Fontmell Close/ Bridle Close

St Albans

Geotechnical Interpretative Report

For Hertfordshire County Council Highways

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Executive Summary

This executive summary presents the salient points of the report only and should not be referred to in isolation from the content of the whole report.

Issue	Summary
Introduction	Opus International Consultants (UK) Ltd (Opus) were commissioned by Hertfordshire County Council Highways (HCC) to act as Consulting Engineers for a Ground Investigation following a recent ground collapse in St Albans in October 2015.
Site Details	Fontmell Close and Bridle Close are located in the Townsend area of St Albans, approximately 1.5km north-north-east of the centre of St Albans and immediately east of Bernard's Heath. The site was divided into two areas by hoarding associated with the 'sinkhole' collapse outside property numbers 8, 9, 10 and 11 of Fontmell Close. The area within the hoarding is not included as part of this investigation, as it forms part of an investigation by Peter Brett Associates on behalf of the Insurers for the affected properties.
Site History	A review of the available historical mapping indicates that the site is partially underlain by an historic brick pit, this extends along the length of Bridle Close. Limekilns are present south of the site, indicating that chalk has been extracted historically locally, however no chalk mine shafts are indicated within this site boundary.
Geology	The site is indicated to be underlain by the Kesgrave Catchment Supergroup overlying the Lambeth Group and the White Chalk. The historical mapping indicates an historic brick pit located underlying parts of the site, therefore deep Made Ground is likely to be present.
Microgravity	Geotechnology Ltd were commissioned by HCC immediately after the recent ground collapse to carry out a microgravity survey of the public highways, Fontmell Close and Bridle Close. The survey identified a number of anomalies which they recommended should be investigated further. The anomalies indicate low density ground or the potential for voided ground, the Opus site works have investigated these features.
Cavities (mining and natural)	A Peter Brett Associates LLP Natural and Man Made Cavities search was carried out, this indicates that historic brick pits and possibly chalk mining (however no actual shafts were identified within the site boundary) are present beneath the site. In addition to this information a Groundsure Report was commissioned by Geotechnology Ltd. The Groundsure Report indicates that there are two mineshafts close to, but not within the study area.
Summary of Fieldwork	ESG Ltd were commissioned by HCC to carry out a Ground Investigation based on recommendations and anomalies identified by Geotechnology Ltd within their report. The investigation comprised Dynamic Probing, Window Sampling, Cable Percussive boreholes, Rotary Boreholes, a topographical survey and ground level monitoring.
Laboratory Testing	The laboratory test results were reasonably consistent and have verified the information obtained within the in-situ testing and classification,

Issue	Summary
	consistency and strength of the soil and rocks encountered during the fieldwork.
Ground Conditions	The ground conditions comprised extensive Made Ground deposits beneath Bridle Close to a depth in the region of 6m to 10m bgl. Shallow Made Ground was encountered beneath Fontmell Close at a depth in the order of 1.2m or less, (except for BH101 located on the eastern edge of the historic brick pit and proved deeper Made Ground in the region of 6.0m bgl). The Made Ground is underlain by the Kesgrave Catchment Supergroup, this is in turn underlain by the Lambeth Group and the White Chalk. In some places the Lambeth Group was not present and the White Chalk was found to be much closer to the surface. The depth to the top surface of the White Chalk was between 6m bgl and 38m bgl indicating that the top of the chalk varied significantly across the site.
Voids Identified	CCTV surveys of penetrated near surface voids were carried out, this confirmed that three voids were present within the initial layers of the White Chalk at depths of between 7.5m and 21.2m bgl, and approximate volume of between 0.4m^3 and 0.7m^3. On completion of drilling the voids were infilled with a wet grout comprising bentonite cement.
Engineering Discussions	Settlement: The investigation has concluded that settlement of the public highway will continue due to near surface soft ground conditions. The settlement should be expected to be greater beneath Bridle Close, and the area to the east along Fontmell Close, due to the proven deep Made Ground encountered. Dissolution: Dissolution of the chalk appears to be occurring as a consequence of the influence of the ground water table at around 47m bgl. Dissolution of the chalk could also occur nearer surface where leaking pipes or soakaways exist. The presence of voids within the chalk has been proven near the surface as detailed above. The voids are, however sufficiently small, and at sufficient depth that they are unlikely to have any direct effect on the stability of the public highway. Any void however, at any depth, if connected to a granular material that is saturated, has the potential for acting as a conduit for the migration of sediments which could cause an effect of subsidence at the surface. Any such dissolution or out washing of fines will cause additional subsidence.
Conclusions and Recommendations	Microgravity has been found to be a useful screening tool and the results have been compared to the actual ground conditions encountered. Correlation between microgravity predictions and actual ground conditions has been found at some locations. Microgravity is however only one tool and this investigation has proven that it is necessary to undertake intrusive confirmatory works to validate the findings. Extensive intrusive works have been undertaken using a variety of techniques, the locations targeted were those recommended within the Geotechnology Report at the anomalies identified within the microgravity survey results. Some voiding has been encountered up to scale of approximately 1.0m in diameter, with an approximate vertical length of 6.4m and at depths of 7.5m, 15.2m and 16.1m. The voids identified are likely to be features caused by

Issue	Summary
	dissolution of the chalk. No direct evidence of historical mining has been found in the boreholes advanced. It is known and suspected that historical chalk mining occurred within the immediate local area, in particular located beneath the "sinkhole" outside 8, 9, 10 and 11 Fontmell Close, however no further evidence of other chalk mine features have been proven by the intrusive investigations undertaken by Opus in this study area. Evidence of clay extraction has however been encountered together with a very variable surface topography of the chalk. There is a likelihood that the site is underlain by karstic features within the chalk bedrock, but based on works to date these are expected to comprise both relatively small infilled or open "pipes" at shallow depth beneath the surface of the chalk, and other features at depth. Whilst the shallow features could potentially cause some localised settlement at the surface of the Highway in the future, the impact should be manageable within normal routine Highway maintenance. The risk associated with the deeper features is extremely small due to their depth below surface. It has been concluded that no historical mine workings have been encountered within the investigation area (excluding the area immediately surrounding the 'sinkhole' and outside of 9-11 Fontmell Close, the PBA report relates direct to that area) and hence future catastrophic collapse of the areas investigated appears unlikely. However it is anticipated that ongoing settlement will occur due to the presence of significant thicknesses of uncontrolled Made Ground within the backfilled brick pits and due to the potential settlement of the natural features identified. These would be expected to have a surface expression and require regular highway maintenance. The situation should be monitored and repairs carried out as necessary at a suitable juncture, any unforeseen subsidence should be immediately investigated. Settlement calculations indicate that a maximum long term consolidation settlement for the public highway of around 20mm at the underside of the road construction would occur for a surface point load of around 100kPa from heavy goods vehicles and service trucks. The infill material encountered over Bridle Close (i.e. soft clays) are likely to exhibit more settlement than the infill deposits at Fontmell Close as the deposits are more extensive. Having reviewed all the information available to Opus to date, it is considered that the overall risk to the existing highway and footpath areas at Fontmell Close and Bridle Close is negligible with respect to chalk mining related activity.

1 Introduction

1.1 Background to the Project

In the early hours of the 1st October 2015, a large subsidence event resulted in a 12m diameter crown hole ("sinkhole") appearing at Fontmell Close in St Albans, Hertfordshire. The crown hole extended across the full width of the public carriageway including the footpath, and encroached into residential gardens on both sides of the road.

Following evacuation of homes in the immediate vicinity of the 'sinkhole', the emergency response has involved backfilling of the resultant void with foamed concrete. It is understood that this has required around 500 cubic metres of concrete. The cul-de-sac estate road known as Fontmell Close has been closed to traffic since the incident of 1st October 2015 and as a result this has also prevented vehicle access onto Bridle Close.

Following the subsidence event of 1st October 2016, Hertfordshire County Council (HCC) and Opus International Consultants (UK) Ltd (Opus) devised a strategy to investigate the risk to the public highway in the vicinity of the collapse, (excluding the area surrounding the 'sinkhole' outside of number 8, 9, 10 and 11 Fontmell Close). The investigation was staged and the scope of works was further defined following the geophysical survey of the public highway that was undertaken by Geotechnology Ltd. This survey covered an area from the junction of Fontmell Close and Seymour Road to include the whole of Fontmell Close and Bridle Close, from footpath to footpath including the public road surface.

1.2 Scope and Objective of the Report

This report describes a Geotechnical Ground Investigation and Interpretation undertaken on behalf of Hertfordshire County Council Highways Department (HCC) for the site located along the public highway and footpaths of Fontmell Close and Bridle Close in St Albans, Hertfordshire. This report follows the 'sinkhole' collapse which occurred on the 1st October 2015, however this report excludes the immediate area of the collapse on Fontmell Close.

This report has been prepared on behalf of HCC to investigate the potential ground instability beneath the public highway of Fontmell Close and Bridle Close following a 'sinkhole' feature opening up on Fontmell Close outside property numbers 8, 9, 10 and 11. The area within the immediate vicinity of the 'sinkhole' has been investigated and reported by Peter Brett Associates LLP (PBA) (report titled 'Ground Subsidence Investigation report' and referenced 36121/3502 R001/Rev00).

Drawing number G-AP011.Y3.101.R1 shows the areas included within this report, and also shows the area being investigated by others.

HCC instructed Geotechnology Ltd to carry out a microgravity survey of Fontmell Close and Bridle Close soon after the 'sinkhole' opened up. The report produced is referenced 1531r1v1d1015.

Opus subsequently carried out a Desk Study Report (G-AP004.Y3.109CO.R1.V1 dated January 2016) on behalf of HCC to collate general background information for a wider study area. The study area included Fontmell Close and Bridle Close, therefore where relevant the information has been summarised within this report.

A ground investigation contractor, namely Environmental Scientifics Group (ESG) Ltd were then instructed by HCC to carry out a Ground Investigation under the supervision of Opus.

The aim of this report is to gain an understanding of the ground model of the **public highway** and to establish if any geological or man-made features are likely to be present beneath the highway that may result in similar large "sinkhole" feature occurring in the future.

This report has been prepared by Opus International Consultants (UK) Ltd (Opus) with all reasonable skill, care and diligence within the terms of the Contract with The Client (HCC) and taking account of the information made available by The Client, as well as the manpower and resources devoted to it by agreement with The Client. Opus disclaims any responsibility to The Client and others in respect of any matters outside the scope of the above Contract.

This report should not be relied upon or transferred to any other parties without the express written authorisation of Opus. If any unauthorised Third Party comes into possession of this report, they rely on it at their own risk and the authors owe them no duty of care or skill.

Whilst this report may express an opinion on the possible configuration of strata, or conditions between or beyond exploratory hole positions or on the possible presence of features based on visual, verbal or published evidence, this is for guidance only, and no liability can be accepted for its accuracy.

The site plans enclosed in this report should not be used for scaling purposes.

1.3 Location and Access

Fontmell Close and Bridle Close are located in the Townsend area of St Albans, approximately 1.5km north-north-east of the centre of St Albans and immediately east of Bernard's Heath.

The site location is shown on the appended Drawing No. MK_-AP011.Y3.101CO_101_R1. The site is located at the following approximate National Grid References (NGR);

Table 1.3 National Grid References for the Site

National Grid Reference	Description of grid reference location
515517, 208471	Junction of Seymour Road and Fontmell Close, approximately 100m north east of 'sinkhole'.
515494, 208437	Located on the highway opposite number 5 Fontmell Close, at the edge of contractor's site hoarding.
515441, 208436	Located on the highway opposite number 16 Fontmell Close, at the other edge of the hoarding, and adjacent to the junction with Bridle Close.
515335, 208524	Located at the north western end of Fontmell Close.
515377, 208376	Located at the south western end of Bridle Close, adjacent to Ariston Fields.

The site was divided into two areas by hoarding associated with the 'sinkhole' outside property numbers 8, 9, 10 and 11 of Fontmell Close.

At the time of the investigation, vehicular access was gained (for the north eastern area of Fontmell Close) off Seymour Road, and for the western area of Fontmell Close and all of Bridle Close via a temporary road recently constructed across Ariston Fields to the west of the site, and accessed through a disused Fire Station off Heathlands Drive.

1.4 Site Description

A walkover survey was undertaken on the 5th December 2015, prior to any intrusive works and continued site observations were recorded during the Ground Investigation carried out by Environmental Scientifics Group Ltd (ESG) until completion on the 2nd February 2016. Selected photographs taken during this period are presented in Appendix 'A'. The aim of the walkover and site observations was to provide a description of the site and place the site "in context" within the surrounding area. The comments provided below give a general description of the site and features of relevance in terms of the requirements of this report, in particular potential for ground movement.

The site comprises a public road and footpath, which prior to the 'sinkhole' feature, was accessed off Seymour Road to the north east. At the time of the walkover survey the site was in two separate sections with a small section of Fontmell Close accessed off Seymour Road, up to property number 5 where Heras fencing was present. This fencing was later replaced with a more permanent wooden hoarding. The remaining section of Fontmell Close and all of Bridle Close was accessed via a temporary road constructed by HCC across Ariston Fields to the west. Pedestrian access to this area of the site was via a temporary footpath constructed by St Albans Council, the footpath started at the end of Bridle Close and crossed an area of open access land joining an existing footpath off Sandridge Road to the south east of the site.

Table 1.4 includes observations of the road surface as noted on site. For convenience the site has been split in to three areas as follows and as shown on the Exploratory Hole Location Plan referenced MK-G-Ap011.Y3.102;

Area 1 – Fontmell Close - north east – separate area accessed off Seymour Road, from the junction of Seymour Road to the edge of hoarding outside number 5 Fontmell Close.

Area 2 – Fontmell Close - north west – area from the edge of the hoarding at Bridle Close/Fontmell Close (Number 16) junction to the far north eastern end of Fontmell Close (Number 50).

Area 3 – Bridle Close – south western area of the site – from the junction of Fontmell Close to the turning head adjacent to Ariston Fields.

Table 1.4 Road Condition Description – Walkover Observations

Area	Description
Area 1	The road surface comprised asphalt, with a line of cobbles at the Junction of Seymour Road. The surface was noted to undulate, in particular it was noted to rise up towards Seymour Road (north east) but dip just prior to the junction. The road sloped gently down towards the south west. The asphalt surface appeared to be generally in good conditions, a small pothole was noted part way down the road. No significant cracks were observed within the asphalt surface. A utility trench that had been recently reinstated with asphalt, crossed the road to the east of number 3 Fontmell Close. The footpaths either side of the road were also surfaced with asphalt. Some trenches were open associated with the reconnection of utility services. The asphalt was in generally a good condition, however the surface showed some undulation.
Area 2	The road surface comprised asphalt. A joint in the asphalt was present along the junction of Bridle Close, with the Bridle Close asphalt appearing to be newer. The road surface was noted to have numerous cracks in the surface, these generally crossed the road in a roughly north to south direction. The cracks are shown on the Topographical Survey referenced R-12889.201 included within the drawings section of this report. Also see photographic Plate 4.

Area	Description
	The footpaths either side of the road were also surfaced with asphalt and the cracks observed within the road did not appear to continue into the surface of the footpaths. The surface of the footpath showed some sign of local depressions and settlement, especially around inspection covers.
Area 3	The asphalt surface of Bridle Close appeared to be relatively newly laid. This was confirmed by a resident who told Opus on site that the surface had been re-laid within the last 6 months. The road sloped gently towards the south west. In the south western area, on the edge of the hammerhead, the road surface was significantly lower than the surrounding area suggesting that there has been some settlement within this area (see photographic Plate 2). The asphalt surfaced footpath also appeared to be newly re-laid and was noted to be in good condition. The footpath mirrored the undulations of the road, particularly in the area to the south west around the hammerhead.

1.5 Information from Residents

During the site walkover and ground investigation supervision period, various anecdotal information was passed onto the Opus site Engineer from residents or other members of the public. All such anecdotal evidence is believed to have been offered in good faith but Opus cannot attest to either its accuracy or completeness. The information that is directly relevant to the study area is included below in Table 1.5. Residents have often asked to remain anonymous, therefore details are just given with a description of the area they relate to;

Table 1.5 Anecdotal Information from Local Residents and Third Parties

Date Information Obtained	Approximate location	Details of verbal information received
14/12/2015	Fontmell Close, area between BH102 and DP102	Four plots were originally on strip or raft foundations, however due to subsidence caused by a water leak they were underpinned. This was carried out by installing piles and a ring beam. In the rear gardens of at least two of these plots the ground surface levels have reduced leaving a surface depression.
15/12/2015	Bridle Close, area between CH104 and BH106	Two houses were demolished in the last 10 years due to subsidence and ground movement, they were rebuilt on piled foundations penetrating to depths of approximately 12m bgl.
22/12/2015	Fontmell Close, area between BH102 and DP102	The first movement issues at these plots affected the garages, they were then knocked down and rebuilt. After the garages were rebuilt a water leak occurred between plots 18 and 20, this caused subsidence of the houses and they were underpinned with piled foundations. The Engineer on site was shown a ground investigation report. This showed that in the area of these plots, boreholes proved Made Ground to 5m bgl, and underlain by alternating layers of sand and gravel, sand, gravelly clay, and clay.

Date Information Obtained	Approximate location	Details of verbal information received
18/01/2016	Fontmell Close, area adjacent to CH102A	A resident informed the supervising Engineer that there had been a historic water leak adjacent to the current working area (CH102A)
26/01/2016	Bridle Close/Fontmell Close Junction	Thames Water were on site and spoke to the supervising Engineer. They informed the Engineer that sewage has been building up in an inspection chamber and along Bridle Close due to damage caused by the "sinkhole". Thames Water were investigating the location of their services.

2 Desk Based Searches

2.1 Review of Opus Desk Study

2.1.1 Introduction

Opus carried out a Desk Study Report (dated January 2016 and referenced G-AP004.Y3.109CO.R1.V1) for a wider search area that included Fontmell Close, Bridle Close, Ariston Fields and the surrounding areas. The report includes data that was available at the time of writing and was aimed at compiling the background information available, to provide a general overview.

2.1.2 Peter Brett Associates Natural and Mining Cavities Database Search

The Peter Brett Associates LLP (PBA) Database searches have indicated both natural and man-made features within the immediate vicinity of the site to include solution pipes, historical brick pits, extensive clay pits, potential chalk mining and a historic limekiln. The grid references have been plotted on the current Ordnance Survey map available and the positons are located as detailed in Table 2.1.2 below.

Table 2.1.2 Summary of PBA Database Searches

Approximate National Grid Reference (as provided by PBA Searches)	Recorded location (from PBA Searches)	Mining/Cavity Details (From PBA Searches)	Description of plotted National Grid Reference on Current mapping
51585 20840 51585 20875 51590 20887 51595 20840 51587 20805 51585 20840	Railway Cutting, Bernard's Heath, St Albans, Hertfordshire	3 Solution Pipes	The National Grid References are all located along a cutting associated with a railway line approximately 750m west of the site.
Centred at 51540 20850*	Fontmell Close/ Seymour Road, Bernard's Heath, St Albans, Hertfordshire	Historical Brick Field/ Extensive Clay Pits- Potential Chalk Mining	The National Grid Reference centres at the location of historic brick pit and located beneath the site.
51550 20840	Heathside/ Sandridge Road, Bernard's Heath, St Albans, Hertfordshire	Historical Limekiln - Potential Chalk Mining	The National Grid Reference centres just to the south of the location of the sinkhole feature that opened up on the 1st October 2016 and is therefore very close to this study area.

Approximate National Grid Reference (as provided by PBA Searches)	Recorded location (from PBA Searches)	Mining/Cavity Details (From PBA Searches)	Description of plotted National Grid Reference on Current mapping
** Centred at 51510 20850	Heathlands Drive, Bernard's Heath, St Albans, Hertfordshire	Historical Brick Field/ Extensive Clay Pits- Potential Chalk Mining	The National Grid Reference is located just west of the Fire Station, and south west of the Judo Club building, approximately 250m west of the site.
51510 20840	East of A101, Harpenden Road, Bernard's Heath, St Albans, Hertfordshire	Historical Limekiln - Potential Chalk Mining	The National Grid Reference is also located west of the Fire Station, and southwest of the Judo Club building in a similar area to the previous location.

**Ground Investigations along Fontmell Close which began following a recent significant ground collapse indicate the potential presence of historical chalk mine workings.*

*** The 1:2500 Ordnance Survey Map dated 1878 showing the area around Heathlands Drive also indicates the presence of 3 mine shafts believed to be associated with historical chalk mine workings.*

Peter Brett Associates have informed Opus that at the time the database search was commissioned, the nature of the recent collapse (1st October 2015) had not been determined and therefore was not in a position to be added to the database. Therefore the entries above do not relate to the new feature adjacent to the site and further features could be present that are not yet recorded.

2.1.3 Previous Reports

There are reports detailing previous ground investigations for areas adjacent to the site that include Ariston Fields, Heathlands School and the Fire Station. These areas are all to the west and north west of Fontmell Close and Bridle Close and as such are not directly relevant to the area under consideration.

These previous reports include the following:

(a) Soil Consultants Ltd. Ground Investigation Report. Land Off Heathlands Drive, St Albans, Hertfordshire. Prepared for Hertfordshire County Council. Report No. 46/SCW/HA/OT. Dated 18 August 2009.

(b) Zetica Limited. Results of Landsweep® Survey Conducted at Heathlands School, St Albans. Prepared for Soil Consultants Ltd. Report No. P1771-09-R1-1. Dated 17 August 2009.

The following reports are directly relevant to the specific site in question.

(a) Groundsure Limited. 11 Fontmell Close, St Albans, AL3 5HU. Prepared for Geotechnology. Report No. GS-2589995. Dated 15 Nov 2015.

(b) Landmark Information Group. Preliminary Unexploded Ordnance (UXO) Risk Assessment 11 Fontmell Close, St. Albans, Hertfordshire, AL3 5HU. Prepared for Hertfordshire County Council. Landmark Order Number: 76753600_1. Dated 11 December 2015.

2.1.4 Soil Consultants Ltd Ground Investigation Report

In August 2014 Soil Consultants Ltd were instructed by Mouchel Group on behalf of Hertfordshire County Council to carry out a Ground Investigation of the area to the west of the site know as Ariston Fields after two small sink hole features opened up in early 2009. Soil Consultants Ltd were commissioned to investigate the appearance of the sinkholes and establish the possible cause and extent. In addition they were also required to make comments with regards to ground stability of the field.

The investigation encountered ground conditions that comprised Made Ground across the area to approximately 2m bgl. A deeper area of fill was identified in areas to the north, south and centrally located. It is noted that window sample borehole 'WSE' did not prove the base of the Made Ground and the borehole completed at 5m bgl. Underlying the Made Ground was a clayey gravel, or a gravelly clay. In window sample borehole 'WSD' the chalk was encountered at 3.7m bgl, therefore indicating the depth to the chalk in the area to be variable.

The report identified that further collapse of the known features, and further collapse of new features leading to significant, widespread surface 'holes' would be medium to high risk based on the investigation work carried out. The report recommended that remediation of the features should be carried out and that until remediation of the identified features had been undertaken, the field should not be used.

2.1.5 Zetica Limited Landsweep® Survey Report

Zetica Limited were commissioned by Soil Consultants Ltd, who were in turn instructed by Mouchel Group Ltd on behalf of Hertfordshire County Council to carry out a Landsweep® Geophysical Survey of the Ariston Field site, west of the subject site, in July 2009. The survey was commissioned following two voids opening up within the area of land. The survey was undertaken using fixed frequency electromagnetic ground (EM) conductivity mapping.

The survey identified a significant variation in apparent ground conductivity across the site indicating that the fill materials used during the backfilling of a historic clay pit are heterogeneous.

Correlation of the electromagnetic survey results with those of subsequent dynamic probing (carried out by Soil Consultants Ltd and discussed in section 2.1.4 above) suggest that the relatively limited extent of the voids (less than 1m in height), and the variable conductivity of the fill material, has masked any direct EM response. A follow up microgravity survey for the area was recommended.

2.1.6 Groundsure Report

As part of the research for this report, Geotechnology Ltd undertook a geophysical (Microgravity) survey in November 2015, commissioned a Groundsure Report. It is noted that the site covers a much wider search area therefore only the entries relevant to the site area are discussed further below.

The Groundsure Report indicates that there are six historical surface ground working features in the immediate area of Fontmell Close and Bridle Close that include unspecified pits (1878 and 1955), a brick field (1878), and unspecified ground workings (1923 and 1938).

The report shows the locations of two non-coal mining cavities to the east and south of Fontmell Close within the rear gardens to properties off Fontmell Close (approximately located in the rear

gardens of property numbers 28 to 34) and Seymour Road (approximately located in the rear garden of property number 59). It shows the data source to be Peter Brett Associates LLP however this information differs slightly from that provided within the PBA Database searches commissioned by HCC directly.

The Groundsure Report shows soils beneath the site to have a negligible hazard rating for shrinking and swelling potential. This indicates that the ground conditions are non-plastic and no special actions are required to avoid problems due to shrinkage/swelling of clays. The site is recorded to have a very low hazard rating for landslides.

Section 4.3 of the Groundsure Report reports a moderate hazard rating for ground dissolution of soluble rocks. The report details state that very significant soluble rocks are present with a moderate possibility of local natural subsidence due to high surface or subsurface water flow. The advice given in the report states the following 'Do not load the land or undertake building work before obtaining specialist advice' and 'Do not dispose of drainage to the ground' and 'Drainage infrastructure should be maintained'. Other comments relate to new buildings, construction and an increased insurance risk due to soluble rocks.

The hazard rating for compressible deposits or ground, or running sand beneath the site is negligible and the hazard rating for collapsible deposits is very low.

To summarise the Groundsure Report indicates that historical surface ground workings have been carried out at the site and in the immediate surrounding area. Non coal mining activities are recorded immediately south and north east of the site. The soils beneath the site are or a moderate hazard rating for ground dissolution of soluble rocks.

2.1.7 Historical Information

The historical mapping referenced as part of the Desk Study were obtained from the appendices of the Geotechnology Microgravity Report referenced above and were originally sourced from Landmark Ltd.

The historical maps available are summarised as follows in Table 2.1.7.

Table 2.1.7 Review of Historical Map Extracts (1878 to present day)

Date	Source Map Scale	Comments
1878	1:2,500	The historical mapping shows that the position of Bridle Close and the southern and eastern part of Fontmell Close (both are currently not yet present) are within a plot of land occupied by two clay pits, one larger centrally located, and a smaller pit in the northern corner of the site. In the southern area, south of where the public highway is located at present day, are lime kilns and brick kilns. To the south east of the present day highway are two ponds. The boundaries of the plot of land is lined with trees. The location of the present day northern end of Fontmell Close in 1878 is part of a much larger plot of land with no shown use. Immediately south east of the site an area of heathland is shown with a pond in it, a track leads to the pond off a larger track that is present southeast of the site, along the line of the present day Sandridge Road. West of the site a large clay pit is shown, and north west of the site further clay pits, two shafts, a lime kiln and a brick kiln are show. Further to the south west of the site gravel pits and depressions in the ground within heathland, these are just north of a farm named 'Heath Farm'.

Date	Source Map Scale	Comments
		The area to the west of the clay pits is denoted as Bernard Heath.
1898	1:2,500	The 1898 map shows that the southern area of the site is part of a sunken feature, likely to be the clay pits present in 1878, however it is now larger in size and no buildings associated with it are shown. The area is shown to be heathland. The northern area remains undeveloped. The clay pits to the west of the site are now further developed and later in size, a number of ponds are present indicating some of the pits are no longer in use. The area to the north west no longer contains shafts, but is occupied by a Tallow Works. A pond is also present. To the south east and east of the site, beyond the track 'Brick and Tile Works' are present, south of the works is a school and some residential houses.
1924	1:2,500	The clay pit appears to be infilled with the exception of an area to the south east that is now located to the rear of some residential properties that front onto Sandridge Road to the east (the former track). The central area of the site (approximately located at the present day location of the Bridle Close and Fontmell Close junction) is occupied by trees and heathland. The Brick and Tile Works to the south east are no longer shown, however some small buildings still remain. An area indicated to be a depression is shown in the previously undeveloped area south of the site. Further residential properties are present south of the site beyond Sandridge Road.
1939	1:2,500	The site is now occupied by numerous plots that include the rear gardens of residential houses that front onto Seymour Road to the north, and larger parcels of land with no use indicated, however showing smaller buildings to be present and a depression in the land that extends beneath the site area. Some residential properties have been constructed at the site of the Brick and Tile Works east of the site, however the area is still partially disused land. The area of land west of the site still contains depressions associated with historic clay pits, however the area is shown to be wooded and occupied by trees. The area of land to the south is still undeveloped, it is shown to be in use as a playing field and has a footpath crossing it. Heath Farm to the south has been surrounded by residential properties, the farm house still remains however the land associated with it is now a residential estate.
1963-1964 and 1965	1:1,250	The site itself remains unchanged, a number of buildings are located in the eastern area however may be just south of the site boundary. A depression shown previously in the central area of the site is now slightly larger in size. The former clay pit immediately west of the site is shown to be steep sided and deep immediately adjacent to the site and encroaching into the site boundary. A well is indicated at the base of the clay pit, west of the site boundary. The majority of the buildings associated with the Tallow Works to the north west are still present, however some appear to have been removed, and some areas are now occupied with trees indicating that the site is no longer in use. The surrounding area is relatively unchanged with the exception of a new school to the north and some new residential properties.
1964-1991	1:1,250	Fontmell Close and Bridle Close are now shown, accessed off Seymour Road to the north west. The highway is lined with residential properties.

Date	Source Map Scale	Comments
		Some small depressions are still shown in land to the south and west of the site. The area immediately west of the site is denoted as a playing field. Beyond the playing field to the west is a Fire and Ambulance Station, and slightly north is a Youth Centre. Two circular features are noted north west and north east of the Youth Centre in areas occupied by trees. There are no significant changes to the areas to the northeast, east and south of the site.
1973-1993	1:1,250	The mapping sheets cover parts of the site and show no change to the site itself. The surrounding areas remain relatively unchanged from the previous mapping.

2.1.8 Unexploded Ordnance

A preliminary risk assessment for potential unexploded ordnance (UXO) has been carried out in general accordance with CIRIA C681 "Unexploded Ordnance (UXO) – A Guide for the Construction Industry" as part of the Desk Study Report. The risk assessment indicated that the site is regarded as being of low to medium risk of encountering UXO's, and no further action is warranted in this regard.

It should be noted that the assessment carried out as part of the Desk Study is for internal use only, for the purposes of assessing risks to operative during site investigation work and further assessment which may be required at a later date prior to any construction operations, should this be applicable.

2.2 Additional Desk Study Data

2.2.1 Aerial Photography

In order to obtain aerial photographs of the site, the Historic England Archive was contracted to conduct a search of their extensive archive. A scrutiny of the search results revealed that there were four photographs in particular that could potentially improve the understanding of the site. Copies of these images were then obtained for detailed analysis.

The initial three photographs obtained were taken as a part of the same Royal Air Force (RAF) sortie (flight), these images are consecutive and the flight was headed northwards. The final image was captured by the Ordnance Survey (OS).

Aerial photographs are presented within Appendix B.

Table 2.2.1 Aerial Photography

Date	Source Map Scale	Comments
1949	1:10,000	RAF/540/166 SFFO-0021(Royal Air Force 1949). The photograph shows that the site is largely undeveloped and mostly covered in trees. The trees also appear to disguise the presence of a sunken feature towards the south of the site. There is a building located toward the centre of the site, it appears to be commercial in nature. North of the site comprises gardens associated with buildings and houses located along Seymour Road. The west of the site also appears to be located within the gardens of houses situated along Seymour Road. A second building is located directly southwest of the site. Located west of this building is a wooded area, the trees also appear to disguise further possible sunken features. To the south of the site there is an open grassed area, this area is enclosed by fences to the west. The north eastern part of this area is occupied by an obviously sunken feature, south of this there is a football pitch including two goal posts. There are two indistinguishable features located within this grassed area one is to the north of the football pitch a smallish dark circular zone, the second is a small white circular feature that is located to the south west of the football pitch and appears to be manmade.
1949	1:10,000	RAF/540/116 SFFO-0022 (Royal Air Force 1949). The building located towards the centre of the site appears to have a cleared area in font and to the sides as well as a number of small out buildings. The photograph further highlights the sunken features evident inside and outside the site. The feature present within the site is harder to distinguish due to the wooded area, but shadows possibly suggest a lower ground surface. The depressions to the south and south west of site are easier to discern because of the open grassed area that extends south. This grassed area is enclosed by a fence, beyond which you can see trees which are only visible from partway up their trunks, indicating a lower ground surface. The grassed area to the south has a swing set is visible north west of the football goal posts, a dark circular feature is also evident to the north east of the football pitch. A feature is evident between Seymour Road and a sunken area south of site, this could possibly be a path or drainage feature.
1949	1:10,000	RAF/540/166 PFFO-0023 (Royal Air Force 1949). The southernmost extent of the site cannot be seen, however the northern areas are visible in greater detail. The possible sunken feature is less distinguishable from the shadows produced by trees however their does still appear to be a depression in the ground. The buildings evident in the north of the site adjacent to Seymour Road are now identifiable as sheds and out builds located with the rear garden of a property situated along Sandridge Road. The building evident in the centre of site now has four identifiable outbuildings, these are located to the east of the largest building. The building south of the west of site appears to be a residential dwelling, associated outhouses also appear to be located within the site boundaries.

Date	Source Map Scale	Comments
1969	1:1,250	OS/64022 Frame-555 (Ordinance Survey 1964). The photograph shows that there are far fewer trees present within the site boundaries as well as to the south west of the site. The buildings evident towards the north of the site within the gardens of properties off Sandridge Road are easily discernible and appear to have increased in number. The buildings situated in the centre of site have increased in size as well as the outbuildings disappearing. Other structures have been built to the east of these they appear to be located close to or within private gardens for properties adjacent to Sandridge Road. Further structures are also visible to the west of the older building these are hidden within the tree line. The area around building situated to the west of the site appears to be over grown, however the track leading to the building is easily discernible. South of the site still appears to show sunken features in the ground. The feature located to the north of the grassed area now appears to have a slide descending into it, while swings and a roundabout are visible directly south within the grassed area, while the football goals previously seen have now disappeared. A path bisects the grassed area running diagonally from north east to south west. West of the grassed area a fence is no longer evident and the trees appear to have grown, however hat are now confined to the edges of an open area which appears to hose a number of sunken features.

2.2.2 Historical Mapping

In order to obtain older or localised historical maps a search was conducted in Hertfordshire County Council's Archive and Local Studies department. This search uncovered a number of records however not all were relevant, those that were, underwent analysis and review which is summarised below.

Table 2.2.2 Review of Historical Map Extracts (Pre 1900)

Date	Source Map Scale	Comments
1766	-	Historical mapping shows that the position of Fontmell Close and Bridle Close (yet to be built) is currently occupied by fields. The site also appears to be located on an area of locally high ground. There is a road running north-south-east of the site, this road appears to be Sandridge Road, some buildings are also evident to the south of site.
1815	-	The site contains no distinguishing features, there appears to be a dwelling south of the site, directly north of the heathland. The road is still present to east of the site, however it now has an associated strip of land its west side, closet to the site.
1820 - 1821	-	The position of the site has no identifying features. Heath Farm is identified to the south of the site. The road is still present to the east of the site along with its associated strip of land.

Date	Source Map Scale	Comments
1822	-	The site is not visible on this map, however directly south of the site of an ancient windmill is noted. This area is also noted to be the property of Lord Spencer.
1900	-	At the time, the future location of Fontmell Close and Bridle Close is represented by an empty field, which is surrounded by other fields to the north west and south. The field directly west of the site is identified as 'Brick Grounds' The road to the east of the site is still visible although and associated parcel of land has disappeared, this may be due to damage to the map as the west most boundary line of the road is missing as it passes the site.

2.2.3 Tithe Map

During a visit to the Hertfordshire Archive and Local Studies Department, the historical parish Tithe maps were also viewed. The site is shown to lie within the Parish of Sandridge, as such the 1843 Tithe Plan (Rumball 1843) was studied to determine which plots were situated on and close to the site, these plot numbers were then cross referenced with the corresponding tithe award to determine the owner, occupier and any additional details. It must be noted that as these records were dated after the Tithe Commutation Act of 1836 (Parliment of Great Britain 1836), the assessment of the tithes was notoriously inconsistent therefore grass could refer to intermittently ploughed land, fallow land or even mining. The site appears to be located within Plot No.549 but it may also cross into the northeast corner of plot No.552 and the northern most eastern of Plot No.548. Plot No. 548 has an interesting name as it is referred to as Brick Close. The details of the plots can be seen in the table below.

Table 2.2.3 Tithe Map

Plot No.	Owner	Occupier	State of cultivation	Additional details
548	Thomas Burningham	Widow Brown	Grass	Harvey Close
549	Thomas Foreman Gape	John Field	Grass	Seven and Eight Acres (17 acres in size)
552	Thomas Burningham	Widow Brown	Grass	Brick Close

2.2.4 Brickworks Searches

To fully understand the history of the area a number of searches were carried out in an effort to determine the size and location of clay pits that were associated with brickworks located on Bernards Heath. These searches included a diverse catalogue of media from books to websites and microfilm, a summary of the information uncovered by these searches can be seen below.

Table 2.2.4 Brickworks searches

Reference	Media	Date	Comments
Hertfordshire Geology and Landscape (Catt 2010)	Book	2010	The book describes how ground chalk was mixed with clay or non-calcareous brick earth to form bricks, helping to reduce the shrinkage of raw bricks before firing, it was also thought to improve frost resistance. The maximum recommended chalk content was 25%, brickworks with associated chalk mines were mainly located where the Reading Formation overlies the chalk. These sites operated a lime kiln as well to make lime mortar and quick lime.
St Albans a history (Freeman 2008)	Book	2008	This book mentions brickmaking in St Albans originating in the fifteenth century, it also references digging on the Heath in the 1780's. Benjamin Fowler and family were producing bricks on the heath from 1813. There are no references to specific areas of the heath in this book.
St Albans 1650-1700 A thoroughfare town and its people (St Albans 17th century Research Group of the St Albans and Hertfordshire Architectural and Archaeological Society 2003)	Book	2003	The book states that while important to the economy of St Albans little is known about brick making in the local area. There is a reference to an order of 184,000 bricks in 1649 and 32,000 in 1653 it is also noted that bricks were made to individual demand for large quantities while stockpiles were used for smaller jobs. The bricks were made just outside the borough of Bernards Heath where place names like Brickkyln and Brick close were recorded in 1726.
Sale Particulars (Unknown 1833 to 1910)	Deeds and Legal Documents	1833 - 1910	A collection of documents pertaining to land on Bernards Heath. One such document dating from 1892 grants the use of a parcel of waste land and associated brick kiln on Bernards Heath. This land is located on the road to Sandridge in the northern portion of the heath.
The Brickworks of Bernards Heath (Unknown 1978)	Magazine Article	1978	This article mentions a number of dells located on Bernards Heath before expanding on the history of brickmaking upon the heath. In the 1870's and 1980's houses sprang up along the road near the brickyards before saying that Jacob Reynolds reopened old brick yards in 1880 before working them for 30 years. The article references a brick works opposite the Infants school, around it were pits of clay, gravel and marl this most likely refers to the site and surrounding area.

Reference	Media	Date	Comments
A Short History of Bernards Heath St Albans (Reynolds 2000)	Website	2010	This website includes information about the history of Bernards Heath, from the Iron Age to recent times. This includes a broad section on brick making stating that the earliest reference to chalk mining in the area of Bernards Heath was recorded in 1437. A map pertaining to brick makers on the heath is also available, this map shows that the site was located on and to the south of the site of William Bennett between about 1833-1865 and later the Miskin's until about 1893.
The Brickmakers of St Albans, Herts. (Reynolds 2011)	Website	2011	This website is a wide-ranging study of brickmaking in St Albans with detailed extracts pertaining to Bernard's Heath and the future site of Fontmell Close and Bridle Close. In 1556 there is reference to 'Brokeclose' which is thought to become Brick Close and in 1564-5 *le kyllnehouse* was granted to John Gape. In 1827 Joseph Fowler was taken to court for leaving brick pits in a dangerous and open state. The Post Office directory dated 1846 lists William Bennett as a builder, brickmaker and lime burner in St Albans. In 1864 James Vass took over William Bennett's brick works and an advert taken out in the Herts Advertiser states fresh lime always on hand. A map entitled Heath Brick and Pottery Works ~1900 indicates the presence of old clay pits and a lime kiln in the area in and around site.

2.2.5 Historic Borehole Data

The historic borehole record available on the British Geological Society Website (British Geological Survey 2015) indicates a well that is located west of the Judo Club, approximately 300m north west of the Bridle Close/Fontmell Close junction. The record indicates that the well was already formed from ground level to 140 feet (42m bgl) and was extended in 1949 to a final depth of 240 feet (73m bgl). Groundwater levels were recorded on 6 dates between November 1949 and May 1950 to be between 41.75m to 42.67m bgl.

2.3 Summary

The database search conducted by PBA produced a number records, two of these pertained to historical brick fields / clay pits and potential chalk mining, a record was situated within the site boundary, and the other was located just south of the site. The Groundsure Report indicates that six historical surface workings are present within the immediate area; these are summarised as unspecified pits in 1878 and 1938, a brickfield in 1878 as well unspecified ground workings in 1923 and 1938. The report references PBA database searches and states that two non-coal mining cavities are also situated to the east and south located with the rear gardens of residential properties, this information differs from that provided by the directly commissioned PBA search.

Further information provided by Groundsure regarding the site states that there is a negligible risk of compressible deposits, running sands or shrinkage and swelling potential. The risk of landslides occurring is very low and the risk of collapsible deposits is low. The risks associated with soluble rock are moderate, therefore there is a risk of local natural subsidence due to high surface or subsurface water flow. Further risk assessment shows that the site has a low to medium risk of encountering UXO's.

The historical mapping shows that a clay pit is present in the southern area of the site in 1878, immediately south of the site limekilns and brick kilns are present. By 1898 the pit is larger and extends further north, east and west. The limekilns and brick kilns are no longer present. By 1924 the pits appear to have been partially infilled and some of the area is shown to contain trees. An area in the west is still shown to contain a sunken feature, it is located within the garden of a residential property fronting onto Sandridge Road. The site by the late 1930's is made up of a number of gardens related to properties that front on to Seymour Road to the north east. By the 1960's it appears that a pit has been either reopened or was omitted off previous mapping, the pit is located in the eastern area of the site, and to the far western extents. By 1964 Bridle and Fontmell close are shown to be present and any pits beneath the site are now assumed to be infilled. Some old pits and depressions are shown to the west and south of the site.

Further historical sources show that the earliest reference to brickmaking in the area is 1437, on the 1843 Tithe map the field to the South west of site is referred to as Brick Close (the earliest reference of this nomenclature is 1726) and on a map dated 1900 that same field is identified as 'brick grounds'. Historical sources also note that opposite the infant's school there were pits of clay, gravel and marl; from 1833-65 these pits were run by William Bennett and later Miskin's until 1893. A separate source states that on William Bennett's death they were taken over by John Vass who took out an advert in the Herts Advertiser stating that there was fresh lime always on hand this is supported by maps from 1900 showing old clay pit and a lime kiln on site.

3 Ground Summary

3.1 Geology

According to the inspected published geological information (British Geological Survey 1978) superficial Glacial Gravel occurs across the site. Beneath these the Reading Beds (mottled clay, sand and pebbles) are recorded to be lying unconformably on the Upper Chalk.

Recent publications (British Geological Survey 2015) employ updated nomenclature with superficial deposits now referred to as the Kesgrave Catchment Supergroup, the Reading Beds have been subsumed into the Lambeth Group while the Upper Chalk has become the White Chalk Supergroup which has been split into individual formations. The formations shown to be present beneath the site are the Lewes Nodular Chalk Formation and the Seaford Chalk Formation (Hopson 2005).

The information from the sources detailed above has been collated to produce the stratigraphic column below, this should be used as a guide to understand the general distribution of strata beneath the site. However it should be noted that not all strata included within the stratigraphic column may be present in all locations.

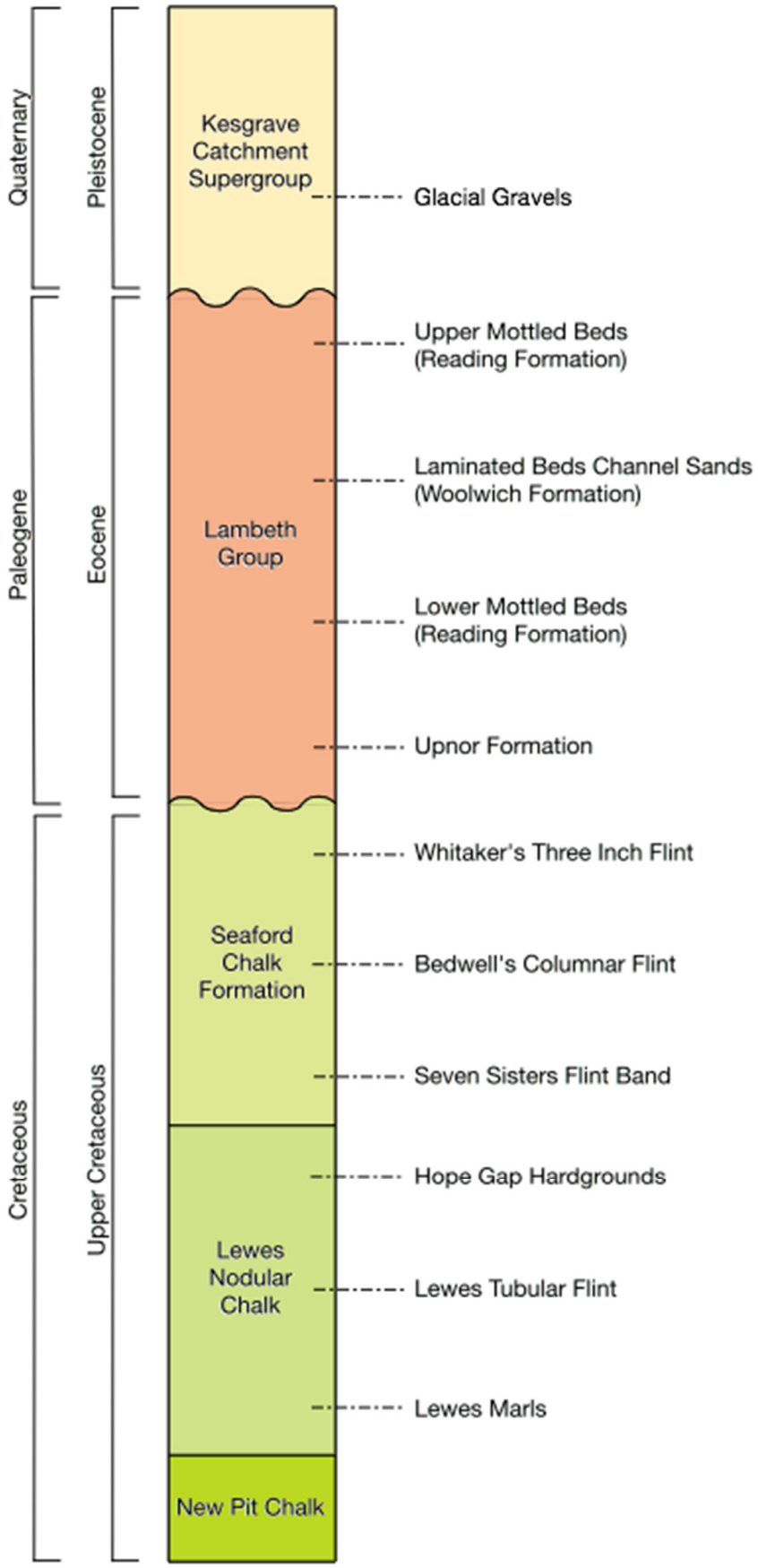
Resting unconformably on the Lambeth Group, the Kesgrave Catchment Supergroup commonly comprises yellow brown massively bedded silt to clay, fluvial gravel aggradations with sedimentary structures, lacustrine silts and clays with uncommon organics. The gravels are usually coarse angular flint fragments with smaller rounded flints, quartz, quartzite, sandstone and chert with occasional volcanic rocks. The gravels are the reason for the units previous description of "Glacial Gravels - with Bunter Pebbles" (Catt 2010). Within the site the lithostratigraphic Westland Green Gravel Member is present, this member typically comprises coarse gravels composed of mainly subrounded flint fragments with smaller but variable amounts of rounded flint, sandstone and chert. The gravels are characterised by quartz and quartzite from the West Midlands, Welsh Borderlands and possibly south western Pennines and by the felsic volcanic rocks from North Wales (British Geological Survey 2016).

The Lambeth Group comprises vertically and laterally variable sequences mainly of clay, some silty or sandy with some sands and gravels, minor limestones and lignites with occasional sandstone and conglomerate (British Geological Survey 2016). The Lambeth Group is also split into beds in particular the Upper Mottled Beds (Reading Formation), comprising stiff to hard fissured and mottled multi-coloured clays-silty sands (Entwisle, Hobbs et al. 2013)., and the Laminated Beds Channel Sands (Woolwich Formation), comprising fine to medium clean or pyritic quartz sand. Beneath this are the Lower Mottled Beds (Reading Formation) which comprise firm to hard fissured mottled multi-coloured clays-silty sands or gravels, they may contain layers cemented with ferricrete, silicrete and calcrete towards the top of the sequence (CIRIA 2004). The Upnor Formation is the basal bed of the group and typically comprises loosely cemented black flints in fine to medium pale grey sand to hard green clay sandy matrix. This is underlain by medium laminated grey clays and light brown or grey sometimes glauconitic fine to medium sands with some cross bedding, lamination and is often bioturbated with occasional shells (British Geological Survey 2016). Frequently at the base of the Upnor Formation there is a thin bed of green-coated flint pebbles and unworn flint nodules in a matrix of brown glauconitic sand or sandy clay. This bed is often mistaken for the Bullhead Bed at the base of the Thanet Sands formation.

The Seaford Chalk Formation consists of firm white chalk with conspicuous semi-continuous nodular and tabular flint seams, some flint nodules are large to very large (CIRIA 2002). There are numerous beds within this formation, three beds of particular note are Whitaker's Three Inch Flint Band (a solid tabular band comprising overgrown horizontal Thalassinoides flint (Hopson 2005)) Bedwell's Columnar Flint Band (a nodular flint band, with large Paramoudra flints, wavy shells of Cladoceramus and basal Santonian index fossils (Hopson 2005) and Seven Sisters Flint Band (a

conspicuous dark coloured sheet flint with a significant inoceramid bivalve content (Hopson 2005)) (CIRIA 2002).

Figure 3.1: Idealised stratigraphic column



The Lewes Nodular Chalk Formation is composed of hard to very hard nodular chalks with interbedded soft to medium hard chalks (some grainy) and marls with regular seams of nodular chalks throughout. Nodular chalks are typically lumpy and iron stained (Hopson 2005). This formation also contain numerous identifiable beds, these include the Hope Gap Hardgrounds, (a conspicuous layer of iron stained nodular white chalk interspaced with soft grey chalk (Mortimore 2011)) Lewes Tubular Flint (comprising ring shaped vertical flints, the inner flint is frequently missing / weathered out leaving a tubular flint (CIRIA 2002)) and the Lewes Marls (which have a 'brittle texture' associated with a detrital marl and are full of mesofossil debris, as well as a number of microfossils (*Hopson 2005*)).

The New Pit Chalk Formation comprises chalk mudstones with at least ten discrete marl seams and very rare nodular flints (Catt 2010). According to the BGS Lexicon, the New Pit Chalk Formation is principally a blocky, white firm to moderately hard chalk with numerous marls or paired marl seams and contains flints.

3.2 Hydrogeology

The hydrogeology of the site is characterised by the Chalk which has a Principal Aquifer Designation, due to its high porosity and abundant fractures resulting in a high permeability (UK Groundwater Forum 1998). Situated above the Chalk, the Lambeth Group is classified as a Secondary 'A' Aquifer also indicating a high permeability. The overlying superficial deposits on site are classified as unproductive strata (negligibly permeable) with negligible significance for water supply or river base flow (Environment Agency 2016).

The site is located within a designated source protection zone, its classification of 'outer zone (zone 2)' this is defined by a 400 day travel time below the water table which requires a 250 or 500m radius. It should also be noted that the site is located approximately 200m north east of an 'inner zone (zone 1)' classified source protection zone which is defined by a 50 day travel time and requires a minimum radius of 50m (Environment Agency 2016).

3.3 Hydrology

The nearest recorded surface water feature is the River Ver approximately 2km south west of the site.

The indicative floodplain map for the area, published by the Environment Agency, indicates that the site does not lie within a floodplain and is not at risk from extreme flooding by rivers or the sea. The north eastern portion of the site is at a low to medium risk of flooding from surface water, however it should be noted that this report does not constitute a detailed flood risk assessment.

3.4 Topography

The area across Fontmell Close and Bridle Close is relatively flat with ground surface levels ranging between 49.8m and 50.5m OD at the far western end of Bridle Close and the north end of Fontmell Close respectively. A Topographical Survey was carried out as part of the investigation works to provide accurate ground levels and co-ordinates for the exploratory hole positions. The survey drawing is included within the drawing section of this report and is referenced R-12889.201.

4 Field and Laboratory Studies

4.1 Non-intrusive investigation

4.1.1 Geophysical Survey

A geophysical survey was carried out by Geotechnology Ltd in November 2015 on behalf of HCC (ref: Ground Collapse at Fontmell Close, St Albans, Microgravity Report, Report Number 1531r1v1d1015, Geotechnology Limited). The fieldwork comprised microgravity across the full length of the public highway at Fontmell Close and Bridle Close. The survey results were initially used to design the intrusive geotechnical investigation.

The information obtained during the geophysical survey has been collated and summarised in a separate report.

A summary and assessment of the geophysical survey data is presented within Section 5.14 of this report.

4.2 Intrusive Investigation

Environmental Scientifics Group Ltd (ESG) were commissioned by HCC to carry out an intrusive ground investigation, and produce a Factual Ground investigation report. The outline scope of the investigation was designed by Geotechnology who carried out a microgravity survey of the site presented as Drawing number 1531/14 and produced a report referenced 1531r1v1d1015 making recommendations for the investigation works. The proposed investigation scope was then developed into a detailed scope of works by HCC. ESG carried out the intrusive investigation works, under the supervision of Opus. The factual report is referenced G5519-15 and dated March 2016. The Geotechnology Report and ESG Factual Report should be read in conjunction with this report, and the relevant information has been appended to this report. ESG were also commissioned by HCC to undertake the Geotechnical Laboratory testing which is reported separately in an addendum report.

4.2.1 Objectives

The ground investigation has been undertaken to provide sufficient information to produce a ground model across Fontmell Close and Bridle Close in order to gain an understanding of the underlying ground conditions to establish if any features are present beneath the site that may develop into "sinkhole" features, and have the potential to cause significant damage to the public highway.

The intrusive fieldworks (carried out by ESG Ltd) comprised boreholes (cable percussion and open hole rotary), window sample holes and super heavy dynamic probes. The ground investigation was intended to supplement and develop the information already gathered from the previous desk study that was previously prepared by Opus.

4.2.2 ESG Factual Report

ESG Ltd were commissioned by HCC to carry out a Ground Investigation at positions based on recommendations made within the Geotechnology Report. The Ground Investigation was designed by Opus to take a phased approach using the least intrusive methods first to gain confidence in the ground beneath the highway. The methods used were dynamic probing, window sampling, cable percussive drilling and rotary open drilling using dynamic sampling, coring and open hole methods. Prior to commencing any intrusive works the service plans were checked and a cable avoidance tool was used to locate positions away from any known services. At all the exploratory hole locations the road surface was cored using a dedicated concrete coring rig, hand excavated starter pits were then excavated to ensure the absence of any ground services below, prior to commencement of drilling.

ESG Ltd have produced a factual report which details the methods used and includes the factual data. The report is referenced G5519-15 and dated March 2016.

The exploratory hole logs are presented within the ESG Ltd Factual Report and are included within Appendix C of this report. An exploratory hole location plan is included within the drawing section of this report and is referenced G-AP011.Y3.102.r0. The factual data has been used for this report and the ground conditions are summarised in Section 5.

4.3 Monitoring Survey Data

For the duration of the intrusive works, the ground levels around the immediate working areas was monitored by a survey. The monitoring data is included within Appendix D.

4.4 CCTV Surveys

During drilling of the cable percussive boreholes and rotary boreholes some potential voids were identified. To confirm the nature of the voided ground Tower Surveys Ltd were commissioned by HCC to carry out CCTV surveys. The CCTV Surveys are included within Appendix E and discussed further in Section 5.7 of this report.

4.5 Laboratory Testing

Geotechnical laboratory testing was scheduled by Opus on undisturbed, disturbed and bulk samples obtained from the ground investigation. Laboratory testing was carried out by ESG in accordance with the relevant standards as quoted within the Factual Report.

Disturbed and undisturbed samples were sent for geotechnical and chemical testing in order to classify the material types encountered, to obtain geotechnical parameters to inform the ground model and for geotechnical assessment and design.

The following laboratory testing was carried out on the soil and rock samples obtained from the investigation to determine the geotechnical parameter of the soils and rock underlying the site area. The laboratory tests carried out included:

- Moisture content
- Atterberg limits
- Particle size distribution by wet sieving and/or pipette
- Oedometer
- Consolidated drained small shear box
- Unconsolidated undrained triaxial compression
- BRE SD1 Suite – Total / water soluble sulphate, pH
- Calcium Carbonate

All laboratory testing was carried out in accordance with BS: 1377 “Method of Testing for Soils for Civil Engineering Purposes”, 1990. The results of the field and laboratory work are contained in ESG factual report number G5519-15 and dated March 2016.

A summary of the laboratory tests scheduled as part of the scheme specific ground investigation is presented in Table 4.5 below.

Table 4.5 Summary of Geotechnical Laboratory Testing

Geotechnical Laboratory Test	Test Method	No. samples scheduled
Moisture Content	BS1377: Part 2: 1990; Clause 3	51
Atterberg limits	BS1377: Part 2: 1990	51
Particle Size Distribution	BS1377: Part 2: 1990	30
Strength / Consolidation		
Undrained triaxial compression	BS1377: Part 6: 1990	6
Oedometer	BS1377: Part 5: 1990	4
Consolidated drained Small Shear Box (set of 3 tests)	BS1377:Part 7: 1990	22
Chemical (tests on soils and groundwater)		
BRE SD1 Suite – Total / water soluble sulphate, pH	BS1377:Part 3:1990	20
Calcium Carbonate	BS1377:Part 3:1990	20

A copy of ESG's addendum report that includes all the laboratory testing is included within Appendix F.

4.6 Concrete Core Testing

Three cores were taken from the concrete road and tested for compressive strength, density and void content to BS EN 12504-1:2009. The tests were carried out by ESG Ltd who are a UKAS accredited testing laboratory. The cores were initially prepared to a size of 100mm diameter, from the 250mm diameter core taken on site. The test results are presented in ESG Addendum report (Appendix F) and tabulated in Section 5.13.

5 Results of the Investigation

This section of the report gives details and descriptions of the various materials encountered, and includes a justification for the parameters selected as characteristic values. The engineering properties of the materials are dependent not only on the inherent characteristics of the deposits encountered, but also upon the nature of the tests undertaken to derive such properties. The derivation of design parameters takes into account the influence of the method of testing, and the differences between mass characteristics and laboratory scale specimens. References are given where generic parameters are adopted.

5.1 Strata Encountered

The geological sequence observed from the ground investigation is in general agreement with the information from published sources. The materials encountered comprised man-made deposits (Made Ground), overlying superficial Kesgrave Catchment Supergroup (Glacial Deposits), which are in turn underlain by the Lambeth Group and in some places the Upnor Formation. The White Chalk (Seaford Chalk Formation and Lewes Nodular Chalk Formation sub-groups) underlie the Lambeth Group and Thanet Formation.

The overall investigation site covers a linear area along Fontmell Close (excluding the area around the 'sinkhole' feature) and Bridle Close, the area has been split into three (as detailed in Section 1) for the purpose of this report and to assist with understanding the detail of the ground conditions beneath the site.

Due to the variably of the strata encountered beneath the site the conditions have been split into the areas identified in Section 1.4 and summarised below. The SPT values recorded below have been corrected in general accordance with BS EN 22476 Part 3, accounting for the rig efficiency, borehole depth and overburden factors etc.

5.2 Summary of Area 1

Made Ground - Asphalt

Asphalt was encountered within all exploratory holes from ground level to 0.10m bgl in CH101.

Made Ground - Concrete

Concrete was encountered within all exploratory holes (except BH101) and was proved to a maximum depth of 0.3m bgl.

Made Ground - Cohesive

Cohesive Made Ground was encountered within all the exploratory holes and was proved to a maximum depth of 6.00m bgl in BH101.

The cohesive Made Ground generally comprised soft to firm, brown sandy gravelly clay. The gravel consisted of fine to coarse, angular to rounded flint, brick, and concrete.

SPT 'N' values obtained during the investigation within the cohesive Made Ground revealed corrected 'N' values in the range of 3 to 23 indicating a very soft to firm consistency cohesive strata. It is noted that the SPT results generally increase with depth.

Kesgrave Catchment Supergroup - Cohesive

Cohesive Kesgrave Catchment Supergroup deposits were encountered within all the exploratory holes and was proved to a maximum depth of 9.00m bgl in BH101.

The cohesive Kesgrave Catchment Supergroup generally comprised soft to firm, orangish brown sandy gravelly clay. The gravel consisted of subangular to rounded flint.

SPT 'N' values obtained during the investigation within the cohesive Kesgrave Catchment Supergroup revealed corrected 'N' values in the range of 27 to 34 indicating a firm to stiff consistency cohesive strata. It is noted that the SPT results generally increase with depth.

Kesgrave Catchment Supergroup - Granular

Granular Kesgrave Catchment Supergroup deposit was encountered within BH101 only and was proved to a maximum depth of 11.50m bgl.

The granular Kesgrave Catchment Supergroup generally comprised very dense light brown slightly clayey fine to medium sand. Gravel is fine to coarse sub-rounded to rounded flint.

SPT 'N' values obtained during the investigation within the granular Kesgrave Catchment revealed corrected 'N' values in the range of 27 to 27 indicating a medium dense granular strata.

Lambeth Group - Granular

Granular Lambeth Group deposits were encountered within all the exploratory holes and was proved to a maximum depth of 13.70m bgl in BH101.

The granular Lambeth Group deposits generally comprised very dense light brown to greenish grey mottled reddish brown gravelly fine to medium sand and dark brown and black clayey gravel. Gravel is fine to coarse angular to rounded flint.

SPT 'N' values obtained during the investigation within the granular Lambeth Group revealed corrected 'N' values of 20 indicating a medium dense granular strata.

White Chalk

The White Chalk Supergroup was encountered within all exploratory holes underlying the Lambeth Group and was proven to a maximum depth of 29.20m bgl, in CH101.

The White Chalk Supergroup generally comprised low to medium density white chalk recovered as white gravelly silt. Gravel is angular to subangular fine to medium speckled black chalk and occasional subangular to subrounded fine to medium flint.

SPT 'N' values obtained during the investigation within the White Chalk Supergroup revealed corrected 'N' values in the range of 8 to 25 indicating a very weak chalk strata.

5.3 Summary of Area 2

Made Ground - Asphalt

Asphalt was encountered within all exploratory holes from ground level and was proved to 0.14m bgl in BH104 and CH103B.

Made Ground - Concrete

Concrete was encountered all exploratory holes and was proved to a maximum depth of 0.36m bgl in CH103B.

Made Ground - Cohesive

Cohesive Made Ground was encountered within all the exploratory holes apart from BH103, CH102A CH103 and WS102. Cohesive Made Ground was proved to a maximum depth of 5.50m bgl in CH102.

The cohesive Made Ground generally comprised soft to firm, brown or grey sandy gravelly clay with cobbles. The gravel consisted of fine to coarse, angular to rounded flint, brick, chalk, clinker, macadam and concrete. Cobbles are angular to sub angular brick.

The SPT 'N' value obtained during the investigation within the cohesive Made Ground revealed corrected 'N' value of 5 indicating a soft consistency cohesive strata.

Made Ground - Granular

Granular Made Ground was encountered within all the exploratory holes except from CH102, CH102C and CH103B. This horizon was proved to a maximum depth of 1.90m bgl in BH102.

The granular Made Ground generally comprised light greyish brown to black clayey silty sandy gravel with cobbles. Gravel is angular to rounded flint brick and concrete. Cobbles are angular brick.

The SPT 'N' value obtained during the investigation within the granular Made Ground revealed corrected 'N' value of 5 indicating a loose consistency granular strata.

Kesgrave Catchment Supergroup - Cohesive

Cohesive Kesgrave Catchment Supergroup deposits were encountered within all the exploratory holes except for CH102B and CH102E. This deposit was proved to a maximum depth of 17.50m bgl in BH104.

The cohesive Kesgrave Catchment Supergroup generally comprised soft to stiff, orangish brown mottled light blueish grey, dark grey sandy gravelly clay. The gravel consisted of sub-angular to rounded flint.

SPT 'N' values obtained during the investigation within the cohesive Kesgrave Catchment Supergroup revealed corrected 'N' values in the range of 12 to 56 indicating a firm to very stiff consistency cohesive strata. It is noted that the SPT results generally increase with depth.

Kesgrave Catchment Supergroup - Granular

Granular Kesgrave Catchment Supergroup deposits were encountered within all exploratory holes except CH102 and were proved to a maximum depth of 16.80m bgl in BH104.

The granular Kesgrave Catchment Supergroup generally comprised very dense light brown to dark brown slightly clayey gravelly sand or sandy gravel. Gravel is fine to coarse subrounded to rounded flint.

SPT 'N' values obtained during the investigation within the Granular Kesgrave Catchment revealed corrected 'N' values in the range of 6 to 56 indicating a loose to very dense granular strata.

Lambeth Group - Cohesive

Cohesive Lambeth Group deposits were encountered within CH102A, CH103, CH103A, CH103B, WS102 and WS103B. The cohesive Lambeth Group deposits were proved to a maximum depth of 14.40m bgl in CH102A.

The cohesive Lambeth Group deposits generally comprised firm to stiff orangish brown and black gravelly sandy clay. Gravel is angular to sub rounded fine to coarse flint. Frequent bands of mudstone / siltstone.

Lambeth Group - Granular

Granular Lambeth Group deposits were encountered within exploratory holes BH102, BH103, CH102A and WS102. These deposits were proved to a maximum depth of 16.50m bgl in CH102A.

The granular Lambeth Group deposits generally comprised dense to very dense yellowish brown, orangish brown to brown clayey gravelly fine to medium sand. Gravel is angular to sub-angular fine to coarse flint.

SPT 'N' values obtained during the investigation within the granular Lambeth Group revealed corrected 'N' values in the range of 12 to 39 indicating a medium dense to dense granular strata.

Voids

A possible void was encountered at 15.20m bgl in CH103A, at 7.50m bgl in BH103 and at 16.50m and 19.10m bgl in CH102A. The voids were confirmed by carrying out a CCTV survey, the surveys are discussed in more details in section 5.9 of this report.

White Chalk

The White Chalk Supergroup was encountered within all exploratory holes except BH102, CH102C, WS102 and WS103B (due to these holes being terminated above the chalk deposits) and was proven to a maximum depth of 29.20m bgl within CH101.

The White Chalk Supergroup generally comprised extremely weak to medium strong low to medium density white chalk recovered as gravelly silt. Gravel is angular to sub-angular fine to medium speckled black chalk and occasional sub-angular to sub-rounded fine to medium flint and chalk.

SPT 'N' values obtained during the investigation within the White Chalk Supergroup revealed corrected 'N' values in the range of 2 to 24.

5.4 Summary of Area 3

Made Ground: Asphalt

Asphalt encountered within all exploratory holes from ground level to 0.10m bgl in BH106 and CH104, CH104A, CH104B, CH105, WS109 and WS110.

Made Ground: Concrete

Concrete was encountered all exploratory holes and was proved to a maximum depth of 0.40m bgl in BH105, CH104B and WS109.

Made Ground - Cohesive

Cohesive Made Ground was encountered within all the exploratory holes apart from CH104 and CH104B. Cohesive Made Ground was proved to a maximum depth of 12.10m bgl in CH104A.

The Cohesive Made Ground generally comprised soft to firm, brown, dark or greenish grey or black sandy gravelly clay with cobbles. The gravel consisted of fine to coarse, angular to rounded flint, brick, chalk, charcoal, glass, metal, pottery and concrete. Cobbles are angular to sub angular concrete.

The SPT 'N' value obtained during the investigation within the cohesive Made Ground revealed corrected 'N' values in the range of 3 to 18 indicating a very soft to firm consistency cohesive strata. It is noted that the SPT results generally increase with depth.

Made Ground - Granular

Granular Made Ground was encountered within all the exploratory holes except from CH102, CH105 and WS110. This stratum was proved to a maximum depth of 6.80m bgl in CH104A.

The granular Made Ground generally comprised red, light brown, light grey to black clayey silty sandy gravel with cobbles or potentially ashy gravelly clayey sand or gravel and cobbles. Gravel is angular to rounded flint, brick, oyster shells, copper, glass, pottery, coal/ charcoal, macadam, clinker and concrete. Cobbles are sub-angular to rounded brick and concrete.

Alluvium

Alluvium was only encountered in BH106 and CH105 at 6.5m bgl and proved to a maximum depth of 9.50m bgl in CH105.

The Alluvium generally comprised soft to firm dark grey mottled brown and bluish grey with depth slightly gravelly clay with frequent organic pockets and rare rootlets. Gravel is sub-rounded quartzite and rare snail shell.

A single SPT 'N' value obtained during the investigation within the Alluvium revealed corrected 'N' value of 6 indicating a soft consistency cohesive strata.

Kesgrave Catchment Supergroup - Cohesive

Cohesive Kesgrave Catchment Supergroup deposits were encountered within all the exploratory holes except for CH104, CH105 and WS110. A maximum depth of 30.00m bgl of this stratum was proven in BH106.

The cohesive Kesgrave Catchment Supergroup generally comprised soft to stiff, orangish brown mottled red mottled light blueish grey, dark grey sandy gravelly clay. The gravel consisted of fine to medium angular to sub-rounded flint and quartzite.

SPT 'N' values obtained during the investigation within the cohesive Kesgrave Catchment Supergroup revealed corrected 'N' values in the range of 5 to 27 indicating a firm to very stiff consistency cohesive strata. It is noted that the SPT results generally increase with depth.

Kesgrave Catchment Supergroup - Granular

Granular Kesgrave Catchment Supergroup deposits were encountered within all exploratory holes except CH104A, CH104B and WS110. A maximum stratum depth of 39.60m bgl was proved in CH105.

The granular Kesgrave Catchment Supergroup generally comprised very dense orangish brown, light brown, dark grey, dark brown slightly clayey gravelly sand or sandy gravel. Gravel is fine to medium angular to rounded flint and quartzite.

SPT 'N' values obtained during the investigation within the Granular Kesgrave Catchment revealed corrected 'N' values in the range of 9 to 39 indicating a loose to dense granular strata.

Lambeth Group - Cohesive

Cohesive Lambeth Group deposits were only encountered within CH104A and were proved to a maximum depth of 14.00m bgl.

The cohesive Lambeth Group deposits generally comprised firm to stiff orangish brown mottled black gravelly sandy clay with laminations. Gravel is angular to sub rounded fine to coarse flint. Frequent bands of mudstone / siltstone.

Lambeth Group - Granular

Granular Lambeth Group deposits were encountered within exploratory holes BH102 and CH104A. These deposits were proved to a maximum depth of 44.00m bgl in CH104A.

The granular Lambeth Group deposits generally comprised dense to very dense yellowish brown, orangish brown to brown clayey gravelly fine to medium sand or dark grey gravel. Gravel is angular to sub-angular fine to coarse flint.

Voids

A possible void was encountered at 46.10 bgl in CH104A.

White Chalk

The White Chalk Supergroup was encountered within CH104, CH104A, CH104B and CH105 and were proved to a maximum depth of 50.00m bgl, in CH104A.

The White Chalk Supergroup generally comprised extremely weak to medium strong low to medium density white chalk recovered as gravelly silt. Gravel is subangular to subrounded fine to coarse flint.

SPT 'N' values obtained during the investigation within the White Chalk Supergroup revealed corrected 'N' values in the range of 2 to 17.

A full description of the ground conditions encountered during the recent investigation is presented within the engineering logs contained within the ESG Factual report and summarised in the following tables (Table 5.1.1 to 5.1.1a)

Table 5.1.1 Summary of Ground Conditions

Soil Type	Depth Encountered m (Unit Thickness (m))												
	BH101	**BH102**	**BH103**	**BH104**	**BH105**	**BH106**	**CH101**	**CH102**	**CH102A**	**CH102B**	**CH102C**	**CH102D**	**CH102E**
MADE GROUND: Asphalt.	0.00 (0.05)	0.00 (0.05)	0.00 (0.08)	0.00 (0.14)	0.00 (0.07)	0.00 (0.06)	0.00 (0.10)	0.00 (0.08)	0.00 (0.10)	0.00 (0.08)	0.00 (0.10)	0.00 (0.09)	0.00 (0.09)
MADE GROUND: Concrete.	0.05 (0.25)	0.05 (0.25)	0.08 to 0.34 (0.08 to 0.18)	0.14 (0.21)	0.07 (0.33)	0.10 (0.20)	0.10 (0.20)	0.08 (0.22)	0.10 (0.20)	0.08 (0.19)	0.10 (0.20)	0.09 (0.15)	0.09 (0.17)
MADE GROUND: Cohesive Generally comprising soft to firm brown sandy gravelly CLAY. Gravel is fine to coarse, angular flint, brick, chalk, glass, pottery, charcoal, concrete and metal.	0.30 (5.70)	0.30 (1.60)	-	0.80 (0.30)	0.40 (8.60)	0.60 (5.40)	0.30 (0.35)	0.30 (5.20)	-	0.45 (1.15)	0.30 (1.00)	0.25 (0.96)	0.26 (0.94)
MADE GROUND: Granular Generally comprising brown gravelly clayey fine to coarse SAND or dark grey sandy clayey GRAVEL. Gravel is fine to coarse angular to sub rounded brick, concrete, flint and asphalt.	-	1.90 (0.90)	0.26 (0.08)	0.35 (0.45)	0.00 to 1.30 (7.10)	0.06 to 0.30 (0.04 to 0.30)	-	-	0.30 (1.00)	0.27 (0.18)	-	1.20 (0.30)	1.20 (2.20)
ALLUVIUM: Generally comprising soft dark grey mottled brown, becoming firm mottled brown and bluish grey with depth slightly gravelly CLAY. Rare fine flint gravel and rootlets.	-	-	-	-	-	6.00 (1.50)	-	-	-	-	-	-	-
KESGRAVE CATCHMENT SUPERGROUP : Cohesive Generally comprising soft to stiff brown or orange brown sandy gravelly CLAY. Gravel is fine to coarse, angular to rounded flint.	6.00 (3.00)	2.80 to 6.10 (1.70 to 2.80)	2.00 (3.20)	1.00 to 17.50 (0.50 to 13.60) *	9.00 (4.00)	7.50 to 26.00 (0.85 to 4.00)*	0.65 (1.15)	5.50 (7.30)	1.30 (2.20)	-	1.30 (4.20)	1.50 (3.90)	-
KESGRAVE CATCHMENT SUPERGROUP : Granular Generally comprising dense to very dense orange brown or brown clayey sandy GRAVEL, or gravelly SAND, or SAND and GRAVEL. Gravel is fine to coarse, angular to rounded flint.	9.00 (2.50)	5.60 (0.50)	-	14.70 to 16.80 (0.70 to 1.30)	13.00 (5.00)*	9.00 to 20.00 (4.00 to 10.30)	-	-	3.50 (8.50)	1.60 (7.40)*	5.50 (1.60)	5.40 (6.70)	3.40 (10.40)
LAMBETH GROUP: Cohesive Generally comprising firm to stiff reddish brown mottled light grey sandy gravelly CLAY. Gravel is fine to coarse, angular to rounded flint.	-	-	-	-	-	-	-	-	13.60 (0.80)	-	-	-	
LAMBETH GROUP: Granular Dense to very dense light grey, orangish brown or yellowish brown clayey fine to medium SAND.	11.50 (2.20)	7.80 (7.65) *	5.20 (2.10)	-	-	-	1.80 (4.00)	-	12.00 to 14.40 (1.60 to 2.10)	-	-	-	
****Possible Void** *****Confirmed Void**	-	-	7.50 (1.50)***	-	-	-	-	-	16.50 to 19.10 (1.70 to 2.10)***	-	-	-	
WHITE CHALK: Generally comprising extremely weak, very weak or weak low density brownish white or white CHALK recovered as gravelly SILT. Gravel is angular, fine to coarse chalk, and rare to occasional angular to sub rounded fine to coarse flint.	13.70 (18.95) *	-	7.30 to 9.00 (0.20 to 21.00) *	-	-	-	5.80 (29.20)*	12.80 (25.70)*	18.20 to 21.20 (0.90 to 12.30)*	-	7.10 (27.90)*	12.10 (22.90)*	13.80 (21.20)*

* Base not proved.

Table 5.1.1 Summary of Ground Conditions (Continued)

Soil Type	Depth Encountered m (Unit Thickness (m))											
	CH103	CH103A	CH103B	CH104	CH104A	CH104B	CH105	WS102	WS103B	WS107	WS109	WS110
MADE GROUND: Asphalt.	0.00 (0.07)	0.00 (0.13)	0.00 (0.14)	0.00 (0.10)	0.00 (0.10)	0.00 (0.10)	0.00 (0.10)	0.00 (0.10)	0.00 (0.10)	0.00 (0.06)	0.00 (0.10)	0.00 (0.10)
MADE GROUND: Concrete.	0.07 (0.23)	0.13 (0.19)	0.14 (0.22)	0.10 (0.20)	0.10 (0.30)	0.10 (0.30)	0.10 (0.21)	0.10 (0.20)	0.10 (0.25)	0.10 (0.20)	0.10 (0.30)	0.10 to 0.50 (0.25 to 0.30)
MADE GROUND: Cohesive Generally comprising soft to firm brown sandy gravelly CLAY. Gravel is fine to coarse, angular flint, brick, chalk, glass, pottery, charcoal, concrete and metal.	-	0.95 (0.55)	0.36 (2.44)	-	2.00 to 6.80 (2.20 to 5.30)	-	0.31 (8.39)	-	0.90 (0.50)	0.65 (3.60)	0.95 to 7.40 (0.60 to 4.90)	0.80 (2.45)
MADE GROUND: Granular Generally comprising brown gravelly clayey fine to coarse SAND or dark grey sandy clayey GRAVEL. Gravel is fine to coarse angular to sub rounded brick, concrete, flint and asphalt.	0.30 (1.30)	0.32 (0.63)	-	0.30 (1.70)	0.40 to 4.00 (1.70 to 2.80)	0.40 (0.80)	-	0.30 (0.65)	0.35 (0.55)	0.06 to 0.30 (0.04 to 0.35)	0.40 to 3.20 (0.20 to 0.80)	-
ALLUVIUM: Generally comprising soft dark grey mottled brown, becoming firm mottled brown and bluish grey with depth slightly gravelly CLAY. Rare fine flint gravel and rootlets.	-	-	-	-	-	-	8.70 (0.80)	-	-	-	-	-
KESGRAVE CATCHMENT SUPERGROUP: Cohesive Generally comprising soft to stiff brown or orange brown sandy gravelly CLAY. Gravel is fine to coarse, angular to rounded flint.	1.60 (3.50)	1.40 (0.50)	2.80 (1.80)	27.20 (7.10)	-	1.20 (15.30)	-	0.95 (2.25)	1.40 to 2.60 (0.30 to 1.30)	-	8.10 (1.50)	3.25 (2.75)*
KESGRAVE CATCHMENT SUPERGROUP: Granular Generally comprising dense to very dense orange brown or brown clayey sandy GRAVEL, or gravelly SAND, or SAND and GRAVEL. Gravel is fine to coarse, angular to rounded flint.	5.10 (23.00)	1.90 (13.30)	4.60 (10.60)	2.00 (25.20)	-	-	9.50 (30.10)	3.20 (0.70)	2.10 to 3.90 (0.40 to 0.50)	4.25 (0.75)*	9.60 (0.40)*	-
LAMBETH GROUP: Cohesive Generally comprising firm to stiff reddish brown mottled light grey sandy gravelly CLAY. Gravel is fine to coarse, angular to rounded flint.	-	-	-	-	12.10 (1.90)	-	-	-	-	-	-	-
LAMBETH GROUP: Granular Dense to very dense light grey, orangish brown or yellowish brown clayey fine to medium SAND.	-	-	-	-	14.00 (28.50)	-	-	3.90 (1.10)	-	-	-	-
****Possible Void** *****Confirmed Void**	-	15.20 (2.50)***	-	-	46.10 (1.20)**	-	-	-	-	-	-	-
WHITE CHALK: Generally comprising extremely weak, very weak or weak low density brownish white or white CHALK recovered as gravelly SILT. Gravel is angular, fine to coarse chalk, and rare to occasional angular to sub rounded fine to coarse flint.	28.10 (6.90)*	17.70 (17.30)*	15.20 (19.80)*	34.30 (10.70)*	44.00 to 47.30 (2.10 to 2.70)*	16.50 (18.00)*	39.60 (6.00)*	-	-	-	-	-

* Base not proved.

Table 5.1.1.1a Summary of In-Situ Testing and Strength Test Results

Soil Type	Made Ground Cohesive			Made Ground Granular			Alluvium			Kesgrave Catchment Supergroup Cohesive			Kesgrave Catchment Supergroup Granular		
Test Type	**SPT 'N'**	**Corrected SPT 'N'**	**Cohesion kPa**	**SPT 'N'**	**Corrected SPT 'N'**	**Cohesion kPa**	**SPT 'N'**	**Corrected SPT 'N'**	**Cohesion kPa**	**SPT 'N'**	**Corrected SPT 'N'**	**Cohesion kPa**	**SPT 'N'**	**Corrected SPT 'N'**	**Cohesion kPa**
BH101	5-35	3-23	-	-	-	-	-	-	-	41-46	27-34	-	50-53	27-29	-
BH102	6	5	-	4	5	-	-	-	-	-	-	-	18-38	6-21	-
BH103	-	-	-	-	-	-	-	-	-	19-49	16-47	-	-	-	-
BH104	-	-	-	-	-	-	-	-	-	14-50	12-56	-	50	56	-
BH105	4-7	3-6	-	-	-	-	-	-	-	5-17	5-18	-	50-58	29-37	-
BH106	5-22	4-18	-	-	-	-	7	6	-	23-48	23-27	-	18-58	9-39	-
CH101	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH102A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH103A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH104A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Soil Type	Lambeth Group Cohesive			Lambeth Group Granular			White Chalk		
Test Type	**SPT 'N'**	**Corrected SPT 'N'**	**Cohesion kPa**	**SPT 'N'**	**Corrected SPT 'N'**	**Cohesion kPa**	**SPT 'N'**	**Corrected SPT 'N'**	**Cohesion kPa**
BH101	-	-	-	50	20	-	24-33	8-10	-
BH102	-	-	-	31-55	17-39	-	-	-	-
BH103	-	-	-	14-36	12-32	-	4-50	3-19	-
BH104	-	-	-	-	-	-	-	-	-
BH105	-	-	-	-	-	-	-	-	-
BH106	-	-	-	-	-	-	-	-	-
CH101	-	-	-	-	-	-	12-50	12-25	-
CH102A	-	-	-	-	-	-	5-50	2-17	-
CH103A	-	-	-	-	-	-	18-50	8-24	-
CH104A	-	-	-	-	-	-	50	12-13	-

Notes:

(1) All SPT's are uncorrected. Density and strength descriptions are reported in accordance with the guidance stated in BS 5930:1999+A2:2-1-, incorporating requirements of BS EN ISO 14688-1:2002, BS EN ISO 14688-2:2004 and BS EN ISO 14689-1:2003.
(2) SPT 'N' values corrected in accordance with BS EN 22476 Part 3, to account for the rig efficiency, borehole depth, overburden factors etc.
(3) Laboratory undrained triaxial compression test in accordance with BS 1377: Part 7: 1990 Clause 8.0.
(4) Open hole rotary holes and window sample boreholes excluded as no SPT's or triaxial's were carried out.
(5) (UU)

5.5 In-situ Strength Testing

In-situ strength testing was carried out during the recent ground investigation using a combination of dynamic probe test holes and SPT N tests within the boreholes and window sample holes.

5.5.1 Dynamic Probe Testing

Eleven Dynamic Probe Super Heavy (DPSH) tests were carried out along Fontmell Close and Bridle Close to provide a continuous profile of the relative density/ compaction of the underlying soil and chalk deposits and also to determine the presence of potential voids. The location of the probe holes were chosen by Opus based on the anomalies identified within Geotechnology Ltd Microgravity Report. The main purpose of the probe holes was to gain some confidence in the ground conditions before bringing larger rigs onto the site, and prior to introducing air flush into the ground during the rotary drilling. This was to ensure the safety of both contractors and members of the public using the footpaths. The results of dynamic probe testing are presented within ESG's Factual Ground Investigation Report included within Appendix C.

The DPSH was carried in accordance with BS EN ISO 22476-2, BS EN 1997-2 AN NA to BS EN 1997-2. Probing involves the driving of a metal cone into the ground using a series of steel rods. These rods are driven into the ground using a hammer system that repeatedly lifts and releases a 63.5kg weight onto the rods from a set height, ensuring a constant energy input. The number of hammer blows required to drive the cone into the ground by 100mm are recorded, giving a comparative assessment from which correlations with engineering parameters can be generated.

Dynamic probing is a method of site investigation allowing a rapid assessment of ground conditions where sample recovery is not required, typically carried out as a precursor to more intrusive forms of investigation. The 'Blow Count' from dynamic probing gives a relative assessment of 'ground strength' but cannot be used to definitively confirm the actual composition of the geological strata. Consequently the probe holes were typically undertaken adjacent or in close proximity to a window sample hole or a borehole in order to assess the soil type.

From the results of the Dynamic Probing it is possible to extrapolate the general strength properties of the ground beneath the site. This classification requires the equivalent SPT 'N' blow counts to be derived from the dynamic probe tests, and this was completed by adding three consecutive results to give the blows per 300mm, to give an approximate equivalent N_{300} value deemed to be equivalent to a proper SPT 'N' value. These were in turn used to calculate the N_{60} value which is used to infer the strength of cohesive soils using the relationship suggested in Stroud (1974).

The following tables have been used to classify the ground strength with respect to the N_{300} blow count from the dynamic probe.

Table 5.5.1 Classification of Relative Density of Non-Cohesive Soils, BS EN1997-2:2007

SPT 'N_{300}' (blows/300mm)	Classification
0 - 3	Very Loose
3 - 8	Loose
8 - 25	Medium Dense
25- 42	Dense
42- 88	Very dense

Table 5.5.2 Classification of Cohesive Soils Using N_{60}, Stroud (1974)

Corrected N_{60} blow count - Clays	Classification
0 - 4	Very Soft
4 - 8	Soft
8 - 15	Firm
15 - 30	Stiff
30 - 60	Very Stiff
>60	Hard

Table 5.5.3 Classification of Rock Using N60, Stroud (1974)

Corrected N_{60} blow count (blows/300mm) - Rock	Classification
0 - 25	Very Weak
25 - 100	Weak
100 - 250	Moderately Weak
>250	Moderately Strong to Very Strong

The dynamic probe holes were undertaken to a depth of between 4.2m and 25.0m to provide an approximate ground strength profile plotted against depth of penetration. The probes were generally terminated/refused on possible obstructions, dense or hard soils or weathered rock deposits. There appears to a slight increase of ground strength with depth within all of the probe holes.

DP101 and DP102 showed a fairly consistent ground profile with a typical equivalent N_{300} values of between 7 and 29 indicating a variable ground strength of between soft to stiff or loose to medium dense in nature.

DP104, DP105, DP108, DP109, DP110 and DP111 showed a similar profile of very soft and very loose conditions, with N_{300} values of around 2 to 4 and then becoming more competent at a depth of around 7.5m bgl, with a typical N_{300} greater than 20, indicating stiff or medium dense conditions.

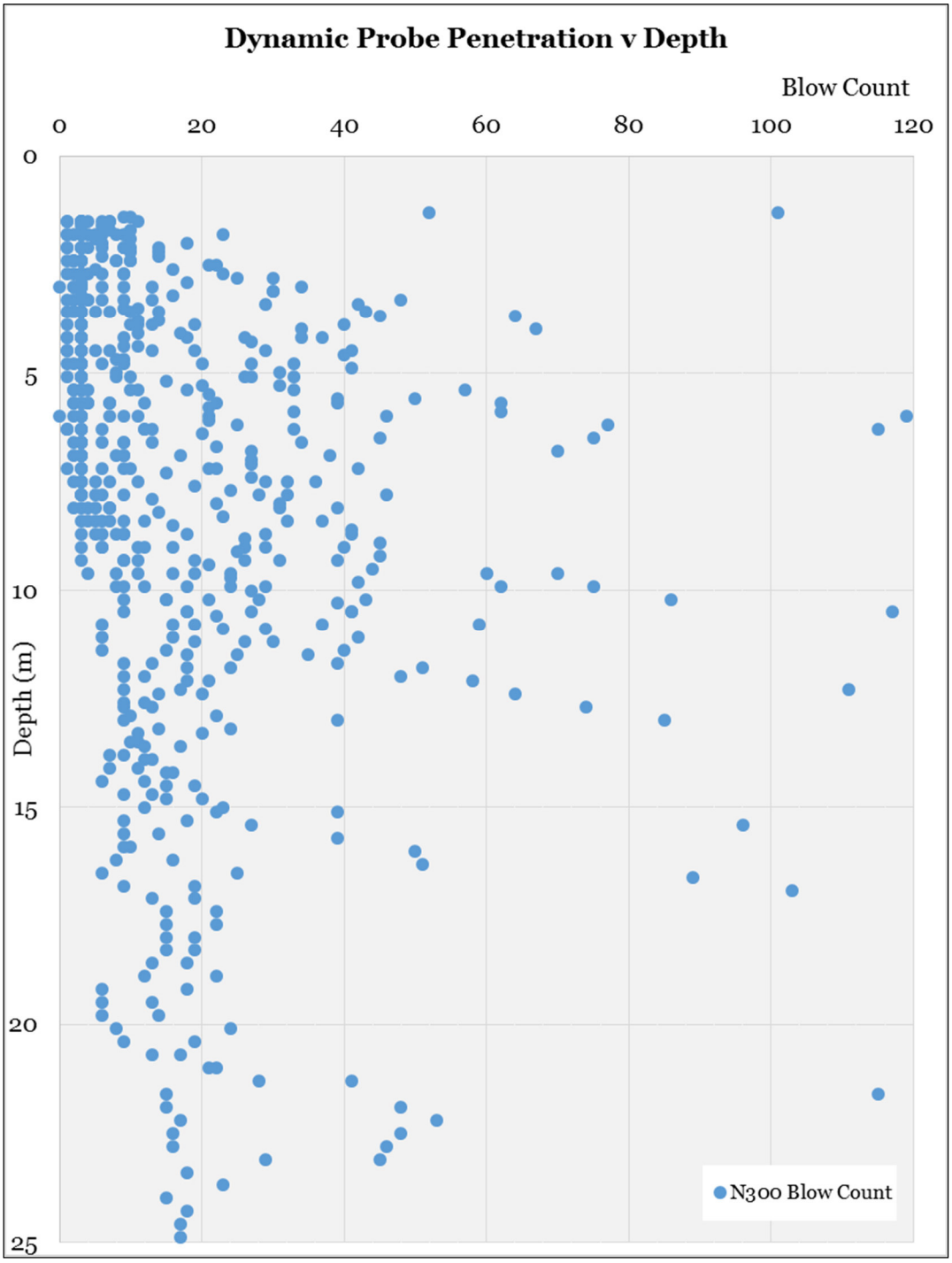
DP103, DP106 and DP107 showed slightly better compacted ground with a typical N_{300} value of around 20, indicating stiff and medium dense conditions (excluding the near surface poorly compacted soils).

Seven of the dynamic probe holes encountered occasional blow counts of zero for 100mm penetration within the superficial deposits to a maximum depth of around 8.5m. The maximum penetration for a zero blow count was 300mm, indicating very soft or very loose conditions.

Ignoring the occasional zero blow counts for 100mm penetration in shallow material, the dynamic probe holes did not indicate the presence of any underlying voids within the superficial or chalk deposits. However, the results appear to indicate depths of variable compacted backfilled ground associated with the infilling of the former clay pits at the site, typically indicating soft or loose ground conditions and better. The test results indicates that void space was not encountered within the probe depths across the site area.

A profile of the dynamic probe test results is presented in Figure 5.5.1.

Figure 5.5.1 Dynamic Probe Penetration v Depth Plot

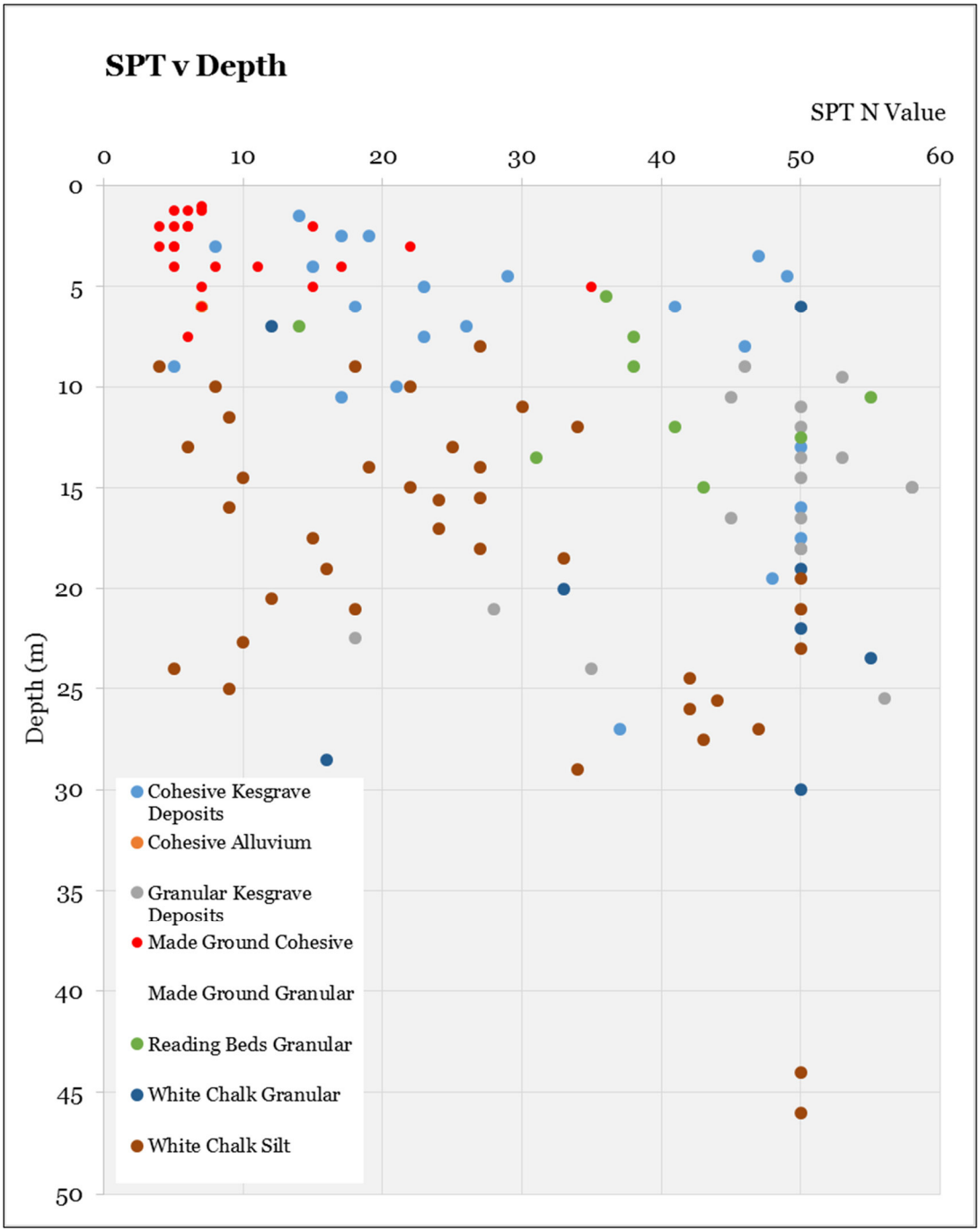


5.5.2 SPT Plots 'v' Depth

SPT were undertaken in the cable percussion, rotary boreholes and window samples holes within the Made Ground, Superficial Soils and White Chalk Deposits at regular intervals of 1.5m. The in-situ SPT recorded N values of between 4 and 58, and typically shown to increase with depth. The SPT N values have been plotted against depth and are presented in Figure 5.5.2 below.

The SPT N values have been used to correlate the strength and density of the underlying soil and chalk deposits, and is discussed in Section 6.

Figure 5.5.2 SPT Values v Depth Plot for all soil and chalk deposits



5.6 Groundwater Observations

Groundwater was encountered within WS103B at 4.00m bgl within the Kesgrave deposits. This is likely to be perched water as the flow rate is recorded as a seepage.

A groundwater strike was also encountered in CH104 at 31m bgl within the White Chalk deposits as observed by the Opus Engineer on site (although not recorded in ESG CH104 log). The borehole was recorded to be dry on completion, therefore this is also considered to be locally perched groundwater.

A groundwater strike within Ch104A was recorded at 47.5m bgl within the White Chalk deposits, this is at a similar depth to the predicted groundwater table recorded in a nearby historic borehole, and therefore it is considered to be the groundwater associated with the principal aquifer within the chalk.

5.7 Ground Model – Cross Section

Three geological cross sections have been produced from the borehole logs in Appendix C. The sections, which are contained in Appendix G include one along Fontmell Close from the cul-de-sac on the western end to the intersection with Bridle Close at BH102 (Section A-A, Drawing MK_G-AP011.Y3.200), a section along Bridle Close from the cul-de-sac to the intersection with Fontmell Close at BH102 (Section B-B, Drawing No. MK_G-AP011.Y3.201) and a section along the north eastern end of Fontmell Close from the "sinkhole" area to the intersection with Seymour Road (Section C-C, Drawing No. MK_G-AP011.Y3.202).

Due to the upper horizons of the Lambeth Group having similar material properties to one another, and since there was depositional variation of materials within each horizon i.e. ranging from clays to gravels, the identification of the four Formations within the Lambeth Group is not clear based on the borehole log descriptions. In addition, some of the logs are based on limited sample recoveries from the boreholes. As such, for the purposes of the geological sections, the main horizons shown are: Made Ground; Kesgrave Catchment Supergroup; undifferentiated Lambeth Group; and White Chalk (Seaford Chalk Formation).

As shown on the geological sections, the depth and thickness of the main stratigraphic horizons are highly variable across the site. This is considered to be due to a number of factors including the following:-

- Erosion of the Cretaceous chalk before deposition of subsequent deposits;
- Dissolution and formation of natural voids within the chalk, followed by natural infilling of the voids with deposits from above;
- Erosion of the Lambeth Group before deposition of subsequent deposits; and
- Historical workings and creation of Made Ground related to clay pit extractions near surface.

The Made Ground horizon is more easily distinguished from the underlying natural strata by its colour and inclusion of man-made artefacts such as ash, timber and brick etc. However, the Made Ground also comprises backfill material obtained directly from disturbed natural strata and therefore do not show any change in colour or contain any noticeable artefacts. As such, the thickness of the Made Ground horizon may differ from that shown on the logs and geological cross sections. Based on where Made Ground was positively identified in the logs, it is noted that Made Ground occurs under all three of the geological section lines. The thickness of the Made Ground was highly

variable, ranging from 0.9m to 12.1m bgl and is mostly associated to the backfilling of clay pits over an extended period of time.

The depth to top of chalk is also extremely variable, ranging from 5.8m to 44.0m below ground level (bgl) along the geological section lines. This variability is likely to be due to natural dissolution of the chalk, and surface erosion of the chalk prior to the deposition of the Lambeth Group and/or Kesgrave Catchment Supergroup. A number of voids were identified during the drilling of the boreholes. However, none were considered large enough to be related to underground mining activities and are therefore believed to have been formed by natural dissolution of the chalk. Where near surface voids were encountered in boreholes, they were backfilled with cement bentonite grout.

When comparing the microgravity survey results to the geological sections (Drawings MK_G-AP011.Y3.200, 201 and 202), the areas with relatively higher microgravity readings (shown in orange and red colours) appears to correspond with the occurrence of thick Lambeth Group deposits.

Based on the information obtained at the positions of the drilled boreholes, there does not appear to be a direct unequivocal correlation between low gravity results and the presence of voids. Where voids were encountered they were relatively small in size.

5.8 Monitoring Data – Summary of Results

Ground surface level monitoring has been undertaken as part of the investigation and the data is included within Appendix D of this report. Some minor ground movement has been recorded, however it is thought that the downward movement noted may be in part due to localised vehicle movements or equipment loading as it was not consistent across an area, or where within the footpath, it is due to vehicles driving along it (the footpath make-up would be less substantial than a road and not designed to take the weight of vehicular traffic). Some of the monitoring points recorded slight uplift in some areas, and this is assumed to be caused by the air flush used when drilling, lifting the asphalt surface upwards. This was visually observed on site by the Engineer, in particular on Fontmell Close. Graphical representation of the monitoring data (along with the raw monitoring data) is presented for each monitoring area at selected monitoring points in order to give a visual representation of the movement recorded. There were four areas that were monitored around the positions of the series of exploratory holes at 101's, 102's, 103's and 104's.

5.9 CCTV Surveys

The table below summarises the depths of encountered possible voided ground and the observations made during the CCTV surveys. It should be noted that the depth of the voided ground was recorded by the driller during the CCTV survey.

Table 5.9 Summary of CCTV Survey Observations

Exploratory Hole Location	Depth of Feature recorded by Drillers (m bgl)	CCTV Observations
BH103	**7.5 to 9.0**	The borehole was surveyed on the 9th January 2016. The images recorded show a void from approximately 8.4m bgl to 10.0m bgl. The void appeared to be a natural feature at the base of the overlying Lambeth Group and is approximately

Exploratory Hole Location	Depth of Feature recorded by Drillers (m bgl)	CCTV Observations
		0.5m in diameter (based on how far the camera can see from the angles available) and over an approximate 1.5m length. The feature is within the top of the chalk and could therefore be considered to be a solution feature.
CH102A	**16.1 to 21.5**	The borehole was surveyed on the 13th January 2016. The survey images show voided ground from approximately 16.1m bgl to 22.5m bgl. The void appeared to be a natural feature and extended beyond the camera's view, therefore it is anticipated to be between 0.5m to 1.0m in diameter and extending over a 6.4m length, however the void narrows with depth, and therefore can be considered to be a solution feature.
CH103A	**15.2 to 17.7**	The borehole was surveyed on the 27th January 2016. The images recorded a vertical crack in the chalk from 16.6m bgl, which extended to 18.1m bgl and became a void from this depth. The void was approximately 1.0m in diameter, the full extents of the void were not observed due to limitations on the camera angles available, however the void was recorded to a depth of 20.0m bgl during the CCTV (although during drilling the SPT recorded an N value of 33 at a depth of 19m). This gives an approximate length of 1.9m bgl. Some evidence of the vertical crack extending deeper was also observed. The restricted width of the 'crack' observed implies that this is a solution feature or a natural open joint rather than a mining feature.

5.10 Backfill Quantities of Boreholes with Voids

The amount of wet grout used to backfill the boreholes was recorded to provide an estimation of the volume of the voids encountered during the investigation works. Table 5.10.1 below summarises the estimated volume of the rotary borehole (150mm in diameter) with no voids/ cracks etc.

Table 5.10.1 Volume of Borehole and Grout Take for Infilling (150mm Rotary BH)

Depth of borehole	Volume (m^3)	Estimated grout in litres
25m	0.440	400
30m	0.530	500
35m	0.620	600
40m	0.710	700
45m	0.800	800

Table 5.10.2 below is a record of the volume of grout used to fill BH103, CH102A and CH103A where the voids were recorded by the drillers, and observed during the CCTV surveys.

Table 5.10.2 Grout Quantity used to Backfill Boreholes

Borehole Location (with voids encountered)	Depth of Borehole	Wet Grout	Cement Bentonite Pellets	Approximate Excess Grout Infilling Voids
BH103 177mm diameter	30.0m	800 litres	3 bags	200 litres
CH102A 150mm diameter	33.5m	1200 litres	2 bags	600 litres
CH103A 150mm diameter	35.0m	700 litres	3 bags	100 litres

The predicted size and extent of the voided ground and implications are further discussed within Section 7 of this report.

5.11 Geotechnical Laboratory Testing

Geotechnical laboratory tests included natural moisture contents, Atterberg limits, undrained triaxial's, oedometers, particle size distributions and shear boxes. Table 5.11 below presents the amount of testing undertaken and range of results of each test.

Table 5.11 Summary of Geotechnical Tests

Geotechnical Test	Number of Tests	Range of Results
Natural Moisture Content	51	6.5% - 33%
Plasticity Limit	51	17% – Non Plastic
Undrained Triaxial	6	70kPa – 204kPa
Oedometer	4	0.101 – 0.338m²MN
Particle Size Distribution	34	Clay to sand with occasional gravel and cobbles. 0.063mm – 63mm
Shear Box	22	Sandy gravelly CLAY c'_p =4.3kPa – 13kPa ϕ_p' = 15° - 36.5° Gravelly clayey silty SAND c'_r =1.2kPa – 22kPa ϕ_r' = 26° - 39.5°

c'_p = peak effective cohesion, ϕ'_p = peak internal shearing resistance
c'_r = residual effective cohesion, ϕ'_r = residual internal shearing resistance

5.12 Chemical Testing

Chemical tests included pH, sulphate and calcium carbonate of the chalk. Table 5.12 below presents the amount of testing undertaken and range of results of each test.

Table 5.12 Summary of Chemical Tests

Type of Chemical Test	Number of Tests	Range of Results	Mean
pH	20	7.2 – 8.7	8.3
Sulphate	20	0.01 – 0.18 g/l	0.03 g/l
Calcium carbonate	20	2.7 – 44 %	38 %

5.13 Concrete Core Testing

Three cores were taken from the concrete road and tested for compressive strength, density and void content to BS EN 12504-1:2009. The core lengths vary from 188mm to 228mm and this shows the measured thickness of the concrete slab to be nominally around 200mm. The tests were carried out by ESG Ltd, who are a UKAS accredited testing laboratory. The cores were prepared from the 250mm diameter cores taken on site to a size of 100mm diameter, they were noted to be unreinforced and vertically drilled through the road pavement. The test results are summarized in Table 5.13 below.

Table 5.13 Summary of Concrete Core Test Results

Laboratory Test Reference Number	Core Length (mm)	Corrected In-Situ Compressive Cube Strength (N/mm²)	Excess Voidage (%)	Saturated Density (kg/m³)
45271686	228	22.1	1.0	2230
45271687	188	17.7	1.5	2290
45271688	198	31.2	1.0	2250

The laboratory test results are presented in Appendix F.

5.14 Summary of Geophysical Interpretation Report

The geophysical survey undertaken by Geotechnology Ltd highlighted six ground anomalies (Labelled as B, C, E, F, G and H) along the highway and footpaths at Fontmell Close and Bridle Close as highlighted on drawing number 1531/14 of the Geotechnology Report and is reproduced in the drawing section of this report. Anomalies labelled A and D in the Geotechnology Report were recorded outside the site area and therefore these are not summarised in this report.

A summary of the anomalies is presented below. *It should be noted that where the text is in italic font, it has been copied directly from the Geotechnology microgravity report.*

*"**Anomaly B** is a modest anomaly lying at the edge of the data at the corner of Fontmell Close and Bridle Close. Little of the anomaly is seen within the data so it is poorly resolved. Without further data an interpretation of the significance of this anomaly is not possible.*

***Anomaly C** is a low magnitude anomaly in the middle of Bridle Close set within an area of higher gravity. The anomaly lies within the area of a recorded clay pit and accordingly it could be expected to be underlain by material of variable compaction. The results of the modelling reveal that the anomaly does not have the characteristics of an anomaly caused by a single low density body. An irregular low density mass of fill material would produce such an anomaly and this is considered to be the most likely explanation for the feature. It should be noted that in the vicinity of this anomaly subsidence has been experienced and anecdotal information suggests that water leakage was considered to be the cause.*

***Anomaly E** is a modest anomaly outside the area of known clay pits. The negative gravity anomaly extends across the carriageway. The anomaly does not show the characteristics of a void modelled to represent the ground prior to the existing collapse, but rather appears to be a linear anomaly crossing the data that has been gathered on the road and footpaths. The presence of the anomaly is strongly influenced by extrapolation from the limited dataset. The deconvolution offers no solutions for this anomaly and therefore it is unlikely to have been caused by a discrete void. This anomaly remains ambiguous and investigation is required to further understand the low gravity at this location.*

***Anomaly F** is also a modest anomaly outside the area of known clay pits. The negative gravity anomaly extends across the carriageway achieving a maximum magnitude of 20microgals. The anomaly does not show the characteristics of a void modelled to represent the ground prior to the existing collapse, but rather appears to be a linear anomaly crossing the data that has been gathered on the road and footpaths. The conceptual model would suggest that any features at this depth lies within the chalk bedrock and accordingly this might reasonably be interpreted as a void or tunnel within the chalk, potentially a chalk mine working.*

***Anomaly G** is a small magnitude anomaly at the extreme edge of the data. The anomaly could be a result of data processing, a common issue at the extreme edges of linear datasets. The anomaly is unresolved in that only one side of the anomaly is within the data and therefore it is not possible to model the feature or to draw any firm conclusions about its origin.*

***Anomaly H** is an apparently significant anomaly at the junction of Fontmell Close and Seymour Road. This anomaly, like Anomaly G lies at the very edge of the dataset, where the process of residualizing commonly achieves a poor fit because of the lack of data. Additional data in Seymour Road would assist in resolving this anomaly. Like Anomaly G the presence of this negative anomaly is suspect."*

The following exploratory holes were undertaken in the vicinity of the identified geophysical anomalies:

- **Anomaly B – DP105** encountered very loose and very soft deposits to a depth of around 9.5m. No void was encountered.
- **Anomaly C – DP104** encountered very loose and very soft deposits to a depth of around 7.5m. No void was encountered.
- **Anomaly E – DP102** encountered loose to medium dense and soft to firm deposits to a depth of around 25m. A 0.5m to 1.0m diameter void was encountered within CH102A at a depth of between 15.2 and 17.7m and a 0.5m diameter void was encountered in BH103 at a depth of between 7.5m and 9.0m.
- **Anomaly F – DP103A** encountered medium dense and firm deposits to a depth of around 15m. A 1.0m diameter void was encountered within CH103A at a depth of between 15.2 and 17.7m.
- **Anomaly G - No dynamic probe**. Nearby BH104 encountered stiff to very stiff clay to a depth of 18m. No void was encountered.
- **Anomaly H – DP101** encountered loose to medium dense and soft to firm deposits to a depth of around 21m. No void was encountered.

5.14.1 Report Conclusions

"Anomalies B and C, lie within the area known to have been worked for brick clay. This area is expected to show variable gravity and Anomaly C in particular shows the characteristics of loose material near the surface, which is consistent with the dynamic probe results. Attempts to model this as a single body such as a void reveal inconsistent depth estimates, suggesting that a single void is not the cause of this feature. Anomaly B lies at the edge of the dataset and little useful modelling can be undertaken as it is poorly resolved.

Anomalies E and F are of modest amplitude and lie in an area where no clay extraction is known to have taken place. Anomaly E remains ambiguous as advanced processing has been unable to produce a consistent model of the feature, which is fairly consistent to the dynamic probe, whereby variable conditions were encountered. Anomaly F, which is of similar magnitude to anomaly E, which exhibits an anomaly shape that can be interpreted as arising from a single discrete body of missing mass. Automated processing indicates that if this was the case the body would lie at a depth of some 15m below ground level. DP103A encountered medium dense and firm conditions to a depth of 15m, where the probe hole was terminated at refusal, so it is possible that a void is present in the chalk beyond this depth. Borehole CH103A encountered a possible 1.5m deep void at 15.2m (ground conditions not recorded on log).

It is considered likely that Anomalies G and H are a function of data processing at the edge of the datasets, though additional data may resolve this.

A number of overall conclusions from the study of available documented sources, published geological data, unpublished reports, anecdotal evidence, gravity mapping and survey can be drawn:

- *A series of smaller anomalies are present beneath the roads and these may be explained by variable backfill and processing effects at the edge of a dataset. However, Anomaly F has been identified in Fontmell Close which modelling reveals could arise from a discrete void at a depth of 15m. This is also expected to lie within the chalk bedrock. Borehole CH103A encountered a possible 1.5m deep void at 15.2m (ground conditions not recorded on log).*

- *Self-supporting voids are feasible in chalk bedrock. Such voids are the result of natural dissolution (swallow-hole features) or potential chalk mining.*

- *There is no documented evidence at the site of the major ground collapse of chalk mining at the base of the clay pit though the presence of a limekiln here is evidence of chalk use. The conditions appear to be suitable for chalk extraction in the bedrock beneath the base of the pit. Gravity surveying indicates that voids are present within the chalk bedrock and therefore chalk excavation is the most likely explanation for the cause of the void that led to the October 2015 collapse.*

- *A second anomaly at the top of Fontmell Close (Anomaly F) has revealed characteristics that suggest there could be smaller scale voiding within the chalk. This was confirmed within Borehole CH103A where a 1.5m deep void was encountered at 15.2m (recorded on the drillers log as a void and further investigation with CCTV confirmed this).*

- *Natural dissolution features can produce similar anomalies and therefore whilst considered less likely these remain possible causes of the existing collapse and the gravity anomalies identified."*

5.14.2 Presence of Sub-Surface Voids - Summary

A void was encountered in BH103 and CH102A at a depth of between 7.5-9.0m and 16.1-21.5m respectively at the location of Anomaly E at the top of the chalk deposits. CCTV observations recorded a 0.5m diameter void between 8.4m-10.0m in BH103 at the top of the chalk. In CH102A, the CCTV observed a 0.5m to 1.0m diameter void between 16.1m-22.5m, where the void narrows with depth.

DP103A was undertaken at Anomaly F and encountered medium dense and firm conditions to a depth of 15m, where the probe hole was terminated at refusal, so it is possible that a void is present in the chalk beyond this depth. Borehole CH103A encountered a possible 1.5m deep void at 15.2m at the location of Anomaly F at the top of the chalk deposits. CCTV observations in CH103A recorded a vertical crack between 16.6m and 18.1m which became a 1.0m diameter void to a depth of 20.0m, with evidence of a vertical crack extending beyond the void.

A possible void was encountered at 46.10 bgl in CH104A.

6 Representative Geotechnical Soil and Rock Parameters

This section outlines the selection of representative geotechnical soil and chalk parameters for design calculations and also includes a justification for the parameters selected as characteristic values. The parameters are based on the sample descriptions, test results from the site investigation and empirical data. Where applicable, graphical representation of the data is included in Section 6.3.

The engineering properties of the materials are dependent not only on the inherent characteristics of the deposits encountered, but also upon the nature of the tests undertaken to derive such properties. The derivation of design parameters takes into account the influence of the method of testing, the differences between mass characteristics and laboratory scale specimens. References are given where generic parameters are adopted.

A combination of the in-situ test results and the laboratory test results have been used to assess the strength properties of the underlying soil and chalk deposits. The data and representative soil parameters are detailed below. The parameters have been obtained using available reference documents and Engineers experience.

6.1 Discussion of Laboratory Test Results

The geotechnical laboratory test results and subsequent geotechnical parameters for the various soil and chalk deposits are discussed below.

6.1.1 Made Ground Cohesive

The Made Ground comprises re-worked clay infill material. This is typically described as firm to stiff slightly sandy gravelly clay. The plasticity data lies in a similar range to the natural Kesgrave material found at the site and it is likely that the Made Ground is reworked Kesgrave materials.

The key characteristics of the Cohesive Made Ground are summarised as follows:

- SPT tests in the material recorded N values in range of 4 to 22 with a mean value of 10 (See Figure 5. 5.2).
- Twenty seven natural moisture content (NMC) test results range from 10 % to 31 % with a mean value of 20 % (See Figure 6.3.1a)
- Eighteen Atterberg limit tests indicated Liquid Limit (LL) in the range 31 % to 72 % with a mean value of 45 % and Plastic Limit (PL) in the range 17 % to 27 % with a mean value of 22 %. Plasticity Index (PI) ranges from 10 % to 47 % with a mean value of 23 %.
- A plot of Liquid Limit against Plasticity Index (See Figure 6.3.1b) indicates that the Made Ground predominantly consists of clay of intermediate plasticity (CI).
- A plot of particle size distribution analyses indicates that the cohesive Made Ground deposits are variable and a combination of sandy CLAY and very clayey SAND, with occasional gravel, containing particle of sizes ranging from less than 0.063mm to 63mm (See Figure 6.3.1c).

The undrained shear strength of the cohesive Made Ground can also be assessed from SPT N values using the relationship proposed by Stroud (1988). The correlation between SPT N value and undrained shear strength is related to the plasticity index of the clay by using the following relationship:

Cu = f1 x N *

Using the mean plasticity index value of 23 % gives an f1 factor of 5. The application of an f1 value of 5 gives a mean undrained shear strength value of 50 kN/m². The NMC of the clay is at the mean plastic limit and the clay would therefore be expected to be firm to stiff.

The modulus of volume compressibility can also be estimated using the relationship proposed by Stroud (1988):

Mv = 1 /f2 x N *

Using the mean plasticity index value of 23% gives an f2 factor of 0.50. This application of an f2 factor and the characteristic SPT N value gives an mv = 0.200 m²/MN.

> * *It should be noted that the relationship by Stroud (1988) is generally applicable to overconsolidated clays and the made ground deposits are considered to be normally consolidated, therefore the above strength and volume compressibility assessment is for indicative purposes only.*

Seven samples of cohesive Made Ground deposits were tested to obtain peak and residual shear stress parameters using the consolidated drained shear box method. The peak effective cohesion (c_p') and peak effective angle of internal shearing resistance (ϕ_p') values were 6kN/m² and 29° respectively (see Figure 6.3.2a). The residual effective cohesion (c_r') and effective angle of internal shearing resistance (ϕ_r') values were 0kN/m² and 27° respectively (see Figure 6.3.3a).

Published parameters suggested by BS8002 (2015) for plasticity index of 23 suggests a ϕ_{cr}' of 25° with a c_{cr}' of 0 kN/m². The effective angle of internal friction for cohesive Made Ground (i.e. re-worked Kesgrave Catchment deposits) can also be derived from plasticity index values as per the method in CIRIA C504. Based on a mean plasticity index of 23 %, ϕ_{cr}' of 30 degrees can be inferred.

6.1.2 Made Ground Granular

Where encountered, the granular Made Ground comprises sandy clayey gravel or clayey gravelly sand.

The key characteristics of the Granular Made Ground are summarised as follows:

- A single SPT N test recorded a value of 4 within the granular Made Ground material.
- A plot of particle size distribution analyses indicates that the granular Made Ground deposits are predominately a slightly clayey SAND, with occasional gravel, containing particle of sizes ranging from less than 0.063mm to 20mm (Figure 6.3.1d).
- A single sample of granular Made Ground tested for peak shear stress parameters produced a peak effective cohesion and effective angle of internal shearing resistance values of 11kN/m² and 39.5 degrees respectively.

6.1.3 Alluvium

The Alluvium was encountered in two boreholes comprising firm to stiff slightly sandy gravelly clay and the key characteristics of the alluvium are summarised as follows:

- Unit weight measured as 18.6kN/m^3 and 19.8 kN/m^3 with a mean value of 19.2 kN/m^3. Based on this test data and the description of the material the characteristic unit weight is 18.6kN/m^3.
- Two NMC test results range from 15 % and 26 %.
- Two Atterberg Limit tests indicated a LL of 36 % to 46 % and a PL of 25 % and 27%. PI is 9 % to 21 %. A plot of Liquid Limit against Plasticity Index (Figure 6.3.1b) indicates that the alluvium consists of clay of intermediate plasticity (CI).
- A single SPT N test recorded a value of 7 within the alluvial material.

The undrained shear strength (c_u) was measured in three single stage triaxial compression tests without measurement of pore pressure. The tests measured values between 114 kN/m^2 and 134 kN/m^2 with a mean value of 125 kN/m^2.

The modulus of volume compressibility can also be estimated using the relationship proposed by Stroud (1988):

Mv = 1 /f2 x N *

Using the mean plasticity index value of 20% gives an f2 factor of 0.60. This application of an f2 factor and the characteristic SPT N value gives an mv = 0.230 m^2/MN.

** It should be noted that the relationship by Stroud (1988) is generally applicable to overconsolidated clays and the alluvium deposits are considered to normally consolidated, therefore the above volume compressibility assessment is for indicative purposes only.*

A single sample of Alluvial clay was tested for peak and residual shear stress parameters. The peak effective cohesion (ϕ_p') and effective angle of internal shearing resistance (ϕ_p') values was 17 kN/m^2 and 20.5 degrees respectively. The residual effective cohesion (c_r') and effective angle of internal shearing resistance (ϕ_r') values were 10 kN/m^2 and 19.5 degrees respectively.

Published parameters suggested by Table 2 of BS8002 (2015) for plasticity index of 20% suggests a ϕ_{cv}' of 25^0 with a c' of 0 kN/m^2. The effective angle of internal friction for the alluvium can also be derived from plasticity index values as per the method in CIRIA C504. Based on a mean plasticity index of 20 %, ϕ_p' of 28 degrees can be inferred.

6.1.4 Kesgrave Catchment – Cohesive

The cohesive deposits of the Kesgrave Catchment Supergroup are described as typically stiff and very stiff sandy gravelly CLAY.

The key characteristics of this deposit are:

- Unit weight measured as 16.2kN/m^3 to 21 kN/m^3 with a mean value of 18.3 kN/m^3. Based on this test data and the description of the material the characteristic unit weight is 19kN/m^3.
- Sixteen NMC test results range from 7 % to 26 % with a mean value of 16%, as presented on Figure 6.3.1a.
- Forty four Atterberg limit tests measured LL in the range 30 % to 76 % with a mean value of 55 % and a PL in the range 19 % to 32 % with a mean value of 24 %. Plasticity index ranges from 9 % to 45 % with a mean value of 31 %. A plot of LL against PI (Figure 6.3.1b) indicates the cohesive Kesgrave deposits is clay of intermediate plasticity (CI) to a silt of high plasticity (MH).
- SPT tests in the material range from 5 to 50 with a mean value of 30 (Figure 5. 5.2). A characteristic SPT N value of 25 is recommended for the material.
- A plot of particle size distribution analyses indicates that the cohesive Kesgrave deposits are variable and a combination of a sandy CLAY or clayey SAND with occasional gravel, containing particle of sizes ranging from less than 0.063mm to 63mm (Figure 6.3.1e).

The undrained shear strength (c_u) was measured in twelve single stage triaxial compression tests without measurement of pore pressure. The results range between 70kN/m^2 and 204 kN/m^2 with a mean value of 126 kN/m^2.

One-dimensional consolidation tests were performed on four samples taken within the cohesive Kesgrave deposits material at depths of between 3.5 and 12m. For consolidation settlement calculations, over the stress range envisaged at the site (50 to 100kPa), the coefficient of consolidation, mv, ranged from 0.101 to 0.338 m^2/MN. This confirms the material has a low to high compressibility.

Five samples of cohesive Kesgrave deposits were tested to obtain peak and residual shear stress parameters using the consolidated drained shear box method. The peak effective cohesion (c_p') and peak effective angle of internal shearing resistance (ϕ_p') values were 9kN/m^2 and 24° respectively (see Figure 6.3.2b). The residual effective cohesion (c_r') and residual effective angle of internal shearing resistance (ϕ_r') values were 7kN/m^2 and 23° respectively (see Figure 6.3.3b).

Published parameters suggested by BS8002 (2015) for plasticity index (PI) of 24% suggest a ϕ' of 26° with c' of 0 kN/m^2. The ϕ' for Kesgrave Catchment Supergroup can also be derived from plasticity index values as per the method in CIRIA C504. Based on a mean plasticity index of 24%, ϕ' of 30 degrees can be inferred.

Based on the above and previous experience of Kesgrave Catchment materials, a ϕ_p' value of 28°, with a c' of 0kN/m^2 is proposed as characteristic.

6.1.5 Kesgrave Catchment – Granular

The granular deposits of the Kesgrave Catchment Supergroup are described as typically dense slightly clayey gravelly SAND with occasional sandy GRAVEL.

Eighteen SPT tests were carried out in the granular Kesgrave deposits, with recorded blow counts giving N values of between 18 and 58, indicating a medium dense to very dense consistency for this material, with a typical N value of 46. The results generally follow a trend of increasing N value with depth (Figure 5. 5.2).

Particle size distribution analyses confirm that the granular Kesgrave deposits are predominately a fine to coarse SAND and occasional sandy GRAVEL, containing particle of sizes ranging from less than 0.063mm to 63mm (Figure 6.3.1f).

Five samples of the granular Kesgrave deposits were tested to obtain peak and residual shear stress parameters using the consolidated drained shear box method. The peak effective cohesion (c_p') and peak effective angle of internal shearing resistance (ϕ_p') values were 0kN/m² and 28° respectively (see Figure 6.3.2a). The residual effective cohesion (c_r') and effective angle of internal shearing resistance (ϕ_r') values were 0kN/m² and 18° respectively (see Figure 6.3.3b).

Published parameters suggested by BS8002 (2015) for an N value of 46 indicates a ϕ_{cr}' in the order of 37° with a c' of 0 kN/m² for the granular Kesgrave deposits.

6.1.6 Lambeth Group – Cohesive

The cohesive deposits of the Lambeth Group are described as typically firm to stiff gravelly very sandy CLAY. Thin layers of cohesive Lambeth Group were encountered within three boreholes during the investigation, and due to minimal amount of samples obtained, laboratory testing was not undertaken.

The geotechnical parameters of the cohesive Lambeth Group presented in Table 6.4 are based on engineering description and experience of similar soils (see accompanying notes at the foot of Table 6.4).

6.1.7 Lambeth Group – Granular

The granular deposits of the Lambeth Group are described as typically dense slightly clayey fine to medium SAND within the engineering logs. However the classification testing confirms the presence of clay and silt content within the main body of the granular Lambeth Group deposit.

Nine SPT tests were carried out in the granular Lambeth Group deposits. The tests recorded blow counts of between 14 and 55 (medium dense to very dense consistency) and generally followed a trend of increasing N value with depth (Figure 5. 5.2). The average N value was 38 (dense consistency).

Four NMC tests indicated moisture content ranging from 10 % to 20 % with a mean value of 16%. The results are presented on Figure 6.3.1a.

Four Atterberg limit tests measured liquid limit in the range 31 % to 34 % with a mean value of 32 % and plastic limit in the range 20 % to 24 % with a mean value of 22 %. Plasticity index ranges from 7 % to 13 % with a mean value of 11 %.

A plot of liquid limit against plasticity index (Figure 6.3.1b) indicates the Lambeth Group deposits is clay of low plasticity (CL).

A plot of particle size distribution analyses confirms that the granular Lambeth Group deposits are predominately a fine to medium slightly gravelly SAND, with clays and silt fractions (up to 25%), containing particle of sizes ranging from less than 0.063mm to 37.5mm (Figure 6.3.1g).

Three samples of the granular Lambeth Group deposits tested for peak shear stress parameters revealed the peak effective cohesion (c_p') and effective angle of internal shearing resistance (ϕ_p') values were 0kN/m² and 31° respectively(see Figure 6.3.2d).

Published parameters suggested by BS8002 (2015) for an N value of 46 indicates a ϕ_{cr}' of 36° with a c' of 0kN/m² for the granular Lambeth Group deposits.

6.1.8 White Chalk

The White Chalk sub-Group strata were encountered as extremely weak to medium strong white CHALK, generally described as a gravelly SILT with flint gravel, or slightly silty GRAVEL.

It should be noted that sampling disturbance in cable percussive boreholes can lead to loss of structure and strength of chalk, so the chalk may be stronger than indicated in the cable percussive borehole logs. The key characteristics of the White Chalk are summarised as follows:

- Nine SPT tests were carried out in the granular White Chalk deposits, with recorded blow counts giving N values of between 12 and 50, recording a typical N value of 40 (see Figure 5. 5.2).
- Thirty eight SPT tests were carried out in the White Chalk SILT deposits, with recorded blow counts giving N values of between 4 and 50, recording a typical N value of 25 (see Figure 5. 5.2).
- Thirteen NMC tests range from 16 % to 33 % with a mean value of 29 % as presented on Figure 6.3.1a.
- Thirteen Atterberg Limit tests measured Liquid Limit in the range 32 % to 37 % with a mean value of 35 % and Plastic Limit in the range 21 % to 28 % with a mean value of 25 %. Plasticity Index ranges from 7 % to 13 % with a mean value of 10 %.
- A plot of Liquid Limit against Plasticity Index (Figure 6.3.1b) indicates the weathered Chalk predominantly consists of clay of low to intermediate plasticity (CL-CI). However the chalk is mainly described as SILT within the engineering logs.

Figure 4.10 of CIRIA C574, shows the relationship between undrained shear strength and moisture content for crushed white chalk. Based on Figure 4.10, and a moisture content range of 16 % to 33 % indicates strength between 50 and 300 kN/m² although would depend on the clay content of the chalk. It should be noted that this relationship is mainly used for crushed white chalk, to assess plant trafficability and should be used with caution. Therefore, a value of 150 kN/m² is recommended as characteristic.

Laboratory testing for effective internal angle of friction was not done during the recent ground investigation. CIRIA C574 suggests that there is surprisingly little variability of effective angle of

friction (assuming c′ = 0) for different chalk horizons with differing calcium carbonate contents and plasticities, Based on extensive testing, the effective angle of friction was found to vary between 29° and 34°, with most values falling in the range 31 to 33°. A characteristic value ϕ_p' of 30° with a c' of 0kN/m² are deemed characteristic.

6.2 Concrete Specification

The White Chalk deposits, pH values and water-soluble sulphate concentrations have been assessed for potential aggressive attack on concrete in accordance with BRE Special Digest 1 'Concrete in Aggressive Ground (2005)'.

The results indicate that the chalk is classified as Design Sulphate DS-1. The results indicate an ACEC (Aggressive Chemical Environment for Concrete) Class of AC-1.

The specific concrete mixes for the DS Class to be used at the site will be determined, mindful of the ACEC Class, by the site-specific concrete requirements in terms of the required durability and structural performance. These are assessed in terms of the Structural Performance Level (SPL) and any Additional Protection Measures (APM).

6.3 Presentation of Laboratory Test Data

This section presents the graphs that have been produced from the laboratory test results for the interpretation of the natural moisture content, Atterberg Limits, particle size distribution and shear box test results for assessment of the geotechnical soil and chalk parameters.

6.3.1 Classification Testing

The natural moisture content, particle size distribution and Atterberg test results have been plotted on graphs and are presented as the following figures.

Figure 6.3.1a – Natural Moisture Content for all Soil and Chalk Deposits

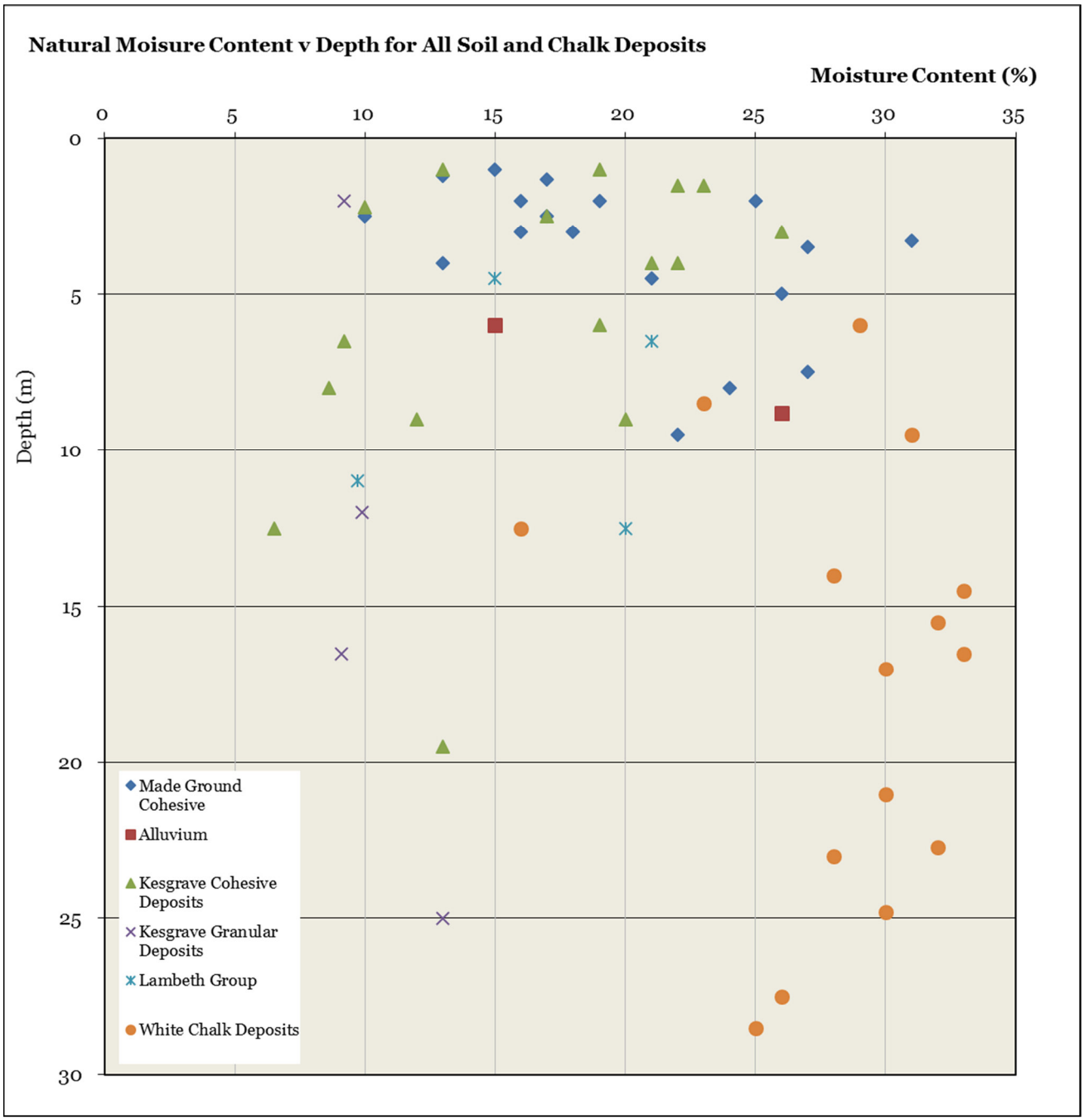


Figure 6.3.1b – Plasticity Chart for all Soil and Chalk Deposits

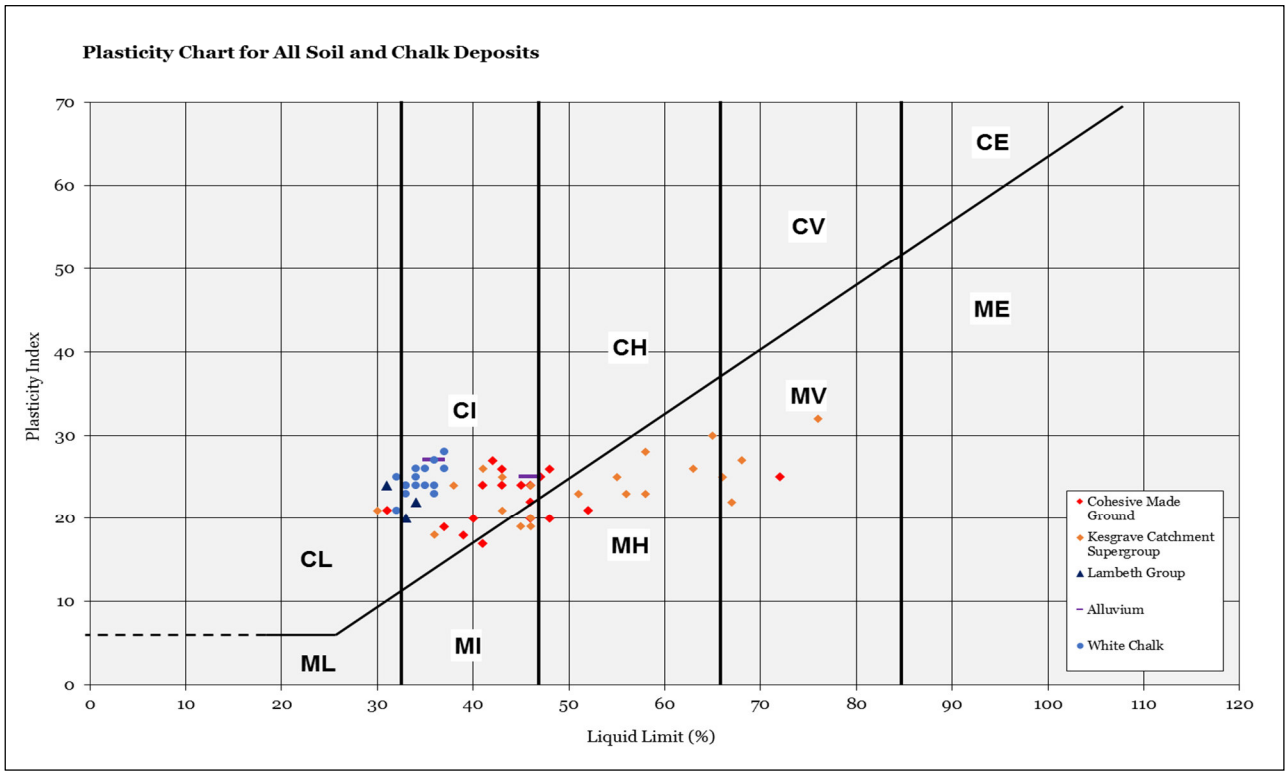


Figure 6.3.1c – Particle Size Distribution for Made Ground Cohesive Deposits

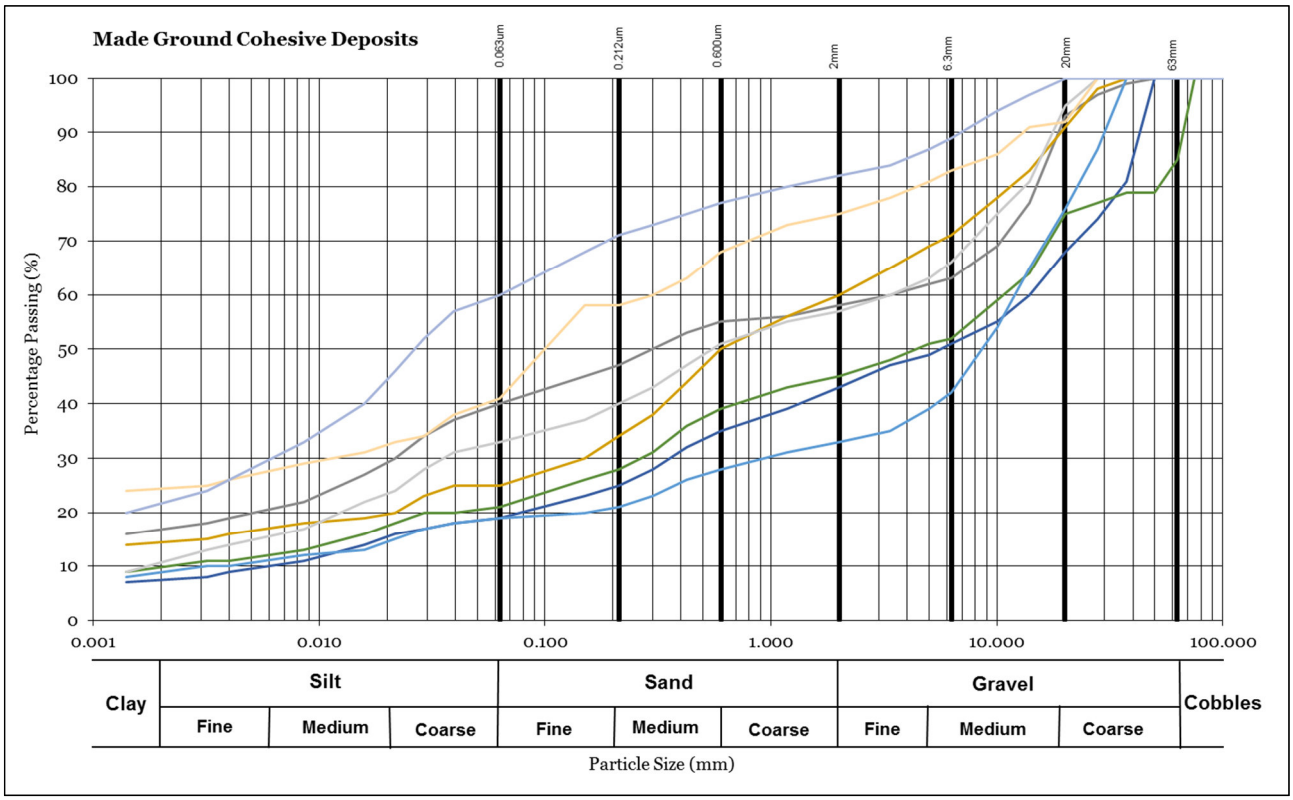


Figure 6.3.1d – Particle Size Distribution for Made Ground Granular Deposits

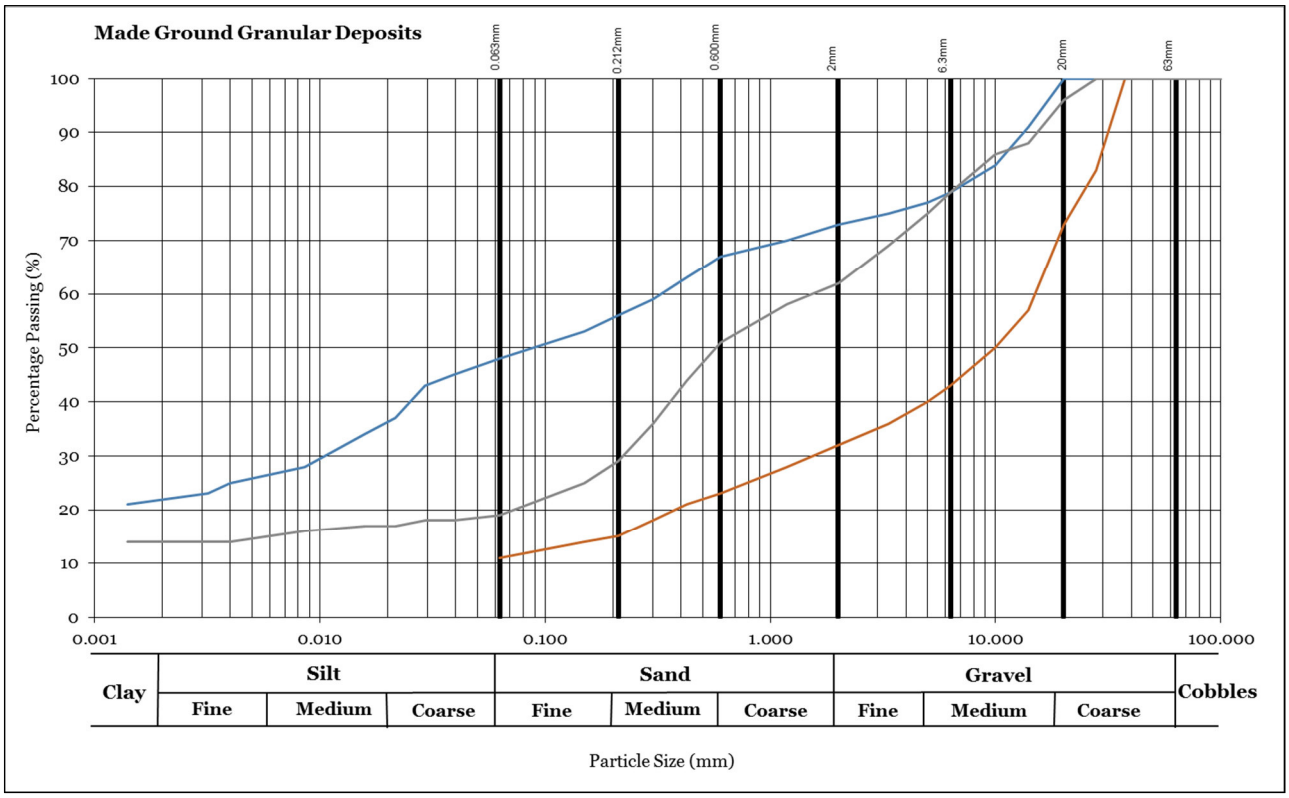


Figure 6.3.1e – Particle Size Distribution for Kesgrave Cohesive Deposits

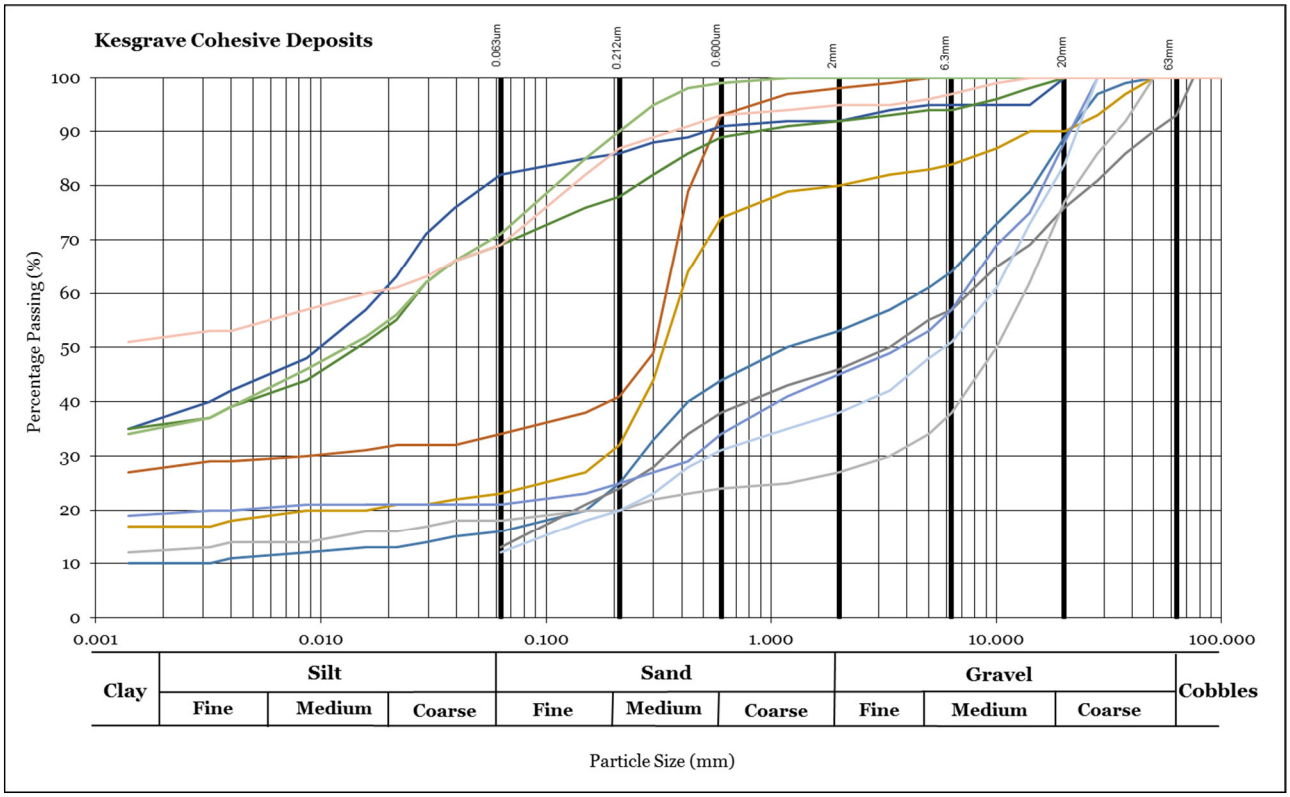


Figure 6.3.1f – Particle Size Distribution for Kesgrave Granular Deposits

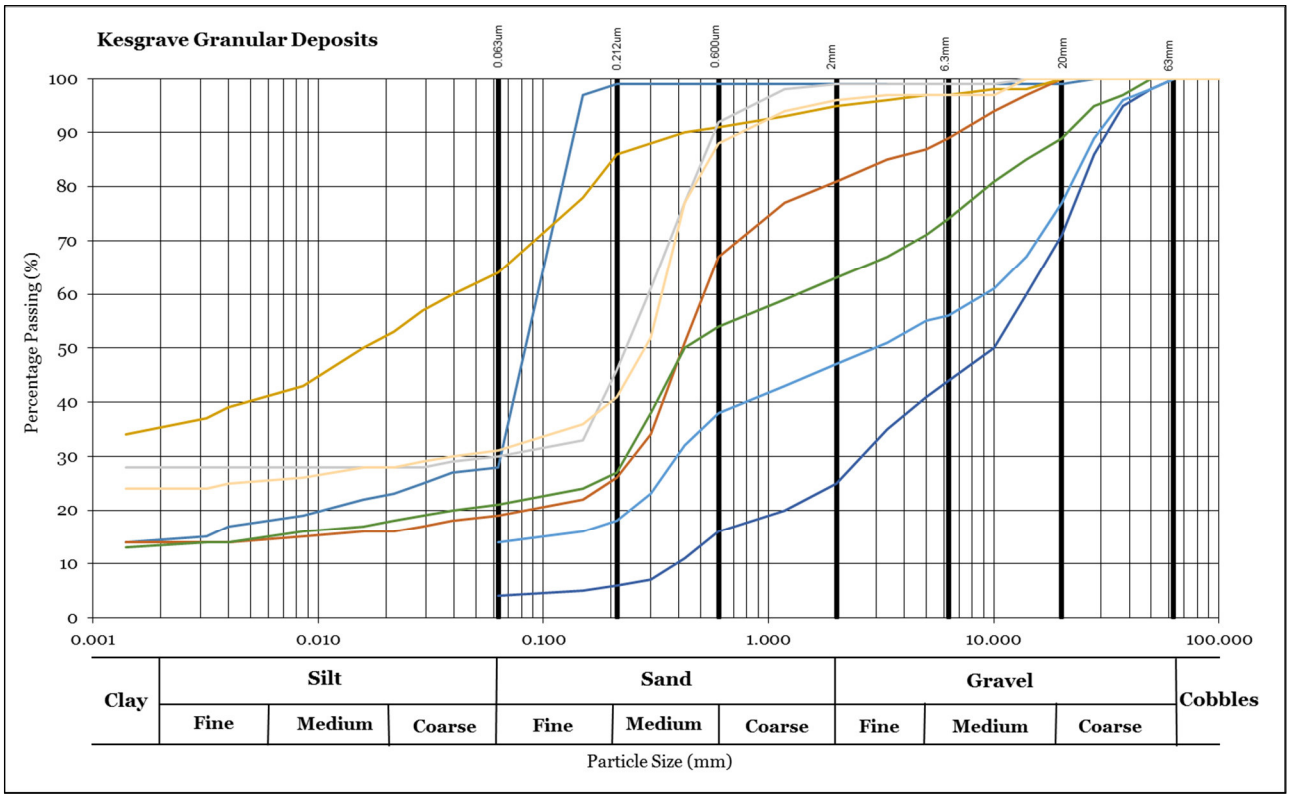
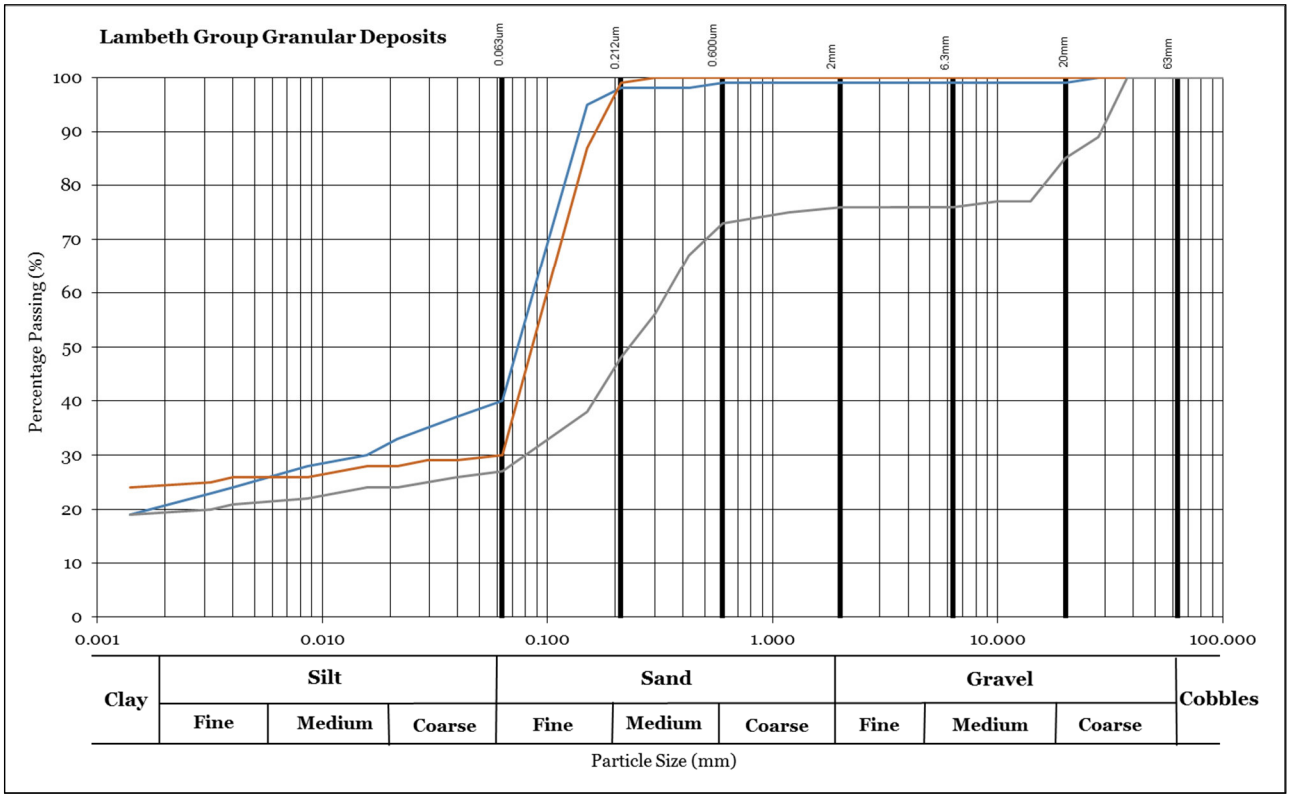


Figure 6.3.1g – Particle Size Distribution for Lambeth Group Granular Deposits



6.3.2 Peak Shear Box Strength Testing

The peak shear box test results have been plotted on graphs and are presented as the following figures.

Figure 6.3.2a – Peak Shear Box Test Results for the Cohesive Made Ground Deposits

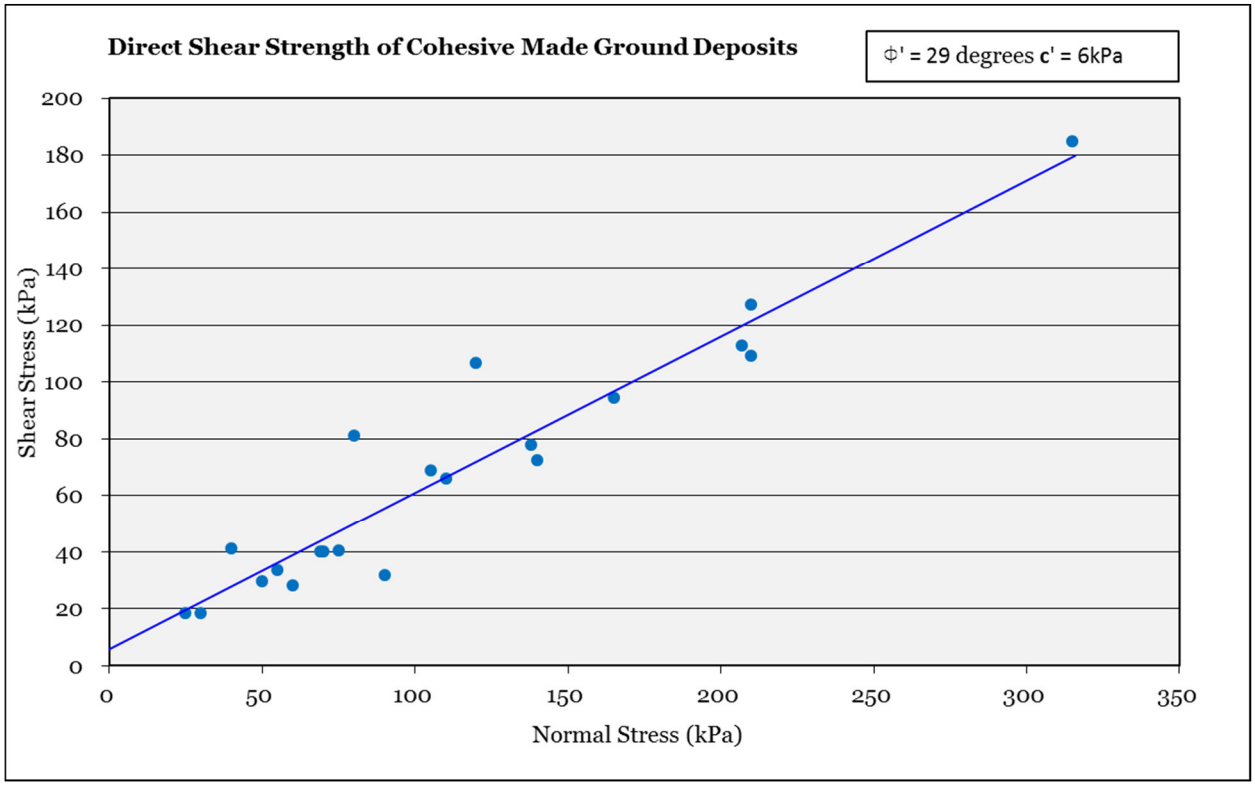


Figure 6.3.2b – Peak Shear Box Test Results For the Cohesive Kesgrave Deposits

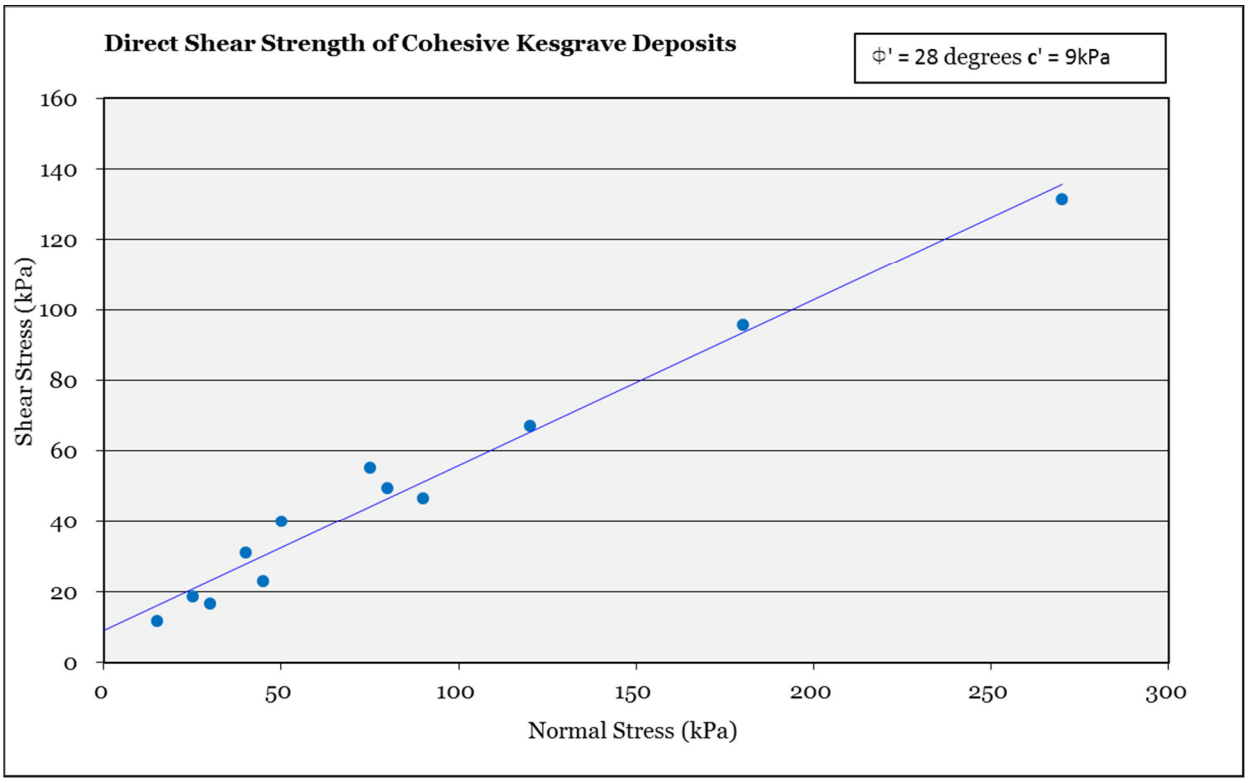


Figure 6.3.2c – Peak Shear Box Test Results for the Granular Kesgrave Deposits

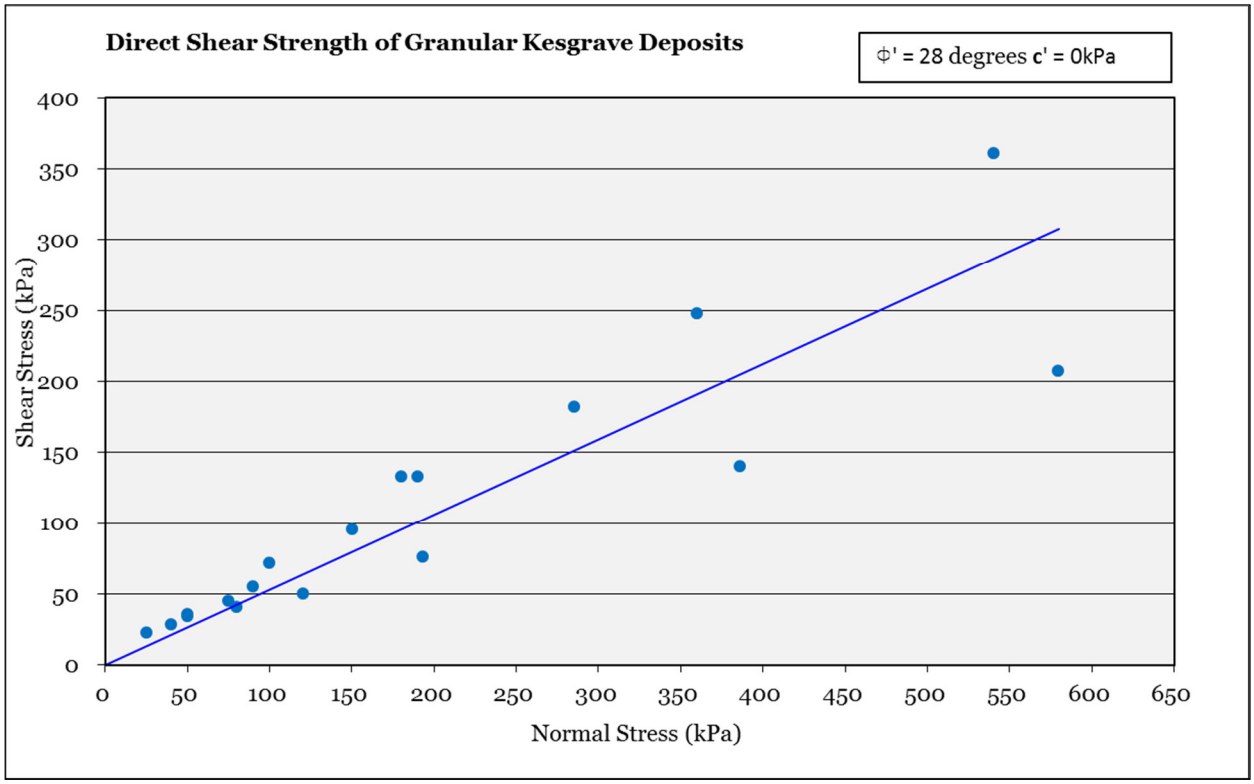
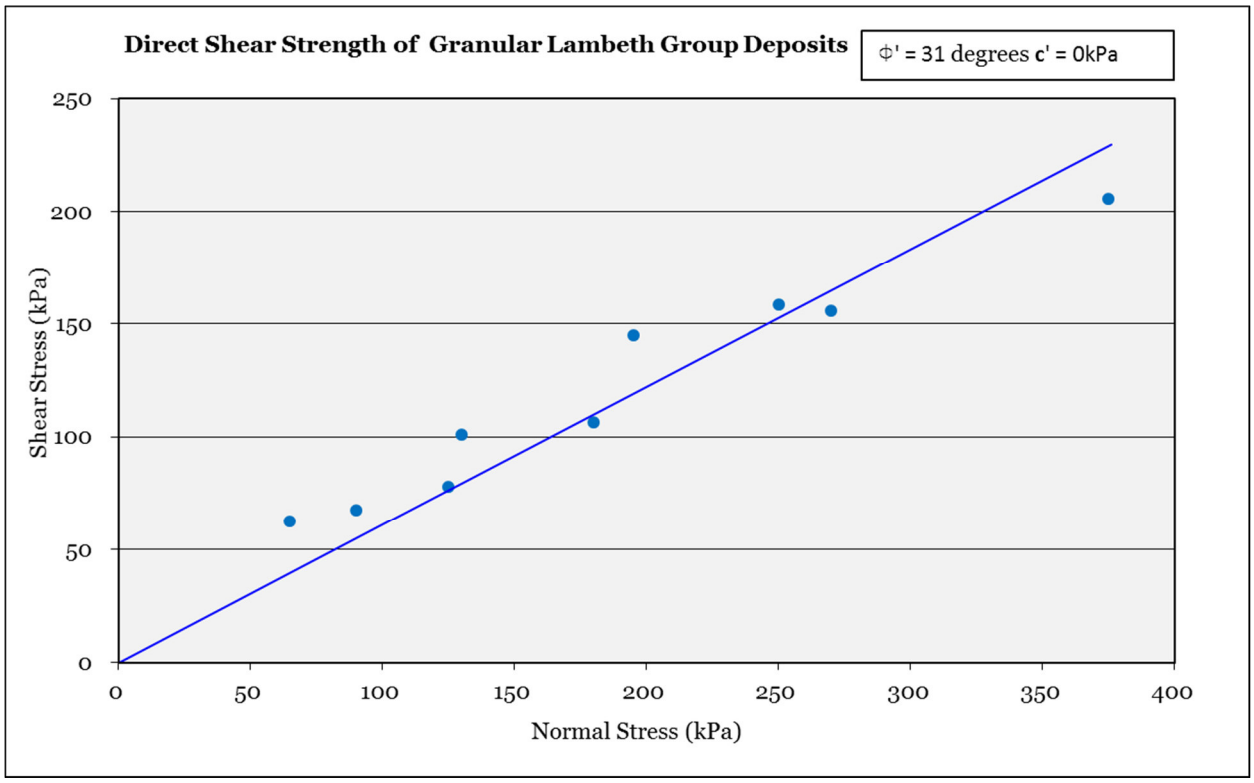


Figure 6.3.2d – Peak Shear Box Test Results for the Granular Lambeth Group Deposits



6.3.3 Residual Shear Box Strength Testing

The residual shear box test results have been plotted graphically below:

Figure 6.3.3a – Residual Shear Box Test Results for the Cohesive Made Ground Deposits

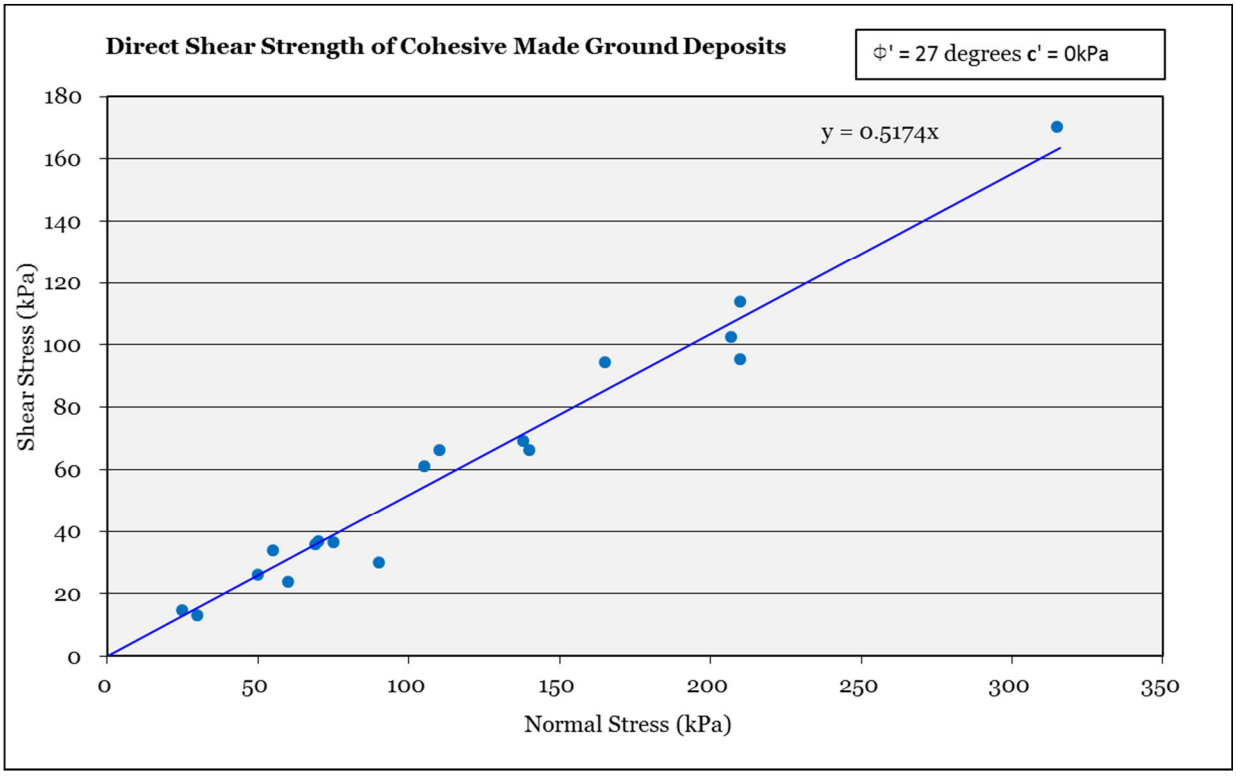


Figure 6.3.3b – Residual Shear Box Test Results for the Granular Kesgrave Deposits

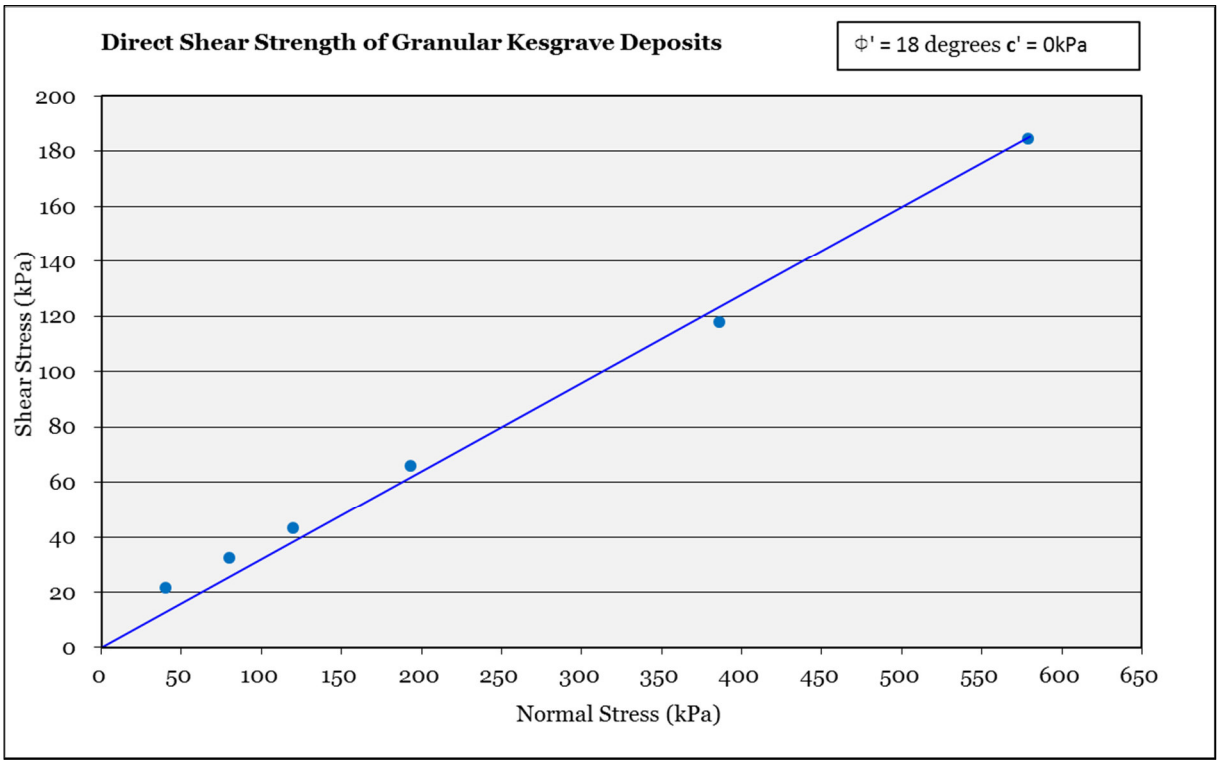
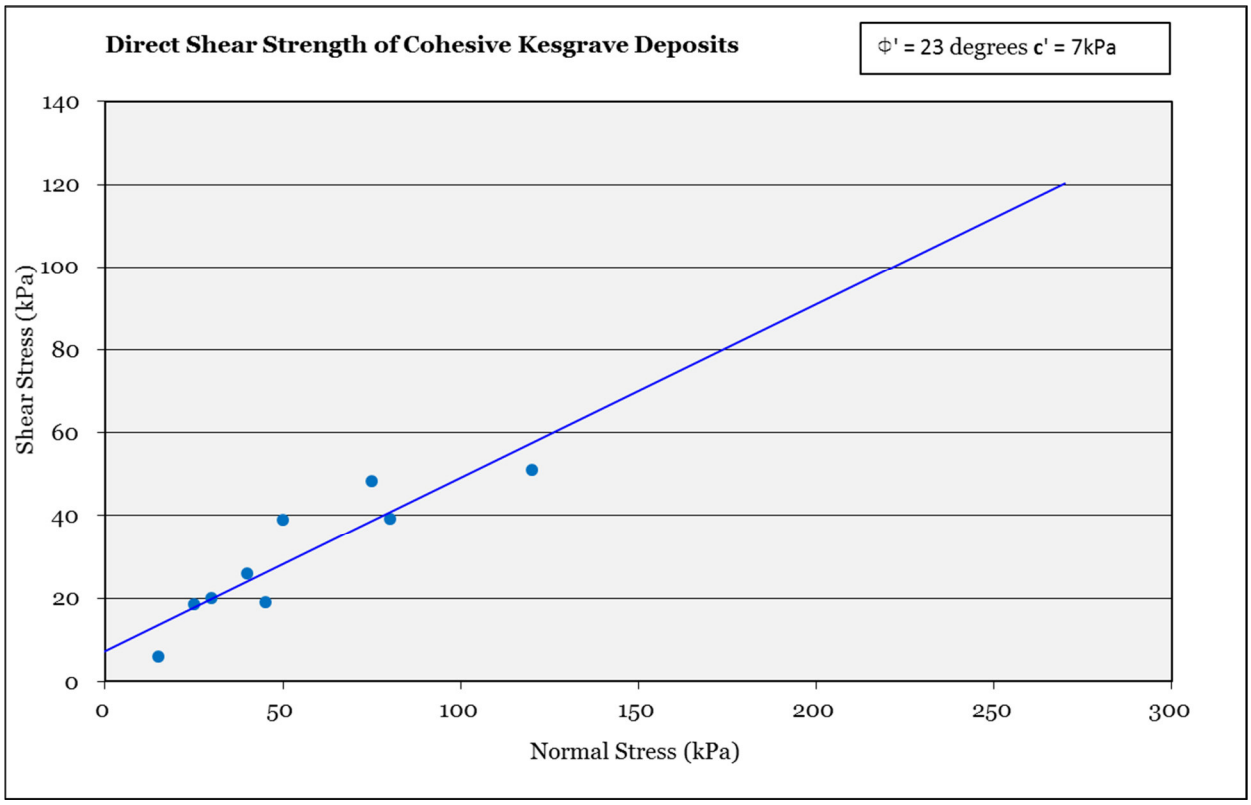


Figure 6.3.3c – Residual Shear Box Test Results for the Cohesive Kesgrave Deposits



6.4 Summary of Geotechnical Soil and Chalk Parameters

The recommended geotechnical parameters for the soil and chalk deposits that may be encountered underlying the area of investigation are presented in Table 6.4 (please refer to the accompanying notes at the foot of the table).

Table 6.4 Summary of Recommended Geotechnical Soil and Chalk Properties

Geotechnical unit	Consistency or density	Unit weight γ (kN/m³)	Undrained shear strength c_u (kPa)	Peak effective shear strength parameters		Coefficient of volume compressibility m_v (m²/MN)	Elastic Modulus E' (MPa)	SPT 'N' Value (Representative)
				Cohesion c_p'(kPa)	Friction angle ϕ_p' (deg)			
Made Ground Cohesive	Firm	17	40	0	24	0.300	6	10
Made Ground Granular	Loose	17	-	0	30	-	4	4
Alluvium	Firm to Stiff	18	100	0	26	0.200	6	7
Kesgrave Catchment Supergroup Cohesive	Soft	16	30	0	22	0.300	8	8
	Firm	17	40	0	24	0.200	15	15
	Stiff	18	75	0-2	26	0.150	20	20
	Very stiff	19	150	2	26	0.100	25	25
	Hard	20	200	2-5	28	0.050	30	30
Kesgrave Catchment Supergroup Granular	Medium Dense	18	-	0	32	-	15	15
	Dense	20	-	0	36	-	30	30

Geotechnical unit	Consistency or density	Unit weight γ (kN/m³)	Undrained shear strength c_u (kPa)	Peak effective shear strength parameters		Coefficient of volume compressibility m_v (m²/MN)	Elastic Modulus E' (MPa)	SPT 'N' Value (Representative)
				Cohesion c_p'(kPa)	Friction angle ϕ_p' (deg)			
Lambeth Group Cohesive	Firm	17	40	0	24	0.200	10	-
	Stiff	18	75	0-2	26	0.150	20	-
	Very stiff	19	150	2	26	0.100	30	-
	Hard	20	300	2-5	28	0.050	40	-
Lambeth Group Granular	Medium Dense	18	-	0	32	-	15	15
	Dense	20	-	0	36	-	30	30
White Chalk	Very weak	22	-	2-5	30	0.075	25	28

Notes:

1. Table 6.4 provides a selection of representative geotechnical parameters for the geological stratum that should be encountered underlying the area of investigation for a range of soil and rock consistencies.
2. Geotechnical laboratory testing was undertaken to provide confirmation and validation of the above parameters. However in some instances the laboratory test results were not characteristic for the geological stratum, subsequently engineering judgement was adopted for selection of the appropriate design parameter.
3. The above design parameters should be selected with full consideration of the purpose for which the parameters are required.
4. It should be noted that the recommended geotechnical parameters presented within Table 6.4 have been produced using a combination of geotechnical laboratory testing, in-situ test data, correlation with published data (such as BS8002, CIRIA 143, CIRIA 504, CIRIA574) and experience of similar soils within the region.
5. Parameters provided are representative and indicative for each unit which may have variable types of material and properties. Consistency/relative density not specified in this table can be interpolated appropriately.

7 Engineering Discussions

This section of the report considers the likely engineering risks associated with the public highway and footpath areas of Bridle Close and Fontmell Close, due to the close proximity of the nearby "sinkhole" collapse.

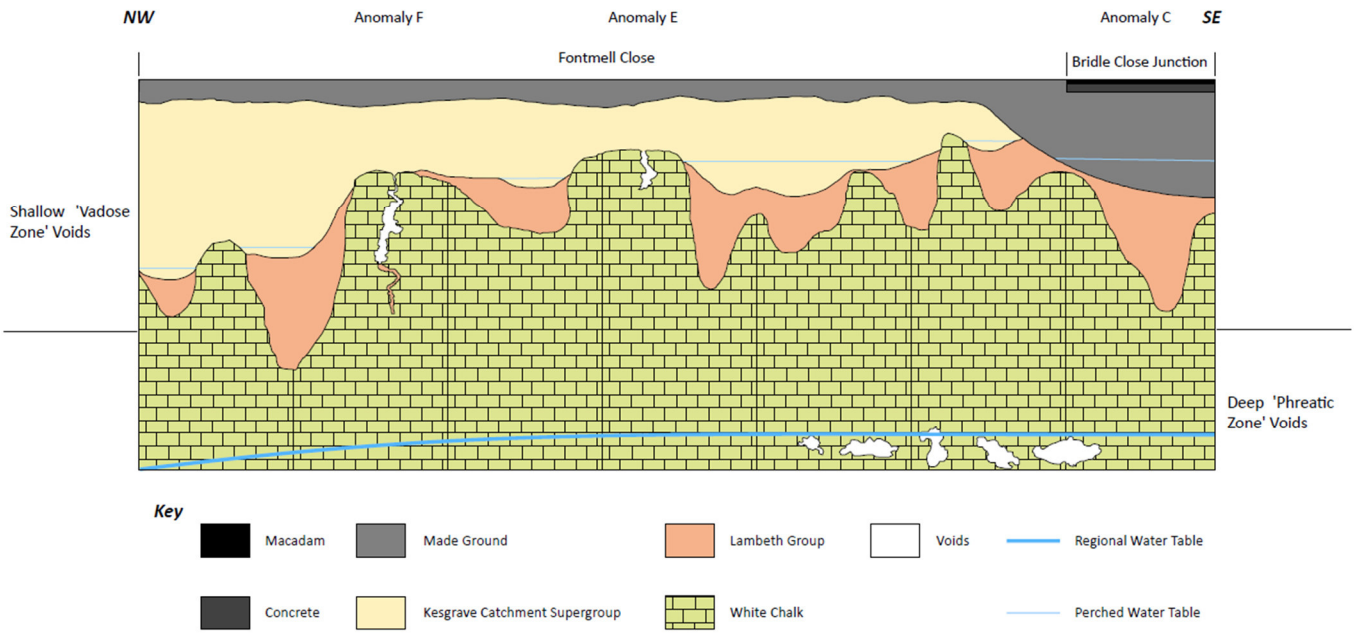
7.1 General

The ground conditions encountered within the investigation test holes during the recent site investigation suggest that variable soil and rock conditions should be encountered across the site area.

A 2D conceptual ground model has been produced for Fontmell Close, including the junction with Bridle Close (see Figure 7.1). The conceptual site model and cross sections indicate that a relatively thin layer of predominately cohesive Made Ground is present underlying the highway, which is underlain by cohesive Kesgrave Supergroup, granular Lambeth group and bedrock of White Chalk respectively.

The 2D conceptual ground model shows three of the anomalies identified during the geophysical survey, which is presented below and also included within Appendix H.

Figure 7.1 Conceptual Site Model



7.2 Void Volume Assessment

During the recent Ground Investigation works, four voids were identified. Three were encountered within 25m of the ground surface, and another encountered at a depth of between 46.1m and 47.3m bgl. The deeper area noted to be a possible void by the drillers, was not investigated further. Based on observations made on site, and the general depth of the ground water table, it is considered that this deep feature is likely to be formed by natural dissolution of the chalk as the base "phreatic" ground water table fluctuates (see Wood, 1995).

The three voids that were then confirmed using a CCTV survey, and are located within 22.0m of the highway surface level are summarised as follows (based on drillers observations, observations made during the CCTV survey's and the recorded approximate volume of grout used to backfill the boreholes, compared to the expected quantity based on a borehole with no voids). All of these features were located within the White Chalk and are believed to be of "vadose" zone origin (Wood, 1995). Similar features to these have been seen by two of the authors (Nicholls & Eastwood) during a recent inspection of the M40 Stokenchurch Cutting (Plate 7) which is cut through the same Lewes Nodular Chalk horizon.

Table 7.2 Void Volume Assessment

Location (Depth of hole (m))	Drillers Observations depth from and to (m)	CCTV Observations	Volume of grout predicted with no voids present (m^3)	Estimated volume based on grout uptake (m^3)	Additional grout used to fill the hole compared to borehole without a void (m^3)
BH103 (30m)	7.5m to 9.5m mOD	0.5m approximate diameter and 1.5m in height (length)	0.37m^3	0.80m^3	0.43m^3
CH102A (33.5m)	16.5m to 18.2m mOD 19.1m to 21.2m mOD	0.5m to 1.0m approximate diameter and approximately 6.4m length. One feature observed.	0.59m^3	1.20m^3	0.61m^3
CH103A (35m)	15.2m to 17.7m mOD	Variable and up to 1.0m approximate diameter and approximately 1.9m in height (length).	0.62m^3	0.70m^3	0.08m^3

Based on the above, the estimated size of the voids encountered range from 0.1m^3 to 0.7m^3. The above only records actual confirmed voids, and it should be noted that in areas not investigated, or between exploratory holes, further voids could be present. The volume of voids is an indicative estimate based on site observations during the ground investigation.

A recent remodelling exercise of the microgravity data has been undertaken feeding back the results of the ground investigation, allowing back analysis and detailed analytical review of the data. The results of that modelling are as follows (as reported by the specialist sub-Contractor, Geotechnology):

"The agreement between the observed gravity and the calculated gravity using the geological section shown is quite good. Throughout the profile the calc and observed are within 5microGals and often much closer. You need to know a bit of the detail:

The superficial strata have been made a little denser than the chalk. This seems reasonable as the chalk is variously described as low density and medium density. Superficials are often described as dense.

I am intrigued that the voids all seem to lie at or very close to rockhead. I am also struck by rapid changes in rockhead elevation. For this reason I have made the "Voids" inverted triangles of low density material suggesting a karst surface with fissures and voids. In places the density contrast suggests open voids and for others partially filled voids. Void 1 you will notice is much larger than the drillhole revealed. If I make the void the same dimension as the drilling void I cannot produce the observed anomaly. The wavelength is a good match but the amount of missing mass has to be greater. Accordingly I have broadened this out to the side of the borehole. With the feature expanded you can see that the fit is pretty good.

Voids 2 is a small feature. If I expand this or increase the density contrast its gravity effect becomes too large.

Void 3 is interesting. This was the only void found beneath the chalk (at the adjacent borehole) and therefore it might be explained by mining. My first models therefore simulated an open tunnel like void in the chalk at this depth. The wavelength is slightly too long and the magnitude slightly too small if I make a realistic shape. I have noticed that the adjacent borehole has rockhead significantly shallower. I have therefore modelled the void as a part open karst void within an inverted triangle of infill. This produces good agreement. I am therefore happier with this also being a karst feature at rockhead.

The conclusion therefore is that the observed gravity is very similar to calculated gravity when the three known features at rockhead are included in the model. Their density contrast varies reflecting different states of infill. Void 1, at the northern end of Fontmell has to be larger than the feature found during the drilling to produce an anomaly of sufficient magnitude. The wavelength is correct so it does appear to be a feature located at this depth and at this location. The other voids discovered produce anomalies that closely match the observed gravity.

You will notice that the southern (right hand) end of the observed gravity has a small negative that is not reflected in the calculated gravity. I can produce this with a small low density body. However, the superficials have been modelled as uniform strata and it would take small differences in density to produce an anomaly of this magnitude."

The section on which this analysis is based is shown in Drawing No: MK_G-AP011.Y3.400.r0 (included herewith). With respect to the findings of small karst features near surface attention is drawn to the similarity between these findings and the observations made of the Lewes Nodular Chalk at outcrop (Stokenchurch Cutting – M40) shown in Plate 7.

7.3 Ground Movements

Historical mapping indicates that the site has been used as a brick works which has involved the extraction of near surface clay deposits and also there is some evidence to suggest that nearby shafts were sunk to allow mining of the chalk deposits for the manufacture of lime.

7.3.1 Types of Ground Movement

Ground movement can be summarised as Settlement or Subsidence, and a distinction should be made between them.

Settlement under a load, is the vertical movement of the ground surface (and structures founded upon it) arising from the weight. The two principal features to be considered are therefore the compressibility of the soil (its behaviour under a net increase or decrease of load) and the loading applied by the structure throughout the development of the full settlement profile.

Subsidence is movement within the ground, usually downwards, independent of the structure load. It results in total and differential vertical movements and horizontal strains of the ground surface, and often includes substantial “catastrophic” movements (e.g. the consolidation of fill) and even larger movements (e.g. those caused by underground mining operations or collapse of natural solution features).

“Sinkholes” can be divided into two categories defined as "induced" and "natural." Induced sinkholes are those related to man's activities whereas natural “sinkholes” are not. Induced “sinkholes” typically develop in a much shorter time-span than those caused by natural processes.

The initial settlement and deformation of the land surface where a new “sinkhole” has formed, or an older “sinkhole” has migrated to the surface can result from continuous solution of bedrock, a natural decline in the water table, erosion by flowing water, or a combination of these processes. It occurs where overlying deposits (where present) collapse into an opening in bedrock progressively enlarged by solution. The collapse of cavities that have formed, as a result of the downward migration of the deposits into underlying openings in bedrock is probably one of the more common modes of development. Many sinkholes develop with little or no warning.

Anomalies E and F were identified during the geophysical survey along Fontmell Close and this was confirmed by small voids encountered at the top of the chalk deposits, indicating the likely presence of natural solution features. Sand and gravel deposits were encountered at the base of the superficial deposits and the top of the chalk deposits. It is typical that perched groundwater is present within the granular superficial deposits which may have assisted with the natural dissolution features/ voids at the top of the chalk deposits due to the higher permeability and groundwater flow through these granular deposits.

No evidence of significant ground surface movement has been recorded along the public highways and footpaths at the location of the voids and anomalies and across the wider site area. Consequently, on the basis of the ground conditions encountered within the recent investigation, it is not anticipated that significant surface subsidence would occur along the public highway and footpath areas of Fontmell Close and Bridle Close (away from the collapse feature itself).

7.3.2 Settlement due to Loading/ Effective Stress Changes

Infill materials/ Made Ground are present underlying the site and are understood to have been deposited over 50 years ago as a result of the former clay pits and mining activities within the local area. Therefore, it is likely that there are areas of uncontrolled fill and the characteristics of the infill materials are often difficult to quantify.

Where the fill material is deep, self-weight will often be the principal cause of long term settlement. However with granular fills, the major compression occurs almost immediately as load is applied and as a consequence most of the settlement due to self-weight occurs as the fill is placed. Nevertheless, some significant further movement will occur under conditions of constant effective stress and moisture and is termed creep settlement. In this case, where the majority of the underlying fill material is typically clay, then it is likely that ongoing long term consolidation settlement will still occur.

Uncontrolled fill materials typically settle with time due to self-weight and subsequent loading, in this case the road construction and associated traffic. The total settlement measured at the top surface of the road is the combination of the self-weight compression of the road construction fill and the consolidation (primary and secondary) settlements of the underlying foundation layer. Generally the self-weight compression settlement of the road fill is insignificant.

The public highway is constructed over variable soils (typically soft compressible cohesive soils), which could still be associated with ongoing settlement.

The mechanical properties of the clay soils are dependent on stress history, part of the stress is hydrostatic, but the remainder is taken by inter-particle contacts, known as effective stress. The effective stress changes of the underlying fill deposits are difficult to quantify, due to the excavation and filling activities associated with the historical mining in the local area.

Settlement calculations indicate that a maximum long term consolidation settlement for the public highway of around 20mm at the underside of the road construction would occur for a surface point load of around 100kPa from heavy goods vehicles and service trucks at Fontmell Close.

The infill material encountered over Bridle Close (i.e. soft clays) are likely to exhibit more long term settlement (in the order of 30mm at this location) than the infill deposits at Fontmell Close as the deposits are more extensive.

7.3.3 Shrink/ Swell "Movement"

Firm shrinkable clays occur widely in the south east of England, such examples are the London Clay, Gault Clay, Wealden Clay, Kimmeridge Clay, Oxford Clay, Woolwich and Reading Beds, Lias Clay, Barton Beds, and the glacial drift clays, such as the chalky glacial tills of East Anglia, that are derived from these clays by glaciation.

It is as much the type of clay mineral in the soil as the quantity that contributes to the behaviour of the clay. The most common clay minerals are kaolinite, illite and montmorillonite. All of them hold water attracted to their molecular structure and therefore tend to shrink and swell as their water content varies. Soils which contain a high proportion of clay minerals are generally called high plasticity clays and in nature, under similar conditions, they tend to hold more water than the low plasticity clays which contain fewer clay minerals.

To quantify some of the characteristics of clay soils, two index properties known as the Liquid and Plastic Limits are measured. The difference between the Plastic and Liquid Limits is the Plasticity Index or simply the 'plasticity' of the clay. As a general rule, the greater the Plasticity Index, the greater will be the soil's potential to volume change. Overconsolidated clays with relatively high Plasticity Indexes are therefore sometimes referred to as 'firm, shrinkable clays', which is typical of soils present on this site. It is also considered, though, that large volume reductions can result from the shrinkage of normally consolidated soft clays with lower plasticity because of their higher natural water contents and greater compressibility.

At water contents above its Plastic Limit, clay tends to be fully saturated (i.e. all the pores are full of water) and it can change volume only by the removal or addition of water. However, the water content can change only as a result of a change in the effective stresses acting on the soil. An increase in effective stress can be brought about in two ways:

- An increase in the imposed loading (e.g. raising the ground level or the addition of foundation loads).
- Reductions in pore water pressure produced by evaporation and/or transpiration through the roots of vegetation: a process known as desiccation.

Similarly, a decrease in effective stress can result from a decrease in the imposed loading or a reduction in the state of desiccation. Whether the clay is swelling or shrinking, because of its low permeability, the volume changes occur only slowly, often over months or even many years. The volume change that occurs is dependent on the magnitude of the effective stress change.

The volume change is dependent on the 'volume change potential' of the soil. The volume change potential is normally inferred from the index properties of the soil. However the plasticity index should be modified in order to take account for the granular content of the underlying cohesive deposits, as appose to the plasticity of a pure clay.

Therefore, the liquid and plastic limits have been tested in order to assess the volume change potential.

The modified plasticity index (I'_p) is given by:

$$I'_p = I_p \times \frac{\% < 425\ \mu m}{100\%}$$

A simplified classification of volume change potential, based on the modified plasticity index, is given in Table 1 of BRE 240 and is presented in Figure 7.3.3 below.

Figure 7.3.3 Table 1 BRE 240

Modified Plasticity Index I'_p %	Volume change potential
>60	Very high
40–60	High
20–40	Medium
<20	Low

Based on the plasticity index test results of all the cohesive deposits encountered underlying the site area, the volume change potential is considered to be low to medium, and therefore the overall risk of shrink/ swell soils is considered to be low.

7.3.4 Mining "Subsidence" – Difference Between Workings/ Shafts and Entrances

Subsidence could arise from partial or total collapse of underground voids or cavities. The importance of the strength properties of overlying strata (in this case Made Ground, Kesgrave Catchment Supergroup, Lambeth Formation and the Upnor Formation) is fundamental for its ability to sustain and support cavities formed by natural dissolution, as evident in BH103, CH102A and CH103A.

In order for underground mine workings to result in surface instability i.e. subsidence, or sink hole creation, the voids would need to be positioned relatively close to surface (i.e. less than 60m depth) and be large enough to accept a sufficient volume of overlying strata. Mobility of the overlying strata is also required. This may be facilitated by weak material being moved by downward percolation of water, or due to sudden movement into the void i.e. collapse of a mine working roof, or shaft backfill material.

The investigation of the Fontmell Close sinkhole carried out by PBA (Report Ref: 36121/3502, February 2016) confirmed that the cause of the Fontmell Close collapse was due to chalk mining (i.e. man-made), where a sufficiently large volumes of void space was created (an irregular pit that was potentially 7m high and 7m radius). The void was also relatively close to the surface (around 30m depth) and was connected to the surface via a backfilled shaft (of perhaps 2m in diameter).

Modern methods commonly used to reduce surface instability of shafts include filling and consolidation of the shaft and / or grouting of the shaft. It is likely that the shaft at Fontmell Close was filled with end-tipped material (i.e. un-compacted) and that a large void was still present below the backfilled material.

It should be noted that the Groundsure Report and the PBA Database Search indicated that historic mine workings are present within the local area, and therefore cannot be ruled out completely based on the investigation carried out.

The boreholes confirm that Made Ground deposits across the site in question are not that extensive, and are typically underlain by natural superficial deposits, to the top of the Chalk. This implies that no mining activities have taken place across the site area as this would require Made Ground to lie immediately above Chalk. However, it is possible that mining features (i.e. vertical shafts and / or horizontal workings at depth) may be present in between boreholes, or just off the section line, and therefore it is considered that the risk of historical mining activities at this study area to be low.

7.3.5 Natural Cavity Collapse

In order for a natural void to result in surface instability, similar factors to those required for surface instability from shafts or underground workings would be required.

Three voids (with a maximum diameter of 1.0m) were encountered during the recent investigation at depths of between 7.5m and 21.5m at the top of the chalk deposits and considered most likely to be a natural dissolution features. The driller reported dense conditions within the gravel deposits

above the voided area in the exploratory holes CH102A and CH103A. Dense sand and stiff clay deposits were encountered above the small 0.5m dimeter voided area in BH103.

However, based on the relatively small void volume, narrow size, and amount of competent cover strata above, it is unlikely that the natural dissolution cavities found within the boreholes of the current investigation (or similar sized voids that may be present elsewhere across the site) would result in significant surface instability/ ground movement at the surface of the public highway along Fontmell Close and Bridle Close.

7.4 Groundwater

Groundwater monitoring installation was not undertaken during the recent ground investigation. The groundwater levels are based solely on the observations recorded by the drillers during the investigation fieldwork.

7.4.1 Shallow Perched Groundwater Table

Groundwater was encountered within a single investigation hole (WS103B) at a depth of 4.0m in the granular Kesgrave deposits, indicating that shallow perched groundwater conditions may locally exist across the site within the Made Ground or Kesgrave deposits. A groundwater strike was also encountered at a depth of 31m bgl within CH104, however the borehole was dry on completion and this is also considered to be representative of perched groundwater.

Perched water tables can be expected to occur anywhere where there is relatively low permeability strata underlying more permeable strata. They may however be ephemeral. Circumstances that would lead to the presence of a perched water table in this geological context include locations where Made Ground overlies clay horizons within the Lambeth Group, where granular glacial outwash deposits overlie highly weathered silty White Chalk, and where low permeability horizons (i.e. marl bands, or extensive tabular flints) occur within the White Chalk.

7.4.2 Deep Groundwater Table

Groundwater was recorded within borehole CH104A at a depth of 47.5m in the chalk strata, at a level consistent with the expected regional groundwater recorded in a nearby historic borehole. This is considered to be indicative of the deep groundwater associated with the principal aquifer within the chalk.

7.4.3 Effect of Mobile Groundwater/ Erosion

Dissolution features have been the subject of numerous studies, however the complex nature of their formation is not fully understood. Dissolution generally takes place over a geological timescale. The extent to which ongoing dissolution is likely to be occurring and at what rate is unknown. The increased permeability of the chalk caused by dissolution means erosion by water flow is also likely to be an active process. Erosion is relatively short-term and occurs as a result of water flow washing away fine particles of chalk or superficial materials. Such fines can arise from crushing of chalk when highly stressed or be a product of chalk collapse, and in both cases, erosion can also promote chalk collapse.

Localised water flow such as through soakaways, leaking water supply pipes, or leaking sewers could be problematic at all locations where significant voids at depth (man-made or natural) are linked to potentially mobile / erodible fine grained soils in the overburden by water migration pathways.

7.5 Mine Voids Size Estimation

Some basic calculations allow an estimate of the bulk filling potential associated with "typical" mine voids being infilled by naturally derived materials.

The first point of note is the "bulking factor" that represents the difference between an undisturbed soil (be it the Lambeth Group, or the Kesgrave Supergroup), and the loose placed "bulk infill" that results from their collapse into an open mine void.

Assuming bulk densities of respectively 1900kg/m^3 and 1650kg/m^3 for clays and granular fill respectively against an assumed loose fill bulk density of 1500kg/m^3 indicates bulking factors of 26% and 10%.

The mine voids into which they will collapse can be estimated based on typical assumed mine workings. It should be noted that none of the investigatory works undertaken to date have given suitable direct evidence of the size of any mine working, mine entrance or below ground gallery.

The mine workings can be considered to be take the form of two separate elements – the shaft, and the working gallery. The volume of any potential shaft can be estimated readily by simple arithmetic. Assuming the shaft is circular, the volume of the shaft (V1) is defined by the equation:

$$V1 = H\pi r^2$$

Where H = the length of the open void, and r = the radius of the shaft (i.e. ½ the diameter).

For a 5m long shaft, of 2m diameter the volume V1 = 16m^3

The volume of the underground galleries is somewhat more difficult to estimate as the styles of working were notoriously variable, and areas of open void may not be filled by collapsing material due to friction build up, or air or water pressure resistance during the infilling event.

An estimate can be made assuming some "probable" working style and dimensions indicating that at the base of the shaft two assumed square section drives will penetrate a distance of 1m in opposite directions into the chalk. The volume of these galleries (V2) is:

> V2 = 2(L) where L = the length of the gallery from shaft to workings, for a 1m X 1m square gallery i.e. V2 = 2m^3.

As a result, these reach chalk workings which are opened up by mining techniques (probably a form of overhand stoping), into single rectangular "rooms" or "stopes" of assumed dimensions 3m high, by 3m deep by 5m breadth giving a volume (V3) of:

$$V3 = 2 \times (3 \times 3 \times 5) = 90m^3.$$

Based on the above assumptions, the Total volume V_T in a "Dene Hole" is estimated to be:

> V_T = V1 + V2 + V3 (for the assumed dimensions indicated above) this indicates a below ground void of 108m^3 .

The collapse into an assumed open Dene Hole will continue until such time as the volume of "bulked up" material derived from the overburden (call it Vs) = V_T, at which time the collapse will stop. The actual amount of material Vs which was involved in a failure can be estimated by simple

trigonometry, if the depth of superficial materials, the temporary angle of repose, and the real extent of the collapse zone at the ground surface are all known.

7.6 Natural Voids Size Estimation

Based on the observations from drilling works, the nature of the chalk / superficial material interface, and the results of the geophysical (microgravity) exploration, it is considered likely that the void features observed at or near the chalk surface are representative of karst weathering features. The largest void encountered to date is Void 1 which it is postulated can be thought of as an inverted cone with approximate dimensions of 6.4m in height (h) and 1.0m in diameter (the borehole is thought to have drilled into the "shoulder" of the feature rather than the crown).

The volume of a cone can be calculated from the formula $Vc= \pi r^2 h/3$. In this case the radius (r) is taken to be 3m. The overall anticipated volume of the feature is therefore of the order of $57m^3$. The detailed reassessment of the microgravity data has indicated that the void is unlikely to be an open void however. The presence of an open void would actually be difficult to explain in this geological environment, and it is probable that any open void will represent only a proportion of the actual enclosed void volume. Based on the observations of grout take during borehole reinstatement, it seems likely that the existing voids are generally close to being full with infill materials, and that void space should be considered to be typically of the order of $1m^3$ or less.

7.7 Concrete Slab (highway)

A number of cores were obtained along the public highway of Fontmell Close and Bridle Close for strength testing.

The date of construction of the concrete road is not known and reference has been made to Dept. of Environment/Road Research Laboratory publication Road Note 29, 3rd edition (RN29), dated 1970, for guidance on the road design criteria which is considered were likely to have applied when the roadway was constructed. Referring to Fig 11 of RN29, a 200mm unreinforced concrete slab would have been a satisfactory construction depth for a residential road with normal subgrades (CBR between 2 and 15%) and with a cumulative number of standard axles up to 5 million.

Referring to paragraph 50 of RN29, the design charts are based on a minimum concrete 28 day cube strength of $28N/mm^2$ and for a concrete mix with air entrainment for improved durability. The minimum air entrainment required presently by the Highways England Standard specification Table 10/3 is 3% and Table 10/1 requires the minimum strength of surface concrete slabs to be C32/40, which corresponds to $40N/mm^2$ cube strength. Minimum density requirements are not given in the RN29 concrete specification.

The test results show a minimum cube strength of $17.7N/mm^2$ which is significantly less than the $28N/mm^2$ required by RN29 and $40N/mm^2$ presently required by the Highways England Standards, hence the capacity of the slab would be reduced and the life would be significantly less than 5 million axles. The voids were also measured in the cores obtained and the test results indicate 1 to 1.5%, which is less than the minimum 3% requirement of RN29. This would affect the durability of the slab, which would be more susceptible to freeze/thaw action.

The visual appearance of the existing concrete slab is understood to be poor due to extensive cracks and deterioration/ settlement in numerous places. This may be due to weak ground below the slab,

however the low concrete strength and insufficient air entrainment may also have contributed to the deterioration.

The concrete slab does not have any reinforcement, and hence should a sinkhole develop beneath the road slab then it is likely that the concrete slab would be unable to span over the sinkhole and would be likely to be pushed downwards and crack extensively under highway vehicle wheel loading.

8 Geotechnical Risks

A Geotechnical Risk Register (GRR) has been produced in accordance with the Highways England HD22/08 document – Managing Geotechnical Risk. The geotechnical risk register is included in Appendix I.

8.1 Assessment of Geotechnical Risks

The geotechnical risk register has been developed to show mitigation measures which could be put in place, in light of this report, to deal with identified geotechnical risks across the site area. The register also describes the risks and consequence of those risks together with the measures taken or proposed to mitigate those risks.

In summary the main potential geotechnical hazards at the site are considered to be:

- Presence of underground chalk mine workings and nearby abandoned shafts.
- Loose deposits and potential voids within the made ground, superficial and chalk deposits.
- Potential for sinkholes to be present on or near the site.
- Surface settlement and void migration.
- Presence of clay pit backfill material.

The strategy to respond to the geotechnical risks identified for this project is noted below:

- Avoid the risk, or
- If unavoidable, transfer the risk, or
- If non-transferable, mitigate the risk, or
- If unable to mitigate, accept and manage the risk.

8.2 Geotechnical Risk Rating

8.2.1 Settlement of Soft and Extensive Infill and Made Ground Deposits

The site is underlain by infill and Made Ground deposits which are predominately cohesive clay materials. The in-situ testing (DCP and SPT) undertaken in the recent ground investigation would suggest that these deposits are typically soft to firm and the typical long term settlements are considered to be insignificant (maximum long term settlement in the order 20mm to 30mm at the underside of the public road construction at Fontmell Close and Bridle Close respectively), and thus considered a long term low risk to affect the users of the highway and the asset owner.

8.2.2 Surface Subsidence following Migration of Natural Voids to the Surface

Considered to be of low relative risk due to the small open void size of typical karst features in the vadose zone of the Chalk. There is no historical record of deep karst features collapsing in the Hertfordshire area (although the geological record of features further afield such as Cheddar Gorge show this is possible). The impact of surface subsidence following collapse of the typical shallow karst feature will typically be localised surface settlement of no more than a few millimetres, provided the collapse is not associated with ongoing erosion due to groundwater.

8.2.3 Potential for Mine Workings

The local working methods adopted with respect to mining appears to be an initial excavation of a clay pit, with chalk mine working being undertaken from shafts sunk from the base of the pit. On this basis, where Made Ground does not overlie Chalk directly, it can be assumed to have not been penetrated by shafts. There is a limited risk that mining occurring off site could penetrate laterally by successive opening up of further "rooms" – however this style of working is relatively modern, and is not typical of Dene Hole mining which typically involves only one or two relatively short drives into "rooms" close to the original shaft position.

8.2.4 Chalk Dissolution Causing Soft Ground at Depth

There is some direct evidence (CH104A) for the existence of potential deep voids associated with the regional groundwater table. Based on the frequent association of voids in White Chalk at the phreatic surface it is entirely expected that these will be present. For the most part, such cavities are considered stable in respect of normal civil engineering design life requirements.

8.2.5 Leakage of Utility Services

Leakage of water pipes/sewage pipes may have the potential to cause wash out of fines from the near surface soils. The control of ground, surface and drainage water is a key element of any ongoing intent to minimise future subsidence. Any scenario that introduces water to ground with potential for voids risks mobilising fines by erosion, if hydraulic gradient and seepage velocities are sufficient. If the drainage routes through the White Chalk lead to open cavities (karst or mine void in origin) at depth then there is a risk that erosion will occur, and further subsidence can be anticipated. The extent to which such further subsidence would be deemed "catastrophic" would depend on the amount of void space available, the seepage forces/ water velocities and the friability/ susceptibility of the soil to erosion. A complete services review should be undertaken in order to assess the potential risk of wash out across the site area.

8.3 Risk Mitigation Measures

The possible mitigation measures in relation to the likely risks that may be encountered along the highway and footpath areas of Fontmell Close and Bridle Close are presented below.

- Option A – Do nothing.
- Option B – Do minimum – Carry out routine monitoring/ site walkover to assess the ongoing geotechnical and site conditions across Fontmell Close and Bridle Close.

  Install survey points in order to monitor any potential ground surface movement of the road and pavement areas.
- Option C – Preventative maintenance (Basic) – Ground improvement. Excavate existing road construction and install geogrid and reinstate road surface.
- Option D – Preventative maintenance (Intermediate) – Partial Ground Treatment. As option C, but locally grout up near surface voids and areas of settlement.
- Option E – Preventative maintenance (Full) – Full Ground Treatment. Full grouting of the underlying ground across Fontmell Close and Bridle Close and construct new road surface.

The likely mitigation measures have been assessed in relation to the information obtained from the recent ground investigation and the classification of the potential and perceived risks.

9 Conclusions and Recommendations

Several low level risks have been identified during the recent ground investigation and are discussed within this report. The following section outlines recommendations for mitigation or further investigation. This should be read in conjunction with the risk mitigation measures (Options) given in Section 8.3.

9.1 Void Migration

Option B – Do minimum – Carry out routine annual monitoring/ site walkover to assess the ongoing geotechnical and surface conditions across the asset.

Install survey points in order to monitor any potential movement of the existing road along Fontmell Close and Bridle Close.

However, should the site walkover verify that soil movement is causing potential long term ground surface movement across the highway, then it is likely that Option C or D should be undertaken, depending on the scale of the ground movement.

9.2 Surface Settlement

Option B – Do minimum – Carry out routine monthly monitoring/ site walkover to assess the ongoing geotechnical and surface conditions across the site area.

9.3 Presence of Underground Chalk Mine Workings and Nearby Abandoned Shafts

Option A – Do nothing – Based on the available evidence there is no significant risk of there being mine workings or shafts beneath the site in question.

9.4 Loose Deposits and Potential Voids within the Superficial and Chalk Deposits

Option B – Do minimum – Undertake a systematic review of drainage provision in respect of all services, sewers, water supply pipes etc. This will help to minimise and reduce the potential through loss of water, and thus flow/ movement of groundwater through the near surface superficial soils and shallow chalk deposits.

9.5 Potential for “Sink holes” to be Present on or Near the Site

Option B – Do minimum – There is no evidence for the potential presence of large near surface voids likely to cause catastrophic collapse. There are risks of localised subsidence / settlement associated with fines migration through karst fissure networks. These can be dealt with by ongoing monitoring and routine highway maintenance, or

Option C – Preventative Maintenance – The impact of any settlement on the highway infrastructure, and in particular with respect to the services, can be minimised by utilising geotextile reinforced fill to give the as built road some strength in tension to resist settlement.

9.6 Presence of Opencast Clay Pit Backfill Material

Option B – Do minimum– At the moment, there is no particular concern with respect to the presence of clay pit backfill materials. Where present they are generally thin (except for occasional thicker infill deposits across Bridle Close), but should be capable of taking general road traffic and highway construction loads (cars, vans and service trucks etc). The only risk to their continued stability comes from their potential degradation resulting from erosion or inundation due to issues arising from drainage failure.

9.7 Summary

Microgravity has been found to be a useful screening tool to assess the potential for loose ground/ voids/ anomalies and the results have been compared to the actual ground conditions encountered across the site area. Correlation between microgravity predictions and actual ground conditions has been found at some locations. Microgravity, is however only one tool and this investigation has proven that it is necessary to undertake intrusive confirmatory works to validate. Extensive intrusive works have been undertaken using a variety of techniques, targeting the locations of the potential void and anomalies recommended within the Geotechnology Report.

Some voiding has been encountered up 1.0m in diameter, with a recorded length of 6.4m and at depths of 7.5m, 15.2m and 16.1m. The voids identified are likely to be features caused by dissolution of the chalk. No direct evidence of historical mining has been found in the investigation holes advanced. It is known and suspected that historical chalk mining occurred, located beneath the sink hole outside 8, 9, 10 and 11 Fontmell Close, however no further evidence of other chalk mine features have been proven by the intrusive investigations undertaken by Opus across Fontmell Close and Bridle Close.

Evidence of clay extraction has however been encountered together with a highly variable topography of the chalk. It has been concluded that no historical mine workings have been encountered outside of 9-11 Fontmell Close (the PBA report relates direct to that area) and hence future catastrophic collapse of the areas investigated appears unlikely. However, it is anticipated that minor ongoing settlement is likely to occur, which would be expected to have a surface expression and require regular highway maintenance. The situation should be monitored and any unforeseen subsidence should be immediately investigated and repairs carried out as necessary at a suitable juncture.

Settlement calculations indicate that a maximum long term consolidation settlement for the public highway of around 20mm across Fontmell Close, at the underside of the road construction would occur for a surface point load of around 100kPa from heavy goods vehicles and service trucks.

The infill material encountered over Bridle Close (i.e. soft clays) are likely to exhibit more long term consolidation settlement, in the order of 30mm, than the infill deposits at Fontmell Close as the deposits are more extensive.

A monitoring plan should be implemented to visually observe any changes in the road and footpath surface, in particular new cracks, settlement and subsidence. The monitoring plan should include the design of the monitoring points across the site area, frequency of site visits and methods of reacting to any future settlement or subsidence of the road surface.

There is a likelihood that the site is underlain by karstic features within the chalk bedrock, but based on works to date these are expected to comprise both relatively small infilled or open "pipes" at shallow depth beneath the surface of the chalk, and other features at depth. Whilst the shallow features could potentially cause some localised settlement at the surface of the Highway in the future, the impact should be manageable within normal routine Highway maintenance. The risk associated with the deeper features is extremely small due to their depth below surface.

Having reviewed all the information available to Opus to date, it is considered that the overall risk to the existing highway and footpath areas at Fontmell Close and Bridle Close is negligible with respect to chalk mining related activity.

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