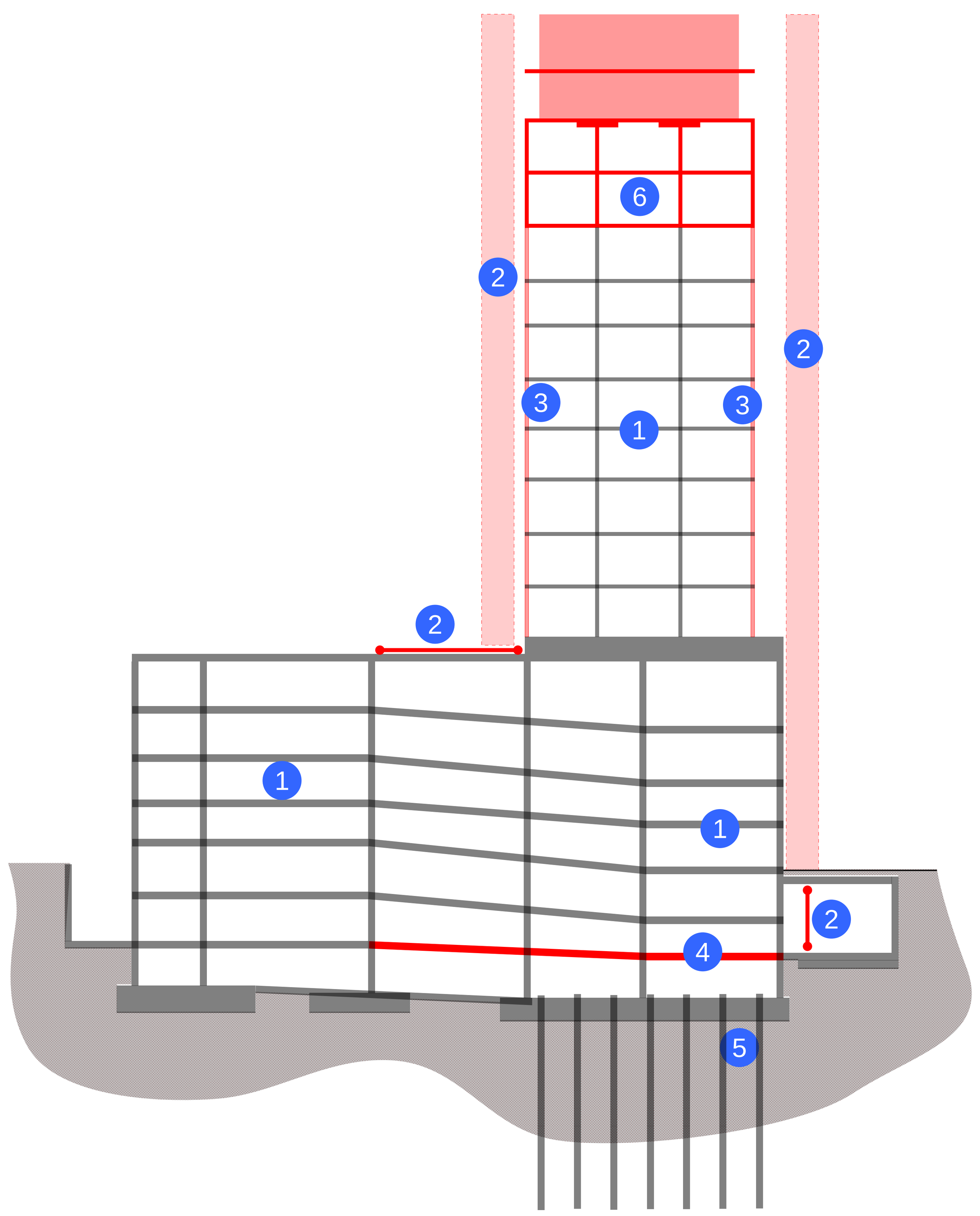
Appendix F – Construction Sequence

ISO A1 841mm x 594mm



SECTION

PHASE 1 - GENERAL DEMOLITION WORKS AND WORKS TO BASEMENT

1) Soft strip all floors, including basement. Decommission existing substation prior to demolition.

2) Install Scaffold above level 04 (on Western facade) and level 00 (on North, South and Eastern facade). Scaffold on Western facade is supported on slab, thus temporary works may be required to spread load at that level. Scaffold on other elevations will be supported at grade, and may need to be coordinated with services within pavement. On the Eastern facade, part of the scaffold will be located above the petrol tank, thus internal propping at that location through the tank may be required to support the scaffold.

3) Remove facade panels installed during 1990's works

4) Locally demolish existing B2 slab and B1 slab where required to install movement control piles around the Post Office tunnel and footprint of the basement, leaving a doughnut to prop the existing retaining walls or temporary props. Prop retaining walls / columns horizontally locally where required and prop slabs vertically where required.

5) Install the movement control piles around the Post Office tunnel using a low headroom pile rig before demolition reaches 4th floor transfer slab level

6) Demolition of tower structure commences / has already commenced

STAGE 3
NOT FOR CONSTRUCTION

REV	DESCRIPTION	BY	DATE

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PROJECT
LABS HOLBORN
1 MUSEUM STREET

CLIENT
LABTECH

TITLE
DEMOLITION AND CONSTRUCTION SEQUENCING SHEET 1

DISCIPLINE	DATE	SCALE @ A3
STRUCTURAL	29/01/21	NTS

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2413-S-SK-253

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P01

DATE: 28/01/2021 12:20:51
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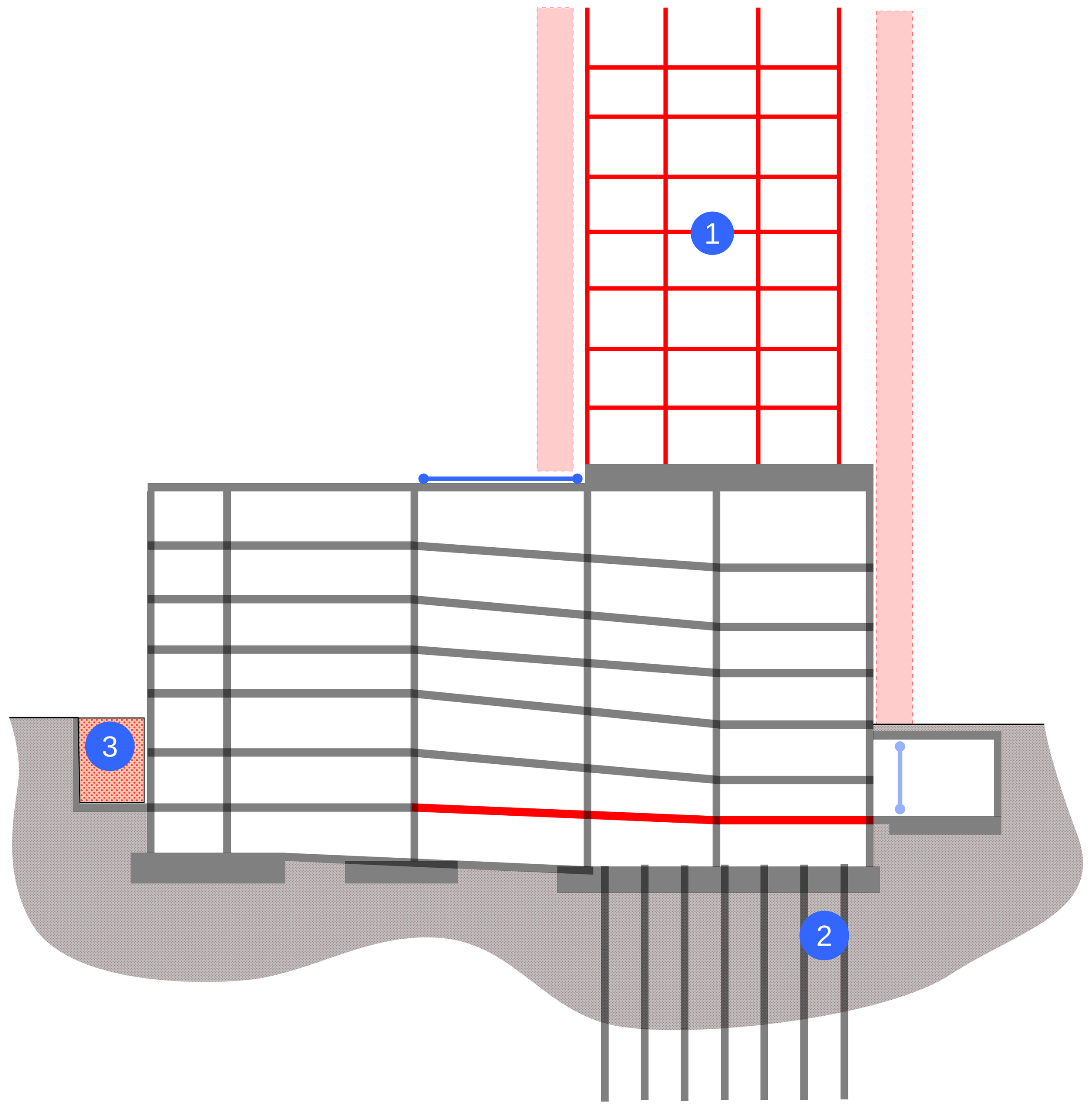

SECTION

PHASE 2 - GENERAL DEMOLITION WORKS AND WORKS TO BASEMENT

1) Demolition of the tower can continue to / past level 04 now that the movement control piles have been installed around the Post Office tunnel

2) Install settlement reducing piles and bearing piles within the footprint of the existing basement using a low headroom pile rig whilst demolition of the tower continues. Note that the piles are not required to be installed at the same time as the movement control piles

3) Remove existing ramp slab and backfill existing ramp void area with demolition rubble and use as a pile mat at grade (subject to survey or existing void under ramp to establish what is there). The existing retaining wall footprint would likely need to be propped ahead of piling works. Surrounding underpins to also be propped (tbc on survey works)

STAGE 3
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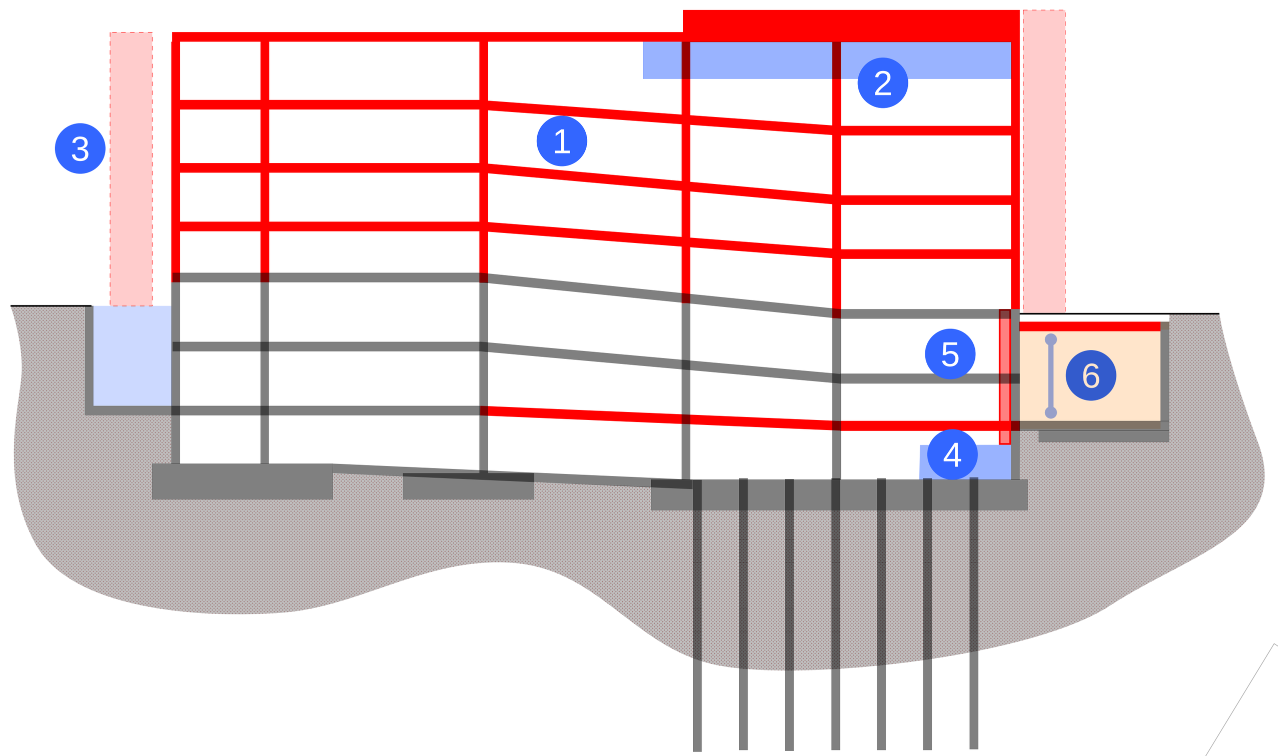

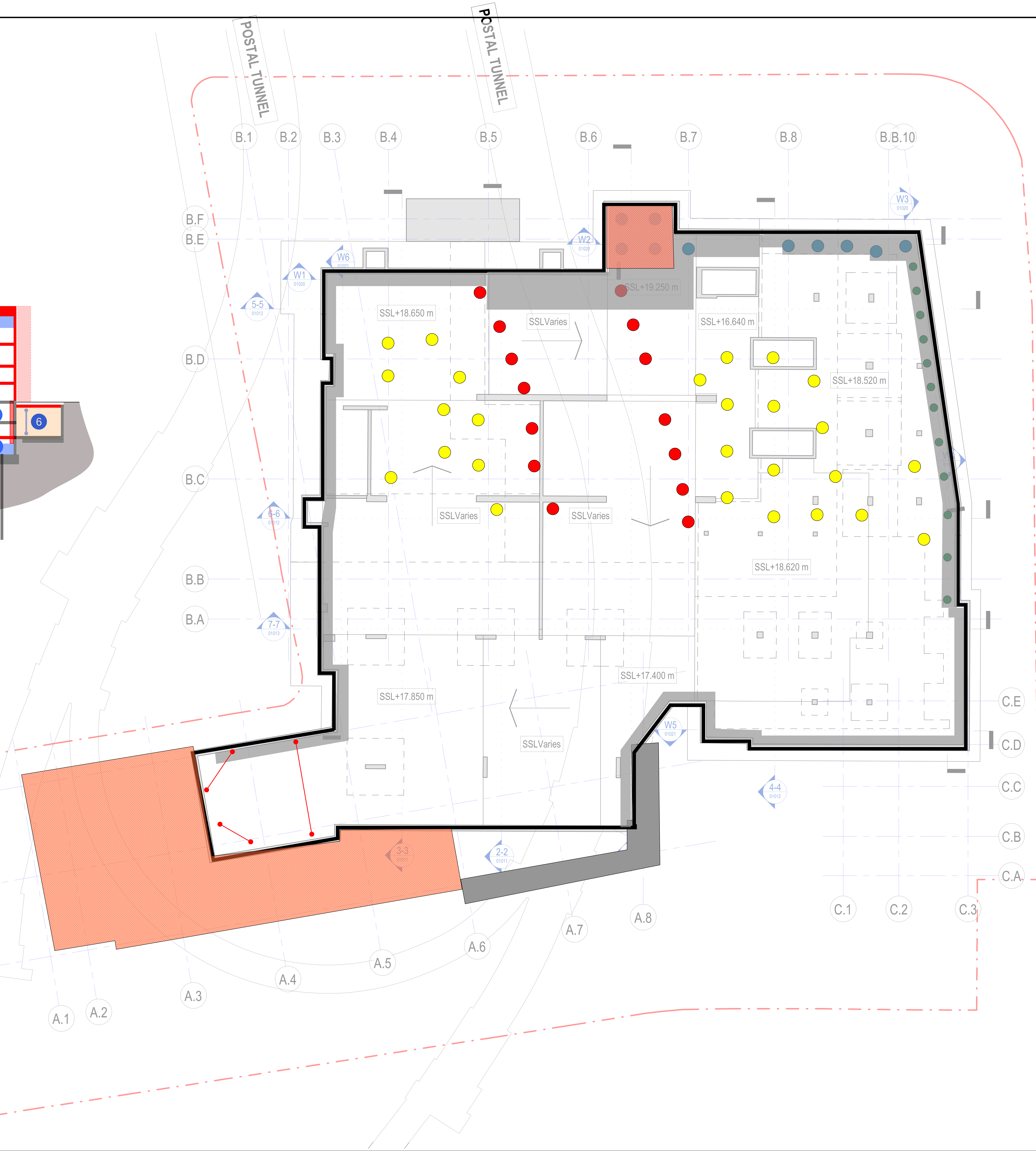

PHASE 3 - GENERAL DEMOLITION WORKS AND WORKS TO BASEMENT

1) Demolish tower down to Ground floor.

2) Temporary works will be required to support the existing thick transfer slab during demolition in the form of a hung deck below the level 04 beams)

3) Install scaffold over ramp area, now filed with demolition rubble

4) Install Foundation bases / ground beams and part of the new raft to support the retaining wall strengthening

5) Form pockets in slabs to install wall strengthening piers where required. Form wall strengthening piers and beams, leaving pull out bars for liner wall to be installed later

6) Upon demolition of levels above ground and removal of scaffold, infill petrol tank, vents and zone south of existing petrol tank within existing basement with demolition rubble and / or engineered piling mat

7) Install engineered piling mat / spreader plates for piling outside the footprint of the building and around the tree root protection areas

STAGE 3
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REV	DESCRIPTION	BY	DATE

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2413-S-SK-255	P01

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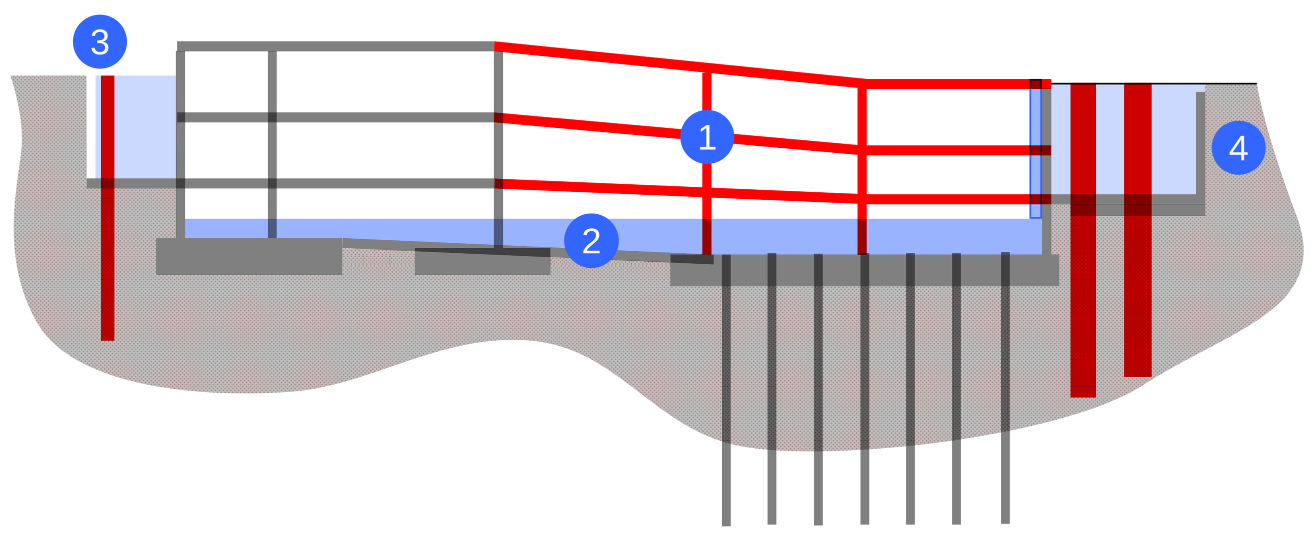

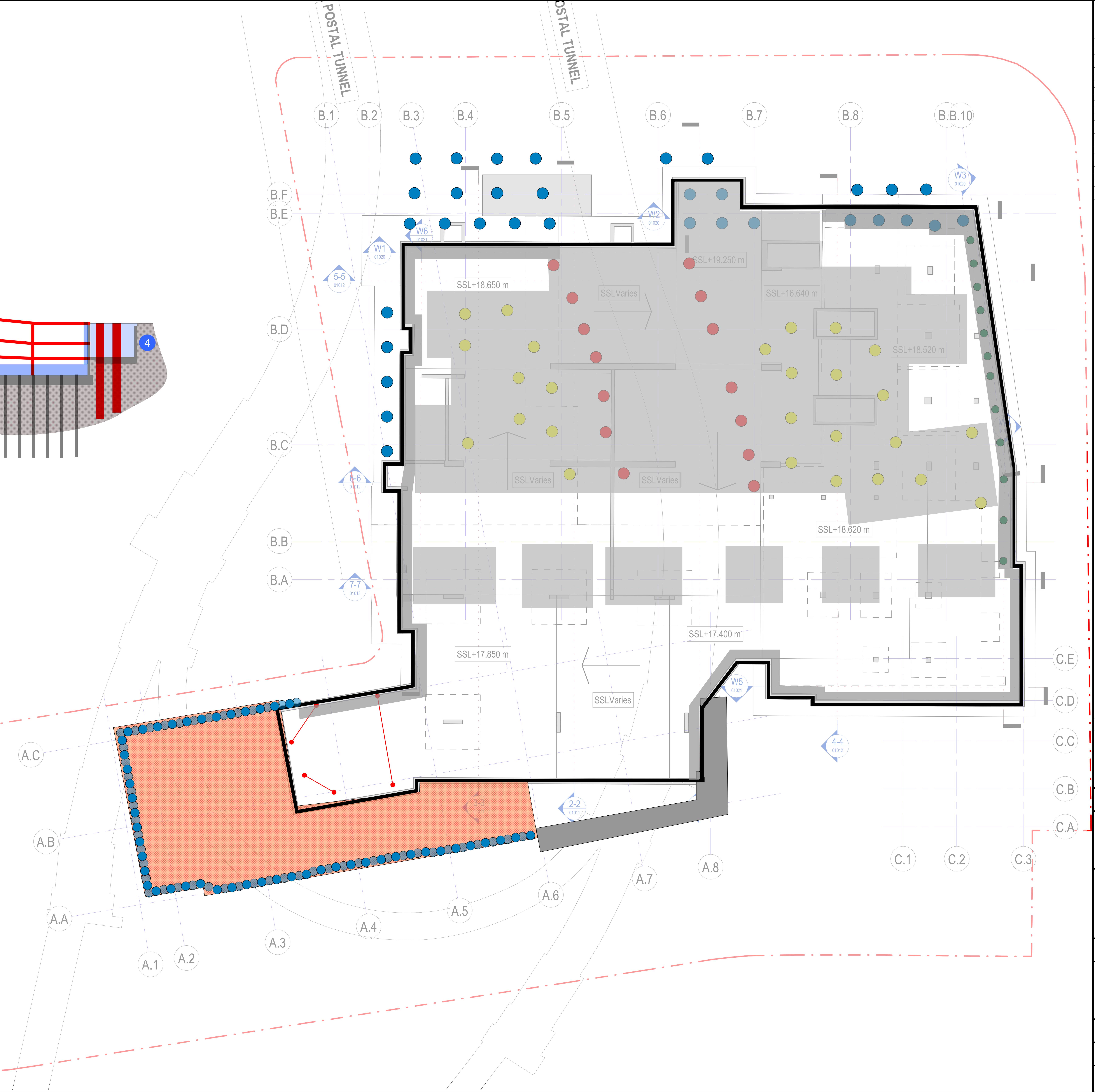

PHASE 4 - GENERAL DEMOLITION WORKS AND WORKS TO BASEMENT

1)Demolish the rest of the basement slabs and ground floor slab. Prop at ground floor level at top of wall and also where required around areas to be piled at grade

2) Cast 1 Museum Street raft foundation and pad foundations along with below ground drainage and attenuation tank

3) Install secant piled wall, remove piling mat and install capping beam in ramp area

4) Install bearing piles north and east of existing basement

5) Demolish High Holborn building, install props at ground floor before demolishing ground floor slab and cast new foundations on top of existing

STAGE 3
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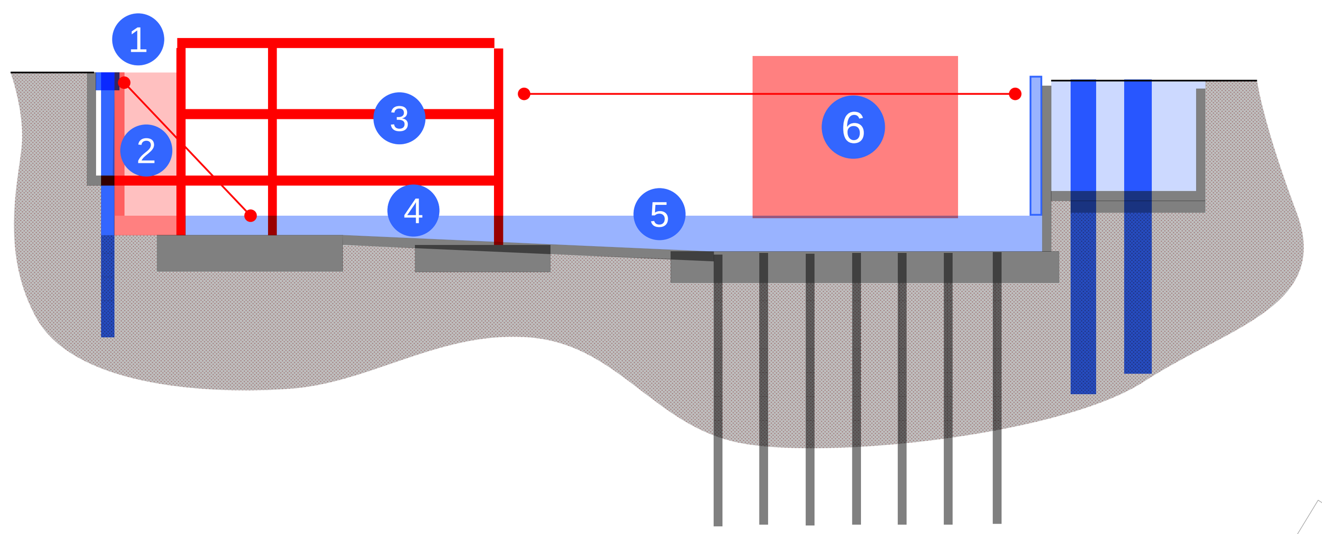

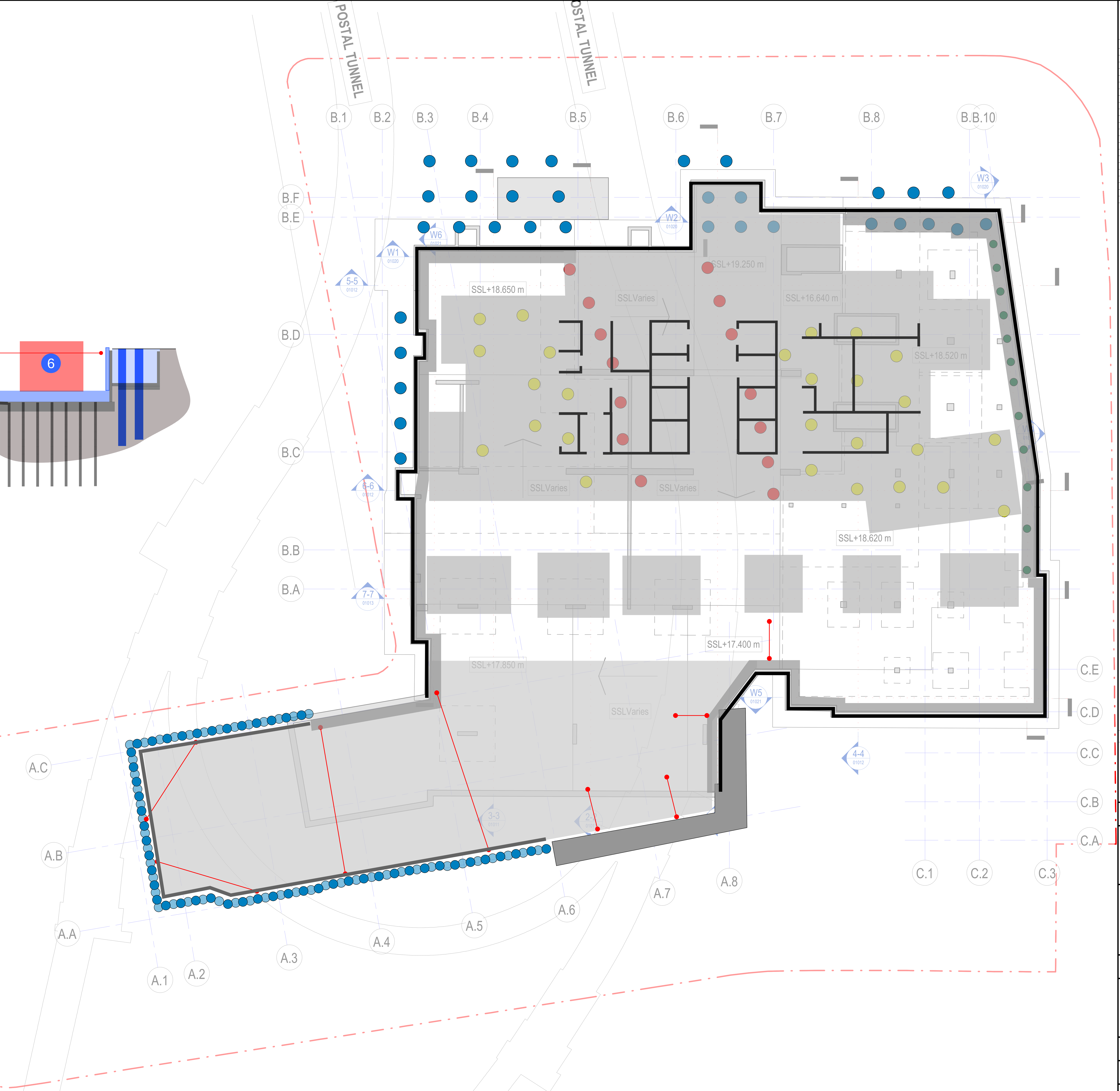

PHASE 5 - GENERAL DEMOLITION WORKS AND WORKS TO BASEMENT

1) Install temporary props at capping beam level to support piled wall. Install raking props to existing underpins / walls

2) Remove demolition fill down to basement formation level

3) Demolish existing building and retaining wall within new basement area

4) Install new raft foundation to new basement and liner wall and install pile caps to foundations outside the basement footprint

5) Install B2 level slab throughout basement

6) Slip / jump form core

STAGE 3
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DEMOLITION AND CONSTRUCTION SEQUENCING SHEET 5

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	ISSUE
2413-S-SK-257	P01

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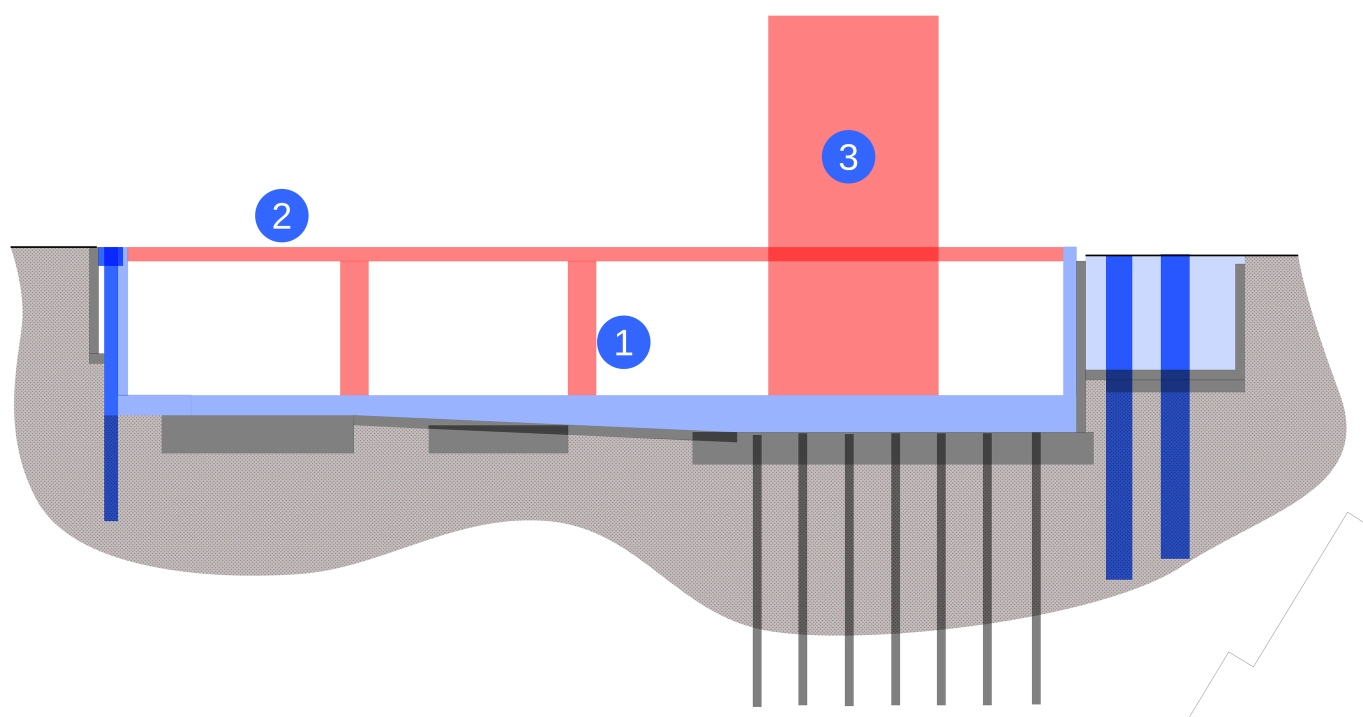
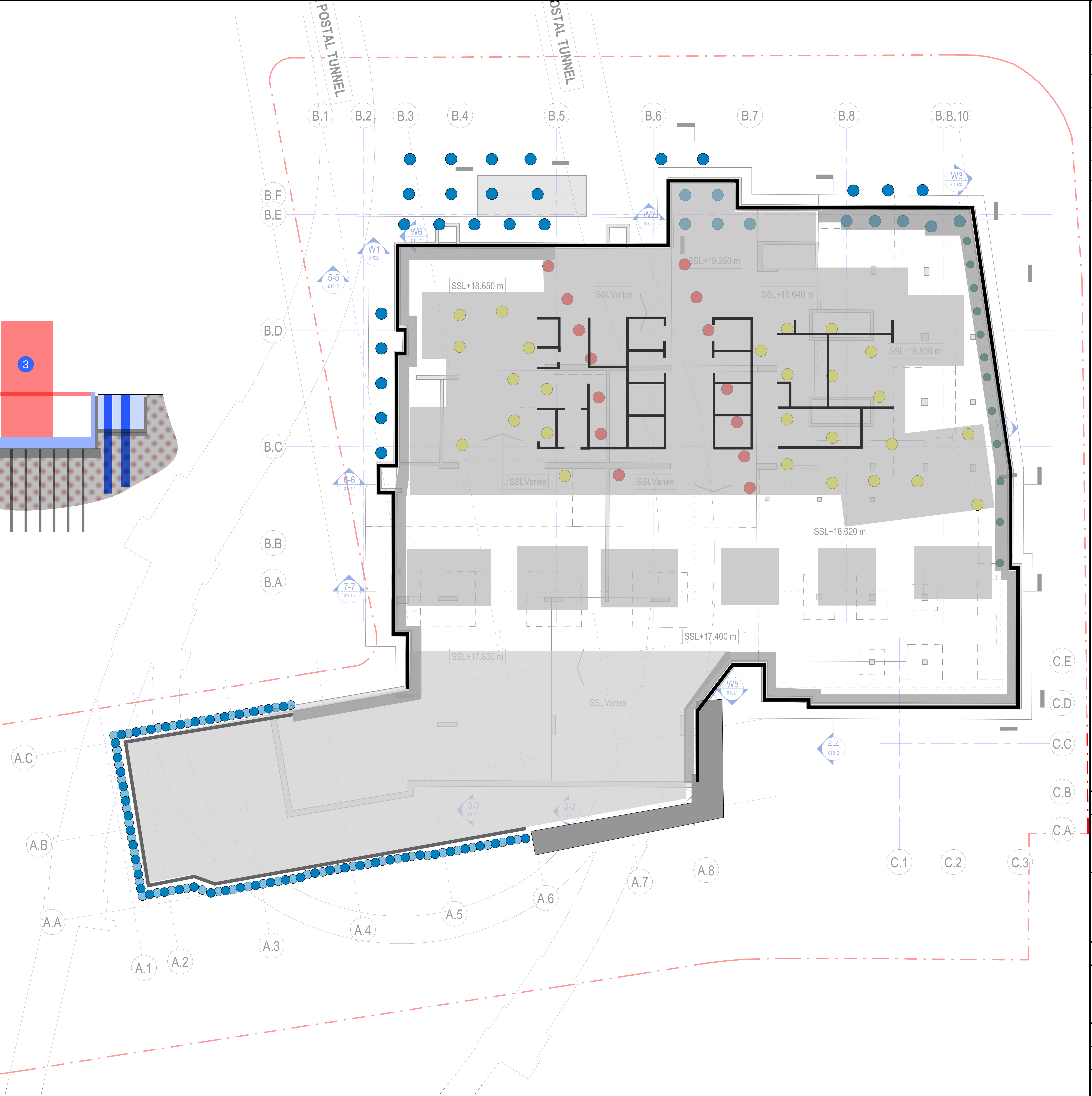


PHASE 6 - GENERAL DEMOLITION WORKS AND WORKS TO BASEMENT

1) Install verticals and B1 slabs

2) Install ground floor slab and then remove temporary props

3) Continue with core construction and construct superstructure



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DEMOLITION AND CONSTRUCTION SEQUENCING SHEET 6

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2413-S-SK-258	P01

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Appendix G – Geotechnical Engineering Reports

Project	1 Museum Street and West Central Street
Project No.	1084
Subject	Tree Protection Zone Pile Design and Construction Considerations
Client	Meinhardt (UK) Ltd

Document Reference	Status	Revision	Issued	Checked	Approved	Date
1084-A2S-XX-XX-TN-Y-0010-00	First Issue	00	HS	TS	AN	01.12.2020

1. Introduction

A-squared Studio Engineers Ltd (A-squared) has been appointed by Meinhardt (UK) Ltd (Meinhardt) to carry out a review of the proposed piling substructure elements for the 1 Museum Street development. The scope of this technical note comprises a review of site-specific considerations relating to the design and construction of bearing piles to the east of the basement footprint adjacent to the existing trees on site. This technical note references selected sections of BS 5837:2012 *Trees in relation to design, demolition and construction – Recommendations*.

2. Scheme Details

The scheme involves the redevelopment of the 1 Museum Street and West Central Street plots in Holborn, London, approximately 300m west of Holborn Underground Station. The two plots are shown in Figure 1.

Figure 1 Location of the proposed development site

The 1 Museum Street site currently houses a sixteen-storey Travelodge hotel tower and multi-storey podium which functions as a carpark. The existing structure is comprised of reinforced concrete and covers the majority of the plot. The carpark extends three-storeys beneath the existing buildings (approximately 8.5m), and the foundation system consists of a ground-bearing raft.

The proposed development for 1 Museum Street comprises a new 21-storey office tower with retail space on the ground floor. The existing ramp will be converted into a four-storey structure with a double height based, known as Grape Street, and a four-storey building, High Holborn, will be constructed in the southwest corner of the site. A new foundation system will be constructed approximately 2m above the lowest point of the top of the existing raft, with large portions of the existing basement refurbished and reused.

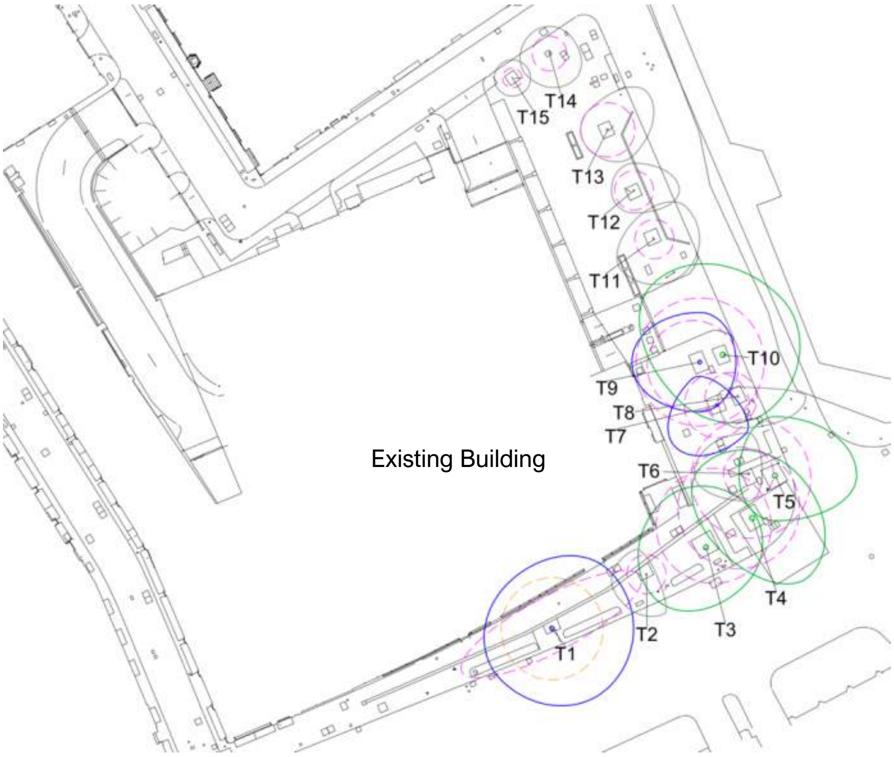
The locations of piles required for the proposed development are shown in Figure 2. Bearing piles to support tower columns landing outside of the existing basement will be required along the north and east perimeter of the basement, at the approximate locations shown in the figure.

Figure 2 Locations of the proposed bearing piles outside of the basement footprint

3. Arboricultural Report Summary

An arboricultural survey of the trees on site was undertaken in October 2019 by Tim Moya Associates Ltd. The survey comprised a review of the trees and expected root zones, and the results of the survey are shown in Figure 3 below. The majority of trees on site have been classified Category C (low quality), however there are several Category B (moderate quality) and Category A (high quality) tree in the southeast corner of the site. These higher quality trees will require careful consideration in relation to the southern-most proposed piles to the east of the existing basement footprint. It is noted that there is a potential overlap between the evaluated root protection areas (RPAs) and approximate extents of concrete backfill to the rear of the existing basement wall.

Selected photos from the survey showing the extent of the tree canopies and space between the stems and existing Travelodge Tower are included in Appendix A.



Legend

Green: Category A (high quality) tree canopy

Blue: Category B (moderate quality) tree canopy

Grey: Category C (low quality) tree canopy

Pink: Root protection area

Figure 3 Findings of the arboricultural survey undertaken for the 1 Museum Street site

The *Arboricultural Report for Stage 2* prepared by Tim Moya Associates Ltd, dated September 2020 (ref. 191004-FD-02) indicates that the Category B tree T1 and Category C trees T6, T8 and T11 to T15 will be removed based on the *Tree Strategy* document prepared by the architect. These trees are not being removed for foundation construction reasons and the removals are not related to the piling works. In addition, Tim Moya Associates Ltd have noted in their report that it is unlikely that the Local Planning Authority (LPA) will accept excessive harm to the canopies or roots of any of the retained Category A and Category B trees in the southeast corner of the site (where excessive is defined as damage exceeding minor works to prune branches and potentially minor damage to roots).

It is recommended that the arboricultural specialist for the project is engaged to review the implications of the mass concrete backfill on the extents of the root protection areas in close proximity to the existing basement wall and piling works proposals from the structural design team. The engagement should be undertaken in advance of the development of an Arboricultural Impact Assessment and Tree Protection Plan. The Arboricultural Impact Assessment will summarise the trees to be retained and will review the impact of the proposed development works on these trees, and the Tree Protection Plan will highlight the mitigation strategies to be employed to protect the trees from significant impact or damage. Both documents will be reviewed by relevant regulatory bodies following the Planning submission.

4. TPZ Design and Construction Considerations

4.1. Piling Rig Summary

Based on the nature of the piles to be installed, the potential presence of significant thicknesses of concrete and headroom/working room restrictions, one of the piling rigs in Table 1 below may be utilised. The data in this table is provided for information only and is subject to change based on specific piling contractor set-up configurations and rig preferences. It is noted that contiguous flight auger (CFA) piling techniques are not expected to be adopted for the piling works due to the presence of significant thicknesses of sub-surface concrete and the requirement of significant enabling works to allow this technique to be used.

Table 1 Summary of piling rigs that may be adopted for the installation of bearing piles

Piling Rig	Operating Weight	Operating Rig Dimensions	Offsets from Pile Centreline[3]	Pile Diameters	Comments
Soilmec SR95[1]	89.9 tonnes	9265mm length 4700mm width	1200mm front 1200mm side	Up to 2100mm	• Large diameter piles standard hydraulic rotary rig. • Capable of coring through 6m of concrete. • Requires clear headroom in excess of 25m.
Martello MP5000[2]	26.5 tonnes	5575mm length 3050mm width	1050mm front 800mm side 1500mm diagonal	450mm to 1200mm	• Restricted headroom rotary bored piling rig. • Capable of coring through 6m of concrete. • Requires clear headroom in excess of 5m. • Maximum pile length of approximately 40m.
Hutte 203	6.8 tonnes	3800mm length 1200mm width	500mm front 800mm side	Up to 600mm	• Restricted headroom mini-piling rig. • Cannot core through significant thicknesses of concrete. • Requires clear headroom in excess of 3.2m. • Maximum pile length of approximately 24m.

1. Alternative piling rigs may be preferred by piling contractors. The Soilmec SR95 has been selected as a typical standard rotary piling rig capable of coring through more than 6m of concrete to allow construction of the bearing piles, however lighter rigs may be selected where significant concrete thickness is not anticipated.
2. The MP5000 is Martello's largest rig capable of coring through more than 6m of concrete. Smaller Martello piling rigs may be adopted where significant thicknesses of concrete is not expected to be present.
3. Minimum offset from centreline of pile to adjacent obstructions or structures.

4.2. Piling Rig Tracking and Loading within Root Protection Areas

As a baseline recommendation, BS 5837:2012 notes that tracking and loading of the RPAs should be avoided where possible. However, the document does provide guidance for protection the RPAs in the event tracking and loading cannot be avoided, which will likely be the case for the Museum Street development.

Where tracking and loading within RPAs is required, either by pedestrians, light vehicles or heavy plant, appropriate ground protection will need to be installed. BS 5837:2012 defines three categories of ground protection:

1 **For pedestrian movements only**: a single thickness of scaffold boards placed either on top of a driven scaffold frame or on top of a compression-resistant layer, laid onto a geotextile membrane.

2 **For pedestrian-operated plant up to a gross weight of 2 tonnes**: proprietary, inter-linked ground protection boards placed on top of a compression-resistant layer, laid onto a geotextile membrane.

3 **For wheeled or tracked construction traffic exceeding 2 tonne gross weight**: an alternative system (for example, proprietary systems, load distribution mats or platforms) to an engineering specification designed in conjunction with arboricultural advice, to accommodate the likely loading to which it will be subjected.

Piling rigs will fall into category 3, and bespoke load protection systems will be required to spread the rig track pressures exerted during the piling works. The arboricultural specialist for the project will be able to advise on the allowable rig track pressures in close proximity to and within the RPAs, and ground protection systems that can be utilised include the following:

- Custom designed sectional metal tracks joined to support vehicle loading.
- Temporary concrete slab cast over existing low-load bearing surfacing, removed once heavy use is finished.
- Proprietary cellular products, such as CORE® or Cellweb®, applicable for piling rigs up to 60 tonnes.

- Proprietary non-cellular products, such as Wrekin ArboRaft.

The locations where ground protection is to be installed should be based on the expected alignment of the piling rig and proposed locations of bearing piles. Based on the current pile layout, ground protection is expected to be required over the RPAs of T3, T4, T5, T7, T9 and T10 to facilitate the installation of the southern-most piles. The locations of ground protection will be agreed with the LPA within the Tree Protection Plan and monitoring will be required to ensure it remains fit for purpose.

4.3. Piling Tracking within Tree Canopy Areas

Where piles are to be installed to the north and northeast of the existing basement footprint, the presence of trees is not expected to impact the use of traditional piling rigs to core through expected significant thicknesses of concrete and install the piles.

Towards the southeast corner of the site where the Category A and B tree canopies are in close proximity to the existing basement and potentially extend over any installed protective fencing and pile locations, careful consideration of the canopies will be required. The following options may be considered:

- Adoption of restricted headroom piling rigs, such as Martello piling rigs, or mini-piling rigs to avoid rig masts damaging overhead branches.
- Facilitation pruning of canopies to allow the use of traditional piling rigs.
- Tying back long branches to allow traditional piling rig access to the pile locations.

The viability of any of these methods should be discussed with the project arboricultural specialist and will likely require a case-by-case review for each tree canopy. To avoid the review process and minimise any commercial risk, proceeding with a restricted headroom rig as the baseline proposed method of piling can be considered. The requirement for pruning or tying back should also be coordinated with other disciplines which may require similar canopy mitigation, such as for the installation of scaffolding or the construction of the façade.

4.4. Intrusive Works within Root Protection Areas

To prevent the introduction of significant commercial risk to the scheme related to the protection of the surrounding trees, it is recommended that intrusive works within RPAs are avoided where possible. Whilst BS 5837:2012 does provide guidance for piling within RPAs, the LPA will likely not accept anything other than minor damage to roots, as noted by Tim Moya Associates Ltd in their reports.

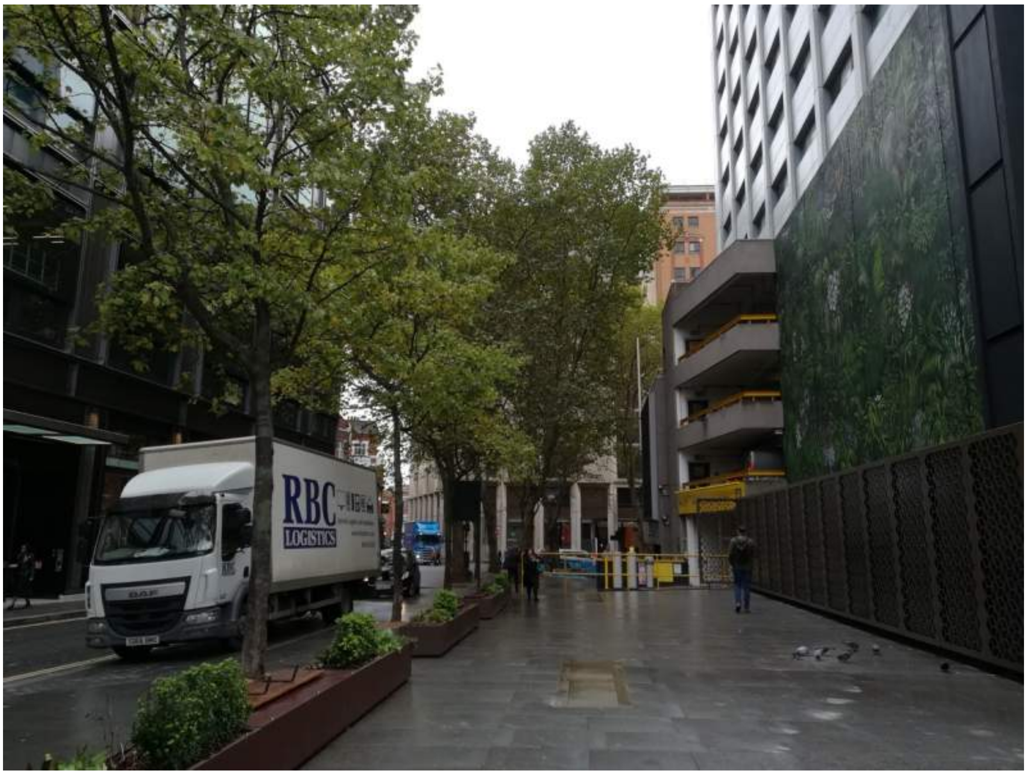
In the instance that piling within RPAs is not reasonably practical to avoid, either due to the presence of significant thicknesses of mass concrete or the sheet wall. The available guidance recommends the use of the smallest possible pile diameter, to reduce the possibility of striking a major tree root and also inherently reduces the size of the piling rig required. This recommendation counters the argument associated with mitigating the impact of encountering obstructions and using fewer larger-diameter piles. The project team will need to balance the impact of the piling works on the trees versus measures adopted to minimise piling through obstructions. At this stage, it is considered that the latter aspect is more critical, and this viewpoint should be presented to the arboricultural specialist.

Additional protection of the trees and surrounding soil from the toxic effects of uncured concrete will be required, in the form of limited sleeving of the bored pile with a non-permeable membrane or similar. The arboricultural specialist should be engaged to determine whether the three piles in the southeast corner will require sleeving and to what depths the sleeving should be taken to.

Appendix A: Selected Photos of the Trees on the Museum Street Site

West Central Street, facing southeast, showing T15, T14, T13 and T12 (in order of increasing distance)

West Central Street, facing south, showing all trees along Museum Street



East of the Museum Street basement, facing south, showing T13, T12, T11 and T10/T9 (in order of increasing distance)

East of the Museum Street basement, facing north, showing T11 to T15 (in order of increasing distance)

East of the Museum Street basement, facing south, showing T11, T9 and T10 (in order of increasing distance)

East of the Museum Street basement, facing east, showing T9, T10 (left) and T7, T8 (right)

Southeast corner of the Museum Street site, facing east, showing T4, T6 and T5 (in order of increasing distance)

Southeast corner of the Museum Street site, facing east, showing the canopies of T4, T6 and T5 (in order of increasing distance)

Southeast corner of the Museum Street site, facing north, showing the canopies of T7, T8, T9 and T10 (in order of increasing distance)

Southeast corner of the Museum Street site, facing west, showing T4, T3, T2 and T1 (in order of increasing distance)

Southeast corner of the Museum Street site, facing west, showing the canopies of T4 and T3 (in order of increasing distance)

High Holborn south of the existing Museum Street basement, facing east, showing T1, T2, T3 and T4 (in order of increasing distance)

High Holborn south of the existing Museum Street basement, facing east, showing the canopies of T1, T2, T3 and T4 (in order of increasing distance)

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A-squared Studio

Technical Note

1084-A2S-XX-XX-TN-Y-0008-01

Project	1 Museum Street and West Central Street
Project No.	1084
Subject	Existing Basement Reuse Groundwater Considerations
Client	Meinhardt (UK) Ltd

Document Reference	Status	Revision	Issued	Checked	Approved	Date
1084-A2S-XX-XX-TN-Y-0008-00	First Issue	00	HS	PS	AN	10.11.2020
1084-A2S-XX-XX-TN-Y-0008-01	Inclusion of Swantest findings and mitigation measures	01	HS	PS	AN	27.11.2020

1. Introduction

A-squared Studio Engineers Ltd (A-squared) has been appointed by Meinhardt (UK) Ltd (Meinhardt) to support the ground engineering scope related to the redevelopment of 1 Museum Street and West Central Street. The scope of this technical note comprises a summary of the key considerations substantiating the recommendation to maintain the provision for additional groundwater control measures during demolition and breaking out works of the existing 1 Museum Street basement.

2. Scheme Details

The scheme involves the redevelopment of the 1 Museum Street and West Central Street plots in Holborn, London, approximately 300m west of Holborn Underground Station.

The 1 Museum Street site currently houses a sixteen-storey Travelodge hotel tower and multi-storey podium which functions as a carpark. The existing structure is comprised of reinforced concrete and covers the majority of the plot. The carpark extends three-storeys beneath the existing buildings (approximately 9.5m), and the foundation system consists of a ground-bearing raft. A temporary sheet pile wall was installed during construction of the existing basement, as shown by selected archive information, however evidence of this wall has not been found during initial intrusive investigative works.

The proposed development for 1 Museum Street comprises a new 21-storey office tower with retail space on the ground floor. The existing ramp will be converted into a four-storey structure with a double height basement, known as Grape Street, and a four-storey building, High Holborn, will be constructed in the southwest corner of the site. A new foundation system will be constructed approximately 2m above the lowest point of the top of the existing raft (at an SSL of 18.65mOD), with large portions of the existing basement refurbished and reused, in particular the existing reinforced concrete retaining walls.

3. Ground Conditions

3.1. Ground Model

The ground conditions of the site have been determined from historical ground investigation information from the British Geological Society (BGS) and the London Borough of Camden Planning Portal. Site-specific ground investigations carried out by Geotechnical & Environmental Associates Ltd on the West Central Street site in 2015 and by Concept Engineering Consultants Ltd on the Post

Building directly east of the site in 2013 have been reviewed. Further information about the findings of these investigations can be found in the *Geotechnical and Geo-environmental Desk Study Report* prepared by A-squared, dated October 2019 (1084-A2S-XX-XX-RP-Y-0001-00).

Table 1 summarises the preliminary stratigraphic profile adopted to inform the preliminary review of ground engineering risks. The ground profiles and associated assumptions will need to be validated and revised based on a site-specific ground investigation, which is currently being procured. The elevations of the top of the strata presented below are approximate, and variability in the level of the top of the Lynch Hill Gravels and London Clay is present. The London Clay was encountered between 17.0mOD and 19.0mOD, as shown in the geological sections included as Appendix A.

Table 1 Preliminary ground model

Unit	Elevation[1] (mOD)	Depth[1] (mBGL)	Thickness (m)	Description	Aquifer Designation
Made Ground	25.0	0.0	4.5	Variable anthropogenic deposits	-
Lynch Hill Gravels	20.5	4.5	2.5	Medium dense to dense sandy gravel	Secondary (A) Aquifer
London Clay	18.0	6.0	21.0	Stiff brown clay with partings of silt fine sand	Unproductive Aquifer

1. Elevation and depth refer to top of stratum.

3.2. Groundwater

Perched groundwater is present within the Lynch Hill Gravels Superficial (A) Aquifer overlying the low permeability London Clay Formation. This is expected to comprise a continuous groundwater table rather than bodies of finite volumes of water.

The historical data suggests that the perched water table is present within the superficial deposits and Made Ground between 17.0mOD (8.0mBGL) and ground level. It is noted that the perched water table is likely to vary seasonally, as a result of human induced phenomena and hydrogeological features in proximity of the site.

To account for potential variability and seasonal changes, a water level of 20.5mOD (4.5mBGL) is considered to be representative of the short-term condition, subject to confirmation by a site-specific ground investigation.

3.3. Swantest Intrusive Works Findings

An initial breaking out and structural investigation exercise was carried out by Swantest in October and November 2020. The works comprised trial pitting and coring through the existing Museum Street substructure. Initial findings indicate the presence of mass concrete backfill behind the basement wall and underneath the basement slab around the existing pad footings. Groundwater ingress during the coring and pitting works in the basement was not encountered.

4. Existing Basement Reuse Groundwater Considerations

As part of the refurbishment and reuse of the existing basement, areas of the existing raft and basement slab will be broken out to facilitate the construction of new shallow foundations and substructure elements. The breaking out works will expose the subgrade beneath the existing substructure elements, expected to comprise mass concrete backfill. Depending on the depth of breaking out required, natural materials below the concrete backfill may be exposed.

Where the basement extends to its deepest point (at an SSL of approximately 16.5mOD), the substructure is fully embedded within the London Clay meaning that groundwater ingress in the short-term condition is not considered to be a major risk. In addition, based on the current scheme proposal, breaking out of concrete elements is not expected to take place in this area.

Other shallower areas of the basement (at SSLs of approximately 18.5mOD or greater), as marked in Figure 1 below, are founded near or above the boundary between the top of the London Clay and overlying permeable Lynch Hill Gravels at an average elevation of 18.0mOD.

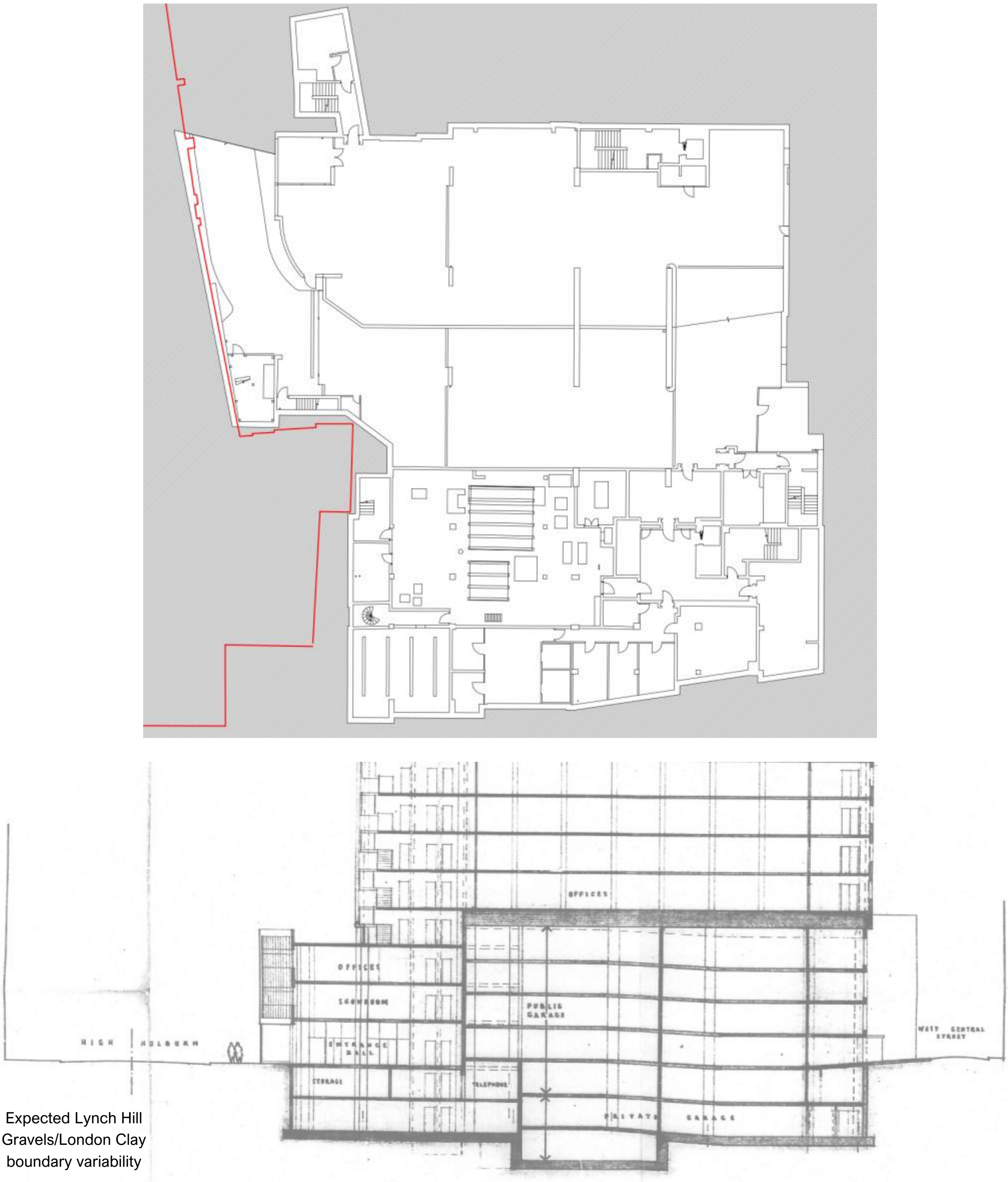


Figure 1 **Areas of the existing substructure founded near or above the interface between Lynch Hill Gravels and London Clay at risk of groundwater ingress during breaking out works**

The concrete elements are expected to be founded in the London Clay, however this observation is marginal, based on relative elevations and it is possible that Lynch Hill Gravels (or granular fill) in connectivity with the Secondary (A) Aquifer is present at subgrade level (due to the variability in the top of the London Clay or as a result of historical earthworks operations). The presence of any gravels or granular materials during breaking out through the mass concrete backfill may result in groundwater ingress into the basement.

Whilst the historical temporary works for groundwater control are expected to be present (potentially in the form of an embedded wall behind the existing reinforced concrete walls) which will provide a temporary groundwater cut-off during the proposed breaking-out works, the decision has been made alongside the project team to not *solely* rely on this, until it has been proven by intrusive works.

5. Concluding Remarks and Groundwater Mitigation Options

Based on the discussion in Section 4, it is recommended that a provision for groundwater control during breaking out works remains in place at this stage, subject to confirmation of the subgrade materials of the existing basement in the site-specific ground investigation. This is due to the close proximity of the formation level of areas of the existing substructure requiring breaking-out, marked in Figure 1, to the interface between the top of the London Clay and the overlying Lynch Hill Gravels.

The scale of groundwater control required cannot be confirmed with certainty due to the aforementioned unknowns. Depending on the presence and condition of the existing historical groundwater cut-off measures, which may be in good condition and adequate/functional for the proposed works, and nature of the subgrade material encountered beneath the existing substructure, the groundwater control measures may include localised dewatering, isolation by means of trench sheeting, injection grouting or similar. In addition, the intent to limit breaking out works to local pad/pile locations and founding the new basement slab above the existing raft means that local groundwater control may be feasible under certain ground conditions.

A tiered breakdown of groundwater mitigation measures has been provided below accounting for potential subgrade and shallow groundwater scenarios. The increasing levels of the tiers represent scenarios requiring more substantial groundwater remediation techniques. At present, based on the information available from the archive drawings, site visit and Swantest pitting, it is expected that Tier 0 or Tier 1 mitigation will be required.

Table 2 Groundwater mitigation tiers based on potential subgrade and shallow groundwater scenarios

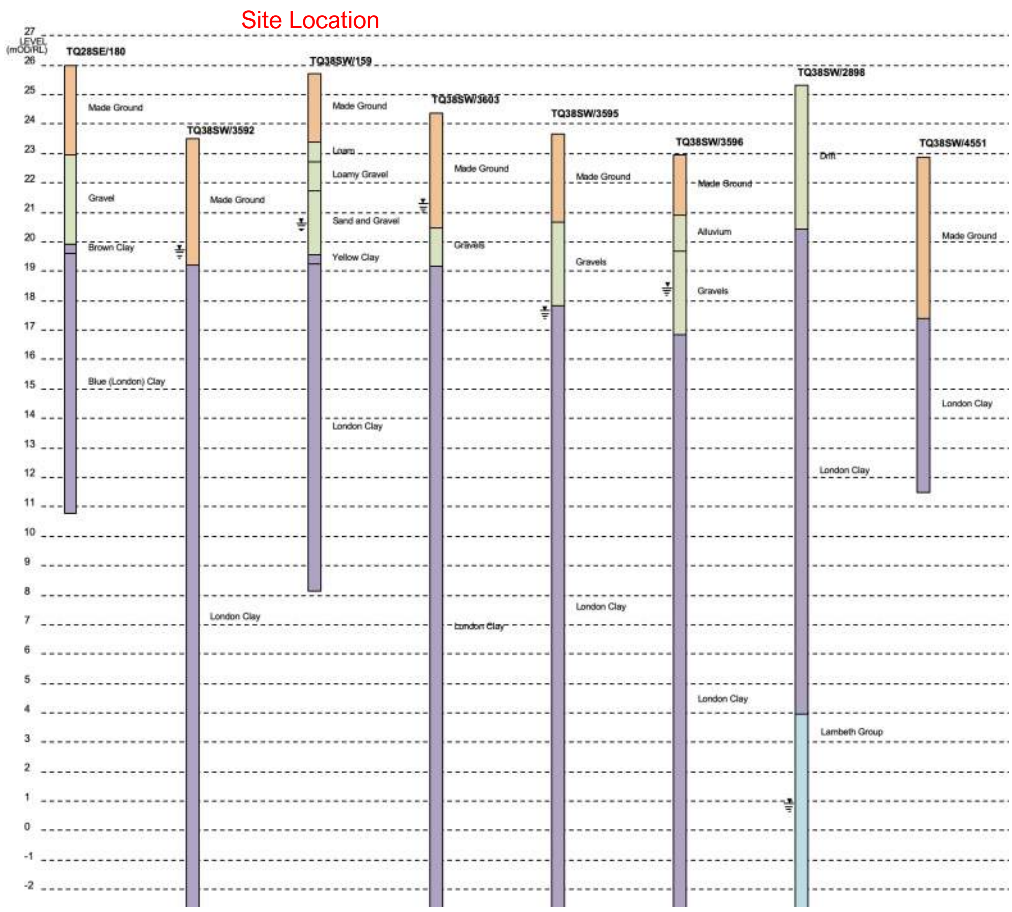
Tier	Subgrade Material Type	Subgrade Material Permeability	Hydraulic Connectivity with Superficial Aquifer	Groundwater Head	Mitigation Measures
0	London Clay or mass concrete backfill overlying London Clay	Very low	No hydraulic connectivity	N/A	No mitigation required. Groundwater risk is negligible
1	Lynch Hill Gravels or granular material backfill	High	No hydraulic conductivity	N/A	Removal of isolated limited volumes of groundwater via sumps or pumps
2	Lynch Hill Gravels or granular material backfill	High	Limited hydraulic conductivity (<1.0m thickness)	Low (<2m above breaking out level)	Permeation/injection grouting or installation of trench sheets and local dewatering
3	Lynch Hill Gravels or granular material backfill	High	Limited hydraulic conductivity (<1.0m thickness)	High (>2m above breaking out level)	Injection grouting through the high permeability subgrade materials

Tier	Subgrade Material Type	Subgrade Material Permeability	Hydraulic Connectivity with Superficial Aquifer	Groundwater Head	Mitigation Measures
3	Lynch Hill Gravels or granular material backfill	High	Significant hydraulic conductivity (>1.0m thickness)	Low (<2m above breaking out level)	Injection grouting through the high permeability subgrade materials
3	Lynch Hill Gravels or granular material backfill	High	Significant hydraulic conductivity (>1.0m thickness)	High (>2m above breaking out level)	Injection grouting through the high permeability subgrade materials

Appendix A: Geological Sections from BGS and Planning Portal Information

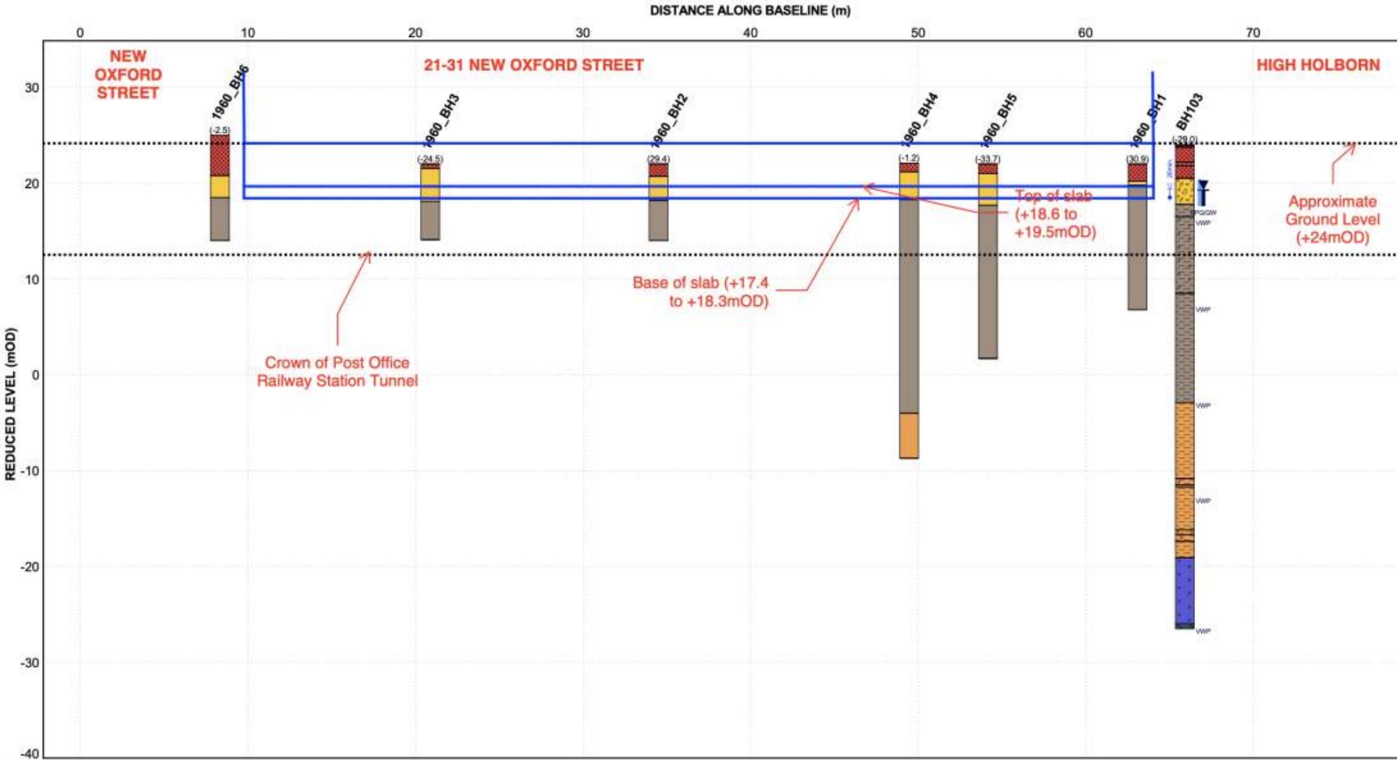
Site boundary marked in red. West-east section shown in figure below marked by black dotted line.

Location of BGS borehole data



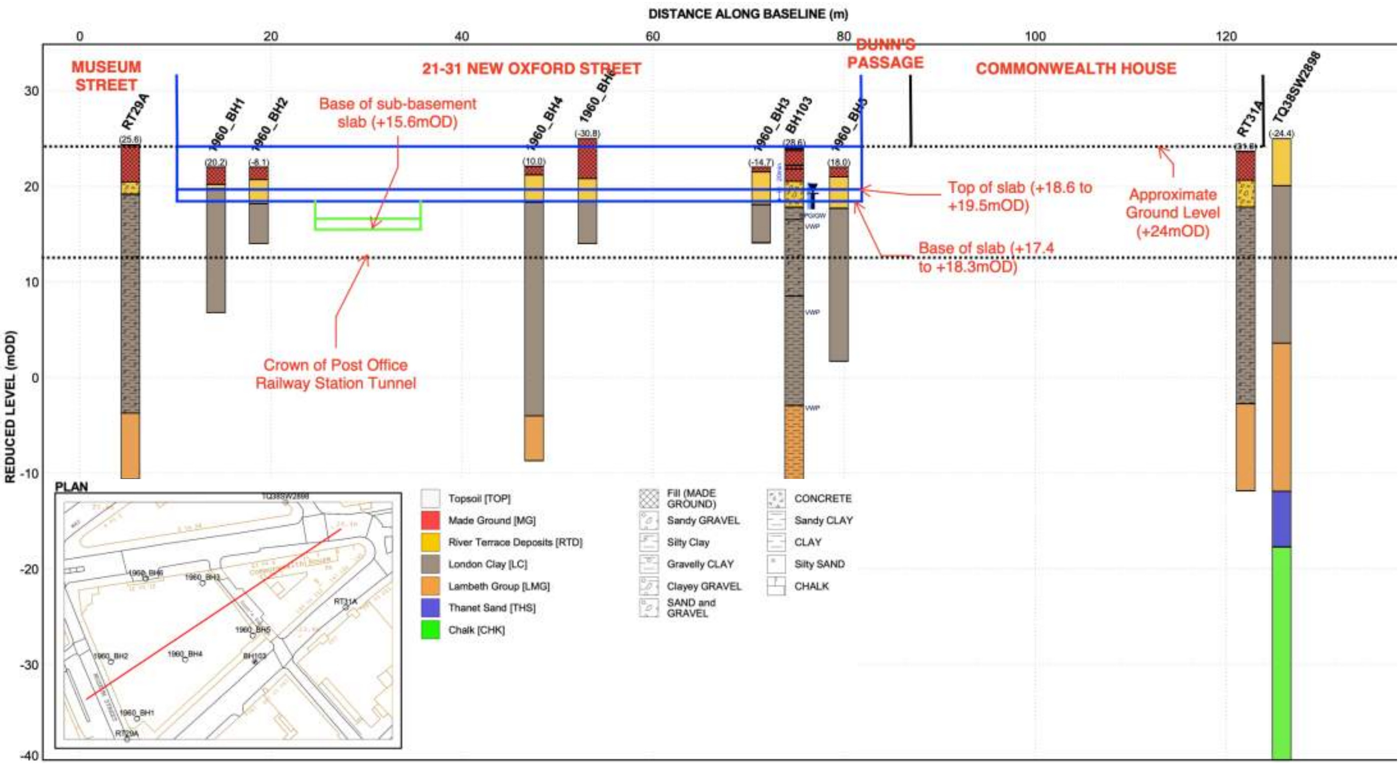
West-east section.

Indicative cross-section through historical BGS borehole data



Source: *Ground Movements and Central Line Tunnel Capacity Calculations* report prepared by Ove Arup & Partners Ltd, June 2015.

North-south geological cross-section through the Post Building to the east of the site



Source: *Ground Movements and Central Line Tunnel Capacity Calculations* report prepared by Ove Arup & Partners Ltd, June 2015.

West-east geological cross-section through the Post Building to the east of the site

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Project	1 Museum Street and West Central Street
Project No.	1084
Subject	Museum Street Piled Raft Foundation Design Summary
Client	Meinhardt (UK) Ltd

Document Reference	Status	Revision	Issued	Checked	Approved	Date
1084-A2S-XX-XX-TN-Y-0013-00	First Issue – Stage 3	00	HS	PS	AN	26.01.2021

1. Introduction

A-squared Studio Engineers Ltd (A-squared) has been engaged by Meinhardt (UK) Ltd (Meinhardt) to support the design of the hybrid piled raft foundation proposed beneath the office tower core at the 1 Museum Street development site in Holborn, London.

The scope of this piled raft design comprises the following elements:

- Ultimate limit state (ULS) and serviceability limit state (SLS) geotechnical assessment of the current design of the piled raft foundation beneath the Museum Street core in general accordance with BS EN 1997-1:2004+A1:2013 (UK N.A.) and industry best practice.
- Review of Grape Street and High Holborn serviceability performance considering the impact of the adjacent Museum Street tower.
- Provision of initial design input for the structural design of the raft foundation (including raft subgrade reactions and pile support stiffness data) and anticipated forces within the settlement-reducing piles.

2. Scheme Details

The scheme involves the redevelopment of the 1 Museum Street and West Central Street plots in Holborn, London, approximately 300m west of Holborn Underground Station.

The 1 Museum Street site currently houses a sixteen-storey Travelodge hotel tower and multi-storey podium which functions as a carpark. The existing structure is comprised of reinforced concrete and covers the majority of the plot. The carpark extends three-storeys beneath the existing buildings (approximately 9.5m), and the foundation system consists of a ground-bearing raft. A temporary sheet pile wall was installed during construction of the existing basement, as shown by selected archive information, however evidence of this wall has not been found during initial intrusive investigative works.

The proposed development for 1 Museum Street comprises a new 21-storey office tower with retail space on the ground floor. The existing ramp will be converted into a four-storey structure with a double height based, known as Grape Street, and a four-storey building, High Holborn, will be constructed in the southwest corner of the site. The new foundation system for Museum Street and Grape Street will be constructed approximately 2m above the lowest point of the top of the existing raft (at an SSL of 18.8mOD), with large portions of the existing basement refurbished and reused, in particular the existing reinforced concrete retaining walls. A new

High Holborn raft foundation will be founded at the first basement level on top of the existing raft at 20.79mOD. At this stage, it is proposed to infill the existing basement.

The Museum Street foundation system will comprise a series of discrete shallow pads at column locations with a larger raft supported by 900mm diameter reinforced concrete bored settlement-reducing piles beneath the tower core and adjacent columns. Columns landing outside of the basement and on a ground beam along the southern edge of the basement will be supported by Eurocode 7-compliant 900mm and 600mm diameter bearing piles, respectively. The Grape Street foundation system will comprise a ground bearing raft tied into the adjacent secant walls. High Holborn is also proposed to be supported by a raft foundation.

The layout of the settlement-reducing piles is shown in Figure 1. The 14no. settlement-reducing piles directly adjacent to the underlying Post Office tunnels are toed at -7.5mOD (approximately 25m below the underside of the raft) and the remaining 28no. settlement-reducing piles are toed at -2.5mOD (approximately 20m below the underside of the raft).

Post Office tunnels and 2m lateral exclusion zone marked in green. Core raft outlined in magenta.

Blue piles: demolition movement-control and settlement-reducing piles toed at -7.5mOD.

Red piles: settlement-reducing piles toed at -2.5mOD.

Figure 1 Museum Street settlement-reducing pile layout

3. Ground Model and Geotechnical Parameters

The ground model and geotechnical parameters adopted for this design have been determined from historical ground investigation information from the British Geological Society (BGS) and the London Borough of Camden Planning Portal. Site-specific ground investigations carried out by Geotechnical & Environmental Associates Ltd on the West Central Street site in 2015 and by Concept Engineering Consultants Ltd on the Post Building directly east of the site in 2013 have been reviewed. The ground model is presented in Table 1.

For the purposes of this assessment, the restorative hydrostatic uplift effects potentially acting at formation level have been ignored by modelling the groundwater below the historical and proposed raft formation levels, at 15.0mOD.

Table 1 Ground model and geotechnical parameters adopted for this analysis

Stratum	Top of stratum (mOD)	Thickness (m)	Undrained Young's Modulus, E_u [2] (MPa)	Drained Young's Modulus, E' [2] (MPa)
Made Ground	+24.00	3.50	-	10.0
Lynch Hill Gravels	+20.50	2.50	-	60.0
London Clay	+18.00	21.00	37.5 + 7.3z[4]	30.0 + 5.1z[4]
Lambeth Group	-3.00	16.50	200.0	160.0
Thanet Sands	-19.50	6.50	-	300.0
Chalk	-26.00	10.50[3]	-	300.0

1. Ground model based on publicly available ground investigation from the BGS and London Borough of Camden. This data has been interpreted for the raft design and is subject to change following site-specific ground investigation.
2. Stiffness data (E_u and E') has been evaluated taking into consideration the nature of the geotechnical / soil-structure interaction mechanisms and level of anticipated strain within the soil mass.
3. *Rigid boundary* assumed at -36.50mOD for analytical purposes.
4. z refers to the depth in metres below the top of the London Clay formation.

4. Piled Raft Design Philosophy

A hybrid piled raft foundation system comprises a combination of raft and settlement-reducing piles. The raft provides structural stability (ULS), and the piles act to enhance the serviceability performance (i.e. reduce the settlements) of the substructure.

The design philosophy of settlement-reducing piles differs from the design of traditional load bearing piles. The piles are not designed to comply with BS EN 1997-1 ultimate limit state criteria, however they are designed within the limits of their ultimate geotechnical capacities (where piles are fully mobilised, soil-structure interaction mechanisms and strain compatibility permitting). The main aim of the design is to mobilise the piles' shaft friction and end bearing as much as reasonably possible, without exceeding their concrete structural capacity. As such, the design working loads of the piles are intended to be greater than what would generally be expected of primary (traditional) load-bearing pile foundations of similar lengths and diameters designed in strict accordance with BS EN 1997-1 ultimate limit state criteria.

It should be noted that, whilst it is possible to greatly reduce the movements of the raft by increasing the length and diameters of the piles to make them stiffer or decreasing the spacing between them, the structural forces within the raft must also be considered. As the geotechnical capacities of the piles increase, they become stiffer relative to the raft and, as such, more load is taken by the stiffer reactions. This leads to a substantial increase in the structural forces within the piles and the raft, to the extent that permissible stresses within structural elements become the governing/limiting state rather than failure of the soil.

By considering the above points, the settlement-reducing pile lengths and diameters have been selected to mobilise as much of their ultimate geotechnical capacities as possible to improve the serviceability limit state performance of the raft while also limiting the increase in structural forces within the raft and piles in order to yield an efficient *strain compatible* foundation solution.

5. Analytical Assessment

5.1. Overview

A series of three-dimensional finite element (FE) simulations have been carried out, using the commercially available software Plaxis 3D, to assess the serviceability limit state (SLS) performance of the proposed piled raft. The soil-structure interaction effects captured in the analyses aim to support the structural design of foundation elements, including the raft and piles. The model also incorporates the additional impact to the SLS performance of the Museum Street bearing piles and pad footings and the Grape Street and High Holborn raft foundations. The layout of the settlement-reducing piles has been assessed and refined, considering the long-term movements and subgrade reactions of the raft with settlement-reducing piles for the design ground model presented in Section 3.

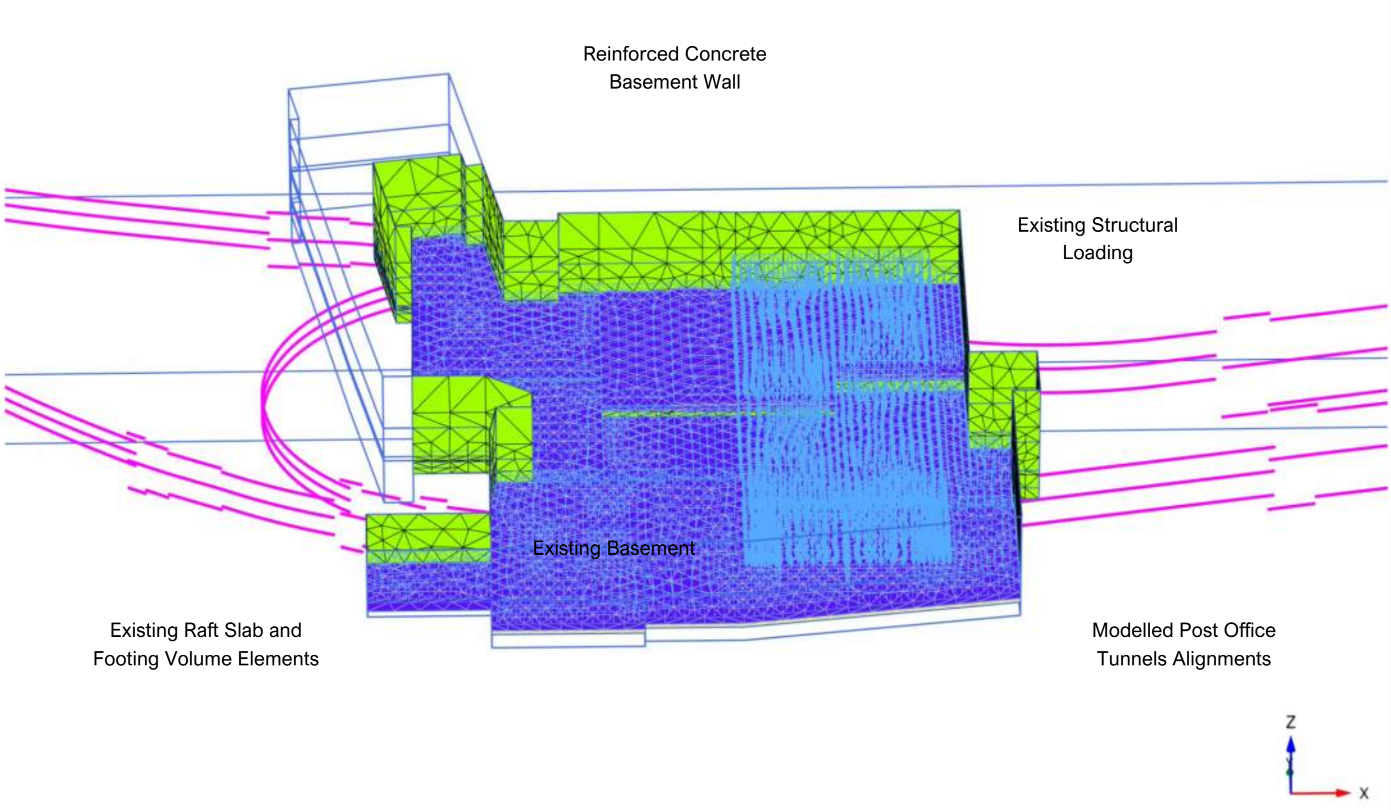
In Plaxis 3D, the soil is modelled as a continuum. All strata have been modelled assuming *linear elastic-perfectly plastic* Mohr-Coulomb constitutive behaviour. Whilst the London Clay strata and Lambeth Group have been modelled as *undrained* materials capable of generating excess pore water pressures following loading or unloading actions, long-term loading has been modelled to capture the largest potential settlements of the raft, i.e. *drained* behaviour of all soils has been modelled.

All proposed reinforced concrete structural elements have been modelled assuming linear elastic behaviour, with a Young's Modulus of 28GPa.

The construction and loading stages analysed in each model are shown in Table 2 below.

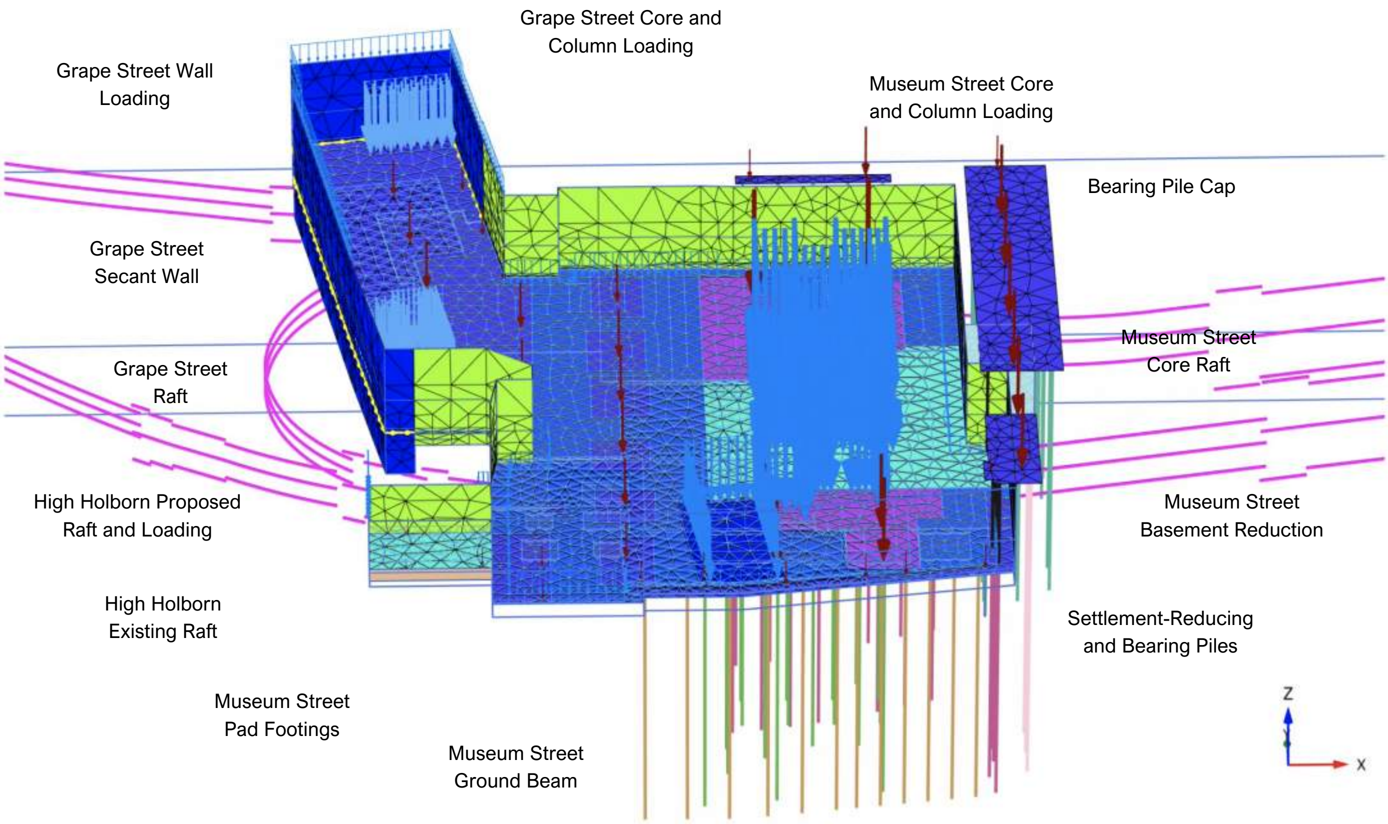
The construction of the existing basement and substructure has been modelled to simulate the anticipated stress history of the underlying soil. This sequence comprises an excavation stage, modelling of the basement construction and applied building loading from the existing tower, and dissipation of all excess pore pressures prior to commencing the proposed construction sequence. The model geometry of the existing substructure is shown in Figure 2.

The proposed construction sequence is split into a demolition stage, including the installation of the movement-control piles adjacent to the Post Office tunnels and removal of the modelled existing tower loading, a cut-and-fill stage where extensions/reductions of the existing below-ground space take place, and a single loading stage in which the full building loading is applied. The model geometry of the proposed basement is shown in Figure 3.



Soil mass and selected structural elements hidden for clarity/presentation purposes.

Figure 2 Plaxis 3D model geometry of the existing substructure



Soil mass and selected structural elements hidden for clarity/presentation purposes.

Figure 3 Plaxis 3D model geometry of the proposed development

Table 2 Modelled stages

Stage	Action
1 – Initial Phase	Initialisation of effective stresses and pore pressures.
2 – Historical Excavation	Installation of reinforced concrete retaining walls. Excavation to existing basement formation level.
3 – Basement Construction	Activation of existing basement substructure elements.
4 – Existing Building Loading	Activation of existing building surface loads.
5 – Historical Consolidation	Dissipation of all historical excess pore water pressures.
6 – Demolition	Installation of the demolition movement-control piles. Deactivation of existing building surface loads.
7 – Cut and Fill Stage	Installation of the Grape Street secant pile retaining wall. Excavation of the Grape Street basement to 17.65mOD. Cut and fill works within the Museum Street basement to a formation level of 17.65mOD.
8 – Building Loading	Installation of raft slabs, pile caps, suspended slabs and all piles. Activation of all permanent and imposed vertical column and core loading. [displacements have been reset to zero at the beginning of this stage]

5.2. Model Geometry

5.2.1. Existing Basement Geometry

The existing raft slab and footings underneath Museum Street and High Holborn have been modelled as explicit volumes of concrete with a reduced Young's Modulus of 5GPa to account for any cracking and creep over their design life. The volumes have been included as explicit 3D elements rather than 2D plates so that their impact on the performance of the proposed raft can be modelled and assessed (as large amounts of concrete will remain in the ground).

The existing reinforced concrete basement retaining walls have been modelled as isotropic 2D plates with the properties of concrete.

5.2.2. Proposed Raft, Pile Caps and Suspended Slabs

The proposed rafts, pile caps and suspended slabs across the development have also been modelled as isotropic 2D plates with the properties of concrete. The plates have been modelled at elevations representing their respective average undersides and have been given thicknesses in accordance with the structural design carried out by Meinhardt. The raft-secant wall connection at Grape Street has been modelled as pinned and unable to transfer bending moments.

The self-weights of all slab elements above the lowest basement levels have not been modelled, as these are included in the applied building loading provided by Meinhardt.

5.2.3. Proposed Secant Wall

The proposed Grape Street secant wall has been modelled as anisotropic plates with equivalent depths representing the proposed secondary piles and their centre-to-centre spacing. The anisotropy has been achieved by altering the stiffness of the plate to mimic the behaviour of the wall piles when bending about the vertical and horizontal axes.

A wall toe level of 14.0mOD has been adopted at this stage, based on the 4m vertical exclusion zone of the underlying Post Office tunnel. It is assumed that the piled wall will be propped during excavation works.

5.2.4. Piles

All piles have been modelled as 1D embedded beam elements. The piles are assumed to have a moment-resisting *fixed* connection to the raft and pile caps and interact with the ground by means of non-linear interface elements, simulating the concrete-ground interface, alongside the end bearing resistance.

The geotechnical design of the piles has been carried out adopting means and methods presented in BS EN 1997-1:2004+A1:2013, BS 8004:2015, and in accordance with industry best practice. The geotechnical capacity of a pile is a combination of frictional forces acting along the area of its shaft $q_{s;k}$ and end-bearing capacity at its base $q_{b;k}$. The ultimate capacity of the pile in compression is the sum of these two components: $q_{c;k} = q_{s;k} + q_{b;k}$. It is noted that, due to the potential presence of significant thicknesses of mass concrete behind the retaining walls and underneath the existing substructure elements, the contribution of pile shaft friction above 15.5mOD has been ignored. This assumption will be revised based on the findings of the upcoming site-specific ground investigation.

For *undrained* materials such as London Clay, the shaft and base capacity of the pile are related to the undrained shear strength of the soil c_u. The shaft friction is calculated using the α-method, where $q_{s;k} = \alpha c_u$ (α is the adhesion factor considering the interaction between the *undrained* material and concrete pile, and 0.5 is generally adopted for London Clay), and end-bearing capacity as $q_{b;k} = N_c c_u$ (N_c is an empirical end-bearing coefficient taken as 9.0 for *undrained* materials).

For settlement-reducing and movement-control piles in this analysis, the shaft friction has not been allowed to exceed 140kPa, and the end-bearing capacity of the piles has been limited to the ultimate end bearing capacity determined at the corresponding pile toe levels.

The capacity of the modelled bearing piles has been limited to their corresponding Eurocode 7 working loads to prevent the elements from attracting large amounts of load from other areas of the proposed substructure and to allow the maximum settlements of the foundation system to be determined.

5.3. Loading

5.3.1. Existing Building

The superstructure loading from the existing structures has been provided as a series of area loads across the site footprint. These have been modelled in Plaxis as surface loads at depths corresponding to the existing substructure.

5.3.2. Proposed Loading

The proposed building loading information has been provided by Meinhardt as a series of permanent and variable unfactored (SLS) forces representing the column, secant wall and core loading to be supported by the foundation system.

All column loading has been modelled as a series of point loads acting on the rafts in Plaxis 3D. The Museum Street core loading has been modelled as a series of uniformly distributed line loads along the geometry of the core walls and the Grape Street cores have been modelled as local surfaced loads.

At this stage, wind loading has not been modelled.

6. Piled Raft Performance Results

The assessment of the piled raft for Museum Street includes a review and interpretation of selected analytical output and performance criteria. The following have been considered in detail:

- SLS performance of the global foundation system, including absolute and differential settlements of the core raft and adjacent substructure elements induced by building gravity loading and the impact on the underlying Post Office tunnels.
- Global ULS performance of the foundation systems in accordance with BS EN 1997-1.
- SLS subgrade reactions beneath the raft for use in the structural design of the system.
- Pile SLS equivalent spring stiffnesses and axial forces for structural design.

6.1. Maximum Absolute and Differential Settlements

The distribution of settlements across the rafts and shallow footings indicates an average settlement of 30mm, with local areas of higher settlements where the Museum Street cores bridges over the Post Office tunnels. The maximum settlement of the Museum Street core is expected to be in the order of 45mm, and differential settlement gradients between column positions are less than $1_{ver}/600_{hor}$.

The maximum settlements induced by building gravity loading (Stage 3) are summarised in Table 3. A settlement plot is included in Appendix A.

At the time of performing this assessment, no scheme-specific settlement criteria have been agreed with the project team. In the absence of criteria, the following indicative thresholds have been adopted:

- Maximum of 50mm absolute raft settlement.
- Maximum $1_{ver}/500_{hor}$ differential settlement gradient between any two column/core positions (tighter criteria imposed by stakeholders have not been considered for this assessment but are expected to be present in High Holborn and in the north of Grape Street, where UKPN substation infrastructure is proposed to be housed).

Table 3 **Maximum raft settlements**

Absolute Settlement (mm)	Differential Settlement [1]
43	$1_{ver}/600_{hor}$

1. Differential settlement between column/core wall positions.

6.2. Impact on the Underlying Post Office Tunnels

A full impact assessment of the proposed development on the Post Office tunnels is included in the *Post Office Tunnels Ground Movement Assessment Report* prepared by A-squared, dated January 2021 (ref. 1084-A2S-XX-XX-RP-Y-0002-00).

The impact of the tunnel segments directly beneath the existing and proposed cores in Stages 6 and 8 are summarised in Table 4 below, confirming that the proposed piled raft foundation system does not induce deformations in the tunnels that exceed the adopted thresholds.

Table 4 **Displacements, radii of curvature and diametrical distortions induced by the proposed development works on the 14"-diameter Post Office tunnel segments directly beneath the existing and proposed tower cores**

Stage	Maximum Axial Vertical Displacement (mm)	Minimum Radius of Curvature (km)	Maximum Diametrical Distortion
Demolition	15	10	0.08%
Building Loading	-13	11	0.03%

Positive displacements indicate upwards movements. Please refer to the *Post Office Tunnels Ground Movement Assessment Strategy Overview* technical note (1084-A2S-XX-XX-TN-Y-0012-00) and the *Post Office Ground Movement Assessment Report* (1084-A2S-XX-XX-RP-Y-0002-00) for more information.

6.3. Raft Subgrade Reactions and Equivalent Pile Spring Stiffnesses

The raft subgrade reactions and equivalent pile spring stiffnesses have been determined for the Museum Street core raft in the building loading stage, calculated as the ratio of the vertical stress/axial force and the corresponding vertical displacement directly beneath the modelled undersides of the raft or at the pile head. The raft subgrade reaction plot is presented in Appendix A, and the associated set of equivalent pile spring stiffnesses are included in Appendix B.

6.4. Pile Forces

The pile axial forces have been assessed for the building loading case, and a schedule showing the SLS (i.e. unfactored) forces is presented in Appendix B. The tension forces induced within the movement-control piles during demolition works (Stage 6) are also included in Appendix B.

6.5. Global Safety Performance

Ultimate limit state (ULS) safety factor checks of the Plaxis 3D model indicate that the piled raft satisfies BS EN 1997-1:2004+A1:2013 criteria by a significant margin. The safety factor check comprised a soil strength reduction approach.

Additional checks of the ULS performance of the raft were carried out, including the following:

- Monolithic raft bearing/stability (i.e. rafts with no piles).
- Piled rafts with additional 50% gravity loading from the structure.

The results of the additional checks also satisfy BS EN 1997-1:2004+A1:2013 criteria from a ULS perspective.

7. Summary

7.1. Conclusion

A-squared Studio Engineers Ltd was appointed by Meinhardt (UK) Ltd to support the design of the hybrid piled raft foundation proposed beneath the office tower at the 1 Museum Street development site in Holborn, London.

The site is underlain by varying thicknesses of Made Ground up to 4.5m-thick, overlying Lynch Hill Gravels, London Clay, Lambeth Group and Thanet Sands. Shallow groundwater was encountered within the Lynch Hill Gravels, however for the purposes of the piled raft design, a groundwater elevation of 15.0mOD was modelled (in order to exclude any restorative effects resulting from groundwater pressure).

The design focused on the ULS and SLS performance of the piled raft foundation system beneath the Museum Street core, with 900-mm-diameter movement-control and settlement-reducing piles. 14no. movement-control piles are toed at -7.5mOD on either side of Post Office tunnels that run directly beneath the core, and another 28no. settlement-reducing piles support the raft in other areas. The movement-control piles also act to mitigate ground movements around the tunnels during demolition.

A number of soil-structure interaction analyses have been carried out, using the finite element software Plaxis 3D, to simulate the settlements and structural forces induced within the rafts and piles by the building loading. The surrounding bearing pile foundations, and Grape Street and High Holborn raft foundations, were included in the analyses to model their impact on the SLS performance of the core raft (thus capturing the global foundation performance).

Selected analytical output and performance criteria have been assessed, including absolute and differential settlements of the entire building footprint (including Grape Street and High Holborn), the impact of the foundation systems on the underlying Post Office tunnels, raft subgrade reactions and equivalent pile spring stiffnesses, and pile forces and moments.

The evaluated absolute and differential settlements of the raft was verified against the criteria selected for the purposes of this assessment. The absolute settlement profile is provided in Appendix A, showing peak settlements in the order of 45mm, and differential gradients within $1_{ver}/600_{hor}$ (in general compliance with the agreed performance criteria of 50mm and $1_{ver}/500_{hor}$ respectively). Stricter performance criteria may be applicable in areas where UKPN infrastructure is proposed and where sensitive façades/finishes, utilities, etc. are present. A coordinated review of the results presented herein should be undertaken by all relevant disciplines.

Raft subgrade reactions and equivalent pile spring stiffnesses are included in Appendices A and B. Tensile forces induced within the movement-control piles during demolition are also included.

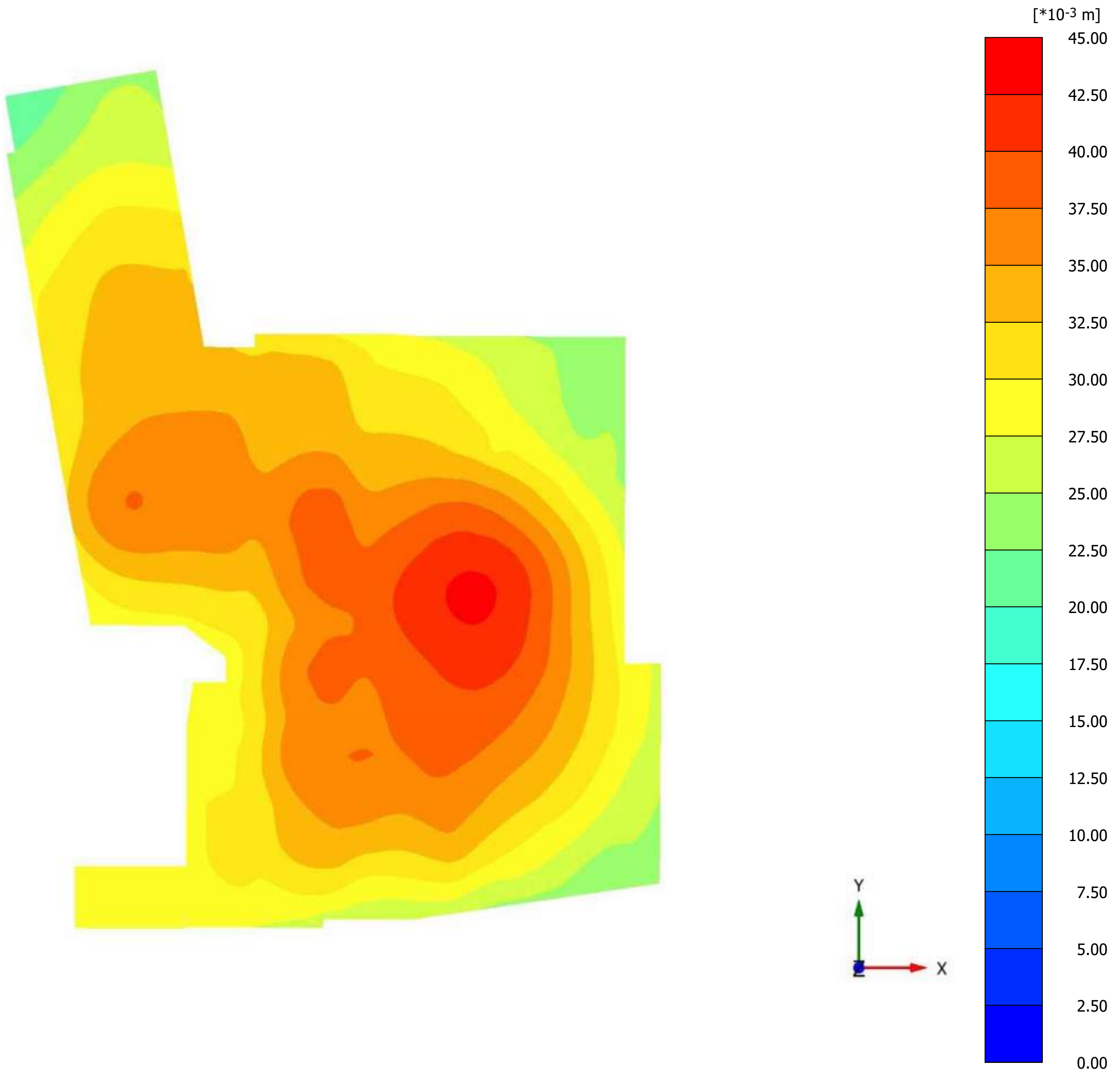
7.2. Further Recommendations

- A review of the impacts of notional horizontal and wind loading on the performance of the raft will be carried out in the next stage of design, primarily within the domain of the structural modelling.
- The performance criteria will need to be reviewed by the relevant disciplines (in terms of both absolute and differential settlements of the foundation and performance of structures and finishes in service). This should include any suppliers/specialists joining the project team, in the event that any particularly sensitive elements or components are introduced into the building fabric or finishes.
- Continued liaison between the design team and the preferred/appointed substructure and piling contractors is strongly recommended in order to ensure that construction aspects are coordinated with the design presented herein.
- Preparation of a robust earthworks specification for the project. For example, the preparation of the raft foundation subgrade is of particular significance for the project, as selected near surface/founding level materials may be particularly sensitive to disturbance from construction operations and environmental conditions.

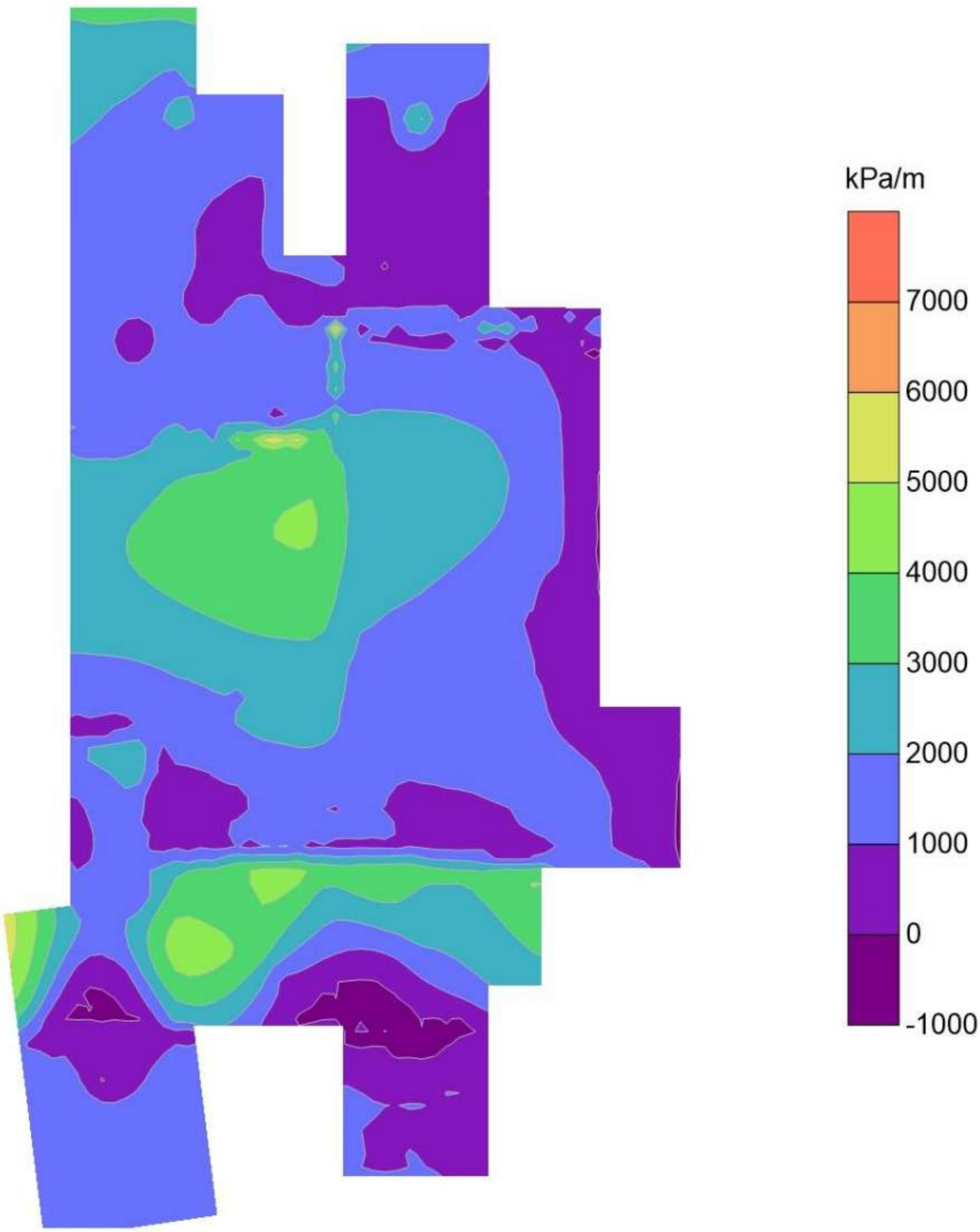
- Review of design assumptions and input parameters against the findings arising from the proposed ground investigation. It is understood that the investigative works have been postponed at the request of the client team. The findings should be reviewed in relation to both design and GMA/impact assessment facets pertaining to the substructure construction and performance in service.
- Review of any contractor driven temporary works proposals and any potential impact on the permanent works proposals presented by Meinhardt and A-squared.

Appendix A: Settlement and Subgrade Reaction Plots

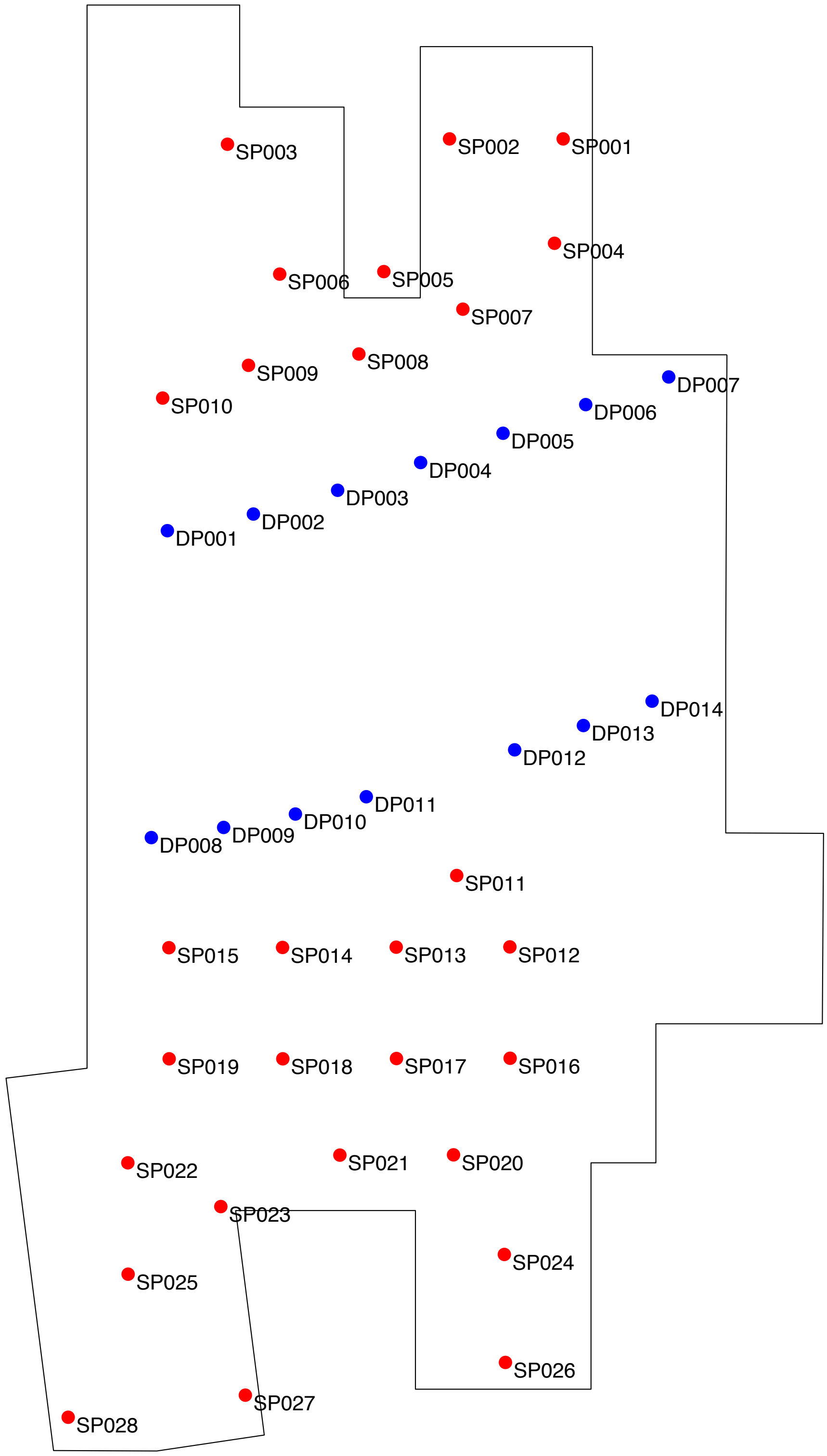
Vertical Settlement



Core Raft Subgrade Reaction



Appendix B: Movement-Control and Settlement-Reducing Pile Forces



Pile No.	Diameter (mm)	Axial Compression (kN) [1]	Axial Tension (kN) [2]	Compression Equivalent Spring Stiffness (kN/m)
DP001	900	7500	2360	190000
DP002	900	7550	2270	187000
DP003	900	7540	2420	190000
DP004	900	7570	2440	203000
DP005	900	7030	2350	209000
DP006	900	6120	2190	206000
DP007	900	5570	2030	212000
DP008	900	7450	2310	191000
DP009	900	7510	2180	187000
DP010	900	7550	2310	184000
DP011	900	7470	2580	181000
DP012	900	7300	2530	192000
DP013	900	6880	2180	197000
DP014	900	6840	2220	217000
SP001	900	4540	-	183000
SP002	900	5010	-	187000
SP003	900	5720	-	186000
SP004	900	3340	-	128000
SP005	900	2610	-	89000
SP006	900	4880	-	152000
SP007	900	4030	-	134000
SP008	900	4960	-	145000
SP009	900	5470	-	154000
SP010	900	5710	-	158000
SP011	900	5480	-	142000
SP012	900	5040	-	139000
SP013	900	5030	-	130000
SP014	900	5280	-	135000
SP015	900	5370	-	140000

Pile No.	Diameter (mm)	Axial Compression (kN) [1]	Axial Tension (kN) [2]	Compression Equivalent Spring Stiffness (kN/m)
SP016	900	4730	-	137000
SP017	900	4790	-	131000
SP018	900	4870	-	129000
SP019	900	5440	-	145000
SP020	900	4550	-	135000
SP021	900	4780	-	134000
SP022	900	5300	-	147000
SP023	900	5590	-	154000
SP024	900	5110	-	169000
SP025	900	5620	-	167000
SP026	900	5010	-	182000
SP027	900	5550	-	181000
SP028	900	5500	-	191000

1. SLS compressive axial loading from Stage 8 – Building Loading.
2. SLS tensile axial loading from Stage 6 – Demolition.

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