Building and Construction Authority

An MND Statutory Board

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Building Engineering Group (#12-00)
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Dear Sir/Madam

FRAMEWORK ON PERFORMANCE BASED IMPACT ASSESSMENT ASSOCIATED WITH EARTH RETAINING OR STABILISING STRUCTURES ("ERSS") AND TUNNELLING WORKS

Objective

This circular is to inform the industry on the Framework on Performance Based Impact Assessment of adjacent buildings associated with ERSS and tunnelling works ("Framework"). The Framework enables engineers to assess and adopt the appropriate approach in assessing the impact to adjacent buildings arising from their projects and is expected to produce a better assessment of impact which in turn will result in a more efficient design.

Background

2 Currently, building impact assessment may be carried out via "Deemed-to-Satisfy Approach" using either empirical or numerical analysis. Where under empirical analysis, the deemed-to-satisfy limits cannot be met, QPs will proceed to carry out numerical analysis. Where a comprehensive numerical analysis is performed, a more appropriate allowable limit may be determined. Hence, BCA has developed a framework to provide clarity on the comprehensive numerical analysis ("Rigorous Approach").

3 Over the past months, BCA has gathered feedback on the Framework from the Institution of Engineers Singapore, Association of Consulting Engineers Singapore, Geotechnical Society of Singapore and Tunnelling and Underground Construction Society (Singapore). This circular, which has incorporated inputs from the professional institutions, is for compliance by Qualified Persons ("QPs"), site supervisors, builders and developers that are submitting plans for ERSS and tunnelling works.

4 The Rigorous Approach set out in the Framework is not applicable to non-GBW projects. For impact assessment of GBW projects, project parties may choose to adopt the Deemed-to-Satisfy or the Rigorous Approach. When adopting the Rigorous Approach, QPs assessing the impact of their proposed GBW ERSS and tunnelling works shall ensure that the specified requirements in this circular are satisfied.

5 Developers/builders are advised to engage QPs who have successfully carried out project with similar scale and in similar ground condition for carrying out Impact Assessment for the proposed ERSS and tunnelling works. Highly skilled and experienced QPs should be able to assess the impact accurately to achieve smooth execution of projects via a more efficient design.

6 Nothing contained in this circular 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.

7 We would appreciate if you could disseminate the contents of this circular to your members. Please contact us at Tel 1800-3425222 or through the online feedback form (https://www.bca.gov.sg/feedbackform/) should you need any clarification. Thank you.

Yours faithfully

Er. Dr. POH TEOH YAW
DIRECTOR, GEOTECHNICAL ENGINEERING DEPARTMENT
BUILDING ENGINEERING GROUP
For COMMISSIONER OF BUILDING CONTROL

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Annex A

Framework on Performance Based Impact Assessment associated with ERSS and Tunnelling Works

Section 1. Introduction

1.1 Regulation 33 of Building Control Regulations 2003 requires impact assessment to adjacent buildings to be conducted, so as to prevent any settlement or other movement which may impair the stability of or cause damage to the whole or part of any premises or building adjacent or in otherwise close proximity to the building works.

1.2 This Framework on Performance Based Impact Assessment associated with ERSS and tunnelling works provides the specific requirements for 1) the default "Deemed-to-Satisfy Approach" (current industry practice) applicable to all projects, and 2) an alternative Rigorous Approach applicable only to GBW projects. During plan submission stage, QPs must state the impact assessment approach which will be adopted for the project. Project parties may adopt for GBW projects either the Deemed-to-Satisfy Approach or Rigorous approach for each of the buildings in the same project.

1.3 Regardless of the approach adopted, QPs must substantiate that adjacent buildings affected by the proposed construction works are safe and will not likely be damaged.

1.4 Requirements of the "Deemed-to-Satisfy Approach" and "Rigorous Approach" are shown in **Section 2** and **Section 3,** respectively. The designers are to have adequate knowledge of the impact assessment approach and shall refer to the relevant literature for full details.

1.5 The affected adjacent buildings/structures are to be monitored closely during construction to verify that the impact of construction works is within the limits assessed and the adjacent buildings/structures remain safe at all times while the ERSS and tunnelling works are ongoing.

Good Practices on ERSS Wall Installation

1.6 Project parties should refer to Appendix D for the good practices of ERSS wall installation for both Deemed-to-Satisfy Approach and Rigorous Approach. This is to ensure the impact to buildings in close proximity are controlled prior to excavation.

Deemed-to-Satisfy Approach (Approach A – applicable to all projects)

1.7 The Deemed-to-Satisfy Approach (see **Section 2** for details) uses the empirical or numerical approach via the staged assessment (preliminary assessment, second stage

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assessment, detailed evaluation) outlined in Mair, Taylor and Burland (1996). QP may refer to Mair et al. (1996), Boscardin and Cording (1989), or other relevant literature when assessing the impact due to ERSS or tunnelling works. This approach will be suitable for most of the projects and is subject to a maximum structure settlement as set out in **Table 2.1-1: Deemed-to-Satisfy Allowable Building Settlement**.

Rigorous Approach (Approach B – applicable only to GBW)

1.8 The Rigorous Approach (see **Section 3** for details) is a comprehensive numerical analysis (e.g. Finite Element) adopting the detailed evaluation principles outlined in Mair, Taylor and Burland (1996) in addition to structural capacity check to substantiate appropriate building settlement. This approach is intended for specific existing structures that the QP assesses to be robust and will be able to sustain larger settlement without being damaged. The Rigorous Approach is subject to a maximum building settlement based on risk as set out in **Table 3.5-1** and **Table 3.6-1: Rigorous Allowable Building Settlement.**

1.9 The Rigorous Approach set out in this Framework is not applicable to non-GBW projects. When adopting the Rigorous Approach, QPs assessing the impact of their proposed GBW ERSS and tunnelling works shall ensure that the specified requirements in this Framework are satisfied.

1.10 Developers/builders are advised to engage QPs who have successfully carried out project with similar scale and in similar ground condition for carrying out Impact Assessment for the proposed ERSS and tunnelling works. Highly skilled and experienced QPs should be able to assess the impact accurately to achieve smooth execution of the project via a more efficient design.

Impact Assessment Report

1.11 For projects that require any impact assessment report, the following items shall be included in the report:-

a) Checklist for impact assessment is submitted;
b) Impact Assessment Report with recommendations for measures to minimise movement or prevent damage are specified on plan during plan submission;

In the impact assessment, QPs are to take into consideration the existing condition of the buildings as revealed through pre-construction survey / inspections. QPs may refer to Goh & Mair (2014) to incorporate the existing condition in the impact assessment.

In the current Deemed-to-Satisfy Approach, the monitoring levels include Work Suspension Level and Alert Level. When Rigorous Approach is adopted, 2 additional monitoring levels shall be included (refer to Section **3.10**).

Section 2. Deemed-to-Satisfy Approach (Approach A) – applicable to all projects

2.1 In the default Approach, building impact assessment may be carried out through an empirical or numerical analysis, via preliminary assessment, second stage assessment, or detailed evaluation outlined in Mair, Taylor and Burland (1996). QPs are to demonstrate that the impact category is up to "Very Slight" (refer to Section **2.2** for the acceptable impact categories).

The assessed building settlement, determined from the analysis of ground and building response via Approach A, is subjected to the Allowable Building Settlement (see **Table 2.1-1**).

Table 2.1-1: Deemed-to-Satisfy Allowable Building Settlement

Group	Type of Building	Allowable Building Settlement	Allowable Relative movement#
Group 1	➢ Conserved buildings ➢ Buildings badly dilapidated or with pre-existing damage ➢ Building with mixed foundation ➢ Structures sensitive to ground movement	Up to 10mm	1:500
Group 2	➢ Building on pile foundation, or ➢ Building without as-built information ➢ MRT, CST and DTSS tunnels ➢ Bridges, POBs, viaduct and piers	Up to 15mm	
	➢ Minor structures on driven or jack-in piles, which do not require AC certifications, for example drain, single-storey substation, single-storey guard house.	Up to 20mm	
	➢ Building or minor structures on shallow foundation	Up to 25mm	

- includes differential settlement, rotation, tilt, relative deflection, relative rotation etc.
QPs shall consult the relevant agencies for the allowable review level for their respective utility.

For Group 1 buildings, which are sensitive to impact of ERSS or tunnelling works, QPs are encouraged to carry out detailed impact assessment ("detailed evaluation" in Mair, Taylor and Burland approach) in addition to adoption of Deemed-to-Satisfy Allowable Building

Settlement, to prevent potential damage.

Building impact category

2.2 When carrying out ERSS and tunnelling works, Building Control Regulations requires that such building works shall not cause damage to adjacent buildings. To achieve the required performance criteria and for practical reasons, the impact category "Negligible" and "Very Slight" (with non-structural crack width <1mm) are considered as equivalent to "no damage".

The description of building impact category is given in the table below.

Table 2.2-1: Classification of building impact category

Building and Structural Damage Classification Mair et al (1996)				Typical Crack Width (Non structural)
Damage category		Description	Limiting tensile strain (%)	
0	Negligible	Hairline cracks (damage unlikely but possible)	0 to 0.05	0.1mm
1	Very Slight	Fine cracks that are easily treated during normal decoration. Damage generally restricted to internal wall finishes. Cracks may be visible on external brickwork or masonry	0.05 to 0.075	<1mm
2	Slight	Cracks easily filled. Redecoration probably required. Recurrent cracks can be masked by suitable linings. Cracking may be visible externally and some repointing may be required to ensure weather-tightness. Doors and windows may stick slightly.	0.075 to 0.15	<5mm
3	Moderate	Cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weather-tightness often impaired	0.15 to 0.30	5 – 15mm or several > 3mm
4/5	Severe to Very Severe	Extensive repair work involving break-out and replacing sections of walls, especially over doors and windows. Door and window frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably; some loss of bearing in beams. Utilities disrupted.	> 0.30	15 – 25mm / >25mm

Section 3. Rigorous Approach (Approach B) – applicable only to GBW projects

3.1 In the alternative Rigorous Approach, building impact assessment may be carried out through a comprehensive numerical analysis (e.g. Finite Element) adopting the principles of the detailed evaluation as outlined in Mair, Taylor and Burland (1996) in addition to structural capacity check to substantiate appropriate building settlement.

3.2 The assessed building settlement, determined from the analysis of ground and building response via Approach B, is subjected to the Rigorous Allowable Building Settlement (see **Table 3.6-1**).

3.3 Submission procedure and requirements for projects adopting Rigorous Approach can be found in **Appendix A**.

Type of buildings where Rigorous Approach is not applicable

3.4 Due to higher risk and/or greater consequence of damage, Rigorous Approach is NOT applicable to the following buildings / structures: -

a) Conserved buildings; or

b) Buildings with pre-existing damage or badly dilapidated[#] unless repair works are carried out prior to ERSS or tunnelling works; or

c) Buildings on mixed-foundation; or

d) Buildings with 30 storeys or more; or

e) MRT structures and tunnel, CST tunnel, DTSS tunnel

[#] QP of the ERSS or tunnelling works is to review the pre-construction survey reports and to conclude whether an existing building is dilapidated.

Building risk category and enhanced Allowable Building Settlement

3.5 Buildings are classified into different risk category based on the severity to public impact (Building Type) and susceptibility to damage (building age) as summarized in **Table 3.5-1**. Notwithstanding the risk category in the table below, the QP is to assess and to increase appropriately the risk category based on the existing condition of the building.

Table 3.5-1: Building risk category

Building Type	(Building Age)		
	< 20 years	**20 – 50 years**	**> 50 years**
≤ 5 storey including drains, canals, retaining walls, substations, etc.	Low	Low	Low
6 – 9 storey	Medium	Medium	Medium
≥ 10 storey and bridges, POBs, piers, viaducts	Medium	Medium	High

Notes: -

a) Building 20 years in age (from first TOP date) aligns with BCA's Periodic Façade Inspection

b) Building 50 years in age aligns with the indicative design life of building structures (Eurocode (EN 1990 Clause 2.3)

c) This risk category above is for building impact assessment and is independent from the risk category for tunnelling works that is for tunnelling incident.

3.6 The allowable building settlement adopting Rigorous Approach is subjected to a limit based on the foundation type of the building as well as the building risk category as summarised in **Table 3.6-1**.

Table 3.6-1: Rigorous Allowable Building Settlement

Risk	**Low**		**Medium**		**High**	
Foundation Type	Shallow foundation	Pile	Shallow foundation	Pile	Shallow foundation	Pile
Rigorous Allowable Building Settlement	Up to 50mm	Up to 35mm	Up to 35mm	Up to 25mm	Up to 25mm	Up to 20mm
Action Level*	25mm	15mm#	25mm	15mm	N/A	15mm
Allowable Relative Movement	1:500					

* Refer to Section **3.10** for definition of Action Level.

Action level of 20mm will be applicable for minor structures on driven or jack-in piles, which do not require AC certifications, for example drain, single-storey substation, single-storey guard house (see **Table 2.1-1**).

QPs shall consult the relevant agencies for the allowable review level for their respective utility/structures.

Soil-Structure Interaction Analysis and Building Structural Capacity Assessment for Rigorous Approach

3.7 Key steps of soil-structure interaction analysis and building structural capacity assessment that are to be carried out for projects that are adopting Rigorous Approach can be found in **Appendix B**. QPs are to demonstrate and include the impact assessment of affected buildings as set out in that Appendix when submitting structural plans for approval.

Requirements on Site Investigation of existing Buildings/Building Works for Rigorous Approach

3.8 As the impact assessment of the existing building can only be effectively assessed via carrying out the analysis adopting accurate soil stratum and design parameters, it is vital to obtain adequate information of the soil underlying the affected building so as not to over or under predict the movements of the affected building. The minimum soil investigation for affected buildings with building settlement limits exceeding the Deemed-to-Satisfy Allowable Building Settlement are as follows: -

For the existing buildings which are within 20m from the ERSS wall
SI boreholes from the ERSS wall which are conducted at every 10m to 30m spacing, as recommended in GeoSS guidelines*, may be used.

For the existing buildings which are more than 20m away from the ERSS wall
A minimum of 1 borehole within 20m from the existing building.

*GeoSS (2015), Guide on Ground Investigation and Geotechnical Characteristic Values to Eurocode 7

Requirements on Additional Instrumentation of existing Buildings/Building Works for Rigorous Approach

3.9 In view of the larger allowable settlement limit for the Rigorous Approach and the higher associated risk of building impact, an enhanced monitoring regime of the affected existing building as per **Table 3.9-1** will be required. This is to ensure that the Rigorous Approach achieve the same performance standard as the Deemed-to-Satisfy Approach.

Table 3.9-1: Enhanced building monitoring for Rigorous Approach

Type of reading	Additional item to be monitored and its requirement
Building/column settlement	Every external column Every internal column where possible To obtain, check and verify the relative movement between adjacent columns and building settlement profile Where applicable, QP may propose appropriate alternative solutions due to site constraints
Building tilt	To measure the tilt of the building in two perpendicular planes.
Crack	Existing crack with width of 1mm or more. WSL for the non-structural cracks that widened by >1mm during construction.

Monitoring regime

3.10 In the current Deemed-to-Satisfy Approach, the monitoring levels of the ERSS or tunnelling works and the nearby buildings include Work Suspension Level and Alert Level.

- Work Suspension Level (WSL) - to be set at the design value that satisfies Building Impact Assessment and subjected to the Rigorous Allowable Building Settlement (see **Table 3.6-1**), whichever is lesser.
- Alert Level (AL) - to be set at 70% of WSL as per current practice.

When Rigorous Approach is adopted, 2 additional monitoring levels shall be included.

- Action Level (ACL) - to be set at the allowable values based on Deemed-to-Satisfy Approach of 15mm, 20mm or 25mm depending on the building foundation type (see **Table 3.6-1**).
- 70% Action Level – to be set at 70% of ACL.

The monitoring regime for Deemed-to-Satisfy Approach and Rigorous Approach are summarized in **Table 3.10-1** below.

Table 3.10-1: Monitoring regime

Monitoring level	**Deemed-to-Satisfy Approach**	**Rigorous Approach**
Work Suspension Level (WSL)	to be set at the design value that satisfies Building Impact Assessment and subjected to the Deemed-to-Satisfy Allowable Building Settlement (see **Table 2.1-1**), whichever is lesser	to be set at the design value that satisfies Building Impact Assessment and subjected to the Rigorous Allowable Building Settlement (see **Table 3.6-1**), whichever is lesser
Alert Level (AL)	to be set at 70% WSL	to be set at 70% WSL
Action Level (ACL)	not applicable	to be set at the Deemed-to-Satisfy Allowable Building Settlement, depending on the building foundation type (see **Table 3.6-1**)
70% Action Level	not applicable	to be set at 70% ACL

The monitoring regime including the actions required from QP(D) and QP(S) in the Deemed-to-Satisfy Approach and Rigorous Approach are illustrated in flow charts in **Appendix C**.

Essentials to Adopting Rigorous Approach

3.11 For effective implementation of Rigorous Approach and to ensure the construction work can be completed without breaching WSL:-

a) QP(S) shall be proactive in monitoring building deformations and critical design parameters (e.g. water draw-down) during construction.
b) QP(D) shall take proactive actions if actual performance is not in accordance to the design predictions during construction.
c) QP(D) shall be proactive in preparing assessment reports and implementing mitigation measures as required when approaching 70%ACL, at ACL and AL before breaching WSL.

References

Mair R.J., Taylor R.N. and Burland J.B. 1996. “Prediction of ground movements and assessment of risk of building damage due to bored tunnelling”, Int. Symp. on Geotechnical Aspects of Underground Construction in Soft Ground, London.

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Geotechnical Society of Singapore. 2015. Guide on Ground Investigation and Geotechnical Characteristic Values to Eurocode 7.

Poh, T.Y., Goh, A.T.C, Wong, I.H., 2001, “Ground Movements Associated with Wall Construction: Case Histories”, ASCE Journal of Geotechnical and Geo-environmental Engineering, Vol 127(12).

Appendix A. Workflow of Rigorous Approach

Stages	Description
Conceptualisation and preparation	1. Inspect the building or review the pre-construction survey report to assess that the building is suitable for adoption of Rigorous Approach. 2. Refer to **Section 3.4** to check that the Rigorous Approach is applicable to this building type. 3. Refer to **Table 3.6-1** for the Allowable Building Settlement under the Rigorous Approach. 4. Check that as-built structural drawings for foundation and superstructure is available. Where as-built structural drawings are not available, foundation and structural investigation survey is to be carried out to substantiate the assumptions made. 5. Carry out adequate SI for ERSS or tunnelling and for the existing buildings to determine the design parameters for analysis adopting advanced soil models. 6. Check that it is feasible to effectively monitor the building. *Note:- "advanced soil models" refer to soil models which can model non-linear behaviour of soil and calibrated to local soil condition, for example the Hardening Soil model.*
Analysis and design	1. Carry out detailed evaluation with soil-structure interaction analysis and building structural capacity assessment for Rigorous Approach as outlined in **Appendix B**. 2. Check that the design building settlement is within the limits of Rigorous Allowable Building Settlement, and the relative movement (including differential settlement, rotation, tilt, relative deflection, relative rotation) is within 1:500.
ST plan submission to BCA	1. QPs to submit the impact assessment along with a comprehensive write-up of the design assumptions considered when adopting the Rigorous Approach. 2. Check that the WSL of the building assessed via Rigorous Approach is set based on the results of the design analysis. 3. Submit a comprehensive instrumentation proposal (see **Section 3.9**) and monitoring regime (see **Table 3.10-1**) that is adequate to verify the performance of the proposed ERSS or tunnelling works and the affected building assessed based on Rigorous Approach. 4. Specify on plan, recommendations for measures to minimise movement or prevent damage 5. Specify on plan the contingency and remedial measures (e.g. compensation grouting) and the conditions to activate these measures. 6. On the structural plans, QP(D) is to specify the PDL for building settlement during ERSS wall installation. The building settlement PDL may be determined by incorporating the design lines of soil settlement (see **Appendix D**) in the numerical

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Stages	Description
	analysis, or may be set to a default value of up to 5mm.
During any construction stage, in the event of damage (non-structural crack > 1mm or any structural crack) to the building	1. QP(S) to stop relevant excavation or tunnelling works and inform CBC. 2. QP(D) to assess whether the building can still take the impact of subsequent construction stages, and to propose strengthening measures. 3. To repair the damage.
During ERSS wall installation	1. When building settlement reached PDL, QP(S) is to stop the work and to review the wall installation procedure.
During construction when building limit reaches 70% of Action Level	1. QP(D) is to assess and submit an assessment report with QP(S)'s inspection report appended. The assessment is to be based on the actual building settlement profile, superimposed with anticipated building settlement for subsequent construction stages.
During construction when building limit reaches Action Level	1. QP(D) is to assess and submit an assessment report with QP(S)' inspection report appended. The assessment is to be based on the actual building settlement profile, superimposed with anticipated building settlement for subsequent construction stages.
During construction when building limit reaches Alert Level	1. QP(D) is to assess and submit an assessment report with QP(S)' inspection report appended. The assessment is to be based on the actual building settlement profile, superimposed with anticipated building settlement for subsequent construction stages. a) If the assessment concludes that the construction is likely to be completed without breaching the WSL, the construction may proceed. b) If the assessment concludes that the WSL is likely to be breached, to activate the contingency measures. 2. Increase monitoring frequency to minimum daily. 3. Prepare strengthening measures, to be activated when necessary.
When building limit reached Work Suspension Level	1. QP(S) to stop relevant excavation or tunnelling works and inform CBC. 2. QP(D) to activate / propose strengthening measures to the buildings. 3. QP(D) to propose enhancement of the ERSS or tunnelling works, when applicable.

Please refer to **Table 3.6-1** and **Table 3.10-1** for description of Action Level. Depending on the design value of building settlement, Action Level may be higher or lower than the Alert Level.

Appendix B. Key steps of soil-structure interaction analysis and building structural capacity assessment for Rigorous Approach

Key step #	Type of Analysis and description
1	**Geotechnical numerical (e.g. Finite Element) analysis** Carry out a staged-construction analysis of the excavation or tunnelling using geotechnical numerical model to include the building stiffness. The analysis shall employ advanced soil models and is to be carried out by an experienced geotechnical engineer. *Note:- "advanced soil models" refer to soil models which can model non-linear behaviour of soil and calibrated to local soil condition, for example the Hardening Soil model.* The assessment should also consider effects of wall installation and groundwater lowering where required. These effects should be considered until the end of construction period. <u>Key items to be demonstrated:</u> a) Appropriate building loads/stiffness are to be considered in the numerical model (see Examples 1.1 to 1.3 for illustration). b) Advanced soil model is to be adopted in the analysis to capture realistic ground behaviour. For design of the ERSS or tunnelling works, characteristic soil parameters, onerous groundwater level shall be used, and separate analyses for drained and undrained conditions shall be carried out. For impact assessment on adjacent buildings, most probable soil parameters and appropriate drainage condition may be used. Realistic groundwater level (based on continuous monitoring over a long period of time covering the wet season) may be used in impact assessment.

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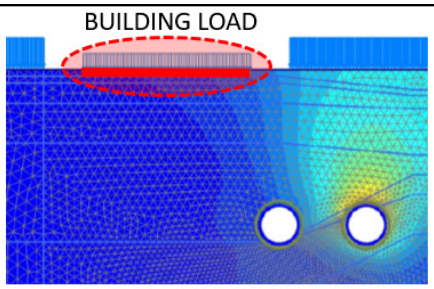
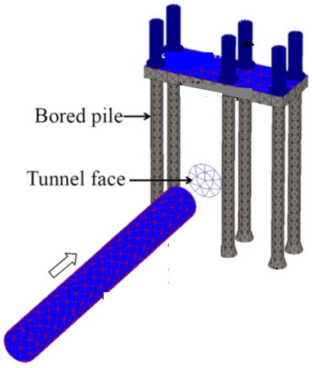
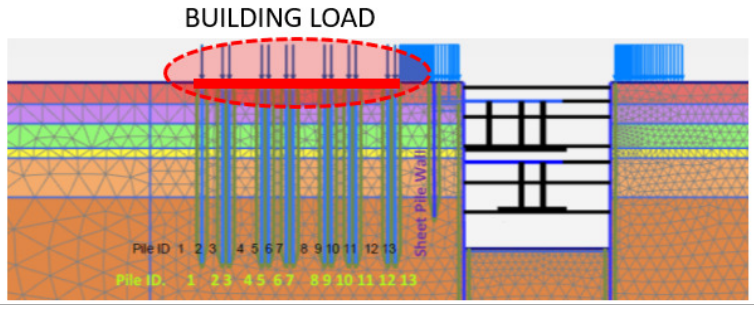
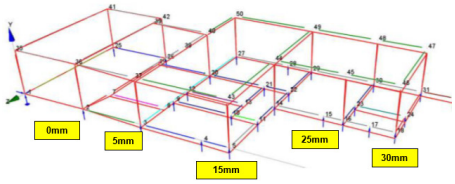
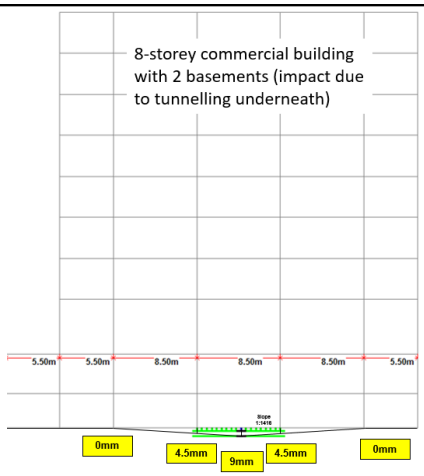
<tr><td> 
</td><td> 
</td></tr>
<tr><td>Example 1.1:- Inclusion of footing and building “plate” stiffness in a 2D geotechnical numerical model.</td><td>Example 1.2:- Inclusion of pile and building “plate” stiffness in a 3D geotechnical numerical model.</td></tr>
<tr><td colspan="2"> 
</td></tr>
<tr><td colspan="2">Example 1.3:- Inclusion of pile and building “plate” stiffness in a 2D geotechnical numerical model.</td></tr>
</table>
</td></tr>
<tr><td>2</td><td>Estimate the impact on the building from the geotechnical numerical analysis in Step 1.

Key items to be demonstrated:
a) the estimated building settlement is less than the allowable limit as defined in Table 3.6-1.
b) the relative movement of the building (including differential settlement, rotation, tilt, relative deflection, relative distortion) does not exceed 1:500
c) the pile forces are within the pile’s geotechnical and structural capacities (if applicable)

The WSL for the building settlement specified on the structural plans shall be based on settlement obtained from geotechnical analysis and shall not exceed the the allowable limit as defined in Table 3.6-1.</td></tr>
<tr><td>3</td><td>Structural analysis

Carry out structural analysis of the adjacent building with consideration of all building loads and the displacements obtained from geotechnical numerical analysis.</td></tr>
</table>

Key step #	Type of Analysis and description
	
	Example 3-1: Structural analysis of a 2-storey landed house on shallow foundation (considering impact of adjacent excavation)
	
	Example 3-2. Structural analysis of a 8-storey commercial building with 2 basement levels (considering impact of tunnelling underneath)
4	Extract building forces (service forces) and change of forces (combined forces) due to excavation or tunnelling works from the Structural Analysis in Step 3.
5	Carry out structural element capacity checks for all the members, including pile foundation, based on as-built structural information (element size, reinforcement). Key items to demonstrate: a) the forces of all the structural elements are within the capacity. b) relative movement of key structural members are within the allowable limit

Note: The above figures and the details shown in the figures are for illustration only and not to be taken as endorsement of any commercial software or any modelling details.

Appendix C. Flow Charts of Monitoring Regime

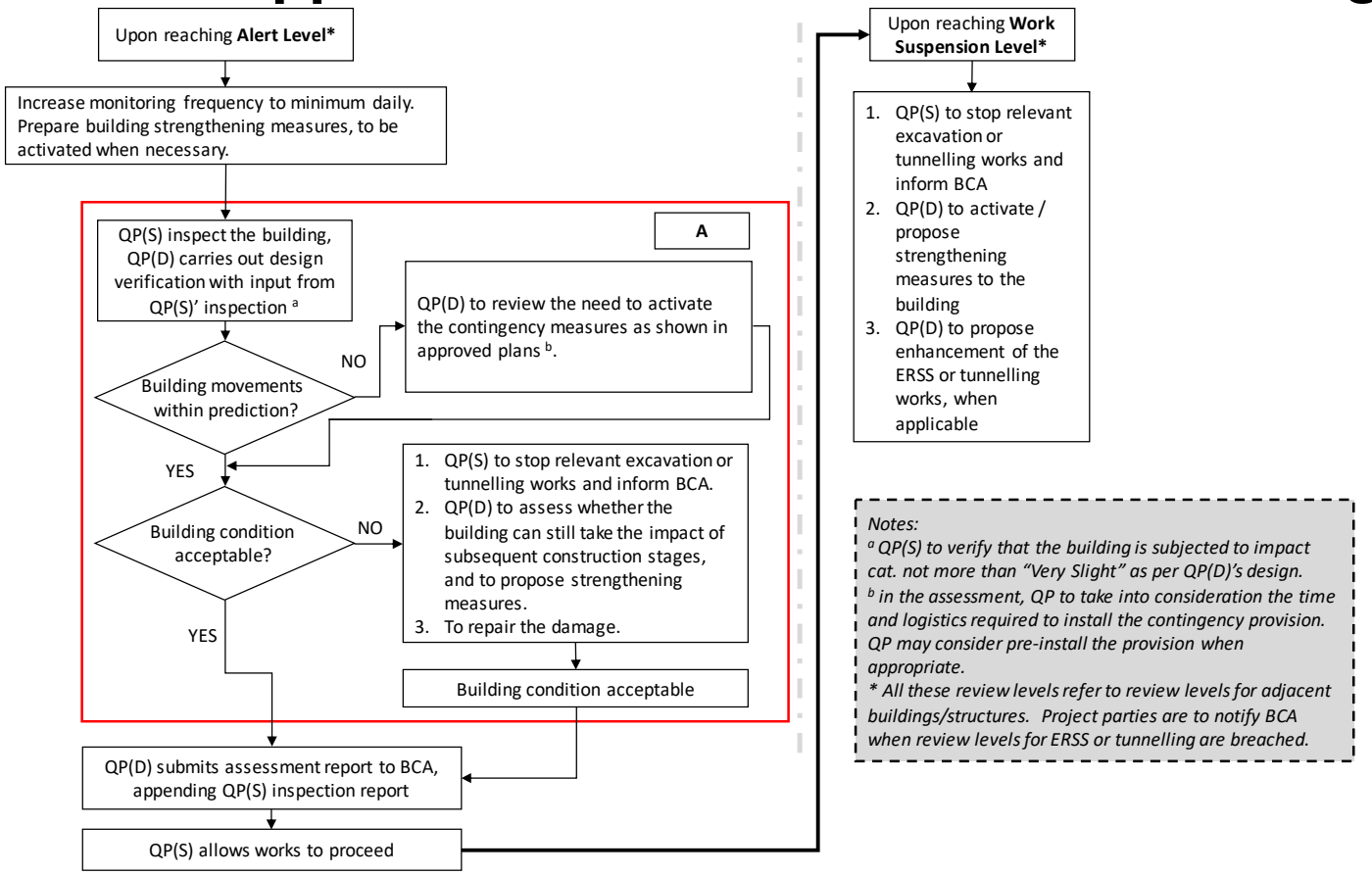


Figure C.1: - Monitoring regime for Deemed-to-Satisfy Approach (Approach A)

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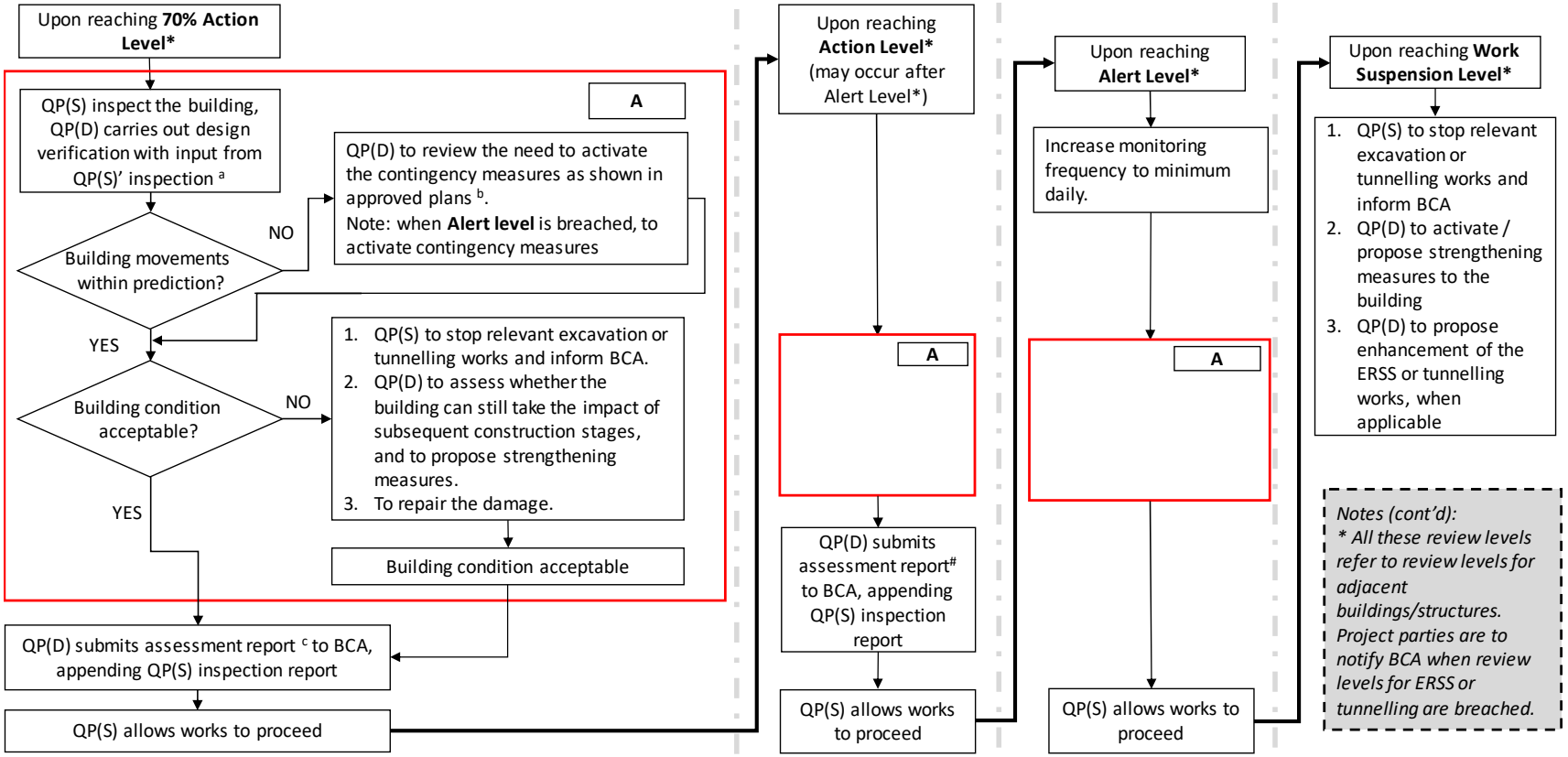

Notes:
[a] QP(S) to verify whether there is any new damage (non-structural crack > 1mm or any structural crack) to the building
[b] in the assessment, QP to take into consideration the time and logistics required to install the contingency provision. QP may consider pre-install the provision when appropriate.
[c] QP(D) to assess the building based on the actual building settlement profile, superimposed with anticipated building settlement for subsequent construction stages.

Figure C.2: - Monitoring regime for Rigorous Approach (Approach B)

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Appendix D. Impact of ERSS Wall Installation

The following good practice shall be considered and implemented, where applicable, for projects involving installation of ERSS wall (for both Deemed-to-Satisfy Approach and Rigorous Approach): -

1. Trench stability calculation shall be prepared with groundwater pressure based on the highest water level measured at site and the lowest slurry density (i.e. after desanding). Trench stability shall be evaluated according to SS EN 1997-1 2004.
2. Length of the wall panel should be minimised especially at critical locations or at challenging/difficult ground condition
3. Slurry level shall always be maintained at least 1m above the highest piezometric level.
4. Bentonite slurry shall be tested for: -
    a. density using a mud balance
    b. viscosity, yield stress and gel strength using a Fann viscometer
    c. viscosity using a Marsh funnel
    d. pH with an electric pH meter
    e. sand content.
5. Bentonite slurry samples from the panel during excavation shall be tested for every 5m depth or each change of soil type.
6. Column grouting shall be carried out where fluvial sand layer or similar difficult ground condition is encountered to prevent piping / loss of fines.

Published local data from various projects and various soil types (see **Figure D.1** for illustration) collected from Diaphragm wall installation more than 20 years ago that could be in either green field or in close proximity to buildings/structures revealed that ground settlement due to diaphragm wall installation ranges from less than 5mm and could go up to as much as 26mm. The zone of influence of the settlement could range from approximately 12m to beyond 24m.

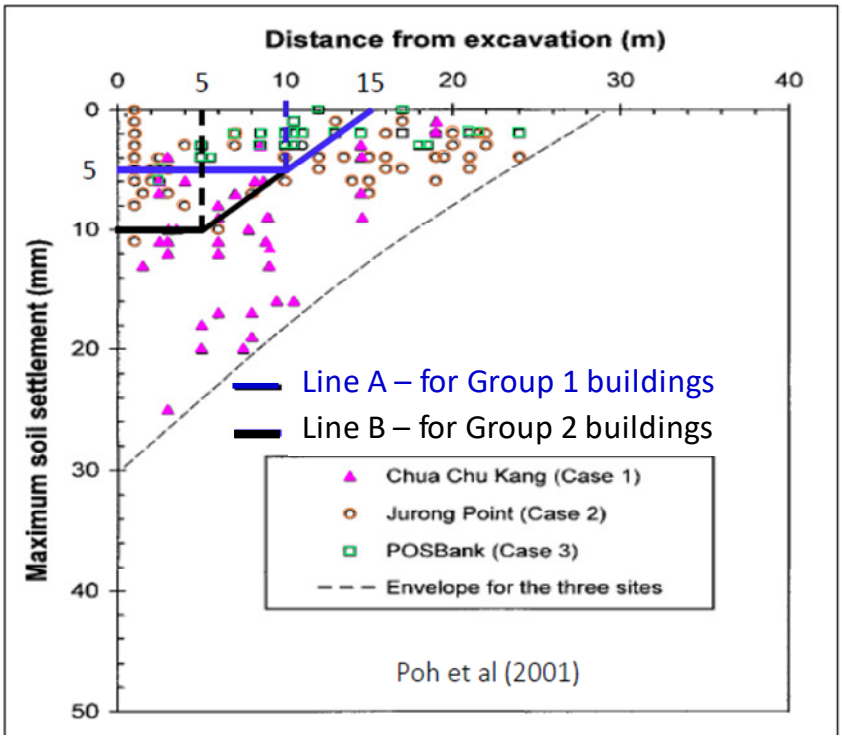
With improved technology, know-how, and the implementation of minimal good practice for wall installation as compared to the technics of wall installation 20 years ago, the effects on ground settlement due to wall installation could and should have improvements in ground settlement control. For the purposes of considering effects of diaphragm wall installation during impact assessment, ground settlement up to 5mm for Group 1 buildings and up to 10mm for Group 2 buildings with their respective influence zones, illustrated as the design lines shown in **Figure D.1** may be considered. For description of Group 1 and 2 buildings, please refer to **Table 2.1-1**.

Note that the values shown in **Figure D.1** are the ground settlement. QPs are to incorporate this ground settlement in the numerical analysis to estimate the impact on the affected buildings.

The designer is allowed to use any value deemed suitable within the stipulated design lines but is reminded to carry out trench stability analysis and implement necessary measures to minimize the effects of wall installation in the design analysis.

The designer is to consider the installation effects of all retaining wall types. The design lines in **Figure D.1** are for diaphragm wall and only for reference. For CBP or SBP wall, the wall installation effects are expected to be smaller than those for diaphragm wall.

On the structural plans, QP(D) is to specify the PDL for building settlement during wall installation. The building settlement PDL may be determined by incorporating the design lines of soil settlement from **Figure D.1** into the numerical analysis. Alternatively, the building settlement PDL may be set to a default value of up to 5mm. When the PDL is breached, QP(S) is to stop the work and to review the wall installation procedure.



Note: See Table 2.1-1 for details of Group 1 and Group 2 buildings

Figure D.1 - Greenfield ground settlement due to diaphragm wall installation