

28 November 2019

Reference No. 19125312-002-L-Rev1

Alain Pavelic

Built Pty Ltd
Level 7/343 George St,
Sydney, NSW 2000

**LIVERPOOL CIVIC PLACE
PRELIMINARY GEOTECHNICAL ASSESSMENT**

Dear Alain,

1.0 INTRODUCTION

Built Pty Ltd (Built) has engaged Golder Associates Pty Ltd (Golder) to carry out a preliminary geotechnical assessment for the Liverpool Civic Place project (the site). We understand that this assessment which involves two-dimensional finite element modelling will be used to inform the structural design of retention for bulk excavation works for the site in an early works contract. The work is carried out in accordance with our proposal in an email sent to you on 5 November 2019 and your approval to proceed in an email dated 6 November 2019.

In this revision, we have considered a bulk excavation level at RL +10.35 m AHD as instructed.

2.0 REFERENCES

The following documents were referred to in order to carry out the preliminary modelling presented in this report.

- Geotechnical and Environmental Investigation Report (ref.: 19125312-001-Rev1) by Golder dated 29 August 2019;
- Structural Drawings for adjacent buildings at 300 Macquarie St (ref.: 2012-176/C01-C04 and S01-S06) by Burgess, Arnott and Grava dated March 2013;
- Construction Staging Plan (ref.: SK-C-0004[D]) by Built received on 6 November 2019; and
- Structural Drawings (ref.: SK-C-0002-0006) by fmjt dated 31 July 2019.

3.0 PROPOSED BULK EXCAVATION

The proposed mixed-use development is understood to consist of a three-level basement car park. Built have informed us that the bulk excavation level (BEL) to be adopted is at RL+10.35 m AHD.

The existing ground level along the southern part of the site along the Terminus Street is approximately at RL+26 m AHD, about 3 m higher than the northern side along the Scott Street (i.e. RL+23 m AHD). The excavation depth for the site range between 15 m and 16 m below ground level (bgl).

The existing building in the vicinity with a basement is located to the north-west of the site. Based on the drawings provided, the bulk excavation for this building is to RL+17.8 m AHD, approximately 7.5 m higher than the proposed BEL.

The groundwater level measured in August 2019 is generally at RL+17.5 m AHD, approximately 7.2 m higher than the proposed BEL. However, an exception was the water level measured in BH304 at RL+15 m AHD.

4.0 ANALYSIS METHODOLOGY

Two analysis sections (as shown in Figure 1) adopted in this preliminary analysis were nominated by RBG.

The project structural engineer, Robert Bird Group (RBG) has advised Golder in an email on 11 November, to adopt the following conditions as summarised in Table 1.

Table 1: Instructions from RBG

Analysis Section 1	Analysis Section 2
■ Retention system consists of anchored soldier piles wall with shotcrete infill and vertical cuts in the underlying competent rock; ■ Spot bolting as required in Unit 3b and 4 depends on defects observed during site inspections; ■ The soldier piles wall consists of 600 mm diameter piles at the spacing of 1.5 m supported by two rows of anchors; ■ Unfactored loading from the existing building on the existing capping beam to be 335 kN/m; ■ Unfactored loading from the existing pad footing (i.e. 1.2 m x 1.6 m) right behind the capping beam to be 1,810 kN; ■ Unfactored loading from the existing pad footing (i.e. 2.4 m x 2.4 m) along Gridline D to be 4,600 kN; and ■ The allowable vertical and lateral displacement of the existing soldier pile wall and pad footing to be less than 10 mm.	■ Retention system consists of anchored soldier piles wall with shotcrete infill and vertical cuts in the underlying competent rock; ■ Pattern rock bolt with shotcrete facing could be adopted for Unit 3a or extending the soldier piles socketing into Unit 3b; ■ Spot bolting as required in Unit 3b and 4 depends on defects observed during site inspections; ■ The soldier piles wall consists of 600 mm diameter piles at the spacing of 2.4 m supported by two rows of anchors; and ■ A surcharge of 20 kPa to be considered from 1 m behind the retaining wall.

- Generate in-situ stresses in the ground using K_0 procedure;
- The surcharge and retaining wall are wished-in-place in the model, where installation effects are not considered;
- Excavation is modelled by deactivating layers of soil in each stage (e.g. 2 m) and the pore-water pressure distribution is calculated by steady-state analysis; and
- Excavation is carried out to 0.5 m below the temporary ground anchors (if any), and the anchors are installed by wished-in-place in the subsequent stage.

We have assumed that all ground anchors provide temporary support only and the ground anchors will be de-stressed as the construction of basement floor slabs progresses. The loads re-distributed to the constructed floor slabs after destressing of ground anchors are to be modelled and considered in the detailed design stage. The base and floor slabs of the basement structure will provide lateral support to the retention system in the permanent condition.

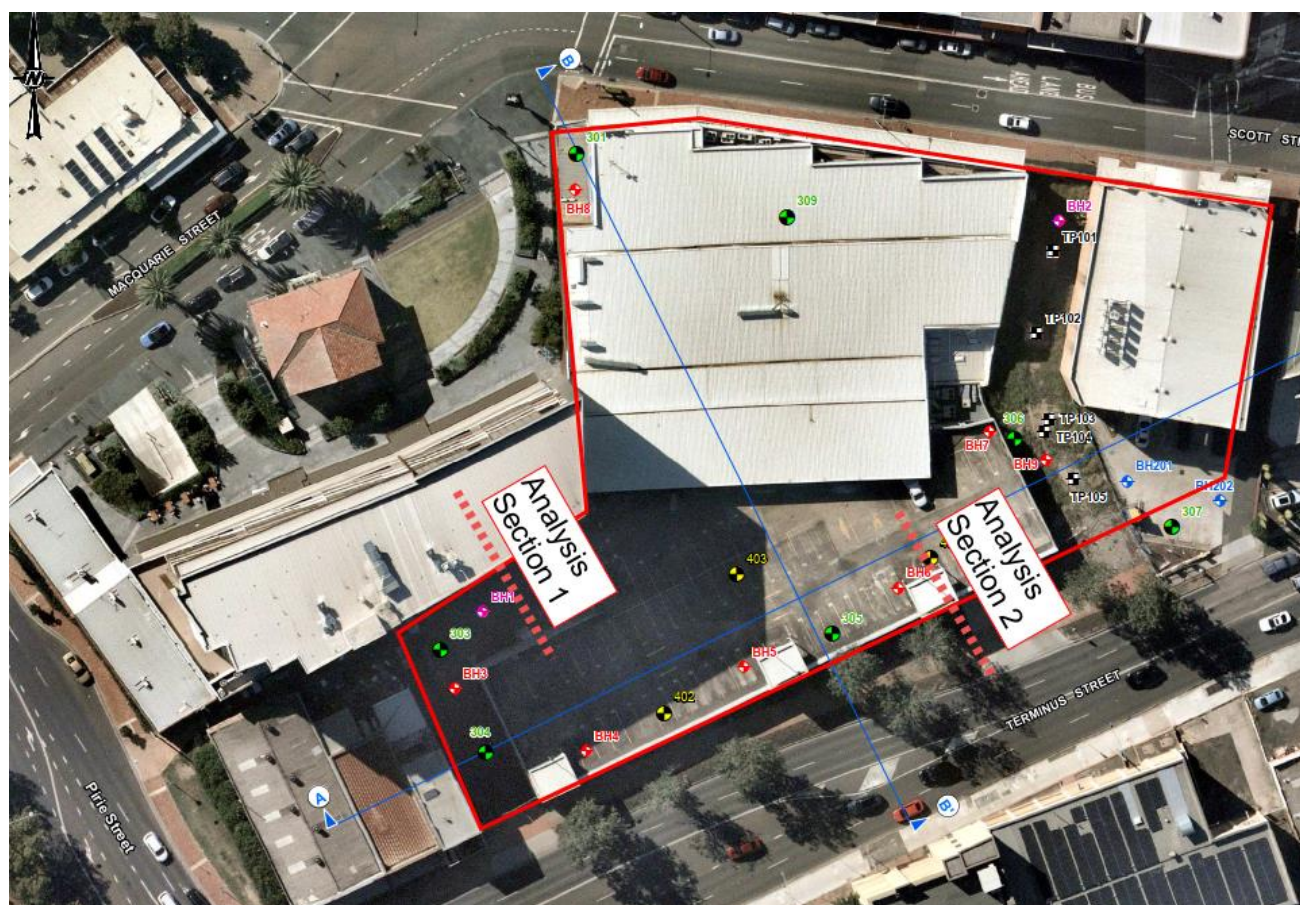


Figure 1: Analysis Section Layout

5.0 GROUND MODEL

Table 2 presents the modelled ground profiles for each analysis section, which are inferred from the following boreholes:

- Analysis Section 1 – BH302 and BH303
- Analysis Section 2 – BH305 and BH306

Based on the available borehole investigations, we anticipate that bedding of the rock units present on site will be primarily horizontal. The defects in Unit 3a, 3b and 4 observed in the available boreholes has been considered in the design parameters proposed in our geotechnical investigation report (ref.: 19125312-001-Rev1).

The highly weathered material interbedded in Unit 3b is modelled with Unit 3a parameters. We have assumed that any possible adverse jointing encountered in Unit 3a, 3b and 4 will be supported (e.g. pattern bolting, spot bolting etc.) at each excavation stage. A 0.1 m thick horizontal joint (bedding plane) has been modelled in Unit 4, 0.3 m below the BEL, to investigate the possibility of excessive rock heave or fracturing of the floor rock from stress concentration.

Table 2: Modelled Ground Profile

Ground Unit	Elevation of Top of Unit (m, AHD)	
	Analysis Section 1	Analysis Section 2
Unit 1 Filling	+22.3	+26.1
Unit 2 St-H Residual clay	+22.1	+24.0
Unit 3a L-M Laminite	+19.7	+21.7
Unit 3b M-H Laminite	+18.0	+17.4
Unit 4 H-VH Sandstone	+13.8	+12.8

An initial groundwater level at RL +18 m AHD has been assumed in the analyses. In the temporary and permanent condition, no groundwater pressure has been considered to act on the rock face, suitably sized drainage will need to be provided behind the shotcrete panels to prevent water pressure build-up.

6.0 DESIGN PARAMETERS

The mechanical behaviour of the soils and rocks are modelled with Hardening Soil Model, which adopted the Mohr-Coulomb failure criterion. The geotechnical parameters adopted are extracted from our geotechnical investigation report (ref.: 19125312-001-Rev1) and summarised in Table 3.

Table 3: Design Parameters for Ground Unit

Ground Unit	γ (kN/m ³)	C' (kPa)	ϕ' (°)	E ₅₀ (MPa)	E _{ur} (MPa)	K _o (-)
Unit 1 Filling	17	0	30	10	20	0.5
Unit 2 St-H Residual clay	18	5	28	20	40	1
Unit 3a L-M Laminite	24	50	38	200	400	1
Unit 3b M-H Laminite	24	200	40	1,200	2,400	2 ¹
Unit 4 H-VH Sandstone	24	400	43	2,000	4,000	6 ¹

¹ –K_o is elevated to generate the estimated locked-in horizontal stress

The structural behaviour of the retaining wall is modelled as a plate element in the model, with normal stiffness (EA) and bending stiffness (EI) smeared in the plane-strain condition. The design parameters adopted for the soldier piles walls are summarised in Table 4 assuming a concrete grade of 32 MPa with a Young's modulus of 30.1 GPa.

Table 4: Design Parameters for Retaining Wall

Retaining Wall	EA (kN/m)	EI (kNm/m)	Poisson's Ratio
600 mm diameter Soldier Pile at 2.4 m spacing	3.55 x10 ⁶	79.8 x10 ³	0.2
600 mm diameter Soldier Pile at 1.5 m spacing	5.67 x10 ⁶	128.0 x10 ³	0.2

The temporary ground anchor is modelled with a fixed-end anchor with an input of EA and spacing (Table 5).

Table 5: Design Parameters for Anchor

Anchor	EA (kN)
40 mm solid steel bar	2.51 x10 ⁵

7.0 RESULT OF ANALYSIS

7.1 Analysis Section 1 – Adjacent to Existing Building

Table 6 summarises the results computed in Analysis Section 1, for the proposed 600 mm diameter soldier pile wall at 1.5 m spacing for each construction stage. The foundation loads from the adjacent building (as provide by RBG) is considered as an equivalent infinite strip load in this plane strain analysis, using the method by Williams and Waite (1993)¹ as presented in CIRIA C760. The maximum wall displacement is computed to be 8 mm.

Table 6: Computed Results of the Proposed Soldier Pile Wall in Analysis Section 1

Construction Stage	Wall Lateral Displacement (mm)	Maximum Bending Moment ¹ (kNm)	Maximum Shear Force ¹ (kN)
Excavate to RL16.3	2	122	229
Excavate to RL15.0	2	91	256
Excavate to RL13.8	3	69	254
Excavate to RL12.3	5	113	183
Excavate to RL10.35	8	132	202

¹ – Value shown is unfactored.

Figure 2 shows the lateral displacement and forces induced in the proposed soldier pile wall for each construction stage.

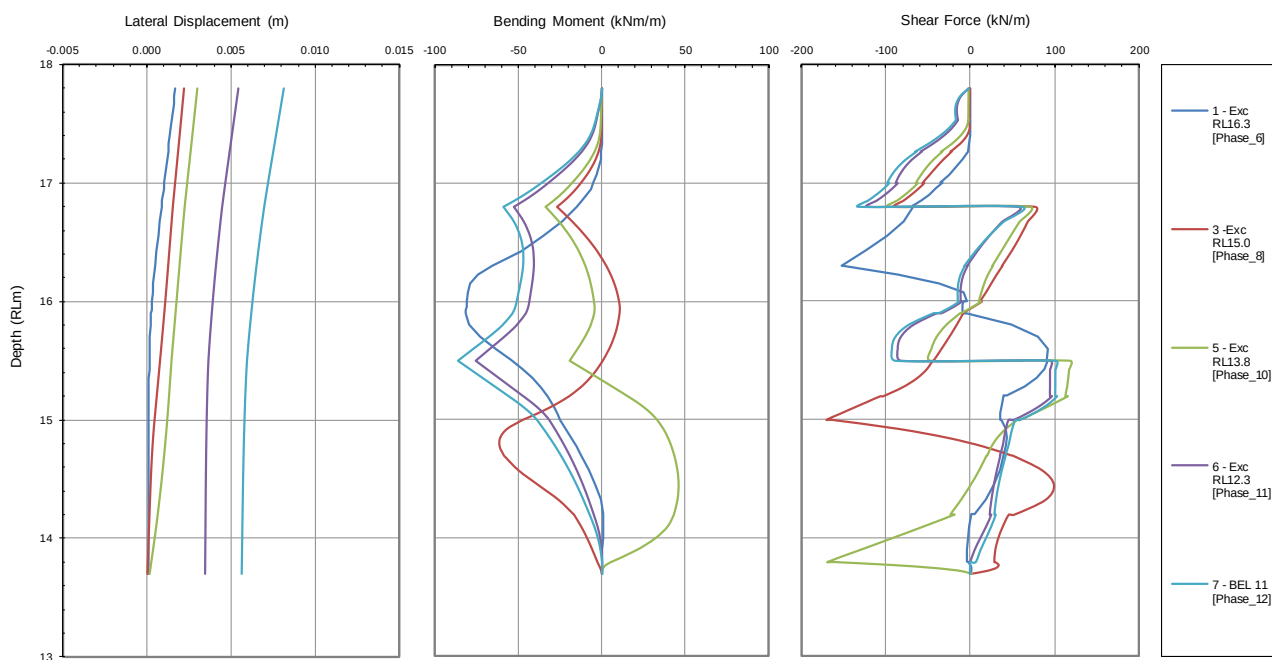


Figure 2: Lateral Displacement and Forces Induced in the Proposed Soldier Pile in Analysis Section 1

¹ Williams, B. P., & Waite, D. (1993). The design and construction of sheet-piled cofferdams (No. 95).

Table 7 summarises the anchor load considered in Analysis Section 1. A relatively high anchor prestress is required to limit the displacement of the existing soldier pile wall to be less than 10 mm as advised by RBG.

A planar wedge limit equilibrium analysis has been carried out, assuming a potential rock wedge formed from the nearest existing pad footing (i.e. 1.8 m behind the soldier pile wall) to the toe of the existing soldier pile (i.e. 2.6 m below the existing basement soffit). Based on the calculation, the proposed anchor loads satisfied the required load to stabilise the rock wedge.

Considering the location of the existing pad footings and the associated stress imposed on the ground, a minimum anchor free-length of 4 m is suggested.

A waler or capping beam is recommended to allow the load from the existing pad footings to be distributed over a greater extent of the wall.

Table 7: Temporary Anchor Force Schedule for Analysis Section 1

Row	Spacing (m)	Inclination (°)	Anchor Prestress Load ¹ (kN/anchor)	Maximum Axial Force ¹ (kN/anchor)
R1	1.5	15	250	350
R2	1.5	15	250	300

¹ – Value shown is unfactored and a waler is required to distribute the load equally in a row.

A lateral earth pressure of 20 kPa is suggested to be adopted for the design of the shotcrete wall between the soldier piles.

The soldier piles are recommended to be socketed 0.5 m in Unit 4. Based on the axial load of 600 kN induced in each of the soldier pile, it is recommended a rock ledge should be formed by having the vertical cut face at 0.2 m away from the piles. We recommend an allowance for rock bolts at 0.5 m below the pile toe. Note that this bearing assessment should be reviewed if there is additional external load applied on the piles or a change in the inclination of anchors.

Table 8 summarises the performance of existing soldier pile wall, which consists of 600 mm diameter piles at 1.5 m spacing. The maximum vertical and lateral displacement computed is 5 mm and 8 mm respectively. Impact assessment due to excavation should consider these displacements and additional induced forces in the existing soldier piles. The displacements (i.e. vertical and lateral) of the existing pad footings are similar to those experienced by the existing soldier piles wall.

Table 8: Computed Results of the Existing Soldier Pile Wall in Analysis Section 1

Construction Stage	Wall Vertical Displacement (mm)	Wall Lateral Displacement (mm)	Additional Induced Bending Moment ¹ (kNm)	Additional Induced Shear Force ¹ (kN)
Excavate to RL16.3	0	1	28	73
Excavate to RL15.0	0	2	31	53
Excavate to RL13.8	2	3	24	37
Excavate to RL12.3	4	5	7	18
Excavate to RL10.35	6	8	3	15

¹ – Value shown is unfactored.

An output for Analysis Section 1 is attached in APPENDIX A.

7.2 Analysis Section 2 – Adjacent to Road

Table 9 summarises the results computed in Analysis Section 2, for the proposed 600 mm diameter soldier pile wall at 2.4 m spacing for each construction stage.

Table 9: Computed Results of the Proposed Soldier Pile Wall in Analysis Section 2

Construction Stage	Wall Lateral Displacement (mm)	Maximum Bending Moment ¹ (kNm)	Maximum Shear Force ¹ (kN)
Excavate to RL23.6	13	41	49
Excavate to RL22.2	11	62	88
Excavate to RL19.7	11	79	118
Excavate to RL17.7	11	86	131
Excavate to RL15.7	13	97	150
Excavate to RL13.7	15	108	170
Excavate to RL10.35	18	126	207

¹ – Value shown is unfactored.

Experience with basement construction in shale and sandstone in Sydney has typically indicated lateral displacements in the order of $H / 1,000$ (where H is the height of the excavation). For excavation of 15 m, the indicated lateral displacement is approximately 15 mm.

Figure 3 shows the lateral displacement and forces induced in the proposed soldier pile wall for each construction stage.

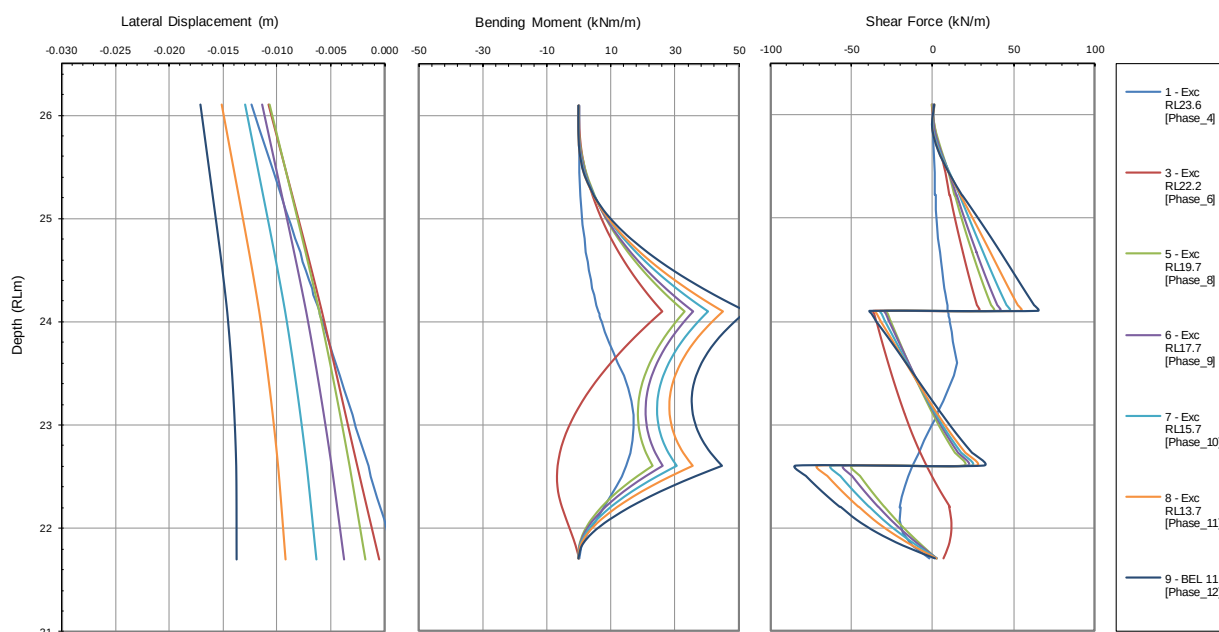


Figure 3: Lateral Displacement and Forces Induced in the Proposed Soldier Pile in Analysis Section 2

Table 10 summarises the proposed anchor load considered in Analysis Section 2.

The proposed depth of 2 m below ground level for the first row is based on the depth of encountered underground services (e.g. Optus cable) approximately 1 m below ground level. The actual alignment and depth of any underground services behind the soldier pile wall should be verified on-site before drilling and installation of the anchor are commenced.

For this analysis, the second row of anchors is proposed to be above the Lower Ground (LG) Floor slab. The subsequent analysis is required to consider the top of slab level for LG Floor and Upper Ground (UG) Floor as it varies across the site.

We have assumed the anchors will be distressed after both LG and UG Floor slab is cast and gained sufficient strength. The design of the slabs should consider the redistribution of anchors loads into the slabs after the anchors have been distressed.

The anchor fixed-length should be located beyond a plane projected at an angle of 45° from the horizontal from the base of Unit 3a. Should the anchor inclination be required to be steeper to avoid underground services or/and achieve a shorter anchor total length, additional analyses are required as the effectiveness of anchor supporting the wall decreases with an increase of anchor inclination from the horizontal and additional axial force will be imposed on the supporting rock ledge. Golder can carry out additional analysis sections upon request.

Table 10: Temporary Anchor Force Schedule for Analysis Section 2

Row	Spacing (m)	Inclination (°)	Anchor Prestress Load ¹ (kN/anchor)	Maximum Axial Force ¹ (kN/anchor)
R1	2.4	15	150	250
R2	2.4	15	150	300

¹ – Value shown is unfactored.

A lateral earth pressure of 20 kPa is suggested to be adopted for the design of the shotcrete wall between the soldier piles.

The soldier piles are recommended to be socketed 0.5 m in Unit 3a. Based on the axial load of 58 kN computed in each of the soldier piles due to the inclination of the anchors, it is recommended that a rock ledge be formed by having the vertical cut face at 0.2 m from the piles. Note that this bearing assessment should be reviewed if there is additional external load applied on the piles or a change in the inclination of anchors.

An output for Analysis Section 2 is attached in APPENDIX B.

8.0 DISCUSSION AND RECOMMENDATIONS

8.1 Proposed Retention System

The proposed retention system consists of anchored soldier pile wall with shotcrete infill and vertical cuts in the underlying competent rock (i.e. Unit 3b and 4). In addition to the recommendations as listed in Section 7.3 in our geotechnical investigation report (ref.: 19125312-001-Rev1), it is worthwhile to note the following:

- We have not considered any long-term loadings. If required, the length of the soldier piles can be extended to achieve sufficient geotechnical resistance depending on the imposed loads;
- We have assumed that a temporary drainage system be designed to manage construction groundwater inflows, which could include strip drains behind the infill shotcrete wall between the anchored soldier piles;
- The installation and testing of the anchors should be in accordance to AS5100.3. Equivalent or better anchor type in term of axial stiffness can be adopted;
- The grouted length of the ground anchor is to be assessed by an anchor contractor and these anchors should be proof load tested to 1.25 times the Maximum Axial Force and locked off at the Anchor Prestress Load as set out in Table 7 and Table 10;
- The ground anchors in the detailed design stage (i.e. inclination, length and depth) should avoid all the underground services;
- In Analysis Section 1, we note that the existing pad footings are spaced approximately 7.5 m apart along with the existing soldier pile wall. Upon request from Built, we can carry out further in-depth analysis such as 3D modelling to refine the anchor and wall requirements
- Excavations through shale and sandstone in Sydney may encounter adversely inclined joints that can result in significant blocks of rock becoming dislodged from the excavation face, which may apply additional loads to the adopted retention system as well as a potential safety risk during construction. We consider that there is a low risk of these blocks occurring and dislodging, assuming the excavation in rock will be carried out in 2 m depth interval and the excavated rock face is inspected by a Geotechnical Engineer. If such inclined joints are identified on-site, it is likely that further analyses will be required;
- We suggest that pattern bolting and shotcrete facing be provided for Unit 3a. We recommend that all Laminites in Unit 3a and 3b are protected by shotcrete to prevent fretting from wetting and drying of the rock face over time; and
- We have not carried out any structural design and assessment of the retention system.

The information contained in this report is sensitive to the suitability of the assumptions made and discussed throughout. If any of these assumptions are found to be inappropriate, it may be necessary to carry out further analyses and to revise this report.

8.2 The Adjacent Building North-West of the Site

An analysis section, Analysis Section 1, has carried out considering the foundation load (provided by RBG) from the adjacent building behind the proposed soldier pile wall. This report has included an estimated displacement of the footings and forces induced in the soldier pile wall due to excavation. We have not assessed the impact of the construction works and excavation on this building.

Due to the relatively high foundation load from this building, the proposed soldier pile is to be constructed through Unit 3b (medium to high strength Laminite) and terminated on the top of Unit 4 (high to very high strength Sandstone).

Based on the drawings provided, the excavation is expected to expose the buried ground anchors of the adjacent building. Prior commencement of excavation, an agreed method of excavating and removal of the existing anchor should be developed with the involvement of the relevant stakeholders and structural engineers.

The proposed soldier piles are designed at 1.5 m spacing, identical to the spacing of the existing soldier pile for this adjacent building. The proposed soldier piles should be installed between the span of the existing soldier piles, allowing the proposed ground anchors can be installed without obstruction by these existing soldier piles.

The proposed ground anchors are below the groundwater table and within the zone providing geotechnical resistance to the foundation of the existing building. The construction and installation of ground anchor should consider any disturbance may reduce the available geotechnical resistance to the existing foundation.

8.3 Temporary batter slope between construction Stage 1 and Stage 2

We understand that temporary batter slopes may be adopted, allowing bulk excavation can commence in the first stage of works. Figure 4 shows an indicative batter slope angle for the temporary batter based on the nearest borehole. A batter slope length of approximately 20 m on the plan may be required for an excavation depth of 15 m.

We have not carried out any analysis to include considerations such as surcharge, groundwater table, construction sequence and defects which may be encountered in Unit 3a, 3b and 4. Surface erosion control may be required for the batter in Unit 1 and 2 depending on the construction duration between stages. Steeper batters in Unit 3b and 4 may be possible subject to further assessments.

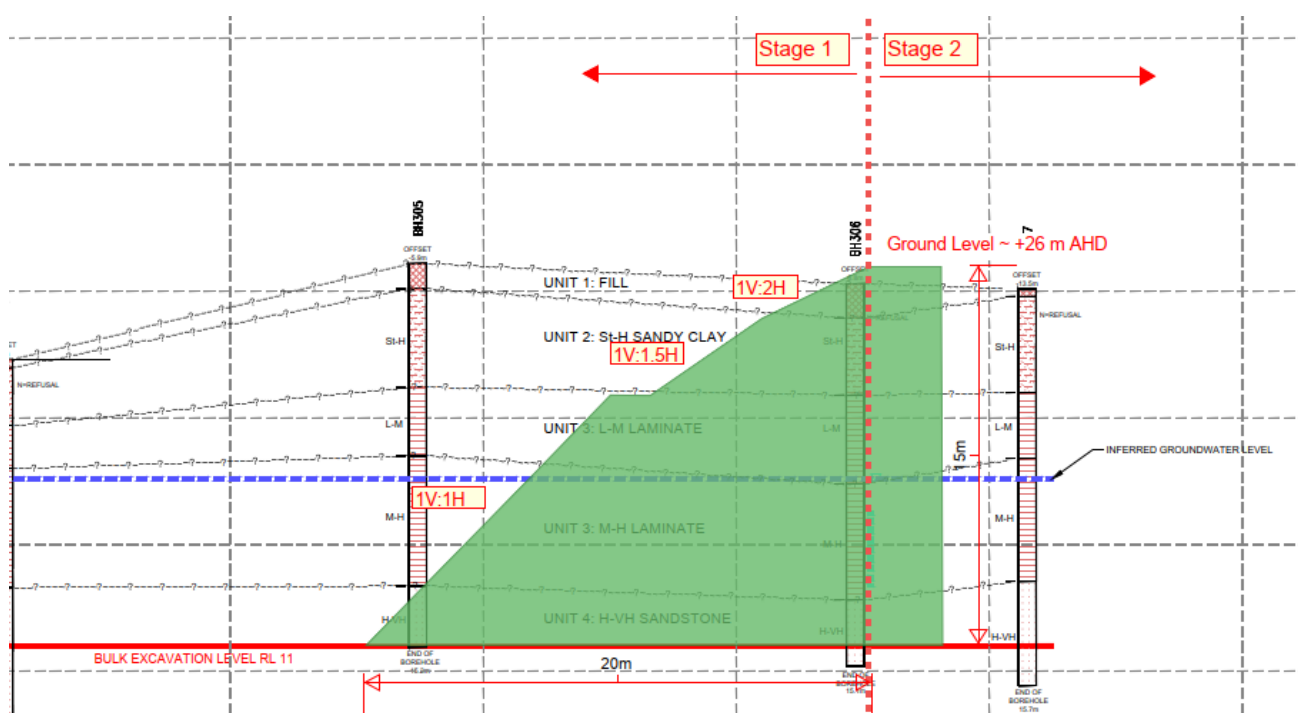


Figure 4: Indicative Batter Slope between Stage 1 and Stage 2

8.4 Indicative Monitoring Requirements

We recommend that monitoring of deformations of the walls of the excavation be undertaken at regular intervals during construction. The performance of the retaining wall and response of the adjacent building during excavation should be monitored with suitable monitoring regime and systems, which can consist of three-dimensional survey targets/monitoring points, settlement monitoring points, and/or inclinometers.

Groundwater monitoring well(s) might be required depending on the requirements by council for a drained basement to monitor the groundwater drawdown.

The settlement monitoring points and groundwater wells should be installed and monitored prior to the commencement of excavation works. The survey targets should be attached to the shotcrete, between anchor heads as soon as practical after the construction of the wall to the level at which the targets will be located.

Due to the proximity of the excavation to the building adjacent to the north-west of the site, the building is expected to be susceptible to damage from vibrations when rock excavations are made in the immediate vicinity. We anticipate vibration monitoring would be required to verify allowable limits is achieved on site.

If requested, we can develop a Geotechnical Monitoring Programme presenting:

- Monitoring and instrumentation requirements;
- Recommended hold points and trigger levels of all monitoring systems; and
- Details of action plan and contingency for the principal building contractor in the event trigger levels are exceeded.

9.0 IMPORTANT INFORMATION

Your attention is drawn to the document “Important Information”, which is attached to APPENDIX C of this report. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be and to present you with recommendations on how to minimise the risks associated with the services provided for this project. The document is not intended to reduce the level of responsibility accepted by Golder Associates, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

Golder Associates Pty Ltd



Eric Woon
Senior Geotechnical Engineer



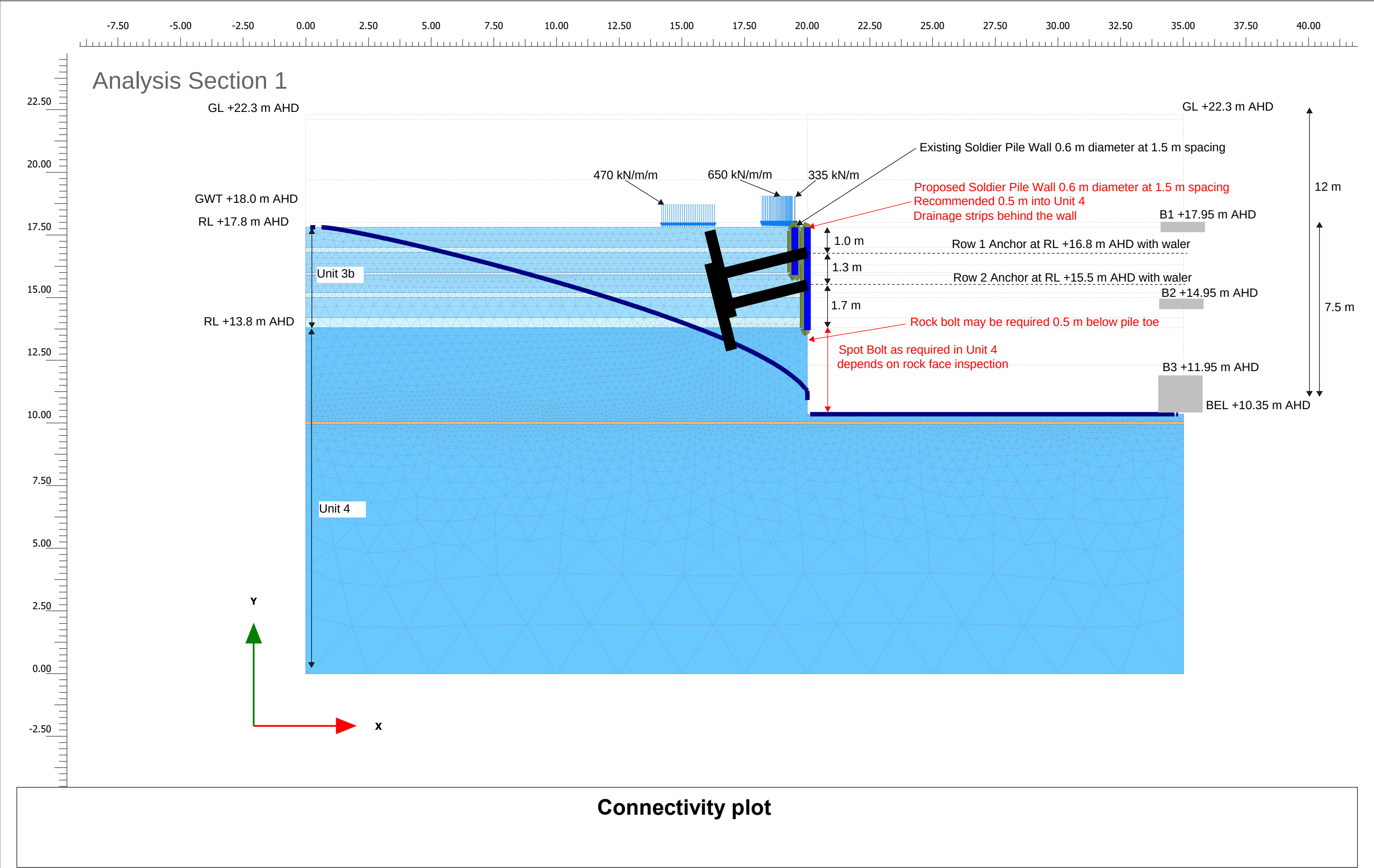
Les McQueen
Principal Engineer

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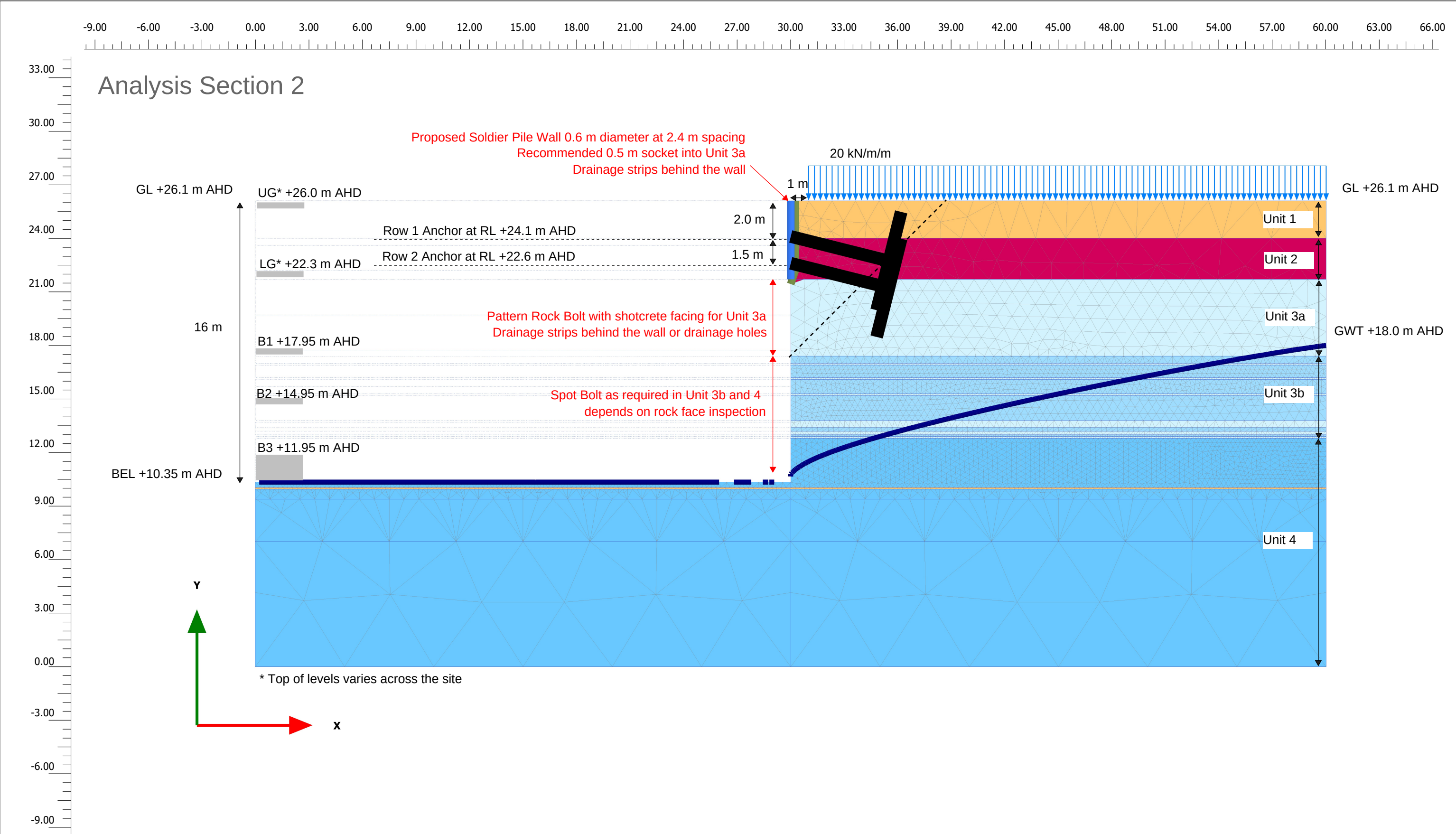
APPENDIX A

Analysis Output for Section 1



APPENDIX B

Analysis Output for Section 2



Connectivity plot

APPENDIX C

Important Information

The document ("Report") to which this page is attached and which this page forms a part of, has been issued by Golder Associates Pty Ltd ("Golder") subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services ("Services") provided by Golder to its client ("Client") under and subject to a contract between Golder and its Client ("Contract"). The contents of this page are not intended to and do not alter Golder's obligations (including any limits on those obligations) to its Client under the Contract.

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This Report has been prepared in the context of the circumstances and purposes referred to in, or derived from, the Contract and Golder accepts no responsibility for use of the Report, in whole or in part, in any other context or circumstance or for any other purpose.

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Having regard to the matters referred to in the previous paragraphs on this page in particular, carrying out the Services has allowed Golder to form no more than an opinion as to the actual conditions at any relevant location. That opinion is necessarily constrained by the extent of the information collected by Golder or otherwise made available to Golder. Further, the passage of time may affect the accuracy, applicability or usefulness of the opinions, assessments or other information in this Report. This Report is based upon the information and other circumstances that existed and were known to Golder when the Services were performed and this Report was prepared. Golder has not considered the effect of any possible future developments including physical changes to any relevant location or changes to any laws or regulations relevant to such location.

Where permitted by the Contract, Golder may have retained subconsultants affiliated with Golder to provide some or all of the Services. However, it is Golder which remains solely responsible for the Services and there is no legal recourse against any of Golder's affiliated companies or the employees, officers or directors of any of them.

By date, or revision, the Report supersedes any prior report or other document issued by Golder dealing with any matter that is addressed in the Report.

Any uncertainty as to the extent to which this Report can be used or relied upon in any respect should be referred to Golder for clarification