adopting raft foundation for any project considering the underlying geological and hydrogeological conditions and likely impact onto buildings, structures, property, building works, slopes that are adjacent or in close proximity. An impact assessment justifying the suitability of adopting raft foundation without posing any adverse effect on adjacent structures and their foundations shall be submitted during plan submission to BCA as required by Building Control Regulation 33.

1.4 Site Investigation and Testing Regime Prior to Design

1.4.1 Adequate site investigation shall be carried out to provide sufficient data, especially on the ground strength and deformation modulus parameters, to derive the characteristic values of these parameters appropriate for the adopted constitutive soil model. In addition, the site investigation shall be planned to delineate each geo-stratum and establish its variabilities accurately.

1.4.2 The proposed boreholes to characterise the soil stratifications below the raft and piled-raft shall comply with requirements in **Table A** according to risk categories of the buildings and structures.

Table A : Borehole Requirement for Raft and Piled-raft

	Low Risk	Medium Risk	High Risk
Number of boreholes, density and spacing	Refer to GeoSS Guidelines	• For raft: Minimum 1 Borehole (BH) per 200m^2 of raft footprint area • For piled-raft: Minimum 1 BH per 300m^2 of piled-raft footprint area **Subject to**: • Minimum 4 BHs per raft or piled-raft • BH spacing[Note 2] between 15m and 40m, depending on ground variability and geological complexity	• For raft: Minimum 1 Borehole (BH) per 150m^2 of raft footprint area • For piled-raft: Minimum 1 BH per 250m^2 of piled-raft footprint area **Subject to**: • Minimum 5 BHs per raft or piled-raft • BH spacing[Note 2] between 10m and 25m, depending on ground variability and geological complexity

	Low Risk	Medium Risk	High Risk
Borehole investigation depth	Refer to GeoSS Guidelines	Same as High Risk	a) For raft, minimum 1.5 x width of raft [Note 5] below its founding level b) For piled-raft, in addition to (a), depth of borehole shall be greater of: i) 5m into hard stratum with SPT N $\geq$ 100; and ii) 3 x the pile diameter beyond the intended pile toe termination depth; and iii) 1 x b_g [Note 6] below pile toe. QP may adopt average or maximum pile lengths, if assessed to be reasonable.

Note:

1) Reference from BCA (2016) Circular, EC7 and Guide on Ground Investigation and Geotechnical Characteristics Values to Eurocode 7 published By GeoSS (2015)

2) The upper bound spacing should only be adopted when soil stratification is quite uniform with little variation.

3) If adjacent buildings/structures/utilities are within 1 time the raft's width from the raft edge, adequate ground investigation at raft's perimeter, wherever possible, needs to be carried out for impact assessment purpose. This is applicable to all sides of raft with adjacent buildings/structures/utilities in close proximity to the raft or piled-raft.

4) For a raft supporting 2 or more building blocks or structures with different risk categories, the requirements of the more onerous risk categories shall be followed for the entire raft.

5) Minimum 2 and 1 number of boreholes per raft or piled-raft respectively for High and Medium risk categories to have investigation depth of 3 times the width of raft below founding level to ensure that the geological conditions within pressure bulb is adequately investigated. This requirement may not be required if:
   (a) substantiated by QP for cases where significant competent rock stratum is encountered within a depth of 1.5 times the width of raft below its founding level;
   (b) assessed so by QP for fully underground structures such as tunnels and MRT station

6) b_g is width of smaller side of the rectangle circumscribing the group of piles forming the foundation at level of piles' toe.

1.4.3 The proposed ground testing regime for each soil stratum below founding level of raft and piled-raft shall comply with requirements in **Table B** according to risk categories of buildings and structures.

Table B : Soil/Ground Test Requirement for Each Soil Stratum below Founding Level of Raft/Piled raft

Type of Tests	Low Risk	Medium Risk	High Risk
Derivation of Strength Parameters			
Triaxial, Unconfined compression test, pressuremeter test, etc	Refer to Guide on Ground Investigation And Geotechnical Characteristics Values To Eurocode 7 Published By GeoSS (2015)		
Derivation of Deformation Moduli Note: For raft or piled-raft founded on ground subjected to past unloading activities such as demolition or excavation, etc; it is recommended to conduct pressuremeter test to determine the ground deformation moduli.			
Pressuremeter test (PMT)	QP to determine	Same as High Risk	a) Minimum 1 test for each soil type / weathering grade for all boreholes under this category b) Test may be carried out within a depth of 1 time raft's width below founding level if assessed to be sufficient by QP
Plate load test	Greater of • Min. 2 tests per 100m^2 part thereof • Min. 3 tests per project site		

1.5 Analysis and Design

General requirements for raft and piled-raft

1.5.1 QP shall evaluate the adequacy of geotechnical bearing resistance of the proposed raft and piled-raft foundation using Eurocode to satisfy the ultimate limit state (ULS).

1.5.2 QP shall also assess raft and piled-raft behaviour in terms of settlement, differential settlement and induced forces, which are influenced by its interaction with the underlying ground under the imposed loadings.

1.5.3 For realistic consideration of this soil-structure interaction satisfying serviceability limit state, QP shall perform the geotechnical analysis based on the risk categories of buildings and structures as shown in **Table C**.

1.5.4 For buildings classified as high risk,

- Three-dimensional geotechnical finite element (FE) analyses are required to replicate the actual subsoil layers according to borehole information, particularly for areas with undulating and erratic soil stratum to enable realistic estimation of total and differential settlements;

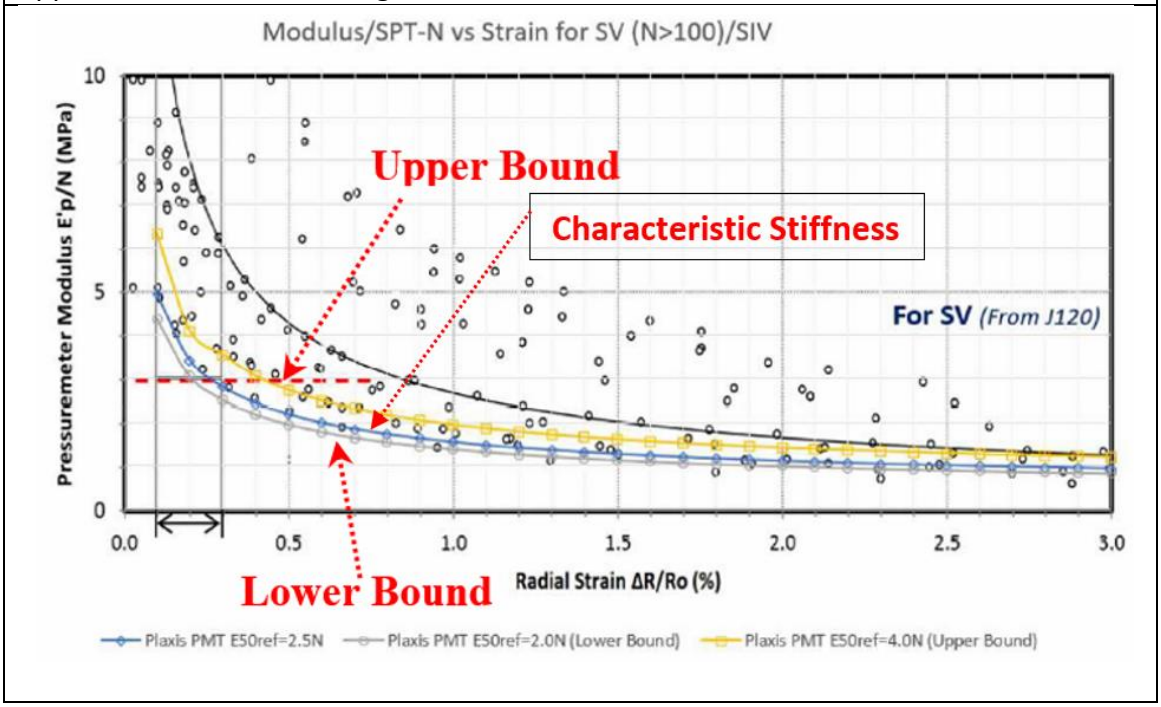
- It is required to adopt advanced constitutive soil models that are capable of modelling the non-linear, stress-dependent, strain-dependent and inelastic behaviour of real soil. One example is the Hardening Soil Model calibrated to local soil conditions. During submission, QPs are to submit details on derivation of the required characteristic soil parameters for such advanced soil models, substantiated by calibration of numerical parameters with field and/or laboratory tests results.

Table C : Constitutive Soil Model and Methodology Required for Geotechnical Analysis of Raft and Piled-raft

Item	Low Risk	Medium Risk	High Risk
Constitutive Soil Model	QP to determine	QP to determine (For ground that had been subjected to past unloading activities, advanced soil model is required)	Advanced soil model
Methodology of geotechnical analysis	QP to determine	2D or 3D FEM (2D FEM analyses suitable if QP assessed that geometry is regular, loading conditions & ground stratifications are uniform)	3D FEM

1.5.5 Raft or piled-raft shall be analysed and designed for variations in deformation modulus of the underlying ground by adopting upper and lower bounds and characteristic values of the deformation modulus established in Section 1.4

Figure 2 Example of selection of strain dependent ground stiffness from PMT results at upper and lower bound ranges and characteristic values



1.5.6 Raft and piled-raft shall be analysed and designed for the actions from columns and core walls for various possible load combinations of vertical and lateral loads acting on the superstructures occurring during their design life span as well as uplift from buoyancy effects, loads and reactions from the ground, in accordance with Eurocodes requirements.

Particular requirement for raft:

1.5.7 When structural program is used to analyse and perform structural design of the raft slab, the subgrade modulus (Winkler Springs) used in the structural program is to be determined iteratively with geotechnical soil structure interaction software until the required convergence is achieved. Refer to **Figure 3** for the flow-chart showing the iterative procedure.

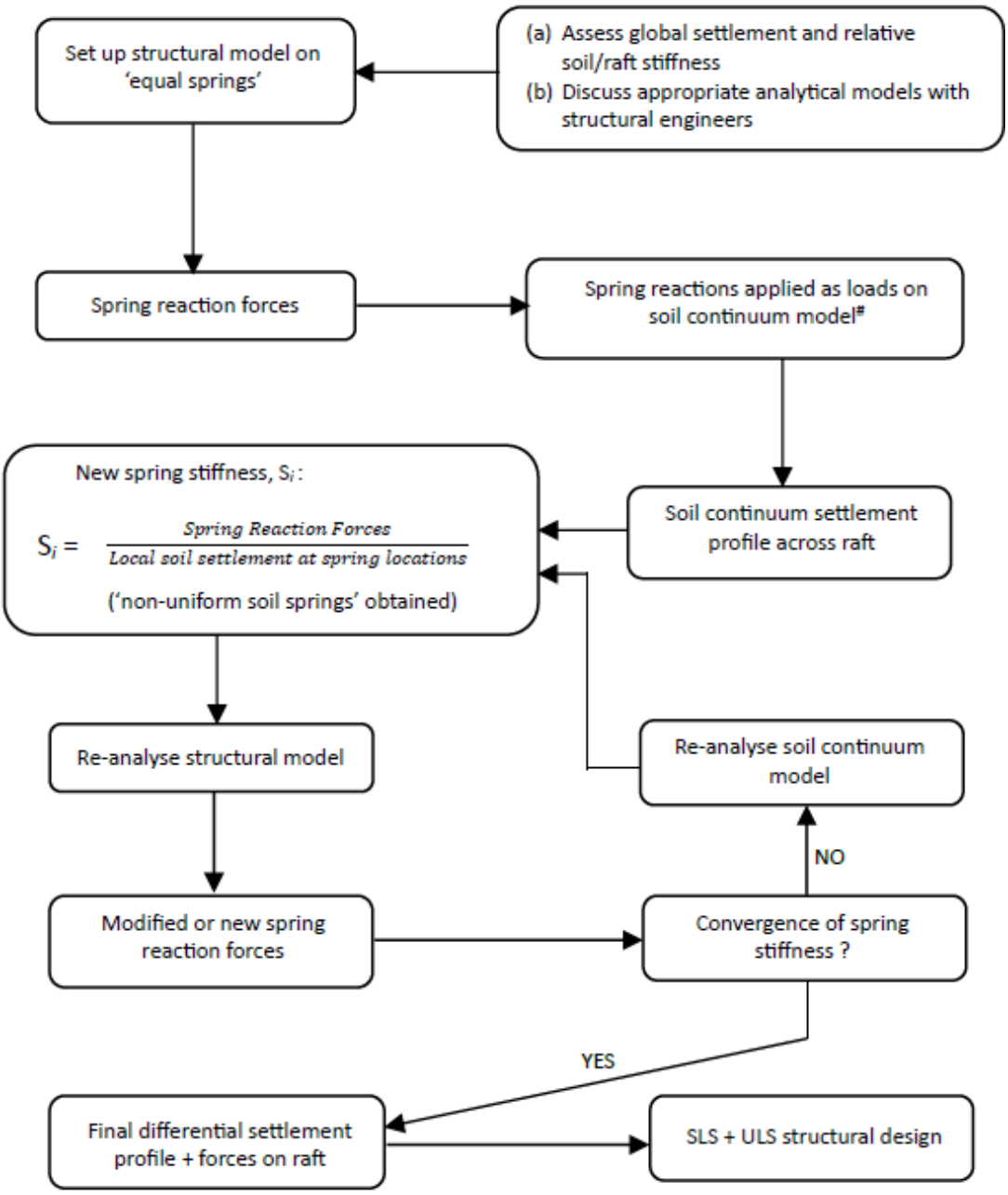
Particular requirement for Piled-raft:

1.5.8 In achieving the ULS requirement, QP shall specify on plan an assumed ratio of pile and raft load distribution that could satisfy the SLS performance requirement of the proposed foundation as stipulated in Para 1.7.

1.5.9 In addition, the actual piles' length, as estimated from the assumed ratio of pile and raft load distribution, should be modelled with interface elements to simulate the interaction

at pile-soil interface. The appropriate pile design parameters of shaft friction and end bearing resistances shall be verified by pile load tests.

Figure 3 Flowchart showing the iterative procedure to determine the structural forces in raft
Adapted from reference (e) in Section 1.8



- Soil continuum model refers to geotechnical soil structure interaction type of analyses where constitutive model is used to simulate the soil behaviour.

1.6 Construction and Supervision

Particular requirements for raft and piled-raft:

1.6.1 The underlying ground at founding level of raft or piled-raft could be weakened/softened by construction activities, exposure to weathering conditions (eg. soil weakening due to ponding of rainwater or cracks in soils due to excessive dry weather) and the action of water infiltrating or ingress into the soil. Hence, adequate protection measures to the ground at founding level to prevent weakening or softening are required. Examples of possible measures include:

- carry out bulk excavation to within 0.5 to 1 meter above the foundation level. The final excavation stage is subsequently carried out as a final task, in short bay widths, and the exposed soil or rock immediately (or within the same work shift) protected by structural quality blinding concrete;

- avoid excavation to expose the founding ground during inclement weather like heavy rains, and minimize the duration of exposure through proper construction planning.

1.6.2 QP shall inspect the actual soil/rock conditions encountered at founding level of raft or piled-raft and verify its geotechnical characteristics to be in consistent with his design assumptions, and conduct the required verification tests to validate the design assumptions. If actual soil encountered at founding level is more inferior than the design assumption, QP shall assess whether ground improvement work need to be carried out or a re-design is required, before allowing the raft slab to be constructed.

1.6.3 Where applicable and without affecting the performance of buildings, QP shall specify on plan details of the construction joint between the tower and podium areas to enable some joint rotation and to reduce the impact of potential differential settlement of the building.

1.6.4 **Table D** summaries the minimum verification tests and instrumentation & monitoring regime to be provided for different risk categories of buildings and structures.

Table D : Site Verification Tests and Construction Monitoring for Raft or Piled-Raft

Type of Tests or Monitoring	Low Risk	Medium Risk	High Risk
Site Verification Tests			
Plate load test	Minimum 1 test every 100m^2 of raft footprint area or part thereof	Minimum 1 test per required borehole within footprint of building works, subject to minimum of 2 tests per raft	Minimum 1 test per required borehole within footprint of building works, subject to minimum of 3 tests per raft
Pile Load Test# (Instrumented Ultimate Load Test, Working Load Test)	QP to determine	• For 5 to 9 storeys building, follow BCA's Circular (2016) minimally • For less than 5 storeys building, QP to determine	Follow BCA's Circular (2016) minimally
# - For piles within the piled-raft that are subject to working pile load tests, pile head settlements at 1.5 or 2.0 times Working Load are to be less than 15mm and 25mm respectively.			
Construction Monitoring			
Raft contact pressure (e.g. earth pressure cell or equivalent)[Note 1]	QP to determine	• Minimum 1 monitoring point per required borehole within footprint of building works • Monitoring duration: Till completion of project • Action Plan: Suspension of construction work will still be based on monitored building settlement and differential settlement/tilt. In the scenario that building settlement reading is breached, raft contact pressure will help QP to assess the cause and propose effective remedial proposal. If only the raft contact pressure is breached, QP should assess whether the actual performance is as per design intent.	

	Low Risk	Medium Risk	High Risk
Raft settlement profile (e.g. horizontal-placed inclinometer, optic fibre or equivalent) Note 1	QP to determine	• Minimum 1 array in each orthogonal direction • The arrays should be positioned at areas with critical loading and settlement.	
Building settlement and tilt / differential settlement during construction	QP to determine	• Minimum 10 building settlement markers and 10 tiltmeters per block, including 2 per corewall • Monitor fortnightly • Monitoring duration to be: a) 6 months after the superstructure construction reached final roof top level OR b) the measured building settlement and tilt/differential settlement have shown stabilising trend during post construction monitoring, whichever is later	

Note:

1) The requirement to monitor raft settlement profile and raft contact pressure may be assessed by QP to be not required for the following types of structures:
   a) Fully underground structures such as tunnels and MRT station.
   b) Underground structures supporting light above ground structures such that sum of its weight and imposed loads is less than or equal to the weight of soil removed for its construction at founding level.

1.7 Performance Requirement at Serviceability Stage

Table E summaries the allowable building settlement and tilt at serviceability stage for different risk categories of buildings and structures. These monitoring limits shall be specified on QP's drawings and submitted for BCA's approval.

Table E : Allowable Building Settlement and Tilt at Serviceability Stage

Foundation Type		Low Risk	Medium Risk	High Risk
To be Specified on Drawings for BCA's Approval				
Raft	Building Settlement	25 mm (See Note 1)	30 mm	30 mm
	Differential Settlement / Tilt	1:500		
Piled-Raft	Building Settlement	25 mm	25 mm	25 mm
	Differential Settlement / Tilt	1:500		
Note 1: QP may adopt higher settlement limit of 30mm for raft foundation provided more stringent requirements detailed in Tables A to D for Medium risk category are complied with.				

1.8 References

(a) Craig's Soil Mechanics book by R.F. Craig
(b) SS EN 1997 Eurocode 7: Geotechnical Design – Part 1 General Rules
(c) SS EN 1997 Eurocode 7: Geotechnical Design – Part 2 Ground Investigation and Testing
(d) Guide on Ground Investigation and Geotechnical Characteristics Values to Eurocode 7 by GeoSS (2015)
(e) ICE Manual of Geotechnical Engineering (2012) – Rafts and Piled Rafts
(f) Poulos H. G. (2001). *Piled Raft Foundations : Design & Applications*, Geotechnique 51, No. 2, 95-113
(g) K.H. Goh, K. Jeyatharan and D. Wen (2012). *Understanding the Stiffness of Soils in Singapore from Pressuremeter Testing,* Geotechnical Engineering Journal of the SEAGS & AGSSEA Vol. 43 No. 4 December 2012