# Albert Street Cavern Assessment Report
# Albert Street - Future Over Station Development
# Brisbane, QLD

Prepared for:
Albert Street Trust

Document Reference:
B01493-1AE

Version:
29 May 2023

PLANS AND DOCUMENTS
referred to in the PDA
DEVELOPMENT APPROVAL

Approval no: DEV2023/1374
Date: 06-Nov-2023

Queensland Government

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Notes:
This version supersedes the previous version dated 21/12/23 and contains additional commentary to address comments raised by EDQ.

EDG consulting

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# 1 Project Background

The CRR Albert Street Pty Ltd (ACN 660 319 693) as trustee for CRR Albert Street Trust (Albert Street Trust) has been awarded the development rights for the Cross River Rail (CRR) precincts, including the proposed development at Albert Street in the Brisbane CBD.

Development of the 101 Albert Street mixed used precinct will include a commercial tower in the order of 200m tall with approximately 45 floors above ground level. The building will include a multi-level basement, which must be designed to satisfy the requirements of the Cross River Rail Delivery Authority (CRRDA), due to the presence of CRR assets below.

RCP Australia Pty Ltd (RCP) has, on behalf of Albert Street Trust, engaged EDG Consulting Pty Ltd (EDG) to provide geotechnical services for the project in three stages:

- Stage 1 – Geotechnical advice to help inform the Development Application (DA).
- Stage 2 – Geotechnical design as part of the detailed design of the building.
- Stage 3 – Geotechnical investigation and reporting to verify the basis of the design.

An assessment of ground stresses and cavern distortions associated with the proposed building loads must be carried out and included in the DA submission. The purpose of the assessment is to allow a comparison of ground stresses and deformations at the Albert Street cavern from the proposed building loads, with those same ground stresses and deformations at the cavern which are associated with the design load cases as nominated in the CRR Project Scope and Technical Requirements (PSTR).

This report presents our assessment of ground stresses and deformations, which adopts details appropriate to inform the DA submission. The assessment is based on a series of Finite Element models that consider inputs appropriate for the Development Application stage of the project. The models incorporate the Development Application stage ground model, groundwater conditions, material parameters, impacts of tunnel excavation, construction stages and applied loads from the 101 Albert Street building development to assess ground stresses and deformations of the Albert Street cavern.

The assessment is intended to provide confidence at this early design stage that the predicted effects associated with the proposed building loads are within those calculated as part of the cavern permanent lining design.

Further analysis will be required at detailed design stage.

# 2 Site Details

Site details, including location, ground stratigraphy, soil and rock parameters, groundwater and geotechnical advice relating to building elements such as the retention system, foundations, construction aspects and the like have been reported in our Geotechnical Engineering report (Ref. B01493-1AC, dated 21 December 2022). Only selected information presented in that report is repeated herein for ease of reference and this report must therefore be read in conjunction with the B01493-1AC report.

# 3 Basis of Analysis

## 3.1 Analysis Methodology

The Albert St cavern designer (PSM) is prohibited from contributing to the development application at this stage due to its existing role on the CRR project. Further, the detailed outcomes of the analyses carried out by PSM as part of the Albert St cavern design are unavailable. Therefore, to provide a comparison between the cavern design load cases and the effects of the proposed building loads, we have developed a 3D finite element model to assess ground stresses and cavern liner distortions associated with the proposed building loads and the Future Over Station Development (FOSD) load cases.

The Finite Element model is considered as simplified at this stage as the ground model comprises horizontal layers only and the applied structural loads have been generated from an early stage structural model. In the detailed design stage, the ground conditions would be based on the actual interpreted stratigraphic layers and the model would incorporate loads from a more developed structural model, which will include wind loads assessed from wind tunnel testing.

The assessment adopts the process shown in Diagram 1.

Develop a 3D FE model representing the Lot 2 site appropriate for analysis at DA stage

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Use the model to assess normal stress on the cavern lining and cavern distortion, arising from the CRR PSTR FOSD Load Cases

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Use the model to assess normal stress on the cavern lining and cavern distortion, arising from the proposed building loads

↓

Compare the analysis outcomes

↓

Smaller ground stresses and deflections from the proposed building load cases compared with the FOSD cases would suggest that the proposed building loads are within design limits.

↓

Further analysis to be carried out during detailed design

Diagram 1 – Analysis Process

### 3.2 Model Calibration

Ideally, the finite element model developed as part of this assessment would be calibrated with the finite element model used in the design of the cavern lining, by comparing the direct analysis outcomes that relate to specific load cases. We have reviewed the information presented in the Albert Street cavern detailed design report, aiming to extract key modelling outcomes that relate to the FOSD load cases, however, the cavern design modelling outcomes are presented in a summarised format and therefore the exact analysis outcomes that directly relate to each FOSD load case are not available.

We have therefore carried out the following comparisons to gain confidence that the cavern design modelling and the modelling as part of this assessment are similar:

- The ground stratigraphy adopted for this assessment was compared with the ground stratigraphy adopted for the cavern design analysis (as presented in the CRR Geotechnical Interpretative Report GIR Ref. CRRTSD-000-0351-RPT-PSMQ-1120-030021), and both were assessed to be sufficiently similar at the cavern location.
- The soil and rock material parameters adopted in the cavern assessment were all the same or similar to those adopted for the cavern design analysis, as presented in the CRR GIR. Please refer to our Geotechnical Engineering report for further details regarding development of the ground model (Ref. B01493-1AC).
- The cavern permanent lining details adopted in the cavern assessment, were based on the IFC drawings and were consistent with the details adopted in the cavern design. Note that the cavern geometry and lining thickness was based on the CRR drawing set: CRRTSD-300-0323-DRG-PSMQ-1330-190000s series.

## 3.3 Load Cases

The CRR PSTR nominates that design of the cavern lining must consider several FOSD load cases. Those load cases are defined in PSTR clauses OSD-31, OSD-46, OSD-47 and OSD-48. For ease of reference, those clauses are presented in Table 1, and are shown graphically on the attached sketches attached in Appendix A.

Table 1 – Assessment Load Cases

| Load Case[1] | Additional Loading | Excavation or Distortion | PSTR Ref. |
|---|---|---|---|
| 1 | 375kPa working load applied over part or the entire Albert Street Lot 2 site, applied at RL +4.0m | | OSD-31 |
| 2 | 375kPa working load applied over part or the entire Albert Street Lot 2 site, applied at RL -8.0m | Excavation over the Albert Street Lot 2 site to RL-8.0m | OSD-31 |
| 3 | | Excavation over the Albert Street Lot 2 site to RL-8.0m | OSD-46 |
| 4 | | Excavation over the Albert Street Lot 2 site to RL-8.0m in the restricted zone and to RL -20m in other parts of the site | OSD-47 |
| 5 | Vertical load of 50kPa acting on the ground 1m from the Tunnel crown, plus an additional 20kPa applied at ground surface | | OSD-48 |

| Load Case[1] | Additional Loading | Excavation or Distortion | PSTR Ref. |
|---|---|---|---|
| 6 | | i) Up to 7m below natural surface to allow for future development<br><br>ii) with a minimum of 10m residual ground cover above the Tunnel crown<br><br>iii) with a minimum 10m pillar width between the side wall of the Tunnel and any adjacent building basement excavation. | OSD-48 |
| 7 | Vertical load of 75kPa acting on the existing ground level, plus an additional 20kPa applied at ground surface | Permanent support to accommodate additional distortion of 15mm/span. | OSD-48 |

Notes: 1 – Load case numbers shown relate to this document only. Load cases may be referred to differently in other relevant documents.

We consider that interpretation of Load Cases 1 to 6 is relatively straightforward and is as illustrated on the sketches included in Appendix A.

Our interpretation of Load Case 7 is that the additional loading of 75kPa acting at existing ground surface and the additional 20kPa applied at ground surface are applied first and the associated cavern distortion calculated. The horizontal stiffness of the ground surrounding the tunnel is then reduced to achieve a distortion of 7.5mm/radius, over and above that associated with application of the 75kPa and 20 kPa surcharges. The total cavern distortion assessed in the design from Load Case 7 is, therefore, the combination of the calculated distortion from the surcharge loads and the additional distortion allowance of 7.5mm/radius.

# 4 Finite Element Modelling

## 4.1 Material Parameters

Modelling of the proposed works was carried out using the commercially available finite element software package Plaxis 3D (2020). The model adopted horizontal soil and rock layers that were generally consistent with the ground stratigraphy adopted in the cavern design as shown on the geological sections presented in the CRR GIR, however for the purpose of this early stage assessment, horizontal soil and rock layers have been adopted. The model is summarised in Table 2.

Table 2 – Interpreted Ground Model

| Material Unit | Unit Description | Unit thickness (m) | Depth Range below ground level[1] (mBGL) | Elevation Range (mAHD) |
|---|---|---|---|---|
| Fill | Sandy Clay / Gravelly Sand: high plasticity, fine to coarse grained sand and gravel, firm to stiff / medium dense. | 1.6 | 0m to 2.6m | RL 4m to RL 2.4m |
| Alluvial | Clay: high plasticity, dark grey, firm | 7.4 | 2.6m to 10m | RL 2.4m to RL -5m |
| Residual | Clay: high plasticity, red-brown motley grey, stiff to very stiff | 4.6 | 10m to 14.6m | RL -5m to RL -9.6m |
| NFG 5 | Sandy Clay: low to medium plasticity, brown and grey, fine to coarse angular gravel and sand, hard with visible rock structure | 1.2 | 14.6m to 15.8m | RL -9.6m to RL -10.8m |

| Material Unit | Unit Description | Unit thickness (m) | Depth Range below ground level[1] (mBGL) | Elevation Range (mAHD) |
|---|---|---|---|---|
| NFG 3 | Phyllite: fine grained, grey and pale brown, distinct laminations, dipping at 60° to 65°, medium strength, moderately weathered. | 2.2 | 15.8m to 18m | RL -10.8m to RL -13m |
| NFG1 / NFG2 | Phyllite: fine grained, pale grey-blue, distinctly laminated, high strength, fresh. | > 10 | 18m to beyond 25.8m | RL -13m to beyond RL -21.8m |

Notes: [1] Ground level refers to top of existing concrete slab at RL 4.0m AHD.

Soil and rock behaviour was represented by a linear-elastic perfectly plastic continuum constitutive model for all material units apart from the Alluvium, where the Hardening Soil constitutive model was used. Plasticity was controlled by a stress-dependent Mohr-Coulomb failure criterion for all soil types, based on the material parameters presented in Table B1, included in Appendix B. Drained shear strength parameters were used for all materials in all stages. Structural loads were defined by RBG and were applied as point loads at the pile heads or at the column location for the shallow footings. A loading plan showing that magnitude and location of structural loads is provided in Appendix C.

## 4.2 Groundwater

Groundwater monitoring data from three vibrating wire piezometers (VWPs) located within proximity of the site location is summarised in Table 3.

Table 3 – Available Groundwater Monitoring Data Summary

| Location | Available Monitoring Period | | Groundwater RL (m AHD) |
|---|---|---|---|
| | From | To | |
| CRR1025 | September 2020 | February 2021 | -22 |
| CRR1026 | October 2020 | August 2021 | -23 |
| CRR1031 | August 2020 | May 2023 | -21 |

Based on the monitoring data presented in Table 3, the groundwater elevation is at approximately RL -20m, which is approximately mid-height of the cavern. We note however, that the cavern design report confirms that the cavern is drained and therefore the groundwater level in the rock would be drawn down locally within proximity of the cavern.

No groundwater monitoring data exists for the shallow materials such as the Fill and Alluvium, however it is possible that a perched water table exists within the fine-grained Alluvium.

Considering the above, two groundwater scenarios have been considered in this assessment, comprising:

- **Groundwater Case 1** – Perched groundwater within Alluvium. Local hydrostatic groundwater conditions within Alluvium, with phreatic surface adopted at the top of the Alluvium layer. The groundwater level within the NFG (rock) units adopted at the cavern invert level at approximately RL -30m.
- **Groundwater Case 2** – As above, but with a higher groundwater level of RL-15m adjacent to the cavern as illustrated in Diagram 2.

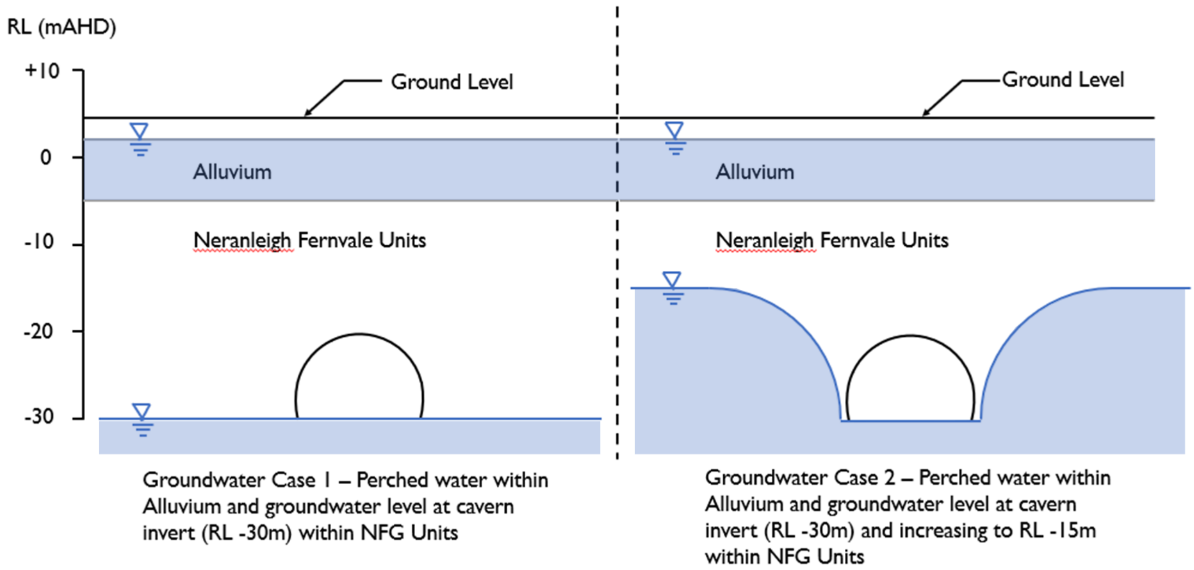


Diagram 2 – Groundwater Cases

## 4.3 Structural Elements

Details of the structural elements used in the analysis are presented in Table 4.

Table 4 – Finite Element Model Structural Elements

| Component | Plaxis Element Type | Details |
|---|---|---|
| Cavern Liner | Plate | The crown and sidewalls are modelled as a 700mm thick plate element. The base slab is modelled as a 300mm thick plate element. An elastic modulus value of 32.8GPa has been assigned to both plates. |
| Retention Piles | Beam | Retention piles are modelled as a 0.9m diameter circular beam with centre to centre spacing of 1.8m. An elastic modulus value of 32.8GPa has been assigned to the beams. |
| Shotcrete for retention wall | Plate | The shotcrete panels between the retention piles are modelled as 150mm thick plate elements. An elastic modulus value of 24GPa has been assigned to all plates. |
| Prop (914x19 CHS GR350LO) | Node to Node Anchor | All props are modelled as node to node anchors. A stiffness value (EA) of 10.7 GN has been assigned to all node to node anchors. No pre-stress was included in any of the props. |
| Twin waler beam (1200WB455 GR400) | Beam | The twin waler beam has been modelled as a single beam element in our model, adopting material properties representative of the twin waler beam. An elastic modulus value of 200GPa has been assigned to all beams. Second moment of area values of $30.67 \times 10^9 mm^4$ and $8.91 \times 10^9 mm^4$ have been adopted in the two orthogonal bending directions. |
| Concrete Core Slab (PC3) | Soil Volume | The concrete core slab has been modelled as a 3m thick volume of linear elastic material. An elastic modulus value of 39.6GPa has been assigned to the volume. |
| Core Piles | Embedded Beam | All core piles are modeled as 1.2m diameter embedded beams. An elastic modulus value of 34.8GPa has been assigned to all beams. Skin friction values as per report Ref. B01493-1AC are adopted for the material units. No skin friction has been allowed for piles within the steel sleeved zones. |

| Component | Plaxis Element Type | Details |
|---|---|---|
| Podium Pile Cap (PC1) | Plate | The podium pile caps are modelled as 2.5m thick plate elements. An elastic modulus value of 39.6GPa has been assigned to all plates. |
| Podium Piles | Embedded Beam | All podium piles are modeled as 1.6m diameter embedded beams. An elastic modulus value of 34.8GPa has been assigned to all beams. Skin friction values as per report Ref. B01493-1AC are adopted for the material units. No skin friction has been allowed for piles within the steel sleeved zones. |
| Shallow Foundation Footing Type 1 (PF1) | Plate | Shallow footings type 1 (PF1) are modelled as 1.5m thick plate elements. An elastic modulus value of 34.8GPa has been assigned to all plates. |
| Shallow Foundation Footing Type 2 (PC2) | Plate | Shallow footings type 2 (PC2) are modelled as 1.2m thick plate elements. An elastic modulus value of 34.8GPa has been assigned to all plates. |

The finite element model is shown indicatively in Diagram 3.

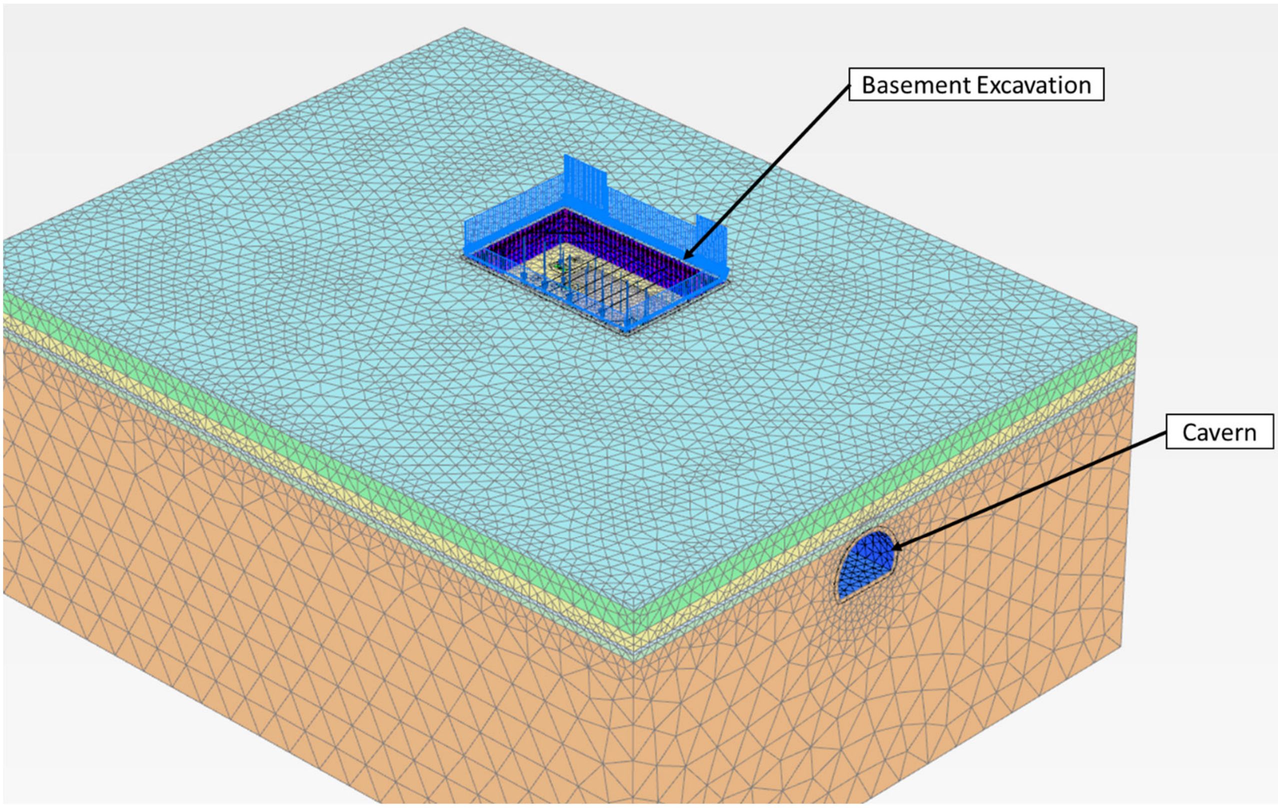


Diagram 3 – Finite Element Model

## 4.4 Construction Stages

The analysis adopted the construction stages as presented in Table 5.

Table 5 – Construction Sequence

| Analysis Stage | Description | Details |
|---|---|---|
| 1 | Initial stage | Initial stresses are defined in the model using the $K_0$ procedure. |
| 2 | Tunnel excavation | The tunnel is excavated across the model. Stress relaxation of the tunnel is represented using the $\Sigma M_{Stage}$ factor. |
| 3 | Tunnel liner installation | The tunnel liner is activated after stress relaxation from the previous stage. The tunnel liner is modelled as plate elements. |
| 4 | Retention piles installation | Retention piles around the perimeter of the site are activated. The retention piles are modelled as beam elements. |
| 5 | Excavation no.1 | Shaft excavation is undertaken in three stages. The first stage of the excavation extends to 0.5m below the elevation of the upper row of strut and waler beams. |
| 6 | Upper prop and waler installation | The upper row of prop and waler beam is activated. The props are modelled as node to node anchors. The waler beams are modelled as beam elements. |
| 7 | Excavation no. 2 | Shaft excavation is undertaken in three stages. The second stage of the excavation extends to 0.5m below the elevation of the lower row of strut and waler beams. |
| 8 | Lower prop and waler installation | The lower row of prop and waler beam is activated. The props are modelled as node to node anchors. The waler beams are modelled as beam elements. |
| 9 | Excavation no. 3 | Shaft excavation is undertaken in three stages. The third stage of the excavation extends to the final excavation elevation. |
| 10 | Shallow footings, core slab, pile cap and pile installation | All shallow footings, core slab, pile caps and piles are installed in a single stage. The shallow footings and pile caps are modeled as plate elements. The core slab is modelled as a material volume. The individual piles are modelled as embedded beam rows. |
| 11 | Apply loading | Axial and lateral loads for the piles, as provided by RBG, are applied at the head of each individual piles as point loads.<br>The vertical loads along the retention system has been modelled as line loads acting at the top of the retaining piles. |

## 4.5 Cavern Construction

We have made allowance for the progressive installation of primary lining by assessing the stress relaxation prior to support installation following the method by Hoek (2008[1]). This method assesses the proportion of convergence experienced at a point of interest back from the tunnel face. Using this method, we are able to estimate the relative proportion of convergence due to tunnelling that

[1] Hoek, E., Carranza-Torres, C., Diederichs, M.S. and Corkum, B. 2008. Integration of geotechnical and structural design in tunnelling. Proceedings University of Minnesota 56th Annual Geotechnical Engineering Conference. Minneapolis, 29 February 2008, 1-53

would have occurred prior to installation of the primary lining. The proportion of total convergence at each analysis stage is considered in the Finite Element (FE) analysis via the PLAXIS "$M_{Stage}$" factor input.

The tunnel relaxation depends on a several factors associated with the method of construction including the plastic radius and the unsupported length prior to support installation. To assess an appropriate range of values that might apply a parametric study considering these variables has been carried out.

Assessment of the $M_{Stage}$ factor was carried out in accordance with the following process:

1. The equivalent cavern radius was adopted based on the cavern cross section dimensions.
2. The plastic zone radius was assessed by running an FE model to identify yield points around the cavern. As the model showed no yield points around the cavern, the plastic radius is assessed to equals the cavern radius.

   For the purpose of this assessment, two scenarios of plastic zone radius have been adopted; 0m based on these FE results and a 2m plastic zone radius to allow for possible rock mass disturbance during cavern excavation.
3. The assessment of the unsupported cavern length was based on the details of the primary support design for the cavern. Three primary support types are nominated for the cavern, as shown on the CRR drawing set: CRRTSD-300-0322-DRG-PSMQ-1330-180000s series. These support types are summarised in Table 6.

Table 6 – Primary Support Types

| Support type | Max. Face Advance (m) | Max. Distance to Bolts (m) | Distance to ≥ 200mm Shotcrete (m) | Unsupported Cavern Length Based on | | Bolt Spacing (m) |
|---|---|---|---|---|---|---|
| | | | | Max. Distance to Completed Primary Shotcrete (m) | Max. Distance to any Shotcrete With 15MPa Strength (m) | |
| AC1-1 | 1.5 | 2.5 | 2.5 | 4 | 5.5 | 1.5 |
| AC1-2 | 1.25 | 2.25 | 2.25 | 3.5 | 4.75 | 1.25 |
| AC1-3 | 1.5 | 2.5 | 4 | 8.5 | 5.5 | 1.5 |

Based on the support types in Table 6, we have considered scenarios that cover the range of unsupported cavern length to any shotcrete with minimum strength of 15MPa and completed primary shotcrete. All scenarios have considered a Plastic Radius of both 0m and 2m. The calculated $M_{Stage}$ factors are summarised in Table 7 and are presented in Appendix D.

Table 7 – Summary of Calculated $M_{Stage}$ Factors

| Cavern Primary Support Type | Distance Description | Distance Length (m) | Plastic Radius (m) | Calculated $M_{Stage}$ Factor |
|---|---|---|---|---|
| AC1-1 | Distance to any shotcrete with minimum strength of 15MPa | 5.5 | 0 | 0.69 |
| AC1-1 | Distance to any shotcrete with minimum strength of 15MPa | 5.5 | 2 | 0.64 |
| AC1-1 | Distance to completed primary shotcrete | 4 | 0 | 0.61 |

| Cavern Primary Support Type | Distance Description | Distance Length (m) | Plastic Radius (m) | Calculated $M_{Stage}$ Factor |
|---|---|---|---|---|
| AC1-1 | Distance to completed primary shotcrete | 4 | 2 | 0.56 |
| AC1-2 | Distance to any shotcrete with minimum strength of 15MPa | 4.75 | 0 | 0.65 |
| AC1-2 | Distance to any shotcrete with minimum strength of 15MPa | 4.75 | 2 | 0.60 |
| AC1-2 | Distance to completed primary shotcrete | 3.5 | 0 | 0.58 |
| AC1-2 | Distance to completed primary shotcrete | 3.5 | 2 | 0.53 |
| AC1-3 | Distance to any shotcrete with minimum strength of 15MPa | 5.5 | 0 | 0.69 |
| AC1-3 | Distance to any shotcrete with minimum strength of 15MPa | 5.5 | 2 | 0.64 |
| AC1-3 | Distance to completed primary shotcrete | 8.5 | 0 | 0.80 |
| AC1-3 | Distance to completed primary shotcrete | 8.5 | 2 | 0.75 |

Our calculations indicate that based on the various scenarios considered, the calculated $M_{Stage}$ factor varies between 0.5 and 0.8. To consider the potential variability in the degree of stress relaxation of the tunnel, we have undertaken sensitivity assessments considering a convergence factor of 50% and 80% (i.e. in PLAXIS, setting $M_{Stage}$ to 0.5 and 0.8). Outcomes of the sensitivity analysis are discussed in Section 4.4.

## 4.6 Analysis Cases

Several analysis cases have been carried out in this assessment which include the *main* analysis cases and a series of sensitivity analysis cases. All analysis cases have been grouped into one of five categories as described below. The analysis results from each analysis case group are discussed in the following sections.

- **Group 1** – Main analysis cases that provide a comparison between the CRR PSTR load cases and the proposed Albert Street FOSD building loads.
- **Group 2** – Sensitivity analysis cases investigating the relative impact of ground relaxation due to tunnel excavation, modelled as the $M_{Stage}$ Factor.
- **Group 3** – Sensitivity analysis cases investigating the relative impact of groundwater level.
- **Group 4** – Sensitivity analysis cases investigating the relative impact of rock stiffness surrounding the cavern.
- **Group 5** – Sensitivity analysis cases investigating the effects of pile steel liners.

## 4.7 Analysis Results

### 4.7.1 Analysis Group 1 – Main Cases

Analysis Group 1 comprises the main part of this assessment in which the CRR PSTR load cases and the proposed building load case are analysed and compared. The results relating to Analysis Group 1 are presented graphically on plots 1A to 1F in Appendix D and are discussed below.

Values of cavern liner displacement are presented in absolute and relative change (or delta) terms. The absolute values are total displacements from (and including) the installation of liner stage, (i.e. they include liner convergence due to construction), whereas the delta values are total displacements following installation of liner and associated construction settlement (i.e. they do not include displacements due to tunnel excavation).

Plot 1A shows that the peak absolute vertical displacement from the PSTR cases is approximately 16mm (Load Case 7) and approximately 8mm from the proposed building loads, indicating that the effects from the proposed building loads are within the design effects. Plot 1D shows that the peak delta vertical displacement from the PSTR cases is approximately 10mm (Load Case 7) and approximately 4mm from the proposed building loads, also indicating that the effects from the proposed building loads are within the design effects.

The proposed building load case results in a slight increase in vertical displacement (both absolute and delta) of approximately 2mm on the side of cavern closest to the proposed building. This indicates that the cavern is subject to a slight rotation of approximately 1 in 10,000 due to load transferred to the ground via the piles. The mechanism of movement is related to elastic settlement of the surrounding rock mass and therefore the calculated liner distortion is not a representation of a change in cavern cross section, but rather a very small translation.

Plots 1B and 1E show that the calculated absolute and delta horizontal displacements from the proposed building load case are generally within those calculated from the CRR PSTR load cases.

Plots 1C and 1F show that the calculated absolute and delta normal stresses from the proposed building load case are generally within those calculated from the CRR PSTR load cases.

### 4.7.2 Analysis Group 2 – Sensitivity Analysis of $M_{Stage}$ Factor

Analysis Group 2 comprises sensitivity analysis cases, where the ground relaxation, or $M_{Stage}$ factor is varied to investigate the relative impact of ground relaxation due to tunnel excavation. The results relating to Analysis Group 2 are presented graphically on plots 2A to 2F included in Appendix D and are discussed below.

Plots 2A, 2B and 2C show that the amount of tunnel relaxation (or value of $M_{Stage}$) affects the absolute vertical and horizontal displacement, and also the cavern normal stress. However, plots 2D, 2E and 2F show that there is negligible effect when looking at the change in (or delta) values of vertical, horizontal displacement and cavern normal stress, therefore indicating that the assessment results are not sensitive to the adopted $M_{Stage}$ factor.

### 4.7.3 Analysis Group 3 – Sensitivity Analysis of Groundwater Level

Analysis Group 3 comprises sensitivity analysis cases, where the groundwater level is varied to investigate the relative impact on the cavern displacement and normal stress. The results relating to Analysis Group 3 are presented graphically on plots 3A to 3F included in Appendix D and are discussed below.

Plots 3A to 3F show varying the groundwater level as per the groundwater cases described in Section 4.2 has little (or negligible) effect on the cavern displacements and normal stress.

### 4.7.4 Analysis Group 4 – Sensitivity Analysis of Rock Stiffness

Analysis Group 4 comprises sensitivity analysis cases, where the stiffness of the rock surrounding the cavern is varied to investigate the relative impact of rock mass stiffness on cavern displacement. The results relating to Analysis Group 4 are presented graphically on plots 4A to 4F included in Appendix D and are discussed below.

The rock mass Young's Modulus adopted for the material that surrounds the cavern is 5GPa. We have considered a sensitivity range equal to 50% and 200% of the adopted value (2.5GPa to 10GPa).

Plots 4A and 4D show that cavern vertical displacement increases due to a reduction in the rock mass stiffness. At the higher values of rock mass stiffness (5GPa and 10GPa), the vertical displacement from the proposed building load case in generally within that calculated from the plotted PSTR load case (Load Case 1). However at the lower stiffness (2.5GPa) there is a small increase of approximately 4mm in cavern vertical settlement on the side of the cavern closest to the proposed building.

Plots 4B and 4E show that the calculated absolute and delta horizontal displacements from the proposed building load case are generally within those calculated from the CRR PSTR load cases.

Plots 4C and 4F show that the calculated absolute and delta normal stresses from the proposed building load case are generally within those calculated from the CRR PSTR load cases.

#### 4.7.5 Analysis Group 5 – Sensitivity Analysis of Pile Steel Liners

Analysis Group 5 comprises sensitivity analysis cases, where pile permanent steel liners have been included in the analysis and compared against analysis where no steel liners are included. The permanent steel liners are represented in the FE model by preventing any distribution of axial force to the ground via skin friction along the length of the pile where the liner is present, (i.e. allowing axial force distribution along the socket only). The socket lengths are considered as the length of pile that extends below the 1:1 line of influence as illustrated in Diagram 4.

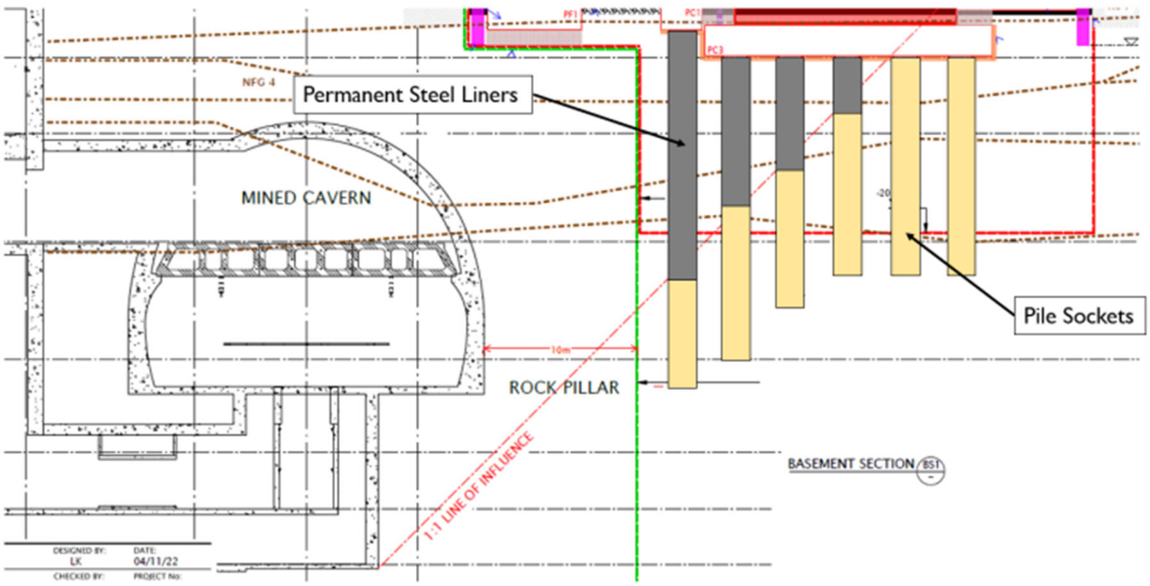


Diagram 4 – Pile Sockets

Plots 5A to 5F show that the presence of pile permanent steel liners has little effect on the cavern displacement and normal stress, which may suggest that permanent steel liners are not required for that purpose. The requirement for permanent pile liners will be further assessed during detailed design.

### 4.8 Discussion

The assessment intends to provide confidence at this early design stage that the predicted effects associated with the proposed building loads are within those calculated as part of the cavern permanent lining design.

The calculated vertical and horizontal distortions associated with the proposed building loads are generally within (or very close to) the calculated values from the CRR PSTR Load Cases 1 to 7.

The proposed building load case results in a slight increase in vertical displacement (both absolute and delta) of approximately 2mm on the side of cavern closest to the proposed building. This indicates that the cavern is subject to a slight rotation of approximately 1 in 10,000 due to load transferred to the ground via the piles. The mechanism of movement is related to elastic settlement of the surrounding rock mass and therefore the calculated liner distortion is not a representation of a change in cavern cross section, but rather a very small translation.

Calculated cavern lining normal stresses from the proposed building load case were within those calculated from Load Cases 1 to 7, however locally spike at the cavern corner closest to applied load. This is considered to be an artefact of the preliminary modelling and not representative of the lining stress. This will be further addressed in subsequent design stages.

We consider that the analysis outcomes indicate that predicted effects associated with the proposed building loads are within the effects associated with the PSTR design load cases.

The sensitivity analysis cases indicate that the outcomes of the assessment are not sensitive to the parameters adopted in the analysis. These include the tunnel relaxation factor, groundwater level (based on credible scenarios) and the presence of permanent steel pile liners.

The level of analysis carried out in this assessment is considered to be appropriate for this design stage and appropriate for a proof of concept assessment. Further work will be required during detailed design including further development of the geotechnical model and updates to the finite element model to include buried infrastructure such as adits that connect to the cavern, etc. and associated backfilling, where necessary.

For and on behalf of EDG Consulting Pty Ltd

**David Cunliffe**
Principal

*Ground conditions and the natural environment often present the highest potential risks to project construction and operation. Helping our clients manage their geotechnical risk is fundamental to the role of EDG. We have prepared these notes to assist our clients to understand the information we provide and to help them to manage their risk. Where there is uncertainty about the site, project or geotechnical conditions, contact EDG for assistance.*

## Scope of Services

The information provided in this document is based on the scope of services defined in the client's agreement with EDG Consulting Pty Ltd (EDG). In undertaking the work, EDG has relied on information provided by the client and other individuals and organisations. Unless stated in the document, EDG has not verified the accuracy of that information and does not accept responsibility for the conclusions, recommendations or designs developed based on that information should it be incorrect, misrepresented or withheld.

Unless specifically stated to the contrary, this document does not cover geo-environmental issues, which require significantly different equipment, techniques and personnel. A geo-environmental specialist should be engaged to provide such advice.

## The document is based on specific project details

The information provided in this document is relevant to the subject site and project only. The document has been prepared based on the specific details and requirements of your project and may not be relevant if any changes to the project occur. Should changes occur, must review the report to identify if and how such changes will affect the conclusions, recommendations or designs provided. EDG accepts no responsibility if the client elects not to consult in the event of changes to the project.

## The document is prepared for a specific purpose

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Should you choose to engage an alternative party for advice based on the information in the document, it must be understood that the alternative party will be less familiar with the site conditions and basis of information provided, and there is a potential for misinterpretation. EDG will not be held liable in any way from such misinterpretation.

EDG will not be liable to update or revise the document to take into account information any events or circumstances or facts occurring or becoming apparent after the date of the report.

## All site conditions cannot be identified

The scope of work undertaken represents a professional assessment of the information cited to develop a basic geotechnical model of the site based on EDG's understanding of the client's risk profile. In some cases, increasing the frequency of investigations and/or sampling, or considering alternative investigation techniques may improve the interpretation, but may not identify all relevant subsurface conditions at the site.

## The document presents an interpretation

Geotechnical information is an interpretation of conditions evident based on a limited number of facts established during a site investigation. Engineering logs are an interpretation of observations of samples and test results at discrete locations in the subsurface profile. A geotechnical model is an interpretation of site conditions, developed using information from discrete locations on the site and an understanding of geological processes. Interpreted conditions at and between investigation locations may be different to those inferred on the engineering logs and geotechnical model. The client must consider how variations in conditions could affect the project and seek advice to reduce risk if it is unacceptable to the client.

## Conditions can change

The geotechnical information provided is based on the conditions observed at the time of the investigation. Such conditions may be time dependent and subject to external influences. Many things could influence the site conditions, including geological processes, variation in groundwater or surface water levels, other natural cycles and influence from human activities (on this site or nearby sites). Specific advice should be sought if conditions on site change from those observed at the time the report was prepared.

## How to deal with different site conditions

The sub-surface conditions on the site may not be as inferred in this report. Geotechnical uncertainties can be managed throughout the project life cycle, but particularly during construction.

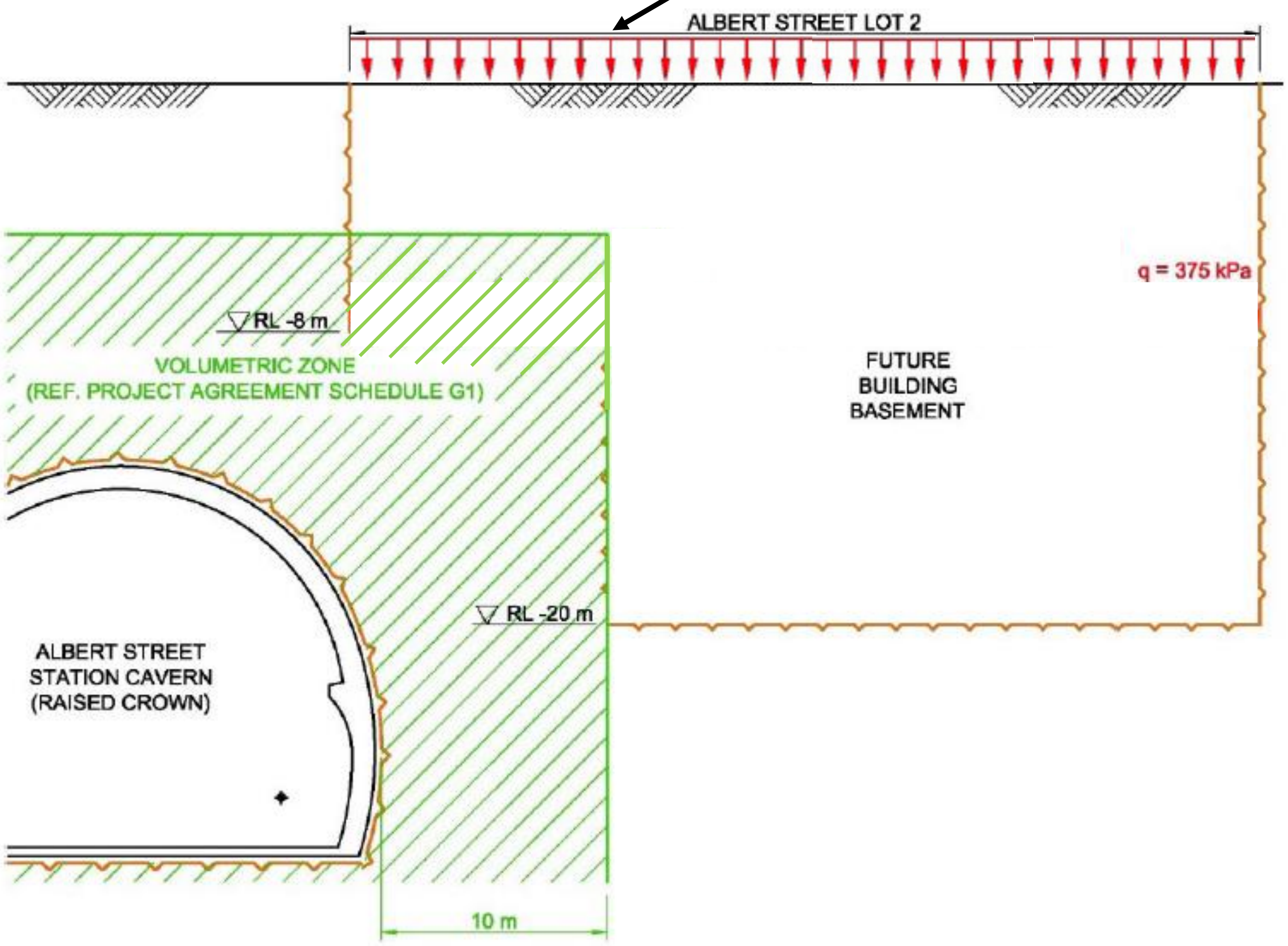
Knowledge of site conditions must be further developed as the ground is exposed during construction and/or operation. It is essential that the client implements the nominated design and construction requirements, including observation, interpretation and assessment of the exposed conditions during construction and operation using skilled staff familiar with the design assumptions and assumed geotechnical conditions, or engaging EDG to undertake this role on your behalf. EDG will not be held liable in any way from such misinterpretation.

# Appendix A

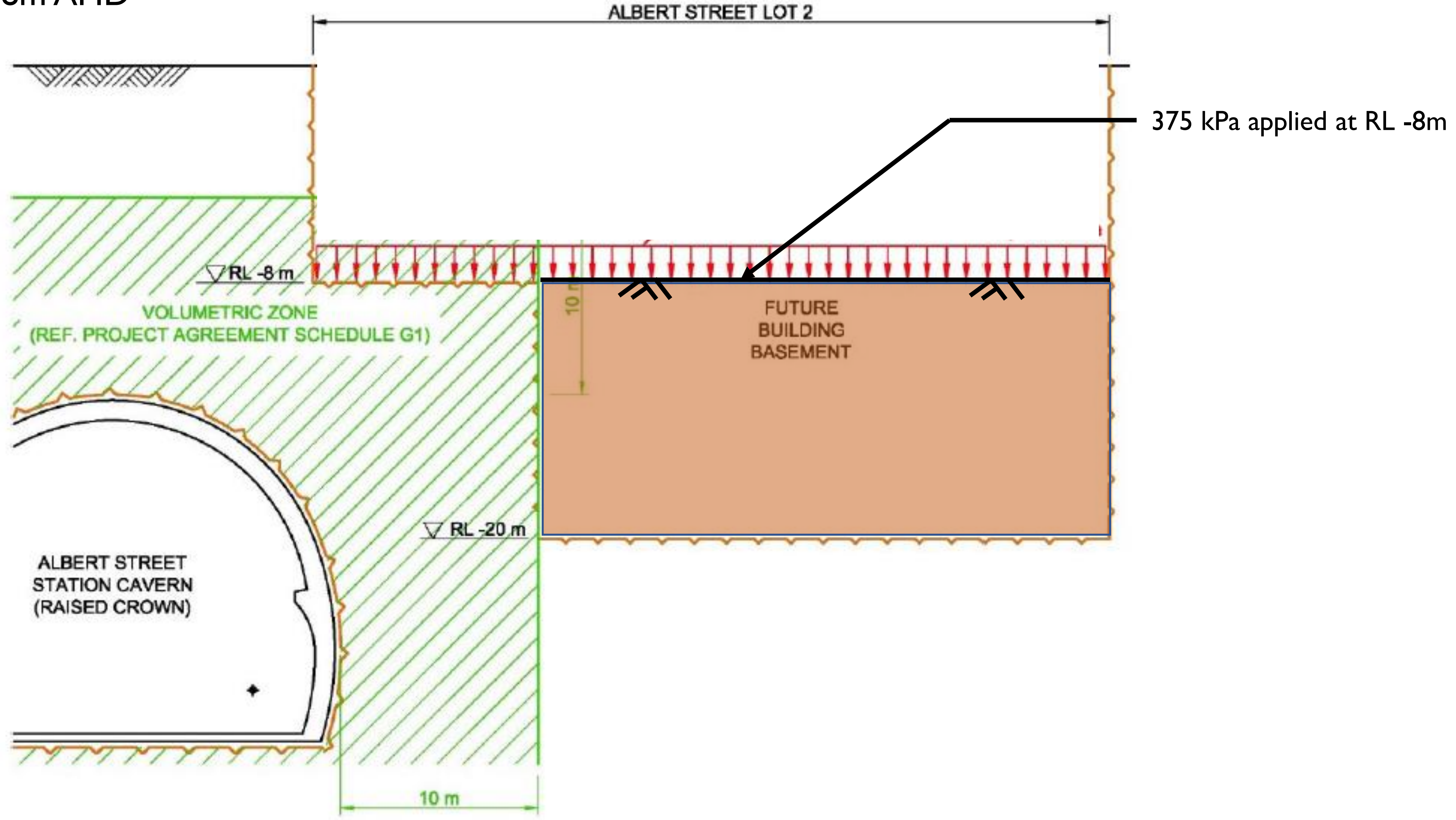
## Sketches Illustrating CRR PSTR Load Cases

**Case 1** – 375kPa over full area of Lot 2, applied at RL 4m AHD **(OSD-31)**

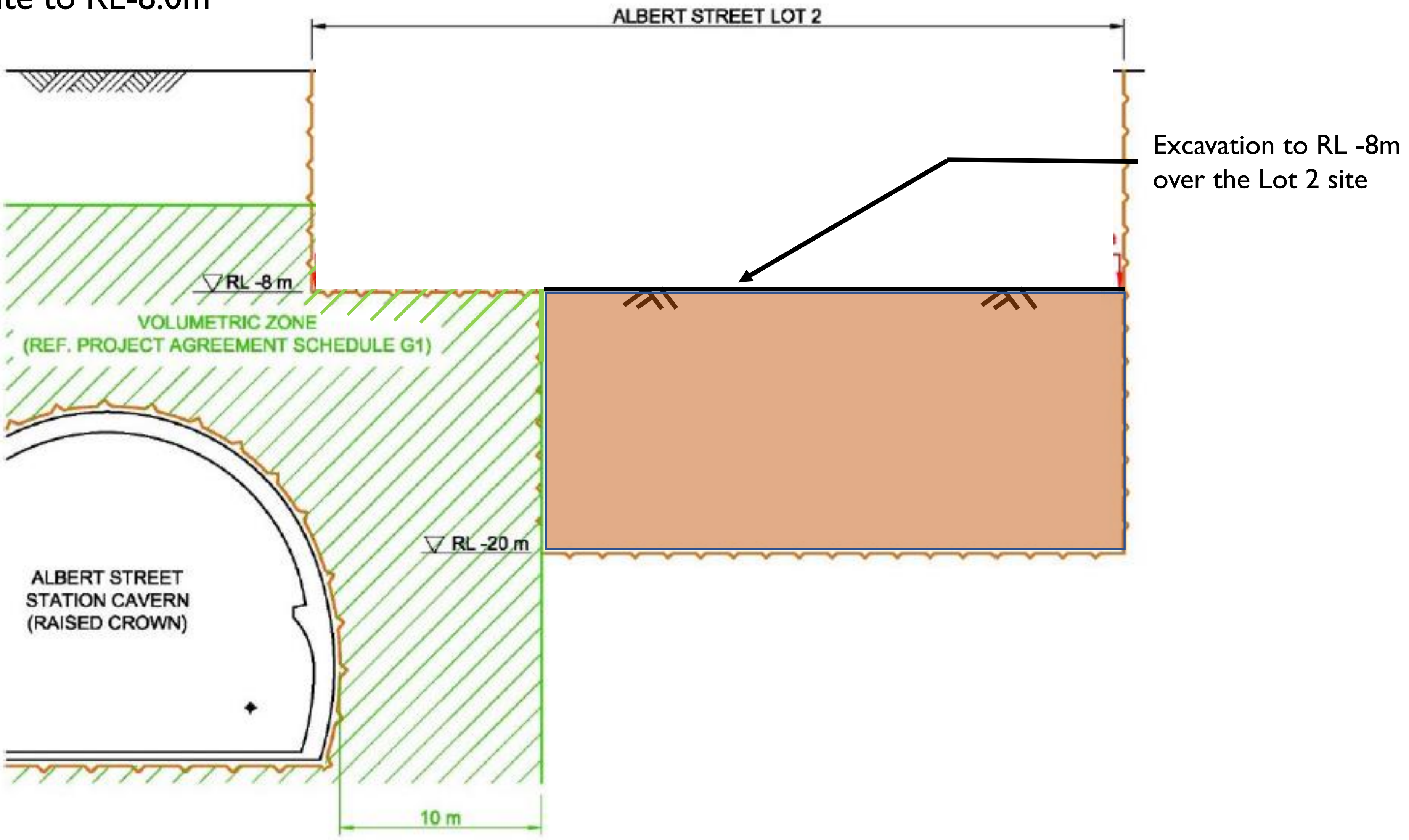
375 kPa applied at RL 4m



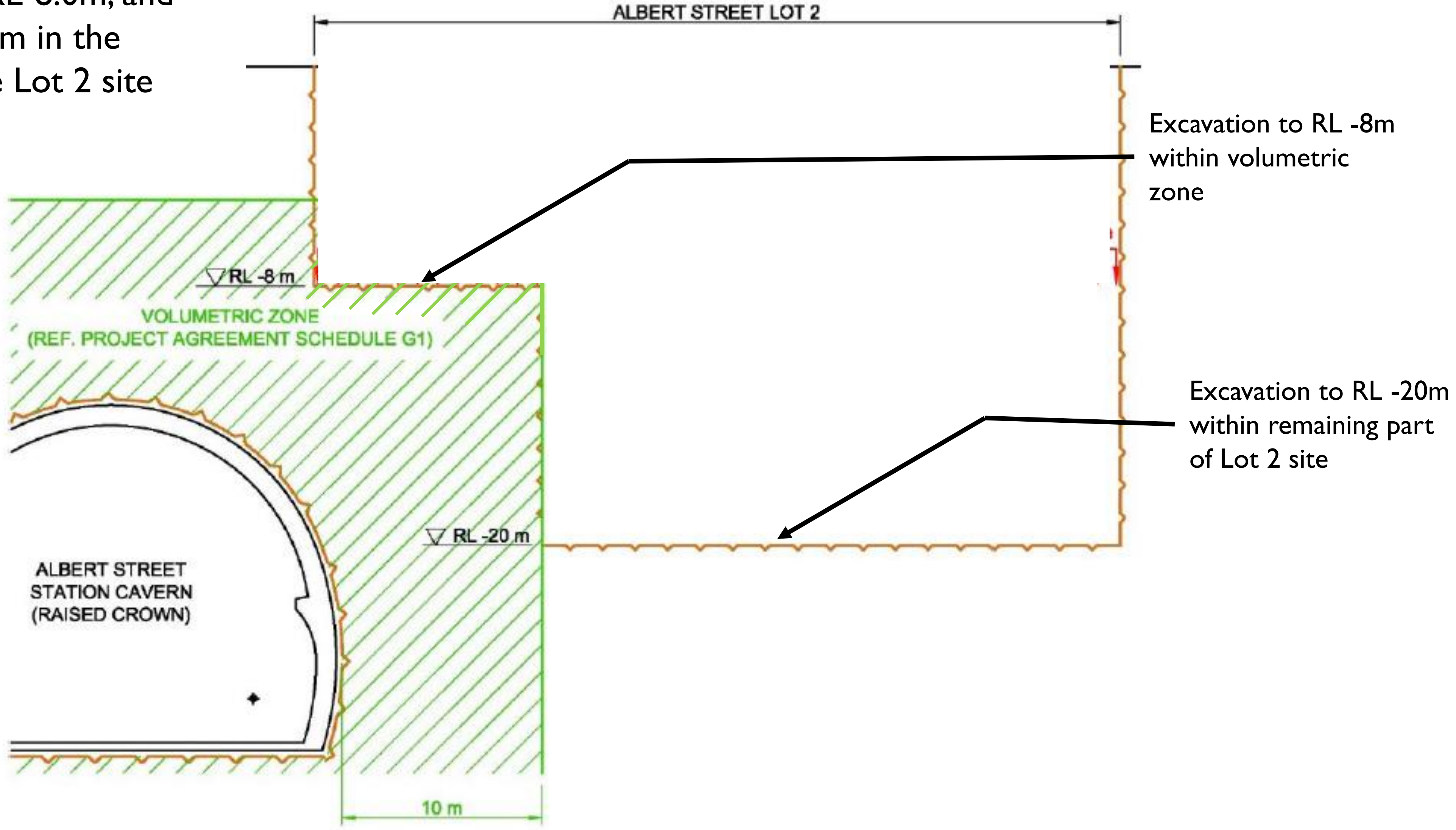
**Case 2** – 375kPa over full area of Lot 2, applied at RL -8m AHD **(OSD-31)**



**Case 3** – Excavation over the entire Albert Street Lot 2 site to RL-8.0m **(OSD-46)**



**Case 4** – Excavation in the volumetric zone to RL-8.0m, and excavation to RL -20m in the remaining part of the Lot 2 site **(OSD-47)**



**Case 5**:

- 50kPa applied at 1m above cavern crown
- 20kPa applied at ground surface

**(OSD-48)**

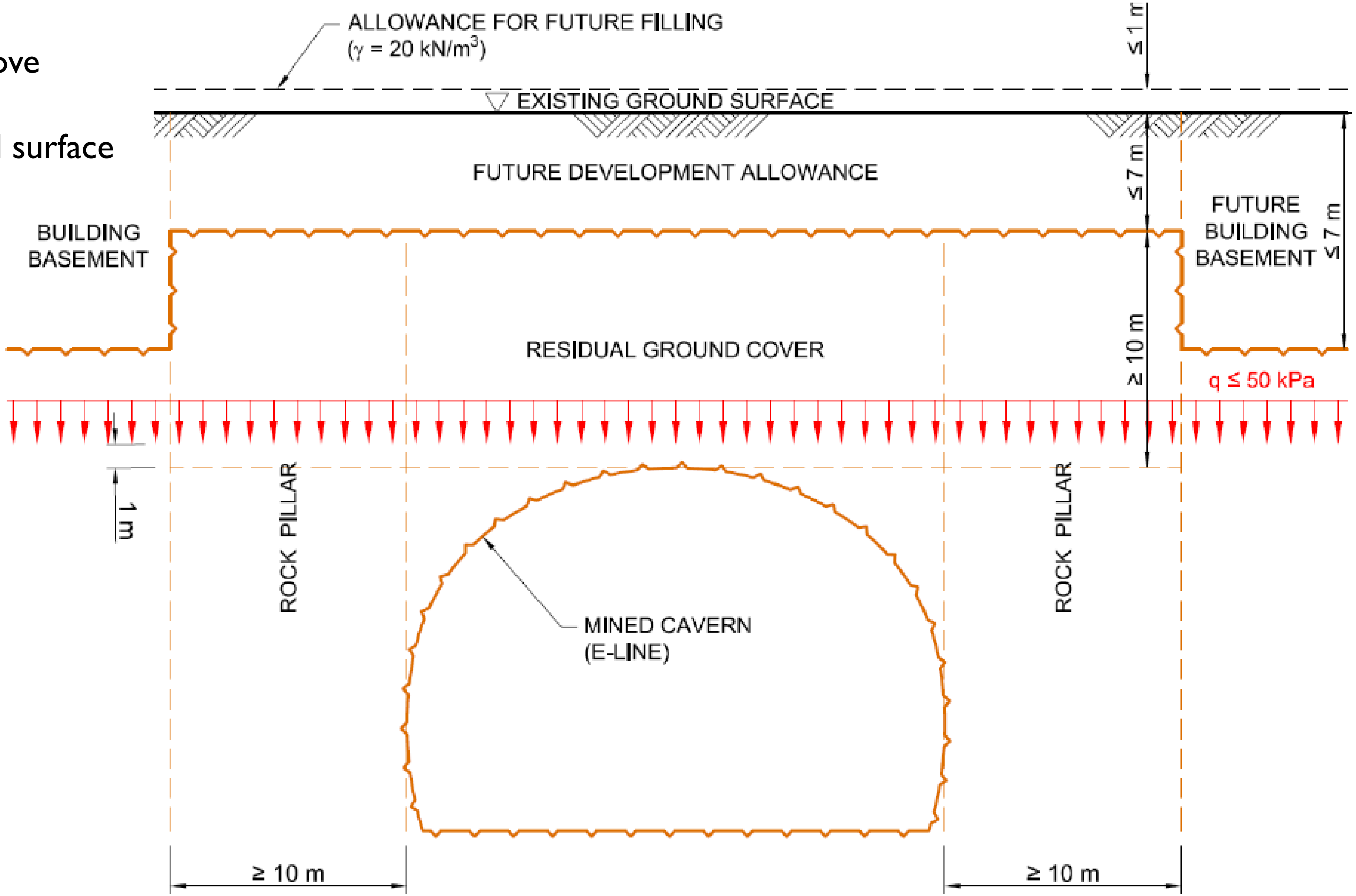



*Figure 13 FOSD loading for caverns – Future development allowance Case 1 (Ref. Table B2-A, Annexure B, PSTR)*

**Case 6**:

- 7m excavation over Lot 2 site to RL -3m

**(OSD-48)**

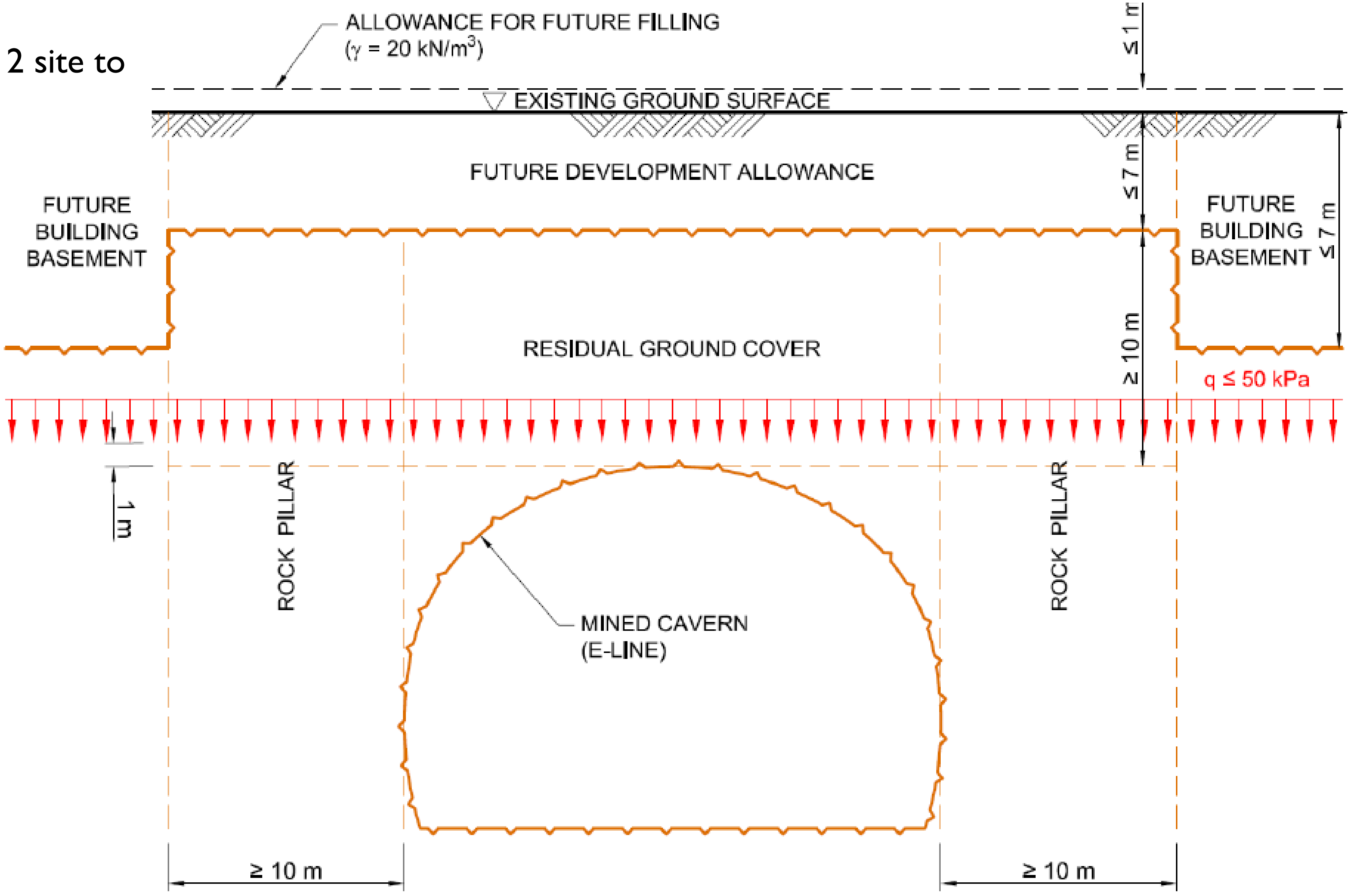



*Figure 13 FOSD loading for caverns – Future development allowance Case 1 (Ref. Table B2-A, Annexure B, PSTR)*

**Case 7**:

- 75kPa applied at ground surface
- 20kPa applied at ground surface
- Additional cavern distortion of ±15mm on diameter

**(OSD-48)**

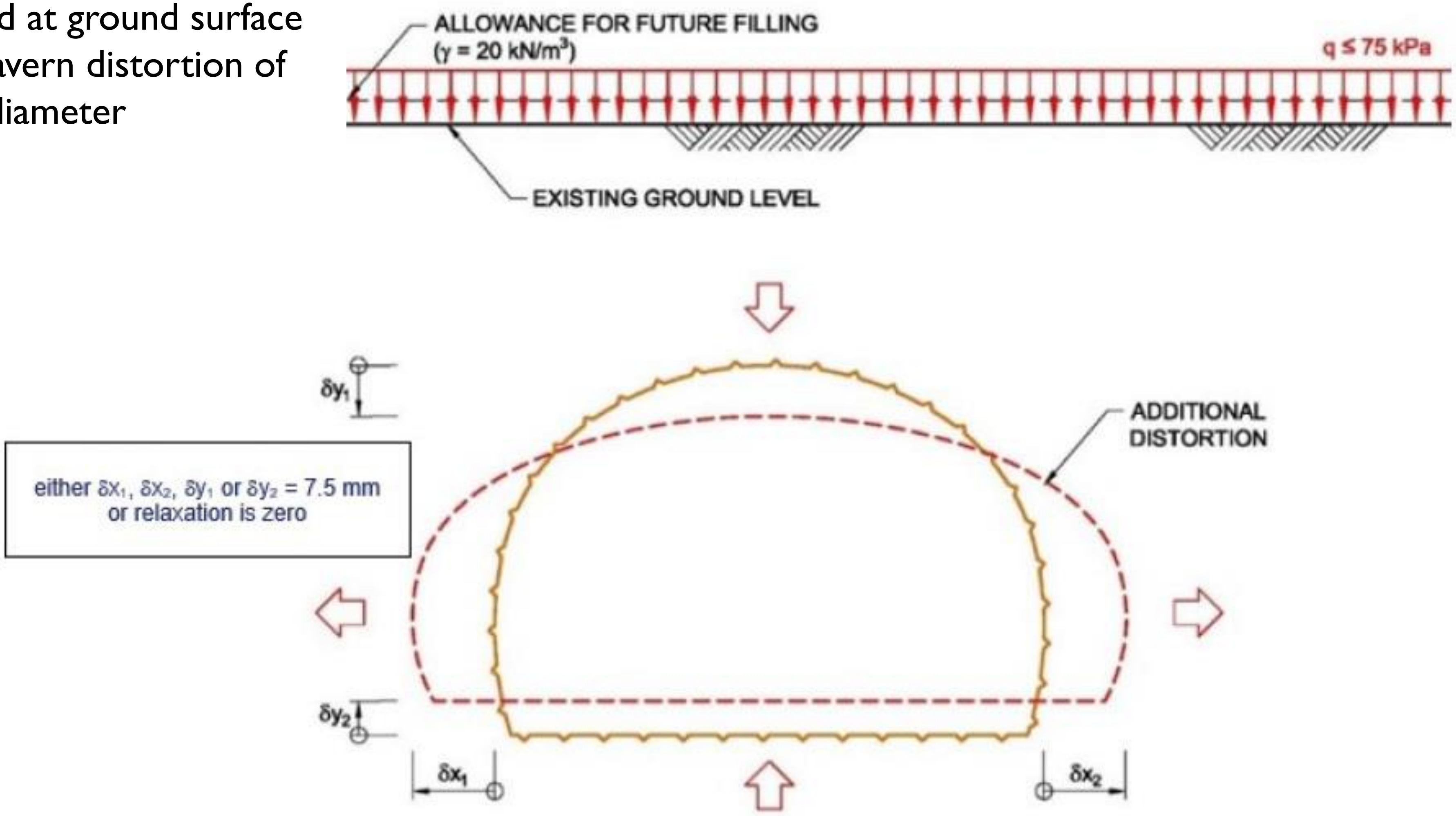
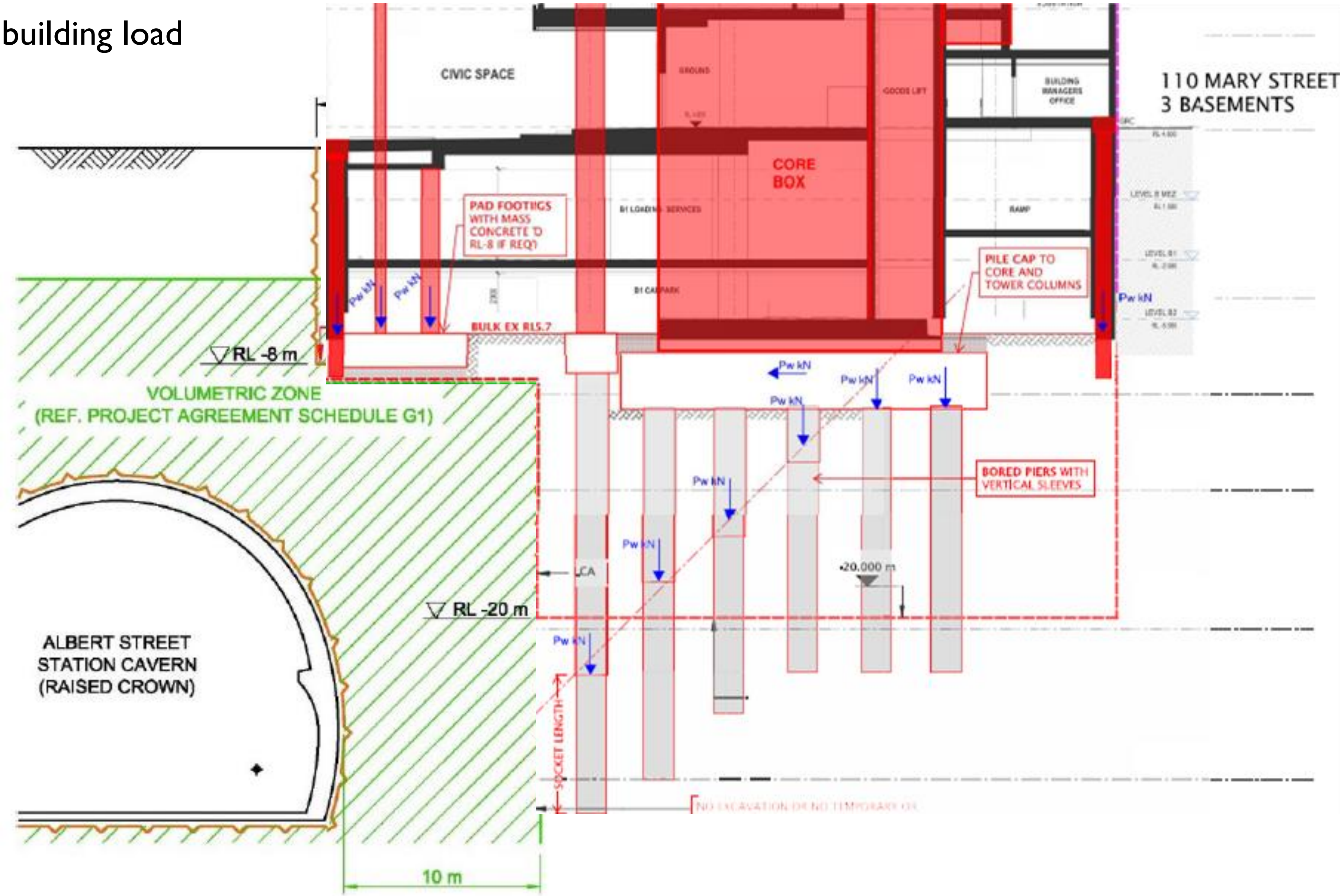



*Figure 15 FOSD loading for caverns – Future development allowance Case 2 (Ref. Table B2-B, Annexure B, PSTR)*

**Case 8** – Proposed building load case



# Appendix B

## Geotechnical Parameters

Table B1 – Geotechnical Parameters

| Geological Age | Unit | Sub Unit | Materials | Unit Weight | | Drained Cohesion | | Drained Friction Angle | | Tensile Strength | | Drained Young's Modulus | | Drained Poisson's Ratio | | Secant Stiffness in Standard Drained Triaxial Test [1] | | Tangent Stiffness for Primary Oedometer Loading [1] | | Unloading / Reloading Stiffness [1] | | Over Consolidation Ratio | | At Rest Earth Pressure Coefficient | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ($kN/m^3$) | | c' (kPa) | | θ' (degrees) | | $\sigma_t$ (kPa) | | E' (MPa) | | ν' | | $E_{50}^{ref}$ (MPa) | | $E_{oed}^{ref}$ (MPa) | | $E_{ur}^{ref}$ (MPa) | | OCR | | $K_0$ | |
| | | | | Note 2 | Note 3 | Note 2 | Note 3 | Note 2 | Note 3 | Note 2 | Note 3 | Note 2 | Note 3 | Note 2 | Note 3 | Note 2 | Note 3 | Note 2 | Note 3 | Note 2 | Note 3 | Note 2 | Note 3 | Note 2 | Note 3 |
| Holocene | Fill | Fill (FL) | Various material including concrete, bricks, granular and fine grained fill | 17 | 16 to 18 | 0 | 0 to 2 | 25 | 25 to 35 | N/A | N/A | 10 | 2 to 10 | 0.3 | N/A | N/A | Not reported in CRR GIR | N/A | Not reported in CRR GIR | N/A | Not reported in CRR GIR | N/A | Not reported in CRR GIR | 0.7 | N/A |
| | Holocene Alluvium | Holocene Clay (AL F) | Mainly clay (soft to firm) | 17 | 16 to 18 | 4 | 0 | 26 | 20 to 35 | N/A | N/A | 5 + 0.4z | 2 to 20 | 0.3 | N/A | 3 | | 2 | | 20 | | 1.5 | | 0.7 | N/A |
| Devonian | Neranleigh Fernvale Beds | Residual Soil (RS F) | Mainly clay (stiff to hard) | 20 | 18 to 20 | 10 | 0 to 5 | 30 | 30 to 35 | N/A | N/A | 25 | 5 to 25 | 0.3 | N/A | N/A | | N/A | | N/A | | 3 | | 1 | N/A |
| | | Extremely Weathered Material to Very Low Strength Rock (NFG 5) | Silt and sand sized sedimentary rocks; slightly metamorphosed (typically called greywacke, phyllite, argillite) | 23 | 23 | 20 | 20 | 30 | 30 | N/A | N.A | 50 | 50 | 0.3 | 0.3 | N/A | | N/A | | N/A | | N/A | | 1 | 1 |
| | | Medium Strength Rock (NFG 3) | | 27 | 27 | 250 | 250 | 45 | 45 | 15 | 15 | 1,000 | 1,000 | 0.2 | 0.2 | N/A | | N/A | | N/A | | N/A | | 1 | 1 to 2 |
| | | High to Very High Strength Rock (NFG 2/1) | | 27 | 27 | 400 | 400 | 55 | 55 | 70 | 70 | 5,000 | 5,000 | 0.2 | 0.2 | N/A | | N/A | | N/A | | N/A | | 1 | 1 to 2 |

Notes:

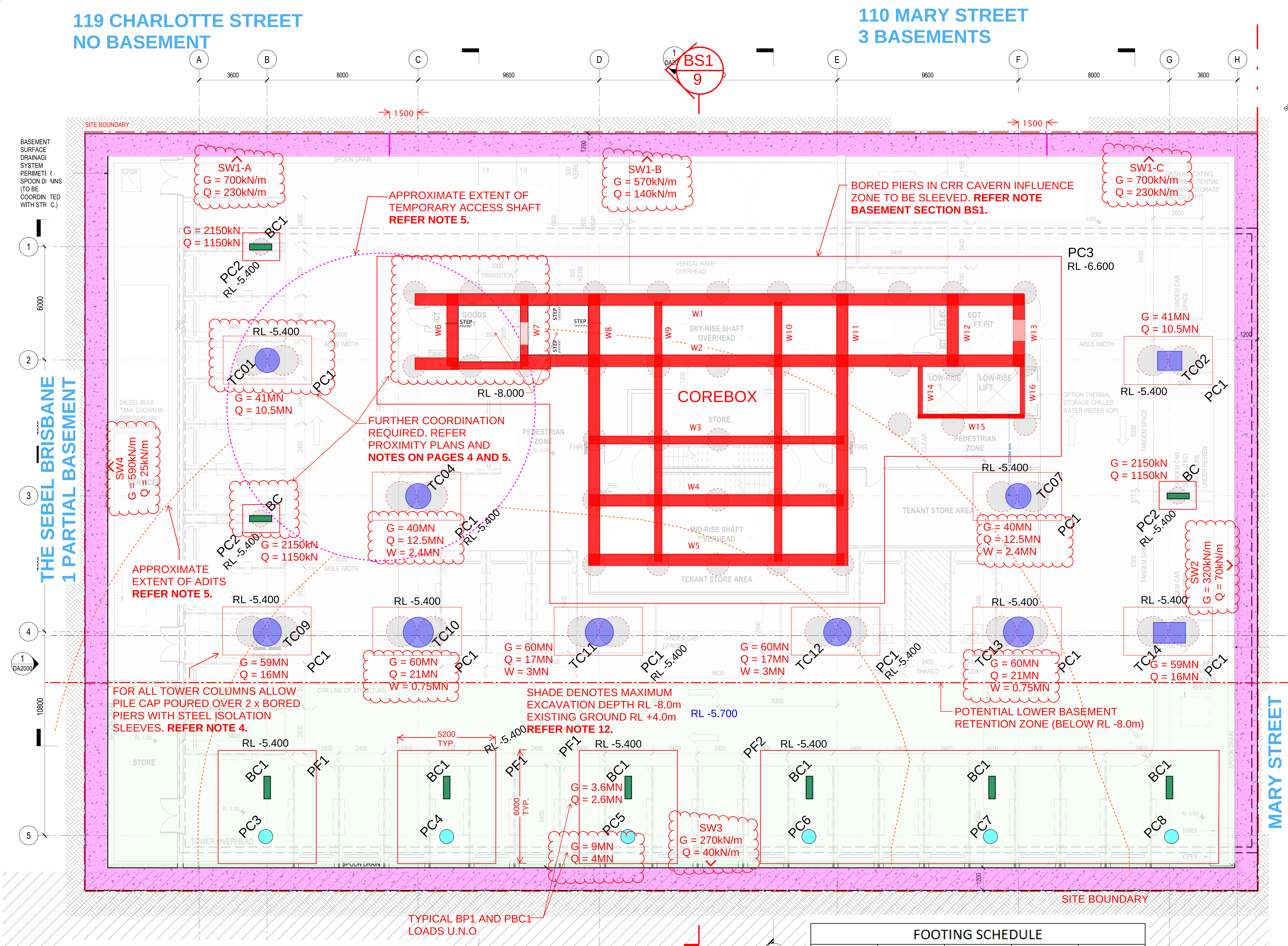
[1] All stiffness parameters associated with the Hardening Soil Model are presented based on a reference pressure equal to 100 kPa.

[2] Parameters adopted in this assessment.

[3] Parameters presented in CRR GIR.

# Appendix C

## Structural Loading Plan




RL -5.400 DENOTES APPROXIMATE TOP OF FOOTING
RL -5.700 DENOTES BULK EXCAVATION

SCALE: 1:200 @ A3

THE FOLLOWING INFORMATION IS BASED UPON A PARTIALLY HYDROSTATIC BASEMENT STRATEGY WITH HYDROSTATIC WALLS AND DRAINED BASEMENT B2 SLAB. TO BE CONFIRMED BY GEOTECHNICAL ENGINEER. REFER **SCHEMATIC REPORT 22131S-RBG-ZZ-XX-RP-ST-00003** FOR MORE DETAILS.

**LEGEND:**

- SW# DENOTES SHORING WALL WITH A THICKNESS PROVISION OF 1200mm TO ALLOW FOR OUT OF POSITION, VERTICALITY, GUIDE WALL, CAPPING BEAM AND PILE DIAMETER/WALL THICKNESS. ALLOW 900mm DIAMETER SOLDIERS AT 1.8m CENTRES WITH SHOTCRETE INFILL PANELS (THK TBC).
- TC DENOTES TOWER COLUMN
- PBC DENOTES PODIUM COLUMN
- BC DENOTES BASEMENT COLUMN
- DENOTES COREBOX WALL
- PF DENOTES PAD FOOTING
- PC DENOTES PILE CAP
- DENOTES BORED PIER

**NOTES:**

1. PILE CAPS TO BE POURED ON COMPRESSIBLE MATERIAL RMAX GEOFOAM OR SIMILAR OUTSIDE OF THE BORED PIER EXTENTS TO CONTROL LOAD DISTRIBUTION INTO THE BORED PIERS.
2. BORED PIERS TO BE SOCKETED INTO VERY HIGH STRENGTH ROCK NFG1. STEEL ISOLATION SLEEVES TO EXTEND 1m BELOW THE 1:1 CRR INFLUENCE LINE.
3. BORED PIER SIZES AND SOCKET LENGTHS INTO NFG2/NFG1, AS FOLLOWS:
**CORE BOX** (REFER GA) - 1200DIA + 8m SOCKET
**TOWER COLUMNS** - TWIN 1600DIA + 10m SOCKET
4. NOT ALL EXISTING IN-GROUND STRUCTURE HAS BEEN SHOWN FOR CLARITY. FURTHER COORDINATION REQUIRED TO RESOLVE CLASHES BETWEEN NEW AND EXISTING IN-GROUND STRUCTURE.
5. CONFIRMATION REQUIRED ON METHODOLGY AND MATERIAL TO BE USED TO FILL ADITS AND ACCESS SHAFT.
6. SHEET PILLING MAY BE REQUIRED SUBJECT TO GEOTECHNICAL ENGINEER REVIEW.
7. THE FOOTING DESIGN CONSIDERS PERMANENT CONDITION ONLY WITH NO ALLOWANCE CURRENTLY MADE FOR TEMPORARY WORKS LOADS, TOP-DOWN CONSTRUCTION METHODOLOGY, STAGED CONSTRUCTION ETC. ADDITIONAL PROVISION TO BE MADE BY CONTRACTOR.
8. BORED PIERS TO COLUMNS AND COREBOX MAY BE INSTALLED FROM GROUND LEVEL PROVIDED ADDITIONAL PROVISIONS ARE MADE AS PER NOTE 7. THE CURRENT DESIGN DOES NOT ALLOW FOR BORED PIER OUT OF POSITION ASSOCIATED WITH THE PRIOR AND THIS WOULD NEED TO BE REVIEWED AS PART OF THE TEMPORARY WORKS PACKAGE. ALLOW FOR A PILING MAT AS PER GEOTECHNICAL REQUIREMENTS.
9. ALLOW FOR COST ASSOCIATED WITH TEMPERATURE MONITORING AND CONTROL TO PILE CAPS DEEPER THAN 1m. THIS MIGHT INCLUDE THERMOCOUPLES, INSULATION, ICE TO THE CONCRETE MIX ETC.
10. PAD FOOTINGS TO BE FOUND ON LOW STRENGTH ROCK WITH MINIMUM 1MPa ALLOWABLE END BEARING CAPACITY. PROVIDE MASS CONCRETE BELOW FOOTING AS REQUIRED TO REACH LOW STRENGTH ROCK TO MAXIMUM DEPTH OF RL-8.
11. EXTENT OF NEW INGROUND SERVICES TO BE CONFIRMED. PAD FOOTINGS TO BE DEEPENED AS REQUIRED TO EXTEND BELOW INFLUENCE ZONE. REFER TO COVER NOTES ON PAGE 1.
12. ALLOW FOR 1500mm THK RAFT TO EXTENT OF MAXIMUM EXCAVATION DEPTH RL -8.0m INCASE ADDITIONAL DISTRIBUTION OF VERTICAL LOAD FROM THE PODIUM AND BASEMENT COLUMNS IS REQUIRED TO ACHIEVE CRR CAVERN DESIGN CRITERIA. SUBJECT TO GEOTECHNICAL ANALYSIS.

**FOOTING SCHEDULE**

| MARK | WIDTH | LENGTH | DEPTH | f'c |
|---|---|---|---|---|
| | mm | mm | mm | (MPa) |
| PC1 | 2000 | 4500 | 2500 | 80 |
| PC2 | 1500 | 2000 | 1200 | 50 |
| PC3 | REFER GA | | 3000 | 80 |
| PF1 | 5200 | 6000 | 1500 | 50 |
| PF2 | 24400 | 6000 | 1500 | 50 |

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| | | |
|---|---|---|
| DRAWING TITLE: FOUNDATION PLAN | DESIGNED BY: MJ | DATE: 30/11/22 |
| PROJECT: ALBERT ST OSD | CHECKED BY: - | PROJECT No: 22131 |
| CLIENT: QIC | DRAWING NO S01-01 | REVISION: P04 |

## COREBOX BORED PIER LOADS

| Pile | 0: Total G (Staged) $P_{MAX}$ [kN] | $P_{MIN}$ [kN] | $V_{x,MAX}$ [kN] | $V_{x,MIN}$ [kN] | $V_{y,MAX}$ [kN] | $V_{y,MIN}$ [kN] | 0: Total Q $P_{MAX}$ [kN] | $P_{MIN}$ [kN] | $V_{x,MAX}$ [kN] | $V_{x,MIN}$ [kN] | $V_{y,MAX}$ [kN] | $V_{y,MIN}$ [kN] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CP01 | 7844 | 0 | 581 | -202 | 244 | 0 | 1491 | 0 | 94 | 0 | 30 | 0 |
| CP02 | 16110 | 0 | 490 | 0 | 50 | -200 | 3524 | 0 | 37 | 0 | 0 | -26 |
| CP03 | 12201 | 0 | 3 | -79 | 169 | 0 | 2439 | 0 | 0 | -31 | 3 | 0 |
| CP04 | 13817 | 0 | 407 | -6 | 92 | -386 | 2701 | 0 | 77 | 0 | 0 | -74 |
| CP05 | 12268 | 0 | 135 | -33 | 84 | -349 | 2331 | 0 | 33 | 0 | 0 | -76 |
| CP06 | 9022 | 0 | 0 | -103 | 150 | 0 | 1646 | 0 | 0 | -9 | 9 | 0 |
| CP07 | 11818 | 0 | 23 | -291 | 83 | -319 | 2258 | 0 | 0 | -45 | 0 | -71 |
| CP08 | 10402 | 0 | 6 | -516 | 61 | -361 | 2025 | 0 | 0 | -90 | 0 | -74 |
| CP09 | 4900 | 0 | 94 | 0 | 129 | 0 | 925 | 0 | 27 | 0 | 4 | 0 |
| CP10 | 8830 | 0 | 0 | -505 | 157 | 0 | 1822 | 0 | 0 | -82 | 9 | 0 |
| CP11 | 9831 | 0 | 294 | -358 | 264 | -122 | 1884 | 0 | 0 | -75 | 0 | -29 |
| CP12 | 8497 | 0 | 853 | -47 | 0 | -136 | 1884 | 0 | 198 | 0 | 17 | 0 |
| CP13 | 17933 | 0 | 492 | 0 | 237 | -129 | 4379 | 0 | 88 | 0 | 105 | 0 |
| CP14 | 12907 | 0 | 34 | -68 | 0 | -166 | 3028 | 0 | 0 | -25 | 16 | 0 |
| CP15 | 12577 | 0 | 283 | 0 | 0 | -296 | 2949 | 0 | 71 | 0 | 0 | -65 |
| CP16 | 11035 | 0 | 50 | 0 | 0 | -221 | 2647 | 0 | 16 | 0 | 0 | -60 |
| CP17 | 6059 | 0 | 8 | -6 | 13 | 0 | 1397 | 0 | 5 | 0 | 1 | 0 |
| CP18 | 10795 | 0 | 0 | -30 | 0 | -230 | 2620 | 0 | 0 | -1 | 0 | -62 |
| CP19 | 9526 | 0 | 0 | -405 | 0 | -276 | 2310 | 0 | 0 | -96 | 0 | -68 |
| CP20 | 7042 | 0 | 458 | 0 | 0 | -134 | 1841 | 0 | 126 | 0 | 0 | -30 |
| CP21 | 11495 | 0 | 0 | -450 | 0 | -102 | 3110 | 0 | 0 | -93 | 9 | 0 |
| CP22 | 13523 | 0 | 133 | -674 | 233 | -139 | 3434 | 0 | 0 | -192 | 96 | 0 |
| CP23 | 2519 | 0 | 0 | -63 | 0 | -32 | 496 | 0 | 0 | -14 | 2 | 0 |
| CP24 | 4580 | 0 | 0 | -132 | 0 | -88 | 1160 | 0 | 0 | -25 | 0 | -13 |
| CP25 | 4979 | 0 | 54 | -115 | 205 | -57 | 1115 | 0 | 0 | -36 | 69 | 0 |
| CP26 | 12010 | 0 | 345 | -78 | 49 | -570 | 3371 | 0 | 110 | 0 | 0 | -248 |
| CP27 | 11973 | 0 | 73 | 0 | 27 | -380 | 3476 | 0 | 13 | 0 | 0 | -164 |
| CP28 | 4620 | 0 | 4 | -1 | 9 | -3 | 1148 | 0 | 2 | 0 | 2 | 0 |
| CP29 | 11335 | 0 | 0 | -71 | 24 | -358 | 3304 | 0 | 0 | -14 | 0 | -160 |
| CP30 | 10734 | 0 | 1 | -380 | 44 | -614 | 3162 | 0 | 0 | -112 | 0 | -245 |
| CP31 | 22190 | 0 | 1199 | -171 | 130 | 0 | 6980 | 0 | 418 | 0 | 0 | -14 |
| CP32 | 23931 | 0 | 506 | 0 | 64 | -10 | 7730 | 0 | 161 | 0 | 0 | -15 |
| CP33 | 12584 | 0 | 5 | -29 | 10 | -33 | 3988 | 0 | 15 | 0 | 3 | 0 |
| CP34 | 22589 | 0 | 0 | -541 | 75 | 0 | 7406 | 0 | 0 | -158 | 0 | -24 |
| CP35 | 20307 | 0 | 117 | -1129 | 130 | 0 | 6492 | 0 | 0 | -391 | 0 | -4 |
| CP36 | 14977 | 0 | 341 | -192 | 1158 | -61 | 4536 | 0 | 130 | 0 | 358 | 0 |
| CP37 | 18662 | 0 | 275 | 0 | 749 | -53 | 6003 | 0 | 61 | 0 | 236 | 0 |
| CP38 | 9864 | 0 | 0 | -35 | 0 | -113 | 3026 | 0 | 0 | -7 | 0 | -1 |
| CP39 | 17820 | 0 | 0 | -226 | 734 | -36 | 5820 | 0 | 0 | -63 | 229 | 0 |
| CP40 | 13797 | 0 | 178 | -294 | 1024 | -67 | 4206 | 0 | 0 | -122 | 332 | 0 |

| Pile | EQ(Response Spectrum) $P_{MAX}$ [kN] | $P_{MIN}$ [kN] | $V_{x,MAX}$ [kN] | $V_{x,MIN}$ [kN] | $V_{y,MAX}$ [kN] | $V_{y,MIN}$ [kN] |
|---|---|---|---|---|---|---|
| CP01 | 6693 | -6693 | 1149 | -1149 | 660 | -660 |
| CP02 | 14889 | -14889 | 1357 | -1357 | 1692 | -1692 |
| CP03 | 10484 | -10484 | 2090 | -2090 | 841 | -841 |
| CP04 | 11224 | -11224 | 2525 | -2525 | 1771 | -1771 |
| CP05 | 9767 | -9767 | 3019 | -3019 | 1019 | -1019 |
| CP06 | 6786 | -6786 | 2948 | -2948 | 153 | -153 |
| CP07 | 10002 | -10002 | 2940 | -2940 | 910 | -910 |
| CP08 | 10140 | -10140 | 2432 | -2432 | 1450 | -1450 |
| CP09 | 5855 | -5855 | 1730 | -1730 | 291 | -291 |
| CP10 | 12075 | -12075 | 2163 | -2163 | 787 | -787 |
| CP11 | 13639 | -13639 | 1551 | -1551 | 2265 | -2265 |
| CP12 | 6759 | -6759 | 1147 | -1147 | 683 | -683 |
| CP13 | 13984 | -13984 | 745 | -745 | 1654 | -1654 |
| CP14 | 6079 | -6079 | 1019 | -1019 | 828 | -828 |
| CP15 | 4923 | -4923 | 702 | -702 | 2283 | -2283 |
| CP16 | 2375 | -2375 | 441 | -441 | 1126 | -1126 |
| CP17 | 544 | -544 | 455 | -455 | 40 | -40 |
| CP18 | 2288 | -2288 | 416 | -416 | 948 | -948 |
| CP19 | 4246 | -4246 | 634 | -634 | 1963 | -1963 |
| CP20 | 2548 | -2548 | 541 | -541 | 376 | -376 |
| CP21 | 7963 | -7963 | 1133 | -1133 | 814 | -814 |
| CP22 | 13861 | -13861 | 1097 | -1097 | 2657 | -2657 |
| CP23 | 2184 | -2184 | 173 | -173 | 259 | -259 |
| CP24 | 4262 | -4262 | 395 | -395 | 301 | -301 |
| CP25 | 5538 | -5538 | 289 | -289 | 1190 | -1190 |
| CP26 | 6897 | -6897 | 565 | -565 | 2452 | -2452 |
| CP27 | 3646 | -3646 | 341 | -341 | 1143 | -1143 |
| CP28 | 515 | -515 | 330 | -330 | 43 | -43 |
| CP29 | 3109 | -3109 | 324 | -324 | 958 | -958 |
| CP30 | 6792 | -6792 | 539 | -539 | 2178 | -2178 |
| CP31 | 12319 | -12319 | 1742 | -1742 | 2604 | -2604 |
| CP32 | 8984 | -8984 | 2506 | -2506 | 1518 | -1518 |
| CP33 | 3555 | -3555 | 2783 | -2783 | 96 | -96 |
| CP34 | 8663 | -8663 | 2508 | -2508 | 1301 | -1301 |
| CP35 | 12084 | -12084 | 1731 | -1731 | 2164 | -2164 |
| CP36 | 9293 | -9293 | 1105 | -1105 | 1593 | -1593 |
| CP37 | 11171 | -11171 | 1467 | -1467 | 1107 | -1107 |
| CP38 | 5081 | -5081 | 1608 | -1608 | 132 | -132 |
| CP39 | 10721 | -10721 | 1464 | -1464 | 981 | -981 |
| CP40 | 9219 | -9219 | 1104 | -1104 | 1433 | -1433 |

| Pile | 0: Wind Envelope $P_{MAX}$ [kN] | $P_{MIN}$ [kN] | $V_{x,MAX}$ [kN] | $V_{x,MIN}$ [kN] | $V_{y,MAX}$ [kN] | $V_{y,MIN}$ [kN] | 0: Robustness Envelope $P_{MAX}$ [kN] | $P_{MIN}$ [kN] | $V_{x,MAX}$ [kN] | $V_{x,MIN}$ [kN] | $V_{y,MAX}$ [kN] | $V_{y,MIN}$ [kN] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CP01 | 10142 | -10142 | 1325 | -1325 | 680 | -680 | 5132 | -5132 | 784 | -784 | 250 | -250 |
| CP02 | 24050 | -24050 | 1169 | -1169 | 1888 | -1888 | 11322 | -11322 | 446 | -446 | 684 | -684 |
| CP03 | 20780 | -20780 | 1364 | -1364 | 971 | -971 | 9559 | -9559 | 202 | -202 | 402 | -402 |
| CP04 | 22208 | -22208 | 1987 | -1987 | 2192 | -2192 | 11692 | -11692 | 410 | -410 | 987 | -987 |
| CP05 | 21054 | -21054 | 1903 | -1903 | 1276 | -1276 | 11717 | -11717 | 294 | -294 | 699 | -699 |
| CP06 | 15535 | -15535 | 1722 | -1722 | 201 | -201 | 9122 | -9122 | 169 | -169 | 151 | -151 |
| CP07 | 21043 | -21043 | 2084 | -2084 | 1098 | -1098 | 12188 | -12188 | 337 | -337 | 673 | -673 |
| CP08 | 19314 | -19314 | 2155 | -2155 | 1781 | -1781 | 10808 | -10808 | 586 | -586 | 856 | -856 |
| CP09 | 11254 | -11254 | 1066 | -1066 | 332 | -332 | 5155 | -5155 | 59 | -59 | 156 | -156 |
| CP10 | 21382 | -21382 | 1545 | -1545 | 821 | -821 | 10063 | -10063 | 296 | -296 | 299 | -299 |
| CP11 | 20285 | -20285 | 1911 | -1911 | 2479 | -2479 | 9606 | -9606 | 755 | -755 | 899 | -899 |
| CP12 | 4843 | -4843 | 722 | -722 | 603 | -603 | 4118 | -4118 | 683 | -683 | 203 | -203 |
| CP13 | 10739 | -10739 | 447 | -447 | 1431 | -1431 | 8409 | -8409 | 564 | -564 | 455 | -455 |
| CP14 | 4988 | -4988 | 606 | -606 | 790 | -790 | 2915 | -2915 | 534 | -534 | 303 | -303 |
| CP15 | 6492 | -6492 | 371 | -371 | 2088 | -2088 | 3366 | -3366 | 439 | -439 | 775 | -775 |
| CP16 | 4709 | -4709 | 194 | -194 | 860 | -860 | 2149 | -2149 | 258 | -258 | 433 | -433 |
| CP17 | 1986 | -1986 | 200 | -200 | 29 | -29 | 1047 | -1047 | 269 | -269 | 40 | -40 |
| CP18 | 5342 | -5342 | 166 | -166 | 615 | -615 | 2585 | -2585 | 237 | -237 | 380 | -380 |
| CP19 | 6474 | -6474 | 357 | -357 | 1649 | -1649 | 3155 | -3155 | 424 | -424 | 609 | -609 |
| CP20 | 3392 | -3392 | 292 | -292 | 354 | -354 | 1905 | -1905 | 187 | -187 | 153 | -153 |
| CP21 | 8204 | -8204 | 763 | -763 | 663 | -663 | 5985 | -5985 | 719 | -719 | 208 | -208 |
| CP22 | 12230 | -12230 | 845 | -845 | 1901 | -1901 | 10057 | -10057 | 871 | -871 | 376 | -376 |
| CP23 | 1883 | -1883 | 114 | -114 | 228 | -228 | 513 | -513 | 107 | -107 | 93 | -93 |
| CP24 | 4811 | -4811 | 270 | -270 | 269 | -269 | 1743 | -1743 | 231 | -231 | 103 | -103 |
| CP25 | 5297 | -5297 | 235 | -235 | 959 | -959 | 1693 | -1693 | 234 | -234 | 264 | -264 |
| CP26 | 6278 | -6278 | 402 | -402 | 1911 | -1911 | 4373 | -4373 | 367 | -367 | 656 | -656 |
| CP27 | 4155 | -4155 | 190 | -190 | 762 | -762 | 2190 | -2190 | 208 | -208 | 355 | -355 |
| CP28 | 264 | -264 | 182 | -182 | 49 | -49 | 58 | -58 | 203 | -203 | 48 | -48 |
| CP29 | 3734 | -3734 | 186 | -186 | 520 | -520 | 1913 | -1913 | 194 | -194 | 304 | -304 |
| CP30 | 6327 | -6327 | 393 | -393 | 1555 | -1555 | 4319 | -4319 | 349 | -349 | 604 | -604 |
| CP31 | 22148 | -22148 | 2037 | -2037 | 2611 | -2611 | 10112 | -10112 | 966 | -966 | 1005 | -1005 |
| CP32 | 21582 | -21582 | 1817 | -1817 | 1453 | -1453 | 11493 | -11493 | 1173 | -1173 | 758 | -758 |
| CP33 | 10375 | -10375 | 1827 | -1827 | 117 | -117 | 5899 | -5899 | 1258 | -1258 | 96 | -96 |
| CP34 | 21981 | -21981 | 1994 | -1994 | 1130 | -1130 | 11382 | -11382 | 1158 | -1158 | 700 | -700 |
| CP35 | 22790 | -22790 | 2135 | -2135 | 2041 | -2041 | 10253 | -10253 | 921 | -921 | 804 | -804 |
| CP36 | 18359 | -18359 | 1225 | -1225 | 2337 | -2337 | 10670 | -10670 | 584 | -584 | 1227 | -1227 |
| CP37 | 24716 | -24716 | 1070 | -1070 | 1612 | -1612 | 14209 | -14209 | 691 | -691 | 914 | -914 |
| CP38 | 12223 | -12223 | 1181 | -1181 | 194 | -194 | 7102 | -7102 | 723 | -723 | 142 | -142 |
| CP39 | 24205 | -24205 | 1187 | -1187 | 1393 | -1393 | 14000 | -14000 | 681 | -681 | 875 | -875 |
| CP40 | 18649 | -18649 | 1293 | -1293 | 2046 | -2046 | 10398 | -10398 | 556 | -556 | 1149 | -1149 |

**NOTES:**

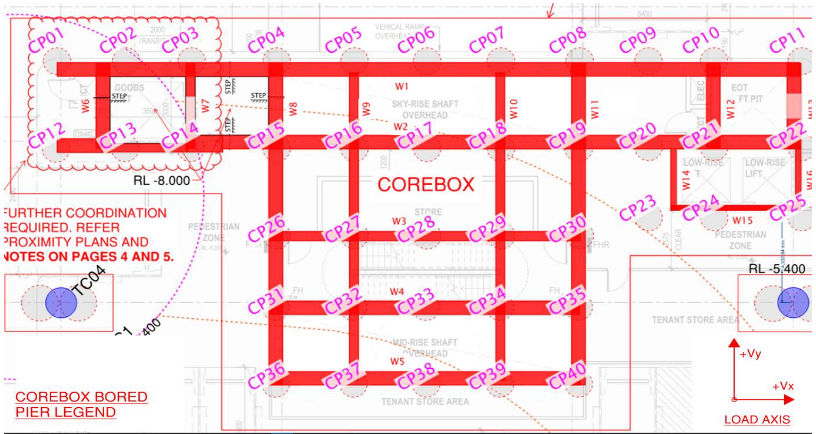
1 (+P) DENOTES VERTICAL LOAD IN SAME DIRECTION AS GRAVITY
(-P) DENOTES VERTICAL LOAD IN OPPOSITE DIRECTION AS GRAVITY (TENSION)

2 WIND LOADS SHOWN ARE ULTIMATE. APPLY 0.64 FACTOR TO CONVERT TO PERMISSIBLE.

3 SEISMIC (EQ) LOADS SHOWN ARE ULTIMATE. APPLY 0.5 FACTOR TO CONVERT TO PERMISSIBLE.

4 WIND AND SEISMIC LOADS ARE FULLY REVERSIBLE.

5 ALLOW AN CONTINGENCY FACTOR OF 1.1 ON ALL LOADS FOR FUTURE CHANGES.



# Appendix D

## Tunnel Relaxation Factor Calculations

## Longitudinal Displacement Profile

(Ref: Hoek et al (2008) *Integration of geotechnical and structural design in tunnelling design* )

| | | | | | | |
|---|---|---|---|---|---|---|
| Tunnel radius | Rt | 10 | m | Pr | =Rp/Rt | |
| Plastic zone radius | Rp | 12 | m | dt | =X/Rt | |
| Convergence | umax | 10 | mm | u (x -ve) | =u0*EXP(dt) | A1.6a |
| | Pr | 1.2 | | u0 | =umax/3*EXP(-0.15*Pr) | A1.5 |
| | | | | u (x +ve) | =umax*(1-(1-u0/umax)*exp(-3/2*dt/Pr)) | A1.7a |

| X (m) | | -12 | -8 | -4 | 0 | 1 | 2 | 3.5 | 4 | 4.75 | 5.5 | 7 | 8.5 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| dt | | -1.2 | -0.8 | -0.4 | 0.0 | 0.1 | 0.2 | 0.4 | 0.4 | 0.5 | 0.6 | 0.7 | 0.9 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 |
| u (mm) | | 0.8 | 1.3 | 1.9 | 2.8 | 3.6 | 4.4 | 5.3 | 5.6 | 6.0 | 6.4 | 7.0 | 7.5 | 7.7 | 7.9 | 8.2 | 8.4 | 8.6 | 8.7 | 8.9 | 9.0 | 9.1 | 9.2 | 9.3 | 9.4 |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
| MStage Factor | | 0.1 | 0.1 | 0.2 | 0.3 | 0.4 | 0.4 | **0.5** | **0.6** | **0.6** | **0.6** | 0.7 | **0.8** | 0.8 | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |

| | | | | |
|---|---|---|---|---|
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| *date:* | 29/05/2023 | *project:* | Albert Street - FOSD | |
| *approved:* | DJC | *location:* | Albert Street | |
| *scale:* | N.A. | *title:* | *Longitudinal Displacement Profile* | |
| | | *job no:* | B01493-1 | *figure:* *1* |

**Longitudinal Displacement Profile**

(Ref: Hoek et al (2008) *Integration of geotechnical and structural design in tunnelling design* )

| | | | | | | |
|---|---|---|---|---|---|---|
| Tunnel radius | Rt | 10 | m | Pr | =Rp/Rt | |
| Plastic zone radius | Rp | 10 | m | dt | =X/Rt | |
| Convergence | umax | 10 | mm | u (x -ve) | =u0*EXP(dt) | A1.6a |
| | Pr | 1 | | u0 | =umax/3*EXP(-0.15*Pr) | A1.5 |
| | | | | u (x +ve) | =umax*(1-(1-u0/umax)*exp(-3/2*dt/Pr)) | A1.7a |

| X (m) | | -12 | -8 | -4 | 0 | 1 | 2 | 3.5 | 4 | 4.75 | 5.5 | 7 | 8.5 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| dt | | -1.2 | -0.8 | -0.4 | 0.0 | 0.1 | 0.2 | 0.4 | 0.4 | 0.5 | 0.6 | 0.7 | 0.9 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 |
| u (mm) | | 0.9 | 1.3 | 1.9 | 2.9 | 3.9 | 4.7 | 5.8 | 6.1 | 6.5 | 6.9 | 7.5 | 8.0 | 8.2 | 8.4 | 8.6 | 8.8 | 9.0 | 9.1 | 9.2 | 9.4 | 9.4 | 9.5 | 9.6 | 9.6 |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
| MStage Factor | | 0.1 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | **0.6** | **0.6** | **0.7** | **0.7** | 0.8 | **0.8** | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 1 | 1 | 1 |

| | | | |
|---|---|---|---|
| *by:* | DL | *client:* | Albert Street Trust |
| *date:* | 29/05/2023 | *project:* | Albert Street - FOSD |
| *approved:* | DJC | *location:* | Albert Street |
| *scale:* | N.A. | *title:* | *Longitudinal Displacement Profile* |
| | | *job no:* | B01493-1 |

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*figure:* 2


CAVERN EXCAVATION SEQUENCE - LONGITUDINAL SECTION
BOLTED SUPPORT TYPES
SCALE 1:50

## GEOMETRIC CONSTRAINTS - BOLTED SUPPORT TYPES

| SUPPORT TYPE | MAX. FACE ADVANCE (A) | MAX. DISTANCE TO BOLTS (B) | DISTANCE TO ≥ 50mm SHOTCRETE (C) | MAX. DISTANCE TO COMPLETED PRIMARY SHOTCRETE (D) | MAX. DISTANCE TO ANY SHOTCRETE WITH MINIMUM STRENGTH OF 15MPa (E) | BOLT SPACING (L) |
|---|---|---|---|---|---|---|
| AA2-1<br>AA3-1<br>AA4-1<br>AA5-1<br>AA6-1<br>AA7-1 | 1500 | 2500 | 2500 | 2500 | 5500 | 1500 |
| AA2-2<br>AA3-2<br>AA4-2<br>AA5-2<br>AA6-2<br>AA7-2 | 1000 | 2000 | 2000 | 3000 | 4000 | 1000 |
| AC1-1 | 1500 | 2500 | 2500 | 4000 | 5500 | 1500 |
| AC1-2 | 1250 | 2250 | 2250 | 3500 | 4750 | 1250 |

## NOTES:

1. PERSONNEL SHALL NOT ENTER ANY AREA OF UNSUPPORTED GROUND OR BELOW ANY AREAS WHERE SHOTCRETE HAS A UCS<1MPa. THE CONTRACTOR SHALL DEMARCATE AREAS OF UNSUPPORTED GROUND.
2. FOR PERSONNEL ENTRY, SUPPORTED GROUND SHALL COMPRISE ALL PATTERN BOLTS, DESIGNATED SPOT BOLTS, FACE SUPPORT AND ≥50mm PRIMARY SHOTCRETE WITH UCS ≥1MPa.
3. WHERE ENCOUNTERED GROUND CONDITIONS DO NOT CONFORM TO THE GROUND TYPE SELECTION CRITERIA, NO PERSONNEL ENTRY IS PERMITTED.
4. MAXIMUM FACE ADVANCE AND MINIMUM DISTANCE TO COMPLETED PRIMARY SHOTCRETE MAY BE REDUCED AT THE DIRECTION OF THE ENGINEER OR CPS TO SUIT CONDITIONS ENCOUNTERED.
5. PRIMARY SUPPORT TO BE INSTALLED UP TO THE CURRENT ADVANCE AND SHALL NOT BE LEFT UNSUPPORTED.

SCALES
0 1000 2000 2500mm
1:100 (A3) 1:50 (A1)

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PRELIMINARY DESIGN - NOT FOR CONSTRUCTION

C:\Users\tony rechsteiner\Desktop\PSM WORKING\Cross river rail\DETAILED DESIGN\01_Drawings\300_Tun_Albert\CRRTSD-300-0322-DRG-PSMQ-1330-180302.dwg

date 1/11/2019 12:14:27 PM

| JOB No | ALTERATIONS | | | | |
|---|---|---|---|---|---|
| PSM3700 | ISSUE | DESCRIPTION | NAME | RPEQ | DATE |
| | A0 | FOR INTERNAL REVIEW | S.CLARKE | | 01.11.19 |
| SCALES SHOWN ARE FOR AN A1 SIZE ORIGINAL DRAWING | | | | | |

CPB CONTRACTORS · bam · Ghella · UGL
CBGU D&C JV

| DESIGNED | C.B. | 01.11.19 |
|---|---|---|
| DES CHK | R.B. | 01.11.19 |
| DRAWN | O.C. | 01.11.19 |
| DRG CHK | T.R. | 01.11.19 |

DESIGN APPROVAL / CERTIFICATION
S.CLARKE 01.11.19
PROFESSIONAL QUALIFICATION DATE

CROSS RIVER RAIL
DELIVERY AUTHORITY

Network - Civil Engineering
ALBERT ST STATION
CROSS RIVER RAIL
PRIMARY SUPPORT
CAVERN SEQUENCE - LONGITUDINAL SECTION

DRAWING NUMBER
PIC CERT No.
180302
ISSUE
A0
CONSULTANT DWG No. CRRTSD-300-0322-DRG-PSMQ-1330-180302


TUNNEL EXCAVATION SEQUENCE
PASSIVE LINING SUPPORT TYPES
SCALE 1:50

## GEOMETRIC CONSTRAINTS – PASSIVE LINING SUPPORT TYPES

| SUPPORT TYPE | MAX. FACE ADVANCE (A) | MAX. DISTANCE TO BOLTS (B) | DISTANCE TO ≥ 200mm SHOTCRETE (C) | MAX. DISTANCE TO COMPLETED PRIMARY SHOTCRETE (D) | MAX. DISTANCE TO ANY SHOTCRETE WITH CHARACTERISTIC STRENGTH OF 15MPa (E) | BOLT SPACING (L) |
|---|---|---|---|---|---|---|
| AA1-3 | 1000 | - | 3000 | 3000 | 4000 | - |
| AA2-3 | | | | | | |
| AA3-3 | | | | | | |
| AA4-3 | | | | | | |
| AA5-3 | | | | | | |
| AA6-3 | | | | | | |
| AA7-3 | | | | | | |
| AC1-3 | 1500 | 2500 | 4000 | 8500 | 5500 | 1500 |

## NOTES:

1. PERSONNEL SHALL NOT ENTER ANY AREA OF UNSUPPORTED GROUND OR BELOW ANY AREAS WHERE SHOTCRETE HAS A UCS<1MPa. THE CONTRACTOR SHALL DEMARCATE AREAS OF UNSUPPORTED GROUND.
2. FOR PERSONNEL ENTRY, SUPPORTED GROUND SHALL COMPRISE ALL PATTERN BOLTS, DESIGNATED SPOT BOLTS, FACE SUPPORT AND ≥200mm THICK PRIMARY SHOTCRETE WITH UCS ≥1MPa.
3. WHERE ENCOUNTERED GROUND CONDITIONS DO NOT CONFORM TO THE GROUND TYPE SELECTION CRITERIA, NO PERSONNEL ENTRY IS PERMITTED.
4. MAXIMUM FACE ADVANCE AND MINIMUM DISTANCE TO COMPLETED PRIMARY SHOTCRETE MAY BE REDUCED AT THE DIRECTION OF THE ENGINEER OR CPS TO SUIT CONDITIONS ENCOUNTERED.
5. PRIMARY SUPPORT TO BE INSTALLED UP TO THE CURRENT ADVANCE AND SHALL NOT BE LEFT UNSUPPORTED.

SCALES
0 1000 2000 2500mm
1:100 (A3) 1:50 (A1)

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PRELIMINARY DESIGN - NOT FOR CONSTRUCTION

| JOB No | ISSUE | DESCRIPTION | NAME | RPEQ | DATE |
|---|---|---|---|---|---|
| PSM3700 | A0 | FOR INTERNAL REVIEW | S.CLARKE | | 01.11.19 |

SCALES SHOWN ARE FOR AN A1 SIZE ORIGINAL DRAWING

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| | | |
|---|---|---|
| DESIGNED | C.B. | 01.11.19 |
| DES CHK | R.B. | 01.11.19 |
| DRAWN | O.C. | 01.11.19 |
| DRG CHK | T.R. | 01.11.19 |

DESIGN APPROVAL / CERTIFICATION
S.CLARKE 01.11.19
PROFESSIONAL QUALIFICATION DATE

CROSS RIVER RAIL DELIVERY AUTHORITY

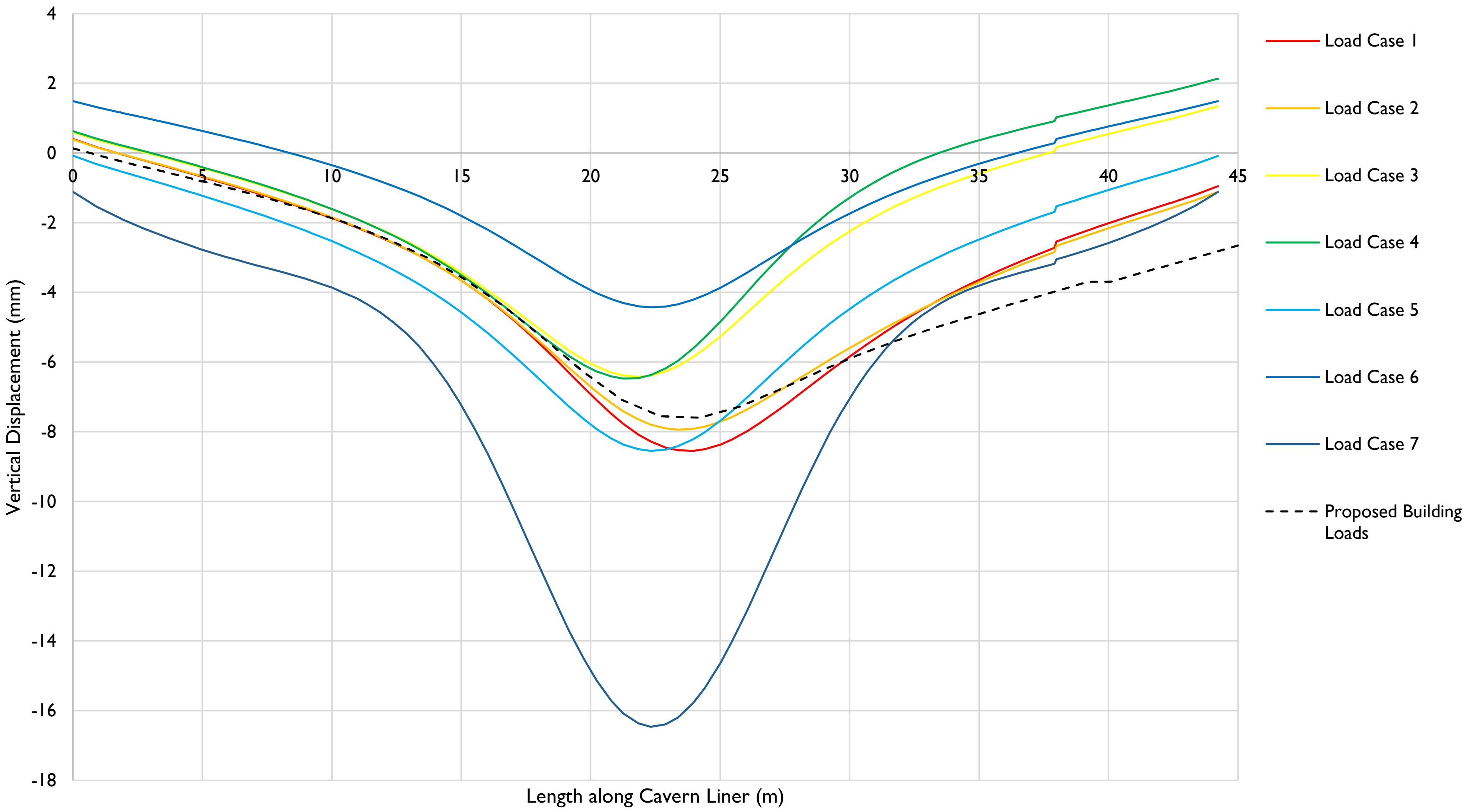
Network - Civil Engineering
ALBERT ST STATION
CROSS RIVER RAIL
PRIMARY SUPPORT
CONSTRUCTION SEQUENCE - PASSIVE LINING SUPPORT

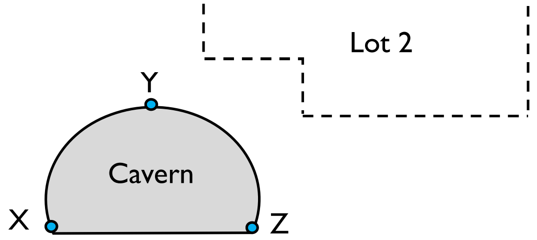
DRAWING NUMBER
PIC CERT No. 180303
ISSUE A0
CONSULTANT DWG No. CRRTSD-300-0322-DRG-PSMQ-1330-180303

# Appendix E

## Calculation Outputs

## Analysis Group 1 (1a) - Total Vertical Displacement on Cavern Liner

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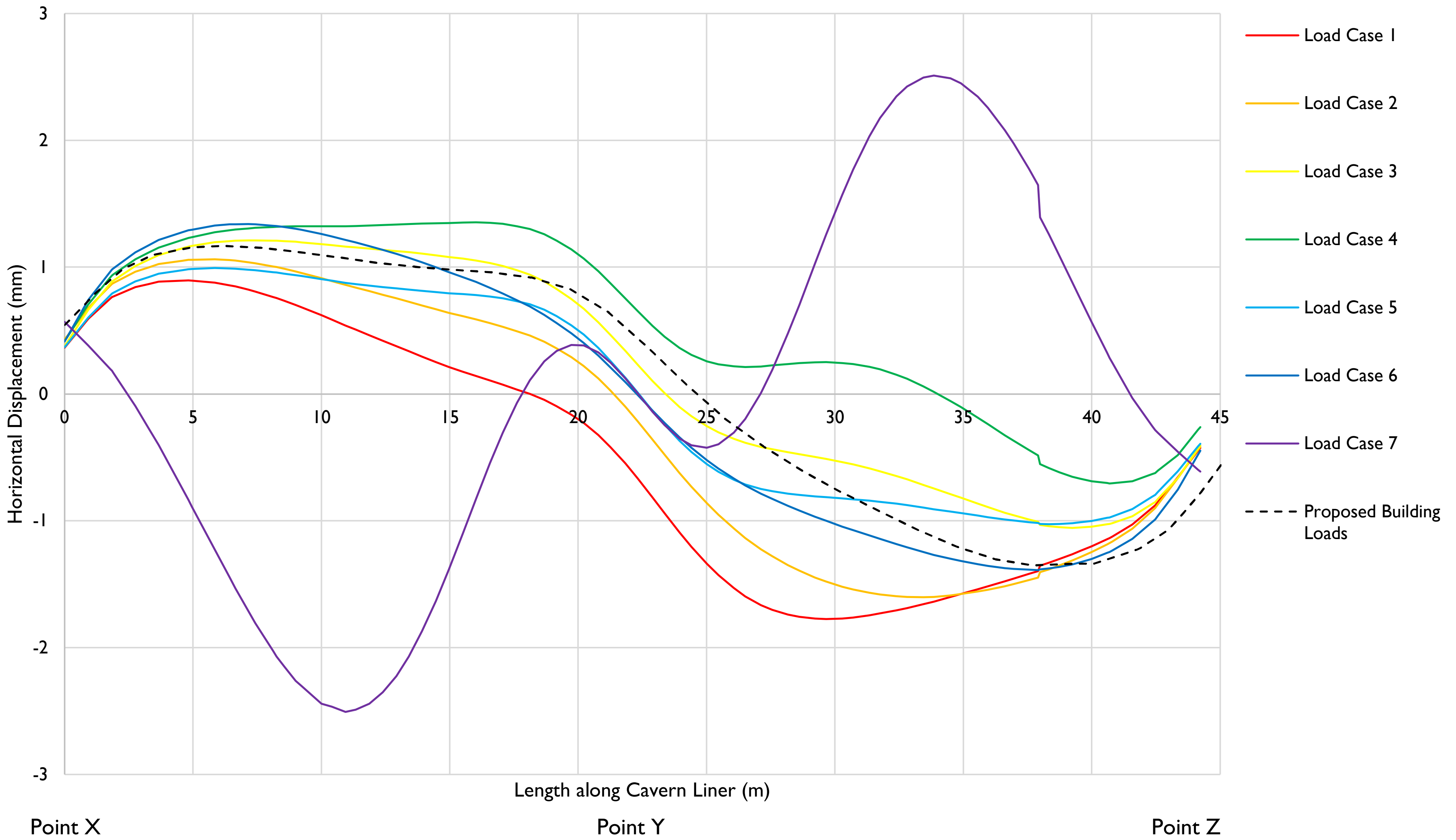
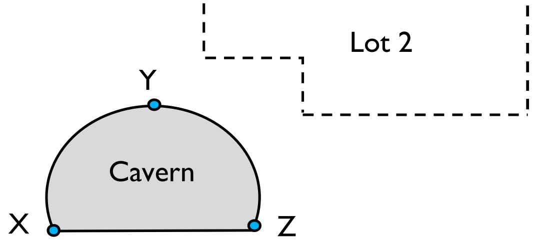
| *date:* | 25/05/2023 | *project:* | Albert Street Development | |
| *approved:* | DJC | *location:* | Brisbane | |
| *scale:* | NTS | *title:* | *Finite Element Outputs* | |
| | | *job no:* | B01493-1 | *figure:* 1a |

## Analysis Group 1 (1b) - Total Horizontal Displacement on Cavern Liner

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| *date:* | 25/05/2023 | *project:* | Albert Street Development |
| *approved:* | DJC | *location:* | Brisbane |
| *scale:* | NTS | *title:* | *Finite Element Outputs* |
| | | *job no:* | B01493-1 |

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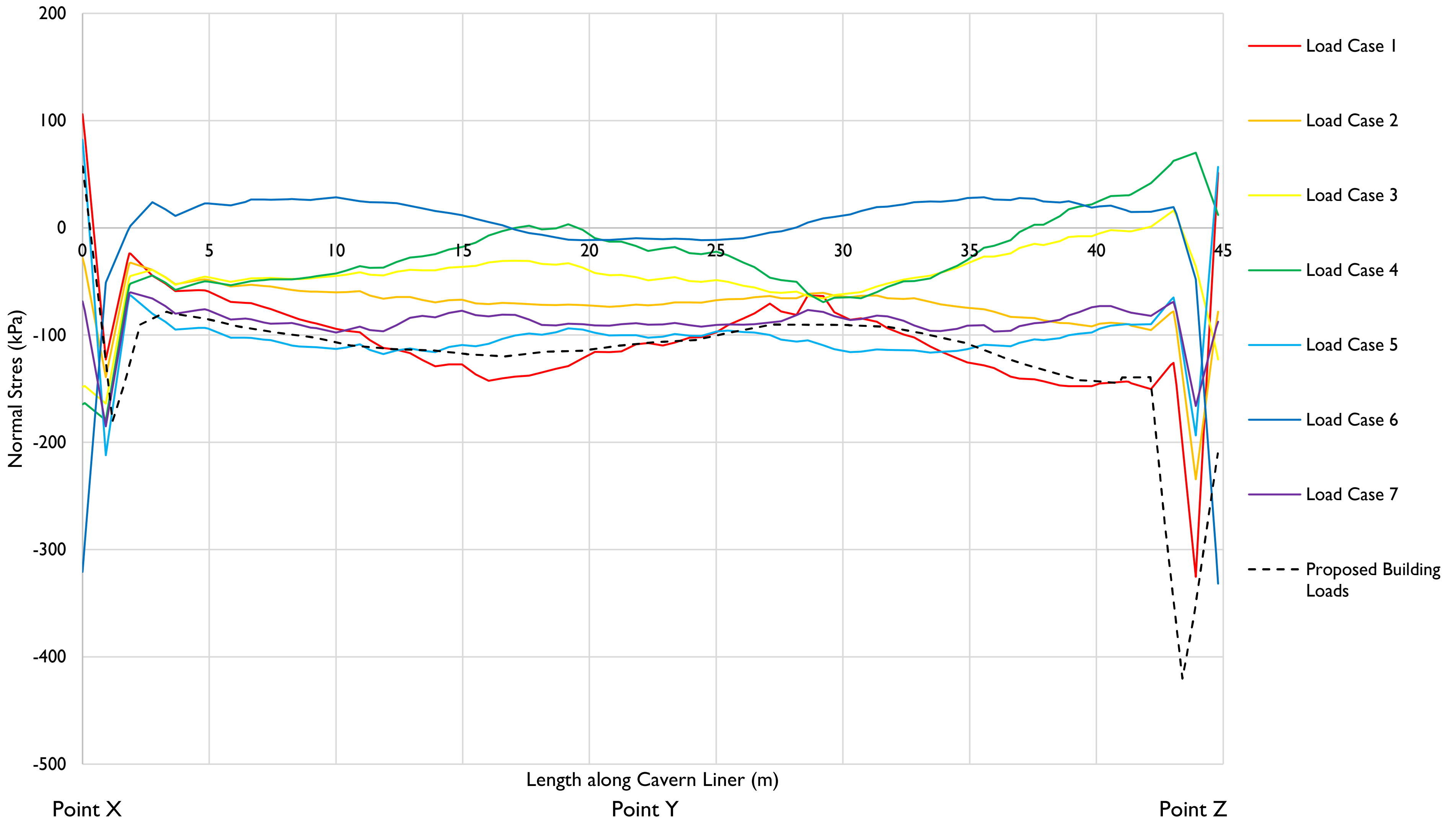
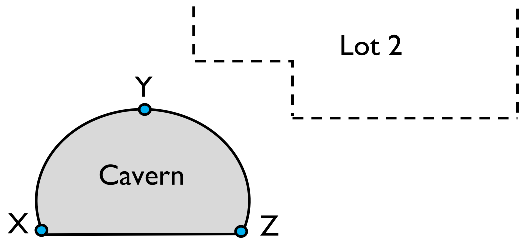
*figure:* *1b*

## Analysis Group 1 (1c) - Total Normal Stress on Cavern Liner

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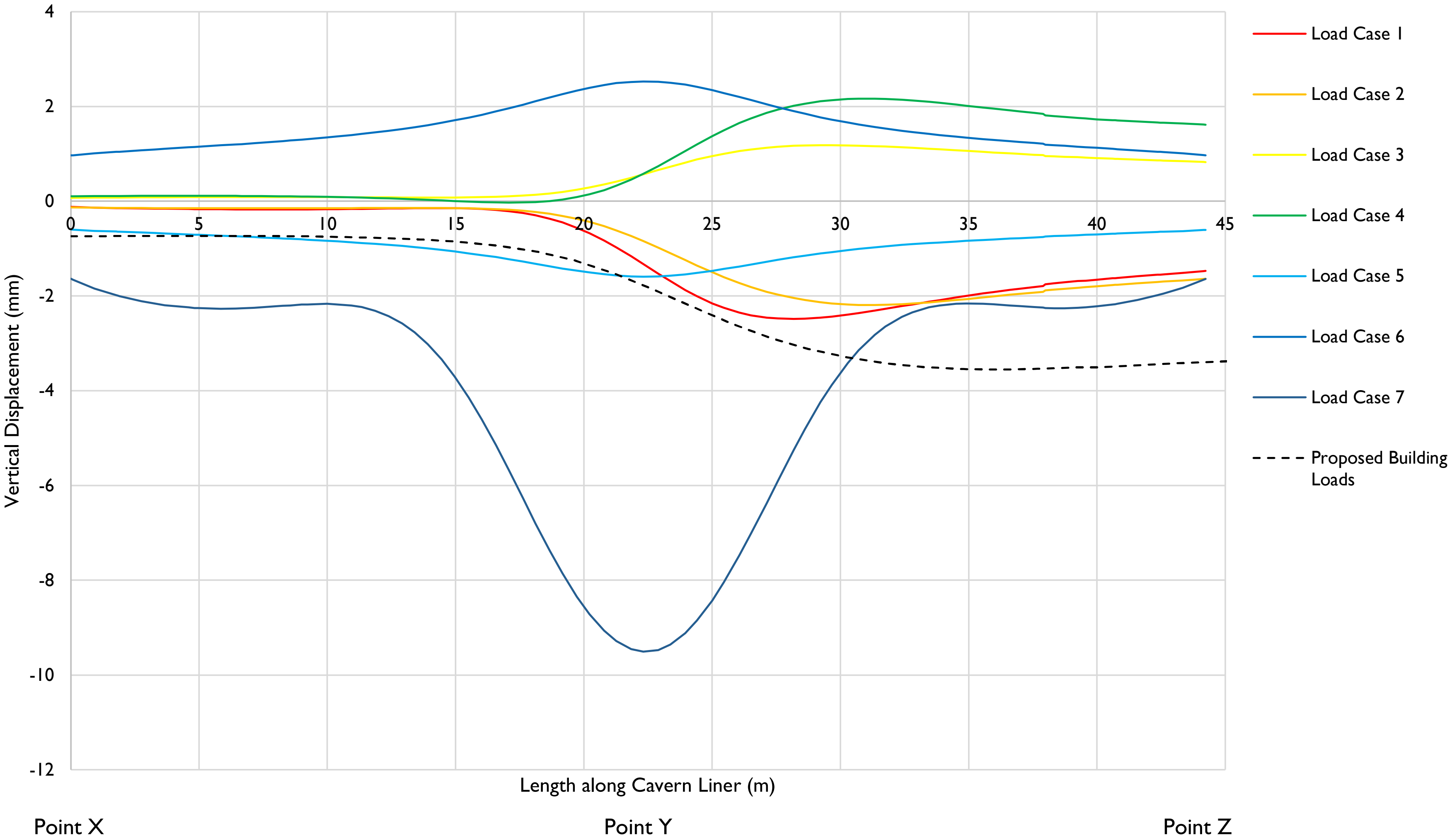
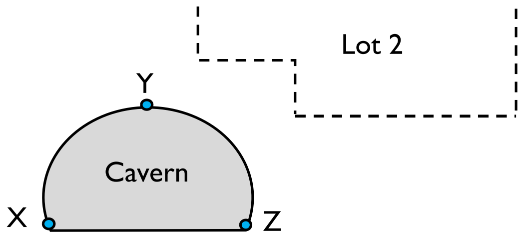
| *date:* | 25/05/2023 | *project:* | Albert Street Development | |
| *approved:* | DJC | *location:* | Brisbane | |
| *scale:* | NTS | *title:* | *Finite Element Outputs* | |
| | | *job no:* | B01493-1 | *figure:* 1c |

## Analysis Group 1 (1d) - Change in Vertical Displacement on Cavern Liner

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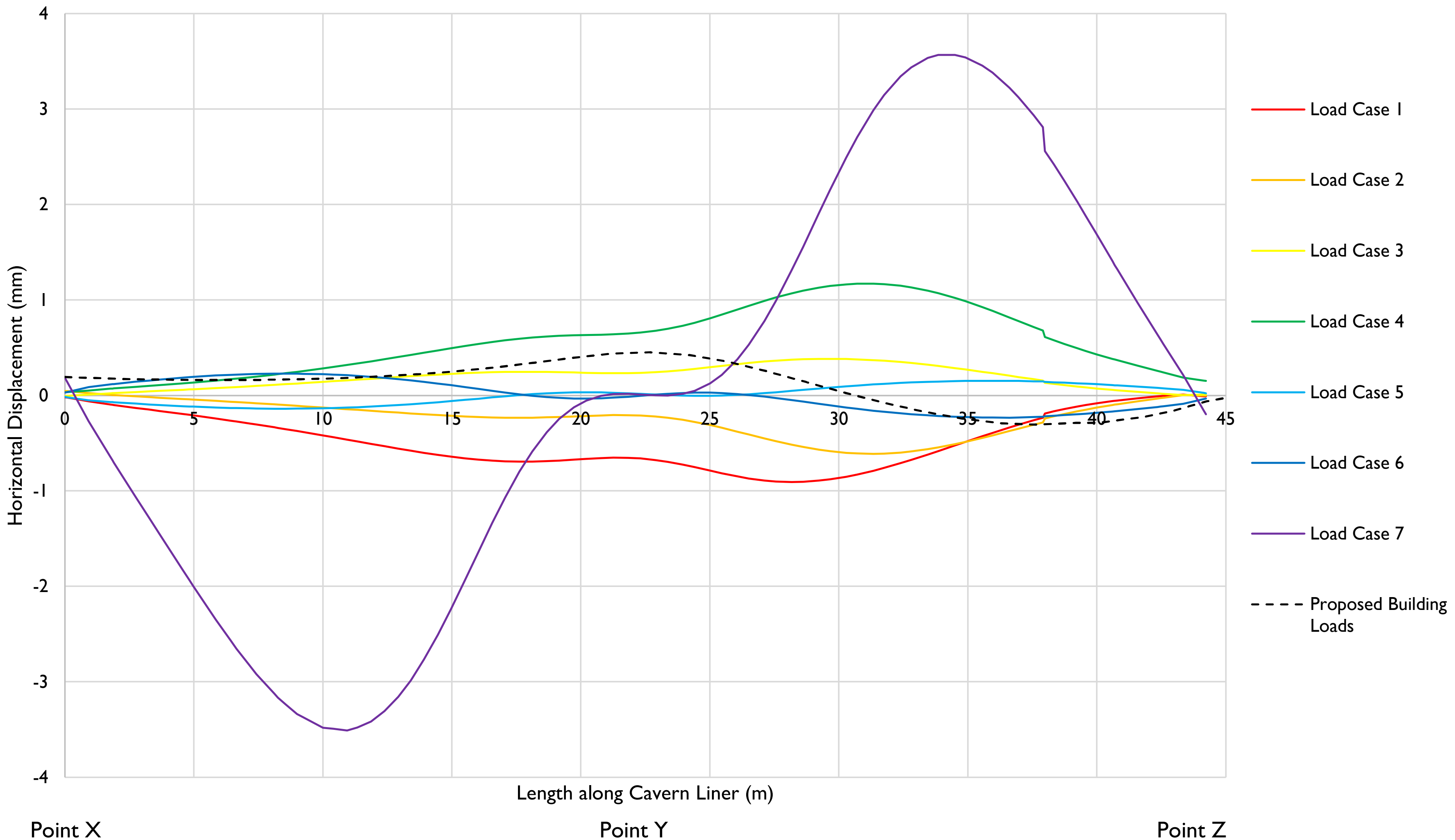
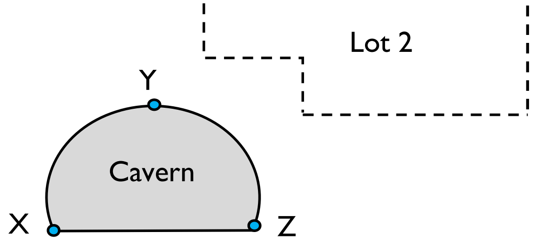
| *by:* | DL | *client:* | RCP | EDG consulting<br>engineering \| design \| geosciences |
| *date:* | 25/05/2023 | *project:* | Albert Street Development | |
| *approved:* | DJC | *location:* | Brisbane | |
| | | *title:* | *Finite Element Outputs* | |
| *scale:* | NTS | *job no:* | B01493-1 | *figure:* *1d* |

## Analysis Group 1 (1e) - Change in Horizontal Displacement on Cavern Liner

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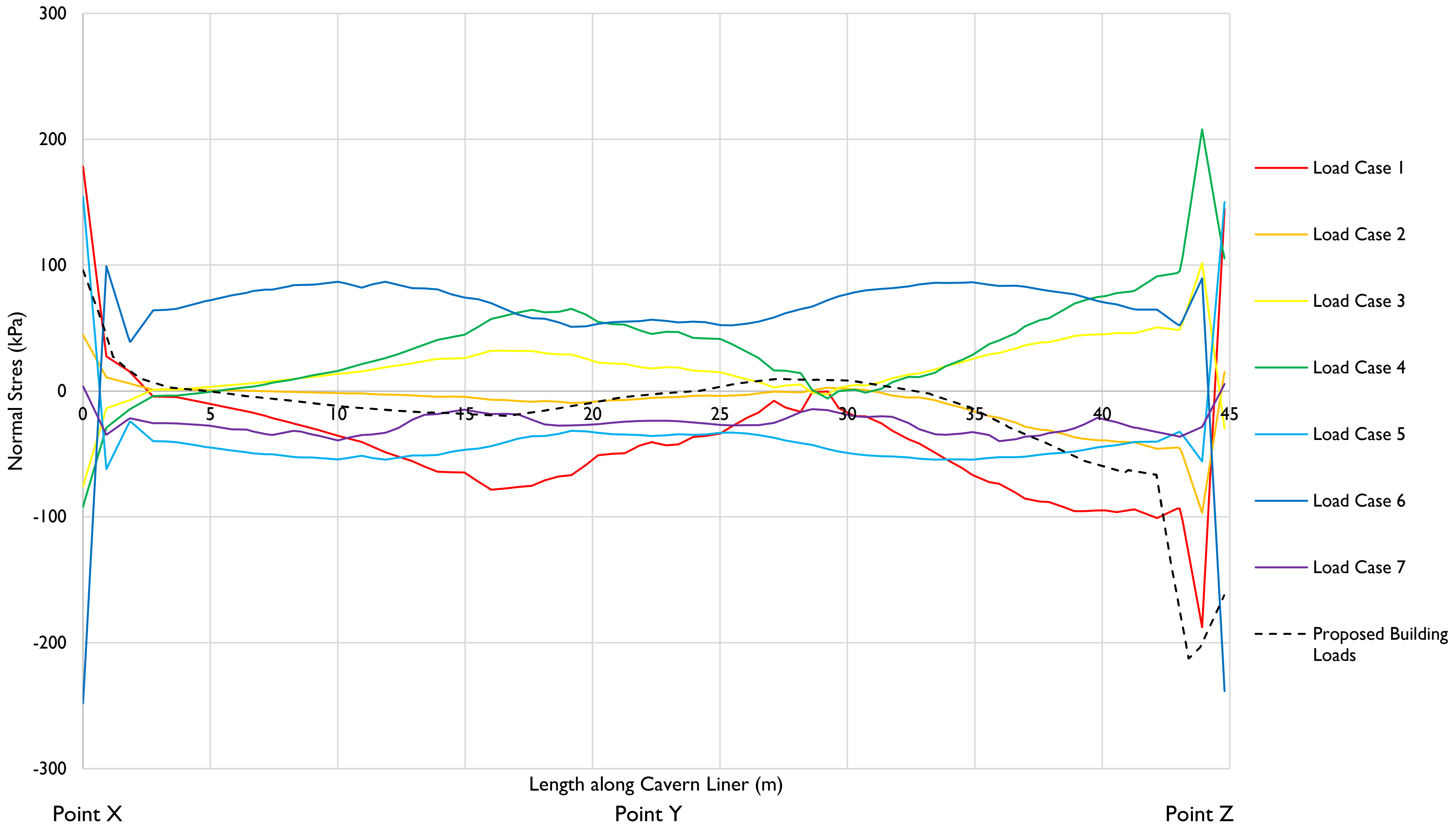
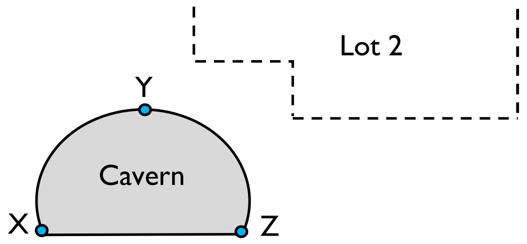
| *date:* | 25/05/2023 | *project:* | Albert Street Development |
| *approved:* | DJC | *location:* | Brisbane |
| *scale:* | NTS | *title:* | *Finite Element Outputs* |
| | | *job no:* | B01493-1 |

*figure:* 1e

## Analysis Group 1 (1f) - Change in Normal Stress on Cavern Liner

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| *date:* | 25/05/2023 | *project:* | Albert Street Development |
| *approved:* | DJC | *location:* | Brisbane |
| | | *title:* | *Finite Element Outputs* |
| *scale:* | NTS | *job no:* | B01493-1 |

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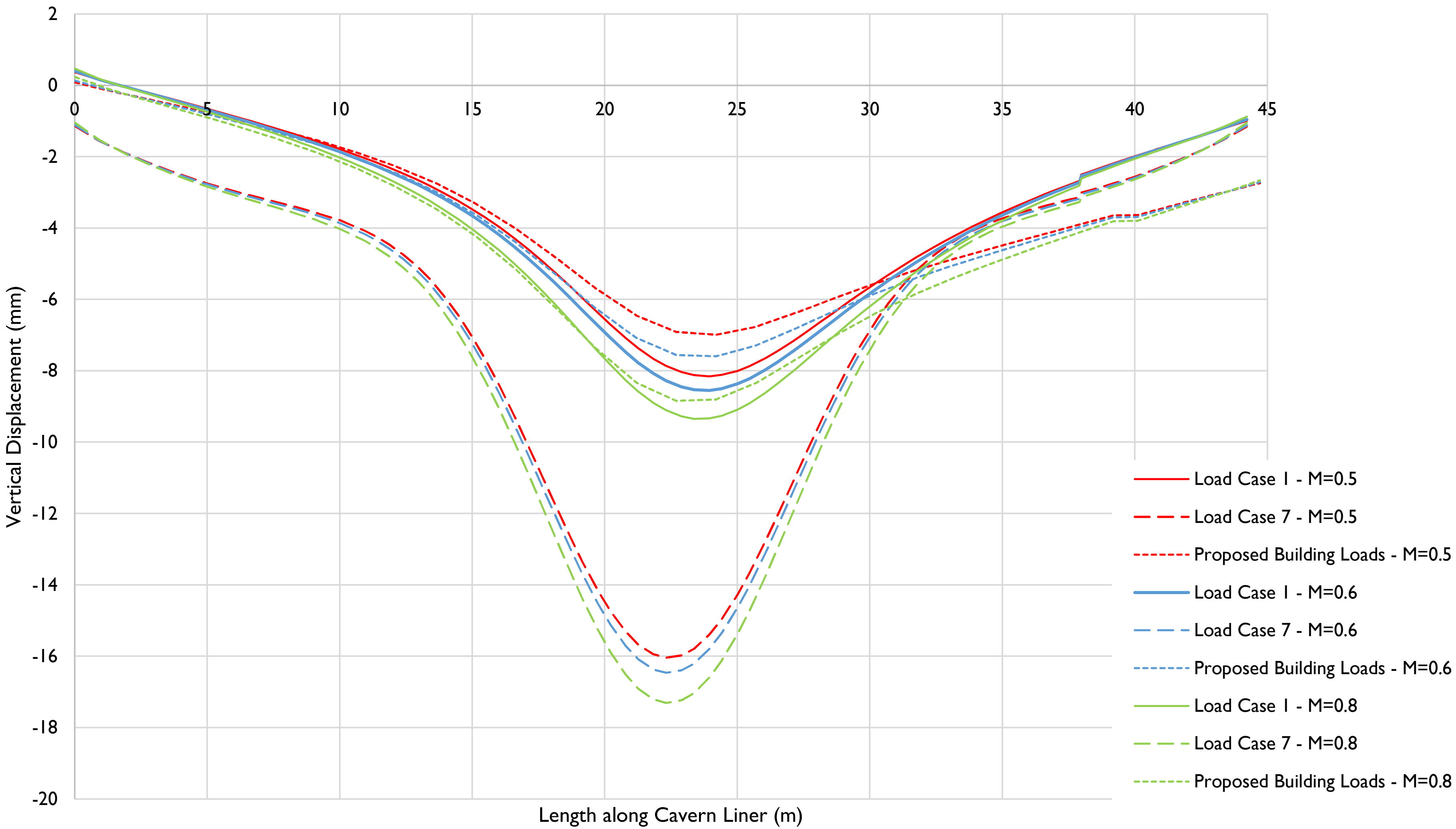
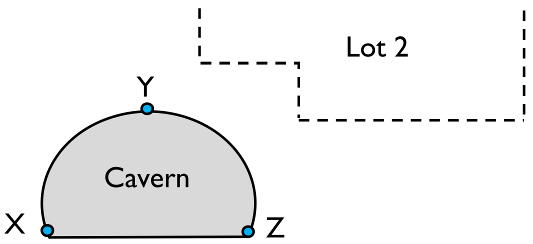
*figure:* *1f*

## Analysis Group 2 (2a) - Total Vertical Displacement on Cavern Liner




Point X Point Y Point Z

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| *scale:* | NTS | *title:* | *Finite Element Outputs* |
| | | *job no:* | B01493-1 |

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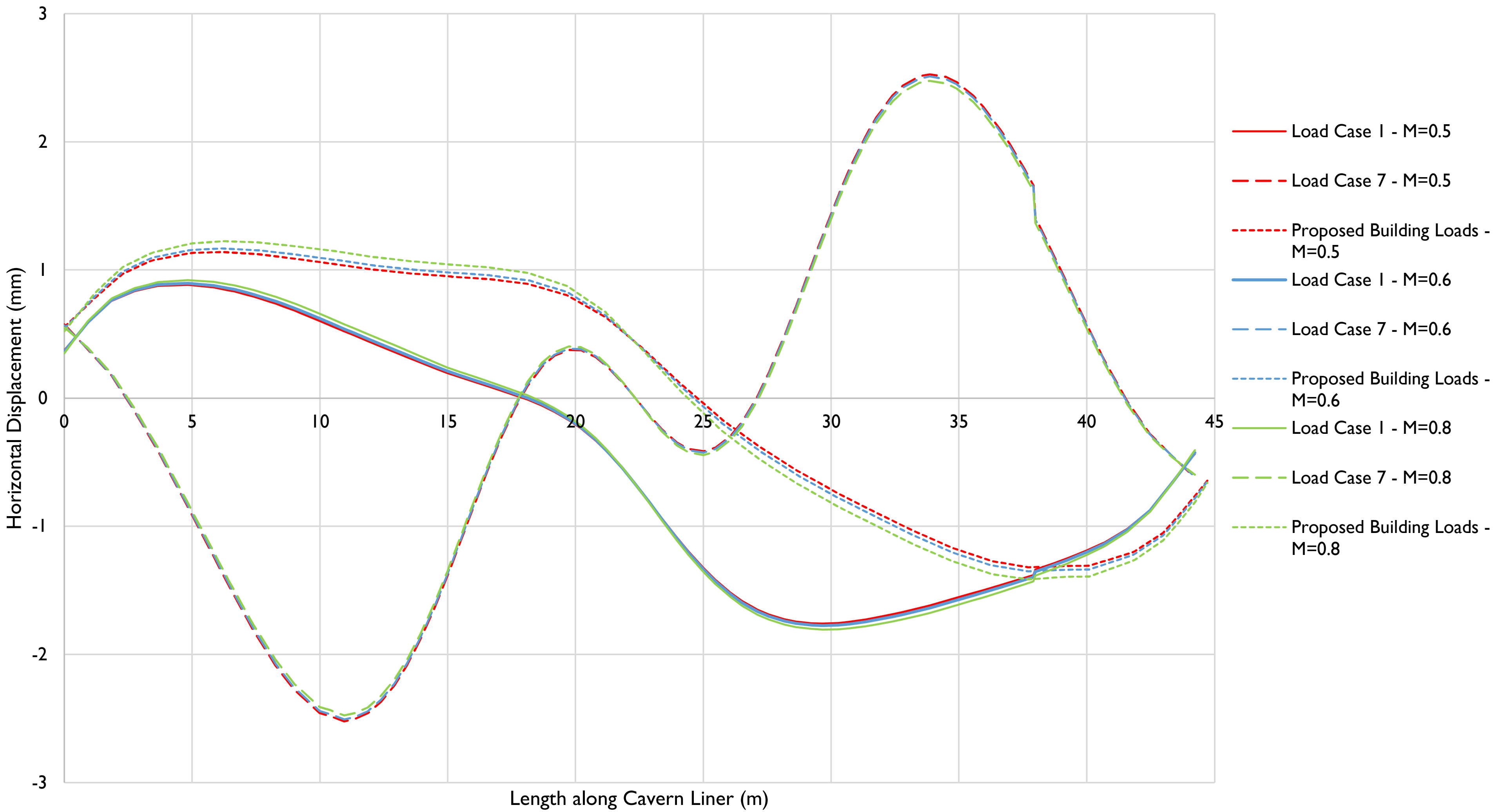
*figure:* *2a*

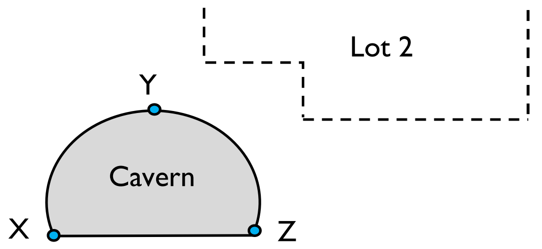
## Analysis Group 2 (2b) - Total Horizontal Displacement on Cavern Liner




Point X

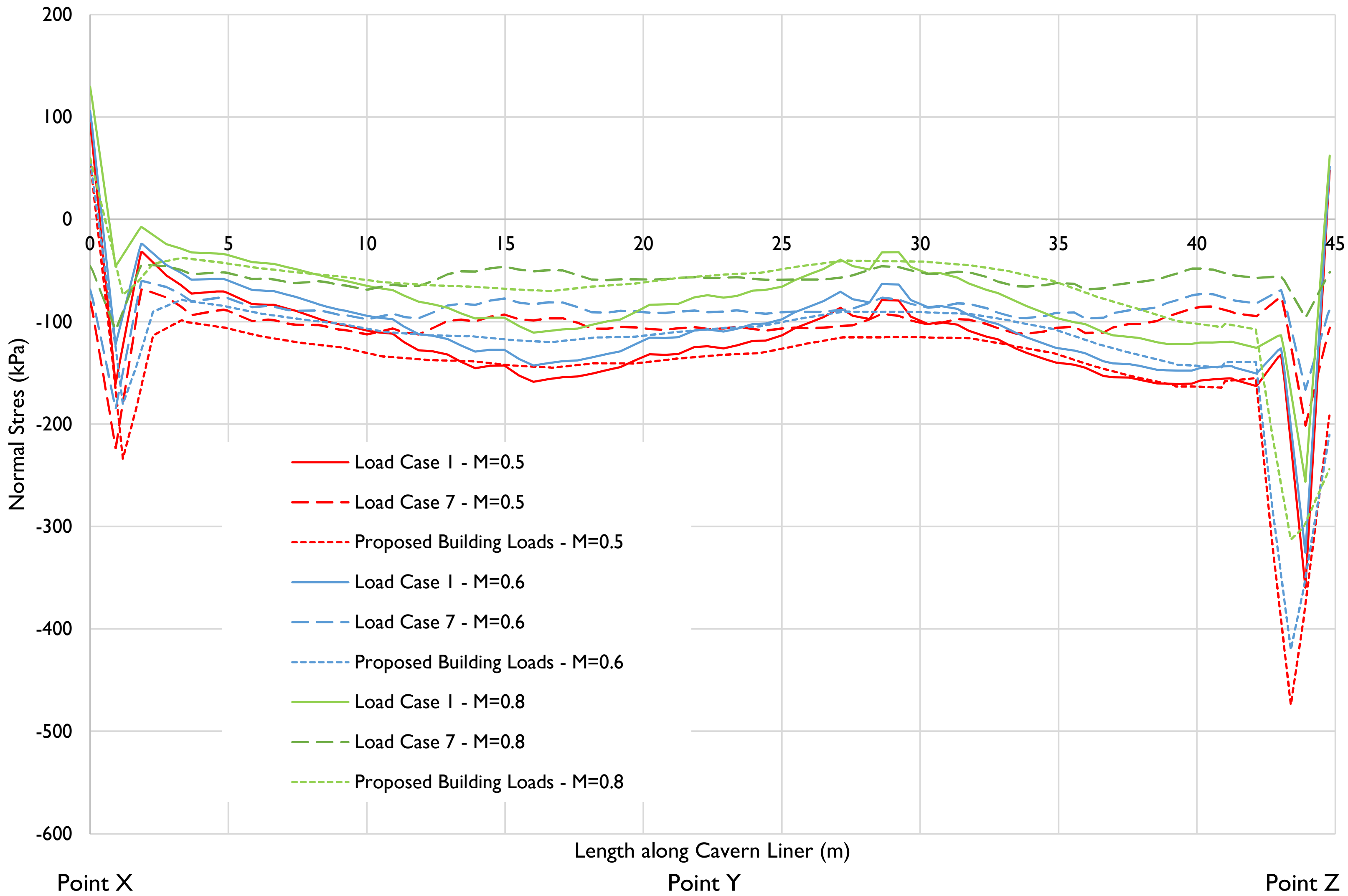
Point Y

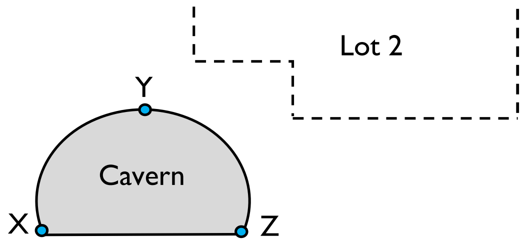
Point Z




| | | | | |
|---|---|---|---|---|
| *by:* | DL | *client:* | RCP | **EDG consulting** engineering \| design \| geosciences |
| *date:* | 25/05/2023 | *project:* | Albert Street Development | |
| *approved:* | DJC | *location:* | Brisbane | |
| *scale:* | NTS | *title:* | *Finite Element Outputs* | |
| | | *job no:* | B01493-1 | *figure:* 2b |

## Analysis Group 2 (2c) - Total Normal Stress on Cavern Liner

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| *by:* | DL | *client:* | RCP | |
| *date:* | 25/05/2023 | *project:* | Albert Street Development | |
| *approved:* | DJC | *location:* | Brisbane | |
| | | *title:* | *Finite Element Outputs* | |
| *scale:* | NTS | *job no:* | B01493-1 | *figure:* 2c |

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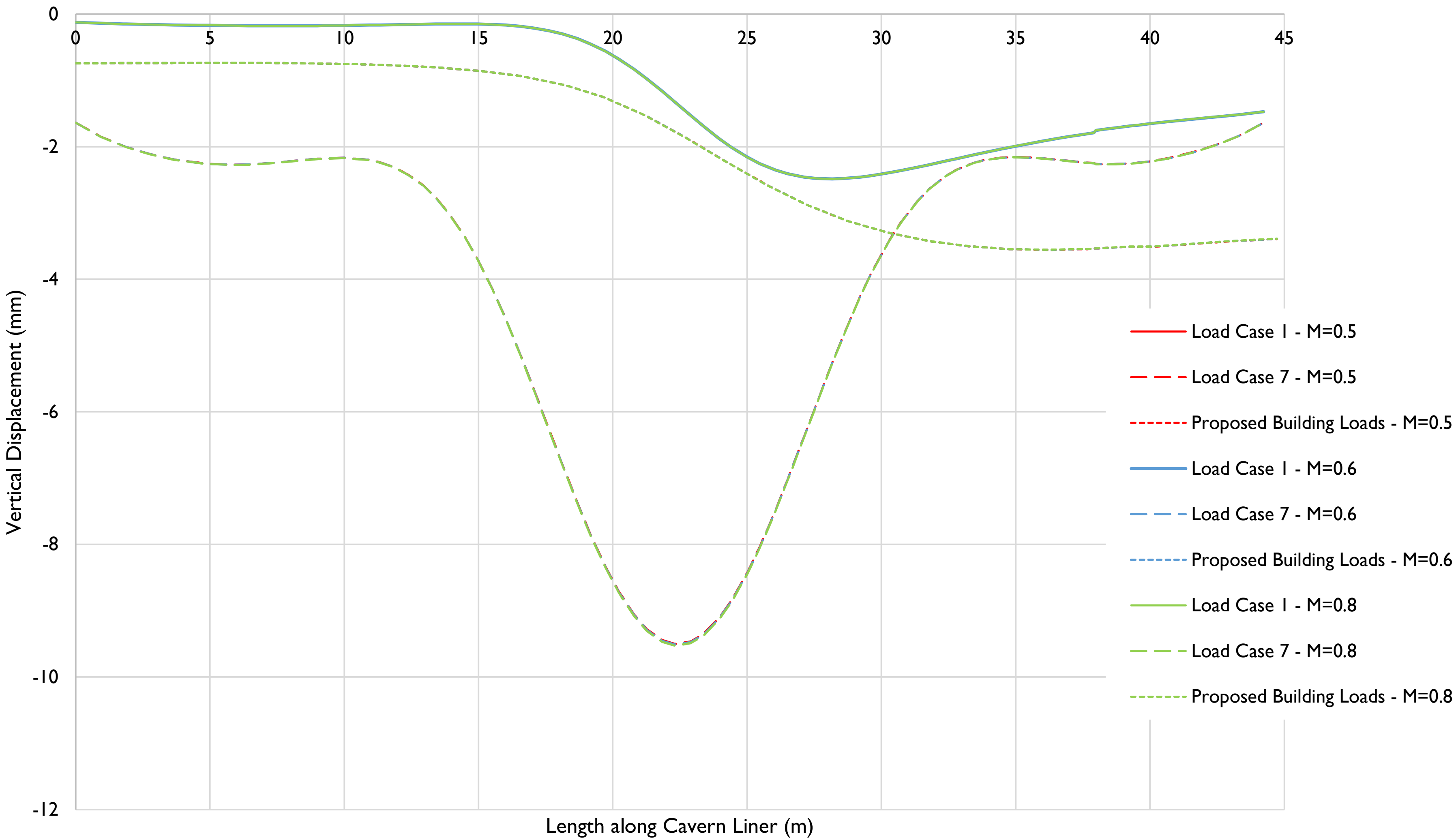
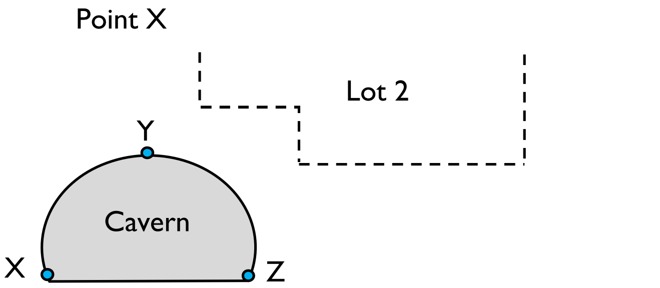
## Analysis Group 2 (2d) - Change in Vertical Displacement on Cavern Liner

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| *approved:* | DJC | *location:* | Brisbane |
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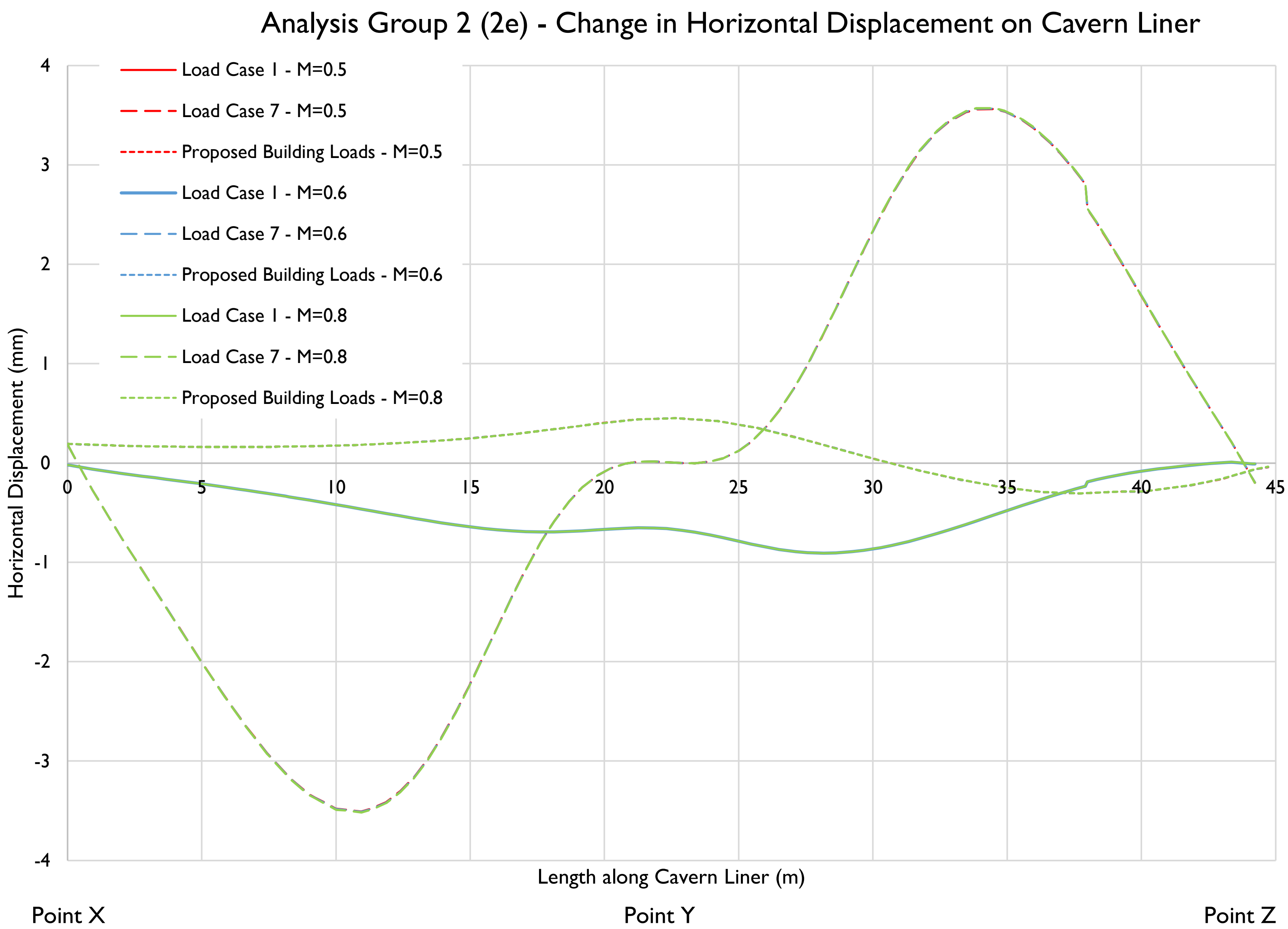
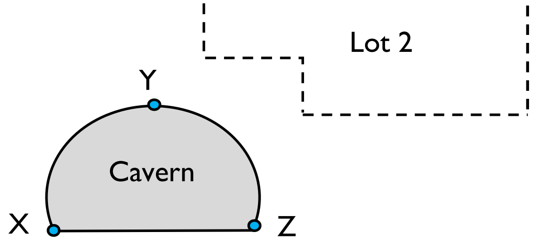
*figure:* 2d

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| date: | 25/05/2023 | project: | Albert Street Development | |
| approved: | DJC | location: | Brisbane | |
| | | title: | *Finite Element Outputs* | |
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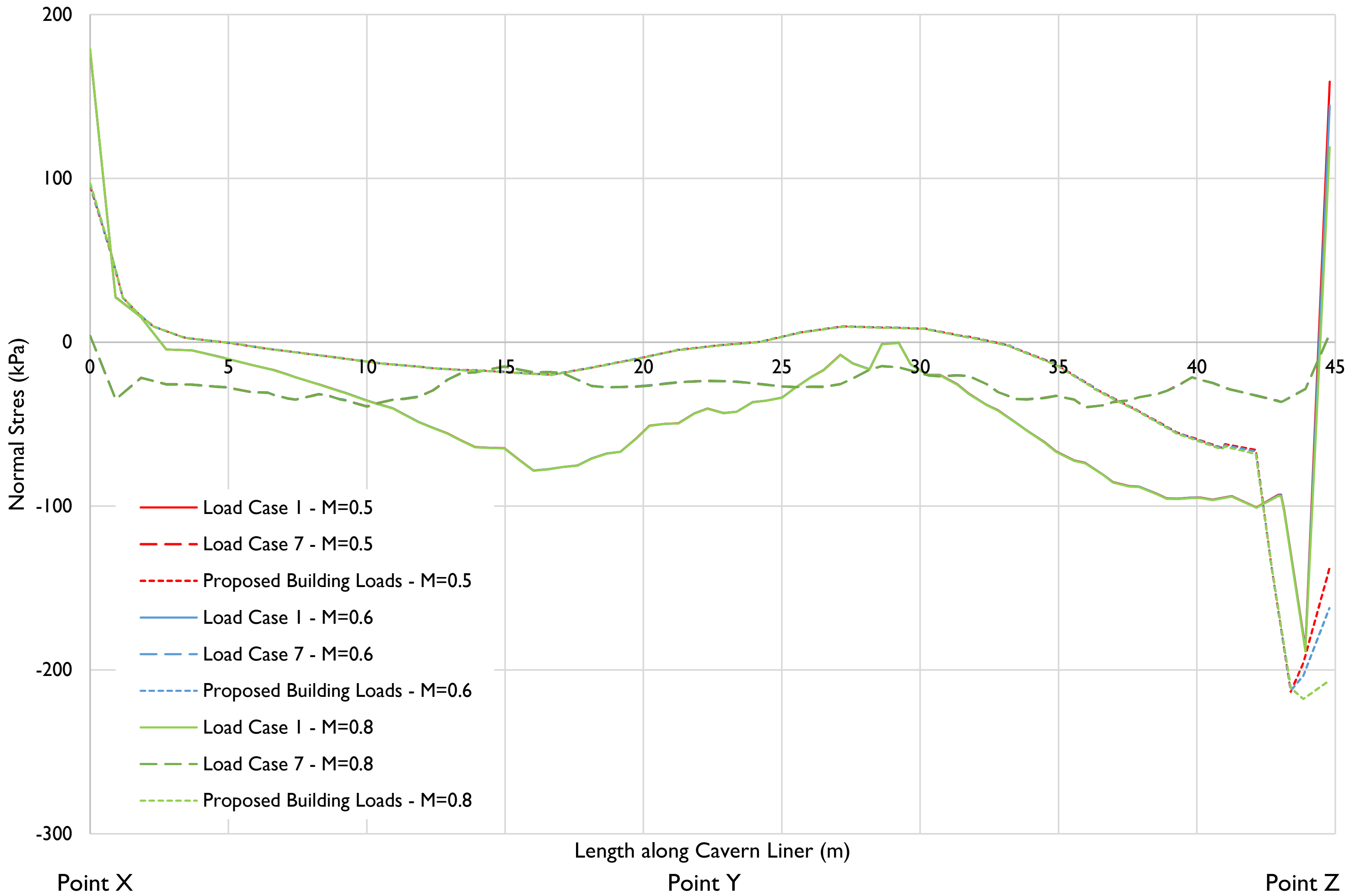
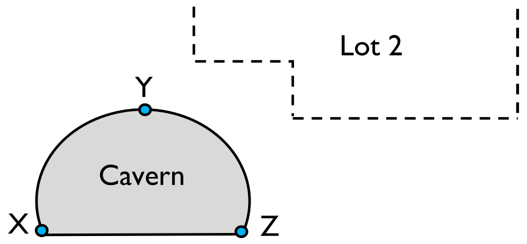
Analysis Group 2 (2f) - Change in Normal Stress on Cavern Liner

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| *approved:* | DJC | *location:* | Brisbane | |
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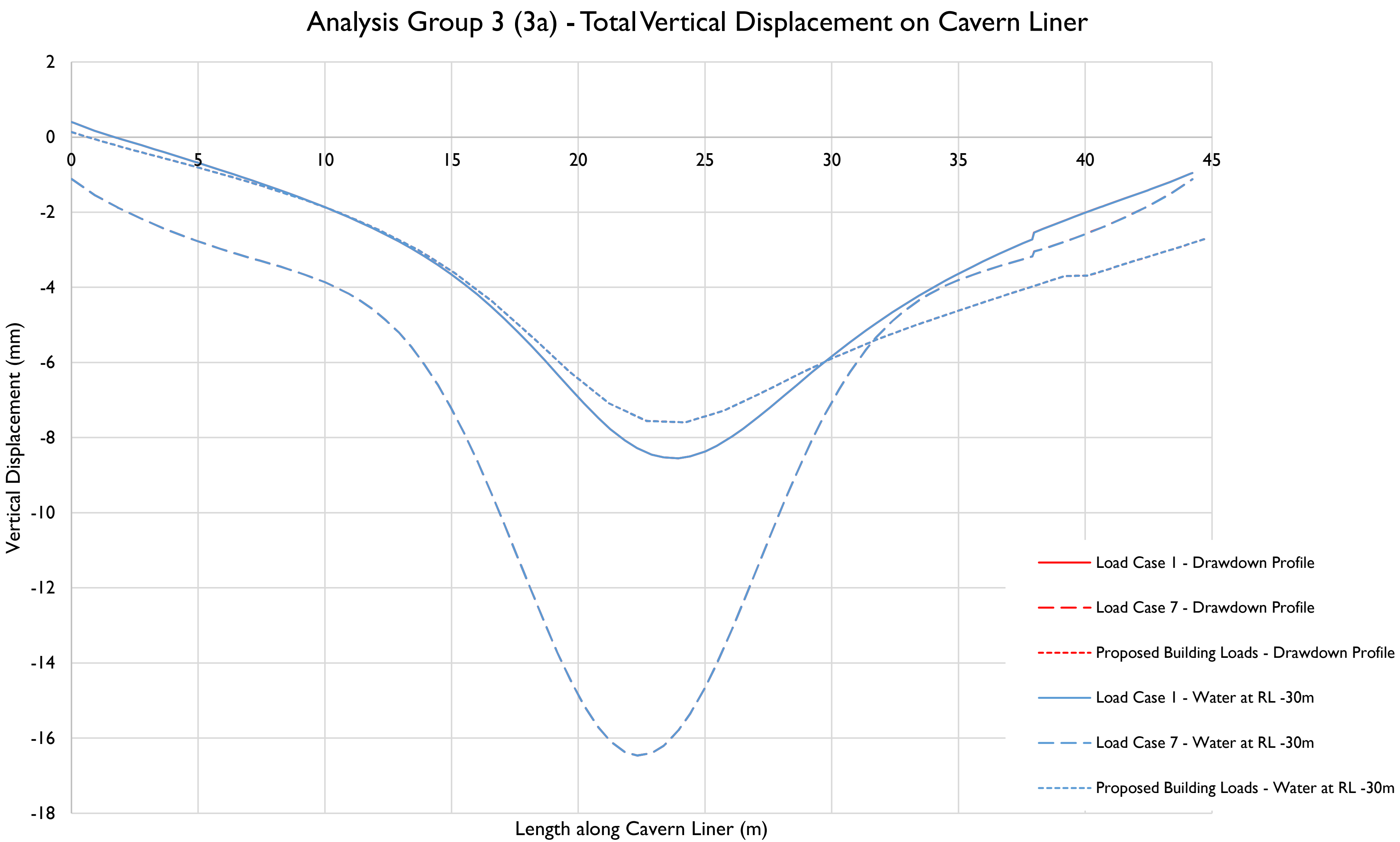


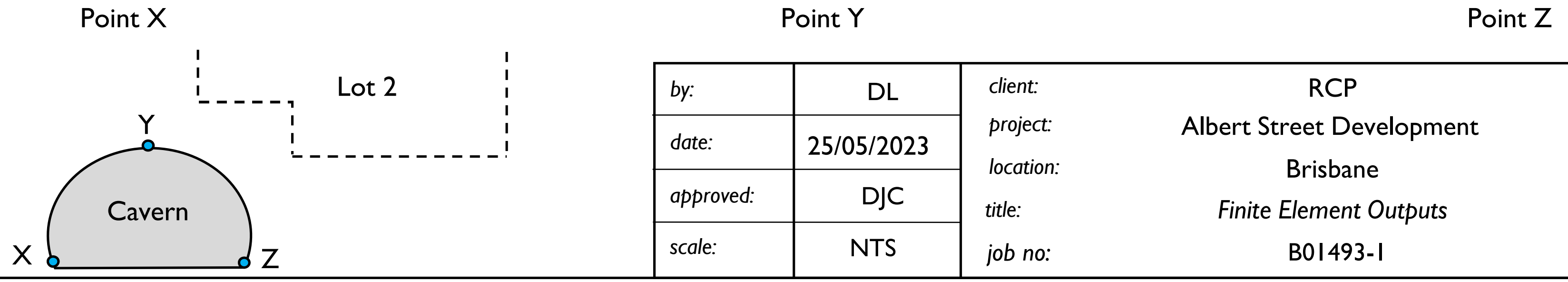


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| *approved:* | DJC | *location:* | Brisbane |
| *scale:* | NTS | *title:* | *Finite Element Outputs* |
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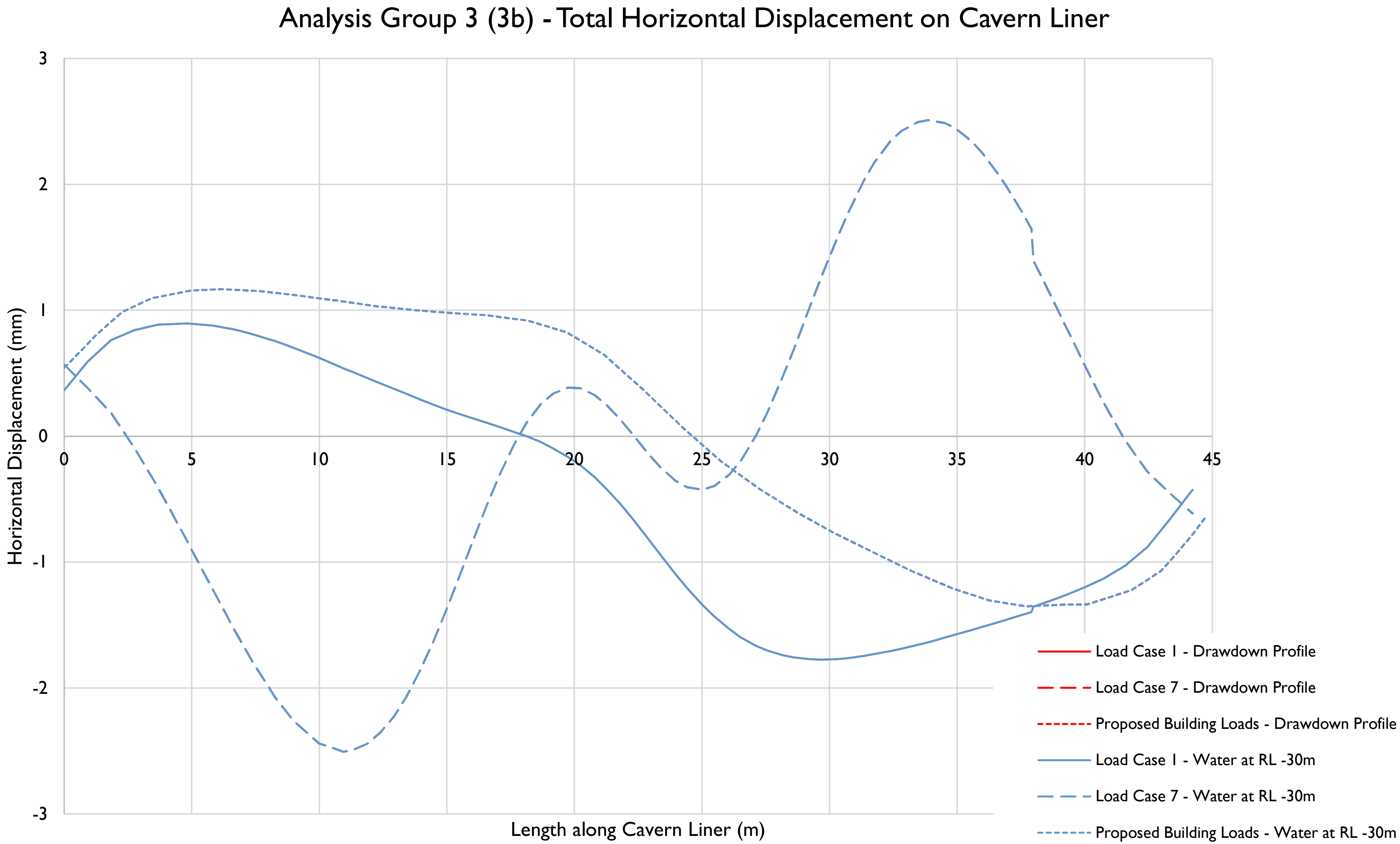
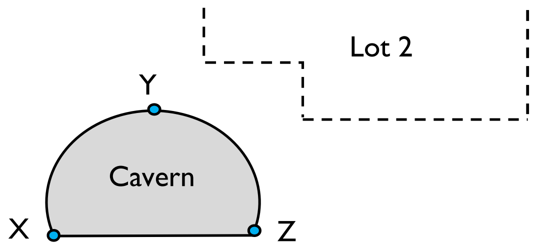
*figure:* *3a*




Point X
Point Y
Point Z

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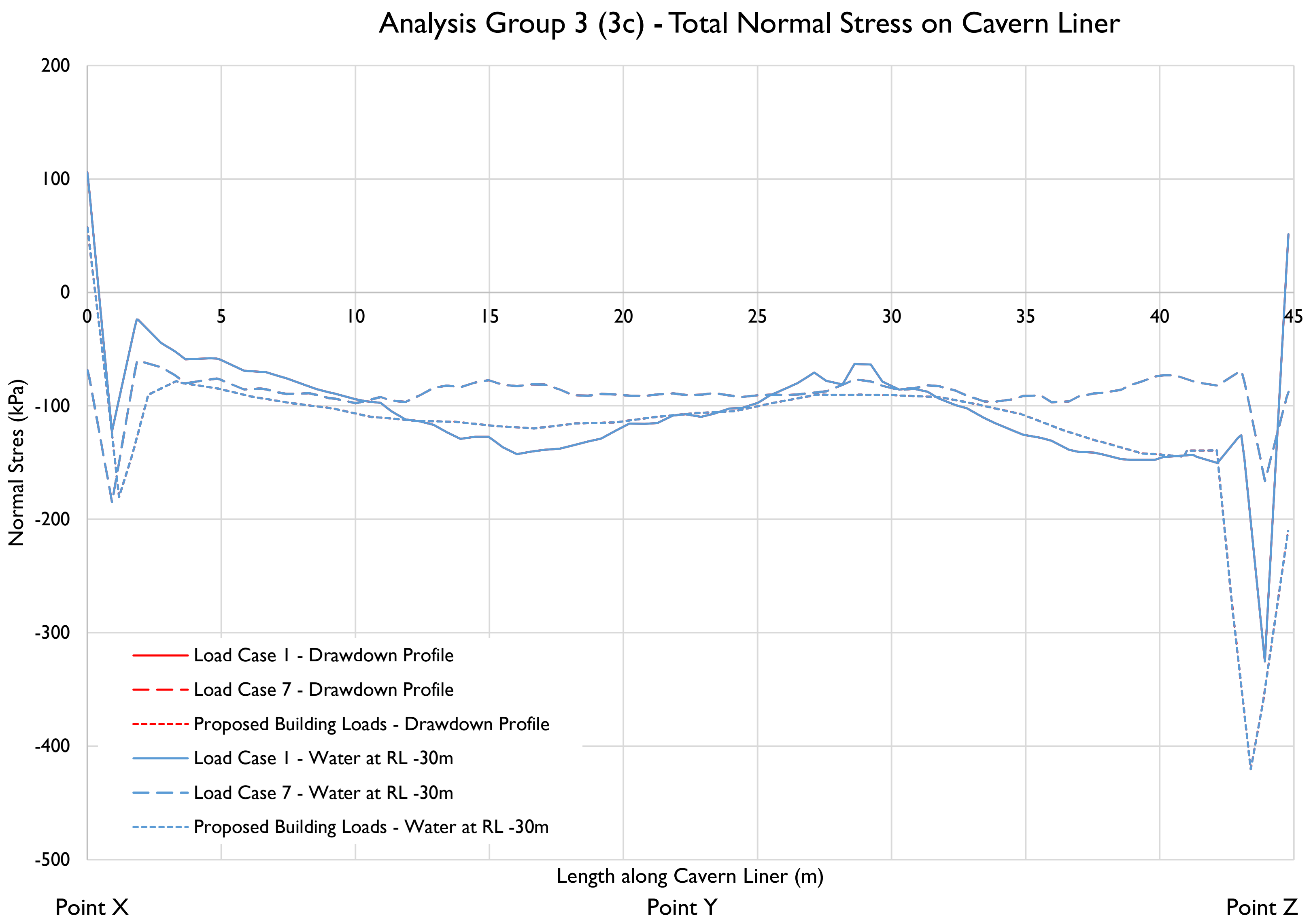


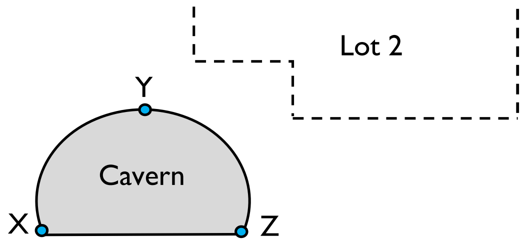


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| approved: | DJC | location: | Brisbane |
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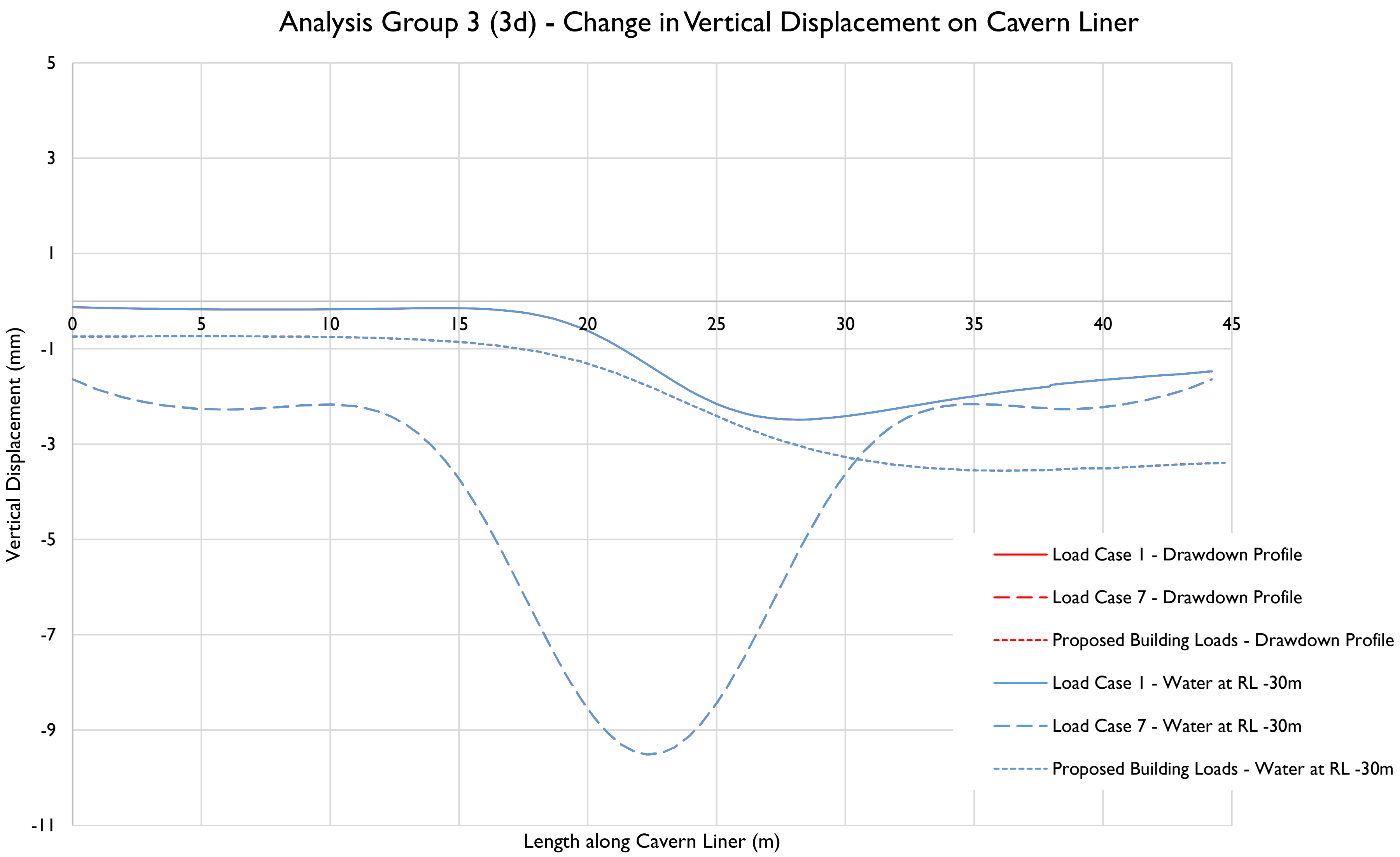
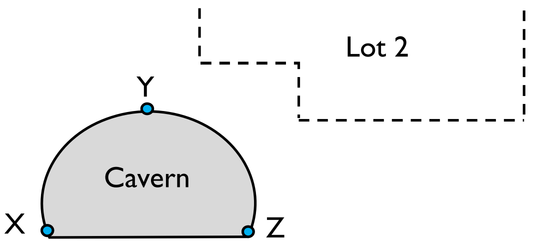
*figure:* 3c




Point X Point Y Point Z

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| *scale:* | NTS | *title:* | *Finite Element Outputs* |
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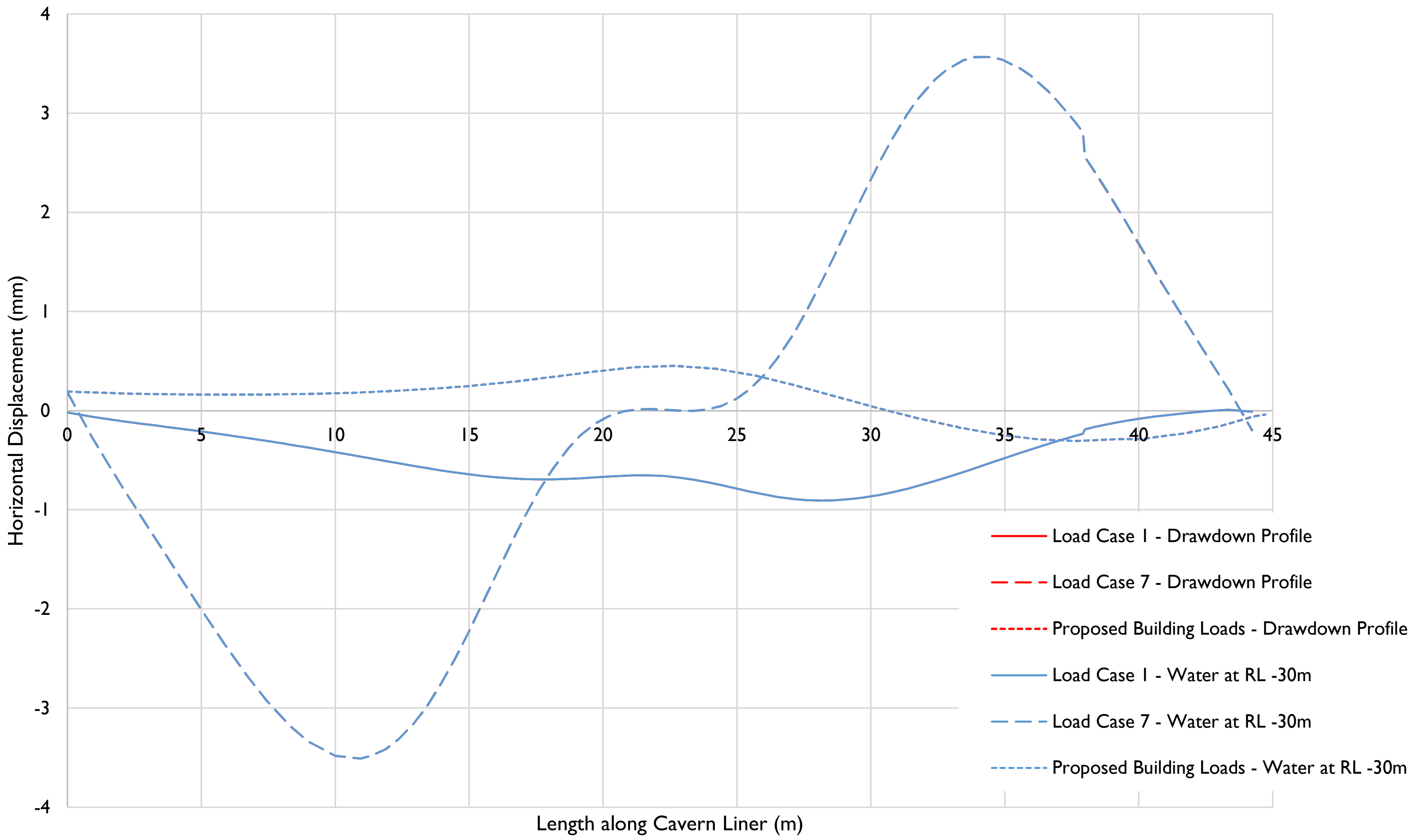
*figure:* 3d

## Analysis Group 3 (3e) - Change in Horizontal Displacement on Cavern Liner




Point X | Point Y | Point Z

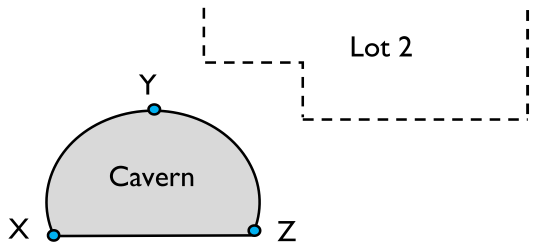



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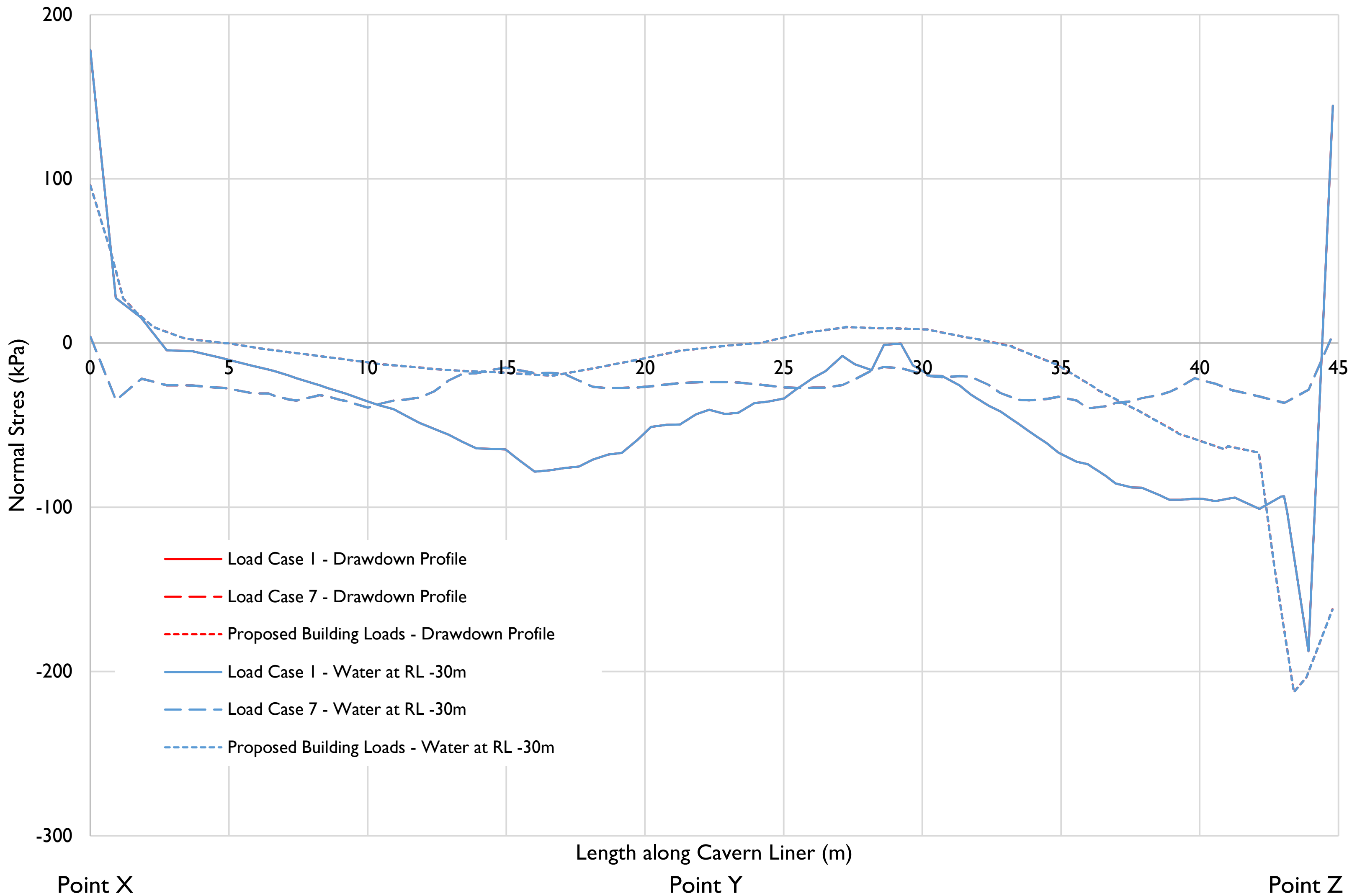
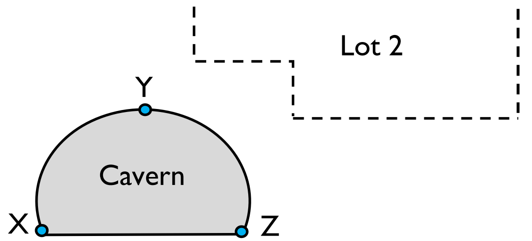
*figure:* 3e

## Analysis Group 3 (3f) - Change in Normal Stress on Cavern Liner

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| *approved:* | DJC | *location:* | Brisbane |
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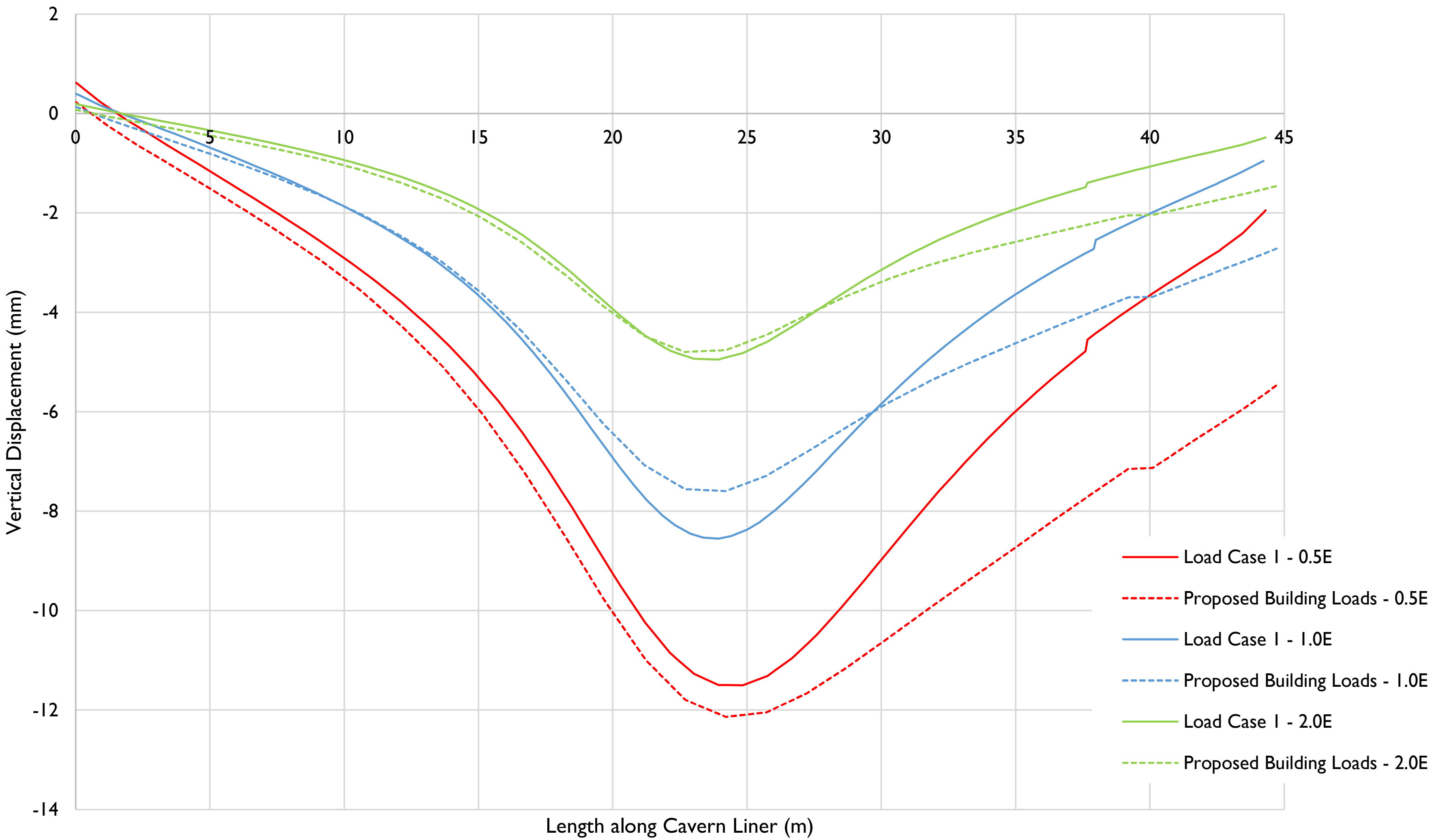
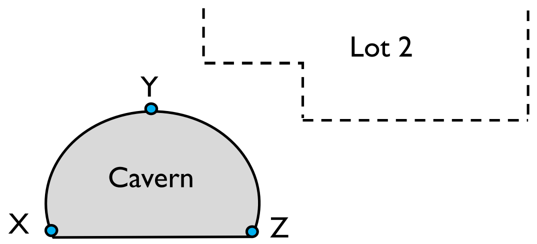
*figure:* *3f*

## Analysis Group 4 (4a) - Total Vertical Displacement on Cavern Liner




Point X | Point Y | Point Z

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| *scale:* | NTS | *title:* | *Finite Element Outputs* |
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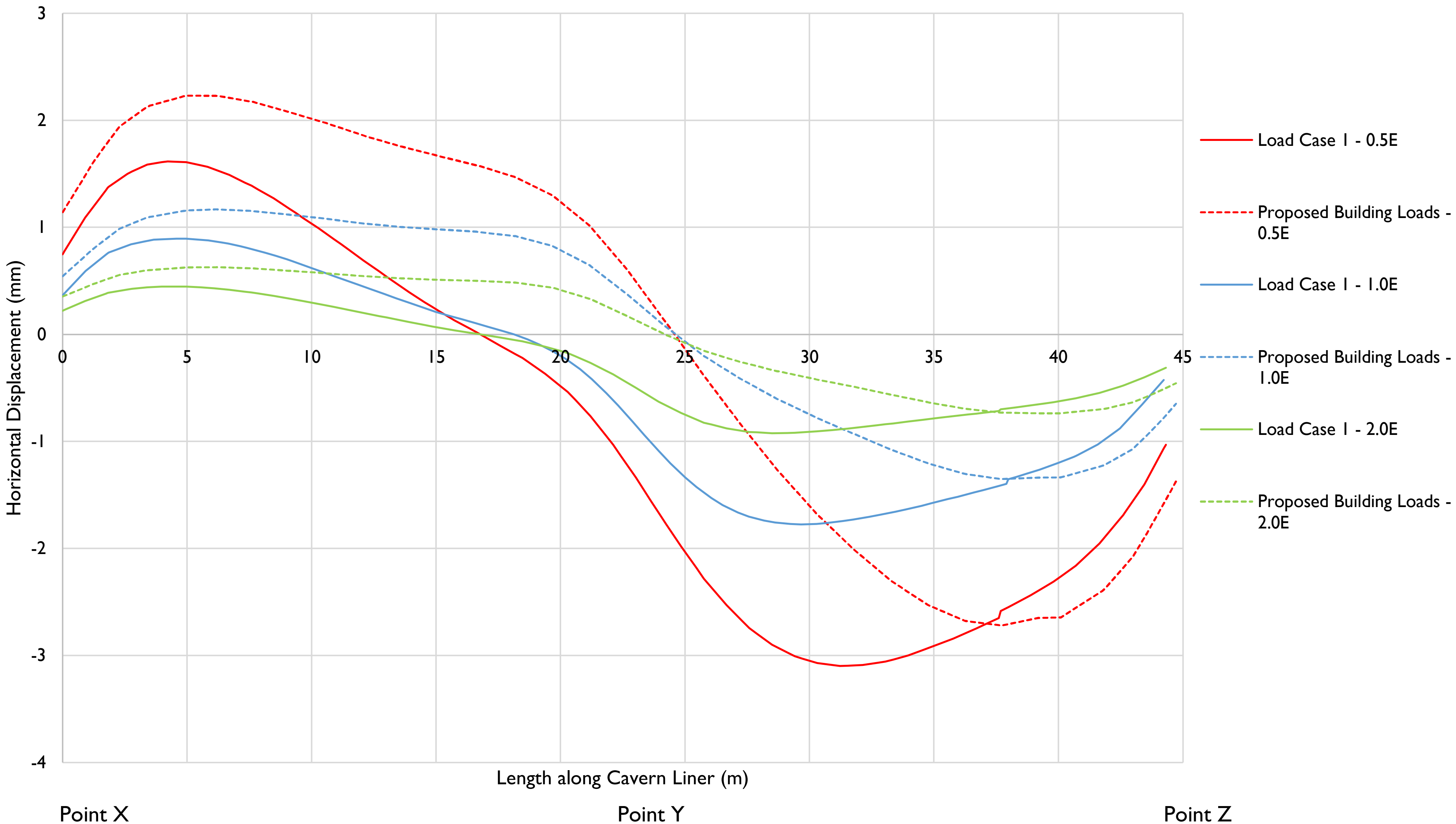
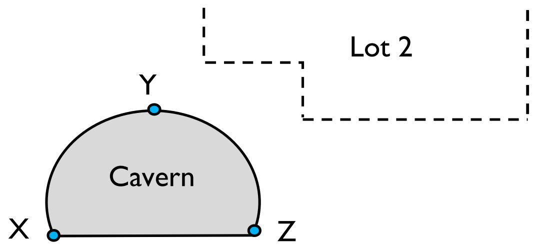
*figure:* 4a

## Analysis Group 4 (4b) - Total Horizontal Displacement on Cavern Liner

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| *scale:* | NTS | *title:* | *Finite Element Outputs* | | |
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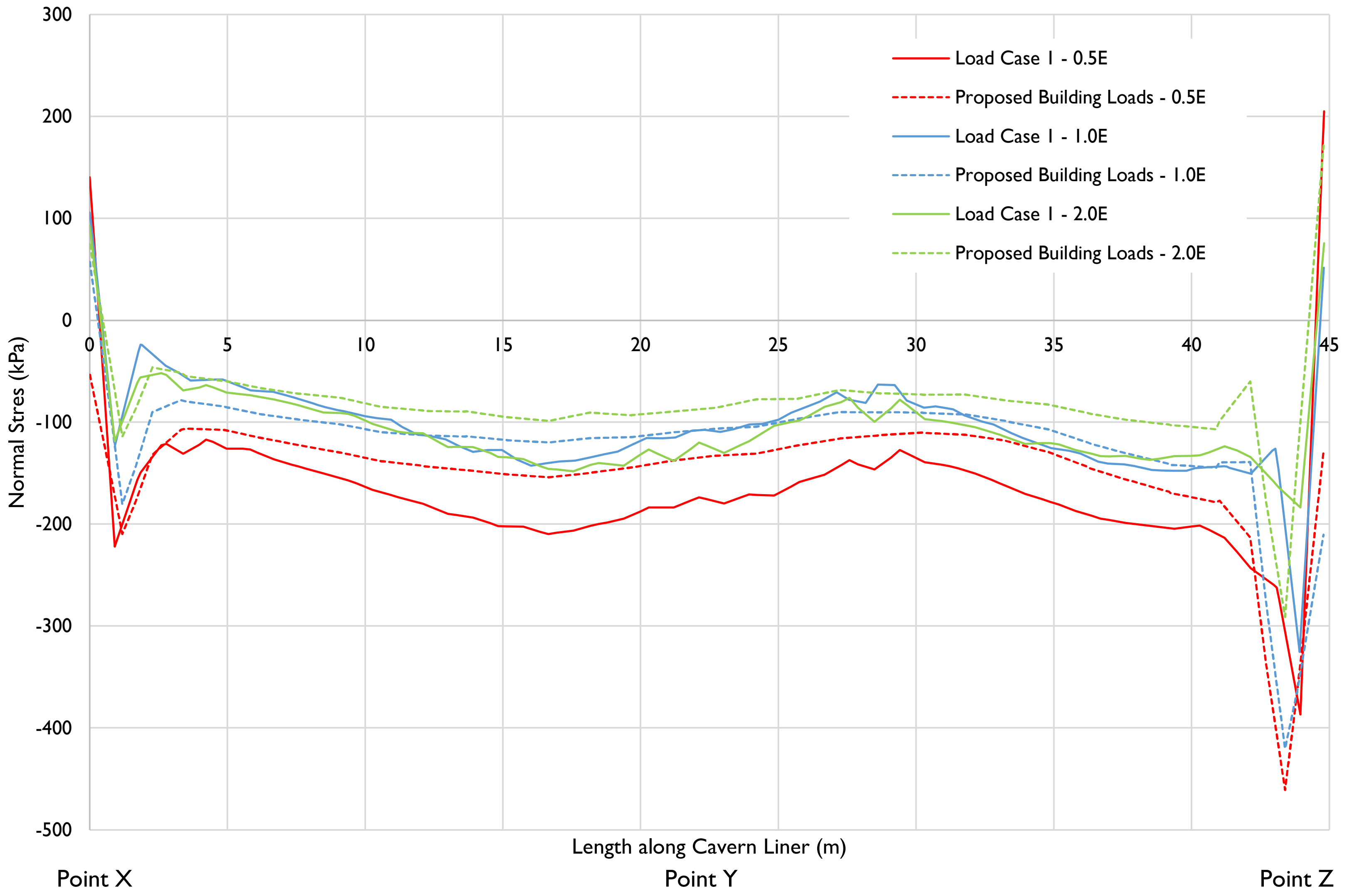
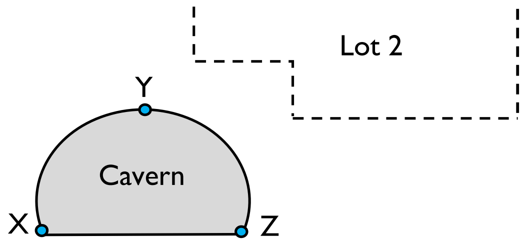
# Analysis Group 4 (4c) - Total Normal Stress on Cavern Liner

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| *date:* | 25/05/2023 | *project:* | Albert Street Development | |
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| *scale:* | NTS | *title:* | *Finite Element Outputs* | |
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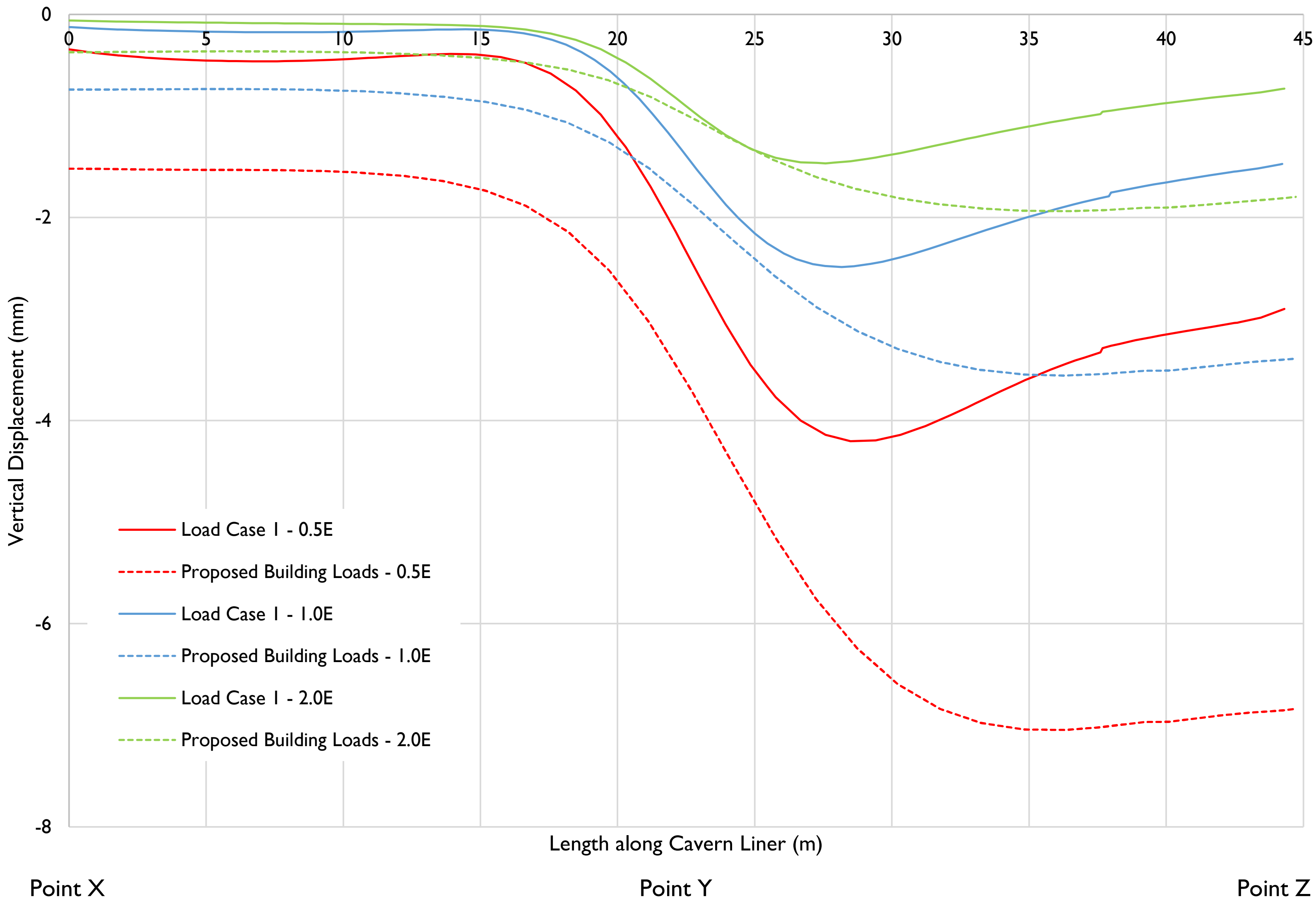
## Analysis Group 4 (4d) - Change in Vertical Displacement on Cavern Liner



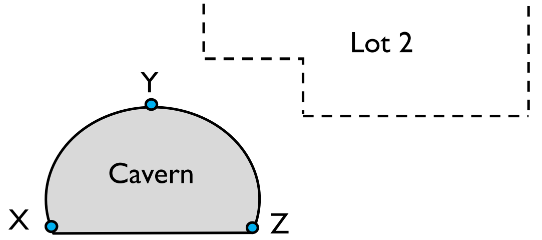




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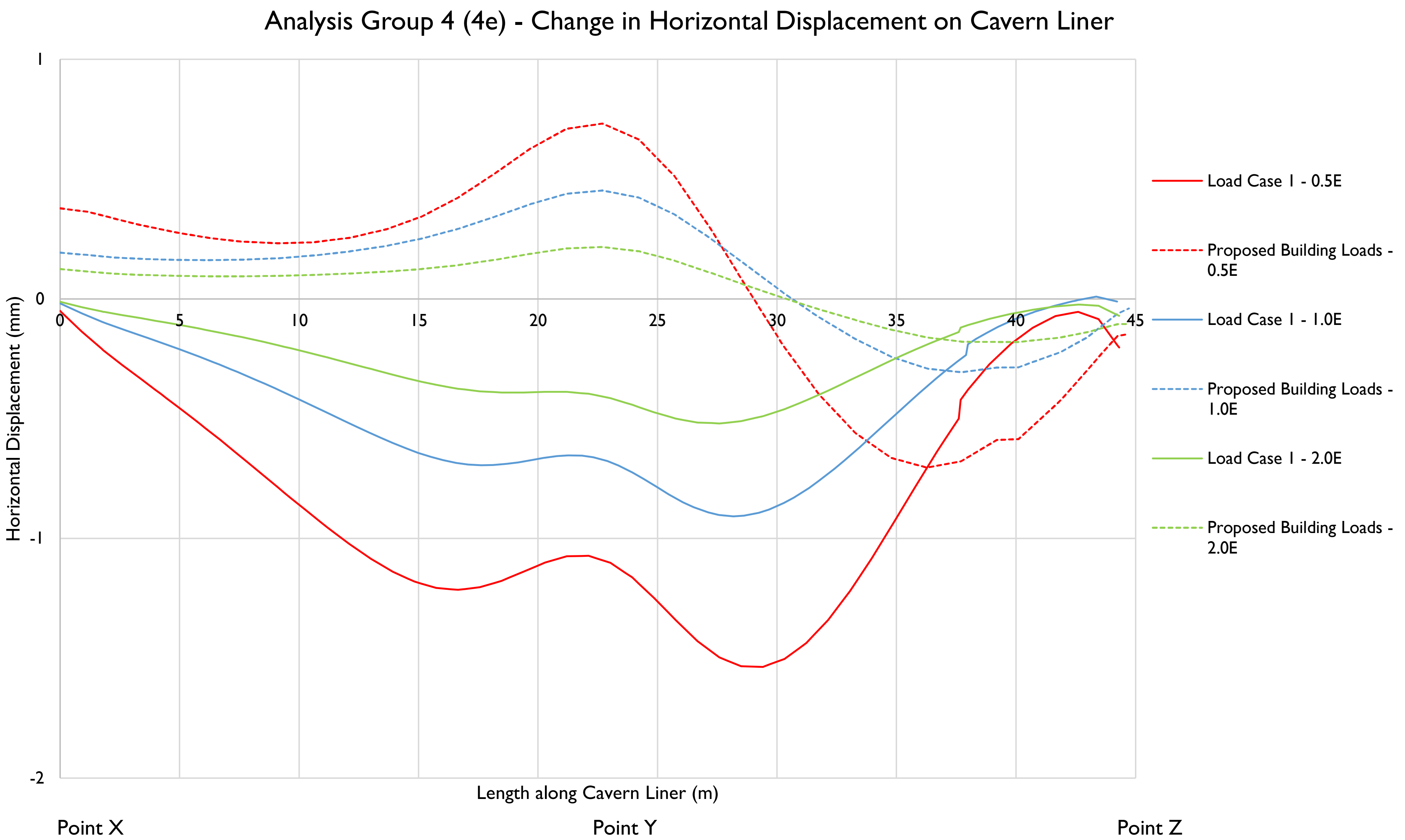
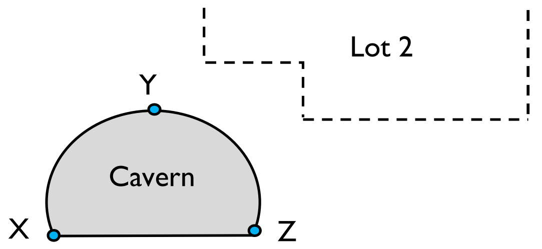
*figure:* *4a*

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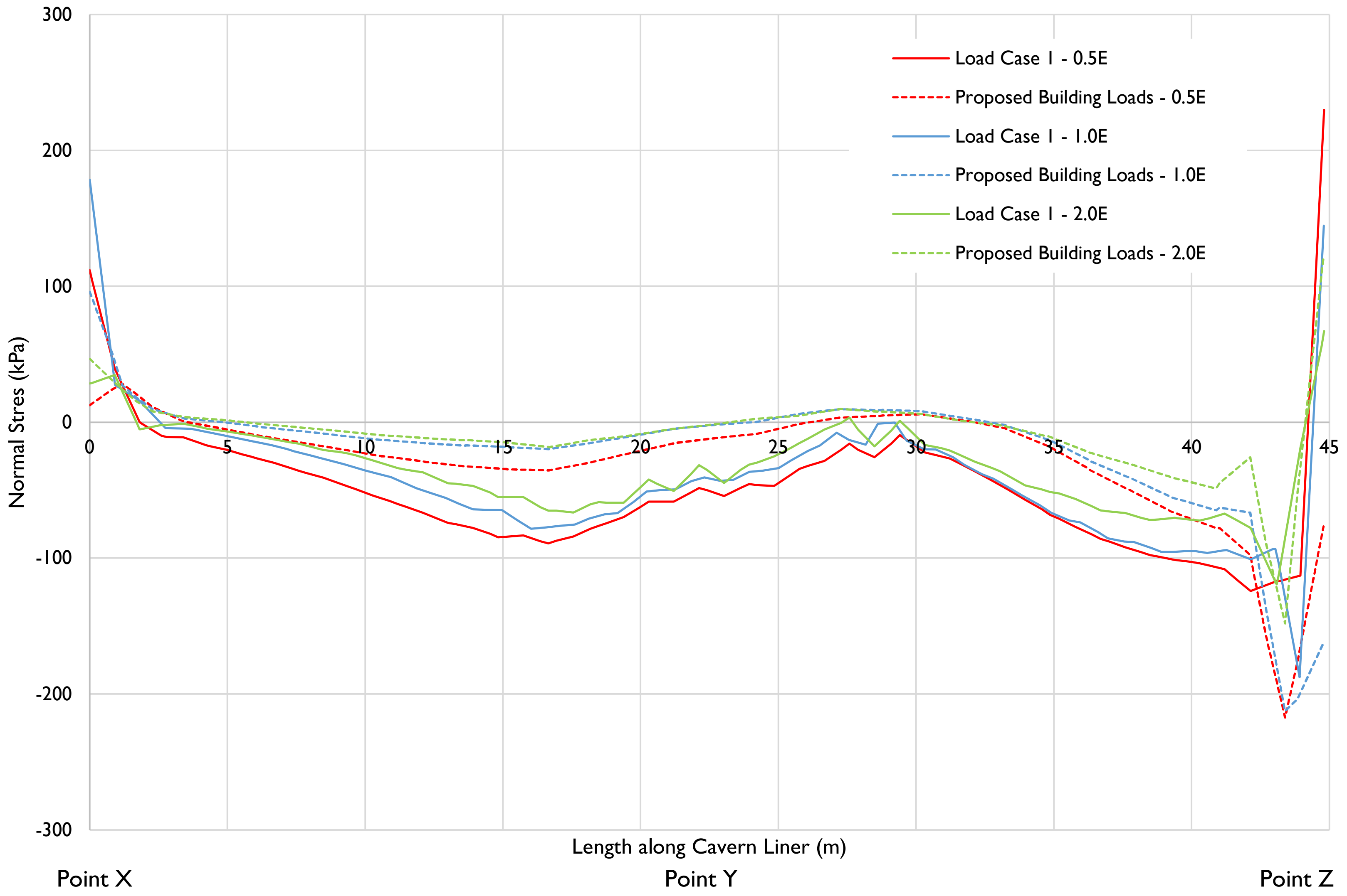
## Analysis Group 4 (4f) - Change in Normal Stress on Cavern Liner



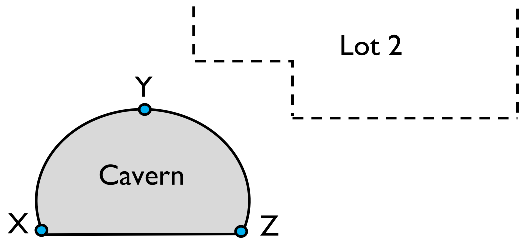




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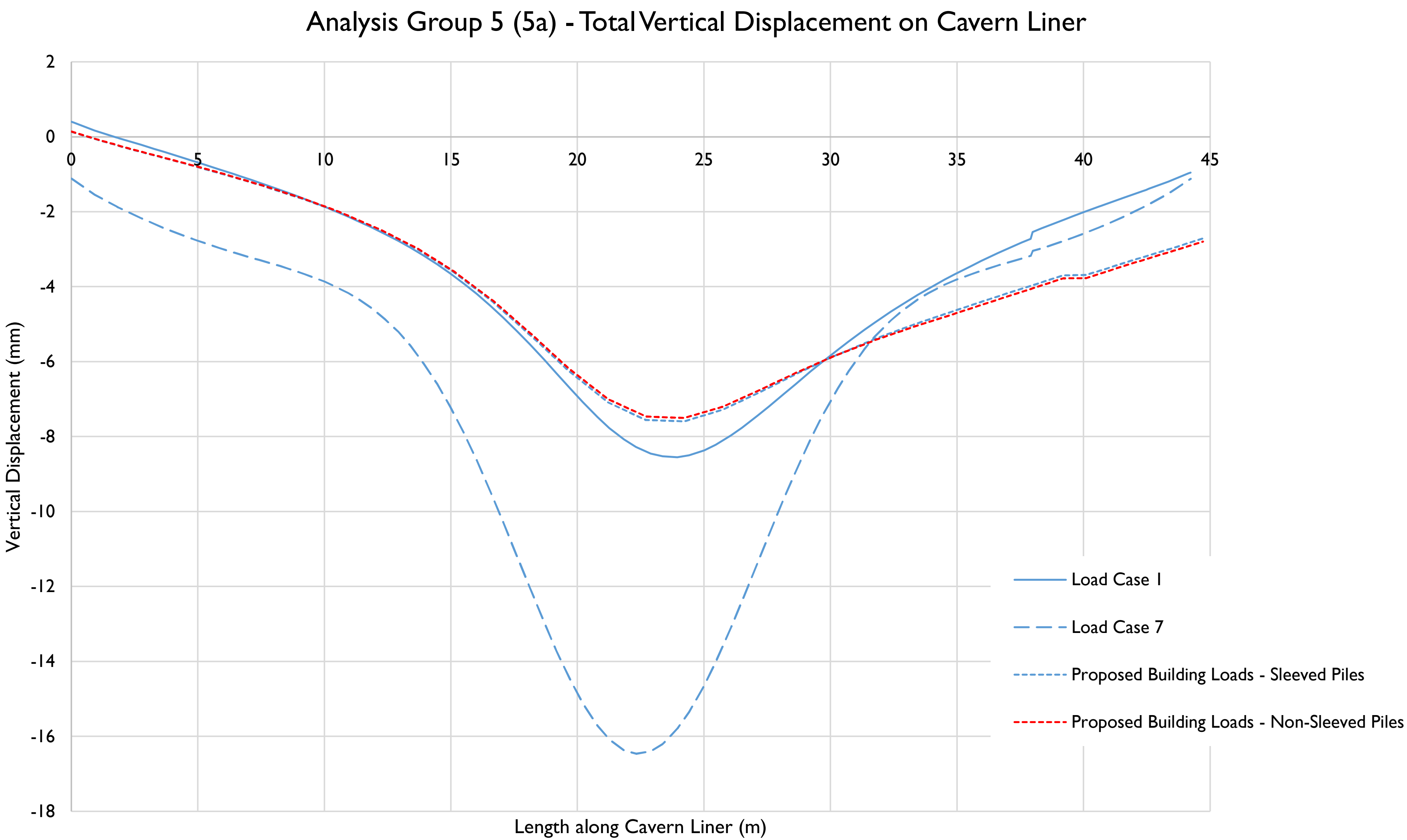
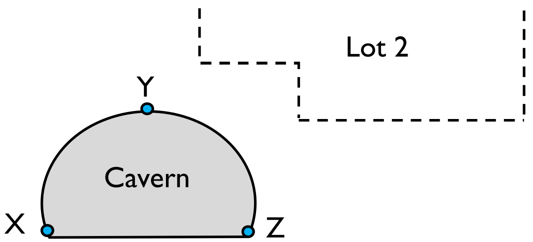
*figure:* 4c




Point X Point Y Point Z

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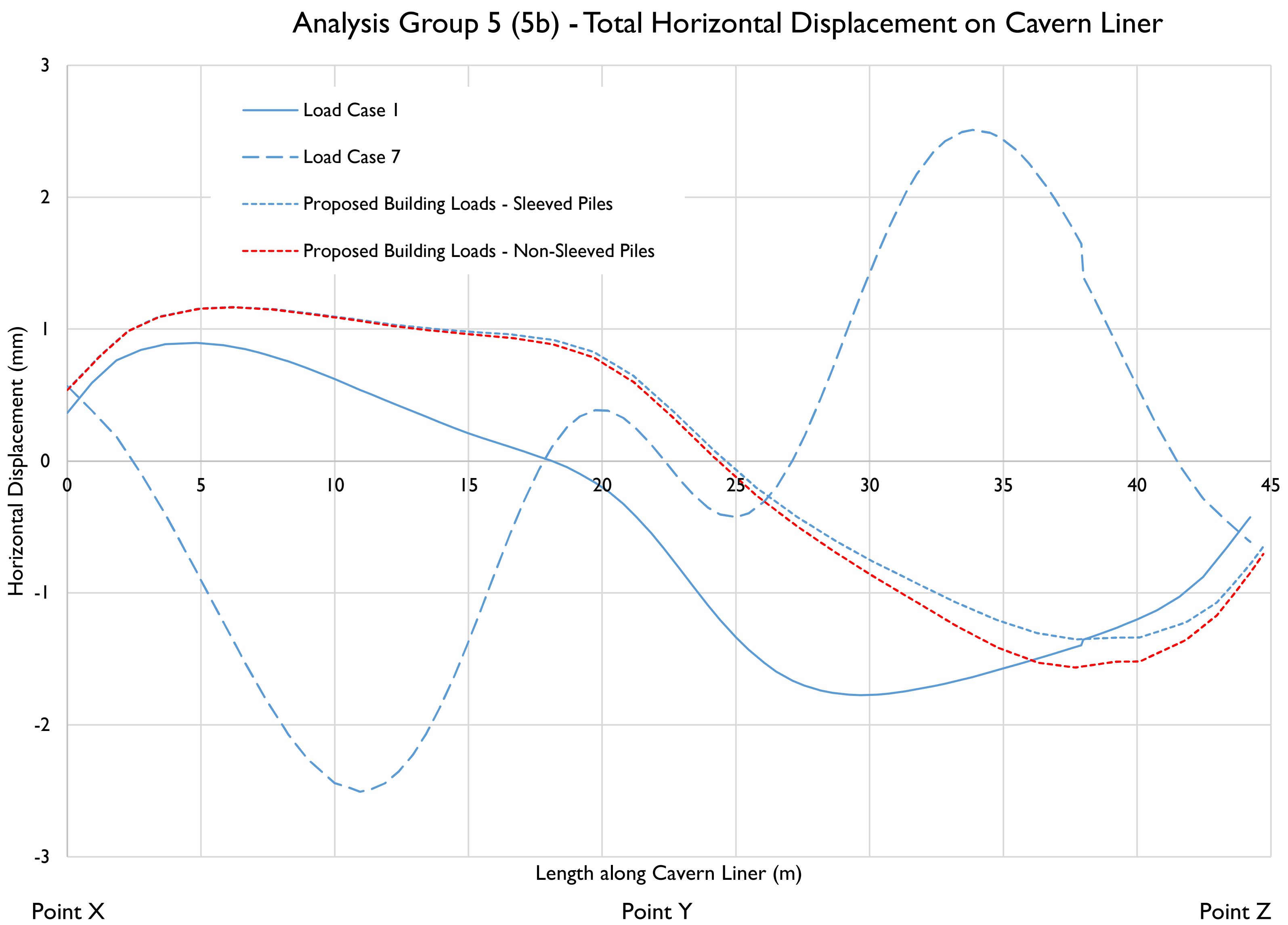


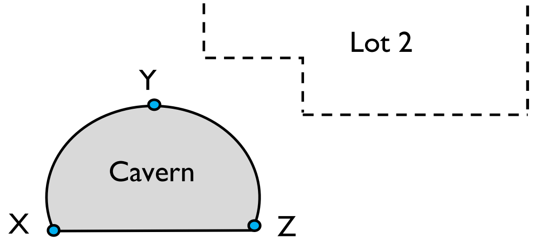


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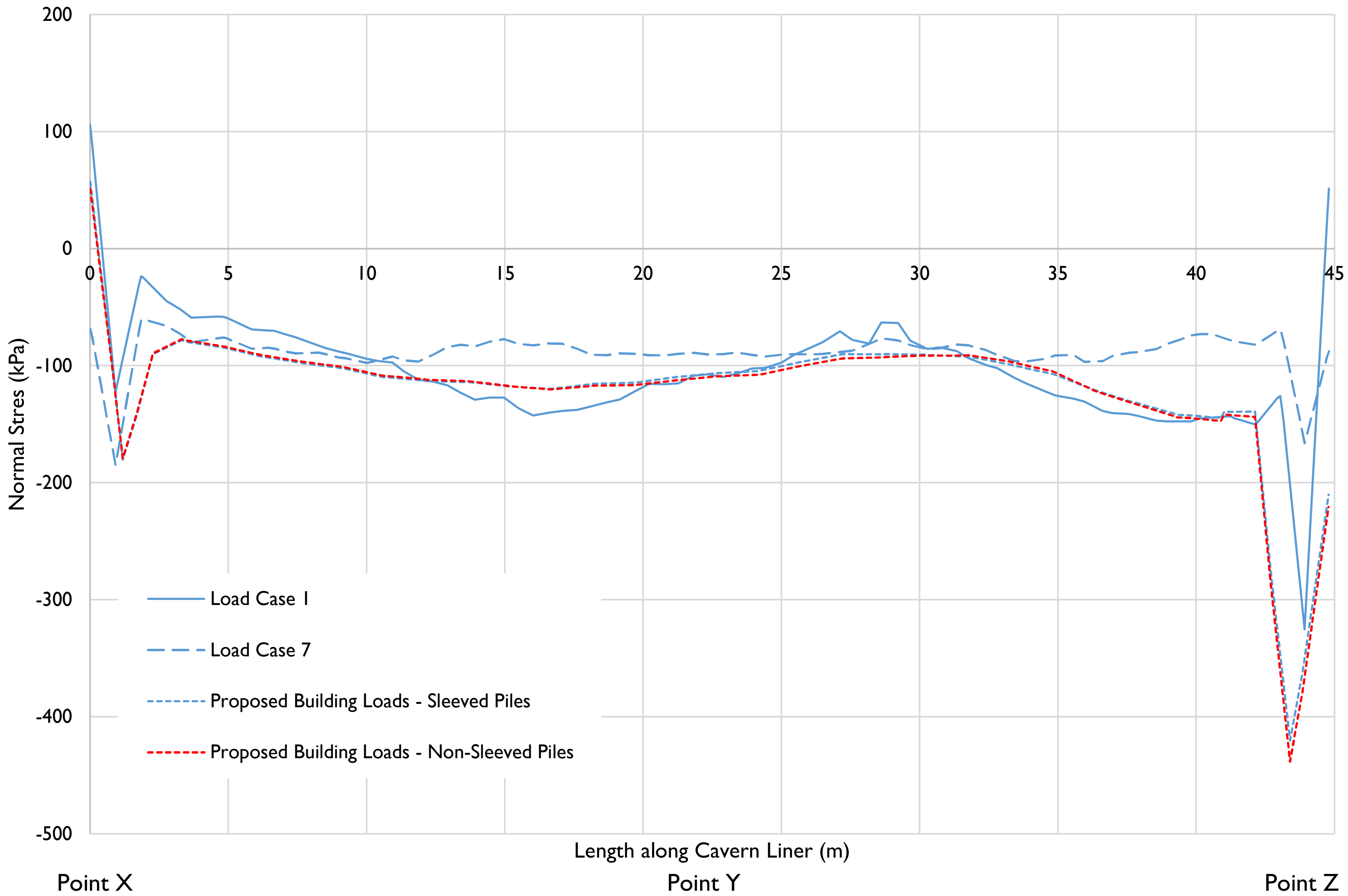
| *scale:* | NTS | *title:* | *Finite Element Outputs* | |
| | | *job no:* | B01493-1 | *figure:* 5b |

## Analysis Group 5 (5c) - Total Normal Stress on Cavern Liner



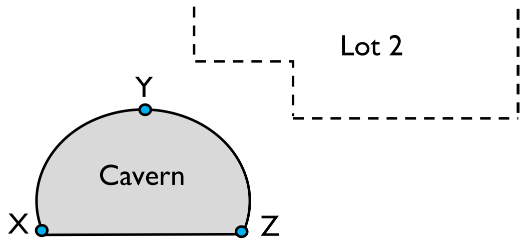




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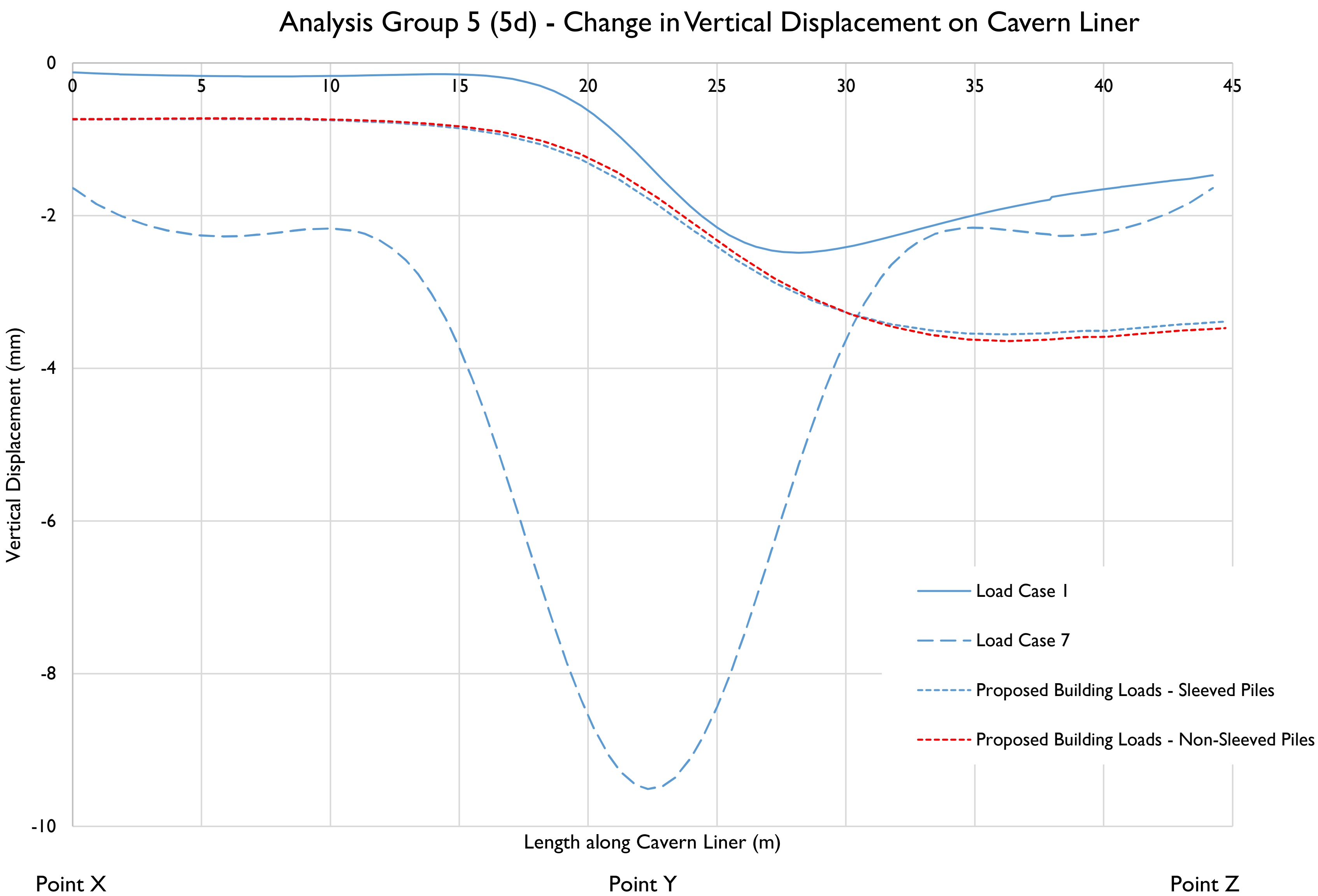
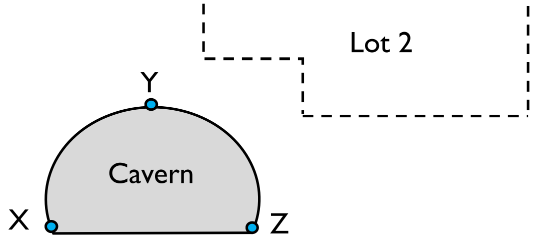
*figure:* 5c

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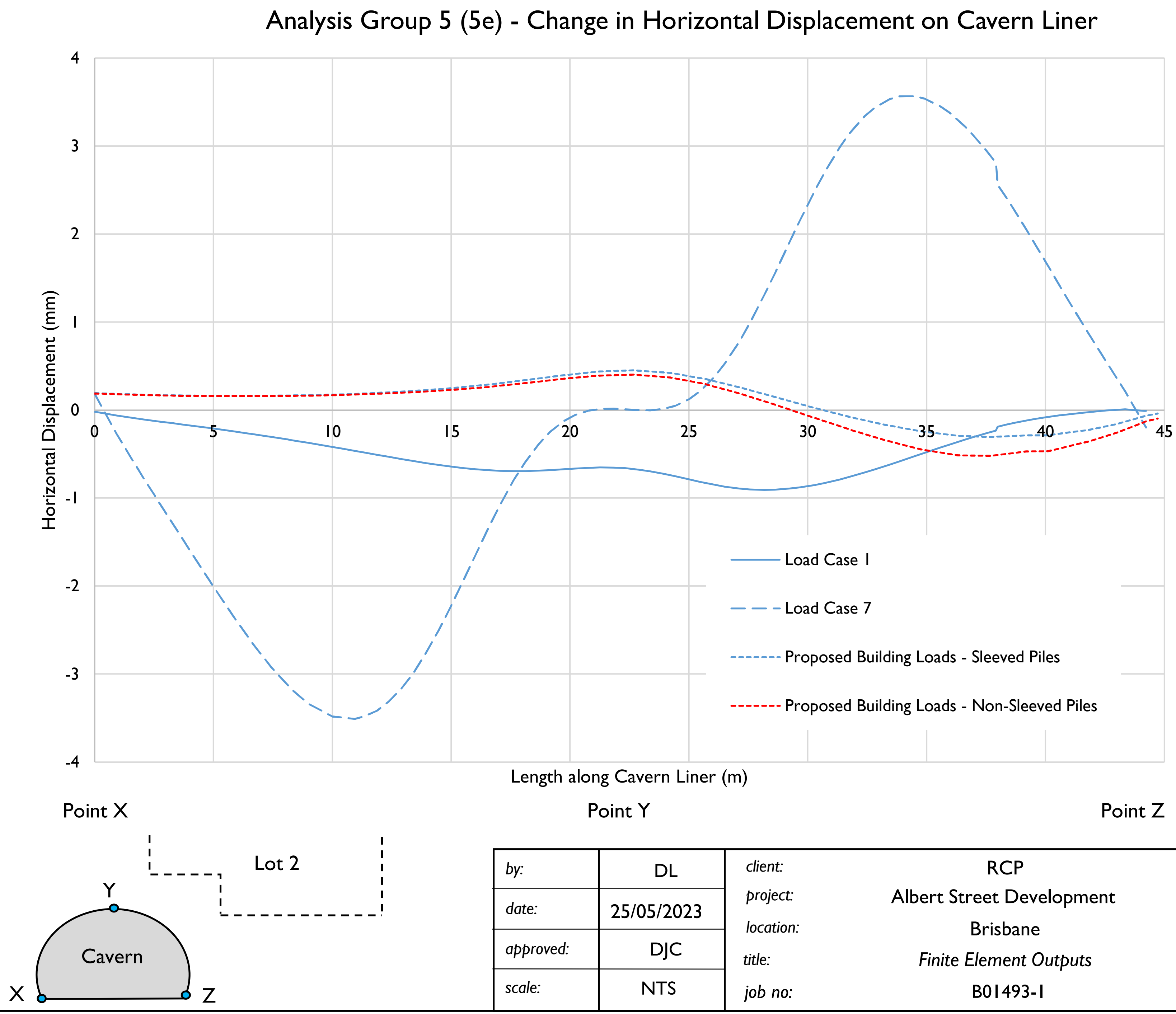


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| *scale:* | NTS | *title:* | *Finite Element Outputs* | |
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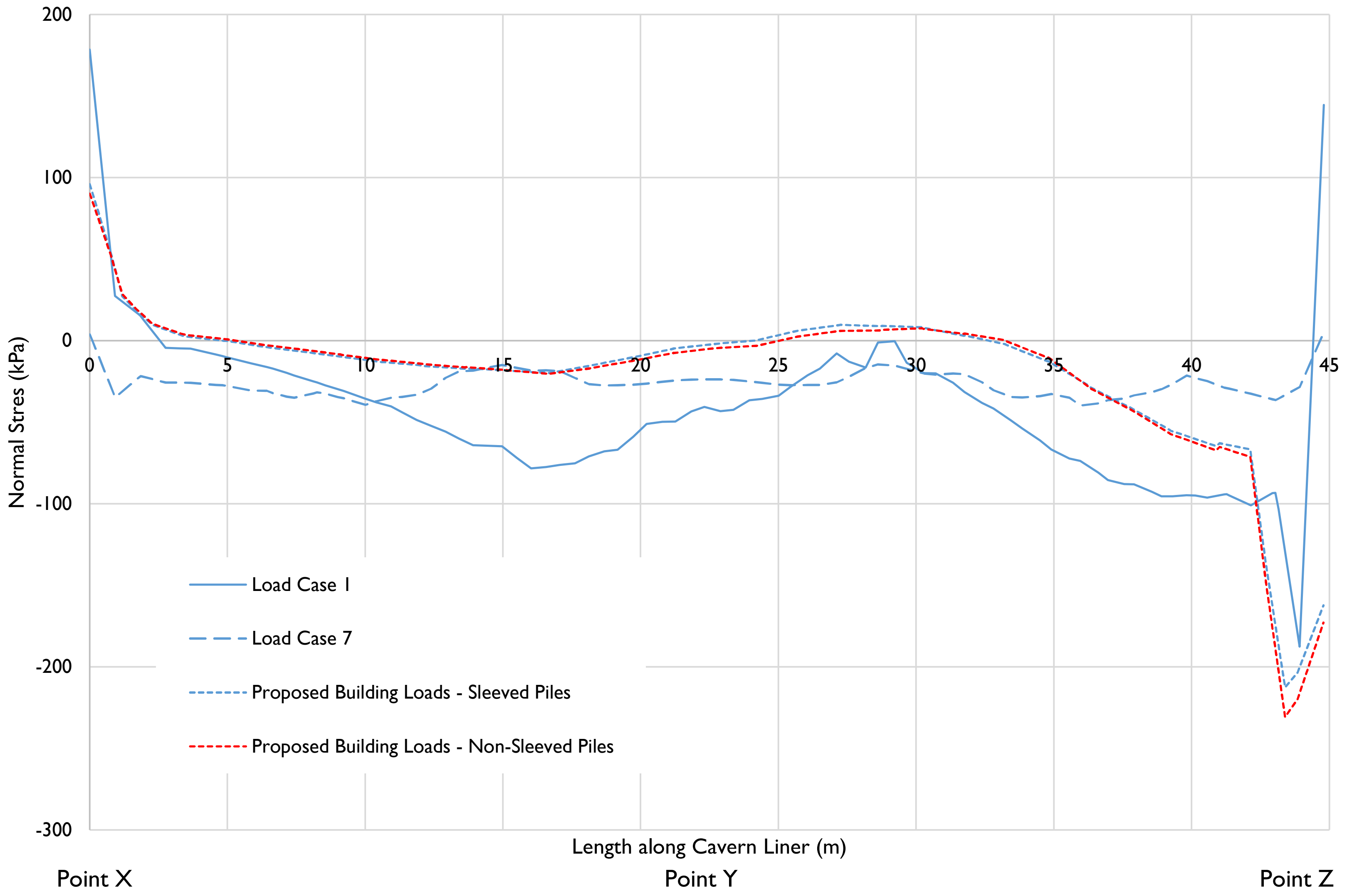
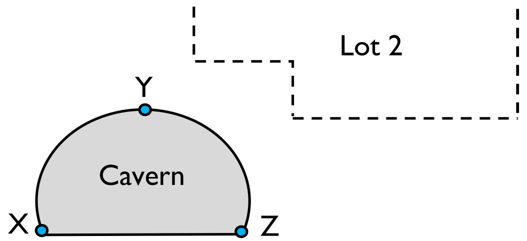
# Analysis Group 5 (5f) - Change in Normal Stress on Cavern Liner

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