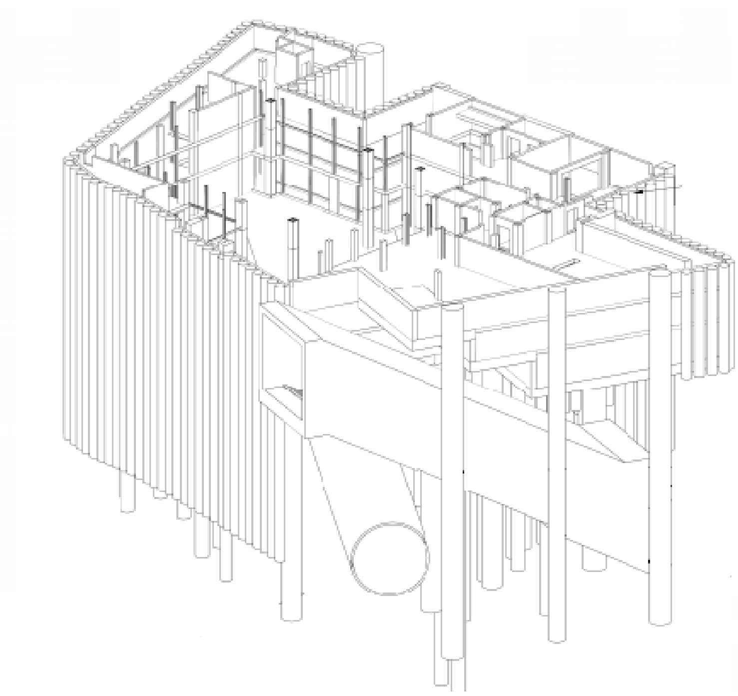
A-squared | Studio

St Giles Circus Development
Category 3 Check
VE Scheme
LUL and Crossrail Infrastructure



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EXCUTIVE SUMMARY

A-Squared Studio Engineers Ltd (Checker) have been appointed by Consolidated Developments Ltd (Client) to undertake a series of Category 3 Checks for the proposed St Giles Circus Development with regards to its impact on existing underground rail infrastructure owned by Crossrail and London Underground Limited (LUL).

This Cat III check supersedes an earlier report (refer 0136-RPT-01) prepared by the Checker on a previous scheme, which has subsequently been revised following a value engineering exercise carried out by the Engineer.

The proposed development comprises the construction of four new building superstructures (identified as A thru D, Figure 1.3), which share a common basement substructure. The maximum retained height of the basement is approximately 14m.

The scope of work is to assess the impact of the proposed development on transport infrastructure under the ownership of Crossrail and London Underground Limited.

To best understand the complex soil-structure interactions occurring between the proposed St Giles development and adjacent LUL/Crossrail infrastructure throughout the construction process and in the long-term condition, a 3D finite element model was developed, as shown in Figure 4.1. The 3D model incorporates the various assets/structures of importance to the Category 3 Checks, including:

- Eastbound Crossrail tunnel.
- North and southbound Northern Line running tunnels and platform tunnels.
- Lower concourse and cross-passage tunnels.
- Northern line escalator box (NLEB).

The numerical analyses assume representative construction sequencing. The simulation is based on an independent assessment of the modelling parameters and interpretative data. Various soil constitutive models have been adopted as part of the analysis process, including a non-linear user-defined model for the strata of key engineering significance. Parametric studies were also undertaken to assess the sensitivity to particular model assumptions surrounding structural element stiffness, initial conditions and sequencing.

The numerical simulation of the proposed development indicates that the Crossrail eastbound tunnel lining, kinematic profile and associated infrastructure are maintained within the specified geometric limits and that the lining is not overstressed based on predicted deflections and ovalisations of the assets.

The southbound and northbound running and platform tunnels of the Northern Line are not anticipated to be significantly affected by the proposed development. Furthermore, the structural capacity of the lining is maintained based on the relatively small predicted deflections and ovalisations. The impact on the track and the kinematic envelope is considered to be negligible.

The findings from the independent check indicate that the maximum total deformation of the NLEB marginally exceeds 5mm. The differential vertical movement, total horizontal movement and tilt are within the amber trigger level movements agreed between the Engineer and LUL (refer Section 7.2.1). Further consultation with LUL may be necessary in relation to this aspect to confirm that the predicted levels of movement are acceptable.

It is noted that further detailed analyses of the NLEB walls are required in order to validate their capacity under ULS conditions in both bending and shear. The current assessment incorporates a simplified staged modelling approach, which assumes that the existing NLEB (and associated LUL infrastructure) are *wished in place*. It is assessed that this methodology will tend to over-predict the stresses within the NLEB walls and slabs. It is recommended that the NLEB box construction sequence is modelled explicitly, so that initial stress conditions within the wall elements are better represented. It is assessed that this will likely reduce the predicted stresses within the structural elements and will provide increased confidence in the current assessment.

The lower concourse tunnels and cross-passages are not expected to be adversely affected by the proposed works.

In general, it is suggested that an appropriate instrumentation, survey and monitoring plan will be essential to ensure that the works are carried out safely and within the predicted ground movement predictions.

It is noted that the redevelopment of the Tottenham Court Road station area (resulting from extensive LUL and Crossrail works) has inherently resulted in a very significant disturbance of the insitu conditions in the ground. The excavation of substantial below ground basements, tunnels and connecting structures will have induced substantial short-term ground movements and will have introduced a global excess pore water pressure field within the low permeability cohesive strata underlying the site, which are arguably of greatest engineering significance in this instance. It is envisaged that the dissipation of the global excess pore water pressure field will take place over a number of years, resulting in further ground movement. In summary, regardless of the proposed St Giles Circus development, both newly built and existing below ground assets are likely to undergo further movement with time.

The implications of this time-dependent phenomenon should be considered (in combination with the relatively limited predicted impact imposed by the St Giles Circus development). It is understood that baseline monitoring of the NLEB and the Crossrail tunnel have been on-going since June 2015. It is recommended that this data be reviewed to identify any ongoing movement trends as well as the presence of cyclic movements, such as changes in perched water table level, thermal effects associated with the operation of the assets and/or similar.

It is noted that the assessment methodology adopted as part of the Category 3 Check presented herein differs substantially from the analytical techniques adopted by the Engineer. The Category 3 Check has adopted a 3D finite element modelling approach of the area of interest surrounding the St Giles Circus development. Considering the fully independent interpretation of the project data and differences in the methods of analysis (including soil constitutive models), the Category 3 Check has achieved good agreement with the findings presented by the Engineer. This is an encouraging finding in light of the construction sequence complexity and below ground congestion in the area. In summary, the findings of the Category 3 Check presented herein is satisfactory provided that the NLEB matters raised above are reviewed and agreed with the asset protection team.

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1 INTRODUCTION

A-Squared Studio Engineers Ltd (Checker) have been appointed by Consolidated Developments Ltd (Client) to undertake a series of Category 3 Checks of the proposed St Giles Circus Development with regards to its impact on existing underground rail infrastructure owned by Crossrail and London Underground Limited (LUL).

A previous Cat III check was carried out by the Checker (refer 0136-RPT-01) for two former design options, which both incorporated *adit beams* to restrain the Crossrail tunnel. A value engineering exercise was carried out by the Engineer (Engenuiti) and their geotechnical subconsultant in consultation with the asset owner (Crossrail). The value engineering exercise identified an alternative design solution, which would omit the requirement for adit beams thereby improving buildability.

The project site (Figure 1.1) is bounded by Andrew Borde Street and Denmark Street to North and South respectively, and by St Giles High Street and Charing Cross Road to the East and West respectively.

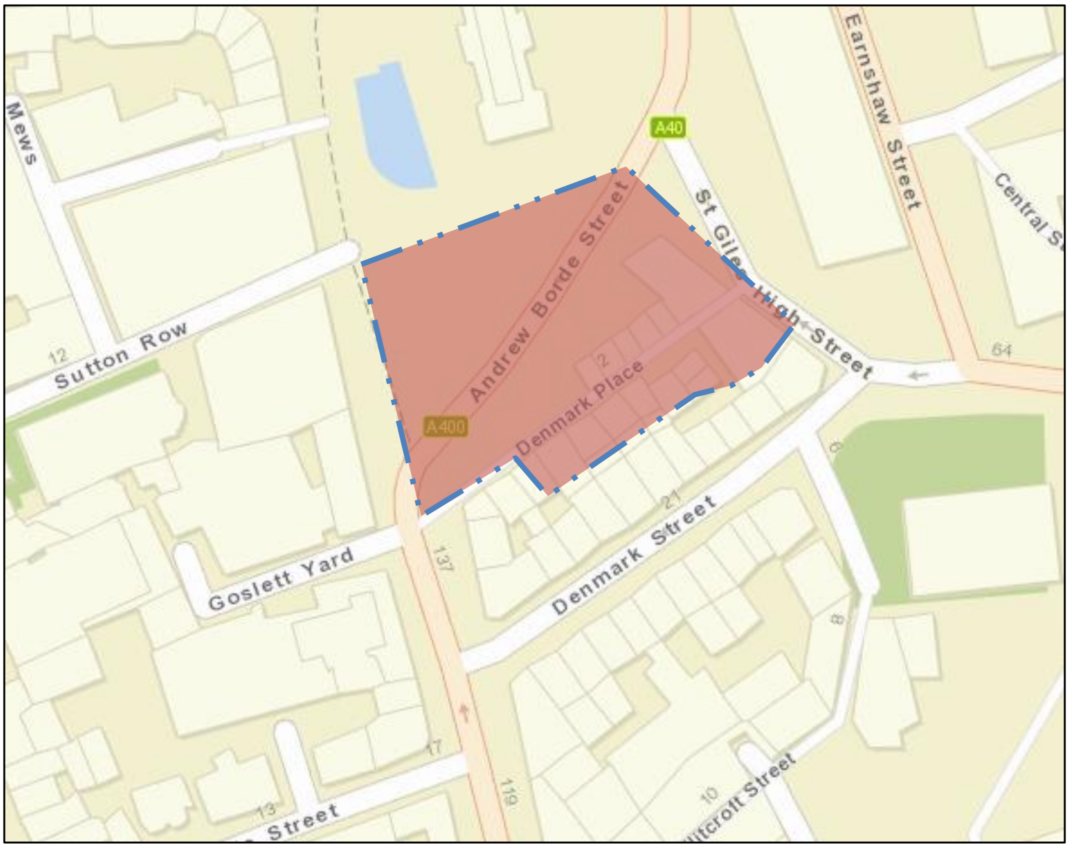

Figure 1.1: St Giles Circus – Proposed Development Footprint (Zone 1 Works)

1.0 PROPOSED DEVELOPMENT

The proposed development comprises the construction of four new building superstructures (identified as A thru D in Figure 1.3), which share a common basement substructure. These developments are part of the Zone 1 works, which form part of the Category 3 Checks presented herein.

The substructure comprises four below ground levels (Figure 1.2):

- Lower Ground (LG) – SSL +121.3 m ATD.
- Basement Mezzanine (BM) – SSL + 117.9m ATD.
- Basement 1 (B1) – SSL +114.6m ATD.
- Basement 2 (B2) - SSL +110.6m ATD.

The existing ground level is at approximately +125.0m ATD and the maximum depth of the basement is approximately 14m.

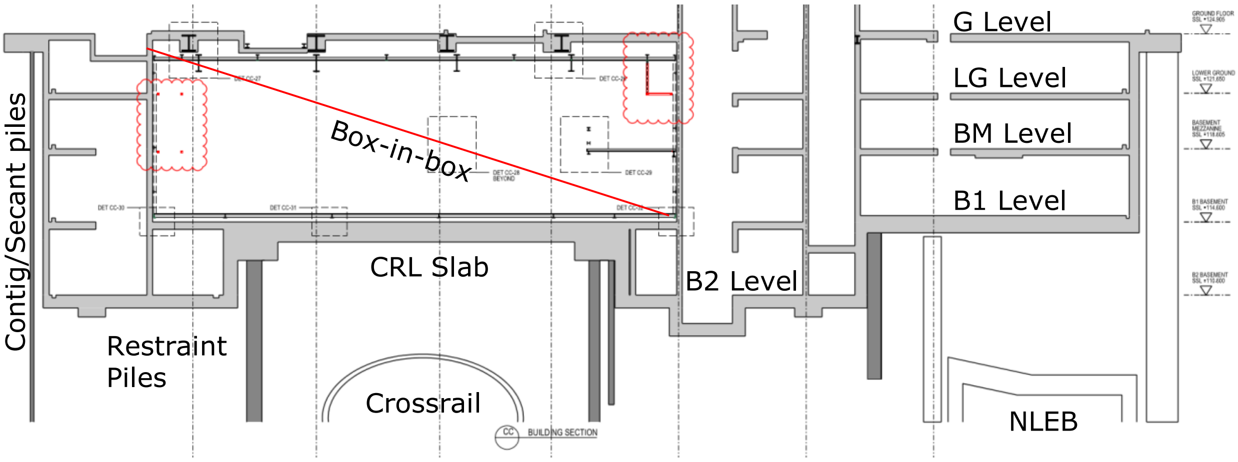

Figure 1.2: Cross-section thru development illustrating salient features

The proposed foundation system consists of the following elements:

- A pile supported flat slab at the B2 basement level. Heave board is proposed beneath the slab to limit heave induced structural forces.
- Slab on grade for the B1, BM and LG levels without heave board above the NLEB.
- A 1.1m thick reinforced concrete slab (*Crossrail Slab – CRL slab*) constructed over the eastbound Crossrail tunnel, to limit tunnel deformations.
- A contiguous pile wall (with high-level secant pile arrange to provide cut-off) to retain the basement excavation, which is propped by suspended slabs in the permanent condition.

Within the substructure, a box-in-box configuration is adopted, which provides the mezzanine level.

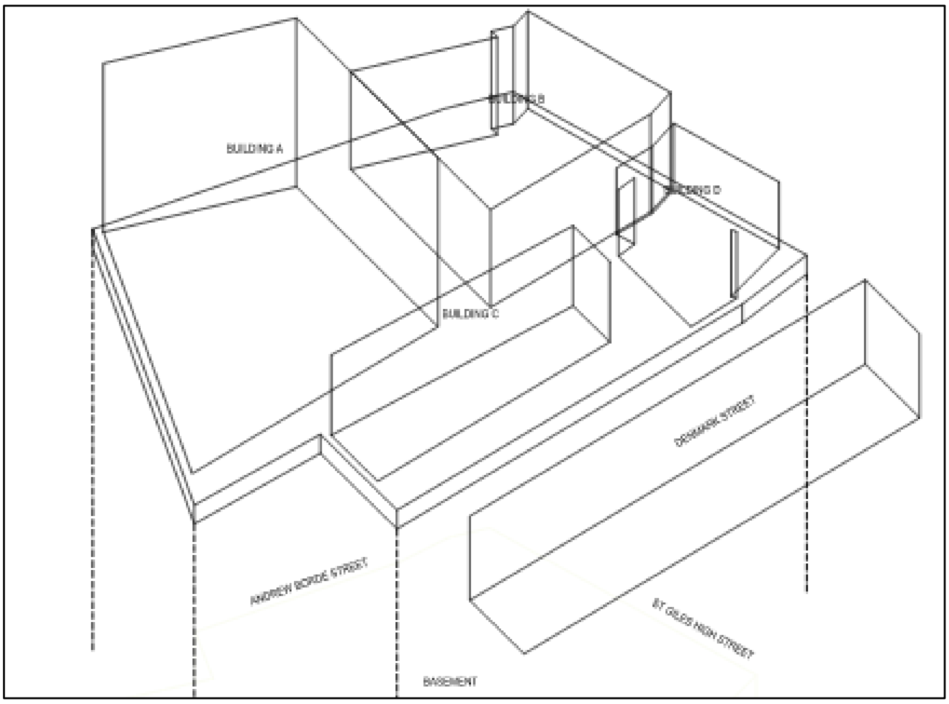

Figure 1.3: Proposed Zone 1 development

1.1 EXISTING UNDERGROUND INFRASTRUCTURE

The major underground rail tunnels and associated infrastructure within the zone of influence of the development include:

- Eastbound Crossrail running tunnel (precast concrete segmental lining).
- Northern Line northbound and southbound running tunnels and platform tunnels, with cast-iron lining.
- Northern line escalator box (NLEB) comprising a reinforced concrete box structure.
- Northern line lower concourse tunnel and cross passages (constructed using SCL method).

The eastbound Crossrail tunnel and the NLEB are both situated beneath the footprint of the proposed development. To the west of the NLEB are the existing north and southbound platform and running tunnels of the Northern Line. Figure 1.4 presents the relative arrangement of existing infrastructure in relation to the proposed St Giles Circus development.

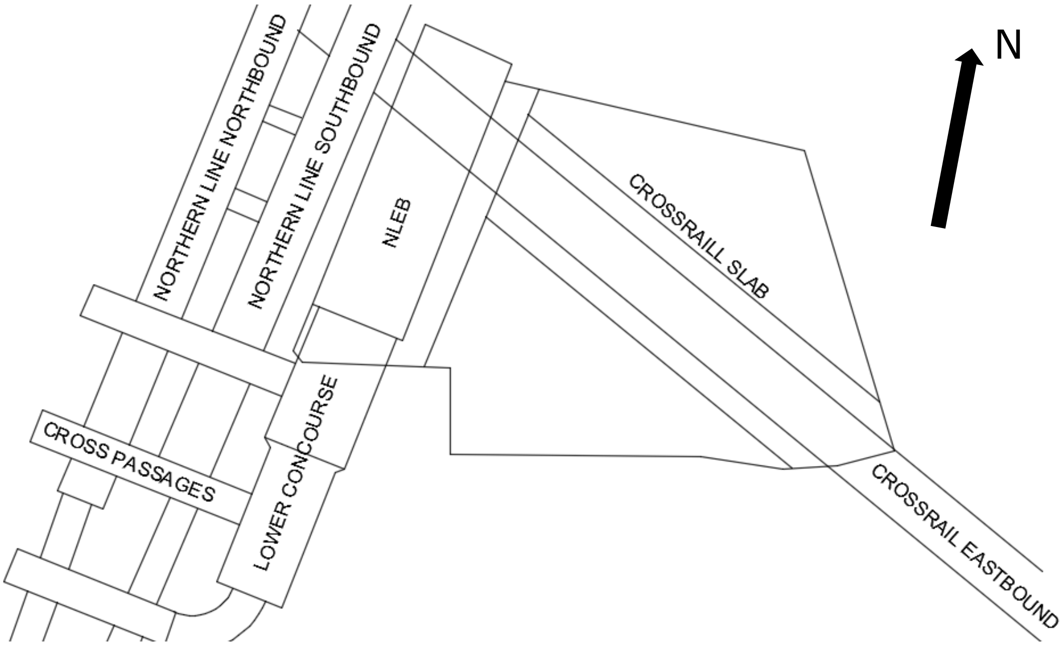

Figure 1.4: Position of existing infrastructure relative to St Giles development

1.2 SUBSTRUCTURE CONSTRUCTION

An abridged construction sequence described below (refer to Engineer's construction sequence sketches 029-Z1-SK-174 for additional detail):

- Demolition of existing buildings within the Zone 1 development footprint.
- Installation of piling platform and construction of blind-bored piles, plunge columns and secant pile walls from platform level (~+125m ATD).
- Install temporary propping within the NLEB and demolish the existing road slab.
- Cast ground floor slab over NLEB and construct Mezzanine and Lower Ground floor slabs within NLEB along with associated earth retaining structures.
- Construct ground floor slab across remainder of project site, with moling-hole leave outs to enable excavation.
- Excavate to Mezzanine level and construct mezzanine slab.
- Undertake excavation to B1 floor level.
- Construct B1 slab and CRL slab and excavate to formation level.
- Install heave board and construct B2 slab

- Construct Lower Ground Floor slab.
- Construction of remaining internal basement structure, including stability walls and box-in-box.

To limit the movement of the ground mass surrounding the eastbound Crossrail tunnel during construction and in the permanent condition, a heave restraint slab (referred to as the *CRL slab*) is proposed to span over the Crossrail tunnel to reduce heave associated with the proposed excavation and in the long term following consolidation induced swelling and a return to hydrostatic pore pressure conditions. The CRL slab evolved from a value engineering exercise undertaken by the Engineer and replaces a formerly proposed series of *adit* beams.

The NLEB is also particularly sensitive to potential ground movements and soil-structure interaction effects. During construction, the excavation surrounding the NLEB will include substantial propping and bracing in order to minimise deflections and mitigate any adverse effects on the sensitive infrastructure housed within the structure.

1.3 SCOPE OF WORKS

The purpose of this Category 3 Check is to assess the impact of the proposed St Giles Circus development on existing underground infrastructure owned by London Underground Limited (LUL) and Crossrail. An itemised summary of the design elements required to be checked is provided in Table 1.1. The assessment presented herein has been undertaken as an independent study using alternative means of analysis (in contrast with the methodology and analytical techniques adopted by the Engineer).

1.4 EXCLUSIONS

The Category 3 Check is limited to the items summarised in Table 1.1. The Category 3 Check excludes:

- Impact assessment on adjacent existing buildings surrounding the development site that do not fall within the scope as defined herein (refer to separate BIA).
- Impact assessment on existing road/highway infrastructure (refer to separate BIA).
- Impact assessment on existing buried and above ground utilities or services (refer to separate BIA).
- Element/scheme design (including both temporary and permanent works).
- All other items not included within the agreed scope of work summarised herein.

Table 1.1: Category 3 Checks completed for the proposed St Giles Circus Development

ITEM	CATEGORY 3 CHECKS	REFERENCE
1.i	***Impact on Crossrail Eastbound Tunnel***	
1.i.a	Movement	§ 6.1
1.i.b	Structural Capacity	
1.i.c	*Effects on Rail Infrastructure*	
1.i.c.1	Track geometry	
1.i.c.2	Clearances	
1.i.c.3	Waterproofing	
1.i.c.4	Overhead Line Equipment	
2.i	***Impact on LUL infrastructure adjacent to site***	
2.i.a	Northern Line Platform Tunnels	§ 7.1
2.i.a.1	Impact on Kinematic Envelope of Northern Line Platform	
2.i.a.2	Structural Capacity of Cast Iron Tunnels	
2.b	Northern Line Escalator Box (NLEB) Deformation	§ 7.2
2.b.i	Structural Capacity of NLEB	
2.c	Lower Concourse Tunnels and Cross Passages	§ 7.3

2 REFERENCES

Reference documentation to undertake the Category 3 Check was provided by the Engineer. Key supporting information is outlined in the following transmittals (refer Appendix A):

- 029-Z1-S-ISS-001

In addition to the reference documents provided by the Engineer, the following additional documents were referenced during the checks.

- Network Rail Document NA NR/L2/TRK/001/C01 (refer to Appendix A).
- Crossrail safeguarding guide: Information for developers, including supporting infrastructure assessment guidance (refer to Appendix A).
- Selected London Underground Standards (as referenced throughout the calculations and report).
- Selected design standards (including but not limited to relevant sections of BSEN1990, 1991, 1992, 1993, 1997) and industry guidance/criteria.
- Halcrow Group Limited design report, 2009, HAG-N105-8742-CIV-X-REP-X-00256-02, *Advanced analytical assessment – tunnels*.
- Temporary and permanent dead loads provided by the Engineer (refer to Appendix A).

3 GROUND MODEL

The adopted ground model is summarised in Table 3.1. The ground model has been developed based on the information provided in the following documents:

- Site Investigation Report prepared by STATS.
- Site Investigation Report prepared by Concept Consultants.
- Ground investigation data available in the public domain (e.g. British Geological Society borehole logs and geology maps).
- Selected data from Crossrail ground investigation.

The 1:50,000 scale Geological Map of North London (Sheet 256) describes the regional geology and stratigraphy. In general, the site comprises superficial drift deposits including Made Ground and Lynch Hill Gravels (river terrace deposits) that are underlain by solid geology, including the London Clay Formation, Lambeth Group, Thanet Sands and the Chalk Formation.

Ground water levels have been identified in the previous ground investigations. The average ground water table level is assumed to be at EL +120.0m OD (this comprises a *perched* water table present within the granular deposits overlying the low permeability London Clay Formation). Groundwater measurements made on site using vibrating wire piezometers (i.e. porewater pressure data) indicated that under-drained conditions are present, which are associated with long term pumping and abstraction from the Chalk aquifer.

Table 3.1: Adopted stratigraphic profile

Elevation (m ATD)		**Unit**	**Description**
From	**To**		
124.7	121.0	Made Ground	Mixture of soil and deleterious materials of manmade origins
121.0	119.0	River Terrace Deposits	Medium dense, sand and gravel mixtures of alluvial origin.
119.0	94.6	London Clay Formation	A2ii and A2i groups encountered. Predominantly stiff and very stiff high plasticity clays with occasional sand lenses and silt partings.
94.6	76.5	Lambeth Group	Very Stiff to Hard, high plasticity clays with variable interbedded sand layers, indicative of past marine transgressions and regression.

Elevation (m ATD)		Unit	Description
From	To		
76.5	71.5	Thanet Sands	Very dense, fine grained, poorly graded marine sands.
71.5	-	Chalk	Weak to moderately weak, medium density white structured chalk, CIRIA Grades A-B / 1-4. (over proven depth)

Pressuremeter testing has confirmed that the London Clay Formation and Lambeth Group clays are heavily overconsolidated. The K_0 profile from pressuremeter testing is shown in Figure 3.1 and demonstrates that the earth pressure coefficient decreases from approximately 2, near to the surface to 1 at depth.

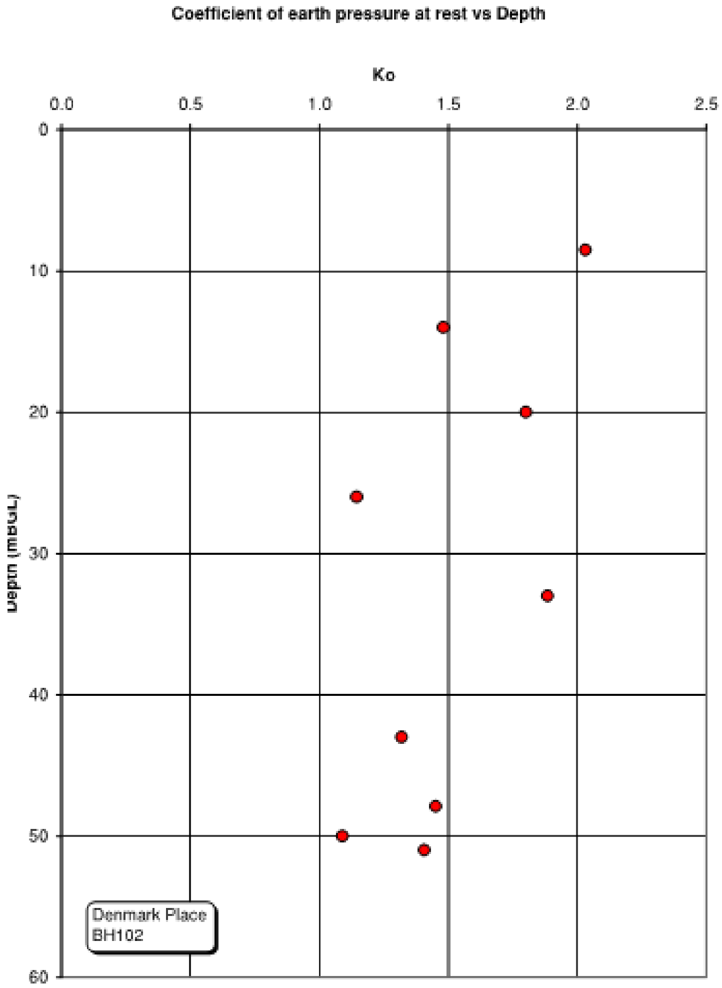

Figure 3.1: Estimated K_0 profile from pressuremeter testing as presented in STATS site investigation report.

4 NUMERICAL MODELLING

4.1 METHODOLOGY

Significant underground construction associated with the new Tottenham Court Road Ticket Hall and Crossrail development have been recently completed within the footprint and adjacent to, the proposed St Giles Circus site.

These recently constructed elements will be subject to complex stress paths due to:

- Stress relief associated with the bulk removal of earth from within the various structures footprints, as necessary for their construction.
- Change of the local ground water flow regime due to the inclusion of tanked structures.
- Change in the local pore pressure conditions and drainage boundaries surrounding the recently completed structures.
- Transient stress conditions associated with consolidation of fine grained deposits such as the London Clay Formation and cohesive Lambeth Group.

The purpose of the Category 3 Checks described herein is to assess the impact of the proposed St Giles Circus development on these recently completed and other existing substructures.

To best understand the complex soil-structure interactions occurring between the proposed St Giles development and adjacent LUL/Crossrail infrastructure, a 3D finite element model was developed, as shown in Figure 4.1. Initial reviews of the broader site arrangement and geometry (and three dimensional interface with a variety of surrounding structures) indicated that the analytical simulation would benefit from the development of a 3D model. Whilst the complexity associated with the development of such a model was acknowledged, it provided a robust means of undertaking an independent assessment of the congested below ground development in the area of the St Giles site. The 3D model incorporates the various structures of importance to the Category 3 Checks, including:

- Eastbound Crossrail tunnel.
- North and southbound northern line running tunnels and platform tunnels.
- Lower concourse and cross-passage tunnels.
- Northern line escalator box (NLEB).
- Tottenham Court Road Ticket Hall.

The model boundaries were taken as approximately 5 times the width of excavation, either side of the proposed development. The model dimensions were approximately 200m x 200m and contained approximately 410,000 elements. The model was developed using the commercially available Plaxis 3D 2015 software.

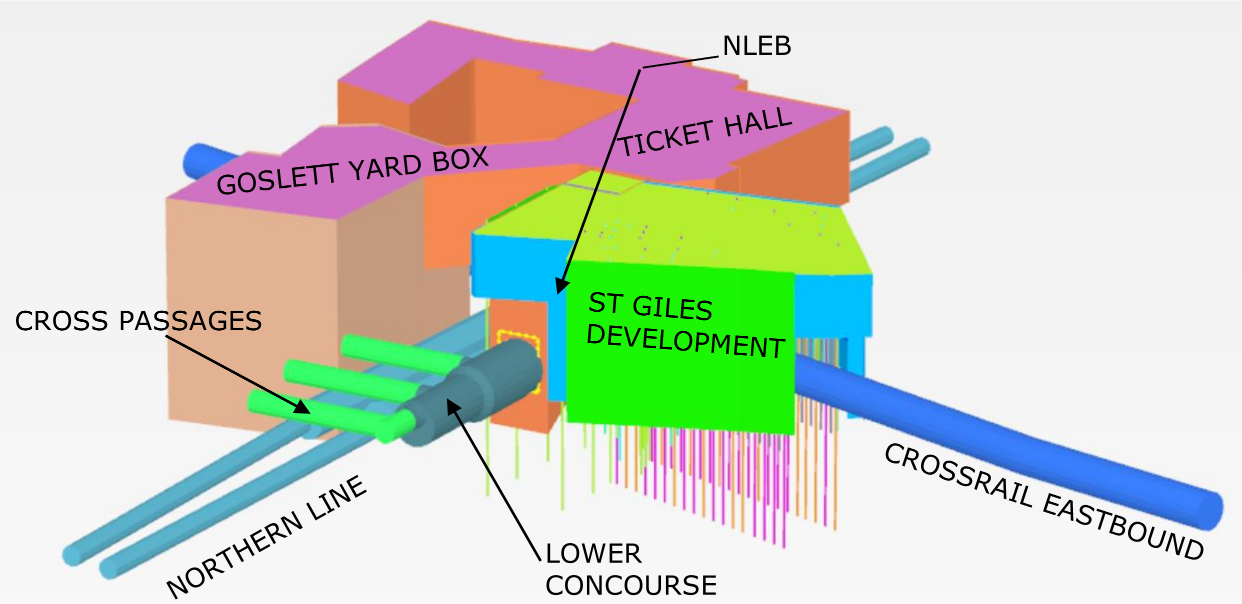

Figure 4.1: 3D finite element model overview (soil and selected structures removed for clarity of presentation)

4.2 SOLID ELEMENT PROPERTIES

The material model and properties of the solid elements modelled in Plaxis 3D are summarised in Table 4.1. The properties have been selected based on available site specific investigation, current industry practice and prior project experience in comparable conditions. The parameter evaluation has also considered the nature of the substructure proposals and proposed geotechnical analysis.

The Young's modulus of the London Clay and Lambeth Group clays was estimated based on an assumed stiffness relationship with strength, whereupon $E_u = 500 \cdot s_u$. The drained modulus was estimated as $E' = 0.8 \cdot E_u$ based on and assuming an isotropic elastic material. These values were adopted when modelling the formation using the Mohr Coulomb soil constitutive model.

The undrained strength profile was estimated as $s_u = 70 + 7z$ (kPa), from the top of London Clay. The profile was based on the results of unconsolidated undrained triaxial tests and standard penetration test (SPT) N values, assuming that $s_u = 4.4N_{60}$ (kPa). Figure 4.2 presents the undrained strength profile.

In addition to the Mohr Coulomb material model, a parametric review was carried out using a user-defined non-linear soil constitutive model, which is capable of providing more representative and realistic soil behavioural response, including:

- Small strain stiffness (i.e. stiffness dependency on strain level).
- Stress dependency / stress path reversal (i.e. stiffness dependency on the level of mean confining pressure).

The small strain stiffness data required for the non-linear material constitutive model was calibrated against published shear modulus/stiffness degradation curves with strain.

Table 4.1: Basic material properties for solid element types

Unit	Material Model	Bulk unit weight γ_b (kN/m^3)	Cohesion c′ (kPa)	Angle of shearing resistance ϕ'(deg)	Young's Modulus E′ (MPa)	Poisson's Ratio ν'	Coeff. of earth pressure K_0
Made Ground	Mohr Coulomb	18	0	30	10	0.2	0.50
River Terrace Deposits	Mohr Coulomb	20	0	34	40	0.2	0.44
London Clay Formation	*Non-linear Model*	20	5	25	Non-linear parameters	0.2	1.5
Lambeth Group Clays	*Non-linear Model*	20	5	25	Non-linear parameters	0.2	1.2
London Clay Formation	Mohr Coulomb	20	5	25	$400 \cdot s_u$	0.2	1.5
Lambeth Group Clays	Mohr Coulomb	20	5	25	$400 \cdot s_u$	0.2	1.2
Thanet Sands	Mohr Coulomb	20	0	35	200	0.2	1.0
Chalk	Elastic	22	-	-	1,000	0.2	-
Concrete	Elastic	24	-	-	25,000	0.15	-

4.3 STRUCTURAL ELEMENT PROPERTIES

4.3.1 BEARING PILES AND PLUNGE COLUMNS

Details of the proposed foundation piles are shown on the Engineer's drawings:

- Z1-S-031 – Zone 1 Piling Layout.
- Z1-S-032 thru Z1-S-037 – Zone 1 Piling Schedule.

The piles were modelled with embedded pile elements (refer to Figure 4.3). These are equivalent 1-D structural elements with an in-built interface material, which provides a facility to explicitly specify the shaft and base capacity. The pile element implementation in Plaxis 3D also allows for representative elastic behaviour within the explicit pile geometry zone. The piles were modelled using a linear elastic constitutive model with a Young's Modulus of E = 25 GPa.

The pile diameter and toe elevations for each pile type are provided in Table 4.2. The toe levels of the piles were rationalised for the analysis. The toe levels for the internal bearing piles were based on those adopted for the previous Cat III report (0136-REP-01). The current value engineered scheme design drawings do not specify toe levels for the bearing piles, as they are to be contractor designed. Minimum diameters, reinforcement and toe levels are specified for the heave restraint piles (type 'G'), either side of the Crossrail Tunnel.

One outcome of the value engineering scheme was that the global stiffness of the heave restraint piles (which were formerly restraining the *adit* piles and are now to restrain the CRL slab) could be reduced. This reduction in stiffness was captured in the 3D model by decreasing the length of those restraint piles, which were not subject to either a temporary or permanent structural load. Piles that were to support a load in the temporary or permanent condition were founded at a toe level of +75m AOD (as per the specified toe level for the Crossrail tension piles). Those that were acting passively, were founded at +95m AOD. This configuration provides relatively high stiffness in the immediate vicinity of the Crossrail tunnel, where it is most needed. At depth, the stiffness of the system is effectively halved, but with relatively little detrimental effect.

Within the London Clay Formation and Lambeth Group the shaft and base capacity was estimated based on an assumed undrained shear strength profile of $s_u = 70 + 7z$ (kPa) from the top of London Clay. An alpha value (α) of 0.5 was adopted and the shaft capacity was limited so that the skin friction would not exceed 140 kPa.

Plunge columns were modelled as linear elastic beam elements with an elastic modulus of E = 200 GPa. Section properties relating to cross-sectional area and moment of inertia were commensurate with the proposed UC356x406 section as shown on 029-Z1-S-003.

Table 4.2: Pile types proposed within St Giles development

Pile Type	Pile Diameter (m)	Toe-Elevation (m ATD)
1	0.6	95.0
2	0.9	95.0
3	0.9	75.0
6	1.2	75.0

4.3.2 CONTIGUOUS PILE WALLS

Contiguous pile walls were modelled using an equivalent, linear elastic plate element. A plate element is a 2D structural element that has been developed to enable direct estimation of structural forces (i.e. axial load, shear and moments) due to deformation. This is opposite to the general solid element type, which resolves stresses.

The properties adopted for the plates are summarised in Table 4.3. The stiffness and flexural rigidity values presented adopt a Young's Modulus for concrete of E = 25 GPa in the *short term* and 12.5 GPa in the *long term*. Figure 4.3 shows the contiguous pile walls of the proposed St Giles Circus development as modelled. The arrangement and loading for the contiguous pile walls was taken from the piling general arrangement plans (as referenced in Section 4.3.1).

Table 4.3: Contiguous pile wall properties used for modelling

Diameter [d] (mm)	Spacing [s] (mm)	Pile bending Stiffness, [EI] (kNm^2/m)		Equivalent plate thickness (mm)
		Short Term	Long Term	
900	1200	1.79×10^6	0.90×10^6	700
1200	1500	0.72×10^6	0.36×10^6	950

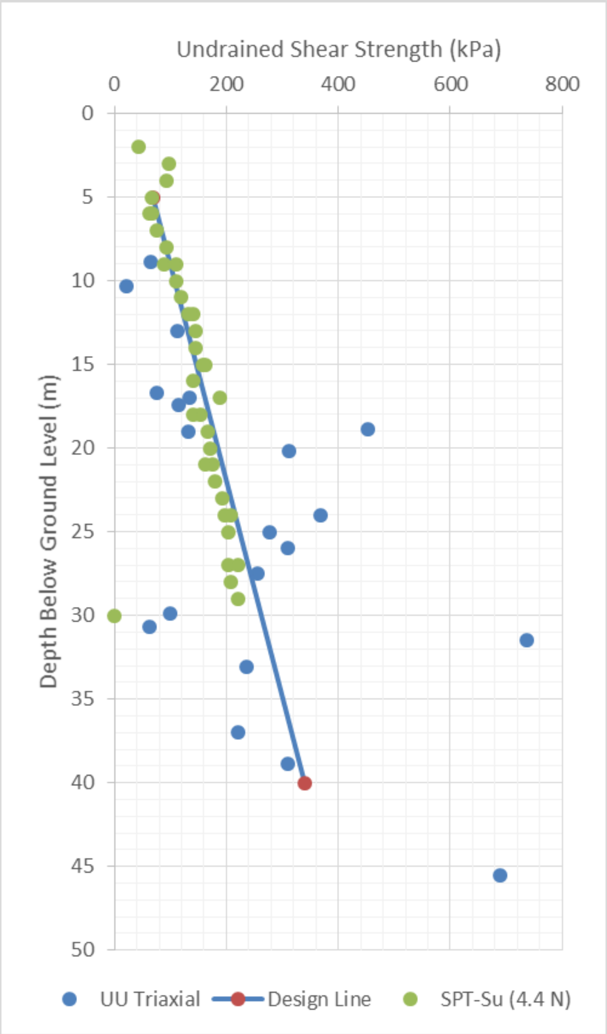

Figure 4.2: Adopted undrained strength profile for LCF and LMBE units

4.3.3 SLABS

The ground floor, B1, B2 and CRL slabs were modelled as plate elements (refer to Figure 4.3). The thickness of these elements varied depending on their location, as shown in drawings Z1-S-061 thru Z1-S-092. The slab thicknesses adopted in the analyses for the structural floor levels were 400mm, 700mm and 900mm, respectively. The CRL slab was modelled with a thickness of 1100mm. The axial and bending stiffness of the sections were determined based on the full section depth and a Young's Modulus of, E_{conc} = 25 GPa in the *short term* and a reducing to 12.5 GPa in the *long term*.

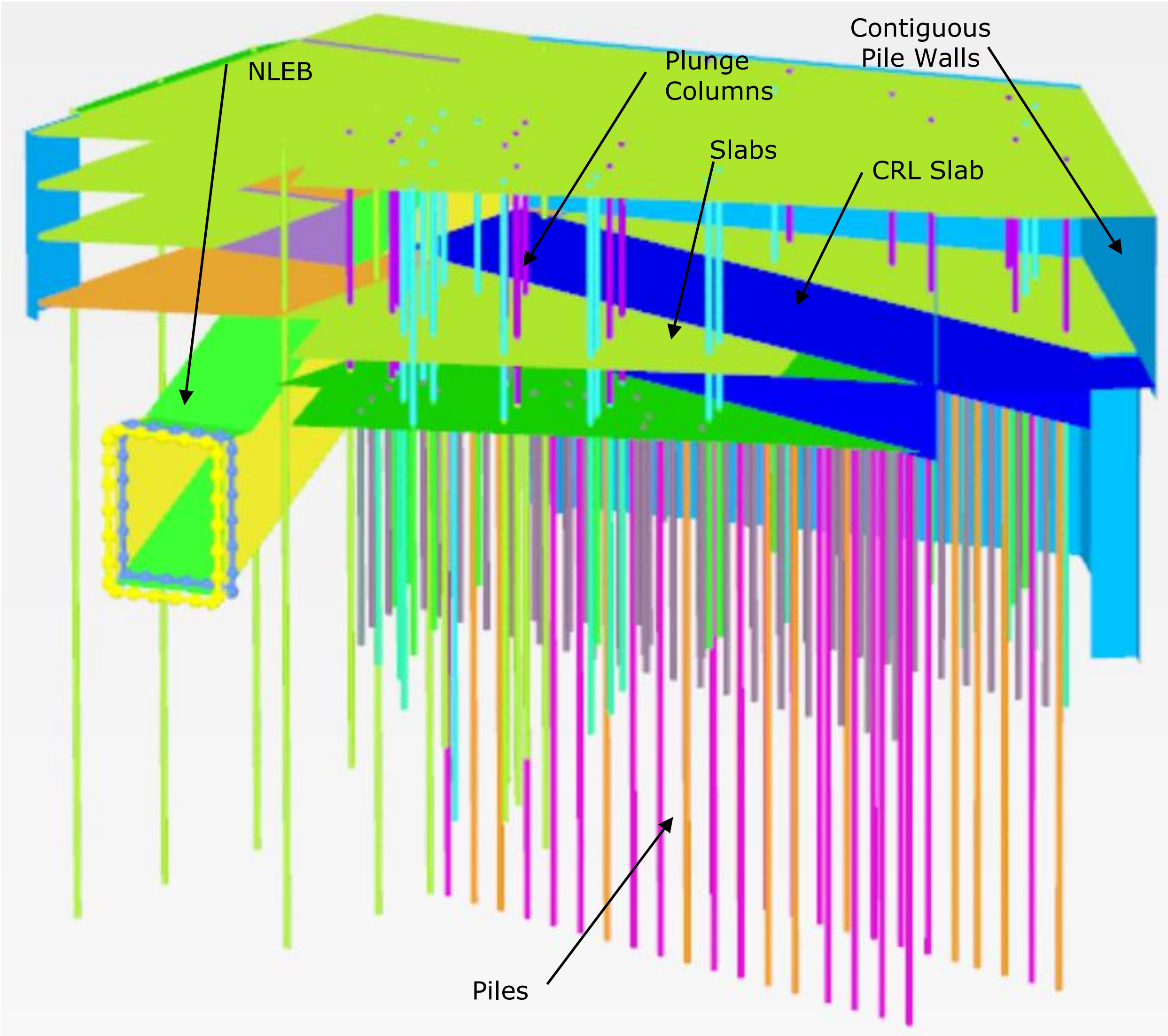

Figure 4.3: Piles, contiguous pile walls and slabs representation in the finite element model (soil and selected elements removed for clarity of presentation)

4.3.4 CROSSRAIL TUNNEL LINING

The Crossrail tunnel lining comprises a staggered arrangement of 300mm thick precast concrete panels, which are connected by means of bolts and dowels. Following installation, the annulus between the soil mass and concrete panels is grouted. As noted in the Crossrail Third Party/Developer Interface document (Section 6), the precast panels are cast using C50/60 concrete.

The mass behaviour of the lining system will be complex as a result of the discontinuous nature of the precast segments, which enhances the modelling complexity. For simplicity, the lining was modelled as a continuous, isotropic material with a reduced Young's Modulus. Linear elastic plate elements were used to model the lining.

Based on the mean cylinder compressive strength ($f_{c,m} = f_{c,k} + 8$), the mean Young's Modulus of concrete is estimated as, $E_m = 22f_{c,m}^{0.3} \approx 37$ GPa.

A reduced concrete stiffness of $E_{c,r} \approx 0.5E_m \approx$ 20 GPa (~50% of E_m) was adopted to provide an allowance for the effects of the discontinuous nature of the concrete segments (both in-plane and longitudinally). A parametric study was undertaken to assess the effect of varying the tunnel lining stiffness (between 100%EI to approx. 30%EI) and it was observed that the magnitude of tunnel deformation was not dramatically altered. It was assessed that the adopted stiffness would provide a reasonable balance between suitably estimating tunnel deformations, whilst providing a relatively conservative assessment of lining stresses.

The Crossrail tunnel was installed adopting *β-stage* approach, to permit a degree of relaxation of the soil mass prior to lining installation. This approach was adopted to ensure that the forces within the lining were not unrealistically high, due to the in-situ ground stresses. The modelling allowed for a 40% relaxation prior to installation of the Crossrail tunnel lining. The effects of grouting were not considered.

4.3.5 NORTHERN LINE CAST-IRON TUNNELS

The Northern Line Cast-Iron running and platform Tunnels were modelled as a plate element with an Elastic Modulus of 100 GPa and equivalent thickness of 95mm. The second moment of inertia for the station and running tunnel linings was estimated as 1.953×10^{-4} m^4/m and 4.127×10^{-5} m^4/m respectively, which were evaluated from first principles on the basis of the particular existing lining segment sections.

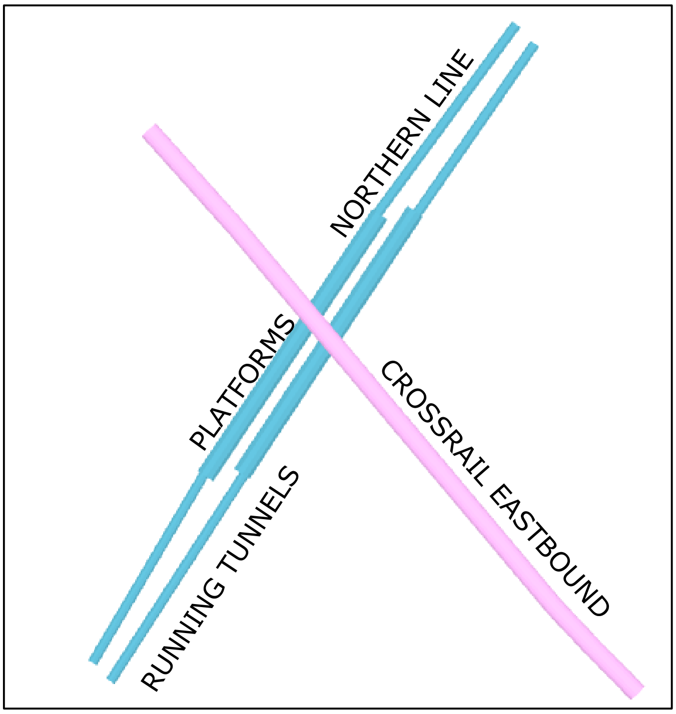

Figure 4.4: Northern Line running tunnels and platform and Crossrail east bound tunnel

4.3.6 NORTHERN LINE ESCALATOR BOX

The Northern Line Escalator Box (Figure 4.5) was modelled as a series of inter-connected concrete isotropic plate elements, with a Young's Modulus, E = 25 GPa applied in the *short term* and reduced to 12.5 GPa in the *long term*. For structural design checks, the C32/40 grade concrete was adopted.

The top and bottom slabs of the NLEB were modelled as 1.1m thick, whilst the thickness of the walls was 0.75m. The NLEB was modelled with approximate cross-sectional dimensions of 7.6m high by 7.7m wide. The height of the NLEB walls increases near to the interface with the Lower Concourse Tunnel. In this region, the wall height is approximately 8.7m.

The NLEB was modelled as having a fixed connection to the TCR station box. The connection at the interface with the Lower Concourse Tunnel was modelled as being free to rotate and move laterally in three dimensions. This is considered to be a reasonable representation of the actual fixity between these two structures.

The detailed historic construction sequence of the NLEB was not incorporated in the simulation (i.e. the structure was introduced in to the over-arching 3D model as a wished-into place element).

The modelling did not consider provision of a heave protection layer at the interface between the fill overlying the NLEB and the soffit of the proposed St Giles basement structure.

4.3.7 NORTHERN LINE LOWER CONCOURSE AND CROSS PASSAGES

The SCL Northern Line Lower Concourse and Cross Passages (Figure 4.5) were modelled as isotropic plate elements, with a Young's Modulus, E = 25 GPa. The geometry of the lower concourse was simplified slightly for analytical purposes to a circular cross-sectional profile. The diameter of the lower concourse tunnel (representative of the largest section) and cross-passages were 9.8m and 4m, respectively.

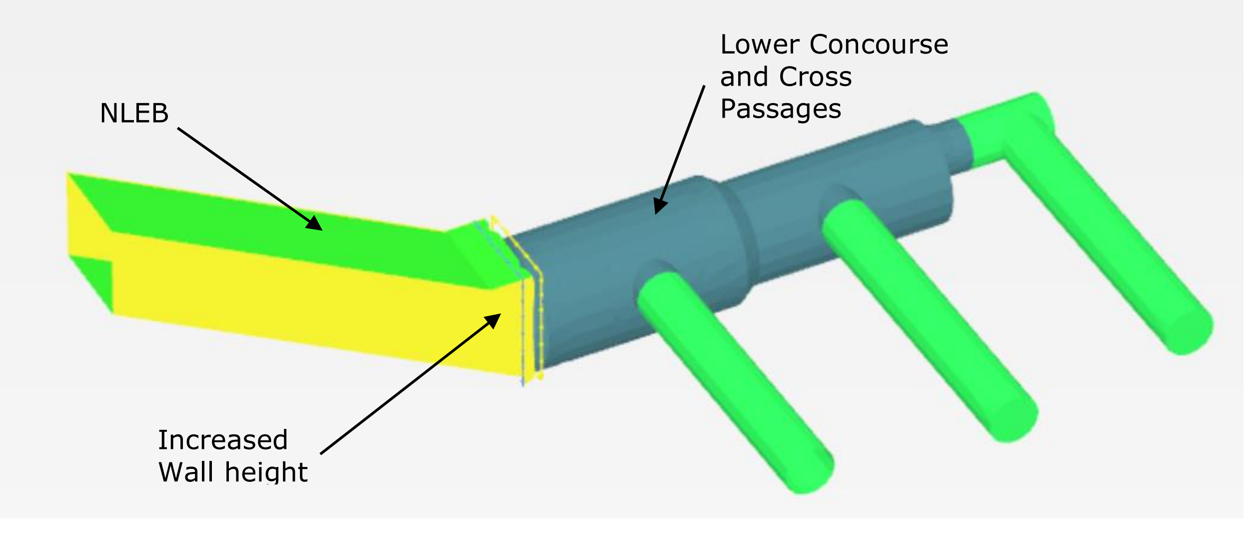

Figure 4.5: Northern Line Escalator Box and Lower Concourse Tunnel

4.4 ACTIONS

4.4.1 DEAD LOADS

The modelling assesses the performance of the ground mass and surrounding structures under *working load* conditions. As such, no partial factors have been applied to the dead loads. Live loads were not considered as their effects were considered to be transient.

Structural loads are applied to the foundation soils via the following mechanisms:

- Bearing of slabs directly on grade.
- Column loads applied to single piles.
- Discrete column loads applied to contiguous pile walls that are connected by a capping beam.

Point loads arising from temporary and permanent dead loads were applied directly to single pile heads. The minimum and maximum estimated dead loads during and after the end of construction were provided by the Engineer and are included in Appendix A for reference. For the purposes of modelling, the minimum estimated dead loads were adopted. This was based on a judgement that within and nearby to the proposed St Giles development, an unloading stress path would predominate within the soil mass. It was assessed then that adopting the minimum estimated dead loads should provide a relatively conservative assessment of ground movements and structural deformation associated with unloading.

Loads applied to the contiguous pile walls were modelled as an equivalent uniformly distributed load.

Ground bearing slabs were modelled with weight, to incorporate the effect of dead load.

4.4.2 GROUND WATER, BUOYANCY LOADS AND HEAVE

The modelling adopted a hydrostatic pore pressure profile throughout the soil mass. It is considered that this should provide a conservative estimate of the buoyancy forces applied to the structure in the *long term*, following consolidation of the London Clay Formation. Figure 4.6 presents a cross-section showing the contours of steady-state pore pressure within model.

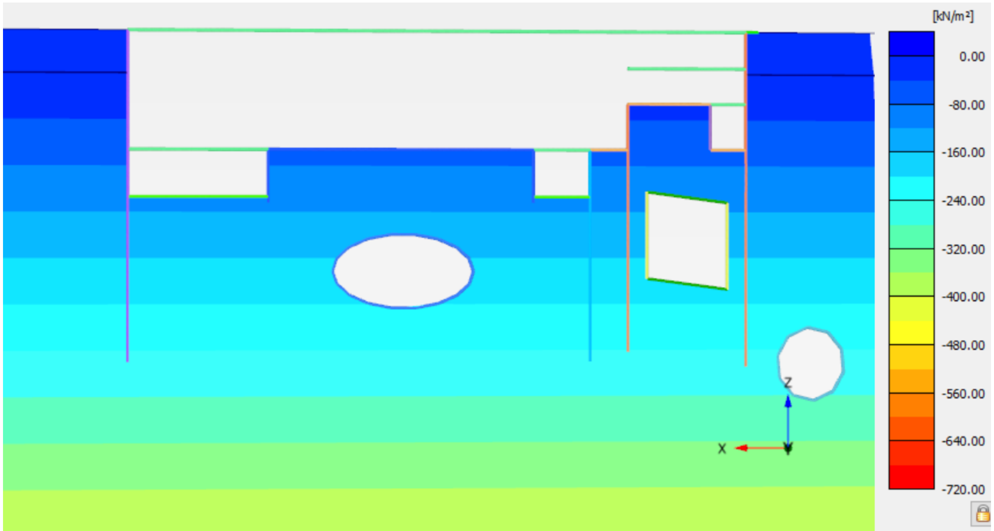

Figure 4.6: Steady-state pore pressures within model

The apparent under-drainage of the London Clay will increase both the effective stress with depth, which will result in an associated increase in strength and stiffness (relative to an assumption of hydrostatic conditions) in the short term. In the very long term, there is a risk that the under-drainage could cease (following cessation of dewatering activities) and there would be a corresponding global increase in the pore pressures at depth. Theoretically, this would lead to an overall heave of the ground surface. However, it is considered that developments on the scale of St Giles would not be adversely affected, because the structure would effectively translate, without significant differential movements being induced.

With regards to the impact on adjacent assets, it is considered that ground water rise on this scale would have global implications on LU and Crossrail assets regardless of the St Giles development proposals.

4.5 MODELLING SEQUENCE

To enable reasonable runtime for the finite element analyses, the number modeling stages were limited to those points assessed to have the greatest impact on the existing LUL and Crossrail infrastructure. To this end, the modelling sequence was distilled into the following stages:

0. Initialisation of insitu stresses (greenfield)
1. Historic and recent construction works for Northern Line, Ticket Hall, Lower Concourse and Cross passages.
2. β-reduction of 40% to allow for relaxation of soil mass during Crossrail drive.
3. Install Crossrail lining.
4. Consolidation to dissipate excess pore pressures and reset mesh displacements.
5. Advanced works within the NLEB box to replace the existing road slab and construct the LG and BM levels.
6. Completion of bulk excavation to formation level (U/S of heave board, ~EL +109.8 m ATD).
    a. Contiguous piles walls and piles installed.
    b. Ground slab constructed over the top of the NLEB.
    c. Ground slab constructed over basement footprint.
    d. Excavate to B1 slab level. Apply minimum temporary dead loads. (N.B. BM slab installation ignored. BM slab will act to stiffen lateral response of basement secant piles within basement excavation depth. Notwithstanding, these effects will be relatively local to the wall and are unlikely to effect the performance of LUL and Crossrail assets)
    e. Install B1 slabs and CRL slab.
    f. Excavate to B2 formation level.

   g. Install heave board, construct B2 slab and complete construction. Apply minimum permanent dead load.

7. Long term consolidation of soil mass.

Figure 4.7 thru Figure 4.13 illustrate the construction sequence as defined in the 3D model.

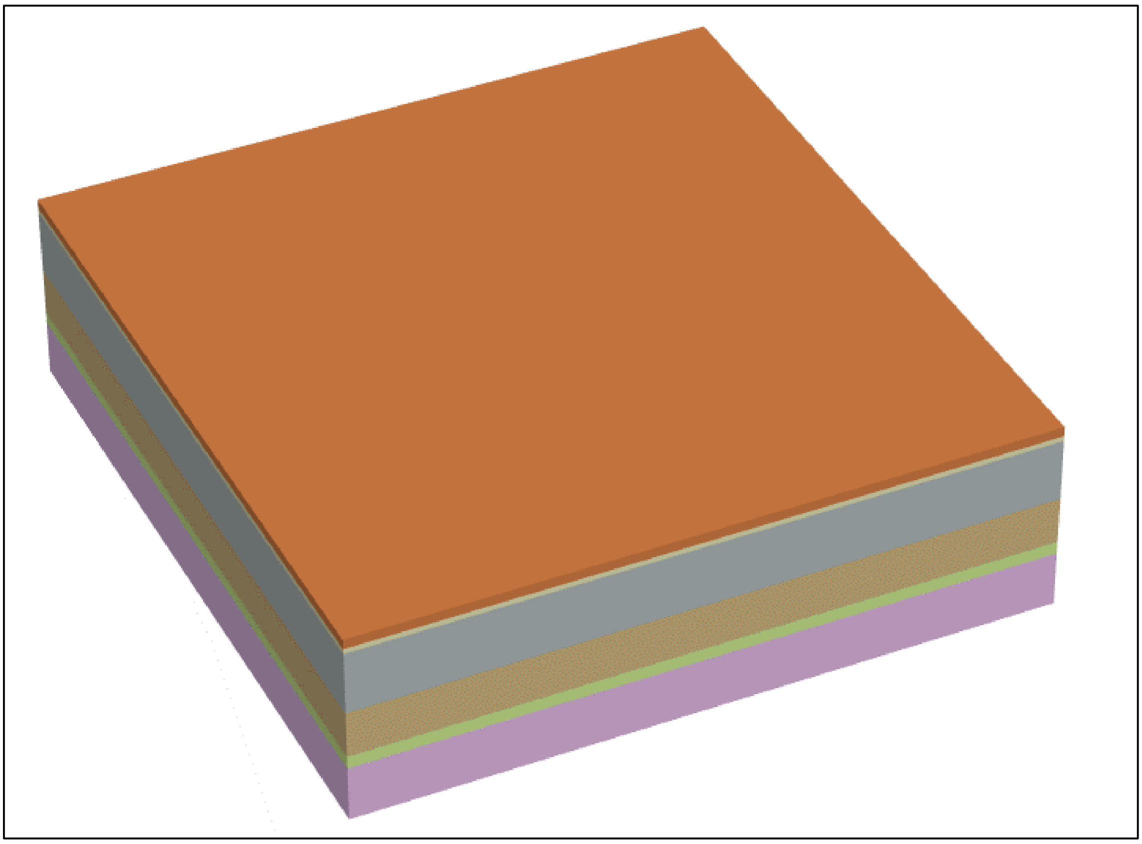

Figure 4.7: Stage 0 – Initialisation of stresses

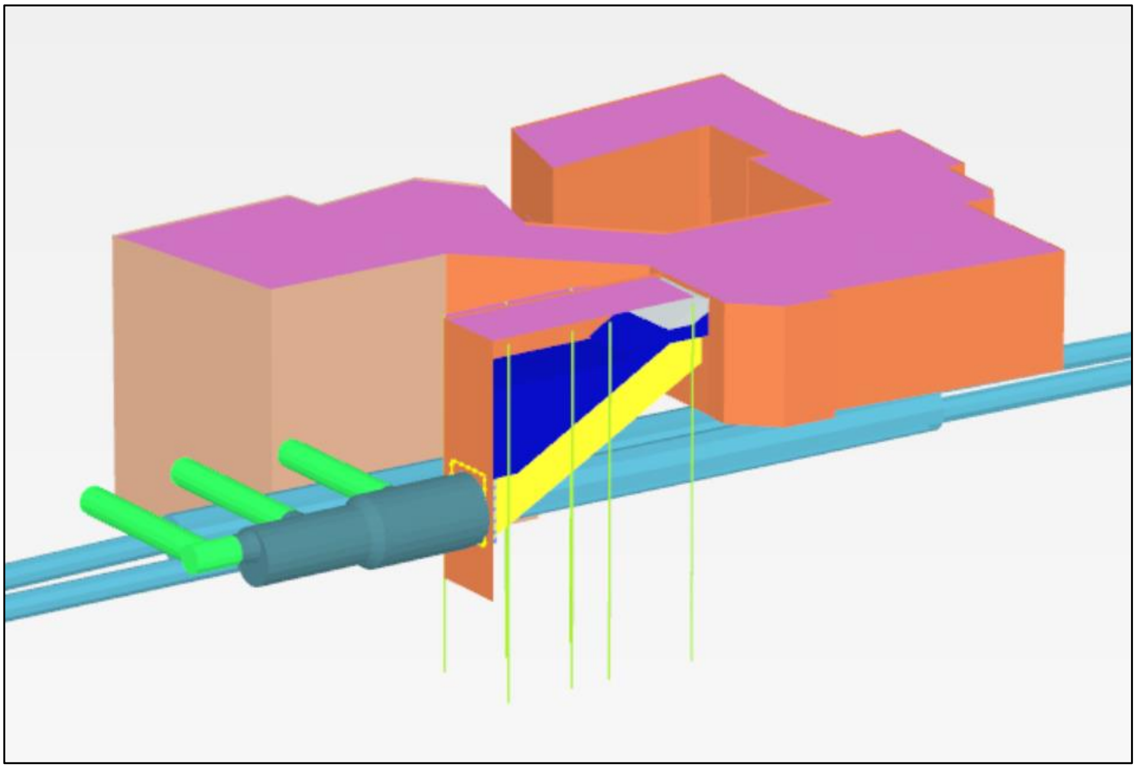

Figure 4.8: Stage 1 - Historic and recent construction (primary infrastructure elements) adjacent to St Giles Circus

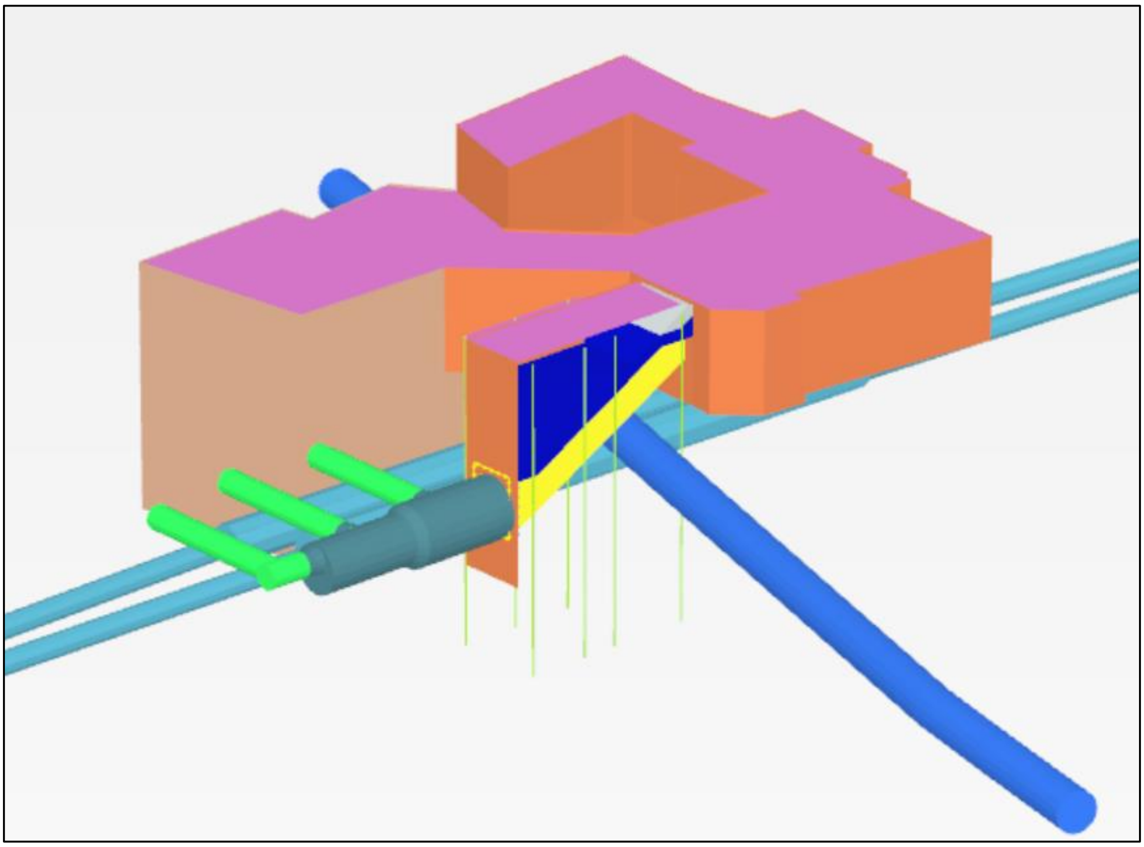

Figure 4.9: Stage 3 – Install Crossrail Lining

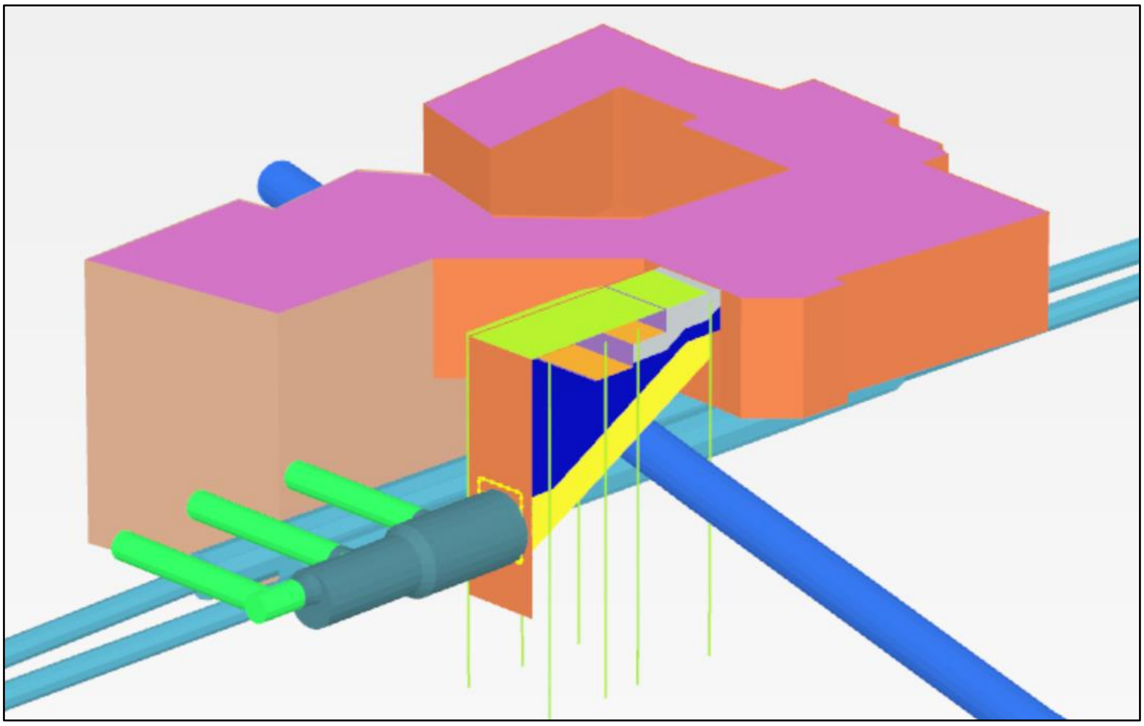

Figure 4.10: Stage 5 – Advanced works within the NLEB

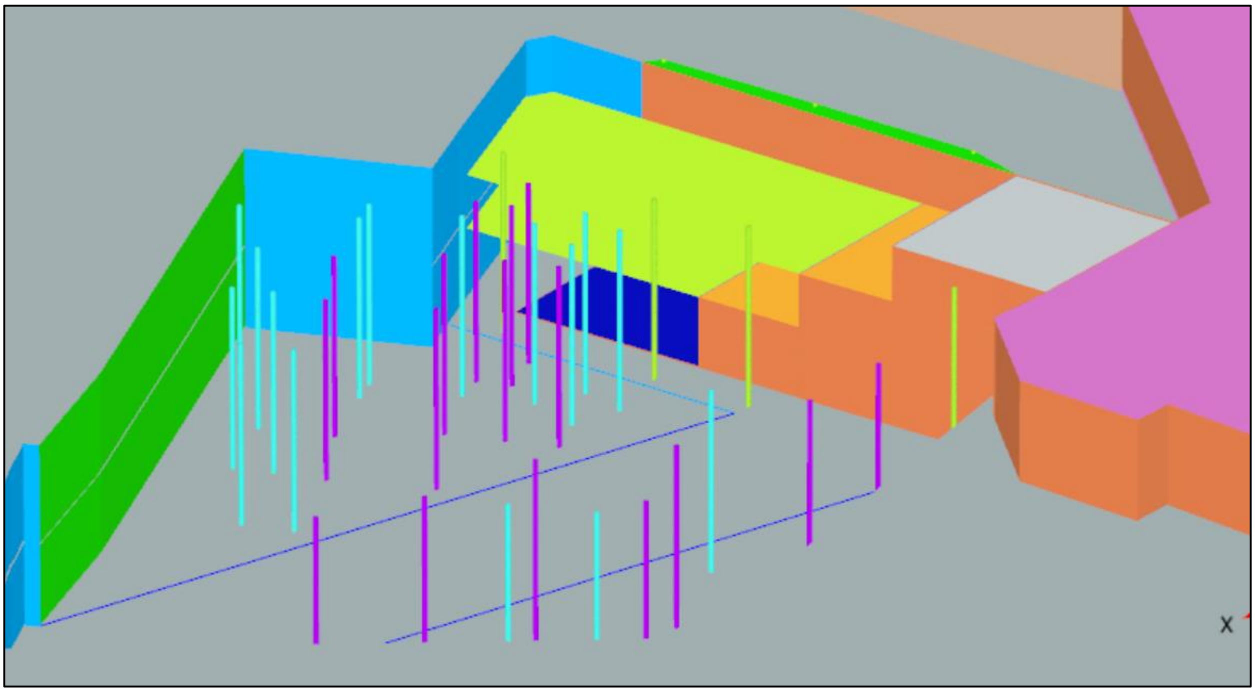

Figure 4.11: Stage 6 – Excavation to B1 level after installation of piles and plunge columns.

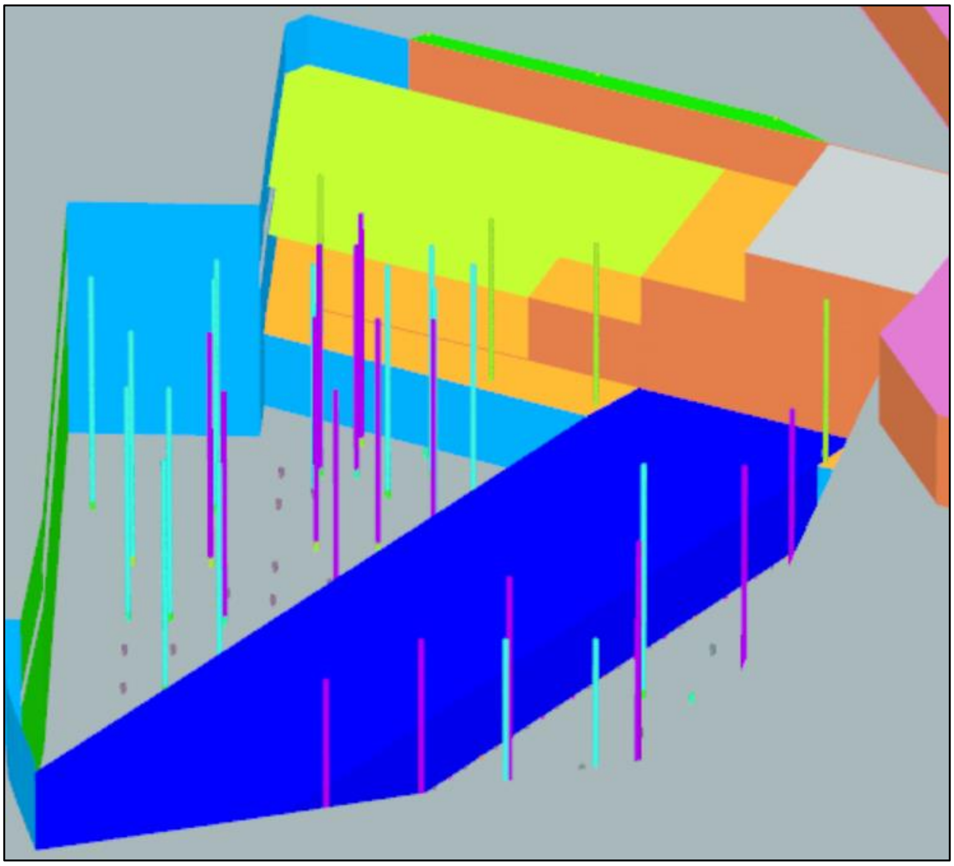

Figure 4.12: Stage 7 – Excavation to B2 formation level (B1 slabs not shown)

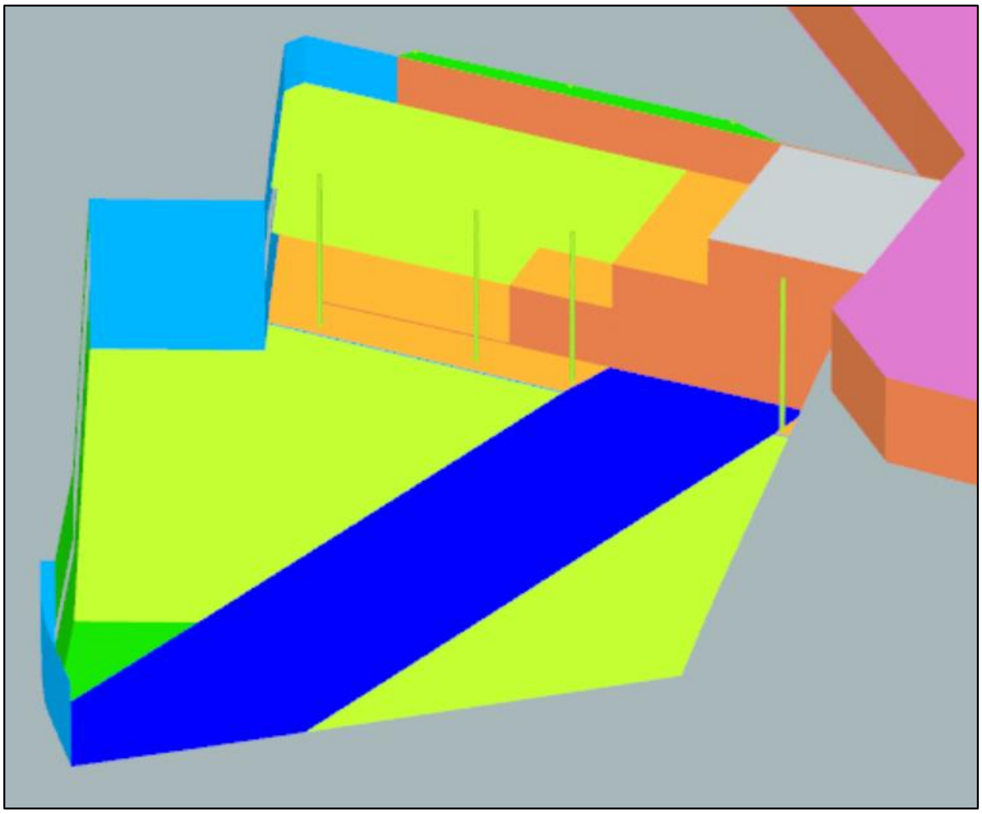

Figure 4.13: Stage8/9 - End of Construction/Long Term

4.6 LIMITATIONS AND KEY ASSUMPTIONS

The following list identifies important simplifications and assumptions that were made during the modelling process:

- Demolition phase is not modelled explicitly.
- Pile installation effects are not modelled.
- Existing transient consolidation conditions.

The existing structures on the site comprise three to five storey masonry buildings (refer to Figure 4.14). The scheme drawings indicate that most buildings include a single-storey basement. The justification to exclude the demolition phase was based on a simplified assessment of the equivalent building surcharge and net unload/load balancing at the basement founding level. It was assessed that the building surcharge would be less than or equivalent to the pressure applied by a mass of soil with a surface elevation commensurate with that of the proposed development. On this basis, the cumulative effect of the demolition phase is included within the modelling as part of the bulk excavation.

Installation effects associated with open-hole boring within the London Clay formation have not been considered. As casing is not proposed to be used within the London Clay, the soil mass will be able to relax surrounding the borehole thus leading to horizontal movements of the soil mass towards the centre of the borehole with an associated reduction in the in-situ horizontal stress. The effect of the stress reduction is considered to be localised to the vicinity of the piles (maybe to a distance of a few diameters from the pile centre). Notwithstanding, the proximity of the bored piles restraining the CRL slab to the Crossrail tunnel could influence the stresses and deformation within the tunnel lining. Additionally, the installation sequence of these piles adjacent to the tunnel (e.g. whether piles are installed simultaneously either side of the tunnel, or if a more complex installation sequence is adopted) may also affect the tunnel lining performance.

It is assessed that the relatively recent completion of the NLEB and associated structures and the Crossrail tunnels will have induced complex stress fields within the surrounding soil mass. In particular, dissipation of excess pore pressures may be on-going. The current model does not capture these transient stress conditions. In order to enable delineation of the effects of the proposed St Giles Development on the LUL and Crossrail elements, the analysis has assumed that excess pore pressures associated with the construction of LUL/Crossrail assets have dissipated.

Additionally, the analysis did not consider partial pore pressure dissipation during construction of the proposed St Giles Circus substructure.

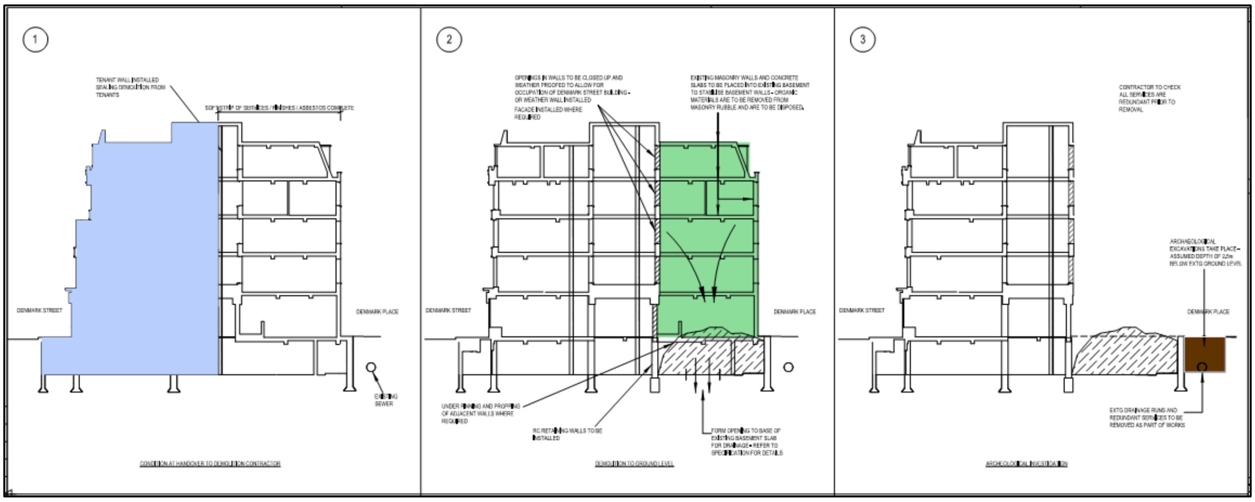

Figure 4.14: Extract of typical demolition procedure proposed for St Giles Circus

5 CATEGORY 3 CHECK DETAILS

5.1 CROSSRAIL ACCEPTANCE CRITERIA

The Crossrail document titled *Crossrail/Third Party Developers Interface* identifies that the following critical items must be shown to stay within tolerable limits:

- The tunnel segments and segment joints do not become overstressed;
- Waterproofing of tunnel segment joints (is unaffected) remains within specified performance criteria;
- Minimum 50mm gauge clearance between the tunnel lining/ (also "structure gauge") and dynamic kinematic envelope of Crossrail trains are not breached;
- Track geometry does not suffer undue movement or distortion, i.e. movements predicted are below the "No Mandated Requirement" thresholds, described for various geometry faults in Appendix A of the Network Rail Standard NR/LR/TRK/001/CO1;
- No adverse impact on track drainage system/s; and
- No adverse impact on Mechanical and Electrical equipment cables, track and internal structures.

In addition to the points listed above, further detail regarding the compliance criteria for Crossrail infrastructure was incorporated based on the *Crossrail Addendum to the Guide for Information Developers – January 2014 v1.65* (refer to Appendix A). This document reflects the criteria outlined above and provides additional criteria on geometric constraints, in particular:

- The minimum predicted curvature induced by ground movements along the axis of the running tunnel in any plane should not reduce below a radius of 10km. This radius is considered the minimum not requiring potential maintenance intervention.
- Predicted ovalisation (diametric distortion) of platform tunnel linings does not exceed more than ±10mm deviation from the theoretical detailed design profile.
- The predicted change in vertical dimension between the top of the rail and the overhead conductor, shall not exceed (+10mm, -2mm).

These criteria have been used to assess compliance of the key Crossrail assets.

5.2 LUL STRUCTURES AND TUNNELS ACCEPTANCE CRITERIA

The acceptance criteria for the LUL structures is summarised as follows:

- NLEB and Lower Concourse Tunnels
  - Deformations to be less than agreed limit, in the order of 5mm.
  - Twist and differential movement to be within agreed limits.

    - Structural capacity not to be exceeded.

- Northern Line Running Tunnels and Platforms:
    - Kinematic profile is not infringed.
    - Tunnel lining structural capacity is not exceeded.

6 CROSSRAIL IMPACT ASSESSMENT SUMMARY

6.1 OUTCOMES OF ANALYSES

Table 6.1 provides a summary of the salient deformation parameters assessed for both the short term and long term conditions for the eastbound Crossrail tunnel.

The results presented herewith are based on the *minimum* temporary and permanent dead loads estimated by the Engineer. This was considered to provide a greater degree of conservatism (relative to the use of the *maximum* temporary and permanent loads), regarding tunnel deformations given that an *unloading* stress path will dominate the soil mass surrounding the Crossrail tunnel.

Output from the analyses for the following items in both *short term* and *long term* conditions are presented thus:

- Figure 6.2 thru Figure 6.5: Deformation, curvature and ovalisation as a function of tunnel chainage (as defined in Figure 6.1)
- Figure 6.6 thru Figure 6.7: Contours of vertical displacement of tunnel crown.
- Figure 6.8 thru Figure 6.9: Deflected shape of tunnel in horizontal plane.
- Figure 6.10 thru Figure 6.13: Typical section illustrating tunnel ovalisation in the horizontal and vertical plane.
- Figure 6.14 thru Figure 6.17: Present east-west and north-south oriented cross-sections through the Crossrail tunnel alignment, which illustrate the deformation patterns of the soil mass in the near vicinity of the tunnel.
- Figure 6.18: Lining capacity assessment

Table 6.1: Crossrail tunnel deformation parameters.

Parameter	**Short Term**				**Long Term**			
	Crown	**Invert**	**North**	**South**	**Crown**	**Invert**	**North**	**South**
Max. Deflection (mm)[1]	20	11	-5	7	9	6	-4	5
Min. Curvature (km)	9.7	30.5	20.0	12.7	20.1	17.4	15.1	15.1
Ovalisation (mm)[2]	12		-12		9		-9	

Notes for Table 6.1:

1. Positive sign indicates heave in the vertical plane or northward translation in the horizontal plane.
2. Positive sign indicates extension along radial lines.

6.2 DISCUSSION

During construction, the tunnel crown is estimated to be subject to a maximum heave of approximately 20mm (refer Figure 6.6). With the application of dead load following completion of construction the heave of the crown is reduced, coming to rest in the long term at approximately 9mm (refer Figure 6.7). The deformation of the tunnel invert is less and is approximately 9mm and 6mm in the *short term* and *long term*, respectively. The heave of the tunnel invert is attenuated by the tension piles parallel to the tunnel alignment, which restrain the overlying *Crossrail slab*. The north-south oriented cross-sections that display the patterns of ground movement surrounding the tunnel (Figure 6.16 and Figure 6.17) demonstrate this effect particularly well. A wedge-shaped zone of soil above the tunnel crown is observed to move relative to the surrounding mass, which is being restrained by the tension piles.

The tunnel alignment appears to undergo an overall northward shift as a result of the excavation, as shown in Figure 6.8 and Figure 6.9.

The minimum estimated radius of curvature of the tunnel lining is 9.7km and occurs at the tunnel crown during *short term* conditions, prior to the end of construction. Following addition of permanent structural dead loads the radius of curvature of the crown increases, reaching a final long term value of approximately 17km after dissipation of excess pore pressures. The minimum radius of curvature of the tunnel invert during construction and in the long term exceeds 10km in both cases. The same is also true for curvature of the tunnel lining in the horizontal plane.

The magnitude of the maximum tunnel ovalisation is equal in both the vertical and horizontal planes. Prior to the end of construction, the maximum ovalisation is 12mm. As indicated by Figure 6.10 thru Figure 6.13 the tunnel undergoes *egging* mode of deformation, with an increase in the length of radial lines within the vertical plane and a corresponding reduction in length in the horizontal plane. The ovalisation of the tunnel reduces following completion of construction and application of dead loads, with a *long term* magnitude of 9mm.

The range of compressive hoop forces and moments within the lining stresses (Figure 6.18) do not change significantly between the *short term* and *long term*. In both cases, the imposed actions on the lining fall within the failure envelope identified by the interaction curve.

Theoretical estimates of the gap that may develop along circumferential joints due to the longitudinal tunnel deformation, indicates that the relative movements of adjacent rings will be less than 1mm in directions parallel-to and perpendicular-to the tunnel axis.

6.3 CONCLUSIONS

With regards to the movement criteria defined for the Crossrail tunnel, the analyses indicate that:

- The structural capacity of the tunnel segments is not exceeded by the effects of actions associated with the proposed development.
- Waterproofing gaskets and dowels are at low risk of exceeding their respective limiting capacities due to the small differential movements imposed on the tunnel by the proposed

development. Furthermore, the estimated incremental relative movements between segments is unlikely to disproportionately exacerbate the existing condition of gaskets and dowels due to construction tolerances.

- The dynamic kinematic envelope allowance of 50mm is not breached by the assessed tunnel deformations. Additionally, the kinematic envelope will improve following completion of construction works and as the soil mass undergoes consolidation. Thus, the worst case deformations estimated in the short term are transitory and likely to have been attenuated by the time Crossrail is in operation.
- The estimated ovalisation is within the allowable tolerance of 1%.
- The minimum curvature of the tunnel occurs at the crown in the *short term* and is slightly less than 10 km. The curvature increases following completion of construction and consolidation. The minimum curvature of the tunnel invert exceeds 10km in both the *short term and long term*. It is assessed that the radius of curvature of the tunnel invert is most suitable to assess the operational performance of the rail line. Accordingly, the imposed effects on the longitudinal profile of Crossrail by the proposed development will be acceptable, and no additional maintenance intervention should be necessary.
- The maximum heave of the tunnel does not exceed the Network Rail 'no mandated action' threshold of 20mm.
- The maximum relative movement between the crown and tunnel invert is estimated at approximately 12mm. This marginally exceeds the specified -2/+10mm limit applied to the Overhead Line Equipment (OLE). The actual impact on Crossrail OLE will depend on the relative timing between the completion of mass excavation at the proposed St Giles development and the installation of the OLE.

With the exception of the tolerances surrounding OLE, the proposed development will not exceed the specified constraints on tunnel movement defined by Crossrail. Some comments regarding the OLE are provided, thus:

- The analysis has taken a conservative approach with regards to adopting lower bound estimates of gravity loads applied during construction and in the permanent condition. The true loads will probably lie somewhere between the minimum and maximum estimated predictions. So it is reasonable to assume that the predicted tunnel deformations should be less than predicted.
- The predicted maximum increase in distance between the crown and invert exceeds the specified upper limit by approximately 2mm. Construction coordination between Crossrail and the Developer may be considered such that, if the OLE is to be installed before mass excavation of the basement is complete the OLE equipment may be installed artificially low (e.g. -2mm from the design level), to provide an allowance for the predicted heave. If the OLE is installed after mass excavation of the proposed basement structure, than existing tolerances may be *built out* during installation of OLE.

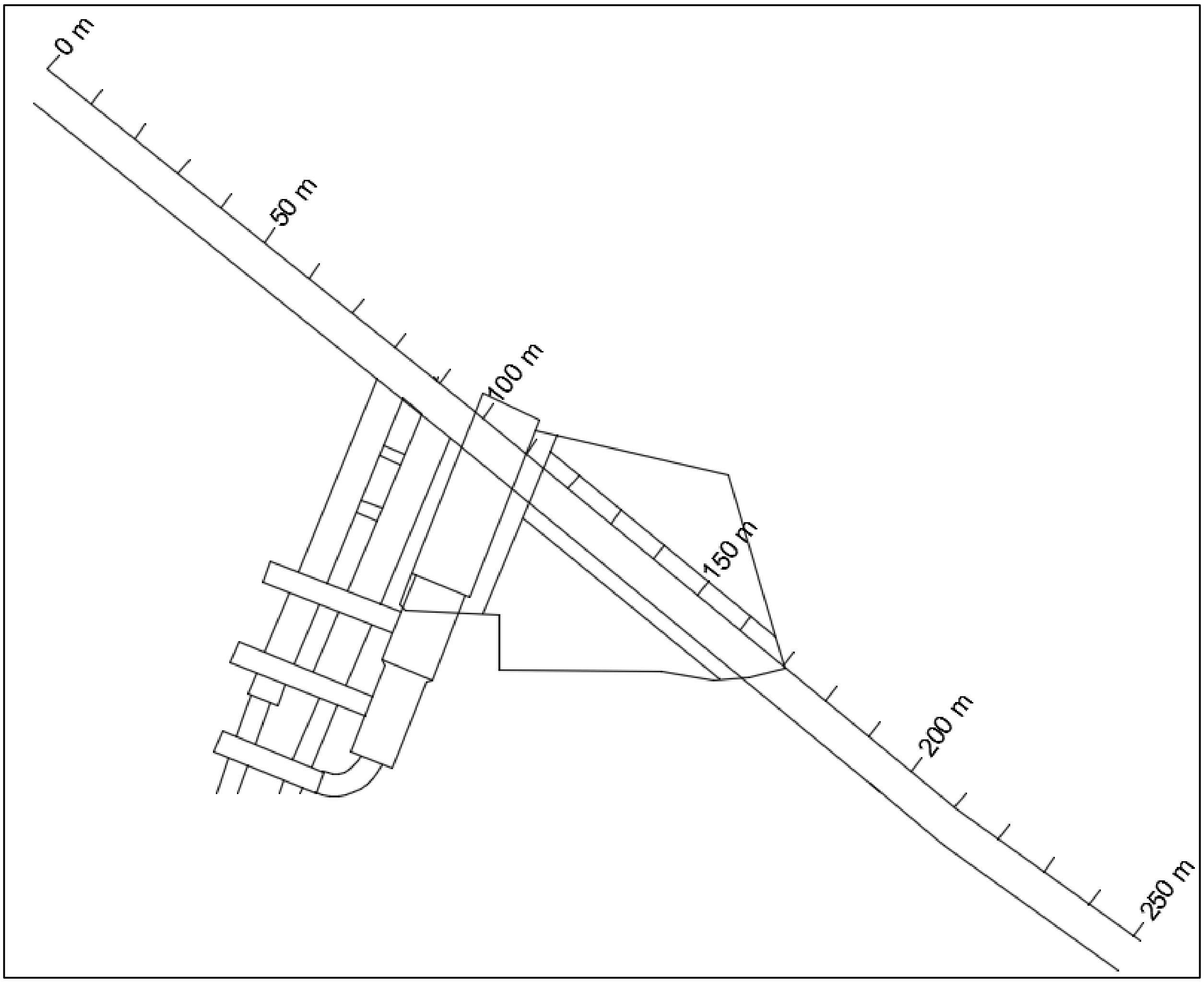

Figure 6.1: Crossrail alignment and reference chainage with respect to the St Giles Circus development footprint

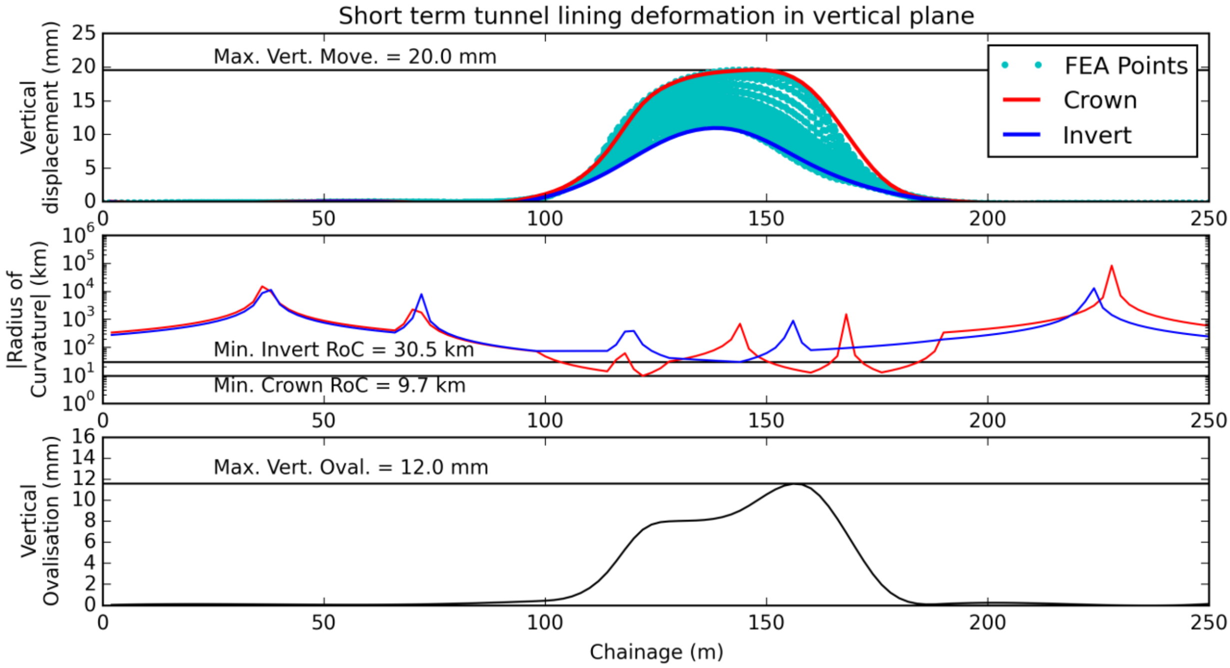

Figure 6.2: ***Short term*** **CRL deformation in vertical plane.**

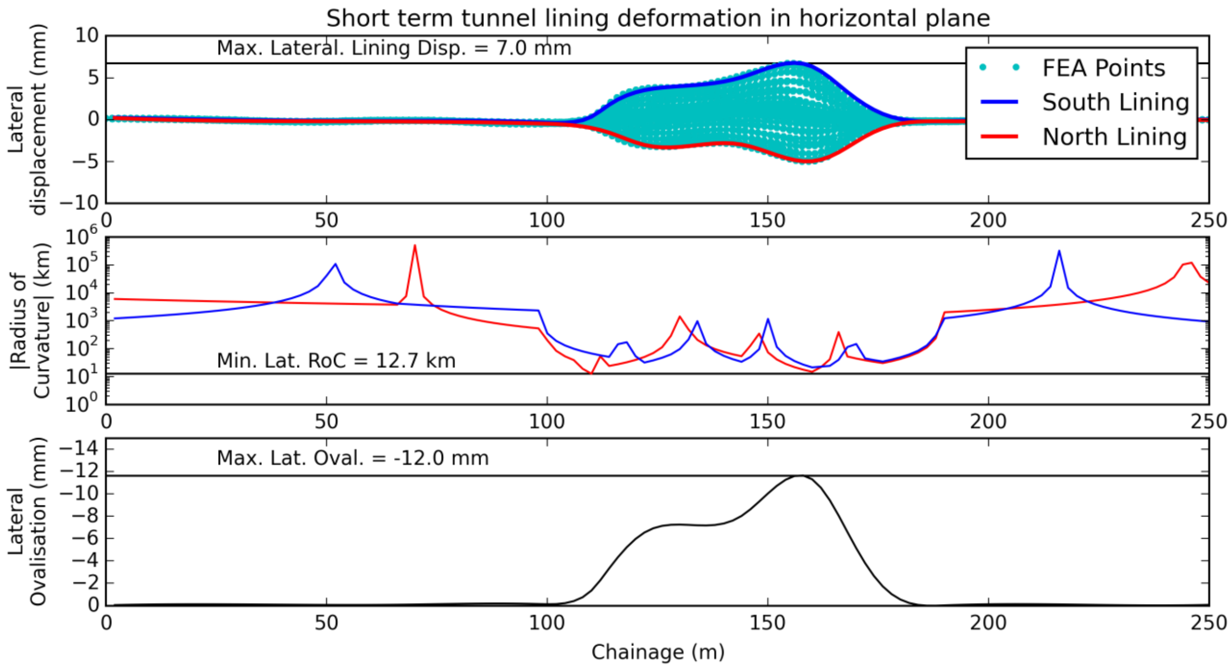

Figure 6.3: ***Short Term*** **CRL deformation in horizontal plane.**

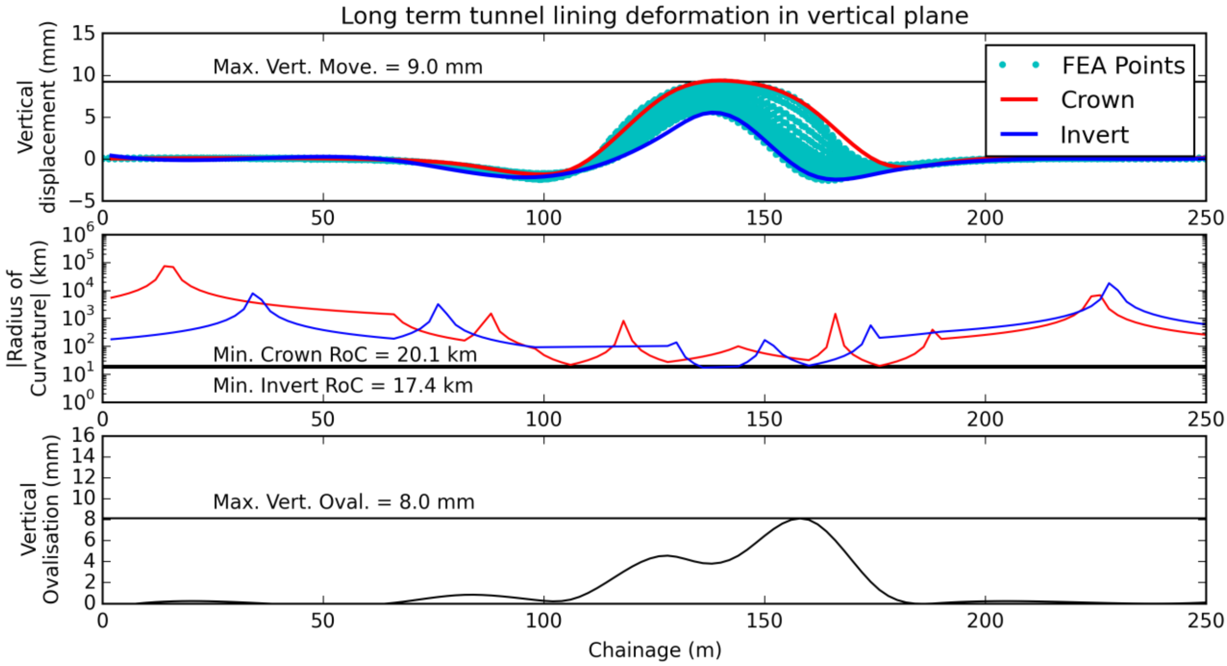

Figure 6.4: ***Long term*** **deformation of CRL in vertical plane.**

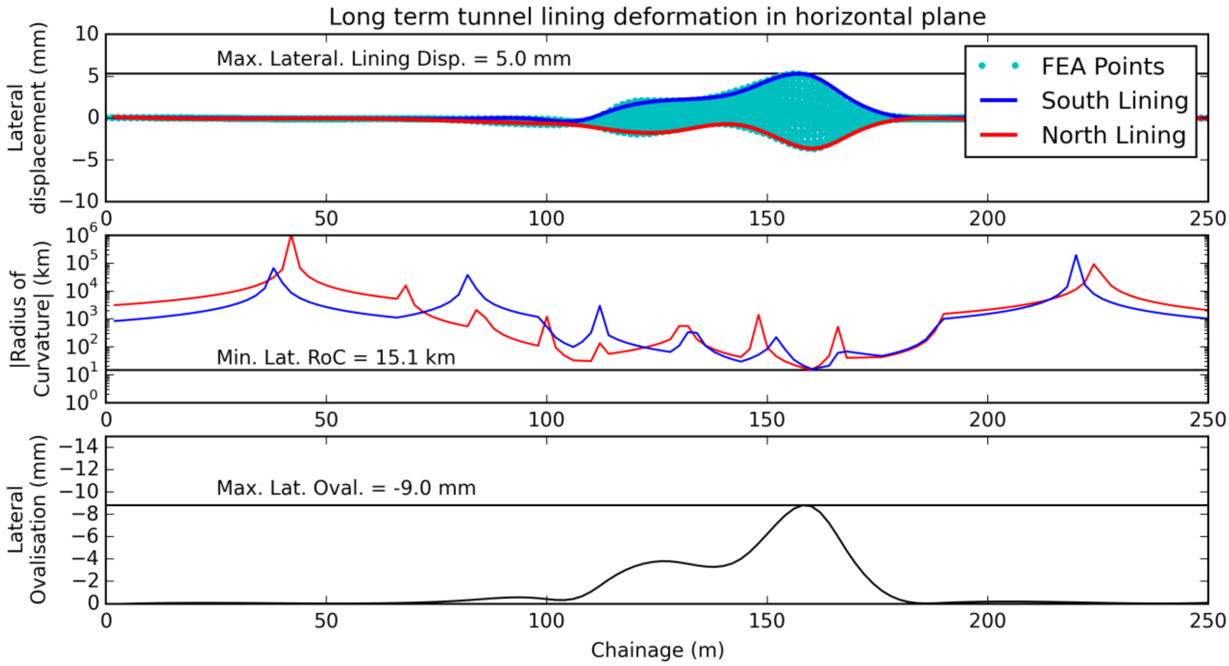

Figure 6.5: ***Long term*** **CRL deformation in horizontal plane.**

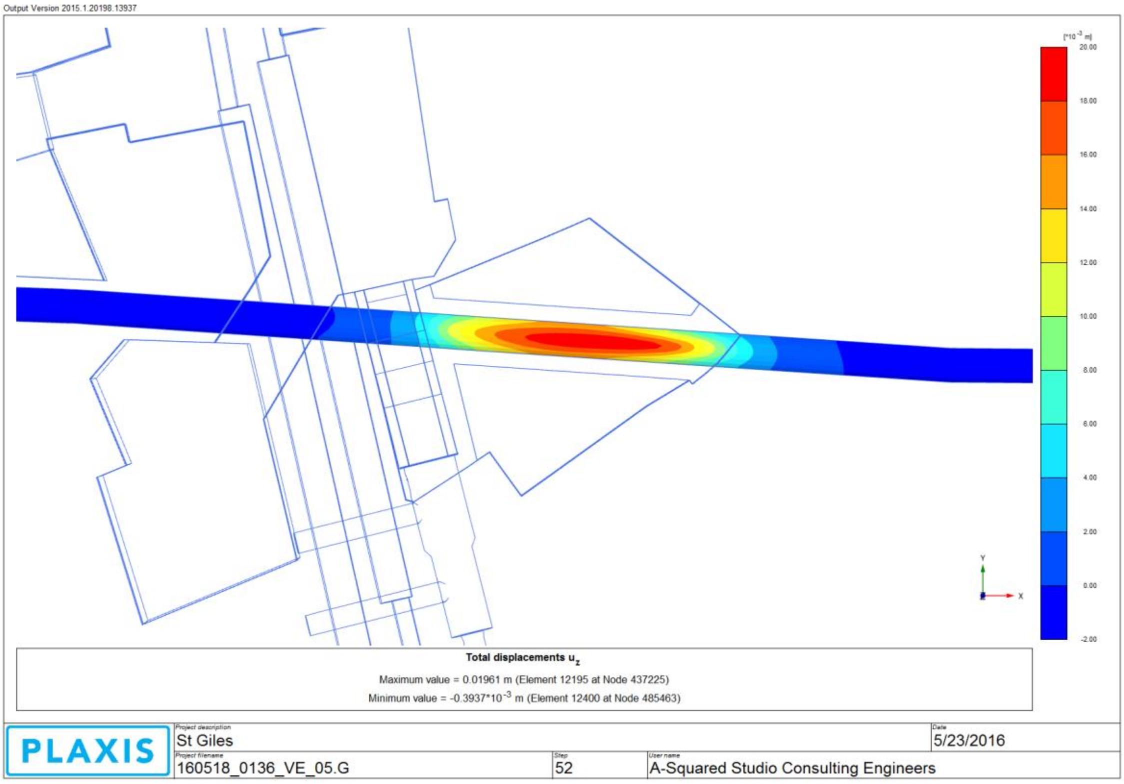

Figure 6.6: *Short term* Crossrail tunnel contours of vertical deformation.

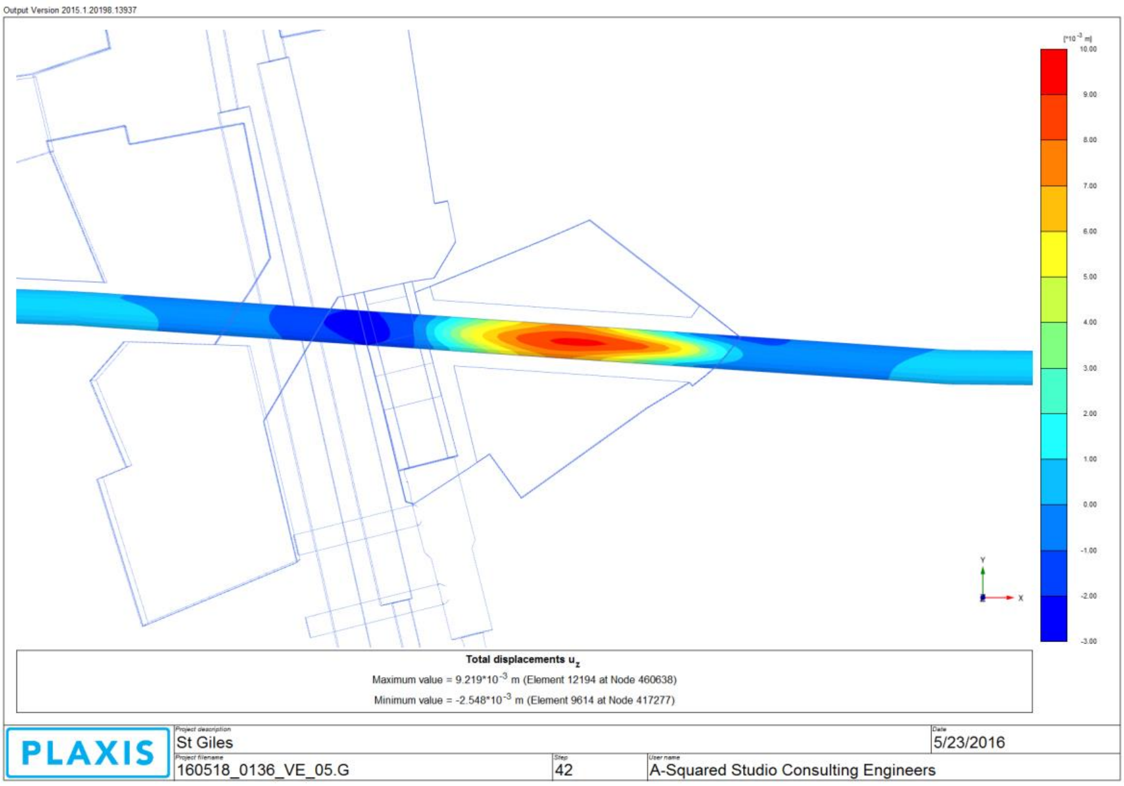

Figure 6.7: *Long term* Crossrail tunnel contours of vertical deformation.

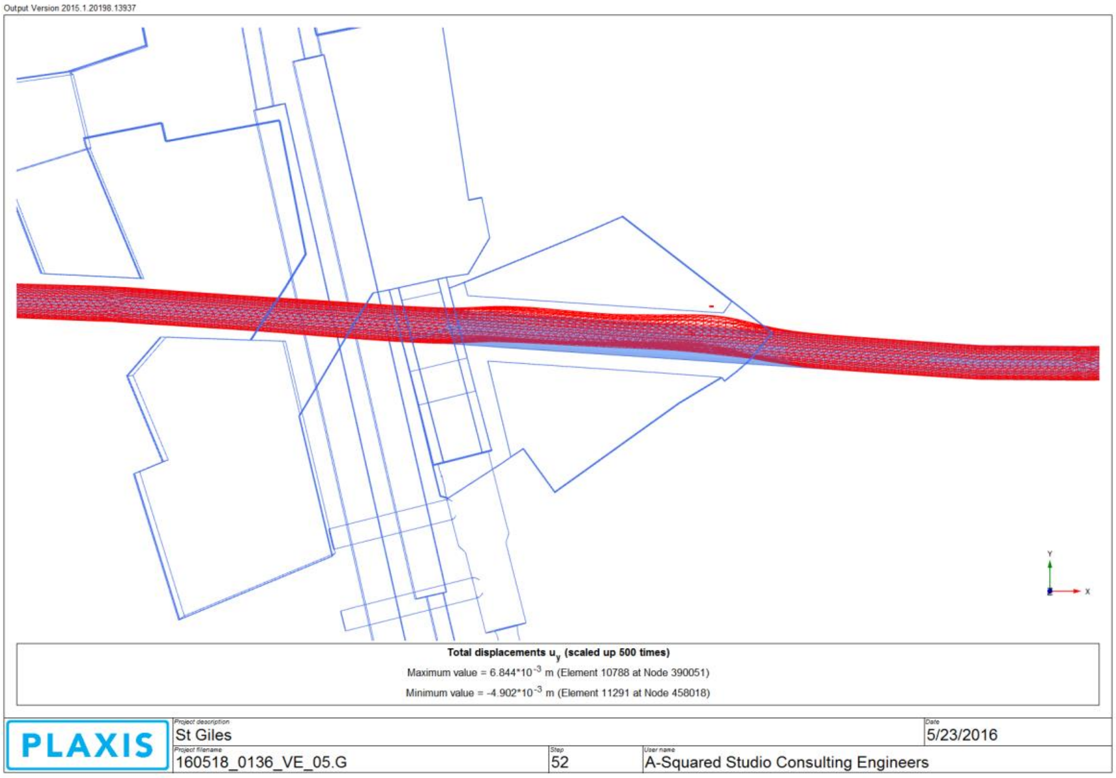

Figure 6.8: ***Short Term*** **Crossrail tunnel deformation in horizontal plane.**

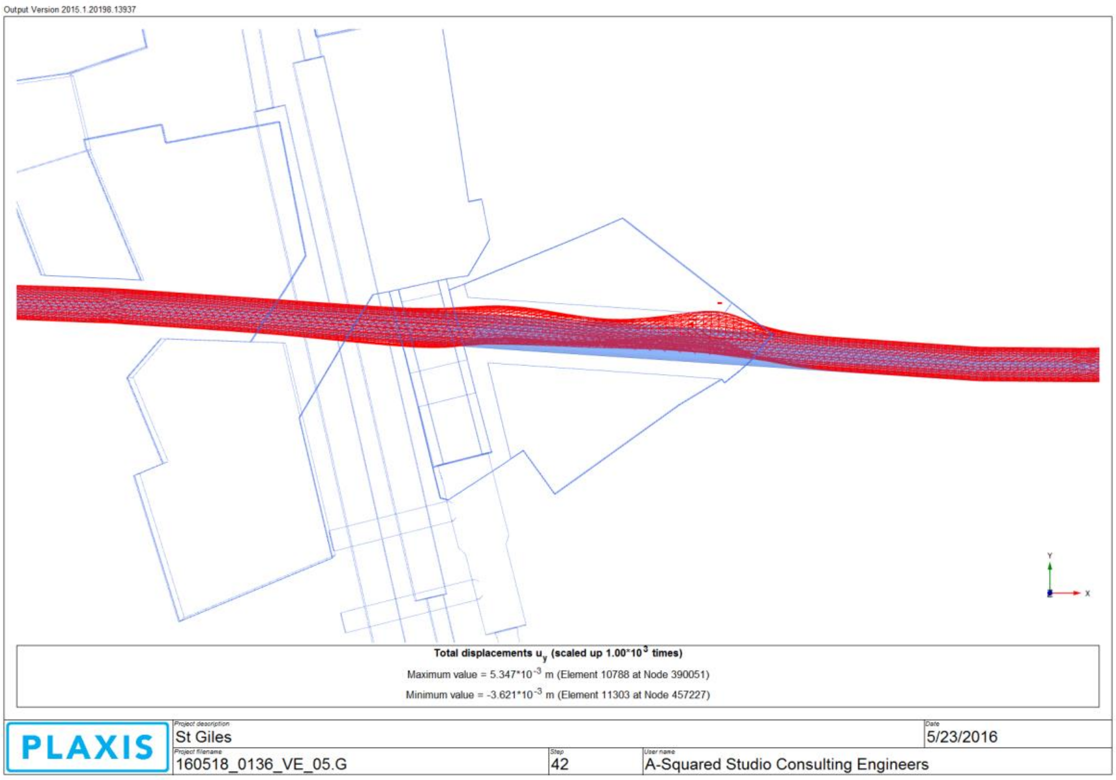

Figure 6.9: ***Long Term*** **Crossrail tunnel deformation in horizontal plane.**

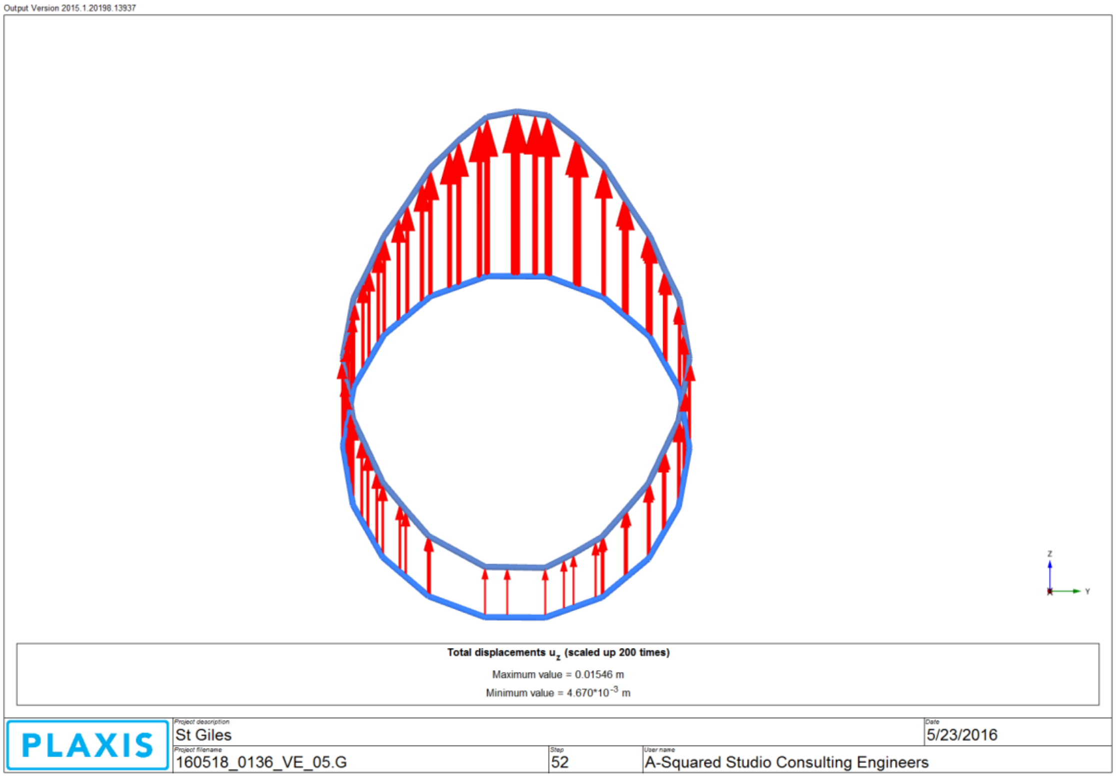

Figure 6.10: *Short term* ovalisation of Crossrail tunnel in vertical plane.

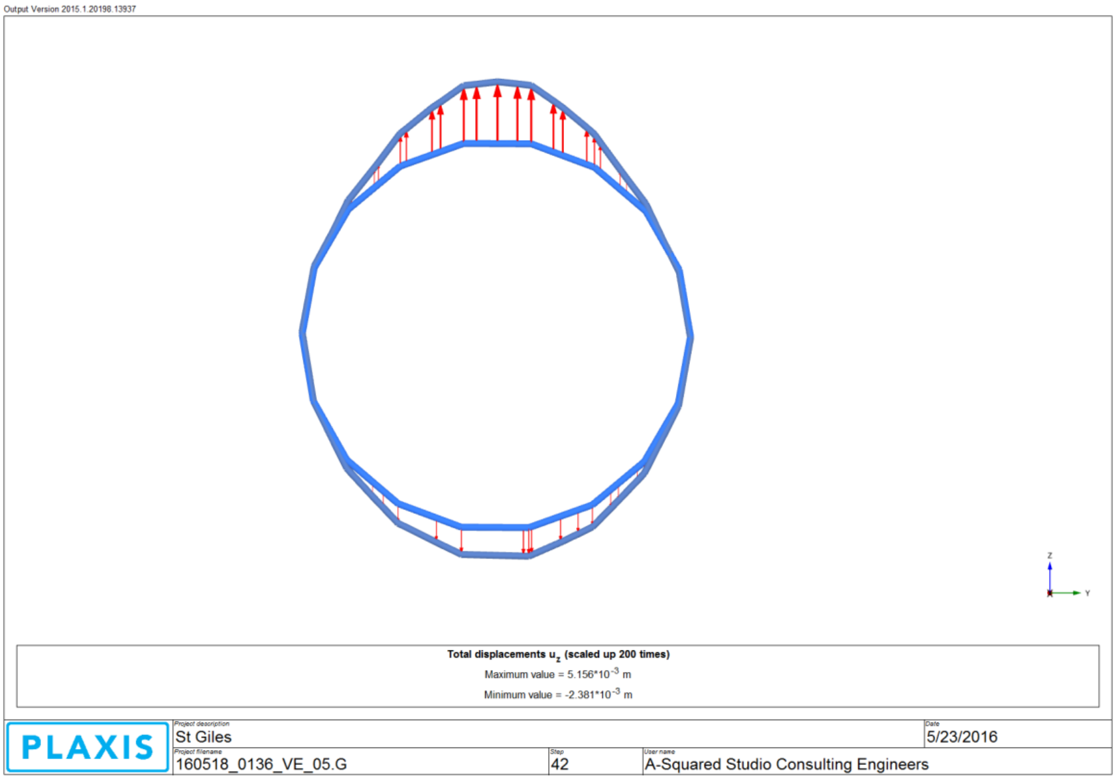

Figure 6.11: *Long term* ovalisation of Crossrail tunnel in vertical plane.

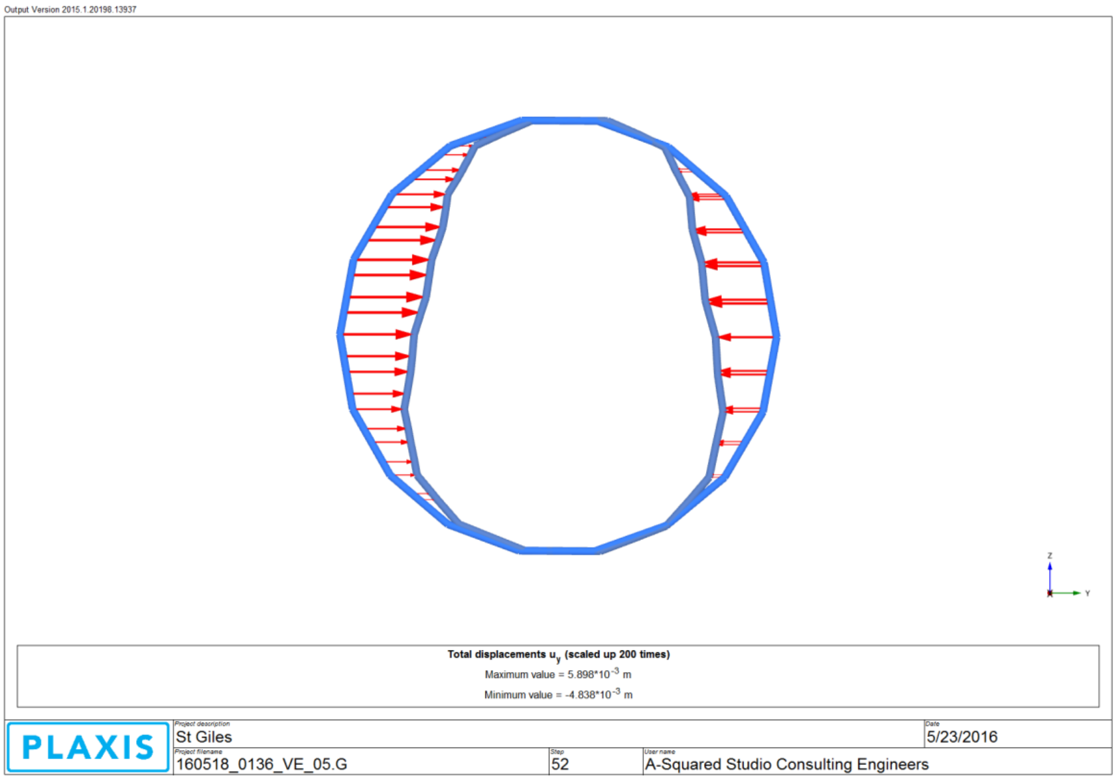

Figure 6.12: *Short term* ovalisation of Crossrail tunnel in horizontal plane.

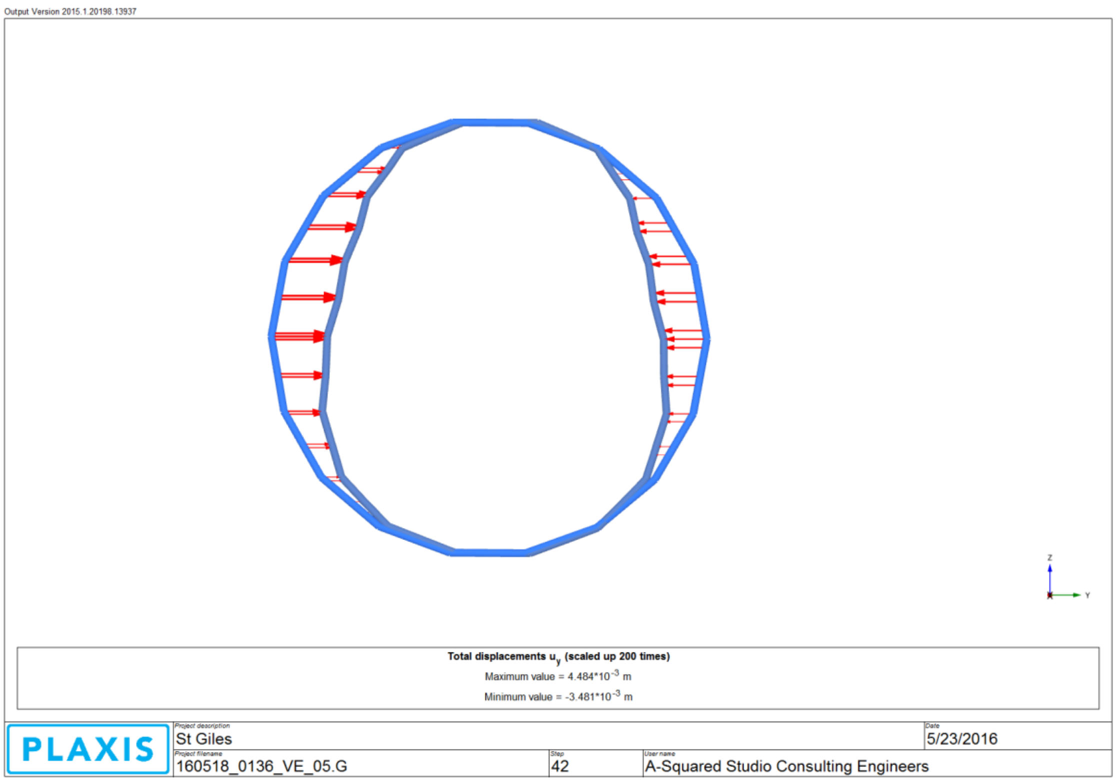

Figure 6.13: *Long term* ovalisation of Crossrail tunnel in horizontal plane.

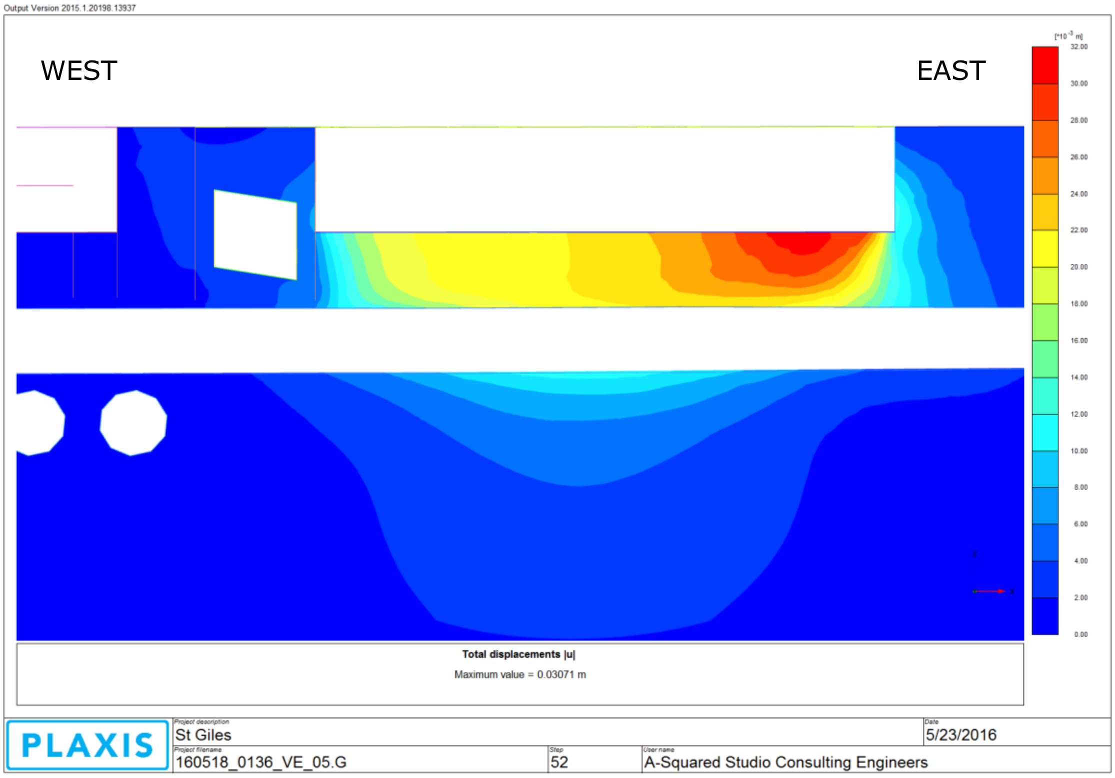

Figure 6.14: ***Short term*** **total deformation of soil mass along E-W section.**

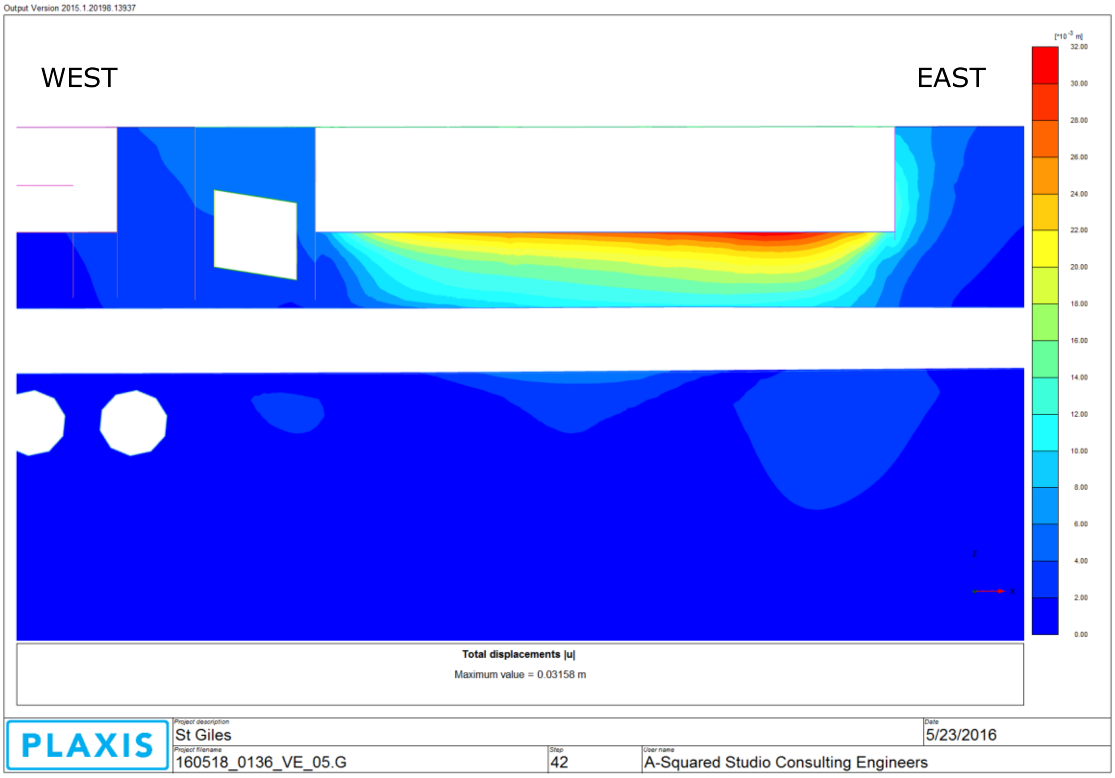

Figure 6.15: ***Long term*** **total deformation of soil mass along E-W section.**

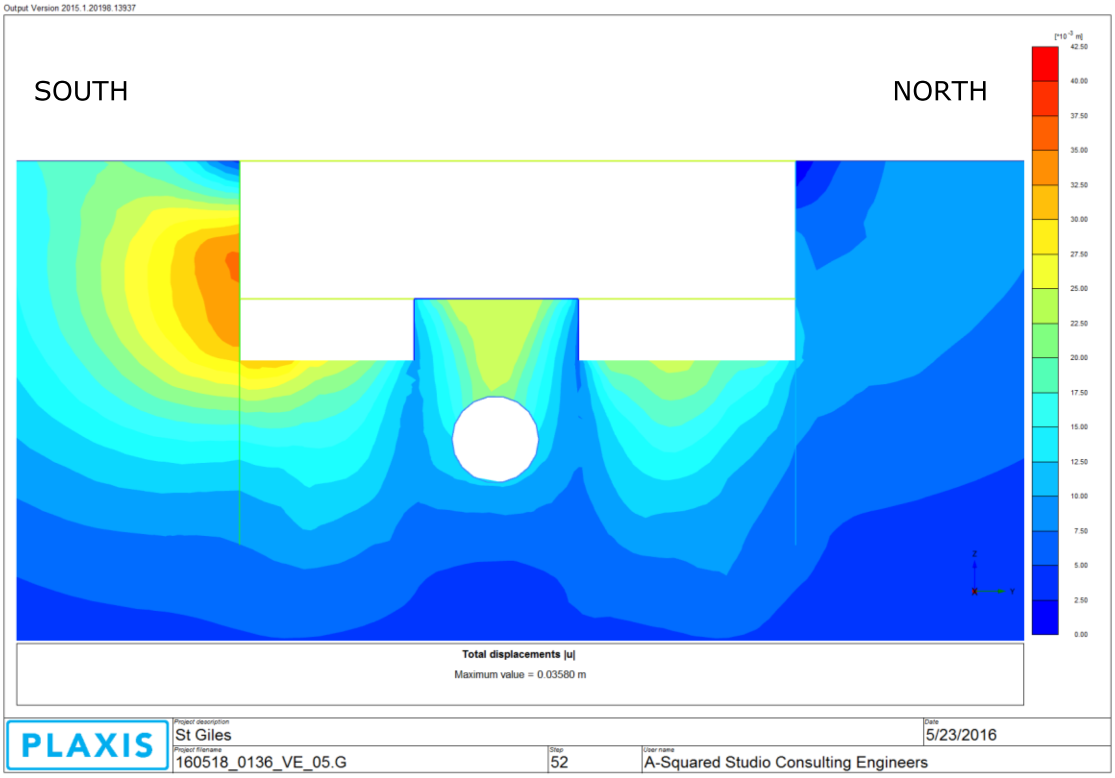

Figure 6.16: ***Short term*** **total deformation of soil mass along N-S section.**

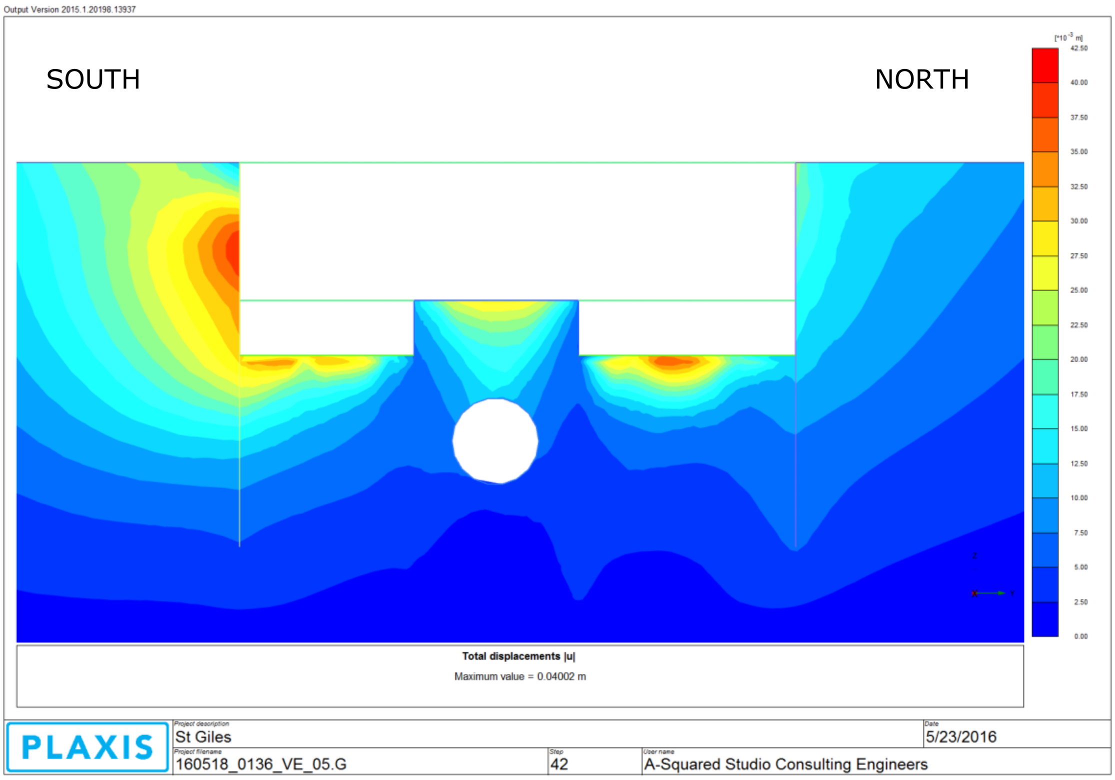

Figure 6.17: ***Long term*** **total deformation of soil mass along N-S section.**

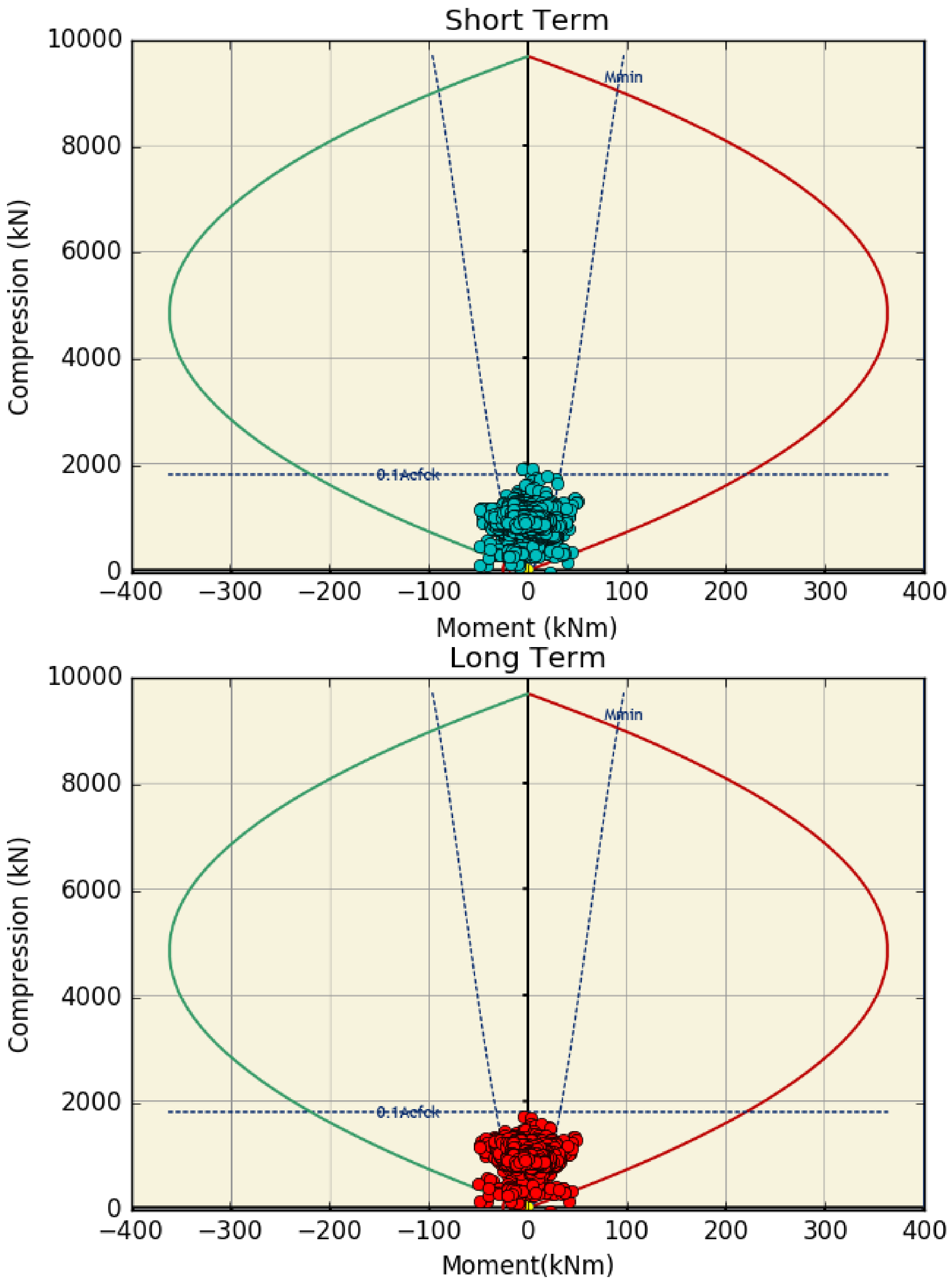

Figure 6.18: Crossrail lining capacity for 300mm thick unreinforced concrete segment

7 LUL IMPACT ASSESSMENT SUMMARY

7.1 NORTHERN LINE RUNNING TUNNELS AND PLATFORM LINING

Table 7.1 provides a summary of the estimated deformations of Northern Line southbound tunnel imposed by the in the *Short Term* up to the end of construction and in the *Long Term* following dissipation of excess pore pressures.

The maximum absolute deformation of the southbound and northbound tunnels was estimated to be less than 3mm. The maximum total deformation occurs towards the southern end of the southbound platform tunnel, adjacent to the Northern Line Escalator Box, following completion of the bulk excavation phase. The running tunnels of both the north and southbound lines are subjected to total deformations of less than 1mm.

Table 7.1: Northern Line Southbound tunnel deformation parameters.

Parameter	Short Term				Long Term			
	Crown	Invert	East	West	Crown	Invert	East	West
Max. Deflection (mm)[1]	< 1	< 1	< -2	< -1	< -1	< -2	< 1	< 0
Min. Curvature (km)	294	125	118	118	485	219	380	380
Ovalisation (mm)[2]	< 1		> -1		< 1		> -1	

Notes for Table 7.1:

1. Positive sign indicates heave in the vertical plane or westward movement in the horizontal plane.
2. Positive sign indicates an increase in the length of radial lines in the plane.

Plots of the estimated deformation, curvature and ovalisation of the Northern Line southbound running tunnel and platform for this stage are presented in Figure 7.1 thru Figure 7.6.

The minimum radius of curvature of the tunnel is estimated to be in excess of 100km.

The maximum ovalisation of the tunnel was estimated to be less than 1mm for all stages modelled. Table 7.2 summarises the existing estimated ovalisation (measured as a percentage of diameter) of the northbound and southbound platform tunnels and running tunnels, based on survey information available from earlier works (refer Doc No. HAG-N105-8742-CIV-X-REP-X-00256-02). Also shown in the table are the predicted additional ovalisations due to works associated with the construction of the NLEB.

The residual capacity of the Northern Line platform and running tunnels was determined as part of the TCR upgrade design works. The residual capacity of the platform and running tunnels, estimated to be equal to a maximum radial distortion at the crown, were 1.2% and 0.35%, respectively. Thus, the residual capacity of the platform and running tunnels is not exceeded, due to the proposed development.

Based on the relatively small estimated deformation of the Northern Line southbound tunnel, it is assessed by inspection that the running and platform tunnels will not be adversely affected by the proposed St Giles Circus development. It is noted that the northbound Northern Line tunnel is located at a greater distance from the proposed development than the southbound tunnel, hence it is considered by inspection that the northbound running and platform tunnels are unlikely to be noticeably affected by the scheme.

Table 7.2: Northern line ovalisation summary

Type	Direction	Diameter (m)	Ave. Measured Ovalisation (%)[1,2]	Predicted Ovalisation from NLEB works (%)[1]	Ovalisation due to St Giles Development (%)	Cumulative Ovalisation (%)[3]
Platform Tunnel	Northbound	7.2	+0.4	+0.2 to -0.4	< +0.05	+0.65
	Southbound		+0.4	+0.2 to -0.4	< +0.05	+0.65
Running Tunnel	Northbound	5.9	-0.3 to -0.6	+0.1 to -0.2	< +0.05	-0.15
	Southbound		-0.3 to -0.7	+0.1 to -0.2	< +0.05	-0.15

Notes on Table 7.2:

1. Values taken from Halcrow design report for Tottenham Court Road extensions (refer Doc No. HAG-N105-8742-CIV-X-REP-X-00256-02)
2. Positive sign ovalisation indicates extension of radial lines in the vertical plane. Negative indicates *squatting.*
3. Cumulative value takes *worst case* combination of measured and predicted ovalisations.

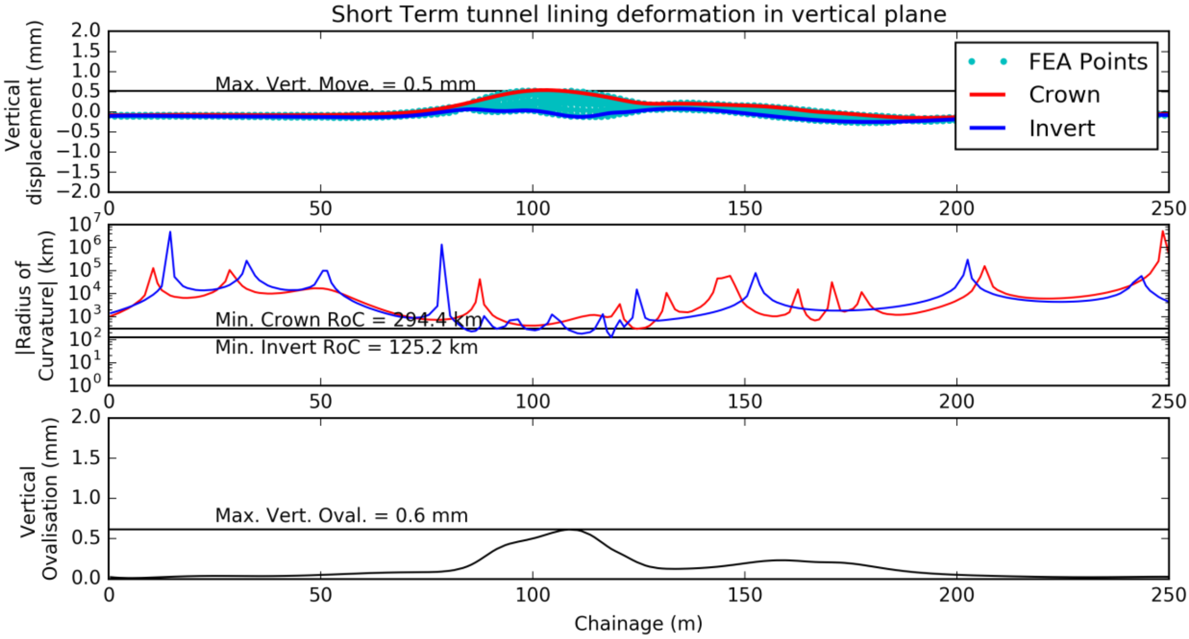

Figure 7.1: *Short term* displacement of Southbound Northern Line in vertical plane

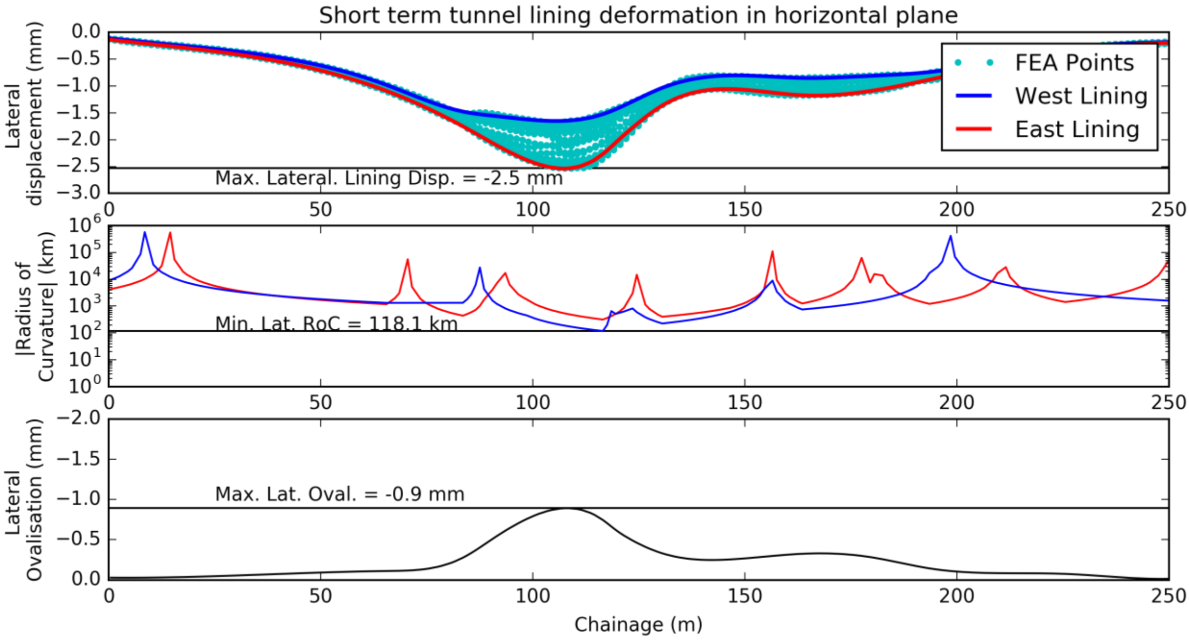

Figure 7.2: *Short term* displacement of Southbound Northern Line in horizontal plane

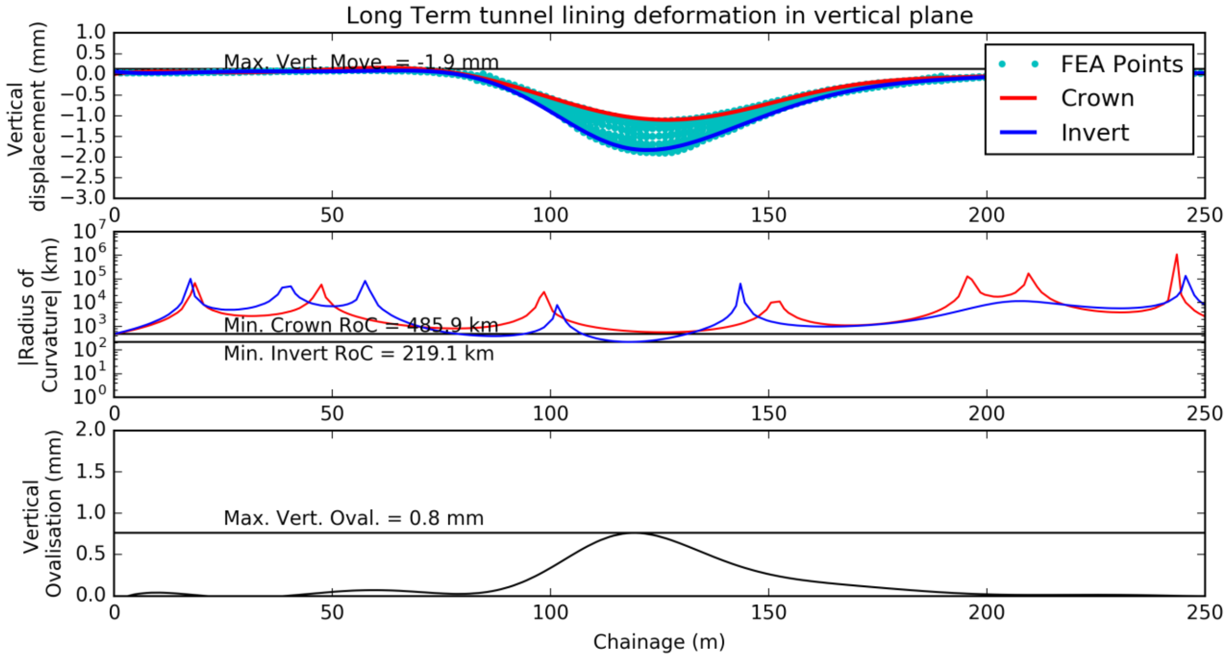

Figure 7.3: ***Long term*** **displacement of Southbound Northern Line in vertical plane.**

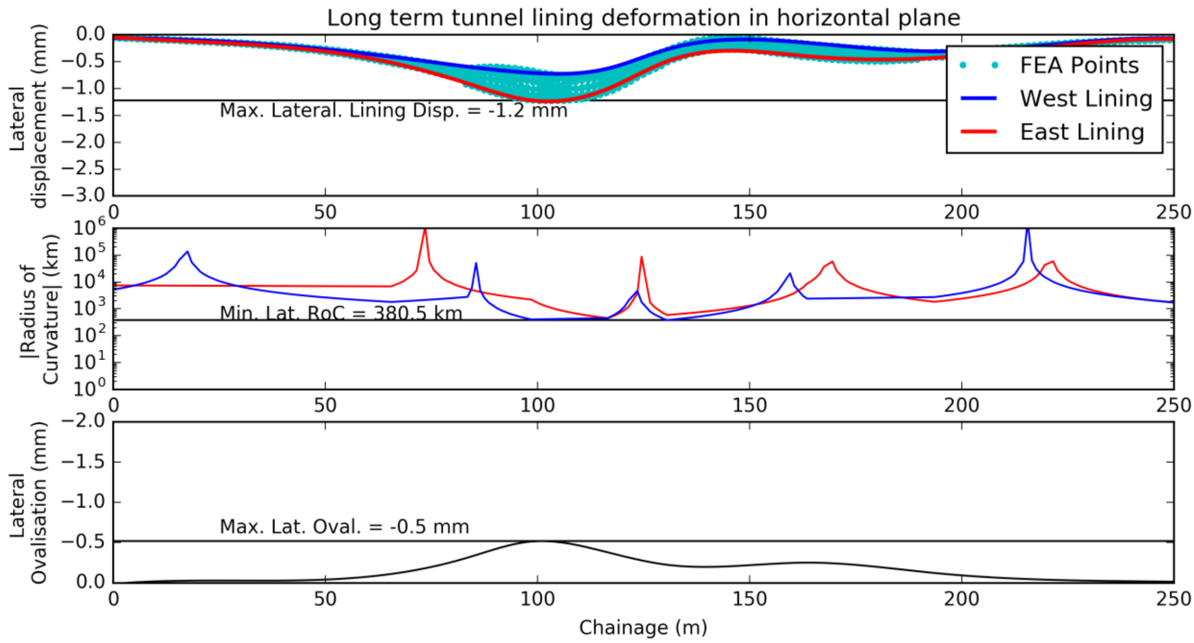

Figure 7.4: ***Long term*** **displacement of Southbound Northern Line in horizontal plane**

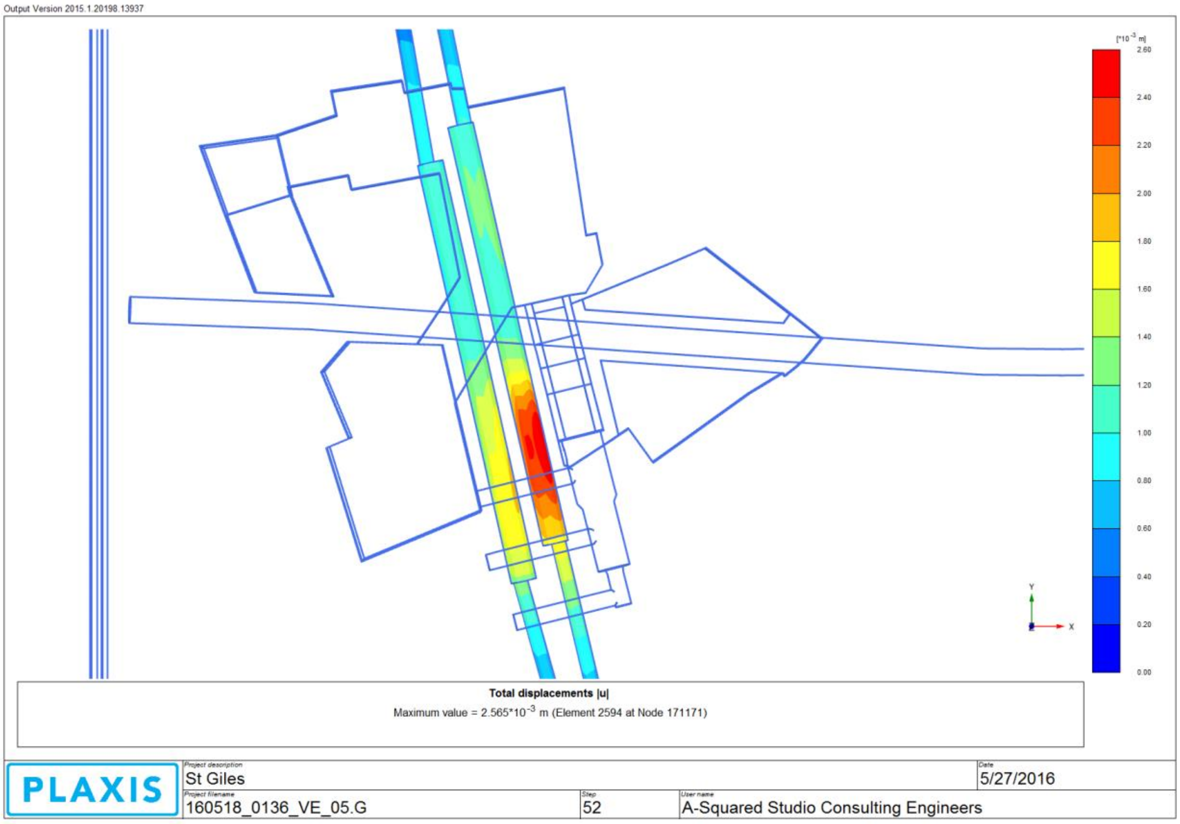

Figure 7.5: ***Short term*** **contours of total displacement of Northern Line tunnels**

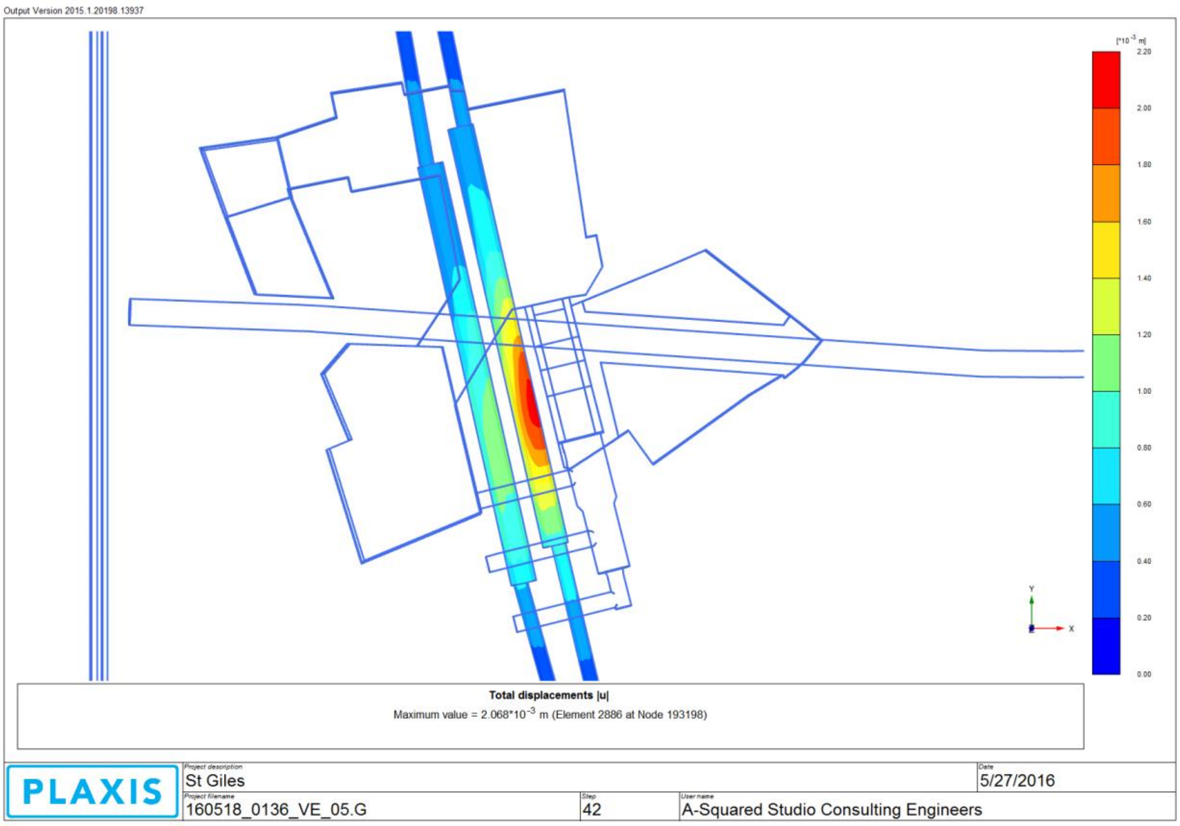

Figure 7.6: ***Short term*** **contours of total displacement of Northern Line tunnels**

7.2 NORTHERN LINE ESCALATOR BOX (NLEB)

7.2.1 DEFORMATIONS

Table 7.3 summarises the maximum displacements estimated for the Northern Line Escalator Box. A maximum total deflection of 6mm for the top slab and 5mm for the base slab, was evaluated following completion of mass excavation to the formation level. At this stage, the maximum vertical and lateral deflections are 3mm and 6mm respectively. Figure 7.7 presents a coloured contour plot showing the total deflection of the NLEB. Figure 7.8 presents a 500x scaled deformed mesh of NLEB that show also shows the overall pattern of total deformation in the *short term*.

The horizontal deflection of the NLEB box after excavation to the formation level is towards the St Giles excavation. Due to the *cantilever-like* end restraints applied to the NLEB (i.e. *fixed* at the junction to Tottenham Court Road station and *free* adjacent to the Lower Concourse Tunnel), the maximum deformation occurs towards to the lower third of the box, adjacent to the Lower Concourse tunnel. The vertical heave of the box is attenuated by the early works construction of the Lower Ground and Mezzanine floors over the NLEB, prior to carrying out mass excavation.

Figure 7.9 presents the *short term* vertical deflections of the NLEB base slab that supports the escalators. It is noted that the slab is subject to an overall tilt, with the eastern edge of the slab adjacent to the excavation heaving relative to the western edge. The heave being associated with the elastic rebound due to unloading of the ground mass following excavation. In the *long term* (Figure 7.10), box undergoes settlement associated with dissipation of excess pore pressure and application of structural dead loads and the overall tilt of the base slab is reduced.

The deformation of the soil mass along the longitudinal axis of the NLEB in the *short term* and *long term* is shown in Figure 7.11 and Figure 7.12, respectively.

It is considered that the performance of the base slab is most critical to ensuring satisfactory operation of the escalators within the NLEB. Table 7.4 summarises the longitudinal and transverse tilt, assessed at the cross-sections shown in Figure 7.13, for both short term (construction) and long term scenarios.

The agreed amber trigger levels for the NLEB are:

- Total deformation of NLEB: 10mm
- Differential vertical movement of base slab: 5mm
- Tilt of base slab about long axis: 2.5mm/m (1 in 400).
- Relative horizontal movement of truss: 3mm

It is assessed that the deformation of the NLEB box and base slab will not exceed the identified amber trigger levels.

Table 7.3: Maximum deformations of NLEB structure[1]

Element	Max Total (mm)	Max Vertical (mm)(2)	Max Horizontal (mm)(3)
Top Slab	6	3	6
Base Slab	5	3	4
East Wall	6	3	6
West Wall	6	1	6

Notes for Table 7.3:

(1) Estimated deformations rounded to the nearest millimetre.

(2) Positive vertical deformations indicate upwards movement.

(3) Positive horizontal deformations are towards the St Giles development.

Table 7.4: Max. longitudinal and transverse tilt of NLEB base slab

Stage	Longitudinal Tilt (V:L)(1)	Transverse Tilt (about long axis) (V:H)		
	Cross section A	Cross Section 1	Cross Section 2	Cross Section 3
Short Term	1:39,700	1:5,000	1:20,000	1:6,600
Long Term	-1:29,000	-1:64,700	-1:17,600	-1:20,300

Notes on Table 7.4:

(1) V:L relates to (V)ertical displacement to (L)ength measured along longitudinal axis of NLEB base slab.

(2) (+ve) slope indicates relative heave of slab.

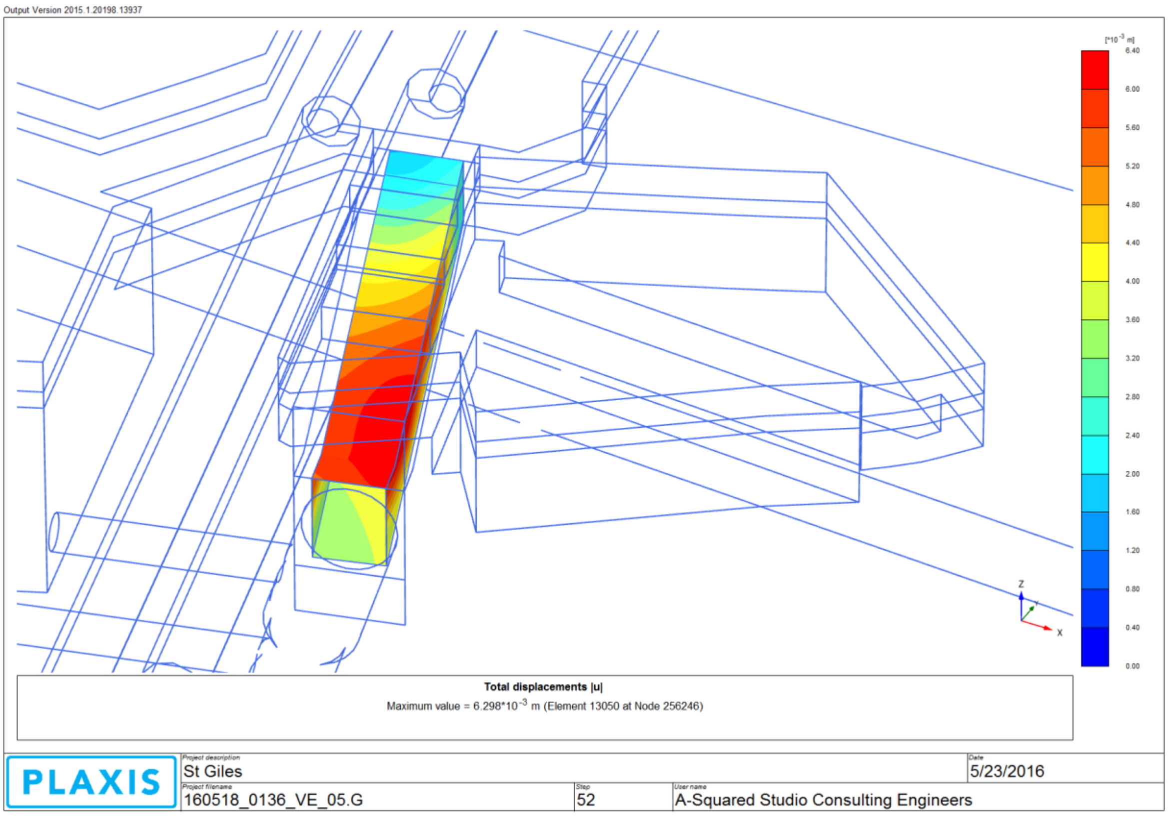

Figure 7.7: Total deformation of NLEB following excavation to formation level

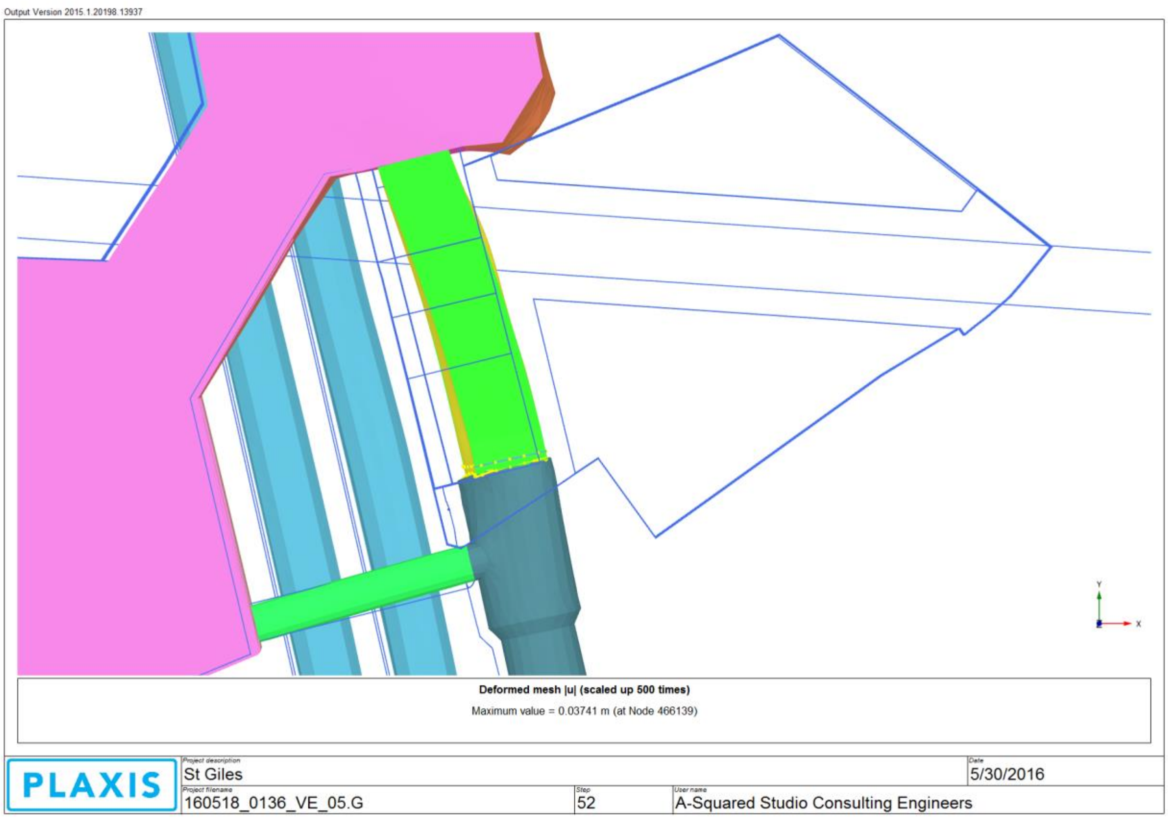

Figure 7.8: 500x magnification of total deformation of NLEB towards excavation

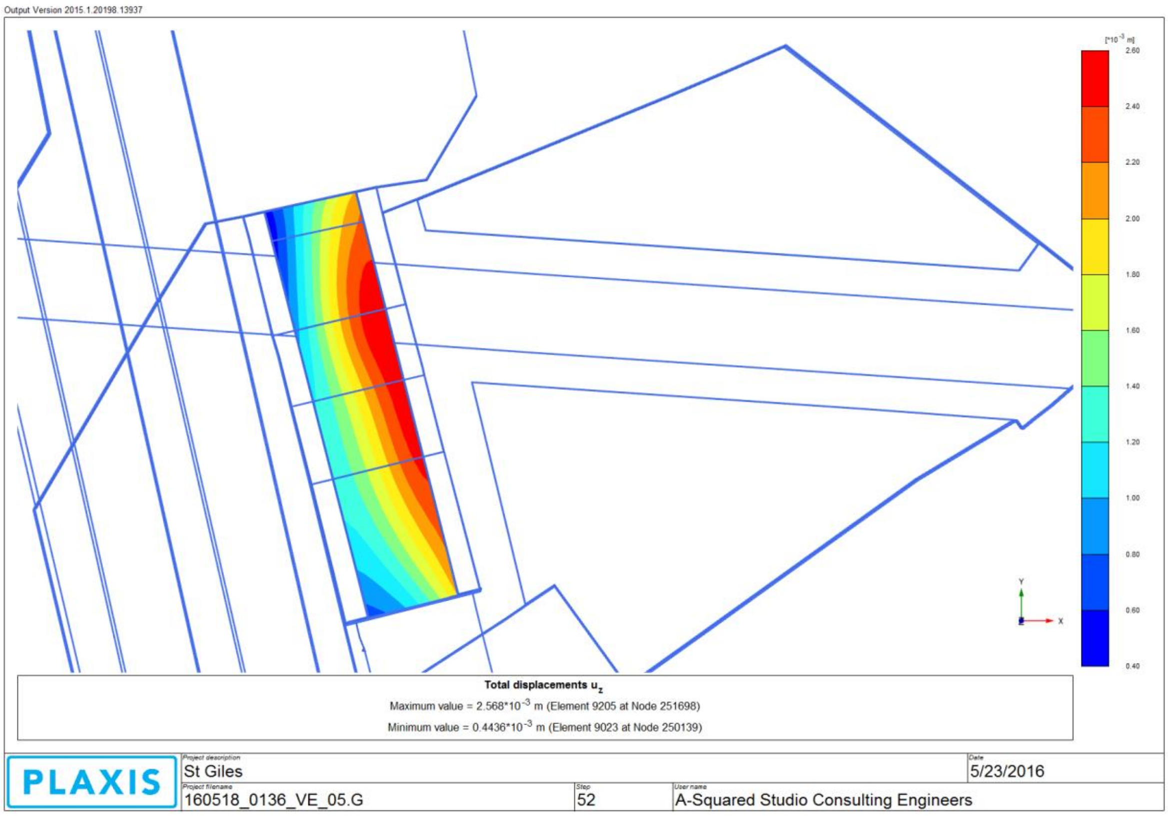

Figure 7.9: ***Short term*** **vertical displacement of NLEB base slab**

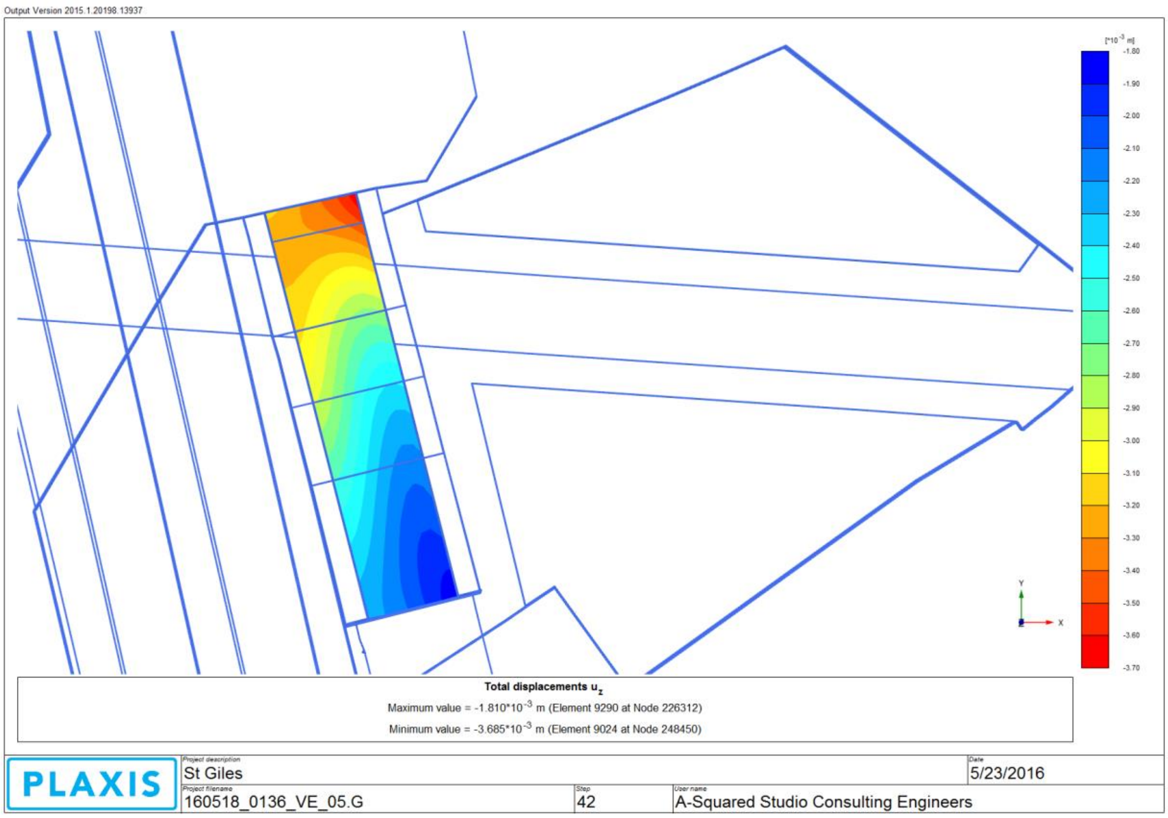

Figure 7.10: ***Long term*** **vertical deflection of NLEB base slab.**

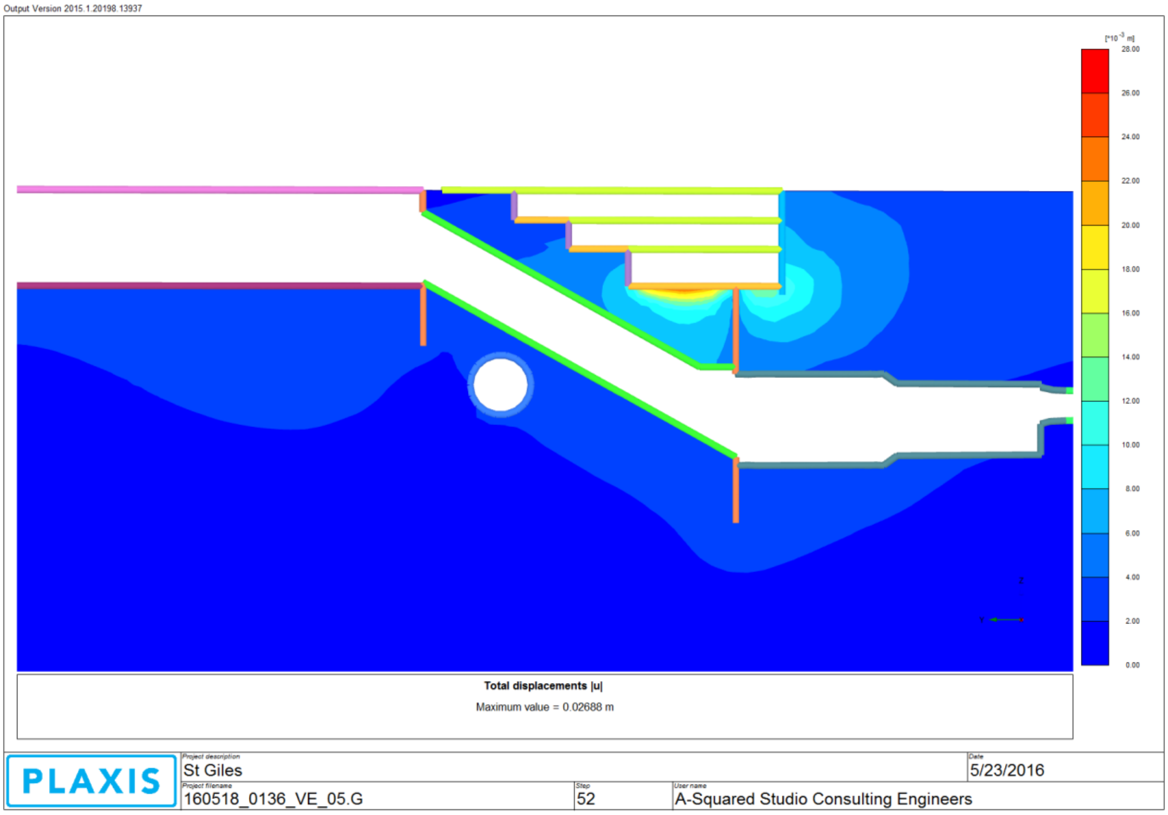

Figure 7.11: ***Short term*** **soil mass deformations along NLEB longitudinal axis**

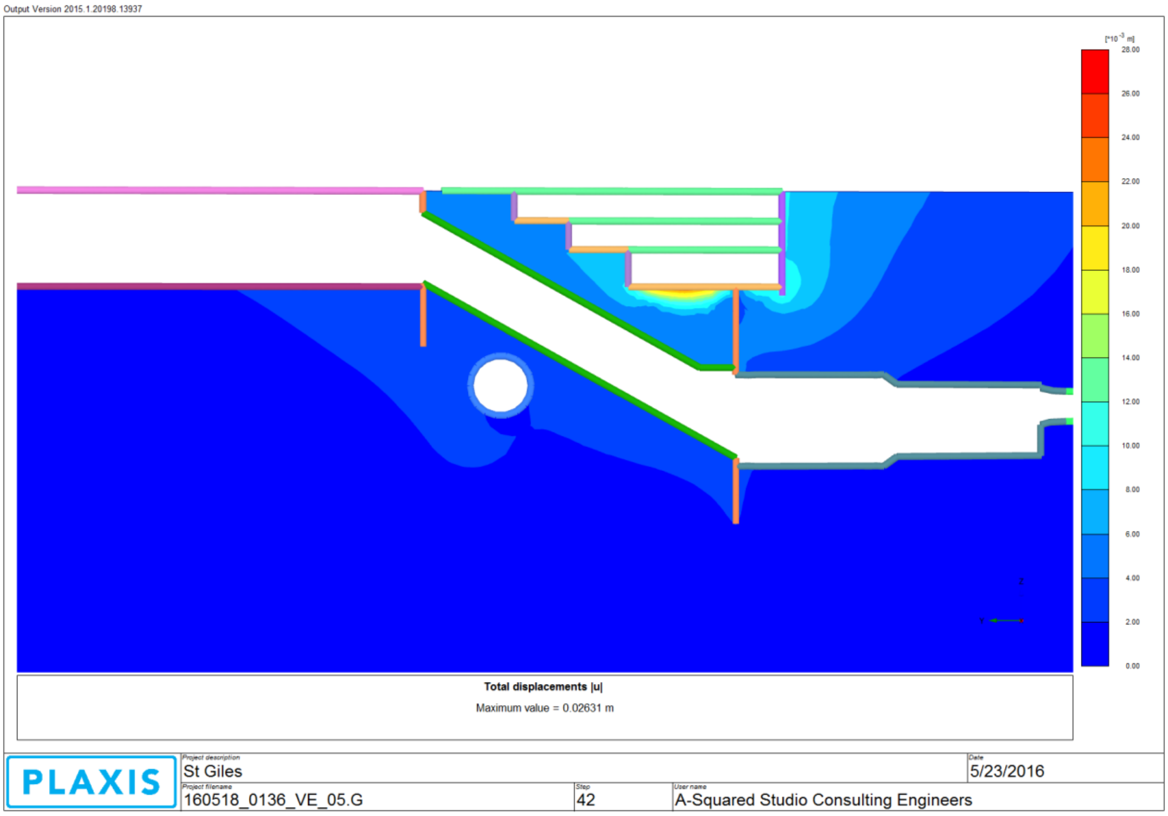

Figure 7.12: ***Long term*** **soil mass deformations along NLEB longitudinal axis**

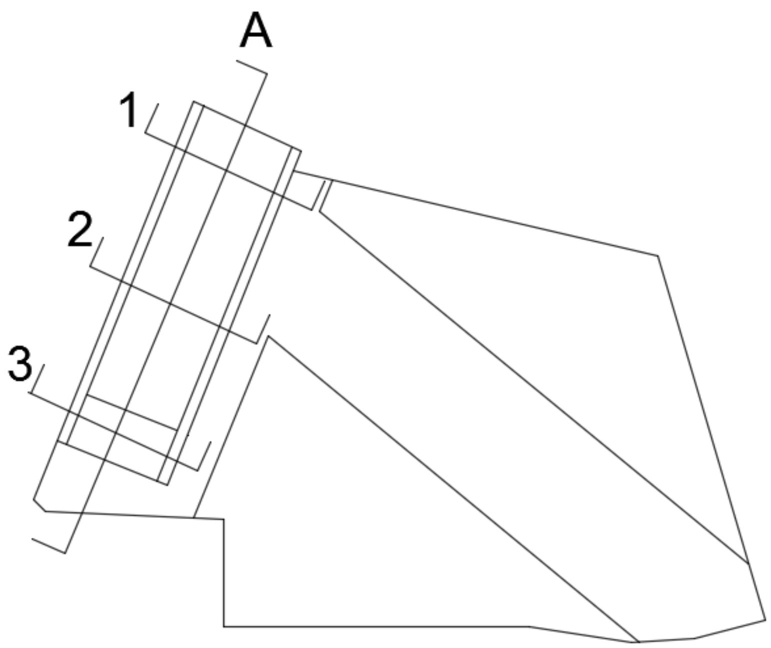

Figure 7.13: NLEB cross-sections to evaluate tilt of base slab

7.2.2 STRUCTURAL CAPACITY

The structural reinforcement of the slabs and walls of the NLEB is summarised in Table 7.5. The design moment and shear forces and estimated utilisation of the NLEB elements are summarised in Table 7.6 and Table 7.7.

Figure 7.15 to Figure 7.20 provide the contour plots of the assessed distribution of bending moments and shear forces within the NLEB structural elements.

To check the section capacity, the structural loads in the plate elements were amplified by a factor of 1.5 to assess the ultimate limit state condition. This is representative of a conservative load factor considering the distribution of permanent (normal load factor 1.35) and imposed (normal load factor 1.5) loading. All checks have been undertaken in general accordance with BSEN1992 and BSEN1997.

The estimated moment distribution can be affected locally by the occurrence of isolated peak moments, which arise for reasons including:

- Proximity of corners between multiple elements (typically more than two).
- Approximations and simplifications in modelling member connections (i.e. connections with finite stiffness modelled as rigid, etc.)
- Use of 2-D plate elements to model thick walls, e.g. ~1200mm.
- Finite element mesh density and localised element discretisation.

Accordingly, the assessment of section capacity provided herewith excludes values that were considered to be spurious. It is also considered that if such localised peaks of limited influence were to develop, this would result in redistribution of moments and forces within the structure.

Furthermore, peak bending moments and shear forces developed at the junction between adjacent walls and slabs of the NLEB are not considered to be realistic. This is because the simplification of modelling NLEB structural elements as 2D plates, ignores the local effects of element thickness. As shown in Figure 7.14, the model will tend to predict spikes in the moment and shear forces at the corners. In reality, these moments are unable to develop due to the relative aspect ratio of the corner elements. To assess the structural forces within the members near these connections, a truncated value of moment or shear force was used. The truncated value was evaluated at a distance equivalent to half the width of the adjoining structural element, away from the junction (Figure 7.14). The effective span of the members is shown as a dashed solid line on the bending moment and shear force output diagrams (Figure 7.15 to Figure 7.20).

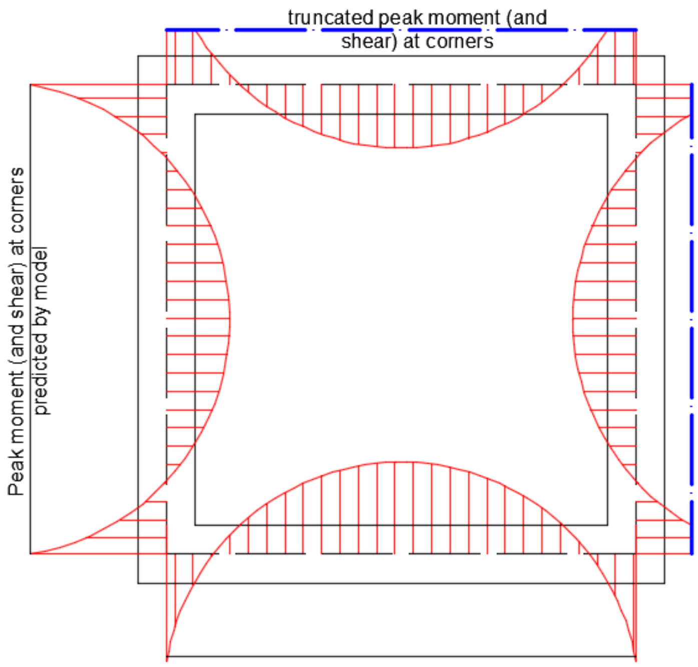

Figure 7.14: Truncation of predicted peak moment and shear at corners of NLEB to account for the effects of wall thickness.

It is evident from Table 7.6 and Table 7.7 that the top and bottom slab of the NLEB appear to be well within their section capacity, based on the estimated by the utilisation. The modelling indicates that the internal forces within the NLEB walls exceeds the shear capacity (at the supports) and for the moment capacity at mid-span. It is noted that the maximum moment and shear forces occurs towards the bottom of the NLEB, where the wall height is at its maximum. It is observed that the peak moment and shear force reduce rapidly with increasing distance from this section. Figure 7.21 shows the moments diagrams evaluated at Sections 2 and 3, as identified in Figure 7.13. The figures indicate that away from the zone with the maximum wall height, the peak mid-span moments are approximately halved. A similar case can be made for the peak shear forces adjacent to the supports. Thus, away from the zone where the NLEB wall height is at a maximum, the internal forces are not expected to exceed the estimated section utilisation.

Notwithstanding the above, the apparent over-utilisation of the NLEB walls, where the wall height is at a maximum, needs to be viewed within context of the modelling process. In particular, the estimated earth pressures applied to the NLEB walls will be sensitive to the initial method of construction and ground retention, backfilling and compaction, structural stiffness of nearby embedded structures and the existing stresses within the surrounding soil mass. Thus, unlike vertical loads, which are predominantly driven by gravity (e.g. those which affect the roof and base slab of the NLEB) and can be estimated with reasonable accuracy, horizontal loads are far more complex and stress-history dependent.

For these reasons, additional insight into the potential future behaviour of the NLEB walls can be gained by considering the estimated change in the internal forces of the NLEB walls prior-to and following the St Giles development works. This assessment indicates that:

- The mid-span moments following excavation to depth are between 98% and 110% of those occurring before excavation.
- The shear forces at the end spans range between 89% and 110% of those occurring before excavation.

It is evident then that based only on the consideration of absolute values of the structural forces alone, the NLEB walls should have exceeded their ULS capacity in the existing condition. This is evidently not the case and a more likely scenario is that the earth pressures resisted by the NLEB box are significantly less than those predicted by the model. Additionally, if the utilisation of the walls at their maximum span in the existing condition were very close to (i.e. >90%) of the ultimate capacity, it is likely that serviceability issues (severe cracking in walls, loss of water-tightness, etc.) would have been identified. Based on the information currently available, such distress has not been identified.

Thus, it is judged that the existing stresses within the NLEB walls are not as close to full utilisation as the modelling would suggest. Therefore, based on a maximum increase in the existing peak structural forces of approximately 10%, it is assessed that significant adverse response of the NLEB walls as a result of the proposed St Giles development is unlikely.

The following could be considered to increase confidence in the existing residual capacity of the NLEB walls:

- Assessing the capacity of wall as a plate rather than through cross-section capacity checks. Allowing for detailed consideration of moment and force redistribution within the structure.
- Conduct further detailed studies of the historic construction of the NLEB and proposed St Giles Circus development to refine the boundary stresses on the NLEB, by considering:
    - Coupled analysis, to simulate effects of consolidation during construction.
    - Increased detail of historic construction sequence of NLEB and of the proposed St Giles development.
- Detailed review of the load factoring to be applied (in light of the moderately conservative approach adopted herein).

7.2.3 CONCLUSIONS

Based on the outcomes of the analyses, it is assessed that the risk of adversely affecting the current condition of the NLEB is low, assuming that the proposed construction sequence is strictly adhered to.

The 5mm tolerance specified for the total movement of the NLEB base slab is not exceeded. Furthermore, the estimated transverse and longitudinal tilts of the base slab are low, and are within representative criteria for comparable sensitive structures.

The stresses within the roof and base slab are not assessed to exceed their respective section capacities. The modelling suggests that the internal forces within the NLEB walls, at the point where the wall height is a maximum, will exceed the section capacity under ultimate limit state conditions. Further assessment, considering the predicted maximum change in the peak internal forces before and after the proposed St Giles development indicates an increase in the maximum peak moment and shear force of approximately 10%. Based on this relatively modest increase, it is assessed that the overall performance of the NLEB walls will be adequate. Avenues to further increase the confidence in the capacity of the NLEB walls have been suggested.

Table 7.5: NLEB reinforcement

Element	Reinforcement Orientation	Mid-span		End-span	
		Top Layer (Near Face)	Bottom Layer (Far Face)	Top Layer (Near Face)	Bottom Layer (Far Face)
Roof Slab	Longitudinal	B16-150	B16-150	B16-150	B16-150
	Transverse	B40-130	B40-130	B40-150	B25-130
Base Slab	Longitudinal	B32-150	B32-150	B32-150	B32-150
	Transverse	B40-130	B25-130	B40-130	B40-130
Walls	Horizontal	B16-150	B16-150	-	-
	Vertical	B40-150	B25-150	-	-

Table 7.6: Section bending capacity check

Element	Direction of Moment	Mid-span		End-span	
		Factored Maximum Moment (kNm/m)	Section Utilisation (%)	Factored Maximum Moment (kNm/m)	Section Utilisation (%)
Roof Slab	Longitudinal	285 (H)	46	530 (S)	85
	Transverse	940 (S)	27	2780 (H)	79
Base Slab	Longitudinal	660 (S)	27	600 (H)	67
	Transverse	1430 (H)	41	1800 (S)	51
Walls	Horizontal	375 (FF)	82	-	-
	Vertical	1650 (FF)	182	-	-

Notes for Table 7.6:

H – Hogging. S – Sagging. NF – Near Face. FF – Far Face.

Table 7.7: Shear capacity check of NLEB walls

Element	Shear Direction	End-span	
		Factored Shear Force (kN/m)	Section Utilisation (%)
Walls	Out-of-plane (1)	2250	157
	Out-of-plane (2)	900(1)	137

Notes:

1.) Peak shear stress is concentrated towards base of NLEB, where the wall height is maximum. The magnitude of the shear stress decreases rapidly away from this peak, such that the majority of the element is within allowable utilisation under ULS conditions.

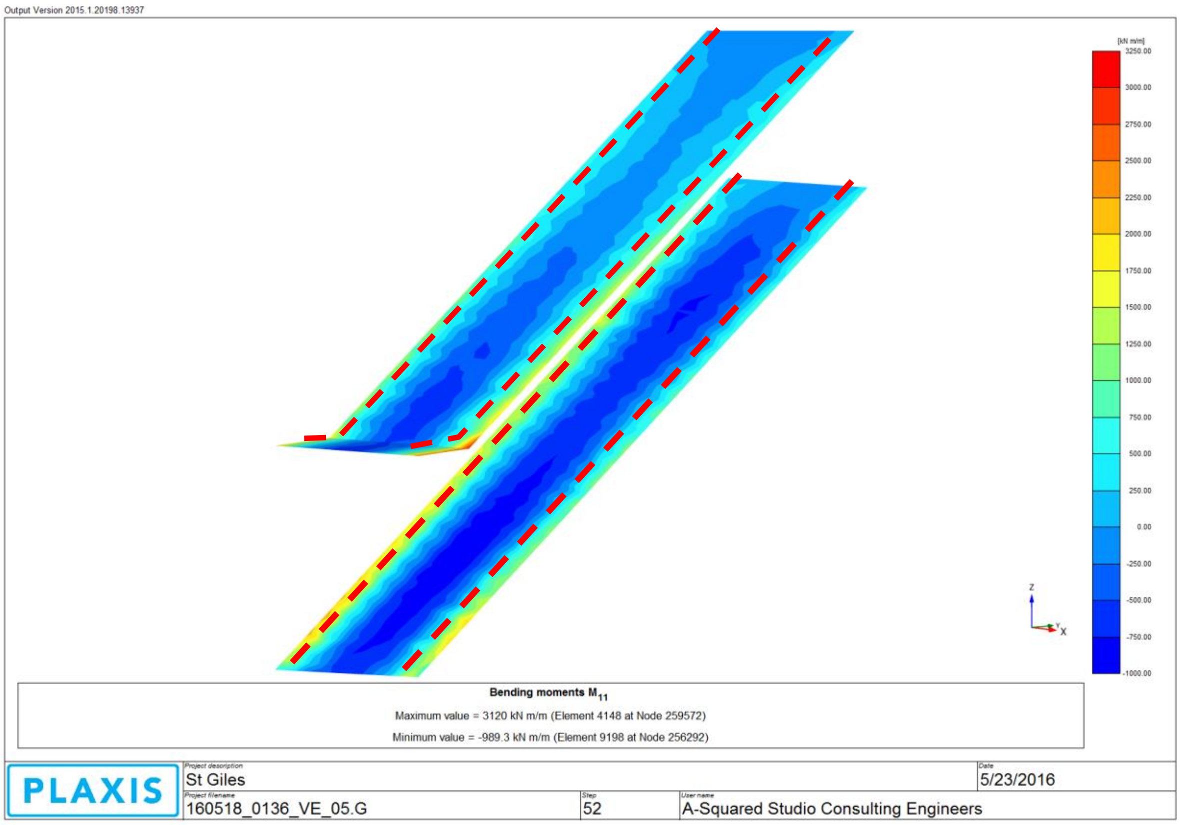

Figure 7.15: ***Short term*** **transverse moments across top and base slab of NLEB**

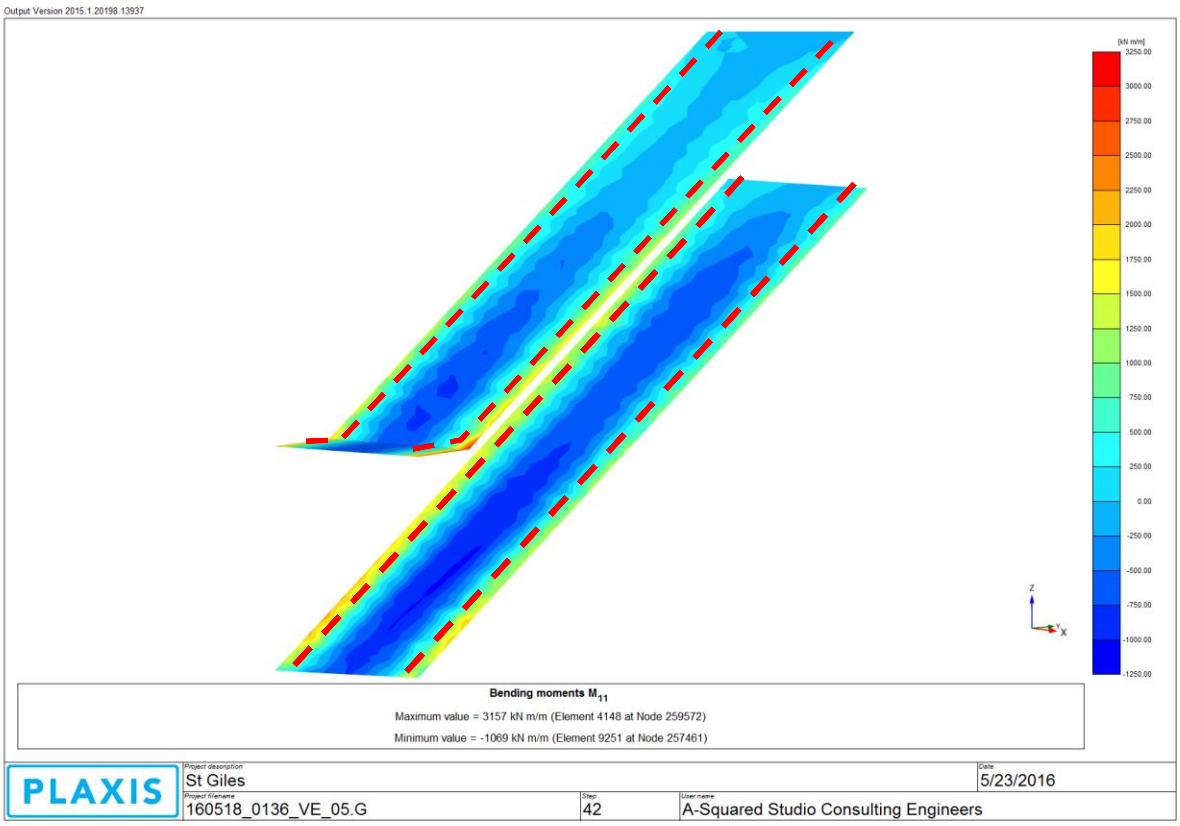

Figure 7.16: ***Long term*** **transverse moment within top and base slab of NLEB**

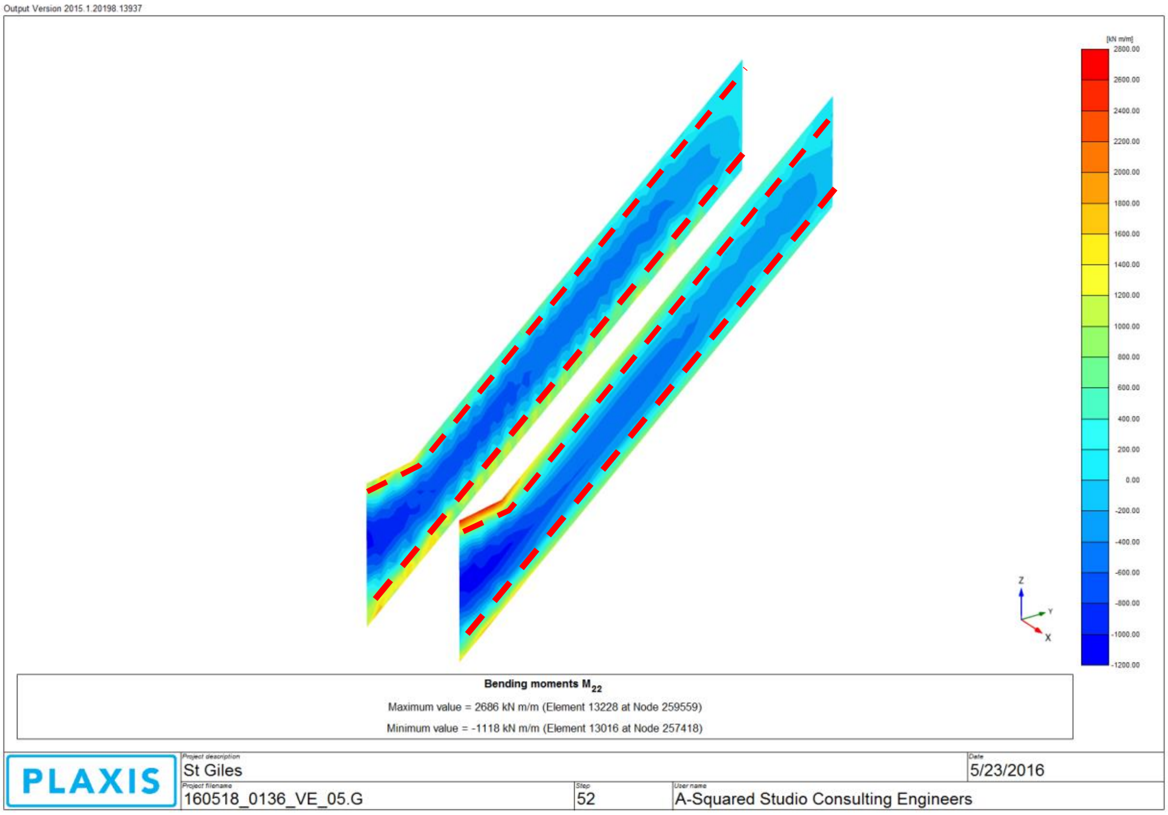

Figure 7.17: *Short term moment within NLEB walls*

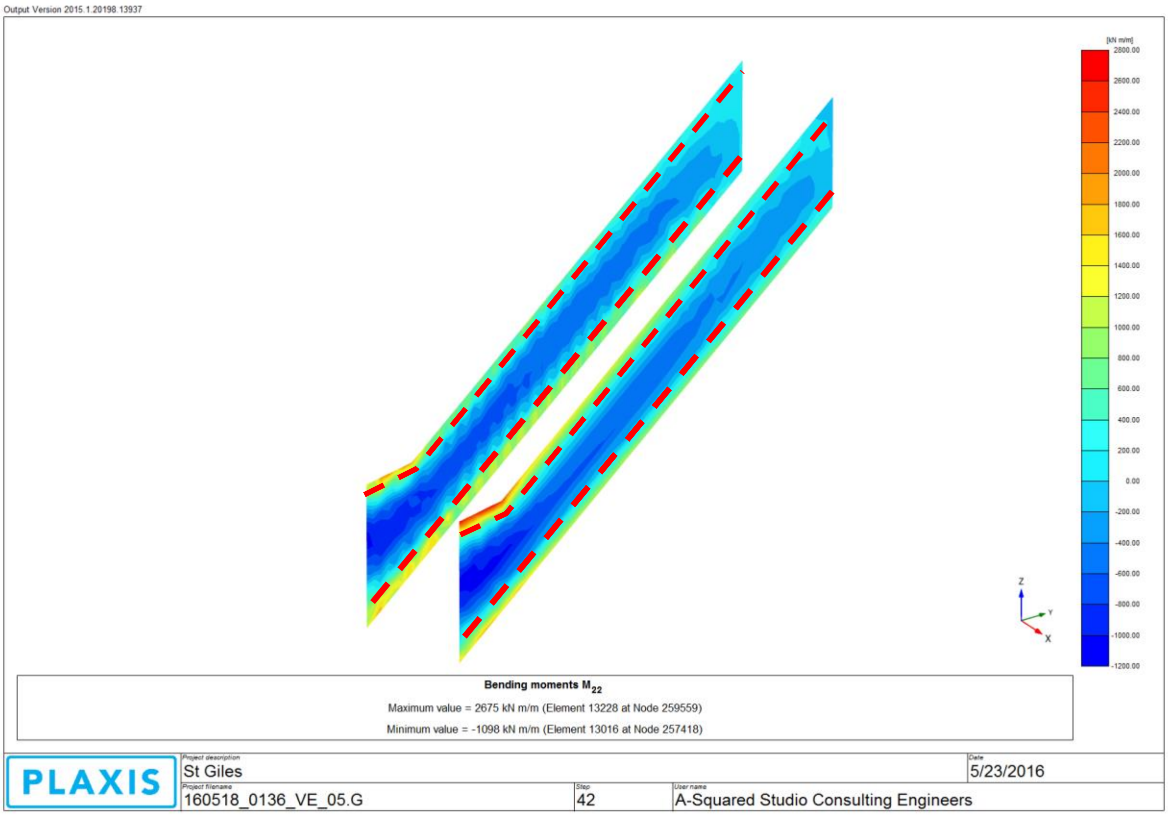

Figure 7.18: *Long term* moments within NLEB wall

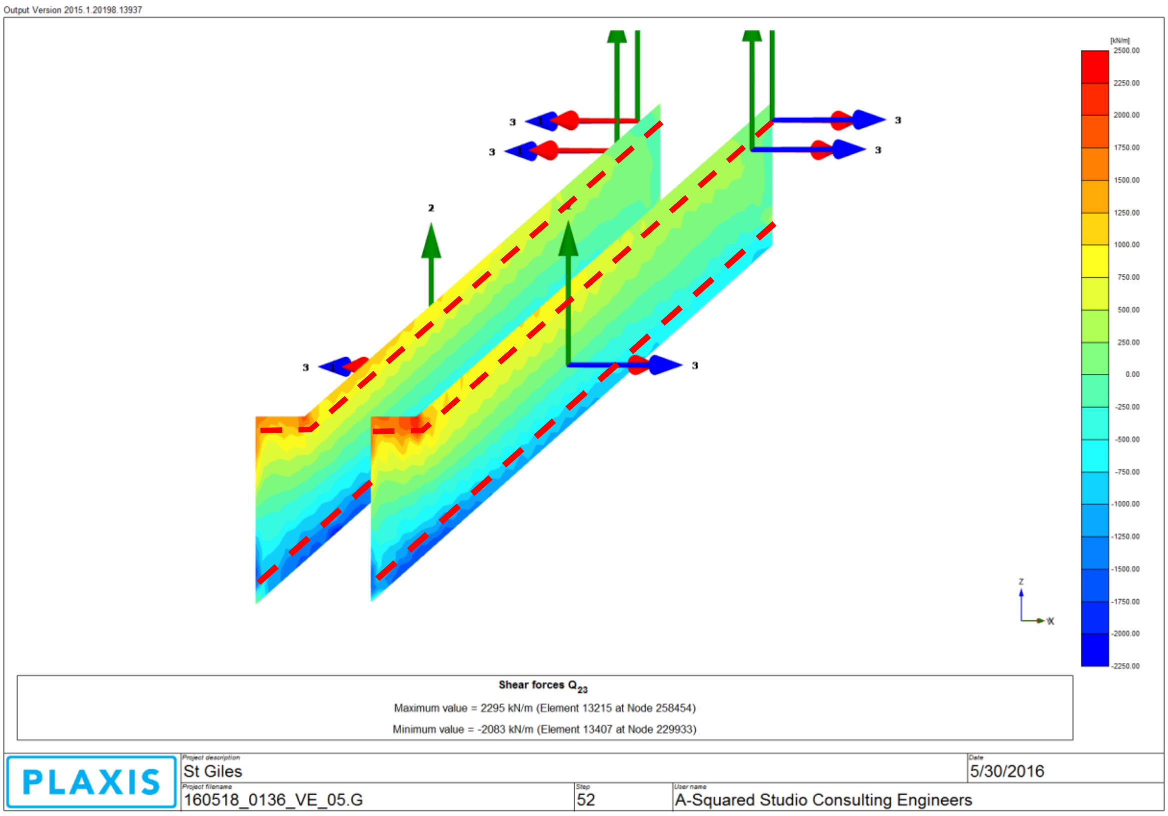

Figure 7.19: ***Short Term*** **shear force in NLEB walls (Out-of-plane 1)**

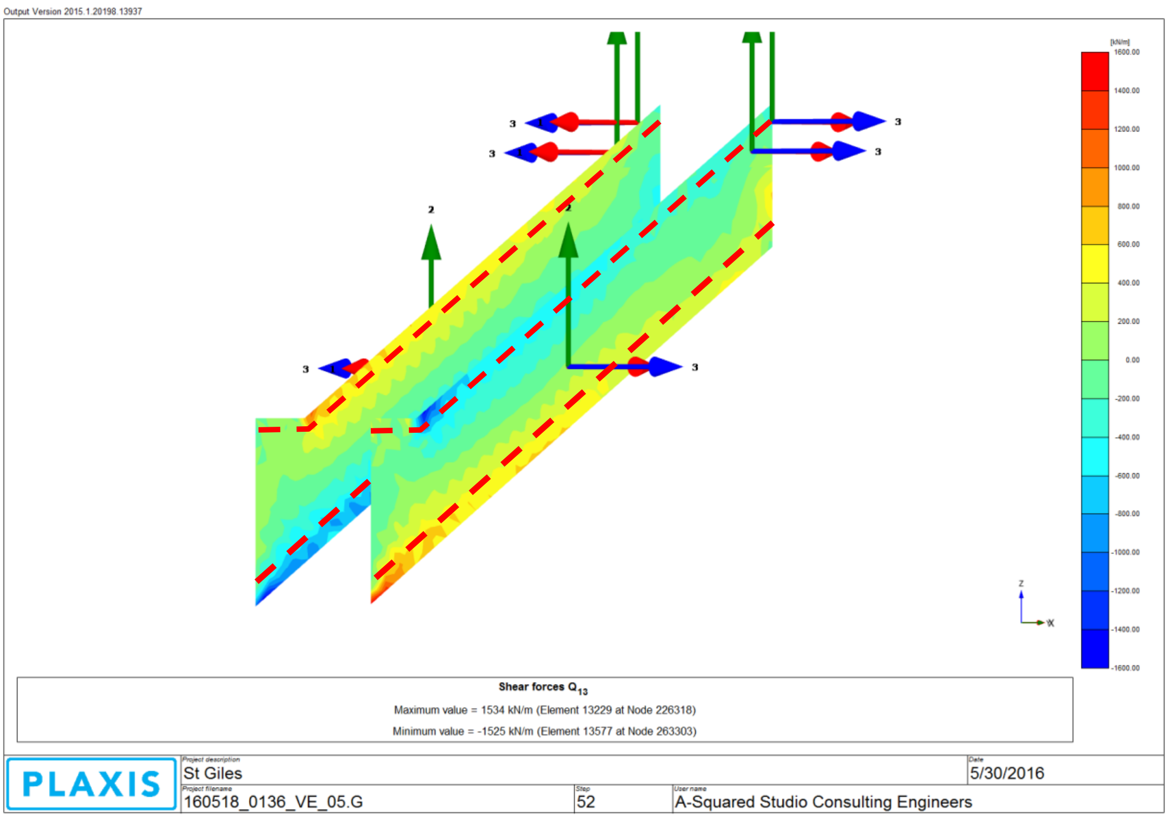

Figure 7.20: ***Short term*** **shear forces within NLEB wall (Out-of-plane 2)**

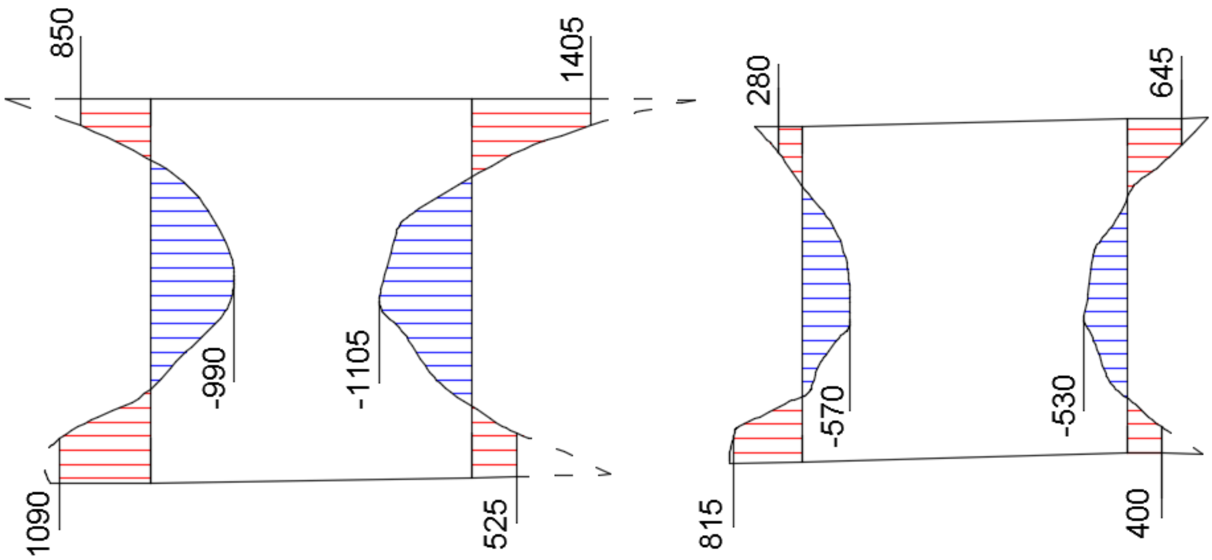

Figure 7.21: Comparison between unfactored bending moments at Section 3: maximum wall height (left) and Section 2: mid span (right).

7.3 LOWER CONCOURSE AND CROSS PASSAGE TUNNELS

Table 7.8 summarises the maximum estimated deformation of the lower concourse tunnel and cross passages. The maximum displacement of the lower concourse tunnels and cross passages occurs in the *short term* following completion of bulk excavation to formation level. Figure 7.22 presents a shaded contour plot displaying the distribution of total displacements during this stage. The total displacement of the tunnel is largest at the interface between the Lower Concourse Tunnel and the NLEB. The magnitude of the peak absolute movement is approximately 6.0mm. Figure 7.23, displays a scaled *deformed mesh*, illustrating the total displacement of the Lower Concourse Tunnel. The total deformations reduce substantially with distance from the NLEB interface. The maximum displacement of the cross passages (Cross Passage 1) is approximately less than 4mm, which occurs in the nearest cross passage to the NLEB. The remaining two cross passages (Cross Passages 2 and 3) experience total deformations of less than 3mm.

The average induced slopes were conservatively estimated by assuming the maximum total deformation was also equal to the maximum differential movement across the tunnel. The realized slope will thus be lower than tabulated.

The reinforcement arrangement details of the lower concourse tunnel and cross passage linings were unavailable. In order to assess the capacity of the existing section, the lining was assumed to be provided with minimum top and bottom steel (in terms of equivalent reinforcement representative of any fibre and/or mesh reinforcement provision).

Table 7.9 summarises the maximum estimated lining moment and axial force in the lower concourse tunnels and cross passages. The estimated section utilisations are also presented. It is evident that the current lining, based on the assumption of minimum steel (provided in both faces), is adequate to resist the applied structural forces. The estimated compressive axial load in the section was also reduced when assessing utilisation, resulting in a conservative assessment.

Based on the outline structural analysis undertaken as part of the checking process, it is assessed that the lower concourse tunnel and cross passages are not over-stressed by the proposed St Giles development and that the deformations induced by the development do not exceed the structures' serviceability limits and performance criteria.

Table 7.8: Deformation of lower concourse

Structure	Max. total deformation (mm)	Max. vertical deformation (mm)	Max. Horizontal deformation (mm)	Ave. slope along tunnel axis (V:H)
Lower Concourse	6	< 3	5	1:6,600
Cross Passage 1	< 4	< 1	< 3	1:6,750
Cross Passages 2	< 3	< 1	< 2	1:10,000
Cross Passages 3	2	< 1	1	1:15,000

Table 7.9: Lower concourse and cross passage structural assessment.

Element	Factored moment (kNm/m)$^{(2)}$	Compression load (kN/m)	Estimated Utilisation of Section (%)
Lower Concourse Tunnel (400 Thick SCL)	240	2000	65
Cross Passage Tunnel (200 Thick SCL)	45	700	43

Notes for Table 7.9:
(1) Min. bending steel assumed top and bottom in SCL lining.
(2) Moments factored by 1.5 for ULS conditions.

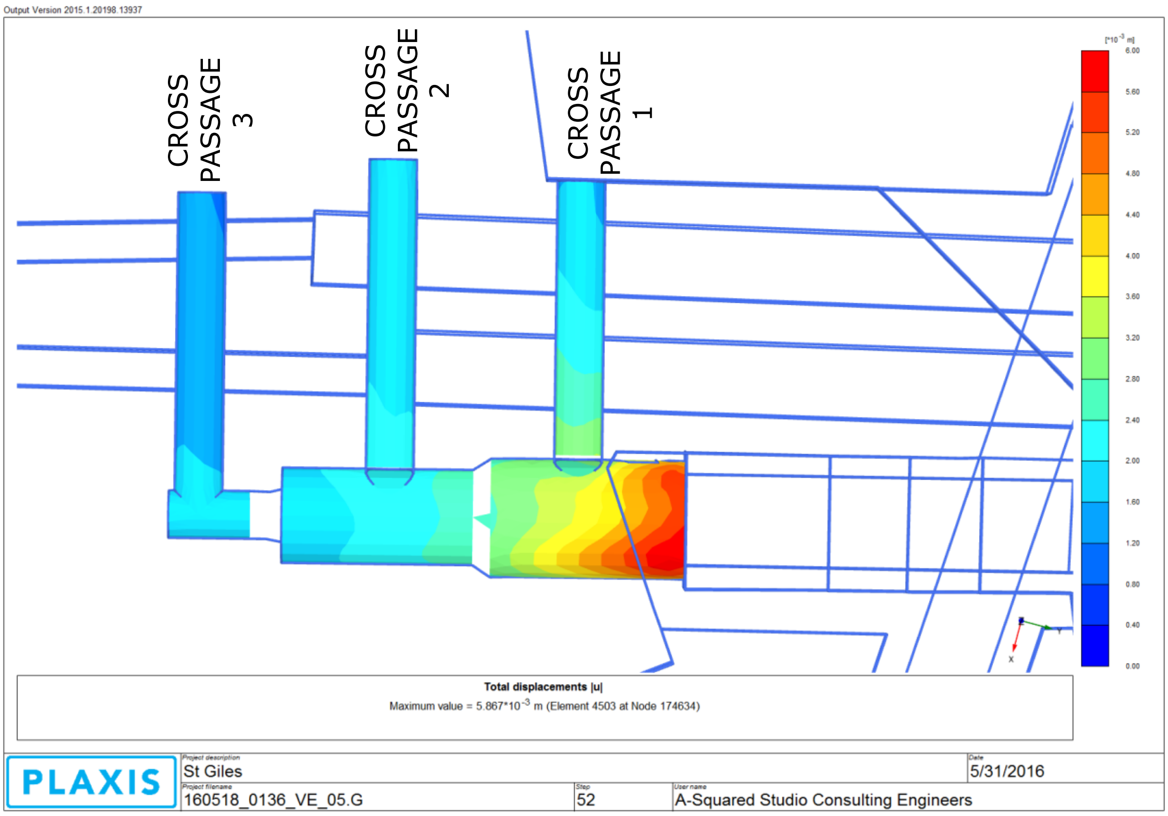

Figure 7.22: Lower concourse tunnel deformations

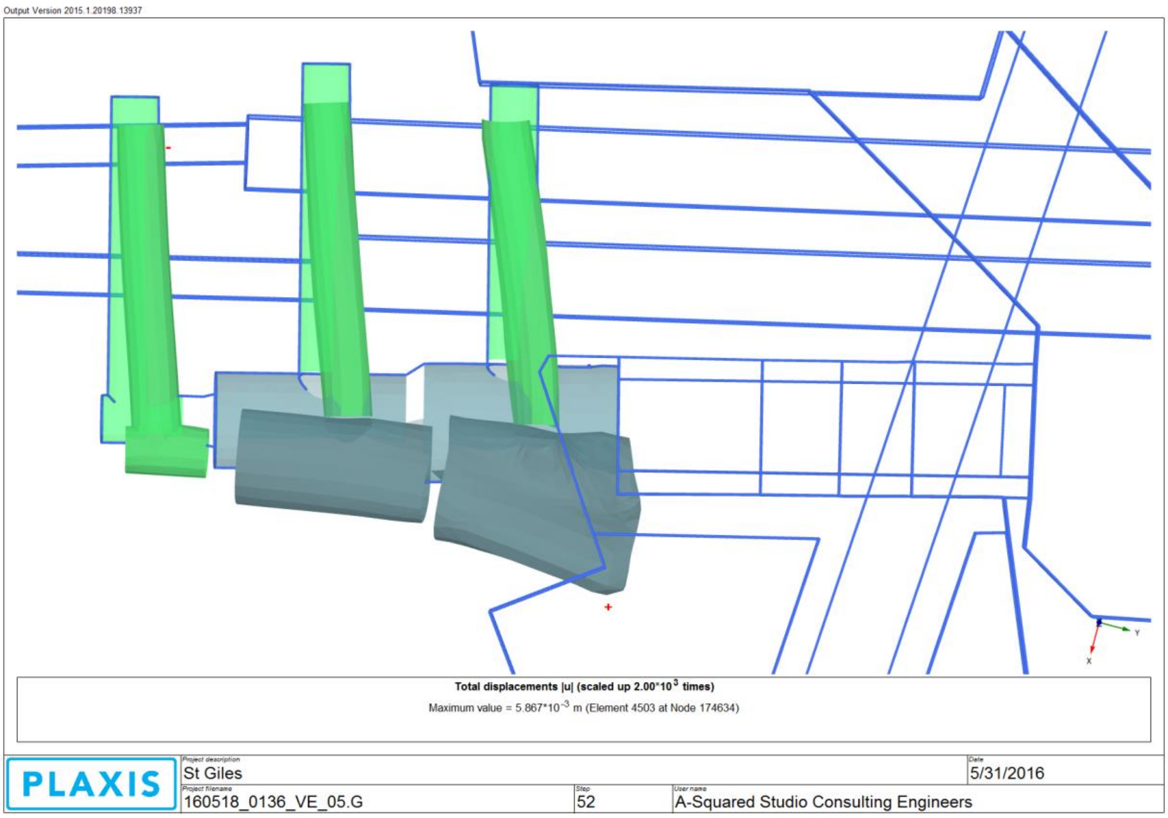

Figure 7.23: *Short term* deformed mesh of Lower Concourse Tunnel and Cross-passages

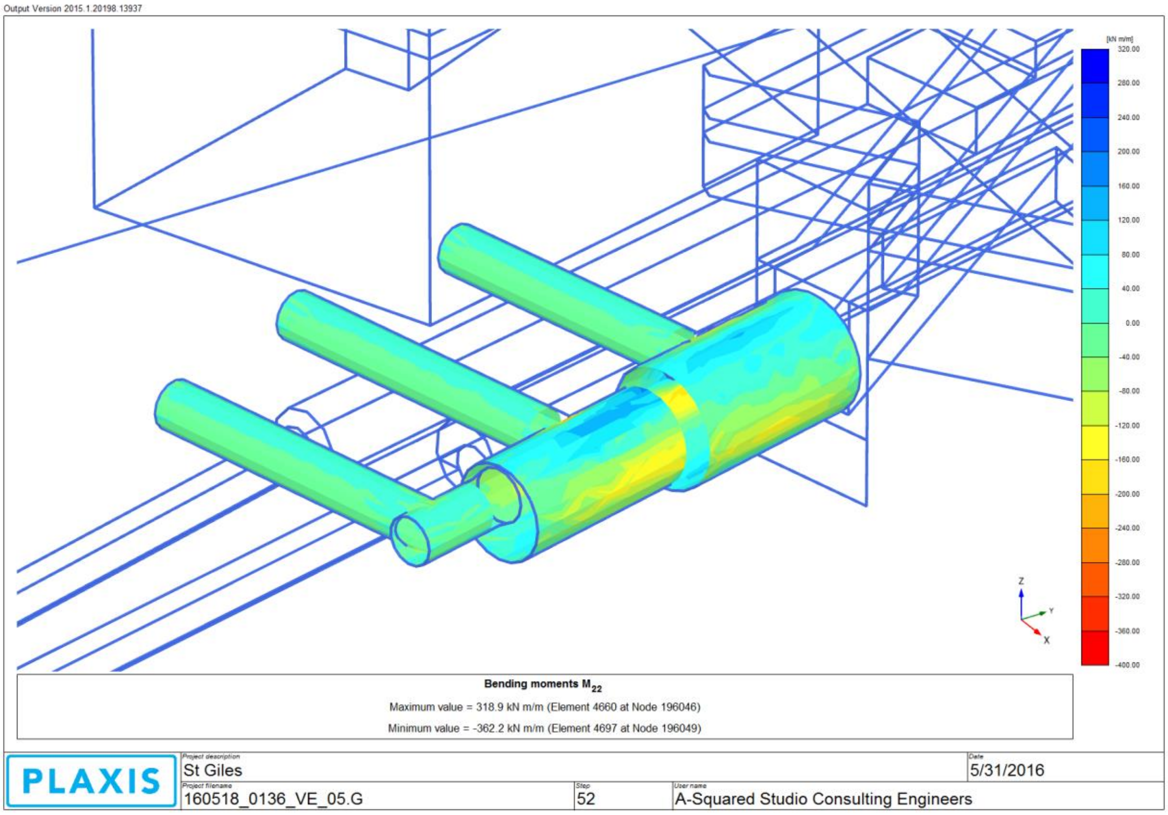

Figure 7.24: *Short term 'hoop'* moment in lower concourse tunnel and cross passages

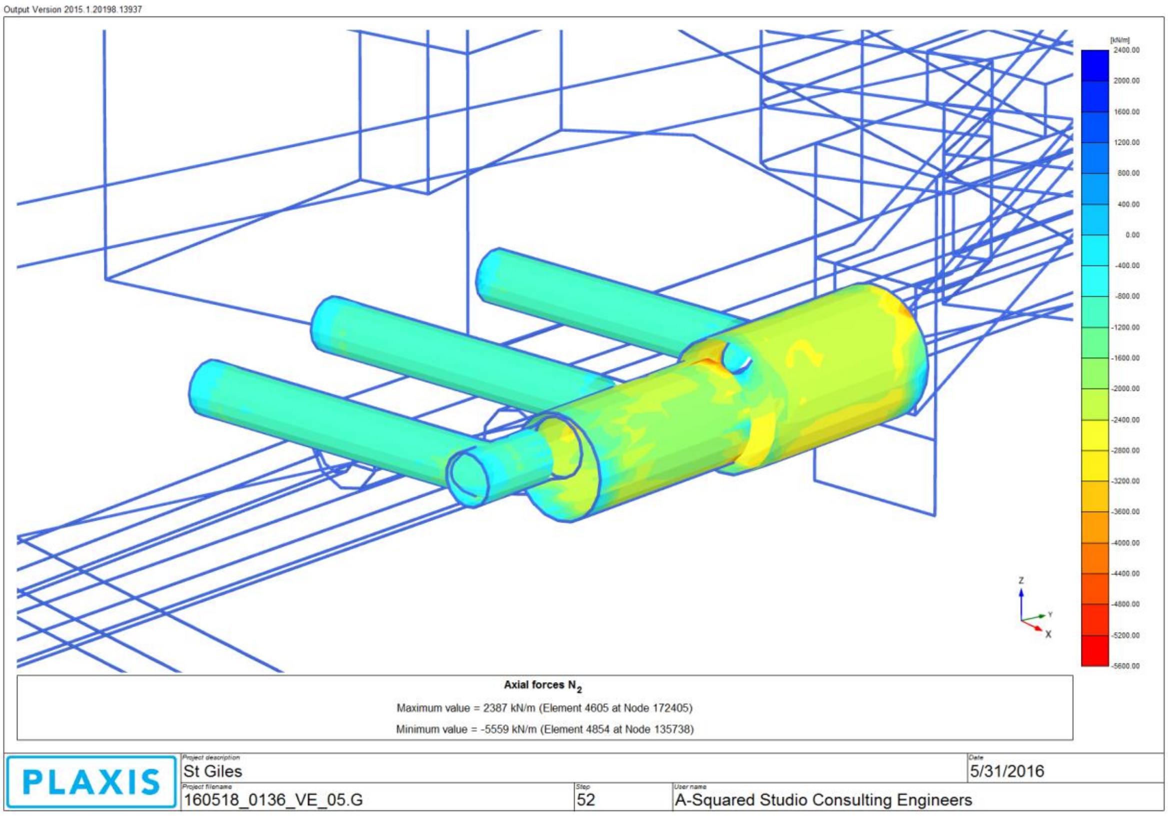

Figure 7.25: *Short term* hoop force in lower concourse tunnel and cross passages

8 CONCLUSIONS AND RECOMMENDATIONS

A 3D finite element model was developed to assess the impact of the construction of the proposed St Giles Circus development on existing Crossrail and LUL infrastructure, including:

- Eastbound Crossrail tunnel.
- Northbound and southbound running and tunnel platforms of the Northern Line.
- The Northern Line escalator box.
- Northern Line lower concourse tunnel and cross passages.

The key findings are summarised below and are numbered for ease of reference:

1. The numerical simulation of the proposed development indicates that the Crossrail eastbound tunnel lining, kinematic profile and associated infrastructure will not be adversely affected as a result of ground movements associated with the proposed St Giles development works. Additionally, the Crossrail tunnel lining will not be overstressed based on predicted deflections and ovalisations of the assets and based on an assessment of the structural capacity of the lining relative to the anticipated internal forces.

   As outlined in the relevant sections of the report, checks of the lining capacity, connections and water-proofing have been reviewed on the basis of the available information. All findings are satisfactory, however it would be prudent to review the as-built condition of the newly constructed tunnels with a view of establishing the current condition of the structure (and correspondence with design assumptions, tolerances and geometrical criteria). Similarly, it is suggested that the as-built information and the Engineer's findings be reviewed with the specialist suppliers (responsible for warranty provision of discrete elements).

2. The southbound and northbound running and platform tunnels of the Northern Line are not anticipated to be significantly affected by the proposed development. Furthermore, the structural capacity of the lining is maintained based on the relatively small predicted deflections and ovalisations. The impact on the track and the kinematic envelope is considered to be negligible.

3. The findings from the independent check indicate that the maximum deformation of the NLEB base slab does not exceed the notional 5mm limit agreed between the Engineer and LUL. Furthermore, the predicted rotations and tilts of the NLEB base slab that supports the movement-sensitive escalators, are low and within differential settlement limits typically specified for such sensitive structures.

   It is noted that further detailed analyses of the NLEB walls are required in order to validate their capacity under ULS conditions in both bending and shear. The analyses indicate that isolated areas/zones of the NLEB walls (mainly toward the bottom of the structure where the walls are highest) may be over-utilised (based on the limited reinforcement provision presented on the drawings provided). It is noted however that the adopted modelling methodology (i.e. having *wished in place* the NLEB) is likely to have exacerbated the magnitudes of the initial stresses within the structural elements and thus the predicted utilisations, too. A better representation of the stresses within the NLEB could be obtained by explicitly modelling the construction sequence of the structure as part of a finite element analysis.

Where localised peak stresses are identified, it is considered that selected bending mechanisms can take advantage of force/moment redistribution. This may result in a marginal increase in deflections, however it is considered that this would provide a robust means of demonstrating structural capacity compliance considering the circumstances presented herein. The shear exceedance mechanisms can be reviewed in a similar light. Whilst this mechanism is frequently regarded as a more brittle phenomenon (in contrast with bending mechanism redistribution), it is recommended that this aspect be assessed in further detail and reviewed/agreed with the asset protection team. At present, other specific mitigation measures have not been considered.

Notwithstanding the findings outlined above, it is assessed that the proposed construction works, carried out in a controlled and managed fashion with tight controls on sequencing and appropriate level of monitoring (survey and instrumentation), can be completed successfully whilst maintaining the serviceability and integrity of the NLEB.

4. The lower concourse tunnels and cross-passages are not expected to be adversely affected by the proposed works.

5. In general, it is suggested that an appropriate instrumentation, survey and monitoring plan will be essential to ensure that the works are carried out safely and within the predicted ground movement predictions. Structure specific trigger levels should be developed and implemented within the structure of the proposed Action Plan for the project. The Action Plan must detail appropriate means of data management and lines of responsibility within the project team (alongside any agreed procedural definition). The substructure contractors will need to provide demonstrable and substantiated means of mitigation (to be adopted in the event of potential trigger level exceedance). The significance of obtaining a robust set of baseline data is highlighted in point 6 below.

6. The redevelopment of the Tottenham Court Road station area (resulting from extensive LUL and Crossrail works) has inherently resulted in a very significant disturbance of the insitu conditions in the ground. The excavation of substantial below ground basements, tunnels and connecting structures will have induced substantial short-term ground movements and will have introduced a global excess pore water pressure field within the low permeability cohesive strata underlying the site, which are arguably of greatest engineering significance in this instance. It is envisaged that the dissipation of the global excess pore water pressure field will take place over a number of years, resulting in further ground movement. In summary,

regardless of the proposed St Giles Circus development, both newly built and existing below ground assets are likely to undergo further movement with time.

The implications of this time-dependent phenomenon should be considered (in combination with the relatively limited predicted impact imposed by the St Giles Circus development). Existing baseline monitoring data should be reviewed to provide an insight into any ongoing movement trends. Also, the baseline monitoring data may also identify other cyclic movements such as changes in perched water table level, thermal effects associated with the operation of the assets and/or similar.

7. It is noted that the assessment methodology adopted as part of the Category 3 Check presented herein differs substantially from the analytical techniques adopted by the Engineer. The Category 3 Check has adopted a 3D finite element modelling approach of the area of interest surrounding the St Giles Circus development. Various material constitutive models have been considered, including a non-linear user-defined model which enables the user to specify stiffness dependency on both mean confining pressure and strain. Considering the fully independent interpretation of the project data and differences in the methods of analysis, the Category 3 Check has achieved good agreement with the findings presented by the Engineer. This is an encouraging finding in light of the construction sequence complexity and below ground congestion in the area. In summary, the findings of the Category 3 Check for both options presented herein is satisfactory provided that the NLEB matters raised in point 3 above are reviewed and agreed with the asset protection team.

APPENDIX A – REFERENCES

DRAWING/DOCUMENT ISSUE SHEET

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Project name: **St. Giles Circus, Zone 1**
Project N#: **029-Z1**
Document no: 029-Z1-S-ISS-001

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				month	04	05	05	07	01	01	02
				year	15	15	15	15	16	16	16
Issued to	**name**				**purpose code / type of issue**						
Client	Richard Metcalfe - Consolidated Developments Ltd				E	E	E		E	E	E
Main Contractor	Kevin Houlihan, Donald Oreilly, Neil Keogh, Jo Delahunty, Beth Jenkins - Skanska								E	E	E
Architect	John McRae, Richard Keating, Ivan Equihua, Andrew McEwan, Antonio Berongoy - Orms				E	E	E		E	E	E
Project Manager	Stewart Holmes, Brandon Bell - Second London Wall				E	E	E		E	E	E
MEP Engineer	Peter Bateman, Owen Emmington-Thomas - Buro Happold				E	E	E		E	E	E
CDM Co-ordinator	Nicholas Payne - RLF				E	E	E		E	E	E
Cost Consultant	Richard Jackson, Richard Warren - Alinea				E	E	E		E	E	E
Theatre Consultant	Paul Crosbie - CharcoalBlue					E	E		E	E	E
Catering Consultant	Gareth Sefton - SHW					E	E		E	E	E
Geotech Consultant	Hilary Skinner - Donaldsons					E	E		E	E	E
Monitoring Contractor	Simon McCabe, Adrain Jonson - SES										
Crossrail	Geoff Rankin										
LUL	William Lau, Chris Barnes, Mike Lewis										
SI Contractor	Darren Seeley - Concept										
Insurer	Danny Toull - Robinson										
Archaeologist	David Diver - MoLA										
Façade Contractor	Rupert Colnago - F&R							E	E	E	E
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drg/doc no.	**drawing/document title**	**size**	**scale**	**last rev**	**issue/revision**						
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029-Z1-S-010	Zone 1 Basement Isometrics	A1	NTS	T3	E1	E2	T1	T1	T2		T3
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029-Z1-S-015	Zone 1 Basement Box in Box Isometrics	A1	NTS	T3	E1	E2	T1	T1	T2		T3
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029-Z1-S-017	Zone 1 St Giles High St Façade Isometrics	A1	NTS	T3	E1	E2	T1	T1	T2		T3
029-Z1-S-018	Zone 1 Denmark Place Isometrics	A1	NTS	T3	E1	E2	T1	T1	T2		T3
029-Z1-S-019	Zone 1 Technical Gantry Isometrics	A1	NTS	T3			T1	T1	T2		T3
029-Z1-S-020	Zone 1 Site Investigation Plan Lower Ground Floor	A1	1:100	T2	E1	E2	T1	T1	T2		
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029-Z1-S-026	Zone 1 Proposed Site Plan	A1	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-031	Zone 1 Piling Layout	A0	1:100	T3	E1	E2	T1	T1	T2		T3
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029-Z1-S-041	Zone 1 Plan at Northern Line Mid Tunnel Axis +96.0m	A1	1:200	T3		E1	T1	T1	T2		T3
029-Z1-S-051	Zone 1 Plan at Crossrail Mid Tunnel Axis +104.0m	A1	1:200	T3		E1	T1	T1	T2		T3
029-Z1-S-061	Zone 1 B2 Basement GA Concrete	A0	1:100	T3	E1	E2	T1	T1	T2		T3
029-Z1-S-071	Zone 1 B1 Basement GA Concrete	A0	1:100	T3	E1	E2	T1	T1	T2		T3
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029-Z1-S-091	Zone 1 Lower Ground Floor GA Concrete	A0	1:100	T3	E1	E2	T1	T1	T2		T3
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029-Z1-S-101	Zone 1 Ground Floor GA Concrete	A0	1:100	T3	E1	E2	T1	T1	T2		T3
029-Z1-S-102	Zone 1 Ground Floor GA Steel Frame	A0	1:100	T3	E1	E2	T1	T1	T2		T3
029-Z1-S-104	Zone 1 Ground Floor Box in Box GA Concrete	A0	1:100	T2	E1	E2	T1	T1	T2		
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029-Z1-S-111	Zone 1 First Floor GA Concrete	A0	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-112	Zone 1 First Floor GA Steel Frame	A0	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-113	~~Zone 1 First Floor GA Cellular Beam Openings~~ *(Superseded by BIM Model)*	A0	1:100	T1		E1	T1	T1			
029-Z1-S-121	Zone 1 Second Floor GA Concrete	A0	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-122	Zone 1 Second Floor GA Steel Frame	A0	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-123	~~Zone 1 Second Floor GA Cellular Beam Openings~~ *(Superseded by BIM Model)*	A0	1:100	T1		E1	T1	T1			
029-Z1-S-131	Zone 1 Third Floor GA Concrete	A0	1:100	T3	E1	E2	T1	T1	T2		T3
029-Z1-S-132	Zone 1 Third Floor GA Steel Frame	A0	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-133	~~Zone 1 Third Floor GA Cellular Beam Openings~~ *(Superseded by BIM Model)*	A0	1:100	T1		E1	T1	T1			
029-Z1-S-141	Zone 1 Fourth Floor GA Concrete	A0	1:100	T3	E1	E2	T1	T1	T2		T3
029-Z1-S-142	Zone 1 Fourth Floor GA Steel Frame	A0	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-143	~~Zone 1 Fourth Floor GA Cellular Beam Openings~~ *(Superseded by BIM Model)*	A0	1:100	T1		E1	T1	T1			
029-Z1-S-151	Zone 1 Fifth Floor GA Concrete	A0	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-152	Zone 1 Fifth Floor GA Steel Frame	A0	1:100	T3	E1	E2	T1	T1	T2		T3
029-Z1-S-153	~~Zone 1 Fifth Floor GA Cellular Beam Openings~~ *(Superseded by BIM Model)*	A0	1:100	T1		E1	T1	T1			
029-Z1-S-161	Zone 1 Sixth Floor GA Concrete	A0	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-162	Zone 1 Sixth Floor GA Steel Frame	A0	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-163	~~Zone 1 Six Floor GA Cellular Beam Openings~~ *(Superseded by BIM Model)*	A0	1:100	T1		E1	T1	T1			
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029-Z1-S-172	Zone 1 Roof Level GA Steel Frame	A0	1:100	T3	E1	E2	T1	T1	T2		T3
029-Z1-S-173	~~Zone 1 Roof Floor GA Cellular Beam Openings~~ *(Superseded by BIM Model)*	A0	1:100	T1		E1	T1	T1			
029-Z1-S-182	Zone 1 Roof Light G.A Steel Frame	A0	1:100	T2	E1	E2	T1	T1	T2		
029-Z1-S-200	Zone 1 Building Section AA	A1	1:100	T3	E1	E2	T1	T1	T2		T3
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029-Z1-S-204	Zone 1 Building Section EE	A1	1:100	T3	E1	E2	T1	T1	T2		T3
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Notes: Purpose: P - Preliminary, A - Approval, I - Information, T - Tender, C - Contract
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029-Z1-S-301	Zone 1 Basement Liner Wall Elevations Sheet 2	A1	1:100	T2		E1	T1	T1			T2
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029-Z1-S-424	Zone 1 Building B Structural Frame Sections / Elevations Sheet 3	A1	1:100	T2	E1	E2	T1	T1	T2		
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029-Z1-S-460	Zone 1 Building D Structural Frame Sections / Elevations Sheet 1	A1	1:100	T3	E1	E2	T1	T1	T2		T3
029-Z1-S-461	Zone 1 Building D Structural Frame Sections / Elevations Sheet 2	A1	1:100	T3	E1	E2	T1	T1	T2		T3
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029-Z1-S-500	Zone 1 Details Basement Sheet 1	A1	1:20	T2		E1	T1	T1			T2
029-Z1-S-501	Zone 1 Details Basement Sheet 2	A1	1:20	T2		E1	T1	T1			T2
029-Z1-S-502	Zone 1 Details Basement Sheet 3	A1	VAR	T2		E1	T1	T1			T2
029-Z1-S-503	Zone 1 Details Basement Sheet 4	A1	1:20	T2		E1	T1	T1			T2
029-Z1-S-510	Zone 1 Section AA Details Sheet 1	A1	VAR	T2		E1	T1	T1			T2
029-Z1-S-511	Zone 1 Section AA Details Sheet 2	A1	VAR	T2		E1	T1	T1			T2
029-Z1-S-515	Zone 1 Section BB Details Sheet 1	A1	VAR	T2		E1	T1	T1			T2
029-Z1-S-516	Zone 1 Section BB Details Sheet 2	A1	VAR	T2		E1	T1	T1			T2
029-Z1-S-517	Zone 1 Section BB Details Sheet 3	A1	1:20	T1							T1
029-Z1-S-520	Zone 1 Section CC Details Sheet 1	A1	1:20	T2		E1	T1	T1			T2
029-Z1-S-521	Zone 1 Section CC Details Sheet 2	A1	1:20	T2		E1	T1	T1			T2
029-Z1-S-522	Zone 1 Section CC Details Sheet 3	A1	1:20	T2		E1	T1	T1			T2
029-Z1-S-523	Zone 1 Section CC Details Sheet 4	A1	1:20	T1							T1
029-Z1-S-525	Zone 1 Section DD Details Sheet 1	A1	1:20	T2		E1	T1	T1			T2
029-Z1-S-526	Zone 1 Section DD Details Sheet 2	A1	VAR	T2		E1	T1	T1			T2
029-Z1-S-530	Zone 1 Section EE Details Sheet 1	A1	1:20	T2		E1	T1	T1			T2
029-Z1-S-540	Zone 1 Section JJ Details Sheet 1	A1	VAR	T2		E1	T1	T1			T2
029-Z1-S-550	Zone 1 Typical Steel Details Sheet 1	A1	1:10	T2		E1	T1	T1			T2
029-Z1-S-551	Zone 1 Typical Steel Details Sheet 2	A1	1:10	T2		E1	T1	T1			T2
029-Z1-S-552	Zone 1 Typical Steel Details Sheet 3	A1	VAR	T2		E1	T1	T1			T2
029-Z1-S-553	Zone 1 Typical Steel Details Sheet 4	A1	1:10	T2		E1	T1	T1			T2
029-Z1-S-560	Zone 1 Typical Masonry Details Sheet 1	A1	1:10	T2		E1	T1	T1			T2
029-Z1-S-561	Zone 1 Typical Masonry Details Sheet 2	A1	1:10	T2		E1	T1	T1			T2
029-Z1-S-562	Zone 1 Typical Masonry Details Sheet 3	A1	1:50	T2		E1	T1	T1			T2
029-Z1-S-575	Zone 1 Details Cast in Plates Sheet 1	A1	1:10	T2		E1	T1	T1			T2
029-Z1-S-576	Zone 1 Details Cast in Plates Sheet 2	A1	1:10	T2							T2
029-Z1-S-580	Zone 1 Details Fabricated Column Base Plates Sheet 1	A1	1:20	T1							T1
029-Z1-S-581	Zone 1 Details Fabricated Column Base Plates Sheet 2	A1	1:20	T1							T1
029-Z1-S-590	Zone 1 Typical Plunge Column Details Sheet 1	A1	1:20	T1							T1
029-Z1-S-591	Zone 1 Typical Plunge Column Details Sheet 2	A1	1:20	T1							T1
029-Z1-S-592	Zone 1 Typical Plunge Column Details Sheet 3	A1	1:10	T1							T1
029-Z1-S-600	Zone 1 Building A Outline Steel Frame Details Columns View Sheet 1	A1	NTS	T1		E1	T1	T1			
029-Z1-S-601	Zone 1 Building A Outline Steel Frame Details Columns View Sheet 2	A1	NTS	T1		E1	T1	T1			
029-Z1-S-602	Zone 1 Building A Outline Steel Frame Details Truss Grid A1	A1	NTS	T1		E1	T1	T1			
029-Z1-S-603	Zone 1 Building A Outline Steel Frame Details Truss Grid AA	A1	NTS	T1		E1	T1	T1			
029-Z1-S-604	Zone 1 Building A Outline Steel Frame Details Truss Grid A5	A1	NTS	T1		E1	T1	T1			
029-Z1-S-605	Zone 1 Building A Outline Steel Frame Details Truss Grid AB	A1	NTS	T1		E1	T1	T1			
029-Z1-S-606	Zone 1 Building A Outline Steel Frame Details Truss Grid AC	A1	NTS	T1		E1	T1	T1			
029-Z1-S-610	Zone 1 Building B Outline Steel Frame Details Columns View Sheet 1	A1	NTS	T1		E1	T1	T1			
029-Z1-S-611	Zone 1 Building B Outline Steel Frame Details Columns View Sheet 2	A1	NTS	T1		E1	T1	T1			
029-Z1-S-612	Zone 1 Building B Outline Steel Frame Details Truss Grid B1	A1	NTS	T1		E1	T1	T1			
029-Z1-S-613	Zone 1 Building B Outline Steel Frame Details Truss Grid B3	A1	NTS	T1		E1	T1	T1			
029-Z1-S-620	Zone 1 Building A Outline Steel Frame Details Columns AA/A1	A1	NTS	T1		E1	T1	T1			
029-Z1-S-621	Zone 1 Building A Outline Steel Frame Details Columns AB/A1	A1	NTS	T1		E1	T1	T1			
029-Z1-S-622	Zone 1 Building A Outline Steel Frame Details Columns AC/A1	A1	NTS	T1		E1	T1	T1			
029-Z1-S-623	Zone 1 Building A Outline Steel Frame Details Columns AD/A1	A1	NTS	T1		E1	T1	T1			
029-Z1-S-624	Zone 1 Building A Outline Steel Frame Details Columns AA/A5	A1	NTS	T1		E1	T1	T1			
029-Z1-S-625	Zone 1 Building A Outline Steel Frame Details Columns AC/A5	A1	NTS	T1		E1	T1	T1			
029-Z1-S-626	Zone 1 Building A Outline Steel Frame Details Columns AD/A5	A1	NTS	T1		E1	T1	T1			
029-Z1-S-630	Zone 1 Building B Outline Steel Frame Details Columns AA/B1	A1	NTS	T1		E1	T1	T1			
029-Z1-S-631	Zone 1 Building B Outline Steel Frame Details Columns AD/B1	A1	NTS	T1		E1	T1	T1			
029-Z1-S-632	Zone 1 Building B Outline Steel Frame Details Columns AA/B3	A1	NTS	T1		E1	T1	T1			
029-Z1-S-633	Zone 1 Building B Outline Steel Frame Details Columns AD/B3	A1	NTS	T1		E1	T1	T1			

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029-Z1-S-640	Zone 1 Building A Outline Steel Frame Details Col AA/A1 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-641	Zone 1 Building A Outline Steel Frame Details Col AA/A1 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-642	Zone 1 Building A Outline Steel Frame Details Col AA/A1 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-643	Zone 1 Building A Outline Steel Frame Details Col AA/A1 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-644	Zone 1 Building A Outline Steel Frame Details Col AA/A1 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-645	Zone 1 Building A Outline Steel Frame Details Col AB/A1 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-646	Zone 1 Building A Outline Steel Frame Details Col AB/A1 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-647	Zone 1 Building A Outline Steel Frame Details Col AB/A1 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-648	Zone 1 Building A Outline Steel Frame Details Col AB/A1 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-649	Zone 1 Building A Outline Steel Frame Details Col AB/A1 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-650	Zone 1 Building A Outline Steel Frame Details Col AC/A1 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-651	Zone 1 Building A Outline Steel Frame Details Col AC/A1 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-652	Zone 1 Building A Outline Steel Frame Details Col AC/A1 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-653	Zone 1 Building A Outline Steel Frame Details Col AC/A1 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-654	Zone 1 Building A Outline Steel Frame Details Col AC/A1 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-655	Zone 1 Building A Outline Steel Frame Details Col AD/A1 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-656	Zone 1 Building A Outline Steel Frame Details Col AD/A1 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-657	Zone 1 Building A Outline Steel Frame Details Col AD/A1 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-658	Zone 1 Building A Outline Steel Frame Details Col AD/A1 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-659	Zone 1 Building A Outline Steel Frame Details Col AD/A1 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-660	Zone 1 Building A Outline Steel Frame Details Col AA/A5 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-661	Zone 1 Building A Outline Steel Frame Details Col AA/A5 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-662	Zone 1 Building A Outline Steel Frame Details Col AA/A5 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-663	Zone 1 Building A Outline Steel Frame Details Col AA/A5 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-664	Zone 1 Building A Outline Steel Frame Details Col AA/A5 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-665	Zone 1 Building A Outline Steel Frame Details Col AC/A5 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-666	Zone 1 Building A Outline Steel Frame Details Col AC/A5 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-667	Zone 1 Building A Outline Steel Frame Details Col AC/A5 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-668	Zone 1 Building A Outline Steel Frame Details Col AC/A5 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-669	Zone 1 Building A Outline Steel Frame Details Col AC/A5 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-670	Zone 1 Building A Outline Steel Frame Details Col AD/A5 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-671	Zone 1 Building A Outline Steel Frame Details Col AD/A5 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-672	Zone 1 Building A Outline Steel Frame Details Col AD/A5 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-673	Zone 1 Building A Outline Steel Frame Details Col AD/A5 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-674	Zone 1 Building A Outline Steel Frame Details Col AD/A5 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-680	Zone 1 Building B Outline Steel Frame Details Col AA/B1 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-681	Zone 1 Building B Outline Steel Frame Details Col AA/B1 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-682	Zone 1 Building B Outline Steel Frame Details Col AA/B1 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-683	Zone 1 Building B Outline Steel Frame Details Col AA/B1 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-685	Zone 1 Building B Outline Steel Frame Details Col AD/B1 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-686	Zone 1 Building B Outline Steel Frame Details Col AD/B1 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-687	Zone 1 Building B Outline Steel Frame Details Col AD/B1 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-688	Zone 1 Building B Outline Steel Frame Details Col AD/B1 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-690	Zone 1 Building B Outline Steel Frame Details Col AA/B3 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-691	Zone 1 Building B Outline Steel Frame Details Col AA/B3 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-692	Zone 1 Building B Outline Steel Frame Details Col AA/B3 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-693	Zone 1 Building B Outline Steel Frame Details Col AA/B3 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-695	Zone 1 Building B Outline Steel Frame Details Col AD/B3 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-696	Zone 1 Building B Outline Steel Frame Details Col AD/B3 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-697	Zone 1 Building B Outline Steel Frame Details Col AD/B3 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-698	Zone 1 Building B Outline Steel Frame Details Col AD/B3 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-700	Zone 1 Building A Outline Steel Frame Details Truss 1 Grid A1 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-701	Zone 1 Building A Outline Steel Frame Details Truss 1 Grid A1 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-702	Zone 1 Building A Outline Steel Frame Details Truss 1 Grid A1 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-703	Zone 1 Building A Outline Steel Frame Details Truss 1 Grid A1 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-704	Zone 1 Building A Outline Steel Frame Details Truss 1 Grid A1 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-705	Zone 1 Building A Outline Steel Frame Details Truss 1 Grid A1 Detail 06	A1	NTS	T1		E1	T1	T1
029-Z1-S-706	Zone 1 Building A Outline Steel Frame Details Truss 1 Grid A1 Detail 07	A1	NTS	T1		E1	T1	T1
029-Z1-S-707	Zone 1 Building A Outline Steel Frame Details Truss 1 Grid A1 Detail 08	A1	NTS	T1		E1	T1	T1
029-Z1-S-708	Zone 1 Building A Outline Steel Frame Details Truss 1 Grid A1 Detail 09	A1	NTS	T1		E1	T1	T1
029-Z1-S-709	Zone 1 Building A Outline Steel Frame Details Truss 1 Grid A1 Detail 10	A1	NTS	T1		E1	T1	T1
029-Z1-S-710	Zone 1 Building A Outline Steel Frame Details Truss 2 Grid AA Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-711	Zone 1 Building A Outline Steel Frame Details Truss 2 Grid AA Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-712	Zone 1 Building A Outline Steel Frame Details Truss 2 Grid AA Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-713	Zone 1 Building A Outline Steel Frame Details Truss 2 Grid AA Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-714	Zone 1 Building A Outline Steel Frame Details Truss 2 Grid AA Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-715	Zone 1 Building A Outline Steel Frame Details Truss 2 Grid AA Detail 06	A1	NTS	T1		E1	T1	T1
029-Z1-S-716	Zone 1 Building A Outline Steel Frame Details Truss 2 Grid AA Detail 07	A1	NTS	T1		E1	T1	T1
029-Z1-S-717	Zone 1 Building A Outline Steel Frame Details Truss 2 Grid AA Detail 08	A1	NTS	T1		E1	T1	T1
029-Z1-S-718	Zone 1 Building A Outline Steel Frame Details Truss 2 Grid AA Detail 09	A1	NTS	T1		E1	T1	T1
029-Z1-S-719	Zone 1 Building A Outline Steel Frame Details Truss 2 Grid AA Detail 10	A1	NTS	T1		E1	T1	T1
029-Z1-S-720	Zone 1 Building A Outline Steel Frame Details Truss 3 Grid A5 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-721	Zone 1 Building A Outline Steel Frame Details Truss 3 Grid A5 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-722	Zone 1 Building A Outline Steel Frame Details Truss 3 Grid A5 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-723	Zone 1 Building A Outline Steel Frame Details Truss 3 Grid A5 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-724	Zone 1 Building A Outline Steel Frame Details Truss 3 Grid A5 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-725	Zone 1 Building A Outline Steel Frame Details Truss 3 Grid A5 Detail 06	A1	NTS	T1		E1	T1	T1
029-Z1-S-726	Zone 1 Building A Outline Steel Frame Details Truss 3 Grid A5 Detail 07	A1	NTS	T1		E1	T1	T1
029-Z1-S-727	Zone 1 Building A Outline Steel Frame Details Truss 3 Grid A5 Detail 08	A1	NTS	T1		E1	T1	T1
029-Z1-S-730	Zone 1 Building A Outline Steel Frame Details Truss 4 Grid AB Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-731	Zone 1 Building A Outline Steel Frame Details Truss 4 Grid AB Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-732	Zone 1 Building A Outline Steel Frame Details Truss 4 Grid AB Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-733	Zone 1 Building A Outline Steel Frame Details Truss 4 Grid AB Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-734	Zone 1 Building A Outline Steel Frame Details Truss 4 Grid AB Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-735	Zone 1 Building A Outline Steel Frame Details Truss 4 Grid AB Detail 06	A1	NTS	T1		E1	T1	T1
029-Z1-S-736	Zone 1 Building A Outline Steel Frame Details Truss 4 Grid AB Detail 07	A1	NTS	T1		E1	T1	T1
029-Z1-S-737	Zone 1 Building A Outline Steel Frame Details Truss 4 Grid AB Detail 08	A1	NTS	T1		E1	T1	T1
029-Z1-S-740	Zone 1 Building A Outline Steel Frame Details Truss 5 & 6 Grid AC Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-741	Zone 1 Building A Outline Steel Frame Details Truss 5 & 6 Grid AC Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-742	Zone 1 Building A Outline Steel Frame Details Truss 5 & 6 Grid AC Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-743	Zone 1 Building A Outline Steel Frame Details Truss 5 & 6 Grid AC Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-744	Zone 1 Building A Outline Steel Frame Details Truss 5 & 6 Grid AC Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-750	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-751	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-752	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-753	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-754	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-755	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 06	A1	NTS	T1		E1	T1	T1
029-Z1-S-756	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 07	A1	NTS	T1		E1	T1	T1
029-Z1-S-760	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 01	A1	NTS	T1		E1	T1	T1
029-Z1-S-761	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 02	A1	NTS	T1		E1	T1	T1
029-Z1-S-762	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 03	A1	NTS	T1		E1	T1	T1
029-Z1-S-763	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 04	A1	NTS	T1		E1	T1	T1
029-Z1-S-764	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 05	A1	NTS	T1		E1	T1	T1
029-Z1-S-765	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 06	A1	NTS	T1		E1	T1	T1
029-Z1-S-766	Zone 1 Building B Outline Steel Frame Details Truss 1 Grid B1 Detail 07	A1	NTS	T1		E1	T1	T1

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029-Z1-S-800	Basement - Indicative Construction Sequence Sheet 1	A1	NTS	T1		E1	T1				
029-Z1-S-802	Basement - Indicative Construction Sequence Sheet 3	A1	NTS	T1		E1	T1				
029-Z1-S-803	Basement - Indicative Construction Sequence Sheet 4	A1	NTS	T1		E1	T1				
029-Z1-S-805	Basement - Indicative Construction Sequence Sheet 1	A1	NTS	T1		E1	T1				
029-Z1-S-806	Basement - Indicative Construction Sequence Sheet 2	A1	NTS	T1		E1	T1				
029-Z1-S-807	Basement - Indicative Construction Sequence Sheet 3	A1	NTS	T1		E1	T1				
029-Z1-S-808	Basement - Indicative Construction Sequence Sheet 4	A1	NTS	T1		E1	T1				
029-Z1-S-820	Building A - Indicative Construction Sequence Stage 1	A1	NTS	T1		E1	T1				
029-Z1-S-821	Building A - Indicative Construction Sequence Stage 2	A1	NTS	T1		E1	T1				
029-Z1-S-822	Building A - Indicative Construction Sequence Stage 3	A1	NTS	T1		E1	T1				
029-Z1-S-823	Building A - Indicative Construction Sequence Stage 4	A1	NTS	T1		E1	T1				
029-Z1-S-824	Building A - Indicative Construction Sequence Stage 5	A1	NTS	T1		E1	T1				
029-Z1-S-825	Building A - Indicative Construction Sequence Stage 6	A1	NTS	T1		E1	T1				
029-Z1-S-826	Building A - Indicative Construction Sequence Stage 7	A1	NTS	T1		E1	T1				
029-Z1-S-827	Building A - Indicative Construction Sequence Stage 8	A1	NTS	T1		E1	T1				
029-Z1-S-828	Building A - Indicative Construction Sequence Stage 9	A1	NTS	T1		E1	T1				
029-Z1-S-829	Building A - Indicative Construction Sequence Stage 10	A1	NTS	T1		E1	T1				
029-Z1-S-830	Building A - Indicative Construction Sequence Stage 11	A1	NTS	T1		E1	T1				
029-Z1-S-831	Building A - Indicative Construction Sequence Stage 12	A1	NTS	T1		E1	T1				
029-Z1-S-832	Building A - Indicative Construction Sequence Stage 13	A1	NTS	T1		E1	T1				
029-Z1-S-833	Building A - Indicative Construction Sequence Stage 14	A1	NTS	T1		E1	T1				
029-Z1-S-834	Building A - Indicative Construction Sequence Stage 15	A1	NTS	T1		E1	T1				
029-Z1-S-835	Building A - Indicative Construction Sequence Stage 16	A1	NTS	T1		E1	T1				
029-Z1-S-836	Building A - Indicative Construction Sequence Stage 17	A1	NTS	T1		E1	T1				
029-Z1-S-837	Building A - Indicative Construction Sequence Stage 18	A1	NTS	T1		E1	T1				
029-Z1-S-838	Building A - Indicative Construction Sequence Stage 19	A1	NTS	T1		E1	T1				
029-Z1-S-839	Building A - Indicative Construction Sequence Stage 20	A1	NTS	T1		E1	T1				
029-Z1-S-840	Building A - Indicative Construction Sequence Stage 21	A1	NTS	T1		E1	T1				
029-Z1-S-841	Building A - Indicative Construction Sequence Stage 22	A1	NTS	T1		E1	T1				
029-Z1-S-842	Building A - Indicative Construction Sequence Stage 23	A1	NTS	T1		E1	T1				
029-Z1-S-843	Building A - Indicative Construction Sequence Stage 24	A1	NTS	T1		E1	T1				
029-Z1-S-844	Building A - Indicative Construction Sequence Stage 25	A1	NTS	T1		E1	T1				
029-Z1-S-845	Building A - Indicative Construction Sequence Stage 26	A1	NTS	T1		E1	T1				
029-Z1-S-846	Building A - Indicative Construction Sequence Stage 27	A1	NTS	T1		E1	T1				
029-Z1-S-847	Building A - Indicative Construction Sequence Stage 28	A1	NTS	T1		E1	T1				
029-Z1-S-848	Building A - Indicative Construction Sequence Stage 29	A1	NTS	T1		E1	T1				
029-Z1-S-849	Building A - Indicative Construction Sequence Stage 30	A1	NTS	T1		E1	T1				
029-Z1-S-850	Building A - Indicative Construction Sequence Stage 31	A1	NTS	T1		E1	T1				
029-Z1-S-851	Building A - Indicative Construction Sequence Stage 32	A1	NTS	T1		E1	T1				
029-Z1-S-855	Building B - Indicative Construction Sequence Stage 1	A1	NTS	T1		E1	T1				
029-Z1-S-856	Building B - Indicative Construction Sequence Stage 2	A1	NTS	T1		E1	T1				
029-Z1-S-857	Building B - Indicative Construction Sequence Stage 3	A1	NTS	T1		E1	T1				
029-Z1-S-858	Building B - Indicative Construction Sequence Stage 4	A1	NTS	T1		E1	T1				
029-Z1-S-859	Building B - Indicative Construction Sequence Stage 5	A1	NTS	T1		E1	T1				
029-Z1-S-860	Building B - Indicative Construction Sequence Stage 6	A1	NTS	T1		E1	T1				
029-Z1-S-861	Building B - Indicative Construction Sequence Stage 7	A1	NTS	T1		E1	T1				
029-Z1-S-862	Building B - Indicative Construction Sequence Stage 8	A1	NTS	T1		E1	T1				
029-Z1-S-863	Building B - Indicative Construction Sequence Stage 9	A1	NTS	T1		E1	T1				
029-Z1-S-864	Building B - Indicative Construction Sequence Stage 10	A1	NTS	T1		E1	T1				
029-Z1-S-865	Building B - Indicative Construction Sequence Stage 11	A1	NTS	T1		E1	T1				
029-Z1-S-866	Building B - Indicative Construction Sequence Stage 12	A1	NTS	T1		E1	T1				
029-Z1-S-867	Building B - Indicative Construction Sequence Stage 13	A1	NTS	T1		E1	T1				
029-Z1-S-868	Building B - Indicative Construction Sequence Stage 14	A1	NTS	T1		E1	T1				
029-Z1-S-869	Building B - Indicative Construction Sequence Stage 15	A1	NTS	T1		E1	T1				
029-Z1-S-870	Building B - Indicative Construction Sequence Stage 16	A1	NTS	T1		E1	T1				
029-Z1-S-871	Building B - Indicative Construction Sequence Stage 17	A1	NTS	T1		E1	T1				
029-Z1-S-872	Building B - Indicative Construction Sequence Stage 18	A1	NTS	T1		E1	T1				
029-Z1-S-873	Building B - Indicative Construction Sequence Stage 19	A1	NTS	T1		E1	T1				
029-Z1-S-875	Building C - Indicative Construction Sequence Stage 1	A1	NTS	T1		E1	T1				
029-Z1-S-876	Building C - Indicative Construction Sequence Stage 2	A1	NTS	T1		E1	T1				
029-Z1-S-877	Building C - Indicative Construction Sequence Stage 3	A1	NTS	T1		E1	T1				
029-Z1-S-880	Building D - Indicative Construction Sequence Stage 1	A1	NTS	T1		E1	T1				
029-Z1-S-881	Building D - Indicative Construction Sequence Stage 2	A1	NTS	T1		E1	T1				
029-Z1-S-882	Building D - Indicative Construction Sequence Stage 3	A1	NTS	T1		E1	T1				
029-Z1-S-883	Building D - Indicative Construction Sequence Stage 4	A1	NTS	T1		E1	T1				
029-Z1-S-884	Building D - Indicative Construction Sequence Stage 5	A1	NTS	T1		E1	T1				
029-Z1-S-900	Superimposed Dead Load Table	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-901	Superimposed Dead Loading Plan at B2 Basement	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-902a	Superimposed Dead Loading Plan at B1 Basement Below Box-in-Box	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-902b	Superimposed Dead Loading Plan at B1 Basement For Box-in-Box	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-903	Superimposed Dead Loading Plan at Basement Mezz	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-904	Superimposed Dead Loading Plan at Lower Ground	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-905	Superimposed Dead Loading Plan at Box in Box at Ground	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-906	Superimposed Dead Loading Plan at Ground	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-907	Superimposed Dead Loading Plan at First	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-908	Superimposed Dead Loading Plan at Second	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-909	Superimposed Dead Loading Plan at Third	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-910	Superimposed Dead Loading Plan at Fourth (Bottom of Slab)	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-911	Superimposed Dead Loading Plan at Fourth	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-912	Superimposed Dead Loading Plan at Fifth	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-913	Superimposed Dead Loading Plan at Sixth	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-914	Superimposed Dead Loading Plan at Roof	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-920	Live Load Table	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-921	Live Loading Plan at B2 Basement	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-922a	Live Loading Plan at B1 Basement Below Box-in-Box	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-922b	Live Loading Plan at B1 Basement For Box-in-Box	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-923	Live Loading Plan at Basement Mezz	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-924	Live Loading Plan at Lower Ground	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-925	Live Loading Plan at Box in Box at Ground	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-926	Live Loading Plan at Ground	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-927	Live Loading Plan at First	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-928	Live Loading Plan at Second	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-929	Live Loading Plan at Third	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-930	Live Loading Plant at Fourth (Bottom of Slab)	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-931	Live Loading Plan at Fourth	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-932	Live Loading Plan at Fifth	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-933	Live Loading Plan at Sixth	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-S-934	Live Loading Plan at Roof	A0	1:100	T2		E1	T1	T1	T2		
029-Z1-SCF-073	Zone 1 B1 Box in Box Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-083	Zone 1 B1M Box in Box Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-092	Zone 1 Lower Ground Floor Box in Box Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-102	Zone 1 Ground Floor Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-105	Zone 1 Ground Floor Box in Box Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-112	Zone 1 First Floor Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-122	Zone 1 Second Floor Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-132	Zone 1 Third Floor Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-142	Zone 1 Fourth Floor Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-152	Zone 1 Fifth Floor Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-162	Zone 1 Sixth Floor Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-172	Zone 1 Roof Level Steel Connection Forces	A0	1:100	T2		E1	T1				T2
029-Z1-SCF-182	Zone 1 Roof Light Steel Connection Forces	A0	1:100	T2		E1	T1				T2

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029-Z1-SCF-401	Zone 1 Building A Structural Frame Sections/Elevations Steel Connection Forces	A1	1:100	T2		E1	T1				T2													
029-Z1-SCF-403	Zone 1 Building A Structural Frame Sections/Elevations Steel Connection Forces	A1	1:100	T2		E1	T1				T2													
029-Z1-SCF-405	Zone 1 Building A Structural Frame Sections/Elevations Steel Connection Forces	A1	1:100	T2		E1	T1				T2													
029-Z1-SCF-408	Zone 1 Building A Structural Frame Sections/Elevations Steel Connection Forces	A1	1:100	T2		E1	T1				T2													
029-Z1-SCF-409	Zone 1 Building A Structural Frame Sections/Elevations Steel Connection Forces	A1	1:100	T2		E1	T1				T2													
029-Z1-SCF-420	Zone 1 Building B Structural Frame Sections/Elevations Steel Connection Forces	A1	1:100	T2		E1	T1				T2													
029-Z1-SCF-428	Zone 1 Building B Structural Frame Sections/Elevations Steel Connection Forces	A1	1:100	T2		E1	T1				T2													
029-Z1-RCM-061	Zone 1 B2 Basement GA Concrete RC Intent	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-062	Zone 1 B2 Basement GA Concrete RC Intent - Walls	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-071	Zone 1 B1 Basement GA Concrete RC Intent	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-072	Zone 1 B1 Box in Box GA Concrete RC Intent	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-074	Zone 1 B1 Box in Box GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-081	Zone 1 B1M Basement GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-082	Zone 1 B1M Basement GA Concrete RC Intent - Walls	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-091	Zone 1 Lower Ground Floor GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-092	Zone 1 Lower Ground Floor GA Concrete RC Intent - Walls	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-101	Zone 1 Ground Floor GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-102	Zone 1 Ground Floor GA Concrete RC Intent - Walls	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-104	Zone 1 Ground Floor Box in Box GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1				T2													
029-Z1-RCM-111	Zone 1 First Floor GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-112	Zone 1 First Floor GA Concrete RC Intent - Walls	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-121	Zone 1 Second Floor GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-122	Zone 1 Second Floor GA Concrete RC Intent - Walls	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-131	Zone 1 Third Floor GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-132	Zone 1 Third Floor GA Concrete RC Intent - Walls	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-141	Zone 1 Fourth Floor GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-142	Zone 1 Fourth Floor GA Concrete RC Intent - Walls	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-151	Zone 1 Fifth Floor GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-152	Zone 1 Fifth Floor GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-161	Zone 1 Sixth Floor GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-162	Zone 1 Sixth Floor GA Concrete RC Intent - Walls	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-171	Zone 1 Roof Level GA Concrete RC Intent - Slabs	A0	1:100	T2		E1	T1		T2															
029-Z1-RCM-172	Zone 1 Roof Level GA Concrete RC Intent - Walls	A0	1:100	T2		E1	T1		T2															
SKETCHES																								
029-Z1-SK143	Indicative Masonry Wind Post Requirements	A1	1:100	T1			T1																	
029-Z1-SK174	Single Basement Construction Sequence	A3	NTS	03						03														
029-Z1-SK179	Basement temporary Works Plans	A3	NTS	02						02														
029-Z1-SK186	Ground Floor Temporary Works Steelwork	A3	NTS								00													

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Addendum to the Crossrail Safeguarding Guide: Information for Developers -January 2014

Additional considerations for complex development close to Crossrail assets completed or under Construction

1 Introduction

1.1. The construction of deep or complex foundations close to Crossrail's developing infrastructure may generate significant ground movements which, if unchecked, may adversely impact Crossrail's buried assets. This addendum sets out deliverables which are additional to the CDS identified in Crossrail Information for Developers March 2012 (the Guide), and which serve to demonstrate how risk mitigation will be undertaken to protect Crossrail's assets in the interim period until Crossrai is handed over to the future Operator.

1.2 Crossrail will review the deliverables and return an endorsement of "No Objection" to the release of its Safeguarding planning conditions, if it is reasonably satisfied that compliance has been demonstrated

2 Compliance Criteria

2.1 If there is considered to be a significant risk of impact to Crossrail's assets then developers are expected to provide evidence to demonstrate that their construction impacts do not breach Crossrail systems compliance requirements, thus:

a) Tunnel, box and shaft structures are not overstressed;

b) waterproofing (particularly of tunnel segment joints) is not impaired;

c) minimum gauge clearance (between the tunnel lining and railway systems), is not infringed;

d) predicted distortion of the track geometry resulting from any movement of the tunnel lining, does not exceed the 'No Mandated Requirement' threshold described in Appendix A of the Network Rail Standard NR/L2/TRK/001/C01 or current Standard if replaced;

e) As a guide the minimum predicted curvature induced by ground movements along the axis of the running tunnel in any plane should not reduce below a radius of 10km. This radius is considered the minimum not requiring potential maintenance intervention (e.g. track adjustment) and applies across the whole of the Central section, except in the area of the

Barbican estate between Farringdon and Liverpool St stations, where tighter constraints are required for the specialised track system in this area.

f) (within influence of running tunnels) predicted ovalisation (distortion) of the running tunnel and lining does not exceed more than ±10mm deviation from the theoretical detailed design profile. There may be scope to relax this limit pending the accuracy of tunnel construction and dimensional tolerance available in the as-built profile;

g) (within influence of station tunnels) predicted ovalisation (distortion) of platform tunnel linings does not exceed more than ±10mm deviation from the theoretical detailed design profile and tunnel intersections and connections are not stressed beyond structural limits, and predicted movements do not exceed the serviceability limits of any sensitive equipment and systems (e.g. escalators) housed within the tunnels;

h) Furthermore if railway systems are already installed then the predicted change in the vertical dimension between the top of the rail and the overhead conductor, shall not exceed (+10mm, -2mm). Subject to acceptance by Crossrail there may be scope to relax the limit pending construction tolerance left over in the as-built profile and systems installed.

Limits on permissible distortion of station tunnel and shaft linings are subject to movement tolerance of the systems (escalators etc.) within and will be considered on a case by case basis;

3 Developer's Ground Movement Impact Assessment

3.1 Pending dialogue with developer's engineers, Crossrail will issue engineering details of affected assets to help Developers' designers to assess the ground movement impact on Crossrail, in order to prove compliance and to develop risk mitigation plans as necessary. The Developers' competent engineers are free to choose their own methods of modelling and analysis provided that:

a) Methods and models are based on proven geotechnical engineering principles and practice for ascertaining the soil-structure interaction in London ground conditions;

b) Methods account for the sequence of construction of the development and the effect of incremental loading and unloading effects and;

c) Crossrail gives its No Objection to the proposed analysis strategy (basis and assumptions) prior to commencement of detailed analysis;

d) Standards are complied with;

e) If design tools are used (software packages etc.) then these have a proven track record in the UK industry;

f) Analysis accounts for other site-specific constraints (e.g. other nearby structures), where these are likely to significantly influence impacts from the development;

g) Results are clearly presented to Crossrail, in a format that does not require further interpretation to prove compliance.

4 Deliverables

4.1 The Developer would be expected to submit a Development Impact Assessment for review comprising the following:

a) A narrative describing the analysis basis and technical assumptions

b) A narrative describing the detailed analysis, results and conclusions of the impact assessment, also explaining any significant effects resulting from the construction sequence;

c) A register of interface risks including tabled recommendations (if required) for risk-based control measures, to contain significant risks to Crossrail's assets, throughout the development programme, including such considerations as unexploded ordnance (UXO) and transmission of groundbourne vibration. The register is to be issued initially and thereafter it should be maintained and updated and be made available to Crossrail upon request;

d) A commitment by the Developer (Client) to adopt designer's recommendations (or valid reasons if Clients choose not to adopt recommendations);

e) A Category 3 Check Certificate (reduced to 2 or 1 at the discretion of Crossrail and pending risk), countersigned by a senior company representative of the Developer's independent checker, which certifies the accuracy and validity of the soil-structure interaction model, the ground movement impact assessment and results (taking into account the construction strategy and site-specific constraints), as verified by the Checker's competent specialists;

f) Details as necessary to explain the construction sequence and demonstrating consistency with the assessment engineer's modelled assumptions;

g) The Monitoring Plan (see 5.1)

h) Readiness Review note (see 5.9)

i) A monitoring Close-out report explaining the extent of movement experienced by the Crossrail asset and demonstrating that stable conditions were reached following completion.

4.2 Crossrail may charge for the time of specialist resources commissioned to review and advise it on the findings of the Developer’s Assessment.

5 Monitoring of Ground Movement

5.1 Pending the risks and impacts identified the Developer shall provide an asset Monitoring Plan prior to commencement of impacting works. The Plan serves to verify that actual movements realised during construction accord with predictions and to aid the Developer’s control of ground movement.

5.2 The extent along which tunnels are to be monitored will depend on the significance and certainty of predicted ground movement impact. As a guide it is suggested that 2mm predicted diametric or radial distortion be adopted as the lower limit of the monitored extent, for conventional developments comprising conventional demolition and basement excavations founded in well determined and understood ground, free of other risk factors, such as large subterranean assets/ structures in close proximity or geological features, etc, that might impair prediction accuracy.

5.3 The Monitoring Plan developed in consultation with Crossrail shall include:

a) The Instrumentation and Monitoring (I&M) scope, developed in consultation with Crossrail and including performance requirements and layout of instrumentation and an interface protocol for managing data transmission between the parties. Crossrail will provide guidance on constraints affecting the choice and installation of monitoring equipment installed in its assets. The scope shall consider the findings of the Developer’s ground movement analysis, state of completion of the asset and construction operations during monitoring and sensitivity to movement;

b) A plan showing the tunnel, development and limits of predicted ground movement impact at tunnel axis level, superimposed on OS mapping and showing the monitored tunnel extents, dimensioned and referenced to mapped setting out points. c) The agreed monitoring schedule including the period and frequency of measurement readings for baseline calibration for the construction period and thereafter. Monitoring frequency shall be governed by the severity of impact risk for each significant stage of construction;

d) The Stability Acceptance Criteria agreed between the Developer and CRL, defining when monitoring may cease after completion;

e) Defined orders of movement for green, amber, red, black trigger response actions to mitigate adverse observed in-tunnel movement trends. The Developer will consult Crossrail to agree the green, amber, red and black (if affecting operational track) movement trigger levels, and to advise response actions to arrest adverse in-tunnel movement trends which might otherwise have long term consequences on the operation of the Crossrail asset. It is worth noting that Crossrail in its construction of tunnels and shafts assumed nominally 75%, 100% and 125% of the predicted movement for its green, amber and red trigger alerts respectively;

f) A communication plan including template(s) for reporting monitoring results and response actions and arrangements for Crossrail review and discussion of monitoring results;

g) Provisions for pre- and post-construction visual inspections of the Crossrail asset to ascertain the condition of the asset before and after completion of the developer's works.

h) Provisions for a close-out report

5.4 The Monitoring Plan shall be submitted to Crossrail for review and acceptance prior to the start of construction of the influential development works.

5.5 Monitoring results shall:

a) Verify designer's modelled predictions for in-tunnel movements;

b) Allow early detection of aberrant movement trends;

c) Inform the Developer's risk-based Response Action Plan which is to be developed in conjunction with Crossrail, and which informs Crossrail's Emergency Response Plan which serves to protect of personnel present in the asset at the time.

5.5 Unless agreed otherwise the Developer shall fund the costs of installation and eventual removal of monitoring to protect the Crossrail asset from its construction impact plus the costs of Crossrail personnel engaged in the review of monitoring results.

5.6 It is envisaged that, during Crossrail' s construction phase it will be most cost effective and most efficient if monitoring on Crossrail's property is procured, installed and measured by Crossrail under terms set out in a Monitoring Agreement between the parties.

5.7 Monitoring equipment and methods shall be installed if required, calibrated, tested and baselined prior to commencement of impact on the assets.

5.8 The Developer shall consult Crossrail in the preparation of an acceptable schedule for the installation of monitoring equipment, taking into consideration reasonable lead times for instruction, procurement and in-tunnel activities being undertaken at the time. The lead time will depend on the state of completion (construction, fit-out, testing and commissioning) of the Crossrail assets affected.
The Crossrail Safeguarding team will facilitate the interface engagement between the Developer and the wider Crossrail team to minimise delay.

5.9 The Developer shall provide evidence that it has undertaken a review prior to commencement of influential works, which certifies the readiness of systems installed to mitigate predicted impacts on Crossrail and procedures to establish and expedite corrective actions in the event that monitoring shows breaches of trigger levels.

5.10 Groundbourne Vibration during construction is a potential risk for Crossrail particularly during open faced construction of its tunnels. Crossrail would object if developers' proposals included percussion driven piling and other vibration inducing methods, within 15m plan distance of its assets. Similarly Crossrail would be concerned if developers' proposals were likely to induce significant vibration in the vicinity, e.g. during demolition and breaking out of buried obstructions. The Developer is expected to consider and show details of appropriate mitigation for these risks and to include this in its interface risk register.

6 Defect Surveys

6.1 Depending on the nature of risk imposed by the development construction Crossrail may insist that pre- and post-construction visual defects inspections of its impacted asset be undertaken jointly with the Developer's representative.

6.2 The Method Statement for conducting in-tunnel defects surveys for the purposes of infrastructure protection is contained in Document No. CRL1-XRL-N3-GMS-CR001-50001. Methods shall adhere to relevant LU Standards contained therein.

6.3 The Developer's engineer will prepare annotated photographic inspection reports which are to be agreed jointly with Crossrail and which will provide evidence of any change in the condition of the asset as a result of construction.

6.4 It is envisaged that defect surveys will be arranged and undertaken under terms set out in a Monitoring Agreement between the parties. 6.5 The Developer should note that the lead time required to undertake surveys is dependent on Crossrail works contractors' planned construction activities taking place in the assets concerned. Surveys will need to be timed to minimise interference with scheduled in-tunnel works.

7 Liaison with Crossrail

7.1 Crossrail's principal points of contact for Planning matters are given in section 5.2 of the Guide. Additionally and unless notified otherwise technical liaison shall be undertaken through the Third Party Developments Manager (Chief Engineers Group), who is currently:

7.2 Geoff Rankin: geoffrankin@crossrail.co.uk; telephone 0203 229 9600

8 Appendix A

Information released to facilitate analysis of Development impact on Specific Crossrail assets

Details to be provided pending confirmation of interface extents

Track movement criteria:

Fault	Trigger Level	Action
Level 1	Difference in consecutive cants over 3m is greater than 1/300 (equivalent to 10mm)	Note
Level 2	Difference in consecutive cants over 3m is greater than 1/200 (15mm)	Report Level 2 fault to Fault Control Centre (FCC). Instruct FCC to report fault to Track Section Manager immediately. The fault shall be rectified within 7 days.
Level 3	Difference in consecutive cants over 3m is greater than 1/125 (24mm)	Report Level 3 fault to FCC. Instruct FCC to report fault to Track Section Manager immediately. The fault shall be rectified within 36 hours.
Level 4	Difference in consecutive cants over 3m is greater than 1/90 (33mm)	The Site Manager shall immediately inform the Signaller that the line shall be blocked with immediate effect because of a dangerous twist fault. Report Level 4 fault to FCC. Instruct FCC to report to Track Section Manager immediately. No rail traffic shall use the line until the fault has been corrected.
Cant variation	*Changes in cant of either (a)* +/- 20mm for non-electrified lines and lines with standard electrification clearances, or (b) +/- 15mm for lines with restricted electrification clearances.	*Report fault to FCC.* Instruct FCC to report fault to Track Section Manager for immediate inspection of track.
Displacement fault	25mm* difference from the original start position in any direction for any point *This may be reduced to 10mm where the length of track is subject to an Enhanced Permissible Speed or where a higher level of track quality is required.	Report fault to FCC. Instruct FCC to report fault to Track Section Manager for immediate inspection of track.
For Level 3 and Level 4 faults, the site works shall stop immediately. A review of the methodology and the cause of the movement shall be undertaken before the site works recommence. The review team shall include the Designer and the Network Rail Project Engineer.		
For a Level 4 fault, the interval between monitoring shall be decreased to at least two-hourly and remain at this until the geometry of the track has stabilised.		

Project no	029	sheet no	01
Calculations by	EL	date	13.05.2016
Checked	JB	rev	1
Project name	ST GILES CIRCUS		
Client	A-SQUARED STUDIO		
Architect	ORMS		
Document ref:	GENERAL PILES MIN MAX REALISTIC FOR CONSTRUCTION AND PERMANENT CASES - DEAD LOAD ONLY		

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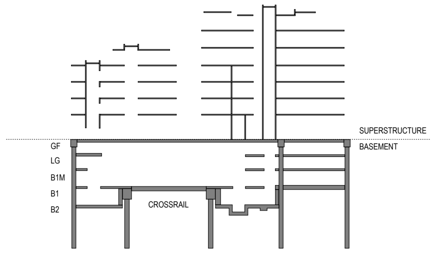
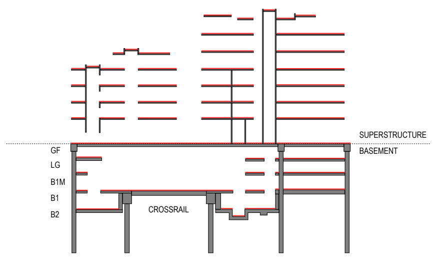
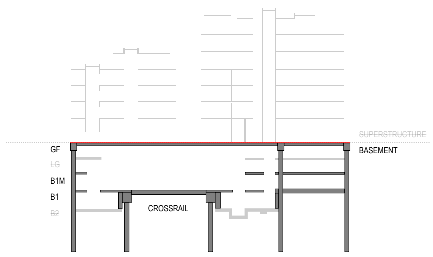
		PERMANENT CASE - DEAD LOAD ONLY				TEMPORARY CASE - DEAD LOAD ONLY		PERMANENT CASE		TEMPORARY CASE	
		Robot	*Tekla*	*Robot*	*Tekla*	*Tekla*	*Tekla*	MIN. REALISTIC	MAX. REALISTIC	MIN. REALISTIC	MAX. REALISTIC
Pile ID	**Pile inclusion**	Type. 1	Type. 1	Type. 2	Type. 2	Type. 3	Type. 4	Type. 1 - Worst case Robot/Tekla	Type. 2 - Worst case Robot/Tekla	Type. 3	Type. 4
CP01	EXISTING	3586	2890	5370	4242	0	0	2890	5370	0	0
CP02	EXISTING	4055	4081	5595	5787	0	0	4055	5787	0	0
CP03	EXISTING	5161	4254	7301	5786	0	0	4254	7301	0	0
CP04	EXISTING	5152	3690	7106	4907	0	0	3690	7106	0	0
CP05	EXISTING	7845	8808	12181	12424	7281	9173	7845	12424	7281	9173
CP06	EXISTING	6646	7077	9940	9439	2733	8357	6646	9940	2733	8357
CP07	EXISTING	6438	7779	9402	10312	4087	9437	6438	10312	4087	9437
P2	PLUNGE COLUMN	817	1111	1264	1752	477	5486	817	1752	477	5486
P3		513	558	779	837	0	0	513	837	0	0
P74		506	593	784	909	0	0	506	909	0	0
P6		453	522	683	796	0	0	453	796	0	0
P8	PLUNGE COLUMN	746	914	1160	1414	465	2398	746	1414	465	2398
P75		1214	1406	1871	2259	0	0	1214	2259	0	0
P11	PLUNGE COLUMN	458	601	710	1049	991	1236	458	1049	991	1236
P77		537	701	829	1126	0	0	537	1126	0	0
P76		527	646	817	1009	0	0	527	1009	0	0
P78		553	766	837	2081	0	0	553	2081	0	0
P18	PLUNGE COLUMN	853	1262	1340	1192	1171	1279	853	1340	1171	1279
P20		865	1137	1322	1784	0	0	865	1784	0	0
P70		792	927	1224	1443	0	0	792	1443	0	0
P71		492	552	745	844	0	0	492	844	0	0
P73	PLUNGE COLUMN	582	749	879	1181	362	659	582	1181	362	659
P22	PLUNGE COLUMN	524	564	776	848	254	279	524	848	254	279
P23	PLUNGE COLUMN	847	1238	1316	2014	877	3437	847	2014	877	3437
P25	PLUNGE COLUMN	599	640	884	977	350	532	599	977	350	532
P26		534	570	766	819	0	0	534	819	0	0
P27		522	528	741	729	0	0	522	741	0	0
P28	PLUNGE COLUMN	551	825	771	1163	326	1155	551	1163	326	1155
P29	PLUNGE COLUMN	549	770	762	1015	286	882	549	1015	286	882
P30	PLUNGE COLUMN	849	836	1181	1118	375	1525	836	1181	375	1525
P31	PLUNGE COLUMN	1757	1811	2536	2575	938	2694	1757	2575	938	2694
P32	PLUNGE COLUMN	1792	1976	2583	2759	512	2420	1792	2759	512	2420
P33	PLUNGE COLUMN	1193	1157	1673	1529	1187	3935	1157	1673	1187	3935
P34	PLUNGE COLUMN	834	929	1184	1239	303	1206	834	1239	303	1206
P35	PLUNGE COLUMN	797	889	1148	1248	149	883	797	1248	149	883
P36	PLUNGE COLUMN	1525	1700	2234	2416	743	1657	1525	2416	743	1657
P37	PLUNGE COLUMN	782	902	1122	1234	206	844	782	1234	206	844
P38	PLUNGE COLUMN	1796	2068	2620	2903	322	1385	1796	2903	322	1385
P39	PLUNGE COLUMN	1722	1871	2406	2447	776	2052	1722	2447	776	2052
P40	PLUNGE COLUMN	1126	1326	1588	1742	239	1160	1126	1742	239	1160
P41	PLUNGE COLUMN	766	922	1076	1210	307	806	766	1210	307	806
P42	PLUNGE COLUMN	725	850	1035	1157	341	733	725	1157	341	733
P43	PLUNGE COLUMN	1490	1740	2166	2439	629	1095	1490	2439	629	1095
P44		609	661	905	977	0	0	609	977	0	0
P45	PLUNGE COLUMN	866	1009	1324	1569	971	1554	866	1569	971	1554
P46		640	724	897	972	0	0	640	972	0	0
P47		636	697	910	956	0	0	636	956	0	0
P49		600	574	877	809	0	0	574	877	0	0
P50		576	579	861	862	0	0	576	862	0	0
P51		599	662	909	1017	0	0	599	1017	0	0
P52		585	563	818	773	0	0	563	818	0	0
P53	PLUNGE COLUMN	917	1027	1305	1444	701	1300	917	1444	701	1300
P54	PLUNGE COLUMN	703	845	1009	1172	583	1070	703	1172	583	1070
P55	PLUNGE COLUMN	1478	1668	2154	2355	796	1671	1478	2355	796	1671
P56		581	572	858	830	0	0	572	858	0	0
P57	PLUNGE COLUMN	871	1097	1310	1647	633	1304	871	1647	633	1304
P58	PLUNGE COLUMN	601	802	904	1212	659	1117	601	1212	659	1117
P59		614	529	854	709	0	0	529	854	0	0
P62	PLUNGE COLUMN	644	798	952	1138	508	944	644	1138	508	944
P63		591	719	878	1030	0	0	591	1030	0	0
P64	PLUNGE COLUMN	616	822	917	1161	621	1076	616	1161	621	1076
P66	PLUNGE COLUMN	1473	1736	2120	2385	517	1440	1473	2385	517	1440
P67	PLUNGE COLUMN	899	1105	1316	1534	590	1123	899	1534	590	1123
P68		592	625	868	855	0	0	592	868	0	0
P74		835	1056	1229	1463	0	0	835	1463	0	0
P103	TEMPORARY PLUNGE COLUMN	1873	1288	2597	1908	2103	2749	1288	2597	2103	2749
P104											
P105		1749	1246	2301	1871	305	305	1246	2301	305	305
P106											
P107		1552	1260	2155	1919	305	305	1260	2155	305	305
P108											
P109	TEMPORARY PLUNGE COLUMN	1455	1226	2023	1881	3706	4018	1226	2023	3706	4018
P110											
P111		1365	1173	1912	1806	305	305	1173	1912	305	305
P112											
P113		1291	1190	1844	1849	305	305	1190	1849	305	305
P114											
P115	TEMPORARY PLUNGE COLUMN	1253	1194	1761	1839	1994	2336	1194	1839	1994	2336
P116											
P117		1207	1270	1704	1892	305	305	1207	1892	305	305
P118											
P119		1243	1085	1719	1579	305	305	1085	1719	305	305
P120											
P121		1304	1058	1800	1519	305	305	1058	1800	305	305
P122											
P123	TEMPORARY PLUNGE COLUMN	1394	1119	1928	1592	4232	4338	1119	1928	4232	4338
P124											
P125		1457	1166	2021	1645	305	305	1166	2021	305	305
P126											
P127		1612	1259	2252	1767	305	305	1259	2252	305	305
P128											
P129		1747	1644	2455	2295	305	305	1644	2455	305	305
P130											
P131	TEMPORARY PLUNGE COLUMN	1884	2063	2659	2861	2871	4030	1884	2861	2871	4030
P132											
P133	PLUNGE COLUMN	2005	2133	2832	2929	2046	3528	2005	2929	2046	3528
P134											
P135	PLUNGE COLUMN	2083	1787	2942	2861	2101	3359	1787	Z	2101	3359
P136											
P137		2118	1930	2991	2929	305	305	1930	2991	305	305
P138											
P139	PLUNGE COLUMN	2187	1946	3091	2423	2356	3030	1946	3091	2356	3030
P140											
P141		2269	1825	3208	2576	305	305	1825	3208	305	305
P142											
P143		2382	2373	3373	2556	305	305	2373	3373	305	305
P144											
P145		2423	1767	3504	2361	305	305	1767	3504	305	305
P146											
P147	PLUNGE COLUMN	2309	1769	3361	3038	2013	3940	1769	3361	2013	3940
P148											
P149	PLUNGE COLUMN	2249	1700	3288	2528	2295	3742	1700	3288	2295	3742
P150											
P151		2174	1819	3195	2544	305	305	1819	3195	305	305
P152											
P153		2112	1930	3120	2452	305	305	1930	3120	305	305
P154											
P155		2031	1554	3027	2636	305	305	1554	3027	305	305
P156											
P157	TEMPORARY PLUNGE COLUMN	1979	1800	2983	2836	3149	3926	1800	2983	3149	3926
P158											
P159		1947	1536	2965	2773	305	305	1536	2965	305	305
P160											
P161		1933	1548	2967	2400	305	305	1548	2967	305	305
P162											
P163	TEMPORARY PLUNGE COLUMN	1932	1598	2981	2425	3143	4289	1598	2981	3143	4289
P164											
P165		1927	1699	2965	2489	305	305	1699	2965	305	305
P166											
P167		1924	1772	2934	2607	305	305	1772	2934	305	305
P168											
P169	PLUNGE COLUMN	1926	1912	2905	2657	3143	3846	1912	2905	3143	3846
P170											
P171	TEMPORARY PLUNGE COLUMN	1917	1830	2865	2793	3215	3887	1830	2865	3215	3887
P172											
P173		1894	1782	2808	2621	305	305	1782	2808	305	305
P174											
P175		1867	1782	2748	2506	305	305	1782	2748	305	305
P176											
P177		1847	1748	2755	2469	305	305	1748	2755	305	305
P701	TEMPORARY PLUNGE COLUMN	1103	729	1530	961	1100	3008	729	1530	1100	3008
P704	TEMPORARY PLUNGE COLUMN	1156	977	1614	1286	1153	2109	977	1614	1153	2109
P709	PLUNGE COLUMN	1454	2565	2036	3470	1459	2757	1454	3470	1459	2757



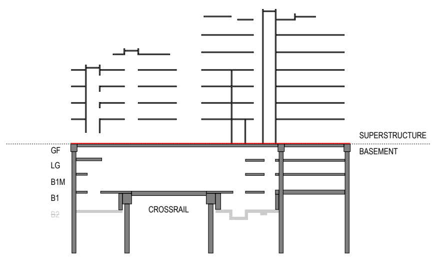
TYPE 1: SELF-WEIGHT WHOLE BUILDING
NO SUPER IMPOSED DEAD LOAD



TYPE 2: SELF-WEIGHT WHOLE BUILDING
PERMANENT SUPER IMPOSED DEAD LOAD WHOLE BUILDING



TYPE 3: SELF-WEIGHT BASEMENT ONLY WITHOUT LOWER GROUND AND B2 FLOORS
TEMPORARY SUPER IMPOSED DEAD LOAD AT GROUND FLOOR



TYPE 4: SELF-WEIGHT WHOLE BUILDING WITHOUT B2 FLOOR
TEMPORARY SUPER IMPOSED DEAD LOAD AT GROUND FLOOR

KEY:
SELF-WEIGHT
SUPER IMPOSED DEAD LOAD

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