M25 junction 28 improvement scheme

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9.25 Ground Investigation Report

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9.25 GROUND INVESTIGATION REPORT

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This document has 163 pages including the cover, not including appendices.

Document history

[redacted]

Summary of Scheme Geotechnical Reports

[redacted]

Table of contents

Tables

Figures

Executive Summary

Scheme Overview

The M25 Junction 28 improvement Scheme (the Scheme) under the Regional Investment Programme (RIP) is expected to comprise

- Minor realignment of the existing A12 trunk road;
- Widening of the M25 anticlockwise carriageway north of J28;
- Construction of a new 'cloverleaf' link road to connect the M25 northbound to the A12 eastbound;
- Construction of a new M25 northbound on-slip;
- Realignment of the Weald Brook watercourse;
- Construction of a new A12 eastbound off-slip to connect to the J28 roundabout;
- Realignment of the existing services; and
- Construction of attenuation ponds across the scheme.

The proposed engineering works include embankment and cutting construction; regrading, widening and/or strengthening of existing earthworks; and construction of various retaining structures.

This document is the Ground Investigation Report for the Scheme which includes an overview of the proposed works , analysis of ground conditions and the assignment of geotechnical parameters for each stratum across the overall scheme. The report also investigates the ground conditions local to the Scheme and provides geotechnical design input for the required earthworks, structures and foundations for the proposed works.

The Scheme has been subdivided into seven key ground models on an area and ground specific basis following the 2019 ground investigation. These have been individually assessed with a ground model and long sections produced to inform the geotechnical design.

Geotechnical Summary

The Scheme generally comprises artificial deposits (including Landfill and Engineered Fill associated with the existing M25 and A12 construction) and/or superficial deposits of Head and Alluvium, overlying London Clay Formation (both weathered and unweathered).

The development proposals for the Scheme include conventional geotechnical activities and no exceptional geotechnical risks have been identified allowing the Scheme to be assigned as Geotechnical Category 2. However, the following should be considered carefully within the Geotechnical Design Report at Project Control Framework Stage 5:

- The variability of the Made Ground, which comprises highly variable heterogenous ground conditions with discontinuous organic layers present, which will lead to material changes at foundation level and mid-slope along the sections of proposed structures;

- Variable compressible fine strata which may result in excessive and differential settlement, and variable rate of consolidation;
- Short- and long-term stability issues due to localised soft ground as well as the potential for relict shear surfaces within the Head deposits which may be reactivated;
- Ground conditions aggressive to concrete;
- Interaction with known existing structures, services and unexploded ordnance; and
- The inherent risks associated with working adjacent to live traffic and construction work.

Geo-Environmental Summary

Based on the available information, human health risk associated with soil, soil-derived dust, fibres, waters, vapours and ground gas were generally found to vary between Very Low and Moderate/Low during construction without mitigation. Assuming that standard good working practice and the recommended mitigation measures are implemented during construction, the level of risk will reduce to Very Low to Moderate/Low. A Very Low to Moderate / Low risk will be present within the operational Scheme and, in general, the identified level of risk for the completed Scheme is the same or lower risk than is present in the current undeveloped Scheme.

Based on groundwater monitoring and screening of soil-derived leachate and groundwater samples, there is considered to be a Moderate risk from perched water within the land fill/recently deposited material to the identified surface water receptors Weald Brook, River Ingrebourne and proposed attenuation ponds from migration of perched and / or surface water via preferential pathways (e.g. attenuation ponds (if unlined) and pond outfalls). All other potential pollutant linkages relating to controlled waters receptors have a lower risk classification.

In addition to mitigation measures presented in the soils and Geology Environmental Statement Chapter Section 10.9 [1] it is recommended that: the risk to surface water receptors from soil-derived leachate and perched water within the landfill is considered during detailed design, such that the risks are managed to an appropriate level; controlled waters piling risk assessment and the use of appropriate piling methods are undertaken; measures in the Construction Environmental Management Plan (e.g. good management of stockpiles) are implemented; and pollution incident control (e.g. plant drip trays and spill kits), control of run off and a dust management system are implemented.

Waste Summary

The preliminary waste classification indicates that overall material at the site is classified as non-hazardous.

Asbestos was positively identified in a low number of samples and quantified below the hazardous threshold of 0.1% w/w. Although asbestos presence is not associated with a particular area within the Scheme, it is expected to be prevalent within the Made Ground - Recently Deposited Material.

Waste Acceptance Criteria indicates that potential wastes from certain areas and some geological units (e.g. Head) could be suitable for acceptance and inert waste facilities. However, further testing and physical/visual inspection will be required to be undertaken by the Earthworks Contractor to characterise and classify waste prior to disposal.

Waste segregation and sustainable materials management should be employed by the Earthworks Contractor during the works, to ensure that materials re-use within the Scheme is maximised, and where surplus materials require removal from site, waste is classified correctly, and that waste disposed of at landfill is minimised.

List of Abbreviations

%	Percentage
(V):(H)	Ratio of vertical to horizontal
ACEC	Aggressive Chemical Environment for Concrete
ACM	Asbestos Containing Material
AGS	Association of Geotechnical and Geoenvironmental Specialists
ATK-XX	Atkins borehole
BGS	British Geological Survey
BPA	British Pipeline Agency Limited
BRE	Building Research Establishment
BS	British Standard
c’	Effective cohesion
C4SL	Category 4 Screening Levels
CAT	Cable Avoidance Tool
CBR	California Bearing Ratio
CH	Chainage
CIRIA	Construction Industry Research and Information Association
CLEA	Contaminated Land Exposure Assessment
CM	Conceptual Model
COMP	Composite Sample
CP	Cable Percussive borehole
CPS	Connect Plus Services
CPT	Cone Penetration Test
CS	Characteristic Situation
c_u	Undrained Shear Strength
DCP	Dynamic Cone Penetrometer
DEFRA	Department for Food and Rural Affairs
DOC	Dissolved Organic Carbon
DS	Design Sulphate class
DS	Dynamic Sample borehole
E	East
EAR	Environmental Assessment Report

EB	Eastbound
EC7	Eurocode 7
EIA	Environmental Impact Assessment
EPS	Expanded Polystyrene
EQS-f	Freshwater Environmental Quality Standards
GAC	Generic Assessment Criteria
GDR	Geotechnical Design Report
GEL	Geotechnical Engineering Ltd.
GI	Ground Investigation
GIR	Ground Investigation Report
GM	Ground Model
GPR	Ground Penetrating Radar
GQRA	Generic Quantitative Risk Assessment
GSV	Gas Screening Value
HAGDMS	Highways Agency Geotechnical Data Managements System
HSV	Hand Shear Vane
IAN	Interim Advice Notice
IP	Hand-Dug Inspection Pit
IP	Plasticity Index
kN	Kilo-newton
kN/m^2	Kilo-newton per meter squared
kPa	Kilopascals
l/hr	Litres per hour
m AOD	Meters above Ordnance Datum
m bgl	Meters below ground level
m	Meters
m/s	Metres per second
m^2/MN	Meters squared per Mega-newton
M-BAT	Environment Agency Water Framework Directive bioavailability tool
MCERTS	Environmental Agency of England and Wales (EA) Monitoring Certification Scheme
MCV	Moisture Condition Value
MDD	Maximum Dry Density

MDL	Method Detection Limit
Mg/m^3	Mega-grams per meter cubed
mm	Millimeters
MMP	Materials Management Plan
MTBE	Methyl Tertiary Butyl Ether
M_v	Coefficient of Volume Compressibility
N	North
N_{60}	Corrected SPT N value
NB	Northbound
NWC	Natural Water Content
O_2	Oxygen
OD	Ordnance Datum
OWC	Optimum Water Content
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PCF X	Project Control Framework Stage
PID	Photoionisation Detector
PNEC	Predicted No-Effect Concentration
POS	Public Open Space
PPE	Personal Protective Equipment
ppm	Parts Per Million
PSD	Particle Size Distribution
PSSR	Preliminary Sources Study Report
RAMS	Risk Assessment Method Statement
RC	Rotary core borehole
RIP	Regional Investment Programme
S	South
SHW	Specification for Highways Works
SOM	Soil Organic Matter
S-P-R	Source-Pathway-Receptor
SPT	Standard Penetration Test
SPZ	Source Protection Zone
SSV	Soil Screening Value

TM	Traffic Management
TOC	Total Organic Carbon
TP	Trial pit
TPH	Total Petroleum Hydrocarbons
TQ	Technical Query
UKAS	United Kingdom Accreditation Service
UKTAG	Water Framework Directive – United Kingdom Technical Advisory Group
UXO	Unexploded ordnance
VCP	Volume Change Potential
VOC	Volatile Organic Compound
VWP	Vibrating Wire Piezometers
W	West
WAC	Waste Acceptance Criteria
WC	Water Content
WEL	Workplace Exposure Limit
WFD	Water Framework Directive
w_L	Liquid Limit
WLS	Windowless Sample borehole
w_P	Plastic Limit
WSI	Written Scheme of Investigation
Φ'_{dil}	Dilatancy factor
$\Phi_{cv;k}'$	Characteristic constant volume effective angle of internal friction
Φ_p'	Peak effective angle of internal friction

1. Introduction

1.1 Overview of the Project

In December 2014, the Department for Transport (DfT) published the Regional Investment Programme (RIP) for 2015 to 2020 [2]. The RIP sets out the list of Schemes that are to be developed by Highways England over the period covered by the RIP (2015 to 2020). Highways England responded to the RIP with the Highways England Delivery Plan for 2015 to 2020 [3] and a number of Schemes have been identified to be constructed within the plan period.

M25 junction 28 Improvements (hereby known as 'the Scheme') is one of over 80 Schemes being considered in the RIP for 2015 to 2020. The Scheme was announced by Highways England in July 2017 and the project completed Project Control Framework Stage 3 (PCF3) in September 2019.

As shown in Figure 1-1, the Scheme is located at junction 28 on the north-eastern quadrant of the M25 London Orbital motorway, on the border between London Borough of Havering to the west and the Borough of Brentwood, in the County of Essex, to the east. M25 junction 28 is at the intersection of the M25 and the A12 (also known as Colchester Road) between Brentwood and Gallows Corner.

A single option (5F, as shown in the Preliminary Sources Study Report (PSSR) [4]) was considered the preferred option and will be progressed through planning and detailed design. The PCF3 design arrangement is provided in Appendix A; these include updates to the original Option 5F proposal. These proposals are correct as of June 2020 but may be subject to change following this date.

The Scheme comprises:

- Realignment of the existing A12 trunk road, this will comprise adjustment to the current road markings of the A12 to introduce an additional lane;
- Widening of the M25 anticlockwise carriageway north of J28, which will require new pavement construction and an extension of a culvert;
- Construction of a new 'cloverleaf' link road to connect the M25 northbound to the A12 eastbound. The works will consist of a set of major structures including multiple overbridges, retaining walls and sections of embankment;
- Construction of a new M25 northbound on-slip, comprising a cutting to take the M25 on-slip below the new M25 off-slip. Works will include a series of cuttings and retaining walls;
- Realignment of the Weald Brook watercourse at three locations;
- Construction of a new A12 eastbound off-slip to connect to the J28 roundabout. This will comprise a bridge over the proposed A12 east bound on-slip road;
- Realignment of the existing Cadent and British Pipeline Agency Limited (BPA) pipelines; and
- Construction of attenuation ponds across the scheme.

1.2 Scope and Objectives of the Report

This Ground Investigation Report (GIR) is an interpretive report as per BS EN 1997-1:2004 +A1:2013 (EC7) [5] and CD 622 [6].

The objective of this GIR is to determine the geotechnical and geo-environmental characterisation of the ground conditions below the Scheme, to develop suitable ground models for detailed design, and to highlight geotechnical and geo-environmental risk in relation to the proposed Scheme. The scope includes a detailed review of ground investigation (GI) data pertinent to the proposed development. The findings of the GI have been used to confirm and/or update the findings provided in the Scheme geology and soils impact assessment within in the ES. This report also provides an assessment of the geotechnical options/solutions that have been proposed for use in the scheme.

A Scheme specific GI was carried out between August and December 2019, referred to as the 2019 GI within this report. The scope and objectives of the 2019 GI are discussed in Section 3.3.

This report details the findings of the 2019 GI and also considers the pertinent historical ground investigation data and published information where available.

1.3 Description of the Scheme Area

M25 junction 28 is located in the north-eastern portion of the M25, to the southwest of Brentwood, Essex. The junction is grade-separated, including a roundabout that provides an interchange between the northwest-southeast orientated M25 and the southwest-northeast orientated A12, as well as providing access to and from Brook Street A1023 at the south-eastern quadrant of the roundabout.

A national grid overhead power line runs north to south approximately 320m to the west of the centre of the junction 28 roundabout. A British Pipeline Agency sub surface pipeline (with 3m exclusion zone) follows approximately the same route as the overhead power line. In addition, a National Grid high pressure gas main runs approximately 300m west of the centre of the junction 28 roundabout in a northwest to southeast orientation.

A Site Location Plan is presented as Figure 1-1, as reproduced by Atkins from Google Maps [7].

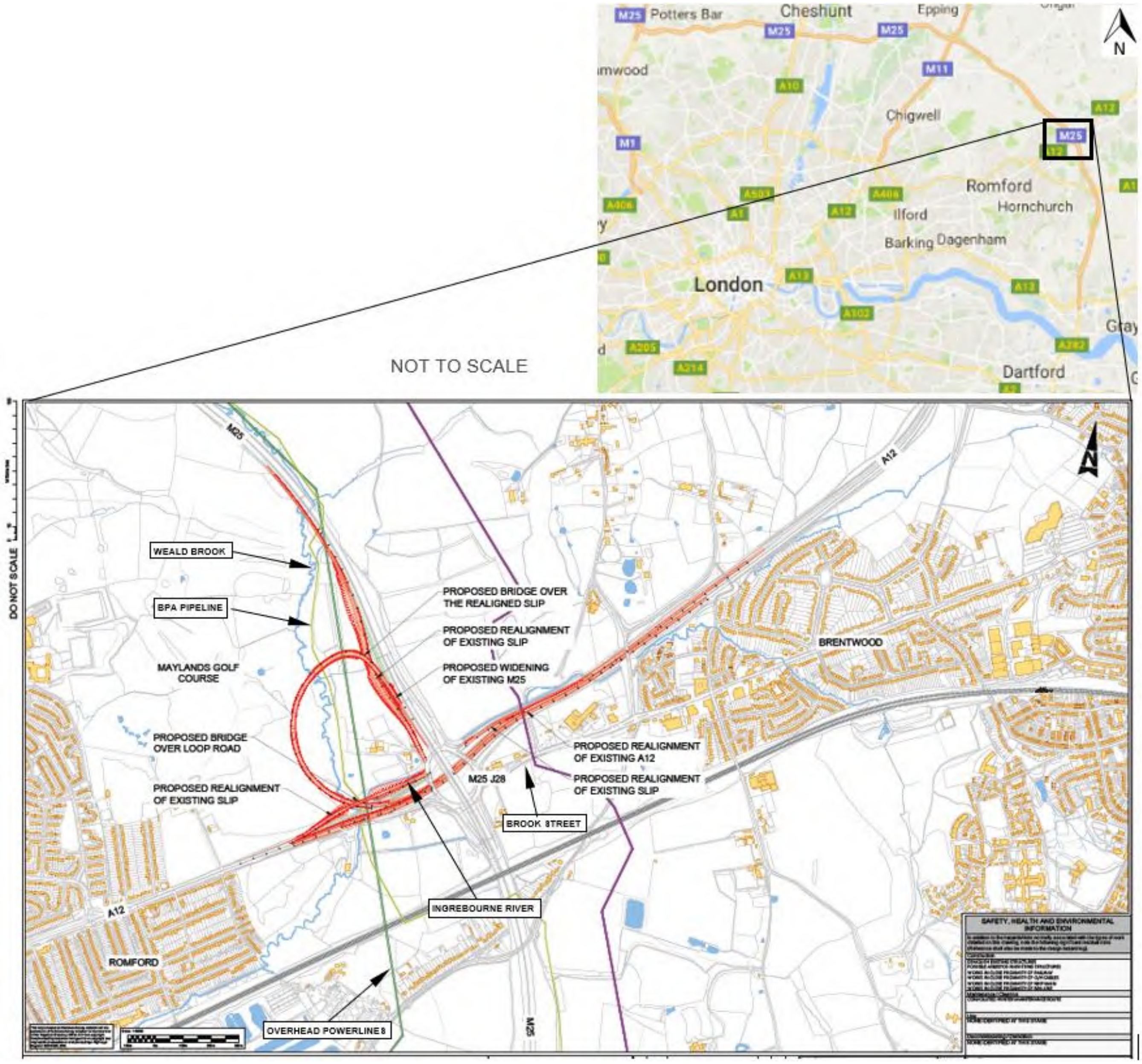

Figure 1-1 Site location plan

1.4 Scheme Chainage

The proposed Scheme has been separated into three distinct chainage sets for each of the three key elements of the Scheme. These are summarised in Table 1-1.

During the preparation of this report, geotechnical line sections have been prepared which broadly follow the alignments of the proposed Scheme. It should be noted that although the chainages on the line sections may be similar to and follow a comparable alignment to the Scheme chainage, they are not directly comparable. This is because the line section chainages required extending to ensure all the pertinent information to the Scheme was presented.

Table 1-1 Scheme and Line Section Chainage Summary

Scheme Chainage Name	Scheme Chainage	Extent of Chainage
M25 Northbound On-Slip	Ch 0 to 1252	South to North
M25 Northbound Off-Slip	Ch 0 to 1448	South to East (anticlockwise around loop)
A12 Eastbound Off-Slip	Ch 0 to 759	West to East

1.5 Geotechnical Category

The current Scheme proposals are considered to be conventional, the construction of which does not pose an exceptional geotechnical risk. The currently proposed geotechnical activities are listed below:

- Earthworks including construction of embankments and cuttings;
- Regrading, widening and/or strengthening of existing earthworks;
- Retaining structures including reinforced earth walls, sheet-piled walls and gravity retaining walls;
- Piled bridge abutments;
- Gantry foundations;
- Culvert foundations;
- Pipeline trenching; and
- Site-won material for reuse.

The ground conditions encountered during the 2019 GI comprised artificial deposits (including Landfill, and Engineered Fill associated with the existing M25 and A12 construction) and/or superficial deposits of Head and Alluvium, overlying London Clay Formation (both weathered and unweathered). No exceptional geotechnical risks or unusual/difficult ground conditions were encountered during the investigation.

Based on the above and in accordance with EC7 [5] and CD 622 [6] the Scheme has been assigned as Geotechnical Category 2, which is defined as “conventional types of structure and foundation with no exceptional risk or difficult ground or loading conditions. This is consistent with the Category determined in the SOI [8].

1.6 Assumptions and Limitations

This report has been produced subject to the following assumptions and limitations:

- This report is prepared and written in the context of an agreed scope of work and should not be used in a different context. This report should be read in line with current legislation, statutory requirements and/or industry good practice applicable at the time of the works being undertaken. Furthermore, new information, improved practices and changes in legislation may necessitate a re-interpretation of the report in whole or in part after its original submission.

- Due to the inherent variability of ground conditions between exploratory hole positions, interpretations should be considered in the context of the relatively small proportion of sub-surface material sampled during investigation works.

2. Existing Information

The following information provides a summary of the site current and historical land use, geological and environmental setting. This section is primarily based on information presented within the PSSR [4] and Environmental Statement [9]. Where other sources have been used these have been documented below.

2.1 Land Use

2.1.1 Current Land Use

The land to the southwest of the junction and along the existing M25 alignment is where the majority of the works are proposed. Current land use for the Scheme is primarily open meadow, wooded areas and industrial land used by Grove Farm and associated businesses. One residential property is also located on the site, associated with Grove Farm.

Other key adjacent land uses include:

- Maylands Golf Course - located at the western extent of the proposed Scheme, land which comprises maintained fairways and forested areas extending c.1km to the north and northeast. Residential properties are also located adjacent to the golf course, to the south of the proposed scheme;
- A cemetery (under construction during the ground investigation) and the traveller's site- located to the south of the A12, approximately 500m west of junction 28;
- Land associated with the existing junction 28, M25 and A12 alignment such as carriageway, highway verges, earthworks and structures;
- The Great Eastern Main Line railway – located approximately 250m to the south-east of the junction, orientated northeast-southwest. The railway line is constructed upon an embankment within the vicinity of the Scheme which crosses the M25 via an overbridge;
- A petrol station and other businesses such as hotel and garden centre are located to the east of the junction on Brook Street; and
- Residential areas are located at a distance in excess of 500m from the proposed Scheme alignment, with Harold Park to the west, Nags Head Lane in the south and Brook Street to the southeast.

2.1.2 Historical Land Use

A review of historical maps dating from 1868 to 2016 included within the Envirocheck Report [10] was carried out as part of the PSSR [4]. A summary of the historical development within 500m of the Scheme extents is presented in Table 2-1; this has been reproduced from the PSSR.

Table 2-1 Historical development of the site (based on Envirocheck 2016)

Date	Development at the site and surrounding area
1868	An unnamed road is mapped, which follows a similar alignment to the current day 'Colchester Road A12' to the southwest of junction 28, and 'Brook Street A1023' to the northeast. The site and surrounding land is situated amongst open fields except for the area to the north of the site which is occupied by Alder Wood and Lower Vicarage Wood. Brook Street is a small village approximately 1km to the northeast of the location currently occupied by junction 28 of the M25. Development within the village includes residential properties, a farm, a public inn and a hospital. The railway line is mapped in its current configuration and is identified as the Great Eastern Railway.
1872	Weald Brook is mapped in its current alignment, joining Ingrebourne River where the watercourse passes under the current A12. Mapping identifies that Putwell Bridge supports the road over the river. Three ponds are situated within 500m of the centre of junction 28; two located approximately 300m and 400m to the northwest in open fields (one situated within the current extents of the M25 main carriageway) and one located approximately 100m south-east of Putwell Bridge. Putwell Farm is situated immediately south of junction 28 in its current location. The Poplars is situated immediately south-east of the junction and the Grove (woodland) is situated immediately to the northwest. A windmill is located 100m to the northeast of the Poplars.
1896	No significant change.
1898	Brentwood Sewage Works is located approximately 840m to the southwest from the centre of the current location of junction 28.
1920	The unnamed road (currently Colchester Road A12 and Brook Street A1023) is mapped as a Roman Road. Old filter beds are located approximately 750m to the south of the centre of junction 28; alongside Nag's Head Lane and close to Brentwood sewage works (now mapped as 'Sewage Works (Billericay & Brentwood Joint Sewage Committee)'). The sewage works development has increased in size and now comprises at least 6 tanks; mapping is not available immediately to the west of the sewage works. Another sewage works is mapper as 'Sewage Works (Billericay R.D.C)' 500m to the southwest of the centre of junction 28, and with it some new filter beds. The aforementioned windmill is no longer shown on the maps.
1938	The railway line is identified as the London and North Eastern Railway. Minor residential development of Harold Park is evident (approximately 1km southwest of junction 28). Mapping is available for the area immediately to the west of Sewage Works (Billericay & Brentwood Joint Sewage Committee), where additional filter beds are mapped.
1947	Aerial photography indicates that Sewage Works (Billericay & Brentwood Joint Sewage Committee) now comprises at least 10 tanks. An airfield was located on the site of the existing golf course and therefore has the potential for fuel storage tanks.
1961	The Roman Road is identified as Brook Street north of junction 28 location and as Colchester Road to the south. Significant residential development has occurred, namely in and around Brook Street and Harold Park and alongside Nag's Head Lane. A coal yard and garage now operate in the village of Brook Street. Pylons and overhead cables are mapped in their current configuration, running approximately north-south and located 320m to the west of junction 28 at their closest point. An unnamed forecourt and buildings are mapped immediately to the west of Putwell Bridge, approximately 400m to the southwest of the centre of junction 28. The 'Sewage Works (Billericay R.D.C)' is no longer mapped.
1968	A roundabout has been constructed at the current location of junction 28; significant earthwork construction has been undertaken to develop what appears to be an elevated roundabout. The Brook Street/Colchester Road follows the current day alignment. The road has seen structural changes and is raised on embankment. An electricity substation is located immediately east of Junction 28, and a garage is mapped to the north of Brook Street 225m to the east of the centre of junction 28.
1973	No significant change.
1978	A hotel has been constructed on the northern side of Brook Street; an electricity substation is situated within its grounds. This is 470m to the east of the centre of the junction.
1984	The M25 has been constructed in its current configuration and embankment extends some 60m either side of the road. The two ponds situated approximately 300m and 400m northwest of junction 28 are no longer mapped (the M25 main carriageway has been built over one of them. The other is located within the vicinity of the recycling centre adjacent to Grove Farm, where a historic landfill site is indicated to be present that ceased receiving waste in 1983 (Environment Agency, 2017)). A reservoir is present approximately 780m to the south-east of the current location of the centre of junction 28. The forecourt and buildings adjacent to Putwell Bridge are labelled as a 'filling station'.
1986	A filling station is shown immediately west of Putwell Bridge and on the southern side of Colchester Road.

Date	Development at the site and surrounding area
1992	The garage north of Brook Street is 225m to the east of junction 28 is no longer mapped. A filling station is mapped adjacent to this and in the location of the current Shell South Weald fuelling station immediately to the east of junction 28.
1999	A building is shown approximately 1.1km to the southwest of the centre of junction 28, which appears to have the same outline as the Esso petrol station currently at its location.
2006	No significant change.
2016	The filling station adjacent to Putwell Bridge is no longer mapped.

2.1.3 Topography

The natural topography at the site appears to be quite variable. At the centre of the site is a north to south trending fluvial valley with the watercourse Weald Brook at approximately 35m above Ordnance Datum (AOD). To the west of the Brook the ground slopes shallowly up to Maylands Golf Club at 45m AOD, whereas to the east the ground rises to approximately 70m AOD to the crest of the hill at Vicarage Wood. The existing alignment of the M25 (from junction 28) is situated to the east of the brook mid-slope at roughly 40m AOD.

The natural topography at the site has been altered significantly with the construction of earthworks associated with the M25 and A12. The M25 at junction 28 is situated upon embankment crossing the A12 and the (now culverted) Ingrebourne River. North of the Junction the M25 is at-grade, followed by cutting (after approximately 850m) through the centre of the hill at Vicarage Wood which extends for approximately 350m, before a section of embankment at the northern extent of the Scheme where the M25 tends to the northwest and crosses the Weald Brook fluvial valley.

2.1.4 Aerial Photographs

A review of the aerial photography available on the Highways Agency (now Highways England) Geotechnical Data Management System (HAGDMS) [11] and Google Earth [12] was undertaken as part of the PSSR [4]. This information has been reviewed again in preparing the current report. Observations from the satellite imagery dated between 1999 and 2019 [12], and of unknown dates [11], are presented within this section of the report.

Throughout the available imagery, the residential and commercial buildings within the vicinity of the Scheme and Maylands Golf Course appear to remain largely unchanged.

Development works at Grove Farm immediately northwest of the junction can be viewed throughout the available imagery. Vegetation clearance and construction of tarmacadam surfacing, and subsequent construction of buildings, carparks and mounds of spoil / waste material can be observed during 2006 to 2019 imagery. Notably, material is observed to be placed at the northern end of the field adjacent to Grove Farm between 07/05/2018 and 25/6/2018 covering an area roughly 200 by 50m.

Road widening works of the A12 eastbound on/off slip roads at the northern portion of the junction and M25 northbound off slip road at the southern appear to have taken place during 2006 to 2008. One additional driving lane can be discerned at the outer edge of the carriageway at these locations.

Current aerial photographs indicate dense vegetation is present on the slopes adjacent to the M25 and within the junction 28 roundabout; vegetation is also present on the slopes adjacent to the M25 and A12 slip roads [12].

2.1.5 Records of Mines and Mineral Deposits

A review of the available mining and mineral deposits records was undertaken as part of the PSSR [4]. The review indicates that the Scheme is located in an area that is not affected by mining or quarrying.

2.2 Published Geology, Hydrogeology and Hydrology

2.2.1 Geological Succession

The published British Geological Survey (BGS) geological mapping [13] indicates localised superficial deposits comprising Head and Alluvium are anticipated at the site. Head deposits are expected to be confined to sloping ground adjacent to the Ingrebourne River, Weald Brook and their tributaries; whereas Alluvium is confined to their associated flood plains.

The Scheme is located within the London Basin, the published geological mapping [13] indicates that the bedrock underlying junction 28 comprises the London Clay Formation. The site is located at upper portion of the stratum with the Claygate Member outcropping adjacent to the site (to the north). The London Clay Formation is anticipated to be in the order of 100m in thickness; other strata such as the Harwich Formation of the Thames Group and the Lambeth Group are likely to be present below the London Clay Formation however are not anticipated to be encountered during the works or pertinent to the construction of the Scheme. The site is located roughly within the centre of the northeast to southwest trending London Basin Syncline and therefore the structure of the bedrock geology is expected to be approximately horizontal.

Although not discussed in the literature, activities which involved the infilling of ground has been identified within the vicinity of the study area, such as landfill sites and infilled ponds. Made Ground and Engineered Fill associated with past activities such as construction of the M25, the A12 and railway line are also present within the Scheme extents [11].

A summary of the local geology of the Scheme, as reported within the literature, is presented in Table 2-2. The descriptions of the units have largely been taken from the BGS Lexicon of Named Rock Units [14].

Table 2-2 Published Geology

Group / Formation / Member			Location (1:50,000 BGS Geological Map) and Description (BGS Lexicon)
Artificial Deposits	Made Ground / Engineered Fill		Highly variable materials associated with construction or infilling of ground. Made Ground is likely associated with the construction of local infrastructure, including the railway line, M25 and A12, and at infilled ponds indicated within the Envirocheck datasheets.
	Landfill		Materials deposited in Brook Street Landfill, situated 350m to the northwest of the centre of the junction 28 roundabout. The exact composition remains unknown, although the landfill is recorded as comprising inert material. Likely variable including materials such as glass, concrete, bricks, tiles and stones [9].
Superficial Deposits	Fluvial Deposits	Alluvium	Found within the floodplain of the Ingrebourne River, Weald Brook and their tributaries Varies from silt to clay, commonly yellow-brown and massive [14]. Formerly referred to as Brickearth, this deposit is described in the BGS memoir for London [15] as firm to stiff and low to medium plasticity very fine-grained sand, silt and clayey silt. Scattered angular flint gravels are common, and irregular nodules of reprecipitated calcium occur below the top metre [15].
	Mass Movement Deposits	Head (undifferentiated)	Generally found within close proximity to Ingrebourne River, Weald Brook and their tributaries. Described as variable *pebbly sandy clay* on the 1:50,000 Geological map [13].
		Head (Gravel)	Not anticipated within the Scheme extents, however situated immediately adjacent to the Scheme. Described as *abundant well rounded flint pebbles in clayey matrix* on the 1:50,000 Geological map [13]. Gravel, sand and clay depending on upslope source and distance from source. Poorly sorted and poorly stratified deposits. Essentially comprises sand and gravel usually containing flint and chalk, locally with lenses of silt, clay or peat and organic material. The BGS memoir for London [15] indicates that the majority of Head situated throughout London usually comprise clayey material, as they are usually derived from the London Clay Formation and are typically less than 2m thick consisting of soft brown silty clay with blue-grey mottling in places. Gravelly and/or sandy Head deposits may be present where derived from River Terrace Deposits.
Bedrock Deposits	Thames Group	London Clay Formation (Claygate Member)	Not anticipated within the scheme extents, however situated immediately adjacent to the Scheme (to the north). Mainly comprises dark grey clays with sand laminae, passing up into thin alternations of clays, silts and fine-grained sand, with beds of bioturbated silts. Ferruginous concretions and septarian nodules occur in places.
		London Clay Formation	Mainly comprises bioturbated or poorly laminated, blue-grey or grey-brown, slightly calcareous, silty to very silty clay, clayey silt and sometimes silt, with some layers of sandy clay. Commonly contains thin courses of carbonate concretions (‘cementstone nodules’) and disseminated pyrite. It also includes a few thin beds of shells and fine sand partings or pockets of sand, which commonly increase towards the base and towards the top of the formation. At the base, and at some other levels, thin beds of black rounded flint gravel occurs in places. Glauconite is present in some of the sands and in some clay beds, and white mica occurs at some levels.

2.2.2 Existing Earthwork Information

Information relating to the condition of existing earthworks within the scheme extents was obtained from HAGDMS [11] on 03/04/2017 and reviewed as part of the PSSR [4]. The review identified 28 earthworks within the scheme extents and two geotechnical defects. The defects were, at the time of writing the PSSR, categorised as Feature Class 1D 'minor defect'. Table 2-3 summarises the recorded geotechnical defects.

The defects were inspected during the site walkover as part of the PSSR to determine whether further deterioration has taken place, or whether the existing geotechnical defects could present a significant problem to the scheme. The following section is extracted from the PSSR:

- Inspections of defect 5_M25_62126_522850 appears largely unchanged when compared to the previous photographs and descriptions.

At the time of writing the PSSR, there was some ambiguity regarding defect 5_M25_62173_570411. A review of the information available on HAGDMS indicated that:

- The defect was initially observed on the 22 April 2013 (HAGDMS ref. 5_M25_62173_523720) and was described as "Minor slip at toe. 0.5m backscar, no toe debris/bulge. Possible site of unbackfilled excavation."
- On 17 June 2016, an amendment to the description was made to include "JB 16/6/16 un-backfilled excavation appears to have been repaired (filled in)", indicating that the defect had been repaired.
- A backscarp (approximately 0.5m) was observed by Atkins on the 17 January 2017 walkover (PSSR [4]). Photographs present are only available for the backscarp from the 22 April 2013, and of the toe dated 16 June 2016, and so the extent of the repair is unknown. It should be noted that no toe bulge was observed during the Atkins 17 January 2017 site visit, indicating no or minimal downslope movement has occurred.
- It seems possible that the June 2016 repair was restricted to the infilling of the toe of the slope, with the backscarp left untouched. If this is the case, it would appear that no further significant movement had occurred between when the defect was first observed and when Atkins viewed the site on 17 January 2017. Consideration should be given to whether the backscarp was repaired in June 2016, and if so, it would appear that further settlement of what seems likely a backfilled excavation had occurred.
- This defect has now been reclassified as a "Poor Backfilled Excavation" as of 10 September 2020 (defect 5_M25_62173_631064).

In the preparation of this report, HAGDMS was reviewed to assess whether any additional defects or further deterioration of the existing defects had occurred since the PSSR was prepared. The current defect record (reviewed 22/09/2020) is consistent with that reviewed within the PSSR, except for the reclassification of defect 5_M25_62173_631064.

Table 2-3 Geotechnical Defects (indicated on HAGDMS)

Unique HAGDMS ref.	Historical Observation Number	Feature Class	Location Index	Description
5_M25_62173 _631064	570411, 523720, 597256	1D - Minor defect	C	Minor slip at toe. 0.5 m backscar, no toe/debris bulge. Possible site of unbackfilled excavation. JB 16/6/16 un-backfilled excavation appears to have been repaired. 0718 not observed due to dense vegetation. 0720 not obs, veg obstructing view, declassified.
5_M25_62124 _522850	522850	1D - Minor defect	C	Minor slip at crest in area steepened for installation of the lighting column. 0.3 m backscar, well vegetated. Occasional tension cracks below backscar in mid slope. TL CL 040718 dense vegetation, no signs of deterioration.

Discussions by Atkins with Connect Plus services (CPS) note that there are numerous earthwork defects between junctions 27 and 30, which are deemed likely related to the presence of Head deposits similar to that which is at the site.

2.2.3 Hydrogeology

The PSSR [4] provides Environment Agency [16] aquifer designations for the superficial deposits and bedrock geology within the vicinity of the scheme; these are summarised in Table 2-4 below. The Environment Agency aquifer designations are defined as follows:

- **Secondary A Aquifer**: "permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers".
- **Secondary (undifferentiated) Aquifer**: "has been assigned in cases where it has not been possible to attribute either category A or B to a rock type. In most cases, this means that the layer in question has previously been designated as both minor and non-aquifer in different locations due to the variable characteristics of the rock type".
- **Unproductive Strata**: "rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow."

Table 2-4 Aquifer designations

Stratum	Environment Agency Aquifer Designation
Made Ground	No designation
Alluvium	Secondary A Aquifer
Head	Secondary (undifferentiated) Aquifer
London Clay Formation	Unproductive Stratum

The site is underlain by superficial aquifers, including Alluvium associated with the Ingrebourne River and Weald Brook and Head. Groundwater within the Alluvium is likely to be in continuity with the rivers. The London Clay Formation beneath the majority of the site is designated as Unproductive Stratum. Therefore, negligible groundwater flow is anticipated, laterally and vertically within the London Clay Formation underlying the site. The London Clay Formation is proven to depths of

30m bgl, within the area of proposed works. It is considered that, due to the large thickness of Unproductive Stratum, underlying aquifers need not be considered further.

2.2.4 Hydrology

At the time of the development of the Environmental Statement and the writing of the report, no known surface water abstraction licences are registered within the study area [9].

2.2.5 Flood Risk

Environment Agency designated Flood Zones 2 and 3 are present across the site and study area [17]. These Flood Zones are associated with the Ingrebourne River, Weald Brook and Paine's Brook watercourses. Other areas at risk from surface water flooding that are not associated with the main watercourses are the drainage channels flowing west to east into Weald Brook on the western side of the study area. The existing drainage system is considered to reduce the surface water risk to an acceptable level along the road network [17].

The groundwater flood risk mapping provided in the Strategic Flood Risk Assessment [18] indicated the study area is predominantly low to moderate risk, with 25 to 50% at risk of groundwater flooding from water within the limited superficial geology deposits. The Cadent gas pipeline intersecting the site is also identified as infrastructure at risk of flooding from groundwater.

2.2.6 Ground Stability

The 1:50,000 scale ground stability maps provided within the Envirocheck Report [10] (available in Appendix B of the PSSR [4]), including potential for collapsible ground, potential for landslides and potential for shrinking or swelling clay, were reviewed as part of the PSSR.

The potential for collapsible ground across the Scheme was determined to be very low.

The potential for landslides within the Scheme extents was determined to be very low to low.

The potential for encountering shrinking and swelling clay across the Scheme was determined to be moderate over the entirety of the Scheme.

The motion map data which provides an indication of long-term stability across the UK, indicates that the site is mainly stable (<1.5mm movement per year). No vertical movements >3.5 mm per year are anticipated within 100 m of the Scheme. Although downward movement of 1.5mm to 3.5mm has been recorded within 1km of the scheme, see PSSR [4] or Envirocheck report [10].

2.3 Historical Ground Investigation

A number of geotechnical reports were identified and reviewed for the PSSR [4]; those which provide factual data have been summarised in Table 2-5. The data available within these reports has been reviewed for the context of this GIR to assess their relevance for the proposed Scheme. Where information is considered relevant, data has been included in the interpretation and assessments within

Section 4 of this report, with exploratory hole locations reflected on drawings contained within Appendix B.

The majority of the historical data used in the assessment of the ground conditions has been digitised from historical records in PDF format downloaded from HAGDMS [11]. The digitised data was then incorporated into the information database for the Scheme in order to supplement the information from the 2019 GI.

Table 2-5 Historical ground investigation data

NOTES

Project	Year	HAGDMS reference	GI contractor	Number of boreholes within Scheme	Borehole log quality	SPTs	Hand penetrometer	Water Content	Liquid and Plastic Limit Tests	Particle Size Distribution	Triaxial testing	Bulk & Dry Density	Compaction testing	California Bearing Ratio	Oedometer testing	Moisture Condition Value testing	BRE chemical testing	Organic matter testing	Geo-Environmental testing	Comments / Historical borehole ID's as used on the ground models and site plans
M25 junction 28 Improvements – Preliminary Ground Investigation	2019	Not currently available	Geotechnical Engineering Limited	12	1	-	-	-	-	-	-	-	-	-	-	-	-	-	A	Borehole ID prefixed 'ATK-P-..' to denote exploration hole associated with the 'Pre-GI'
M25 Widening Junction 27 to 30	2006	20320	May Gurney	11	1	A	A	A	A	A	A	A	-	-	-	-	A	-	-	Original boreholes ID prefix amended to 'MG…'
M25 junction 28 / A12 / Brook Street Improvement	2006	20508	Structural Soils	31	1	A	A	N	A	N	A	N	N	N	N	-	A	-	N	Original boreholes ID prefix amended to 'SS…'. Boreholes not directly below proposed Scheme alignment and data not included in analysis.
M25/A12 Brook Street Interchange	1988	8599	Suffolk County Laboratory	6	3	-	-	A	A	-	-	-	-	-	-	-	A	A	-	Original boreholes ID prefix amended to 'SCL…'
M25 Ringway 3 (A13-A12, including Thurrock MSA, Junctions 28-30)	1973	4155	Ground Engineering Limited	15	3	-	-	A	A	-	A	A	-	A	A	-	A	A	-	Borehole numbers increase sequentially from 111 to 124. Original boreholes ID prefix amended to 'BHGE…'
M25 (M16) Orbital Road – M11 to A12 Section	1973	17280 & 4097	Soil Mechanics Ltd	28	2	-	-	A	A	-	N	N	-	-	-	-	A	-	-	BH285 to BH295; BH147 to BH163; BH571 & BH572
M12 Motorway Havering Park to Brentwood Section	1970	4091	Nuttall Geotechnical Services	23	3	-	-	A	A	N	A	N	N	-	N	-	-	-	-	Original boreholes ID prefix amended to 'BHN….'
A12 Radial Route Seven	1967	4086	Le Grand Adsco	2	3	A	-	A	A	-	A	A	-	A	A	-	A	-	-	Original boreholes ID prefix amended to 'BHLG….'
A12 Brentwood By-Pass	1962	3407	Le Grand Adsco	29	3															Original boreholes ID prefix amended to 'BHLG….'

NOTES

1. Quality of borehole logs has been assessed based on the following, with the lowest rating category for each borehole series providing the overall rating:

Category	Description	Rating
Legibility	Legible	1
	Illegible	4
Quality of logging	Logs are consistent with current standards, providing details on consistency/density and grain size and shape.	1
	Logs are of reasonable quality, providing geological information and limited geotechnical information.	2
	Logs provide basic geological information.	3
	Logs do not provide useful information.	4
Co-ordinates and ground levels	Ground levels and co-ordinates are provided for all exploratory holes	1
	Ground levels are provided, and the exploratory hole location is determinable through a location plan.	2
	The location is determinable, but ground levels are not provided.	3
	The location is not determinable.	4

2. Data available has rated based on how it has been used as follows:

Rating	Description
A	Data incorporated into AGS data used in graphs and sections.
B	Data not incorporated into AGS dataset, but pdf reports have been considered alongside AGS dataset.
N	Data available but omitted from analysis.
-	Data not available

2.4 Land Quality

2.4.1 Sensitive Sites

Sensitive land within the site and study area (within 250m) include deciduous woodland, ancient woodland, areas of adopted Green Belt, grassland and woodland priority habitat network and Nitrate Vulnerable Zones. No statutory environmentally sensitive land uses (i.e. Area of Outstanding Natural Beauty, SSSI) have been identified within the site or study area [19].

There are three listed buildings (Nag's Head Inn, 17-21 Brook Street and the Bull Inn) [20] located along Brook Street between 210 m and 240 m south-east of the site.

2.4.2 Groundwater Sensitivity

The Environment Agency aquifer designations for the geological units at the site are described in Section 2.2.3 of this report and within the Environmental Statement [9].

A Source Protection Zone (SPZ) outer zone III is designated across the south and east of the site [19]. The SPZ is associated with an inner zone SPZ/abstraction location approximately 12.5km to the south-southeast of junction 28, at Stifford Pumping Station [20]. Groundwater is abstracted from Essex and Suffolk Water Company from the deep chalk aquifer at this location.

2.4.3 Radon

Public Health England information [21] indicates that the study area is not located in an area that is affected by radon.

2.4.4 Regulatory Records

The historical Brook Street Landfill was located beneath the site and extended approximately 350m north-west of junction 28. The landfill is recorded to have accepted inert waste associated with the construction of the M25 prior to 1983 [9]. No active licensed landfill sites are present within 250m of the DCO boundary. During a recent preliminary GI associated with the Scheme (see Section 2.3 for further details), material encountered within the footprint of the historical landfill mostly comprised inert waste materials (wood, glass and brick).

A waste management, recycling, skip hire and rubbish clearance company is located at Grove Farm in the study area, approximately 260m to the north-west from the centre of junction 28 at its closest point [12].

Twelve pollution incidents to controlled waters have been recorded within the study area, of which four occurred on the site [9]. The pollution incidents were classified as minor and occurred between 1989 and 1999 and are therefore not considered to represent a significant concern.

Google© satellite imagery [12], the Environmental Statement [9] (which contains Envirocheck© datasheets [10] of the study area) and information obtained during site walkovers and investigations undertaken between 2017 and 2020 have been used to identify historical and active industrial land uses on the site and within

250m of the DCO boundary other than previously identified in the PSSR [4]. These are shown on Figure 10.2 in the Environmental Statement and include:

- On-site: Former Old Maylands Aerodrome (including hangers and a fuel storage area [22]) located in the west of the site and extending to the west between Woodstock Avenue, Weald Brook, the A12 and Maylands Golf Club.
- Off-site: The following offsite industrial land uses have been identified. All distances stated are from the centre of junction 28:
  - Two active fuel stations (15m east and 1.2km south-west);
  - Two former fuel stations (230m north-east and 400m south-west);
  - Electrical substations (130m east and 155m north-west);
  - farms (135m north-west and 250m south-west)
  - Railway tracks (400 m south);
  - British Pipeline Agency (BPA) fuel pipeline (355m south-west); and
  - Sewage treatment works (780m south-west and mostly outside of the 250 m study area).

2.4.5 Potentially Infilled Land

Potential infilled land (water features), in the study area have been identified [9], including:

- Three beneath the current M25 alignment in the northern extent;
- One within the location of the historical Brook Street Landfill site, 150 m west of the M25 and approximately 120m north of development at Grove Farm;
- Three between 5m and 200m to the south of the eastern extent of the site close to Belvedere Road;
- One alongside Brook Road, approximately 220m to the south of the eastern extent of the site;
- One 250m to the north of the western limb of the site, towards the golf course;
- One in the study area, approximately 460 m to the north of the centre of junction 28; and
- One immediately south of the site, approximately 590m to the west from the centre of junction 28.

2.4.6 Previous Geo-environmental Assessment

A preliminary GI [23] (as described in row 1 in Table 2-5) was carried out on-site in 2019 in the north-west quadrant of junction 28, where recently deposited material had been identified during a site walkover in 2017. At that time the material took the form of stockpiles that were noted to have been spread across this part of the site on subsequent walkovers. The area of recently deposited material coincides with a portion of the historical Brook Street Landfill.

The preliminary GI comprised ten trial trenches, six shallow hand pits and two dynamic samples. A total of 37 no. geo-environmental soil samples were sent to a laboratory for analysis (the chemical results are summarised below and are included in the assessment in Section 4.10) Headspace screening of each stratum sampled for geo-environmental testing was undertaken with a photo-ionisation detector (PID) for concentrations of ionisable volatile organic compounds (VOCs). The preliminary GI did not include groundwater monitoring or sampling, surface water sampling or ground gas monitoring.

As part of the preliminary GI report [23], an assessment of the risk to human receptors and surface water receptors was undertaken by comparing the results of chemical testing of the soil samples against appropriate Generic Assessment Criteria (GAC). Full details of the preliminary GI are provided in the preliminary ground investigation report [23], the main pertinent findings included:

- The material encountered within the former landfill and recently deposited material mostly comprised inert waste materials (wood, glass and brick);
- Faint hydrocarbon odours were noted in borehole ATK-P-101 at 0.50 to 2.00m and again at 2.45-3.05 m bgl. This location is detailed on the exploratory hole plan, Appendix B and in the 2019 GI Factual Report [24] provided in Appendix C. The corresponding PID readings were <0.1ppm and 5.9ppm respectively, suggesting low concentrations of ionisable VOCs. It is considered possible that the odours originated from decomposing organic material. No other odours were noted in the preliminary GI.
- Black staining was encountered in three of the boreholes, confined to deeper Made Ground and was considered likely to have originated from decomposing organic material.
- All geo-environmental headspace test readings taken were <10ppm therefore the potential effect on human receptors from hydrocarbon vapours in the area was considered to be limited. Further information on the PID readings is provided in Section 4.13 of this report.
- Asbestos was identified in four of 105 soil samples screened for asbestos. The asbestos was not concentrated within a particular geographical location nor associated with a particular stratum but were generally associated with the more recent deposition of materials within the top 1.00m bgl and not the historical landfilling. Further information on the identified asbestos is provided in Section 4.10 of this report.
- A marginal exceedance of the human health generic assessment criteria (GAC) for public open space [25] was identified for beryllium at one location within the historical landfill material at 2.50m to 3.00m bgl. As the level of exposure to end users at this location (cutting for a new slip road) would be far less than the GAC for public open space (parks) assumes, the exceedance was not considered to be of concern.
- Elevated concentrations of metals and inorganics were identified within soil-derived leachate samples, when compared to Freshwater Environmental Quality Standards (EQS-f) as set out in the Water Framework Directive [26] (although the assessment did not consider bioavailability and so is considered conservative). At the time of the investigation no continuous shallow groundwater was identified, and the strata encountered comprised predominantly clay, it was therefore considered to have limited potential for the migration of contamination to the surface water and groundwater receptors within the study area.

Preliminary design does not specify if proposed attenuation ponds within the scheme are to be lined. The risks to controlled waters from contamination within the recently deposited material, associated with the proposed development, were considered to be low although further investigation, monitoring and assessment was recommended to confirm the level of risk.

2.4.7 Outline Conceptual Model

As per guidance document Land Contamination: Risk Assessment [27], land contamination is assessed in the UK through the identification and assessment of Source-Pathway-Receptor (S-P-R) linkages displayed in a Conceptual Model (CM) with the associated risk rating generally using the methodology provided in CIRIA C552 [28]. The S-P-R linkages provided in the Outline CM below have been obtained from Chapter 10 (Geology and Soils) of the Environment Statement [9]. The Outline CM developed in the Environmental Statement is presented in Appendix D.

Sources of potential contamination identified on the site and within the study area included:

- On-site recently deposited material. Investigated during the preliminary GI – infrequent asbestos identified. Overall potential risks to human health and controlled waters receptors are considered to be low;
- On-site historical Brook Street Landfill (comprising inert material associated with the construction of M25 with overall potential risks to human health and controlled waters receptors considered to be low);
- On-site and off-site Made Ground/infill in areas not previously investigated beneath areas of existing development (i.e. along the M25, A12, watercourses, embankments and railway) and potentially infilled water features; and
- On-site former aerodrome, railway line, BPA fuel pipeline, vehicle emissions, unrecorded spills and leaks from the long-term use of the roads; and
- Off-site land uses including fuel stations (two active and two former); electricity substations, sewage treatment works, railway line, vehicle service garages, commercial activities (recycling and waste storage etc) and other activities and land uses at Grove Farm, other farms and associated agricultural activities, vehicle cleaning services.

Based on the historical and current land use, the following chemical and gaseous parameters are considered to be potentially present in the soils and shallow groundwater:

- Metals, metalloids, polycyclic aromatic hydrocarbons (PAH) and total petroleum hydrocarbons (TPH) associated with onsite Made Ground/infilled areas, former aerodrome and railway line and off-site commercial activities at Grove Farm, sewage treatment works, farms and vehicle service garages;
- Benzene, toluene, ethylbenzene and xylene (BTEX) and TPH associated with the onsite BPA fuel pipeline and offsite fuel stations and vehicle service garages;
- Solvents associated with the former aerodrome on-site and the off-site vehicle service garages and vehicle cleaning services;

- Asbestos associated with Made Ground/infilled ground and recently deposited material on-site;
- Pesticides and herbicides associated with agricultural activities off-site;
- Polychlorinated biphenyls (PCBs) associated with electrical substations off-site; and
- Ground gases (methane and carbon dioxide) potentially associated with the historical Brook Street Landfill.

Potential human health receptors include:

- On-site members of the public using public rights of way and public spaces (non-motorised users);
- On-site future construction workers and site maintenance workers associated with the Scheme;
- Off-site residents (including Grove Farm and traveller's site); and
- Off-site workers/visitors/users of commercial/industrial premises and recreational areas including those at Grove Farm and Maylands Golf Club, members of public using public rights of way and public spaces and workers/visitors at industrial, agricultural and commercial premises and recreational facilities.

Potential controlled waters receptors include:

- Surface water receptors on the site and within study area, including the Ingrebourne River and Weald Brook; and
- Potential new surface water features including attenuation ponds and drainage features.

An outer SPZ is present over the eastern and southern sections of the site, this zone is associated with an inner SPZ 12.5km south of the centre of junction 28, the abstraction is known to be from the Chalk Group. Deeper groundwater held within the Lambeth Group, Thanet Sands Formation and Chalk Group within the scheme boundary and for approximately 12 km to the south is located beneath a thickness of London Clay. The London Clay at the site is proven to be over 30m thick and provides a hydraulic barrier between shallow and deep groundwater. Based on the preliminary design the scheme will not extend past 40m bgl therefore the scheme is not considered to have any potential impact on deeper groundwater of the Lambeth Group, Thanet Sands Formation and Chalk Group including the SPZ.

Groundwater within the superficial deposits is likely to be in direct hydraulic connection with the surface water bodies and due to the lithology of these units, it is considered unlikely to have any potential to be utilised as a resource (drinking water). Therefore, groundwater as a resource has not been considered as a controlled water receptor for this assessment.

Potential property receptors include:

- On-site underground services existing structures, piles and foundations associated with residential, industrial, agricultural and commercial properties and future structures, services, piles and foundations; and

- Off-site existing structures, services, piles and foundations associated with residential, industrial, agricultural and commercial properties including listed buildings.

2.4.8 Potential Pathways

Possible human exposure pathways include:

- Inhalation, ingestion and/or dermal contact with elevated chemical parameters in soil, soil-derived dust and asbestos fibres;
- Inhalation, ingestion and/or dermal contact with elevated chemical parameters in perched water and shallow groundwater;
- Migration and accumulation of ground gases and/or vapours followed by inhalation and/or ignition causing asphyxiation and/or explosion; and
- Inhalation, ingestion and dermal contact with elevated chemical parameters in surface water.

Possible controlled waters exposure pathways include:

- Leaching/vertical migration of elevated chemical parameters in soils into underlying shallow groundwater;
- Lateral migration of elevated chemical parameters in shallow groundwater;
- Migration of elevated chemical parameters entrained in surface water/run-off;
- Lateral migration of elevated chemical parameters in shallow groundwater/perched water to surface waters; and
- Migration of perched/shallow groundwater and/or surface water via preferential pathways e.g. attenuation ponds and pond outfalls.

Possible property exposure pathways include:

- Chemical attack of buried structures in contact with chemical parameters in soil or groundwater;
- Migration of ground gases and/or vapours along preferential pathways including permeable ground, services trenches and service entry points and accumulation in enclosed spaces (i.e. services ducts or access points);
- Lateral migration of elevated chemical parameters in shallow groundwater/perched water to surface waters, followed by crop uptake; and
- Inhalation, ingestion and dermal contact with elevated chemical parameters in windblown soil-derived dust by livestock.

In the completed scheme the site would be covered in roads and landscaped areas. Landscaped areas are likely to be grassed/vegetated and areas of bare soils would be minimised, therefore direct contact, ingestion pathways and the generation of soil derived dusts would be restricted.

3. Field and Laboratory Studies

3.1 Walkover Survey

An initial walkover survey was carried out prior to specifying the ground investigation; a summary of the findings from the survey is provided within the PSSR [4].

A further walkover survey was undertaken alongside the Principal Contractor and GI Contractor ahead of the 2019 GI. The following aims and observations were considered pertinent to the proposed Scheme:

- To determine the condition of the ground (trafficability) and access requirements to inform the design of the 2019 GI;
- To confirm the extent and composition of recently deposited Made Ground associated with the activities on Grove Farm, resulting in pre-GI works to determine the absence of Asbestos Containing Material (ACM);
- Deer were encountered across the scheme in large numbers and observed stampeding; this was added to the project risk register;
- Deer hunters with rifles appear to frequent the land in the vicinity of Grove Farm and the scheme, presenting a significant health and safety hazard; this was added to the project risk register; and
- Landowners and works at Grove Farm had the potential for hostility towards project staff onsite.

3.2 Geomorphological / Geological Mapping

No geomorphological or geological mapping was undertaken as part of the investigation works.

3.3 Ground Investigation Scope and Rationale

The 2019 ground investigation was designed by Atkins and presented in the Ground Investigation Specification [29].

The 2019 ground investigation was carried out by Geotechnical Engineering Limited (GEL) as sub-contractor commissioned by Geoffrey Osborne Limited (Osborne) (Principal Contractor) on behalf of Highways England (Client), with Atkins (Principal Designer) providing Designer Representative, Investigation Supervisor and on-site technical supervision responsibilities.

The fieldwork took place between August and December 2019, and had the following technical objectives:

- Investigate the ground and groundwater conditions below the proposed foundations;
- Establish geotechnical parameters for design purposes by undertaking in-situ and laboratory testing;
- Determine potential ground and groundwater aggressiveness by undertaking geochemical testing;

- Determine ground contamination concentrations by undertaking contamination laboratory testing;
- Determine the re-use potential and Waste Acceptance Criteria of the strata present at the site;
- Carry out soakaway testing for pipeline routing;
- Carry out in-situ groundwater and ground gas monitoring;
- Locate existing services;
- Investigate the historical landfill on site; and
- Identify potential geotechnical and geo-environmental hazards and their risks to the project.

The investigation was undertaken in accordance with the general requirements of BS EN ISO 5930: 2015 [30], EC7 [5], BS EN ISO 22475-1: 2006 [31] and other relevant related standards identified in the factual report [24]. Borehole logging was carried out in accordance with BS EN ISO 14688-1:2018 [32] for soils, as specified by BS 5930:2015 [30]. The exploratory hole locations, logs and photos are provided within the ground investigation factual report [24].

Engineering Geologists from GEL logged all boreholes, obtained soil samples and organised delivery of the samples to their in-house geotechnical laboratory and a third party geo-environmental laboratory. Osborne site engineers surveyed the exploration hole positions and provided the coordinates to GEL for inclusion within the factual report.

Atkins Engineering Geologists were on-site for the duration of the fieldworks and scheduled testing on the samples where required to meet the technical aims of the investigation.

3.4 Intrusive Investigation

The exploratory hole locations were provisionally specified by Atkins, with the final locations decided on site in agreement with the Osborne and GEL, taking account of constraints such as buried services, access, topography and vegetation.

All positions were surveyed on site by Osborne, with co-ordinates and ground levels taken in accordance with National Grid and Ordnance Datum (OD). A site plan providing the positions of all exploratory holes is presented in Appendix B.

Prior to breaking ground at each exploratory hole location, a ground penetrating radar (GPR) survey was undertaken at all locations as well as Cable Avoidance Tool (CAT) and Genny scanning. A hand dug inspection pit was undertaken at each exploratory hole location (except trial pits) to 1.2m below ground level (bgl), with regular clearance from the CAT and Genny scan before intrusive works were commenced.

3.4.1 Exploration Holes

The 2019 Scheme specific Ground Investigation comprised 91 no. intrusive positions as well as seven static cone penetrometer tests (SCPTs) which are further discussed in Section 3.4.3 of this report. A summary of the different exploratory hole types is presented in Table 3-1 and their locations is provided in Appendix B.

Table 3-1 Summary of Exploration Holes (2019 GI)

Exploration Hole Positions	Abbreviation	Number of positions	Range depths (m bgl)	Comment
Cable Percussive	CP	2	15.45 – 20.25	Six proposed CP locations changed to DS + RC following technical queries (TQ) due to unavailability of CP rig.
Dynamic Sample	DS	4	6.00 – 8.80	Three proposed WLS locations changed to DS following TQ due to refusal of rig on gravels.
Dynamic Sample with Rotary Coring	DS + RC	25	10.65 – 40.75	
Windowless samples	WLS	23	3.00 – 10.45	ATK-073 undertaken with handheld WLS rig.
Trial Pits	TP	24	1.20 – 4.00	23 no. machine excavated; ATK-009A excavated using hand tools.
Hand-Dug Inspection Pits	IP	13	0.50 – 1.20	Eight IP undertaken for service clearance ahead of DCP; five IP terminated due to possible services or ACM

Terminations, refusals and temporary stability

ATK-081 (windowless sample) was terminated early due to slow penetration of the road coring unit through the road tarmacdam and concrete, as well as encountering shallow groundwater, inhibiting excavation during limited working hours of the night shift.

ATK-089 was completed with a windowless sample rig, however due to the casing penetrating through alluvial gravels with high groundwater levels and low strength soils, it was stuck in the ground following hole completion and required additional hydraulic jacks to remove.

ATK-090 was initially attempted with a windowless sample rig, however due to concerns over potentially getting the casing stuck in the ground (as per ATK-089) the hole was temporarily terminated. In order to proceed to depth through the difficult drilling conditions of the alluvial gravels, the hole was completed with a dynamic sample rig to depth.

The sidewalls of the machine excavated trial pits largely remained stable and vertical throughout the course of the investigation across all strata, with the exception of ATK-027. Spalling was observed in this exploratory hole between 1.90 and 2.50m within Made Ground – Landfill (slightly gravelly silty CLAY); this was attributed to groundwater seepage noted at 1.90m.

3.4.2 Sampling

A summary of the geotechnical, environmental and waste acceptance criteria sampling undertaken during the 2019 Ground Investigation is presented in Table

3-2. The number and location of samples taken were as per the Atkins GI Specification [29] and under direction of the Investigation Supervisor on site.

Table 3-2 Summary of Sampling (2019 Ground Investigation)

Sample Name		Size / Requirements	Exploration Hole Positions
Geotechnical	Small Disturbed (D)	Greater than 1kg and contained within airtight plastic tubs.	All locations
	Bulk Disturbed (B)	Samples taken in fine material shall weight no less than 10kg, samples in coarse material no less than 20kg.	All locations
	Large Bulk Disturbed (LB)	Samples shall be collected in multiple containers and have a weight not less than 30kg.	As specified in Trial Pits
	UT100	Thin wall open tube (UT100) sampling, typically at 1m centres in fine material alternating with SPT tests	Cable percussive and dynamic sampling
	Core Samples (CS)	Class 1 core samples, 300mm long, sub sampled from core runs in fine material.	Rotary Core
Environmental Samples (ES)		Environmental sample containers as per the selected laboratory including plastic tubs, jars and vials. Samples undertaken within Made Ground and from top of natural strata where specified.	All locations (as per specification)
Waste Acceptance Criteria (WAC) samples		WAC sample containers as per the selected laboratory including plastic tubs, jars and vials. Composite samples (COMP) to be undertaken over the depth range of each stratum encountered to a depth of 5m.	All locations (as per specification)
Water Samples		Sample to be collected in plastic bottles, quantity as per selected laboratory.	All locations (as per specification), groundwater monitoring and from surface water.

3.4.3 In Situ Testing

The following types of in situ testing were undertaken during the 2019 Ground Investigation, the results are summarised in Section 3.5:

- Standard Penetration Tests (SPT) for determining in situ stiffness of the soil and to provide correlations for geotechnical parameters;
- Static Cone Penetration Tests (SCPT) for determining in situ soil behaviour type index, stiffness, compressibility and undrained shear strength of the soil;
- Static Cone Dissipation Tests to provide in situ pore water pressures of the soil;
- Dynamic Cone Penetrometers (DCP) to provide correlations for in situ Californian Bearing Ratio of the soil;
- Hand Shear Vanes (HSVs) undertaken both in situ and in the laboratory, to provide undrained shear strength of the soil;
- Soakaway Tests to determine the in situ permeability of the soil; and
- Photoionisation Detector (PID) to identify the presence of hydrocarbons within the soil.

SCPTs and Static Cone Dissipation Tests were undertaken by Lankelma, a sub-contractor to GEL. All other *in situ* testing was undertaken by GEL operatives.

3.5 Results of In-situ Tests

A summary of the *in situ* testing results is provided in Table 3-3. The results of the *in situ* testing have been interpreted through various correlations to inform geotechnical and geoenvironmental analysis of the encountered strata, the results of which are presented in Section 4.

The results of the in-situ testing, such as SPT, HSV and PID are provided on the corresponding exploratory hole logs within the factual report [24]; whereas the results of the DCP probes and SCPT are presented separately within the factual report.

Table 3-3 Summary of *in situ* testing (2019 Ground Investigation)

In-situ Test	Exploration Hole	Number of tests	Range of results	Comment
SPT	All CP, DS, DS+RC and WLS holes	428	N_{60} = 0 – 50+ (Refusal)	2 No. SPT results were considered to refuse (SPT N > 50)
SCPT	ATK-009, ATK-011, ATK-013, ATK-033, ATK-041, ATK-046, ATK-049	7	N/A	
Static Cone Dissipation Tests	ATK-009, ATK-011, ATK-013, ATK-049	5	N/A	5 tests undertaken; 3 valid results. Two tests were undertaken in ATK-009
DCP	IP, TP, WLS	21	N/A	DCP probes undertaken from ground level adjacent to cleared service inspection pits.
HSVs	All Exploratory Holes where material suitable	192	42 – 150 kPa	The results of the HSV tests are provided on the borehole and trial pit logs within the factual report
		26	6 – 44 kPa	
Soakaway Tests	ATK-035, ATK-036, ATK-093, ATK-094	4	N/A	Undertaken in accordance with BRE Digest 365.

For PID results, see Section 4.10.1 of this report.

3.5.1 Dissipation Tests

Five dissipation tests were undertaken within SCPT positions, of which three gave valid results; the results are summarised in Table 3-4.

Table 3-4 Summary of dissipation testing with SCPT positions (2019 Ground Investigation)

Exploration Hole	Depth	Stratum	Coefficient of consolidation (C_{vh} m^2/year)
ATK-009	2.56	Alluvium - Undifferentiated	13.80
ATK-011	2.22	Weathered London Clay Formation	1.30
ATK-013	2.10	Alluvium - Undifferentiated	4.60

3.5.2 Soakaway Tests

Four soakaway tests were undertaken in trial pit positions, the results of all tests indicated that the rate of water loss was insufficient to calculate the infiltration rate. The results are summarised in Table 3-5.

Table 3-5 Summary of soakaway testing

Exploration Hole	Depth Range (m BGL)	Stratum	Soil Infiltration Rate
ATK-035	2.20-0.94	Head - Fine	Insufficient water infiltration to calculate rate.
ATK-036	4.00 – 1.99	Made Ground – Landfill & Weathered London Clay Formation	Insufficient water infiltration to calculate rate.
ATK-093	3.50 – 1.70	Head – Fine & Weathered London Clay Formation	Insufficient water infiltration to calculate rate.
ATK-094	2.00 – 0.32	Head - Gravel	Insufficient water infiltration to calculate rate.

3.6 Groundwater Installations

Wells for groundwater monitoring and sampling were installed in 18 no. exploratory boreholes and the details are summarised in Table 3-6 below. ATK-004 and ATK-015 were installed for geotechnical monitoring purposes and the remainder were installed for geo-environmental monitoring and sampling. Wells from the preliminary GI (ATK-P-101 and ATK-P-102) have been added for comparison.

Table 3-6 Well installation summary

Well ID	Ground level (m AOD)	Strata screened	Screen (m bgl)	Screen (m AOD)
ATK-003	39.95	Made Ground – Recently Deposited Material & Landfill.	1.0 - 7.0	32.95 - 38.95
ATK-004	35.30	Alluvium	1.0 - 2.3	33.0 - 34.3
ATK-005	33.00	Alluvium	0.9 - 4.7	28.3 - 32.1
ATK-006	31.20	Alluvium, Head, Weathered London Clay	0.9 - 6.2	25.0 - 30.3
ATK-008	31.15	Alluvium	1.9 - 4.9	26.25 - 29.25
ATK-014	32.60	Alluvium	0.6 - 2.8	29.8 – 32.0

Well ID	Ground level (m AOD)	Strata screened	Screen (m bgl)	Screen (m AOD)
ATK-015	35.40	Alluvium, Weathered London Clay	1.0 - 2.0	33.4 - 34.4
ATK-048	43.90	Weathered London Clay	1.7 - 9.3	34.6 - 42.2
ATK-056	31.90	Alluvium	0.8 - 2.4	29.5 - 31.1
ATK-058	35.60	Head, Weathered London Clay	0.5 - 6.0	29.6 - 35.1
ATK-079	35.70	Alluvium	1.0 - 2.7	33.0 - 34.7
ATK-086	44.55	Made Ground – Recently Deposited Material & Landfill, Weathered London Clay	1.3 - 5.7	38.85 - 43.25
ATK-087	44.35	Made Ground - Landfill	1.5 - 3.0	41.35 - 42.85
ATK-088	43.55	Made Ground - Landfill	1.5 - 3.0	40.55 - 42.05
ATK-089	33.10	Alluvium	1.0 - 4.5	28.6 - 32.1
ATK-090	32.70	Alluvium	0.8 - 3.5	29.2 - 31.9
ATK-091	41.70	Made Ground - Landfill, Weathered London Clay	1.0 - 6.0	35.7 - 40.7
ATK-092	43.20	Made Ground	2.0 - 5.5	37.7 - 41.2
ATK-P-101	39.95	Made Ground – Landfill	1.0 - 4.0	35.95 - 38.95
ATK-P-102	43.50	Made Ground – Landfill	2.0 - 6.0	37.50 - 41.50

Vibrating Wire Piezometers (VWP) were installed within Weathered London Clay Formation and in London Clay Formation in exploratory holes ATK-042 (at 6.85 and 16.85m bgl), ATK-052 (at 7.0 and 17.0m bgl) and ATK-061 (at 4.85 and 14.85m bgl).

3.7 Geophysical Surveys

Ground Penetrating Radar was undertaken as part of the service clearance process prior to intrusive investigation works. These were undertaken by GEL. No other geophysical surveys were carried out as part of these works.

3.8 Other Fieldwork

3.8.1 UXO Risk Assessment

Prior to the 2019 GI, Brimstone Site Investigation, a specialist contractor regarding UXO was contracted by the ground investigation contractor GEL to produce a UXO risk assessment. The Stage 2 Detailed UXO Risk assessment indicated a Low to Moderate risk from UXO for the ground investigation works [33]. Following this report, no further action was required for the 2019 GI.

The report indicates that this assessment was undertaken with respect to the ground investigation phase of works and that a separate risk assessment should be carried out by UXO specialists with respect to the proposed construction works prior to breaking ground, as the risks correspond to the proposed works.

3.9 Test Pile Results

No pile load tests were carried out as part of these works.

3.10 Geotechnical Laboratory Testing

The ground investigation included the collection of disturbed and undisturbed soil samples, on which geotechnical laboratory testing was undertaken. The geotechnical laboratory testing comprised the following:

Table 3-7 Geotechnical Lab Testing Summary

Laboratory Test	Testing Standard	No. of tests
Water Content Determination	BS EN ISO 17892-1:2014	272
Liquid and Plastic Limit Tests	*BS 1377: Part 2:4.3, 5.3 and 5.4	225
Particle Size Distribution (PSD)	BS EN ISO 17892-4:2016	110
Particle Density	BS EN ISO 17892-3:2015	16
Bulk & Dry Density	BS EN ISO 17892-2:2014	193
Total Stress Triaxial Compression Tests	** BS 1377: Part 7:8	161
Effective Stress Triaxial Compression Tests	***BS 1377: Part 8:4	32
Hand Vane Tests	BS 1377: Part 9:4.4	212
Dry Density/ Water Content Relationship, 2.5 kg rammer	BS 1377: Part 4:3.2 and 3.3/3.4	17
Moisture Condition Value relationship	BS 1377: Part 4:5.5	21
Determination of swelling and collapse characteristics	****BS 1377: Part 5:4.3	23
One Dimensional Consolidation	****BS 1377: Part 5:3	49
Organic Matter Content	BS 1377: Part 3	36
BRE Chemical Testing	BS 1377: Part 3	52

* Liquid and Plasticity Limit testing was undertaken according to superseded standard, updated standard is BS EN ISO 17892-12:2018 [34], this is not anticipated to affect the test results.

** Total Stress Triaxial Compression Testing was undertaken according to superseded standard, updated standard is BS EN ISO 17892-8:2018, this is not anticipated to affect the test results [35].

*** Effective Stress Triaxial Compression Testing was undertaken according to superseded standard, updated standard is BS EN ISO 17892-9:2018 [36], this is not anticipated to affect the test results.

**** Oedometer and Swelling Laboratory testing was undertaken according to superseded standard, updated standard is BS EN ISO 17892-5:2017 [37], this is not anticipated to affect the test results.

3.11 Geo-environmental Laboratory Testing

A total of 77 no. geo-environmental soil samples were collected from 45 no. exploratory holes from depths between ground level to 6.80m bgl. The soil samples were sent to an MCERT/UKAS laboratory for analysis for a selected suite of the following parameters based on field observations made during the GI:

- General inorganics: pH, electrical conductivity, cyanide (total and free), sulphate, ammonia (as NH3), ammonium (as NH4), fraction organic carbon (FOC), total organic carbon (TOC) and total phenols (monohydric);

- Heavy metals/metalloids: arsenic, barium, beryllium, boron, cadmium, chromium, chromium (hexavalent), copper, lead, mercury, nickel, selenium, vanadium and zinc;
- Asbestos: Fibrous screening and quantification if the screen is positive;
- BTEX and methyl tertiary butyl ether (MTBE), PAH - speciated EPA-16, TPH-CWG, VOCs and semi-VOCs; and
- Soil-derived leachate analysis of pH, electrical conductivity, TOC, dissolved organic carbon (DOC), sulphate, sulphide, phenols - total (monohydric), cyanide (total and free), ammonium (as NH4), chloride, antimony, arsenic, barium, beryllium, boron, cadmium, chromium (dissolved, trivalent and hexavalent), cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, phosphorus, selenium, tin, vanadium, zinc, calcium, magnesium, potassium and sodium.

3.12 Waste Classification Laboratory Testing

A sampling strategy was prepared for the 2019 GI, with the purpose to obtain soil samples to develop a preliminary waste classification of the material that may be excavated during the construction phase and therefore may require disposal off site. The sampling strategy included a methodology for collecting composite samples (COMP) from in-situ material during the ground investigation. These were used for preliminary waste classification and WAC laboratory data was screened against WAC thresholds.

Composite samples were specified in line with BS EN 14899:2005 [38], which is based on PD CEN/TR 15310-1:2006 [39]. Each composite sample comprised a minimum of four increments, with the aim to provide a characterisation of the soil as comprehensive as possible at this stage.

Where composite samples could not be collected (due to limited amount of material excavated within a geological unit), data from the corresponding environmental sample was used for the preliminary waste classification. However, unlike composite samples, these are point samples and provide a limited characterisation of the soil.

A total of 76 no. composite samples were collected from within the Scheme and scheduled for soil suites analysis comprising general inorganics, metal/metalloids, polyaromatic hydrocarbons, total petroleum hydrocarbons, asbestos, volatile and semi-volatile organic compounds. Out of these, a total of 23 no. samples were also scheduled for WAC analysis.

3.13 Post Fieldwork Monitoring and Sampling

Surface water samples were collected from Weald Brook sampling locations SW01 and SW02 (see Appendix E) during six monitoring rounds between November 2019 and February 2020. The 12 no. samples were sent to an MCERT/UKAS laboratory. Sample point SW01 was located upstream of the historical landfill and main works area and SW02 was located downstream of the historical landfill and main works area. The samples were tested for a range of inorganics, biochemical oxygen demand (BOD) metals and metalloids, hydrocarbons, BTEX and MTBE, VOCs, semi-VOCs, PCBs, pesticides and herbicides.

A total of 60 no. groundwater samples were collected from the 18 no. monitoring wells installed during the 2019 GI and two monitoring wells installed during the preliminary GI across six monitoring rounds between November 2019 and February 2020 and sent to an MCERT/UKAS laboratory. Groundwater was sampled using low-flow purging until in-situ water quality parameters (i.e. pH, redox and dissolved oxygen) indicated equilibrium before taking the sample. The samples were tested for the same chemical suite as the surface water samples.

A trip blank, a field blank and a duplicate of one of the water samples were sent with the samples to the laboratory for each of the six monitoring rounds.

Ground gas monitoring was carried out over six monitoring visits between November 2019 and February 2020 from 18 monitoring wells installed during the 2019 GI and two monitoring wells installed during the preliminary GI. Each well was monitored at least three times (except for ATK-079 and ATK-087 which were monitored once and twice respectively). Concentrations of carbon dioxide, methane, oxygen, hydrogen sulphide, carbon monoxide and the ground gas flow rates were recorded as well as atmospheric pressure. PID readings were taken from just inside the top of the monitoring wells on each visit.

4. Ground Summary

4.1 General Description

The ground conditions encountered during the investigation generally confirmed the geological succession as described in Table 2-2. This section provides a discussion about the ground conditions encountered, utilising information from both the 2019 investigation and historical investigations.

The ground summary section comprises information considered pertinent to the Scheme within proximity of the proposed works. Although present within the historical reports reviewed at PSSR stage, historical geotechnical information to the south and east of junction 28 has been considered only in a broader context of the ground conditions and not with specific detail within the ground summary section.

Three geological long sections have been produced for the Scheme including interpretation of both the 2019 GI and historical boreholes, this is included in Appendix F.

4.2 Summary of Ground Conditions

Table 4-1 below summarises each geological stratum encountered within the Scheme, including typical description, thickness and distribution.

Table 4-1 Summary of ground conditions

Stratum		Typical Description	Typical Depth Top (m BGL)	Elevation Top (Range) (m OD)	Typical proven Thickness (m)	Distribution
Topsoil*		Grass over soft brown slightly gravelly sandy silty CLAY / clayey SILT with frequent roots and rootlets	0.00	31.15 – 55.60	0.30 (0.05 – 0.50)	Whole of study area
Artificial Deposits	Made Ground – Engineered Fill	Soft to firm (occasionally stiff) brown mottled orangish brown slightly sandy to sandy, slightly gravelly to gravelly CLAY. Gravel is angular to subrounded fine to coarse flint	0.20 (0.00 – 0.50)	32.55 – 47.60	2.90*** (0.70 – 8.80**)	Localised distribution to existing M25 and A12 alignment
	Made Ground – Recently Deposited Material	Soft to firm, brown slightly sandy to sandy, slightly gravelly to very gravelly CLAY with low cobble content. Gravel and cobbles comprising flint, concrete, limestone, glass, ceramics, plastic and brick.	0.00 (0.00 – 0.40)	37.00 – 45.00	0.40 (0.05 – 2.00)	Localised distribution to north of Grove Farm
	Made Ground – Landfill	Soft to stiff, greyish brown mottled orangish brown (frequently stained black) slightly sandy slightly gravelly CLAY	0.65 (0.00 – 2.00)	36.75 – 44.60	3.40*** (1.20 - 5.55)	Localised distribution to north of Grove Farm
	Made Ground - Undifferentiated	Soft to stiff, brown (commonly noted as mottled orangish brown)	0.00 (0.00 – 0.30)	30.85 – 43.75	0.85*** (0.10 – 3.00)	Whole of study area

Stratum		Typical Description	Typical Depth Top (m BGL)	Elevation Top (Range) (m OD)	Typical proven Thickness (m)	Distribution
		slightly sandy slightly gravelly CLAY or clayey SILT. Gravel is predominantly angular to sub-rounded fine to coarse flint.				
Superficial Deposits	Alluvium - Undifferentiated	Soft or firm, light grey, brown mottled orangish brown slightly sandy slightly gravelly silty CLAY with pockets of black carbonaceous / decomposed organic material. At the base of the stratum: grey and brown clayey sandy sub angular to rounded fine to coarse flint GRAVEL was occasionally encountered.	0.70 (0.00 – 7.60)	30.45 – 38.00	2.45*** (0.80 – 4.25)	Localised distribution within floodplain of Weald Brook and Ingrebourne River.
Superficial Deposits	Head – Fine	Soft to firm (occasionally stiff), brown mottled orangish brown light grey slightly sandy slightly gravelly silty CLAY.	0.90 (0.00 – 5.90)	28.40 – 55.30	1.50*** (0.20 – 4.88)	Widespread distribution generally localised on sloping ground adjacent to existing watercourses.
Superficial Deposits	Head – Gravel	Brown slightly clayey to clayey sub angular to rounded fine to coarse flint GRAVEL with occasional low subangular flint cobble content	1.00 (0.15 – 2.00)	31.25 – 44.45	0.60*** (0.10 – 1.50)	Localised distribution to southwest of the Scheme adjacent to A12.
Bedrock	Weathered London Clay Formation	Firm becoming stiff brown mottled orangish brown (occasionally closely fissured) silty CLAY with rare pockets of orangish brown silty fine sand and frequent selenite crystals (1 – 15mm)	2.20 (0.00 – 9.60)	26.20 – 54.83	5.60*** (1.20 – 10.37)	Whole of study area
Bedrock	London Clay Formation	Stiff or very stiff thinly laminated fissured greyish brown (with occasional bluish grey mottling) silty CLAY with rare selenite crystals (from 1 – 25mm)	8.00 (2.00 – 13.60)	22.05 – 46.58	> 31.75**	Whole of study area

* The topsoil encountered across the Scheme comprised both natural and artificial material, the components have not been differentiated within this report.

** Maximum thickness of stratum unproven.

*** Average given due to variable results.

4.3 Geotechnical Parameter Rationale

4.3.1 Introduction

The following sections summarise the derivation of the geotechnical parameters using results provided from the historical and recent ground investigations. The approach to selection of characteristic values provided in this report are generally in accordance with EC7. Values of geotechnical parameters are expressed in terms of ranges and Characteristic Values, which are defined in EC7 [5] as:

"(1)P The selection of characteristic values for geotechnical parameters shall be based on results and derived values from laboratory and field tests, complemented by well-established experience.

(2)P The characteristic value of a geotechnical parameter shall be selected as a cautious estimate of the value affecting the occurrence of the limit state."

EC7 further recommends that where the zone of ground governing the limit state is large, the governing parameter is the mean, and hence the characteristic value should be a cautious estimate of the mean (Clause 2.4.5.2 (7)). For statistical implementation, EC7 recommends the cautious estimate should be a mean value with a confidence level of 95% (Clause 2.4.5.2 (11) Note).

Where the material and or geotechnical parameter is variable, the soil not considered uniform and the origin of the material unknown, characteristic values have not been provided. For these materials, such as Made Ground – Undifferentiated, the mean or a range of values has been presented only and no characteristic values determined.

The results are plotted against depth below ground level for each geological unit, the characteristic value is provided in relation to change in depth where appropriate. The data was reviewed with respect to elevation during preparation of this report, however, did not appear to show any discernible relationship due to the variation in topography across the site. If a change with elevation has been noted, more than one characteristic value may be provided for each geological unit.

The materials considered within this report have been described in terms of fine and coarse soils, based on field logging and likely behaviour and not grading alone, as per the basis of soil description in Section 33.2 of BS EN ISO 5930 [30].

4.3.2 Classification and Index Properties

Classification and index tests do not provide engineering parameters directly but are used to classify soils, identifying trends, strata changes and apply empirical correlations to obtain estimates of other parameters. The classification tests undertaken during the ground investigations comprise water content tests, Atterberg Limits, particle size distribution (PSD) gradings, organic content, density and particle density. These tests were carried out on disturbed and undisturbed samples.

<u>Natural Water Content and Atterberg Limits</u>

Water content (WC) of the soil is referred to as moisture content (MC) in historical reports; these test results have been renamed WC in line with the latest Standard BS EN ISO 17892-1 [40], as the testing procedure is not considered to have changed.

The Atterberg Limits is the range of water content over which the soil exhibits plastic behaviour, defined as the liquid limit (w_L) and the plastic limit (w_P), respectively. The water content range itself is defined as the plasticity index (I_P), i.e.:

$$I_P = w_L - w_P$$

Particle Size Distribution

Wet sieving particle size distribution tests were carried out to determine the grading of coarse sized materials. In order to establish the proportion of the fine sized materials (<0.063mm particles), hydrometer tests were carried out on tested samples with >15% clay and silt.

Organic Content

Two methods of testing were undertaken to determine the organic content of samples: organic matter content tests and loss on ignition (LOI). LOI testing is considered likely to provide a higher content and less representative result; this is likely due to the heterogeneous nature of the sampled material. BS1377-3 [41] indicates that other factors unrelated to organic content could be responsible for the major proportion of the mass lost on ignition therefore the organic matter content test is considered more reliable where the results significantly contrast.

Characteristic values have not been presented as the organic content is considered variable due to the heterogenous nature of natural strata.

Bulk and Dry Density

Values of bulk and dry density have been determined from laboratory tests on undisturbed samples. Characteristic values have not been presented based on these results, however they have been used to inform a characteristic bulk unit weight for the strata.

A characteristic bulk weight density has been determined based on bulk density results, undrained shear strength and log descriptions in accordance with BS 8004:2015 Figure 2 [42] for soils below the groundwater table.

Particle Density

Values of particle density have been determined from laboratory tests on undisturbed UT100 driven samples during the 2019 GI. The Characteristic particle density is presented for each stratum where sufficient testing is available to determine a value. For other strata where sufficient testing was not undertaken, the Designer should determine values appropriate for the proposed design based on engineering judgment and published values where available.

Permeability

No direct measurements for hydraulic conductivity have been undertaken during the ground investigation. However, correlations based on the dissipation test results undertaken during the SCPT results have been presented where available.

A hydraulic gradient considered typical for the strata has been presented based on the typical stratum description in accordance with Table 3.3 in Barnes (2010).

4.3.3 Standard Penetration Tests

The N-values derived from SPT results can be correlated with engineering soil parameters by means of established empirical relationships and site-specific correlations where these can be established. Table 4-2 below summarises the properties that can be derived from SPT results [43].

Table 4-2 Determination of Parameters from SPT Results (after CIRIA, 1995)

Parameter	Material Type	
	Coarse Soil	Fine Soil
Undrained Shear Strength (c_u)		✓
Stiffness (E')	✓	✓
Consolidation (m_v)		✓

Where SPTs met refusal (>50 blows for less than 300mm penetration), the results have been extrapolated to give an N value for the full test drive of 300mm using the following equation [43]:

$$N = \frac{blows\ during\ test\ drive}{penetration\ during\ test\ drive\ (mm)} \times 300$$

The N-values derived from SPT results from the recent GI have been corrected to N_{60} using the energy ratio (Er_r) of the SPT hammer as reported in the 2019 GI factual report [24] in the following equation:

$$N_{60} = \frac{N \times Er}{60}$$

Note: The N-values for the historical ground investigations have not been corrected to N_{60} as no energy certificates are available. The lower N-values from uncorrected results have been considered when determining characteristic values.

4.3.4 Strength

Undrained Shear Strength

The undrained shear strength (c_u) has been assessed using the following tests:

- Unconsolidated undrained triaxial tests;
- Hand shear vane;
- Hand Penetrometer;
- SPTs; and
- SCPT results.

Laboratory unconsolidated undrained triaxial tests provide an undrained shear strength value.

Field hand shear vanes and hand penetrometers provide a direct reading of undrained shear strength either *in situ* in the ground or on recovered samples of sufficient size and quality.

In fine soils it is possible to correlate SPT 'N' values to undrained shear strength using the following relationship proposed by Stroud and Butler (1975 [43]:

$$c_u = f_1\ N_{60}$$

The value of f_1 is determined by the characteristic plasticity index and obtained from the Stroud and Butler (1975) figure of f_1 plotted against plasticity index [43]. The f_1 values used for each stratum is given below:

- Made Ground – Engineered Fill – 4.5
- Made Ground – Landfill – 4.5
- Alluvium – 4.5
- Head – 4.5
- Weathered London Clay Formation – 4.5
- London Clay Formation – 4.5

SCPT cone tip resistance is used as an estimate of undrained shear strength, based on the following formula [44].

$$s_u = \frac{q_c - \sigma_{v0}}{N_k}$$

Where S_u is the undrained shear strength, q_c cone resistance, σ_{vo} total overburden pressure and N_k is an empirical cone factor. The empirical cone factor has been determined per stratum, as outlined in Table 4-3 taken from Mayne and Peuchen (2018).

Table 4-3 Summary of N_k cone factor used to determine undrained shear strength

Stratum	N_{kt}	Comment
Made Ground - Landfill	13.33	All Clays (undifferentiated)
Alluvium - Fine	12	Onshore Normally consolidated.
Head - Fine	13.33	All Clays (undifferentiated)
Weathered London Clay	22.47	Over-consolidated Fissured Clay
London Clay Formation	22.47	Over-consolidated Fissured Clay

Residual Shear Strength

The residual undrained shear strength of fine soil was determined through *in situ* hand shear vane tests during taken as part of the 2019 GI. A limited number of tests were undertaken; therefore, these have not been assessed as part of this report.

Remoulded Shear Strength

The remoulded shear strength of fine soil has been determined by hand shear vane tests on recompacted samples used in the compaction and Moisture Condition Value (MCV) testing.

Effective Shear Strength (c' and φ')

For fine materials, the effective peak angle of shearing resistance has been obtained from s'-t' plots derived from effective stress triaxial tests. Note that the characteristic value for effective cohesion (c') is a best estimate of the data set rather than a design value. Therefore, it may not be appropriate to use this value as a design parameter in all situations. This is particularly important in the design of earthwork slopes.

Where effective stress tests have not been undertaken on fine soil, a correlation based on plasticity index has been solely used to determine characteristic constant volume effective angle of shearing resistance ($\varphi'_{cv,k}$), applying BS 8004:2015 [42].

$$\varphi'_{cv,k} = (42° - 12.5log_{10}(I_P))$$

Where I_p is the characteristic value provided for each strata.

To determine peak effective angle of shearing resistance (φ'_{pk}), a soil dilatancy contribution (φ'_{dil}) has been considered based on the stress history of the soil. Values of φ'dil are typically 0-4° known to increase with a fine soil's overconsolidation ratio and are greater than or equal to zero. Where:

$$\varphi'_{pk} = \varphi'_{cv,k} + \varphi'_{dil}$$

Residual shearing resistance (φ'_r) has been presented where the stratum is considered to contain relict shear surfaces. Estimations for residual shear strength were determined based on test result relationships between residual shearing resistance and plasticity index or clay fraction presented in Figure 11.3 within Nowak and Gilbert (2015), based on test results presented by Skempton et al (1989).

For coarse materials (siliceous sands and gravels), the characteristic constant volume effective angle of friction ($\varphi'_{cv;k}$) has been determined using the equation presented within BS 8004:2015 Section 4.3.1.3.5 [42]:

$$\varphi'_{cv,k} = 30 + \varphi'_{ang} + \varphi'_{PSD}$$

The characteristic peak effective angle of shearing resistance ($\varphi'_{pk,k}$) may be estimated with an additional φ'_{dil} contribution should the fines content be less than 15%.

$$\varphi'_{pk,k} = \varphi'_{cv,k} + \varphi'_{dil}$$

Stiffness (E')

SPT 'N' values can be correlated to provide stiffness, Drained Young's Modulus (E'), for fine soils using the following relationship provided by the CIRIA (1995):

$$E' = 0.9 \times N$$

In this report, 'N_{60}' value has been used instead of 'N' for consistency.

The Young's Modulus was also determined from the SCPT Cone Resistance in accordance with the method proposed by Robertson [45]. The method and results are outlined within the 2019 GI factual report [24] and have been presented as a comparison against the SPT N value derived results.

4.3.5 Consolidation

Oedometer consolidation tests were undertaken on undisturbed samples of fine material. The oedometer testing results have been used to derive the coefficient of compressibility (m_v) of fine soil and the coefficient of consolidation (C_v) vertical component.

The value of m_v is not constant, but depends on the stress range over which it is calculated, the characteristic value of m_v is calculated in accordance with BS 1377-5:1990 [46] at a stress increment 100 kN/m^3 in excess of the effective overburden pressure. Where the oedometer results show a clear trend within over-consolidated strata, the C_v over the recompression stage at relatively low stresses and primary compression at higher stresses has been distinguished.

SPT 'N' values can be correlated to provide the coefficient of compressibility for fine soils using the following relationship provided by the CIRIA (1995) and the corresponding errata [47]:

$$m_v = \frac{1}{f_2 \times N_{60}}$$

Figure 41 within CIRIA (1995) provides a plot of f_2 plotted against plasticity index. Based on characteristic or mean plasticity index where appropriate; the f_2 values (kN/m^2) used for each stratum is given below:

- Made Ground – Engineered Fill – 450
- Alluvium – 450
- Head – 450
- Weathered London Clay Formation – 450
- London Clay Formation – 450

The coefficient of consolidation (C_{vh}) and the value of m_v were determined through the interpretation of dissipation test results and CPTu respectively, undertaken by the specialist SCPT Contractor Lankelma. The results and methodology are presented within the 2019 GI factual report [24] and the corresponding values presented against the laboratory derived values within this report.

4.3.6 Compaction

Compaction results, including optimum water content (OWC) and maximum dry density (MDD) have been determined from laboratory tests on disturbed bulk samples. These have been undertaken using a light compaction 2.5kg rammer and heavy 4.5kg rammer. Moisture Condition Value (MCV) testing has been undertaken as single point tests on disturbed samples at natural water content and over a range to determine MCV relationship with water content.

Note: the guidance given in BS1377-4:1990 [48] has not been updated since the revision of MC to WC within BS EN ISO 17892-1:2014 [40]. As such the present guidance refers to Optimum Moisture Content (OMC) rather than OWC. This report will use the term OWC when discussing the results of water content / compaction relationship testing.

Characteristic values have not been determined for these test results. The Designer should select design values from the available testing appropriate to the proposed earthworks design and specification.

4.3.7 Volume Change Potential

Volume change potential (VCP) of a soil is the relative change in volume to be expected with changes in soil water content and is reflected by shrinking and swelling of the ground. The most widely used parameter for determining the shrinkage and swelling potential of a soil is the plasticity index (I_P). Such plasticity parameters, being based on remoulded samples, cannot precisely predict the shrink-swell behaviour of an in-situ soil. Therefore, a Modified Plasticity Index (I_P') is used, which includes particle size data to get a more accurate result. This is done by using the following formula:

$$I_P' = I_P \times \frac{\% < 425\mu m}{100}$$

This result is then used to determine the VCP of a clay using Table 4-4 below, after Building Research Establishment (BRE) (1993) [49].

Table 4-4 Classification of Volume Change Potential

Classification	IP' (%)	VCP
A	< 10	Non-Plastic
B	10 – 20	Low
C	20 – 40	Medium
D	40 – 60	High
E	> 60	Very High

4.3.8 Consistency Index (CI)

The consistency index (CI) is a quantifying term which can be used to describe soils i.e. soft to very stiff. Within this report, CI has been used to help determine the reusability of soil for embankment fill. The CI is calculated using the following equation given in Nowak and Gilbert (2015):

$$CI = \frac{LL - \omega}{PI}$$

4.3.9 Concrete Classification

Chemical tests on potentially aggressive ground/groundwater have been conducted to determine the type of concrete which will be needed for buried structure design. The results of these tests have been correlated with the tables in the BRE Special Digest 1:2005 [50] to determine the Design Sulphate Class (DS) and Aggressive Chemical Environment for Concrete Class (ACEC) of each unit.

4.3.10 California Bearing Ratio

California Bearing Ratio (CBR) is a measure of the bearing value of subgrade. CBR values have been obtained by the following methods for the Scheme:

- Correlation with dynamic cone penetration (DCP) testing data (in situ CBR); and
- Laboratory testing of undisturbed samples – historical test results
- Published values based on correlation with material type and index testing data.

CBR values derived in-situ DCP testing were converted from typical mm/blow to a CBR value through the relationship provided below [51]. These values are considered short-term values, representative of the water conditions at the time of test as well as the test elevations. The DCP values presented in the subsequent section represent the typical mm/blow value for the stratum, a significant softening of the material was identified at a shallow depth which has not been considered as it is likely to be stripped and removed prior to construction.

$$Log_{10}(CBR) = 2.43 - 1.057 \times Log_{10}\,(mm/blow)$$

In addition, the long-term CBR has also been estimated from Table 5.1 of Interim Advice Note (IAN) 73/06 [51] based on correlations with soil type, plasticity index and likely subgrade moisture conditions. These CBR values assume a high-water table and that the foundations may be wetted by ground water during their life.

CD 225 'Design for New Pavement Foundations' [52] states that to calculate the design CBR, the lower of the short term and the long term CBR values is to be taken. The short term is derived from the DCP testing and the long term from published values for average construction conditions based on correlation with material type, index testing data published values in HD25/94 [51].

IAN 73/06 [51] states that experience suggests that materials with DCP penetration rate of less than 17mm per blow (>15% CBR) are likely suitable for direct trafficking.

The design CBR value can then be implemented into the following equation to calculate the estimated subgrade surface modulus. This equation is to only be used with CBR values in the range of 2 to 12% [51].

$$E = 17.6(CBR)^{0.64}\,MPa$$

Where:

CBR = California bearing ratio of the subgrade

E = estimated subgrade surface modulus

4.4 Strata Encountered

This section discusses the geological characteristics of each geological stratum encountered within the Scheme, as determined from the field observations (current and historical), in-situ and geotechnical laboratory testing. Characteristic parameters have been provided for each stratum. Groundwater and ground aggressivity to concrete are discussed in Section 4.8 and 4.6 respectively.

Geotechnical plots which have been used to help derive the geotechnical parameter values have been included within Appendix G of this report.

4.4.1 Topsoil

Description

The Topsoil encountered comprised both natural and artificial material; the components have not been differentiated within this report. The artificial material is typically brick and has been interpreted as being either 'trodden' in by activities on the site, or as being part of the drainage system. The stratum was typically fine, described as soft brown slightly gravelly sandy silty CLAY / clayey SILT with frequent roots and rootlets. Typically, this was overlain by grass.

Coarse Topsoil was also encountered across the Scheme, although presented a minor portion of the overall stratum. This is typically described as brown slightly clayey fine and medium SAND with frequent rootlets.

Thickness and Distribution

Topsoil ranged in thickness from 0.05 to 0.50m, with a typical thickness of 0.30m. The stratum was largely encountered across the entire Scheme at the ground surface (0m; 31.15 to 55.60m OD), although was generally absent (see ATK-008 GM01) where Made Ground was encountered at the surface.

The major area where Topsoil was absent within the proposed Scheme was across exploration holes undertaken at Grove Farm (GM-03). It should also be noted that in certain exploration holes, it is possible that Topsoil was not distinguished from the underlying strata by the logging engineer, this appears to be common within historical records.

Summary of Geotechnical Testing and Parameter Values

No testing was undertaken within this stratum or geotechnical parameters were determined. It is anticipated that the topsoil across the site will be removed and stockpiled ahead of the works for re-use on the Scheme – however will not be used as engineered fill in the proposed works.

4.4.2 Made Ground

Artificial soils, referred to within this report as Made Ground, have been separated into three separate groups based on distinct spatial distribution or source where known. As provided below:

Made Ground – Engineered Fill

Material associated with the M25 and A12 construction which is likely to have been placed and compacted in a controlled manner.

Made Ground – Recently Deposited Material

Material placed recently at Grove Farm as observed around 07 May 2018; this is generally located at the shallow surface.

Made Ground – Landfill

Material placed as landfill to a significant depth at Grove Farm.

Where the source of Made Ground was unknown or did not have a distinct spatial distribution, a fourth group has been presented to capture occurrences across the Scheme which were not be differentiated. As provided below:

Made Ground – Undifferentiated

Material placed across the Scheme has that not been attributed to a specific source or distribution, as above.

4.4.3 Made Ground – Engineered Fill

Description

The majority of the Made Ground – Engineered Fill encountered was a fine material, found to comprise soft to firm (occasionally stiff) brown mottled orangish brown slightly sandy to sandy, slightly gravelly to gravelly CLAY. Gravel is angular to subrounded fine to coarse flint. Other constituents noted within the gravel include brick, glass and limestone.

In a minor number of occurrences loose to medium dense brown SAND and GRAVEL of varying portions, was encountered, typically at a shallow depth. Other minor portions of this stratum include Made Ground associated with road construction such as Tarmacadam, concrete and sand and gravel (sub-grade).

The make-up of the Engineered Fill is anticipated to vary in line with the engineered components of the area, such as pavement or earthwork construction.

Thickness and Distribution

Engineered Fill ranged in thickness from 0.70 to 8.80m, with an average thickness of 2.90m. The stratum has a localised distribution along the existing M25 and A12 alignment, typically at surface or underlying Topsoil (0.00 to 0.50m bgl; 32.55 to 47.60m OD). The thickness of Engineered Fill is anticipated to vary in line with earthwork heights, HAGDMS indicates that embankment heights are typically in the order of 3-6m, with a maximum of 8.6m in the Scheme area [11].

Summary of Geotechnical Testing and Parameter Values

The geotechnical testing undertaken within the Made Ground – Engineered Fill stratum has been presented in Table 4-5 below. Considering the inherent variability of Made Ground, where the test results are variable with no clearly defined trend, characteristic values have not been presented.

Table 4-5 Summary of test results within Made Ground – Engineered Fill

Test type		Units	Number of tests	Range	Average Value (standard deviation)*	Characteristic Value	Figure Ref
Water Content		%	37	16 - 34	28 (4.0)	28	01-1
Atterberg Limit	Liquid Limit	%	28	32 - 92	69 (11.0)	72	02-1 03-1
	Plastic Limit	%	28	21 - 32	25 (2.7)	24	
	Plasticity Index	%	28	6 - 60	43 (10.1)	48	
Modified Plasticity Index		%	-	-	-	43	-
Consistency Index		-	28	0.7 – 5.3	1.3 (0.85)	1.0	-
Particle Size Distribution		-	8	-	-	-	04-1
Organic Matter Testing	OGM	%	1	-	0.5	-	-
Dry Density		Mg/m^3	16	1.40 - 1.64	1.5 (0.1)	1.5	05-1
Bulk Density		Mg/m^3	16	1.85 - 2.05	1.95 (0.1)	1.95	
Bulk Weight Density		kN/m^3	-	-	-	17 - 20	-
Standard Penetration Test		N_{60}	22	3 - 23	12 (5.6)	12**	06-1
Undrained Shear Strength (c_u)	Derived from SPT N_{60}	kPa	22	14 - 101	53 (25.6)	50 to 3m bgl; 75 thereafter	07-1
	Hand Shear Vane	kPa	5	104 - 123	116 (8.2)		
	Hand Penetrometer	kPa	24	50 - 220	94 (45.3)		
	Unconsolidated Undrained Triaxial	kPa	13	46 - 160	90 (31.6)		
Φ'cv,k derived from IP		°	-	-	-	21	-
Φ'p,k derived from IP		°	-	-	-	23	-
E' derived from SPT N60		MPa	22	3 - 20	11 (5.1)	11**	-
DCP result (typical penetration)		mm/blow	2	1.5 - 49	15 (9)	20	12-1
CBR derived from DCP		%	-	-	13	2 - 2.5	-
CBR derived from I_P		%	-	-	2 – 2.5		-

Test type		Units	Number of tests	Range	Average Value (standard deviation) *	Characteristic Value	Figure Ref
Estimated Design Sub-Grade Modulus		MPa	-	-	-	27 - 32	-
Hydraulic Conductivity		m/s	-	-	-	1x 10^{-08} to 10^{-06}	-
Geotechnical Chemistry Testing	pH	-	3	7.6 – 9.5	-	7.6***	-
	Water Soluble Sulphate	Mg/l	3	80 - 3320	-	3320***	-

‘z’ denotes per metre depth below top of stratum.

* Average and standard deviation not including obvious outliers within the dataset.

** Average given due to variability of results.

*** Determined in accordance with BRE SD1 [50].

Classification Testing

Atterberg Limit test results indicate the Made Ground – Engineered Fill stratum is predominantly a high to very high plasticity clay. There is one clear outlier classifying as a low plasticity silt, with single results classifying as intermediate clay and extremely high plasticity clay. The outliers are all from historical ground investigation and attest to the inherent variability of Made Ground.

The modified plasticity index has been determined for the characteristic I_P based on the average percentage passing 425µm. This classifies the VCP as high for this stratum.

The water content results are variable; however, a cautious estimate of the mean is 28%. When compared to the Atterberg Limits, this suggests that the material is typically saturated above the plastic limit. Several tests at a shallow depth are noted as semi-plastic (water content below plastic limit). The low water content attributed to vegetation adjacent to the sample location.

One organic matter content test was undertaken on this stratum, the test was below the limit for classification according to BS EN ISO 14688-2:2017 [53]. The organic content is considered likely to be low or absent from this stratum as organic matter is typically removed prior to placement as engineered fill.

The available PSD testing shows a bimodal distribution. Five plots indicate a predominantly fine material with an average fines content of 85%, which is consistent with a slightly sandy slightly gravelly silty CLAY [30]. The gradings are consistent with the typical field description for this stratum. Two plots indicate approximately 35% fine material, although were still classified in the field as fine described as slightly sandy gravelly CLAY. There is a further plot comprising sandy GRAVEL, however this was taken during a historical investigation to classify trench drain fill. The average percentage passing 425µm is 91% based on the fine portion of the stratum.

The material gradings and Atterberg Limit results are in line with the assessment that the majority of existing earthworks comprise reworked London Clay Formation.

Based on the bulk density results and undrained shear strength and log descriptions (in accordance with BS 8004:2015 Figure 2 [54] for soils below the groundwater table) the characteristic bulk weight density is expected to range from 17.0 to 20.0 kN/m^3.

No direct measurements for Hydraulic Conductivity have been undertaken during the ground investigation. Based on the typical fines portion description the hydraulic conductivity is anticipated to be in the region of 1x 10^{-08} to 10^{-06} m/s according to Barnes (2010), however due to the inherent variability of this material this parameter is likely to vary considerably.

Strength Testing

The SPT results indicates an average N_{60} of 12. a degree of uniformity has been considered for engineered fill as was placed for the purposes of highways construction, although as with any area of Made Ground there is potential for variability, the designer should consider this when determining parameters for design.

The undrained shear strength of the Made Ground – Engineered Fill has been determined using four methods as listed below:

- Correlation through N_{60} values;
- Unconsolidated undrained triaxial tests;
- Hand shear vane tests; and
- Hand penetrometer tests.

The derivation of undrained shear strength from the above listed methods indicates a variable range of values which is expected in Made Ground. The strength tests indicate that the material strength ranges from very low to very high strength in accordance with BS EN ISO 14688-2:2017, Table 6 [53].

The undrained shear strength of Made Ground – Engineered Fill has been selected as 50kPa to 3m bgl; 75kPa thereafter. Which corresponds to an increase in material strength from medium to high strength in accordance with BS EN ISO 14688-2:2017, Table 6 [53].

The characteristic effective angle of friction has been determined using the equation presented within BS 8004:2015 Section 4.3.1.4.8 [42]. Taking a characteristic I_P of 48%, the derived characteristic effective constant volume angle of friction ($\varphi'_{cv;k}$) is 21°. Values of φ'_{dil} are known to increase with a fine soil's over-consolidation, considering the engineered nature of the stratum a 2° φ'_{dil} component has been adopted for this stratum, resulting in a φ'_{pk} of 23°.

A characteristic constant volume effective cohesion ($c'_{cv;k}$) of 0 kPa is provided in accordance with BS 8004:2015 Section 4.3.1.4.9 [42].

Geotechnical Chemical Testing

The pH and Water Soluble Sulphate test results have been used to determine the stratum concrete classification, in accordance with BRE SD1 [50], Refer to Section 4.6.

4.4.4 Made Ground – Recently Deposited Material

Description

The majority of the Made Ground – Recently Deposited Material encountered was fine material with a significant coarse component. This stratum was described as soft or firm, brown slightly sandy to sandy, slightly gravelly to very gravelly CLAY with low cobble content. Gravel and cobbles comprised flint, concrete, limestone, glass, ceramics, plastic and brick.

A minor portion of the stratum was classified as behaving as a coarse material, described as brown slightly clayey slightly gravelly fine SAND or slightly sandy clayey GRAVEL.

Thickness and Distribution

Recently Deposited Material ranged in thickness from 0.05 to 2.00m, with an average thickness of 0.40m. The stratum was encountered at the ground surface or underlying Topsoil (0.0 to 0.4m bgl; 37 to 45m OD). This stratum is associated with the material placed between 07 May 2018 and 25 June 2018, as observed within the aerial photographic record [12]. This material is localised to the northern end of the field adjacent to Grove Farm, covering an area roughly 200m by 50m.

Summary of Geotechnical Testing and Parameter Values

The geotechnical testing undertaken within the Made Ground – Recently Deposited Material stratum has been presented in Table 4-6 below. Considering the inherent variability of Made Ground, limited data available and that it is not anticipated to be re-used during the proposed works characteristic values have not been presented.

Table 4-6 Summary of test results within Made Ground – Recently Deposited Material

Test type		Units	Number of tests	Range	Average Value (standard deviation)	Figure reference
Water Content		%	2	23	23 (0)	-
Atterberg Limit	Liquid Limit	%	2	47 – 49	48 (1.4)	02-2
	Plastic Limit	%	2	25 – 29	27 (2.8)	
	Plasticity Index	%	2	20 - 22	21 (1.4)	
Modified Plasticity Index		%	-	-	11	-
Consistency Index		-	2	1.07 – 1.28	1.18 (0.15)	-
Particle Size Distribution		-	2	-	-	04-2
Organic Matter Testing	OGM	%	1	-	2	-
	LOI	%	1	-	4.2	-
Bulk Weight Density		kN/m³	-	-	17 – 19*	-

Test type		Units	Number of tests	Range	Average Value (standard deviation)	Figure reference
Standard Penetration Test		N_{60}	1	-	<1	06-2/3
$\Phi'_{cv;k}$ derived from I_P		°	-	-	25	-
Φ'_{pk} derived from I_P		°	-	-	25	-
Compaction (2.5 kg rammer)	MDD	Mg/m³	1	-	1.64	11-2
	OWC	%	1	-	19	
Moisture Condition Value	MCV	-	1	7.6 – 13.3	-	
	Remoulded c_u	kPa	3	79 - >150	-	-
CBR derived from I_P		%	-	-	4 - 5	-
Estimated Design Sub-grade Modulus		MPa	-	-	43 - 49	-
Hydraulic Conductivity		m/s	-	-	1x 10^{-07} to 10^{-05}	-

* Based on published values due to limited laboratory results.

Classification Testing

Atterberg Limit test results are limited, with only two results available. The tests indicate that the Made Ground – Recently Deposited Material is situated on the A-line boundary classifying as an intermediate plasticity silt/clay.

The Modified Plasticity Index has been determined for the average I_P based on the average percentage passing 425µm. This classifies the VCP as low for this stratum, albeit based on limited data.

The water content results indicate that the existing water content of the material is below the plastic limit and therefore the material behaves as semi-plastic (water content below plastic limit). Only two tests are available for this stratum, so interpretation of results should be treated with caution.

The organic content was determined through two tests, both soil organic matter and loss on ignition tests were undertaken on this stratum. The test results indicated a similar organic content (albeit from limited tests) which classify the material as low-organic according to BS EN ISO 14688-2 [32]. The organic content is likely to be variable within this stratum and higher organic contents are anticipated.

Limited PSD testing is available, with two tests undertaken within this stratum. The plots show a consistent distribution across both samples with a gravel content of 40%, sand content of 30% and fines content of 30%, consistent with a slightly sandy gravelly silty CLAY. The gradings appear to be generally consistent with the field descriptions, showing a similar degree of variation as encountered in the field. Considering the inherent variable nature of Made Ground, this stratum is considered to have a highly variable composition, in line with the description outlined above. The average percentage passing 425µm is 48%.

Based on the log descriptions (in accordance with BS 8004:2015 Figure 2 [42] for soils below the groundwater table) the bulk weight density is expected to range from 17.0 to 19.0kN/m³.

No direct measurements for Hydraulic Conductivity have been undertaken during the ground investigation. Based on the typical description the hydraulic conductivity is anticipated to be in the region of 1x 10^{-07} to 10^{-05} m/s according to Barnes (2010), however due to the inherent variability of this material, this parameter is likely to vary considerably.

Strength Testing

One SPT was carried out within the Made Ground – Recently Deposited Material, this test recorded an N_{60} value of <1, as the sampler achieved full penetration under self-weight before being subject to any blows from the SPT hammer. This value corresponds to a very soft material consistency, in line with the typical description.

The undrained shear strength of the Made Ground – Recently Deposited Material was not determined through any direct measurements during the investigation. Considering the limited thickness and extent of this material the undrained shear strength has not been determined through empirical relationships for this stratum.

The characteristic effective angle of friction has been determined using the equation presented within BS 8004:2015 Section 4.3.1.4.8 [42]. Considering the characteristic I_P, the derived characteristic effective constant volume angle of friction ($\varphi'_{cv;k}$) is 25°. The φ'_{dil} component was determined as 0° due to the variability and unknown stress history of the material, therefore the φ'_{pk} is also 25°.

A characteristic constant volume effective cohesion ($c'_{cv;k}$) of 0 kPa is provided in accordance with BS 8004:2015 Section 4.3.1.4.9 [42].

Compaction and Re-usability

One 2.5kg rammer compaction test was undertaken which indicated a Maximum Dry Density of 1.64Mg/m^3 and an Optimum Water Content of 19%. Due to the inherent variability of this material, this parameter is likely to vary considerably.

The results of the Moisture Condition Value tests undertaken, indicate a range of 7.6 to 13.3, with corresponding remoulded undrained shear strengths ranging from 79 to over 150kPa increasing with MCV. Note two laboratory vane refusals occurred for the 13.1 and 13.3 test results.

4.4.5 Made Ground – Landfill

Description

The majority of the Made Ground – Landfill encountered was fine, although highly variable in composition and strength. This stratum was described from soft to stiff, greyish brown mottled orangish brown (frequently stained black) slightly sandy slightly gravelly CLAY. The gravel component typically comprised angular to sub-rounded fine to coarse flint; however, other constituents noted include brick, glass, sandstone, limestone and organic matter.

Frequent pockets (between 20 and 300mm in size) of black carbonaceous / organic material were noted throughout this stratum, including what appeared to be sawn branches (noted by the Atkins engineer on site during the 2019 GI). Rare selenite crystals are also noted in some occurrences.

The Made Ground – Landfill stratum appears to comprise reworked London Clay Formation, however with the addition of discrete pockets of black organic carbonaceous material. The source of the organic matter is not known; however, it is possibly derived from previous topsoil layers (not stripped prior to excavation of this material) and/or vegetation which has since partially decomposed following burial.

Thickness and Distribution

The Landfill stratum ranged in thickness from 1.20 to 5.55m and was on average 3.40m thick. The stratum was encountered with a localised distribution to the north of Grove Farm, typically underlying Topsoil or Made Ground – Recently Deposited Material (0.0 to 2m bgl; 36.8 to 44.6m OD).

Summary of Geotechnical Testing and Parameter Values

The geotechnical testing undertaken within the Made Ground – Landfill stratum has been presented in Table 4-7 below. Considering the inherent variability of Made Ground and limited data available, where the test results are variable with no clearly defined trend, characteristic values have not been presented.

Table 4-7 Summary of test results within Made Ground – Landfill

Test type		Units	Number of tests	Range	Average Value (standard deviation)	Characteristic Value	Figure Reference
Water Content		%	26	18 – 39	29 (4.6)	28	01-3
Atterberg Limit	Liquid Limit	%	22	43 – 76	62 (9)	68	02-3 03-3
	Plastic Limit	%	22	19 – 27	22 (2.2)	23	
	Plasticity Index	%	22	23 - 51	39 (8)	45	
Modified Plasticity Index		%	-	-	-	42	-
Consistency Index		-	22	0.67 – 1.06	0.83 (0.11)	0.8	-
Particle Size Distribution		-	12	-	-	-	04-3
Organic Matter Testing	OGM	%	15	0.1 – 3.6	1.2 (1.06)	-	-
	LOI	%	6	1.9 – 4.4	3.4 (0.73)	-	-
Dry Density		Mg/m³	7	1.26 – 1.67	1.45 (0.13)	-	05-3
Bulk Density		Mg/m³	7	1.75 – 2.0	1.85 (0.09)	-	
Bulk Weight Density		kN/m³	-	-	-	17 - 19	-

Test type		Units	Number of tests	Range	Average Value (standard deviation)	Characteristic Value	Figure Reference
Particle Density		Mg/m³	1	-	2.68	-	-
Standard Penetration Test		N_{60}	37	3 – 24	11 (5.6)	6	06-2/3
Undrained Shear Strength (c_u)	Derived from SPT N_{60}	kPa	37	11 - 107	48 (25.1)	40	07-3
	Hand Shear Vane	kPa	5	44 - 76	64 (14)		
	Unconsolidated Undrained Triaxial	kPa	5	38 - 57	47 (6.9)		
$\Phi'_{cv;k}$ derived from I_P		°	-	20.5 - 25	-	21	
Φ'_{pk} derived from I_P		°	-	-	-	21	
E' derived from SPT N_{60}		MPa	37	2 – 21	10 (5.0)	2.5	-
Coefficient of volume compressibility (m_v)	Oedometer	m²/MN	2	0.11 – 0.43*	-	0.4	09-3
	Derived from SPT N_{60}	m²/MN	-	-	0.37		-
	Derived from CPT	m²/MN	2	0.2 – 0.9	0.4		-
Coefficient of consolidation from Oedometer		m²/year	6	0.11 - 34	0.3* (0.24)	-	10-3
Compaction (2.5 kg rammer)	MDD	Mg/m³	7	1.54 – 1.72	1.62 (0.06)	-	11-3
	OWC	%	7	18 – 26	22.2 (2.7)	-	
Moisture Condition Value MCV	MCV	-	9	5.7 – 17.9	-	-	
	Remoulded cu	kPa	30	20.5 - >150	-	-	-
CBR derived from I_P		%	-	-	-	2 – 3	-
Estimated Design Sub-Grade Modulus		MPa	-	-	-	27 – 32	-
Hydraulic Conductivity		m/s	-	-	-	1×10^{-09} to 10^{-06}	-

Test type		Units	Number of tests	Range	Average Value (standard deviation)	Characteristic Value	Figure Reference
Geotechnical Chemistry Testing	pH	-	2	8 – 8.1	-	8**	-
	Water Soluble Sulphate	Mg/l	2	180 – 2300	-	2300**	-

* m_v results provided on unload reload tests and therefore states values not at overburden +100 kPa

** Determined in accordance with BRE SD1 [50].

Classification Testing

The Atterberg Limit test results indicate the Made Ground – Landfill has a bimodal distribution and predominantly behaves as a high to very high plasticity clay, however there are five results classifying this unit as an intermediate to high plasticity clay. To account for the bimodal distribution a conservative characteristic plasticity index has been adopted based on a high plasticity.

The Modified Plasticity Index has been determined for the characteristic I_P based on the average percentage passing 425µm. This classifies the volume change potential as high for this stratum.

The water content results are variable, however typically in the order of 28%. When compared to the Atterberg Limits, this suggests that the material is typically saturated above the plastic limit.

The organic content was determined through 21 no. tests; both soil organic matter and loss on ignition tests were undertaken on this stratum. The samples classify this unit as either below the classification limit or as a low organic material organic according to BS EN ISO 14688-2 [53]. The organic content is likely to be variable within this stratum and higher organic contents are anticipated locally.

The available PSD testing shows a consistent distribution across the tested samples. The fines content varies from 63 to 96%; 83% on average. This is consistent with a slightly sandy (slightly gravelly) silty CLAY. The gradings appear to correlate with the typical field descriptions. The gravel portion was not present within all samples tested. The average percentage passing 425µm is 94%.

The material gradings and Atterberg Limit results are in line with the assessment that the Made Ground – Landfill comprises reworked London Clay Formation, with high organic content. Although as the variability in the Atterberg limit results indicates, the composition and behaviour of the material is not uniform.

Based on the bulk density results, undrained shear strength and log descriptions (in accordance with BS 8004:2015 Figure 2 [42] for soils below the groundwater table) the characteristic bulk weight density is expected to range from 17.0 to 19.0kN/m^3.

No direct measurements for Hydraulic Conductivity have been undertaken during the ground investigation. Based on the typical description the hydraulic conductivity is anticipated to be in the region of 1x 10^{-09} to 10^{-06} m/s for a clay/silt/silty sands according to Barnes (2010). Due to the inherent variability of this material, this parameter is likely to vary considerably.

Strength Testing

The SPT N_{60} data does not appear to show any trend with depth, and therefore an N_{60} value of 6 is considered representative, although the stiffness of this stratum is inherently variable with very soft portions encountered, notably to the west of the lateral extent of the stratum.

The undrained shear strength of the Made Ground – Landfill has been determined using three methods as listed below:

- Correlation through N60 values;
- Unconsolidated undrained triaxial tests; and
- Hand shear vane tests.

The derivation of undrained shear strength from the above listed methods indicates a variable range of values which is expected in Made Ground. The strength tests indicate that the material strength ranges from very low to high strength in accordance with BS EN ISO 14688-2:2017, Table 6 [32].

The data does not present a clear trend with regards to change of undrained shear strength with depth; the suggested characteristic value for the undrained shear strength of Made Ground – Landfill has been selected as 40kPa. This corresponds to a low strength in accordance with BS EN ISO 14688-2:2017, Table 6 6 [32] . It should be noted that the strength of this stratum is variable and very low portions are present, especially to the west of the lateral extent of the stratum.

The characteristic effective angle of friction has been determined using the equation presented within BS 8004:2015 Section 4.3.1.4.8 [42]. Considering the characteristic I_P, the derived characteristic $\varphi'_{cv;k}$ is 21°. Considering the variability associated with this stratum a 0° φ'_{dil} component has been adopted for this stratum, resulting in a φ'_{pk} of 21°.

A $c'_{cv;k}$ of 0 kPa is provided in accordance with BS 8004:2015 Section 4.3.1.4.9 [42].

Compressibility

The compressibility of the material is provided by the coefficient of volume compressibility m_v, during the investigation this was derived through:

- Oedometer tests;
- Correlation through N_{60} values; and
- SCPT correlations.

The m_v varies with depth / applied stress depending on method of testing. In accordance with BS1377-5 [46] the characteristic m_v for this stratum has been determined for 100kN/m^3 in excess of the effective overburden pressure. The characteristic value of 0.4m^2/MN is representative of a high compressibility material in accordance with Table 2.6 of Tomlinson (2001).

An area or structure specific characteristic value of m_v will need to be derived at detailed design stage once loading is confirmed, the Designer should consider the inherent variability of the material in determining a suitable value.

Compaction and Re-usability

The 2.5kg rammer compaction tests indicated a Maximum Dry Density range of 1.54 to 1.72Mg/m^3, and an Optimum Water Content range of 18 to 26%.

The results of the Moisture Condition Value (MCV) tests undertaken, indicate a range of 5.7 to 17.9, with corresponding remoulded undrained shear strengths ranging from 20 to over 150kPa increasing with MCV. Note, five laboratory vane results for samples from ATK-032 and ATK-036 appeared to conflict with the corresponding MCV values and therefore were not included in the plots.

Geotechnical Chemical Testing

The pH and Water Soluble Sulphate test results have been used to determine the stratum concrete classification, in accordance with BRE SD1 [50], Refer to Section 4.6.

4.4.6 Made Ground – Undifferentiated

Description

This stratum represents other occurrences of Made Ground not associated with the construction of the M25 and A12 or with land filling activities at Grove Farm.

The majority of the Made Ground – Undifferentiated encountered was fine, although highly variable in composition and strength. This stratum was described as between soft to stiff, brown (commonly noted as mottled orangish brown) slightly sandy slightly gravelly CLAY or clayey SILT. Gravel is predominantly angular to subrounded fine to coarse flint; however, other constituents are noted including brick, concrete, plaster, tarmacadam and wood.

Thickness and Distribution

The Made Ground – Undifferentiated stratum ranged in thickness from 0.10 to 3.00m and was on average 0.85m thick. The stratum was encountered across the entire Scheme, typically underlying Topsoil (0.00 to 0.30m bgl; 30.85 to 43.75m OD).

Summary of Geotechnical Testing and Parameter Values

The geotechnical testing undertaken within the Made Ground – Undifferentiated stratum has been presented in Table 4-8 below. Considering the inherent variability of Made Ground and that the origin of this material has not been differentiated during the investigation, characteristic values have not been provided for the testing results of this stratum.

Table 4-8 Summary of test results within Made Ground – Undifferentiated

Test type		Units	Number of tests	Range	Average Value (Standard Deviation)	Figure reference
Water Content		%	8	10 – 26	21 (6.4)	01-4
Atterberg Limit	Liquid Limit	%	8	43 – 80	65 (15)	02-4
	Plastic Limit	%	8	21 – 29	25 (2.6)	
	Plasticity Index	%	8	17 – 55	40 (14)	
Modified Plasticity Index		%	-	8.5 – 53	33 (15.5)	-
Consistency Index		-	8	0.83 – 1.97	1.2 (0.38)	-
Particle Size Distribution		-	6	-	-	04-4
Bulk Weight Density		kN/m^3	-	-	18 - 20	-
Particle Density		Mg/m^3	1	-	2.57	-
Undrained Shear Strength (c_u)	Hand Shear Vane	kPa	1	105	75	07-4
	Hand Penetrometer	kPa	41	5 - 150		
	Unconsolidated Undrained Triaxial	kPa	1	60		
$\Phi'_{cv;k}$ derived from I_P		°	-	20 – 27	-	-
Φ'_{pk} derived from I_P		°	-	20 – 27	-	-
Compaction (2.5 kg rammer)	MDD	Mg/m^3	1	-	1.47	11-4
	OWC	%	1	-	28	
Moisture Condition Value MCV	MCV	-	1	9.5 – 15.2	-	
	Remoulded c_u	kPa	5	43.5 - 115	-	-
DCP result (typical penetration)		mm/ blow	4	5 – 128	29 (19)	12-4
CBR derived from DCP		%	-	-	8.8	-
CBR derived from I_P		%	-	-	2.5 - 3	-
Estimated Design Sub-Grade Modulus		MPa	-	-	32 – 36	-
Geotechnical Chemistry Testing	pH	-	4	6 – 8.7	6*	-
	Water Soluble Sulphate	Mg/l	1	900	900*	-

* Determined in accordance with BRE SD1 [50].

Classification Testing

The Atterberg Limit test results indicate the Made Ground – Undifferentiated has a bimodal distribution and predominantly behaves as a high to very high plasticity clay; however, there are three results classifying as an intermediate to high plasticity clay.

The Modified Plasticity Index has been determined for the range of I_P based on the percentage passing 425µm where PSD testing is available. The volume change potential classification varies from non-plastic to high for this stratum.

The water content results indicate a typical value of 25%. This suggests that the material is typically below the plastic limit, although two tests indicate a semi-plastic material (water content below plastic limit), the low water content is attributed to adjacent vegetation.

The available PSD testing shows a bimodal distribution. Three plots indicate a high fine component with over 75% fines content, consistent with a slightly sandy silty CLAY to clayey SILT. Whereas the other three plots indicate a lower fines content with approximately 40% fines, consistent with a slightly sandy gravelly SILT. This demonstrates the inherent variability of undifferentiated Made Ground. The PSD gradings generally correlate with the typical field descriptions considering the variability of the material.

The composition of the high fine component is considered to be reworked London Clay Formation, this is further indicated by the Atterberg Limit testing which suggests a high to very high plasticity for a portion of this stratum.

Based on the undrained shear strength and the log descriptions, (in accordance with BS 8004:2015 Figure 2 [42] for soils below the groundwater table), the bulk weight density ranges from 18.0 to 20.0 kN/m^3.

Strength Testing

The undrained shear strength of the Made Ground – Undifferentiated has been determined using three methods as listed below:

- Unconsolidated undrained triaxial tests;
- Shear Vane (HSV) tests; and
- Hand penetrometer tests.

The derivation of undrained shear strength from the above listed methods indicates a variable range of values, which is expected in Made Ground. The strength tests indicate that the material strength ranges from extremely low to high strength in accordance with BS EN ISO 14688-2:2017, Table 6 [32].

The characteristic effective angle of friction has not been determined for this stratum due to the inherent variability and the φ'_{dil} component considered to be 0°. Considering the range in I_P results, the derived range in effective constant volume angle of friction ($\varphi'_{cv;k}$) is 20 to 27°, in accordance with the equation presented within BS 8004:2015 Section 4.3.1.4.8 [42].

Compaction and Re-usability

The 2.5kg rammer compaction test indicated a Maximum Dry Density of 1.47 Mg/m^3, and an Optimum Water Content of 28.4%.

The results of the Moisture Condition Value test undertaken, indicates a range of 9.5 to 15.2, with corresponding remoulded undrained shear strengths ranging from 43.5 to 115kPa increasing with MCV.

Geotechnical Chemical Testing

The pH and Water Soluble Sulphate test results have been used to determine the stratum concrete classification, in accordance with BRE SD1 [50], Refer to Section 4.6.

4.4.7 Alluvium

Description

Most of the Alluvium encountered was fine in constituency although gravel was occasionally noted at the base. This stratum was typically described as soft or firm, light grey, brown mottled orangish brown slightly sandy slightly gravelly silty CLAY with pockets of black carbonaceous / decomposed organic material.

At the base of the stratum, grey and brown clayey sandy subangular to rounded fine to coarse flint GRAVEL was occasionally encountered. This likely represents river basal gravels and varied in thickness from 0.2 to 1m.

Thickness and Distribution

The Alluvium stratum ranged in thickness from 0.80 to 4.25m, and was on average 2.45m thick. This stratum has a localised distribution within the floodplain of Weald Brook and Ingrebourne River and typically underlies Topsoil (0.00 to 7.60m bgl; 30.45 to 38.00m OD).

Alluvium is anticipated below the Scheme at the following chainages:

- M25 NB Onslip (CH 800 to 1000);
- M25 NB Offslip Loop (CH 550 to 600 and CH 1090 to 1300); and
- A12 EB Offslip (CH 400 to 759).

Summary of Geotechnical Testing and Parameter Values

The geotechnical testing undertaken within the Alluvium and associated results has been presented in Table 4-9 below.

Table 4-9 Summary of test results within Alluvium

Test type		Units	Number of tests	Range	Average Value (Standard Deviation)	Characteristic Value	Figure reference
Water Content		%	53	8 – 43	26 (7.8)	26	01-5
Atterberg Limit	Liquid Limit	%	27	34 – 87	57 (15)	69	02-5 03-5
	Plastic Limit	%	27	18 – 31	23 (4.4)	24	
	Plasticity Index	%	27	16 - 56	35 (11.2)	45	
Modified Plasticity Index		%	-	-	-	43	-
Consistency Index		-	27	0.60 – 1.35	0.87 (0.18)	0.86	-
Particle Size Distribution		-	16	-	-	-	04-5
Organic Matter Testing	OGM	%	10	<0.1 – 4.2	2 (1.46)	-	-
	LOI	%	2	2 – 3.9	3 (1.34)	-	-
Dry Density		Mg/m^3	11	1.33 – 1.68	1.50 (0.12)	-	05-5
Bulk Density		Mg/m^3	11	1.83 – 2.00	1.91 (0.07)	-	
Bulk Weight Density		kN/m^3	-	-	-	18 - 19	-
Particle Density		Mg/m^3	3	2.59 – 2.76	2.66 (0.09)	2.66	-
Standard Penetration Tests		N_{60}	25	3 – 31	10 (6.0)	6	06-5
Undrained Shear Strength (c_u)	Derived from SPT N_{60}	kPa	25	11 - 141	36 (22)	40	07-5
	Hand Shear Vane	kPa	3	66 - 119	93 (26.5)		
	Hand Penetrometer	kPa	2	50 - 75	63 (0)		
	Unconsolidated Undrained Triaxial	kPa	6	30 - 82	67 (18.7)		
$\Phi'_{cv;k}$ derived from I_P		°	-	20 - 27	-	21	-
Φ'_{pk} derived from I_P		°	-	-	-	22	-
E' derived from SPT N_{60}		MPa	25	2 – 28	9	5	-

Test type		Units	Number of tests	Range	Average Value (Standard Deviation)	Characteristic Value	Figure reference
Coefficient of volume compressibility (m_v)	Oedometer	m^2/MN	6	0.19 – 0.45	0.27 (0.1)	0.3	09-5
	Derived from N_{60}	m^2/MN	-	-	0.32		-
	Derived from CPT	m^2/MN	3	0.2 – 0.4	-		-
Coefficient of consolidation	Oedometer	$m^2/year$	26	0.24 - 62	6 (14)	-	10-5
	C_{vh} derived from CPT	$m^2/year$	2	4.6 – 13.8	-	-	-
CBR (laboratory testing of undisturbed samples)		%	1	1.5 – 1.7	1.6 (0.14)	<2%	-
CBR derived from I_P		%	-	-	2 - 3		-
Estimated Design Sub-Grade Modulus		MPa	-	-	-	27 - 32	-
Hydraulic Conductivity – Fine (from SCPT testing)		m/s	3	$5x10^{-07}$ – $5x10^{-11}$	-	$1x 10^{-09}$ to 10^{-07}	-
Hydraulic Conductivity – Coarse (from SCPT testing)		m/s	2	$>1x10^{-05}$	-	$1x 10^{-07}$ to 10^{-03}	-
Geotechnical Chemistry Testing	pH	-	12	6.5 – 8.3	-	6.6*	-
	Water Soluble Sulphate	Mg/l	10	20 – 360	-	350*	-

* Determined in accordance with BRE SD1 [50]

Classification Testing

The Atterberg Limit test results indicate that Alluvium has a highly variable plasticity index, classifying between a low to very high plasticity clay, although generally from intermediate to very high plasticity clay. To account for the material variability a conservative characteristic I_P has been adopted.

The Modified Plasticity Index has been determined for the characteristic I_P based on the average percentage passing 425µm. This classifies the volume change potential as high for this stratum.

The water content results are highly variable from 8 to 43%, although typically in the order of 26%. When compared to the Atterberg limits, this suggests that the material predominantly behaves as a plastic material, although portions are noted as semi-plastic (water content below plastic limit). The low water content is attributed to vegetation adjacent to the sample location.

The organic content was determined through 23 no. tests; both soil organic matter and loss on ignition tests were undertaken. The samples classify either below the classification limit or as a low organic material according to BS EN ISO 14688-2

[53]. Due to the heterogenous nature of the stratum the organic content is considered likely to vary with higher organic contents anticipated locally.

The available PSD testing shows a bimodal distribution across the tested samples, which reflects the change from fine Alluvium in the upper portion to the basal river gravels. The fine portion has a fines content of over 75%, typically consistent with a slightly sandy silty CLAY. Whereas the basal gravels are consistent with a clayey sandy GRAVEL, with typically less than 20% fines. The average percentage passing 425µm for the fine portion is 96%. The PSD gradings generally correlate with the typical field descriptions for both portions, however it should be noted that the fine portion was considered slightly gravelly in the field.

Based on the bulk density results, undrained shear strength and log descriptions (in accordance with BS 8004:2015 Figure 2 [42] for soils below the groundwater table) the characteristic bulk weight density is expected to range from 18.0 to 19.0kN/m^3.

No direct measurements for Hydraulic Conductivity have been undertaken during the ground investigation, however correlations based on the SCPT results indicates that the permeability of this stratum is variable.

The fine portion ranged from 5x10^{-11} to 5x10^{-07}. This is consistent with the hydraulic conductivity based on the typical description which is anticipated to be in the region of 1x 10^{-09} to 10^{-07}m/s for a clay/silt deposit according to Barnes (2010).

The coarse portion was indicated to exceed 1x10^{-05}. Based on the typical description the permeability is anticipated to be in the region of 1x 10^{-07} to 10^{-03}m/s depending on the fines content within the stratum according to Barnes (2010).

Strength Testing

The SPT N_{60} data does not appear to show any trend with depth, and therefore an N_{60} value of 6 is considered representative; it should be noted that the strength of this stratum is variable and very soft portions are noted across the Scheme, especially within the upper 2m.

The undrained shear strength of the Alluvium has been determined using four methods as listed below:

- Correlation through N_{60} values;
- Unconsolidated undrained triaxial tests;
- Hand shear vane tests; and
- Hand penetrometer tests.

The derivation of undrained shear strength from the above listed methods indicates a variable range of values which is expected in Alluvium. The strength tests indicate that the material strength ranges from low to high strength in accordance with BS EN ISO 14688-2:2017, Table 6 [53].

The data does not present a clear trend of a change of undrained shear strength with depth; the suggested characteristic value for the undrained shear strength of Alluvium has been selected as 40kPa, this corresponds to a low/medium strength in accordance with BS EN ISO 14688-2:2017, Table 6 [53]. It should be noted that the strength of this stratum is variable and very low portions are noted across the Scheme, especially within the upper 2m.

The characteristic effective angle of friction has been determined using the equation presented within BS 8004:2015 Section 4.3.1.4.8 [42]. A conservative sitewide representative I_P of 45% was adopted with the corresponding derived $\varphi'_{cv;k}$ of 21°. It should be noted that considering the range in I_P results across the Scheme, the derived effective constant volume angle of friction ($\varphi'_{cv;k}$) may be locally higher, varying from 20 to 27°.

Values of φ'_{dil} are known to increase with a fine soil's over-consolidation, considering the normal consolidation nature stress history, a 1° φ'_{dil} component has been adopted for this stratum, resulting in a $\varphi'_{p,k}$ of 22°.

A $c'_{cv;k}$ of 0kPa is provided in accordance with BS 8004:2015 Section 4.3.1.4.9 [42].

Compressibility

The compressibility of the material is provided by the coefficient of volume compressibility m_v, during the investigation this was derived through:

- Oedometer tests;
- Correlation through N_{60} values; and
- SCPT correlations.

The m_v varies with depth / applied stress depending on method of testing. In accordance with BS1377-5 [46] the characteristic m_v for this stratum has been determined for 100kN/m^3 in excess of the effective overburden pressure. The characteristic value of 0.3m^2/MN is representative of a medium to high compressibility material in accordance with Table 2.6 of Tomlinson (2001) which is consistent with expected values for normally consolidated alluvial clays.

An area or structure specific characteristic value of m_v will need to be derived at detailed design stage once loading is confirmed.

Compaction and Re-usability

No tests undertaken.

Geotechnical Chemical Testing

The pH and Water Soluble Sulphate test results have been used to determine the stratum concrete classification, in accordance with BRE SD1 [50], Refer to Section 4.6.

4.4.8 Head - Fine

Description

The majority of the Head deposits were fine and relatively consistent in composition and strength. This stratum was typically soft to firm (occasionally stiff), brown mottled orangish brown light grey slightly sandy slightly gravelly silty CLAY. Gravel is predominantly subangular to subrounded fine to coarse flint.

A minor portion of the Head deposits comprised gravel, this has been differentiated as a separate stratum within this report.

The Head deposits are considered to comprise reworked, generally locally derived material. The mechanism for the reworking has been attributed to solifluction, hillwash and soil creep. As head deposits are formed by mass movement processes, there is a strong possibility that relict shear planes are present.

Movement may take place along these shear planes when the equilibrium of forces acting on the deposit are altered i.e. removal or addition of load / new drainage paths during proposed works. Head should be treated with caution because strength parameters may be at, or near, their residual values and relict shear planes although not identified during the 2019 GI may be present

Thickness and Distribution

The Head - Fine stratum ranged in thickness from 0.20 to 4.90m, and was on average 1.5m thick. The stratum has a widespread distribution which is generally localised to sloping ground adjacent to existing watercourses. This stratum typically underlies Topsoil or Made Ground (0.00 to 5.90m bgl; 28.4 to 55.30m OD).

Summary of Geotechnical Testing and Parameter Values

The geotechnical testing undertaken within the Head - Fine stratum has been presented in Table 4-10 below. Where the test results are variable with no clearly defined trend, characteristic values have been determined based on a cautious estimate of the mean and the published literature.

Table 4-10 Summary of test results within Head - Fine

Test type		Units	Number of tests	Range	Average Value (Standard Deviation)	Characteristic Value	Figure reference
Water Content		%	84	10 – 42	26 (6.0)	28	01-6
Atterberg Limit	Liquid Limit	%	55	38 – 90	67 (14.6)	75	02-6 03-6
	Plastic Limit	%	55	17 – 33	24 (3.9)	25	
	Plasticity Index	%	55	16 – 63	43 (11.8)	50	
Modified Plasticity Index		%	-	-	-	47	-
Consistency Index		-	55	0.69 – 1.63	0.99 (0.16)	0.97	-
Particle Size Distribution		-	24	-	-	-	04-6
Organic Matter Testing	OGM	%	1	-	0.3	-	-
Dry Density		Mg/m^3	13	1.35 – 1.66	1.43 (0.09)	-	05-6
Bulk Density		Mg/m^3	13	1.73 – 2.00	1.86 (0.09)	-	
Bulk Weight Density		kN/m^3	-	-	-	17 - 20	-

Test type		Units	Number of tests	Range	Average Value (Standard Deviation)	Characteristic Value	Figure reference
Particle Density		Mg/m^3	2	2.6 – 2.62	2.61 (0.01)	2.61	-
Standard Penetration Test		N_{60}	25	3 – 24	14 (7.0)	10	06-6
Undrained Shear Strength	Derived from SPT N_{60}	kPa	25	11 - 110	63 (31.5)	60	07-6
	Hand Shear Vane	kPa	11	62 – 124	91 (21.0)		
	Hand Penetrometer	kPa	70	23 – 200	93 (36.4)		
	Unconsolidated Undrained Triaxial	kPa	11	44 - 220	89 (50.5)		
$\Phi'_{cv;k}$ derived from I_P		°	-	19.5 - 27	-	21	-
Φ'_{pk} derived from I_P		°	-	-		21	-
Φ'_r derived from I_P & Clay fraction		°	-	-	-	10	-
E' derived from SPT N_{60}		MPa	25	2.7 – 21.6		5	-
Coefficient of volume compressibility	Oedometer	m^2/MN	3	0.13 – 0.36	0.20 (0.12)	0.2	09-6
	derived from N_{60}	m^2/MN	-	-	0.19		-
	derived from CPT	m^2/MN	1	0.05	-		-
Coefficient of consolidation from Oedometer		m^2/ year	3	0.21 – 13	0.6 (3.6)	-	10-6
Compaction (2.5 kg rammer)	MDD	Mg/m^3	4	1.52 – 1.77	1.63 (0.09)	-	11-6
	OWC	%	4	19 – 25	22 (2.6)	-	
Moisture Condition Value MCV	MCV	-	5	5.1 – 17.9	-	-	
	Remoulded c_u	kPa	25	39 - >150	-	-	-
DCP result (typical penetration)		mm/ blow	12	12 – 56	26 (16.7)	40	12-6/7
CBR derived from DCP		%	-	-	6	2 – 2.5	-
CBR (laboratory testing of undisturbed samples)		%	1	3.8 – 4.4	4.1 (0.42)		-
CBR derived from I_P		%	-	-	2 – 2.5		-

Test type		Units	Number of tests	Range	Average Value (Standard Deviation)	Characteristic Value	Figure reference
Estimated Design Sub-Grade Modulus		MPa	-	-	-	27 - 32	-
Hydraulic Conductivity		m/s	-	-	-	1x 10^{-07} to 10^{-09}	-
Geotechnical Chemistry Testing	pH	-	12	5.4 – 8.4	-	6.4*	-
	Water Soluble Sulphate	Mg/l	11	20 – 1600	-	1110*	-

* Determined in accordance with BRE SD1 [50].

Classification Testing

The Atterberg Limit test results indicate the Head - Fine has a highly variable plasticity index, classifying between an intermediate to very high plasticity clay. Two results indicate an intermediate to high plasticity silt although the results are situated close to the A-line. The results indicate a bi-modal distribution with the majority of the results classifying as high and very high plasticity clay, whereas there is a second portion of results at the boundary between an intermediate and high plasticity clay. Based on the available testing the characteristic I_P was conservatively determined for the predominant higher plasticity data group.

The Modified Plasticity Index has been determined for the characteristic I_P based on the average percentage passing 425µm. This classifies the volume change potential as high for this stratum.

The water content results are highly variable from 10 to 42%; although are typically in the order of 25 to 30%. When compared to the Atterberg limits, this suggests that material predominantly behaves as a plastic material, although portions notably at a shallow depth are noted as semi-plastic (water content below plastic limit). The low water content is attributed to vegetation adjacent to the sample location.

The organic content was determined through one organic matter test. The result is below the classification limit according to BS EN ISO 14688-2 [53]. Due to the heterogenous nature of the stratum the organic content is considered likely to vary with higher organic contents anticipated locally, although the contents are considered to be typically low.

The available PSD testing shows a reasonably consistent distribution across the tested samples, with a fines content varying from 55 to 100%, although typically above 80%. The average percentage passing 425µm is 94% and 2µm is 55% (for residual effective angle of shearing resistance correlations). The material typically classifies as a slightly sandy slightly gravelly silty CLAY, although a minor portion appear to comprise clayey SILT. The results of the PSD tests appear to correlate with the typical field descriptions.

Based on the bulk density results and undrained shear strength and log descriptions (in accordance with BS 8004:2015 Figure 2 [42] for soils below the groundwater table) the characteristic bulk weight density is expected to range from 17.0 to 20.0kN/m^3.

No direct measurements for Hydraulic Conductivity have been undertaken during the ground investigation. However, soakaway tests which measure infiltration rate were undertaken; these can be considered a proxy for permeability although not directly comparable. The tests indicated that there was insufficient water infiltration to calculate the rate, suggesting that the hydraulic conductivity is low. The anticipated hydraulic conductivity based on the typical description is anticipated to be in the region of 1x 10^{-07} to 10^{-09}m/s for a stratified clay/silt deposit according to Barnes (2010).

Strength Testing

The SPT N60 data does not appear to show any trend with depth, and therefore an N60 value of 10 is considered representative; it should be noted that the strength of this stratum is variable and very soft portions are noted across the Scheme, especially within the upper 3m.

The undrained shear strength of the Head – Fine stratum has been determined using four methods as listed below:

- Correlation through N_{60} values;
- Unconsolidated undrained triaxial tests;
- Hand shear vane tests; and
- Hand penetrometer tests.

The derivation of undrained shear strength from the above listed methods indicates a variable range of values which is expected in Head deposits. The strength tests indicate that the material strength ranges from low to very high strength in accordance with BS EN ISO 14688-2:2017, Table 6 [53]. Soft portions were encountered across GM-05, possibly due to the lower tree cover and higher water content within the stratum.

The suggested characteristic undrained shear strength based on the available information is 60 kPa. This corresponds to a medium undrained shear strength in accordance with BS EN ISO 14688-2:2017, Table 6 [32]. it should be noted that the strength of this stratum is variable with very low to low strength portions noted across the Scheme, especially within the upper 3m.

The characteristic effective angle of friction has been determined using the equation presented within BS 8004:2015 Section 4.3.1.4.8 [42]. A conservative sitewide representative I_P of 50% was adopted with the corresponding derived $\varphi'_{cv;k}$ of 21°. It should be noted that considering the range in I_P results across the Scheme, the derived effective constant volume angle of friction ($\varphi'_{cv;k}$) may be locally higher, varying from 19.5 to 27°.

Considering the normal consolidation nature of the material and possible reworking, 0° φ'dil component has been adopted for this stratum, resulting in a $\varphi'_{p,k}$ of 21°.

The head deposits are considered to comprise reworked material which has the potential to contain relict shear surfaces. These surfaces are likely to be at residual shear strength. Estimations for residual shearing resistance based on I_P and clay fraction indicate a φ'_r of 10° based on Figure 11.3 of Nowak and Gilbert (2015).

A characteristic constant volume effective cohesion ($c'_{cv;k}$) of 0 kPa is provided in accordance with BS 8004:2015 Section 4.3.1.4.9 [42].

Compressibility

The compressibility of the material is provided by the coefficient of volume compressibility, during the investigation this was derived through:

- Oedometer tests;
- Correlation through N_{60} values; and
- CPT correlations.

The m_v varies with depth / applied stress depending on method of testing. In accordance with BS1377-5 [46], the characteristic m_v for this stratum has been determined for 100kN/m^3 in excess of the effective overburden pressure. The characteristic value of 0.2m^2/MN is representative of a medium compressibility material in accordance with Table 2.6 of Tomlinson (2001).

An area or structure specific characteristic value of m_v will need to be derived at detailed design stage once loading is confirmed.

Compaction and Re-usability

The 2.5kg rammer compaction tests indicated a Maximum Dry Density from 1.52 to 1.77Mg/m^3, and an Optimum Water Content of between 19 to 25.4%.

The results of the Moisture Condition Value test undertaken, indicates a range of 5.1 to 17.9, with corresponding remoulded undrained shear strengths ranging from 39 to over 150 kPa increasing with MCV.

Geotechnical Chemical Testing

The pH and Water Soluble Sulphate test results have been used to determine the stratum concrete classification, in accordance with BRE SD1 [50], Refer to Section 4.6.

4.4.9 Head - Coarse

Description

A minor portion of the Head deposits were coarse in composition, described as brown slightly clayey to clayey sub angular to rounded fine to coarse flint GRAVEL with occasional low subangular flint cobble content.

Thickness and Distribution

The Head – Coarse stratum ranged in thickness from 0.10 to 1.50m and was on average 0.60m thick. The stratum has a Localised distribution to the southwest of the Scheme, adjacent to A12. This stratum typically underlies Topsoil or Head - Fine deposits (0.15 to 2.00m bgl; 31.25 to 44.5m OD).

Summary of Geotechnical Testing and Parameter Values

The geotechnical testing undertaken within the Head – Coarse stratum has been presented in Table 4-11 below. Where the test results are variable with no clearly defined trend, characteristic values have been determined based on a cautious estimate of the mean and the published literature.

Table 4-11 Summary of test results within Head – Coarse

Test type	Units	Number of tests	Range	Average Value (Standard Deviation)	Characteristic Value	Figure reference
Particle Size Distribution	-	5	-	-	-	04-7
Bulk Weight Density	kN/m^3	-	-	-	19 - 21	-
$\Phi'_{cv;k}$	°	-	-	-	32	-
DCP result (typical penetration)	mm/blow	2	1.9-69	14.7 (16.5)	15	-
CBR derived from DCP	%	-	-	17	15	-
CBR derived from Grading	%	-	-	60		-
Hydraulic Conductivity	m/s	-	-	-	1x 10^{-07} to 10^{-05}	-

Classification Testing

The PSD testing within the Head – Coarse stratum indicates similar fines contents across the tested samples, however the coarse content was highly variable. The fines content was noted at between 12 to 30%, whereas the sand content varied from 3 to 48% and gravel from 27 to 82%

The material is generally consistent with a clayey very sandy GRAVEL, although the composition varies between clayey to very clayey and slightly sandy to very sandy. The gradings are consistent with the variation within the field descriptions. Due to the variability, the coefficient of curvature and uniformity coefficients could not be determined. The gradings appear to vary between evenly graded, multi-graded and gap graded.

Based on the log descriptions (in accordance with BS 8004:2015 Figure 2 [42] for soils below the groundwater table) the characteristic bulk weight density is expected to range from 19 to 21kN/m^3.

No direct measurements for Hydraulic Conductivity have been undertaken during the ground investigation. However, soakaway tests were undertaken which can be considered a proxy for permeability although not directly comparable. The tests indicated that there was insufficient water infiltration to calculate the rate, suggesting that the hydraulic conductivity is low.

The anticipated hydraulic conductivity based on the typical description is anticipated to be in the region of 1x 10^{-07} to 10^{-05}m/s for a silty sand deposit according to Barnes (2010). This is significantly lower than a clean gravel and is likely due to the clay content within the stratum reducing the hydraulic conductivity.

Strength Testing

The $\varphi'_{cv,k}$ has been determined using the equation presented within BS 8004:2015 Section 4.3.1.3.5 [42]. Taking representative contributions to $\varphi'_{cv,k}$ of: φ'_{ang} of 2° (sub-angular to sub-rounded) and φ'_{PSD} of 0° (as gradings variable between evenly graded, multi-graded and gap graded). $\varphi'_{cv;k}$ is therefore considered to be 32°.

As the fines content typically exceeds 15% the $\varphi'_{pk,k}$ was not be determined.

The Calculated Bearing Ratio derived from DCP and grading exceeds 15%, therefore as per Interim Advice Note 73/06 [51] the design value was stated as 15%. The estimated subgrade surface modulus could not be determined as the CBR value exceeds the valid range.

4.4.10 Weathered London Clay Formation

Description

The London Clay Formation has been differentiated into weathered and non-weathered portions based on the borehole stratum descriptions.

Weathered London Clay was typically described as firm becoming stiff brown mottled orangish brown (occasionally closely fissured) silty CLAY with rare pockets of orangish brown silty fine sand and frequent selenite crystals (1 to 15mm). The orangish brown silty fine sand pockets were more frequent at the top of the stratum indicating that Scheme is located near the boundary of the overlying Claygate Member consistent with the Published Geological Record (see Section 2.2).

Thickness and Distribution

The Weathered London Clay Formation ranged in thickness from 1.20 to 10.37m, and has an average thickness of 5.60m. The stratum was encountered across the whole study area, underlying Topsoil, Made Ground, Alluvium or Head deposits (0.00 to 9.60m bgl; 26.20 to 54.83m OD).

Summary of Geotechnical Testing and Parameter Values

The geotechnical testing undertaken within the Weathered London Clay Formation is presented in Table 4-12 below. Where the test results are variable with no clearly defined trend, characteristic values have been determined based on a cautious estimate of the mean and the published literature.

Table 4-12 Summary of test results within Weathered London Clay Formation

Test type		Units	Number of tests	Range	Average Value (Standard Deviation)	Characteristic Value	Figure reference
Water Content		%	350	5.2 – 40.8	30 (4.4)	30	01-8
Atterberg Limit	Liquid Limit	%	147	39 – 101	75* (7.2)*	77	02-8 03-8
	Plastic Limit	%	147	18 – 48	26* (2.4)*	27	
	Plasticity Index	%	147	17 – 72	49* (5.6)*	50	
Modified Plasticity Index		%	-	-	-	50	-
Consistency Index		-	147	0.54 – 2.24	1.00 (0.21)	0.96	-
Particle Size Distribution		-	23	-	-	-	04-8
Organic Matter Testing	OGM	%	9	<0.1 – 1.2	0.4 (0.45)	-	-
Dry Density		Mg/m^3	103	1.32 – 1.71	1.45 (0.07)	1.45	05-8
Bulk Density		Mg/m^3	103	1.79 – 2.05	1.9 (0.05)	1.9	
Bulk Weight Density		kN/m^3	-	-	-	18 – 20	-
Particle Density		Mg/m^3	8	2.63 – 2.72	2.66 (0.03)	2.66	-
Standard Penetration Tests		N_{60}	115	6 – 77	20 (10.2)	11+1d	06-8 06-8/9
Undrained Shear Strength	Derived from SPT N_{60}	kPa	115	27 - 347	90 (47.2)	40+4.5d	07-8 07-8/9
	Hand Shear Vane	kPa	41	63 – 145	107 (22.0)		
	Hand Penetrometer	kPa	83	75 – 200	120 (27.0)		
	Unconsolidated Undrained Triaxial	kPa	121	27 – 361	106 (53.1)		
$\Phi'_{cv,k}$ derived from I_P		°	-	19 - 27	-	21	-
$\Phi'_{p,k}$ derived from I_P		°	-	-	-	23	-
Consolidated Undrained Triaxial	Φ_{pk}'	°	16	-	23		08-8
	c'	kPa	16	-	11.1	3	

Test type		Units	Number of tests	Range	Average Value (Standard Deviation)	Characteristic Value	Figure reference
E' derived from SPT N_{60}		MPa	115	5 – 69	18 (9.4)	10	-
Coefficient of volume compressibility	Oedometer**	m^2/MN	30	0.06 – 0.32	0.14 (0.07)	0.15	09-8
	derived from SPT N_{60}	m^2/MN	-	0.1 – 0.2	-		-
	derived from CPT	m^2/MN	6	0.05 - 0.22	0.1 - 0.2		-
Coefficient of consolidation from Oedometer	All Data	m^2/ year	94	0.17 – 14	1.6 (2.6)	-	10-8
	Recompression curve		17	0.33 – 8	2.1 (2.7)	-	
	Primary Consolidation		18	0.17 – 0.39	0.3 (0.07)	0.3	
C_{vh} derived from CPT		m^2/ year	1	-	1.3	-	-
Compaction (2.5 kg rammer)	MDD	Mg/m^3	4	1.41 – 1.61	1.53 (0.09)	-	11-8
	OWC	%	4	23 - 31	26.1 (3.4)	-	
Moisture Condition Value MCV	MCV	-	5	1 - 17	-	-	
	Remoulded c_u	kPa	25	26 - >150	-	-	-
DCP result (typical penetration)		mm/ blow	12	4 – 69	21 (9.8)	25	12-8
CBR derived from DCP		%	-	-	10	2 – 2.5	-
CBR (laboratory testing of undisturbed samples)		%	9	5.1 – 11	7.3 (1.6)		-
CBR derived from I_P		%	-	-	2 – 2.5		-
Estimated Design Sub-Grade Modulus		MPa	-	-	-	27 – 32	-
Hydraulic Conductivity		m/s	3	$5x10^{-09}$ – $1x10^{-07}$	-	$1x10^{-08}$ to $1x10^{-07}$	-
Geotechnical Chemistry Testing	pH	-	30	6.6 -8.2	-	6.9***	-
	Water Soluble Sulphate	Mg/l	17	100 - 4050	-	3883***	-

'd' denotes per metre below ground level
* Mean and Standard Deviation consider 2019 GI results only due to high variability within historical results.
** m_v values determined from loading only, not including results derived through unload reload tests.
***Determined in accordance with BRE SD1 [50]

Classification Testing

The Atterberg Limit test results indicate that Weathered London Clay has a reasonably consistent plasticity, classifying principally as a very high plasticity clay, with a minor portion as a high plasticity clay. The historical ground investigation results show significantly more variation than the 2019 GI data, with low to extremely high plasticity results indicated and seven results classifying as a high to very high plasticity silt. Due to the significant variation in results which could be due to changes in testing methods or poor sample quality assurance outside of this Schemes control, the characteristic plasticity has been determined based on the Scheme specific ground investigation results only.

The Modified Plasticity Index has been determined for the characteristic I_P based on the average percentage passing 425µm. This classifies the volume change potential as high for this stratum.

The water content results are reasonably consistent with depth, typically in the order of 25 to 35%. When compared to the Atterberg limits, this suggests the material predominantly behaves as a plastic material, although portions notably at a shallow depth are noted as semi-plastic (water content below plastic limit). The low water content attributed to vegetation adjacent to sample location.

The organic content was determined from nine organic matter tests. The results are below the classification limit according to BS EN ISO 14688-2 [53]. Due to the homogeneous nature of the stratum the organic content is considered to absent or very low with rare pseudo fibrous rootlets encountered.

The available PSD testing shows a consistent gradings distribution across the tested samples. The fines content varied from 90 – 100%, of which 35 – 50% (average 41%) comprised silt and 46 – 64% (average 55%) comprised clay. The average % passing 425µm is 99%. Whereas the coarse content varied from 0 – 10% generally comprising sand, with 5 samples indicating 1-2% gravel attributed to selenite crystals or rare claystone within the stratum. The stratum is consistent with a slightly sandy silty CLAY, this is comparable to the typical field description.

Based on the bulk density results, undrained shear strength and log descriptions (in accordance with BS 8004:2015 Figure 2 [42] for soils below the groundwater table) the characteristic bulk weight density is expected to range from 18 to 20kN/m^3.

No direct measurements for Hydraulic Conductivity have been undertaken during the ground investigation, however correlations based on the CPT results indicates that the permeability of this stratum ranges from 5x10^{-09} to 1x10^{-07}m/s although is typically in the order of 1x10^{-08} to 1x10$^{-07m/s}$. This is consistent with the anticipated hydraulic conductivity of 1x10^{-09} to 10^{-07}m/s for a clay/silt based on the typical description, modified by the effects of fissuring and weathering, as per Barnes (2010).

Strength Testing

The SPT N_{60} data shows a trend of increasing strength with depth, with a characteristic trendline of 11 + 1d, where d is depth below ground level (extrapolated to 10m depth). This trend indicates that the material strength is typically firm (at a shallow depth) increasing linearly to stiff with depth. It should be noted that the strength is variable at a shallow depth with several soft localised portions noted.

The undrained shear strength of the Weathered London Clay Formation has been determined using four methods as listed below:

- Correlation through N_{60} values;
- Unconsolidated undrained triaxial tests;
- Hand shear vane tests; and
- Hand penetrometer tests.

The derivation of undrained shear strength from the above listed methods indicate a variable range of values from low to very high strength in accordance with BS EN ISO 14688-2:2017, Table 6 [53]. The results show softening at a shallow depth where the stratum has been exposed to greater weathering notably where present at the base of Alluivum (GM-01), Made Ground – Landfill (GM-03) and at localised areas below Head Deposits (GM-05).

The data presents a trend of increasing undrained shear strength with depth; the suggested characteristic trendline for the undrained shear strength of Head has been selected as 40+4.5d kPa, where d is depth below ground level (extrapolated to 12m depth). This corresponds to a medium strength increasing to high strength with depth in accordance with BS EN ISO 14688-2:2017, Table 6 [53].

The peak effective angle of shearing resistance was determined through single stage consolidated undrained triaxial tests. A trendline through the results indicates an effective cohesion of 11kPa and slope gradient which equates to a peak effective angle of shearing resistance of 23°. The result from the tested core sample was not included in determining the trendline as it appeared to skew the data slightly, increasing the slope gradient. The core samples appear to provide inconsistent results and therefore, the validity of this data has been carefully considered.

The characteristic effective angle of friction has been determined using the equation presented within BS 8004:2015 Section 4.3.1.4.8 [42]. Taking a representative I_P of 50%, the derived $\varphi'_{cv;k}$ is 21°. Values of φ'_{dil} are known to increase with a fine soil's over-consolidation, therefore 2° φ'_{dil} component has been adopted for this stratum, resulting in a φ'_{pk} of 23°.

Considering the test results, engineering judgement and published literature, a characteristic peak effective angle of friction of 23° and 3kPa effective cohesion has been adopted for this stratum.

A $c'_{cv;k}$ of 0kPa is provided in accordance with BS 8004:2015 Section 4.3.1.4.9 [42].

Compressibility

The oedometer test results indicate that the stratum is overconsolidated, meaning that the present *in situ* effective stress is lower than a previous stress.

The compressibility of the material is provided by the coefficient of volume compressibility m_v, during the investigation this was derived through:

- Oedometer tests;
- Correlation through N_{60} values; and
- SCPT correlations.

The m_v varies with depth / applied stress depending on method of testing. In accordance with BS1377-5 [46] the characteristic mv for this stratum has been determined for 100kN/m^3 in excess of the effective overburden pressure. The characteristic value of 0.15m^2/MN is representative of a medium compressibility material in accordance with Table 2.6 of Tomlinson (2001) and consistent with expected values for Weathered London Clay Formation.

An area or structure specific characteristic value of m_v will need to be derived at detailed design stage once loading is confirmed.

Compaction and Re-usability

The 2.5kg rammer compaction tests indicated a Maximum Dry Density of between 1.41 and 1.61Mg/m^3, and an Optimum Water Content of between 23 to 31%.

The results of the Moisture Condition Value test undertaken, indicates a range of 1 to 17, with corresponding remoulded undrained shear strengths ranging from 26 to over 150 kPa increasing with MCV.

Geotechnical Chemical Testing

The pH and Water Soluble Sulphate test results have been used to determine the stratum concrete classification, in accordance with BRE SD1 [50], Refer to Section 4.6.

4.4.11 London Clay Formation

Description

The non-weathered London Clay Formation was typically described as stiff or very stiff thinly laminated fissured greyish brown (with occasional bluish grey mottling) silty CLAY with rare selenite crystals (from 1 to 25mm). The fissures were generally described as between 40 and 70 degrees, very closely spaced, planar and undulating, smooth and slightly polished.

Thickness and Distribution

The total thickness of the London Clay Formation is unproven from the available ground investigation information, the maximum thickness encountered 31.75m (to a depth of 40.75m bgl and a level of -5.8m OD. The London Clay Formation was encountered underlaying the Weathered London Clay Formation across the whole study area (2.00 to 13.60m; 22.05 to 46.58m OD).

Summary of Geotechnical Testing and Parameter Values

The geotechnical testing undertaken within the London Clay Formation is presented in Table 4-13 below. Where the test results are variable with no clearly defined trend, characteristic values have been determined based on a cautious estimate of the mean and the published literature.

Table 4-13 Summary of test results within London Clay Formation

Test type		Units	Number of tests	Range	Average Value (Standard Deviation)	Characteristic Value	Figure reference
Water Content		%	331	24 – 38	30 (2.6)	30	01-9
Atterberg Limit	Liquid Limit	%	79	43 – 102	80 (7.5)	80	02-9 03-9
	Plastic Limit	%	79	18 – 54	28 (4)	28	
	Plasticity Index	%	79	25 – 69	52 (6.2)	52	
Modified Plasticity Index		%	-	-	-	52	-
Consistency Index		-	79	0.6 – 1.63	0.98 (0.14)	0.96	-
Particle Size Distribution		-	15	-	-	-	04-9
Organic Matter Testing	OGM	%	6	<0.1 – 0.25	0.16 (0.06)	-	-
Dry Density		Mg/m^3	186	1.13 – 1.78	1.48 (0.08)	1.48	05-9
Bulk Density		Mg/m^3	186	1.49 – 2.34	1.93 (0.09)	1.93	
Bulk Weight Density		kN/m^3	-	-	-	19 - 21	-
Particle Density		Mg/m^3	1	-	2.7	-	-
Standard Penetration Tests		N_{60}	200	14 – 66	32 (10.5)	11+1*d*	06-9
Undrained Shear Strength	Derived from SPT N_{60}	kPa	200	64 - 297	142 (47.0)	40+4.5*d*	07-9
	Hand Shear Vane	kPa	26	70 – 146	117 (18.2)		
	Unconsolidated Undrained Triaxial	kPa	172	23 – 335	103 (46.0)		
$\Phi'_{cv;k}$ derived from I_P		°	-	19 - 22	-	21	-
Φ'_{pk} derived from I_P		°	-	-	-	23	-
Consolidated Undrained Triaxial	Φ_{pk}'	°	15	-	21		08-9
	c'	kPa	15	-	14	3	
E' derived from SPT N_{60}		MPa	200	13 – 60	28 (9.4)	10+1*d*	-

Test type		Units	Number of tests	Range	Average Value (Standard Deviation)	Characteristic Value	Figure reference
Coefficient of volume compressibility	Oedometer	m²/MN	28	0.8 – 0.24	0.13 (0.04)	0.15	09-9
	Derived from SPT N_{60}	m²/MN	-	0.007 – 0.2	-		
	Derived from CPT	m²/MN	6	0.06 – 0.12	0.06 – 0.1		
Coefficient of consolidation from Oedometer	All data	m²/ year	80	0.062 – 6.8	0.72 (1.2)	-	10-9
	Recompression curve		21	0.18 – 6.8	1.3 (2)	-	
	Primary Consolidation		30	0.2 – 0.45	0.31 (0.07)	0.31	
Hydraulic Conductivity		m/s	3	$1x10^{-09}$ to $5x10^{-08}$	-	$1x10^{-09}$ to $5x10^{-08}$	-
Geotechnical Chemistry Testing	pH	-	22	6.8 -9.5	-	7.1*	-
	Water Soluble Sulphate	Mg/l	18	188 - 1200	-	1180*	-

'd' denotes per metre below ground level

* *Determined in accordance with BRE SD1* [50]

Classification Testing

The Atterberg Limit test results indicate that the (unweathered) London Clay Formation has a consistent plasticity, principally classifying as a very high plasticity clay.

The Modified Plasticity Index has been determined for the characteristic I_P based on the average percentage passing 425µm. This classifies the volume change potential as high for this stratum.

The water content results are reasonably consistent with depth typically in the order of 26 to 34%. When compared to the Atterberg limits, this suggests that the material is situated at and in some cases below the plastic limit, with some material behaving as semi-plastic.

The organic content was determined through six organic matter tests. The results are below the classification limit according to BS EN ISO 14688-2 [53]. Due to the homogeneous nature of the stratum the organic content is considered to absent or very low with rare pseudo fibrous rootlets encountered.

The available PSD testing shows a consistent gradings distribution across the tested samples. The fines content varied from 93 to 100%, of which 37 to 52% (average 42%) comprised silt and 45 to 63% (average 56%) comprised clay. The average percentage passing 425µm is 100%. Whereas the coarse content varied from 0 to 7% generally comprising fine sand, with 35 no. samples indicating 1 to 2% gravel attributed to selenite crystals or rare claystone within the stratum. The stratum is consistent with a slightly sandy silty CLAY, which is similar to the field stratum description although the sand content was delineated in the field.

Considering the dry and bulk density is based on the testing of core samples which are considered to have degraded through swelling prior to testing, the characteristic weight density is based primarily on the undrained shear strength and log descriptions. In accordance with BS 8004:2015 Figure 2 [42] for soils below the groundwater table the characteristic bulk weight density is expected to range from 19 to 21kN/m^3.

No direct measurements for Hydraulic Conductivity have been undertaken during the ground investigation, however correlations based on the SCPT results indicate that the permeability of this stratum is in the order of 1x 10^{-09} to 5x10^{-08}m/s. This is consistent with the anticipated hydraulic conductivity based on the typical description; this is anticipated to be in the region of 1x 10^{-09} to 10^{-07} m/s for a typical stratified clay/silt deposit modified by the effects of fissuring according to Barnes (2010).

Strength Testing

The SPT N_{60} data shows a trend of increasing strength with depth, with a characteristic trendline of 11 + 1d, where d is depth below ground surface (extrapolated to 30m depth). This trend indicates that the material strength is typically firm (at a shallow depth) increasing linearly to very stiff with depth.

The undrained shear strength of the London Clay Formation stratum has been determined using three methods as listed below:

- Correlation through N_{60} values;
- Unconsolidated undrained triaxial tests; and
- Hand shear vane tests.

The derivation of undrained shear strength from the above listed methods indicates a variable range of values. This is not anticipated for this stratum which is generally shows an increase in strength with depth. The unconsolidated undrained triaxial tests for this stratum were typically undertaken from core samples as the material was too stiff for UT100s to be undertaken without significant disturbance. The results from testing the core samples were significantly lower than anticipated, this was attributed to sample degradation due to the length of time between sampling and testing which allowed the sample to swell and weaken.

Therefore, the characteristic undrained shear strength for this stratum is primarily based on the results from historical undrained triaxial test, correlation through N_{60} values and *in situ* hand shear vane tests. The data presents a trend of increasing undrained shear strength with depth; the suggested characteristic trendline for the undrained shear strength of Head has been selected as 40+4.5*d* kPa, where *d* is depth below ground level (extrapolated to 30m depth). Which corresponds to an increase in material strength from medium to very high strength in accordance with BS EN ISO 14688-2:2017, Table 6 [53].

The peak effective angle of shearing resistance was determined through single stage consolidated undrained triaxial tests. A trendline through the results indicates an effective cohesion of 14kPa and slope gradient which equates to a φ'_{pk} of 21°. The results from testing the core samples were significantly lower than anticipated, this was attributed to sample degradation due to the length of time between sampling and testing which allowed the sample to swell and weaken.

The characteristic effective angle of friction has been determined using the equation presented within BS 8004:2015 Section 4.3.1.4.8 [42]. Taking a representative I_P of 52%, the derived $\varphi'_{cv;k}$ is 21°. Values of φ'_{dil} are known to increase with a fine soil's over-consolidation, therefore a 2° φ'_{dil} component has been adopted for this stratum, resulting in a φ'_{pk} of 23°.

Considering the test results, engineering judgement and published literature a characteristic peak effective angle of friction of 23° and 3kPa effective cohesion has been adopted for this stratum.

A characteristic constant volume effective cohesion ($c'_{cv;k}$) of 0kPa is provided in accordance with BS 8004:2015 Section 4.3.1.4.9 [42].

Compressibility

The oedometer test results indicate that the stratum is over-consolidated, that the present *in situ* effective stress is lower than previous stresses.

The compressibility of the material is provided by the coefficient of volume compressibility m_v, during the investigation this was derived through:

- Oedometer tests;
- Correlation through N_{60} values; and
- SCPT correlations.

The m_v varies with depth / applied stress depending on method of testing. In accordance with BS1377-5 [46], the characteristic m_v for this stratum has been determined for 100kN/m^3 in excess of the effective overburden pressure. The characteristic value of 0.15 m^2/MN is representative of a medium compressibility material in accordance with Table 2.6 of Tomlinson (2001) and is consistent with expected values for the London Clay Formation.

An area or structure specific characteristic value of m_v will need to be derived at detailed design stage once loading is confirmed.

Compaction and Re-usability

No testing undertaken as material as stratum considered too deep to be encountered within proposed cutting earthworks. The stratum is only anticipated to be encountered within piled foundations.

Geotechnical Chemical Testing

The pH and Water Soluble Sulphate test results have been used to determine the stratum concrete classification, in accordance with BRE SD1 [50], Refer to Section 4.6.

4.5 Ground Models

4.5.1 Introduction

The Scheme was separated into seven key ground models (GM) on an area and ground specific basis following the 2019 ground investigation, these are shown in Figure 4-1 and outlined below; further detail is presented in Section 4.5 of this report and corresponding cross-sections are provided in Appendix F. It should be noted that a series of ground models was determined during the preliminary design stage on an alignment specific basis:

- GM-01 - Northern M25
- GM-02 - Central M25
- GM-03 - Grove Farm
- GM-04 - Alder Wood & Weald Brook
- GM-05 – Glebelands
- GM-06 - A12 & Ingrebourne River
- GM-07 - junction 28

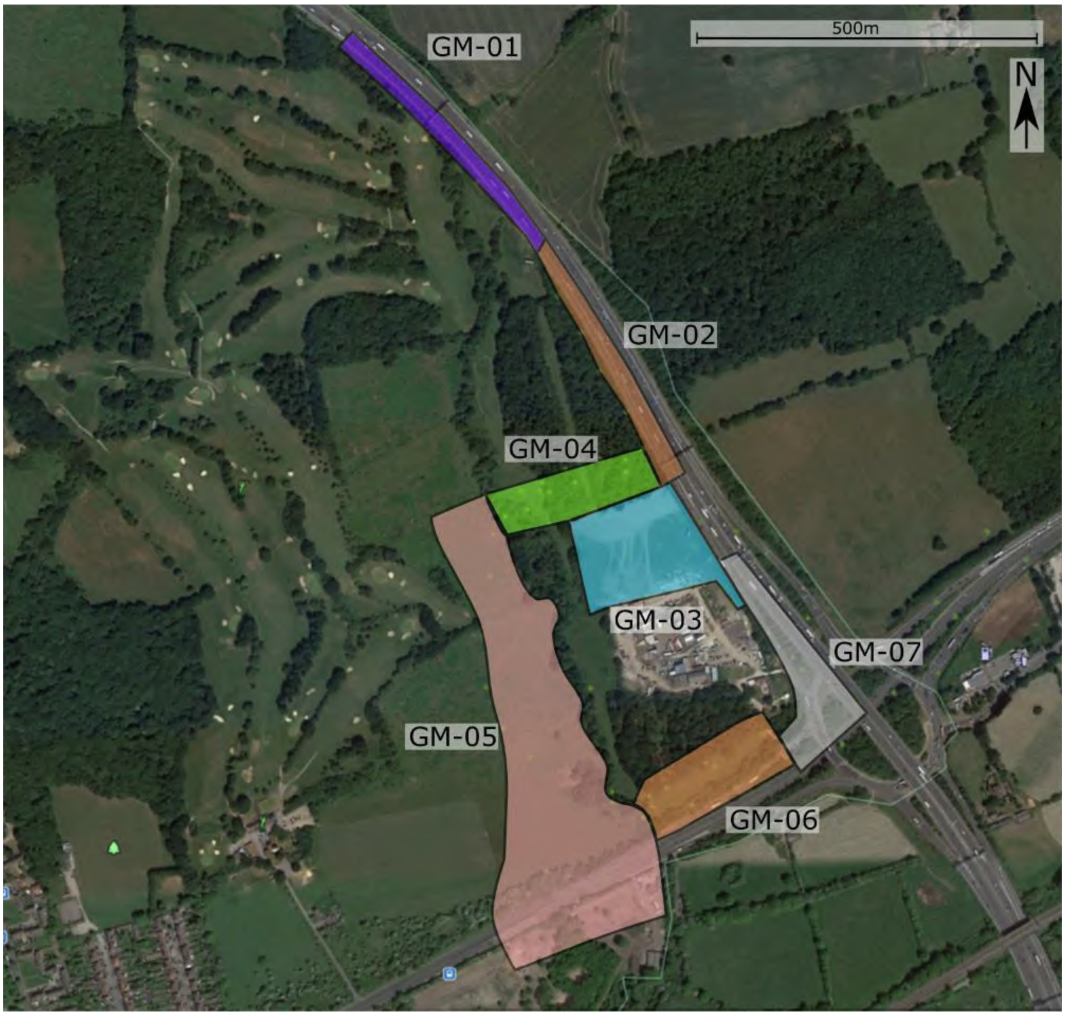

Figure 4-1 GIR Ground Model location plan (based on Google Earth [12])

It should be noted that a series of ground models (TNxx) was determined during the preliminary design stage on an alignment specific basis [55], these do not directly correlate to the ground models outlined above.

Table 4-14 Summary of ground models

Name	Location	Chainage		Corresponding Preliminary Design stage TN series ground model	Corresponding Section Drawing
		Range	Chainage Scheme		
GM-01	Northern M25	800 to 1250	M25 Northbound (NB) On-Slip	TN02 (northern section)	HE551519-ATK-HGT-XX-DR-CE-001005
GM-02	Central M25	350 to 800	M25 NB On-Slip	TN02 (southern section)	HE551519-ATK-HGT-XX-DR-CE-001005 & 001004
GM-03	Grove Farm	100 to 350	M25 NB On-Slip	TN01 & TN03 (eastern section)	HE551519-ATK-HGT-XX-DR-CE-001002
		200 - 350	M25 NB Off-Slip Loop		
GM-04	Alder Wood & Weald Brook	350 to 610	M25 NB Off-Slip Loop	TN03 (central section)	HE551519-ATK-HGT-XX-DR-CE-001002
GM-05	Glebelands	610 to 1090	M25 NB Off-Slip Loop	TN03 (western section), TN04 (northern section) & TN05 (western section)	HE551519-ATK-HGT-XX-DR-CE-001003
		0 to 400	A12 eastbound (EB) Off-Slip		
GM-06	A12 & Ingrebourne River	1090 to 1370	M25 NB Off-Slip Loop	TN04 (southern section) TN05 (central/eastern section)	HE551519-ATK-HGT-XX-DR-CE-001001 & 001003
		400 to 700	A12 EB Off-Slip		
GM-07	junction 28	0 to 200, & 1370 to 1450	M25 NB Off-Slip Loop	TN01 (southern section) TN05 (central/eastern section)	HE551519-ATK-HGT-XX-DR-CE-001001, 001002 & 001004
		700 to 759	A12 EB Off-Slip		

4.5.2 GM-01 – Northern M25

Description of Extent

GM-01 is located at the northern extent of the Scheme on the proposed M25 NB On-Slip realignment (chainage (CH) 800 to 1250). The M25 in this section is largely situated on an embankment crossing a valley where a flood plain and the Weald Brook are present. A Summary of the ground conditions is included in Table 4-15 below and the section line is shown on Drawing HE551519-ATK-HGT-XX-DR-CE-001005 in Appendix F.

The embankment height is in the order of 3m, although the base of the Engineered Fill stratum has not been determined, therefore the extent embankment construction into the underlying Alluvium it is not known. The presence of Head deposits have been identified locally on the valley sides, including below the road construction. The bedrock, London Clay Formation, is present throughout the section varying in depth below Topsoil, Made Ground – Engineered Fill, Alluvium and Head; the weathered horizon of the London Clay Formation extends consistently across the area to approximately 30m AOD.

Made Ground – Undifferentiated is present to west of the M25 (ATK-080 and ATK-081); this is associated with an artificial bund approximately 3m high which acts as a noise and visual barrier between the motorway and Maylands Golf Club.

Table 4-15 Ground Summary GM01

Stratum	Description	Thickness* (m)		Top of Stratum depth (m)		Upper level range (m AOD)	Basal level range * (m AOD)
		Typical	Range	Typical	Range		
Topsoil	Grass over soft brown slightly gravelly sandy silty CLAY / clayey SILT with frequent roots and rootlets.	0.3	0.1 – 0.4	0	0	35.4 – 39.2	35.0 – 39.2
Made Ground – Undifferentiated	Made Ground associated with the bund at Maylands Golf Course: 0 – 0.7m Grass over soft brown slightly gravelly sandy CLAY. Gravel is angular to subrounded fine to coarse flint and brick. 0.7 – 1.2m Firm becoming stiff orangish brown mottled light grey slightly gravelly silty CLAY with pockets (up to 50mm) of orangish brown fine sand. Gravel is angular and subangular fine to coarse flint.	Variable	~3.0 (unproven; estimated based on approximate height of the bund)	0	0	41.8 – 43.8	-
Made Ground – Engineered Fill	0 – 1.2m Road Construction 1.2 – 3.0m Firm (occasionally stiff) brown mottled orangish brown slightly to sandy, slightly gravelly to gravelly CLAY. Gravel is angular to sub-rounded fine to coarse flint and chalk.	Variable	1.2 – >3.0	0	0 – 0.2	38.1 – 38.9	35.7 – 38.0
Alluvium	Soft or firm, light grey, brown mottled orangish brown slightly sandy slightly gravelly silty CLAY with pockets of black carbonaceous / decomposed organic material. At the base of the stratum: grey and brown clayey sandy sub angular to rounded fine to coarse flint GRAVEL was occasionally encountered.	2.3	2.2 – 2.5	0.3	0 – 0.4	35.0 – 35.8	32.7 – 33.5
Head - Fine**	Firm brown mottled orangish brown light grey slightly sandy slightly gravelly silty CLAY.	1.2	-	1.25	-	37.2	36.0
Weathered London Clay Formation	Firm becoming stiff brown mottled orangish brown (occasionally closely fissured) silty CLAY with rare pockets of orangish brown silty fine sand and frequent selenite crystals (1 – 15mm).	4.1	2.4 – 7.6	2.0	0.4 – 2.8	32.7 – 37.6	29.7 – 31.6
London Clay Formation	Stiff or very stiff thinly laminated fissured greyish brown (with occasional bluish grey mottling) silty CLAY with rare selenite crystals (from 1 – 25mm).	-	4.8 – 22.4	6.2	5.7 – 7.2	29.6 – 31.6	-

* Proven thickness provided where base of stratum is encountered.

** Encountered in only one exploratory hole (ATK-080).

4.5.3 GM-02 – Central M25

Description of Extent

GM-02 is located at the central-northern extent of the Scheme on the M25 NB On-Slip realignment (CH 350 to 800). The M25 in this section is situated through an existing cutting up to approximately 6m high. A Summary of the ground conditions is included in Table 4-16 and the section line is shown on Drawings HE551519-ATK-HGT-XX-DR-CE-001004 and 001005 in Appendix F .

Engineered Fill was encountered to a shallow depth at the base of the cutting, associated with the construction of the M25.

Head deposits have been identified at a shallow depth at the southern extent of this area and follow the crest of the cutting along the section, the previous ground surface prior to the construction of the cutting. The deposits appear to be absent at the northern extent of the cutting crest slope, where a portion of the crest appears to have been excavated.

The bedrock, London Clay Formation, is present throughout the section below the Topsoil, Made Ground – Engineered Fill and Head deposits. A significant portion of the stratum was excavated to form the existing M25 cutting in this area. The section indicates that the weathered horizon appears to shallow towards the centre of the cutting, from a level of approximately 33m AOD at the southern and c. 30m AOD at the northern extent (see GM-01) to a level of roughly 40m AOD in the centre. The shallowing of the weathered portion of the London Clay Formation is consistent with the pre-cutting ground surface; indicating that the majority of the weathered portion was removed during the construction of the cutting.

Table 4-16 Ground Summary GM02

Stratum	Description	Thickness(m)*		Top of Stratum depth (m)		Upper level range (m AOD)	Basal level range* (m AOD)
		Typical	Range	Typical	Range		
Topsoil	Grass over soft brown slightly gravelly sandy silty CLAY / clayey SILT with frequent roots and rootlets.	0.3	0.1 – 0.5	0	0	39.9 – 48.3	39.7 – 48.0
Made Ground – Engineered Fill**	Soft to firm (occasionally stiff) brown mottled orangish brown slightly sandy to sandy, slightly gravelly to gravelly CLAY. Gravel is angular to subrounded fine to coarse flint.	Variable	1.0	0.2	-	39.8	38.8
Head - Fine	Soft becoming firm brown mottled orangish brown light grey slightly sandy slightly gravelly silty CLAY. 0.1m thick Head – Gravel was noted in ATK-071.	1.5	0.3 – 3.5	0.2	0.15 – 0.2	39.7 – 47.0	36.2 – 45.9
Weathered London Clay Formation	Firm becoming stiff brown mottled orangish brown (occasionally closely fissured) silty CLAY with rare pockets of orangish brown silty fine sand and frequent selenite crystals (1 – 15mm).	5.8	1.7 – 9.8	0.8	0 – 3.7	36.2 – 48.0	32.8 – 39.9

Stratum	Description	Thickness(m)*		Top of Stratum depth (m)		Upper level range (m AOD)	Basal level range* (m AOD)
		Typical	Range	Typical	Range		
London Clay Formation	Stiff thinly laminated fissured greyish brown (with occasional bluish grey mottling) silty CLAY with rare selenite crystals (from 1 – 25mm).	-	1.2 – 15.3	7	2 – 9.8	32.8 – 39.9	-

* Proven thickness provided where base of stratum is encountered.

** Encountered in only one exploratory hole (ATK-073).

4.5.4 GM-03 – Grove Farm

<u>Description of Extent</u>

GM-03 is located at Grove Farm at the south-eastern portion of the Scheme, from the M25 NB On-Slip (CH 100 to 350). The proposed M25 NB On-Slip is situated within a cutting within this section and an overbridge is proposed for the M25 NB Off-Slip. A summary of the ground conditions is included in Table 4-17, the section line is shown on Drawing HE551519-ATK-HGT-XX-DR-CE-001002 in Appendix F .

There is a significant thickness of Made Ground over this area, comprising both fine and coarse materials separated into two strata, Landfill (fine) overlain by Recently Deposited Material (coarse). The thickness of the landfill is relatively consistent across the area, with the coarse material generally confined to the northwest of the area although is locally present throughout.

Head deposits appear to be absent in this area. The profile of the Made Ground indicates removal of 1 to 2m of natural material prior to placement of Landfill material, including the Head deposits.

The bedrock, London Clay Formation, is present throughout the section below the Made Ground. The depth to the base of the weathered horizon is consistent in this area at approximately 32m AOD.

Table 4-17 Ground Summary GM03

Stratum	Description	Thickness* (m)		Top of Stratum depth (m)		Upper level range (m AOD)	Basal level range* (m AOD)
		Typical	Range	Typical	Range		
Topsoil	Grass over soft brown slightly gravelly (locally gravelly) sandy silty CLAY / slightly clayey fine and medium SAND with frequent roots and rootlets.	0.2	0.1 – 0.4	0	0	39.3 – 44.6	39.2 – 44.2
Made Ground – Recently Deposited Material	Soft to firm, brown slightly sandy to sandy, slightly gravelly to very gravelly CLAY with low cobble content. Gravel and cobbles comprising flint, concrete, limestone, glass, ceramics, plastic and brick.	Variable	0.1 – 2.0	0	0 – 0.4	37.0 – 45.0	36.8 – 44.6

Stratum	Description	Thickness* (m)		Top of Stratum depth (m)		Upper level range (m AOD)	Basal level range* (m AOD)
		Typical	Range	Typical	Range		
Made Ground - Landfill	Soft to stiff, greyish brown mottled orangish brown (frequently stained black) slightly sandy slightly gravelly CLAY.	3.3	1.2 – 5.4	0.6	0 – 2.0	36.8 – 44.6	33.8 – 41.9
Weathered London Clay Formation	Firm becoming stiff brown mottled orangish brown (occasionally closely fissured) silty CLAY with rare pockets of orangish brown silty fine sand and frequent selenite crystals (1 – 15mm).	7.6	5.4 – 9.1	3.9	1.6 – 6.1	33.8 – 41.9	31.8 – 33.1
London Clay Formation	Stiff thinly laminated fissured greyish brown (with occasional bluish grey mottling) silty CLAY with rare selenite crystals (from 1 – 25mm).	-	4.2 – 30.0	11.5	10.4 – 12.6	31.8 – 33.1	-

* Proven thickness provided where base of stratum is encountered.

4.5.5 GM-04 – Alder Wood & Weald Brook

Description of Extent

GM-04 is located at the central section of the Scheme along the alignment of the proposed M25 NB Off-Slip loop (from M25 NB Off-Slip CH 350 to 610). The proposed works in this area comprise an embankment with an overbridge over the realigned Weald Brook. A summary of the ground conditions is included in Table 4-18 and the section line is shown on Drawing HE551519-ATK-HGT-XX-DR-CE-001002 in Appendix F.

The head deposits encountered in this area comprise fine material and are present across the area of the ground model, with the exception of the flood plain of Weald Brook where up to 4.4m of Alluvium is present and the Head deposits appear to have been eroded away prior to the deposition of the Alluvium.

The bedrock, London Clay Formation, is present throughout the section below the Head deposits and Alluvium. The section indicates a gradual deepening of the weathered zone towards Weald Brook from approximately 32m AOD adjacent to the M25 to 25m AOD at the brook (ATK-089) and appears to shallow on the western side to *circa* 28m AOD.

Table 4-18 Ground Summary GM04

Stratum	Description	Thickness* (m)		Top of Stratum depth (m)		Upper level range (m AOD)	Basal level range* (m AOD)
		Typical	Range	Typical	Range		
Topsoil	Grass over soft brown slightly gravelly sandy silty CLAY with frequent roots and rootlets	0.2	0.1 – 0.4	0	-	33.1 – 40.1	32.9 – 40.0
Alluvium	Very soft to firm, light grey, brown mottled orangish brown slightly sandy slightly gravelly silty CLAY with fine to coarse flint gravel and wood fragments noted. At the base of the stratum: grey and brown clayey sandy sub angular to rounded fine to coarse flint GRAVEL was encountered	Variable	1.2 – 4.4	0.3	0.2 – 0.4	30.1 – 33.3	28.7 – 32.9
Head - Fine	Firm brown mottled orangish brown light grey slightly sandy slightly gravelly silty CLAY.	1.6	0.3 – 3.5	0.2	0.1 – 1.35	32.4 – 40.0	30.2 – 38.1
Weathered London Clay Formation	Firm becoming stiff thinly laminated brown mottled orangish brown silty CLAY with rare pockets of orangish brown silty fine sand and frequent selenite crystals (1 – 15mm)	5.3	2.1 – 8.9	2.3	0.6 – 4.4	28.7 – 38.1	24.7 – 32.8
London Clay Formation	Stiff thinly laminated fissured greyish brown (with occasional bluish grey mottling) silty CLAY with rare selenite crystals (from 1 – 25mm)	-	2.1 – 31.8	7.6	5.0 – 9.5	24.7 – 32.8	-

* Proven thickness provided where base of stratum is encountered.

4.5.6 GM-05 – Glebelands

Description of Extent

GM-05 is located at the western section of the Scheme and incorporates the area west of Weald Brook extending south of the A12. This area corresponds to areas of the Scheme from M25 NB Off-Slip CH 610 to 1090 and A12 EB Off-Slip CH 0 to 400. The proposed works in this area comprise bridge approach embankments and at grade carriageway as well as a proposed gas pipe diversion. A summary of the ground conditions is included in Table 4-19 and the section line is shown on Drawing HE551519-ATK-HGT-XX-DR-CE-001003 in Appendix F.

Made Ground was encountered to a shallow depth at a number of exploration hole locations, the material appears to be sporadic and localised, attributed to the agricultural land use.

Head deposits encountered in this area predominantly comprise fine material overlying bedrock, although coarse deposits (termed Head – Gravel) were present in localised pockets to the north and south of the A12.

The Bedrock, London Clay Formation, is present throughout the section below the Head Deposits. The section indicates a relatively consistent depth to the base of the weathered zone at approximately 29m AOD.

Table 4-19 Ground Summary GM05

Stratum	Description	Thickness* (m)		Top of Stratum depth (m)		Upper level range (m AOD)	Basal level range* (m AOD)
		Typical	Range	Typical	Range		
Topsoil	Grass over soft brown slightly sandy slightly gravelly silty CLAY / clayey SILT with frequent roots and rootlets.	0.3	0.2 – 0.4	0	-	32.7 – 37.7	32.4 – 37.4
Made Ground-Undifferentiated	Soft to firm, dark brown slightly sandy slightly gravelly CLAY or clayey SILT. Gravel is predominantly angular to sub-rounded fine to coarse flint although includes brick, concrete and tarmac.	0.4	0.2 – 0.6	0	0 – 0.25	31.6 – 38.3	31.1 – 37.8
Alluvium	Soft or firm, light grey, brown mottled orangish brown slightly sandy silty CLAY with rare pockets of black carbonaceous / decomposed organic material. At the base of the stratum: grey and brown clayey sandy sub angular to rounded fine to coarse flint GRAVEL was occasionally encountered.	Variable	1.6	Variable	0.5 – 3.0	31.1 – 31.7	29.5 – 30.1
Head - Fine	Soft to firm (occasionally stiff), brown mottled orangish brown light grey slightly gravelly silty CLAY.	1.6	0.2 – 4.1	0.6	0.2 – 4.6	30.1 – 37.5	28.2 – 36.6
Head - Coarse	Brown slightly clayey to clayey sub angular to rounded fine to coarse flint GRAVEL with occasional low subangular flint cobble content.	0.7	0.3 – 1.8	0.9	0.2 – 1.7	31.3 – 37.8	30.8 – 36.0
Weathered London Clay Formation	Firm becoming stiff brown mottled orangish brown (occasionally closely fissured) silty CLAY with rare pockets of orangish brown silty fine sand and frequent selenite crystals (1 – 15mm).	4.0	1.4 – 7.7	2.2	0.3 – 6.5	28.2 – 36.7	23.8 – 29.8
London Clay Formation	Stiff or very stiff thinly laminated fissured greyish brown (with occasional bluish grey mottling) silty CLAY with rare selenite crystals (from 1 – 25mm).	-	2.2 – 24.5	6.9	5.0 – 9.2	23.8 – 29.8	-

* Proven thickness provided where base of stratum is encountered.

4.5.7 GM-06 – A12 & Ingrebourne River

Description of Extent

GM-06 is located in the southern section of the Scheme and incorporates the area adjacent to Ingrebourne River and land parallel with the A12. This area corresponds to the Scheme from A12 Eastbound Off-Slip CH 400 to 700 and M25 NB Off-Slip loop CH 1090 to 1370. The proposed works in this area comprise bridge approach embankments, reinforced earth embankments and foundations for bridge abutments. A summary of the ground conditions is included in Table 4-20 and the section line is shown on Drawings HE551519-ATK-HGT-XX-DR-CE-001001 and 001003 in Appendix F .

Made Ground – Undifferentiated was encountered to the north of this area outside the flood plain directly overlying Weathered London Clay Formation. The material appears to be placed in the form of a localised *circa* 1.5m high bund, approximately 200m in the length, the source of this material is unknown.

Head deposits are potentially present to the south of this area, however are likely to have been largely removed during the construction of the A12. This stratum is present across the Scheme on sloping ground and therefore may be present below Alluvium where previous valleys have been infilled with alluvial material.

The Bedrock, London Clay Formation, is present throughout the section below the artificial and superficial deposits. The exploratory holes indicate a reasonably consistent depth to the base of the weathered zone at approximately 26m AOD; although appears to deepen to the south in ATK-002.

Table 4-20 Ground Summary GM06

Stratum	Description	Thickness* (m)		Top of Stratum depth (m)		Upper level range (m AOD)	Basal level range* (m AOD)
		Typical	Range	Typical	Range		
Topsoil	Grass over soft brown slightly sandy slightly gravelly silty CLAY / slightly gravelly clayey SAND with frequent roots and rootlets.	0.2	0.1 – 0.4	0	-	31.2 – 35.0	30.9 – 34.7
Made Ground – Undifferentiated	Soft to firm, dark brown slightly sandy gravelly CLAY or clayey SILT.	1.7	0.4 – 2.0	0.1	0.1 – 0.3	30.9 – 34.3	30.5 – 32.9
Alluvium	Soft or firm, light grey, brown mottled orangish brown slightly sandy silty CLAY with rare pockets of black carbonaceous / decomposed organic material. At the base of the stratum: grey and brown clayey sandy sub angular to rounded fine to coarse flint GRAVEL was occasionally encountered.	3.3	1.8 – 4.3	0.3	0 – 0.7	30.5 – 34.7	26.2 – 29.6
Head - Fine**	Soft to firm brown mottled orangish brown light grey slightly gravelly silty CLAY.	-	1.8	0.3	-	31.8	30.0
Weathered London Clay Formation	Firm becoming stiff brown mottled orangish brown (occasionally closely fissured) silty CLAY with rare pockets of orangish brown silty fine sand and frequent selenite crystals (1 – 15mm).	3.3	1.2 – 9.7	2.9	0.8 – 5.0	26.2 – 32.9	22.1 – 26.3
London Clay Formation	Stiff or very stiff thinly laminated fissured greyish brown (with occasional bluish grey mottling) silty CLAY with rare selenite crystals (from 1 – 25mm).	-	9.2 – 25.6	6.6	5.0 – 10.5	22.1 – 26.3	-

* Proven thickness provided where base of stratum is encountered.

** Encountered in only one exploratory hole (ATK-073).

4.5.8 GM-07 – M25 junction 28

Description of Extent

GM-07 is located in the south-eastern section of the Scheme and incorporates the area of the northwest quadrant of the existing M25 junction 28. This area of the Scheme extends from M25 NB Off-Slip CH 0 to 200 and 1370 to 1450. The proposed works in this area comprise the installation of a gantry, extension of culvert and construction of an expanded polystyrene (EPS) fill embankment. A summary of the ground conditions is included in Table 4-21 and the section line is shown on Drawings HE551519-ATK-HGT-XX-DR-CE-001001, 001002 and 001004 in Appendix F.

Made Ground – Engineered Fill was encountered across this area forming the existing earthworks for the Junction, A12 and M25. The Engineered Fill typically comprised fine fill material, with coarse material noted at the base in ATK-017, possibly attributed to an embankment drainage blanket.

Alluvium was not encountered within the available ground investigation information; however it is likely to be present below the junction following the previous alignment of the Ingrebourne River which is now culverted below the junction. Head deposits are present across this area, typically within 1.5m of the historical ground surface prior to existing M25 and A12 construction.

The Bedrock, London Clay Formation, is present throughout the section below the artificial and superficial deposits. The exploratory holes indicate a reasonably consistent depth to the base of the weathered zone at approximately 29m AOD, although appears to be shallowing to the north in BHN78.

Table 4-21 Ground Summary GM07

Stratum	Description	Thickness* (m)		Top of Stratum depth (m)		Upper level range (m AOD)	Basal level range* (m AOD)
		Typical	Range	Typical	Range		
Topsoil	Grass over brown slightly gravelly clayey fine to medium SAND with frequent roots and rootlets	0.3	0.1 – 0.4	0	-	36.4 – 42.3	36.1 – 41.9
Made Ground – Engineered Fill	Soft to firm, dark brown mottled orangish brown slightly sandy slightly gravelly silty CLAY	Variable	0.7 – 9.1	0.1	0 – 0.3	38.3 – 47.6	32.4 – 39.4
Alluvium**	Soft or firm, light grey, brown mottled orangish brown slightly sandy silty CLAY with rare pockets of black carbonaceous / decomposed organic material.	-	-	-	-	-	-
Head - Fine	Firm brown mottled orangish brown light grey slightly sandy slightly gravelly silty CLAY.	1.5	0.4 – 2.6	Variable	0 – 5.9	32.4 – 41.9	29.8 – 41.0
Weathered London Clay Formation	Firm becoming stiff brown mottled orangish brown (occasionally closely fissured) silty CLAY with rare pockets of orangish brown silty fine sand and frequent selenite crystals (1 – 15mm)	7.7	6.1 – 8.7	Variable	0.2 – 5.2	34.2 – 41.0	27.7 – 33.5

Stratum	Description	Thickness* (m)		Top of Stratum depth (m)		Upper level range (m AOD)	Basal level range* (m AOD)
		Typical	Range	Typical	Range		
London Clay Formation	Stiff or very stiff thinly laminated fissured greyish brown (with occasional bluish grey mottling) silty CLAY with rare selenite crystals (from 1 – 25mm)	-	0.3 – 20.8	8.6	7.9 – 9.2	27.7 – 33.5	-

* Proven thickness provided where base of stratum is encountered.

** Not encountered during the GI's, however, is expected to be present.

4.6 Concrete Classification

The concrete classification was determined in accordance with BRE SD1 [50] based on water soluble sulphate and pH derived from samples undertaken during the investigation and provided in Section 4.4. The Design Sulphate (DS) and Aggressive Chemical Environment for Concrete (ACEC) classifications are presented in Table 4-22.

The materials encountered are considered to have been weathered, and no further sulphides present with the exception of unweathered London Clay Formation. The amount of oxidizable sulphides within the London Clay Formation stratum could not be determined as the acid-soluble sulphate test was not undertaken; therefore, the DS Class and ACEC Class provided is based on more onerous designation derived for the weathered portion of the London Clay Formation.

Table 4-22 DS and ACEC Class

Stratum		Material designation	Groundwater designation	DS Class	ACEC Class
Artificial Deposits	Made Ground – Engineered Fill	Brownfield pyrite present	Mobile	DS-4	AC-4
	Made Ground – Recently Deposited Material	Brownfield pyrite present	Mobile	DS-4*	AC-3*
	Made Ground – Landfill	Brownfield pyrite present	Mobile	DS-4**	AC-3
	Made Ground - Undifferentiated	Brownfield pyrite present	Mobile	DS-2	AC-3z
Superficial Deposits	Alluvium	Greenfield pyrite present	Mobile	DS-1	AC-1
	Head – Fine	Greenfield pyrite present	Mobile	DS-2	AC-2
	Head – Coarse	Greenfield pyrite present	Mobile		
Bedrock	Weathered London Clay	Greenfield pyrite present	Static	DS-4	AC-3s
	London Clay Formation	Greenfield pyrite present	Static	DS-4***	AC-3s***

* No test results are available therefore the classification consistent with the nearest material in composition, has been used.

** As this material is considered to be comprised of re-worked London Clay Formation, the DS class has been increased from DS-3 to be consistent with its source material.

*** Weathered London Clay Formation result has been used as a worst-case value (original results are DS-2 AC-1s).

4.7 Summary of Geotechnical Parameters

A summary of the geotechnical parameter values for geological units present at the Study Area is summarised in Table 4-23 below. The parameters are primarily based on the results of the ground investigation with consideration of published literature and engineering judgement. Where values cannot be given due to variation within the test results the range in values has been provided. These are site-wide values and the designer should review the parameters and determine values appropriate for the proposed element of design.

Table 4-23 Summary of Geotechnical Parameters for strata encountered along the Scheme.

Test Type	Parameter	Units	Made Ground				Alluvium	Head – Fine	Head - Coarse	London Clay Formation	
			Engineered Fill	Recently Deposited Material	Landfill	Undifferentiated				Weathered	Unweathered
Index Testing	Water content	%	28	(23)	28	(21)	26	28	-	30	30
	Plasticity index	%	48	(21)	45	(40)	45	50	-	50	52
Density Testing	Bulk weight density		17 – 20	(17 – 19)	17 - 19	(18 – 20)	18 - 19	17 - 20	[19 - 21]	18 - 20	19 - 21
Undrained Shear Strength (Short term)	c_u	kPa	50 to 3m bgl; 75 thereafter	-	40	(75)	40	60	-	40+4.5d	40+4.5*d*
Drained Strength (Long Term	c', φ'_{pk}	kPa, °	0, 23	(0, 25)	0, 21	(0, 20 – 0, 27)	0, 22	0, 21	32	3, 23	3, 23
	φ'_r		-	-	-	-	-	10	-	-	-
Consolidation Testing	m_v	m^2/MN	-	-	0.4	-	0.3	0.2	-	0.15	0.15
Compaction Testing	MDD	Mg/m^3	-	(1.64)	1.54 – 1.72	(1.47)	-	1.52 – 1.77	-	1.41 – 1.61	-
	OWC	%	-	(19)	18 – 26	(28)	-	19 – 25	-	23 - 31	-
	MCV	-	-	(7.6 – 13.3)	5.7 – 17.9	(9.5 – 15.2)	-	5.1 – 17.9	-	1 - 17	-
Minimum *in situ* design CBR		%	2 – 2.5	(4 – 5)	2 -3	(2.5 – 3)	<2	2 – 2.5	15	2 – 2.5	-
Stiffness	E'	-	(11)	-	5	-	4	5	-	10+1d	10+1d
Concrete Classification	DS Class	-	DS-4	(DS-4)	DS-4	(DS-2)	DS-1	DS-2	DS-2	DS-4	DS-4
	ACEC Class	-	AC-4	(AC-3)	AC-3	(AC-3z)	AC-1[d]	AC-2	AC-2	AC-3s	AC-3s

() parameter shown in brackets where there is a high level of uncertainty due to limited data.

[] parameter shown in brackets is based entirely on published data and engineering judgement, as no testing was undertaken during the ground investigation

z = Top of stratum

d = Depth below ground level

4.8 Hydrogeology

Water strikes were encountered in 14 exploratory holes during the 2019 GI. The descriptions are summarised in 4-24. Generally, there were little variations in depths after 20 minutes of rest time, suggesting slow recharge. Reference to the borehole log indicates that perched water encountered in ATK-019 was present above a membrane in the Made Ground and therefore this is not considered to be representative of the wider ground conditions at the site.

Table 4-24 Groundwater strikes during 2019 GI

Hole ID	Ground level (m AOD)	Stratum of strike	Strike in m AOD (m bgl)	Level after 20 or 70 mins in m AOD (m bgl)
ATK-005*	33.00	Alluvium	31.80 (1.2)	-
ATK-006*	31.20	Alluvium	30.30 (0.9)	-
ATK-007	32.65	Alluvium	31.75 (0.9)	-
ATK-012	31.50	Gravel (Alluvium)	29.30 (2.2)	29.68 (1.82)
ATK-019	38.80	Above membrane	38.45 (0.35)	37.70 (1.1)
ATK-044	43.30	Weathered London Clay	35.10 (8.2)	35.20 (8.1)
ATK-045	38.40	Head	38.00 (0.4)	-
ATK-061	31.30	Alluvium	30.10 (1.2)	-
		Weathered London Clay	26.50 (4.8)	-
ATK-078	35.80	Alluvium	34.00 (1.8)	34.72 (1.08)
ATK-086*	44.55	Weathered London Clay	39.42 (5.13)	40.77 (3.78)
ATK-087*	44.35	Weathered London Clay	39.42 (4.93)	40.12 (4.23)
ATK-089*	33.10	Alluvium	30.87 (2.23)	31.35 (1.75)
ATK-090*	32.70	Alluvium	30.03 (2.67)	30.89 (1.81)
ATK-091*	41.70	Made Ground	37.34 (4.36)	-

* Denotes exploratory holes installed with monitoring wells.

4-25 shows the range of groundwater levels monitored during the monitoring rounds.

Table 4-25 Groundwater monitoring summary

Hole ID	Base of screen (m AOD)	Screened strata	Range of water levels recorded (m AOD)	
			Min	Max
ATK-003	32.84	Made Ground	34.30	36.51
ATK-004	32.79	Alluvium	34.54	35.29
ATK-005	28.3	Alluvium	31.30	32.83
ATK-006	25	Alluvium, Head, weathered London Clay	29.92	30.74
ATK-008	26.26	Alluvium	28.35	29.97
ATK-014	29.8	Alluvium	30.15	32.07
ATK-015	33.41	Alluvium, weathered London Clay	34.55	34.55

Hole ID	Base of screen (m AOD)	Screened strata	Range of water levels recorded (m AOD)	
			Min	Max
ATK-048	34.9	Weathered London Clay	37.17	38.74
ATK-056	29.4	Alluvium	30.71	31.62
ATK-058	29.6	Head, weathered London Clay	34.67	35.35
ATK-079	33.2	Alluvium	34.85	35.03
ATK-086	39.06	Made Ground, weathered London Clay	41.38	42.14
ATK-087	41.34	Made Ground	42.27	42.57
ATK-088	40.54	Made Ground	40.75	42.92
ATK-089	29.09	Alluvium	31.43	32.35
ATK-090	29.20	Alluvium	31.31	31.70
ATK-091	35.70	Made Ground, weathered London Clay	40.99	42.45
ATK-092	37.69	Made Ground	40.61	42.36
ATK-P-101	35.95	Made Ground	36.41	36.93
ATK-P-102	37.50	Made Ground, weathered London Clay	40.66	41.94

Pairs of vibrating wire piezometers (shallow and deep) were installed at ATK-042, ATK-052, and ATK-061. Graphs displaying the data plotted with daily, local precipitation volumes are provided in Figure 4-2, Figure 4-3 and Figure 4-4; further discussion is below in Section 4.10.2.

4.9 Visual and Olfactory Evidence of Contamination

Visual and olfactory indicators of possible chemical impact observed during the 2019 GI are presented in 4-26. Relevant information includes staining, odour and anthropogenic materials (other than the more inert materials such as plastic, brick, glass and concrete).

Table 4-26 Visual and olfactory signs of contamination

Exploratory hole	Depth (m bgl)	PID reading in stratum (ppm)	Description
ATK-001	0.00 - 0.15	0.9	Wood and metal fragments in Made Ground
ATK-017	2.60 - 3.20	6.5	Hydrocarbon odour in Made Ground and wood present
ATK-019	0.60 - 1.00	Not recorded	Coarse gravel size coal in Made Ground
ATK-025b	1.20 - 3.30	0.2	Black decomposed wood in Made Ground
ATK-028a	2.20 - 3.50	3.8	Black, partially decomposed organic fragments of wood in Made Ground
ATK-036	0.50 - 1.40	17.7	Hydrocarbon / tar odour in Made Ground
ATK-041	0.25 - 1.00	Not recorded	Wood in Made Ground
ATK-071	0.00 - 0.15	Not recorded	Wood in Made Ground
ATK-078	0.00 - 0.30	Not recorded	Metal fragment (no detail provided) in Made Ground
ATK-087	2.00 - 4.30	1.3 at 2.0 m bgl 2.6 at 3.0 m bgl 2.0 at 4.0 m bgl	Frequent black staining and decomposed organic material (black abundant

Exploratory hole	Depth (m bgl)	PID reading in stratum (ppm)	Description
			decomposed rootlets and wood fragments in Made Ground
ATK-091	2.90 - 3.05	8.1	Pieces of decomposed wood in Made Ground
ATK-092	0.15 - 0.90	3.2	Black staining on clay and fragments of wood/ decomposed wood in Made Ground
	1.45 - 5.35	1.2	
ATK-097	0.70 - 1.00	Not recorded	Rare coal in Made Ground
	1.00 - 3.40	3.2	Frequent pockets of black carbonaceous material in Made Ground

4.10 Geo-Environmental Risk Assessment

4.10.1 Human Health

Introduction and Background - Human Health GQRA

The human health Generic Quantitative Risk Assessment (GQRA) provided in this section evaluates the potential risks to the identified human health receptors using data obtained during the 2019 GI.

The geo-environmental soil laboratory analytical results certificates are presented in Appendix C and the GQRA screening tables in Appendix H.

Methodology – Human Health GQRA

The laboratory chemical analysis results from the geo-environmental soil samples were compared with the GAC which were taken from the sources detailed below.

The primary source of GAC used for the assessment were the Atkins AtRisk® soil screening values (SSVs) which have been created using the contaminated land exposure assessment (CLEA) model [9]. SSVs are available for a variety of standard land uses. Given the size and nature of the proposed development, two separate assessment scenarios were considered most appropriate depending upon the proximity of the development to residential properties as follows.

Where residential properties are within 250m of a sample location, the Public Open Space (POS) (residential) SSVs were adopted. This scenario, which represents a conservative approach, is relevant for 43 no. of the 77 no. geo-environmental soil samples.

Where residential properties were not present within 250m of a sample location, the POS (parks) SSVs were adopted. Taking this into consideration, a total of 34 no. of the 77 no. geo-environmental soil samples were assessed against the POS (parks) scenario.

The POS (residential) SSV exposure scenario assumes that a female child aged 4 to 9 years is the most sensitive receptor. Exposure in this scenario is by direct ingestion, dermal contact, and inhalation of soil-derived dusts and vapours for a period of 170 days per year.

Input parameters for the POS (parks) SSVs are similar to those used for POS (residential). However, the effect of tracked-back soil and related indoor exposure pathways are not considered relevant due to the increased distance from residential properties.

Given the generic nature of the selected SSVs, it should be noted that these exposure scenarios do not exactly reflect anticipated conditions on-site and assume a level of conservatism in relation to the likely human exposure profile at the Scheme.

Both sets of SSVs are available for soil organic matter (SOM) contents of 1% and 6%. A site-specific SOM has been derived from the values reported in the laboratory soil analysis. The average total organic matter (TOC) value for the geo-environmental samples was 0.78% which corresponds to a SOM concentration of 1.34%. This assessment has adopted a conservative approach and the SSVs based on a 1% SOM have been selected.

Category 4 Screening Levels (C4SL) are also modelled using CLEA for standard land uses and relate to concentrations of contamination in soil (with 6% SOM) which are considered by the Department for Food and Rural Affairs (DEFRA) to represent a 'low risk', and are derived using updated exposure assessment parameters and toxicological data based on a 'Low Level of Toxicological Concern' [56]. As per the accompanying Policy Statement, DEFRA state that:

"A Low Level of Toxicological Concern represents an exposure equivalent to an intake of low concern but that definitely does not approach an intake level that could be defined as causing a Significant Possibility of Significant Harm to human health" [56].

Although C4SLs consider a different SOM to the site-specific value and the selected Atkins SSVs (with the exception of benzene, for which a 1% value is available), the C4SLs were derived on the basis of remaining 'strongly precautionary' for the purposes of generic screening. Therefore, where appropriate, Atkins has adopted the C4SLs in this assessment.

Construction and maintenance workers have been included in the outline CM. However, the GAC used for the assessment do not cover these receptors as these criteria specifically relate to chronic health effects rather than possible acute exposures. Risks to construction and maintenance workers are expected to be managed by their employers, based on risk assessment and method statements (RAMS) documentation and a hierarchy of controls in accordance with codes of construction practices, appropriate working methods and Personal Protective Equipment (PPE) as required by the Health and Safety Executive [57].

UK based GAC are not available for asbestos in soils and CIRIA C733 [58] does not advocate the use of GAC for risk assessment of ACMs and asbestos in soil. The risk from asbestos (where identified) has therefore been subjected to qualitative assessment only.

Composite samples collected for waste classification have not been considered within the human health GQRA (see Section 4.11). However, where asbestos may have been identified within composite samples, this has been included in the assessment given the qualitative approach taken for this material.

Ground investigation has previously been undertaken on-site as part of the preliminary investigation [23] and other historical GIs undertaken at the site. Relevant geo-environmental test results from these investigations were screened for human health risk assessment in the Preliminary Geo-environmental Assessment Report [59] following the same methodology as detailed above. These results will not be re-screened as part of the human health risk assessment in this report but relevant findings from the Preliminary Geo-environmental Assessment Report are discussed for completeness.

<u>Results</u>

The results of the screening of soil analytical data against GAC for the two different exposure scenarios (POS parks / residential) are presented in Appendix H.

POS (Parks) Scenario

No exceedances of the GAC for public open space (parks) were identified in the 34no. samples that were assessed using this scenario.

POS (Residential) Scenario

No exceedances of the GAC for public open space (residential) were identified in the 43 no. samples that were assessed using this scenario.

Asbestos

Asbestos was positively identified in three of the 33 no. samples tested for this parameter. These instances are shown in Table 4-27.

Table 4-27 Summary of locations of identified asbestos

Exploratory Hole Location (Section, nearest chainage)	Depth (m bgl)	Type	Concentration	Description of material
ATK-081A (Section GM-01, M25, chainage 1175)	0.50	Chrysotile (sheeting/ board debris)	0.001%	Soft brown slightly gravelly sandy clay with fine to coarse flint and rare brick (MADE GROUND). Possible ACM tile logged at 0.55 m bgl.
ATK-205 (Section GM-06, A12, chainage 300)	0.20	Amosite (loose fibres)	<0.001%	Sandy gravelly clay with medium brick and concrete cobble content. Gravel is fine to coarse brick, flint and concrete (MADE GROUND)
ATK-206 (Section GM-06, A12 chainage 300)	0.20	Chrysotile (loose fibres)	<0.001%	Sandy gravelly with medium concrete and brick cobble content. Gravel is brick, concrete and tarmacadam (Made Ground)

<u>Discussion</u>

The following is a discussion of the findings of the human health risk assessment and a summary of other pertinent findings, including those from the Preliminary Geo-environmental Assessment Report [59].

Beryllium

During the preliminary GI, an elevated concentration of beryllium (2.6mg/kg) was identified within ATK-P-007 at 2.5 to 3.0m bgl associated with Made Ground – Landfill in the north-west of the Scheme in Section GM-04. This was a marginal and isolated exceedance of the GAC (2.19mg/kg, POS - Parks). Further, it should be noted that the sample was collected at depth in the profile and beryllium is a non-volatile compound. The Preliminary Geo-environmental Assessment Report concluded that this was unlikely to pose an unacceptable risk.

Asbestos

Amosite and chrysotile asbestos containing materials were identified in the vicinity of the proposed A12 eastbound off-slip, Section GM-06, and adjacent to mainline chainage 300. These ACMs were at shallow depth (0.2m) within adjacent boreholes ATK-205 and ATK-206 and were associated with cohesive Made Ground containing inclusions of concrete and brick. Further chrysotile asbestos containing material was identified within ATK-081A at 0.50m at the northern extent of the Scheme (Section GM-01). This exploratory hole was located at a proposed gantry at approximate chainage 1175 and was associated with cohesive Made Ground containing brick. A suspected ACM tile was identified at 0.55m bgl at ATK-081A and the exploratory hole was terminated. Given the shallow depth of these ACMs and the possibility that they will be excavated during the proposed works it is recommended that the potential health risk from these materials is considered when planning and carrying out works at these locations. In all cases, these ACMs were quantified at or less than 0.001% (laboratory limit of detection), suggesting the level of risk may be limited and that standard codes of construction practices for brownfield development, including PPE and working practices, should mitigate the potential risks.

As reported in the Preliminary Geo-environmental Assessment Report [59], further ACMs were identified during the preliminary investigation within the historic landfill in the north-west of the Scheme and associated with recently deposited material (4 out of 95 no. samples tested). As with the 2019 GI, the ACM was present in a sample collected from shallow depth (<0.8m bgl) and quantified at <0.001%. It was concluded that, given the limited and sporadic presence of ACM at concentrations less than the limit of detection, the risk to human health was low. Further information can be found in the Preliminary Geo-environmental Assessment Report.

Given the nature of the proposed scheme it is unlikely that there will be a pathway to human health receptors during the operational phase given the predominance of hard-cover and constructed landscaping.

PID Readings

During the 2019 GI, PID readings were taken throughout the Made Ground and natural deposits in exploratory holes across the site and the majority of these showed readings of <10 ppm. PID readings provide an indication of the presence of ionizable volatile organic compounds and the intensity of the vapours associated with these compounds. PID readings do not quantify the concentration of any organic compounds that might be present, although the readings indicate that concentrations are likely to be low.

During the 2019 GI, a PID reading that was greater than 10ppm was only recorded at one location (ATK-036 at 0.50m bgl; 17.7ppm). A hydrocarbon / tar odour was also noted in Made Ground – Recently Deposited Material between ground level and 1.40m bgl at this location although the PID readings decreased below 0.50m bgl to 0.2ppm or lower. This exploratory hole was located to the north of the historic landfill and so the noted hydrocarbons may be related to this land use. Chemical testing of a geo-environmental sample taken from 0.5m bgl detected TPH and PAH in the sample, but at concentrations below the GAC for POS parks, and therefore the risk to human health is considered to be acceptable. Chemical testing for phenol, VOCs and SVOCs did not detect organic compounds above the laboratory detection limits, providing further evidence that the ground conditions do not represent an unacceptable risk to human health.

No PID readings were measured above 10ppm during the Preliminary GI.

Material Reuse

As described above, only a localised and minor GAC exceedance for beryllium was identified within the Scheme and is likely to remain in situ in the completed Scheme. Asbestos was identified at shallow depth in approximately 4% of tested samples and there is a possibility that ACM material will be excavated during construction. Asbestos was quantified at <0.001% in all instances indicating low risk to health. However, it would be prudent to adopt appropriate health and safety measures during earthworks and to consider these materials when planning the reuse of materials.

With regards reuse, materials potentially containing ACMs should be reused at depth within embankments or below hardstanding / other soils at the Scheme and its location documented. Alternatively, these materials can be reused at appropriate off-site locations or disposed off-site at an appropriately licensed facility. Exposed soils at the ground surface are not anticipated in the completed Scheme and therefore a realistic viable pollutant linkage to human receptors is unlikely and therefore ACMs are unlikely to represent an unacceptable risk in the completed Scheme. Future intrusive works should consider the potential for exposure to ACM material. Based on the available chemical test results it is likely that the majority of excavated materials are geochemically suitable for reuse on site. Further reuse testing will be required on any excavated materials during construction in line with the earthworks specification for the Scheme to confirm the level of risk.

If areas of suspected gross contamination or ACM are identified during future earthworks, then it is recommended that DCO requirements for this eventuality are followed.

To ensure excavated materials are managed in a sustainable and effective manner, a Materials Management Plan (MMP) should be implemented during the construction phase. Further information on the requirements of the MMP are provided by the CL:AIRE Definition of Waste: Code of Practice [60].

Human Health Risk Assessment Conclusions

ACMs were identified at isolated locations at the site; however, these were all quantified at or less than detectable limits which would indicate a limited risk from this contaminant. Whilst there is a potential for soils containing ACMs to be disturbed during the construction works it is considered that the level of risk will be acceptable assuming that appropriate mitigation measures are implemented during these works.

An isolated beryllium exceedance of the GAC was identified associated with the historic landfill. This was only identified within ATK-P-007 between 2.5 - 3m bgl with the beryllium concentration within other tested samples from the landfill indicated be present at concentrations less than the GAC. The level of risk was considered to be acceptable given its localised nature, non-volatile form and depth of origin in the ground profile, and the fact that the beryllium concentration within ATK-P-007 was only marginally elevated compared to the GAC.

Based on the results of the human health risk assessment undertaken on soil samples obtained during the Preliminary GI and 2019 GI, it is concluded that there is unlikely to be an appreciable significant risk to human health based on the areas investigated.

Ground Gas Risk Assessment

The approach to the assessment of ground gas monitoring results consists of two tiers as set out below.

Tier 1

Tier 1 screening for methane and carbon dioxide consists of a preliminary screening of gas concentrations against threshold concentrations provided by BS8485:2015+A1:2019 [61] and CIRIA C665 [62]. As a preliminary exercise, the gas monitoring data has been assessed against the following thresholds:

- Methane, 1%
- Carbon dioxide, 5%.

The HSE EH40/2005 (updated 2020) document [63] includes Workplace Exposure Limits (WELs) for carbon monoxide (30ppm long-term exposure limit and 200ppm for short-term exposure limit) and hydrogen sulphide (5ppm long-term exposure and 10ppm short-term exposure limit) which have been adopted for the assessment.

Tier 2 – Methane and Carbon Dioxide Only

Gas screening values (GSVs) are calculated by multiplying borehole gas concentration (% v/v) by borehole flow rate (l/h). The maximum gas concentration and flow rates for each borehole have been selected irrespective of whether they are from the same monitoring visit as an initial conservative approach. The GSVs are calculated using the formula:

- GSV = Borehole flow rate (l/h) x Gas concentration (% v/v) / 100

In accordance with BS8485:2015+A1:2019, the assessment has used the maximum gas concentration and maximum flow rate at each borehole location and has discounted peak instantaneous flows. The assessment has adopted a conservative approach and has considered negative flow rates as being positive. Gas concentrations below the monitoring equipment’s limit of detection have been assumed to be at the limit of detection (<0.1l/h) for the purposes of the assessment.

Using the calculated GSVs, the site has been assessed using the modified Wilson and Card methodology for commercial development to allow a Characteristic Situation (CS) and risk level to be calculated. This is considered a conservative approach given that the guidance documents specifically relate to risk scenarios for occupied buildings and are not directly applicable to a road improvement scheme.

Ground Gas Results

A maximum of four rounds of gas monitoring were undertaken from the 20 no. borehole installations between 01 November 2019 and 04 February 2020 as part of the 2019 GI. Monitoring was undertaken during periods of rising and falling atmospheric pressure although as the dates of monitoring were different for each monitoring well the atmospheric conditions also varied from borehole to borehole. The results from the gas monitoring are in Table 4-28. The full set of results are presented in the factual report [24].

Gas monitoring was not undertaken during the Preliminary GI. However, two ground gas monitoring wells (ATK-P-101 and ATK-P-102) were installed and monitored during the 2019 GI.

Table 4-28 Summary of gas monitoring

Hole ID	Max. CH_4 (%vol)	Max. CO_2 (%vol)	Min. O_2 (%vol)	Max. H_2S (ppm)	Max. CO (ppm)	Max. Flow (l/hr)	Max. CH4 GSV	Max. CO_2 GSV	Characteristic Situation	
									CH_4	CO_2
ATK-003	<0.1	8.0	1.0	0	10	<0.1	0.0001	0.008	CS1	CS2*
ATK-004	<0.1	0.8	1.8	0	10	-0.1	0.0001	0.0008	CS1	CS1
ATK-005	<0.1	0.6	19.1	0	10	-0.1	0.0001	0.0006	CS1	CS1
ATK-006	<0.1	4.2	18.1	0	0	1.2	0.0012	0.0504	CS1	CS1
ATK-008	<0.1	1.7	18.2	0	0	-0.1	0.0001	0.0017	CS1	CS1
ATK-014	<0.1	0.8	17.1	0	0	-0.1	0.0001	0.0008	CS1	CS1
ATK-015	<0.1	0.6	13.5	0	0	-0.2	0.0002	0.0012	CS1	CS1
ATK-048	<0.1	2.0	12.9	0	10	<0.1	0.0001	0.002	CS1	CS1
ATK-056	<0.1	2.0	18.3	0	0	-0.3	0.0003	0.006	CS1	CS1
ATK-058	<0.1	<0.1	19.6	0	0	-0.3	0.0003	0.0001	CS1	CS1
ATK-079	<0.1	0.7	19.0	0	10	-3.1	0.0031	0.0217	CS1	CS1
ATK-086	<0.1	6.1	0.1	0	10	0.1	0.0001	0.0061	CS1	CS2*
ATK-087	0.8	3.3	16.5	0	10	<0.1	0.0008	0.0033	CS1	CS1
ATK-088	12.3	11.5	10.6	0	10	<0.1	0.0123	0.0115	CS2*	CS2*
ATK-089	<0.1	1.1	16.1	0	10	<0.1	0.0001	0.0011	CS1	CS1
ATK-090	<0.1	2.9	15.8	0	0	0.1	0.0001	0.0029	CS1	CS1
ATK-091	<0.1	0.8	18.7	0	0	<0.1	0.0001	0.0008	CS1	CS1
ATK-092	39.2	6.9	6.8	0	10	3.0	1.276	0.207	CS3	CS2
ATK-P-101	1.7	7.0	0.6	0	0	-0.3	0.0051	0.021	CS1	CS2*
ATK-P-102	<0.1	6.9	17.0	0	0	-0.1	0.0001	0.0069	CS1	CS2*

* Characteristic Situation classification increased from CS1 to CS2 where maximum methane or carbon dioxide concentrations exceed 1% and 5% respectively, but where the calculated GSVs have indicated CS1 due to lack of significant gas flow rates as recommended in BS8485:2015+A1:2019.

Summary of Ground Gas Assessment

The maximum carbon monoxide concentration was recorded at 10ppm and hydrogen sulphide was not detected and, therefore, these parameters did not exceed the Tier 1 threshold concentrations for workplace exposure risk.

The calculated GSV for methane was CS1 (very low risk; no special precautions required for any type of habitable development) in 19 of the 20 no. monitored boreholes.

The calculated GSVs for methane for ATK-092 is CS3 (moderate risk) due to a measured maximum concentration of 39.2% and a flow rate of 3l/h. The response zone within ATK-092 is within natural clay that contained decomposed wood fragments and black organic matter between 1.45 and 5.35m bgl. The nearest enclosed space where ground gas could accumulate is a building approximately 180 m south of this location. ATK-091 was located between this building and ATK-092 and had a response zone at the same depth although only a very low risk from ground gas was identified at this location. This suggests that the elevated risk at ATK-092 is isolated with no pathways present to the nearest building. The preliminary design includes a proposed access road to Infiltration Pond 2 at the location of ATK-092. It is unlikely that the excavations required will extend to the depth of the clay material or that they would redirect gas flow towards the building. Based on the preliminary design information, no enclosed spaces such as inspection chambers are proposed in the vicinity of Infiltration Pond 2; however, if this changes, then it is recommended that appropriate mitigation measures are adopted within these features.

British Standard 8485:2015+A1:2019 indicates that locations with calculated GSVs resulting in CS1 classification should be considered for upgrade to CS2 where methane concentrations exceed 1%. This, therefore, applies to location ATK-088 where the maximum methane concentration was 12.3% but where the calculated GSV is low due to lack of positive gas flow rate. However, this result does not impact the scheme given that no habitable buildings are proposed at this location. Any future habitable buildings at this location should be designed in accordance with British Standard 8485:2015+A1:2019.

The calculated GSV for carbon dioxide was CS1 (very low risk; no special precautions required for any type of habitable development) in 14 of the 20 monitored boreholes. The calculated GSV for carbon dioxide for ATK-092 is CS2 (low risk).

British Standard 8485:2015+A1:2019 indicates that locations with calculated GSVs resulting in CS1 classification should be considered for upgrade to CS2 where carbon dioxide concentrations exceed 5%. This therefore applies to locations ATK-003, ATK-086, ATK-088, ATK-101 and ATK-102 where the maximum carbon dioxide concentrations ranged between 6.1% and 11.5% but where the calculated GSV is low due to lack of significant positive gas flow rates. However, these results do not impact the scheme given that no habitable buildings are proposed at these locations. Any future habitable buildings at these locations should be designed in accordance with British Standard 8485:2015+A1:2019.

Initial flow readings higher than those provided in Table 4-28 were recorded in several boreholes. These flow rates quickly dissipated in all instances and as the guidance recommends discounting peak instantaneous flows these have not been considered as they are unlikely to be representative of the true ground gas regime.

Overall, the ground gas data reviewed shows that the earthworks for the Scheme are unlikely to result in a significant risk to construction workers, future maintenance workers or off-site human health receptors.

4.10.2 Controlled Waters

Introduction

This GQRA has been designed to assess the potential risks to the identified controlled water receptors using soil-derived leachate and groundwater data obtained for the scheme through the preliminary GI and the 2019 GI.

The identified controlled water receptors identified in Sections 2.2 and 2.4 as part of the Environmental Statement were as follows:

- Superficial groundwater bodies beneath the Scheme and within the study area, including localised deposits of Alluvium (secondary A aquifer) and Head deposits (secondary (undifferentiated) aquifer) and the secondary A aquifers associated with the Bagshot Formation and Claygate Member bedrock in the study area.
- Surface water receptors within the Scheme and study area, including the Ingrebourne River and Weald Brook.
- Potential new surface water features including attenuation ponds and drainage features.

The Preliminary Geo-Environmental Assessment Report undertook a preliminary assessment of the potential for unacceptable risk associated with soil derived leachate and the water environment. This assessment will incorporate and update the results of previous preliminary assessment [59].

Groundwater strikes are presented in the geotechnical long-sections in Appendix F and selected monitoring results are displayed on schematic cross sections provided in Appendix J.

The soil-derived leachate and groundwater analytical results are provided in the 2019 GI Factual Report (Appendix C) and in Appendix A of the Preliminary Geo-environmental Assessment Report [59]. Groundwater samples were collected from the monitoring wells listed in Table 4-25, except for ATK-004 and ATK-015, and from the two wells installed during the preliminary GI.

Groundwater Conceptualisation

Groundwater at the site is variable in elevation based on both ground level/proximity to the Weald Brook and underlying geology. Cross sections A, B and C show that the shallow locations across the site contain water that is at a higher elevation than the level of Weald Brook. This higher elevation groundwater within shallow installations in the landfill and area surrounding the river suggests that there is a possible gravity-driven connection.

Geology present at the site, including Made Ground and landfill material directly above London Clay Formation, and the recorded low groundwater gradient in the landfill area indicate that the shallow water is perched and not connected to a substantial groundwater aquifer. This perched water is, therefore, not considered to be in direct connection to the brook and is more likely to recharge/discharge primarily from surface infiltration/evaporation.

Groundwater elevation data shows a maximum variability of approximately 2.2 m across the monitoring period with an average variability of 1.11m with higher elevations in January/February.

The three pairs of VWPs installed at the site, details of which are provided in Section 3.4, show similar variations between each pair of shallow and deep installations across the monitoring period. The data have been presented on Figure 4-2, Figure 4-3 and Figure 4-4, presented below. Location ATK-042 was set up and recorded pressure changes between September and October 2019 as well between December 2019 and February 2020. The other two locations, ATK-052 and ATK-061, only monitoring pressure in winter months between November 2019 and February 2020 and December 2019 and February 2020 respectively.

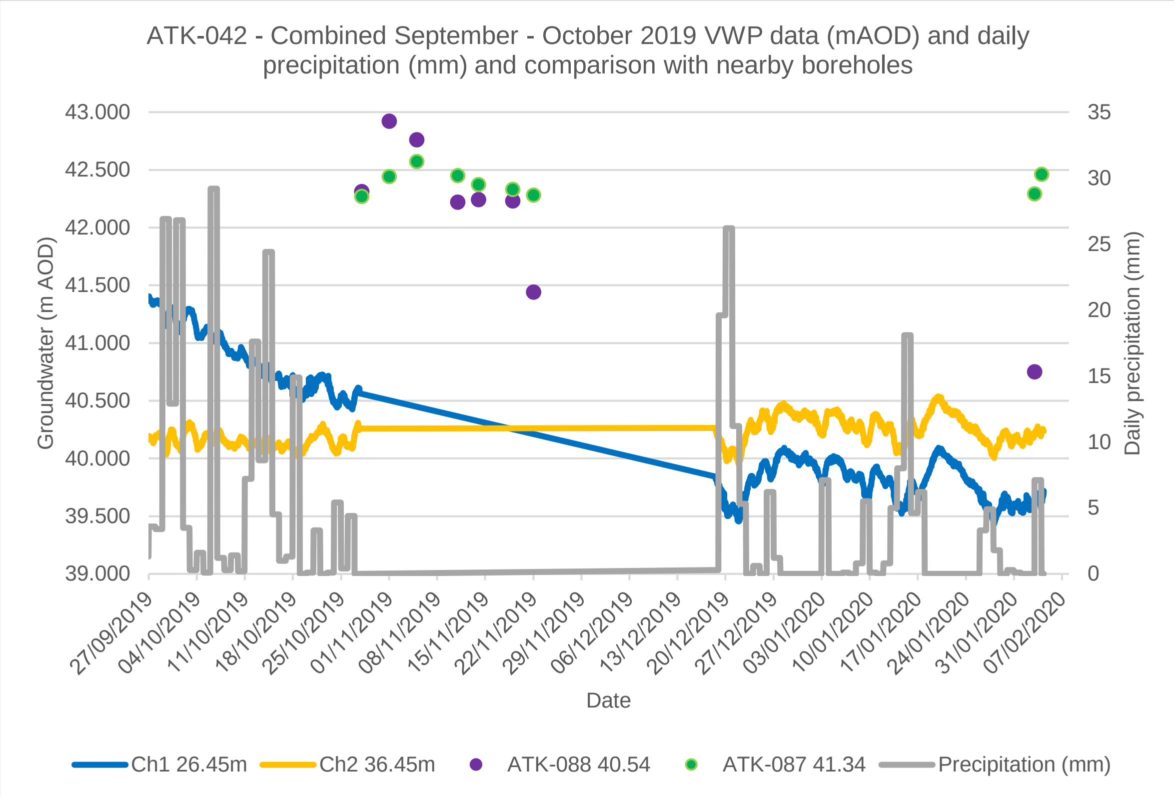

Figure 4-2 Groundwater Elevation Graph, ATK-042

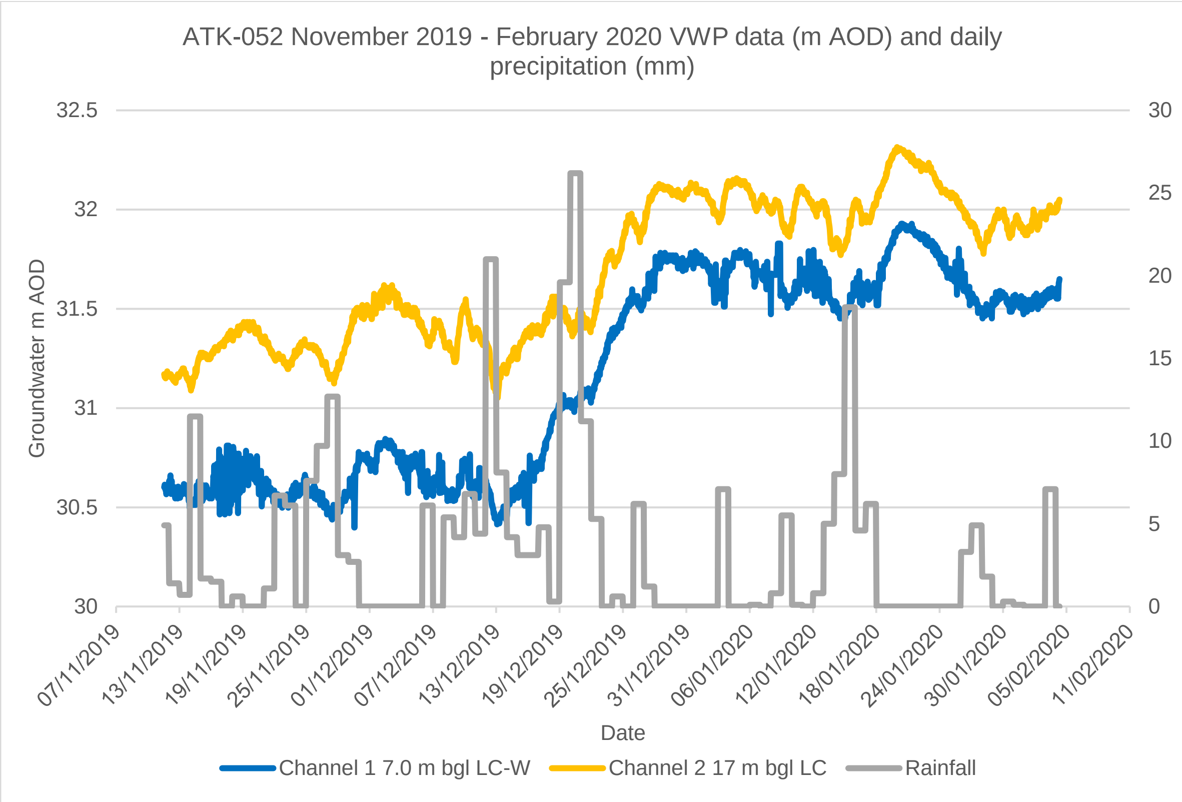

Figure 4-3 Groundwater Elevation Graph, ATK-052

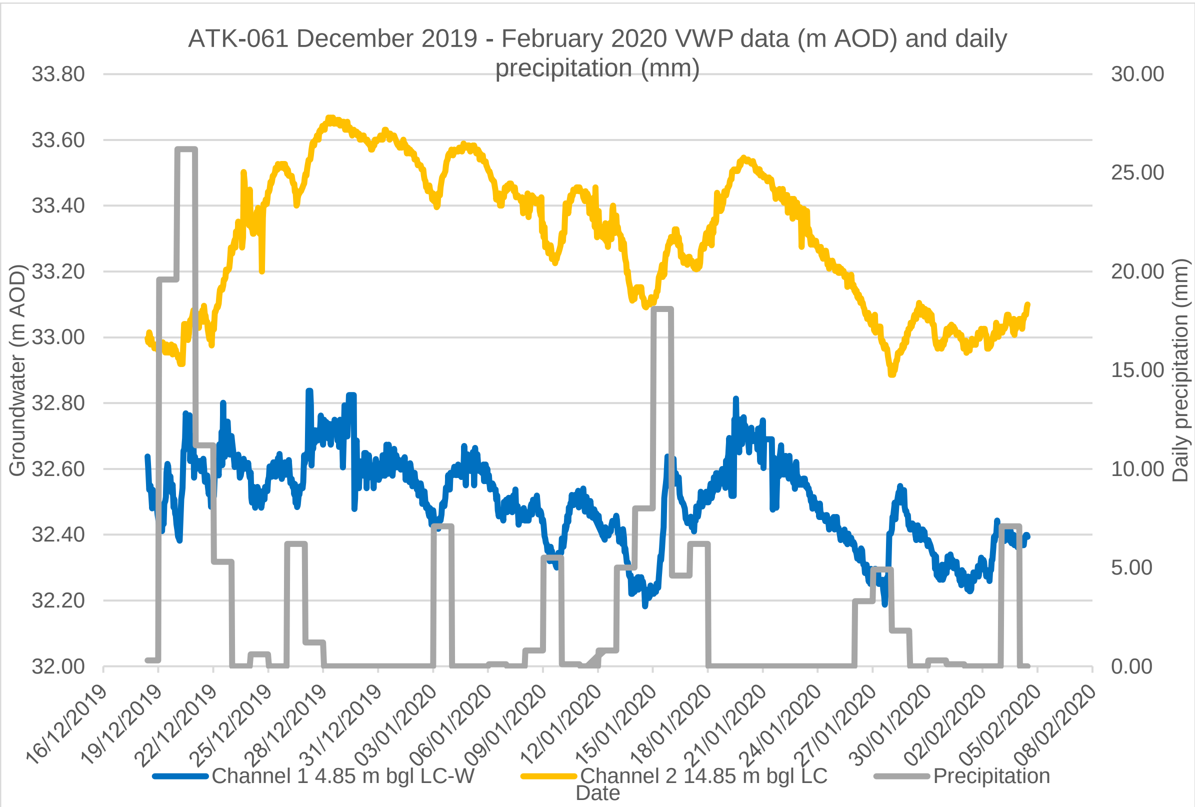

Figure 4-4 Groundwater Elevation Graph, ATK-061

The VWPs installed were non-vented, meaning that they are affected by changes in barometric pressure. The data has not been corrected; however, all three locations show similar patterns within the winter months with the deeper installation recording a higher groundwater elevation (pressure) than the shallow installation, representing an upward vertical hydraulic gradient at the site. All three locations also show peaks in groundwater elevation (pressure) after rainfall events with gradual declines and a general increase in groundwater levels between December and March.

Location ATK-042 presents a different pattern between September and October 2019 with groundwater in the deeper installation being at a lower elevation (pressure) than the shallower install. This indicates that there is a downward vertical hydraulic gradient present within the London Clay, the opposite that is observed in all three locations during the winter monitoring period. Furthermore, the deeper install shows decreasing groundwater elevations (pressure) across the monitoring period. This represents a decrease in pressure above the monitoring point. Both shallow and deep locations also show a limited response to rainfall during summer monitoring which may be the result of increased water loss from evapotranspiration during the summer months [64].

Controlled Waters GQRA Methodology

The potential risks to the identified receptors have been assessed by comparison of 61 soil-derived leachate and 60 groundwater analytical data sets against Freshwater Environmental Quality Standards (EQS-f) as set out in the 2015 Water Framework Directive (WFD) [26]. Where values are not specified within the WFD, non-statutory guidance values have been adopted to assess the potential risk to controlled waters.

The Environment Agency Water Framework Directive bioavailability tool (M-BAT) [26] has been used to derive site-specific screening values for copper, lead, manganese, nickel and zinc based on the EQS-f long-term bioavailability freshwater concentrations in line with guidance [26]. These screening values are derived from analytical data of water samples recovered from one of the receiving surface water receptors (Weald Brook). pH, calcium and DOC are required to calculate the predicted no-effect concentration (PNEC) which is defined as the concentration of a chemical which marks the limit at which below no adverse effects are expected. PNEC values are intended to be precautionary and predict the concentration at which a chemical will likely have no toxic effect.

Samples were taken from Weald Brook (SW01 considered to be located upstream from the main proposed works area and SW02 located close to the A12) during the six monitoring rounds (locations shown on Appendix E). The average pH and calcium concentrations and the median value of dissolved organic carbon were 7.86, 103.92mg/l and 12.95mg/l respectively. These values were applied to M-BAT to generate PNEC values. The M-BAT outputs are provided in Appendix I.

Under the WFD guidance, the PNEC for zinc is adjusted by the addition of a background concentration, which is dependent upon the catchment of the receiving water. Background concentrations of zinc have been published in a report produced by the Water Framework Directive – United Kingdom Technical Advisory Group (UKTAG) [65]. The background concentration for zinc based on freshwater data for the Thames catchment is 0.002 mg/l.

The PNECs generated were and used within this assessment are:

- Copper: 0.035mg/l;
- Lead: 0.016mg/l;
- Manganese:0.29mg/l;
- Nickel: 0.023mg/l; and
- Zinc: 0.056mg/l.

EQS-f for ammonium can be adjusted based on the receiving water body's elevation and alkalinity as calcium carbonate (CaCO3) as per the WFG UKTAG standards [65]. The most recent readings of the Environment Agency's Ingrebourne River monitoring point where the water passes beneath the A12 [66] (sampling point TH-PRGR0017 from 2016 to 2018) have an average CaCO3 of 158mg/l and the river is at an elevation of approximately 40m AOD. The resulting river classification for ammonia standards is Type 5. The 'high' standard for a Type 5 river is 0.3mg/l total ammonia as nitrogen.

The receiving water is classified as Class 5 as per the WFD [67] and so the EQS-f for cadmium is 0.00025mg/l.

Soil-derived Leachate Screening Results

The soil-derived leachate sample exceedances of the adopted screening criteria are summarised in Table 4-29 below. Exceedances occurred in 24 no. exploratory holes drilled in the 2019 GI and in 12 no. exploratory holes in the preliminary GI. The laboratory method detection limit (MDL) for free cyanide and hexavalent chromium exceeded their corresponding GAC and, therefore, the results reported at less than MDL have not been included in the summary as they are not considered to represent known exceedances. The MDL for mercury also exceeds the corresponding criteria however exceedances were reported within soil samples as well as within soil-derived leachate and so cannot be discounted as not representing potential exceedances. The table below presents only the exceedances where mercury was detected above MDL.

Table 4-29 Exceedances of assessment criteria within soil-derived leachate

Chemical Parameter	EQS-f /PNEC (mg/l)	Max Conc. (mg/l)	No. of excds.	Location of exceedances (Borehole ID and depth in m bgl)
Ammonium	0.3	9.1	15 (9)	ATK-017 2.40 (MG), ATK-024 2.50 (MG), ATK-026 1.50 (MG), ATK-036 0.50 (MG), ATK-086 1.80 (MG), **ATK-091 3.00 (MG)**, ATK-P-001 0.70 (MG), ATK-P-006 0.50 (MG), ATK-P-007 1.20 (MG), ATK-P-007 2.50 (MG), ATK-P-009 0.80 (MG), ATK-P-010 0.80 (MG), ATK-P-101 2.00 (MG), ATK-P-102 1.50 (MG), ATK-P-102 4.20 (MG)
Sulphate	400	2080	21 (18)	ATK-036 0.50 (MG), ATK-044 0.50 (MG), ATK-088 0.50 (MG), ATK-P-001 0.00 (MG), ATK-P-002 0.80 (MG), ATK-P-003 0.00 (MG), ATK-P-004 0.00 (MG), ATK-P-004 0.60 (MG), ATK-P-005 0.00 (MG), ATK-P-005 0.60 (MG), ATK-P-006 0.30 (MG), ATK-P-006 0.50 (MG), ATK-P-008 0.00 (MG), ATK-P-009 0.00 (MG), ATK-P-010 0.00 (MG), **ATK-P-010 0.80** (MG), ATK-P-101 0.20 (MG), ATK-P-101 0.50 (MG), ATK-P-101 1.00 (MG), ATK-P-102 0.20 (MG), ATK-P-102 1.00 (MG)

Chemical Parameter	EQS-f /PNEC (mg/l)	Max Conc. (mg/l)	No. of excds.	Location of exceedances (Borehole ID and depth in m bgl)
Trivalent chromium	0.0047	0.01	2 (1)	ATK-008 2.00 (AL), **ATK-P-102 1.50 (MG)**
Iron	1	4.2	11 (4)	**ATK-008 2.00 (AL)**, ATK-024 2.50 (MG), ATK-079 1.80 (AL), ATK-087 0.50 (MG), ATK-090 1.00 (AL), ATK-091 3.00 (MG), ATK-205 0.20 (MG), ATK-P-002 0.00 (MG), ATK-P-007 1.20 (MG), ATK-P-101 2.00 (MG), ATK-P-102 2.50 (MG)
Manganese	0.29*	0.62	5 (2)	ATK-026 1.50 (MG), **ATK-036 0.50 (MG)**, ATK-206 0.20 (MG), ATK-P-006 0.50 (MG), ATK-P-101 2.00 (MG)
Mercury	0.00007	0.001	2 (2)	ATK-P-002 0.80 (MG), **ATK-P-102 0.20 (MG)**

* Site specific EQS-f (PNECS) calculated using Environment Agency M-BAT.

Exceedances noted in **bold** denote maximum concentrations.

Exceedance numbers in brackets () denote number of exceedances previously identified preliminary GI in historical landfill/material deposition area.

Soil-derived Leachate Discussion

The method of screening soil-derived leachate data is considered a conservative approach to risk assessment for controlled waters, as the laboratory method utilises conditions to extract the leachate, which the site soils are not expected to be exposed to under normal circumstances.

Where tested, concentrations of cadmium, free cyanide, total cyanide, selenium and sulphide were all present below MDL in the soil-derived leachate results.

The majority of the exceedances in Table 4-29 are associated with shallow samples collected from less than 1.1m bgl within the footprint of the historical landfill / recently deposited material. The shallow average depth indicates that the majority of the exceedances were present within the recently deposited material. The deepest recorded exceedance was reported at 4.2m bgl (ATK-P-102) within the historical landfill. The strata logged in the footprint comprised clay dominated Made Ground over London Clay Formation. Based on the lithology of these units and the conceptual understanding presented in Section 2.4, it is considered likely that water movement and in turn migration of contamination from the Landfill / recently deposited material to identified controlled waters receptors would be limited.

Ammonium was measured at concentrations of one or the same orders of magnitude of the EQS-f in 15 no. soil-derived leachate samples from the Made Ground. Fourteen of the 15 no. samples were from the footprint of the historical landfill/ recently deposited material. The other exceedance was from a sample in ATK-017 (2.40 m bgl), between the M25 and the M25 on-slip northbound slip-road from junction 28. Weald Brook is approximately 330m to the west from this location. A groundwater strike was not encountered in this exploratory hole and no groundwater monitoring well was installed.

The EQS-f for sulphate was exceeded on 21 no. occasions from Made Ground samples. The maximum concentration was identified in ATK-P-010 from within the footprint of the historical landfill/ recently deposited material in Made Ground comprising waste concrete, underlain by weathered London Clay. All exceedances were identified at depths equal to or less than 1.0m and from the recently deposited material. London Clay is known to contain naturally elevated concentration of sulphate [68, 69].

The EQS-f for trivalent chromium was marginally exceeded in two samples, which were collected from Alluvium in ATK-008, located east of the Weald Brook north of the A12, and Made Ground in ATK-P-102, located within the historical landfill / recently deposited material. Both exceedances were within the same order of magnitude as the EQS-f. Hexavalent chromium was not detected at concentrations greater than MDL in the same soil-derived leachate samples.

The concentrations of iron measured from eight Made Ground and three Alluvium samples exceeded the EQS-f. A total of seven of the 11 elevated results were from samples obtained from exploratory holes drilled within the footprint of the historical landfill/ recently deposited material (ATK-024, ATK-087, ATK-091 and four preliminary GI locations). Iron is naturally present in elevated concentrations within the underlying weathered London Clay [68]. The concentrations which exceeded were within the same order of magnitude as the EQS-f.

The manganese PNEC was marginally exceeded in five Made Ground samples. Four of the samples, including highest observed concentration, were from locations drilled within the footprint of the historical landfill / recently deposited material. ATK-206 was drilled on land in close proximity to the former petrol filling station to the south-west of junction 28. The concentration which exceeded was the same order of magnitude as the PNEC.

Mercury exceedances were identified in two samples from shallow Made Ground within the recently deposited material at locations ATK-P002 and ATK-P-102. The most elevated concentration was identified as one order of magnitude greater than the EQS-f from location ATK-P-102.

Groundwater Screening Results

Groundwater samples have been screened against the adopted assessment criteria, exceedances of which are summarised in Table 4-30. The laboratory MDLs for benzo(a)pyrene, fluoranthene, free cyanide, hexachlorobutadiene, hexavalent chromium and total trichlorobenzene exceeded their corresponding criteria and therefore the results reported less than MDL have not been included in the summary, as they are not considered to represent known exceedances. The MDL for mercury also exceeds the corresponding criteria; however, exceedances were reported within soil samples as well as within soil-derived leachate and so cannot be discounted as not representing potential exceedances. The table below presents only the exceedances where mercury was detected above MDL in groundwater.

Table 4-30 Exceedances of assessment criteria within groundwater

Chemical Parameter	EQS-f /PNEC (mg/l)	Max Conc. (mg/l)	No. of excds.	No. of occasions exceeded, Well ID and screen section
Ammonium	0.3	19	37	No.1 in ATK-008 (AL); No.4 in ATK-003 (MG); No.3 in ATK-048 (LC-W); No.1 in ATK-079 (AL); No.3 in ATK-086 (MG); No.4 in ATK-087 (MG); No.3 in ATK-088 (MG); No.4 in ATK-089 (AL); No.4 in **ATK-091** (MG/LC-W); No.4 in ATK-092 (MG/LC-W); No.3 in ATK-P-101 (MG); No.3 in ATK-P-102 (MG)

Chemical Parameter	EQS-f /PNEC (mg/l)	Max Conc. (mg/l)	No. of excds.	No. of occasions exceeded, Well ID and screen section
Chloride	250	770	10	No.4 in ATK-003 (MG); No.1 in **ATK-079** (AL); No.3 in ATK-092 (MG/LC-W); No. 2 in ATK-P-101 (MG)
Sulphate	400	4560	37	No.1 in ATK-008 (AL); No.4 in **ATK-003** (MG); No.2 in ATK-014 (AL); No.3 in ATK-048 (LC-W); No.3 in ATK-056 (AL); No.1 in ATK-079 (AL); No.3 in ATK-086 (MG); No.4 in ATK-087 (MG); No.3 in ATK-088 (MG); No.2 in ATK-089 (AL); No.4 in ATK-090 (AL); No.4 in ATK-092 (MG); No.3 in ATK-P-101 (MG)
Boron	2	4.6	1	No.1 in ATK-006 (AL, HD, LC-W)
Cobalt	0.003	0.04	38	No.4 in ATK-003 (MG); No.3 in **ATK-006** (AL, HD, LC-W); No.3 in ATK-048 (LC-W); No.2 in ATK-056 (AL); No.1 in ATK-079 (AL); No.3 in ATK-086 (MG); No.3 in ATK-087 (MG); No.3 in ATK-088 (MG); No.4 in ATK-089 (AL); No.2 in ATK-090 (AL); No.2 in ATK-091 (MG/LC-W); No.2 in ATK-092 (MG); No.3 in ATK-P-101 (MG); No.3 in ATK-P-102 (MG)
Iron	1	140	25	No.1 in ATK-003 (MG); No.3 in ATK-006 (AL, HD, LC-W); No.3 in ATK-048 (LC-W); No.1 in ATK-079 (AL); No.1 in ATK-086 (MG); No.4 in ATK-087 (MG); No.2 in ATK-088 (MG); No.1 in ATK-089 (AL); No.3 in ATK-091 (MG/LC-W); No.3 in ATK-092 (MG); No.3 in **ATK-P-102** (MG)
Manganese	0.29*	11	48	No.1 in ATK-008 (AL); No.4 in ATK-003 (MG); No.3 in ATK-005 (AL); No.3 in **ATK-006** (AL, HD, LC-W); No.1 in ATK-014 (AL); No.3 in ATK-048 (LC-W); No.3 in ATK-056 (AL); No.1 in ATK-079 (AL); No.3 in ATK-086 (MG, LC-W); No.3 in ATK-087 (MG); No.3 in ATK-088 (MG); No.4 in ATK-089 (AL); No.3 in ATK-090 (AL); No.3 in ATK-091 (MG, LC-W); No.4 in ATK-092 (MG); No.3 in ATK-P-101 (MG); No.3 in ATK-P-102 (MG)
Mercury	0.00007	0.00012	2	No.1 in **ATK-087** (MG); No.1 in ATK-P-102 (MG)
Nickel	0.023*	0.029	3	No.3 in ATK-006 (AL, HD, LC-W)
Phenol	0.0077	0.01	1	No.1 in ATK-092 (MG)

Exceedances noted in **bold** denote location of maximum concentration of determinand.

* Site specific EQS-f (PNEC) calculated using Environment Agency M-BAT.

Groundwater Discussion

The majority of chemical parameters that exceed their respective EQS-f were within one order of magnitude, except for ammonium, sulphate, iron and manganese.

Ammonium exceeded the EQS-f by two orders of magnitude in a number of the groundwater samples. All exceedances of one or greater orders of magnitude were from locations within the historical landfill/ recently deposited material. Ammonium could be present as a result of the long-established agricultural use of nearby land, the decomposition of inert waste material or from breakdown of organic material.

Sulphates concentrations are expected to be elevated across the site as a result of naturally occurring minerals such as pyrite and gypsum within the London Clay. Iron EQS-f was exceeded by two orders of magnitude. Similar to the sulphate concentrations, iron could be present as a result of weathering of pyrite in the London Clay. Exceedances of sulphate and iron, including the most elevated concentrations, were primarily located within the historical landfill/ recently deposited area. The most elevated concentration outside the historical landfill area was from ATK-048, located north of the historical landfill area.

The elevated manganese concentrations, primarily located within the historical landfill/ recently deposited material, are potentially naturally occurring in the groundwater as a result of weathered London Clay [68]. Other possible sources could be from fertilisers and fungicides, with the maximum concentrations identified in ATK-06 located west of the Weald Brook.

Phenol exceeded the EQS-f in one groundwater sample from a monitoring well centred within the historical landfill/ recently deposited material. In the remainder of the groundwater samples tested phenol was not detected above MDL, therefore, this isolated occurrence of one order of magnitude above the EQS-f is not considered representative of an unacceptable risk.

The chemical parameters measured in groundwater samples, except trivalent chromium, were more elevated than those measured in soil-derived leachate samples. This could be a result of accumulation in perched water due to limited migration suggested by the elevation data; the likely recharge/discharge mechanisms are likely concentrating concentrations of determinands within the perched water.

Surface Water Results

Weald Brook has an entirely rural upstream catchment and has a natural floodplain approximately 100 m wide [70]. Surface water samples from Weald Brook were collected from upstream and downstream of the historical landfill/ recently deposited material during the post GI monitoring. Sampling locations are presented in Appendix E.

Table 4-31 below shows the chemical parameters that were measured in soil-derived leachate and groundwater and the location where the highest concentration (if present above MDL) was obtained on the Weald Brook during each monitoring round. This was undertaken to determine whether the downstream concentrations from the Weald Brook (SW2) are similar to the upstream (SW1) results or are impacted by the historical landfill material.

Table 4-31 Summary of surface water analysis (Weald Brook)

Determinand	Location of highest concentration in surface water samples per round						
	1	2	3	4	5	6	Per determinand
Sulphate	SW01	SW02	SW02	SW02	SW01	SW02	Down-stream
Chloride	Equal	SW01	SW01	SW02	SW01	SW02	Up-stream
Ammonium	SW01	SW01	SW01	SW02	SW01	SW02	Up-stream
Boron	SW01	SW02	SW01	SW02	SW01	SW02	Equal
Chromium	SW02	SW02	SW01	SW02	SW01	equal	Down-stream
Cobalt	SW01	Equal	SW01	SW01	SW01	SW02	Up-stream
Iron	SW02	SW02	SW02	SW01	equal	SW01	Down-stream
Manganese	SW01	SW02	SW01	SW01	SW01	SW02	Up-stream

Nickel	SW01	SW02	SW01	SW02	SW01	SW02	Equal
Per round	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream	

Overall, the range of concentrations detected in the surface water samples suggest there is no apparent change between upstream and downstream of the historical landfill/ recently deposited material when observed per monitoring round. However, marginally more chemical parameters are detected at higher concentrations at the upstream monitoring point.

The surface water results have been screened against the adopted criteria. Copper, lead, nickel and zinc did not exceed the PNEC values, therefore, it is considered that soil and groundwater within the scheme is currently not impacting the surface water course and, as such, does not represent an unacceptable risk to the quality of water in the Weald Brook;

Iron, sulphate and manganese which were present two orders of magnitude higher than the assessment criteria in groundwater samples, were not detected at concentrations that exceeded the assessment criteria in the surface water.

Ammonium exceeded the EQS-f on five occasions in both upstream and downstream samples. The maximum concentration detected was within a sample collected from SW01. This exceedance was two orders of magnitude greater than the EQS-f.

Controlled Waters Risk Assessment Conclusions

Chemical parameters have been detected at elevated levels within the soil-derived leachate and in groundwater samples collected within the historical landfill/ recently deposited material area. The differences in concentrations, elevation data and geology suggest that perched water is relatively static within the relatively impermeable strata and not significantly migrating towards identified controlled waters receptors. Given the magnitude of exceedances and the lack of a significant pathway between the historical landfill/ recently deposited material area and the Weald Brook, there is not currently considered to be an unacceptable risk to controlled waters from this source.

Ammonium was measured at concentrations that exceeded the EQS-f in groundwater and soil-derived leachate samples from across the site and in various soil types. However, ammonium was also measured at concentrations that exceeded the EQS-f from Weald Brook samples upstream and downstream of the historical landfill. Elevated ammonium concentrations may therefore be generally elevated in the wider environment in the Weald Brook catchment.

Both a potential source, elevated ammonium concentrations in shallow (potentially perched) groundwater, and a potential receptor, the Weald Brook, have been identified at the site. However, the pollutant linkage is uncertain as there is only a limited viable pathway between them. It is recommended that this linkage is considered during the development of the detailed design to ensure that construction and operation of the scheme does not result in an increase in risk to surface water bodies from the creation of a potential pathway between the identified source and receptor. Alternatively, that suitable mitigation is proposed to remove the potential source of contamination.

4.10.3 Updated Conceptual Model

In line with Environment Agency guidance [71], the outline CM as presented in the Environmental Statement [1] has been updated and revised based on the findings of the ground investigation, collection and interrogation of site data, and GQRA presented within this report. This process has allowed the S-P-R linkages recorded in the outline CM to be reassessed and for relevant pollutant linkages (RPLs) to be identified.

A qualitative assessment of the level of risk associated with each RPL has been undertaken based on the recommendations of R&D66 [72] this is provided within the updated CM. In line with R&D66, where a risk level of moderate or above has been assessed, further assessment and possible remedial measures may be required.

The updated CM is provided in Appendix D and a summary of risk classifications is provided below.

Based on the updated CM and qualitative assessment of risk the impact assessment presented in the Environmental Statement soils and geology chapter [1] has been updated and is presented in Appendix D. For full details on the methodology for the impact assessment refer to the Environmental Statement [1].

With design and mitigation measures including the adoption of best available techniques, the impact assessment indicates that the construction with mitigation and operational phase would have negligible to minor beneficial, permanent effects and are assessed as not significant.

Human Health Risks

Based on the available GI data, the assessment found that the current risks associated with human health generally vary between Very Low and Moderate / Low (baseline). It is considered that during construction, the implementation of standard good working practice, mitigation through design and the other mitigation measures recommended in Appendix D will ensure that risks associated with construction are low Therefore, based on the available information, no further assessment or additional remedial measures (beyond which have already been specified) are considered necessary.

Risks associated with inhalation, ingestion and/or dermal contact with chemical parameters in soil, soil-derived dust and ACM fibres were generally found to be acceptable. These were generally assessed as Very Low and Low risks during construction (with mitigation) and during operation. A potential Low to Moderate/Low risk level of risk was identified to construction workers during construction, although this can be reduced to acceptable levels through appropriate mitigation measures as specified in Appendix D. This elevated level of risk is predominantly due to the presence of asbestos fibres at isolated locations across the site. Beryllium was also found to be present in exceedance of the GAC at one location, although the level of risk from this exceedance is considered to be very limited given that it was isolated, non-volatile, located at depth and only marginally elevated compared to the GAC.

Surface water and groundwater were not indicated to pose an unacceptable risk to human health with a very low to low level of risk generally identified. Chemical testing and visual / olfactory evidence generally did not indicate that gross contamination was present in groundwater or surface waters and there will be a limited potential for -S-P-R linkages to be formed assuming appropriate mitigation measures are adopted during construction.

The risk from ground gas was generally found to be Moderate / Low due to localised elevated concentrations of carbon dioxide and methane with a reduced level of risk outside these areas. Given the distance from these localised areas to habitable buildings, it is considered that an unacceptable risk from ground gas is not present.

Controlled Waters Risks

Groundwater monitoring undertaken as part of the 2019 GI has indicated that shallow groundwater, particularly in areas of landfill / recently deposited material, is perched. The limited potential for lateral migration between or from perched groundwater has been reflected in the unlikely likelihood assigned to the relevant pollutant linkages in the CM. This applies to baseline, construction with mitigation and operational scenarios, but not construction without mitigation which could potentially enable lateral migration of previously perched water through the creation of temporary pathways (e.g. excavations, dewatering).

Screening of soil-leachate and groundwater results from the site have identified limited exceedances except for ammonium, sulphate, iron and manganese. Sulphate, iron, and manganese are naturally abundant in the London Clay geology underlying the site. Ammonium is also elevated in the wider area as evidenced from upstream surface water samples. Therefore, the consequences associated with potential on-site contaminant sources have been reduced from Medium to Mild, given the absence of significant hazardous contaminants or those which are not present widely in the surrounding area.

The likelihood of relevant pollutant linkages between the landfill and surface water receptors has been increased during construction without mitigation, This is based on the exceedances of GAC within the landfill, particularly the elevated concentrations of ammonium that have been proven. Without mitigation there is potential for a linkage between the landfill and the surface water course. As a consequence, the risk to Weald Brook and the River Ingrebourne and proposed attenuation ponds from migration of perched / shallow groundwater and / or surface water via preferential pathways (e.g. attenuation ponds (if unlined) and pond outfalls) is considered Moderate. It has been recommended that this is considered during detailed design to ensure that this potential risk is managed, such that no adverse effects are caused to surface water receptors. All other controlled waters risks during baseline, construction and operation have been assessed as Moderate / Low risk, Low risk, or Very Low risk.

4.11 Waste Assessment

4.11.1 Introduction

Excavated material which is surplus to design and construction requirements, and which is intended or required to be discarded, is classified as waste and should be managed in accordance with relevant waste legislation.

Waste classification is required for excavated material which is transferred off site for processing, treatment or disposal. WAC testing is also required for waste requiring disposal, to determine the appropriate class of landfill.

This section sets out the preliminary waste classification of material sampled, tested and analysed as part of the 2019 GI. It should be noted that the assessment is based on a limited number of samples collected from *in situ* material, and it is the responsibility of the earthworks contractor as the waste producer to classify, treat, manage and dispose of the waste appropriately, in accordance with relevant waste guidance and legislation.

4.11.2 Results and Discussion

A total of 23 no. composite samples were tested for a range of parameters and chemical testing suites. The details of the testing suites and the laboratory certificates for the samples are provided in the Factual Ground Investigation Report [24].

The Atkins online waste classification tool CATWaste Soil [73] was used for the assessment of the anticipated waste soils and their classification as either hazardous and non-hazardous waste. The outputs of the CATWaste Soil tool are provided in Appendix K.

All the samples assessed were classified as non-hazardous.

Asbestos was positively identified in three of the 33 no. samples tested for this parameter. A summary of the samples and locations where asbestos was identified is provided in Table 4-27. All measured asbestos concentrations were 0.001%, below the hazardous waste threshold of 0.1%. The asbestos was recorded as free fibres and sheeting/board debris.

Overall, asbestos was not associated with a particular area within the Scheme or geological unit, but it is assumed to be more prevalent within the Made Ground – Recently Deposited Material.

Twenty-three (23 no.) composite samples were tested for WAC and the data reviewed against the relevant thresholds for the different classes of landfill. A summary of the results is provided in Table 4-32 below.

Table 4-32 Waste Acceptance Criteria Summary

Exploratory hole	Depth (m bgl)	Stratum	WAC classification	Compounds*
ATK-005	0.30-1.20	Head	Inert	
ATK-014	1.00-3.00	Alluvium	Non-Hazardous	Sulphate
ATK-022	0.1-0.8	Made Ground – Engineered Fill	Non-Hazardous	Fluoride
ATK-022	1.20-1.40	London Clay Formation	Non-Hazardous	Fluoride
ATK-024	1.80-3.00	Made Ground – Landfill	Inert	
ATK-027	0.20-1.00	Made Ground – Recently Deposited Material	Inert	
ATK-028A	1.20-3.20	Made Ground – Landfill	Non-Hazardous	Fluoride
ATK-030	0.20-0.50	Made Ground – Recently Deposited Material	Non-Hazardous	Fluoride
ATK-030	3.00-3.50	London Clay Formation	Non-Hazardous	Fluoride
ATK-034	0.20-0.40	Made Ground – Recently Deposited Material	Non-Hazardous	Sulphate. Total dissolved solids

Exploratory hole	Depth (m bgl)	Stratum	WAC classification	Compounds*
ATK-035	0.25-0.70	Head	Inert	
ATK-035	0.25-3.00	Head	Inert	
ATK-044	0.40-1.30	Made Ground - Landfill	Non-Hazardous	Sulphate
ATK-048	0.30-0.60	Head	Inert	
ATK-058	0.30-1.20	Head	Inert	
ATK-065	1.20-3.90	London Clay Formation	Non-Hazardous	Sulphate
ATK-069	0.50-1.00	Head	Inert	
ATK-071	0.20-0.80	Head	Inert	
ATK-080A	0.30-0.50	Made Ground - Undifferentiated	Inert	
ATK-093	0.25-1.40	Head	Inert	
ATK-098	0.25-2.00	Made Ground – Undifferentiated / Head	Inert	
ATK-202	0.40-0.80	Head	Non-Hazardous	Fluoride
ATK-205	0.00-0.60	Made Ground - Undifferentiated	Inert	

* Compounds listed have exceeded inert threshold and triggered non-hazardous class based on the WAC analysis.

The WAC results indicate that overall material at the site is suitable for disposal as non-hazardous waste, with certain geological units (e.g. Head) and areas within the Scheme potentially being classified as inert. However, further testing and physical/visual inspection will be required to be undertaken by the Earthworks Contractor to characterise and classify waste prior to disposal.

Waste segregation and sustainable materials management should be employed by the Earthworks Contractor during the works, to ensure that materials re-use within the Scheme is maximised, and where surplus materials requires removal from site, waste is classified correctly, and that waste disposed of at landfill is minimised.

5. Geotechnical and Geo-environmental Risk Register

5.1 Introduction

Geotechnical Risk is defined as the possibility of an adverse consequence arising from a ground hazard or circumstance.

The Geotechnical Risk Register considers the identified geotechnical constraints for the Scheme at the time, along with additional project details to ensure that all known significant geotechnical risks are identified, recorded, analysed and controlled. The geotechnical risks are discussed in terms of likelihood, severity and risk, as defined below:

Likelihood (L): The perceived likelihood of the identified geotechnical hazard occurring (defined as a rating in).

Severity (S): The perceived severity, in terms of capital cost, programme, safety, environment and reputation, of the occurrence of the identified geotechnical hazard on the identified receptor (s) (defined as a rating in).

Risk (R): The perceived level of concern which should be assigned to the identified hazard, based on the likelihood of occurrence, and taking into account the perceived severity of the impact.

The Geotechnical Risk Register and terminology adopted for this project is based on Highways England (2019) [6] on managing geotechnical risk. It is a semi-quantitative assessment based on engineering judgement. The classification of likelihood and severity used in this Geotechnical Risk Register is summarised in Table 5-1. The degree of risk is determined through the Risk Matrix Table 5-2, which uses the equation:

$$Degree\ of\ Risk\ (R) = Likelihood\ (L)\ x\ Severity\ (S)$$

The explanation of the Risk Classification is given Table 5-3, which gives the assessed risk level and appropriate actions.

The hazards identified for this project are set out in the Geotechnical Risk Register, which is a ‘live’ document and will need to be updated regularly.

The Scheme is progressing as a Single Option scheme. A risk register for the Scheme is presented in Table 5-4 and includes risks relating to geotechnical and construction works. The geotechnical and geo-environmental risks for the Scheme shall continually be reassessed, and the risk register updated in the Geotechnical Design Report (GDR).

Table 5-1 Likelihood and Severity Ratings

Likelihood		Severity	
5	**Almost certain.**	5	**Catastrophic** Catastrophic loss or damage (multiple fatalities)
4	**Extremely likely**	4	**Major** Major damage or loss (fatal injury)
3	**Likely**	3	**Serious** Substantial damage or loss (serious injury or illness)
2	**Unlikely**	2	**Moderate** Moderate damage or loss (slight injury or illness)
1	**Extremely unlikely**	1	Minor Minor damage or loss (no human injury)

Table 5-2 Risk Matrix

		Likelihood				
		1	2	3	4	5
Severity	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

Table 5-3 Risk Classification

Risk Classification	
Low (1-8)	Ensure assumed control measures are maintained and reviewed as necessary.
Medium (9-19)	Additional control measures needed to reduce risk rating.
High (20-25)	Activity is not permitted. Hazard to be avoided or risk to be reduced to a tolerable level.

5.2 Risk Register

Table 5-4 Risk Register for Scheme Geotechnical and Environmental Risks

Hazard Reference	**Hazard:** Activity/Process/ Material/Element	**Consequence:** (also indicate what is the risk)	Stage of Work	Initial Risk Level			Risk Control Measures: Design action taken, record of decision process including option considered, design constraints and justification for options/actions not having been taken	Residual Risk Level			Is there a 'significant' residual risk to be passed on? (Y/N)	Status (Active / Closed)
				Likelihood	Severity	Risk Level		Likelihood	Severity	Risk Level		
Design and build risks												
1	Ground conditions differ to that expected	Designs not appropriate for encountered conditions and would lead to instability and/or long term serviceability issues. Redesign required. Risk of programme delays, cost implications.	Construction	3	2	6	1. Should the proposed design change substantially at PCF5 or should uncertainties regarding the ground conditions arise following the GI, supplementary GI may be required. 2. Continuous monitoring during construction by an engineering geologist or geotechnical engineer is advised.	1	2	2	Y	Active
2	High Groundwater table, water ingress into excavations and perched groundwater	Excavations flooded causing instability during construction and difficulties in construction. Redesign required. Risk of programme delays, cost implications.	Construction	3	3	9	1. Further groundwater level monitoring undertaken as part of the post-GI to inform fluctuation. 2. Should the proposed design change substantially at PCF5 or should uncertainties in the ground conditions arise following the GI, supplementary GI may be required. 3. Continuous monitoring during construction by an engineering geologist or geotechnical engineer is advised.	2	3	6	Y	Active
3	Presence of ground conditions with shrink-swell potential (e.g. Head Deposits & London Clay Formation)	Post construction structural damage. Redesign required. Risk of programme delays, cost implications, long term maintenance costs, disruption and damage to reputation.	Construction and maintenance	3	2	6	1. All works undertaken in accordance with current standards and best practice. 2. Highways England Managing Agent Contractor to identify acceptable limits for development tolerances. Information relating to geotechnical defects (including HAGDMS) caused by earthwork and structural settlement during maintenance and operation reviewed to identify and manage problematic ground conditions. 3. Ground improvement to be designed and implemented if deemed necessary at PCF5.	2	2	4	Y	Active
4	Encountering soft/low strength ground conditions (e.g. Made Ground, Alluvium and Head) and potential relict shear surfaces at residual strength present within Head Deposits	Post construction structural damage. Redesign required. Risk of programme delays, cost implications, long term maintenance costs, disruption and damage to reputation.	Construction and maintenance	5	3	15	1. All works undertaken in accordance with current standards and best practice. 2. Should soft/low strength ground conditions be encountered, or relict shear surfaces anticipated; the use of ground improvement techniques may be required for specific structures, to be determined at PCF5. 3. Continuous monitoring during construction by an engineering geologist or geotechnical engineer is advised.	2	3	6	Y	Active
5	Foundation stratum changes along length of proposed earthworks / structures with variable strength and geotechnical properties	Post construction structural damage such as differential settlement. Redesign required. Risk of programme delays, cost implications, long term maintenance	Construction and maintenance	4	3	12	1. All works undertaken in accordance with current standards and best practice. 2. Geotechnical supervision required for the duration of the earthworks program, with considerable attention to key areas where foundation stratum considered to vary laterally.	2	3	6	Y	Active

Hazard Reference	**Hazard:** Activity/Process/ Material/Element	**Consequence:** (also indicate what is the risk)	Stage of Work	Initial Risk Level			Risk Control Measures: Design action taken, record of decision process including option considered, design constraints and justification for options/actions not having been taken	Residual Risk Level			Is there a 'significant' residual risk to be passed on? (Y/N)	Status (Active / Closed)
				Likelihood	Severity	Risk Level		Likelihood	Severity	Risk Level		
		costs, disruption and damage to reputation.					3. Should the proposed design change substantially at PCF5 to account for the change in stratum or should uncertainties in the ground conditions arise following the GI supplementary GI may be required. 4. If variable, poor ground conditions encountered, the use of ground improvement techniques may be required.					
6	Encountering hardgrounds in the London Clay Formation (e.g. cementstone nodules and disseminated pyrite) and Alluvium (gravel layer at base of stratum).	Piled foundations unable to get to design depth. Redesign or alternative construction methods required. Risk of programme delays, cost implications.	Construction	3	3	9	1. Adequate GI undertaken to inform material properties, behaviour and anticipated spatiality. 2. All works undertaken in accordance with current standards and best practice. 3. Where unanticipated hard layers are encountered at shallow depths hindering development, appropriate pneumatic plant or localised blasting may be required for removal. 4. The pile foundation installation technique should make allowance for unanticipated hard layers encountered at depth.	2	3	6	Y	Active
7	Presence of aggressive ground conditions for concrete	Post construction structural damage causing longterm instability and serviceability issues. Redesign required. Risk of programme delays, cost implications, long term maintenance costs, disruption and damage to reputation.	Construction and maintenance	4	3	12	1. Concrete is to be specified as per BRE SD1 guidance and classifications presented in this report.	2	3	6	Y	Active
8	Presence of potentially contaminated ground (including asbestos), and localised groundwater	Coming into contact with contaminated ground/groundwater, waste disposal and potential redesign required. Potential for inhalation of asbestos fibres and contaminated dust in localised areas Risk of injury or illness to site personnel, the public and end user, programme delays and cost implications.	Construction	3	3	9	1. Contractors to wear appropriate PPE at all times and to consider detailed health and safety procedures for executing required works should contamination be present. 2. Where unidentified contamination is identified further assessment may be required and a remediation strategy may be necessary to suitably manage the hazard. 3. Where contamination or asbestos are identified, it is to be considered with regards to its influence on the proposed design and in relation to the S-P-R principle. The design should ensure that unacceptable risks from localised asbestos and contamination are not present. 4. Supplementary ground investigation and testing to better delineate areas of significant contamination may be required. 5. In regard to asbestos, a suitably qualified and experienced asbestos specialist should be appointed to assess the level of risk and appropriate mitigation measures.	1	3	3	Y	Active
9	Destabilisation of excavation side walls or of existing slopes due to	Collapse of excavations or landslides. Risk of injury or fatality to site personnel or members of the public,	Construction	3	3	9	1. Design of natural cut slopes to be undertaken in accordance with the current guidance and best practice.	2	3	6	Y	Active

Hazard Reference	**Hazard:** Activity/Process/ Material/Element	**Consequence:** (also indicate what is the risk)	Stage of Work	Initial Risk Level			Risk Control Measures: Design action taken, record of decision process including option considered, design constraints and justification for options/actions not having been taken	Residual Risk Level			Is there a 'significant' residual risk to be passed on? (Y/N)	Status (Active / Closed)
				Likelihood	Severity	Risk Level		Likelihood	Severity	Risk Level		
	excavation (e.g. Made Ground, Head Deposits)	programme delays, damage of reputation and cost implications.					2. Slope stability design to take account of Scheme wide and targeted GI to inform characteristic design parameter selection. 3. A competent Contractor shall be employed to carry out site works. 4. Highways England shall agree Risk Assessment & Method Statements (RAMS) prior to the start of works. 6. Geotechnical supervision required for the duration of earthworks program.					
10	Piling works in contaminated ground	Opening of contamination pathways during piling work. Risk of contamination of groundwater or further soils, injury or illness to site personnel or the public, programme delays, damage of reputation and cost implications.	Construction	3	3	9	1. Piling risk assessment shall be produced. 2. Options appraisal to be undertaken to determine most suitable piling technique. Method to be agreed by Geotechnical Team prior to design. 3. A competent Contractor shall be employed to carry out site works. 5. Highways England shall agree RAMS prior to the start of works. 6. Principal Contractor shall be appointed prior to the start of works. 7. Geotechnical supervision required for the duration of geotechnical site activities.	2	3	6	Y	Active
11	Settlement of carriageway (differential, excessive; including from Made Ground, Head Deposits and Alluvium, as well as infilled waterbodies)	Structural damage to carriageway, services and related assets. Risk of long-term maintenance costs, disruption and damage to reputation.	Construction and maintenance	3	3	9	1. Ground improvement to be designed and implemented if deemed necessary at PCF5. 2. Design pavement thickness to be determined in accordance with DMRB Highways Standards. 3. Should CBR achieved during construction validation testing be found lower than design CBR proposed, Client Engineer to be notified immediately.	2	3	6	Y	Active
12	Interaction with known existing structures (existing highways infrastructure, BPA line, overhead powerlines and Cadent gas line).	If services damaged or struck during works, there is the potential for a catastrophic loss of life event. Risk of injury or fatality to site personnel or members of the public, programme delays, cost implications, disruption and damage to reputation.	Construction	4	5	20	1. Highways England to provide latest set of as-built drawings containing existing Highway infrastructure and services (including culverts). 2. Scheme proposals include realignment of a Cadent gas line to ensure it is not located below proposed structures due to loading considerations. 3. Assessment of existing Highway infrastructure, BPA line and other services to be included in GDR and detailed design.	2	5	10	Y	Active

Hazard Reference	**Hazard:** Activity/Process/ Material/Element	**Consequence:** (also indicate what is the risk)	Stage of Work	Initial Risk Level			Risk Control Measures: Design action taken, record of decision process including option considered, design constraints and justification for options/actions not having been taken	Residual Risk Level			Is there a 'significant' residual risk to be passed on? (Y/N)	Status (Active / Closed)
				Likelihood	Severity	Risk Level		Likelihood	Severity	Risk Level		
13	Unidentified existing Highways infrastructure and services (including culverts, wells and disused water mains)	Structural damage to existing unidentified highways infrastructure which may damage existing carriageway or services. Additional design to mitigate encountered infrastructure may be required. Risk of programme delays, cost implications.	Construction	3	4	12	1. Highways England to provide latest set of as-built drawings containing existing Highway infrastructure and services (including culverts). 2. Assessment of existing Highway infrastructure and services to be included in GDR and detailed design.	2	4	8	Y	Active
14	Existing earthwork defects and unidentified or developing defects within Highways England's responsibility (M25 and A12)	Instability of existing asset, resulting in landslides and/or damaged to existing carriageway, services and related assets. Design and construction of mitigations may be required. Risk of Injury or fatality to site personnel or the public, programme delays, damage of reputation, cost implications.	Construction and maintenance	3	3	9	1. Two existing 1D geotechnical defects were recorded within the Scheme boundary on HAGDMS prior to the GI, both indicating minor slips. One defect is situated at the location of a proposed cutting widening and the other adjacent to a proposed gantry location. 2. Designer to carry out repeat inspections within the area of the proposed Scheme and consider presence of defect and potential residual shear strengths within design at PCF5. 3. Assessment of earthwork during and post-construction.	2	3	6	Y	Active
15	Existing earthwork defects and unidentified or developing defects affect land outside of Highways England responsibility	Instability of existing asset, resulting in landslides and/or damaged to existing carriageway, services and related assets. Design and construction of mitigations may be required. Risk of Injury or fatality to site personnel or the public, programme delays, damage of reputation, cost implications.	Construction and maintenance	3	3	9	1. Where appropriate earthwork defects are included within the GIR. 2. Where appropriate, design should take into account the stability of areas outside of Highways England's responsibility to ensure they are not negatively impacted by the proposed works. 3. Geotechnical supervision of geotechnical construction works is recommended.	2	3	6	Y	Active
16	Accidental flooding of carriageway, or flood water potentially impounded behind the proposed structures during a flood event.	Post construction structural damage through internal and external erosion of the embankment and stratum below the earthwork leading to long term instability of asset. Redesign required. Risk of programme delays, cost implications, long term maintenance costs, disruption in operation and damage to reputation.	Construction and maintenance	3	4	12	1. Impacts of climate change and accidental groundwater conditions to be taken forward in detailed design. 2. Designer is to consider potential for water to be impounded behind structures and whether internal and external erosion mechanisms should be considered. 3. Should the proposed design change substantially at PCF5 or should uncertainties regarding the ground conditions arise following the GI, supplementary GI may be required.	1	4	4	Y	Active
17	Scour or Erosion of foundations situated adjacent to Weald Brook or Ingrebourne River	River erosion may potentially undermine foundations resulting in loss of support and post construction structural damage. Long term maintenance costs, disruption in operation and damage to reputation.	Maintenance	3	4	12	1. Impacts of climate change and accidental groundwater conditions to be taken forward in detailed design. 2. Designer should consider areas susceptible to scour or erosion and ensure mitigations in place to prevent failure within or structural damage within design life.	2	4	8	Y	Active

Hazard Reference	**Hazard:** Activity/Process/ Material/Element	**Consequence:** (also indicate what is the risk)	Stage of Work	Initial Risk Level			Risk Control Measures: Design action taken, record of decision process including option considered, design constraints and justification for options/actions not having been taken	Residual Risk Level			Is there a 'significant' residual risk to be passed on? (Y/N)	Status (Active / Closed)
				Likelihood	Severity	Risk Level		Likelihood	Severity	Risk Level		
							3. Should the proposed design change substantially at PCF5 or should uncertainties regarding the ground conditions arise following the GI, supplementary GI may be required					
18	Variability of strata for material re-use, notably fine/coarse horizons of Head Deposits which could be mixed resulting in noncompliant material.	Instability or construction difficulties for earthworks constructed from site won material which may result in post construction structural damage. Redesign may be required or importing of fill material. Risk of programme delays, cost implications, long term maintenance costs, disruption in operation and damage to reputation.	Construction	4	2	8	1. Subject to material re-use assessment, careful management of excavated material is required to ensure it is not mixed of different constituents and a single product of single stratum type is maintained. 2. All works undertaken in accordance with current standards and best practice. 3. Geotechnical supervision required for the duration of earthworks programme.	2	2	4	Y	Active
19	Poor trafficability due to soft shallow predominantly fine soil ground conditions	Construction difficulties for plant movements due to poor trafficability Risk of programme delays, cost implications and damage to reputation.	Construction	4	2	8	1. Contractor should consider potential mitigations such as all-weather haul roads or employ lighter plant. 2. Contractor should consider weather seasonality and schedule works to minimise plant movements during winter months where trafficability issues more likely to arise.	3	2	6	Y	Active
20	Attenuation Ponds situated in areas of mixed fine and coarse Head Deposits which may have significantly higher infiltration rate than single soakaway test indicates should fines content be reduced in coarse horizons.	Infiltration may vary from assumed, resulting in high infiltration into strata. Risk of contamination of surrounding area and operational failure. May require redesign, long term maintenance costs, disruption in operation and damage to reputation.	Construction and maintenance	3	3	9	1. Geotechnical supervision is required for the duration of the earthworks programme. 2. The Designer should consider the potential to encounter coarse material with high infiltration rate within their design. 3. Ground improvement or the requirement for a liner should be considered during design at PCF5.	2	3	6	Y	Active
21	Encountering UXO	Striking unexploded ordnance (UXO) causing an explosion. Risk of injury or fatality of site personnel and the public	Construction	3	5	15	1. A detailed desk study should be carried out by UXO specialists with respect to the proposed construction works prior to breaking ground, as the risks correspond to the proposed works. 2. Should a residual risk remain following production of the site-specific desk study/risk assessment, then recommendations from a UXO specialist/the risk assessment shall be sought and adhered to.	1	5	5	Y	Active
22	Highway pavement design and construction	Foundation stratum too soft for pavement design leading to long term damage to new carriageway. Safety issues and disruption to road users.	Construction and maintenance	3	3	9	1. The Designer should consider the results of the ground investigation to ensure that the pavement design is suitable for the ground conditions. 2. The Designer may be required to dig a replace material at the shallow surface to ensure foundation suitable for road construction. 3. Geotechnical supervision is required for the duration of the earthworks programme to identify any soft portions and ensure that these are removed and suitably managed.	1	3	3	Yes	Active

Hazard Reference	**Hazard:** Activity/Process/ Material/Element	**Consequence:** (also indicate what is the risk)	Stage of Work	Initial Risk Level			Risk Control Measures: Design action taken, record of decision process including option considered, design constraints and justification for options/actions not having been taken	Residual Risk Level			Is there a 'significant' residual risk to be passed on? (Y/N)	Status (Active / Closed)
				Likelihood	Severity	Risk Level		Likelihood	Severity	Risk Level		
23	Earthwork failure due to construction on existing Head deposits.	Instability of embankments and cuttings built on existing Head deposits may occur due to reactivation of shear surfaces. May require redesign, long term maintenance costs, disruption in operation and damage to reputation.	Construction and maintenance	3	4	12	1. The Designer should take into account the presence and thickness of Head deposits across the scheme. 2. Where possible, the removal of Head deposits should be considered. 3. Where removal is not possible, stabilisation of the natural ground should be considered. 4. Geotechnical supervision is required for the duration of the earthworks programme to confirm the removal of Head deposits (if being undertaken).	1	4	4	Y	Active

Totally, 18no. geotechnical and geoenvironmental hazards identified for the proposed scheme are classified at medium risk level with one at high risk level prior to any risk control measures. Please consider that there are inherent risks associated with working adjacent to live traffic as well as driving to, from and accessing the Scheme. . Construction related hazards such as temporary works, moving plant, lane closures and night works should also be considered as part of the risk assessment, however, have not been included within the Geotechnical Risk Register at this stage.

Following the application of risk control measures the majority of the potential hazards classified at a low residual risk level with one risk outstanding within the medium residual risk level category:

- Interaction with known existing structures, notably the BPA line. This is a medium residual risk due to the residual high severity should the hazard occur. Additional control measures needed to reduce risk rating are to be considered through assessment of existing Highway infrastructure, BPA line and other services at GDR and detailed design stage.

The Designer should consider the risk control measures outlined in the geotechnical risk register, at PCF Stage 5 (PCF5), and consider controls to manage the hazards identified at a high residual risk level.

6. Preliminary Engineering Assessment

6.1 Geotechnical Considerations and Recommendations

6.1.1 Introduction

This section provides a preliminary assessment of the proposed geotechnical activities across the Scheme and highlights any risks that may be associated with these activities given the ground conditions local to their proposed locations.

Geotechnical activities proposed as part of the Scheme include:

- Cut slopes;
- Embankment construction and widening;
- Retaining structures (including reinforced earth walls);
- Bridge foundations;
- Gantry foundations; and
- Other structures (including culvert extensions and utility pipelines).

A Geotechnical Design Report (GDR) is anticipated to be produced as part of PCF5, which will need to consider the outcomes of this preliminary engineering assessment and findings from the ground investigation.

Earthwork and retained heights have been obtained from the verge schedule produced during PCF3. This is presented alongside the verge schedule key plan in Appendix L.

Low height retaining structures and earthworks (i.e. less than 1.5m retained height) will not require technical approval. They are not individually considered within the preliminary engineering assessment, however, should be considered at PCF5 (detailed design) by the Designer. This includes the RN20 named structure which has not been critically evaluated as part of this report.

The preliminary engineering assessment reviews the current proposals and considers their feasibility. It should be noted that mitigation measures such as dig and replace of low strength highly compressible materials were previously identified within the preliminary design at PCF3, however have not been referred to specifically within this assessment. The Designer should review the mitigation measure identified within the preliminary design as well as the geotechnical constraints identified within this assessment.

6.1.2 Cut Slopes

The proposed cut slopes are at varying slope gradients depending on the ground conditions adopted during the preliminary slope stability analysis at PCF3 [74]. The scheme-specific 2019 GI data was not available for the preliminary analysis and therefore the slope gradients may be subject to change during detailed design at PCF5. A summary of the proposed cut slopes is presented in Table 6-1, with the proposed gradient where available [74, 75].

Table 6-1 Summary of proposed cutting or excavations

Ground Model	Proposed Solution	Maximum Earthwork Height (m)	Anticipated stratum	Comments
GM-02	Widening of existing cutting (1V:3.5H to 1V:3H)	7.2	Head - Fine; Weathered London Clay Formation.	The ground conditions and geotechnical parameters adopted within the preliminary design are in line with those encountered during the 2019 GI with the exception of the Head Deposits at the crest. The proposed cutting solution is appropriate for the ground conditions with significant space at the crest for widening. The Designer may consider additional measures necessary to ensure the geotechnical risks posed by the Head Deposits are reduced and managed. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Relict shear surfaces may be present within head deposits at the crest of the cutting which could be at residual shear strengths and impact long-term slope stability if reactivated. - Shallow groundwater may migrate along the interface between the Head deposits and Weathered London Clay, especially if coarse horizons are present.
GM-03	Cutting into landfill material and Attenuation Pond 2 (1V:3.5H)	6.4	Made Ground – Recently Deposited Material; Made Ground – Landfill; Weathered London Clay Formation.	The ground conditions adopted within the preliminary design are consistent with those encountered during the 2019 GI. The geotechnical model varies slightly, with lower drained parameters for the Made Ground – Landfill than those adopted in the preliminary design. This may possibly lead to a shallower slope gradient than proposed however a cutting is still considered an appropriate solution considering the findings of the 2019 GI and other site constraints. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Highly variable heterogenous ground conditions with discontinuous organic layers present. The foundation stratum changes at foundation level and mid-slope along the section of the proposed cutting. - Material of variable strength is anticipated with local horizons of very low shear strength present, organic layers may form planes of weakness which could impact the global stability of the cutting. - The proposed works without mitigation may potentially enable lateral migration of previously perched water through the creation of temporary pathways (e.g. excavations, dewatering) daylighting mid-cut slope at the interface between strata.
GM-05	Attenuation Pond 1 & 3.	-	Head – Fine; Head – Gravel; Weathered London Clay Formation.	The ground conditions adopted for the preliminary design are reasonably consistent with those encountered during the 2019 GI, although the thickness and extent of the Head Deposits has been further constrained. Cuttings for the proposed Attenuation Ponds are an appropriate cost-effective solution considering spatial and construction constraints, however the Designer may want to consider additional measures to mitigate the potential relict surfaces within the Head deposits. This may include excavation and recompaction of the Head.

Ground Model	Proposed Solution	Maximum Earthwork Height (m)	Anticipated stratum	Comments
				The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Relict shear surfaces may be reactivated within head deposits which could be at residual shear strengths and impact long-term slope stability. - Excavation of the Head deposits for material reuse (if deemed suitable) requires careful material management to ensure separation of the coarse and fine fraction to prevent mixing of materials. - Shallow groundwater may migrate along the interface between strata, notably through coarse portions of Head deposits.
GM-07	Widening of existing cutting (1V:3.5H)	6.9	Made Ground – Engineered Fill; Alluvium; Head – Fine; Weathered London Clay Formation.	The ground conditions adopted within the Structures Options Report (SOR) [55] are inconsistent with those encountered during the 2019 GI. Localised pockets of Alluvium and or Head deposits is anticipated within the vicinity of this proposed structure (where not removed prior to existing earthwork construction). A cutting is considered an appropriate geotechnical solution, however careful consideration should be taken to mitigate the potential variable poor strength material. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Highly variable ground conditions anticipated which may result in foundation and mid-slope stratum changes along the proposed section. - Slope material is anticipated to be of variable strength with low undrained shear strength present at a shallow depth, which could impact global stability of the cutting.

6.1.3 Embankments

The proposed embankment slopes are at varying slope gradients from 1V:2.5H to 1V:3.5H depending on the ground conditions, loading and proposed fill type adopted during the preliminary slope stability analysis at PCF3 [74]. The Scheme-specific 2019 GI was not available to verify the assumptions used in the preliminary analysis and therefore the slope gradients may be subject to change during detailed design at PCF5. A summary of the proposed embankment slopes is presented in Table 6-2 [74, 75].

Table 6-2 Summary of proposed embankments

Ground Model	Proposed Solution	Maximum Earthwork Height (m)	Anticipated formation stratum	Comments
GM-01	Widening of existing embankment	1.5 – 3.3	Alluvium; Head – Fine. Weathered London Clay Formation.	This proposed structure was not subject to preliminary design during PCF3. Considering the geotechnical constraints and wider scheme constraints, an embankment is considered an appropriate solution. However, the Designer should consider measures to reduce potential settlement and stability issues posed by the superficial strata such as dig and replace of soft and compressible material. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Differential settlement and changes in the rate of consolidation of the embankment due to changes in the founding stratum along the section; - Excessive settlement of the Alluvium stratum; - Shallow groundwater entering temporary works excavations; - Potential for scour or erosion of foundation adjacent to Weald Brook; - Short term overall stability issues due to low undrained shear strength of founding materials; - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and impact long-term stability.
GM-04	Construction of new embankments for M25 off-slip loop. (1V:3.5H)	5.4 – 6.9	Alluvium (local to Weald Brook); Head – Fine; Weathered London Clay Formation	The ground conditions adopted within the preliminary design are reasonably consistent with those encountered during the 2019 GI, with the exception of an area of Alluvium likely to be present below the eastern section of the TN03 western embankment. An embankment is considered an appropriate solution for the ground conditions, although the Designer should consider measures to reduce potential differential settlement and localised instability issues such as dig and replace of soft and compressible material with suitable fill where present below the structure. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Differential and excessive settlement is anticipated where the proposed embankment is situated overlying Alluvium (adjacent to Weald Brook). Shallow groundwater is present which may enter temporary works; - Short term overall stability issues due to low undrained shear strength of founding materials; - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and impact long-term stability; - The potential for flood water to be stored behind the proposed structure during a flood event which could lead to internal and external erosion of the embankment and stratum below the earthwork.
GM-05	Construction of new embankments for M25 off-	5.1 – 9.7	Head – Fine; Head – Gravel;	The ground conditions adopted within the preliminary design are reasonably consistent with those encountered during the 2019 GI, although the

Ground Model	Proposed Solution	Maximum Earthwork Height (m)	Anticipated formation stratum	Comments
	slip loop (1V:3H to 1V:3.5H)		Weathered London Clay Formation.	thickness, composition and extent of the Head Deposits has been further constrained. An embankment is considered an appropriate solution for the ground conditions, although the Designer should consider measures to reduce the potential instability issues posed by the possible presence of relict surfaces within the Head Deposits and potential differential settlement such as dig and replace of soft and compressible material with suitable fill where present below the structure. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Relict shear surfaces may be reactivated within head deposits which could be at residual shear strengths and impact long-term stability; - Consideration should be given to differential settlement and changes in the rate of consolidation of the embankment due to changes in the founding stratum from coarse to fine along the section.
GM-06	Construction of new embankments for M25 off-slip loop and A12 off-slip (1V:2.5H (coarse) to 1V:3.5H (fine))	3.7 – 9.7	Alluvium; Head – Fine; Weathered London Clay Formation.	The ground conditions adopted within the preliminary design are reasonably consistent with those encountered during the 2019 GI, although Head deposits were not considered within the associated ground models, they are likely to be present locally below the Alluvium and on the valley slopes. An embankment is considered an appropriate solution for the ground conditions, although the Designer should consider measures to reduce potential differential settlement and instability issues posed by the possible presence of relict surfaces, such as dig and replace of soft and compressible material with suitable fill. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Consideration should be given to differential settlement and changes in the rate of consolidation of the embankment due to changes in the founding stratum along the section; - Excessive settlement is anticipated where the proposed embankment is situated overlying Alluvium. Shallow groundwater is present which may enter temporary works excavations; - Short term overall stability issues due to low undrained shear strength of founding materials; - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and impact long-term stability; - The potential for flood water to be stored behind the proposed structure during a flood event which could lead to internal and external erosion of the embankment and stratum below the earthwork.
GM-07	Construction of new embankment for A12 off-slip comprising Expanded	7.4 – 7.5	Made Ground – Engineered Fill Alluvium; Head – Fine;	The ground conditions adopted within the preliminary design are consistent with those encountered during the 2019 GI. Considering the geotechnical constraints and wider scheme constraints with close properties adjacent to the location, the EPS fill embankment is considered an appropriate solution for this earthwork.

Ground Model	Proposed Solution	Maximum Earthwork Height (m)	Anticipated formation stratum	Comments
	Polystyrene (EPS) fill. (1V:1H to 1V:3.5H)		Weathered London Clay Formation.	The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Differential settlement and changes in the rate of consolidation of the embankment due to changes in the founding stratum along the section; - The variability and suitability of the Made Ground as a foundation stratum; - Short term overall stability issues due to low undrained shear strength of founding materials; - Excessive settlement where the proposed embankment is situated overlying Alluvium. Shallow groundwater is present which may enter temporary works; - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and impact long-term stability.

6.1.4 Retaining Structures

A critical assessment of the retaining structures optioneering was undertaken at PCF stage 3 within the overriding Scheme specific retaining wall structures options report [55] and within the structure specific options reports:

- Duck Wood Bridge (BN02) [76];
- Grove Bridge (BN03) [77]; and
- Maylands Bridge (BN04) [78].

The SORs provide a detailed justification of the geotechnical options considered for use in the Scheme based on the information available prior to the 2019 GI. The following section validates the chosen geotechnical options following the investigation to ensure they are still appropriate for the ground conditions and identified constraints such as: buildability, maintenance requirements, whole life cost, health and safety, environment and aesthetics. This section should be reviewed alongside the relevant SOR, as detailed above.

Where the proposed structure crosses multiple ground models, it has been considered included against all relevant ground models.

Table 6-3 Summary of proposed retaining structures.

Ground Model	Proposed Solution	Maximum retained height (m)	Anticipated stratum	Comments
GM-01	Driven sheet pile wall RN09 & RN10	2.4	Made Ground – Undifferentiated; Alluvium; Head; Weathered London Clay Formation.	The ground conditions adopted within the SOR are consistent with those encountered during the 2019 GI. A sheet pile wall is considered appropriate for mitigating potential differential and excessive settlement of the retaining structure along the structure (if sufficient embedment), no cut is required into a variable strength material and due to the fast installation (reducing impact on traffic) and low maintenance requirements.

Ground Model	Proposed Solution	Maximum retained height (m)	Anticipated stratum	Comments
				The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Variable foundation strata at length of wall; - Hardgrounds within the London Clay Formation or granular material in the Made Ground or Head making drivability difficult; - Coarse Alluvium (gravel) and stiff underlying strata at depth causing drivability issues; - Shallow groundwater potentially entering temporary works within the Alluvium stratum. - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and lead to higher active pressures and lower passive pressures than anticipated potentially impacting long-term stability; - Erosion of toe of wall by Weald Brook during the structure's lifespan reducing lateral restraint; - Potential for settlement of backfill placed behind retaining wall. According to the SOR, the proposed retaining wall will clash with a drainage in the existing bund.
	Gabion gravity retaining wall RN08	4.0	Made Ground – Engineered Fill; Alluvium; Head; Weathered London Clay Formation.	Alluvium was identified within the 2019 GI along the alignment of the proposed solution, this was not adopted within the SOR. The proposed structure is suitable to accommodate an element of excessive and differential settlement caused by the presence of the Alluvium stratum. A gabion gravity retaining wall is considered an appropriate solution considering the ground conditions, environmental suitability and final aesthetics sensitive to the adjacent Brook. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Excessive and differential settlement of both the structure and the retained fill which may impact on the long-term condition of the road during operation; - Low undrained shear strength causing bearing capacity and global stability failure during construction and short-term instability; - Shallow groundwater entering temporary works excavations; - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and lead to higher active pressures and lower passive pressures than anticipated potentially impacting long-term stability; - Potential for scour or erosion of foundation adjacent to Weald Brook.
GM-03	Modular Block Wall RN04	2.3	Made Ground – Landfill; Weathered London Clay Formation.	The ground conditions adopted within the SOR are consistent with those encountered during the 2019 GI. The Made Ground – Landfill is inherently variable and may give rise to excessive settlement and

Ground Model	Proposed Solution	Maximum retained height (m)	Anticipated stratum	Comments
				localised soft spots. Discontinuous layers of high organic matter may present planes of weakness leading to short and long-term stability issues and may control the flow of groundwater through the landfill material. A Modular block retaining wall was considered an appropriate solution considering the ground conditions, quick installation with minimal maintenance requirements and was the preferred option of the Contractor consulted. However, the Designer should consider whether the preferred wall option is still the most appropriate option considering the following (non-exhaustive) list of geotechnical constraints within design: - Highly variable heterogenous ground conditions with discontinuous organic layers present. The foundation stratum changes at foundation level and mid-slope along the section of proposed structure; - Differential settlement and changes in the rate of consolidation of the structure due to changes in the founding stratum along the section - Material of variable strength is anticipated with local horizons of very low shear strength present. Organic layers may form planes of weakness which could lead to global instability and higher lateral earth pressures than anticipated; - The proposed works without mitigation may potentially enable lateral migration of previously perched water through the creation of temporary pathways (e.g. excavations, dewatering) daylighting mid-cut slope at the interface between strata.
	Contiguous Anchored Pile Wall RN05, RN06 & RN07	6.7	Made Ground – Landfill; Weathered London Clay Formation.	The ground conditions adopted within the SOR are consistent with those encountered during the 2019 GI. A contiguous pile wall is considered an appropriate solution considering the ground conditions, fast top-down installation, low maintenance requirements and minimal disturbance to adjacent ground. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within the design: - Failure of anchors founding within or through inherently variable landfill material; - Material of variable strength is anticipated with local horizons of very low shear strength present, organic layers may form planes of weakness which could lead to global instability and higher lateral earth pressures than anticipated; - Hardgrounds within the London Clay Formation making pile drivability difficult; - Stiff underlying strata at depth causing drivability issues. - The proposed works without mitigation may potentially enable lateral migration of previously perched water through the creation of temporary pathways (e.g. excavations, dewatering)

Ground Model	Proposed Solution	Maximum retained height (m)	Anticipated stratum	Comments
				daylighting mid-cut slope at the interface between strata.
GM-04	Construction of new reinforced earthwork wall for M25 offslip loop, bridge abutments and Grove Farm Underpass RN11, RN12, RN13 & RN14	8.1	Head – Fine; Weathered London Clay Formation	The ground conditions adopted within the SOR are consistent with those encountered during the 2019 GI. A reinforced soil retaining wall is considered an appropriate solution considering the ground conditions, simple construction with minimal requirement for specialised plant and low maintenance requirements. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and impact long-term stability; - Variable undrained strength, potentially low undrained shear strength causing short-term global stability issues.
	Reinforced Soil retaining wall to bridge abutment RN15	5.8	Alluvium (local to Weald Brook); Head – Fine; Weathered London Clay Formation	Alluvium and Head deposits were identified during the 2019 GI below an area of the proposed solution; this was not adopted within the SOR. The proposed structure is considered suitable however measures will be required to accommodate excessive and differential settlement caused by the presence of the Alluvium stratum and other hazards posed by the presence of Head deposits. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Differential settlement and changes in the rate of consolidation of the structure due to changes in the founding stratum along the section; - Excessive settlement where the proposed structure is situated overlying Alluvium. Shallow groundwater is present which may enter temporary works - Short term overall stability issues due to variable low undrained shear strength of founding materials; - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and impact long-term global stability. - The potential for flood water to be stored behind the proposed structure during a flood event which could lead to internal and external erosion of the structure and stratum below the earthwork.
GM-05	Construction of new reinforced earthwork wall for M25 offslip loop and retaining wall to bridge abutments	9.7	Head – Fine; Head – Gravel; Weathered London Clay Formation.	The ground conditions adopted within the SOR are consistent with those encountered during the 2019 GI (for RN16 & RN17) and are better than those considered for RN01 as Head deposits were encountered rather than Alluvium. RN15 is considered separately within GM-04 above. A reinforced soil retaining wall is considered an appropriate solution considering the ground

Ground Model	Proposed Solution	Maximum retained height (m)	Anticipated stratum	Comments
	RN01, RN15, RN16 & RN17			conditions, simple construction with minimal requirement for specialised plant and low maintenance requirements. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Variable foundation strata with potential for coarse and fine material which may impact bearing capacity as well as differential settlement and changes in the rate of consolidation of the structure. - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and impact long-term global stability.
GM-06	Reinforced Soil retaining walls for M25 offslip loop, A12 offslip and to bridge abutments RN02, RN16, RN17, RN18 & RN19	11.2	Made Ground – Undifferentiated. Alluvium; Head – Fine; Weathered London Clay Formation.	The ground conditions adopted within the SOR are consistent with those encountered during the 2019 GI. A reinforced soil retaining wall is considered an appropriate solution considering the ground conditions, low maintenance, simple construction with minimal requirement for specialised plant and allows space for the creation of a flood plain alongside the diverted river. Measures will be required to accommodate excessive and differential settlement caused by the presence of the Alluvium stratum and other hazards posed by the presence of Head deposits. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Shallow groundwater entering temporary works excavations; - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and impact long-term global stability. - Short term overall stability issues due to variable low undrained shear strength of founding materials; - Differential settlement and changes in the rate of consolidation of the structure due to changes in the founding stratum along the section; - Excessive settlement where the proposed structure is situated overlying Alluvium. Shallow groundwater is present which may enter temporary works - Potential deep temporary works to excavate and replace Alluvium (up to 4.3m thickness encountered in 2019 GI); - The potential for flood water to be stored behind the proposed structure during a flood event which could lead to internal and external erosion of the structure and stratum below the earthwork.
GM-07	Modular Block Wall RN03 & RN04	2.6	Made Ground – Engineered Fill Alluvium; Head – Fine;	The ground conditions adopted within the SOR are consistent with those encountered during the 2019 GI. A Modular block retaining wall was considered an appropriate solution considering the ground

Ground Model	Proposed Solution	Maximum retained height (m)	Anticipated stratum	Comments
			Weathered London Clay Formation.	conditions, fast and simple installation with minimal maintenance requirements and was the preferred option of the Contractor consulted. However, the design should consider whether preferred wall option is likely to still be the most appropriate option considering the following (non-exhaustive) list of geotechnical constraints within design: - Variable foundation strata which may impact bearing capacity as well as differential settlement and changes in the rate of consolidation of the structure. - Excessive settlement where the proposed structure is situated overlying Alluvium. Shallow groundwater is present which may enter temporary works - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and impact long-term global stability.

6.1.5 Bridge Foundations

A critical assessment of the proposed bridge foundations was undertaken at PCF stage 3, with the optioneering process reported within the overriding Scheme specific structures options report (SOR) [55] and within the structure specific options reports:

- Alder Wood Bridge (BH01) [79];
- Duck Wood Bridge (BN02) [76];
- Grove Bridge (BN03) [77]; and
- Maylands Bridge (BN04) [78].

The SORs provide a detailed justification of the geotechnical options considered for use in the Scheme based on the information available prior to the 2019 GI. The following section validates the chosen geotechnical options following the 2019 investigation to ensure they are appropriate for the ground conditions and identified constraints such as: buildability, maintenance requirements, whole life cost, health and safety, environment and aesthetics. This section should be reviewed alongside the relevant SOR, as detailed above.

Where the proposed structure crosses multiple ground models, it has been considered included against all relevant ground models.

It should be noted that at the time of writing this report, specific type or founding depths of the piled foundations have not been confirmed.

Table 6-4 Summary of proposed bridge foundations

Ground Model	Proposed Solution	Proposed Foundation depth (m bgl)	Anticipated stratum	Comments
GM-02 & GM-03	Alder Wood Bridge	Not specified	Made Ground – Landfill;	The ground conditions adopted within the preliminary design are consistent with those encountered during the

Ground Model	Proposed Solution	Proposed Foundation depth (m bgl)	Anticipated stratum	Comments
	(BN01); piled foundation		Weathered London Clay Formation; London Clay Formation	2019 GI. The proposed piles founding in the London Clay Formation are considered appropriate for the structure. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Buried services associated with the M25; - Highly variable heterogenous ground conditions with discontinuous organic layers present within the landfill, reducing shaft friction; - Aggressive ground to concrete, especially within the Weathered London Clay Formation; and - Hard ground within the London Clay Formation or granular material in the Made Ground or Head Deposits making pile drivability difficult.
GM-04 & GM-05	Duck Wood Bridge (BN02); piled foundation	Not specified	Head – Fine; Weathered London Clay Formation; London Clay Formation	The ground conditions adopted within the preliminary design are consistent with those encountered during the 2019 GI. The proposed piles founding in the London Clay Formation are considered appropriate for the structure. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Buried services such as the Cadent gas line; - Aggressive ground to concrete, especially within the Weathered London Clay Formation; and- Hard ground within the London Clay Formation or granular material in the Head deposits making pile drivability difficult; - Shallow groundwater entering temporary works excavations; and - Relict shear surfaces may be present within the Head deposits which could be reactivated at residual shear strengths, leading to a higher lateral earth pressures and lower passive pressures than anticipated.
GM-05 & GM-06	Grove Bridge (BN03); piled foundation	Not specified	Alluvium; Head – Fine; Weathered London Clay Formation; London Clay Formation	The ground conditions adopted within the preliminary design are consistent with those encountered during the 2019 GI. The proposed piles founding in the London Clay Formation are considered appropriate for the structure. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Buried services such as the Cadent gas line; - Aggressive ground to concrete, especially within the Weathered London Clay Formation; - Hard ground within the London Clay Formation or Head deposits making pile drivability difficult; - Shallow groundwater entering temporary works excavations; and - Relict shear surfaces may be present within the Head deposits which could be reactivated at residual shear strengths, leading to a higher lateral earth pressures and lower passive pressures than anticipated.
	Maylands Bridge (BN04); piled foundation	Not specified		

6.1.6 Gantry Foundations

A summary of the geotechnical considerations for the proposed gantry foundations is presented in Table 6-5. The following section validates the chosen geotechnical options following the investigation to ensure they are still appropriate for the ground conditions. This section should be reviewed alongside the preliminary design, as provided in the gantry foundations preliminary design report [80].

Table 6-5 Summary of gantry foundations

Ground Model	Proposed Solution	Anticipated stratum	Comments
GM-01	45m span portal gantry	**West:** Weathered London Clay Formation. **East:** Alluvium; Head – Fine; Weathered London Clay Formation.	The ground conditions adopted within the preliminary design are consistent with those encountered during the 2019 GI, however the preliminary design does not consider variations in ground conditions across the structure. Superficial deposits, including localised Head – Deposits are anticipated at the eastern extent of the proposed structure; however, these are likely to be absent in the west. The proposed piled foundations are considered appropriate for the structure and should be designed to accommodate anticipated changes in superficial deposits. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Hardgrounds within the London Clay Formation or granular material in the Head making pile drivability difficult; - Shallow groundwater entering temporary works excavations; - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths, leading to a higher lateral earth pressures and lower passive pressures than anticipated.
GM-03	63m span portal gantry	**West:** Made Ground – Landfill; Weathered London Clay Formation; & **East:** Made Ground – Engineered Fill; Head – Fine; Weathered London Clay Formation.	The ground conditions adopted within the preliminary design are consistent with those encountered during the 2019 GI, however the preliminary design does not consider variations in ground conditions across the structure. The proposed piled foundations are considered appropriate for the structure. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Hardgrounds within the London Clay Formation or granular material in the Made Ground or Head making pile drivability difficult; - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths, leading to a higher lateral earth pressures and lower passive pressures than anticipated.
GM-07	Cantilever Gantry	Made Ground – Engineered Fill; Head – Fine; Weathered London Clay Formation.	The ground conditions adopted within the SOR are consistent with those encountered during the 2019 GI. The proposed piled foundations are considered appropriate for the structure. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Piled foundations are to be principally found in the existing Engineered Fill, consideration should be given to the variability of the Made Ground in design within the GDR; - Hardgrounds and stiffness of the London Clay Formation making pile drivability difficult; - Relict shear surfaces may be reactivated within Head deposits at depth which could be at residual shear strengths, leading to a higher lateral earth pressures and lower passive pressures than anticipated.

6.1.7 Other Structures

A summary of the geotechnical considerations for other proposed structures within the Scheme is presented in Table 6-6.

The SOR for the modification of existing culverts [81] provides a detailed justification of the geotechnical options considered for use in the Scheme based on the information available prior to the 2019 GI. The following section validates the chosen geotechnical options following the investigation to ensure they are still appropriate for the ground conditions. This section should be reviewed alongside the relevant SOR.

Table 6-6 Summary of other structures

Ground Model	Proposed Structure	Anticipated stratum	Comments
GM01	Weald Brook Culvert Extension CX-02	Alluvium; Weathered London Clay	Alluvium was identified within the 2019 GI along the alignment of the proposed solution; this was not adopted within the SOR. The proposed structure at PCF3 is a box culvert on shallow foundations. This is not considered appropriate for the ground conditions; additional measures will be required to accommodate excessive and differential settlement caused by the presence of the Alluvium stratum, such as dig and replace with suitable fill. The Designer should consider whether the preferred foundation is still the most appropriate option considering the following (non-exhaustive) list of geotechnical constraints within design: - Differential and excessive settlement where the proposed structure is situated overlying Alluvium; - Short term overall stability issues due to variable low undrained shear strength of founding materials; - Shallow groundwater entering temporary works excavations;
GM-05	Cadent gas pipeline realignment	Head – Fine; Head – Gravel; Weathered London Clay Formation.	Preliminary design of the gas pipeline realignment was not undertaken at PCF3, the proposed works are to be undertaken by a separate Contractor to the main works package. From assessment of the available data, the construction of the realignment of the gas pipeline is not considered to pose an exceptional geotechnical risk. The Designer should consider the following (non-exhaustive) list of geotechnical constraints within design: - Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths and impact temporary excavation slope stability; - Excavation of the Head deposits for material reuse (if deemed suitable) requires careful material management to ensure separation of the coarse and fine fraction to prevent mixing of materials; - Shallow groundwater has the potential to ingress into temporary excavation works, notably through coarse portions of Head deposits where locally present.
GM-06	Grove Culvert Extension CX-01	Alluvium; Head – Fine; Weathered London Clay Formation	Alluvium was identified within the 2019 GI along the alignment of the proposed solution, this was not adopted within the SOR. The proposed structure at PCF3 is a box culvert on shallow foundations. This is not considered appropriate for the ground conditions; additional measures will be required to accommodate excessive and differential settlement caused by the presence of the Alluvium stratum, such as dig and replace with suitable fill. The Designer should consider whether the preferred foundation is still the most appropriate option considering the following (non-exhaustive) list of geotechnical constraints within design: - Differential and excessive settlement where the proposed structure is situated overlying Alluvium. Shallow groundwater is present which may enter temporary works;

Ground Model	Proposed Structure	Anticipated stratum	Comments
			- Relict shear surfaces may be reactivated within head deposits which could be at residual shear strengths and lead to be higher lateral earth pressures on the structure than anticipated, possibly resulting in failure of the structure; - Short term overall stability issues due to variable low undrained shear strength of founding materials.
GM-07	Grove Culvert Extension CX-01	Made Ground – Engineered Fill; Alluvium; Head – Fine; Weathered London Clay Formation	Alluvium was identified within the 2019 GI along the alignment of the proposed solution, this was not adopted within the SOR. The proposed structure at PCF3 is a box culvert on shallow foundations. This is not considered appropriate for the ground conditions; additional measures will be required to accommodate excessive and differential settlement caused by the presence of the Alluvium stratum, such as dig and replace with suitable fill. The Designer should consider whether the preferred foundation is still the most appropriate option considering the following (non-exhaustive) list of geotechnical constraints within design: - Differential and excessive settlement where the proposed structure is situated overlying Alluvium. Shallow groundwater is present which may enter temporary works; - Relict shear surfaces may be reactivated within head deposits which could be at residual shear strengths and lead to be higher lateral earth pressures on the structure than anticipated, possibly resulting in failure of the structure; - Short term overall stability issues due to variable low undrained shear strength of founding materials.

6.1.8 Subgrade Strength

The California Bearing Ratio (CBR) for proposed subgrade materials have been determined through in-situ TRL DCPs and correlations with published literature, design values presented in Table 4-23.

The minimum in-situ design CBR value was generally determined through correlations with PI as the in-situ test results (from DCP tests) reflect a short-term value, representative of moisture conditions at the time of the test and not long-term conditions. Due to the high plasticity, the minimum sitewide design CBR was typically 2 – 2.5% depending on subgrade thickness. The Designer should review the available data and revise the design CBR on a area or location specific basis.

A cautious approach should be adopted when using the in-situ test results due to the potential for seasonal influence to affect the results. Surface stiffness either increases or decreases due to changes in the in-situ water content. When assessing Made Ground materials false high value may be recorded due to the presence of larger particles (coarse gravel and cobbles) within the material.

Design values have been presented in accordance with the literature, taking into consideration the seasonality of in-situ water conditions and that the formation may be left exposed during construction following removal of vegetation which may result in an increase in water, which could lead to a decrease in surface stiffness. Undertaking additional CBR testing ahead of material placement to confirm as-encountered conditions may be advisable to ensure an economic pavement design.

6.1.9 Trafficability

Trafficability is defined as the ability of a specified vehicle to traverse a given terrain [82]. The majority of the strata encountered on site is composed of fine material with the earthworks generally founding within Made Ground – Landfill, Alluvium, Head and Weathered London Clay Formation.

Close to the ground surface the undrained strength can be as low 10 to 50kPa across all strata, which could create considerable issues for efficient plant operation. In addition, the fine nature of the materials will render them susceptible to significant reductions in undrained strength in periods of wet weather. The undrained strength of clay materials controls its trafficability and at strengths below approximately 50kPa, significant rutting/deformation under the weight of compaction or construction plant can, and is likely, to occur, (Nowak & Gilbert, 2015). Thus, all strata have the potential to have low trafficability during earthworks operations, which will be exacerbated in sustained periods of wet weather. Should works be proposed within winter or wetter months the Contractor should consider forms of mitigation such as all-weather haul roads or by employing lighter plant where possible.

Trafficability issues were encountered during the ground investigation, with extensive rutting and access difficulties which results in delays and access restricted to tracked vehicles. Images of access track conditions is provided in Figure 6-1 below.

Figure 6-1 Images of trafficability issues around site taken 01/11/2019 during the 2019 GI.

6.1.10 Site-won Material Re-use

In accordance with the guidance and material properties required for acceptability as presented within the Specification for Highways Works (SHW) Series 600 [83], materials encountered on site have been classified according to their suitability for re-use as site-won fill. The material bounds have been presented on the gradings curves for the corresponding stratum within Appendix G.

The classification of unweathered London Clay Formation has not been undertaken as the stratum is considered too deep to be encountered during the proposed major excavation works. Areas of Made Ground – Undifferentiated may be suitable for material re-use and testing is available, however classification is required on an area specific basis which should be undertaken as part of the detailed design at PCF5.

Based on the limited testing available, it is anticipated that site-won materials may classify as 'General Cohesive Fill' Class 2A and 2C in accordance with SHW Series 600 [83]. A summary of the material classification is presented in Table 6-7.

Table 6-7 Summary of material re-use classification in accordance with SHW Series 600 [83]

Stratum	Material Classification
Made Ground – Engineered Fill	Fines - Class 2A – Wet cohesive material
Made Ground – Recently Deposited Material	Class 2C – Stony cohesive material
Made Ground – Landfill	Fines – Class 2A – Wet cohesive material
Alluvium	Fines – Class 2A – Wet cohesive material Coarse – Class 2C – Stony cohesive material
Head – Fine	Class 2A – Wet cohesive material
Head – Gravel	Class 2C – Stony cohesive material
Weathered London Clay Formation	Class 2A – Wet cohesive material

The potential for re-use of site won material will also depend on the manner in which excavations are formed. Unless segregation of different materials can be undertaken at source it is likely that re-use of fill will be limited by the various constituent materials at any location, in particular where Made Ground or Head – Fine and Head – Gravel will form part of the excavated material.

The potential for re-use of site won fill material will also vary seasonally and spatially. The material generally classified as a Class 2A - Wet cohesive fill, however the investigation was undertaken from late summer to early winter with ground saturation changing considerably due to seasonal rainfall fluctuation. The potential for re-use based on water contents recorded at the time of the 2019 GI should be taken into consideration. Areas of lower water content were identified in areas of high vegetation and dense woodland, this material may require different treatment to ensure placement suitability than material won from other areas of the site.

Once development levels and excavation volumes have been confirmed, and should re-use be required, validation testing should be undertaken in accordance with the guidelines provided within SHW Series 600 [83], to confirm these preliminary classifications. Should validation testing find that site-won materials are unsuitable for the proposed use (geotechnical and geoenvironmental), import of suitable engineering fill will be required.

Compaction

Compaction tests were undertaken on strata where significant areas of excavation are proposed for the Scheme. The OWC and MDD was determined through numerous 2.5kg rammers tests and the range of results has been presented in the geotechnical parameters section of the ground summary for the Designer to select an appropriate value for use in the earthworks design.

A review of the range of OWC against natural in-situ water content indicates that, on average the natural materials are higher than the OWC, in the order of 4 to 6% so would require drying prior to placement. Although the variability of the natural water content should be considered by the Designer, with highly variable values present near the ground surface both significantly higher and lower than the OWC. In addition, the Designer should consider seasonality changes in the natural water content as well as how materials may respond following vegetation clearance.

Managing the water content of fill material is critical to achieve a suitable OWC. Should the material be wetter than the OWC then construction difficulties such as over-compaction, mattressing, rutting and the formation of shear surfaces may take place. Whereas if the placed material is drier than OWC then there is potential for changes in water content after the earthwork has been construction which may result in loss of strength, collapse settlement or heave [82].

Shrink-Swell Potential

Shrink-swell of cohesive soil may result in desiccation of the embankment at surface which in turn can cause water pathways and deeper weathering of the fill material. Furthermore, shrink-swell has the potential to cause ‘ratcheting’ where horizontal swelling in wet periods does not recover in dry periods, leading to progressive settlement of the embankment crest.

The Modified Plasticity Index (I_P’) and corresponding Volume Change Potential (VCP) for each stratum was determined using the calculation given in Section 4.3 of this report. The VCP provides a guide as to the swelling potential of over-consolidated fine soil. The VCP for each stratum is provided in Table 6-8. The VCP for each fine stratum encountered is high with the exception of the Made Ground – Recently Deposited Material which is low.

Table 6-8 Summary of shrink swell potential of strata

Stratum		Volume Change Potential
Artificial Deposits	Made Ground – Engineered Fill	High
	Made Ground – Recently Deposited Material	Low
	Made Ground – Landfill	High
	Made Ground - Undifferentiated	Non – Plastic to High
Superficial Deposits	Alluvium - Fine	High
	Head – Fine	High

Stratum		Volume Change Potential
Bedrock	Weathered London Clay	High
	London Clay Formation	High

Consistency Index

The consistency index (CI) has been determined for each stratum with the purpose of identifying any negative CI values. All of the strata have positive CI values and are not expected to be difficult to handle and compact.

6.1.11 Attenuation Ponds

Soakaway Tests were undertaken during the investigation to determine the soil infiltration rate at the proposed location of the three attenuation ponds. The tests indicated that there was insufficient water infiltration to calculate the rate, therefore the soil infiltration was indicated as low for all three locations. Consideration should be given to the variability of the Made Ground and Head Deposits below the proposed locations.

At Attenuation Pond 1, fine and coarse Head Deposits were identified. Although both materials appeared to indicate a low infiltration rate, variability in the composition of the coarse fraction, notably a reduction in fines within the soil matrix, would increase the infiltration rate significantly and shallow groundwater may daylight at the interface between the strata. Similar ground conditions are anticipated at the proposed location of Attenuation Pond 3, although the coarse fraction was not encountered during the Scheme specific 2019 GI.

Made Ground – Landfill is present at the proposed location of Attenuation Pond 2. The material is highly variable and heterogeneous with discontinuous organic layers. The 2019 GI indicated that the majority of this material is fine in composition, although as the upper portion (Made Ground – Recently Deposited) has a higher granular content and the Made Ground is heterogenous, preferential pathways with a higher infiltration rate may be present.

6.1.12 Ground Aggressivity

The BRE SD1 test results for the aggressivity of the soil to concrete (presented in Section 4.6) show that the strata present at the Study Area has a classification ranging from DS-1 AC-1 to DS-4 AC-4 (reduced to AC-3s where the groundwater is considered to be static).

The Designer should determine a suitable classification appropriate for the proposed structure. Where the proposed structure abuts multiple strata, the Designer should consider the most onerous classification.

6.2 Summary of Engineering considerations

The ground conditions across the site are reasonably well constrained spatially, however likely to have variable geotechnical properties especially in areas of Made Ground.

The proposed geotechnical activities are relatively simple and as such the ground conditions are not considered to present exceptional geotechnical risk. However, the following should be considered carefully within the GDR at PCF5:

- The variability of the Made Ground; this includes highly variable heterogenous ground conditions with discontinuous organic layers present which will lead to material changes at foundation level and mid-slope along the sections of proposed structures;
- Relict shear surfaces may be reactivated within Head deposits which could be at residual shear strengths;
- Variable compressible strata (Alluvium and Head deposits) which may result in excessive and differential settlement, and a variable rate of consolidation;
- Localised soft, compressible ground with low undrained shear strength which may cause short-term instability issues and settlement;
- Poor trafficability due to soft predominantly fine soil ground conditions;
- Shallow groundwater which has the potential to ingress into temporary excavation works, notably through Alluvium and coarse portions of Head deposits where present;
- Ground conditions aggressive to concrete;
- Interaction with known existing structures, notably the Cadent and BPA line; and
- Other considerations such as construction risks associated with working adjacent to live traffic. Construction work includes hazards such as temporary works, moving plant, lane closures and night works. Buried services and UXOs pose high levels of risk of injury or death which cannot be eliminated but have measures in place to control the risks.

6.3 Geoenvironmental Considerations and Recommendations

The following is a summary of the main findings of the geo-environmental risk assessment.

Based on the available information, human health risks associated with soil, soil-derived dust, fibres, waters, vapours and ground gas were generally found to vary between Very Low and Moderate/Low during construction without mitigation. Assuming that standard good working practice and the recommended mitigation measures are implemented during construction, the level of risk will reduce to Very Low to Moderate/Low. A Very Low to Moderate / Low risk will be present within the operational Scheme and, in general, the identified level of risk for the completed Scheme is the same or lower than is present in the current baseline condition of M25 junction 28.

Based on groundwater monitoring and screening of soil-derived leachate and groundwater samples, there is considered to be a Moderate risk from on-site perched water within the historical landfill / recently deposited material to surface water receptors Weald Brook, River Ingrebourne and proposed attenuation ponds from migration of perched / shallow groundwater and / or surface water via preferential pathways (e.g. attenuation ponds (if unlined) and pond outfalls). All other potential pollutant linkages relating to controlled waters receptors have a lower risk classification. With design and mitigation measures including the adoption of best available techniques, the impact assessment indicates that the construction with mitigation and operational phase would have negligible to minor beneficial, permanent effects and are assessed as not significant.

n addition to mitigation measures presented in the soils and Geology Environmental Statement Chapter Section 10.9 [1] it is recommended that: the risk to surface water receptors from soil-derived leachate and perched water within the landfill is considered during detailed design, such that the risks are managed to an appropriate level; controlled waters piling risk assessment and the use of appropriate piling methods are undertaken; measures in the Construction Environmental Management Plan (e.g. good management of stockpiles) are implemented; and pollution incident control (e.g. plant drip trays and spill kits), control of run off and a dust management system are implemented.

6.4 Waste Considerations and Recommendations

Waste segregation and sustainable materials management should be employed by the Earthworks Contractor during the works, to ensure that materials re-use within the Scheme is maximised. Where surplus materials require removal from site, further testing and physical/visual inspection will be required to be undertaken by the earthworks contractor to ensure that waste is classified correctly, and that waste disposed to landfill is minimised.

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