I2: Halcrow - Ground Settlement Report

Environmental Statement

Volume II

Buro Happold

Northern Line Extension Reference Design TWAO

GRNLEB-BHD-00-XX-TNT-GEO-00049-06-01

Settlement Report

026932

21 March 2013

Revision 06-01

Revision	Description	Issued by	Date	Checked
01-01	For Information (Based on August 2012 Scheme Freeze)	JJD	October 2012	JP
02-01	For Information (Based on Stage C Drawing Issue - December 2012) – Cross passages added and utility damage updated.	JJD	January 2013	JP
03-01	For Information (Based on Stage C Drawing Issue – December 2012) – Adits and substation added.	JJD	February 2013	JP
04-01	For Information (Based on Stage C Drawing Issue – December 2012) – Refined analysis for BDCH.	JJD	February 2013	JP
05-01	For Information (Based on Stage C Drawing Issue – December 2012) – Deeper Kennington Green adit modelled, change to damage limits for Cast Iron Gas Pipes and amendments to text.	JJD	March 2013	JP
06-01	For Information (Based on Stage C Drawing Issue December 2012) – Alternative construction option drawings amended (Appendix A5) and Appendix C amended.	JJD	March 2013	JP

author **Jonathan Dewsbury**

signature

date **21st March 2013**

approved **Justin Phillips**

signature

date **21st March 2013**

..

Contents

Table of Tables

Executive Summary

This report presents the ground surface settlement, building damage assessment, and potential utility damage due to the proposed Northern Line Extension (Kennington to Battersea). The assessment has been carried out using the geotechnical software X-DISP and the procedure set out in LUL Standard 1-050 Issue A2 (January 2009) Section 3.6. Due to the stage of the project only a Phase 1 and Phase 2 assessment has been conducted. A Phase 2 assessment is a conservative greenfield analysis that does not take into account the stiffening effect of buildings or infrastructure on the settlement trough.

The results can be summarised as follows:

- The maximum settlement is approximately 70mm and occurs at the west end of the Battersea station box. This is due to the platform tunnels (9.4mED) and large diameter over-run tunnels (7.5mED) in that area. The maximum settlement around the Nine Elms station box is approximately 40mm and occurs at the east end of the box, near Wandsworth Road.
- There is approximately 50mm of settlement at the southbound step-plate junction and 60mm around the northbound step-plate junction.
- The majority of buildings fall within Building Damage Category 0 (Negligible) or Category 1 (Very Slight). However, a number of buildings exceed these categories. These are:
    - The Kent Building and the Cattery associated with the Battersea Dogs and Cats Home to the west of the Battersea Station Box fall within Category 2 (Slight) to Category 3 (Moderate).
    - Approximately 30 No. residential buildings around the step-plate junction fall within Category 2 (Slight).
- Allowance should be made for stabilising structures that are deemed to be in category 3 (Moderate) or structures in category 2 (Slight) that are considered sensitive. Methods of stabilisation may include underpinning or compensation grouting.
- 34 No. Gas, 3 No. Sewers, and 24 No. Water Services are deemed critical due to the ground surface settlements.

In addition to the Reference Design detailed above, the predicted ground surface settlement and building damage classification for an alternative construction option are also presented. The alternative construction option uses a sprayed concrete lining (SCL) tunnel between the Kennington Park and Kennington Green shaft and the step-plate junction. It also uses a temporary gallery tunnel parallel to the running tunnel for compensation grouting and control of groundwater (instead of temporary grout shafts).

The results from the alternative construction option showed that:

- The maximum settlement around the northbound step-plate junction would be 50mm (instead of 60mm). This is due to the removal of the temporary grout shafts.
- The 10mm settlement contour would extend over a greater area due to the presence of the temporary gallery tunnels and the SCL running tunnels.
- An additional 4 No. buildings around the step-plate junction would be within Category 2 (Slight).

When reviewing the results from the analysis the following points should be considered:

- All analysis has been conducted using the data available at the time of Reference Design.

- The available information about buildings and utilities along the route is variable, both in terms of quantity, quality, clarity and completeness. Where information is not available, conservative assumptions have been made. Utilities data for this report have been based on a Groundwise search originally used for the Real Estate Opportunities 2010 Reference Design. No account has been taken of development works currently in planning or not constructed.
- Assumptions regarding parameters such as volume loss and building and utility damage criteria are based on published data (See Appendix C) and the experience of the designers from similar projects in London.
- The analyses only take account of the effects of the Northern Line Extension. The impact of the wider masterplan development at Battersea Power Station, including basements, has not been considered.
- In accordance with LU guidance all buildings within a 1mm settlement contour have been considered.
- Only structures that fall within the 10mm predicted settlement contour have undergone a Phase 2 assessment. The Phase 2 assessment classifies the structures into building damage category (As per LUL Standard 1-050 Issue A2 (January 2009) Section 3.6).
- Only gas, sewer, and water utilities that fall within the 10mm predicted ground settlement contour, and are at an angle of between 35° and 90° to the line of the predicted ground settlement contours, have been assessed for potential damage.
- Further work during detailed design will be required in terms of refining the analysis assumptions e.g. volume loss values, building stiffness's, and utility input data (in terms of pipe material, size, depth, and joint make-up). Any refinements are to be incorporated into Phase 3 analysis e.g. finite element and more rigorous soil deformation models.
- Additional ground investigation works are recommended, including more closely spaced boreholes and targeted investigation at sensitive structures and utilities.
- Buildings greater than 4 storeys in height are considered an obstruction risk to tunnelling due to the potential presence of deep piled foundations. Where construction records are not available from the building owners it will be necessary to undertake building inspections and limited intrusive foundation investigations to manage the construction risk ahead of tunnelling.

1 Introduction

It is proposed to extend the Charing Cross Branch of the Northern Line (NLE). The planned route is from the existing Kennington Loop, which forms the end of the Charing Cross Branch, to a new station at Battersea Power Station, with an intermediate station at Nine Elms. Connection to the Kennington Loop will be via two step-plate junctions. It is anticipated that there will be two ventilation shafts at Kennington Green and Kennington Park, and two temporary grout shafts at each step-plate junction beneath Radcot Street (Northbound) and Harmsworth Street (Southbound).

An alternative construction option for the step-plate junction is also being considered. The alternative construction option adopts a temporary gallery tunnel (for grouting and ground water control), and sprayed concrete lining (SCL) tunnels between the ventilation shafts and the step-plate junction. The construction method for the step-plate junction will be confirmed during the detailed design stage or when the contractor is appointed.

This report outlines the tunnel and station box ground settlement analyses that have been undertaken following the December 2012 Stage C Drawing Issue (at which the alignment and dimensions of the running/overrun tunnels, crosspassages and stations was frozen). The following results are presented:

1. Predicted ground surface settlement due to the proposed NLE, the station boxes, and the various ventilation and temporary grout shafts.
2. Building damage classification of existing structures at ground level due to the predicted settlement.
3. Potential utilities damage due to the predicted ground settlement.

In addition:

- Buildings overlying the tunnel alignment that may be on piled foundations are identified.
- Recommendations for areas that require further investigation and analysis are highlighted.
- Predicted ground surface settlements due to an alternative construction option at the step-plate junction developed through Early Contractor Involvement (ECI) are presented.
- Building damage classification of existing structures at ground level due to the alternative construction option at the step-plate junction.

All analyses and building damage classification has been carried out in accordance with the procedure set out in *LUL Standard 1-050 Issue A2 (2009) Section 3.6* and *LUL Guidelines on ground movement due to tunnelling and deep excavations*. Full details are given in Section 4.

2 Background

This section details information that was available at the time of the Reference Design and was subsequently used to inform the ground settlement analysis, building damage classification, and utility damage assessment.

2.1 Historical ground investigation information

The following historical information is available:

- Parsons Brinckerhoff Ltd, Northern Line Extension to Battersea Power Station Engineering and Architectural Feasibility Study. Feasibility Report , ref: UMD90388A/0039/03, dated 10th December 2008
- Parsons Brinckerhoff Ltd, Northern Line Extension to Battersea Power Station Engineering and Architectural Feasibility Study. Feasibility Report Addendum, ref: UMD90388A/0041/03, dated 27th October 2009
- Buro Happold Ltd, Battersea Power Station Summary of Site Wide Geotechnical Data, ref: BHB/AD210/$$/RE/000/00004/DOC, dated 7th January 2005.
- Assorted borehole records obtained from the British Geological Survey and other Buro Happold projects in the Battersea, Nine Elms and Oval areas.

The reader should refer to the Northern Line Extension to Battersea Reference Design – Design Submission Report, dated February 2013 for further details.

2.2 2010 Ground Investigation

A further 10 No. cable percussion boreholes were drilled (at approximate 300m spacings) to supplement the existing records and to provide information at critical locations along the route. The findings can be found in Concept Site Investigation Ltd's Factual Report reference 10/2254-FR01, dated 7th July 2010.

2.3 Buildings information

General form and size of structures along the proposed NLE route to be used in the building damage classification has been inferred from several sources, these include:

- The 1:50,000 Ordnance Survey Ordnance Landranger maps (License Number: AL100005517) available at the time of analysis (December 2012).
- A walkover survey carried out by Buro Happold Ltd personnel on the 4th of March 2010.
- Satellite Images and Google Earth Pro (License: 2012 Infoterra Ltd & Bluesky).

Where possible the local Building Control offices have been contacted to obtain records of critical structures, particularly structural form and foundations. However the available information is very limited and much of the data is restricted under copyright or incomplete. Thus the information used, was that available at the time of the Reference Design. It is likely that during the Reference Design process some existing buildings have been demolished, or new buildings constructed. Therefore it will be necessary in the next phase of design to contact local building owners, and the local councils to provide sufficient details on the buildings along the proposed NLE route.

2.4 Utility information

Utility drawings along the route were obtained from Groundwise Ltd, 2010. The extent and quality of the information contained in the service plans is highly variable and in many cases is incomplete e.g. pipe material and depth is missing. Furthermore, the utility plans do not give any indication of planned works e.g. pipe replacements or diversions.

In particular the plans of the water and sewers provided by Thames Water did not detail pipe or sewer construction material. Following discussions with Thames Water conservative assumptions about the pipe material and sewer construction have been made, these are fully detailed in Section 4.5.

3 Ground conditions

3.1 Ground model

The ground model detailed in Table 3 -1 is based on the historical ground investigation information (detailed in Section 2.1) and the 2010 Ground Investigation. Geological long sections have been produced from the numerous boreholes available along the proposed NLE route. These geological long sections are shown in drawings GRNLEB-BHD-TU-XX-DR-GEO-14100-05-01 to GRNLEB-BHD-TU-XX-DR-GEO-14102-05-01 (Appendix A1).

The following should be noted:

- Logging of the interface between the London Clay and Lambeth Group has been historically misinterpreted. This is particularly the case where there are sandy horizons towards the base of the London Clay.
- The top of the London Clay around in the Battersea and Kennington areas is known to be significantly deeper in localised areas due to the presence of scour features that have been filled with other depositional material. These scour features can be less than 50m across in plan and 30m to 40m deep. A potential scour feature that will require further investigation in the next phase of design is shown on drawing GRNLEB-BHD-TU-XX-DR-GEO-14100-04-01.
- The ground investigation carried out to date is sufficient for the purposes of the Reference Design. A more thorough and targeted ground investigation will be required for the final design phase. Recommendations are made in Section 8.

Table 3—1 Summary of ground conditions

Stratum	Elevation of Top of Stratum (m OD)	Range of Thickness (m)	Brief Description
Made Ground	+5.50 to +1.60	0.50 to 3.95	Loose to dense clayey sandy gravel with occasional cobbles to soft to firm sandy gravelly clay. Gravel and cobbles comprise flint, brick and concrete with occasional ash, clinker, metal and timber. Localised contamination evident.
Alluvium	+4.60 to -0.75	0.00 to 3.95	Soft grey clay with varying quantities of organic material, including localised bands of fibrous peat. Locally absent.
River Terrace Deposits	+4.10 to -1.95	1.25 to 10.00	Loose to dense brown sandy gravel varying to sand & gravel or locally very gravelly sand. Gravel is predominantly flint. (River Terrace Deposits may be up to 22.85m deep in local scour features)

Stratum	Elevation of Top of Stratum (m OD)	Range of Thickness (m)	Brief Description
London Clay Formation	0.00 to -9.00	19.0 to 37.00	Stiff to very stiff grey brown becoming bluey grey fissured clay with sand and silt laminations, thin bands and nodules of calcareous material, pyrite or selenite, and fragments of wood. The base of the London Clay is marked by a thin layer of sandy gravelly clay (Harwich Formation) and on occasions with particularly sandy in the basal layers
Lambeth Group	-19.00 to -41.60	5.95 to 18.90	A complex accumulation of deposits including: • Very stiff/hard shelly clay with occasional limestone concretions (Upper Shelly Clay) • Very dense interbedded silts, sands and very stiff/hard clays. Water bearing (Laminated Beds) • Very stiff/hard shelly clay with numerous calcareous nodules (Lower Shelly Clay) • Very stiff/hard mottled clays with thin bands of very dense silt (Lower Mottled Clay) • Rounded gravel pebbles over very dense green find to medium sand (Upnor Formation) Base of the Lambeth Group is often misinterpreted as Thanet Sand.
Thanet Sand	-23.00 to -56.80	8.50 to 12.20*	Very dense greyish green silty fine sand
Upper Chalk*	-63.90 to -69.00	Base not penetrated	Moderately weak to moderately strong medium density white chalk with flint bands (Grade B2)

* Information on thickness of Thanet Sand and top of Upper Chalk is taken from the report *Buro Happold Ltd, Battersea Power Station, Summary of Site Wide Geotechnical Data,* as detailed in Section 2.1.

3.2 Groundwater

Localised perched water table may be encountered within the Made Ground and Alluvium. The main groundwater table is found in the River Terrace Deposits at an approximate level of +1.00m OD and increases hydrostatically (10kPa per metre depth) to the top of the London Clay. Monitoring data obtained during the 2010 ground investigation indicates that the water pressure within the London Clay Formation and Lambeth Group increases at a lower rate than hydrostatic. This indicates that a deeper formation e.g. sandy beds within the Lambeth Group or Thanet Sand, is acting as an underdrain, especially at the Kennington end of the route. The picture, however, is less than definitive at this stage and it is recommended that further monitoring of the ground water is undertaken.

3.3 Soil parameters

XDISP only requires the soil type at tunnel level to be entered e.g. cohesive or granular; specific soil parameters are not required. The settlement trough width is calculated from the specified k-derivation model which is based on the selection of cohesive or granular as the soil type at tunnel level. See Section 4 for further details.

3.4 Conflict with buildings potentially founded on piles

Given that existing Building Control records are incomplete, buildings greater than 4 storeys in height are considered an obstruction risk to tunnelling due to the potential presence of deep piled foundations. Where construction records are not available from the building owners it will be necessary to undertake building inspections and limited intrusive foundation investigations to manage the construction risk ahead of tunnelling.

The following buildings may be founded on piles and overlie the tunnel alignment (Based on the December 2012 Stage C Drawing Issue, at which the alignment of the running tunnels and cross passages was frozen):

- Adrian House/ Basil House, on the corner of the Wandsworth Road and Wilcox Street.
- Beaminster House (Dorset Road)
- No. 1 to 15 Branksome House
- Branksome House (Meadow Road)
- Ibberton House (Meadow Road)
- Horton House (Meadow Road)
- Sherwin House (Clayton Street)
- Telephone Exchange (Kennington Park Road)
- Wareham House (Carroun Road)
- Melbury House (Meadow Road)
- King's House (South Lambeth Road)
- No. 38 to 105 South Lambeth Road (Opposite King's House)
- Kent Building (Battersea Dogs and Cats Home)
- Part of the Post Office sorting house on Nine Elms Lane.
- No. 19 to 89 Cottingham Road

The above buildings have been highlighted with red hatching on drawings on drawings *GRNLEB-BHD-TU-XX-DR-GEO-14600* to *GRNLEB-BHD-TU-XX-DR-GEO*-14604. It should be noted that above list of piled buildings is not exhaustive. It will be necessary to undertake building inspections and where required limited intrusive foundation investigations to manage the construction risk ahead of tunnelling.

3.5 Battersea Dogs and Cats Home (Kent Building)

Available foundation records for the Kent Building have identified that 450mm diameter bored cast *in situ* piles of *c.* 20m length are situated beneath the proposed tunnel alignment (see Northern Line Extension to Battersea Reference Design – Design Submission Report, dated February 2013 for further details). Tunnelling will reduce the existing piles by a significant length reducing their capacity below acceptable levels. Remedial measures have been outlined during the Reference Design, involving either underpinning from within the Kent building, or a transfer structure. The option to decant the current users of the Kent Building to a new location within the BDCH site is also being considered using a modular construction system. The development of remedial measures for the Kent building is reported separately (GRNLEB-BHD-00-XX-TNT-MDR-00054-02-01).

4 Analysis

4.1 Introduction

This section details the analysis conducted to predicted the ground surface settlement, and the associated building and utility damage classification. The analysis has been carried out following the three phase procedure set out in LUL Standard 1-050 Issue A2 (January 2009) Section 3.6, and described in Section 3.7 of CIRIA Special Publication 200. The three phases of analysis are briefly described in Table 4-1. Only a Phase 1 and a Phase 2 analysis are appropriate for a Reference Design. A Phase 3 analysis is reserved for detailed design.

Table 4—1 Summary of analysis phases outlined in LUL Standard 1-050 Issue A2 (January 2009) and LUL Guidelines on ground movement due to tunnelling.

Phase	Clause	Description
1 (Green field predictions of settlement)	3.6.1.4 (1-050) or 2.3 (LUL Guidelines)	1. Settlement predictions for bored tunnels should be produced using empirically validated methods such as O'Reilly and New (1982), using parameters for ground loss determine from case histories. 2. For excavations, assessment should be undertaken using models validated by empirical date based on case studies of similar excavations. 3. For buildings that experience less than 10mm no further assessment is necessary. 4. Buildings with settlement or heave greater than 10mm or predicted ground slope of 1:500 or steeper are subject to a Phase 2 assessment.
2	3.6.1.5 (1-050) or 2.4 (LUL Guidelines)	5. The movements predicted for green field conditions are imposed on buildings. (Buildings are assumed to behave flexibly and their own stiffness has no influence on ground settlement). 6. The potential for damage is defined using the procedures described by Burland et al. (1977, cited in CIRIA 200, 2001) and placed into one of six risk categories (numbered 0 – 5). 7. Buildings assessed to be in risk category 0, 1 or 2 are not subjected to further assessment. (Exceptions include listed buildings or building with shallow foundation in close proximity to excavations), 8. All buildings which are placed in risk category 3 or above are subject to a Phase 3 assessment.
3*	3.6.1.6 (1-050) or 2.5 (LUL Guidelines)	Each building is considered separately. The assessment will involve the development of a building specific detail model rather than the more generic model forms used in Phase 2.

*Phase 3 level of detail exceeds the requirements of the Reference Design and should be carried out during the detailed design phase.

4.2 Phase 1 - Ground settlement analysis

Ground surface settlements have been calculated using the latest version of software XDISP 19.3, produced by OASYS Ltd. This software package, formerly known as TUNSET, calculates the vertical displacement due to tunnels and excavations.

Surface displacements due to tunnelling have been calculated using O'Reilly & New (1982). The settlement trough width is based on the distance from the centreline of the tunnel to the inflexion point on the settlement curve (i). XDISP uses a 'k-derivation method' to determine the distance 'i 'and there are a number of options available within XDISP. O'Reilly & New's 'k-derivation method' has been adopted for the following reasons:

- The thickness of Made Ground, Alluvium (where present) and River Terrace Deposits is thin relative to the thickness of London Clay that is above the tunnel crown, so a single cohesive ground model is appropriate for this design stage. More detailed ground models can be assumed at later design phases.
- O'Reilly & New's method gives a slightly wider settlement trough compared with Boscardin's method. This is considered more applicable at this stage of the design as a greater number of buildings will be captured by the settlement analysis. A wider settlement trough will ensure that more buildings are captured by the requirement to carry out a condition survey. Boscardin's method will predict a steeper settlement trough, which will potentially predict higher strains in the buildings. However, as the buildings are only approximated in the current analysis, a small difference in predicted strain will not be critical at this stage of design.
- O'Reilly & New is the approach recommended by LUL Standard 1-050 (CL. 3.6.1.4).

For the analysis the geological model has been simplified to a single layer, and assigned a 'k' value of 0.4. A value of 0.4 is representative of stiff fissured clay (CIRIA 200, 2001, pg. 26). This is deemed appropriate for the Reference Design because the tunnel, in general, is situated within the London Clay. In the zones where the tunnel passes through the Lambeth Group, part of the tunnel is still in the London Clay, or the tunnel is only at the very top of the Lambeth Group. Thus it is assumed that the majority of settlement will still derive from the London Clay (i.e. the stratum governing the general mechanisms analysed).

It should be noted that the settlement analysis only takes into account the impact of the NLE and associated infrastructure e.g. station boxes. The effects of the Battersea Power Station redevelopment masterplan, including basements, have not been incorporated into this analysis.

4.2.1 Analysis for the December 2012 Stage C Drawing Issue

The structural elements and adopted parameters for the December 2012 Stage C Drawing Issue are summarised in Table 4-2. The adopted volume loss values are considered to be moderately conservative and are based on the recommendations from CIRIA Special Publication 200 (2001), published data (See Appendix C), as well as evidence from recent comparable tunnel projects in similar ground in London. The alignment for analyses has been taken from drawing GRNLEB-HGL-00-XX-M2-PWY-00010-02-01, and the location of the cross passages from GRNLEB-HGL-00-XX-DR-TUN-20402-03-01.

It should be noted that settlement due to station excavations are based on curves from CIRIA C580. This ignores any reduction in ground movement that might occur because of the increased stiffness at the corner of the excavations. Thus the ground movement curves used represent a 100% ground movement profile. Consequently the settlement contours around the excavation are a conservative estimate.

Table 4—2 Summary of structural elements and modelling parameters for December 2012 Stage C Drawing Issue

Structure	Plan Dimensions/ External tunnel diameter (m)	Volume Loss (%)	Model
Running tunnels	5.95	1.5	
Battersea over-run tunnels	7.5	2.0	
Battersea platform tunnels	9.4	2.0	
Battersea station box and crossover box	235 x 26 (23m deep)	N/A	CIRIA C580 Fig 2.11(b) – Excavation in front of high stiffness wall in stiff clay
Nine Elms station box	142 x 30 (28m deep)	N/A	CIRIA C580 Fig 2.11(b) – Excavation in front of high stiffness wall in stiff clay
Kennington Green ventilation shaft	13.50 (27m deep)	N/A	New & Bowers (1994)
Kennington Green adit between ventilation shaft and headhouse	27 x 30 x 9 (L-shaped) (7.2m deep)	N/A	CIRIA C580 Fig 2.12 – Excavation in front of high stiffness wall in sand
Kennington Park ventilation shaft	13.50 (27m deep)	N/A	New & Bowers (1994)
Kennington Park substation	39m x 17m (12.5m deep)	N/A	CIRIA C580 Fig 2.11(b) – Excavation in front of high stiffness wall in stiff clay
Radcot Street temporary grouting shaft	5.00 (25m deep)	N/A	New & Bowers (1994)
Radcot Street adit between temporary grouting shaft and tunnel	2.74	2	
Harmsworth Street temporary grouting shaft	5.00 (25m deep)	N/A	New & Bowers (1994)
Harmsworth Street adit between temporary grouting shaft and tunnel	2.1	2	
Cross passage 1	4.8	2	
Cross passage 2	4.8	2	
Cross passage 3	4.8	2	
Cross passage 4	5.25	2	
Cross passage 5	5.25	2	

Structure	Plan Dimensions/ External tunnel diameter (m)	Volume Loss (%)	Model
Cross passage 6	5.45	2	
Northbound step-plate Junction (See Plate 1 below for location Rings.).	Ring 11600 (T14.1) – 12.2m Ring 10000 (T15.1) – 10.6m Ring 8250 (T16.1) – 8.85m Ring 7700 (T16.2-3) – 8.3m Ring 6500 (T17.1) – 7.1m Ring 5750 (T18.1) – 6.35m	2	
Southbound step-plate Junction (See Plate 2 below for location Rings).	Ring 11600 (T21.1) – 12.2m Ring 10000 (T22.1) – 10.6m Ring 7700 (T23.1) – 8.3m Ring 6500 (T24.1) – 7.1m Ring 5750 (T26.1-2) – 8.85m	2	

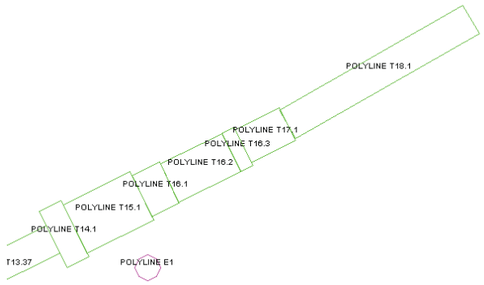


Plate 1: Modelling representation of Northbound step-plate junction

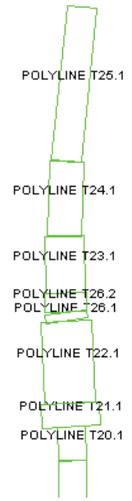


Plate 2: Modelling representation of Southbound step-plate junction

4.2.2 Alternative construction option at step-plate junction (Gallery Tunnel)

Early contractor involvement led to an alternative proposal for the construction of the step-plate junction. The alternative option uses a temporary gallery tunnel (parallel to the step-plate junction) to provide access for grouting and ground water control, instead of two grout shafts at Radcot Street and Harmsworth Street. The alternative also includes SCL running tunnels between the ventilation shafts and the step-plate junction. Additional settlement analysis was conducted to see the effect of the gallery tunnel and SCL running tunnels on predicted ground settlement.

The additional structural elements and parameters used for the analysis of the alternative construction option are summarised in Table 4-3.

Table 4—3 Summary of structural elements and modelling parameters for alternative construction option

Structure	Plan Dimensions/ External tunnel diameter (m)	Volume Loss (%)	Model
Gallery Tunnel+	4.1	2	
Hand dug tunnel (SCL) between ventilation shaft and step-plate Junction.	6.5	2	

+For the alternative construction option the Radcot Street and Harmsworth Street grout shafts are not modelled.

4.3 Phase 2 - Building classification analysis

Buildings within the 10mm settlement contour were identified from the 1:50,000 Ordnance Survey Ordnance Landranger map (License Number: AL100005517) that was available at the time of analysis.

Following the procedure outlined by Burland *et al.* (1977, cited in CIRIA 200, 2001) the buildings were represented by a rectangular beam of length 'L' and height 'H'. This was achieved in X-Disp by defining a series of facades, and specifying the height. The stiffness of the building is modelled in XDISP by defining an E/G stiffness ratio value. All affected structures along the route have been allocated an E/G value of 2.6. This assumes that the buildings behave like an isotropic beam, and represents a conservative assumption. For a phase two analysis it is assumed that the buildings behave completely flexibly and their own stiffness (E/G) has no influence on the ground settlement.

As the Reference Design affects a large amount of structures a general building height of 10m was assumed for all buildings along the alignment. Where buildings have been shown to be critical (i.e. exceeding Category 2 – Slight), or buildings were known to exceed 10m in height, a more thorough analysis has been adopted using the specific building heights. The two main areas that required specific analysis were to the west of the Battersea station box, and the residential dwellings around the step-plate junction. If a basement was noted, the basement depth was included in the building height.

X-Disp determines the building damage category by comparing the computed strain for each of the buildings with the limits of tensile strain defined by Burland et al. (1977) and reproduced in Table 4 -3.

Building damage results are presented in Section 5. Any structures that exceed Damage Category 2 (Slight) have been highlighted as requiring a Phase 3 analysis in Section 5.

Table 4—4 Building damage categories (after Burland et al., 1977)

Category of Damage	Normal degree of severity	Limiting Tensile Strain (%)
0	Negligible	0 – 0.05
1	Very Slight	0.05 – 0.075
2	Slight	0.075 – 0.15
3	Moderate	0.15 – 0.3
4 to 5	Severe	>0.3

4.3.1 Specific analysis for Battersea Dogs and Cats Home

The buildings associated with the Battersea Dogs and Cats Home (BDCH) are located to the west of the Battersea station box, in area where large settlements (up to 70mm) are expected. To assess the requirement for any ground treatment or underpinning for the BDCH, further analysis was conducted to refine the building damage classification predicted from the simple analysis detailed above. The refined analysis was required during the Reference Design because any worksites required for underpinning or ground treatment would need to be included in the TWAO submission that outlines the safeguarded zone.

The refined analysis for the Cattery and the Kent Building (which form the Battersea Dogs and Cats Home campus) adopted the following methodology:

1. Ascertain the structural form, key structural walls and columns of the building from available building records and planning drawings;
2. Calculate the greenfield settlement at the locations of the key structural walls, façades and columns;
3. Compute the deformation parameters (Figure 3.1 of CIRIA SP201, pg. 24) at the locations of the key structural walls, façades, and columns;
4. Assess the potential for the building and its foundations to stiffen the greenfield settlement predictions, and alter the greenfield settlement predictions if necessary; and
5. Compare calculated deformation parameters to published limits and make recommendations on potential damage.

The results from the refined analysis of the buildings associated with the Battersea Dogs and Cats home are given in Section 5.4.

4.4 Sensitivity analysis

The sensitivity of building damage classification to change in volume loss and tunnel diameter was investigated to the west of the Battersea Station box. Results show that a minor increase or decrease in volume loss (+/- 0.25%) or tunnel diameter (+/- 0.25m) will not significantly alter building damage classification around the Battersea Station Box.

For information some of the results for the sensitivity analysis are provided in Appendix D. These drawings are provided for information only and are not for interpretation with regards to building damage classification.

4.5 Utility damage assessment

The utilities deemed to be the most critical and selected for analysis had both of the following characteristics:

1. They were located within the 10mm settlement contour; and
2. Were aligned between 35^{o} and 90^{o} to the settlement contours.

A list of all the utilities that have been analysed is presented in Appendix B. Where the service plans did not contain information on pipe diameter or depth, conservative assumptions have been made based on the prevailing pipe size and depth within the vicinity.

In general, all the gas service plans specified the material of the pipes. Thames Water services plans, in general, did not contain information about the material used for construction of the sewers or water mains. Consultation with Thames Water concluded that for this stage of design it should be conservatively assumed that all sewers are brick, and all water pipes are cast iron.

The method used to determine the limiting strain, joint rotation, and joint pull follows the procedure outlined by Bracegirdle *et al.*, (1996) and the ground surface settlement predicted by the X-Disp analysis in Section 4.2.1.

The limiting criteria for the different utility and material types are summarised in Table 4-4 below. The following assumptions have been made:

Joint Rotation – 10% of the values suggested by Bracegirdle *et al.,* (1996. Table 2, p. 661) for a service with intact joints. This has been assumed to take account of the unknown condition of the service joints. For cast iron gas services, that are particularly susceptible to movement, 1% of the values suggested by Bracegirdle *et al.,* (1996, Table 2, p. 661) have been used.

Tensile Strain – The recommended allowable increase in strain for different materials as outlined in Table 4 (Bracegirdle *et al.,* 1996, p. 662)

Joint Pull-out – Gas services made of cast iron, steel or ductile iron are assumed to have older joints that may be damaged and unable to sustain movement. Therefore 5% of the pull-out values recommended by Bracegirdle *et al.* (1996, Table 2) have been used. For cast iron water services the joints are assumed to be lead yarn joints. To take account of the unknown condition of the joints 50% of the values recommended by Bracegirdle et al. (1996) have been adopted. Services made of polyethylene are assumed to be modern and have rubber gasket joints. Therefore the total pull-out values recommended by Bracegirdle et al. (1996) have been adopted for polyethylene services.

For services made of materials that cannot sustain tensile bending (such as brick) the distance between the neutral axis and the computed bending strain has been assumed to be the full diameter/height of the service/pipe.

Table 4—5 Summary of limiting criteria for utility damage assessment

Service Type	Material	Limiting Criteria/Allowable Values		
		Tensile Strain (%)	Joint Rotation (degrees)	Joint Pull-out (mm)
Gas	Polyethylene	0.075	0.25	25
	Steel	0.05	0.01	0.5
	Cast Iron	0.01	0.01	0.5
	Ductile Iron	0.05	0.01	0.5
Sewers	Brick	0.05 (Cat 1 – V.Slight in Table 4-3)	N/A	N/A
Water	Polyethylene	0.075	0.25	25
	Cast Iron	0.01	0.15	7.5

5 Results

5.1 Phase 1: Ground surface settlement - December 2012 Stage C Drawing Issue

The results of the settlement analysis are presented in drawing numbers GRNLEB-BHD-TU-XX-DR-GEO-14600 to GRNLEB-BHD-TU-XX-DR-GEO-14604, inclusive, and can be found in Appendix A2. The maximum settlement (70mm) occurs at the west end of the Battersea station box. This is because of the combination of the station box excavation and the large diameter sprayed concrete lined platform tunnels (9.4m External Diameter). Other key areas of settlement include the east end of the Nine Elms station box (40mm), Radcot Street adjacent to the grout shaft (60mm), and De Laune Street (50mm) adjacent to the step-plate junction.

5.2 Phase 1: Ground surface settlement – Alternative construction option

The results of the settlement analysis for the alternative construction option are presented in drawing GRNLEB-BHD-TU-XX-DR-GEO-14701. The maximum predicted settlement around the northbound step-plate junction is 50mm (instead of 60mm). This is due to the removal of the temporary grout shafts. However the 10mm settlement contour extends over a greater area due to the presence of the gallery tunnels and the SCL running tunnels.

5.3 Phase 2: Building Damage Classification – December 2012 Stage C Drawing Issue

The results of the building damage assessment are presented in drawing numbers GRNLEB-BHD-TU-XX-DR-GEO-14605 to GRNLEB-BHD-TU-XX-DR-GEO-14609, inclusive (Appendix A3). The majority of the structures fall within Damage Categories 0 (Negligible) and 1 (Very Slight).

Structures that fall within Category 2 (Slight), or Category 3 (Moderate) are summarised in Table 5-1. It should be noted that the whole building is assigned a category based on the worst case category for any part of the building. As an example, if one wall of a building is classified as ‘Moderate’, although the majority of the building is classified as ‘Slight’ the whole building will be marked as ‘Moderate’.

According to LUL guidance, only structures within Category 3 (Moderate) or above will require further analysis (Stage 3). However due to the sensitive nature of some of the structures, it is recommended that further analysis (Stage 3) been conducted for all structures listed in Table 5-1.

In addition it will be necessary to consult with Network Rail to ascertain acceptable methods of analysis for their assets. Network Rail assets that may require additional analysis have been hatched red on drawings GRNLEB-BHD-TU-XX-DR-GEO-14605 to GRNLEB-BHD-TU-XX-DR-GEO-14609. Recommendations of potential remedial measures or ground treatment to prevent damage to Network Rail assets is reported separately (GRNLEB-HGL-00-XX-TNT-MDR-00067-02-01). It should be noted that worksite areas surrounding Network Rail assets (that are marked on the limit of deviation drawings) are based on the 5mm settlement contour. The 5mm settlement contour has been chosen to provide sufficient area around Network Rail assets to carry out any remedial measures or underpinning that may be required.

Table 5—1 Summary of structures within damage category 2 (Slight) or category 3 (Moderate) for December 2012 Stage C Drawing Issue

Drawing No	Damage Category	Structure Name	Location	Anticipated Structural Form
GRNLEB-BHD-TU-XX-DR-GEO-14605	Moderate (3)	Battersea Dogs & Cats Home (Kent Building)	Battersea Park Road – near over-run tunnels	Brick structure with steel lintels and occasional steel columns
GRNLEB-BHD-TU-XX-DR-GEO-14605	Slight (2)	Cattery (Battersea Dogs & Cats Home)	Battersea Park Road – near over-run tunnels	RC and Steel Frame with Glass Cladding
GRNLEB-BHD-TU-XX-DR-GEO-14605	Very Slight (1)	Bridge 330 and associated wingwalls	Battersea Park Road, near Battersea Power Station	Brick/RC Road bridge
GRNLEB-BHD-TU-XX-DR-GEO-14606	Slight (2)	No. 39 Pascal Street	Nine Elms station box	Brick (Residential)
GRNLEB-BHD-TU-XX-DR-GEO-14606	Slight (2)	Adrian and Basil House	Between Wandsworth Road & Luscombe Way – near Nine Elms station box	Concrete frame with brick cladding
GRNLEB-BHD-TU-XX-DR-GEO-14608	Slight (2)	No. 19 Cottingham Road	Cottingham Road near Claylands Road	Brick
GRNLEB-BHD-TU-XX-DR-GEO-14606	Slight (2)	No. 45, 49, 51 Claylands Road	Claylands Road	Brick
GRNLEB-BHD-TU-XX-DR-GEO-14609	Slight (2)	No. 366 Kennington Road	Kennington Road/Montford Place	Brick (Listed)
GRNLEB-BHD-TU-XX-DR-GEO-14609	Slight (2)	No. 1 to 10 and No. 8 to 14 Stannary Street. No. 1 to 7 Stannary Place	Near Kennington Road/Oval Cricket ground	Warehouse – steel frame/brick
GRNLEB-BHD-TU-XX-DR-GEO-14609	Slight (2)	Gateway House	373 Milverton Street (near to the Old Town Hall)	Brick warehouse

Drawing No	Damage Category	Structure Name	Location	Anticipated Structural Form
GRNLEB-BHD-TU-XX-DR-GEO-14609	Slight (2)	No. 5,7,9, 8, 10, 12 and 14 Ravensdon Street	Ravensdon Street – near northbound step-plate junction	Brick with half-level basement
GRNLEB-BHD-TU-XX-DR-GEO-14609	Slight (2)	No. 1 to 6 Radcot Street	Radcot Street – near northbound step-plate junction	Brick with basement level
GRNLEB-BHD-TU-XX-DR-GEO-14609	Slight (2)	No. 1 to 6, and No. 68 to 72 De Laune Street	De Laune Street – near southbound step-plate junction	Brick with basement level
GRNLEB-BHD-TU-XX-DR-GEO-14609	Slight (2)	No. 135, 139, 141, 143 Kennington Park Road	Kennington Park Road near step-plate junction	Brick with basement (Listed Buildings)

5.4 Results from specific analysis conducted on Battersea Dogs and Cats Home

The specific analysis for the Cattery and the Kent Building which form the Battersea Dogs and Cats Home followed the methodology outlined in Section 4.3.1. The results are presented for each building over the following sections.

Building form for the Cattery was inferred from the planning drawings by Charles Knowles Design: Architects No. 8375 (21 to 33). They are available through the Wandsworth Planning Portal (http://ww3.wandsworth.gov.uk/Northgate/PlanningExplorer). Building information on the Kent Building was taken from the Cairns Smith Partnership Consulting Engineers drawings 'The Dogs Home Battersea' No. 56932 101 to 501.

5.4.1 Cattery

The planning drawings show that the Cattery is a modern flat slab building (either steel or reinforced concrete), with columns typically spaced on a 6m grid. The south façade is combination of brick and glass, although the brick provides no structural support. The east façade is a curved glass, which is detailed as a Schuco Facetted Curtain Wall System. Curtain wall systems are typically attached to the main structure via the floor slab using connections that allow some degree of movement. It is likely that the building is founded on piles.

Greenfield settlements and deformation parameters have been calculated at the key structural components and facades, and are shown in Table 5-2.

Table 5-2 shows that the relative rotation and differential movement between columns of the Cattery are small (the maximum differential movement of 5mm occurs between column C2 and C3). The relative rotations between columns does not exceed 1/500 between any columns (maximum relative rotation between C2 and C3 is 1/530). This is below the limits suggested by EC7 Annex H (2) to avoid serviceability damage.

The composite brick and glass façade that runs parallel to the tunnel direction is subjected to very small rotations (1/20,000) and differential movement (<1mm). The values are so low because of the façades orientation to the settlement contours. Such small deformations are unlikely to cause damage to the façade.

The glass curtain wall which forms the east façade is likely to be the most sensitive part of the Cattery to movements. The analysis shows that the curtain wall is subject to very small relative rotations and strains. The deflection ratio (which is used to assess the potential for building damage) is very small (1/5000). Burland and Wroth (1974) argued that only deflection ratios greater than 1/1000 would cause serviceability damage in sensitive brick structures. Despite the small relative rotation along the façade it does undergo significant tilt (1/550) and rotation (1/470). This amount of tilt and rotation along the glass curtain wall should not be problematic providing:

- The curtain walling was installed after completion of the structural frame (i.e. the rotation due to tunnel construction will not be in addition to rotation from the settlement of the building under its own load);
- The connections between panels of the curtain wall allow some degree of movement; and
- The connection between curtain wall and structural frame has been installed to allow some relative movement between frame and façade. (Inspection of the technical details of the Schuco Facetted Curtain Wall System suggest that it is designed to accommodate such movement).

Based on the above assessment and the building information available at the time of Reference Design, the prediction from the simple analysis (that the Cattery is at Slight risk - Cat 2 of building damage) seems appropriate at this stage. Consequently it is unlikely that the Cattery will require underpinning or ground treatment. However, during the detailed design stage inspection of the structure (with particular reference to how the curtain wall system is attached to the structural frame) will be required to confirm the assumptions that these recommendations have been based on.

Table 5—2 Deformations for key structural components of the Cattery, Battersea Dogs and Cats Home.

	Location		Column			
	Brick Façade	Glass Façade	A1 to A2	A2 to A3	C1 to C2	C2 to C3
Wall direction to tunnel	Parallel	Perpendicular	Perpendicular	Perpendicular	Perpendicular	Perpendicular
Max settlement (mm)	3	42	6	5	7	11
Differential (mm)	0.7	31	2	2	1.2	5
Tilt (Rds)	0.00004 (1/25000)	0.0018 (1/550)				
Max Rotation (Rds)	0.00005 (1/20000)	0.0021 (1/470)				
Relative Rotation (Rds)	0.00001 (1/100000)	0.0003 (1/3000)	0.0016 (1/615)	0.0016 (1/620)	0.0012 (1/825)	0.0019 (1/530)
Relative Deflection (mm)	0.1	2				
Deflection ratio	1/250000	1/5000				
Max horizontal strain (%)	0.038	0.083				

5.4.2 Kent Building

The record drawings show that the Kent Building comprises of several buildings of different stories. These include:

- Kennel Block 1 (4 Storey)
- Kennel Block 2 (4 Storey)

- Visitor Block Centre (Single Storey with four storey stair cores at each end)
- Clinic (Single Storey)
- Ramp Hall (2 storey)

In general the buildings comprise of brick and blockwork structural walls spaced on a 4m x 6m grid, with steel lintels over window and door openings. The ground floor slab is reinforced concrete suspended between reinforced concrete ground beams. The reinforced ground beams are founded on piles spaced at approximately 2m centres. Notable exceptions include the visitor centre which is a steel frame on a 5m x 6m grid, and the ramp hall which utilises circle steel hollow sections.

Settlements and deformation parameters have been calculated at the key structural walls and facades, and are shown in Table 5-3. It should be noted that the critical deflection ratios and horizontal strain presented in Table 5-3 have been modified to account of the local stiffening effect of the structure using the method presented by Potts and Addenbrooke (1997). The other deformation parameters such as the tilt or rotation have not be altered. This is because the settlement trough is wide (120m) in comparison to the width of the building (20m). Thus whilst the structure will locally stiffen the ground response, altering the strain across the building, it will not alter the overall shape of the settlement trough. Thus the tilt or rotation the building is exposed to will not be reduced.

The results of the greenfield analysis (detailed in Section 5.3) indicated that the Kent building was at risk of moderate damage (Category 3). Interrogation of the analysis shows that this is due to the large bending strain induced across the internal walls of Kennel Block 2 (See Table 5-3). Modification of the ground movement beneath the internal walls to take account of the local stiffening effect of the building reduced the deflection ratio across the internal walls from 1/650 to 1/2000. This downgrades the building damage classification from Moderate (Category 3) to Slight (Category 2).

Despite the reduced bending strain across the building the Kent Building is still exposed to a large amount of tilt, rotation, and differential movement (See Table 5-3). The maximum tilt (1/445), rotation (1/330), and differential movement (47mm) occurs along the walls of the Kennel Blocks that run parallel to the tunnel alignment. EC7 Annex H (2) states that maximum rotations of 1/500 are acceptable for most structures and rotations of 1/150 are likely to cause ultimate limit state. This suggests that underpinning (or other similar techniques) will be required for the Kent building to stop serviceability damage to the building and ensure continued connectivity into utilities. Therefore, at this stage of design, the Kent Building should still be classified as being at a moderate (Category 3) risk of damage. Potential remedial measures for the Kent Building are reported separately (GRNLEB-HGL-00-XX-TNT-MDR-00067-02-01 and GRNLEB-BHD-00-XX-TNTMDR-00054-02).

Table 5—3 Deformations for the key structural components of the Kent Building, Battersea Dogs and Cats Home (*modified to take into account building stiffness)

	Visitor Block	Kennel Block 1		Kennel Block 2			
Wall direction to tunnel	Perpendicular	Perpendicular	Parallel	Perpendicular	Parallel	Core wall (parallel)	Core wall (perpendicular)
Max settlement (mm)	59	63	63	60	12	30	28
Differential (mm)	42	40	5	47	5	2	0.6
Tilt (Rds)	0.0001 (1/10000)	0.0019 (1/525)	0.0003 (1/2900)	0.0022 (1/445)	0.0004 (1/3000)	0.0029 (1/345)	0.0005 (1/2000)

Max Rotation (Rds)	0.0031 (1/330)	0.0029 (1/340)	0.0003 (1/3500)	0.0017 (1/590)	0.0003 (1/3500)	0.0028 (1/355)	0.0007 (1/1400)
Relative Rotation (Rds)	0.0032 (1/315)	0.0017 (1/600)	0.0001 (1/13000)	0.0005 (1/2000)	0.0004 (1/2000)	0.0001 (1/10000)	0.0006 (1/1600)
Relative Deflection (mm)	40	10	0.3	3	0.4	1.3	1.5
Deflection ratio	1/950	1/2140	1/50000	1/5000	1/30000	1/2000*	1/2000*
Max horizontal strain (%)	0.132	0.104	0.043	0.105	0.041	0.001*	0.001*

5.5 Phase 2: Building Damage Classification – Alternative construction option

The results of the building damage assessment for the alternative construction option at the Kennington Loop are presented in drawing GRNLEB-BHD-TU-XX-DR-GEO-14703 (Appendix A5).

Again, the majority of the structures fall within Damage Categories 0 (Negligible) and 1 (Very Slight). However, a greater number of structures fall within Category 1 (Very Slight) and Category 2 (Slight), when compared to the December 2012 Stage C Drawing Issue. This is because the temporary gallery tunnel and hand dug (SCL) tunnel between the ventilation shaft and step-plate junction cause greater settlement around the Kennington Loop. It should be noted that the presence of the temporary gallery tunnel does not cause any buildings to exceed Category 2 (Slight). The additional structures that fall within Damage Category 2 (Slight) due to the presence of the temporary gallery tunnel are summarised in Table 5—4.

Table 5—4 Additional structures within damage category 2 (Slight) due to the alternative construction option.

Drawing No	Damage Category	Structure Name	Location	Anticipated Structural Form
GRNLEB-BHD-TU-XX-DR-GEO-14703	Slight (2)	No. 1-41 Kennington Road	Kennington Road, near to Kennington Green	Brick (4 storey- Listed Buildings)
GRNLEB-BHD-TU-XX-DR-GEO-14703	Slight (2)	No. 18 Aulton Place	Kennington Road/Montford Place	Brick (3 storey)
GRNLEB-BHD-TU-XX-DR-GEO-14703	Slight (2)	No. 1 to 7 Stannary Place	Near Kennington Road/Oval Cricket ground	Warehouse – steel frame/brick
GRNLEB-BHD-TU-XX-DR-GEO-14703	Slight (2)	No. 25 Cleaver Square	Near northbound step-plate junction	Brick (3 storey – Listed Building)

5.6 Utility damage assessment – December 2012 Stage C Drawing Issue

The results of the utility damage assessment can be found in drawings GRNLEB-BHD-00-XX-DR-GEO-14610 to 14614, GRNLEB-BHD-00-XX-DR-GEO-14615 to 14619, and GRNLEB-BHD-00-XX-DR-GEO-14620 to 14624 for gas, sewers, and water respectively. A full list of the services analysed and the calculated pipe strains, joint rotations and joint pull-outs can be found in Appendix B.

Any utilities that are affected by the proposed extension to the Northern Line are highlighted in yellow in the drawings listed above. Those utilities that exceed any of the limiting criteria (tensile strain, joint pull-out, or joint rotation) are highlighted in red on the drawings listed above.

It is recommended that preliminary allowances for strengthening or pipe replacement are made for all those utilities highlighted in red in the drawings above (and summarised in Table 5-5 below).

Table 5—5 Summary of critical utilities due to December 2012 Stage C Drawing Issue (The full list of utilities, material types, and predicted strains are given in Appendix A).

Utility Type	Dwg Ref/Location	XDISP Structure Ref	Assumed Material	Pipe diameter/Sewer height (m)	Criteria Exceeded
Gas (34 No.)	1 (West of Battersea station box)	B41.1	Polyethylene	0.09	Rotation (°) (0.3 >0.25)
	3 (Nine Elms Lane)	B35.1	Cast Iron	0.08	Pull-out (mm) (5.1>0.5) Rotation (°) (0.08 >0.01)
	3 (Nine Elms Lane)	B35.2	Cast Iron	0.05	Pull-out (mm) (5.1>0.5) Rotation (°) (0.05 >0.01)
	3 (Nine Elms Lane)	B79.1	Steel	0.92	Pull-out (mm) (5.2>0.5) Rotation (°) (0.07 >0.01)
	3 (Nine Elms Lane)	B79.2	Steel	0.92	Pull-out (mm) (4.9>0.5) Rotation (°) (0.08 >0.01)

Utility Type	Dwg Ref/Location	XDISP Structure Ref	Assumed Material	Pipe diameter/Sewer height (m)	Criteria Exceeded
	3 (Nine Elms Lane)	B82.1	Cast Iron	0.15	Pull-out (mm) (4.0>0.5) Rotation (°) (0.08 >0.01)
	3 (Nine Elms Lane)	B83.1	Cast Iron	0.61	Pull-out (mm) (5.2>0.5) Rotation (°) (0.08 >0.01)
	3 (Nine Elms Lane)	B83.2	Cast Iron	0.61	Pull-out (mm) (4.2>0.5) Rotation (°) (0.08 >0.01)
	3 (Nine Elms Lane)	B84.1	Steel	0.91	Pull-out (mm) (5.2>0.5) Rotation (°) (0.05 >0.01)
Gas (34 No.)	5 (East of Nine Elms station box)	B1.1	Cast Iron	0.51	Pull-out (mm) (5.1>0.5) Rotation (°) (0.03 >0.01)
	5 (East of Nine Elms station box)	B1.2	Cast Iron	0.51	Pull-out (mm) (4.6>0.5) Rotation (°) (0.04 >0.01)
	5 (East of Nine Elms station box)	B1.3	Cast Iron	0.51	Pull-out (mm) (4.6>0.5) Rotation (°) (0.06 >0.01)
	5 (East of Nine Elms station box)	B1.4	Cast Iron	0.51	Pull-out (mm) (3.8>0.5) Rotation (°) (0.07 >0.01)

Utility Type	Dwg Ref/Location	XDISP Structure Ref	Assumed Material	Pipe diameter/Sewer height (m)	Criteria Exceeded
	5 (East of Nine Elms station box)	B1.5	Cast Iron	0.51	Pull-out (mm) (4.6>0.5) Rotation (°) (0.07 >0.01)
	5 (East of Nine Elms station box)	B1.6	Cast Iron	0.51	Pull-out (mm) (1.5>0.5)
	6 (Old South Lambeth Road)	B73.1	Cast Iron	0.51	Pull-out (mm) (4.5>0.5) Rotation (°) (0.07 >0.01)
	8 (Around Cottingham Road)	B12.1	Ductile Iron	0.1	Pull-out (mm) (3.7>0.5) Rotation (°) (0.04 >0.01)
Gas (34 No.)	8 (Around Cottingham Road)	B13.1	Cast Iron	0.08	Pull-out (mm) (4.4>0.5) Rotation (°) (0.04 >0.01)
	8 (Around Cottingham Road)	B25.1	Ductile Iron	0.1	Pull-out (mm) (3.9>0.5) Rotation (°) (0.04 >0.01)
	8 (Around Cottingham Road)	B25.2	Ductile Iron	0.1	Pull-out (mm) (3.5>0.5) Rotation (°) (0.05 >0.01)
	8 (Around Cottingham Road)	B27.1	Ductile Iron	0.1	Pull-out (mm) (2.7>0.5) Rotation (°) (0.04 >0.01)

Utility Type	Dwg Ref/Location	XDISP Structure Ref	Assumed Material	Pipe diameter/Sewer height (m)	Criteria Exceeded
Gas (34 No.)	8 (Around Cottingham Road)	B64.1	Ductile Iron	0.1	Pull-out (mm) (4.3>0.5) Rotation (°) (0.05 >0.01)
	9 (Camberwell New Road)	B58.1	Cast Iron	0.9	Pull-out (mm) (3.2>0.5) Rotation (°) (0.04 >0.01)
	9 (Camberwell New Road)	B59.1	Cast Iron	0.61	Pull-out (mm) (3.1>0.5) Rotation (°) (0.04 >0.01)
	9 (Camberwell New Road)	B60.1	Cast Iron	0.4	Pull-out (mm) (3.1>0.5) Rotation (°) (0.04 >0.01)
	9 (Camberwell New Road)	B61.1	Cast Iron	0.3	Pull-out (mm) (3.1>0.5) Rotation (°) (0.04 >0.01)
	9 (Camberwell New Road)	B61.2	Cast Iron	0.3	Pull-out (mm) (3.2>0.5) Rotation (°) (0.04 >0.01)
	9 (Camberwell New Road)	B62.1	Cast Iron	0.5	Pull-out (mm) (3.3>0.5) Rotation (°) (0.04 >0.01)
	10 (Harleyford Street)	B56.1	Cast Iron	0.9	Pull-out (mm) (3.2>0.5) Rotation (°) (0.05 >0.01)

Utility Type	Dwg Ref/Location	XDISP Structure Ref	Assumed Material	Pipe diameter/Sewer height (m)	Criteria Exceeded
Gas (34 No.)	10 (Harleyford Street)	B57.1	Cast Iron	0.9	Pull-out (mm) (3.2>0.5) Rotation (°) (0.05 >0.01)
	11 (Kennington Park Place)	B43.1	Steel	0.6	Pull-out (mm) (3.9>0.5) Rotation (°) (0.05 >0.01)
	11 (Kennington Park Place)	B63.1	Cast Iron	0.3	Pull-out (mm) (4.2>0.5) Rotation (°) (0.04 >0.01)
	11 (Kennington Park Place)	B63.2	Cast Iron	0.3	Pull-out (mm) (4.0>0.5) Rotation (°) (0.05 >0.01)
	12 (Kennington Green)	B20.1	Cast Iron	0.15	Pull-out (mm) (4.1>0.5) Rotation (°) (0.06 >0.01)
	12 (Kennington Green)	B20.2	Cast Iron	0.15	Pull-out (mm) (3.6>0.5) Rotation (°) (0.06 >0.01)
Sewers (3 No.)	18 (Southbound Step-plate)	B21.1	Brick	0.31	Strain (%) (0.06 > 0.05)
	18 (Southbound Step-plate)	B22.1	Brick	0.31	Strain (%) (0.1 > 0.05)
	20 (Northbound Step-plate)	B3.1	Brick	0.31	Strain (%) (0.2 > 0.05)

Utility Type	Dwg Ref/Location	XDISP Structure Ref	Assumed Material	Pipe diameter/Sewer height (m)	Criteria Exceeded
Water (24 No.)	21 (Battersea station box)	B49.1	Cast Iron	0.1	Rotation (°) (0.32 >0.15) Pull-out (mm) (12>7.5)
	21 (Battersea station box)	B82.1	Cast Iron	0.1	Rotation (°) (0.16 >0.15) Pull-out (mm) (14>7.5)
	22 (Nine Elms Lane)	B47.2	Cast Iron	0.1	Strain (%) (0.012 >0.01)
	23 (Nine Elms Lane)	B61.1	Cast Iron	0.051	Strain (%) (0.013>0.01)
	23 (Nine Elms Lane)	B69.1	Cast Iron	0.45	Strain (%) (0.015>0.01)
	23 (Nine Elms Lane)	B70.1	Cast Iron	0.05	Strain (%) (0.012 >0.01)
	24 (Wandsworth Rd)	B19.1	Cast Iron	0.1	Strain (%) (0.012 >0.01)
	24 (Wandsworth Rd)	B20.1	Cast Iron	0.1	Strain (%) (0.011 >0.01)
	27 (Kennington Park Rd)	B37.1	Cast Iron	0.1	Strain (%) (0.011 >0.01)
	27 (Kennington Park Rd)	B37.1	Cast Iron	0.1	Strain (%) (0.012 >0.01)
	28 (Oval)	B35.1	Cast Iron	0.1	Strain (%) (0.014 >0.01)
	28 (Oval)	B55.1	Cast Iron	0.1	Strain (%) (0.013 >0.01)

Utility Type	Dwg Ref/Location	XDISP Structure Ref	Assumed Material	Pipe diameter/Sewer height (m)	Criteria Exceeded
Water (24 No.)	28 (Oval)	B81.1	Cast Iron	0.1	Strain (%) (0.011 >0.01)
	29 (Brixton Rd)	B107.1	Cast Iron	0.25	Strain (%) (0.012 >0.01)
	30 (Southbound step-plate)	B39.1	Cast Iron	0.1	Pull-out (mm) (11>7.5)
	30 (Southbound step-plate)	B111.1	Cast Iron	0.1	Rotation (°) (0.23 >0.15)
	31 (Kennington Shaft)	B2.1	Cast Iron	0.08	Strain (%) (0.014 >0.01)
	31 (Kennington Shaft)	B5.1	Cast Iron	0.1	Pull-out (mm) (11>7.5)
	31 (Kennington Shaft)	B6.1	Cast Iron	0.1	Pull-out (mm) (10>7.5)
	31 (Kennington Shaft)	B6.2	Cast Iron	0.1	Pull-out (mm) (14>7.5)
	31 (Kennington Shaft)	B21.1	Cast Iron	0.1	Strain (%) (0.011 >0.01)
	31 (Kennington Shaft)	B38.1	Cast Iron	0.08	Strain (%) (0.012 >0.01)
	31 (Kennington Shaft)	B43.2	Cast Iron	0.1	Rotation (°) (0.17 >0.15) Pull-out (mm) (14>7.5)

Utility Type	Dwg Ref/Location	XDISP Structure Ref	Assumed Material	Pipe diameter/Sewer height (m)	Criteria Exceeded
	31 (Kennington Shaft)	B43.3	Cast Iron	0.1	Pull-out (mm) (9.7>7.5)

6 Discussion

6.1 Further work

Further Phase 3 (LUL Standard 1-050) analysis will be required during the final detailed design stages to gain a clearer understanding of which structures and utilities require remedial work. This additional analysis is likely to comprise the following elements:

Ground surface settlement

- Reassess the volume loss parameter and reduce to 1% for the TBM methodology if at all possible.

Building damage assessment

- Obtain further record drawings of critical structures identified during this stage of the design process, including details of foundations.
- Refine the building stiffness parameters such that specific values are assigned for each structure.
- For critical structures carry out the building movement analysis using more rigorous numerical models e.g. finite element methods and more representative soil deformation behaviour models (i.e. constitutive models).

All structures within the 10mm settlement contour (or 1mm if a listed building) will require condition surveys (See Section 7). Provisional allowance should be made for underpinning or compensation grouting for all structures exceeding Damage Category 2 – Slight. Examples include the Kent Building associated with Battersea Dogs and Cats Home (as detailed in Section 5.4.2).

Utility damage assessment

- Obtain further records of utilities, particularly material that service pipes are made of, diameter and depth, and nature of joints.
- Expose critical services to confirm information with regards to depth, material, diameter, nature of joints and condition.
- Further consultation with utility owners to define limiting criteria values for tensile strain, joint rotation and joint pull-out based on sensitivity of individual utilities, and to determine suitable analysis methodologies for later design phases. To minimise the impact of utilities, further consultation will also establish what strategic upgrading works are expected in the Vauxhall Nine Elms Battersea Opportunity area at the time of the NLE construction.

6.2 Possible remedial measures

Consideration should be given to the tunnelling methodology to determine the feasibility of alternative methods that will provide greater support at or near the face. This deals with the impact on adjacent structures and utilities by reducing the volume loss which in turn reduces the ground movements. Where alternative tunnelling methods are not feasible, the following options could be considered during detailed design:

Buildings

Possible options that could be considered include:

- Strengthening the ground either by injecting grout or freezing.
- Strengthening the structure.
- Jacking the structure.
- Underpinning.
- Installing a physical barrier between the foundation and tunnel to modify the settlement trough and reduce ground movements.
- Compensation grouting.

Provisional allowance should be made for stabilisation of structures that have a damage criteria exceeding Category 2 (Slight). Remedial measures for the Kent Building (Battersea Dogs and Cats Home) and Network rail assets are reported in technical note GRNLEB-HGL-00-XX-TNT-MDR-00067-02-01.

Utilities

Potential options include:

- Diversion.
- Locally replace existing services.
- Strengthen joints.
- Observational approach (monitoring).

During detailed design appropriate liaison with the authorities should be undertaken to develop a risk based methodology for dealing with potential service damage.

7 Outline monitoring strategy

The outline monitoring strategy is summarised in Table 7-1 below. Table 7-1 should be read in conjunction with drawing numbers GRNLEB-BHD-TU-XX-DR-GEO-14605 to GRNLEB-BHD-TU-XX-DR-GEO-14609 (Appendix A3). It should be noted that all buildings within the 10mm settlement contour (or 1mm if a listed building) will require a condition survey as a minimum. Those buildings that are listed and fall within the 1mm settlement contour are shown in drawings GRNLEB-BHD-TU-XX-DR-GEO-15605 to GRNLEB-BHD-TU-XX-DR-GEO-15609 (Appendix A4).

To conduct the monitoring strategy outlined in Table 7-1, deep datum points outside the predicted settlement contours will be required to provide a reference for monitoring. Consultation with Soldata (monitoring specialist) concluded that at least one deep datum point would be required every 1km of tunnel to provide sufficient coverage. This is equivalent to three deep datum points between the Battersea station box and the step-plate junction.

The areas chosen are typically in public spaces, or in car parks (away from actual car park spaces to avoid the datum being parked over) and are summarised below:

- Datum 1: Kennington Park (within worksite for Kennington Park substation)
- Datum 2: New Covent Garden Market car park.
- Datum 3: Near to Battersea Power Station and adjacent to the proposed conveyer belt for spoil removal from the Battersea station box (within temporary worksite for Battersea station box)

The deep datum reference points will require boreholes of at least 20m depth. However in places this may be up to 60m to reach sufficient stratum. Installation of the deep datum points will require a temporary worksite area of approximately 8m^2. Datum sites 1 and 2 were visited by Buro Happold Ltd. personnel on the 25th February 2013 to check the suitability and accessibility of the datum sites. The location of Datum 3 was instructed by TfL.

Table 7—1 Critical assets outline monitoring strategy

Required Possibly required Not required

Ref No	Asset	Asset Owner	Key Issues	Condition Survey	Total Station Surveying	Precise Levelling	Inclinometer/ Tiltmeter	Vibrating Wire Piezometer	Façade Crack Surveys (DEMEC/Tape)	Electro-Level	Extensometer (Rod/Magnet)
1	Victoria Line Viaduct Up/Down Chatham Lines Chatham/Battersea Reversible	Network Rail	Track v/h alignment, cant and twist. Risk of viaduct structural damage exceeding category 2.	Minimum of 12 months baseline monitoring and 6 months post construction.	Automatic Total Stations (ATS) every 20m with manual backup. Prisms will be required at maximum of 3m centres		On viaduct façade.		On viaduct façade - Measurement between demec studs using calipers or automatic crack meters and data loggers.		
2	Running train lines to Victoria Up/Down Stewarts Lane Depot/Freight Sidings	Network Rail	Track v/h alignment, cant and twist	Minimum of 12 months baseline monitoring and 6 months post construction.	Automatic Total Stations every 20m with manual backup. Prisms will be required at maximum of 3m centres						
3	Bridge 330 and Wingwalls	Network Rail/ TfL	Existing poor condition with visual cracks identified and historically monitored. Shallow foundations to wingwalls.								
4	Critical "Shallow" Utilities	Various – refer to drawings GRNLEB-BHD-00-XX-DR-GEO-14610 to 14624, and tables in Appendix B	Utilities sensitive to vertical and horizontal movement, joint rotation, pull out, and tensile strain. Key utilities: water mains, gas and sewers.								

Ref No	Asset	Asset Owner	Key Issues	Condition Survey	Total Station Surveying	Precise Levelling	Inclinometer/ Tiltmeter	Vibrating Wire Piezometer	Façade Crack Surveys (DEMEC/Tape)	Electro-Level	Extensometer (Rod/Magnet)
5	Heathwall Sewer (No. 14 in Appendix B)	Thames Water	Very close proximity to proposed tunnelling, potential clash to construction. Cast iron construction with concrete/brick invert. Foundations within River Terrace Deposits.				Horizontal in place inclinometers in crown of tunnel			Electrolevel strings and Bassett meters.	Rod extensometers installed perpendicular to tunnel alignment to monitor ground settlement
6	SW Storm Sewer (No. 14 in Appendix B)	Thames Water	Very close proximity to proposed tunnelling, Cast iron ring with internal concrete lining. Potential clash to construction.				Horizontal in place inclinometers in crown of tunnel			Electrolevel strings and Bassett meters	Rod extensometers installed perpendicular to tunnel alignment to monitor ground settlement
7	Ring Main	Thames Water	High pressure (3-4.5 bar) water main, essential infrastructure, wedge block construction. Risk of unloading, potential leakage of high pressure water, increasing pwp and reducing effective stress.				Horizontal in place inclinometers in crown of tunnel				Rod extensometers installed perpendicular to tunnel alignment to monitor ground settlement
8	Battersea Station Box/Switch and Crossing Box	TfL and BPSDC	Ground heave, lateral displacement of diaphragm walls, groundwater ingress.								
9a	Buildings within 10mm settlement contour (or 1mm if a listed building)	Various	General v/h ground movements (heave or settlement), and building damage.				For tall buildings		Measurement between demec studs using calipers or automatic crack meters and data loggers.		

Ref No	Asset	Asset Owner	Key Issues	Condition Survey	Total Station Surveying	Precise Levelling	Inclinometer/ Tiltmeter	Vibrating Wire Piezometer	Façade Crack Surveys (DEMEC/Tape)	Electro-Level	Extensometer (Rod/Magnet)
9b	Listed buildings (Grade II) within 1mm settlement contour and politically sensitive buildings.	Various	General v/h ground movements (heave or settlement), and building damage.	Churches and Embassies may require vibration (geophones) and noise (microphone) monitoring	Prisms typically on each corner of the building, monitored by ATS (or manual TS).		For tall buildings		Measurement between demec studs using calipers or automatic crack meters and data loggers.		
9c	Grade I and Grade II* within 1mm settlement contour and those buildings in the moderate classification (Category 3)	Various	General v/h ground movements (heave or settlement), and building damage				For tall buildings		Measurement between demec studs using calipers or automatic crack meters and data loggers.	Electrolevel beams around building with automatic system	
10	Low Level No 1 Sewer (No. 14 in Appendix B)	Thames Water	Masonry construction, foundations within River Terrace Deposits.				Horizontal in place inclinometers in crown of tunnel				
11	Cable Tunnel	EDF	Potential ground heave around tunnel, distortion of lining. Allowance to be made for gauging runs.								
12	North/South Bound Victoria Line (Vauxhall to Brixton) North/South bound	London Underground	Potential ground heave around tunnel, distortion of lining, groundwater ingress.							In accordance with LUL Standard G-055	
13	Northern Line (Kennington to Morden) North/South bound	London Underground	Potential ground heave around tunnel, distortion of lining, groundwater ingress. Allowance to be made for gauging runs.							In accordance with LUL Standard G-055	

Ref No	Asset	Asset Owner	Key Issues	Condition Survey	Total Station Surveying	Precise Levelling	Inclinometer/ Tiltmeter	Vibrating Wire Piezometer	Façade Crack Surveys (DEMEC/Tape)	Electro-Level	Extensometer (Rod/Magnet)
14	Waterloo Line Viaduct	Network Rail	Track v/h alignment, cant and twist. Risk of viaduct structural damage exceeding category 2.	Minimum of 12 months baseline monitoring and 6 months post construction.	Automatic Total Stations (ATS) every 20m with manual backup. Prisms will be required at maximum of 3m centres		On viaduct façade.		On viaduct façade - Measurement between demec studs using calipers or automatic crack meters and data loggers.		
15	Nine Elms Station Box	TfL	Ground heave, lateral displacement of diaphragm walls, groundwater ingress.								
16	Kennington Park Green Vent Shaft and associated adits	TfL	Lateral displacement of wall lining, ground heave, groundwater ingress, sandy layers under high pressure near base.								
17	Kennington Park Vent Shaft and Substation	TfL	Lateral displacement of wall lining, ground heave, groundwater ingress, sandy layers under high pressure near base.								
18	Radcot Street Temporary Shaft & Step-plate Junction	TfL	Lateral displacement of wall lining, ground heave, groundwater ingress, sandy layers under high pressure near base. Risk of excessive ground movements due to prevailing hand mining procedure.								
19	Harmsworth Street Temporary Shaft & Step-plate Junction	TfL	Lateral displacement of wall lining, ground heave, groundwater ingress, sandy layers under high pressure near base. Risk of excessive ground movements due to prevailing hand mining procedure.								

8 Conclusions and recommendations

8.1 General

To provide information for the final design stage it will be necessary to conduct a more sophisticated ground investigation. This is likely to include:

- Boreholes at 50m spacing.
- Boreholes targeted at sensitive structures and utilities, e.g. buildings around the step-plate junctions, Battersea Dogs and Cats Home and Network Rail Bridge 330.
- Installation of groundwater and ground gas monitoring equipment, with regular data acquisition, up to the time of construction.
- Static cone penetration tests (CPTs) to probe for scour features within the London Clay, with particular attention to the areas identified in drawing GRNLEB-BHD-TU-XX-DR-GEO-14100 (Appendix A1).
- High quality sampling, in situ testing (self-boring pressuremeter) and laboratory testing (small strain stiffness) to assist with Phase 3 finite element building damage and utility damage assessments.
- Ground and structural movement monitoring stations to establish baseline conditions ahead of construction.

8.2 Ground surface settlement

Refine volume loss assumptions, with consideration given to reducing the value to 1% for the sections constructed using a TBM.

8.3 Buildings

Further investigation should be undertaken by TfL's Land and Property Agent, making direct contact with the building owners for all buildings that may be piled. Buildings that may be piled are given in Section 3.4 and shown in drawings GRNLEB-BHD-TU-XX-DR-GEO-14600 to GRNLEB-BHD-TU-XX-DR-GEO-14604 (Appendix A2). It should be noted that any buildings greater than 4 storeys in height are considered an obstruction risk to tunnelling due to the potential presence of deep piled foundations. Where construction records are not available from the building owners it will be necessary to undertake building inspections and where necessary limited intrusive foundation investigations to manage the construction risk ahead of tunnelling.

Carry out Phase 3 assessment of critical structures (exceeding Damage Category 2 – Slight):

- Obtain further information on structures including foundations.
- Undertake preliminary condition surveys and structural assessments.
- Where considered necessary numerical modelling of critical assets e.g. finite element analysis.

For listed buildings:

- Obtain further information on listed structures, including foundations.

- Carry out Phase 3 assessment of all listed structures within the 10mm settlement contour irrespective of damage classification.
- Undertake preliminary conditions surveys and structural assessments of all listed buildings within the 1mm settlement contour (as shown in drawings GRNLEB-BHD-TU-XX-DR-GEO-15605 to 15609).

8.4 Network Rail assets

- Drawings GRNLEB-BHD-TU-XX-DR-GEO-14605 to 14609 show Network Rail assets that may require further analysis (hatched in red).
- Engage with Network Rail to establish the process and requirements for bespoke analysis.
- It should be noted that worksite areas surrounding Network Rail assets (that are marked on the limit of deviation drawings) are based on the 5mm settlement contour. The 5mm settlement contour has been chosen to provide sufficient area around Network Rail assets to carry out any remedial measures or underpinning that may be required.

8.5 Utilities

Carry out Phase 3 assessment:

- Engage with utility companies and finalise the AIP process. This may include requesting more information or surveying any areas of utilities that are currently incomplete.
- Opening up work for critical assets to determine pipe and joint types.
- For critical assets undertake preliminary condition surveys.
- Numerical modelling of critical assets.
- 34 No. gas mains, 3 No. sewers, and 24 No. water mains should be provisionally strengthened at joints and/or replaced (Drawing numbers GRNLEB-BHD-00-XX-DR-GEO-14610 to GRNLEB-BHD-00-XX-DR-GEO-14624).

8.6 Provisional allowances

- All buildings within the 10mm settlement contour will require a condition survey (GRNLEB-BHD-TU-XX-DR-GEO-14600 to 14604).
- All listed buildings within the 1mm settlement contour will require a condition survey (GRNELB-BHD-TU-XX-DR-GE0-15605 to 15609).
- Compensation grouting for buildings in close proximity to the step-plate junctions. (Drawing number GRNLEB-BHD-TU-XX-DR-GEO-14609).
- Remedial measures for those structures exceeding Damage Category 2 (Slight). Specific remedial measures for the Kent Building (Battersea Dogs and Cats home) have been outlined in technical note GRNLEB-BHD-00-XX-TNT-MDR-00054-02-01.
- Under-pinning (or similar) of critical Network Rail assets, particularly west of Battersea Station. Potential measures have been outlined in technical note GRNLEB-HGL-00-XX-TNT-MDR-00067-02-01.
- Stabilise foundations to Bridge 330 and associated wing-walls adjacent to the Battersea station box (Drawing number GRNLEB-BHD-TU-XX-DR-GEO-14605).

9 References

- CIRIA Special Publication 200 (2001), Building Response to Tunnelling – Case studies from construction of the jubilee line extension, London; Volume 1: Projects and Methods (Ed. Burland, Standing & Jardine). Chapter 3 – Assessment methods used in design, Burland J. B. Thomas Telford Publishing, London.
- Mair (2008), Tunnelling and geotechnics: new horizons, Geotechnique, Vol. 58, No. 9, p. 695 -736
- Standing and Selman (2001), The response to tunnelling of existing tunnels at Waterloo and Westminster, Building Response to tunnelling. Case Studies from the Jubilee Line Extension, London. Volume Case Two studies, pg. 509.
- New and Bowers (1994). Ground Movement model validation at the Heathrow Express Trial Tunnel. Proc. Tunnelling 1994. IMM, London pp. 301 – 327.
- Bracegirdle, Mair, Nyren, and Taylor, (1996). A methodology for evaluating potential damage to cast iron pipes induced by tunnelling, Geotechnical Aspects of Underground Construction in Soft Ground, Mair and Taylor (eds), pg. 659 to 664.
- Mair and Taylor (2001), Elizabeth House: settlement predictions, Building Response to tunnelling. Case Studies from the Jubilee Line Extension, London. Volume Case On: Project and Methods pg. 195.
- Burland and Wroth (1974). Settlement of Buildings and Associated Damage. *In:* COSO (ed.), *Settlement of Structures,* 1974, Cambridge, Pentech Press, 611-654.
- Potts and Addenbrooke (1997). A structures influence on tunnelling-induced ground movements. *Proc. Instn. Civ. Engrs. Geotech. Engng.,* 125, 11048, 109-125.
- Bowers and Moss (2006). Settlement due to tunnelling on the CTRL London Tunnels, Geotechnical aspects of underground construction in soft ground, Bakker et al. (eds), Taylor and Francis Group, London, p. 203-209.
- London Underground Limited– LUL Guidelines on ground movement due to tunnel and deep excavations, July 2008.
- London Underground Limited Standard 1-050 Civil Engineering – Common Requirements, issue A2, January 2009.
- London Underground Limited Manual of Good Practice G-050 Civil Engineering – Common Requirements, issue A2, October 2008.
- London Underground Limited Standard 1-053 Civil Engineering – Building and Station Structures, issue A1, October 2007.
- London Underground Limited Manual of Good Practice G-053 Civil Engineering – Building and Station Structures, issue A2, February 2008.
- London Underground Limited Standard 1-055 Civil Engineering – Deep Tube Tunnels and Shafts, issue A1, October 2007.

- London Underground Limited Manual of Good Practice G-055 Civil Engineering – Deep Tube Tunnels and Shafts, issue A1, October 2007.

Appendix A Drawings

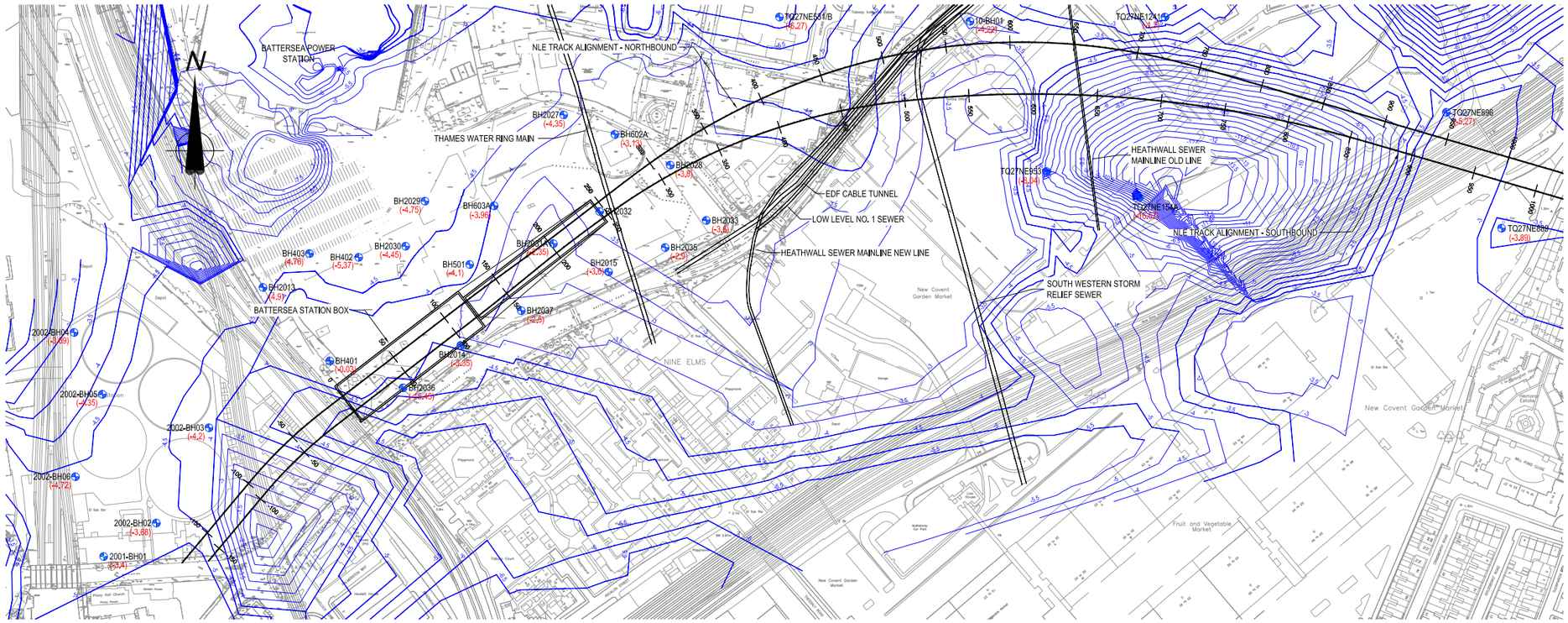
A1 - Geological long sections

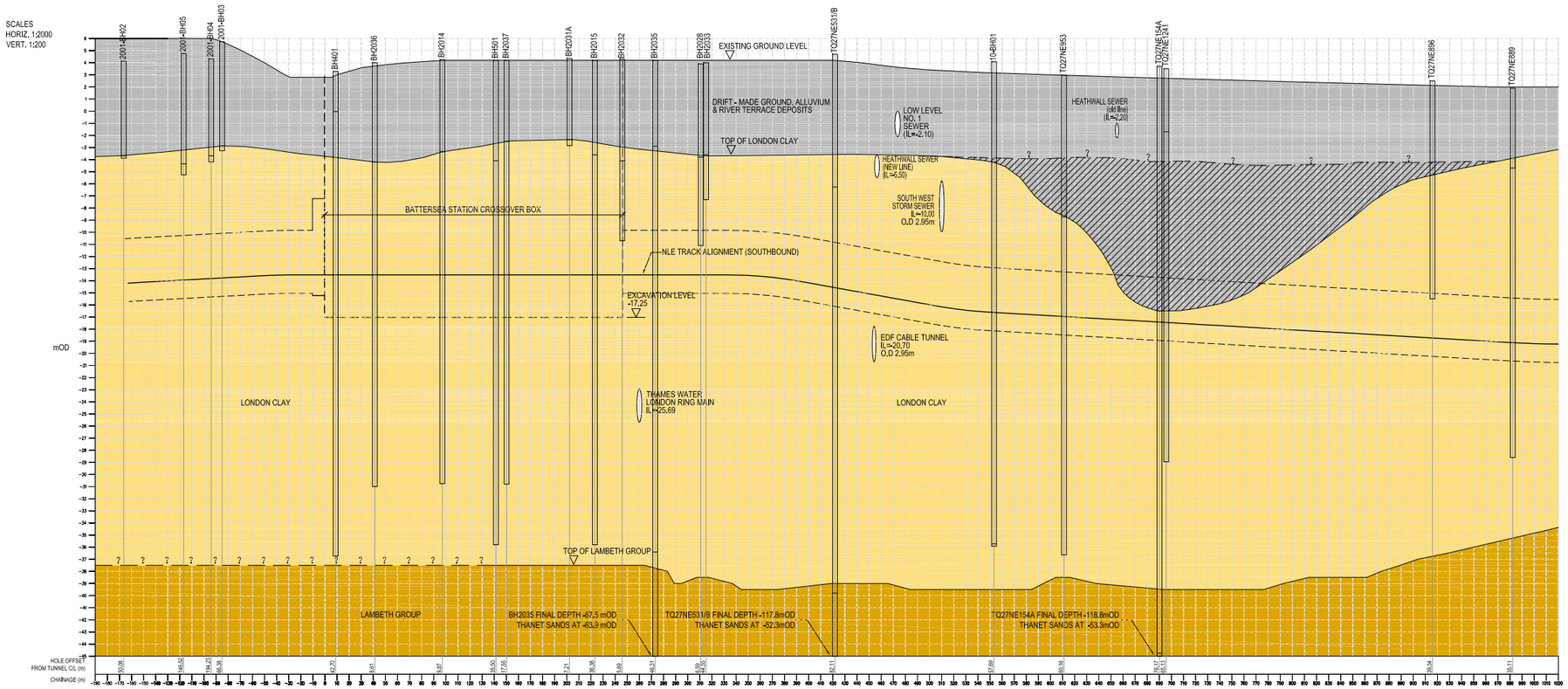
Drawing numbers:

GRNLEB-BHD-TU-XX-DR-GEO-14100-05-01

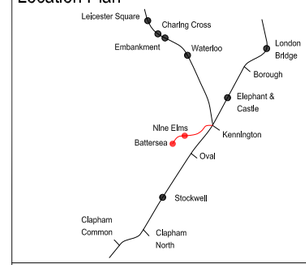
GRNLEB-BHD-TU-XX-DR-GEO-14101-05-01

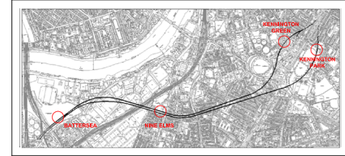
GRNLEB-BHD-TU-XX-DR-GEO-14102-05-01





Location Plan





CONTOURS USED TO CREATE GROUND MODEL FROM PARSONS BRINCKERHOFF FEASIBILITY REPORT UMD90388A-0039-03, DEC. 2008 & BURO HAPPOLD FACTUAL REPORT, OCTOBER 2004.

GEOLOGICAL PROFILE DEVELOPED FOR THE REFERENCE DESIGN IS BASED ON THE GROUND INVESTIGATION UNDERTAKEN BY CONCEPT (REF. 10/2554 19/05/2010) USING BOREHOLE DRILLED AT APPROXIMATELY 300M CENTRES ALONG THE ROUTE AND OTHER DATA HELD BY BURO HAPPOLD (BGS AND OTHER SITE E.G. BATTERSEA POWER STATION)

DRAWINGS BASED ON THE INFORMATION AVAILABLE AT THE TIME OF DESIGN

NLE TRACK ALIGNMENT BASED ON HALCROW DRAWING GRNLEB-HGL-00-XX-M2-PWY-00010-02-01

—?—?—?— INSUFFICIENT DATA TO DEFINE INTERFACE

POTENTIAL SCOUR FEATURE

-2.5 CONTOUR - TOP OF LONDON CLAY (mOD)

(5.9) TOP OF LONDON CLAY IN EXPLORATORY HOLE (mOD)

NOTE

INTERPRETATION OF STRATIGRAPHY BASED ON DATA CLOSEST TO TUNNEL ALIGNMENT - SEE HOLE OFFSET AT BASE OF SECTION.

Rev	By	Chkd	Apprvd	Date	Description
05	NG	JD	SL	13/02/13	LONDON CLAY CONTOURS ADDED
04	NG	JD	SL	06/02/13	CHANGE TO NOTES
03	NG	JD	SL	11/01/13	BOREHOLE SECTIONS ADDED
02	NG	JD	SL	11/12/12	S4-FORMAL ISSUE TO CLIENT

Client

Transport for London

studiodareARCHITECTS

Buro Happold Consulting Engineers

Halcrow Group Ltd.
A CH2M HILL COMPANY
Elms House, 43 Brook Green
Hammersmith, London W6 7EF
TEL: 020 3479 8000
FAX: 020 3479 8001
www.halcrow.com

Halcrow

Project:

NORTHERN LINE EXTENSION TO BATTERSEA TWAO FOR TfL

Drawing:

GEOLOGICAL PROFILE OF REFERENCE DESIGN ALIGNMENT SHEET 1 OF 3

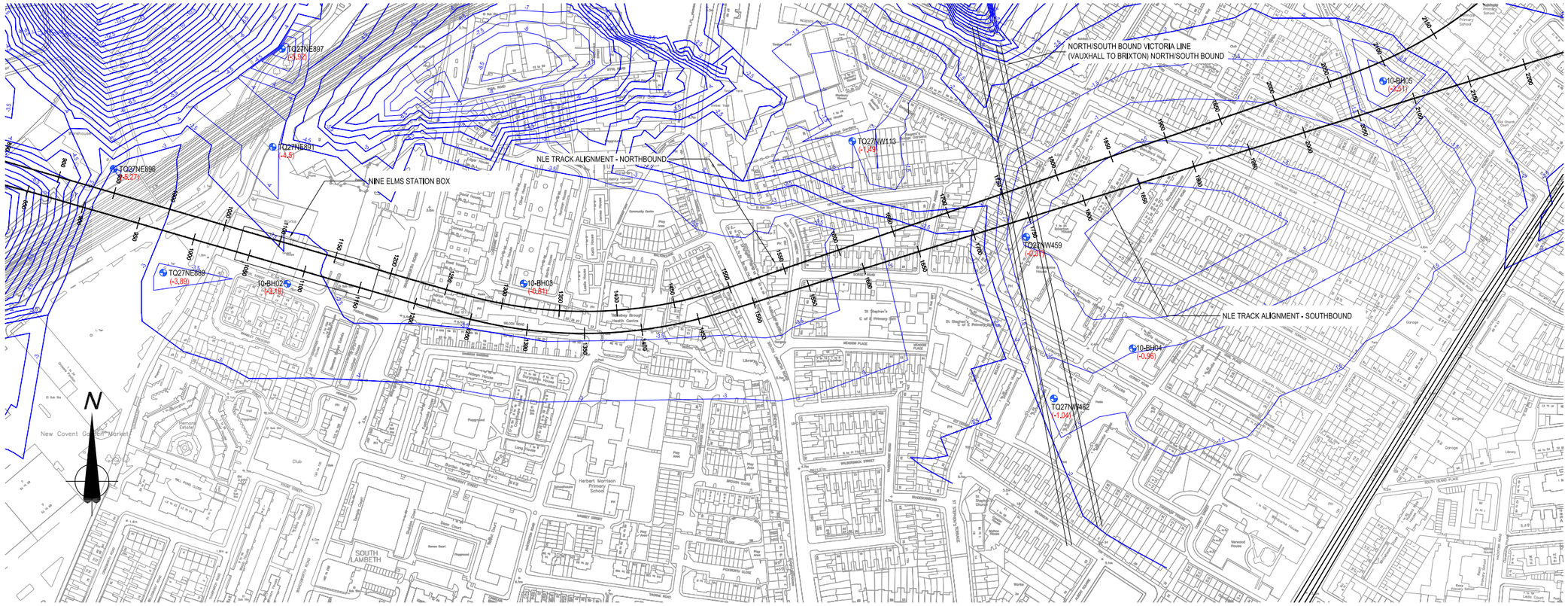
Suitability: S4_FORMAL_ISSUE_TO_CLIENT

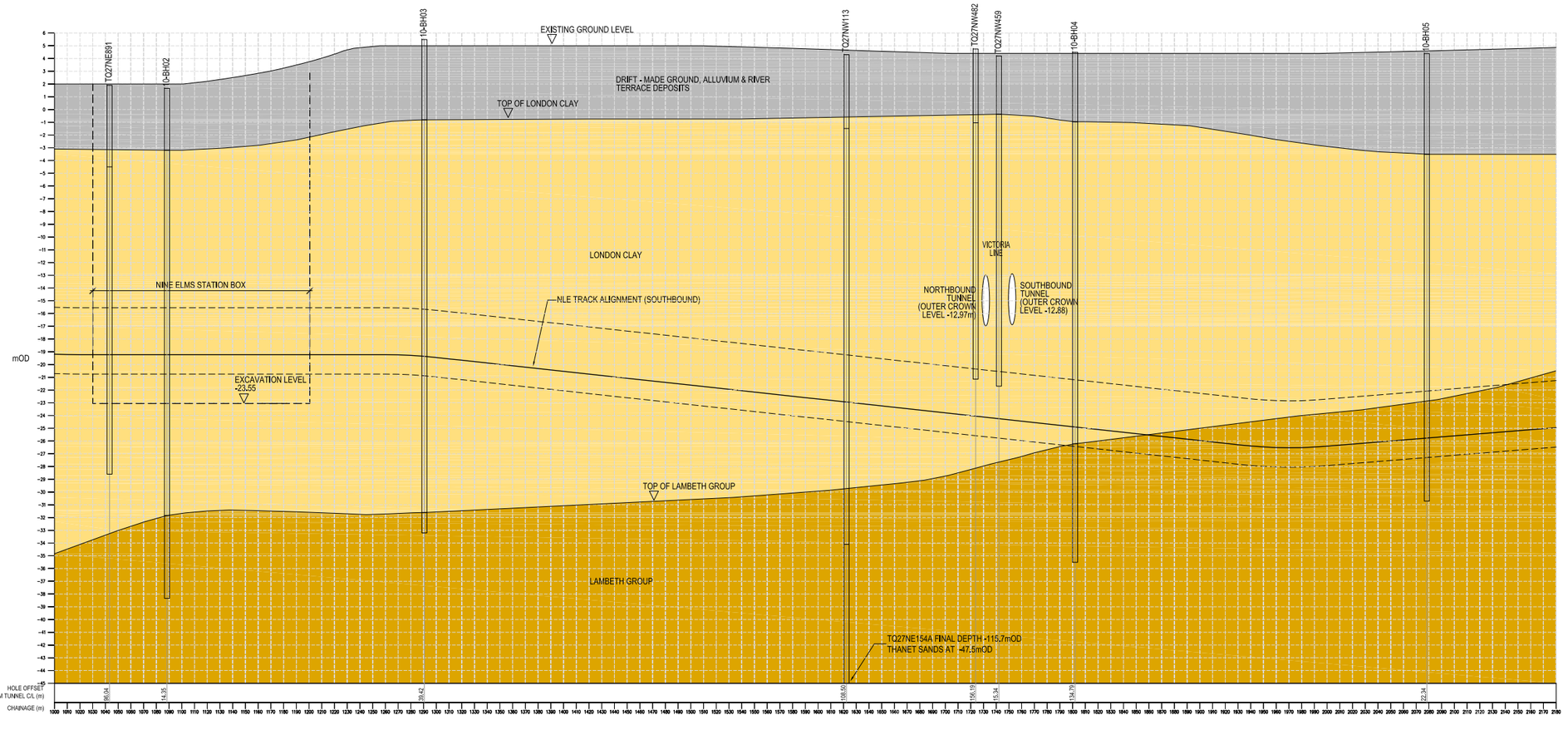
Drawn by: NG	Date:	06/02/13
Checked by: JD	Date:	06/02/13
Approved by: SL	Date:	06/02/13

Drawing Scale: AS SHOWN

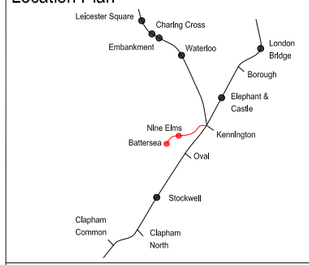
Drawing No.:	Revision:
GRNLEB-BHD-TU-XX-DR-GEO-14100	05-01

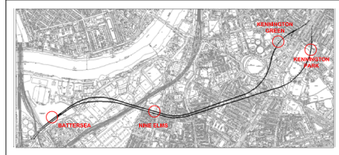
Drawing file path & name : - User and Plot Date : nghbour2 13.2.2013 - 2:3 pm





Location Plan





CONTOURS USED TO CREATE GROUND MODEL FROM PARSONS BRINCKERHOFF FEASIBILITY REPORT UMD90388A-0039-03, DEC. 2008 & BURO HAPPOLD FACTUAL REPORT, OCTOBER 2004.

GEOLOGICAL PROFILE DEVELOPED FOR THE REFERENCE DESIGN IS BASED ON THE GROUND INVESTIGATION UNDERTAKEN BY CONCEPT (REF. 10/2554 19/05/2010) USING BOREHOLE DRILLED AT APPROXIMATELY 300M CENTRES ALONG THE ROUTE AND OTHER DATA HELD BY BURO HAPPOLD (BGS AND OTHER SITE E.G. BATTERSEA POWER STATION)

DRAWINGS BASED ON THE INFORMATION AVAILABLE AT THE TIME OF DESIGN

NLE TRACK ALIGNMENT BASED ON HALCROW DRAWING GRNLEB-HGL-00-XX-M2-PWY-00010-02-01

—?—?—?— INSUFFICIENT DATA TO DEFINE INTERFACE

POTENTIAL SCOUR FEATURE

-2.5 CONTOUR - TOP OF LONDON CLAY (mOD)

(5.9) TOP OF LONDON CLAY IN EXPLORATORY HOLE (mOD)

NOTE

INTERPRETATION OF STRATIGRAPHY BASED ON DATA CLOSEST TO TUNNEL ALIGNMENT - SEE HOLE OFFSET AT BASE OF SECTION.

Rev	By	Chkd	Apprvd	Date	Description
05	NG	JD	SL	13/03/13	LONDON CLAY CONTOURS ADDED
04	NG	JD	SL	06/02/13	CHANGE TO NOTES
03	NG	JD	SL	11/01/13	BOREHOLE SECTIONS ADDED
02	NG	JD	SL	11/12/12	S4-FORMAL ISSUE TO CLIENT

Client

Transport for London

studiodare ARCHITECTS

Buro Happold Consulting Engineers

Halcrow Group Ltd.
A CH2M HILL COMPANY
Elms House, 43 Brook Green
Hammersmith, London W6 7EF
TEL: 020 3479 8000
FAX: 020 3479 8001
www.halcrow.com

Halcrow

Project:

NORTHERN LINE EXTENSION TO BATTERSEA TWAO FOR TfL

Drawing:

GEOLOGICAL PROFILE OF REFERENCE DESIGN ALIGNMENT SHEET 2 OF 3

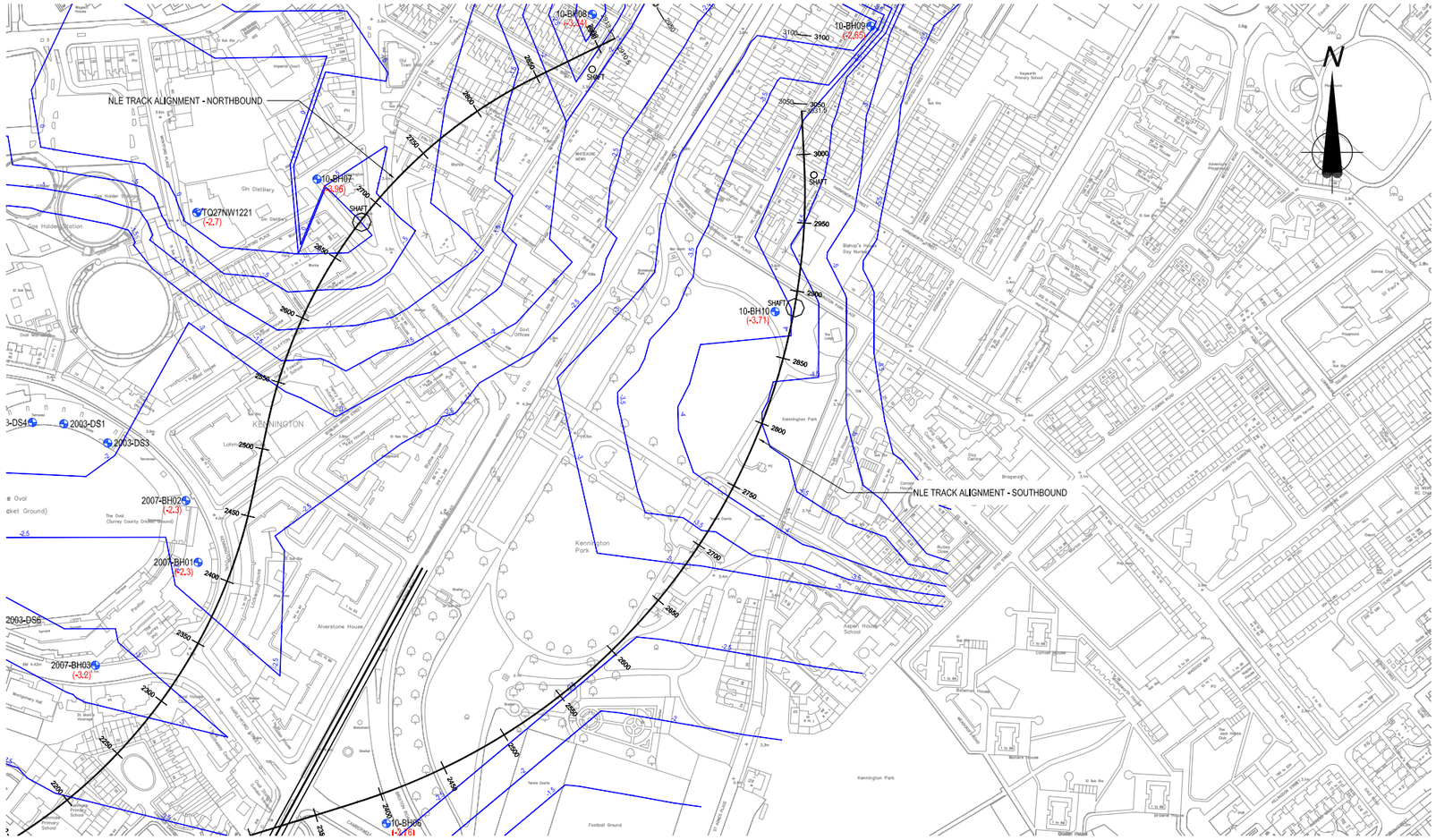
Suitability: S4_FORMAL_ISSUE_TO_CLIENT

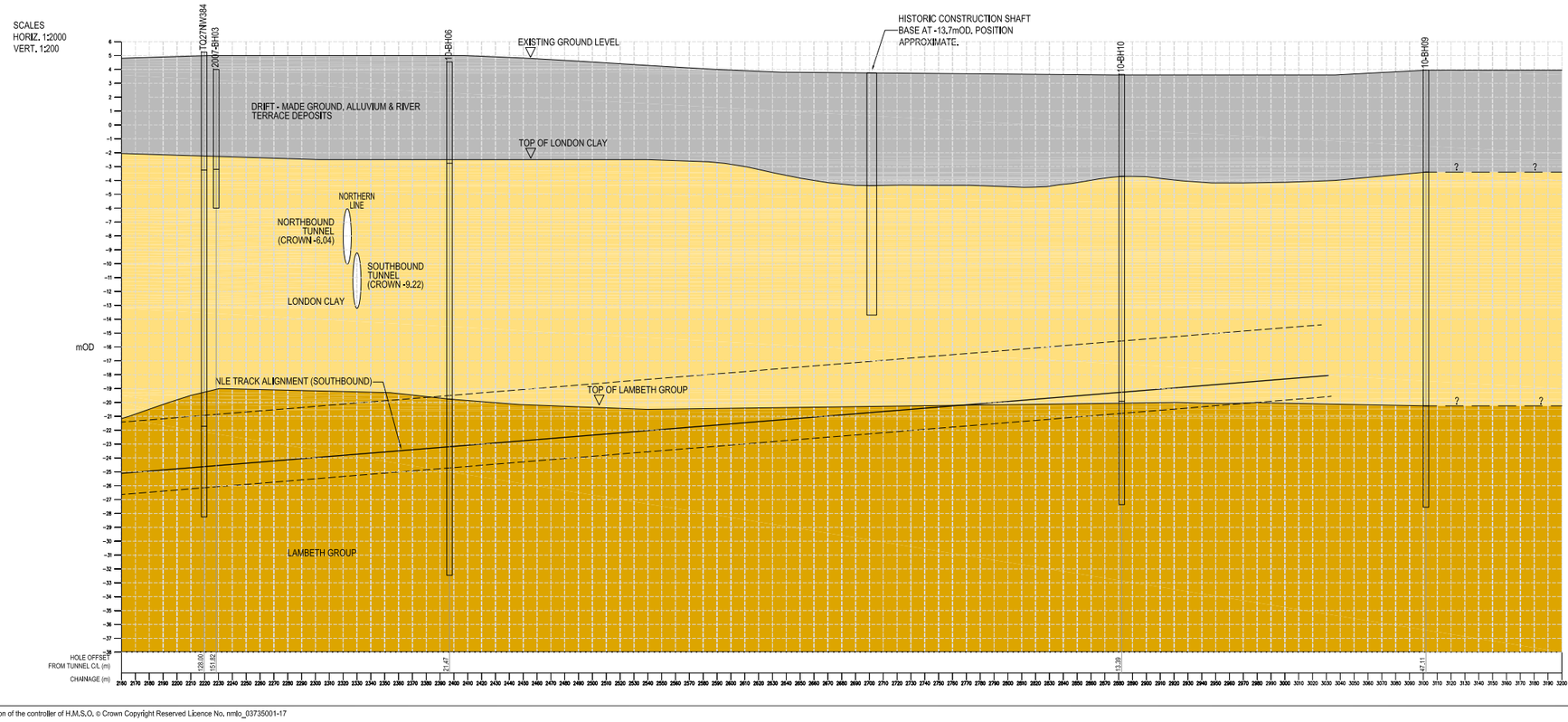
Drawn by: NG	Date: 06/02/13
Checked by: JD	Date: 06/02/13
Approved by: SL	Date: 06/02/13
Drawing Scale: AS SHOWN	

Drawing No.: GRNLEB-BHD-TU-XX-DR-GEO-14101

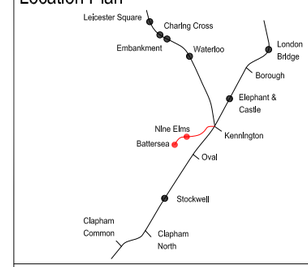
Revision: 05-01

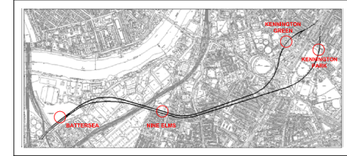
Drawing file path & name : - User and Plot Date : ngibson2 - 13.3.2013 - 4:3 pm





Location Plan





CONTOURS USED TO CREATE GROUND MODEL FROM PARSONS BRINCKERHOFF FEASIBILITY REPORT UMD90388A-0039-03, DEC. 2008 & BURO HAPPOLD FACTUAL REPORT, OCTOBER 2004.

GEOLOGICAL PROFILE DEVELOPED FOR THE REFERENCE DESIGN IS BASED ON THE GROUND INVESTIGATION UNDERTAKEN BY CONCEPT (REF. 10/2554 19/05/2010) USING BOREHOLE DRILLED AT APPROXIMATELY 300M CENTRES ALONG THE ROUTE AND OTHER DATA HELD BY BURO HAPPOLD (BGS AND OTHER SITE E.G. BATTERSEA POWER STATION)

DRAWINGS BASED ON THE INFORMATION AVAILABLE AT THE TIME OF DESIGN

NLE TRACK ALIGNMENT BASED ON HALCROW DRAWING GRNLEB-HGL-00-XX-M2-PWY-00010-02-01

—?—?—?— INSUFFICIENT DATA TO DEFINE INTERFACE

-2.5 CONTOUR - TOP OF LONDON CLAY (mOD)

(5.9) TOP OF LONDON CLAY IN EXPLORATORY HOLE (mOD)

NOTE

INTERPRETATION OF STRATIGRAPHY BASED ON DATA CLOSEST TO TUNNEL ALIGNMENT - SEE HOLE OFFSET AT BASE OF SECTION.

Rev	By	Chkd	Apprvd	Date	Description
05	NG	JD	SL	13/03/13	LONDON CLAY CONTOURS ADDED
04	NG	JD	SL	06/02/13	CHANGE TO NOTES
03	NG	JD	SL	11/01/13	BOREHOLE SECTIONS ADDED
02	NG	JD	SL	11/12/12	S4-FORMAL ISSUE TO CLIENT

Client

Transport for London

studiodare ARCHITECTS

Buro Happold Consulting Engineers

Halcrow Group Ltd.
A CH2M HILL COMPANY
Elms House, 43 Brook Green
Hammersmith, London W6 7EF
TEL: 020 3479 8000
FAX: 020 3479 8001
www.halcrow.com

Halcrow

Project:

NORTHERN LINE EXTENSION
TO BATTERSEA
TWAO FOR TfL

Drawing:

GEOLOGICAL PROFILE OF REFERENCE DESIGN ALIGNMENT SHEET 3 OF 3

Suitability: S4_FORMAL_ISSUE_TO_CLIENT

Drawn by: NG	Date:	06/02/13
Checked by: JD	Date:	06/02/13
Approved by: SL	Date:	06/02/13
Drawing Scale: AS SHOWN		

Drawing No.: GRNLEB-BHD-TU-XX-DR-GEO-14102

Revision: 05-01

Drawing file path & name : -
User and Plot Date : ngibson2 - 13.02.2013 - 4:3 pm

Buro Happold

A2 - Settlement Contour Drawings – December 2012 Stage C Drawing Issue

Drawings numbers:

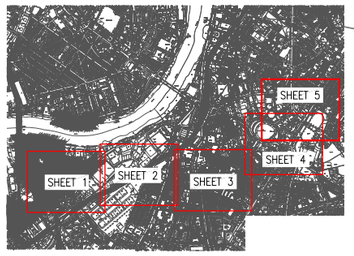
GRNLEB-BHD-TU-XX-DR-GEO-14600-04-01

GRNLEB-BHD-TU-XX-DR-GEO-14601-04-01

GRNLEB-BHD-TU-XX-DR-GEO-14602-04-01

GRNLEB-BHD-TU-XX-DR-GEO-14603-04-01

GRNLEB-BHD-TU-XX-DR-GEO-14604-05-01



BUILDINGS POTENTIALLY FOUNDED ON PILED FOUNDATIONS (SEE SETTLEMENT REPORT FOR FULL LIST OF PILED BUILDINGS)

- SETTLEMENT CONTOUR - 0MM
- SETTLEMENT CONTOUR - 1MM
- SETTLEMENT CONTOUR - 5MM
- SETTLEMENT CONTOUR - 10MM
- SETTLEMENT CONTOUR - 15MM
- SETTLEMENT CONTOUR - 20MM
- SETTLEMENT CONTOUR - 30MM
- SETTLEMENT CONTOUR - 40MM
- SETTLEMENT CONTOUR - 50MM
- SETTLEMENT CONTOUR - 60MM
- SETTLEMENT CONTOUR - 70MM

BUILDINGS ASSUMED DEMOLISHED

TUNNEL CENTRELINE - NORTHBOUND

TUNNEL CENTRELINE - SOUTHBOUND

CROSS PASSAGE No 4

CROSS OVER BOX

STATION BOX

CROSS PASSAGE No 5

CROSS PASSAGE No 6

Nine Elms (South Lambeth) Freight Depot

NINE ELMS

Battersea Power Station (disused)

Cringle Dock Refuse Transfer Station

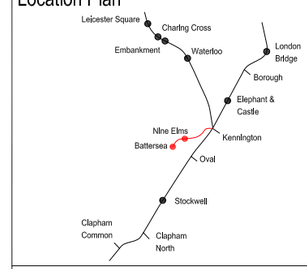
Tideway Industrial Estate

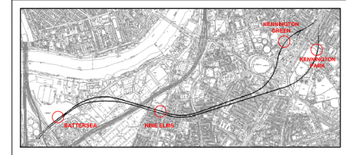
New Covent Garden Market

Fruit and Vegetable Market

Multistorey Car Park

Location Plan





Notes:

1. ALL CONTOURS SHOWN ARE IN MM.
2. ANALYSIS HAS BEEN BASED ON THE INFORMATION AVAILABLE AT THE TIME OF DESIGN.
3. MODELLING ONLY TAKES ACCOUNT OF THE IMPACT OF THE NORTHERN LINE EXTENSION AND ASSOCIATED INFRASTRUCTURE E.G. STATION BOXES. THE EFFECTS OF BATTERSEA POWER STATION REDEVELOPMENT HAVE NOT BEEN INCORPORATED.
4. TUNNEL ALIGNMENT IS BASED ON DRAWING GRNLEB-HGL-00-XX-M2-PWY-00010-02-01.
5. CROSS PASSAGE LOCATION IS BASED ON DRAWING GRNLEB-HGL-00-XX-DR-TUN-20402-03-01.
6. SUBSTATION AT KENNINGTON PARK IS BASED ON DRAWING GRNLEB-BHD-ST-XX-DR-STR-13120-01-01. ADIT BETWEEN SHAFT AND HEADHOUSE AT KENNINGTON GREEN IS BASED ON DRAWING GRNLEB-HGL-00-XX-DR-TUN-23000-03-01.
7. SETTLEMENT DUE TO RUNNING TUNNELS ARE BASED ON A 1.5% VOLUME LOSS. SEE SETTLEMENT REPORT FOR FULL DETAILS ON OTHER TUNNEL TYPES.
8. SETTLEMENT DUE TO STATION EXCAVATIONS ARE BASED ON CURVES FROM CIRIA C580 FIGURE 2.9 (B) . EXCEPT THE ADIT AT KENNINGTON GREEN WHICH IS BASED ON CIRIA C580 FIGURE 2.12. THE GROUND MOVEMENT CURVES ARE CONSIDERED TO REPRESENT 100% GROUND MOVEMENT PROFILE. HOWEVER THE STATION EXCAVATIONS WILL HAVE AN INCREASED STIFFNESS AT THE CORNERS, THEREFORE THE SETTLEMENT CONTOURS AROUND THE EXCAVATIONS ARE A CONSERVATIVE ESTIMATE.
9. SETTLEMENT DUE TO EXCAVATIONS OF SHAFTS IS BASED ON THE LONDON UNDERGROUND MANUAL OF GOOD PRACTICE USING G-058 NEW AND BOWERS (1994) .
10. THE MAP IS BASED ON ORDNANCE SURVEY, REPRODUCED FROM LANDRANGER 1:50,000 MAP BY PERMISSION OF ORDNANCE SURVEY ® ON BEHALF OF THE CONTROLLER OF HER MAJESTY'S STATIONARY OFFICE. © CROWN COPYRIGHT 1988. ALL RIGHTS RESERVED. LICENSE NUMBER: AL 100005517. THE ORDNANCE SURVEY DATA USED WAS THAT AVAILABLE AT THE TIME OF 2012 REFERENCE DESIGN, AND THUS ANY RECENT CHANGES WILL NOT BE REFLECTED IN THE MAPS USED FOR ANALYSIS.

Rev	By	Chkd	Apprvd	Date	Description
04-01	JMB	JD	SL	01/02/13	INCLUSION OF ADITS & SUBSTATION
03-01	JMB	JD	SL	18/01/13	CROSS PASSAGES ADDED
02-01	JMB	JP	JP	02/11/12	CHANGE IN ALIGNMENT
01-01	JMB	JD	JP	19/10/12	FOR INFORMATION

Client

Transport for London

studiodare ARCHITECTS

Buro Happold Consulting Engineers

Halcrow Group Ltd.
A CH2M HILL COMPANY
Elms House, 43 Brook Green
Hammersmith, London W6 7EF
TEL: 020 3479 8000
FAX: 020 3479 8001
www.halcrow.com

Halcrow

Project:

NORTHERN LINE EXTENSION TO BATTERSEA TWAO FOR TfL

Drawing:

SURFACE SETTLEMENT CONTOURS SHEET 1 OF 5

Suitability:

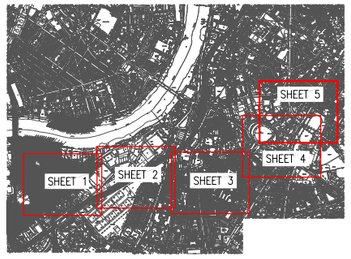
S4 - FORMAL ISSUE TO CLIENT

Drawn by: JMB	Date:	01/02/13
Checked by: JD	Date:	01/02/13
Approved by: SL	Date:	01/02/13
Drawing Scale: 1:1000		

Drawing No.: GRNLEB-BHD-TU-XX-DR-GEO-14600

Revision: 04-01

Drawing file path & name : -
User and Plot Date : jmbaire : 6/2/2013 - 2:22 pm



SETTLEMENT CONTOUR - 0MM
SETTLEMENT CONTOUR - 1MM
SETTLEMENT CONTOUR - 5MM
SETTLEMENT CONTOUR - 10MM
SETTLEMENT CONTOUR - 15MM
SETTLEMENT CONTOUR - 20MM
SETTLEMENT CONTOUR - 30MM
SETTLEMENT CONTOUR - 40MM
SETTLEMENT CONTOUR - 50MM
SETTLEMENT CONTOUR - 60MM
SETTLEMENT CONTOUR - 70MM

BUILDINGS POTENTIALLY FOUNDED ON PILED FOUNDATIONS (SEE SETTLEMENT REPORT FOR FULL LIST OF PILED BUILDINGS)

TUNNEL CENTRELINE - NORTHBOUND

TUNNEL CENTRELINE - SOUTHBOUND

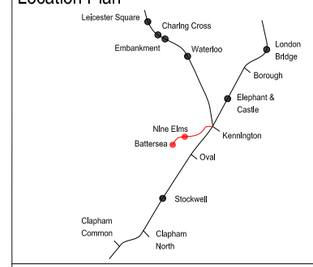
BUILDINGS ASSUMED DEMOLISHED

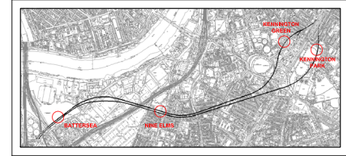
STATION BOX

0
1
5
10
15
20
30

N

Location Plan





Notes:

1. ALL CONTOURS SHOWN ARE IN MM.
2. ANALYSIS HAS BEEN BASED ON THE INFORMATION AVAILABLE AT THE TIME OF DESIGN.
3. MODELLING ONLY TAKES ACCOUNT OF THE IMPACT OF THE NORTHERN LINE EXTENSION AND ASSOCIATED INFRASTRUCTURE E.G. STATION BOXES. THE EFFECTS OF BATTERSEA POWER STATION REDEVELOPMENT HAVE NOT BEEN INCORPORATED.
4. TUNNEL ALIGNMENT IS BASED ON DRAWING GRNLEB-HGL-00-XX-M2-PWY-00010-02-01.
5. CROSS PASSAGE LOCATION IS BASED ON DRAWING GRNLEB-HGL-00-XX-DR-TUN-20402-03-01.
6. SUBSTATION AT KENNINGTON PARK IS BASED ON DRAWING GRNLEB-BHD-ST-XX-DR-STR-13120-01-01. ADIT BETWEEN SHAFT AND HEADHOUSE AT KENNINGTON GREEN IS BASED ON DRAWING GRNLEB-HGL-00-XX-DR-TUN-23000-03-01.
7. SETTLEMENT DUE TO RUNNING TUNNELS ARE BASED ON A 1.5% VOLUME LOSS. SEE SETTLEMENT REPORT FOR FULL DETAILS ON OTHER TUNNEL TYPES.
8. SETTLEMENT DUE TO STATION EXCAVATIONS ARE BASED ON CURVES FROM CIRIA C580 FIGURE 2.9 (B) . EXCEPT THE ADIT AT KENNINGTON GREEN WHICH IS BASED ON CIRIA C580 FIGURE 2.12. THE GROUND MOVEMENT CURVES ARE CONSIDERED TO REPRESENT 100% GROUND MOVEMENT PROFILE. HOWEVER THE STATION EXCAVATIONS WILL HAVE AN INCREASED STIFFNESS AT THE CORNERS. THEREFORE THE SETTLEMENT CONTOURS AROUND THE EXCAVATIONS ARE A CONSERVATIVE ESTIMATE.
9. SETTLEMENT DUE TO EXCAVATIONS OF SHAFTS IS BASED ON THE LONDON UNDERGROUND MANUAL OF GOOD PRACTICE USING G-058 NEW AND BOWERS (1994) .
10. THE MAP IS BASED ON ORDNANCE SURVEY, REPRODUCED FROM LANDRANGER 1:50,000 MAP BY PERMISSION OF ORDNANCE SURVEY ® ON BEHALF OF THE CONTROLLER OF HER MAJESTY'S STATIONARY OFFICE. © CROWN COPYRIGHT 1988. ALL RIGHTS RESERVED. LICENSE NUMBER: AL 100005517. THE ORDNANCE SURVEY DATA USED WAS THAT AVAILABLE AT THE TIME OF 2012 REFERENCE DESIGN, AND THUS ANY RECENT CHANGES WILL NOT BE REFLECTED IN THE MAPS USED FOR ANALYSIS.

Rev	By	Chkd	Apprvd	Date	Description
04-01	JMB	JD	SL	01/02/13	INCLUSION OF ADITS & SUBSTATION
03-01	JMB	JD	SL	18/01/13	CROSS PASSAGES ADDED
02-01	JMB	JP	JP	02/11/12	CHANGE IN ALIGNMENT
01-01	JMB	JD	JP	19/10/12	FOR INFORMATION

Client

Transport for London

studiodareARCHITECTS

Buro Happold Consulting Engineers

Halcrow Group Ltd.
A CH2M HILL COMPANY
Elms House, 43 Brook Green
Hammersmith, London W6 7EF
TEL: 020 3479 8000
FAX: 020 3479 8001
www.halcrow.com

Halcrow

Project:

NORTHERN LINE EXTENSION
TO BATTERSEA
TWAO FOR TfL

Drawing:

SURFACE SETTLEMENT
CONTOURS
SHEET 2 OF 5

Suitability:

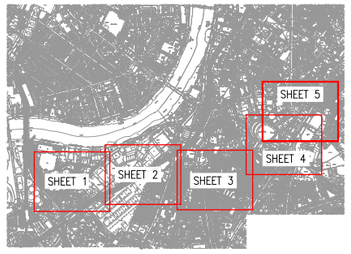
S4 - FORMAL ISSUE TO CLIENT

Drawn by: JMB	Date:	01/02/13
Checked by: JD	Date:	01/02/13
Approved by: SL	Date:	01/02/13
Drawing Scale: 1:1000		

Drawing No.: GRNLEB-BHD-TU-XX-DR-GEO-14601

Revision: 04-01

Drawing file path & name : - ; Jmbome : 6/2/2013 - 2:2 pm
User and Plot Date



BUILDINGS POTENTIALLY FOUNDED ON PILED FOUNDATIONS (SEE SETTLEMENT REPORT FOR FULL LIST OF PILED BUILDINGS)

- SETTLEMENT CONTOUR - 0MM
- SETTLEMENT CONTOUR - 1MM
- SETTLEMENT CONTOUR - 5MM
- SETTLEMENT CONTOUR - 10MM
- SETTLEMENT CONTOUR - 15MM
- SETTLEMENT CONTOUR - 20MM
- SETTLEMENT CONTOUR - 30MM
- SETTLEMENT CONTOUR - 40MM
- SETTLEMENT CONTOUR - 50MM
- SETTLEMENT CONTOUR - 60MM
- SETTLEMENT CONTOUR - 70MM

TUNNEL CENTRELINE - NORTHBOUND

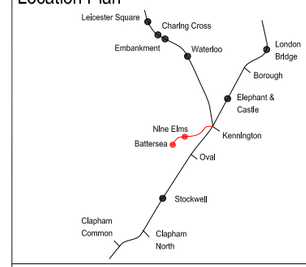
TUNNEL CENTRELINE - SOUTHBOUND

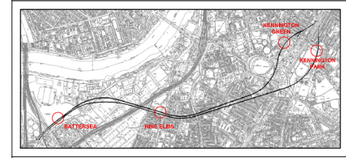
CROSS PASSAGE No 2

CROSS PASSAGE No 3

N

Location Plan





Notes:

1. ALL CONTOURS SHOWN ARE IN MM.
2. ANALYSIS HAS BEEN BASED ON THE INFORMATION AVAILABLE AT THE TIME OF DESIGN.
3. MODELLING ONLY TAKES ACCOUNT OF THE IMPACT OF THE NORTHERN LINE EXTENSION AND ASSOCIATED INFRASTRUCTURE E.G. STATION BOXES, THE EFFECTS OF BATTERSEA POWER STATION REDEVELOPMENT HAVE NOT BEEN INCORPORATED.
4. TUNNEL ALIGNMENT IS BASED ON DRAWING GRNLEB-HGL-00-XX-M2-PWY-00010-02-01.
5. CROSS PASSAGE LOCATION IS BASED ON DRAWING GRNLEB-HGL-00-XX-DR-TUN-20402-03-01.
6. SUBSTATION AT KENNINGTON PARK IS BASED ON DRAWING GRNLEB-BHD-ST-XX-DR-STR-13120-01-01. ADIT BETWEEN SHAFT AND HEADHOUSE AT KENNINGTON GREEN IS BASED ON DRAWING GRNLEB-HGL-00-XX-DR-TUN-23000-03-01.
7. SETTLEMENT DUE TO RUNNING TUNNELS ARE BASED ON A 1.5% VOLUME LOSS. SEE SETTLEMENT REPORT FOR FULL DETAILS ON OTHER TUNNEL TYPES.
8. SETTLEMENT DUE TO STATION EXCAVATIONS ARE BASED ON CURVES FROM CIRIA C580 FIGURE 2.9 (B) . EXCEPT THE ADIT AT KENNINGTON GREEN WHICH IS BASED ON CIRIA C580 FIGURE 2.12. THE GROUND MOVEMENT CURVES ARE CONSIDERED TO REPRESENT 100% GROUND MOVEMENT PROFILE, HOWEVER THE STATION EXCAVATIONS WILL HAVE AN INCREASED STIFFNESS AT THE CORNERS, THEREFORE THE SETTLEMENT CONTOURS AROUND THE EXCAVATIONS ARE A CONSERVATIVE ESTIMATE.
9. SETTLEMENT DUE TO EXCAVATIONS OF SHAFTS IS BASED ON THE LONDON UNDERGROUND MANUAL OF GOOD PRACTICE USING G-058 NEW AND BOWERS (1994) .
10. THE MAP IS BASED ON ORDNANCE SURVEY. REPRODUCED FROM LANDRANGER 1:50,000 MAP BY PERMISSION OF ORDNANCE SURVEY ® ON BEHALF OF THE CONTROLLER OF HER MAJESTY'S STATIONARY OFFICE. © CROWN COPYRIGHT 1988. ALL RIGHTS RESERVED. LICENSE NUMBER: AL 100005517. THE ORDNANCE SURVEY DATA USED WAS THAT AVAILABLE AT THE TIME OF 2012 REFERENCE DESIGN, AND THUS ANY RECENT CHANGES WILL NOT BE REFLECTED IN THE MAPS USED FOR ANALYSIS.

Rev	By	Chkd	Apprvd	Date	Description
04-01	JMB	JD	SL	01/02/13	INCLUSION OF ADITS & SUBSTATION
03-01	JMB	JD	SL	18/01/13	CROSS PASSAGES ADDED
02-01	JMB	JP	JP	02/11/12	CHANGE IN ALIGNMENT
01-01	JMB	JD	JP	19/10/12	FOR INFORMATION

Client

Transport for London

studiodare ARCHITECTS

Buro Happold Consulting Engineers

Halcrow Group Ltd,
A CH2M HILL COMPANY
Elms House, 43 Brook Green
Hammersmith, London W6 7EF
TEL: 020 3479 8000
FAX: 020 3479 8001
www.halcrow.com

Halcrow

Project:

NORTHERN LINE EXTENSION
TO BATTERSEA
TWAO FOR TfL

Drawing:

SURFACE SETTLEMENT CONTOURS SHEET 3 OF 5

Suitability:

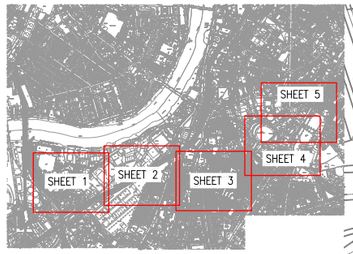
S4 - FORMAL ISSUE TO CLIENT

Drawn by: JMB	Date:	01/02/13
Checked by: JD	Date:	01/02/13
Approved by: SL	Date:	01/02/13
Drawing Scale: 1:1000		

Drawing No.: GRNLEB-BHD-TU-XX-DR-GEO-14602

Revision: 04-01

Drawing file path & name : - ; Jmborne - 6:22:2013 - 2:22 pm
User and Plot Date



BUILDINGS POTENTIALLY FOUNDED ON PILED FOUNDATIONS (SEE SETTLEMENT REPORT FOR FULL LIST OF PILED BUILDINGS)

- SETTLEMENT CONTOUR - 0MM
- SETTLEMENT CONTOUR - 1MM
- SETTLEMENT CONTOUR - 5MM
- SETTLEMENT CONTOUR - 10MM
- SETTLEMENT CONTOUR - 15MM
- SETTLEMENT CONTOUR - 20MM
- SETTLEMENT CONTOUR - 30MM
- SETTLEMENT CONTOUR - 40MM
- SETTLEMENT CONTOUR - 50MM
- SETTLEMENT CONTOUR - 60MM
- SETTLEMENT CONTOUR - 70MM

TUNNEL CENTRELINE - NORTHBOUND

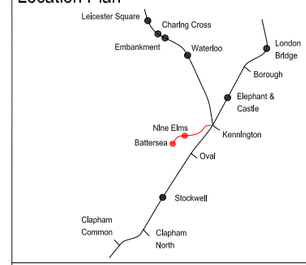
TUNNEL CENTRELINE - SOUTHBOUND

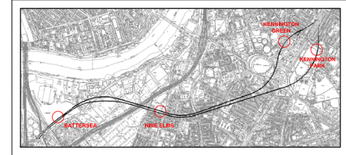
CROSS PASSAGE No 1

0 1 5 10 15

N

Location Plan





Notes:

1. ALL CONTOURS SHOWN ARE IN MM.
2. ANALYSIS HAS BEEN BASED ON THE INFORMATION AVAILABLE AT THE TIME OF DESIGN.
3. MODELLING ONLY TAKES ACCOUNT OF THE IMPACT OF THE NORTHERN LINE EXTENSION AND ASSOCIATED INFRASTRUCTURE E.G. STATION BOXES. THE EFFECTS OF BATTERSEA POWER STATION REDEVELOPMENT HAVE NOT BEEN INCORPORATED.
4. TUNNEL ALIGNMENT IS BASED ON DRAWING GRNLEB-HGL-00-XX-M2-PWY-00010-02-01.
5. CROSS PASSAGE LOCATION IS BASED ON DRAWING GRNLEB-HGL-00-XX-DR-TUN-20402-03-01.
6. SUBSTATION AT KENNINGTON PARK IS BASED ON DRAWING GRNLEB-BHD-ST-XX-DR-STR-13120-01-01. ADIT BETWEEN SHAFT AND HEADHOUSE AT KENNINGTON GREEN IS BASED ON DRAWING GRNLEB-HGL-00-XX-DR-TUN-23000-03-01.
7. SETTLEMENT DUE TO RUNNING TUNNELS ARE BASED ON A 1.5% VOLUME LOSS. SEE SETTLEMENT REPORT FOR FULL DETAILS ON OTHER TUNNEL TYPES.
8. SETTLEMENT DUE TO STATION EXCAVATIONS ARE BASED ON CURVES FROM CIRIA C580 FIGURE 2.9 (B) . EXCEPT THE ADIT AT KENNINGTON GREEN WHICH IS BASED ON CIRIA C580 FIGURE 2.12. THE GROUND MOVEMENT CURVES ARE CONSIDERED TO REPRESENT 100% GROUND MOVEMENT PROFILE. HOWEVER THE STATION EXCAVATIONS WILL HAVE AN INCREASED STIFFNESS AT THE CORNERS. THEREFORE THE SETTLEMENT CONTOURS AROUND THE EXCAVATIONS ARE A CONSERVATIVE ESTIMATE.
9. SETTLEMENT DUE TO EXCAVATIONS OF SHAFTS IS BASED ON THE LONDON UNDERGROUND MANUAL OF GOOD PRACTICE USING G-058 NEW AND BOWERS (1994) .
10. THE MAP IS BASED ON ORDNANCE SURVEY, REPRODUCED FROM LANDRANGER 1:50,000 MAP BY PERMISSION OF ORDNANCE SURVEY ® ON BEHALF OF THE CONTROLLER OF HER MAJESTY'S STATIONARY OFFICE. © CROWN COPYRIGHT 1988. ALL RIGHTS RESERVED. LICENSE NUMBER: AL 100005517. THE ORDNANCE SURVEY DATA USED WAS THAT AVAILABLE AT THE TIME OF 2012 REFERENCE DESIGN, AND THUS ANY RECENT CHANGES WILL NOT BE REFLECTED IN THE MAPS USED FOR ANALYSIS.

Rev	By	Chkd	Apprvd	Date	Description
04-01	JMB	JD	SL	01/02/13	INCLUSION OF ADITS & SUBSTATION
03-01	JMB	JD	SL	18/01/13	CROSS PASSAGES ADDED
02-01	JMB	JP	JP	02/11/12	CHANGE IN ALIGNMENT
01-01	JMB	JD	JP	19/10/12	FOR INFORMATION

Client

Transport for London

studiodare ARCHITECTS

Buro Happold Consulting Engineers

Halcrow Group Ltd.
A CH2M HILL COMPANY
Elms House, 43 Brook Green
Hammersmith, London W6 7EF
TEL: 020 3479 8000
FAX: 020 3479 8001
www.halcrow.com

Halcrow

Project:

NORTHERN LINE EXTENSION
TO BATTERSEA
TWAO FOR TfL

Drawing:

SURFACE SETTLEMENT CONTOURS SHEET 4 OF 5

Suitability:

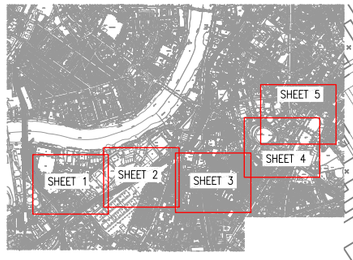
S4 - FORMAL ISSUE TO CLIENT

Drawn by: JMB	Date:	01/02/13
Checked by: JD	Date:	01/02/13
Approved by: SL	Date:	01/02/13
Drawing Scale: 1:1000		

Drawing No.: GRNLEB-BHD-TU-XX-DR-GEO-14603

Revision: 04-01

Drawing file path & name : - : jmbarne : 6.2.2013 - 2.2 pm
User and Plot Date



BUILDINGS POTENTIALLY FOUNDED ON PILED FOUNDATIONS (SEE SETTLEMENT REPORT FOR FULL LIST OF PILED BUILDINGS)

- SETTLEMENT CONTOUR - 0MM
- SETTLEMENT CONTOUR - 1MM
- SETTLEMENT CONTOUR - 5MM
- SETTLEMENT CONTOUR - 10MM
- SETTLEMENT CONTOUR - 15MM
- SETTLEMENT CONTOUR - 20MM
- SETTLEMENT CONTOUR - 30MM
- SETTLEMENT CONTOUR - 40MM
- SETTLEMENT CONTOUR - 50MM
- SETTLEMENT CONTOUR - 60MM
- SETTLEMENT CONTOUR - 70MM

KENNINGTON GREEN ADIT BETWEEN SHAFT AND HEADHOUSE

TUNNEL CENTRELINE - NORTHBOUND

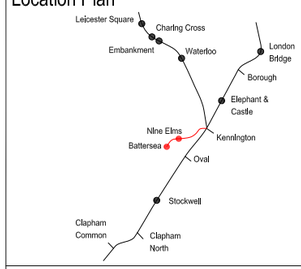
TUNNEL CENTRELINE - SOUTHBOUND

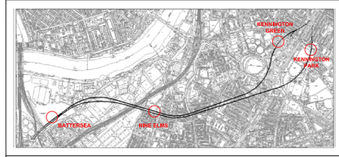
SHAFT

KENNINGTON PARK SUBSTATION

0 1 5 10 15

Location Plan





Notes:

1. ALL CONTOURS SHOWN ARE IN MM.
2. ANALYSIS HAS BEEN BASED ON THE INFORMATION AVAILABLE AT THE TIME OF DESIGN.
3. MODELLING ONLY TAKES ACCOUNT OF THE IMPACT OF THE NORTHERN LINE EXTENSION AND ASSOCIATED INFRASTRUCTURE E.G. STATION BOXES. THE EFFECTS OF BATTERSEA POWER STATION REDEVELOPMENT HAVE NOT BEEN INCORPORATED.
4. TUNNEL ALIGNMENT IS BASED ON DRAWING GRNLEB-HGL-00-XX-M2-PWY-00010-02-01.
5. CROSS PASSAGE LOCATION IS BASED ON DRAWING GRNLEB-HGL-00-XX-DR-TUN-20402-03-01.
6. SUBSTATION AT KENNINGTON PARK IS BASED ON DRAWING GRNLEB-BHD-ST-XX-DR-STR-13120-01-01. ADIT BETWEEN SHAFT AND HEADHOUSE AT KENNINGTON GREEN IS BASED ON DRAWING GRNLEB-HGL-00-XX-DR-TUN-23000-03-01.
7. SETTLEMENT DUE TO RUNNING TUNNELS ARE BASED ON A 1.5% VOLUME LOSS. SEE SETTLEMENT REPORT FOR FULL DETAILS ON OTHER TUNNEL TYPES.
8. SETTLEMENT DUE TO STATION EXCAVATIONS ARE BASED ON CURVES FROM CIRIA C580 FIGURE 2.9 (B) . EXCEPT THE ADIT AT KENNINGTON GREEN WHICH IS BASED ON CIRIA C580 FIGURE 2.12. THE GROUND MOVEMENT CURVES ARE CONSIDERED TO REPRESENT 100% GROUND MOVEMENT PROFILE, HOWEVER THE STATION EXCAVATIONS WILL HAVE AN INCREASED STIFFNESS AT THE CORNERS. THEREFORE THE SETTLEMENT CONTOURS AROUND THE EXCAVATIONS ARE A CONSERVATIVE ESTIMATE.
9. SETTLEMENT DUE TO EXCAVATIONS OF SHAFTS IS BASED ON THE LONDON UNDERGROUND MANUAL OF GOOD PRACTICE USING G-058 NEW AND BOWERS (1994) .
10. THE MAP IS BASED ON ORDNANCE SURVEY, REPRODUCED FROM LANDRANGER 1:50,000 MAP BY PERMISSION OF ORDNANCE SURVEY ® ON BEHALF OF THE CONTROLLER OF HER MAJESTY'S STATIONARY OFFICE. © CROWN COPYRIGHT 1988. ALL RIGHTS RESERVED. LICENSE NUMBER: AL 100005517. THE ORDNANCE SURVEY DATA USED WAS THAT AVAILABLE AT THE TIME OF 2012 REFERENCE DESIGN, AND THUS ANY RECENT CHANGES WILL NOT BE REFLECTED IN THE MAPS USED FOR ANALYSIS.

Rev	By	Chkd	Apprvd	Date	Description
05-01	JMB	JD	SL	14/03/13	AMENDED CONTOURS
04-01	JMB	JD	SL	01/02/13	INCLUSION OF ADITS & SUBSTATION
03-01	JMB	JD	SL	18/01/13	CROSS PASSAGES ADDED
02-01	JMB	JP	JP	02/11/12	CHANGE IN ALIGNMENT
01-01	JMB	JD	JP	19/10/12	FOR INFORMATION

Client

Transport for London

studiodare ARCHITECTS

Buro Happold Consulting Engineers

Halcrow Group Ltd.
A CH2M HILL COMPANY
Elms House, 43 Brook Green
Hammersmith, London W6 7EF
TEL: 020 3479 8000
FAX: 020 3479 8001
www.halcrow.com

Halcrow

Project:

NORTHERN LINE EXTENSION
TO BATTERSEA
TWAO FOR TfL

Drawing:

SURFACE SETTLEMENT
CONTOURS
SHEET 5 OF 5

Suitability:

S4 - FORMAL ISSUE TO CLIENT

Drawn by: JMB	Date:	14/03/13
Checked by: JD	Date:	14/03/13
Approved by: SL	Date:	14/03/13
Drawing Scale: 1:1000		
Drawing No.: GRNLEB-BHD-TU-XX-DR-GEO-14604		Revision: 05-01

Drawing file path & name : -
User and Plot Date : jmbaine : 14.3.2013 - 5.3 pm