

2&3 Angel Square

Ground Engineering Summary Report

050930-BH-XX-XX-RP-GE-0001

050930

19 April 2023

Revision P05

Revision	Description	Issued by	Date	Checked
P01	Ground Investigation Summary and Assessment – Draft for comment	LR	29/10/2021	PH
P02	Ground Investigation Summary and Assessment	LR	08/11/2021	PH/COH
P03	Updated with Deloitte Comments	LR	16/12/2021	PH/COH
P04	Buro Happold ref change from 043434 to 050930 Update to latest scheme	LR	30/03/2023	PH
P05	Updated with Deloitte Comments	LR	19/4/23	PH

<https://burohappold.sharepoint.com/sites/050930/Shared Documents/Ground/03 Reports/GE Summary/050930-BH-XX-XX-RP-GE-0001-P05.docx>

Report Disclaimer

This Report was prepared by Buro Happold Limited ("BH") for the sole benefit, use and information of MEPC For Information. BH assumes no liability or responsibility for any reliance placed on this Report by any third party for any actions taken by any third party in reliance of the information contained herein. BH's responsibility regarding the contents of the Report shall be limited to the purpose for which the Report was produced and shall be subject to the express contract terms with MEPC. The Report shall not be construed as investment or financial advice. The findings of this Report are based on the available information as set out in this Report.

author **Louise Richards**

date **19/04/2023**

approved **Pip Hunsworth**

signature



date **30/03/2023**

Contents

1	Executive Summary	7
2	Introduction and The Site	8
3	Ground Investigation	13
3.1	General	13
3.2	Material Type and Distribution	13
3.3	In Situ Testing	14
3.3.1	Made Ground	15
3.3.2	Superficial Deposits	15
3.3.2.1	Cohesive Glacial Till	15
3.3.2.2	Granular Glaciofluvial Deposits	15
3.3.3	Weathered Sandstone/Sandstone	16
3.4	Rock Strength	17
3.5	Groundwater	17
3.5.1	Historical Groundwater Data	17
3.5.2	SSL 2021 Groundwater Data	17
3.6	Ground Gas	18
3.6.1	SSL 2021 Gas Monitoring Data	18
3.6.2	SSL 2021 Bulk Gas Suite Analysis	19
3.6.3	Solution Choice and Detailed Design	19
3.6.4	Building Type Classification	19
3.6.5	Minimum Gas Protection Score	19
3.7	Obstructions	20
3.8	Unexploded Ordnance (UXO)	20
3.9	Archaeology	20
4	Geoenvironmental Summary	21
4.1	General	21
4.1.1	Historical Data	21

Soil Results	21
Leachate Results	22
Groundwater Results	22
4.1.2 SSL 2021 GI Data	22
4.2 Asbestos Containing Material (ACM)	23
4.3 Waste Acceptance Criteria	23
4.4 pH and Sulphate	23
4.5 Final Risk Assessment	24
4.5.1 Potential Sources of Contaminants	24
4.6 Receptors and Pathways	24
4.7 Final Risk Assessment	24
4.8 Remediation Strategy	25
5 Geotechnical Considerations	26
5.1 General	26
5.2 Excavation and Earthworks	26
5.3 Foundations	27
5.3.1 General	27
5.3.2 Shallow Foundations	27
5.3.3 Piled Foundations	27
5.4 Ground Bearing Slabs	28
5.5 Highways and Permissions	28
6 Anticipated Design for Costing Purposes	29
Appendix A Structural Soils Information	31
Appendix B Updated Risk Assessment	32
Appendix C Monitoring Visit Dates and Access	34

Tables

Table 1: Conceptual Ground Model based on SSL 2015 / 2021 GI data.	14
Table 2: SPT Results for SSL 2021 GI (2021) Boreholes	16
Table 3: Summary of groundwater monitoring installations	17
Table 4: Summary of ground gas monitoring installations	18
Table 4-1: Potential Sources of Contamination	24
Table 4-2: Receptor and Pathways	24

Figures

Figure 2—1 Site Location Plan	8
Figure 2—2 2&3 Angel Square with redline boundary	9
Figure 2—3 NMS March 2023	10

1 Executive Summary

Buro Happold has been appointed by MEPC to undertake site investigation works for the proposed development of two new build office developments on 2&3 Angel Square within the NOMA Masterplan, Manchester and the new build temporary NOMA Marketing Suite (NMS). A site specific ground investigation (GI) was undertaken by Structural Soils Limited (herein referred to as SSL) between the 19th of July and 3rd of August 2021, under the supervision of Buro Happold (BH) and is herein referred to as the SSL 2021 GI. The ground conditions encountered comprise varying depths of Made Ground which is underlain by superficial deposits (very dense sand, and gravel and firm to stiff gravelly clay), underlain by very weak to weak sandstone bedrock (Chester Formation).

A number of obstructions were recorded within the Made Ground during the SSL 2021 GI which are likely to be associated with relic substructure from historic buildings located on site, most notably a 3.2 m deep chamber in TP110a. This chamber and any other insitu obstructions will require removal prior to installation of the new foundations.

Based on the monitoring data obtained to date, a deeper groundwater regime is recorded within the sandstone bedrock (Chester Formation). Perched groundwater was also recorded locally within the Made Ground. Although some localised shallow groundwater was recorded onsite, it is not anticipated that groundwater ingress will cause significant problems for the envisaged excavation works in the temporary case. Any perched water seepages which may be encountered during excavation construction works are likely to be relatively minor and could be controlled by localised sump pumping methods. It should be noted, that should more significant water ingress be encountered, then more substantial water control measures may be required.

6 No. rounds of ground gas monitoring have been undertaken as part of the SSGL. The data has classified the site as Characteristic Situation 1 (CS1) so far.

A series of chemical tests have been undertaken on the material encountered during the SSL 2021 GI. 2 No. of the 10 No. soil samples tested record determinands exceeding the relevant 'commercial threshold' criteria, namely for Lead (TP104 at 0.50 m BGL and TP111 at 1.80 m BGL). Asbestos fibres were recorded within 1 No. of the 14 No. samples tested in the Made Ground (TP108 at 0.60 m BGL). Asbestos quantification tests were undertaken and the results recorded 0.003% by mass. In accordance with CAR-SOIL¹ Watch Point 12 the concentrations of asbestos recorded is 'low'. The remediation strategy is provided in Section 4.8.

10 No. chemical samples were also tested for the Waste Acceptance Criteria. 7 No. meet the non-hazardous waste criteria for inert landfill, however 3 No. soil samples meet the hazardous criteria.

The existing documentation in relation to unexploded ordnance (UXO) advises that the site is 'medium risk' from UXO. UXO supervision was provided during the SSL 2021 GI, and although no evidence of UXO was found during the investigation at the locations of the exploratory boreholes, window samples and trial pits, it is considered that UXO mitigation is required during ground investigation and construction phases of work.

The proposed foundation solution for 2&3 Angel Square is envisaged to be bored cast in-situ piled foundations, due to building height, envisaged column loads along with a vertical embedded retaining wall comprising a secant piled wall.

¹ CAR-SOIL Control of Asbestos Regulations (2012), Interpretation for Managing and working with asbestos in soil and construction demolition materials – Industry Guidance. Published by Contaminated Land: Applications if Real Environments (CL/AIRE).

2 Introduction and The Site

Buro Happold has been appointed by MEPC to undertake site investigation works for the proposed development of two new build office developments on 2&3 Angel Square within the NOMA Masterplan, Manchester and the new build temporary NOMA Marketing Suite (NMS). Please note, for the purposes of this report, 2&3 Angel Square & NMS have been evaluated as one proposed development site herein referred to as 'the Site'. This document provides a summary of the ground investigation works undertaken by SSL and includes an updated risk assessment in relation to planning condition 8a for NMS.

The Site is located to the north of Manchester City Centre, approximately 220 m east of Manchester Victoria Railway Station. It is also in the immediate vicinity of the existing Co-operative Insurance Society (CIS) Tower which lies just beyond the corner of the western boundary. The site area is currently occupied by public car parking areas, managed by RCP Parking, with the main access from Angel Street. The immediate surrounding area comprises urban development including residential, warehouses, offices and manufacturing facilities. A site location plan is included as Figure 1.

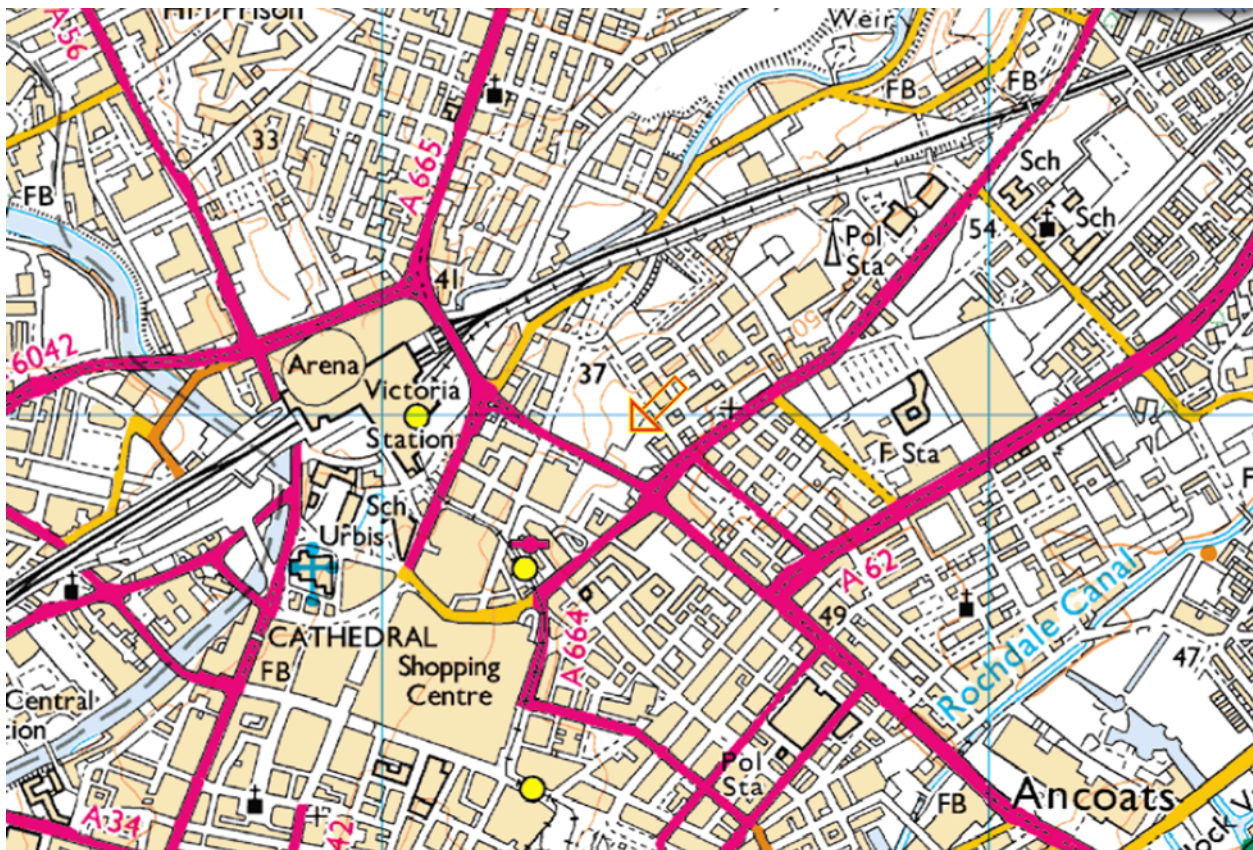


Figure 2—1 Site Location Plan

The Proposed Development is for offices (Use Class B1a), with ground floor retail and commercial units, external terraces at upper levels, car parking and cycle facilities. The Proposed Development will comprise two buildings, one of lower and upper ground plus 14 storeys (2 Angel Square), and one of lower and upper ground plus 13 storeys (3 Angel Square) and will also include a comprehensive public realm scheme with hard and soft landscaping, car parking, and highways and other associated works (Figure 2—2 refers). In advance of works starting on 2 & 3 Angel Square, the NMS is proposed to be erected on site as a temporary building in the southwestern corner of the Site and will consist of a single storey building with associated car parking and public realm. The NMS has been constructed and is currently in use by the client (Figure 2—3 refers).



Figure 2—2 2&3 Angel Square with redline boundary



Figure 2—3 NMS March 2023

The data sources reviewed can be summarised as follows:

- Wessex Archaeology Report entitled 'Arkwright's Mill, NCP Car Park, Miller Street, Manchester' (Report No. 59471.01), dated April 2006, on behalf of Videotext Communications Limited;
- Gifford Report entitled 'Land off Miller Street, Manchester: An Archaeological Desk-Based Assessment' (Report No. 14039.R01), dated May 2007, on behalf of The Cooperative Group Limited;
- EOD Contracts Limited Report Entitled 'Explosive Ordnance Desk Top Study, Miller Street Manchester for the Co-operative Group' (Ref: No: ECL/09/10360/DTS/MillerStManchester/Rev2), dated March 2009, on behalf of The Co-operative Group Limited;
- Buro Happold Report entitled 'Ground Engineering Desk Study Report – The Co-Operative Group HQ Building, Manchester' (Ref: 023842), dated July 2009, on behalf of The Co-operative Group Limited;
- Structural Soils Report entitled 'Report on Ground Investigation at the co-operative Head Office, Manchester' (ref: 761072), dated September 2009, on behalf of The Co-operative Group Limited (ref: SSL 2009 GI);
- Buro Happold Report entitled 'Ground Engineering Interpretative Report – The Co-Operative Group Head Office, Manchester' (Ref: 023842), dated October 2009, on behalf of The Co-operative Group Limited;

- Buro Happold Report entitled 'Ground Engineering Desk Study Report – NOMA Plot L, Manchester' (Ref: 032922), dated November 2013, on behalf of The Co-operative Group Limited;
- Buro Happold Report entitled 'Ground Engineering Interpretative Report – NOMA Plot L, Manchester' (Ref: 023922), dated November 2013, on behalf of The Co-operative Group Limited;
- Structural Soils Report entitled 'Factual Report on Ground Investigation at NOMA Plot L, Manchester' (ref: 762850), dated January 2014, on behalf of The Co-operative Group Limited (ref: SSL 2013 GI);
- Oxford Archaeology North Report entitled 'NOMA Regeneration, Miller Street, Manchester' (Report No. L10460), dated February 2013, on behalf of The Co-operative Group Limited;
- Oxford Archaeology North Report entitled 'NOMA Plot L, Miller Street, Manchester – Archaeological Evaluation' (Report No. L10761), dated July 2014, on behalf of NOMA Plot L Limited;
- Oxford Archaeology North Report entitled 'NOMA Plot L, Angel Square, Miller Street, Manchester – Archaeological Desk-based Assessment' (Report No. L10812), dated December 2014, on behalf of Moda Living;
- Oxford Archaeology North Report entitled 'NOMA Plot M, Miller Street, Manchester – Archaeological Desk-based Assessment' (Report No. L10755), dated June 2014, on behalf of NOMA;
- Oxford Archaeology North Report entitled 'Arkwright's Shudehill Mill, Miller Street, Manchester – Archaeological Assessment' (Report No. L10772), dated September 2014, on behalf of NOMA;
- Oxford Archaeology North Report entitled 'Shudehill Mill, Miller Street, Manchester – Archaeological Excavation, Written Scheme of Investigation', dated January 2015, on behalf of NOMA & Moda Living;
- Sanctus Report entitled 'Angel Square – Site Investigation Report' (Report No. S1933-001), dated May 2015, on behalf of NOMA;
- Sanctus Limited report entitled 'Contract Completion Report, Angel Square, Manchester' (Report No. S1918), dated June 2015, on behalf of NOMA;
- Structural Soils Limited Report entitled 'Factual Report on Ground Investigation – 2&3 Angel Square, Manchester (Ref: 763315 Rev 2 Final), dated July 2015, prepared on behalf of the Co-operative Group Limited (ref: SSL 2015 GI);
- Sanctus testing – 6 No. samples SS1 - SS4, EMB1 - EMB2: plan and chemical results only, dated September/October 2015, on behalf of Turner & Townsend Limited;
- W.Maher testing - 6 No. samples Stockpile 1 – Stockpile 4, Embankment 1 – Embankment 2: plan and chemical results only, dated October/November 2015, on behalf of Turner & Townsend Limited;
- Churchill Enviro Limited report entitled 'Validation Report For Works Carried Out By W Maher and Sons At Angel Gardens, Manchester', dated March 2016, on behalf of Turner & Townsend;
- RSK report entitled 'NOMA Angel Gardens, Manchester – Geo-environmental site assessment' (Report No. 322162), dated January 2016, on behalf of Moda Living (Angel Gardens) Limited;

- Churchill Enviro Limited report entitled 'Validation Report For Remediation Work Carried Out as Part of the Enabling Works Contract by W Maher and Sons at Angel Gardens, Manchester', dated October 2016, on behalf of Turner & Townsend;
- Buro Happold Report entitled 'Ground Engineering Desk Study Report – NOMA, 2&3 Angel Square' (Ref: 043434), dated September 2019, on behalf of NOMA (GP) Limited;
- Salford Archaeology report entitled 'NOMA Plots 2&3, Angel Street, Manchester – Archaeological Evaluation Report' dated June 2021, on behalf of NOMA GP Limited;
- Salford Archaeology Written Scheme of Investigation (WSI) for an Archaeological Evaluation. NOMA 2 & 3 Public Realm. Dated February 2023;
- The British Geological Survey (BGS) - England & Wales Sheet 85 'Manchester';
- The Coal Authority;
- Published technical reports;
- Historical literature;
- Documents found during internet searches; and
- Any information provided by the Client i.e. previous desk study or ground investigation / utilities information.

All the aforementioned reports/information should be read in conjunction with this report.

3 Ground Investigation

3.1 General

Information from the BGS along with historic GI data available from the surrounding area was initially reviewed to generally establish the envisaged ground conditions across the development area. Two site specific GI's have been undertaken by SSL, both under the supervision of Buro Happold.

The SSL 2015 GI was undertaken during January 2015 and comprised 13 No. machine excavated trial pits (TP1 - TP4, TP4A, TP5 – TP10, TP10A and TP11) across the Site and its surrounds, along with associated chemical testing including asbestos identification and quantification. Groundwater and ground gas monitoring was also carried out in historical borehole BHL01 on the Angel Gardens site. All other historical borehole installations could not be found.

The second site specific ground investigation was undertaken by SSL between the 19th of July and the 3rd of August 2021, (herein referred to as the SSL 2021 GI). It comprised 4 No. boreholes (BH101-104), 5 No. window samples (WS101-105) and 12 No. trial pits (TP101-112 and 110a) across the Site. The boreholes were drilled to depths ranging between 25.00 and 31.00 m BGL using cable percussive drilling with rotary drilling follow to obtain rock core. Sampling, geotechnical and geo-environmental testing (including asbestos identification and quantification) and groundwater and ground gas monitoring was also undertaken as part of the SSL 2021 GI.

Please note, during the archaeological excavation of Arkwrights Mill, the presence of asbestos within the Made Ground was recorded. A strategy for dealing with asbestos contamination within the footprint of Arkwrights Mill was completed during May 2015 comprising the removal of all Asbestos Containing Material (ACM) off site (refer to Sanctus Report²).

The following sections of this document outline the findings of the SSL 2015/2021 GI's, and assess the ground conditions and associated risk for the proposed developments in relation to human health. The updated risk assessment is contained within Appendix B.

The SSL 2021 Factual Report on Ground Investigation³ should be read in conjunction with this report.

3.2 Material Type and Distribution

The ground conditions have been assessed on the basis of the available information. The general sequence of strata encountered based on available BGS borehole logs in the surrounding area and that of the ground conditions encountered during the SSL 2015/2021 GI's are summarized in **Table 1**.

² Sanctus Report on behalf of the client, NOMA, entitled "Contract Completion Report, Angel Square, Manchester, ref S1918, Dated June 2015.

³ Structural Soils Limited, Report on Ground Investigation, 2 & 3 Angel Square and NOMA Marketing Suite, Manchester (ref:765325-1(2)) Revision 2, 3rd November 2021.

Table 1: Conceptual Ground Model based on SSL 2015 / 2021 GI data.

Depth to Top of Strata (m BGL)	Typical Thickness (m)	Generalised Description
0.00	0.15 – 5.00	Black brown slightly clayey slightly sandy angular to subangular GRAVEL of brick and ash with high cobble and medium boulder content. Gravel comprises various materials including sandstone, mudstone, limestone, glass, tarmac, coal, slag, concrete, slate, clinker, brick, rare granite and ceramic fragments. AND Black sandy fine to coarse GRAVEL in clayey matrix with pottery and snail shells (1.80 - 2.20 m BGL in TP5 only – former reservoir) [MADE GROUND]
0.35 – 4.65	>0.20 - 14.80	Firm to very stiff brown/red brown slightly sandy silty gravelly CLAY. Gravel is fine to coarse angular to rounded of sandstone & mudstone. AND Orange brown, slightly clayey, slightly gravelly fine to coarse SAND. Gravel is fine to coarse, subangular to rounded of quartzite, limestone, sandstone and ironstone. Occasional layers of brown, sandy, gravel. [GLACIAL TILL / GLACIOFLUVIAL]
11.10 – 15.50	>10.00 - >17.00 (thickness not proven)	Very dense reddish brown slightly gravelly fine to coarse SAND. Gravel is subrounded to rounded fine to coarse of quartzite. AND Very weak to weak, red/brown, medium to coarse grained sandstone with occasional layers of marl. [CHESTER FORMATION]

Note: During the SSL 2015 GI groundwater was recorded in TP1, TP5 and TP7 as 'slight seepage' at 1.10, 1.80 and 0.50 m BGL (44.56, 45.57 and 44.24 m AOD respectively).

During the SSL 2021 GI groundwater was recorded in: BH101 at 11.70 m bgl, BH103 at 5.70 m bgl, and BH104 at 5.20 m bgl. No groundwater strikes were recorded within the window samples or trial pits during the SSL 2021 GI.

The ground conditions comprise varying depths of Made Ground which is underlain by superficial deposits (dense to very dense sand, gravel and firm to very stiff clay), underlain by completely weathered sandstone bedrock, in turn underlain by very weak to weak sandstone bedrock (Chester Formation). Relevant exploratory hole logs and location plans are included in Appendix A. It is considered that the seepages encountered are localised and variable perched groundwater may be encountered within the Made Ground and superficial deposits.

3.3 In Situ Testing

In-situ testing undertaken during the SSL 2021 GI included 65 No. standard penetrations tests (SPTs). The results are summarized in the subsequent sections of this report. SPTs were undertaken in both the 5 No. Window Samples and 4 No. boreholes. The results are presented in the Structural Soils Factual Report on Ground Investigation and are summarized in the following sections.

3.3.1 Made Ground

A total of 9 No. SPTs are available for Made Ground and can be summarized as follows:

- Minimum Value: $N = 7$ – recorded in WS102 at 1.00 m bgl
- Maximum Value: $N = 39$ – recorded in WS105 at 2.00 m bgl

The interpolated material strength assessment based on the SPT results indicates the Made Ground (predominantly granular) to range typically between Loose to Medium Dense.

3.3.2 Superficial Deposits

3.3.2.1 Cohesive Glacial Till

A total of 15 No. SPTs are available in the cohesive Glacial Till superficial deposits and can be summarized as follows:

- Minimum Value: $N = 12$ – recorded in WS104 at 1.00 and 2.00 m bgl
- Maximum Value: $N = 200^*$ - recorded in WS102 at 4.80 m bgl
- Typical Values: $N = 12 - 200^*$

The interpolated material strength assessment based on the SPT results indicates the Glacial Till Deposits to have undrained shear strengths ranging between 54 and 100 kPa. It should be noted that 5 No. SPT results undertaken in the Glacial Till reached refusal indicating a material strength greater than that for which the test was originally designed.

3.3.2.2 Granular Glaciofluvial Deposits

A total of 22 No. SPTs are available in the granular glaciofluvial superficial deposits and can be summarized as follows:

- Minimum Value: $N = 12$ – recorded in BH103 at 3.50 m bgl (39.50 m AOD)
- Maximum Value: $N = 950^*$ - recorded in WS102 at 4.50 m bgl (38.50 AOD).
- Typical Values: $N = 12 - 400^*$

The interpolated material strength assessment based on the SPT results indicates the Glaciofluvial Deposits to be Medium Dense to Very Dense. It should be noted that 17 No. SPT results undertaken in the Glaciofluvial Deposits reached refusal indicating a material strength greater than that for which the test was originally designed.

**Extrapolated 'N' value where full penetration was not achieved. Extrapolated 'N' values where SPT reached refusal indicate a material strength that is greater than that of which the test was designed.*

3.3.3 Weathered Sandstone/Sandstone

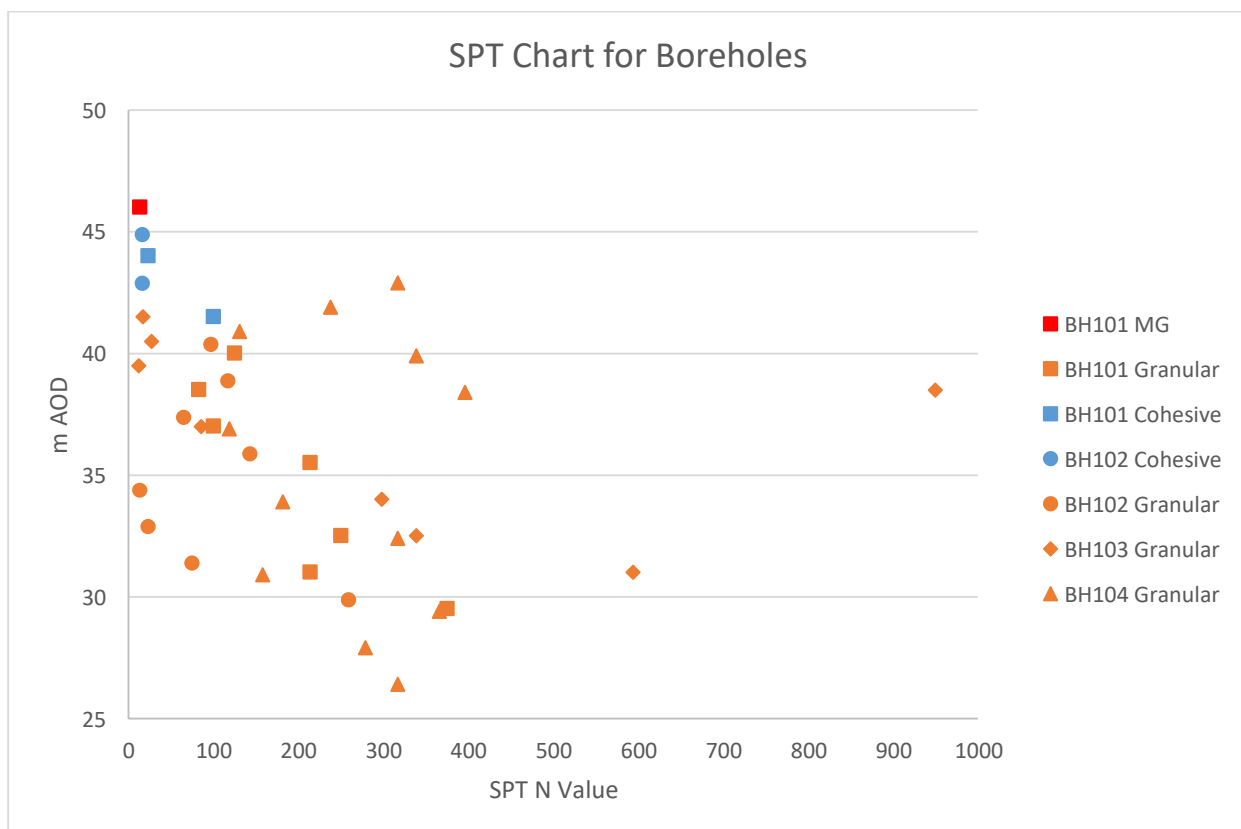
A total of 17 No. SPTs are available in the weathered sandstone/sandstone deposits and can be summarized as follows:

- Minimum Value: N = 75* – recorded in BH102 at 15.50 m bgl (31.38 m AOD)
- Maximum Value: N = 594* - recorded in BH02 at 22.50 m bgl (21.90 m AOD).
- Typical Values: N 75*-594*

It should be noted that SPTs were requested by Buro Happold in the sandstone bedrock where 2 No. consecutive core runs achieved <95% core recovery.

The interpolated material strength assessment based on the SPT results indicates the Weathered sandstone/sandstone to be Very Dense. It should be noted that all 17 No. SPT results undertaken in the exploratory holes reached refusal indicating a material strength greater than that for which the test was originally designed.

Table 2: SPT Results for SSL 2021 GI (2021) Boreholes



3.4 Rock Strength

A total of 31 No. point load tests (PLT) were undertaken on rock core samples obtained during the ground investigation. Rock strength varied from 0.24 MPa (BH101 at 18 m bgl (29.52 m AOD)) to 20 MPa (BH104 at 28 m bgl (16.20 m AOD)). The PLT indicate that the sandstone is very weak (UCS between 1-5 MPa) between 30.00 and 17.00 m AOD (~13.00 to 29.00 m bgl) and becomes weak (UCS between 1-25 m MPa) below 17.00 m AOD (>24.00 m bgl). This also correlates to the borehole records that frequently record non-intact rock core recovery.

3.5 Groundwater

3.5.1 Historical Groundwater Data

A total of 12 No. groundwater monitoring visits were undertaken as part of the SSL 2009 GI for 1 Angel Square and the SSL 2013 GI for Angel Gardens. A further 3 No. visits were carried out to monitor any historical installations left in-situ, namely BHL01 (SSL 2013 GI).

The majority of the post fieldwork groundwater monitoring results for the Chester Formation show a typical range of between 25.49 m AOD and 26.20 m AOD (~20.00 to 23.30 m bgl).

3.5.2 SSL 2021 Groundwater Data

As part of the SSL 2021 GI groundwater and gas monitoring wells were installed in the 4 No. boreholes and 5 No. window samples. Refer to Table 3 for details of the installations.

Table 3: Summary of groundwater monitoring installations

Borehole Identification	Installation Type	Response Zone (m BGL)	Stratum
BH101	19 mm piezometer	17.00-28.00 (Tip at 25)	sandstone
BH101	50 mm standpipe	1.00-2.00	Made Ground
BH102	19 mm piezometer	20.00-28.00 (Tip at 24)	Sandstone
BH103	19 mm piezometer	16.00-25.00 (Tip at	sandstone
BH103	50 mm standpipe	2.00-4.00	Made Ground
BH104	19 mm piezometer	15.00-21.00	sandstone
WS101	50 mm standpipe	1.00-2.00	Made Ground
WS102	50 mm standpipe	0.50-1.00	Made Ground
WS103	50 mm standpipe	0.25-1.00	Made Ground
WS104	50 mm standpipe	0.25-1.00	Made Ground
WS105	50 mm standpipe	1.00-4.00	Made Ground

All (6 No.) post-fieldwork monitoring visits have been undertaken, between the 13th of August 2021 and the 22nd of October 2021. The SSL 2021 GI groundwater data indicates static water level (SWL) between ~30.08 m AOD and 24.97 m AOD (15.69 to 21.92 m bgl) within the sandstone bedrock (Chester Formation). Localised perched groundwater is also recorded within the Made Ground/superficial deposits (~0.50 to 3.95 m BGL). It is worthy of note that there were no groundwater strikes within the trial pits or window samples during the SSL 2021 GI.

The hydraulic regime within the bedrock is considered to be controlled by the nature of the cementation and fracturing of the rock mass. It is also important to note that the Chester Formation is classified as a Principal Aquifer

by the Environment Agency, therefore consideration for the prevention of the migration of contamination (if any) and protection of the Principal Aquifer may be required.

3.6 Ground Gas

3.6.1 SSL 2021 Gas Monitoring Data

As part of the SSL 2021 GI, 11 No. ground gas monitoring wells were installed for monitoring. The wells are summarised below in Table 4.

Table 4: Summary of ground gas monitoring installations

Borehole Identification	Installation Type	Response Zone (m BGL)	Stratum
BH101	50 mm standpipe	1.00-2.00	Made Ground
BH101	19 mm piezometer	17.00-29.00	Sandstone
BH102	19 mm piezometer	23.70-24.00	Sandstone
BH103	50 mm standpipe	2.00-4.00	Made Ground
BH103	19 mm piezometer	15.60-25.00	Sandstone
BH104	19 mm piezometer	15.60-21.10	Sandstone
WS101	50 mm standpipe	1.00-4.00	Made Ground
WS102	50 mm standpipe	0.25-1.00	Made Ground
WS103	50 mm standpipe	0.25-1.00	Made Ground
WS104	50 mm standpipe	0.25-1.00	Made Ground
WS105	50 mm standpipe	1.00-4.00	Made Ground

All post-fieldwork monitoring visits have been undertaken between on the 13th of August 2021 and the 22nd of October 2021. It should be noted that in a number of occasions it was not possible to access the monitoring wells due to cars being parked over the exploratory position (refer to Appendix C), however, this is not considered to have a significant influence over the final classification of characteristic situation. The ground gas concentrations and flow rates obtained from the installations to date have been assessed against the classification scheme presented in CIRIA C665 (Assessing risks posed by hazardous ground gas to buildings (2007)). A short summary is provided below;

- Gas flow rates recorded to date suggest very low flow ranging between -1.5 and 1.0 l/hr.
- Oxygen (O₂) levels generally range between 19.0 and 21.0 % in all boreholes. A relatively low oxygen concentration of 9.8 % was recorded in WS102 (response zone 0.00-1.00 m bgl in Made Ground) on the 6th October 2021 and 13.0% in WS105 (response zone 0.00-4.00) on the 13th August 2021.
- Carbon Dioxide (CO₂) levels generally range between 0.1 and 1.0% across the site. An elevated concentration of 5.0 % was recorded in WS105 (in Made Ground) on the first monitoring visit (13th August 2021). It is envisaged that this elevated CO₂ is related to a reducing environment causing nitrogen to replace the O₂ & CO₂ to be elevated.
- Methane (CH₄) levels generally ranged between 0.0 and 0.1% across all monitoring wells. Slightly elevated Methane (CH₄) concentrations were noted in BH102 (Sandstone) ranging between 1.3% and 1.4% on the 22nd of October 2021 and 6th of October 2021. It is noted that no identifiable sources of methane were recorded in the exploratory logs during the SSL 2021 GI. It is also considered that the pathway between the Sandstone (bedrock) and the proposed building is broken by the superficial glacial till / glaciofluvial deposits.

At present the ground gas results classify the ground gas characteristic situation to typically be CS1. Given the ground gas monitoring results, it is considered that ground gas protection designed in accordance with the BS 8485 to provide a suitable level of protection to end users is required.

3.6.2 SSL 2021 Bulk Gas Suite Analysis

During the final monitoring visit undertaken on 22nd October as part of the SSL 2021 GI, 1 No. bulk gas sample was collected from WS102 for bulk gas suite laboratory analysis. The sample was collected due to the reduced Oxygen (O₂) concentration recorded on numerous visits (visit 1,2,5 & 6). The bulk gas analysis from the 22nd of October is as below:

- Carbon Dioxide (CO₂ %) – 0.14;
- Carbon Monoxide (CO%) - <0.05;
- Hydrogen (H₂%) – <0.5;
- Methane (CH₄%) - <0.05;
- Methane (CH₄ ppmV) - <5;
- Nitrogen (N₂%) – 82.9; and
- Oxygen (O₂%) – 17.

3.6.3 Solution Choice and Detailed Design

The purpose of this section is to identify the building classification and the appropriate ground gas protection measures based on the characteristic situation on-site. The BS 8485:2015+A1:2019⁴ “Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings” has been consulted and is referred to in this section of the report in order to achieve the above.

3.6.4 Building Type Classification

The proposed development, 2 & 3 Angel Square, comprises two commercial buildings, one of lower and upper ground plus 10 storeys (2 Angel Square) and one of lower and upper ground plus 11 storeys (3 Angel Square). NMS comprises a temporary single storey smaller commercial building located in the southwestern corner of the Site. It is therefore considered that the relevant building type classification with reference to BS 8485:2015+A1:2019 is “Type B Building” for both. A description of Type B buildings in the BS 8485:2015+A1:2019 is below:

Type B building: *private or commercial property with central building management control of any alterations to the building or its uses but limited or no central building management control of the maintenance of the building, including the gas protection measures. Multiple occupancy. Small to medium size rooms with passive ventilation of rooms and other internal spaces throughout ground floor and basement areas. May be conventional building or civil engineering construction. Examples include managed apartments, multiple occupancy offices, some retail premises and parts of some public buildings (such as schools, hospitals, leisure centres) and parts of hotels.*

3.6.5 Minimum Gas Protection Score

The post-fieldwork ground gas monitoring results, as discussed in Section 1, identified a maximum Characteristic Situation 2 (CS2) (1 No. location from a flooded well in the sandstone) and a typical Characteristic Situation CS1 for the proposed site. It should be noted that the monitoring well recording a CS2 was a deep flooded well located in the sandstone and that the pathway between the sandstone and the proposed building is considered to be broken by the

⁴ BS8485:2015+A1:2019, Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings, January 2019.

overlying superficial glacial till and glaciofluvial deposits. In addition, the maximum Characteristic Situation recorded in the Made Ground material (the most likely source of any ground gas) is CS1. Considering the aforementioned it is considered that Characteristic Situation 1 (CS1) is a suitable classification for the site. In accordance with Table 4 (page 22, BS 8485:2015+A1:2019) if the Site is classified as CS1, 0 points are required and thus ground gas protection is therefore not required.

3.7 Obstructions

The Site has an extensive and rich development history (BH Desk Study⁵ refers). Based on the historic data, it was envisaged that large amounts of the substructure were likely to be encountered during the GI. As anticipated, the information obtained during the SSL 2021 GI indicates that some relic substructure and infrastructure currently remains in-situ below the site and as such, a number of these are likely to cause obstructions during the installation of the new substructure. As such, in advance of the new substructure installation it is envisaged that any such areas where old and new substructure clash, then these areas of old substructure will need to be removed in advance of the new foundation installation. It is currently envisaged that such obstructions will be removable using conventional plant and equipment including the use of pneumatic breakers.

It should also be noted that during the SSL 2021 GI a ~3.2 m below ground chamber was encountered in TP110a. This is recorded on any previous surveys, therefore it is recommended that further investigation is undertaken to understand if the existing chamber / infrastructure is still in use and requires diverting, or if it is part of an abandoned system to be grubbed up/ grouted up.

3.8 Unexploded Ordnance (UXO)

The proposed developments is situated in an area identified as being at 'moderate' risk from unexploded ordnance (UXO) as detailed in the relevant Zetica UXB (Unexploded Bomb) risk map for the site⁶. A Detailed Unexploded Ordnance (UXO) Risk Assessment⁷ was undertaken by 1st Line Defence on behalf of the Client, MEPC. The conclusion of the UXO Risk Assessment was that the site is 'medium risk' therefore UXO mitigation is considered to be required during ground investigation and construction phases of work.

During the SSL 2021 GI, UXO engineer supervision was provided to prove positions 'clear' of any UXO. No UXO was identified or uncovered as part of the Ground Investigation works. However, it is considered that UXO mitigation is required during any intrusive works on site (intrusive enabling works and piling).

3.9 Archaeology

The site has undergone various archaeological investigations over the years, primarily associated with Arkwrights Mill and other areas of historical significance (Section 2 refers). The findings from the most recent Salford Archaeology investigations should be read alongside this report. A programme of archaeological monitoring via a watching brief is proposed to be undertaken during any groundworks at the site⁸.

⁵ Buro Happold Ground Engineering Desk Study Report, NOMA, 2 & 3 Angel Square (ref: 043434), Dated 4th September 2019.

⁶ Zetica, Regional Unexploded Bomb Risk Map, Site Location Map Centre 399468,651513

⁷ 1st Line Defence, Detailed Unexploded Ordnance (UXO) Risk Assessment, 2 & 3 Angel Square, Manchester, ref: DA13039-00, 16/04/2021.

⁸ Salford Archaeology, Written Scheme of Investigation for an Archaeological Evaluation. NOMA 2 & 3 Public Realm, February 2023.

4 Geoenvironmental Summary

4.1 General

A geoenvironmental assessment of the Site has been undertaken to assess the degree of contamination present, if any, in respect of the proposed development, the health and safety of the construction work force and to allow characterization of material for the waste disposal of surplus arisings.

Soil samples have been obtained during the historical and recent site specific investigations and submitted for chemical testing as summarised in subsequent sections.

4.1.1 Historical Data

Chemical testing was carried out during the SSL 2015 GI in respect of end use, health and safety considerations in addition to waste disposal categorization as detailed below:

- 19 No. samples of Made Ground and natural material (Buro Happold General Suite – soil and leachate),
- 10 No. stockpile samples (Waste Acceptance Criteria only – soil and leachate)
- 6 No. samples of Made Ground and natural material (additional asbestos identification only)
- 3 No. samples of Made Ground (Asbestos Quantification only)

Soil Results

All Made Ground sampled recorded concentrations of all determinants below commercial thresholds with the exception of Lead at a concentration of 3750 mg/kg in TP4A at 2.00 m BGL. Please note, TP4A is not located within the confines of the proposed 2&3 Angel Square development boundary and as such is not discussed further.

All natural soils sampled recorded concentrations of all determinants below commercial thresholds.

5 No. samples recorded the presence of asbestos as detailed in Table 2 below. Please note, the Made Ground within the footprint of Arkwrights Mill (containing asbestos) has now been removed from Site and the excavation has been infilled (with 6F2 – the details of which Buro Happold are not currently aware of). Waste materials including old shoes, plastic ties and fabrics were recorded in the Made Ground in TP10A between 0.50 – 2.00 m BGL. This material is proposed to be segregated and removed during the enabling works for 2&3 Angel Square and the NMS. Section 4.8 details the methodology.

Exploratory Hole	Sample Depth (m BGL)	Asbestos Type	Quantification (%)	Comments
TP1	0.30	Chrysotile fibres	-	Arkwrights Mill footprint. Removed
TP2	0.30	Chrysotile fibres	-	Arkwrights Mill footprint. Removed
TP4A	2.00	Chrysotile fibres	<0.001	Located offsite
TP10A	1.00	Chrysotile fibres	<0.001	To be removed & segregated if encountered. Material can also be left insitu and capped appropriately (no change from existing situation).
TP10A	2.00	Chrysotile cement	0.006	

Leachate Results

The leachate results record a number of minor exceedances (less than an order of magnitude) of lead, barium, antimony, sulphate and fluoride. Given the extremely limited number of exceedances, the magnitude of the exceedances, the low soil concentrations recorded on the respective samples and the fact that the assessment criteria used are considered to be overly onerous for the purpose of the analysis, it is considered that leaching of such determinands to controlled water receptors is unlikely and as such no further analysis on the associated leachate concentrations is considered necessary.

Groundwater Results

A total of 2 No. groundwater samples from the Chester Formation were tested during the SSL 2015 GI. No elevated determinands were found with the exception of sulphate in BH01 which recorded of 440 mg/l - a slight exceedance of the Environment Agency Non Statutory assessment value of 400 mg/l.

1 No. groundwater sample from the Made Ground was tested during the SSL 2015 GI within TP5 at 1.80 – 2.20 m BGL – thought to represent the presence of Arkwrights Mill historical reservoir. Arsenic, Nickel, Antimony, Benzo(a)pyrene and Total Polyaromatic Hydrocarbons (PAH) were elevated with respect to the relevant assessment criteria. Please note, both the soil and leachate results from TP5 at 1.80 m BGL recorded no exceedances of any determinands, therefore, the groundwater in this area of the Site is considered to be a localized pocket of perched water which is not in hydraulic continuity with the Principal Aquifer (Chester Formation).

Based on the foregoing, no further analysis on groundwater concentrations is considered necessary as it is considered that the determinands do not pose a significant threat to controlled waters and, as such, do not require further consideration.

4.1.2 SSL 2021 GI Data

Chemical testing was carried out during the SSL 2021 GI in respect of end use, health and safety considerations in addition to waste disposal categorization as detailed below:

- 10 No. samples of Made Ground (Buro Happold General Suite – soil and leachate),
- 6 No. samples of Made Ground (additional asbestos identification only)
- 1 No. sample of Made Ground (Asbestos Quantification only)

A total of 10 No. soil chemical tests were undertaken in Made Ground. Based on the proposed development end use and in respect of contaminated land threshold criteria for the site, 'commercial' threshold criteria are considered to be most relevant. The chemical data has been screened against the C4SL and S4UL criteria for each associated threshold.

2 No. of the 10 No. samples tested recorded determinands that exceeded the relevant 'commercial' threshold for lead (2,330 mg/kg). The samples and determinands that exceeded commercial thresholds are listed below. Given the depths of the samples, is likely that this material will be removed from site during basement excavation.

- TP104 at 0.50 m BGL – Lead: 5910 mg/kg (located under 2 AS plot)
- TP111 at 1.80 mg/kg – Lead: 4300 mg/kg (located in between 3 AS and NMS)

4.2 Asbestos Containing Material (ACM)

14 No. tests on samples within Made Ground deposits were screened for ACM. 1 No. sample recorded the presence of asbestos fibres, namely Chrysotile in TP108 at 0.60 m BGL (located under 3 AS plot). Asbestos quantification was undertaken on the sample which recorded ACM at 0.003%. In accordance with CAR-SOIL⁹ Watch Point 12 the concentrations of asbestos recorded is 'low'.

In the instance that any asbestos containing material is encountered during the enabling works for NMS or 2 & 3 Angel Square, a Plan of Work, created by a suitably competent person is to be followed in order to adopt the appropriate actions to control risk and prevent harm.

4.3 Waste Acceptance Criteria

A two-tier Waste Acceptance Criteria assessment has been undertaken on a total of 10 No. soil samples as part of the SSL ground investigation and the results are summarised below.

Tier One – Hazwaste online

10 No. soil samples were tested for a suite of chemical determinands. The results of the chemical tests were input into the HazWaste online software to establish if the samples were 'Non-Hazardous' or 'Hazardous'. Based on the Tier One assessment, 7 No. soil samples tested were classified as 'Non-Hazardous' and 3 No. soil samples were classified as 'Hazardous'.

The 3 No. 'Hazardous' soil samples were classified for the following properties:

- TP102 at 0.70 m bgl – Lead (1060 mg/kg) and Zinc (1580 mg/kg - located under 2 AS plot);
- TP104 at 0.50 m bgl – Lead (5910 mg/kg - located under 2 AS plot); and
- TP111 at 1.80 m bgl – Lead (4300 mg/kg - located in between 3 AS and NMS)).

Tier Two – Waste Acceptance Criteria

4 No. soil samples were tested for the Waste Acceptance Criteria leachate test to further understand which landfill the materials tested would likely be accepted at. The 3 No. samples above are verified as Hazardous with the rest as Non-Hazardous.

Notwithstanding this preliminary assessment, it is the contractor's responsibility, in association with the operator and / or owner of the landfill to classify the materials for disposal in line with current guidance. Landfill waste acceptance criteria (WAC) leachate testing and classification prior to disposal to landfill should be undertaken to confirm the waste classification.

4.4 pH and Sulphate

The site is classified as 'Brownfield' in accordance with BRE Special Digest 1 in respect to chemical attack on buried concrete. As part of the SSL 2021 GI, 26 No. pH and Sulphate tests (2:1 water extract) were undertaken. Based on the laboratory data available to date, the results identify that a concrete class of DS1-AC1 is suitable.

⁹ CAR-SOIL Control of Asbestos Regulations (2012), Interpretation for Managing and working with asbestos in soil and construction demolition materials – Industry Guidance. Published by Contaminated Land: Applications in Real Environments (CL/AIRE).

4.5 Final Risk Assessment

4.5.1 Potential Sources of Contaminants

Potential contamination sources from review of regulatory data, historical maps have been identified and are summarised in Table 4-1. The 'Contaminants of Concern' in this risk assessment are based primarily on information from the review of historical information & various site walkovers.

Table 4-1: Potential Sources of Contamination

Potential Source	Location	Likely Age	Potential Contaminants of Concern
Made Ground	Onsite	From 1800s to present	Metals, sulphates, PAHs, solvents, fuel and oil waste and asbestos.
Fuel and oil spills from car parking retained within soils	On and off site	From 1970s to present	Petroleum hydrocarbon, fuel, oils.
Ground gas sourced from Made Ground and nearby infilled reservoir	On and off site	From 1800s to present	Methane, carbon dioxide.
Various commercial / industrial site uses	On and off site	From 1800 to present	Leachable contaminants: metals, PAHs, petroleum, hydrocarbons.

4.6 Receptors and Pathways

Site specific pathway-receptor linkages have been identified in Table 4-2 with respect to the sources outlined in Table 4-1 and with respect to the anticipated future uses.

Table 4-2: Receptor and Pathways

Receptor		Pathway
Human Health	Future site users / visitors.	Direct / dermal contact. Inhalation of contaminated dusts, gas & vapour.
	Offsite land users.	Inhalation / ingestion of contaminated dust.
	Investigation and construction workers.	Direct / dermal contact. Ingestion / inhalation of contaminated soils. Inhalation of gas / vapour.
Controlled Waters	Principal Aquifer within the Chester Formation.	Leaching of contaminants through permeable strata.
Below Ground Infrastructure	Buried concrete foundations. Services pipework (if any).	Direct contact.

4.7 Final Risk Assessment

The updated qualitative risk assessment of the potential pollutant linkages described above is presented in Appendix B. Based on the assessment, the likelihood of potential ground contamination affecting the Proposed Development is considered to be low.

It should be noted that the project "red line" boundary (refer to Figure 2—2) differs slightly from when the two ground investigations were specified and undertaken (refer to Appendix A). It is considered that the findings from the two ground investigations that have been undertaken across the site are sufficient for the proposed development as the data is representative across the site, despite the slight changes to the project boundary. The likelihood of potential

ground contamination affecting the Proposed Development is considered to be low, therefore no further investigation and testing is considered to be required.

4.8 Remediation Strategy

The preliminary risk assessment is set out in the BH Desk Study. The site specific ground investigations by SSL (2015 / 2021) provide a geoenvironmental assessment of the site. The final risk assessment is provided in Appendix B of this report.

The long industrial history of the site, the heavy bombing of the site that occurred during the Manchester Blitz and the redevelopment of the site into a car park with associated terraces has led to a varying thickness of MG across the site with recorded localised evidence of ground contamination. Elevated levels of lead above commercial thresholds in TP104 and TP111 have been recorded within the Made Ground (MG).

In addition to lead, the MG on site has also recorded the presence of loose fibres of ACM in TP108 of 0.003% (below 0.1% - Hazardous Waste threshold). The source of these asbestos fibres is likely to be the uncontrolled demolition of the buildings that were bomb damaged and the levelling of this debris over the site. It should be noted that during the SSL 2015 GI and 2021 GI's, 25 No. additional ACM identification tests did not record any ACM across the site. In addition, the area of Arkwrights Mill has been remediated by Sanctus. The natural materials underlying the MG have been found to be free from contamination.

The proposed development of the site involves the excavation of a significant area of the site (approximately 60-70%) for basement/undercroft construction, foundation excavation and a piled wall with the remaining site area being covered by hard standing or soft landscaping with appropriate build ups. This will result in the vast majority of MG being removed from the site with the remaining materials being located beneath hard standing. Any earthworks shall be completed in accordance with the project earthworks specification. There is therefore no need for specific remedial measures above those that will be achieved by the proposed construction.

The extent of proposed basement/undercroft, hard landscaping & soft landscaping (minimum 0.60m clean build ups) within the development proposals, a significant amount of the source is to be removed, thus the source-pathway-receptor linkage is broken. The remaining pathways are blocked by the presence of hardstanding and proposed soft landscaping build up's (tree pits/planters – lined/separate from the existing material). It is therefore anticipated that upon completion of the proposed development risks to future site users from the identified site contamination will have been suitably mitigated.

Validation testing shall be undertaken during any enabling/construction works and a Verification report shall be produced at the end of the works for submission to Manchester City Council (MCC). During construction, suitable and appropriate health and safety measures/procedures will need to be implemented to protect the workforce from any associated risk, in particular appropriate mitigation measures and methodology to minimise the production of dust. How this is to be managed during the site works will need to be included in the contractors Risk Assessment along with details of any watching briefs for areas of concern. All validation works are to be supervised by a suitably qualified professional from the Enabling Works Contractor and Main Contractor. Details/qualifications of the suitably qualified professional undertaking the works for the contractor(s) are to be submitted for approval to the Local Authority prior to commencement on site.

Any fill material, either site won arisings or imported onto site, and imported topsoil material, will be tested for a specific list of determinands (including ACM) to ensure suitability for use.

5 Geotechnical Considerations

5.1 General

An engineering assessment of the geotechnical constraints of the proposed development has been carried out on the basis of the information available. The key elements in respect of the groundworks and foundations to the proposed development are summarised in the following sections.

5.2 Excavation and Earthworks

There is a substantial change in level across the Site, with levels falling away from Angel Street down to Miller Street. Overall, the proposed development site generally slopes in a westerly direction towards the western corner of the Site midway along Miller Street. The Site can be split into two areas separated by an existing rough S Shaped embankment, namely:

- The eastern area predominantly comprises the former archaeological excavation for Arkwrights Mill. The majority of the platform is between 46 – 47 m AOD, however, the maximum elevation (to the nearest metre) is ~48 m AOD in the far eastern corner of the platform, with a minimum elevation of ~45 m AOD in the northern corner.
- The western area currently comprises existing car parking, however, during the construction of 1 Angel Square this area of site was utilised as a site compound with two temporary buildings. The area slopes to the southwest from a maximum elevation of ~44.5 m AOD in the northern corner, with a minimum elevation of ~41 m AOD in the western corner.

There is thus currently a ~7 m difference in height across the Site separated by slopes with localised or potentially buried retaining structures.

Reduced level excavations to achieve formation level and those excavations for internal structural foundations and service trenches are likely to encounter Made Ground, superficial deposits (Glacial Till and Glaciofluvial deposits) and relict substructure. Excavations should be feasible using conventional plant although allowance should be made for the use of pneumatic breakers to assist in the removal of any buried foundations or similar obstructions along with excavations into rock. All excavations should be supported in accordance with the guidelines presented in CIRIA Report 97¹⁰.

During construction, it is envisaged that any perched water seepages will be relatively minor and could be controlled by sump pumping methods. It should be noted, however, that where locally more significant water ingress is encountered then more substantial water control measures may be required.

Any cohesive materials encountered during excavation are likely to be prone to deterioration from moisture and uncontrolled seepages. As such, any excavations in such materials should be covered by a blinding layer of concrete or other approved material as soon as they are exposed and formations for infrastructure should be protected by a sacrificial layer until the Permanent Works are installed.

Any excavated material and existing below ground obstructions encountered could be crushed and processed for re-use elsewhere subject to suitability and acceptability testing. Any unsuitable material/arising leaving site will need to be classified for waste disposal purposes in the usual way.

¹⁰ CIRIA Report 97. *Trenching Practice*. CIRIA R97, 1983.

5.3 Foundations

5.3.1 General

Based on the available information, a ground model has been created in respect of the ground conditions under the site, which are likely to influence the proposed foundation solution.

Assessment has been made in respect of shallow and deep options for foundation solutions. However, based on the information obtained to date it is considered likely that a piled solution will provide the most cost-effective foundation solution for the proposed basement, external columns, and internal columns. The piles will be used to transfer the loads of the buildings down to a suitable bearing stratum, namely the sandstone bedrock (Chester Formation).

The sulphate content and pH of soil indicate that a minimum concrete class of DS-1 with an ACEC Class of AC-1 could be adopted for buried structures in accordance with BRE Special Digest 1 (refer to Section 4.4).

5.3.2 Shallow Foundations

Based on the current development proposals and the SSL 2021 GI information available, the stratum likely to be encountered at a sensible founding level for a shallow foundation solution for internal columns will include superficial deposits (Glacial Till and Glaciofluvial Deposits). Due to the indicative in-situ strengths of these materials, allowable bearing capacities are unlikely to be sufficient for the column loads associated with the proposed 14 and 13 storeys.

5.3.3 Piled Foundations

Due to the relatively heavy column loads for 2&3 Angel Square, a bored piled foundation solution is considered to be the most appropriate foundation solution that is practical and comparatively predictable in terms of buildability.

The piling technique, method of installation and design will depend on many factors, such as applied load, groundwater level, bearing strata, presence of obstructions, cost and speed of construction. Given the ground conditions encountered and that the current development proposal includes a structure with large spans and/or high loads, it is anticipated that piled foundations will be the most cost-effective solution.

If a piled foundation solution is adopted, the pile design and piled retaining wall design should be undertaken by a specialist piling contractor but for guidance purposes a rock socketed pile, socketed into the sandstone bedrock strata (Chester Formation) should provide the following capacities:

- 600 or 750 mm diameter piles approximately 20-25 m long (approximately 10m rock socket) with an anticipated capacity of 2000 kN or 2,750 kN per pile respectively. The pile diameters have been assumed for design purposes, the final design of the piles will be the responsibility of a specialist subcontractor.
- Where the building is split level (lower and upper ground floor levels) and retaining walls will be required to accommodate the change in level. The vertical (secant) piled retaining wall is anticipated to consist of 750 mm diameter piles to approximately 20-25 m long with an anticipated capacity of 2,750 kN per pile respectively. Again, the pile diameters and pile lengths have been assumed for design purposes, the final design of the piles will be the responsibility of a specialist subcontractor. The piled wall will need to retain the northern boundary and be propped where necessary in the temporary case, whilst in the permanent case, the wall will be propped by floor slabs, and the wall will also support the external/internal building column loads. The retaining structure will also need to be protected from water ingress. A suitable tanking system is to be incorporated in accordance with the architect's specification and detailing.

- Please note, it may be possible to batter back the ground to allow a concrete cast in-situ wall to be locally constructed on specific elevations to each building. This will be investigated during the subsequent design process once additional information becomes available. The retaining walls will be propped in the permanent case, but may require temporary propping during construction – to be designed and completed by others.
- Please note, it is likely that piling will have to be completed at various levels due to the nature of the sloping site (i.e. secant piled retaining wall/bearing piles installed at grade and bearing piles at a lower level within the lower ground floor footprint). Construction sequencing of the substructure should be discussed at an early stage in the development process for risk management and to ensure an efficient approach is adopted.
- Based on the current anticipated building heights and associated envisaged loads, internal columns are likely to require multiple piles per column. Although multiple piles per column will generally be used in this instance, due to the relatively high column loadings the pile design will need to allow for any minor eccentric loadings arising from the offset between the axis of the pile and the axis of the structural column caused by the limitations in the tolerance of installation. It should also be noted that due to the piling platform level likely being higher than the envisaged pile cut off levels, the limitations on such tolerances is likely to be challenging and as such, internal pile caps are likely to require oversizing to manage any associated risks.

5.4 Ground Bearing Slabs

A suspended floor slab should be utilised on NMS. The use of ground bearing slabs can be considered within the proposed 2 & 3 Angel Square development, assuming typical loadings of 20 kN/m². A typical under slab formation may generally comprise 150 mm of compacted stone, sand layer and a damp proof membrane.

The formation will need to be proof rolled to ensure suitability. It should be noted that any soft spots encountered should be removed and replaced with appropriate structural fill. Any obstructions encountered should also be removed.

The compacted stone should be DTp Type 1¹¹ in frost susceptible areas but in non-frost susceptible areas, such as within the confines of the proposed buildings, alternative materials such as DTp Class 6F2¹² may be considered. Recycled site won material could be considered for re-use subject to suitability.

5.5 Highways and Permissions

The Site is currently bounded to the north by Angel Street and to the south by Miller Street. Appropriate permits and permissions will be required from the relevant authorities to allow the construction works to be undertaken.

It is currently understood that any existing site services are to be diverted around or grubbed up/grouted up as required prior to commencement on the main construction works and as part of a separate works package, however this should be verified prior to commencement on site.

Any such works will need to be undertaken in accordance with the relevant permits and permissions from the relevant authorities.

¹¹ DTp (2001). *Specification for Highway Works, Volume 1 Series 800: Clause 803*. Department of Transport, HMSO, May 2001.

¹² DTp (2003). *Specification for Highway Works, Volume 1 Series 600: Table 6/1*. Department of Transport, HMSO, November 2003.

6 Anticipated Design for Costing Purposes

The anticipated design for costing purposes can be summarised as follows:

2&3 AS

- Site clearance and removal of obstructions in areas of proposed substructure.
- Earthworks re-profiling. Site won material to be processed and re-used on-site (dependant on chemical and geotechnical suitability) or disposed of to a suitable waste acceptance facility.
- Installation of the vertical embedded retaining wall (secant piled wall currently envisaged) along with the installation of the piled foundations for up to 14 and 13 storeys.
- Installation of associated piled wall capping beam.
- The ground floor slab is proposed to be ground bearing.

General Risk Items

- Final piled foundation and retaining wall design should be undertaken by a specialist piling contractor as part of the detailed design.
- Physical obstructions from historic walls/floor slabs/substructure/infrastructure – potential risk for installation of secant piled wall and piled foundation solution. A series of trial trenches are may be required to reduce/remove the risk of obstructions prior to pile installation.
- The site is located in a busy city centre environment and as such, noise and vibration restrictions may be imposed.
- The site is classified as 'medium' risk from UXO, therefore it is considered that UXO engineer supervision is required during intrusive works onsite (enabling works and piling).
- Post fieldwork groundwater levels from the SSL 2021 GI undertaken to date identify a groundwater regime within the sandstone bedrock (~26). It should be noted that any localised groundwater encountered within the Made Ground and superficial deposits may vary across the site. An allowance should be made for sump pumping within the cost plan.
- The SSL 2021 GI ground gas monitoring data available to date indicates a typical ground gas regime of Characteristic Situation 1 (CS1).
- The site is classified as 'Brownfield' in accordance with BRE Special Digest 1 in respect to chemical attack on buried concrete. A concrete class of DS1 –AC1 is suitable for the proposed development.
- Any Temporary Works requirements are the responsibility of the Main Contractor (MC). Where temporary excavations are required, temporary support is likely to be needed. Subject to sequencing and proposed construction methodology from the MC, temporary excavations requiring backfill should be replaced with suitable fill material in accordance with an Excavation and Filling Specification. In addition, when preparing formations, all soft spots are to be removed and replaced with suitable fill material/upfill concrete.

Appendix A Structural Soils Information

A.1 Exploratory Hole Location Plan

A.1.1 Exploratory Hole Logs

Appendix B Updated Risk Assessment

B.1 Chemical test results

B.2 Final Risk Assessment

Pollutant Linkage				Risk Assessment			Description of source [bold text] Comment on hazard realisation [normal text]
Source	Contaminants of Concern	Pathway	Receptor	Consequence	Probability	Risk	
Historic warehouses Made Ground material used to backfill basements Car parking Urban Made Ground material	Metals, cyanide, chlorides, phenols, PAHs, solvents, fuel and oil wastes and asbestos	The site has a variety of historic uses which has led to limited contamination within the MG					
		Direct /dermal contact, ingestion, inhalation	Construction / Maintenance workers	Medium	Unlikely	Low	Potential for direct contact with contaminated materials during excavations / earthworks. Can be mitigated by good working practice, health and safety and use of PPE if necessary.
		Direct / dermal contact, ingestion, inhalation	Future site occupants and visitors	Medium	East of Cannon Place: Low Likelihood	Low	Pathway likely be removed in the end use as the site is envisaged to be covered either by the building(s) or hard / soft landscaping with clean build-ups. To be finalised as the development proposals evolve.
					West of Cannon Place: Unlikely	Low	
		Ingestion / inhalation	Occupants and visitors of neighbouring properties	Medium	Unlikely	Low	Residential / commercial neighbours surrounding and adjacent to the site. Good working practices i.e. dust suppression will need to be in place.
		Migration via permeable strata	Groundwater (Principal A Aquifer – Chester Fm.)	Medium	Unlikely	Low	Downward leaching of contaminants into the Principal A Aquifer (Chester Fm) due to infiltration is considered unlikely – current information suggests that there is a thickness of low permeability clay (Glacial Till) above the Chester Fm. Further prevention will be provided in the end use by drainage networks and potentially cover by hardstanding (depending on exact development proposals – to be reviewed). Procedures must be taken to avoid the creation of pathways during construction.
		Direct contact	Below ground services / infrastructure	Mild	Low Likelihood	Low	Any new services likely to be in clean corridors / trenches. Underground substructure will be designed to withstand appropriate concentrations of any chemicals that may be encountered (e.g. sulphate).
Potentially contaminative historic land uses to east / northeast (mills, warehouses, existing car parking etc.)	Leachable contaminants – metals, fuels, PAHs, petroleum hydrocarbons etc.)	Mills/Warehouses recorded from1848 until 1933. Existing car parking potential source contamination from petrol and oils spills.					
		Direct / dermal contact, ingestion, inhalation	Construction / Maintenance workers	Medium	Unlikely	Low	Potential for exposure to contaminated waters during foundation / service run excavation and ground works. Capable of mitigation by good working practice and use of PPE.
		Direct / dermal contact, ingestion, inhalation	Future site occupants and visitors	Medium	Unlikely	Low	Pathway likely be removed in the end use as the site is envisaged to be covered either by the building(s) or hard / soft landscaping with clean build-ups. To be finalised as the development proposals evolve.
Asbestos fibres and fragments within Made Ground	Asbestos	Asbestos Containing Material (ACM) is likely to be present in Made Ground beneath the site because historic buildings were present.					
		Inhalation	Construction / Maintenance workers	Severe	Low likelihood	Low	1 No. of 16 No. soil samples from the SS:L 2021 GI recorded asbestos within Made Ground. Asbestos Quantification recorded 0.003% by total mass. Also, Arkwrights Mill has been remediated. Mitigation by good working practice and use of PPE will be required and potentially special protective measures.
			Future site occupants and visitors	Severe	Unlikely	Low	Pathway between any asbestos in Made Ground and receptors is likely to be removed in the end use as the site is envisaged to be covered by either a building, hard landscaping with clean build-up, or soft landscaping with clean topsoil. This will need to be reviewed as the development proposals evolve.
Made Ground	Gas and vapour	A variable thickness of Made Ground is anticipated to be present onsite, and there is the potential for this to be contaminated and provide a source of hazardous gas and vapour beneath the site.					
		Inhalation Explosion (methane)	Construction / maintenance workers	Severe	Unlikely	Low	No methane recorded in the ground gas monitoring results. No source of methane on site. Limited potential for uncontrolled exposure to hazardous ground gas / vapour (if present) in confined unventilated excavations (if required). Capable of mitigation by gas monitoring to define the risks from ground gas and good construction practice e.g. avoiding works in confined spaces, where required PPE and air quality monitoring.
		Inhalation Explosion (methane)	Future site occupants and visitors	Severe	Unlikely	Low	No methane recorded in the ground gas monitoring results. No source of methane on site. Ground gas monitoring within Made Ground deposits has been undertaken as part of the SSL 2021 GI and classifies the site as CS1. No methane recorded in the ground gas monitoring results. No source of methane on site. It is considered that ground gas protection in accordance with the BS8485:2015+A1:2019 is not required.

Appendix C Monitoring Visit Dates and Access

BHID	Monitoring Visit Date (DD/M/YY)	Access Possible / Monitored
BH101	13.08.21	Yes
	26.08.21	Yes
	07.09.21	No Access
	20.09.21	No Access
	06.10.21	Yes
	22.10.21	Yes
BH102	13.08.21	Yes
	26.08.21	Yes
	07.09.21	Yes
	20.09.21	No Access
	06.10.21	Yes
	22.10.21	Yes
BH103	13.08.21	Yes
	26.08.21	Yes
	07.09.21	Yes
	20.09.21	No Access
	06.10.21	Yes
	22.10.21	Yes
BH104	13.08.21	Yes
	26.08.21	Yes
	07.09.21	Yes
	20.09.21	No Access
	06.10.21	Yes
	22.10.21	Yes
WS101	13.08.21	Yes
	26.08.21	No Access
	07.09.21	No Access
	20.09.21	Yes
	06.10.21	No Access
	22.10.21	No Access
WS102	13.08.21	Yes
	26.08.21	Yes
	07.09.21	No Access
	20.09.21	No Access
	06.10.21	Yes
	22.10.21	Yes
WS103	13.08.21	Yes
	26.08.21	Yes

BHID	Monitoring Visit Date (DD/M/YY)	Access Possible / Monitored
	07.09.21	Yes
	20.09.21	Yes
	06.10.21	Yes
	22.10.21	No Access
WS104	13.08.21	Yes
	26.08.21	Yes
	07.09.21	Yes
	20.09.21	Yes
	06.10.21	Yes
	22.10.21	Yes
WS105	13.08.21	Yes
	26.08.21	Yes
	07.09.21	No Access
	20.09.21	Yes
	06.10.21	Yes
	22.10.21	Yes

Louise Richards
Buro Happold Limited
3 Wellington Place
Leeds
LS1 4AP
UK

T: +44 (0)113 204 2200

F: +44 (0)870 787 4144

Email: louise.richards@burohappold.com