Cardiff Coastal Defence Scheme

Ground Investigation Report (GIR)

July 2020

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Revision history

Revision Ref	Date	Amendments	Issued to
P01	July 2020	Draft Report Suitable for Comment and Review	Dave Brain Cardiff City Council

Contract

This report describes work commissioned by David Brain, on behalf of Cardiff City Council. Callum Hanson and Maarten Kamper of JBA Consulting carried out this work.

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Purpose

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Abbreviations

AGC	Alun Griffiths Contractors
AGS	Association of Geotechnical Specialists
BGS	British Geological Survey
CCC	Cardiff City Council
CPT	Cone Penetration Test
HSV	Hand Shear Vane
JBA	JBA Consulting Limited
Ltd.	Limited
mAOD	metres Above Ordnance Datum
No.	Number
PSD	Particle Size Distribution
Quantum	Quantum Geotech Limited
SPT	Standard Penetration Test
NRW	Natural Resource Wales
DCWW	Dwr Cyru Welsh Water

1 Introduction

1.1 Scheme Proposal

Cardiff City Council propose to improve coastal defences around the mouth of the Rhymney River. The proposed coastal defences include the coastline along Rover Way, beginning at the eastern end of the privately owned *Dwr Cyru Welsh Water* (DCWW) defences, extending along the coast and up the west bank of the river as far as the railway line. The defence continues down the east bank of the river and along the coast around Lamby Way Landfill Site to the location of the recently constructed Natural Resources Wales (NRW) defences. Figure 1-1 shows the extent of the proposed coastal defences.

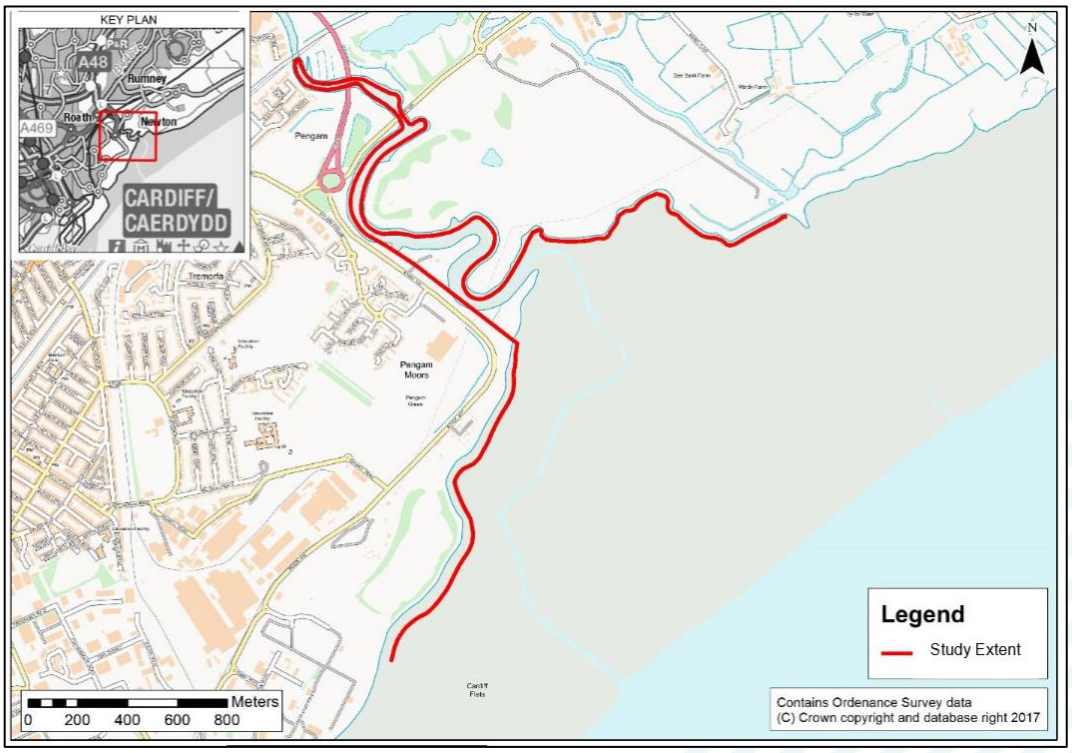


Figure 1-1: Extent of the proposed coastal defence works.

There are six main elements to the scheme:

- Section 1 - Raising existing flood embankments and forming new embankments on the west bank between the Railway Bridge and Lamby Way.
- Section 2 - Raising existing flood embankments along the frontage of Parc Tredelerch.
- Section 3 - Sheet piling and construction of a rock armour revetment along the frontage of the Lamby Way Landfill Site.
- Section 4 - Sheet piling and raising existing flood embankments on the west bank between Lamby Way and the mouth of the river.
- Section 5 - Construction of a rock armour revetment along the shore between the mouth of the river and the eastern end of the 'Frag Tip'.
- Section 6 - Construction of a rock armour revetment along the shore frontage of 'Frag Tip' extending west to the privately owned DCWW defences.

To inform the design of the permanent works, a ground investigation was scoped by JBA Consulting (JBA) and undertaken by Quantum Geotechnic Limited (Quantum) (subcontracted by Alun Griffith Contractors (AGC)) between 02 March and 20 May 2020. Site works were paused between to 23 March and 11 May 2020 during initial stage of the Coronavirus pandemic.

1.2 Aims and Objectives

This ground investigation report has been commissioned by Cardiff City Council (CCC) for the proposed Cardiff Coastal Defence Scheme.

The aim of this ground investigation report is to assess the ground conditions beneath the areas proposed for development. The objectives are:

- To summarise and interpret the information presented in the factual ground investigation report produced by Quantum
- To develop a ground model and determine the geotechnical properties of each unit based on in-situ and laboratory testing results;
- To review geotechnical risk associated with the proposed flood defence works.

1.3 References

This report should be read in conjunction with the following documentation:

- JBA Consulting. 2016. Cardiff Flood and Coastal Erosion Risk Management. Outline Business Case.
- JBA Consulting. 2017. Cardiff Flood and Coastal Erosion Risk Management. Outline Business Case. Engineering Report.
- JBA Consulting. 2017. Cardiff Flood and Coastal Erosion Risk Management. Outline Business Case. Geo-Environmental and Geotechnical Desk Study Assessment.
- JBA Consulting. 2019. Cardiff Coastal Defence Scheme. Ground Investigation Specification.
- Quantum Geotechnic Limited. 2020. Cardiff Coastal Defence Scheme. Ground Investigation Factual Report (Appendix A).
- Drawings 0001 to 0007 (Appendix B).

2 Desk Study

A desktop study for the Cardiff Coastal Defence Scheme was undertaken as part of the Outline Business Case in 2017 (ref. JBA Consulting. 2017. Cardiff Flood and Coastal Erosion Risk Management. Outline Business Case. Geo-Environmental and Geotechnical Desk Study Assessment). Additional site information is recorded within the GI Specification (ref. JBA Consulting. 2019. Cardiff Coastal Defence Scheme. Ground Investigation Specification). Information presented in the desk study assessment and GI specification reports are summarised in the following subsections.

2.1 Site Description and Location

The site has been divided into six sections as shown in Figure 2-1.

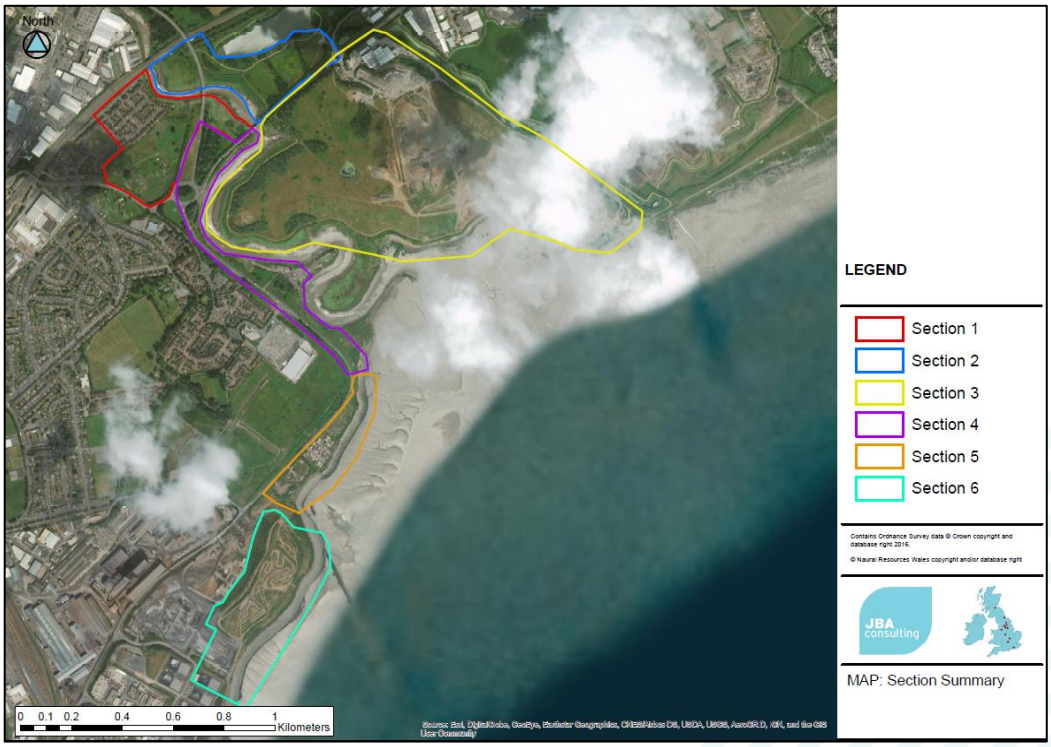


Figure 2-1: Subdivisions of the site into six sections

A description of each of the respective sections is presented below:

2.1.1 Section 1 - West Bank, Railway Bridge to Lamby Way

The land adjacent to the river frontage in Section 1 is occupied to the west by a residential area around Beaufort Square and to the east by allotments. The river frontage, north of the existing flood embankment comprises open grassland and reedbeds and extends east beneath the A4232 road bridge. There is localised slumping along the riverbank, especially along the river frontage of Glan Rhymni.

2.1.2 Section 2 - Frontage of Parc Tredelerch

The land adjacent to the river frontage in Section 2 is occupied by public parkland and a large lake forming Parc Tredelerch. The river frontage comprises a vegetated flood embankment that extends beneath the A4232 road bridge.

2.1.3 Section 3 - Frontage of the Lamby Way Landfill Site

The land adjacent to the river frontage in Section 3 is occupied by the Lamby Way Landfill Site. The river frontage comprises a revetment extending down into open grassland and reedbeds crossed by small channels. Approximately 200m downstream of the Lamby Way bridge erosion of the riverbank prevents vehicle access along the river side of the revetment. Further east, opposite the Rhymney River Motor Boat Sail and Angling Club, erosion associated with a small stream and an area of rough ground will require enabling works for plant access. The coastal frontage comprises a narrow strip of land occupied by Wales Coast Path adjacent to the existing revetment which drops steeply onto a stony foreshore extending out into mudflats.

2.1.4 Section 4 – West Bank - Lamby Way and the mouth of the river

The land adjacent to the river frontage is occupied Lamby Way and Rover Way. The river frontage comprises wooded areas and grassland adjacent to Lamby Way and a flood embankment carrying the Wales Coast Path adjacent to Rover Way.

2.1.5 Section 5 – shore between the river mouth and the eastern side of the 'Frag Tip'

The land adjacent to the beach is occupied Rover Way and, from east to west, an area of open grassland and bushes, a residential site and a walled compound thought to be operated by Welsh Water. The Wales Coast Path runs across the section.

2.1.6 Section 6 – The Frag Tip

The land adjacent to the foreshore comprises the 'Frag Tip', now used as a motocross track, and the access road leading from the DCWW Treatment Plant to the west. The Wales Coast Path runs across the section.

2.2 Topography

The site is a generally flat coastal region, forming the mouth and floodplain of Rhymney River, with a general elevation of 7-9 m AOD. There are areas of infilling adjacent to the south (in an area of extended coastline) and north (adjacent to the river) of the site extent that are up to 30m AOD.

2.3 Site History and Land Use

Historical land use at the site has been determined from a review of historical OS mapping summarised within the Geo-Environmental and Geotechnical Desk Study Assessment (JBA 2017). The historic and existing land use across the site are shown on Figure 2-2. Notable land uses include an airport on the south side of Rhymney River mouth (1948 map edition), extensive infilling to extent coast line in the southern section, with a large 'works' building just west of it (1965 map edition), expansion of Made Ground and works in the south extent, including new slag reduction works (1973 map edition) and infilling of Lamby Way Landfill which involved realignment of the river to its present day configuration. Some historical land use is as shown by Figure 2-2.

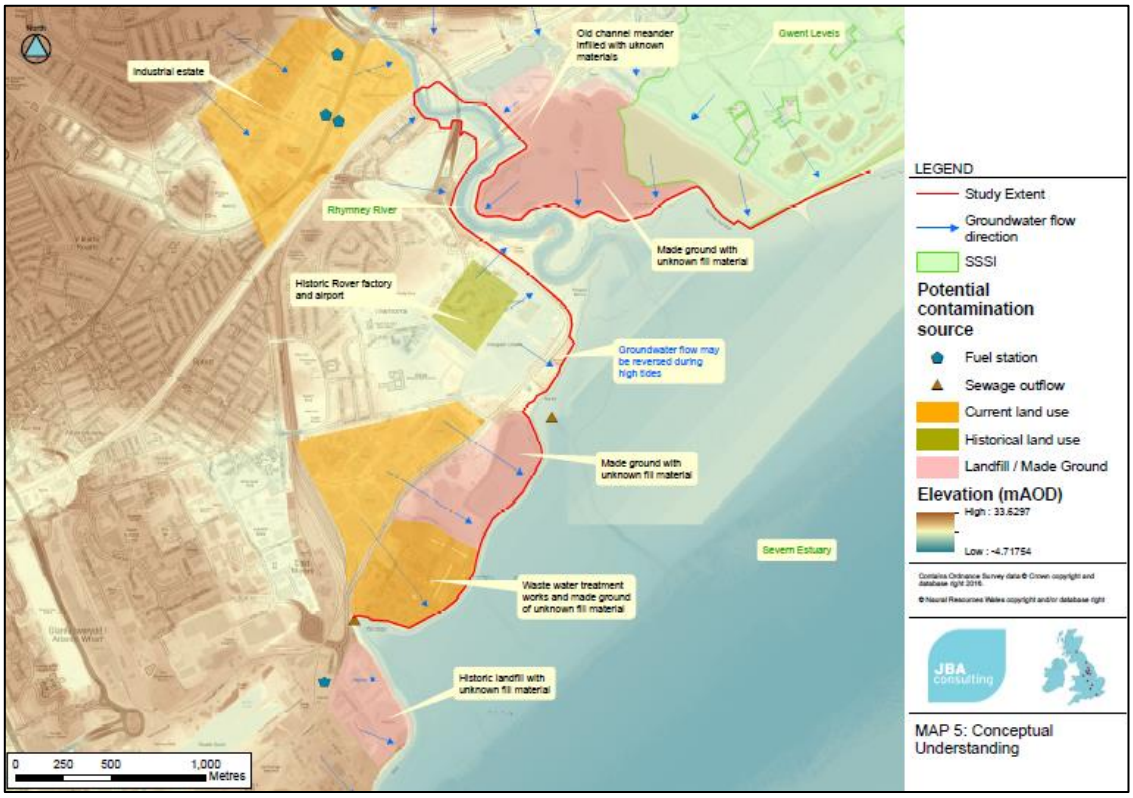


Figure 2-2: Historic and existing land use across the site

2.4 Geology

Information on the soils and geology of the site and surrounding area has been derived from the Soil Survey of England and Wales (1983), 1:50,000 BGS geology mapping (Sheet 263: Cardiff), and the BGS online borehole archive. The geology beneath the site is summarised in subsections below. Extracts of the superficial and bedrock geology maps are presented in Figure 2-3 and Figure 2-4 respectively.

2.4.1 Soils

The Soil Survey of England and Wales (1983) classifies the soils on site as Newchurch 2 association, relating to marine alluvium. This is described as 'deep stoneless mainly calcareous clayey soils'. Groundwater is controlled by ditches and pumps. Flat land. Risk of flooding in places'. The areas adjacent to Rhymney River are classified as 'un-surveyed' which generally applies to urban and industrial areas.

2.4.2 Made Ground

BGS borehole logs in the area of infilling to the north of Rhymney River show that there is approximately 0.7m of fill material, containing sand, clay, ash, brick and gravel, overlaying clay superficial deposits.

Logs for the area of Made Ground to the south show fill to 7.5m consisting of brick, stones, ash, slag, clay and silt over clay superficial deposits.

It is anticipated, based upon the known history of the site (section 2.3) that there are significant thicknesses of Made Ground along the broad line of the proposed flood defences resulting from historic waste disposal and land reclamation.

2.4.3 Superficial Geology

The superficial deposits covering the site are categorised by the BGS as Tidal Flat Deposits, comprising of clay, silt and sand. To the north of the site, within the Rhymney Valley, Alluvium deposits of clay, silt, sand and gravel are recorded.

To the west of the site, south of Roath Brook is an area of Glaciofluvial deposits, containing sands and gravels. Borehole logs show that clays beneath the site contain some organic matter and, locally, layers of peat.

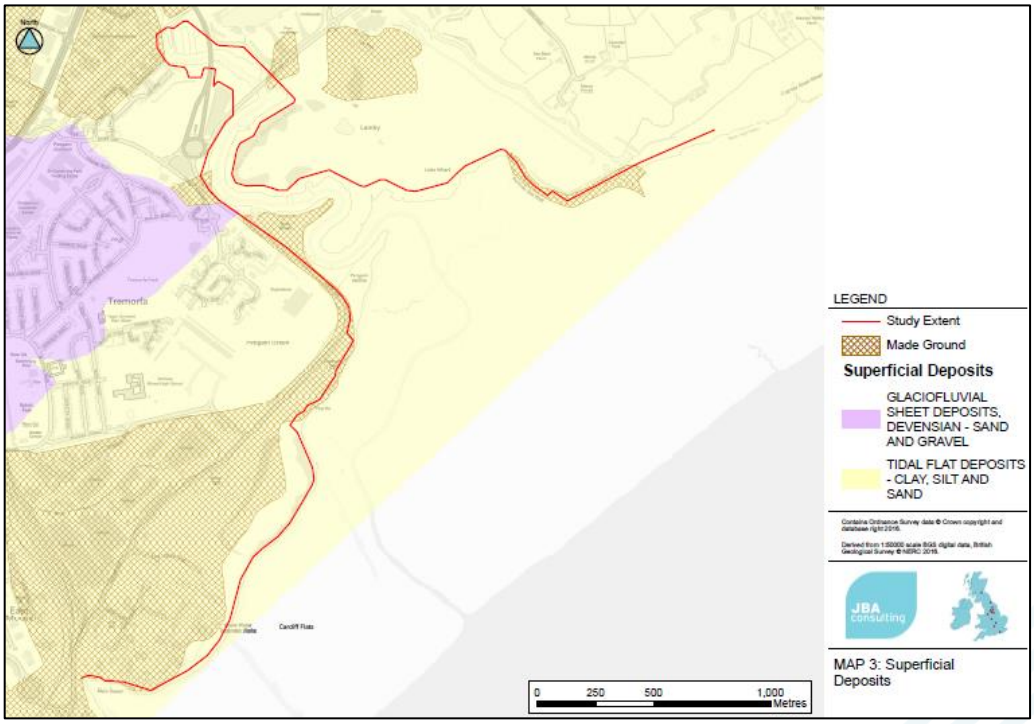


Figure 2-3: BGS superficial geology map

2.4.4 Bedrock Geology

The site is largely underlain by the Mercia Mudstone Group, which is described as 'dominantly red, less commonly green-grey, mudstones and subordinate siltstones with thick halite-bearing units in some basinal areas. Thin beds of gypsum/anhydrite widespread; sandstones are also present.' BGS borehole logs record 'stiff red friable marl with lenses of grey marl and thin bands of hard marl' at approximately 18mbgl to the south of the site. The site extent to the east is underlain by a subcrop of the Cae Castell Formation (sandstone) and the Cardiff Group (mudstone, siltstone and sandstone).

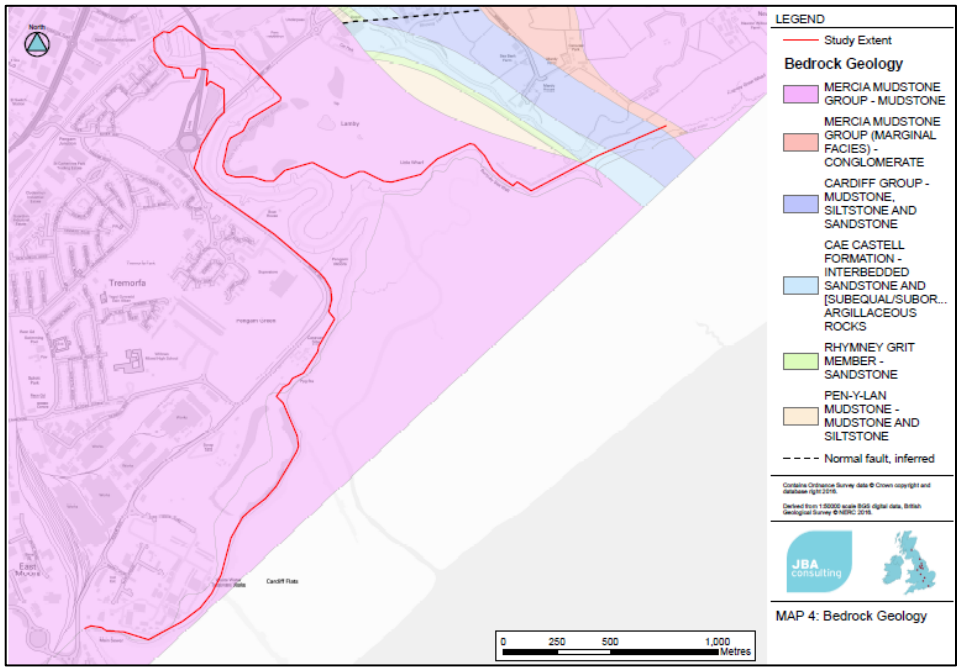


Figure 2-4: BGS bedrock geology map

2.5 Hydrogeology

2.5.1 Aquifer Designation

The superficial deposits found on site are classified by the BGS as a 'Secondary - Undifferentiated' aquifer, which describes aquifers of low importance, with some areas being classified as non-aquifer.'

The Mercia Mudstone Group bedrock strata underlying the site is classified as a 'Secondary B' aquifer, which is 'predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering.'

2.5.2 Aquifer Properties

The groundwater-bearing characteristics of the Mercia Mudstone Group derive from the interbedding of effectively impermeable mudstones interbedded with occasional thin impersistent siltstones and sandstones (skerries). Despite being generally thin (often less than 1 m thick) and very well cemented, the sandstone and siltstone horizons may contain and transmit limited quantities of groundwater, largely through fractures.

2.5.3 Source Protection Zones

There are no Source Protection Zones (SPZs) within 500m of the site.

2.5.4 Groundwater Quality

The groundwater body beneath the site has 'good' quantitative, chemical and overall quality.

2.6 Ecological Designations

There are four Sites of Special Scientific Interest (SSSI), one Special Area of Conservation (SAC), and one Special Protection Area (SPA) within 1km of the site extent. Immediately adjacent to the site are the Seven Estuary SSSI, SAC and SPA and the Gwent Levels - Rumney and Peterstone SSSI.

A summary of the designations and the potential environmental receptors at the site are presented in the Geo-Environmental and Geotechnical Desk Study Assessment (JBA, 2017).

3 Ground Investigations

3.1 Quantum Geotechnic Limited Ground Investigation 2020

A ground investigation scoped by JBA (ref. JBA Consulting. 2019. Cardiff Coastal Defence Scheme. Ground Investigation Specification) was carried out by Quantum Geotechnic Limited (Quantum) who were subcontracted by Alun Griffiths Contractors (AGC) on behalf of Cardiff City Council. AGC were present as the Principal Contractor overseeing the works. JBA engineers were on site to supervise the investigation works. The purpose of the ground investigation was to determine the ground and groundwater conditions at the site to inform engineering design.

The findings from the ground investigation, laboratory testing and monitoring are recorded within the Cardiff Coastal Defence Scheme Factual Ground Investigation Report (Quantum, 2020). The report is presented within Appendix A.

3.1.1 Field Works

The ground investigation was undertaken between 02 March and 20 May 2020. Site works were paused between to 23 March and 11 May 2020 during initial stage of the Coronavirus pandemic. The ground investigation comprised:

- 30No. rotary open hole boreholes to a maximum depth of 40.0mbgl (D1 to D5).
- 16No. dynamic windowless sampling boreholes with rotary follow-on using a Multipurpose rig on to a maximum depth of 20.0mbgl (A1 to A14, A3a, A3b, A12a).
- 15No. dynamic windowless sampling boreholes using a Terrier rig to a maximum depth of 8.0mbgl (WS1 to WS12, WS3a, WS6a, WS12a).
- 11No. cable percussive boreholes to a maximum depth of 20.0mbgl (B1 to B11).
- Three cone penetration test (CPT) boreholes with magcone to a maximum depth of 5mbgl (CPT1 to CPT3).
- In situ hand vane tests within inspection pits and U100 samples.
- Groundwater observation and monitoring records.
- Geotechnical and contamination testing on soil samples.
- Factual reporting and AGS data.

3.1.2 Laboratory Testing and Analyses

A programme of laboratory testing and analyses, scheduled by JBA, was carried out by Quantum on samples recovered during intrusive field works. The following geotechnical testing was undertaken in accordance with BS1377:

- Atterberg limits and Particle Size Distribution
- Compaction
- Compressibility
- Aggressivity
- Tri-axial testing
- Vane testing

3.1.3 Ground Model

Geological long sections have been drawn for the site using information from both the Quantum investigation and historic BGS boreholes (see Appendix B). For the area referred to as Section 6, the geological correlations show a significant thickness of Made Ground present which can be attributed with the land use history. As the geology within Section 6 is different to that encountered in Sections 1 to 5, it is reviewed separately in Part 5 of this report.

3.2 Ground Conditions – Sections 1-5

The ground conditions encountered during the ground investigation have been interpreted into geological units (strata) based on their location, description, stratigraphy, and engineering properties. The units assigned correspond to the names used on the geological maps produced by the BGS. The ground conditions encountered across Sections 1 to 5 are summarised in

Table 3-1 and presented in geological long section drawings in Appendix B.

Table 3-1: Summary of Defined Geological Units from the Ground Investigation (Sections 1 to 5)

Strata	Typical Description	Top Level (m AOD) [Thickness (m)]
Made Ground	Cohesive Made Ground: Brown, red, black slightly sandy gravelly CLAY with low cobble content. Gravel is fine to coarse angular to sub-angular concrete, slag, sandstone metal fragments, brick, plastics debris. Cobbles are angular slag concrete. Granular Made Ground: Black brown slightly clayey sandy GRAVEL. Gravel is fine to coarse angular to sub-angular brick, concrete, slag, sandstone, mudstone.	9.2 to 4.7 [0.4 to 3.0] 9.3 to 3.5 [0.5 to 2.3]
Tidal flat deposits	Grey locally brown black slightly silty to silty CLAY.	6.8 to -5.2 [6.8 to 10.3]
Glaciofluvial deposits	Grey slightly clayey slightly sandy fine to coarse sub-angular to well-rounded siltstone sandstone GRAVEL with high cobble/boulder content. Sand is fine to coarse.	-0.4 to -6.1 [0.5 to 4.5]
Weathered Mercia Mudstone	Red brown slightly sandy gravelly CLAY. Gravel is fine to coarse sub-angular to sub-rounded mudstone. Sand is fine to medium. Little to no trace of original structure though lithorelics within friable mudstone nodules.	-3.7 to -9.3 [0.5 to 4.4]
Mercia Mudstone Bedrock	Very weak fissile dark brown red structureless moderately/ chemically weathered fractured MUDSTONE.	-5.0 to -8.9 [13.5m proven]

3.2.1 Groundwater conditions

Groundwater observations recorded during the ground investigation are summarised below. The groundwater strike and rise levels are also presented on the geological long sections in Appendix B.

Daily readings of depth to water in installations were made during the ground investigation. A round of three groundwater monitoring visits at two, four and six weeks after the completion of site works were undertaken. Groundwater monitoring information is presented in Part 3.4 of this report.

Two significant groundwater strikes were observed during the ground investigation:

- Groundwater seepage or slow inflow encountered perched at the top of the tidal flat deposits.
- Medium inflow during advancement of borehole through the top of the glaciofluvial deposits, exhibiting a maximum difference of 2.2m between strike and rise levels.

The perched groundwater is associated with the top of the tidal flat deposits and are unable to infiltrate due to the units' low permeability.

During the ground investigation there appeared to be a direct connection between the fluvial water levels in the Rhymney River and the groundwater strikes encountered on advancement through the top of the glaciofluvial deposits. As the glaciofluvial deposits are largely confined above by the tidal flat deposits and below by the Mercia Mudstone, when the fluvial levels were higher than the top of the glaciofluvial deposit, sub-artesian conditions were observed. The observations of groundwater are summarised in Table 3-2.

Table 3-2: Summary of Groundwater Observations made during the Ground Investigation (Sections 1 to 5)

Hole ID	Water strike mbgl/[mAOD]	Water rise level after 20 minutes mbgl/[mAOD]	Water Strike Remarks	Stratum
A1	4.1	-	Seepage	Top of tidal flat
A1	7.6	6.5	Medium inflow	Top of glaciofluvial
A2	1.0	0.8	Seepage	Top of tidal flat
A3b	12.2	10.7	Medium inflow	Top of glaciofluvial
A4	1.2	1.0	Slow inflow	Top of tidal flat
A9	6.2	6.0	Slow inflow	Top of tidal flat
B8	10.5	9.6	Medium inflow	Within tidal flat
B8	15.1	12.9	Medium inflow	Top of glaciofluvial

3.2.2 Groundwater Monitoring Results

Groundwater monitoring was undertaken as daily readings using a dip meter in installations during the ground investigation. A round of three groundwater monitoring visits were undertaken at two, four and six weeks after the completion of site works.

Four standpipe installations were made in boreholes across Sections 1 to 5. The standpipes were fitted with gas monitoring caps and a bung to enable groundwater monitoring. Groundwater levels from monitoring wells have been obtained between 05 May and 02 June 2020 (Table 3-3).

Table 3-3: Summary of Groundwater Monitoring Results (Sections 1 to 5)

Date	Hole ID	Stratum	Response zone mbgl/[m AOD]	Water Level mbgl/[mAOD]
05.05.20	B2	Glaciofluvial deposits	7.5 to 10.5 [-3.9 to -6.9]	5.3 [-1.6]
21.05.20				5.7 [-2.1]
02.06.20				5.8 [-2.2]
05.05.20	B3	Glaciofluvial deposits	9.6 to 14.1 [-2.9 to -7.4]	7.2 [-0.4]
21.05.20				6.9 [-0.1]
02.06.20				6.9 [-0.2]
05.05.20	B4	Glaciofluvial deposits	8.1 to 10.5 [-4.9 to -7.3]	5.6 [-2.4]
21.05.20				7.7 [-4.4]
02.06.20				5.6 [-2.4]
05.05.20	B10	Tidal flat - glaciofluvial deposits	12.0 to 17.0 [-3.6 to -8.6]	16.9 [-8.5]
21.05.20				17.0 [-8.6]
02.06.20				17.0 [-8.6]

3.2.3 Gas Monitoring Results

Ground gas results recorded during monitoring visits on the 5th of May, the 21st of May and the 2nd of June 2020 within the installed boreholes B2, B3, B4 and B10 are presented in Table 3-4. All ground gas monitoring results recorded a value of zero ppm for CO and H_2S so these have been omitted from Table 3-4.

Table 3-4: Summary of ground gas monitoring results for boreholes B2, B3, B4 and B10 (Section 1 to 5)

Date	Hole ID	Flow (L/hr)	CH_4 (%)	CO_2 (%)	O_2 (%)
05.05.20	B2	-1.1	0.0	0.6	20.3
21.05.20		-13.7	0.0	2.6	18.0
02.06.20		-1.9	0.0	1.4	19.7
05.05.20	B3	-0.8	0.1	2.1	19.0
21.05.20		2.5	0.0	2.4	20.2
02.06.20		0.3	0.0	2.3	20.4
05.05.20	B4	0.4	0.0	0.0	20.8
21.05.20		0.0	0.0	0.0	19.7
02.06.20		-0.7	0.0	0.0	20.2
05.05.20	B10	1.3	0.1	1.1	14.6
21.05.20		0.1	0.1	2.3	6.2
02.06.20		0.1	0.1	1.9	9.7

3.3 Ground Conditions - Section 6 ('Frag Tip')

The ground conditions encountered within boreholes undertaken in Section 6 (the 'Frag Tip') comprising boreholes D1 to D5, A11 and A12 along with A10 located at the margin of Section 5 are summarised in **Error! Reference source not found.**5.

Table 3-5: Frag Tip Ground Conditions (Section 6)

Stratum	Typical Description (drillers log)	Top Level (m AOD) [Thickness (m)]
Made Ground Landfill	Brown clay LANDFILL and crushed slag.	31.0 to 12.0 [0.8 to 21.0]
Made Ground Slag	Steel concrete slag FILL and colliery spoil.	30.2 to 3.5 [1.0 to 11.5]
Tidal flat deposits	Grey Clay.	0.0 to -1.2 [3.3 proven]

3.3.1 Groundwater conditions

The observation of the groundwater levels are presented in Tables 3-6 and 3-7.

Table 3-6: Summary of Frag Tip Groundwater Observations (Section 6)

Hole ID	Water strike mbgl/[mAOD]	Water rise level after 20 minutes mbgl/[mAOD]	Water Strike Remarks	Stratum
D1a.5	5.0 [6.8]	5.0 [6.8]	Seepage	Made Ground slag
D2a.1	22.7 [3.5]	22.5 [3.7]	Seepage	Made Ground slag
D2b	22.5 [2.9]	21.9 [3.5]	Medium inflow	Made Ground slag
D3a.3	18.0 [3.6]	17.0 [4.6]	Medium inflow	Made Ground slag
D4a	17.5 [2.3]	15.9 [3.9]	Medium inflow	Made Ground slag
D4b	15.5 [4.2]	14.1 [5.6]	Medium inflow	Made Ground slag
D5a	23.0 [3.5]	21.2 [5.3]	Medium inflow	Made Ground slag
D5b.1	22.5 [4.0]	21.3 [5.2]	Medium inflow	Made Ground slag
D5c	23.0 [3.2]	21.1 [5.1]	Medium inflow	Made Ground slag
D6a.3	17.0 [5.0]	17.0 [5.0]	Seepage	Made Ground slag

Table 3-7: Summary of Frag Tip Groundwater Monitoring Results (Section 6)

Date	Hole ID	Stratum	Response zone mbgl/[mAOD]	Water Level mbgl/[mAOD]
05.05.20	D1a	Made Ground landfill	5.0 to 9.0 [5.0 to 1.0]	7.6 [2.5]
21.05.20				7.7 [2.4]
02.06.20				7.8 [2.3]
05.05.20	D1b	Made Ground slag	6.5 to 8.5 [2.2 to 0.17]	
21.05.20				7.6 [1.0]
02.06.20				7.7 [0.9]
05.05.20	D2a	Made Ground slag	22.5 to 23.5 [-1.3 to -2.3]	
21.05.20				22.2 [0.0]
02.06.20				22.3 [-0.1]
05.05.20	D3a	Made Ground slag	18.0 to 22.0 [-0.5 to -4.5]	
21.05.20				
02.06.20				17.4 [0.1]
05.05.20	D4a	Made Ground slag	15.5 to 20.5 [2.3 to -2.7]	15.6 [2.2]
21.05.20				15.7 [2.1]
02.06.20				15.7 [2.1]
05.05.20	D5a	Made Ground slag	21.0 to 27.0 [3.6 to -2.4]	22.2 [2.4]
21.05.20				22.3 [2.3]
02.06.20				22.3 [2.3]
05.05.20	D5c	Made Ground slag	19.0 to 22.0 [5.7 to 2.7]	21.9 [2.7]
21.05.20				22.0 [2.6]
02.06.20				22.0 [2.6]
05.05.20	D6a	Made Ground slag	14.0 to 18.0 [7.3 to 3.3]	17.7 [3.6]
21.05.20				17.8 [3.5]
02.06.20				17.9 [3.4]

3.3.2 Ground gas monitoring

Ground gas monitoring was undertaken on the 5th of May, the 21st of May and the 2nd of June 2020 within all installed boreholes on the Frag Tip. The ground gas monitoring results are presented in **Error! Reference source not found.**. All g round gas monitoring results recorded a value of 0.0ppm for H_2S and are not included in the results table.

Table 3-8: Summary of Frag Tip Ground Gas Monitoring Results (Section 6)

Date	Hole ID	Flow (L/hr)	CH_4 (%)	CO_2 (%)	O_2 (%)	CO (ppm)
05.05.20	D1a	-0.3	0.0	0.0	21.3	0.0
21.05.20		0.0	0.0	0.0	19.7	0.0
02.06.20		-0.1	0.0	0.0	19.6	0.0
05.05.20	D1b					
21.05.20		0.0	0.6	0.0	16.8	9.0
02.06.20		-0.2	0.9	0.0	8.7	1.0
05.05.20	D2a					
21.05.20		0.0	0.3	0.0	18.7	6.0
02.06.20		0.1	0.2	0.1	18.2	4.0
05.05.20	D3a					
21.05.20						
02.06.20		0.3	7.5	0.0	0.8	0.0
05.05.20	D4a	0.7	1.4	0.4	4.8	2.0
21.05.20		0.6	0.1	0.0	7.5	0.0
02.06.20		0.2	0.2	0.0	7.1	0.0
05.05.20	D5a	0.8	0.1	0.0	8.6	0.0
21.05.20		0.3	0.1	0.0	8.8	0.0
02.06.20		0.5	0.1	0.0	7.4	0.0
05.05.20	D5c	0.8	0.1	0.1	12.3	5.0
21.05.20		0.3	0.0	0.0	8.8	1.0
02.06.20		0.3	0.1	0.0	8.5	0.0
05.05.20	D6a	-0.2	0.3	0.4	7.3	0.0
21.05.20		0.2	1.2	0.8	3.2	0.0
02.06.20		0.2	0.2	0.1	13.8	0.0

The ground gas monitoring results recorded maximum levels of:

- Methane (CH_4) within Borehole D3a at 7.5%.
- Carbon dioxide (CO_2) within Borehole D6a at 0.8%.
- Oxygen (O_2) lowest value in Borehole D3a at 0.8%.
- Carbone Monoxide (CO) within Borehole D1b at 9ppm.

4 Material Properties and Parameters

4.1 Cohesive Made Ground

Cohesive Made Ground was encountered between ground level and a depth of 4.5mbgl (9.2m AOD and 4.7m AOD) with a maximum recorded thickness of 3.0m. The unit was not recorded in boreholes A2, A4, A5, B2 and B4 located in Section 3 - Lamby Way Landfill. Cohesive Made Ground is generally described as slightly sandy gravelly CLAY with a low cobble content.

4.1.1 Weight Density (γ)

The dry and bulk weight density of the Cohesive Made Ground has been determined during compaction and oedometer testing. The test results record bulk densities ranging from 14.7 to 18.8 kN/m^3 and dry densities ranging between 13.5 and 15.4 kN/m^3. The compaction testing determined the maximum dry density of the Cohesive Made Ground samples analysed as 15.6kN/m^3 at a moisture content of 18% (Sample A1; Figure 4-1).

A bulk weight density of 16kN/m^3 has been selected for design.

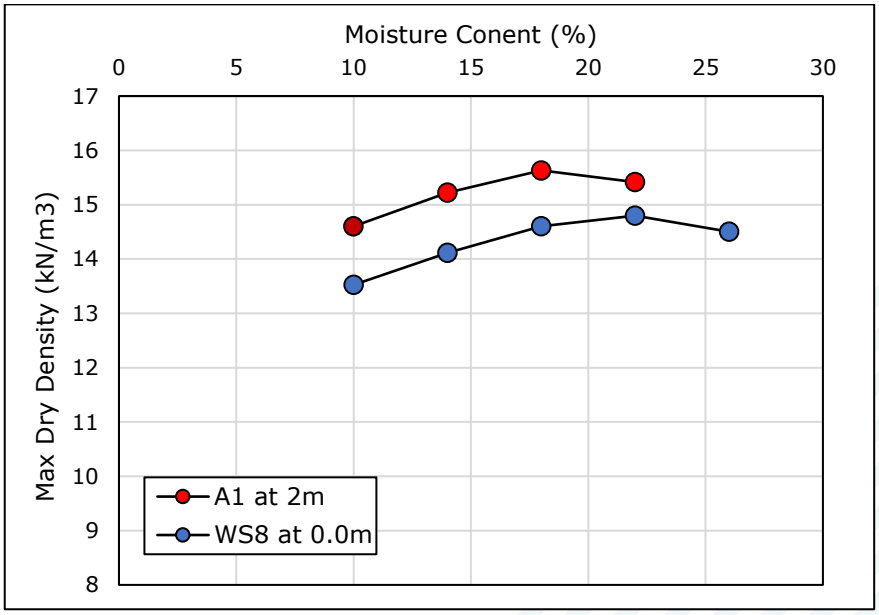


Figure 4-1: Maximum dry densities and the optimum moisture contents for the Cohesive Made Ground

4.1.2 Classification Tests

Eleven PSD tests were undertaken on Cohesive Made Ground samples collected from cable percussive and dynamic sampling boreholes across the site. The PSD tests show the unit to comprise well graded very gravelly sandy CLAY to slightly gravelly very sandy CLAY with low cobble content (Figure 4-2). The PSD test results are therefore in agreement with the field description of *sandy gravelly CLAY with low cobble content.*

The variation of the PSD results is considered typical of Made Ground. It is anticipated that this unit has been derived partially from reworking of the underlying Tidal Flat Deposits mixed with historic material dredged from the adjacent Rhymney River.

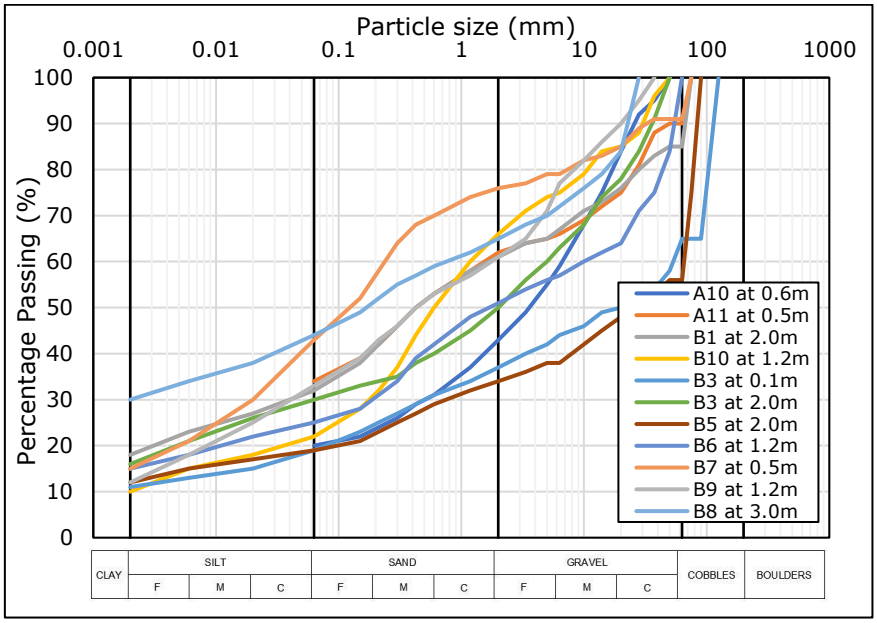


Figure 4-2: PSD Test Results for the Cohesive Made Ground unit

4.1.3 Standard Penetration Test (SPT)

Fourteen SPTs were undertaken on the Cohesive Made Ground unit. Six SPTs refused with a N value of greater than 50, between 1.5 and 3.0m depth and one SPT recorded a value of 49 (Figure 4-3). The location of the refusals was primarily within Section 5 along the frontage adjacent to Rovers Way. Given the historic industrial usage, recent fly tipping and the presence of large cobbles and boulders these high SPT N values are not considered representative of the unit. The N values recorded in Sections 1 to 4 and are between 9 and 36, corresponding to a *firm* to *very stiff* consistency (Figure 4-3).

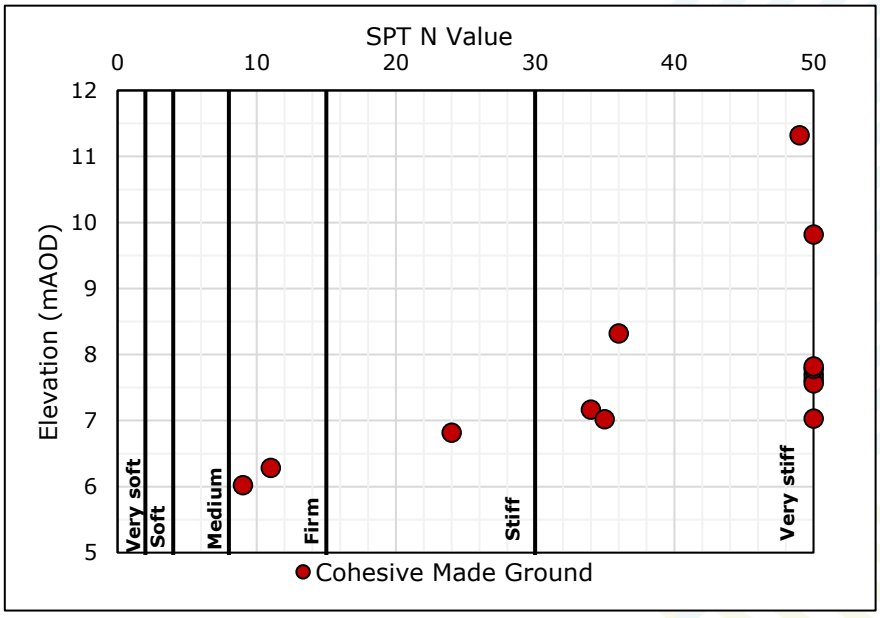


Figure 4-3: SPT Results for the Cohesive Made Ground unit

4.1.4 Index Tests

Thirty-one moisture content tests were undertaken on Cohesive Made Ground samples and recorded values between 5 and 65%. Eighteen index tests were also carried out and determined plasticity index values between 10 and 40% and liquid limit values between 26 and 65% (Figure 4-4). The results demonstrate a plasticity range between a *low* and a *very high* plasticity, predominantly *intermediate* to *high plasticity* clays. The *intermediate* to *high* plasticity silts recorded coincide with locations of the windowless sampling boreholes in Section 1 and 2 of the schemes.

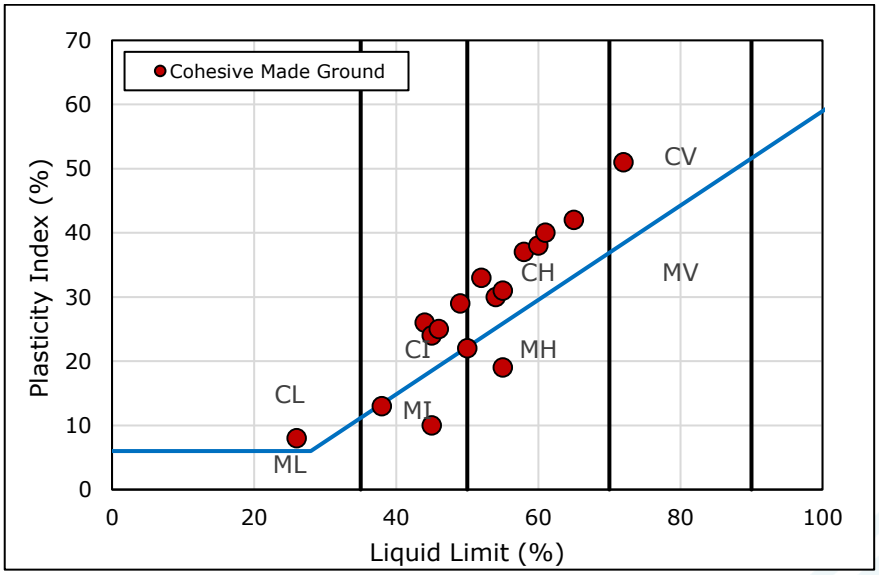


Figure 4-4: Index Test Results for the Cohesive Made Ground unit

4.1.5 Effective Strength (ø', c')

The effective angle of shearing resistance for the Cohesive Made Ground unit has been determined through correlations presented in *BS8002:2015* as no direct testing was undertaken. Using the plasticity index results which range between 10% and 42% the effective angle of shearing resistance of the unit is calculated to range from 21° to 30° (Figure 4-5). Because of the variation in Made Ground materials a conservative value of 23° has been selected for design. The effective cohesion is assumed to be 0 kPa.

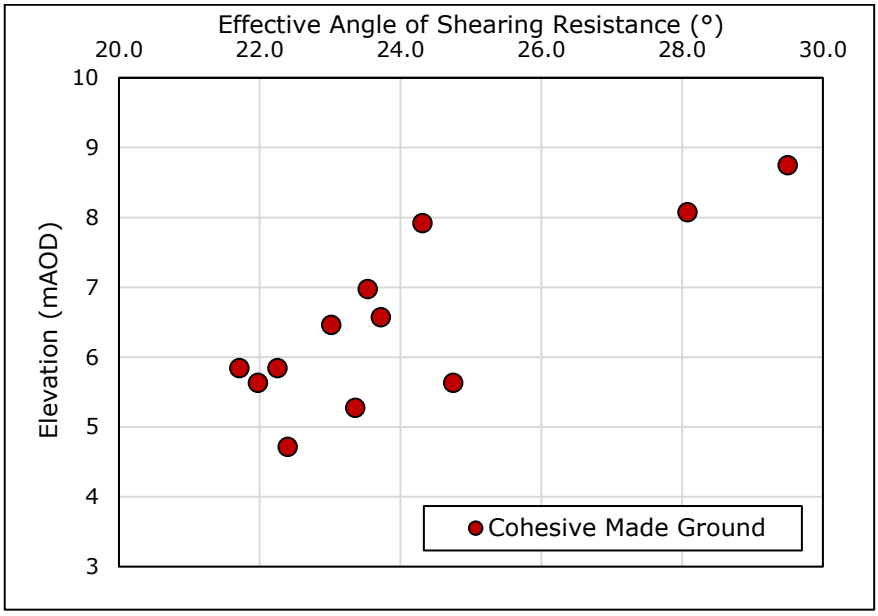


Figure 4-5: Effective angle of shearing resistance for the Cohesive Made Ground unit

4.1.6 Undrained Shear Strength (c_u)

Four hand vane shear tests were undertaken on Cohesive Made Ground within inspection pits. The hand vane shear tests recorded *very low* to *low* peak undrained shear strength values between 11 and 40kPa (Figure 4-6).

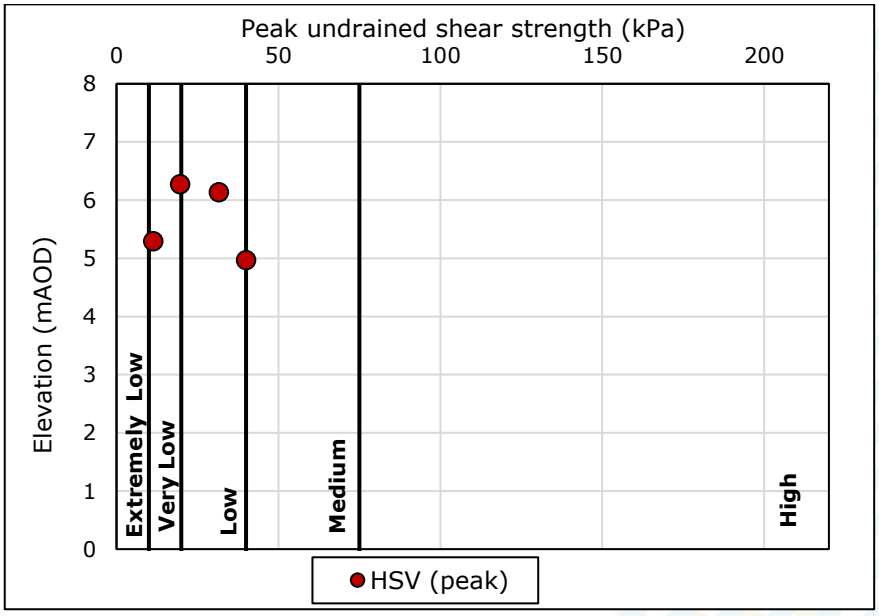


Figure 4-6: Hand vane shear test results for the Cohesive Made Ground unit

No oedometer testing was undertaken on the Cohesive Made Ground to directly determine the coefficient of volume compressibility (m_v). The coefficient of volume compressibility has been estimated using SPT N value correlations with Plasticity Index as proposed by Stroud and Butler (1975):

$$m_v = 1 / (f_2 \times N)$$

The SPTs that refused ('N' = 50) are considered unrepresentative for the unit. A characteristic N value of 34 has been applied. Using Plasticity Index values between 9 and 42%, an f_2 correlation between 0.45 and 0.55 has been determined providing an m_v value between 0.03 and 0.09kN/m^3 (Figure 4-7).

A conservative value of 0.1 m^2/MN for the coefficient of volume compressibility has been selected for design.

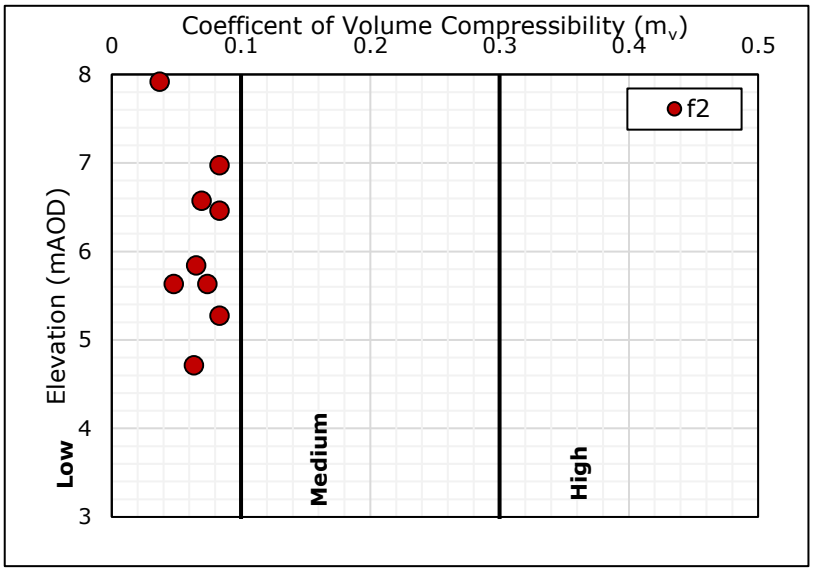


Figure 4-7: Determination of m_v for the Cohesive Made Ground unit from f_2 correlations (Stroud and Butler, 1975)

4.1.7 Young's Modulus (E')

The effective Young's modulus (*E'*) and undrained Young's modulus (E_u) have been determined following the method of Stroud (1974) and the *Plaxis User Manual* (2020):

$$E_u = 15 \times (c_u / PI) \qquad E' = E_u \times 0.8$$

Using c_u values recorded during field hand vane shear testing, an E_u range between 4.6 and 14.3 MPa and *E'* values ranging between 3.7 and 11.4 MPa have been determined (Figure 4-8). A value of 10 MPa for E_u and 8 MPa for *E'* has been selected for design.

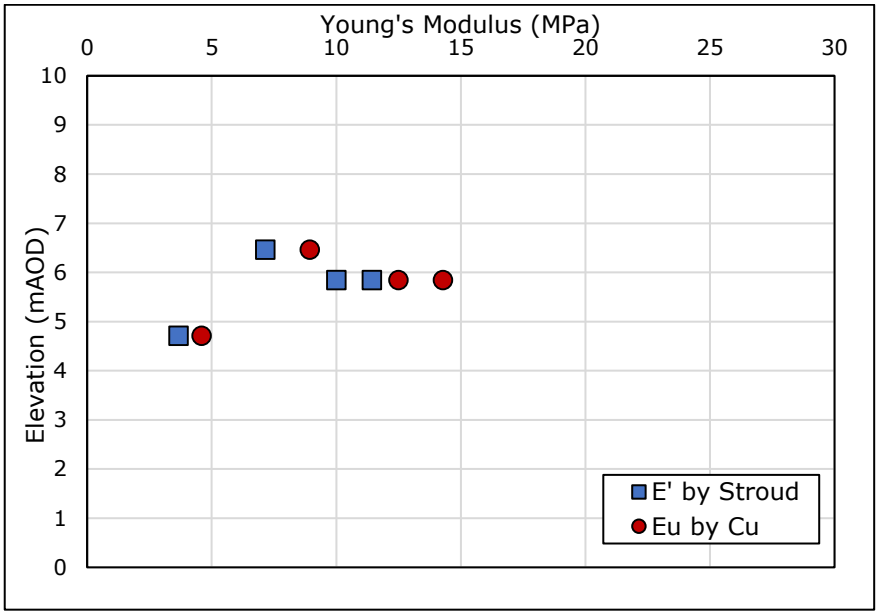


Figure 4-8: Determination of E_u and E' for the Cohesive Made Ground unit using Stroud (1974) and the *Plaxis User Manual* (2020)

4.1.8 Coefficient of Permeability (*k*)

No direct testing has been undertaken to determine the coefficient of permeability of the Cohesive Made Ground unit. A conservative value of 1.0×10^{-5} m/s to reflect variability in ground conditions has been selected based on the material properties and the PSD test results.

4.2 Granular Made Ground

The Granular Made Ground unit was encountered between the ground level and 3.85mbgl (9.3m and 3.5m AOD) with a maximum recorded thickness of 2.3m. The unit was recorded in exploratory locations A3, A7, B1, B5, B6, B7, B9, WS3 and WS5 located across Sections 1 to 5. The Granular Made Ground is generally described as slightly clayey sandy GRAVEL. Gravel is fine to coarse, angular to sub-angular brick, concrete, slag, sandstone, mudstone.

The Granular Made Ground unit (Made Ground Landfill, Made Ground Slag) encountered within Section 6 known as the Frag Tip is excluded from the following description as they will not be encountered during construction of the proposed defences.

4.2.1 Weight Density (γ)

No laboratory testing was undertaken to determine the bulk and dry density of the Granular Made Ground unit. Using the field description of "slightly clayey sandy GRAVEL", a bulk weight density of 20kN/m^3 and dry unit weight of 19kN/m^3 have been selected, based on guidence provided in *BS8002:2015*.

4.2.2 Classification Tests

Six PSD tests were undertaken on samples of the Granular Made Ground unit. The PSD test results are broadly consistent and record the Granular Made Ground unit to comprise sandy Gravels with low cobble content. A maximum of 20% fines was recorded in the samples analysed (Figure 4-9). The test results correlate well with the field descriptions of slightly clayey sandy GRAVEL.

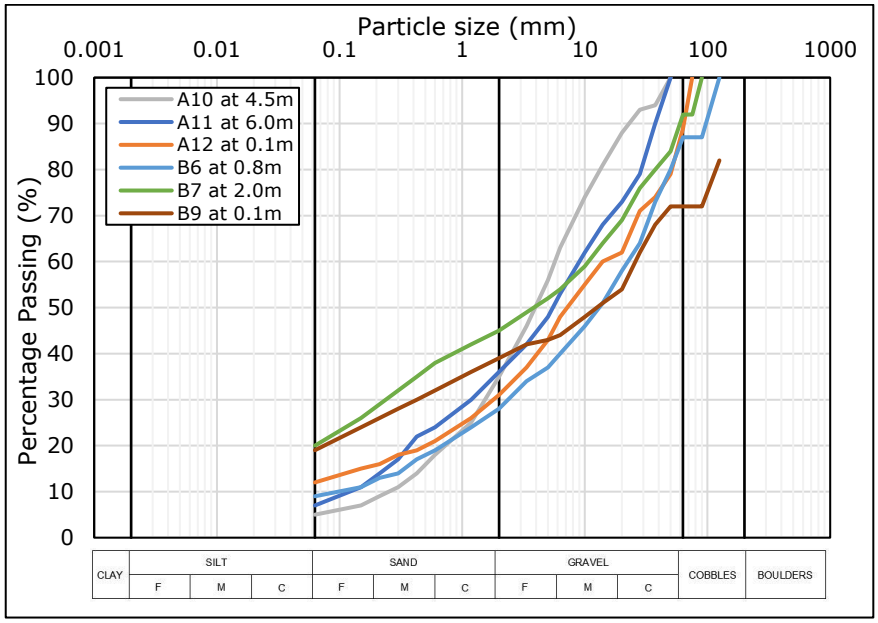


Figure 4-9: PSD Test Results for the Granular Made Ground unit

4.2.3 Standard Penetration Tests

No SPTs were undertaken on the Granular Made Ground unit across Sections 1-5.

4.2.4 Effective Strength (ø', c')

No direct testing was undertaken to determine the effective strength parameters for the Granular Made Ground unit. The effective angle of internal friction has been estimated as 30° using guidance provided in *BS8002:2015*. This value remains consistent with depth. The effective cohesion (c') is assumed to be 0kPa.

4.2.5 Young's Modulus (*E'*)

No laboratory testing was undertaken to determine the drained Young's Modulus (*E'*) for the Granular Made Ground unit. An *E'* value of 15 MPa has been estimated for the unit using engineering judgement and typical values of the Young's Modulus proposed by Obrzurd & Truty (2012).

4.2.6 Coefficient of Permeability (*k*)

No direct testing has been undertaken to confirm the coefficient of permeability of the Granular Made Ground unit. A value of 1 x 10^{-4} m/s has been selected based on the Hazen (1892) D_{10} correlation.

4.3 Tidal Flat Deposits

Tidal Flat Deposits were recorded immediately below Made Ground deposits between 1.7m and 13.7mbgl (6.8m and -5.2mAOD) with thicknesses recorded between 6.8m and 10.3m. In boreholes A2, A4, B2, B4 and WS8 where Made Ground was absent Tidal Flat Deposits were recorded at the ground surface.

4.3.1 Weight Density (γ)

The bulk and dry weight density of the Tidal Flat Deposits has been determined during compaction testing, oedometer testing and consolidated undrained triaxial

testing. The recorded bulk weight density ranges from 16.2kN/m^3 to 21.1kN/m^3 and the dry weight density ranges from 14.7kN/m^3 to 17.5kN/m^3.

The bulk density of 17kN/m^3 has been selected.

4.3.2 Optimum Moisture Content

Two compaction tests were carried out on samples of the Tidal Flat Deposits from boreholes B1 and B2. The tests determined an optimum moisture content of 18% and 19% respectively. The in-situ moisture content of these samples were 58% and 47% (Figure 4-10).

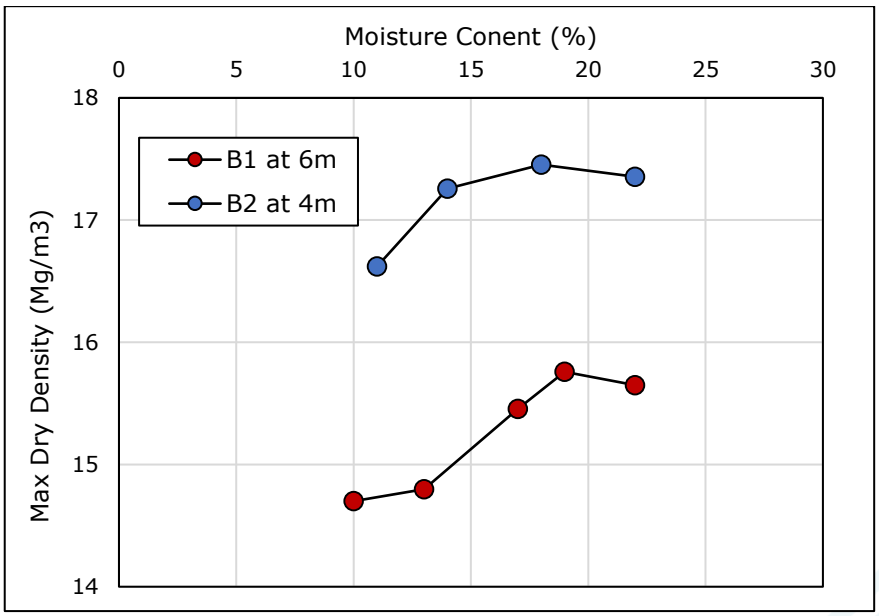


Figure 4-10: Maximum dry densities and the optimum moisture contents for the Tidal Flat Deposits

4.3.3 Classification Tests

Fifteen PSD tests by wet sieving and sedimentation were undertaken on samples from the Tidal Flat Deposits. The PSD test results record a slightly gravelly slightly sandy to sandy silty CLAY (Figure 4-11).

The PSD test on the sample from 8.0mbgl in borehole B2 recorded a sandy clayey silt. The PSD test on a sample from 3.8mbgl in borehole B1 recorded a slightly gravelly sandy silty clay, but as this sample is not wholly within the Tidal Flat Deposit this result is not considered representative.

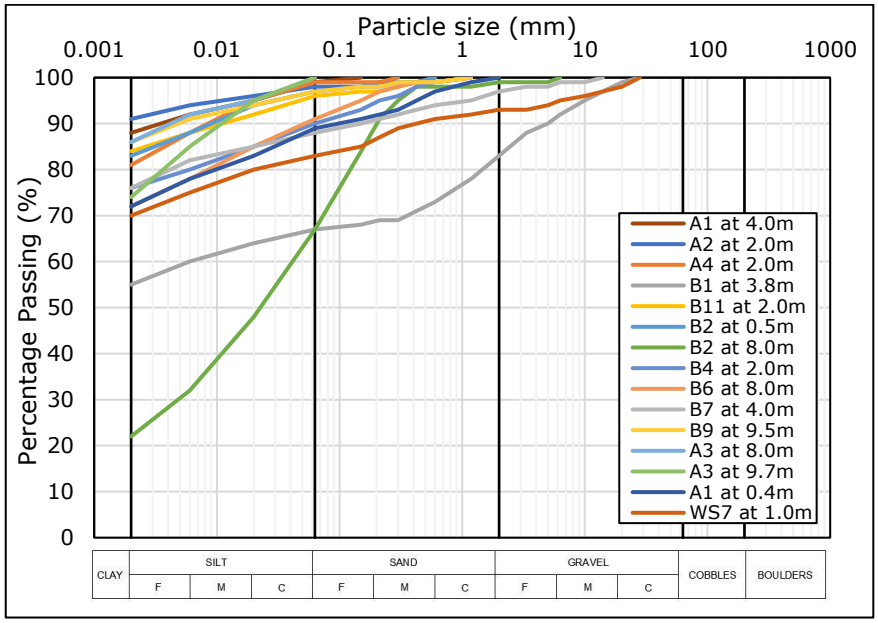


Figure 4-11: PSD Test Results for the Tidal Flat Deposits

4.3.4 Standard Penetration Tests

Fifty SPTs were undertaken in the Tidal Flat Deposit unit. The SPT N values range from 0 to 19, indicating a very soft to firm, occasionally stiff consistency (Figure 4-12).

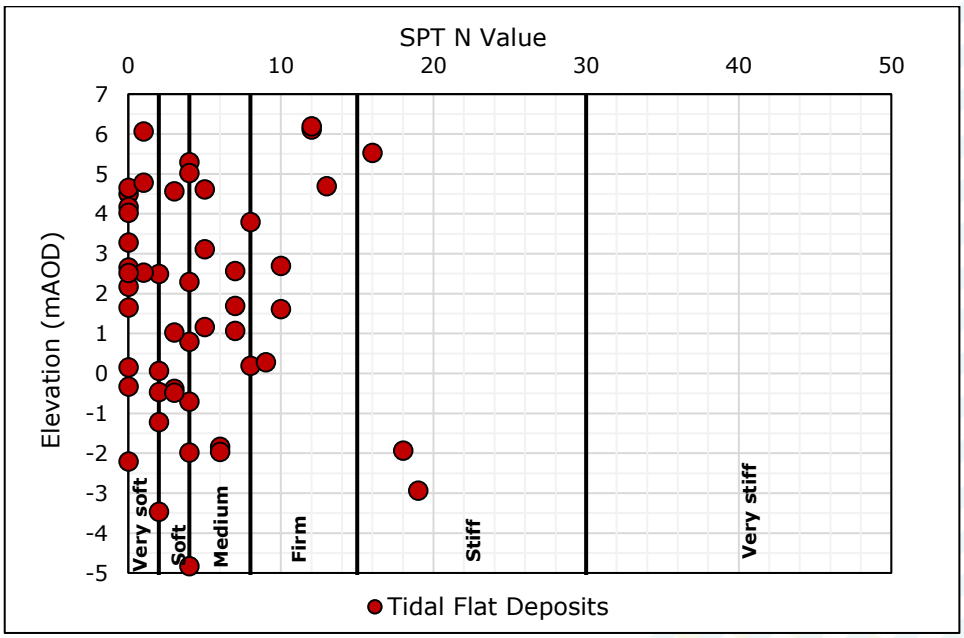


Figure 4-12: SPT results for the Tidal Flat Deposits

4.3.5 Index Tests

Fifty-six index tests were carried out on the Tidal Flat Deposits and determined plastic limit values between 25 and 65% and liquid limit values between 45 and 90%. The results demonstrate a plasticity range between *medium* and *very high* plasticity, however predominantly *intermediate* to *high* plasticity clays (Figure 4-13).

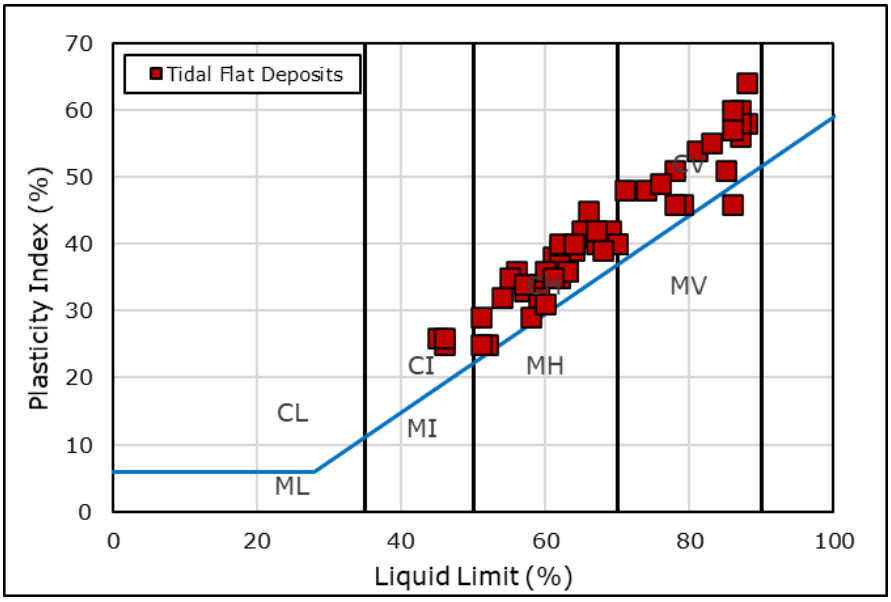


Figure 4-13: Index Test Results for the Tidal Flat Deposits

4.3.6 Effective Strength (ø', c')

The effective angles of shearing resistance for the Tidal Flat Deposits unit have been determined through triaxial testing and correlations presented in *BS8002:2015* (Figure 4-14).

Six triaxial tests provided values for the effective angle of shearing resistance between 16.5° and 24.5° with effective cohesion ranging between 15 and 29kPa. Using the plasticity index results, which range between 25% and 64%, calculated values for the effective angle of shearing resistance of the unit range from 19.4° to 24.5° (Figure 4-14). A value of 22° has been selected for design. The effective cohesion (c') is assumed to be 0kPa.

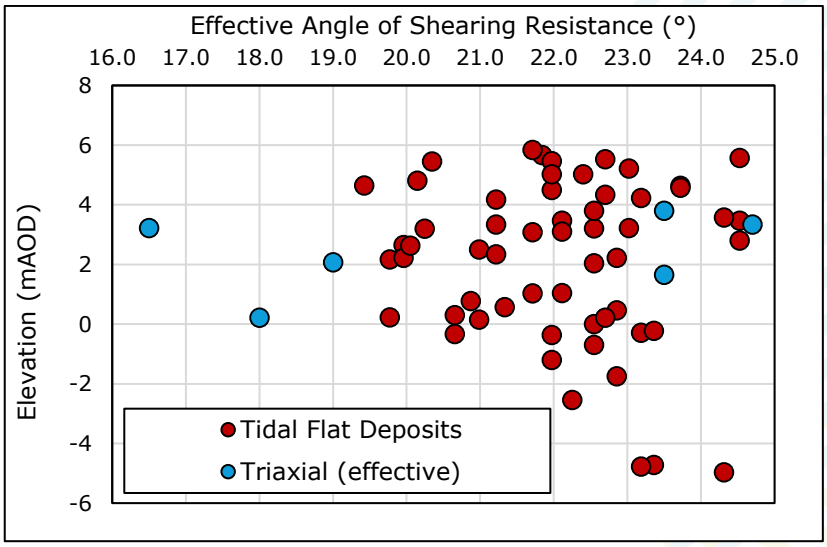


Figure 4-14: Effective angle of shearing resistance

4.3.7 Young's Modulus (*E'*)

The effective Young's modulus (*E'*) and undrained Young's modulus (E_u) have been determined following the method of Stroud (1974) and the *Plaxis User Manual* (2020) (see part 4.1.7 for more information.) (Figure 4-15).

The calculated values show significant variation but based on experience and field observations values of 3MPa and 4MPa for E' and Eu respectively have been selected for design

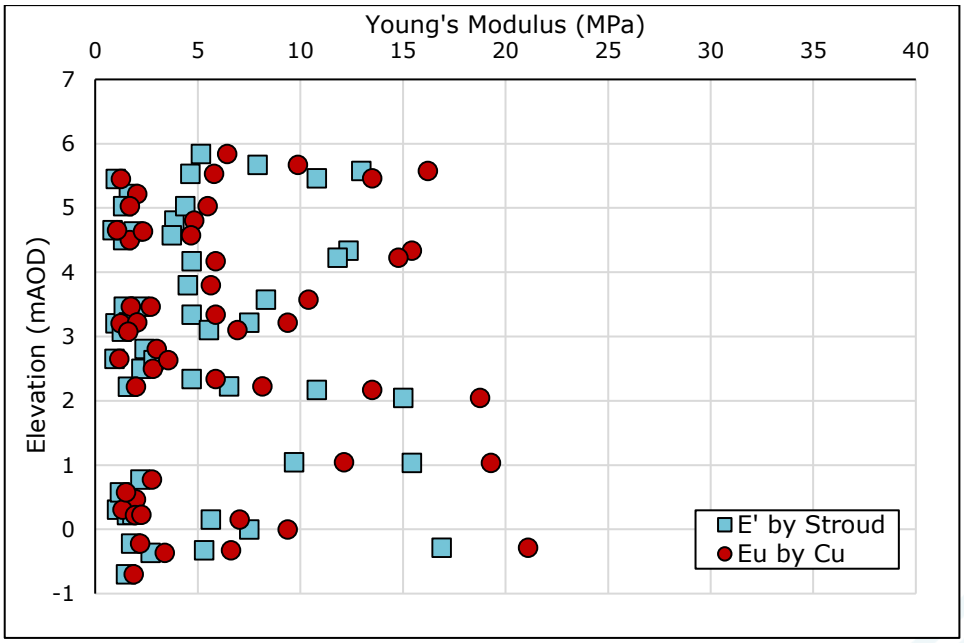


Figure 4-15: Determination of E_u and *E'* for the Tidal Flat Deposits using Stroud (1974) and the *Plaxis User Manual* (2020)

4.3.8 Coefficient of volume of compressibility (m_v)

The coefficient of volume compressibility m_v was determined from oedometer testing and cone penetration testing (CPT) completed as part of the GI along with historic CPT data, located offshore, obtained from the BGS (Figure 4-16).

m_v values calculated from top resistance recorded during CPT testing completed during the GI range from 0.2m^2/MN to 0.5m^2/MN which is toward thje lower end of the range of values obtained from oedometer testing (Figure 4-16). Figure 4-16 shows that m_v values from the oedometer testing are also greater than those recorded in historic CPTs.

The value of 0.9m^2/MN was selected for the Tidal Flat Deposits, although a lower value may be appropriate for the coastal sections.

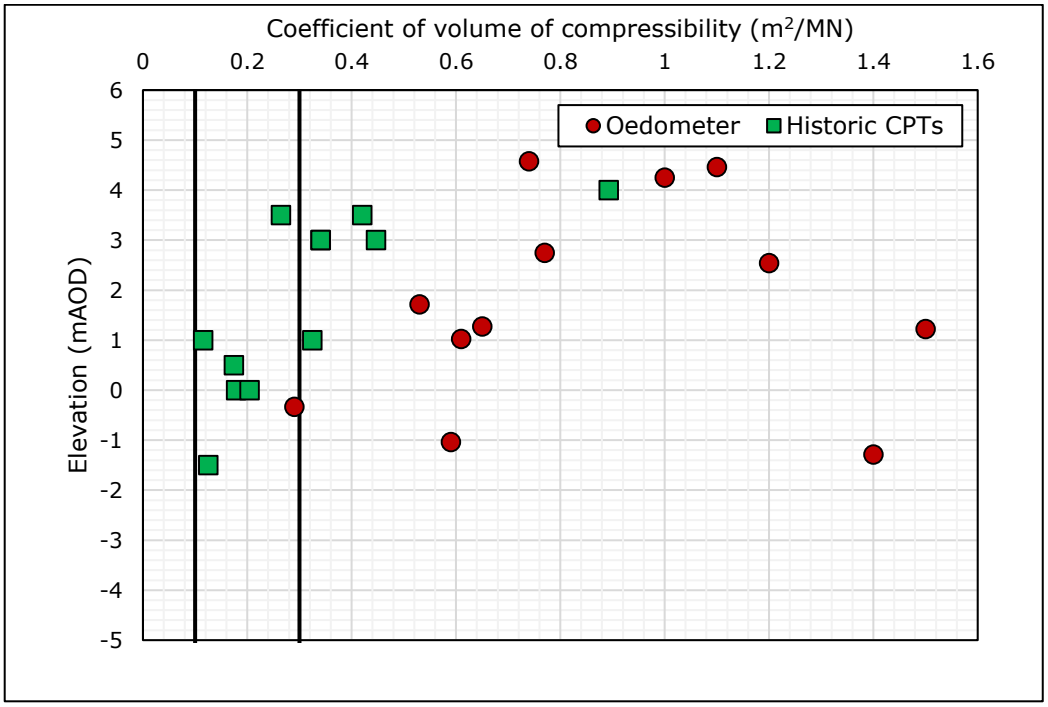


Figure 4-16: Coefficients of volume compressibility (m_v) for the Tidal Flat Deposits

4.3.9 Undrained shear strength

The undrained shear strength of the Tidal Flat Deposits was determined from hand shear vanes, triaxial tests, CPT and historic CPT (Figure 4-17). The different techniques provide consistent results with the undrained shear strength ranging from 0 to 40 kPa. A value of 15kPa has been selected for design.

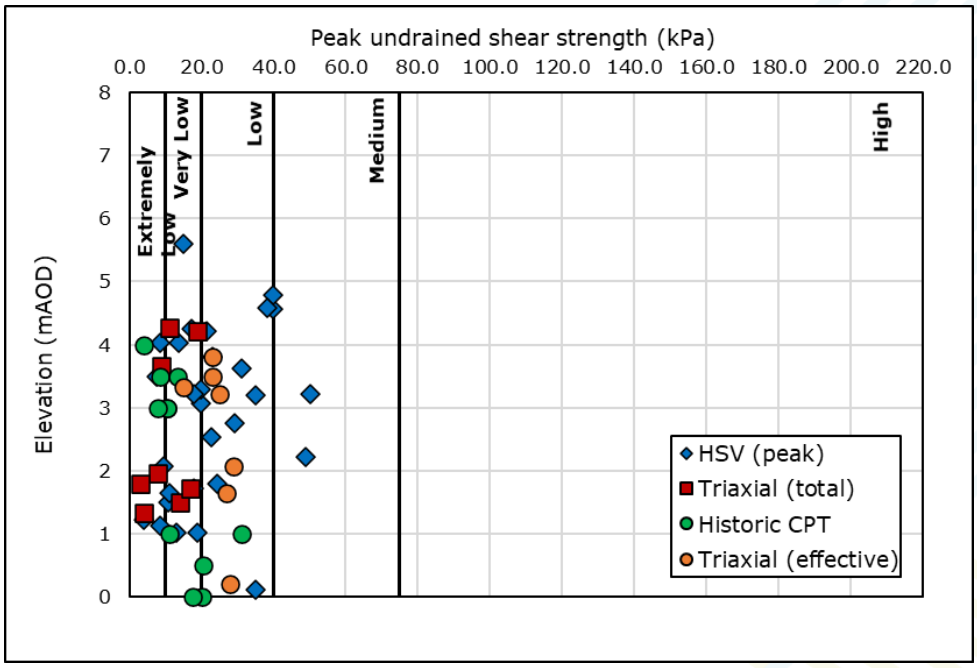


Figure 4-17: Undrained shear strengths for the Tidal Flat Deposits

4.4 Glaciofluvial deposits

The Glaciofluvial deposits were encountered between 8.0m and 15mbgl (-0.4m and -6.1mAOD) with a maximum recorded thickness of 4.6m. The unit was recorded in A1, A2, A3, A4, A7, B1, B2, B3, B4, B5, B7, B8, B9 & B11. It was recorded by Quantum on the borehole logs as "Tidal Flat deposits" but has been interpreted as Glaciofluvial deposits by JBA.

4.4.1 Weight Density (γ)

No laboratory testing was undertaken to determine the bulk and dry density of the Glaciofluvial deposits. Using the field description a bulk weight density of 21kN/m^3 and dry unit weight of 19kN/m^3 have been selected, based on values provided in BS8002:2015.

4.4.2 Classification Tests

Eleven PSD tests were undertaken on samples collected from bulk bags of cable percussive and dynamic sampling boreholes across the site. The PSD tests show the unit to comprise well graded sandy gravel (Figure 4-18).

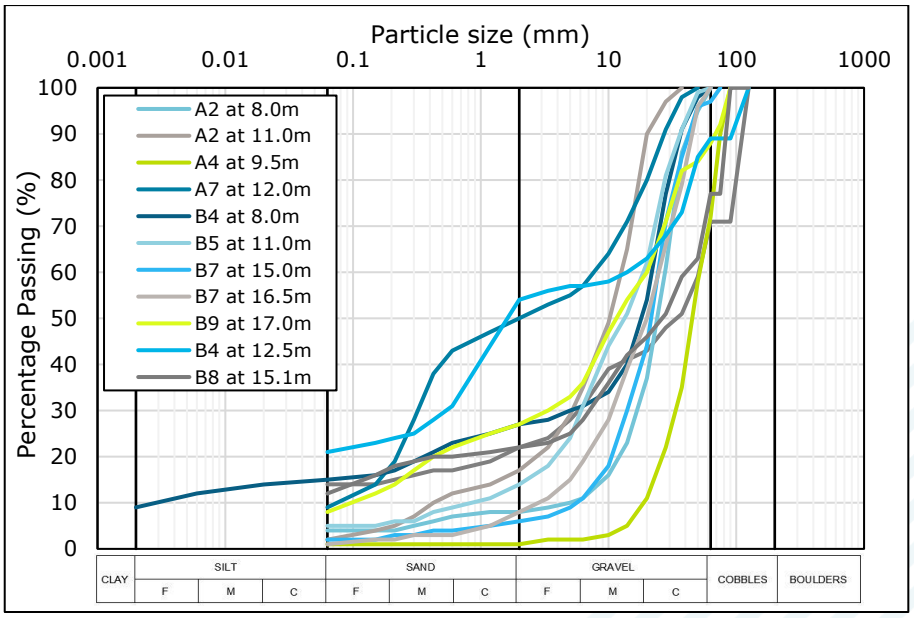


Figure 4-18: PSD Test Results for the Glaciofluvial deposits

4.4.3 Standard Penetration Test (SPT) and drained modulus (E')

Fifteen SPTs were undertaken on the Glaciofluvial deposits (Figure 4-19). The majority if the N values show the Glaciofluvial deposits to be medium dense or dense.

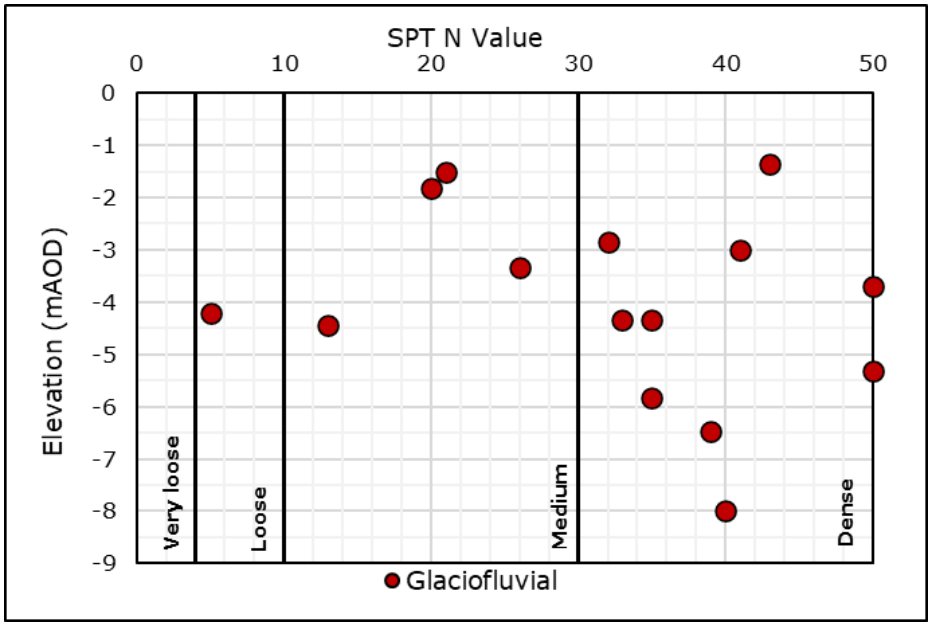


Figure 4-19: SPT Results for the Glaciofluvial deposits

4.4.4 Effective Strength (ø', c')

Two shear box tests were carried out and recorded the peak angle of friction as 16° and 25° with peak cohesion as 21 and 20kPa. Using the results from SPT testing, the effective angle of shearing resistance was determined between 28° and 42° using the relation of Peck (1967) (Figure 4-20).

The results from the shear box testing are evidently lower that that shown by the SPT testing. The reason for the low values recorded by the shear boxes is unclear but may be due to the combination of samples used to undertake the test and the requirement to remove larger partical sizes. Based on material descriptions, engineering judgement and the guidance provided in BS8002:2015 a value of 35° has been selected for design.

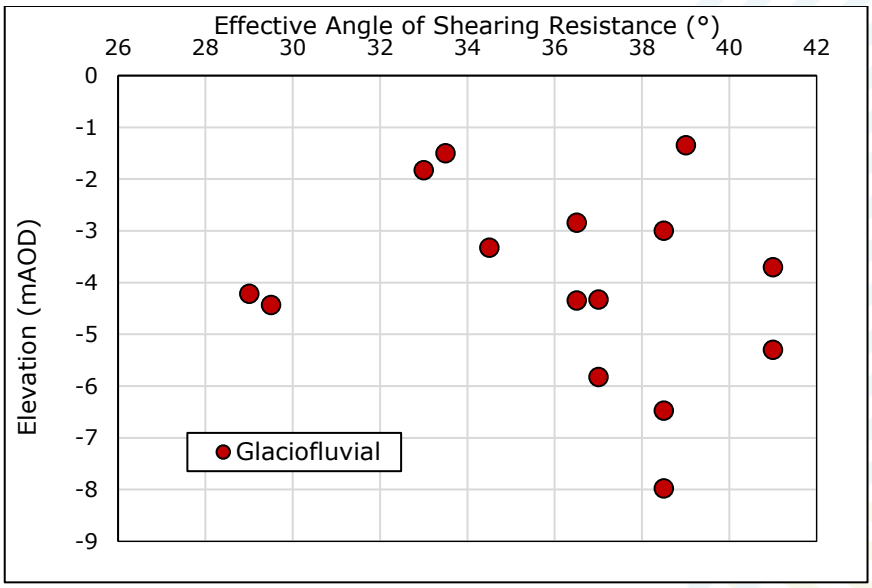


Figure 4-20: Effective angle of shearing resistance for the Glaciofluvial deposits

4.4.5 Youngs modulus (*E'*)

The Young's modulus (E') of the Glaciofluvial deposits was determined using the relationship presented by Stroud (1974) (see part 4.1.7) (Figure 4-21). Figure 4-21 shows significant scatter. A value of 24MPa has been selected.

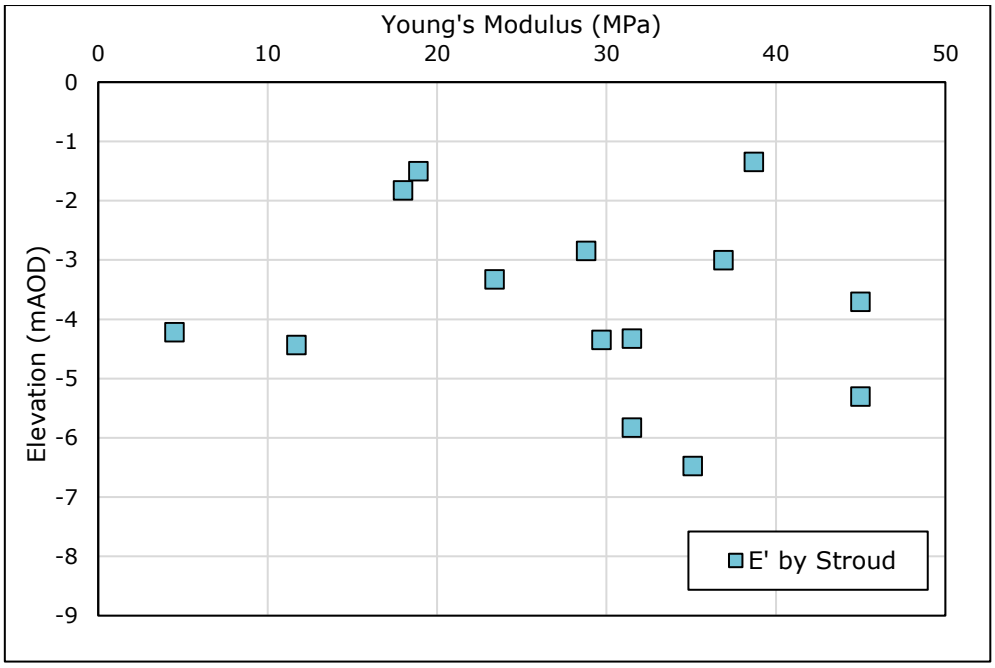


Figure 4-21: Young's modulus (E') for the Glaciofluvial deposits

4.4.6 Coefficient of Permeability (k)

No direct testing has been undertaken to measure the coefficient of permeability of the Glaciofluvial deposits. A value of $1x10^{-4}$ m/s has been selected based on Hazen's (1892) method using D_{10} values derived from the PSD.

4.5 Mercia Mudstone Group

Bedrock was encountered between 10.2m and 15mbgl (-3.7m and -9.3mAOD), all boreholes which penetrated the Mercia Mudstone Group terminated within it. The thickness of the weathered zone varied significantly. In borehole A2R the Weathered mudstone was first recorded as Grade IV, i.e. "highly weathered" and changed to Grade I (un-weathered) within 2.3m. In contrast in borehole A3BR the bedrock remained Grade IV for more than 11m until the termination of the borehole. The Mercia Mudstone Group was recorded in A1R, A2R, A3BR, A4R, A2, A4, B1, B3, B4, B5, B6, B7, B8, B9 & B10.

4.5.1 Classification Tests

Three PSD tests were undertaken on samples collected from bulk bags of cable percussive and dynamic sampling boreholes across the site. The PSD tests show the unit to comprise predominantly silt and clay (Figure 4-22).

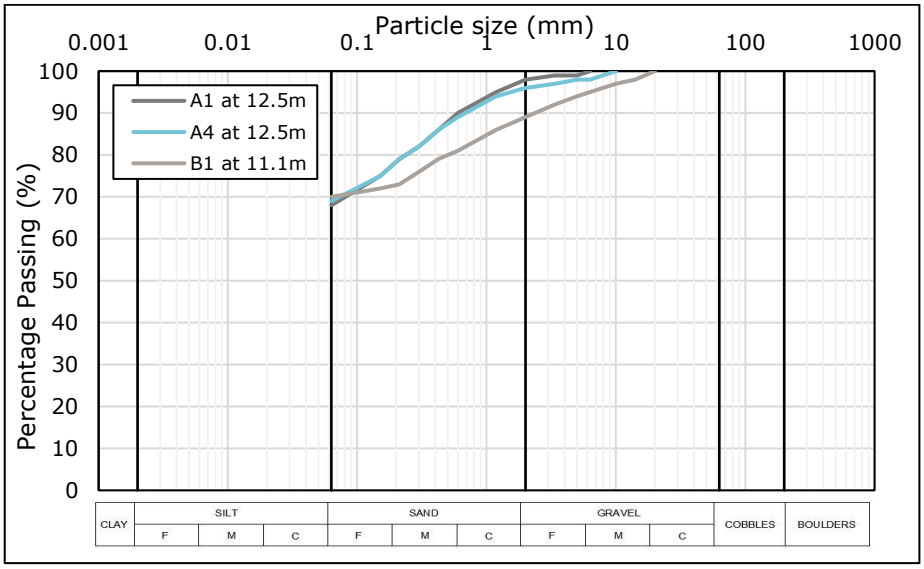


Figure 4-22: PSD Test Results for the Mercia Mudstone

4.5.2 Index Tests

One test was carried out on a sample of the weathered Mercia Mudstone Group and determined the plasticity index as 32% and liquid limit as 51%.

4.5.3 Standard Penetration Test (SPT) and drained modulus (E')

Eight SPTs were undertaken on the Weathered Mercia Mudstone unit. The majority if the N values show the mudstone to be of a *dense* consistency (Figure 4-23).

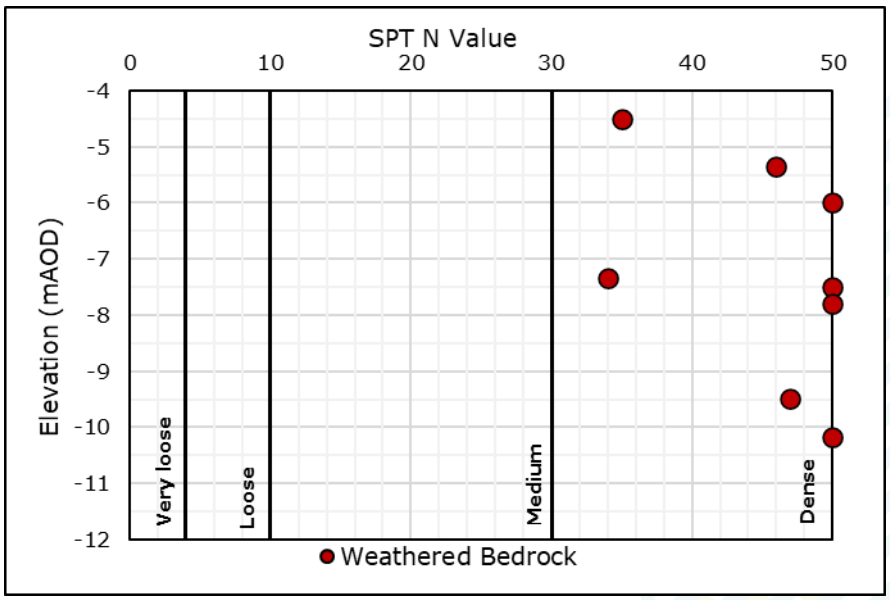


Figure 4-23: SPT Results for the Mercia Mudstone

4.5.1 Effective Strength (ø')

Using the results from SPT testing, the effective angle of shearing resistance was determined using the relation of Peck (1967) (Figure 4-24). Values of 30° and 38° were selected for the weathered and unweathered Mercia Mudstone respectively.

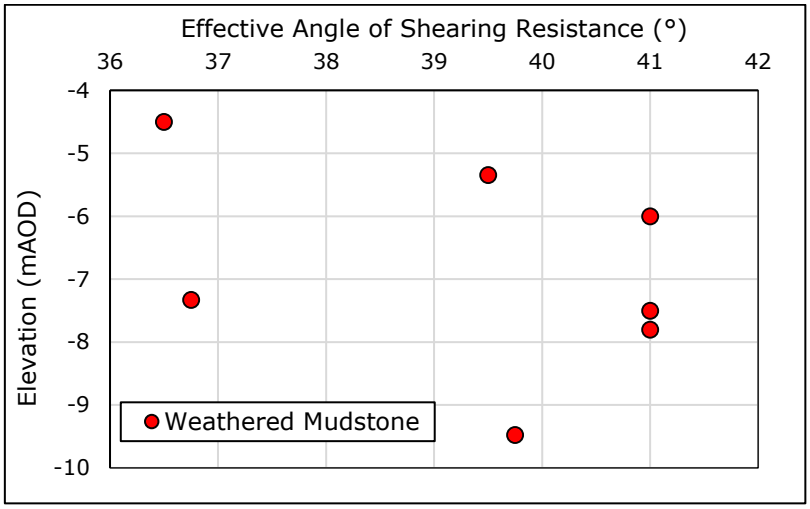


Figure 4-24: Effective angle of shearing resistance

4.5.2 Youngs modulus (*E'*)

Using CIRIA 143 (1995), a relation of E' (MPa) = 2.0 x SPT N was used to determine the drained modulus for the mudstone rock (Figure Fig 4-25). Because of the weathering in the upper part of the unit conservative values of 12MPa and 40MPa were selected for the weathered and unweathered Mercia Mudstone respectively.

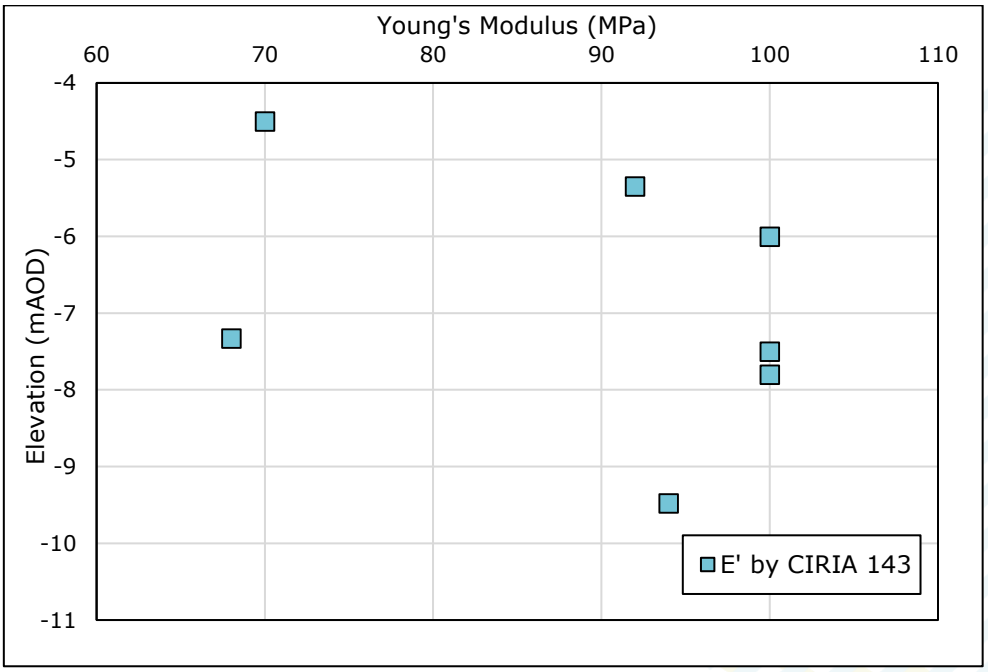


Figure 4-25: Young's Modulus (E') for the Mercia Mudstone

4.6 Summary of characteristic parameters

A summary of the parameters for use in design is provided in Table 4-1.

Table 4-1: Summary of Geotechnical parameters for use in design

Stratum	Made ground (cohesive)	Made ground (granular)	Tidal flat deposits	Glaciofluvial deposits	Weathered Mercia Mudstone	Mercia Mudstone Bedrock
Weight density γ (kN/m^3)	16 (bulk) 14 (dry)	20 (bulk) 19 (dry)	18 (bulk) 15 (dry)	21 (below WT) 19 (dry)	22	22
Coefficient of volume compressibility m_v (m^2/MN)	0.03 to 0.25 [0.1]	-	0.5 to 1.5 [0.9] *Lower offshore*	-	[0.1]*	-
Effective cohesion c' (kPa)	0	0	0	0	0	0
Effective angle of shearing resistance φ (°)	[23]	[30]	[21]	[35]	[30]*	[38]*
Undrained Shear Strength c_u (kPa)	19 - 40 [35]	-	1 - 50 [15]	-	[100]*	-
Drained Youngs Modulus E (MPa)	[8]	[15]	[3]	[24]	[12]*	[40]*
Undrained Youngs Modulus E_u (MPa)	[10]	-	[4]	-	[15]*	-
Hydraulic conductivity k (m/s)	[1.0E-05]	[1.0E-04]	[1.0E-07]	1.2E-00 to 1.4E-04 [1.0E-03]	[1.0E-08]	-

5 Contamination Testing

Laboratory testing results are provided in Appendix A. Results for Sections 1-5 are summarised in tables 5-1 and 5-2. Results for Section 6 (the 'Frag Tip') are summarised in table 5-3.

Table 5-1 Chemical Testing Results (soils) for Sections 1-5

Chemical Determinant	Unit	Locations	Recorded Value Range
Acenaphthene	mg/kg	A3b, WS1, WS4, WS8, WS9	0.26 – 0.92
Acenaphthylene	mg/kg	A7, WS1, WS4, WS8, WS9	0.12 – 0.37
Anthracene	mg/kg	A7, B3, B9, B11, WS1, WS3, WS4, WS8, WS9	0.16 - 0.71
Arsenic	mg/kg	All tested samples	6.70 - 27.0
Benzo (g,h,i) perylene	mg/kg	A7, B9, B11, WS1, WS4, WS8, WS9	0.30 – 2.40
Benzo(a)anthracene	mg/kg	A7, B3, B9, B11, WS1, WS3, WS4, WS8, WS9	0.49 – 2.10
Benzo(a)pyrene	mg/kg	A7, B9, WS1, WS4, WS8, WS9	0.57 – 2.30
Benzo(b)fluoranthene	mg/kg	A7, B9, B11, WS1, WS4, WS8, WS9	0.85 - 2.40
Benzo(k)fluoranthene	mg/kg	A7, B9, B11, WS1, WS4, WS8, WS9	0.39 – 1.30
Boron	mg/kg	All tested samples	1.40 - 58.0
Cadmium	mg/kg	All tested samples	0.13 - 5.10
Chromium	mg/kg	All tested samples	21.0 - 1100
Chrysene	mg/kg	A7, B3, B9, B11, WS1, WS3, WS4, WS8, WS9	0.54 - 2.30
Copper	mg/kg	All tested samples	12.0 - 1400
Cyanide	mg/kg	WS8	0.00 – 1.7
Dibenz[A,H]anthracene	mg/kg	A7, B11, WS1, WS4, WS8, WS9	0.29 – 1.70
Fluoranthene	mg/kg	A3b, A7, B3, B9, B11, WS1, WS3, WS4, WS8, WS9	0.82 – 3.10
Fluorene	mg/kg	A7, WS1, WS4, WS8, WS9	0.28 – 1.30
Indeno(1,2,3-cd)pyrene	mg/kg	A7, B9, B11, WS1, WS4, WS8, WS9	0.29 – 2.30
Lead	mg/kg	All tested samples	25.0 - 210
Mercury	mg/kg	A3b, A7, B3, B11, WS1, WS3, WS4, WS5, WS7, WS8, WS9, WS11	0.11 - 1.20
Naphthalene	mg/kg	A7, WS1, WS4, WS8, WS9	0.32 – 3.10
Nickel	mg/kg	All tested samples	23.0 - 43.0
Organic matter	%	All tested samples	1.30 - 17
Pah,Total	mg/kg	A7, B3, B9, B11, WS1, WS3, WS4, WS8, WS9	3.6 - 26.0
pH	-	All tested samples	7.80 - 11.4
Phenanthrene	mg/kg	A7, B3, B9, B11, WS1, WS3, WS4, WS8, WS9	0.54 – 3.10
Phenols	mg/kg	None	0.00
Pyrene	mg/kg	A3b, A7, B3, B9, B11, WS1, WS3, WS4, WS8, WS9	0.30 – 2.60
Sulphate as SO4	g/l	A3b A7, B2, B9, B11, WS3	0.01 - 0.92
TPH >C6-40	mg/kg	A7, B3, B9, WS1, WS4	34 - 270
Zinc	mg/kg	All tested samples	86 - 550

Table 5-2 Chemical Testing Results (water) for Sections 1-5

Chemical Determinant	Unit	Locations	Min Value	Max Value
Ammoniacal Nitrogen as N	mg/l	B2, B3, B4, B10	380	1400
Ammonium	mg/l	B2, B3, B4, B10	0.12	4.80
Arsenic	ug/l	B2, B3, B4, B10	5.00	32.0
Biochemical oxygen demand	mg O2/l	B2, B3, B4, B10	1.00	1.00
Boron	ug/l	B2, B4, B10	1400	1800
Cadmium	ug/l	B2, B3, B4, B10	0.10	0.52
Calcium	mg/l	B2, B3, B4, B10	99.0	480
Chloride	mg/l	B2, B3, B4, B10	2500	9500
Chromium	ug/l	B2, B3, B4, B10	33.0	91.0
Chromium - Hexavalent	ug/l	B2, B3, B4, B10	1.20	4.90
Conductivity- Electrical 20deg	uS/cm	B2, B3, B4, B10	8600	22000
Copper	ug/l	B2, B3, B4, B10	17.0	83.0
Dissolved Organic Carbon.	mg/l	B2, B3, B4, B10	4.60	14.0
Fluoride	mg/l	B2, B3, B4, B10	0.16	0.51
Hardness,Total as CaC03	mg/l	B2, B3, B4, B10	660	3500
Iron	ug/l	B2, B3, B4, B10	170	1600
Kjeldahl Nitrogen	mg/l	B2, B3, B4, B10	5.80	10.0
Lead	ug/l	B10	4.50	
Magnesium	mg/l	B2, B3, B4, B10	100	590
Manganese	ug/l	B2, B3, B4, B10	81.0	4000
Mercury	ug/l	B2, B10	2.50	3.40
Nickel	ug/l	B2, B3, B4, B10	1.80	14.0
Nitrate as N	mg/l	B3	0.72	
Nitrate as NO3	mg/l	B2, B3	0.59	3.20
Nitrite as NO2	mg/l	B2, B3, B4	0.92	5.80
Nitrogen	mg/l	B2, B3, B4	5.90	10.0
O-Xylene	ug/l	B10	1.00	
pH	-	B2, B3, B4, B10	8.10	8.50
Phosphates	mg/l	B2, B3, B4, B10	0.21	3.60
Phosphorus as P	mg/l	B2, B3, B4, B10	0.07	1.20
Potassium	mg/l	B2, B3, B4, B10	51.0	170
Selenium	ug/l	B2, B3, B4, B10	33.0	48.0
Sodium	mg/l	B2, B3, B4, B10	1700	4800
Solids, Suspended	mg/l	B2, B3, B4, B10	390	1000
Sulphate as SO4	mg/l	B2, B3, B4, B10	440	1200
Zinc	ug/l	B2, B3, B4, B10	36.0	62.0

Table 5-3 Groundwater testing results for Section 6 (the 'Frag Tip')

Chemical Determinant	Unit	Locations	Min Value	Max Value
2-Methylnaphthalene	ug/l	D5c	22.0	
Acenaphthylene	ug/l	D5c	9.70	
Alkalinity	mg/l	All tested locations	60.0	200
Ammoniacal Nitrogen as N	mg/l	All tested locations	0.93	4.80
Ammonium	mg/l	All tested locations	0.53	5.6
Anthracene	ug/l	D5c	2.40	
Arsenic	ug/l	All tested locations	2.40	9.70
Benzo (g,h,i) perylene	ug/l	D5c	0.91	
Benzo(a)anthracene	ug/l	D5c	4.9	
Benzo(a)pyrene	ug/l	D5c	3.2	
Benzo(b)fluoranthene	ug/l	D5c	5.7	
Benzo(k)fluoranthene	ug/l	D5c	1.6	
Biochemical oxygen demand	mgO2/l	D1a, D1b, D2a, D5c,D6a	1.00	9.00
Boron	ug/l	All tested locations	480	8600
Cadmium	ug/l	All tested locations	0.12	0.39
Calcium	mg/l	All tested locations	100	470
Carbazole	ug/l	D5c	1.80	
Chloride	mg/l	All tested locations	140	1500
Chromium - Hexavalent	ug/l	D1a, D4a, D5a, D5c	0.22	0.58
Chrysene	ug/l	D5c	7.80	
Conductivity- Electrical 20deg	uS/cm	All tested locations	1500	5400
Copper	ug/l	All tested locations	1.10	8.20
Dibenzofuran	ug/l	D5c	6.60	
Dissolved Organic Carbon.	mg/l	All tested locations	5.90	43.0
Fluoranthene	ug/l	D5c	15.0	
Fluorene	ug/l	D5c	4.10	
Fluoride	mg/l	All tested locations	0.11	1.40
Hardness,Total as CaC03	mg/l	All tested locations	340	1200
Indeno(1,2,3-cd)pyrene	ug/l	D5c	1.00	
Iron	ug/l	All tested locations	430	1300
Kjedhal Nitrogen	mg/l	D4A, D5A, D5C, D6AC, D1B, D2A3	5.10	13.0
Lead	ug/l	D1b, D2a, D5c	2.50	5.60
Magnesium	mg/l	D1a, D1b, D2a, D5a, D5c	0.62	38.0
Manganese	ug/l	All tested locations	3.90	210
Mercury	ug/l	All tested locations	3.70	36.0
Naphthalene	ug/l	D5c	22.0	
Nickel	ug/l	All tested locations	1.10	18.0
Nitrate as N	mg/l	D4a, D5a	0.70	1.70
Nitrate as NO3	mg/l	D4a, D5a	3.10	7.50
Nitrite as NO2	mg/l	D1a, D4a, D6a	0.03	0.04
Nitrogen	mg/l	All tested locations	5.10	13.0
Nitrogen total organic as N	mg/l	D4a, D5a	0.70	1.70
pH	-	All tested locations	8.30	10.1
Phenanthrene	ug/l	D5c	15	
Phosphates	mg/l	All tested locations	0.07	0.36
Phosphorus as P	mg/l	All tested locations	0.10	0.12
Potassium	mg/l	All tested locations	21.0	310
Pyrene	ug/l	D5c	8.30	

Table 5-3 continued

Chemical Determinant	Unit	Locations	Min Value	
Selenium	ug/l	All tested locations	7.00	96.0
Sodium	mg/l	All tested locations	140	530
Solids, Suspended	mg/l	All tested locations	520	25000
Sulphate as SO4	mg/l	All tested locations	460	740
Zinc	ug/l	All tested locations	21.0	68.0

6 Summary and assessment of Geotechnical Risk

The ground investigation has demonstrated that the overall geological succession does not vary significantly across the site out with those areas in which landfill materials have been deposited. The general vertical succession with increasing depth comprises Made Ground, Tidal Flat Deposits, Glaciofluvial deposits and bedrock. Material descriptions and testing have been interpreted in order to determine characteristic parameters for use in the design of the proposed flood defences.

A summary of geotechnical risks for each element of the scheme and proposed mitigation measures for design is provided in Table 6-1.

Table 6-1 Geotechnical risk Register

Sections affected	Geotechnical Risk	Consequence	Proposed Mitigation
3, 5 & 6	Bearing capacity failure during placement of the rock armour revetment.	Failure during construction, injury or death, increased construction cost.	Ground investigation has identified ground conditions and determined parameters for use in design. This enables risk of low bearing capacity to be managed in design.
1, 2, 3, 4, 5 & 6	Excessive settlement beneath the rock armour revetment or embankments.	Failure to maintain flood protection level.	Ground investigation has identified ground conditions and determined parameters for use in settlement analysis. Revetment and embankment crest levels to be constructed to accommodate anticipated settlement over the design life.
1, 2 & 4	Seepage through earth embankments.	Failure to maintain required level of flood protection.	Ground investigation has identified ground and groundwater conditions to enable seepage risk to be managed in design. Seepage cutoffs/ impermeable fill will be specified as required.

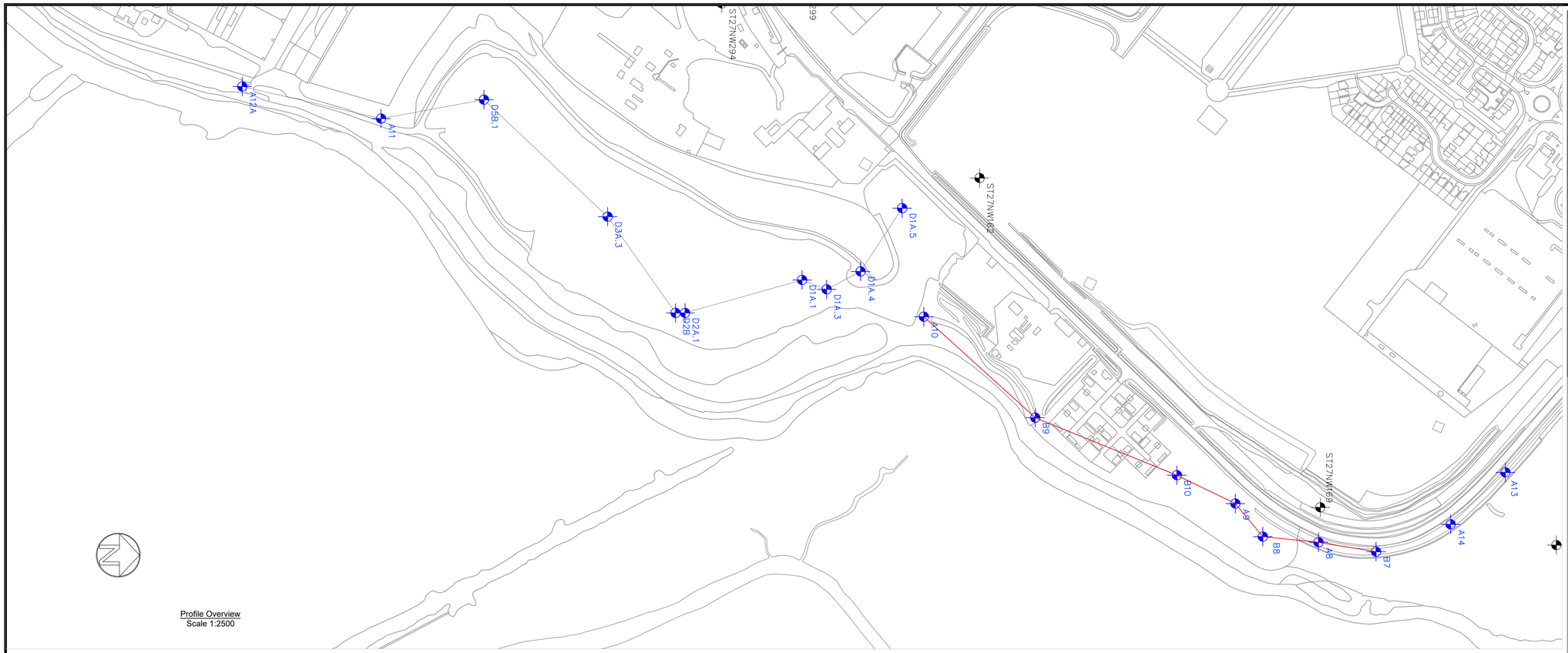
Table 6-1 (continued)

Sections affected	Geotechnical Risk	Consequence	Proposed Mitigation
3 & 4	Insufficient embedment of sheet piles due to obstructions or hard driving conditions.	Failure of sheet piles due to erosion resulting in instability in retained ground and failure to maintain flood protection level.	Ground investigation has identified ground conditions which may prove problematic for sheet piles (bedrock & dense Glaciofluvial deposits). The design will include and accommodate these restrictions.
1, 2, 3 & 4	Riverbank erosion/ slope failure resulting.	Riverbank failure resulting in failure of the flood defence.	Ground investigation has identified ground conditions and parameters for slope stability analysis. Environmental constraints limit the engineering solutions possible. JBA to develop options and agree approach that balances the needs of project stakeholders.
1, 2, 3, 4, 5 & 6	Variable ground conditions that do not meet requirements of the design.	Failure to maintain flood protection level or redesign required	Ground investigation has determined that, overall ground conditions do not vary significantly. However, there remains the potential for variability within Made Ground deposits. This risk will be mitigated, as far as possible, in design.
1, 2 & 4	Rapid drawdown conditions following a flood event	Rapid drawdown conditions initiate failure of flood embankment resulting in failure to maintain crest level.	Ground investigation has determined ground conditions and parameters for use in rapid drawdown analysis. Embankment side slopes to be constructed to resist rapid drawdown failure
4	Ponding of water behind new flood defence embankments	Increased flood risk on dryside	Design to include suitable drainage through the new embankments as required.

Appendices

A Quantum Geotechnic Limited Factual Report

B Exploratory Hole Plan and Geological Long Sections



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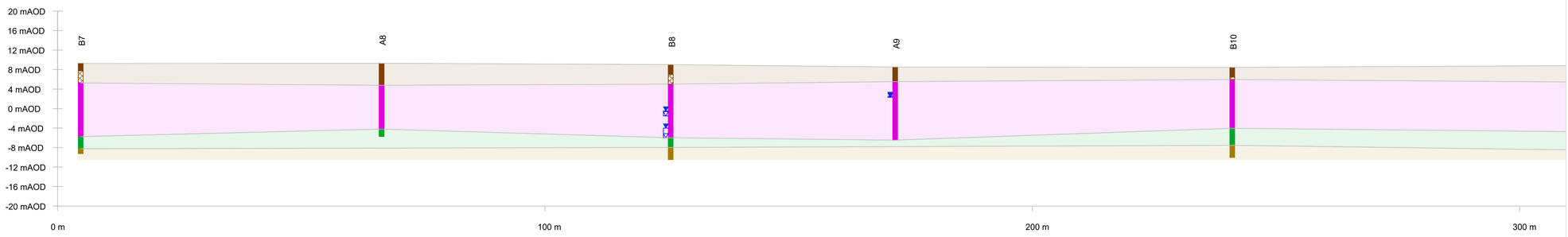
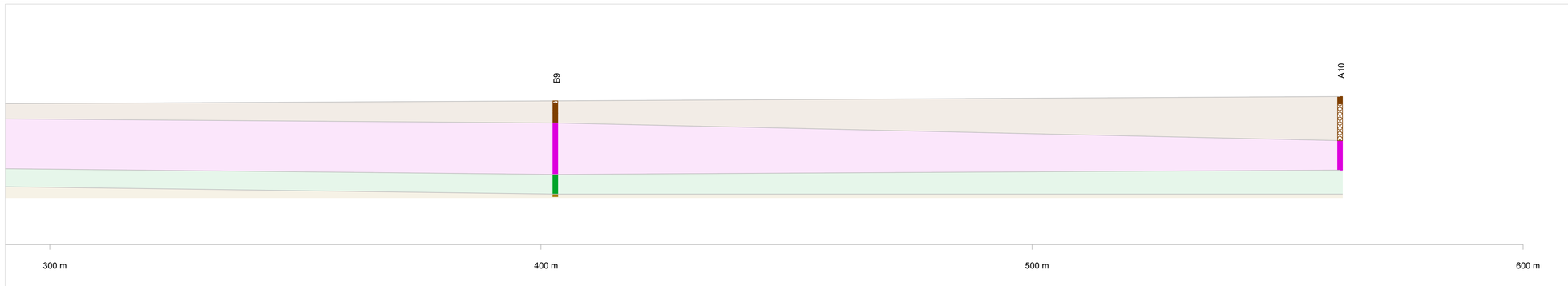
Geological Profile
Scale 1:500





No.	Construction Risk	Maintenance Risk	Demolition Risk
1			
2			

In addition to the hazards/risks normally associated with the types of work detailed on this drawing take note of the above.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION BOX

Drawing Notes

1. This drawing is to be read in conjunction with:-

LEGEND

- GLACIAL FLUVIAL
- MUDSTONE
- TIDAL FLAT DEPOSITS
- CLAY
- MADE GROUND (NOT SPECIFIED)
- GRANULAR MADE GROUND
- COMPOSITE MADE GROUND
- WATER LEVEL
- EXISTING BOREHOLE
- JBA BOREHOLE

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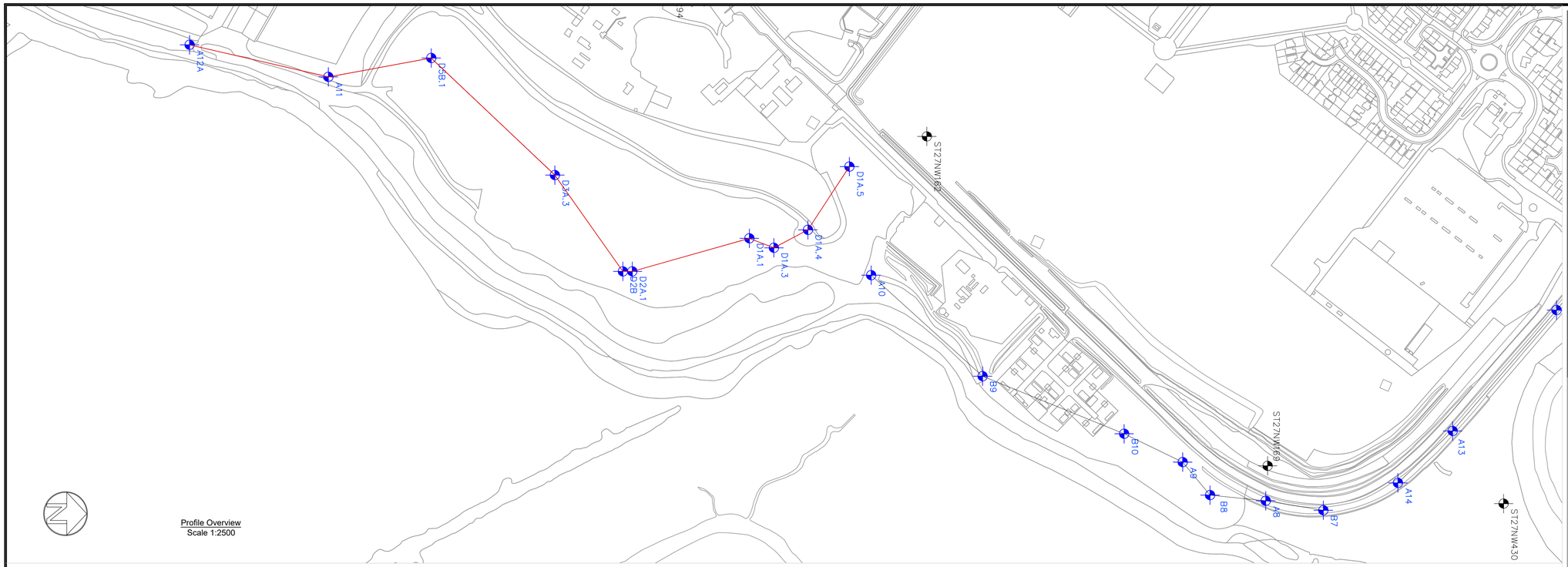
Project
2019s0183 - Cardiff Coastal Design

Title
Ground Investigation Report
Rover Way
for
Client
Cardiff Council

Drawn: KSSahajpal 03/08/2020	Designed: RVarga-Schembri 07/07/2020		
Checked: RVarga-Schembri 03/08/2020	Approved: JHoward 03/08/2020		
Project Reference 2019s0183	Scale: As Shown @ A1		
Drawing Number: 0001	Status: S3	Revision: P01.01	Sheet Size: A1



Profile Overview
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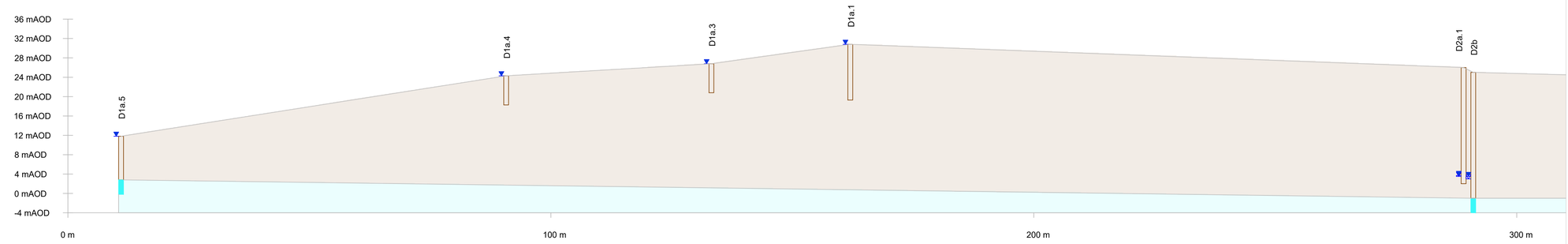
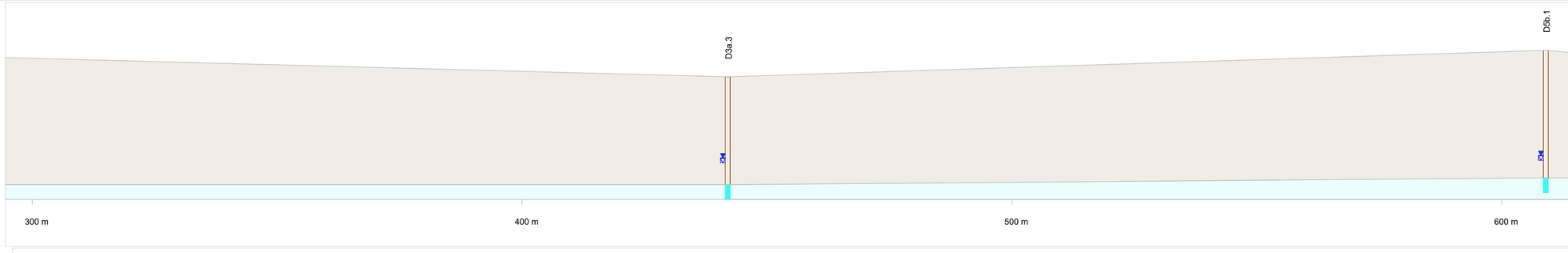
Geological Profile
Scale 1:500





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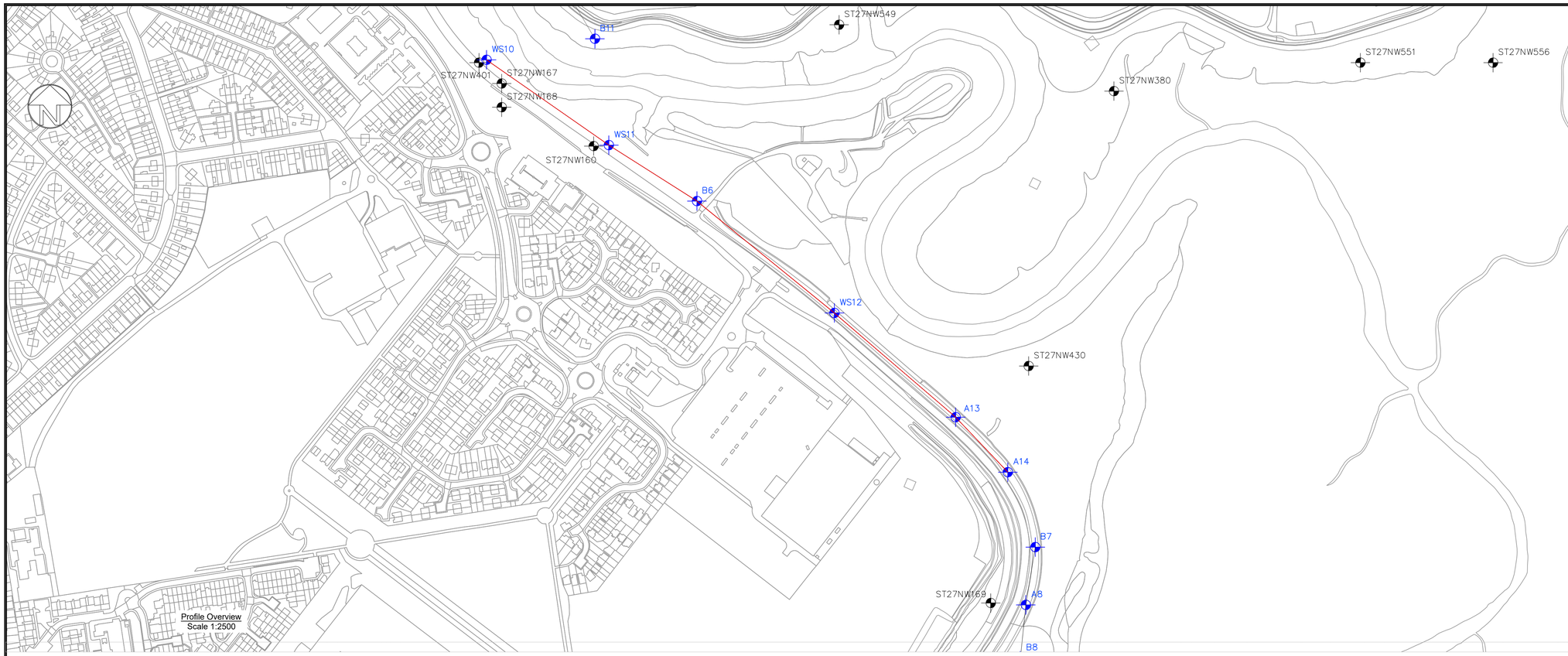
Project
2019s0183 - Cardiff Coastal Design

Title
Ground Investigation Report
Frag Tip
for

Client
Cardiff Council

Drawn:	KSSahajpal	03/08/2020	Designed:	RVarga-Schembri	07/07/2020
Checked:	RVarga-Schembri	03/08/2020	Approved:	JHoward	03/08/2020
Project Reference	2019s0183		Scale:	As Shown @ A1	
Drawing Number:	0002		Status: S3	Revision: P01	Sheet Size: A1



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Geological Profile
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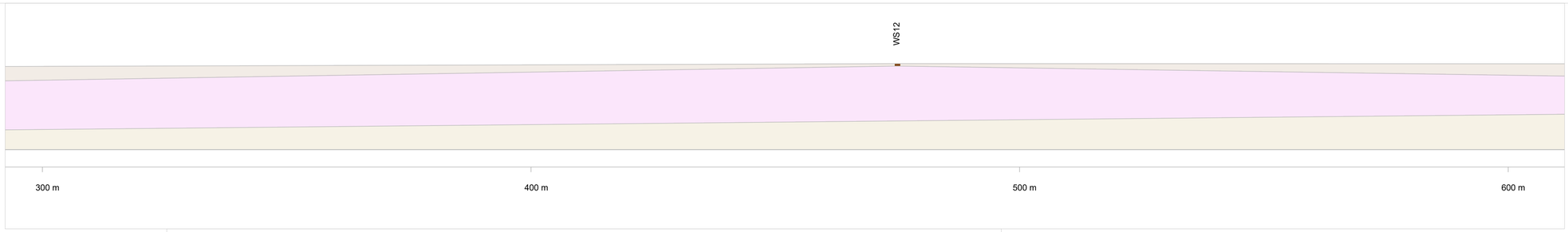

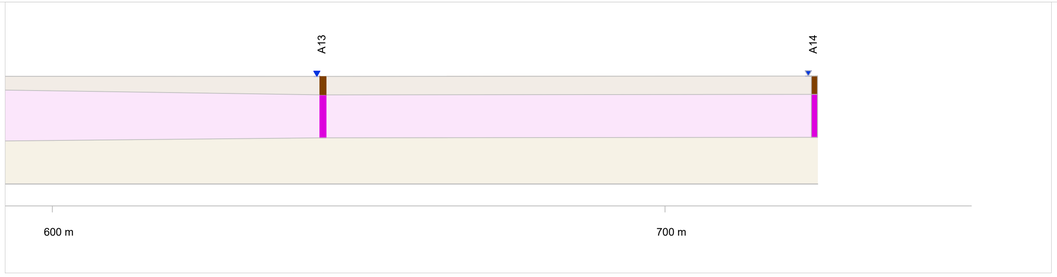

No.	Construction Risk	Maintenance Risk	Demolition Risk
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SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION BOX

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DRAFT

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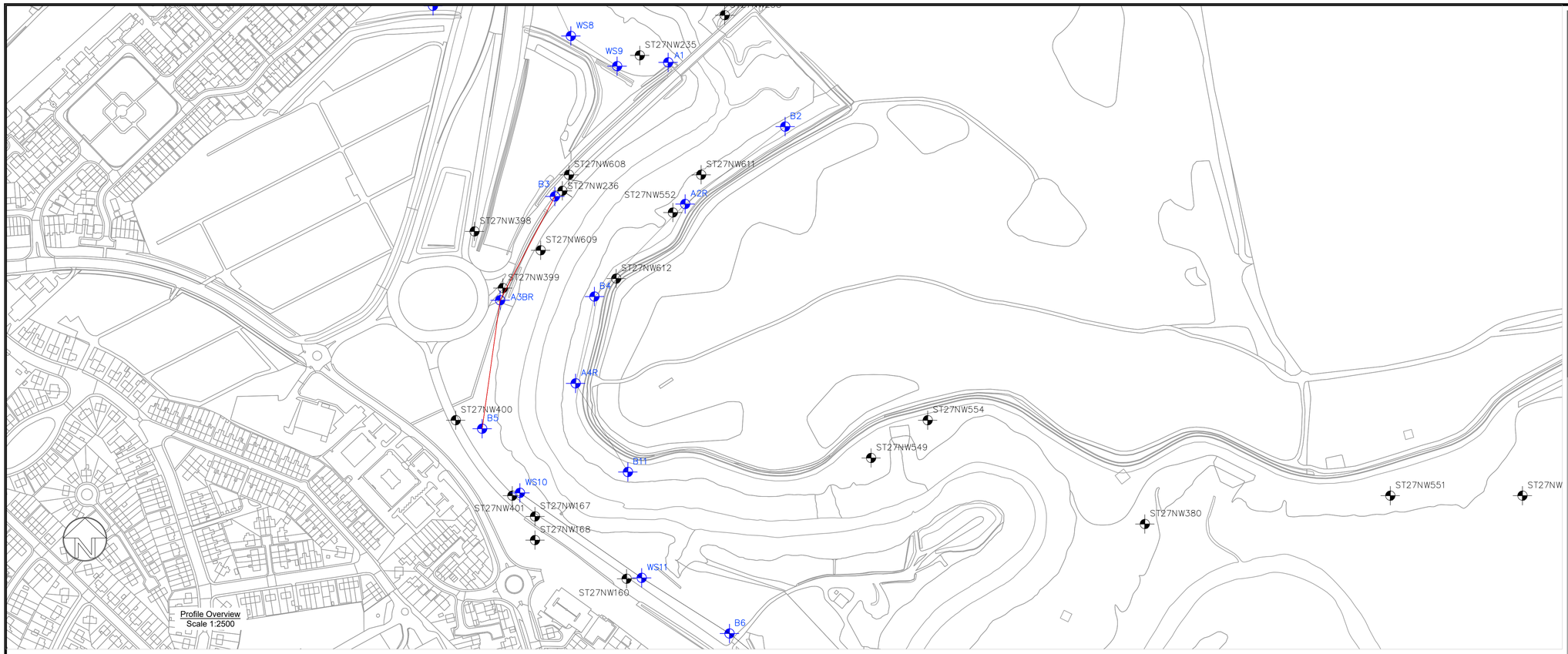
Checked: RVarga-Schembri 03/08/2020	Approved: JHoward 03/08/2020		
Project Reference 2019s0183	Scale: As Shown @ A1		
Drawing Number: 0003	Status: S3	Revision: P01	Sheet Size: A1



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Geological Profile
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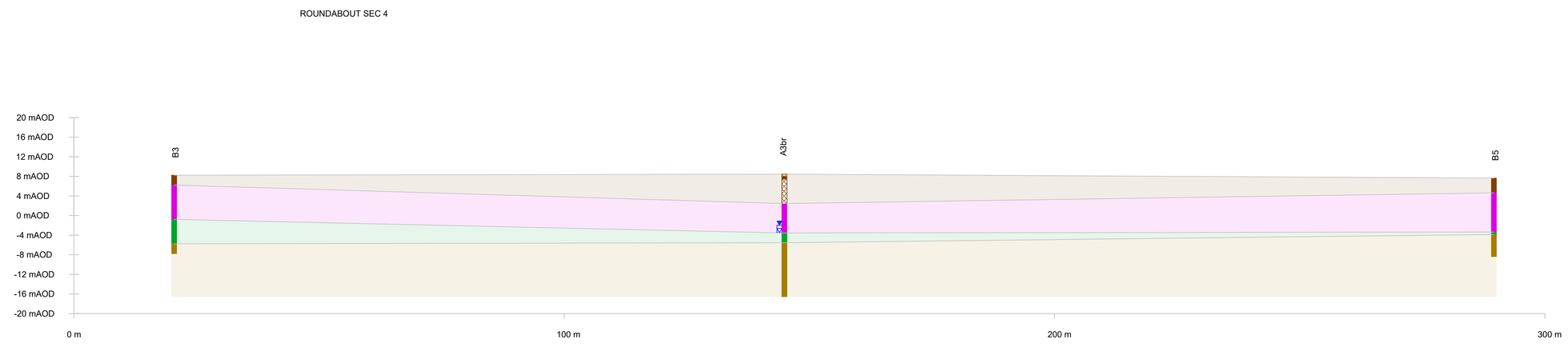

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- MADE GROUND (NOT SPECIFIED)
- GRANULAR MADE GROUND
- COMPOSITE MADE GROUND
- WATER LEVEL
- EXISTING BOREHOLE
- JBA BOREHOLE

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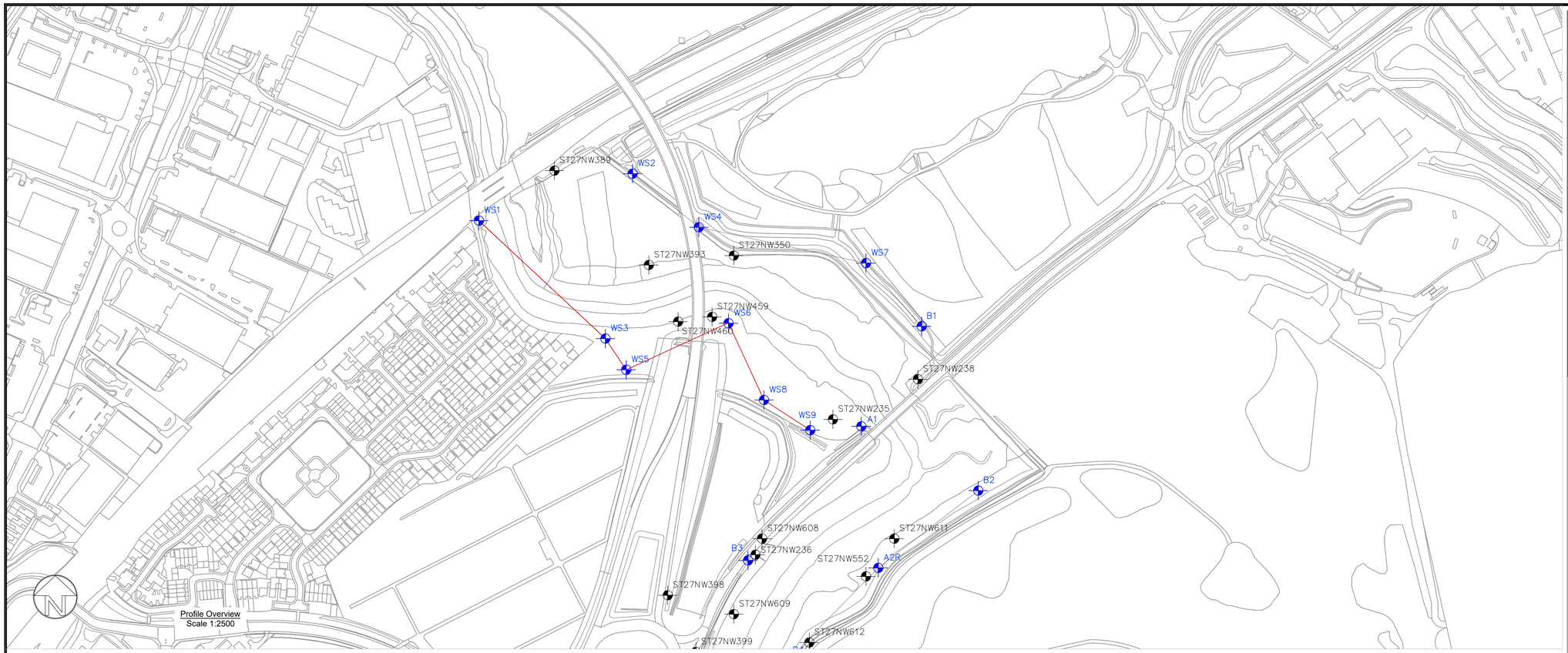
Project
2019s0183 - Cardiff Coastal Design

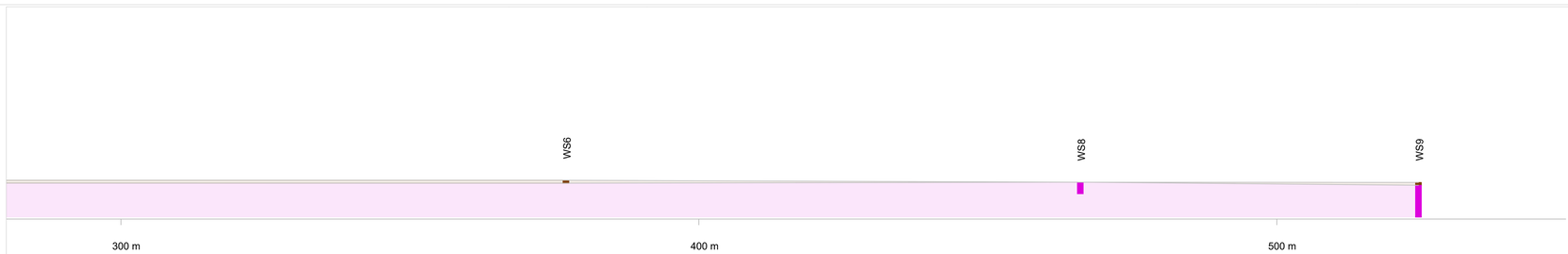
Title
Ground Investigation Report
Roundabout
for
Client
Cardiff Council

Drawn: KSSahajpal 03/08/2020	Designed: RVarga-Schembri 07/07/2020		
Checked: RVarga-Schembri 03/08/2020	Approved: JHoward 03/08/2020		
Project Reference 2019s0183	Scale: As Shown @ A1		
Drawing Number: 0004	Status: S3	Revision: P01	Sheet Size: A1



Profile Overview
Scale 1:2500

Geological Profile
Scale 1:500



No.	Construction Risk	Maintenance Risk	Demolition Risk
1			
2			

In addition to the hazards/risks normally associated with the types of work detailed on this drawing take note of the above.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION BOX

Drawing Notes

1. This drawing is to be read in conjunction with:-

LEGEND

- GLACIAL FLUVIAL
- MUDSTONE
- TIDAL FLAT DEPOSITS
- CLAY
- MADE GROUND (NOT SPECIFIED)
- GRANULAR MADE GROUND
- COMPOSITE MADE GROUND
- WATER LEVEL
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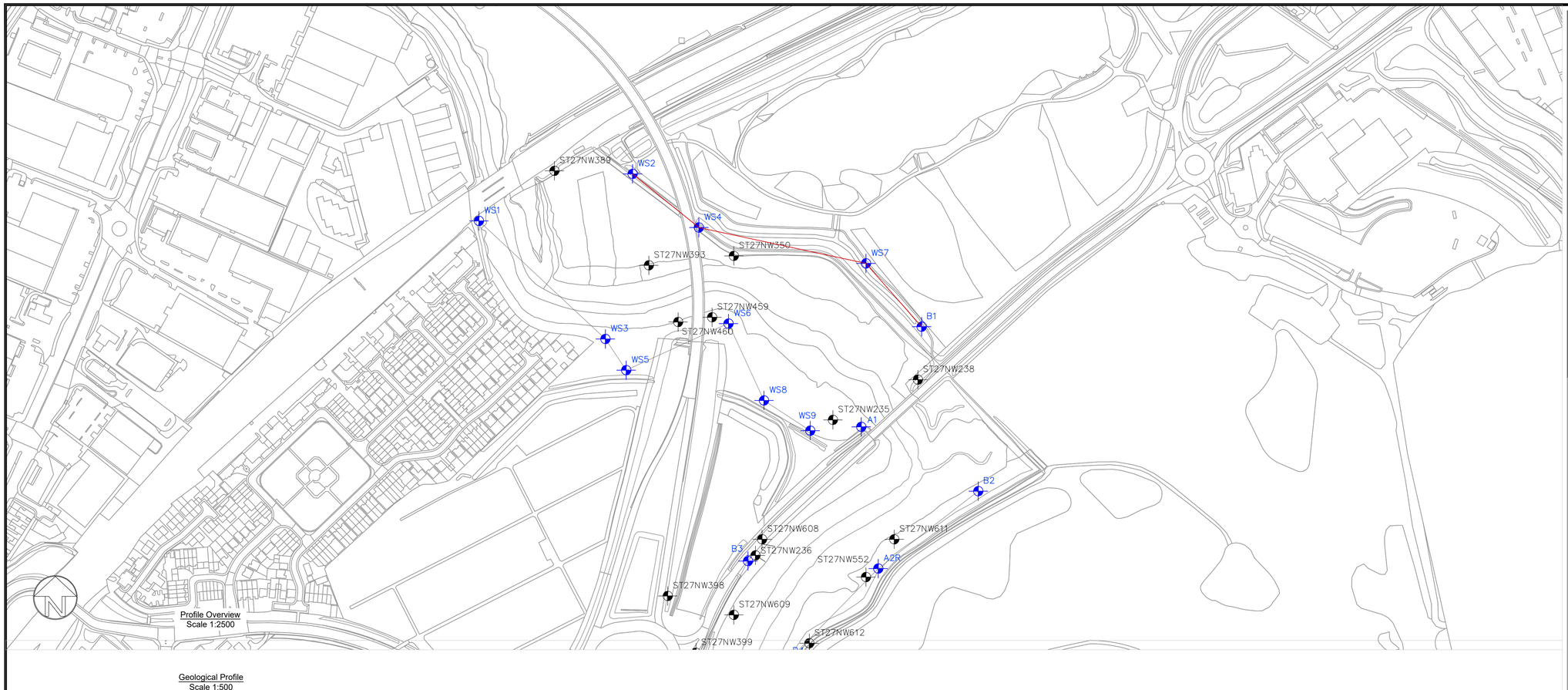
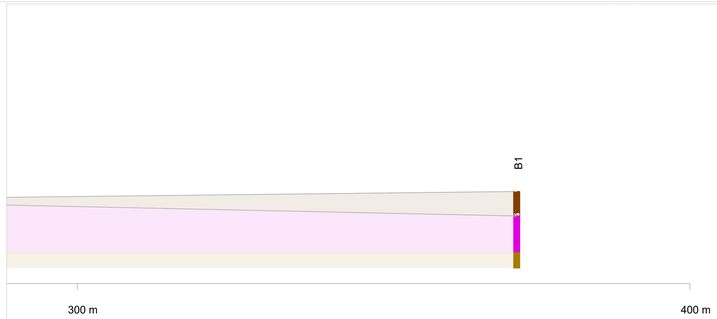
Project
2019s0183 - Cardiff Coastal Design

Title
Ground Investigation Report
Windsor Gardens
for
Client
Cardiff Council

Drawn: KSSahajpal 03/08/2020	Designed: RVarga-Schembri 07/07/2020		
Checked: RVarga-Schembri 03/08/2020	Approved: JHoward 03/08/2020		
Project Reference 2019s0183	Scale: As Shown @ A1		
Drawing Number: 0005	Status: S3	Revision: P01.01	Sheet Size: A1



Geological Profile
Scale 1:500



No.	Construction Risk	Maintenance Risk	Demolition Risk
1			
2			

In addition to the hazards/risks normally associated with the types of work detailed on this drawing take note of the above.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION BOX

Drawing Notes

1. This drawing is to be read in conjunction with:-

LEGEND

- GLACIAL FLUVIAL
- MUDSTONE
- TIDAL FLAT DEPOSITS
- CLAY
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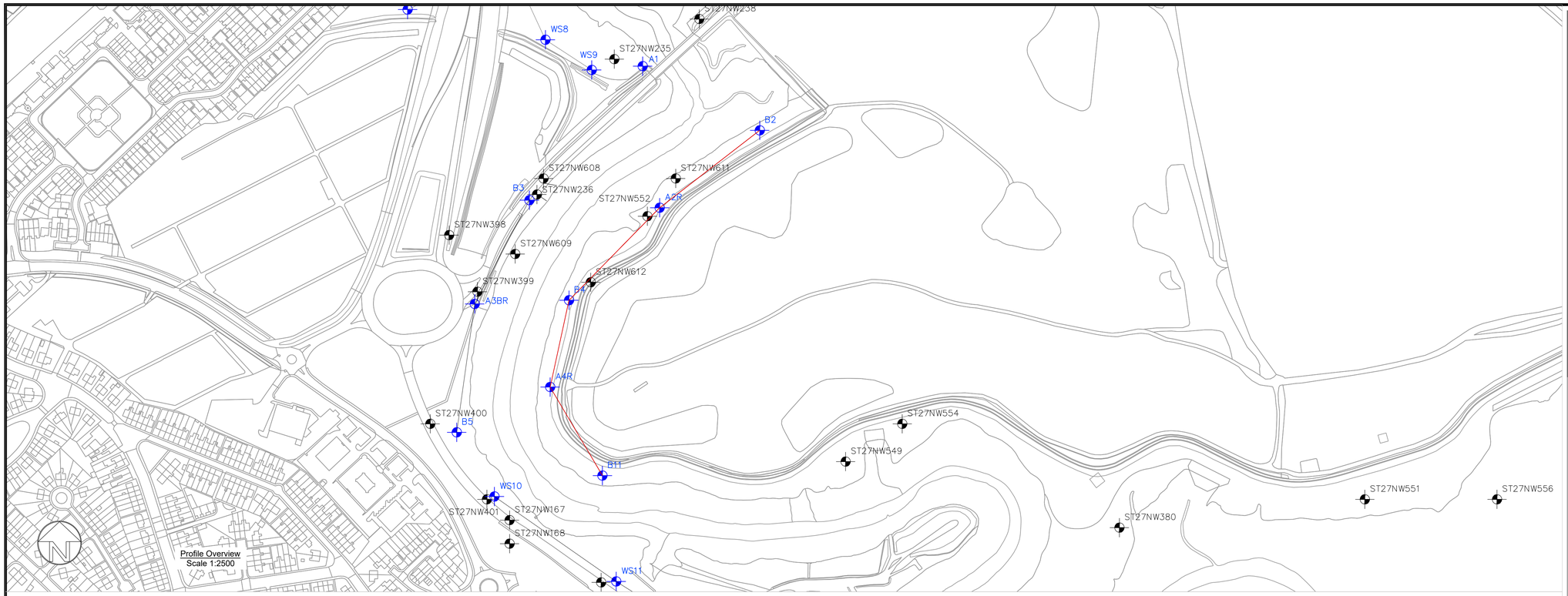
DRAFT

Project
2019s0183 - Cardiff Coastal Design

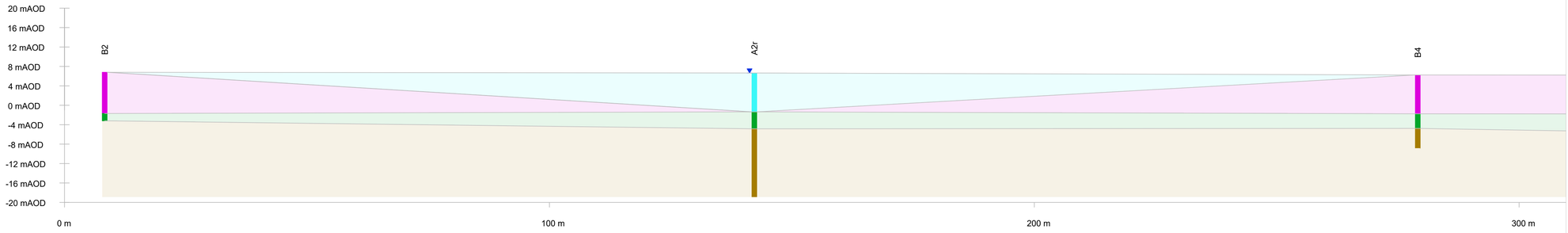
Title
Ground Investigation Report
Park
for
Client
Cardiff Council

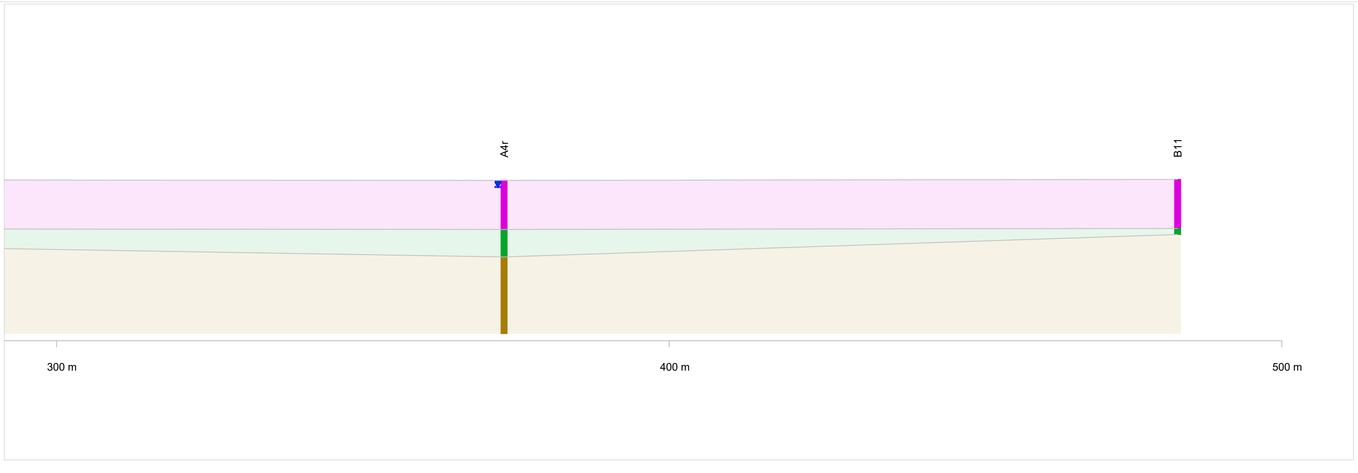
Drawn: KSSahajpal 03/08/2020	Designed: RVarga-Schembri 07/07/2020		
Checked: RVarga-Schembri 03/08/2020	Approved: JHoward 03/08/2020		
Project Reference 2019s0183	Scale: As Shown @ A1		
Drawing Number: 0006	Status: S3	Revision: P01.01	Sheet Size: A1



Profile Overview
Scale 1:2500

Geological Profile
Scale 1:500





No.	Construction Risk	Maintenance Risk	Demolition Risk
1			
2			

In addition to the hazards/risks normally associated with the types of work detailed on this drawing take note of the above.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION BOX

Drawing Notes

1. This drawing is to be read in conjunction with:-

LEGEND

- GLACIAL FLUVIAL
- MUDSTONE
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- CLAY
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Project
2019s0183 - Cardiff Coastal Design

Title
Ground Investigation Report
Lambey Way
for
Client
Cardiff Council

Drawn: KSSahajpal 03/08/2020	Designed: RVarga-Schembri 07/07/2020		
Checked: RVarga-Schembri 03/08/2020	Approved: JHoward 03/08/2020		
Project Reference 2019s0183	Scale: As Shown @ A1		
Drawing Number: 0007	Status: S3	Revision: P01	Sheet Size: A1

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