Appendix E.2
Geotechnical Report - GIR

Ground Investigation Report

Lucan to City Centre CBC06
BCIDA-ACM-ERW_GI-0006_XX_00-RP-CE-0001

Client - National Transport Authority

Project number: 60599126
BCIDA-ACM-ERW_GI-0006_XX_00-RP-CE-0001

22 December 2020

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1. Introduction

1.1 Scope and objective of the report

The BusConnects Dublin - Core Bus Corridors Infrastructure Works (herein after called the CBC Infrastructure Works) involves the development of continuous bus priority infrastructure and improved pedestrian & cycling facilities on sixteen radial core corridors in the Greater Dublin Area,

The National Transport Authority (NTA) have appointed AECOM in association with Mott Macdonald to undertake the design of the infrastructure works for Package A of the BusConnects Programme. Package A includes the following four Core Bus Corridors (CBC):

- Clongriffin to City Centre (CBC 01);
- Lucan to City Centre (CBC 06);
- Clondalkin to Drimnagh (CBC 08); and
- Tallaght to City Centre (CBC 09).

This Ground Investigation Report (GIR) has been prepared in support of the scheme preparation for CBC 06 Lucan to City Centre.

The geotechnical input to the scheme follows the procedures set out in TII Managing Geotechnical Risk DN-ERW-03083

The report provides a summary of the desk study and commentary on the findings of ground investigations that have been undertaken for the proposed route. A summary of factual data, which have been gathered for the scheme, is provided with interpretation of design parameters.

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

- Preliminary Sources Study Report: Bus Connects Corridor Route 06 Lucan to City Centre dated December 2019 and herein referred to as the PSSR.

One specific preliminary ground investigation has been undertaken to date as follows:

- Bus Connects Route 6 Lucan to City Centre conducted between 24th September and 24th October 2020

The above preliminary ground investigation was carried out, by Causeway Geotech, to inform the geotechnical design of key structures in support of the planning application. A further stage of preliminary investigation is proposed following submission of the planning application.

This Ground Investigation Report is based on the results of the above ground investigation.

The report uses the scheme chainage system shown on the proposed alignment plan included in Appendix A.

1.2 Description of the project (including site description)

This Ground Investigation Report is based on the proposed route alignment shown on the drawing contained within Appendix A.

1.2.1 Site description

Table 1 summarises the proposed works to CBC 06.

Table 1. CBC 06 Scheme, Bridges and Structures

Earthworks Reference/Chainage	High Level General Description	Relevant Structures Reference and Drawings
Section 1 N4 Junction 3 Ballyowen Road to Hermitage Golf Course (Ch A0 - A500)	Lucan Road: Widening on Lucan Road localised pavement reconstruction N4 Outbound off-ramp :Pavement reconstruction works from widening on outbound N4 off ramp	
Section 2 Hermitage Golf Course to N4 Junction 2 off ramp (Ch A500 to A1300)	N4 Inbound: Widening at Hermitage Golf Course for two-way cycle track, removal & reconstruction of boundary wall, removal and replanting of new trees, new golf screen netting. N4 Outbound: Localised pavement works on N4 outbound direction.	CBC06-RW04 Retaining Wall – drawing: BCIDA-ACM-SPW_SQ-0006_RW_00-DR-CR-0001 CBC06-RW01 Hermitage Golf Club Retaining Wall – drawing: BCIDA-ACM-STR_GA-0006_RW_01-DR-CB-0101
Section 3 Junction 2 off ramp to Old Lucan Road (Global Ch A1300 to A1650/ Local Ch E0 to E305 & F0 to F149)	Inbound off-ramp: Widening for new two-way cycle track at grade. N4 inbound: Removal of existing bus stop	
Section 4 Old Lucan Road to Liffey Valley Interchange (Global Ch A1650 to A2150/ Local Ch G0 to G522)	Lucan Road: New two way cycle track at grade. N4 inbound on-ramp: At grade widening for pavement reconstruction for Bus Lane	
Section 5 Liffey Valley Interchange to M50 Junction (Global Ch A2100 - A2550/ Local Ch H0 to H295)	Lucan Road: New two-way cycle track at grade on Old Lucan Road. New cycle links at existing bridge from old Lucan Road to N4. minor retaining walls may be required for new links. N4 Inbound: At grade widening for bus stop lay-by pavement construction & new bridge foundations - shallow foundations on rock or mini piles to relatively shallow rock. N4 outbound : 200m long 2.5 - 3.5m high retaining wall & widening for bus stop lay-by pavement construction & new bridge foundations . Removal of existing bridge ramp (Ch2400) and reinstatement [Outbound side].	CBC06-ST01 N4 Pedestrian Bridge-Drawing: BCIDA-ACM-STR_GA-0006_BR_03-DR-CB-0101 CBC06-RW01 N4 Retaining Wall - Drawing: BCIDA-ACM-STR_GA-0006_RW_03-DR-CB-0101
Section 6 M50 Junction to Kennelsfort Road (Global Ch Ref: A2550 - A3600/ Local Ch Ref I200 to J750)	New two-way cycle track at grade on Old Lucan Road. R148 Inbound/outbound: Localised widening and pavement works throughout	

Earthworks Reference/Chainage	High Level General Description	Relevant Structures Reference and Drawings
Section 7 Kennelsfort Road Bridge & Junction to Chapelizod Bypass (Global Ch Ref A3600 - A4300/Local Ch Ref J750 to L300)	Old Lucan Road: New two-way cycle track at grade on Old Lucan Road. R148 Inbound/outbound: Localised widening and pavement works throughout Kennelsfort Road Bridge: At grade widening for pavement construction for junction/bus stop lay-by's & new bridge ramp foundations	
Section 8 Chapelizod Bypass - Old Lucan Road to Chapelizod Hill Road (Global Ch A4300 - A5550)	Inbound/outbound: Erection of signage for speed limit change.	
Section 9 Chapelizod Bypass Chapelizod Hill Road Bus Stop (Global Ch A5550 - A5650)	Inbound: New bridge structure adjacent to existing & earthworks retaining ramp structure - likely reinforced soil embankment. Outbound: Earthworks retaining ramp structure - likely reinforced soil embankment	CBC006-ST02 Chapelizod Hill Road Bridge Widening – drawing :BCIDA-ACM-STR_GA-0006_BR_06-DR-CB-0101
Section 10 Chapelizod Hill Road Bus Stop to Con Colbert Road (Global Ch A5650 - A7550)	Inbound/outbound: Erection of signage for speed limit change.	
Section 11 Con Colbert Road to Heuston Station (Global Ch A7550 - A9618	Inbound/outbound: At grade widening for cycle track & junction modifications	

1.3 Geotechnical Category of the Project

IS EN 1997-1 includes three geotechnical categories that may be introduced to establish the geotechnical design requirements.

- Geotechnical Category 1 is for small and relatively simple structures with negligible risk. These procedures should only be used where there is negligible risk in terms of overall stability or ground movement and in ground conditions, which are known from comparable local experience to be sufficiently straightforward. Additionally, in order to use these Category 1 procedures there must be no excavation below the water table.
- Geotechnical Category 2 is for conventional types of structure and foundations with no exceptional risk or difficult loading conditions. This includes spread footing, raft foundations, piled foundations, walls or other structures retaining or supporting water, excavations, bridge piers and abutments, embankments and earthworks, ground anchors and other systems and tunnels in hard, non-fractured rock and not subjected to special water tightness or other requirements.
- Geotechnical Category 3 includes structures or parts of structures, which fall outside the limits of Geotechnical Categories 1 and 2. This includes very large or unusual structures involving abnormal risks or unusual loading conditions, structures in high seismic areas and structures in area of probable site instability or persistent ground movements that require separate investigation or special measures.

Considering the guidance in IS EN 1997-1, it is considered that Geotechnical Category 2 is currently the most appropriate for the Scheme.

1.4 Other relevant information

The ground investigation is split into different phases of investigation. The initial phase was concerned with carrying out testholes at key locations to inform design to facilitate the planning phase of the project. It is anticipated that additional ground investigation, locations and spacings generally conforming to guidelines of EC7, will be carried out at later date.

2. Existing Information

2.1 Topographical maps

A review and commentary of Topographical features along the route alignment is contained in the PSSR.

2.2 Geological Maps and memoirs

The available Solid and Drift Geological Map Sheets were reviewed along the proposed route corridor during the Preliminary Sources Study Reports. Information and map excerpts from this review are provided in the PSSR.

2.3 Aerial Photographs

Available aerial photographs for the route were reviewed and described in the PSSR.

2.4 Records of mines and mineral deposits

A review and commentary on mining and mineral deposits along the route alignment is contained in the PSSR.

2.5 Land Use and Soil Survey

The predominant land use along the proposed route is existing road and footpath infrastructure in an urban environment. Some widening is expected into existing public, residential and commercial properties.

2.6 Archaeological and Historical Investigations

Information on historical investigations is available in the PSSR,

2.7 Existing Ground Investigations

A review of existing ground investigation information was undertaken and is available in the PSSR.

2.8 Consultation with Statutory Bodies and Agencies

To be updated in a further revision.

2.9 Flood Records

Information on flood records is available in the PSSR.

2.10 Contaminated Land

Both former and present land use may have resulted in the presence, along the proposed route corridor, of potentially toxic or other hazardous material, which may pose a threat to human health, controlled waters or other sensitive receptors.

The PSSR collected information on potentially contaminative land use within the route corridor.

Contamination testing was undertaken on Made Ground encountered during the 2020 investigation. Contamination testing consisted of the following:

- Rialta Suite
- Suite E soil samples

2.11 Other Relevant Information

2.11.1 Hydrology

Information on hydrology over the route extents is available in the PSSR.

2.11.2 Groundwater Vulnerability

Information on groundwater vulnerability over the route extents is available in the PSSR.

2.11.3 Hydrogeology

Information on hydrogeology over the route extents is available in the PSSR.

2.11.4 Landslides

According to the Geological Survey of Ireland (GSI) records, there are no recorded landslides along the proposed route.

3. Field and Laboratory Studies

3.1 Walkover Survey

Site walkovers were carried out along the proposed route extents, prior to the undertaking of the Preliminary Ground Investigations. The primary purpose of the site walkover was a review of access and limitations to access for ground investigation plant. The geotechnical constraints of the scheme were also reviewed.

3.2 Geomorphological/Geological Mapping

No mapping has been undertaken.

3.3 Ground Investigation

To date, one project specific ground investigation has been undertaken, by Causeway Geotech, as follows:

- Bus Connects Route 6 Lucan to City Centre conducted between 24th September and 24th October 2020

AECOM GIR Drawings in Appendix B show the ‘as-built’ exploratory hole locations undertaken for the ground investigations referenced above.

3.3.1 Description of Fieldwork

In general, the ground investigations utilised the following exploratory techniques:

- Cable percussion (CP) boring sunk using shell and auger techniques. This technique was used to investigate the superficial ground conditions, undertaking in-situ testing and taking undisturbed and disturbed samples for geotechnical/geochemical laboratory testing. Typically, CP boreholes were terminated on encountering refusal on very dense/stiff soils, boulders or weathered bedrock, or at a predefined depth based on the design and construction requirements for the proposed structure/earthwork.
- Rotary drilling both with and without core recovery. Generally, when using rotary drilling within soils standard penetration tests (SPTs) were taken at regular intervals below the depth attained by the CP boring.
  - Rotary drilling without core recovery (RO) was typically used to identify rockhead level and extend CP boreholes to rockhead when the CP could not advance due to obstructions (i.e. very dense/stiff soils or boulders).
  - Rotary drilling with core recovery (RC) was typically used in soils to extend CP boreholes beyond obstructions (i.e. very dense/stiff soils or boulders), where more soil information was required than would be recovered by RO methods. The use of a geotechnical wireline triple tube core barrel S-size (“Geobor”) allowed recovery of good quality (Class 1) samples.

    RC was typically used in rock to provide information on the rock (i.e. lithology, discontinuities, strength, etc.) and recover core samples suitable for laboratory testing.
- Groundwater monitoring standpipes, installed to identify groundwater levels, provide water samples for geochemical testing and monitor groundwater flow.
- Machine excavated trial pits sunk to identify the near surface ground conditions and, at specific locations, to identify whether there was any archaeological significance. Disturbed samples and, where contamination was suspected, environmental samples were recovered from the trial pits to allow for geotechnical and geochemical testing. In-situ hand vane testing was also carried out in suitable cohesive soils. Dynamic Cone Penetrometers (DCPs) were carried out adjacent to trial pits to provide a profile of penetration with depth and to a derive a CBR value.

- Window sampling boreholes at locations, which were unsuitable to access by means of CP rigs, RC rigs or excavators; the window sampling rig was smaller and easier to mobilise to difficult locations. The window sampler was used to identify superficial ground conditions, taking disturbed samples for geotechnical/ geochemical testing and carrying out SPTs. Typically, the window sampling boreholes were terminated on very dense/stiff soils or on possible boulders or bedrock.

3.3.1.1 CBC 06 September 2020 Investigation

Site operations, which were conducted between 24th September and 24th October 2020, comprised:

- Thirteen boreholes (R6CP01-R6CP11 and R6WS01-R6WS02) were put down in a minimum diameter of 150mm through soils and rock strata to their completion depths by a combination of methods, including light percussion boring using Dando Terrier rigs, light cable percussion boring by Dando 2000 rigs, and rotary drilling (by Hanjin D8 rotary drilling rigs).
- Six boreholes (R6-CP01, R6-CP03 and R6-CP08 – R6-CP11) were put down to completion in minimum 200mm diameter using Dando 2000 light cable percussion boring rigs. All boreholes were terminated on encountering virtual refusal on obstructions.
- One borehole (R6-CP07) was put down by a combination of light percussion boring and rotary follow-on drilling techniques with core recovery in bedrock. Where the light percussion borehole had not been advanced onto bedrock, rotary percussive methods were employed to advance the borehole to completion/bedrock. Symmetrix cased full-hole drilling was used, with SPTs carried out at standard intervals as required.
- Six boreholes (R6-CP02, R6-CP04 – R6-CP06, R6-WS01 & R6-WS02) were put down to completion by light percussion boring techniques using a Dando Terrier dynamic sampling rig. The boreholes were put down initially in 150mm diameter, reducing in diameter with depth as required, down to 50mm by use of the smallest sampler.
- One slit trench (R6-TP01) was excavated by a combination of hand digging and mechanical excavation using a compact 3t tracked excavator fitted with a 600mm wide toothless bucket, to locate and identify buried services at the site. An attempt was also made to investigate foundations of existing bridge abutments at this location.
- A groundwater monitoring standpipe was installed in R6-CP07.

3.3.2 Ground Investigation Factual Reports

The results of the factual geotechnical report are available at:

- Causeway Geotech Report No: 20-0399D Bus Connects Route 6 Lucan to City Centre dated December 2020

3.3.3 Results of in-situ tests

The in-situ testing undertaken during the ground investigation comprised of standard penetration testing (SPT) and dynamic probing.

The results of the in-situ testing are included in the relevant ground investigation factual reports as listed in Section 4.3.2, and summarised in Section 5.0 of this report (where applicable), with relevant charts presented in Appendix C.

3.4 Drainage Studies

Not used

3.5 Geophysical Studies

Not used

3.6 Pile Tests

Not Used

3.7 Other Field Work

Not used

3.8 Summary of Results of Laboratory investigation

A range of geotechnical, geochemical and contamination testing was undertaken on samples of soil, rock, groundwater recovered during the ground investigation. The geotechnical tests were typically carried out in Causeway Geotech's accredited laboratories located in the Ballymoney Co. Antrim. Environmental tests were generally carried out by Eurofins Chemtest Ltd.

A list of the laboratory tests undertaken across the ground investigations is presented in the following subsections, with results presented and discussed in Section 5, and charts provided in Appendix C.

The Ground Investigation Factual Report provides the laboratory test results/reports and details of the testing methods.

3.8.1 Description of tests

3.8.1.1 Soil Testing

Soils tests, undertaken as part of the ground investigation, include the following:

- Classification tests: moisture content, Atterberg Limits, and particle size distribution by wet sieving and sedimentation
- Compaction related tests: Moisture Condition Value (MCV)
- Shear strength (total stress): unconsolidated undrained, single stage triaxial tests on nominal 100mm diameter specimens prepared from U100 samples

3.8.1.2 Rock Testing

Rock tests, undertaken as part of the ground investigations, are detailed below:

- Point load strength tests
- Uniaxial compressive strength (UCS) tests

3.8.1.3 Chemical Testing

The following chemical tests were undertaken:

- pH
- Water soluble sulfate content
- Acid soluble sulfate content
- Total sulfur content

3.8.1.4 Contamination Testing

A suite of contamination testing was scheduled on selected soil and water samples recovered at various locations along the proposed scheme. The full lists of tests and the test results are included in the Ground Investigation Factual Report.

3.8.2 Summary of test results

The results of the test results are described in the Ground Investigation Factual Report. Where relevant the results of testing are discussed in Section 5 Ground Summary and Material Properties.

3.9 Evaluation of geotechnical information

A number of undrained triaxial tests were scheduled in the soil but not undertaken due to unsuitable sample. Similarly, UCS testing of rock core was not possible on all scheduled samples and was replaced with point load testing where applicable.

4. Ground Summary and Material Properties

4.1 Ground Conditions

4.1.1 Route summary

Diagrammatic geotechnical long sections have been prepared from the findings of the ground investigations along the route. These sections are presented on the drawings that form Appendix B.

The following lithologies have been assigned to the ground types encountered in the ground investigations:

- Topsoil (TS)
- Made Ground/Highway Fill (MG)
- Glacial Till (GT) deposits –subdivided into brown Dublin boulder Clay (br DBC), and black Dublin boulder clay (bl DBC).
- Sand and Gravel deposits (S&G)
- Glacial Till (GT) deposits –subdivided into brown Dublin boulder Clay (br DBC), and black Dublin boulder clay (bl DBC)..
- Bedrock (ROCK) – subdivided into Limestone (LMST)

Table 2 summarises the ground conditions encountered in Route 06 in approximate lithological order.

Table 2. CBC 06 Summary of soil units encountered

Stratum	Depth to Top of Stratum (m bgl)	Level at Top of Stratum (m AOD)	Thickness (m)
Topsoil	0	64.42 to 45.94	0.10 to .4
Made Ground	0 to 0.3	60.62 to 19.45	0.5 to 4.3*
Glacial Till	0.7 to 3**	59.62 to 22.13**	0.5 to 4.3*
Sands and Gravels	0.3 to 5.2	64.12 to 49.87	0.2 to 1*
Possible Rock	3.7 to 4.8	55.92 to 41.14	Not Cored
Limestone	7.6	48.45	3.1**

**not proven in all testholes*
***Glacial Till described as Possible Made Ground*
**** not proven*

The strata of each exploratory hole shown on the geotechnical long sections have been assigned to one of the above lithologies by considering:

- strata descriptions and laboratory test results;
- published geology and interpreted geomorphology; and
- topography in the area

The following sections of the report describe the general nature of the identified lithologies and the primary locations where they have been identified in the ground investigations.

4.1.2 Made Ground

Made ground is present in various areas along the length of the route corridor. Highway fill is associated with existing roads or areas of hard standing; it typically comprises general fill of reworked clay/silt/sands and selected fills formed by silty sandy gravels.

Paved surface: boreholes R6-CP10 & R6-CP11 encountered 0.3 m of macadam surfacing with approximately 1.0m of aggregate fill beneath the paved surfaces. In addition, R6-TP01 penetrated concrete down to 100mm. Concrete was encountered at 4.0mbgl in borehole

Made Ground (fill) comprising of reworked sandy gravelly clay fill occasionally with fragments of concrete extending to a maximum depth of 4.0m in R6-CP10. The main occurrences encountered in exploratory holes along the route, with approximate chainage are summarised in the following Table 3.

Table 3. CBC 06 occurrences of Made Ground

Approximate Chainage	Testhole	Depth range (m bgl)	Thickness (m)	Description
A 1288	R6-CP01	0.1 - 1	0.9 m	MADE GROUND: Soft brown sandy gravelly CLAY.
A 1522	R6-CP02	0.2 – 0.7	0.5 m	MADE GROUND: Grey angular to subangular fine to coarse GRAVEL of mixed lithologies
A 2199	R6-CP03	0.1 – 1	0.9 m	0.1 – 0.4 m bgl :MADE GROUND: Soft brown sandy gravelly CLAY. 0.4 -0.6 m bgl :MADE GROUND: Grey sandy subrounded GRAVEL of mixed lithologies 0.6 – 1 mbgl: MADE GROUND: Soft brown sandy gravelly CLAY.
A 2237	R6-CP04	0.10 – 1.7	1.6 m	MADE GROUND: Stiff brown sandy gravelly CLAY with high cobble content and concrete fragments.
A 2252	R6-CP05	0.1 – 1.9	1.8	MADE GROUND: Firm becoming stiff brown sandy gravelly CLAY with high cobble content.
A 2235	R6-CP06	0.1 – 1.8	1.7	0.1 – 0.6 m bgl : MADE GROUND: Grey sandy angular to subangular fine to coarse GRAVEL of mixed lithologies. 0.6 – 1.2 m bgl : MADE GROUND: Light grey angular to subangular fine to coarse GRAVEL of mixed lithologies. 1.2 – 1.80 m bgl : MADE GROUND: Loose light grey angular to subangular fine to coarse GRAVEL of mixed lithologies.
A 2242	R6-CP07	0.2 – 1	0.8	MADE GROUND: Firm brown sandy gravelly CLAY.
A 2150	R6-CP08	0 – 0.4	0.4	MADE GROUND: Soft brown sandy gravelly CLAY
A 3675	R6-CP09	0.3 – 3	2.7	0.3 – 1.2 m bgl : MADE GROUND: Soft to firm brown sandy gravelly CLAY 1.2 – 3 m bgl : MADE GROUND: Very soft brownish grey sandy gravelly CLAY
A 5596	R6-CP10	0 – 4	4	0 - 0.3 m bgl : BITMAC 0.3 – 1 m bgl : MADE GROUND: Black slightly sandy angular fine to coarse GRAVEL of limestone. 1 – 3 m bgl : MADE GROUND: Firm becoming stiff brown slightly sandy slightly gravelly CLAY. 3 – 4 m bgl : MADE GROUND: Very stiff brown sandy gravelly CLAY.
A 5622	R6-CP11	0 – 4.2	4.2	0 - 0.3 m bgl : BITMAC 0.3 – 1.1 m bgl : MADE GROUND: Black sandy angular fine to coarse GRAVEL of limestone. 1 – 3 m bgl : MADE GROUND: Firm becoming stiff brown slightly sandy slightly gravelly CLAY. 3 – 4 m bgl : MADE GROUND: Very stiff brown sandy gravelly CLAY.
A 5636	R6-TP01	0 -1.10	1.10	0 – 0.18 m bgl: MADE GROUND: Grey slightly sandy angular fine to coarse GRAVEL of limestone. 0 – 0.48 m bgl : MADE GROUND: Dark grey slightly sandy angular fine to coarse GRAVEL of limestone 0.48 – 1.10 m bgl :MADE GROUND: Brown slightly sandy clayey angular fine to coarse GRAVEL of limestone

4.1.3 Sands and Gravels

Underlying the topsoil, sands and gravels were encountered in R6-WS01 and R6WS-02. These testholes effectively refused at 1.4 and 0.87 m bgl, respectively. Published geological mapping indicate the superficial deposits are in an area of gravels derived from limestone.

A 0.9 m thick loose brown gravelly silty fine to coarse sand was encountered at 0.4 m bgl in R6-CP08.

Thin granular deposits were also encountered in R6-CP03 and R6-CP07.

4.1.4 Glacial Till

The Glacial Till is typical of the drift cover in much of the Dublin area, comprising boulder clay, a lodgement till deposited during the last ice age, about 10,000 years ago. Farrell et al. (1995) made the distinction between the 'Brown Boulder Clay' and the 'Black Boulder Clay', stating that the Brown Boulder Clay was a weathering product of the Black Boulder Clay, and is broadly similar to it in terms of particle size distribution.

The brown Dublin boulder clay generally consists of sandy gravelly silt/clay with low to medium cobble content; occasionally soft to firm to 0.5 m; typically, firm / firm to stiff to maximum of about 3 m.

The black Dublin Boulder clay is found underlying the brown Dublin Boulder Clay and consists of Generally stiff / very stiff / sandy gravelly silt/clay with high cobble content and occasional boulders are typical below 2.0m bgl.

For the purposes of interpretation where a very stiff brown slightly sandy slightly gravelly CLAY was encountered underlying the very stiff black Dublin Boulder clay it was still classified as the black Dublin Boulder Clay for interpretation and presentation purposes.

The Glacial Till was encountered in the majority of testholes generally described as sandy gravelly clay, typically firm or stiff in upper horizons, becoming very stiff with increasing depth.

Soft deposits of Glacial till were encountered as follows:

- In R6-CP03, from 1.2 to 3.7 m bgl described as soft becoming firm brown slightly gravelly sandy silty CLAY
- In R6-CP04, from 3 to 3.6 m bgl described as soft brown sandy gravelly SILT with low cobble content
- In R6-CP07, from 1 to 2.5 m bgl described as soft brown slightly sandy slightly gravelly CLAY

It's possible that water strikes due to shallow bedrock may have contributed to the softening at the above locations.

A very soft brown sandy gravelly CLAY was encountered in R6-CP09 with an undrained shear strength of 15 kPa from 3 to 4 m bgl, although the geological mapping indicates this is in an area of glacial till, it's possible this was a pocket of alluvium from an old river tributary/stream.

4.1.5 Bedrock

In R6-CP07 from 6.85 to 7.10 m bgl, a possible shelf of Limestone bedrock was encountered This was underlain by a 0.5 m thick layer of brown silty gravelly fine to coarse Sand. A medium strong thinly bedded dark grey Limestone was encountered at 7.6 m bgl extending to the borehole completion depth of 10.7 m bgl.

Although not proven, possible bedrock was noted in the borehole logs at depths ranging from 3.7 to 4.8 to in R6-CP01,R6-CP03, RP-CP08, and R6-CP09 with descriptions generally comprising of grey sandy angular coarse GRAVEL of limestone. Figure R6.WR.1 details the SPT blow counts on possible bedrock.

Full descriptions are available in the borehole logs.

4.2 Groundwater

4.2.1 Groundwater Monitoring

A standpipe was installed in R6-CP07. The results of ground water monitoring are as follows:

Table 4. Groundwater Monitoring

Testhole	Standpipe Depth	Slotted Screen Range (m bgl)	Response Zone	Water Level 19-11-2020
R6-CP07	6.38	1- 6.38	Typically, fine grained Glacial till deposits. Granular deposits from 5.2 to 5.50 m and 6.2 to 6.38 m bgl	6.3

4.2.2 Groundwater Strikes

Groundwater strikes were as follows:

Table 5. Groundwater Strikes

Testhole	Water struck at (m)	Casing to (m)	Time (min)	Rose to (m)	Drilling Remarks
R6-CP03	3	3			Water strike at 3.00m
R6-CP04	3	3	20	2.7	Water strike at 3.00m
R6-CP05	3.10	3.10	20	2.9	Water strike at 3.10m
R6-CP07	2.5	2.5			Seepage at 2.5 m
R6-TP01	0.65				Slow seepage at 0.65 m

4.3 Manmade Features

The existing N4 road bridge approach embankments were mainly found to comprise cohesive materials, probable reworked glacial till.

Other man made features encountered along the route corridor include:

- Infilling of probable historical sand and gravel pits near Hermitage golf course.
- The presence of Made ground comprising of reworked cohesive material and construction waste in the majority of test holes with reworked sandy gravelly clay fill occasionally with fragments of concrete extending to a maximum depth of 4.0m in R6-CP10

  Boreholes R6-CP10 & R6-CP11 encountered 0.3 m of macadam surfacing with approximately 1.0m of aggregate fill beneath the paved surfaces. In addition, R6-TP01 had concrete down to 100mm.

4.4 Material properties

4.4.1 Introduction

The properties of the main soil and rock types are presented as summary tables and charts of material properties.

A series of charts, relating laboratory and in-situ test results for the main materials encountered in the ground investigations, are included in Appendix C. Charts have been divided into soils and rock and are listed in table 6 below.

Table 6. List of Soil Charts

Chart Title	Chart Type
Natural moisture content versus depth	Soil
Plasticity Index versus depth	Soil
Plastic Limit versus depth	Soil
Liquid Limit versus depth	Soil
Casagrande (plasticity) chart	Soil
Moisture Condition Value (MCV) versus natural moisture content	Soil
Undrained shear strength (cu) versus natural moisture content	Soil
Standard Penetration Test N versus depth	Soil
Particle size distribution (PSD) plots	Soil
UCS and point load versus depth below rockhead.	Rock
Fracture index versus depth below rockhead	Rock

Geotechnical parameter tables for material types encountered are summarised below. These tables are intended to be reviewed in conjunction with the parameter summary charts provided in Appendices C.

4.4.2 Made Ground

Table 7 presents a summary of geotechnical and soil/rock chemistry parameters encountered within the soil unit.

Table 7. Summary of Geotechnical Laboratory and in-situ results on Made Ground

Geotechnical Property	Unit	No. Tests	Min Value	Mean Value	Max Value	Figure No.
Particle Size Distribution						
Clay	%	2	10	14.5	19	R6.MG.1
Silt			27	27.5	28	
Sand			28	30.5	33	
Gravel			25	27.5	30	
Cobbles			0	0	0	
Atterberg Limits						
Moisture Content	%	10	10	17.5	26	R6.MG.2
Liquid Limit (LL)		5	28	32.4	41	R6.MG.3, R6.MG.4, R6.MG.5, R6.MG.6
Plastic Limit (PL)		5	15	17.6	23	
Plasticity Index (PI)		5	11	14.8	18	
In-situ testing						
Standard Penetration Test		12	2	21.25	50	R6.MG.7
Soil Chemistry						
pH		8	8.2	8.6	9.4	NA

Geotechnical Property	Unit	No. Tests	Min Value	Mean Value	Max Value	Figure No.
Water soluble sulfate	g/l	7	<0.010*	NA	1.2	

** two samples less than limit of detection*

4.4.3 Sands and Gravels

Table 8 presents a summary of geotechnical and soil/rock chemistry parameters encountered within the soil unit.

Table 8. Summary of Geotechnical Laboratory and in-situ results on Sands and Gravels

Geotechnical Property	Unit	No. Tests	Min Value	Mean Value	Max Value	Figure No.
Particle Size Distribution						
Clay	%	2	4	5	6	R6.SaG.1
Silt			12	21	30	
Fines		4	11	18.75	34	
Sand			10	38	77	
Gravel			12	36.75	52	
Cobbles			0	6.5	26	
In-situ testing						
Standard Penetration Test	Blows per 300 mm	2	50	50	50	R6.SaG.2
Soil Chemistry						
pH		3	8.7	8.76	8.8	NA
Water soluble sulfate	g/l	3	<0.010*	NA	0.024	

**two samples less than limits of detection*

4.4.3.1 Bulk densities

No weight density related tests were carried out for this material type. However, suggested weight density published in Figure 1 and Figure 2 of BS 8004:2015 can be used as a guide as well as assessing the relative density based on the measured SPT results.

4.4.3.2 Effective stress Parameters

Using the guidance of BS8004 (British Standards Institution, 2015), a characteristic critical state angle of shearing resistance for the sand and gravel deposits can be derived from the combination of the following:

- 30° + “contribution from angularity of the particles (0-4°)” + “contribution the soil’s particle size distribution (0-4°)”

A characteristic peak angle of shearing resistance can be derived by including the contribution from the soil’s relative density (0-9°) to the above equation.

4.4.3.3 Stiffness

The drained Young’s modulus can be derived/correlated by using SPT ‘N’ value $E = N_{60}$ (MPa) and $E' = 2N_{60}$ (MPa) as indicated in CIRIA R143, as based on Stroud (1989) results.

Allowing for anisotropy, 1.5 (or more) times the vertical stiffness may be taken for the prediction of horizontal modulus values.

The Poisson's ratio υ can be conservatively selected using the range of values quoted in Tomlinson, Foundation Design and Construction 7th Edition (page 74)or CIRIA Report 103 Table 2. Appropriate design value shall be used in the design, depending on the type of analyses, calculations and geotechnical risks. Typical drained values range between 0.1 and 0.3 are considered appropriate.

4.4.4 Glacial Till

Table 9 presents a summary of geotechnical and soil/rock chemistry parameters encountered within the soil unit.

Table 9. Summary of geotechnical laboratory and in-situ results on Glacial Till in CBC 06

Geotechnical Property	Unit	No. Tests	Min Value	Mean Value	Max Value	Figure No.
Particle Size Distribution						
Clay	%	7	2	4	9	R6.GT.1
Silt			13	27.5	45	
Sand			20	32	55	
Gravel			3	36.5	65	
Cobbles			0	0	0	
Atterberg Limits						
Moisture Content	%	22	9.6	16.9	33	R6.GT.2
Liquid Limit (LL)		7	28	31.4	40	R6.GT.3, R6.GT.4 R6.GT.5 R6.GT.6
Plastic Limit (PL)		7	13	19.2	25	
Plasticity Index (PI)		7	9	12.1	16	
In-situ testing						
Standard Penetration Test	blows per 300 mm	16	4	22.6	50	R6.GT.7
MCV		1	9.3			R6.GT.8
Shear strength (total stress)						
UU Triaxial test, cu	kPa	1	15			R6.GT.9 R6.GT.10
SPT, cu	kPa	16	24	136	300	
Soil Chemistry						
pH		8	8.2	8.65	8.9	NA
Water soluble sulfate	g/l	8	<0.010*		0.069	

**seven samples less than limits of detection*

4.4.4.1 Bulk densities

No specific weight density related tests were carried out for this material type. Bulk densities were recorded as part of the Unconsolidated Undrained Triaxial compression tests and are available in the factual report.

Published literature from the Dublin Port Northern cut-and-cover site measured average bulk densities of 2.228, 2.337, 2.883, and 2.284 Mg/m3 for the upper brown boulder clay, upper black boulder clay, lower brown boulder clay and lower black boulder clay, respectively. The specific gravity of DBC is typically 2.70. There is no clear difference in the results from the various formations. Ref: (Long & Menkiti 2007)

Suggested weight density published in Figure 1 and Figure 2 of BS 8004:2015 can be used as a guide.

Lower bulk densities are likely in glacial till described as soft.

4.4.4.2 Undrained shear strength

Where appropriate, undrained shear strength (c_u) plots include data from triaxial testing, shear vane tests, and SPT values. For SPT values in Glacial Till, a multiplier has been applied on SPT values to convert to an appropriate c_u value as follows:

$C_u = f_1 \times N_{60}$

Guidance on the value of f1 is provided in Figure 1 (Stroud & Butler,1975) who related the parameter to the soil plasticity index as shown on the following chart.

A value of 6 was used for f_1 which is consistent with the typical plasticity indices of the Glacial Till encountered across the site.

For the purpose of applying the above correlation, a value of E_r = 60% was adopted, resulting in N_{60} = N. This is considered reasonable given the inherent approximation involved in applying the SPT results to estimate c_u. In addition, it is a conservative assumption based on the available hammer energy certificates.

For the purpose of this report, the values of undrained shear strength derived are considered to provide a good overview of undrained material strengths across the site. Further review and interpretation of these results should be undertaken during the detailed design stage on a localised basis along the route (eg for a specific structure or earthwork).

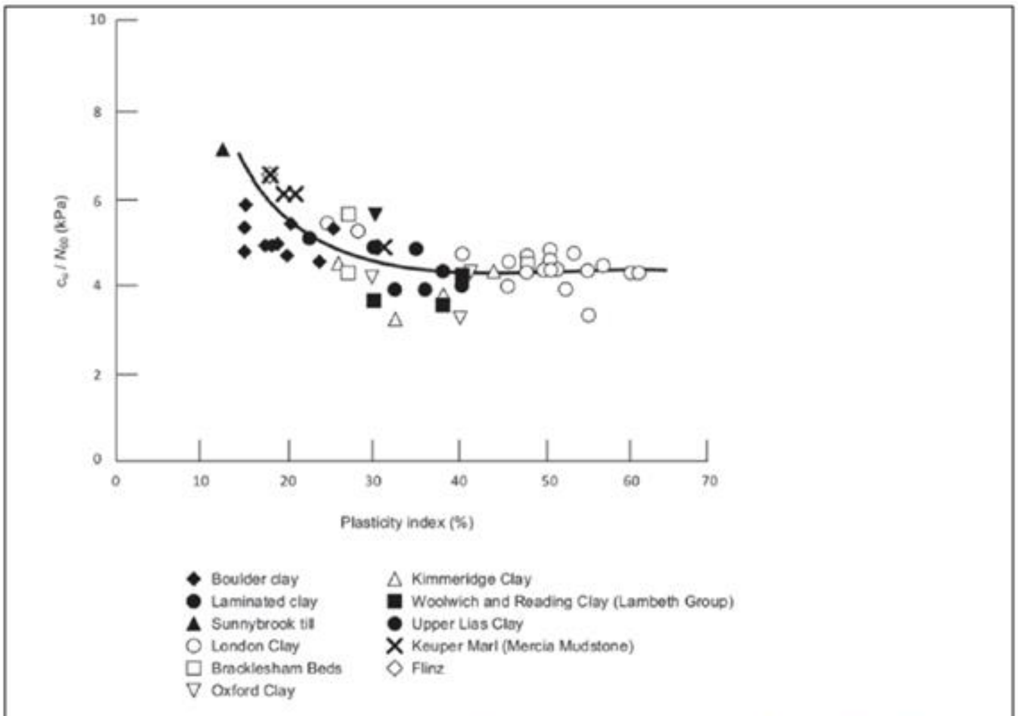
4.4.4.3 Effective Stress Parameters

Published case studies of construction in Dublin Boulder Clay report peak values of the angle of shearing resistance of 30 - 38°. The gravel content of the soils would provide additional frictional resistance, due to interlock, and there is likely to be some long-term effective cohesion. Long & Menkiti 2007 measured a peak effective friction angle of about 44° at the Dublin Port Tunnel.

BS8002 (British Standards Institute, 1994) can be used to relate plasticity index to $\varnothing'_{crit}$, the critical state angle of shearing resistance. Adopting a plasticity index of 15% for soils at greater than 1 m depth, Table 2 of BS8002 provides a “conservative” value for $\varnothing'_{crit}$ of 30°.

The relationship published by Knappet & Craig (Craig’s Soil Mechanics, 8th Edition, 2012) provides a $\varnothing'_{crit}$ of approximately 32°.

Lehane & Faulkner (1998) suggest a critical state friction angle of 34+/- 1° which is similar to the large deformation strength friction angle of 36° measured by Long & Menkiti.



Correlation between N_{60} value and undrained shear strength and plasticity index for insensitive clays (after Stroud and Butler, 1975)

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Figure 1. Stroud & Butler (1975)

4.4.4.4 Stiffness Parameters

The stiffness of the black Dublin boulder clay (DBC) is complex as it has a non-linear stress/strain relationship which also depends on the effective confining stress, on stress history and whether it is loaded in an undrained or drained condition.

At present in Ireland, practising engineers usually adopt a simple linear elastic perfectly plastic constitutive model. A single 'operational' value of Eu = 100 MPa is used, as derived from field observations by Farrell et al. (1995b). The relationship shown in Figure 2 by Jamiolkowski et al. (1979) relating ratios of Undrained modulus (Eu)/ Undrained shear strength (C_u) to both plasticity and the overconsolidation ratio may also be considered.

Current practice in Dublin (e.g. Dougan et al., 1996; Long, 1997) is to use K_0 values for DBC in the range 1.0–1.5.

For routine foundation design, which is generally carried out assuming a linear elastic E' soil, a value of 80 MPa is generally considered appropriate for the Dublin Boulder Clay for very high compressive stresses.

The stiffness also depends on the loading situation and E'≈ 150MPa more closely models the behaviour of a driven pile (Farrell et al. 1995b)

Cautious engineering judgment should be applied to glacial deposits with stiffness described as very soft to firm.

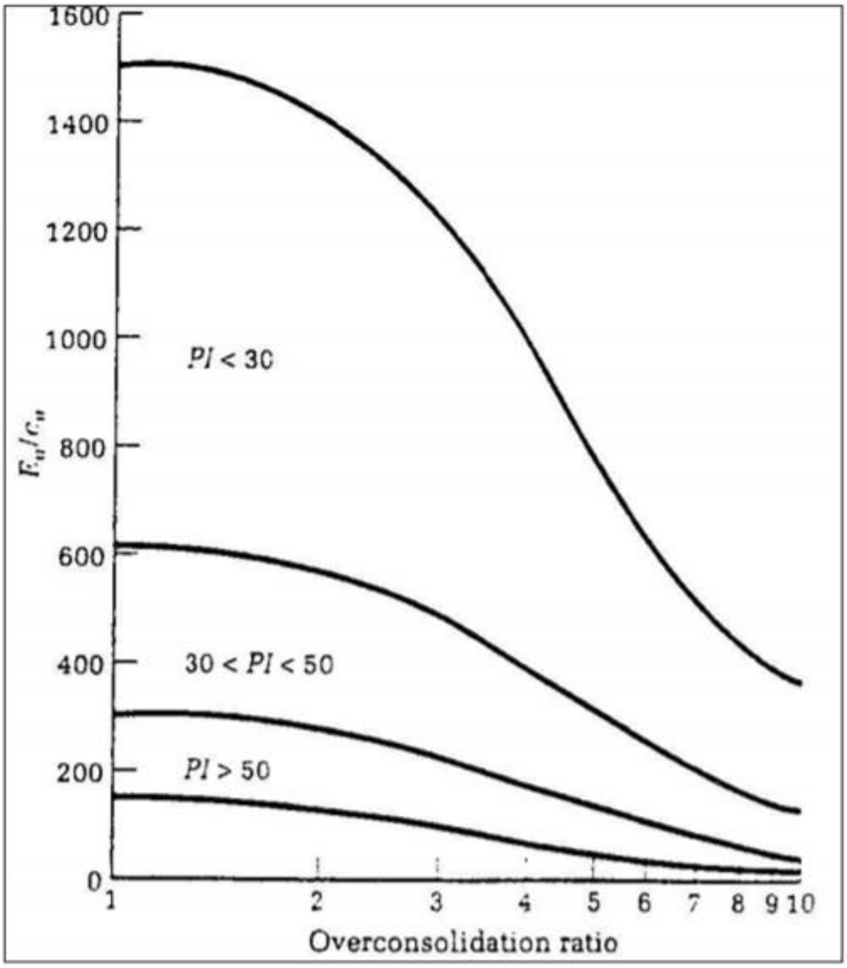

Figure 2. Relationship between Eu / cu Ratio for Clays with Plasticity Index and Degree of Overconsolidation (after Jamiolkowski et al., 1979)

4.5 Bedrock

Table 10 presents a summary of geotechnical and soil/rock chemistry parameters encountered within the rock units in CBC 06.

Table 10. Summary of geotechnical laboratory and in-situ results on Bedrock in CBC 06

Geotechnical Property	Unit	No. Tests	Min Value	Mean Value	Max Value	Figure No.
Rock Strength						
Uniaxial Compressive Strength	MPa	1	35.6			R6.ROCK.3
Point Load Index	MPa	6	0.9	2.22	4.10	R6.ROCK.2
Discontinuities						
Fracture Index	Nr/m	2	5	7.5	10	R6.ROCK.1
Chemistry						
pH		1	8.6			NA
Water soluble sulfate	%	1	0.09			

Limestone was encountered in CBC 06.

Rock UCS plots and charts include a correlation with Point Load test results. A multiplication factor of 20 was selected to obtain indicative values of UCS for the rock types encountered across the scheme.

Inspection of the UCS plots in Appendix C, show a reasonable agreement for all rock types between the data derived directly from UCS testing, and data converted to UCS from Point Load testing. On this basis, and for the purpose of this report, the use of a single multiplication factor for the rock types encountered is considered appropriate. Further review and interpretation of these results should be undertaken during the detailed design stage on a localised basis along the route (eg for a specific structure or earthwork).

4.5.1 Bulk densities

The bulk densities of a sample selected for UCS testing was 2.67 Mg/m^3.

4.5.2 Shear Strength

Suggested values for the presumed design unit bearing resistance of square pad foundations on rock (for settlements not exceeding 0.5% of the foundation width) may be obtained from BS EN 1997-1:2004+A1:2013, Annex G.

CIRIA C760 provides guidance for derivation of rock strength parameters for use in design calculations based on the methodology described by Hoek et al (2002) using unconfined compressive strength data and rock quality information and borehole descriptions.

4.6 Geo-environmental testing results summary

4.6.1 CBC 06

Samples for geo-environmental testing were taken from made ground along the proposed route.

A list of the main made ground deposits encountered during the ground investigations is provided in Section 5.4.2.

The following samples were tested.

Table 11. Summary of Samples Tested

Testhole	Depth
R6-CP09	1
R6-CP07	0.5
R6-CP10	1

The following table summarise the soil laboratory test results. Full details are available in Report No: 20-0399D Bus Connects Route 6 Lucan to City Centre dated December 2020.

Table 12. Summary of Soil Geo-environmental Test Results

Determinand	Unit	No. of samples	Minimum Concentration	Maximum Concentration
Organics		No.	Min	Max
Total Organic Carbon		1	1.40	1.40
Organic Matter	%	2	1.90	2.20
Mineral Oil & TPH				
Mineral Oil	mg/kg	1	<10	<10

Determinand	Unit	No. of samples	Minimum Concentration	Maximum Concentration
Total Petroleum Hydrocarbons (by IR)	mg/kg	2	230.00	230.00
Aliphatic TPH >C5-C6	mg/kg	1	< 1.0	< 1.0
Aliphatic TPH >C6-C8	mg/kg	1	< 1.0	< 1.0
Aliphatic TPH >C8-C10	mg/kg	1	< 1.0	< 1.0
Aliphatic TPH >C10-C12	mg/kg	1	< 1.0	< 1.0
Aliphatic TPH >C12-C16	mg/kg	1	< 1.0	< 1.0
Aliphatic TPH >C16-C21	mg/kg	1	< 1.0	< 1.0
Aliphatic TPH >C21-C35	mg/kg	1	< 1.0	< 1.0
Aliphatic TPH >C35-C44	mg/kg	1	< 1.0	< 1.0
Total Aliphatic Hydrocarbons	mg/kg	1	< 5.0	< 5.0
Aromatic TPH >C5-C7	mg/kg	1	< 1.0	< 1.0
Aromatic TPH >C7-C8	mg/kg	1	< 1.0	< 1.0
Aromatic TPH >C8-C10	mg/kg	1	< 1.0	< 1.0
Aromatic TPH >C10-C12	mg/kg	1	< 1.0	< 1.0
Aromatic TPH >C12-C16	mg/kg	1	< 1.0	< 1.0
Aromatic TPH >C16-C21	mg/kg	1	< 1.0	< 1.0
Aromatic TPH >C21-C35	mg/kg	1	< 1.0	< 1.0
Aromatic TPH >C35-C44	mg/kg	1	< 1.0	< 1.0
Total Aromatic Hydrocarbons	mg/kg	1	< 5.0	< 5.0
Total Petroleum Hydrocarbons	mg/kg	1	< 10	< 10
BTEX & MTBE				
Benzene	µg/kg	1	< 1.0	< 1.0
Toluene	µg/kg	1	< 1.0	< 1.0
Ethylbenzene	µg/kg	1	< 1.0	< 1.0
m & p-Xylene	µg/kg	1	< 1.0	< 1.0
o-Xylene	µg/kg	1	< 1.0	< 1.0
Methyl Tert-Butyl Ether	µg/kg	1	< 1.0	< 1.0
PAH				
Naphthalene	mg/kg	3	< 0.10	9.20
Acenaphthylene	mg/kg	3	< 0.10	0.57
Acenaphthene	mg/kg	3	< 0.10	5.70
Fluorene	mg/kg	3	< 0.10	4.80

Determinand	Unit	No. of samples	Minimum Concentration	Maximum Concentration
Phenanthrene	mg/kg	3	< 0.10	18.00
Anthracene	mg/kg	3	< 0.10	3.10
Fluoranthene	mg/kg	3	< 0.10	11.00
Pyrene	mg/kg	3	< 0.10	10.00
Benz(a)anthracene	mg/kg	3	< 0.10	4.50
Chrysene	mg/kg	3	< 0.10	4.70
Benzo(a) pyrene	mg/kg	3	< 0.10	4.00
Indeno(1,2,3-c,d)pyrene	mg/kg	3	< 0.10	2.10
Dibenz(a,h)anthracene	mg/kg	3	< 0.10	0.98
Benzo(g,h,i)perylene	mg/kg	3	< 0.10	2.20
Benzo(b)fluoranthene	mg/kg	2	<0.1	4.80
Benzo(k)fluoranthene	mg/kg	2	<0.1	2.00
PAHs (Sum of total)	mg/kg	3	<2	88.00
SVOC				
Coronene	mg/kg	3	<0.1	<0.1
PCB				
PCB 28	mg/kg	1	< 0.010	< 0.010
PCB 52	mg/kg	1	< 0.010	< 0.010
PCB 90+101	mg/kg	1	< 0.010	< 0.010
PCB 118	mg/kg	1	< 0.010	< 0.010
PCB 153	mg/kg	1	< 0.010	< 0.010
PCB 138	mg/kg	1	< 0.010	< 0.010
PCB 180	mg/kg	1	< 0.010	< 0.010
Total PCBs (7 Congeners)	mg/kg	1	< 0.10	< 0.10
Phenolics				
nonchlorinated phenols	mg/kg	3	<0.3	<0.3
Metals				
Arsenic	mg/kg	3	4.80	20.00
Antimony	mg/kg	1	<2	<2
Barium	mg/kg	1	42.00	42.00
Boron	mg/kg	3	<0.4	0.56
Cadmium	mg/kg	3	<0.1	1.60

Determinand	Unit	No. of samples	Minimum Concentration	Maximum Concentration
Chromium (III+VI)	mg/kg	3	13.00	29.00
Chromium (Trivalent)	mg/kg	1	29.00	29.00
Chromium (Hexavalent)	mg/kg	1	<0.5	<0.5
Copper	mg/kg	3	15.00	24.00
Lead	mg/kg	3	14.00	27.00
Mercury	mg/kg	3	<0.1	<0.1
Molybdenum	mg/kg	1	<0.2	<0.2
Nickel	mg/kg	3	25.00	41.00
Selenium	mg/kg	1	<0.2	<0.2
Zinc	mg/kg	3	50.00	79.00
Inorganic				
Cyanide Total	mg/kg	2	<0.5	<0.5
Moisture	%	3	9.60	14.00
Sulphate (soluble)	g/L	3	<0.01	0.50
pH (Lab)	pH_Units	3	8.30	8.70
Asbestos				
Asbestos		3	NAD	NAD

5. Geotechnical Risk Register

Risk Reference	Description of Risk	Initial Risk Rating (See matrix below)			Consequence	Control Measures to Reduce Risk	Residual Risk Rating (See matrix below)		
		P	I	R			P	I	R
EWK	Potential for ULS failure (global instability, local instability, bearing resistance failure, extrusion of foundation soils) of embankments due to the presence of loose / very soft / soft soils and/or made ground	4	5	20	Embankment failure along carriageway could result road traffic accident if loss of road pavement / road edge support occurs. Services and drainage infrastructure could be damaged requiring repair or replacement.	Scheme Designer to design and supervise solutions to prevent ULS failure of embankments in accordance with National Standards and good practice.	1-2	5	5-10
EWK	Potential for unacceptable magnitudes of differential settlement along embankment long/cross sections due to variations in compressible soil thickness and/or soil compressibility characteristics.	4	5	20	Differential road pavement deformations may result in road traffic operations that could result in impar to road users. Services or infrastructure may be damaged requiring repair or replacement as a result of differential settlement.	The Scheme Designer to identify areas where differential settlement potential may exist because of variable compressible soil thickness during the detailed design phase and design construction measures to reduce expected differential settlement to tolerable magnitudes.	1-2	5	5-10
EWK	Potential for differential settlement in cross section where widening existing earthworks.	4	5	20	Differential road pavement deformations may result in road traffic operations that could result in impar to road users. Services or infrastructure may be damaged requiring repair or replacement as a result of differential settlement.	The Scheme Designer to identify areas where differential settlement potential may exist because of variable compressible soil thickness during the detailed design phase and design construction measures to reduce expected differential settlement to tolerable magnitudes.	1-2	5	5-10
EWK	Unstable widened / new cutting Slopes including temporary works	4	5	20	Cutting failure that is costly to repair. Potential for under cutting carriageway, which could lead to a road traffic accident or partial/full road blockage/closure. Road traffic accident could lead to injury/death to road users.	The Scheme Designer to design a solution that prevents ULS failure of cut slopes. Where uncertainty in ground or groundwater conditions is identified during ground model development, further GI to be implemented prior to commencing construction activities to verify the design ground model.	1-2	5	5-10

Risk Reference	Description of Risk	Initial Risk Rating (See matrix below)			Consequence	Control Measures to Reduce Risk	Residual Risk Rating (See matrix below)		
		P	I	R			P	I	R
EWK	Encountering soils of unexpectedly low CBR value, at road pavement subgrade level.	4	5	20	Pavement design requires adjustment resulting in construction delays. Pavement design is not adjusted leading to poor pavement performance in pavement design life that requires costly repair or reconstruction.	Scheme Designer to design pavement foundation solutions for the range of CBRs expected site wide and inspect formations regularly to verify pavement is being construction in accordance with the design/design philosophy. Where uncertainty in the nature of subgrade soils is identified during ground model development, further GI to be implemented prior to commencing construction activities to verify the design ground model.	1-2	5	5-10
EWK	The volumes of organic and/or very soft soils and/or made ground, to be excavated and replaced below embankments are greater than anticipated based on the available ground investigation data.	4	5	20	Greater volume of excavated material to be disposed of, and an increase in the required volume of replacement fill. Construction delays. Increased construction costs.	Where uncertainty in the nature of subgrade soils is identified during ground model development, further GI to be implemented prior to commencing construction activities to verify the design ground model.	1-2	5	5-10
EWK	Higher cobble and boulder content in Glacial Till than anticipated	4	5	20	Increased requirement to separate and sort excavated material to allow placement and compaction as fill.	Utilisation of appropriate plant to allow sorting before placement in fill areas.	1-2	5	5-10
EWK	Absence of adequate locations, on or close to the site, for disposal of of unacceptable soils.	4	5	20	Absence of adequate locations, on or close to the site, for disposal of unacceptable soils.	Early in the works programme, the Contractor to source locations of possible local disposal areas and obtain necessary landowner and statutory approvals.	1-2	5	5-10
EWK	Absence of adequate locations, on or close to the site, for storage of of reusable soils.	4	5	20	Absence of adequate locations, on or close to the site, for disposal of suitable soils.	Early in the works programme, the Contractor to source locations of possible local storage areas and obtain necessary landowner and statutory approvals.	1-2	5	5-10

Risk Reference	Description of Risk	Initial Risk Rating (See matrix below)			Consequence	Control Measures to Reduce Risk	Residual Risk Rating (See matrix below)		
		P	I	R			P	I	R
STR	Potential for bearing resistance failure / unacceptable total or differential settlement magnitudes where spread foundations are underlain by soil of inadequate bearing resistance or piles have inadequate load bearing capacity.	4	5	20	Significant structure damage requiring costly extensive repairs or replacement.	Scheme Designer to design solutions to prevent ULS failure of foundations, or unacceptable settlements.. Spread foundation formation to be inspected to verify ground conditions, and piles to be adequately tested. Where uncertainty in the nature of subgrade soils is identified during ground model development, further GI to be implemented prior to commencing construction activities to verify the design ground model.	1-2	5	5-10
STR	Potential for inducing negative skin friction / lateral loads onto existing and new piled foundations resulting in increased pile loads and potential pile failure and/or piled foundation settlement.	4	5	20	Significant structure settlement / damage requiring costly extensive repairs or replacement.	Scheme Designer to identify areas where compressible soils exist adjacent to existing or new piled foundations and inform Contractor of such locations. Scheme Designer to design adjacent new/widened earthworks to prevent lateral loading /inducing negative skin friction on existing piles. New piles to be designed to allow for expected lateral / negative skin friction loads. Where working platforms are required for new piled structures, negative skin friction induced by settlement of the working platform after pile construction, to be allowed for in the design. Where increased lateral and/or negative skin friction loads on existing piled foundations cannot be avoided, the impact of such increases to be investigated to demonstrate that there will not be any detrimental impact on the existing piles.	1-2	5	5-10
STR	Potential for foundation construction difficulties/delays where depth to competent founding strata is unconfirmed or increased thickness of made ground	4	5	20	Construction delays where competent founding strata is situated at a significantly greater depth than envisaged in the detailed design ground model.	Where uncertainty in the nature of subgrade soils is identified during ground model development, further GI to be implemented prior to commencing construction activities to verify the design ground model.	1-2	5	5-10

Risk Reference	Description of Risk	Initial Risk Rating (See matrix below)			Consequence	Control Measures to Reduce Risk	Residual Risk Rating (See matrix below)		
		P	I	R			P	I	R
STR	Encountering higher than interpreted groundwater levels and unexpected groundwater during excavation or piling that requires groundwater control measures / design modifications during excavation.	4	5	20	Construction delays / unstable excavations. Risk of construction plant/personnel falling into excavations if they collapse.	Scheme Designer to determine expected groundwater levels at all proposed areas of temporary excavation / piling and to inform Contractor. Contractor to plan for groundwater control measures at locations identified by the Scheme Designer. Contractor to design all temporary excavation works to account for groundwater where expected. Water head to be balanced during construction of bored piles.	1-2	5	5-10
STR	Potential for ground subsidence related damage to existing nearby structures, buildings or other sensitive infrastructure due to consolidation settlement induced by temporary groundwater lowering whilst excavating.	4	5	20	Subsidence may result in foundation / structure damage where existing structures are situated in area where groundwater lowering is expected to induce subsidence. Structures may require costly repairs or reconstruction depending on degree of damage.	Where groundwater control measures are required during construction, the Contractor to undertake site-specific assessments to establish if there is a risk of groundwater extraction induced subsidence and the presence of any potential receptors such as existing spread or piled foundations.	1-2	5	5-10
	Encountering unexpected contamination on the site including potential areas of “fly-tipping”, or infilled former surface depressions / gravel pits.	4	5	20	Health and safety impact on construction workers and third parties. Potential impact on environmental receptors, including watercourses. Increase in cost of treatment of contaminated ground if encountered	The ground investigation data includes exploratory holes, lab testing and monitoring in positions of known/potential contamination. Site clearance and excavations on site to be monitored for the presence of potential contaminants. Contractor to undertake additional ground investigation, including geotechnical environmental laboratory testing, if additional areas of suspected contamination are encountered and, if necessary, devise remedial works.	2	5	10
	Encountering ground gases generated in organic alluvium or Made Ground.	4	5	20	Health and safety impact (asphyxiation/fire/explosion) on construction workers and third parties, particularly where gases accumulate in confined spaces.	Adopt appropriate precautions including gas monitoring during construction and minimise creation of confined spaces within the temporary works	1-2	5	5-10

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Appendix A Proposed Alignment Plan and Structures Reference Plan

Project Ireland 2040
Building Ireland's Future

Rev	Date	Drn	Chk'd	App'd	Description
L01.1	17/12/20				

W.I.P.

Client: NTA Údarás Náisiúnta Iompair National Transport Authority

Engineering Designer: AECOM / MOTT MACDONALD

Programme Title: **BUSCONNECTS DUBLIN**
CORE BUS CORRIDORS INFRASTRUCTURE WORKS

Drawing Title:
CBC06
LUCAN TO CITY CENTRE
GROUND INVESTIGATION GEOLOGICAL LONGITUDINAL SECTIONS
KEY PLAN

Date	Scale	Drawn	Checked	Approved
17/12/20	1:12500 @ A1 1:25000 @ A3			

Project Code	Originator Code	QMS Code	Drawing File Name	Sheet Number	Status	Rev
BCIDA	ACM		BCIDA-ACM-ERW_KP-0006_XX_00-DR-CE-0001	01 of 01		L01.1

DO NOT SCALE USE FIGURED DIMENSIONS ONLY

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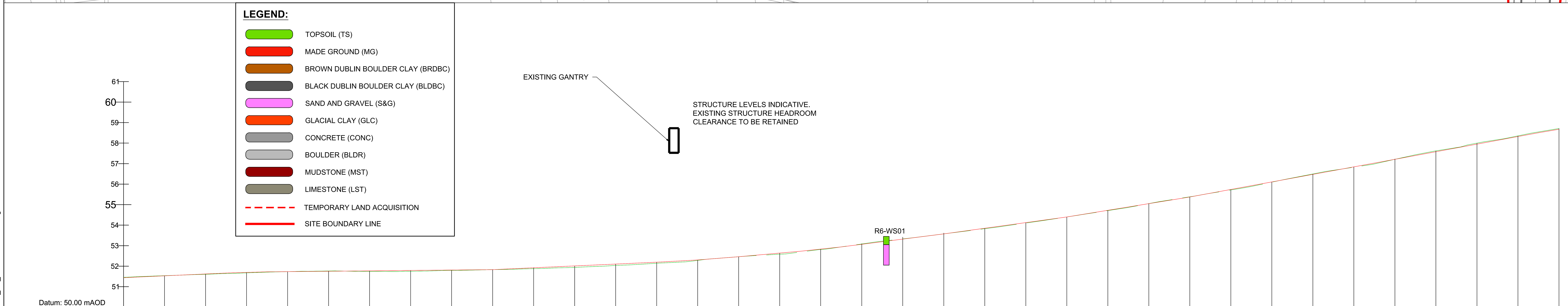
Appendix B Combined Ground Investigation Plan and Geological Longitudinal Sections



PROPOSED LEVELS	51.4	51.5	51.6	51.7	51.7	51.8	51.8	51.8	51.8	51.8	51.9	52.0	52.1	52.2	52.3	52.5	52.6	52.8	53.1
EXISTING LEVELS	51.5	51.5	51.6	51.7	51.7	51.8	51.7	51.8	51.8	51.8	51.9	51.9	52.0	52.1	52.3	52.5	52.6	52.8	53.1
GLOBAL CHAINAGE	350	360	370	380	390	400	410	420	430	440	450	460	470	480	490	500	510	520	530

PROPOSED LEVELS	53.3	53.6	53.9	54.1	54.4	54.7	55.0	55.4	55.7	56.1	56.5	56.8	57.2	57.6	58.0	58.3	58.7
EXISTING LEVELS	53.3	53.6	53.8	54.1	54.4	54.7	55.1	55.4	55.7	56.1	56.5	56.8	57.2	57.6	58.0	58.4	58.7
GLOBAL CHAINAGE	540	550	560	570	580	590	600	610	620	630	640	650	660	670	680	690	700

GEO_HV-0006_ML_00-M3-CR-0001-A01 LONGITUDINAL SECTION
SCALE: H 1:500,V 1:100

Project Ireland 2040
Building Ireland's Future

Rev	Date	Drn	Chk'd	App'd	Description
L01.1	16/12/20				

W.I.P.

Client: NTA Údarás Náisiúnta Iompair National Transport Authority

Engineering Designer: AECOM / MOTT MACDONALD

Programme Title: **BUSCONNECTS DUBLIN**
CORE BUS CORRIDORS INFRASTRUCTURE WORKS

Drawing Title: CBC06
LUCAN TO CITY CENTRE
GROUND INVESTIGATION GEOLOGICAL LONGITUDINAL SECTIONS

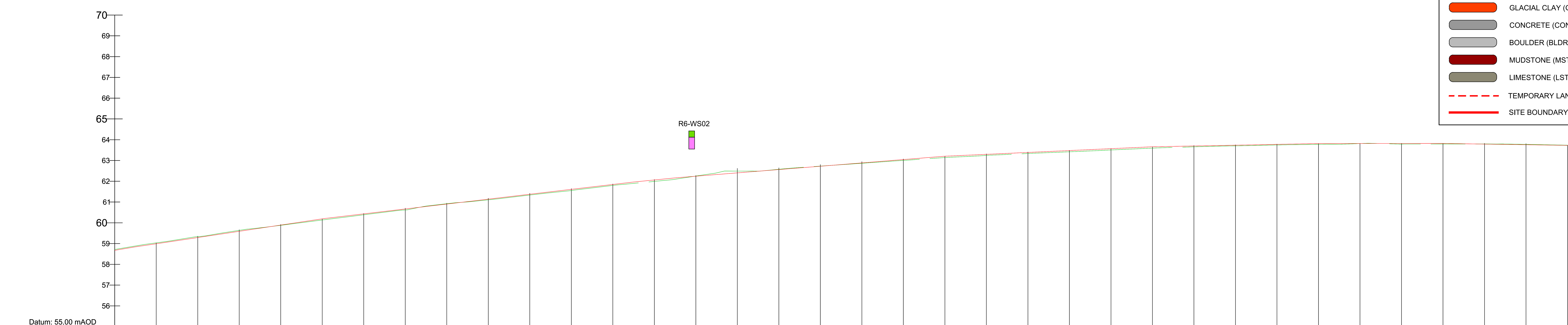
Date	Scale	Drawn	Checked	Approved
16/12/20	1:500 @ A1 1:1000 @ A3			

Project Code	Originator Code	QMS Code	Drawing File Name	Sheet Number	Status	Rev
BCIDA	ACM		BCIDA-ACM-ERW_GI-0006_XX_00-DR-CE-0002	2 of 28	S0	L01.1

DO NOT SCALE USE FIGURED DIMENSIONS ONLY

LEGEND:

- TOPSOIL (TS)
- MADE GROUND (MG)
- BROWN DUBLIN BOULDER CLAY (BRDBC)
- BLACK DUBLIN BOULDER CLAY (BLDBC)
- SAND AND GRAVEL (S&G)
- GLACIAL CLAY (GLC)
- CONCRETE (CONC)
- BOULDER (BLDR)
- MUDSTONE (MST)
- LIMESTONE (LST)
- TEMPORARY LAND ACQUISITION
- SITE BOUNDARY LINE



PROPOSED LEVELS	58.7	59.0	59.3	59.6	59.9	60.2	60.4	60.7	60.9	61.1	61.4	61.6	61.8	62.1	62.2	62.4	62.6	62.7
EXISTING LEVELS	58.7	59.0	59.3	59.6	59.9	60.1	60.4	60.6	60.9	61.1	61.3	61.6	61.8	62.0	62.2	62.5	62.6	62.7
GLOBAL CHAINAGE	700	710	720	730	740	750	760	770	780	790	800	810	820	830	840	850	860	870

PROPOSED LEVELS	62.9	63.0	63.2	63.3	63.4	63.5	63.6	63.7	63.7	63.7	63.8	63.8	63.8	63.8	63.8	63.8	63.8	63.7
EXISTING LEVELS	62.9	63.0	63.1	63.2	63.3	63.4	63.5	63.6	63.7	63.7	63.7	63.8	63.8	63.8	63.8	63.8	63.8	63.7
GLOBAL CHAINAGE	880	890	900	910	920	930	940	950	960	970	980	990	1000	1010	1020	1030	1040	1050

GEO_HV-0006_ML_00-M3-CR-0001-A01 LONGITUDINAL SECTION
SCALE: H 1:500,V 1:100

Project Ireland 2040
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Rev	Date	Drn	Chk'd	App'd	Description
L01.1	17/12/20				

W.I.P.

Client: NTA Údarás Náisiúnta Iompair National Transport Authority

Engineering Designer: AECOM; MOTT MACDONALD

Programme Title: BUSCONNECTS DUBLIN
CORE BUS CORRIDORS INFRASTRUCTURE WORKS

Drawing Title: CBC06
LUCAN TO CITY CENTRE
GROUND INVESTIGATION GEOLOGICAL LONGITUDINAL SECTIONS

Date	Scale	Drawn	Checked	Approved
17/12/20	1:500 @ A1 1:1000 @ A3			

Project Code	Originator Code	QMS Code	Drawing File Name	Sheet Number	Status	Rev
BCIDA	ACM		BCIDA-ACM-ERW_GI-0006_XX_00-DR-CE-0003	3 of 28	S0	L01.1

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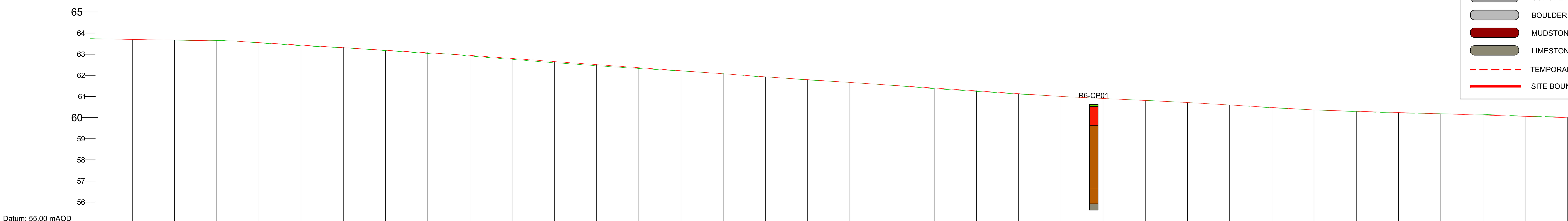
LEGEND:

- TOPSOIL (TS)
- MADE GROUND (MG)
- BROWN DUBLIN BOULDER CLAY (BRDBC)
- BLACK DUBLIN BOULDER CLAY (BLDBC)
- SAND AND GRAVEL (S&G)
- GLACIAL CLAY (GLC)
- CONCRETE (CONC)
- BOULDER (BLDR)
- MUDSTONE (MST)
- LIMESTONE (LST)
- TEMPORARY LAND ACQUISITION
- SITE BOUNDARY LINE



GLOBAL CHAINAGE	1050	1060	1070	1080	1090	1100	1110	1120	1130	1140	1150	1160	1170	1180	1190	1200	1210	1220
PROPOSED LEVELS	63.7	63.7	63.7	63.6	63.6	63.4	63.3	63.2	63.1	62.9	62.8	62.7	62.5	62.4	62.2	62.1	61.9	61.8
EXISTING LEVELS	63.7	63.7	63.7	63.6	63.5	63.4	63.3	63.2	63.0	62.9	62.8	62.6	62.5	62.3	62.2	62.1	61.9	61.8

GLOBAL CHAINAGE	1230	1240	1250	1260	1270	1280	1290	1300	1310	1320	1330	1340	1350	1360	1370	1380	1390	1400
PROPOSED LEVELS	61.7	61.5	61.4	61.3	61.1	61.0	60.9	60.8	60.7	60.6	60.5	60.4	60.3	60.2	60.2	60.1	60.1	60.0
EXISTING LEVELS	61.7	61.5	61.4	61.2	61.1	61.0	60.9	60.8	60.7	60.6	60.5	60.4	60.3	60.2	60.2	60.2	60.1	60.0

GEO_HV-0006_ML_00-M3-CR-0001-A01 LONGITUDINAL SECTION
SCALE: H 1:500,V 1:100

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L01.1	17/12/20				

W.I.P.

Client: NTA Údarás Náisiúnta Iompair National Transport Authority

Engineering Designer: AECOM / MOTT MACDONALD

Programme Title: **BUSCONNECTS DUBLIN CORE BUS CORRIDORS INFRASTRUCTURE WORKS**

Drawing Title: CBC06 LUCAN TO CITY CENTRE GROUND INVESTIGATION GEOLOGICAL LONGITUDINAL SECTIONS

Date	Scale	Drawn	Checked	Approved
17/12/20	1:500 @ A1 1:1000 @ A3			

Project Code	Originator Code	QMS Code	Drawing File Name	Sheet Number	Status	Rev
BCIDA	ACM		BCIDA-ACM-ERW_GI-0006_XX_00-DR-CE-0004	4 of 28	S0	L01.1

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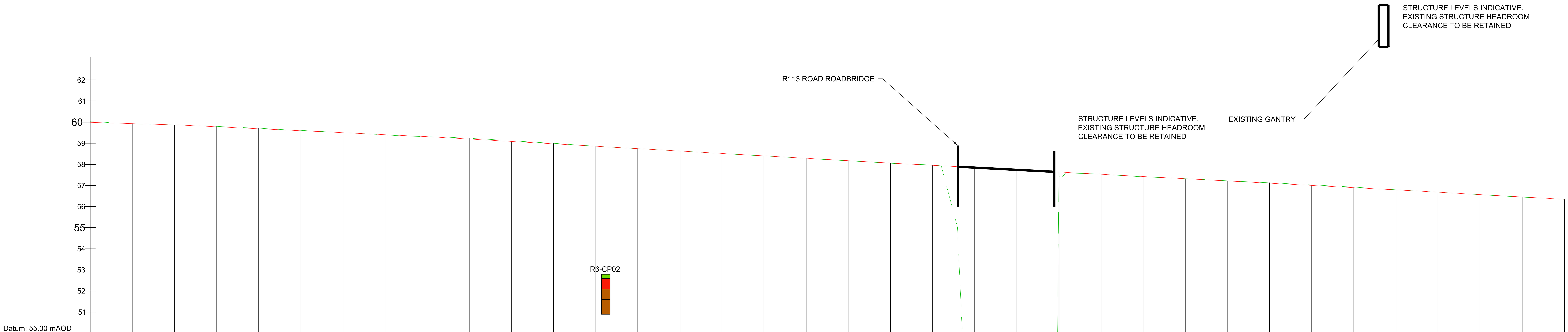

PROPOSED LEVELS	60.0	59.9	59.9	59.8	59.7	59.6	59.5	59.4	59.3	59.2	59.1	59.0	58.9	58.7	58.6	58.5	58.4	58.3
EXISTING LEVELS	60.0	59.9	59.9	59.8	59.7	59.6	59.5	59.4	59.3	59.2	59.1	59.0	58.9	58.7	58.6	58.5	58.4	58.3
GLOBAL CHAINAGE	1400	1410	1420	1430	1440	1450	1460	1470	1480	1490	1500	1510	1520	1530	1540	1550	1560	1570

PROPOSED LEVELS	58.2	58.1	58.0	57.8	57.7	57.6	57.5	57.4	57.3	57.2	57.1	57.0	56.9	56.8	56.7	56.6	56.5	56.3
EXISTING LEVELS	58.2	58.1	58.0	50.1	50.0	57.5	57.5	57.4	57.3	57.2	57.1	57.0	56.9	56.8	56.7	56.6	56.4	56.3
GLOBAL CHAINAGE	1580	1590	1600	1610	1620	1630	1640	1650	1660	1670	1680	1690	1700	1710	1720	1730	1740	1750

GEO_HV-0006_ML_00-M3-CR-0001-A01 LONGITUDINAL SECTION
SCALE: H 1:500,V 1:100

Project Ireland 2040
Building Ireland's Future

Rev	Date	Drn	Chk'd	App'd	Description
L01.1	17/12/20				

W.I.P.

Client: NTA Údarás Náisiúnta Iompair National Transport Authority

Engineering Designer: AECOM / MOTT MACDONALD

Programme Title: BUSCONNECTS DUBLIN
CORE BUS CORRIDORS INFRASTRUCTURE WORKS

Drawing Title: CBC06
LUCAN TO CITY CENTRE
GROUND INVESTIGATION GEOLOGICAL LONGITUDINAL SECTIONS

Date	Scale	Drawn	Checked	Approved
17/12/20	1:500 @ A1 1:1000 @ A3			

Project Code	Originator Code	QMS Code	Drawing File Name	Sheet Number	Status	Rev
BCIDA	ACM		BCIDA-ACM-ERW_GI-0006_XX_00-DR-CE-0005	5 of 28	S0	L01.1

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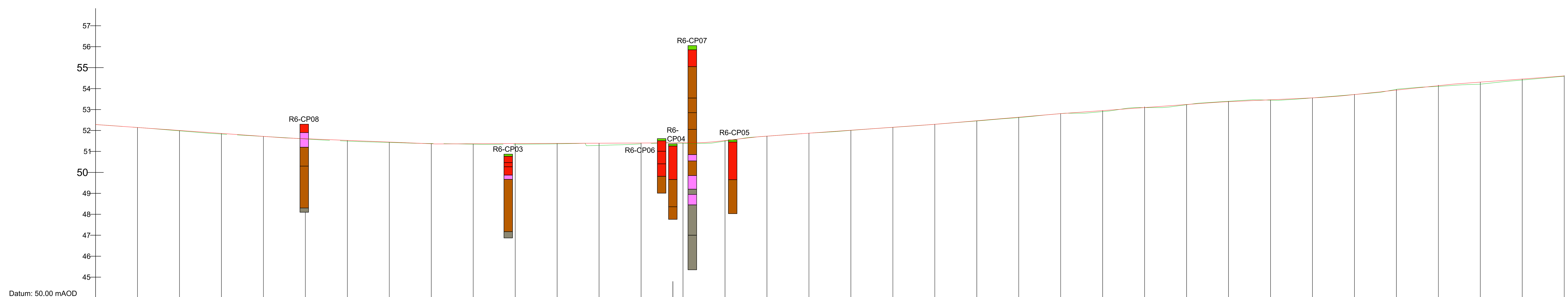

GLOBAL CHAINAGE	PROPOSED LEVELS	EXISTING LEVELS
2100	52.3	52.3
2110	52.1	52.1
2120	52.0	52.0
2130	51.9	51.8
2140	51.7	51.7
2150	51.6	51.6
2160	51.5	51.5
2170	51.4	51.4
2180	51.4	51.4
2190	51.4	51.3
2200	51.4	51.3
2210	51.4	51.4
2220	51.4	51.3
2230	51.4	51.4
2240	51.4	51.4
2250	51.5	51.5
2260	51.7	51.7
2270	51.9	51.9
2280	52.0	52.0
2290	52.2	52.2
2300	52.3	52.3
2310	52.5	52.5
2320	52.6	52.6
2330	52.8	52.8
2340	53.0	52.9
2350	53.1	53.1
2360	53.2	53.2
2370	53.4	53.4
2380	53.5	53.4
2390	53.6	53.6
2400	53.7	53.7
2410	53.9	54.0
2420	54.1	54.1
2430	54.3	54.2
2440	54.5	54.4
2450	54.6	54.6

GEO_HV-0006_ML_00-M3-CR-0001-A01 LONGITUDINAL SECTION
SCALE: H 1:500,V 1:100

Project Ireland 2040
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L01.1	17/12/20				

W.I.P.

Client: NTA Údarás Náisiúnta Iompair National Transport Authority

Engineering Designer: AECOM / MOTT MACDONALD

Programme Title: **BUSCONNECTS DUBLIN**
CORE BUS CORRIDORS INFRASTRUCTURE WORKS

Drawing Title: CBC06
LUCAN TO CITY CENTRE
GROUND INVESTIGATION GEOLOGICAL LONGITUDINAL SECTIONS

Date	Scale	Drawn	Checked	Approved
17/12/20	1:500 @ A1 1:1000 @ A3			

Project Code	Originator Code	QMS Code	Drawing File Name	Sheet Number	Status	Rev
BCIDA	ACM		BCIDA-ACM-ERW_GI-0006_XX_00-DR-CE-0007	7 of 28	S0	L01.1

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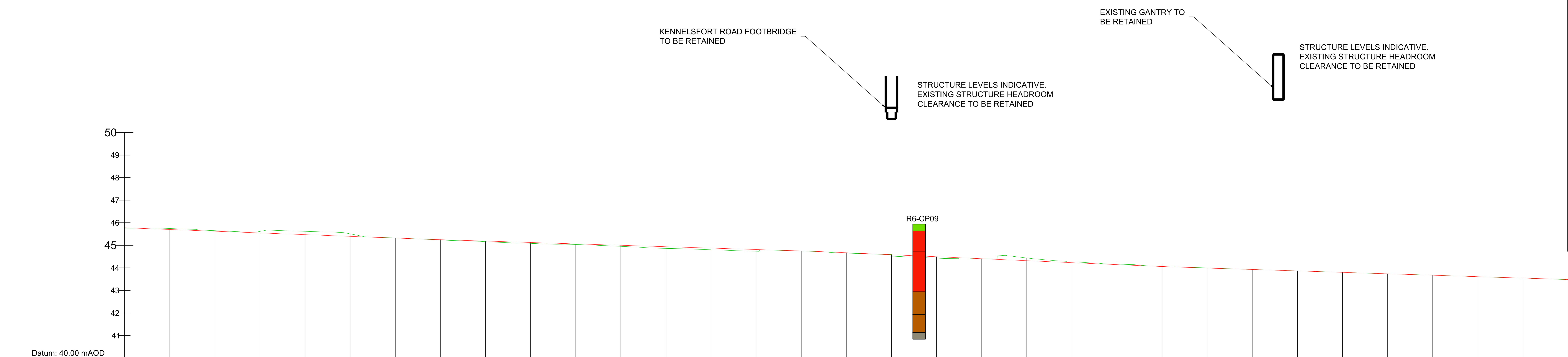

PROPOSED LEVELS	45.8	45.7	45.6	45.5	45.5	45.4	45.3	45.3	45.2	45.1	45.1	45.0	44.9	44.9	44.8	44.8	44.7	44.6
EXISTING LEVELS	45.8	45.7	45.6	45.6	45.6	45.5	45.3	45.2	45.2	45.1	45.0	45.0	44.9	44.8	44.7	44.7	44.7	44.6
GLOBAL CHAINAGE	3500	3510	3520	3530	3540	3550	3560	3570	3580	3590	3600	3610	3620	3630	3640	3650	3660	3670

PROPOSED LEVELS	44.5	44.4	44.3	44.2	44.1	44.1	44.0	43.9	43.9	43.8	43.7	43.7	43.6	43.5	43.5	43.4	43.4	43.3
EXISTING LEVELS	44.4	44.4	44.4	44.3	44.2	44.1	44.0	43.9	43.9	43.8	43.7	43.7	43.6	43.5	43.5	43.4	43.4	43.3
GLOBAL CHAINAGE	3680	3690	3700	3710	3720	3730	3740	3750	3760	3770	3780	3790	3800	3810	3820	3830	3840	3850

GEO_HV-0006_ML_00-M3-CR-0001-A01 LONGITUDINAL SECTION
SCALE: H 1:500,V 1:100

LEGEND:

- TOPSOIL (TS)
- MADE GROUND (MG)
- BROWN DUBLIN BOULDER CLAY (BRDBC)
- BLACK DUBLIN BOULDER CLAY (BLDBC)
- SAND AND GRAVEL (S&G)
- GLACIAL CLAY (GLC)
- CONCRETE (CONC)
- BOULDER (BLDR)
- MUDSTONE (MST)
- LIMESTONE (LST)
- TEMPORARY LAND ACQUISITION
- SITE BOUNDARY LINE

Project Ireland 2040
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Rev	Date	Drn	Chk'd	App'd	Description
L01.1	17/12/20				

W.I.P.

Client: NTA Údarás Náisiúnta Iompair National Transport Authority

Engineering Designer: AECOM / MOTT MACDONALD

Programme Title: BUSCONNECTS DUBLIN CORE BUS CORRIDORS INFRASTRUCTURE WORKS

Drawing Title: CBC06 LUCAN TO CITY CENTRE GROUND INVESTIGATION GEOLOGICAL LONGITUDINAL SECTIONS

Date	Scale	Drawn	Checked	Approved
17/12/20	1:500 @ A1 1:1000 @ A3			

Project Code	Originator Code	QMS Code	Drawing File Name	Sheet Number	Status	Rev
BCIDA	ACM		BCIDA-ACM-ERW_GI-0006_XX_00-DR-CE-0011	11 of 28	S0	L01.1

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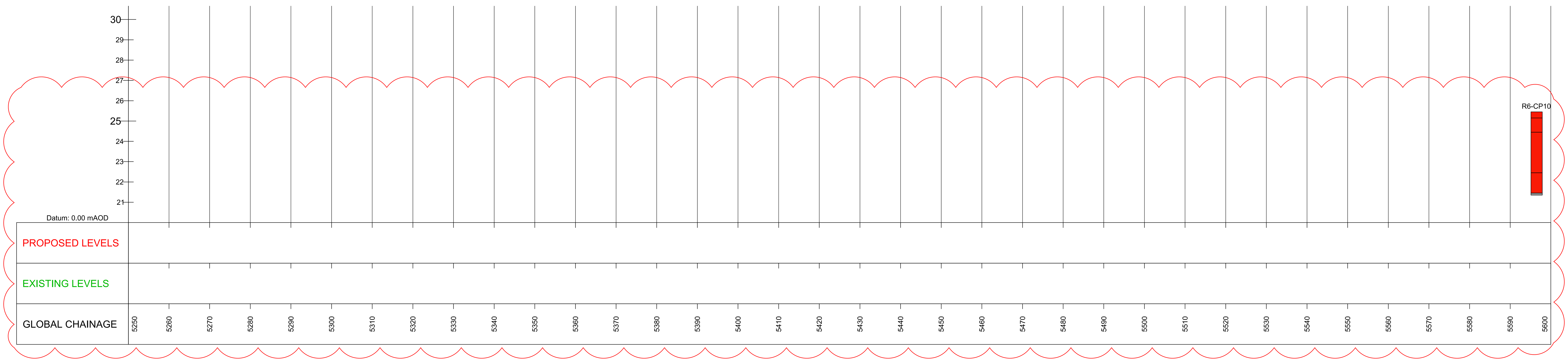

GEO_HV-0006_ML_00-M3-CR-0001-A01 LONGITUDINAL SECTION
SCALE: H 1:500,V 1:100

SUBJECT TO DESIGN DEVELOPMENT

Project Ireland 2040
Building Ireland's Future

Rev	Date	Drn	Chk'd	App'd	Description
L01.1	17/12/20				

W.I.P.

Client: NTA Údarás Náisiúnta Iompair National Transport Authority

Engineering Designer: AECOM MOTT MACDONALD

Programme Title: BUSCONNECTS DUBLIN CORE BUS CORRIDORS INFRASTRUCTURE WORKS

Drawing Title: CBC06 LUCAN TO CITY CENTRE GROUND INVESTIGATION GEOLOGICAL LONGITUDINAL SECTIONS

Date	Scale	Drawn	Checked	Approved
17/12/20	1:500 @ A1 1:1000 @ A3			

Project Code	Originator Code	QMS Code	Drawing File Name	Sheet Number	Status	Rev
BCIDA	ACM		BCIDA-ACM-ERW_GI-0006_XX_00-DR-CE-0056	16 of 28	S0	L01.1

DO NOT SCALE USE FIGURED DIMENSIONS ONLY

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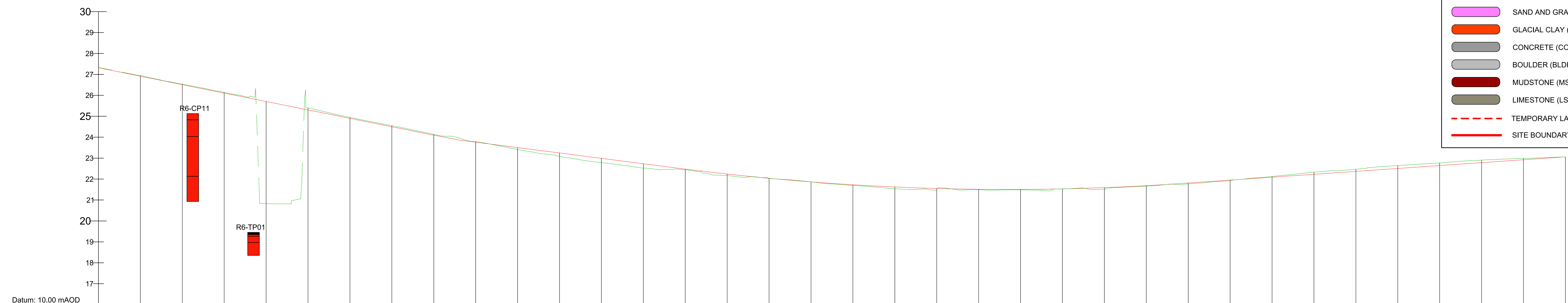
LEGEND:

- TOPSOIL (TS)
- MADE GROUND (MG)
- BROWN DUBLIN BOULDER CLAY (BRDBC)
- BLACK DUBLIN BOULDER CLAY (BLDBC)
- SAND AND GRAVEL (S&G)
- GLACIAL CLAY (GLC)
- CONCRETE (CONC)
- BOULDER (BLDR)
- MUDSTONE (MST)
- LIMESTONE (LST)
- TEMPORARY LAND ACQUISITION
- SITE BOUNDARY LINE



PROPOSED LEVELS	27.3	26.9	26.5	26.1	25.7	25.3	24.9	24.5	24.1	23.8	23.5	23.2	23.0	22.7	22.5	22.2	22.0	21.9
EXISTING LEVELS	27.3	26.9	26.5	26.1	20.8	25.4	25.0	24.6	24.1	23.8	23.4	23.1	22.8	22.5	22.4	22.2	22.0	21.9
GLOBAL CHAINAGE	5600	5610	5620	5630	5640	5650	5660	5670	5680	5690	5700	5710	5720	5730	5740	5750	5760	5770

PROPOSED LEVELS	21.7	21.6	21.5	21.5	21.5	21.5	21.6	21.7	21.8	21.9	22.1	22.2	22.4	22.5	22.6	22.8	22.9	23.1
EXISTING LEVELS	21.7	21.5	21.5	21.5	21.5	21.5	21.5	21.7	21.8	21.9	22.1	22.3	22.5	22.6	22.8	22.9	23.0	23.1
GLOBAL CHAINAGE	5780	5790	5800	5810	5820	5830	5840	5850	5860	5870	5880	5890	5900	5910	5920	5930	5940	5950

GEO_HV-0006_ML_00-M3-CR-0001-A01 LONGITUDINAL SECTION
SCALE: H 1:500,V 1:100

Project Ireland 2040
Building Ireland's Future

Rev	Date	Drn	Chk'd	App'd	Description
L01.1	17/12/20				

W.I.P.

Client: NTA Údarás Náisiúnta Iompair National Transport Authority

Engineering Designer: AECOM / MOTT MACDONALD

Programme Title: **BUSCONNECTS DUBLIN CORE BUS CORRIDORS INFRASTRUCTURE WORKS**

Drawing Title: CBC06 LUCAN TO CITY CENTRE GROUND INVESTIGATION GEOLOGICAL LONGITUDINAL SECTIONS

Date	Scale	Drawn	Checked	Approved
17/12/20	1:500 @ A1 1:1000 @ A3			

Project Code	Originator Code	QMS Code	Drawing File Name	Sheet Number	Status	Rev
BCIDA	ACM		BCIDA-ACM-ERW_GI-0006_XX_00-DR-CE-0017	17 of 28	S0	L01.1

DO NOT SCALE USE FIGURED DIMENSIONS ONLY

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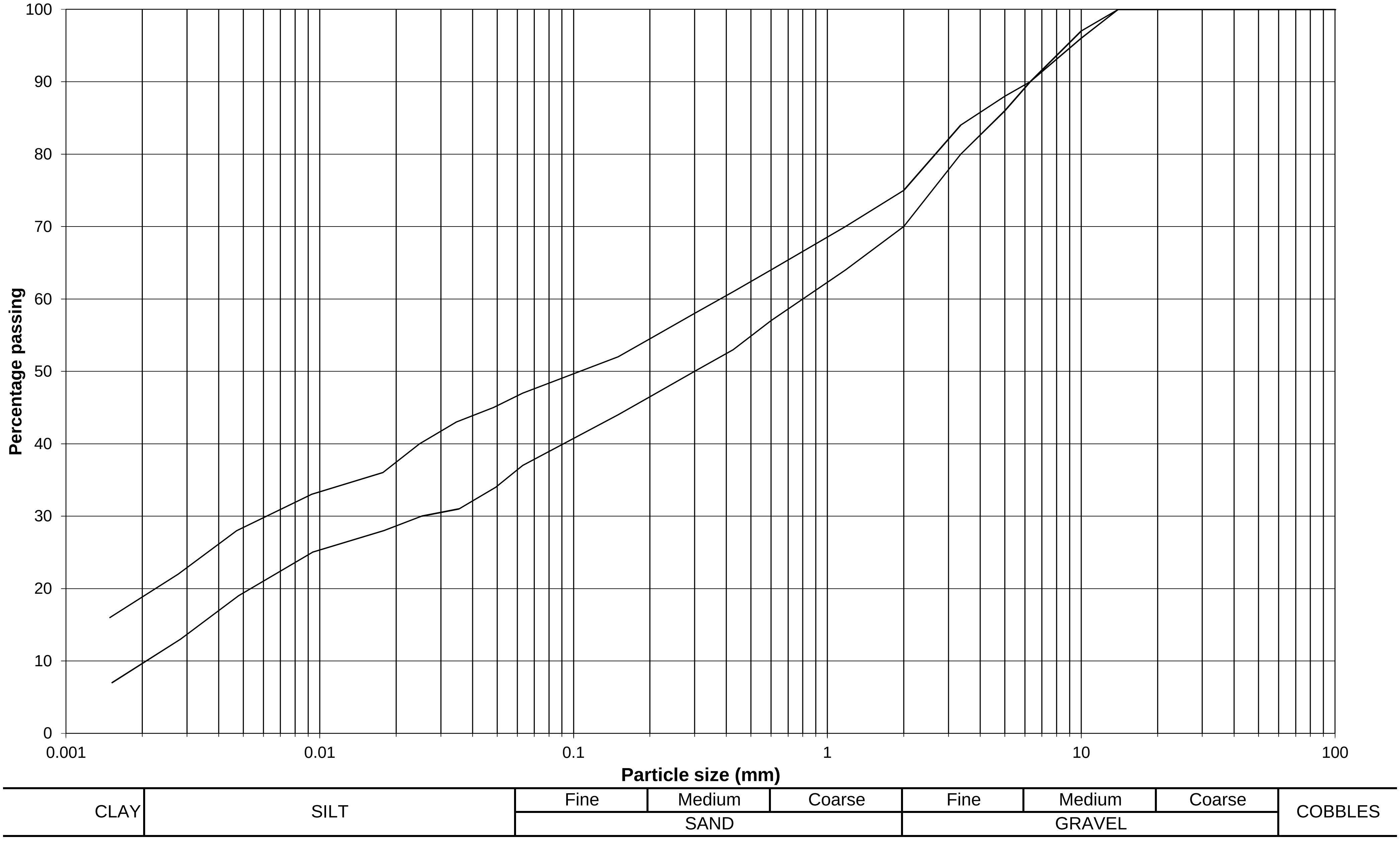
Appendix C Laboratory Test Summary Charts



Made Ground- particle size distribution

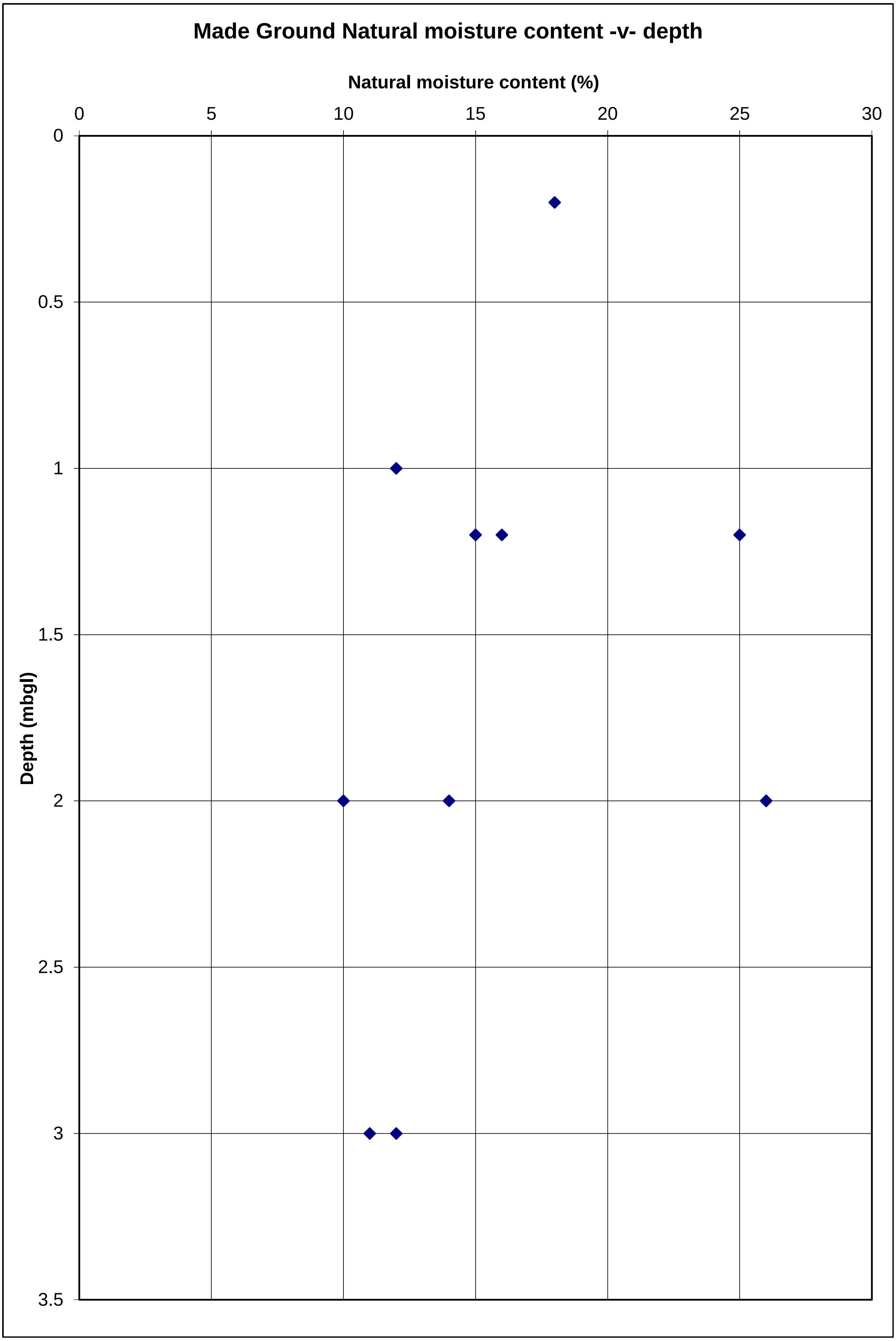


Figure R6.MG.2

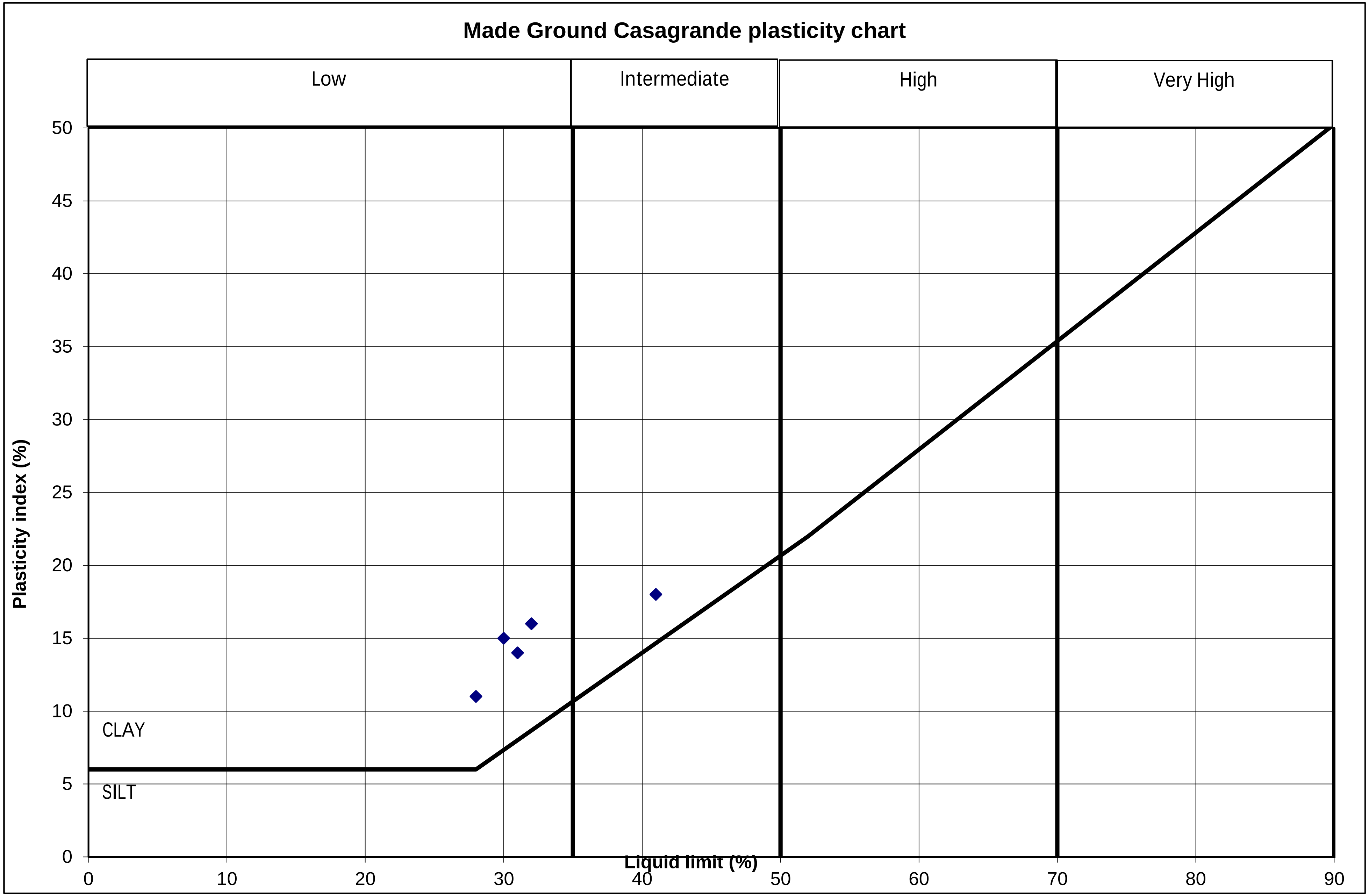
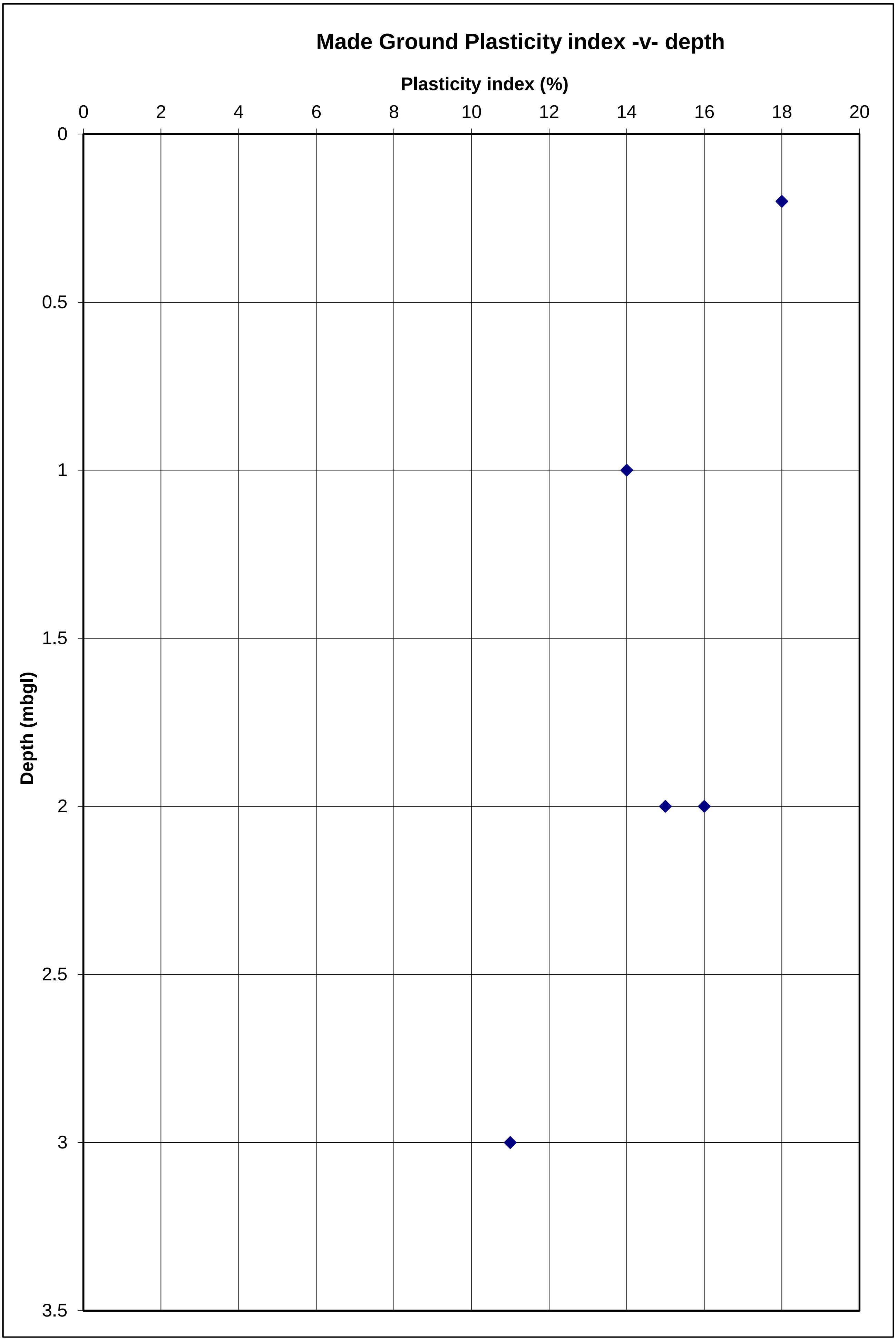
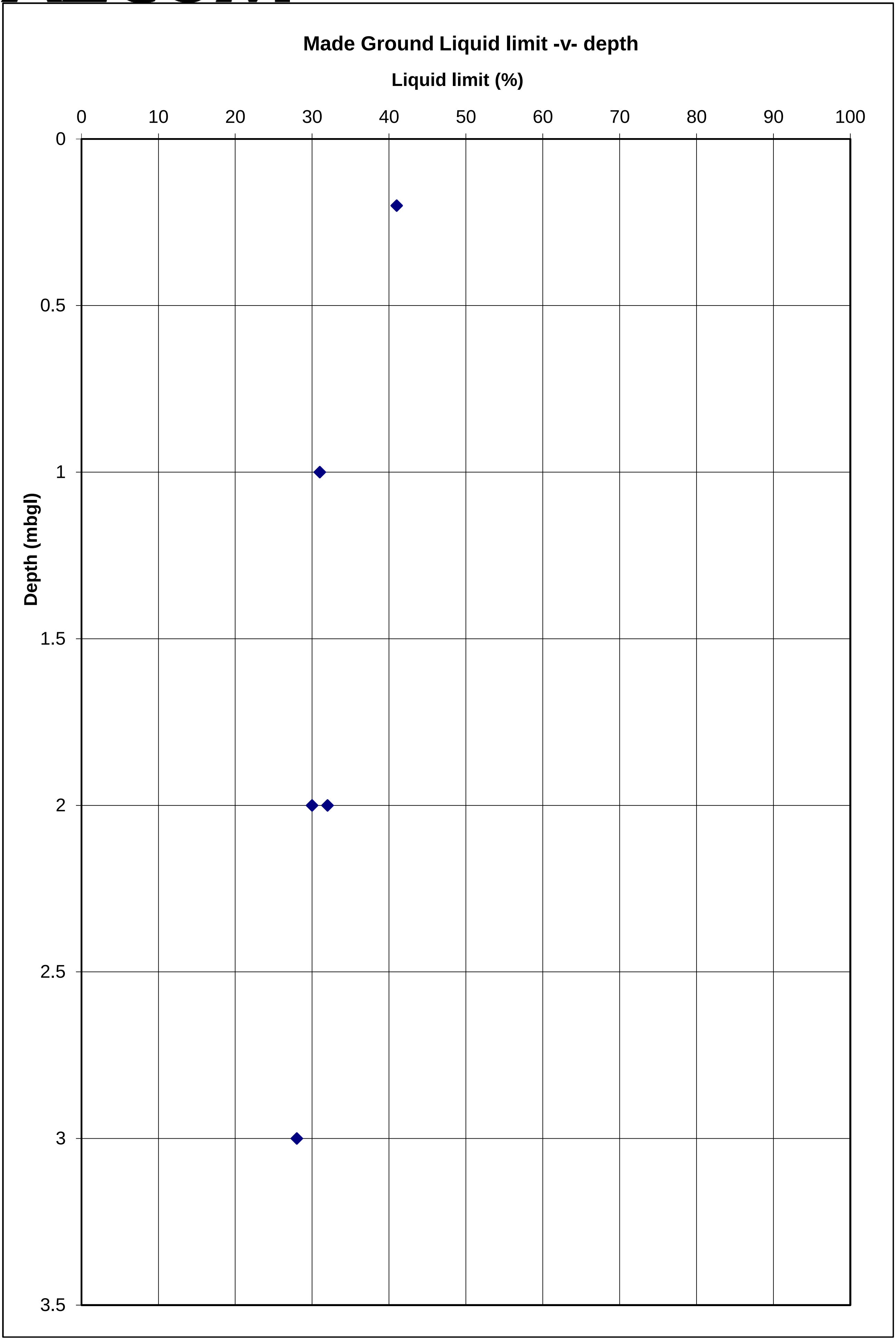
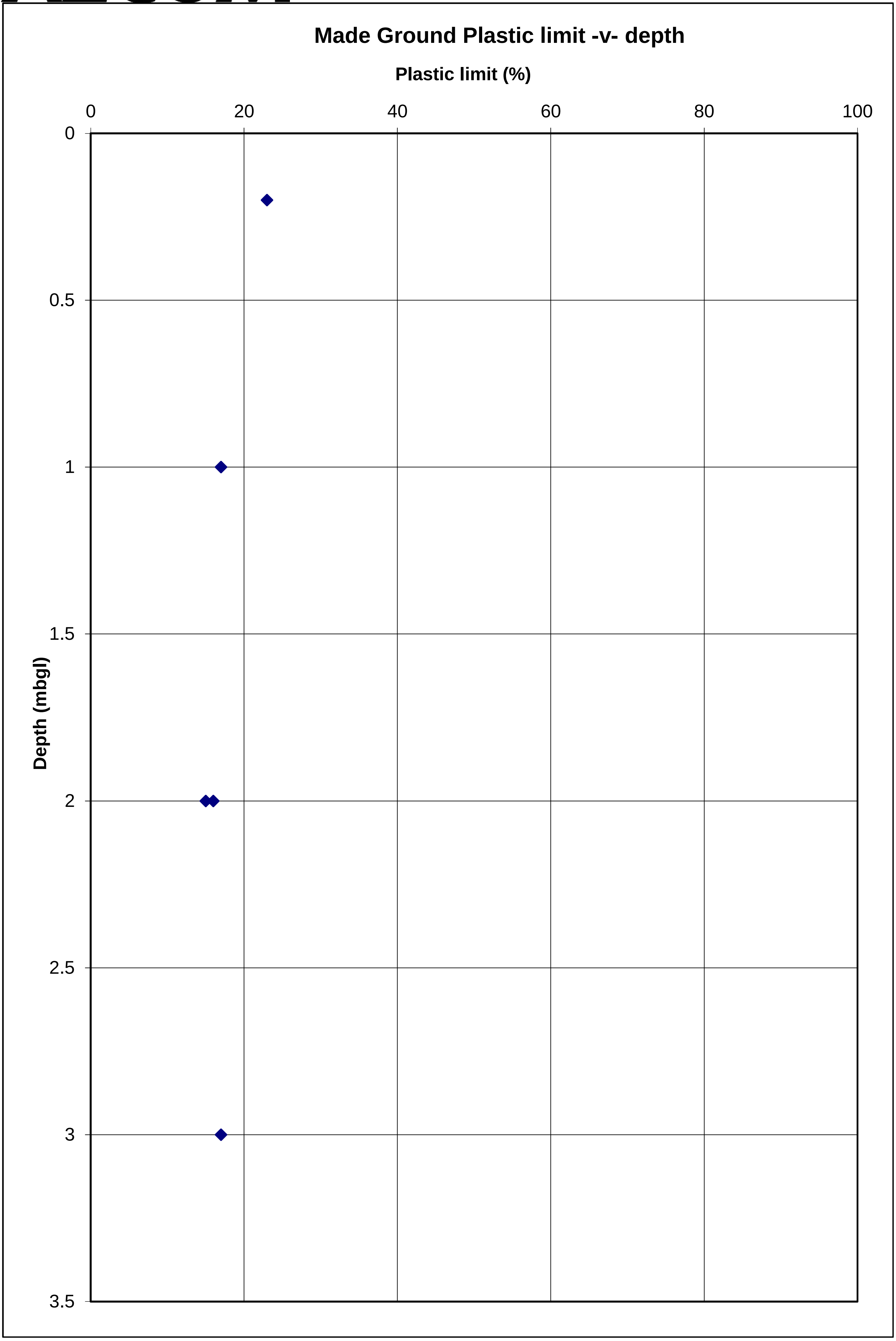
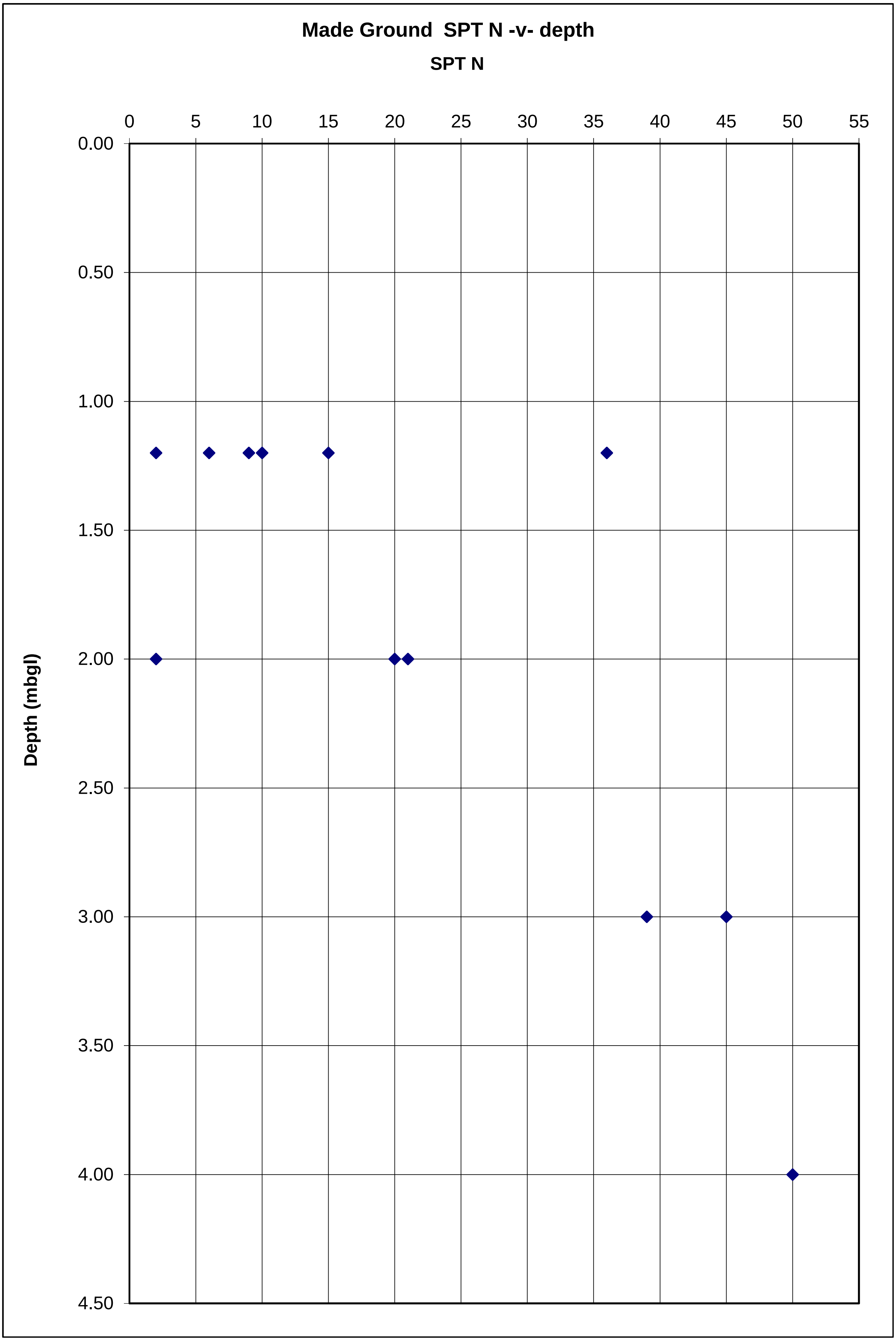


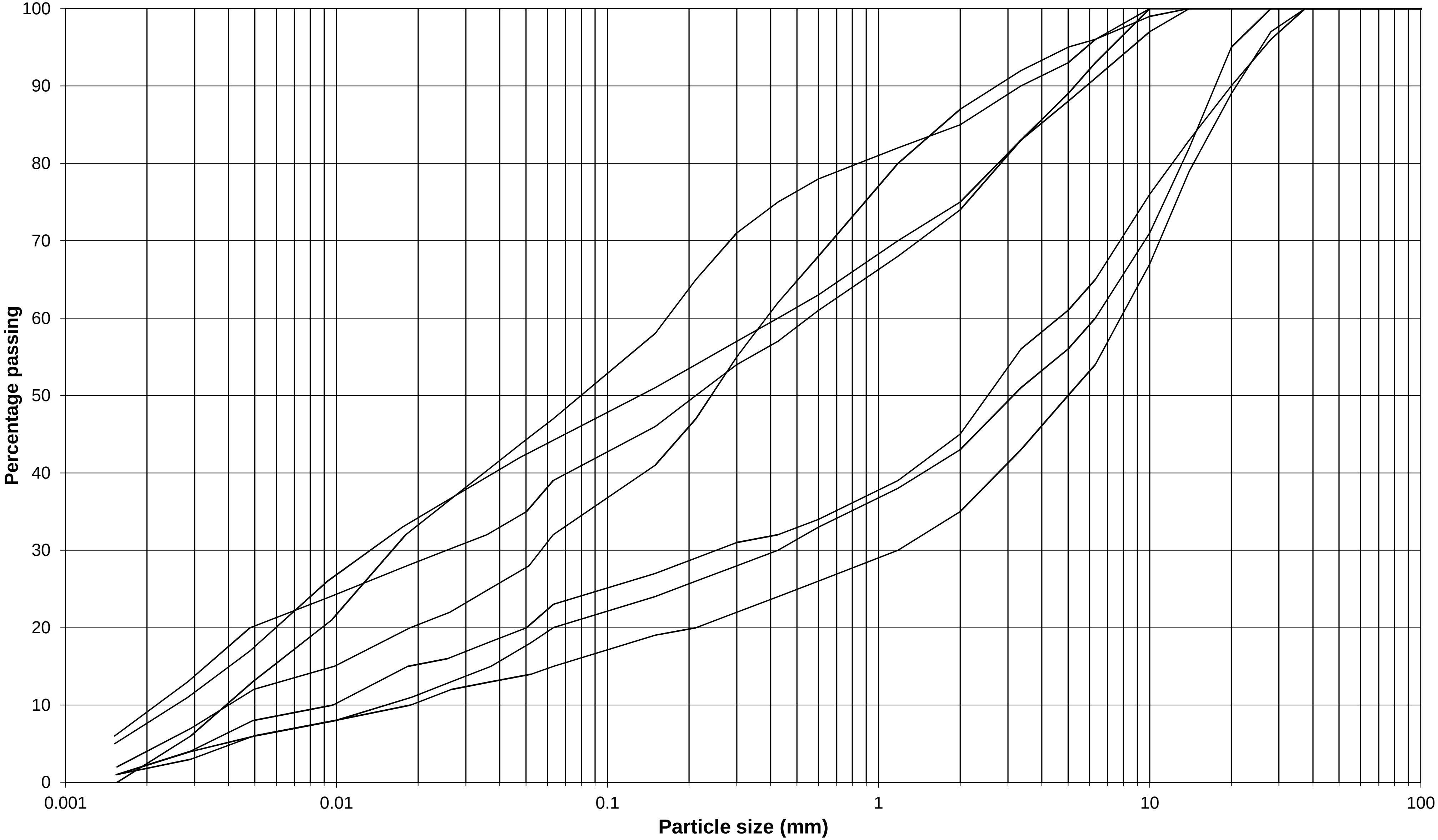
Figure R6.MG.3


Made Ground Plasticity index -v- depth
Plasticity index (%)
0
2
4
6
8
10
12
14
16
18
20
Depth (mbgl)
0
0.5
1
1.5
2
2.5
3
3.5


Made Ground Liquid limit -v- depth
Liquid limit (%)
0
10
20
30
40
50
60
70
80
90
100
Depth (mbgl)
0
0.5
1
1.5
2
2.5
3
3.5

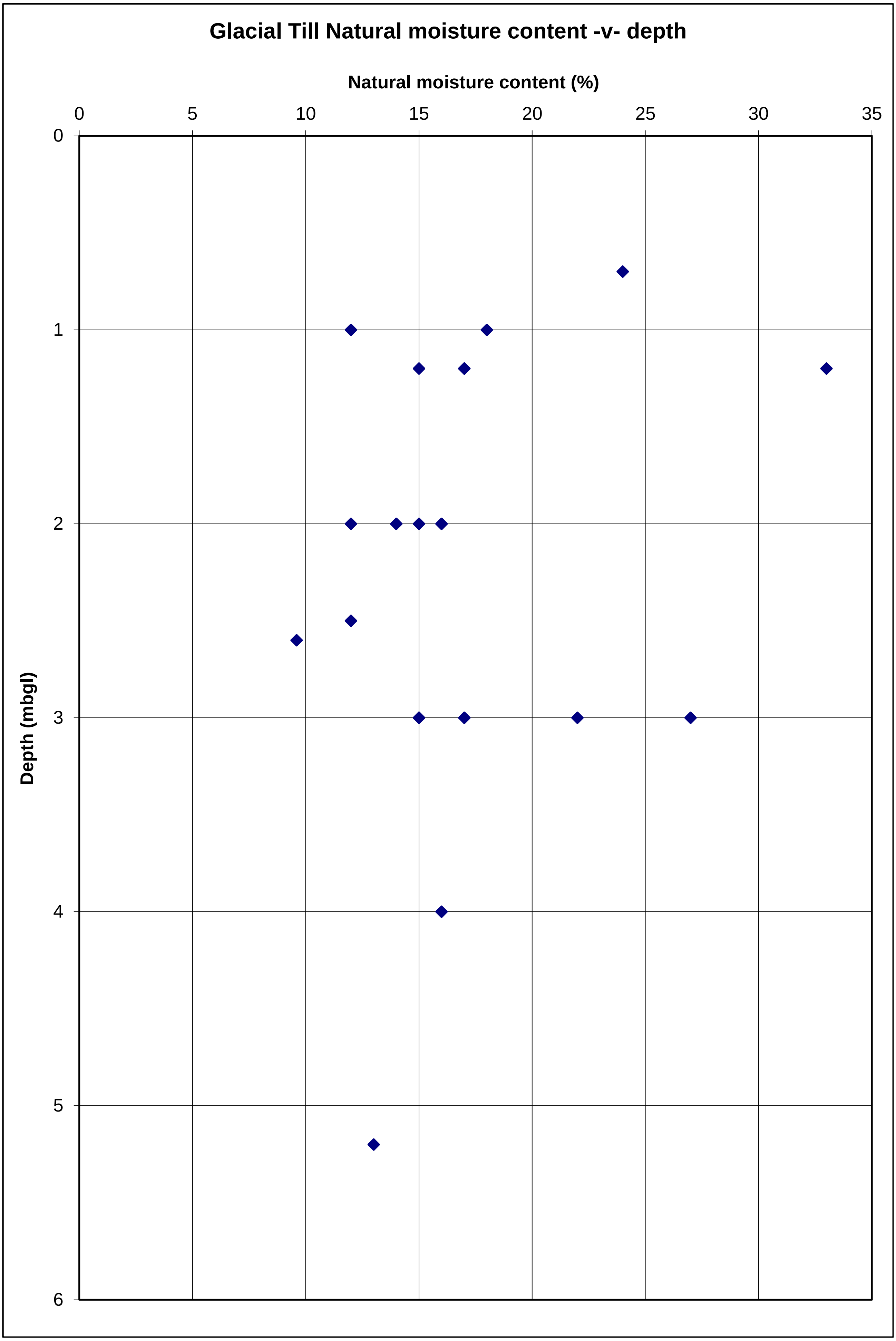

Made Ground Plastic limit -v- depth
Plastic limit (%)
0
20
40
60
80
100
0
0.5
1
1.5
2
2.5
3
3.5
Depth (mbgl)

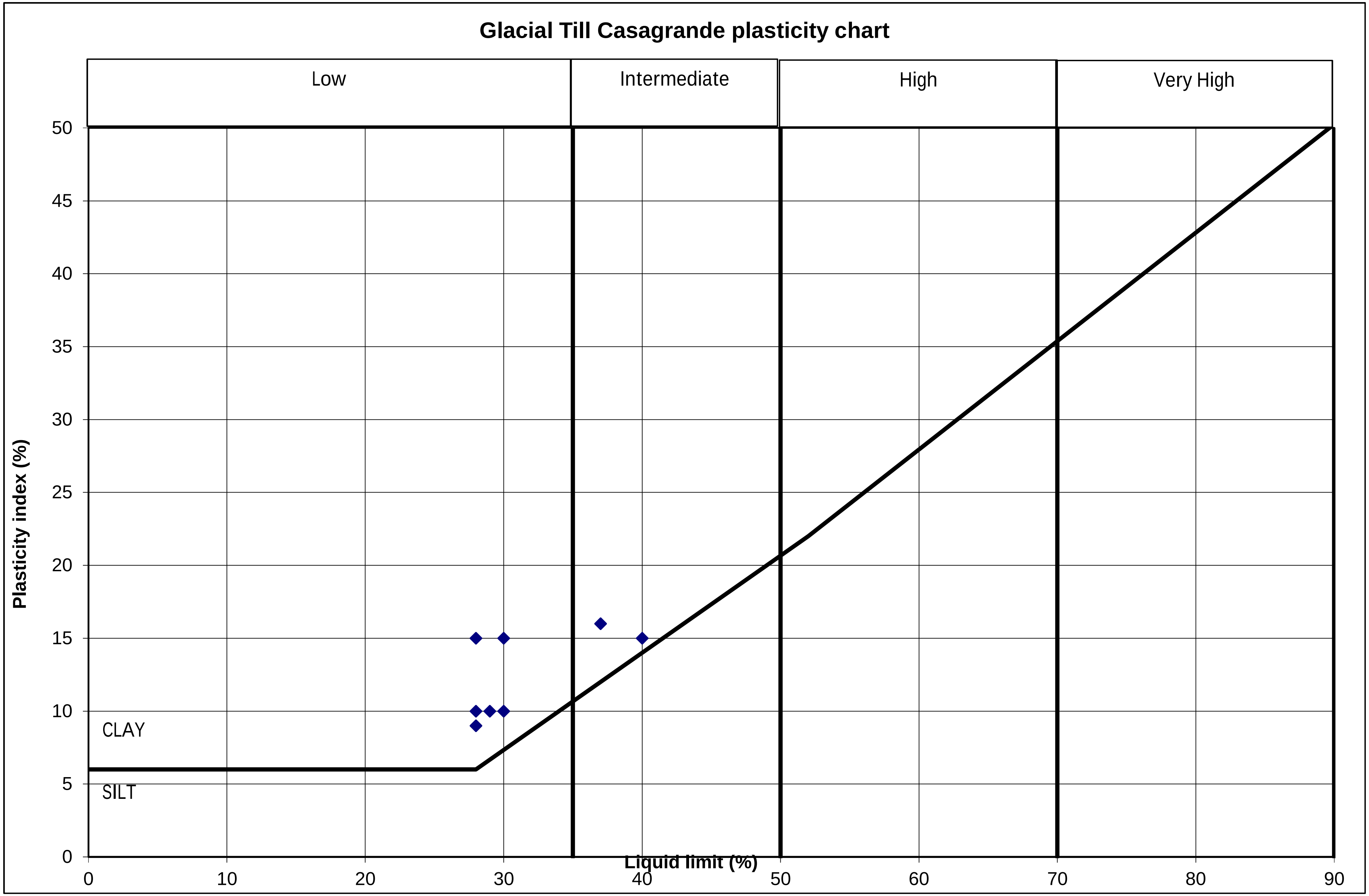

Made Ground SPT N -v- depth
SPT N
0
5
10
15
20
25
30
35
40
45
50
55
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
Depth (mbgl)

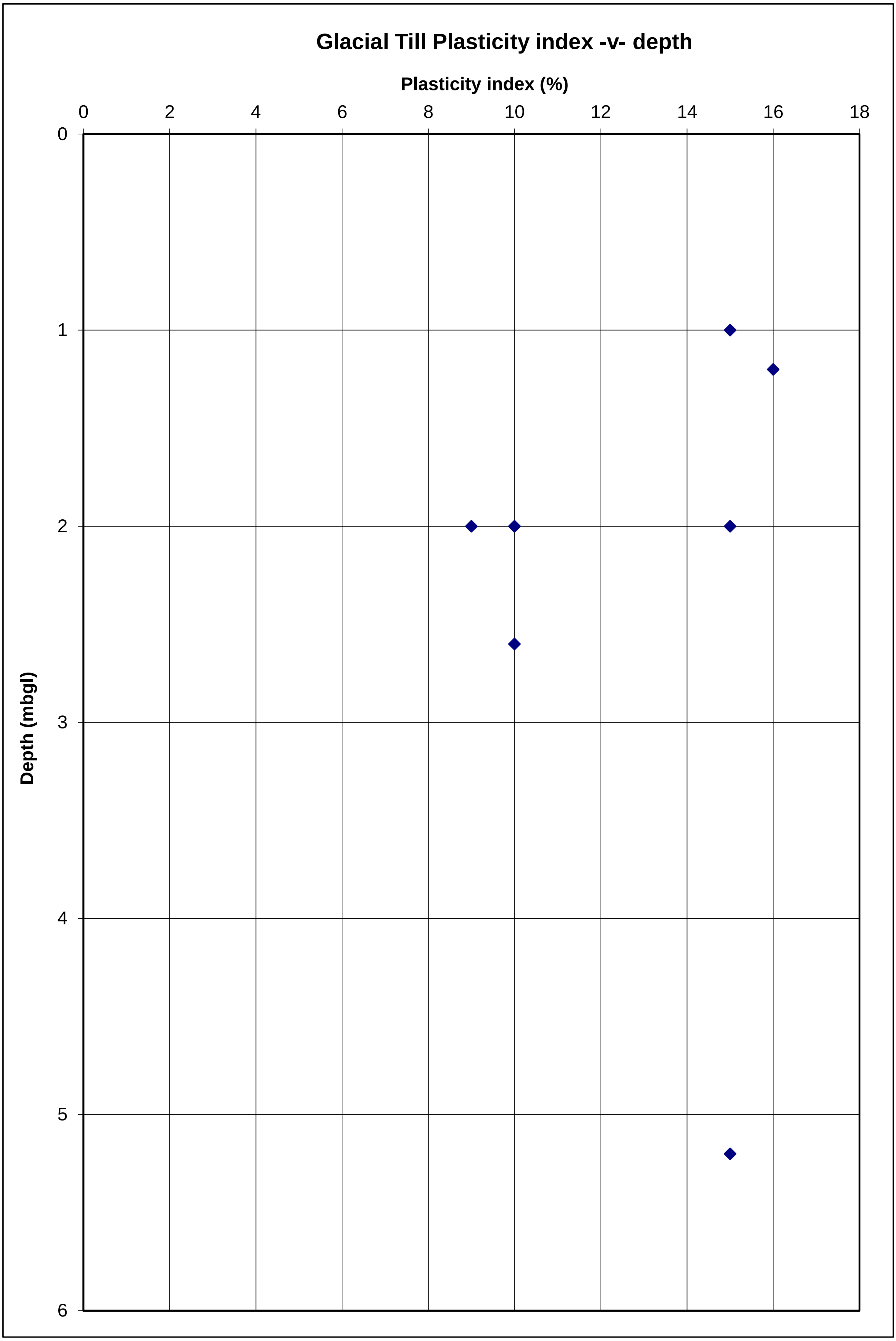


CLAY	SILT	SAND			GRAVEL			COBBLES
		Fine	Medium	Coarse	Fine	Medium	Coarse	

Glacial Till- particle size distribution


Glacial Till Natural moisture content -v- depth
Natural moisture content (%)
0
5
10
15
20
25
30
35
Depth (mbgl)
0
1
2
3
4
5
6


Glacial Till Casagrande plasticity chart
Low
Intermediate
High
Very High
Plasticity index (%)
Liquid limit (%)
CLAY
SILT
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90


Glacial Till Plasticity index -v- depth
Plasticity index (%)
0
2
4
6
8
10
12
14
16
18
Depth (mbgl)
0
1
2
3
4
5
6

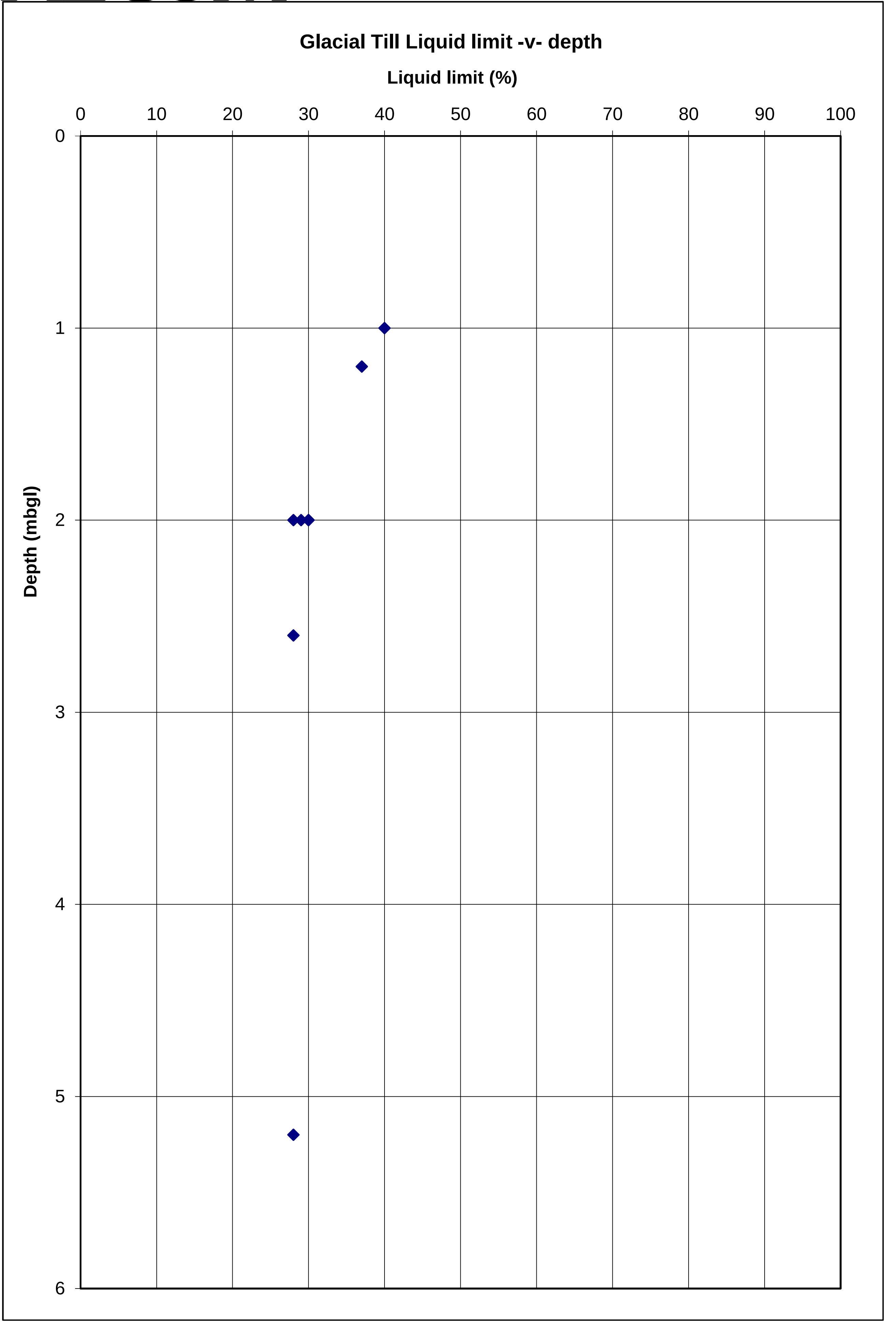
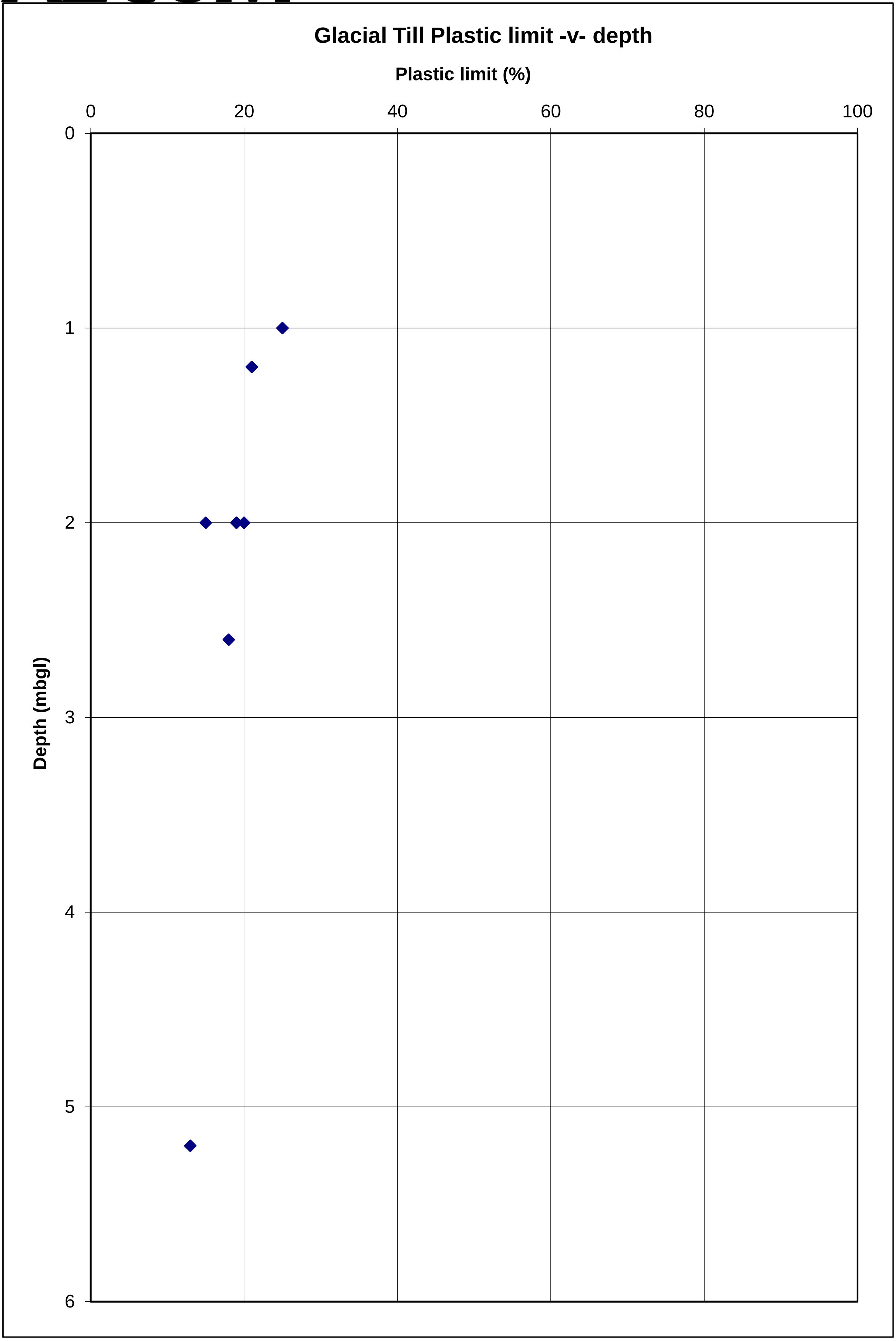
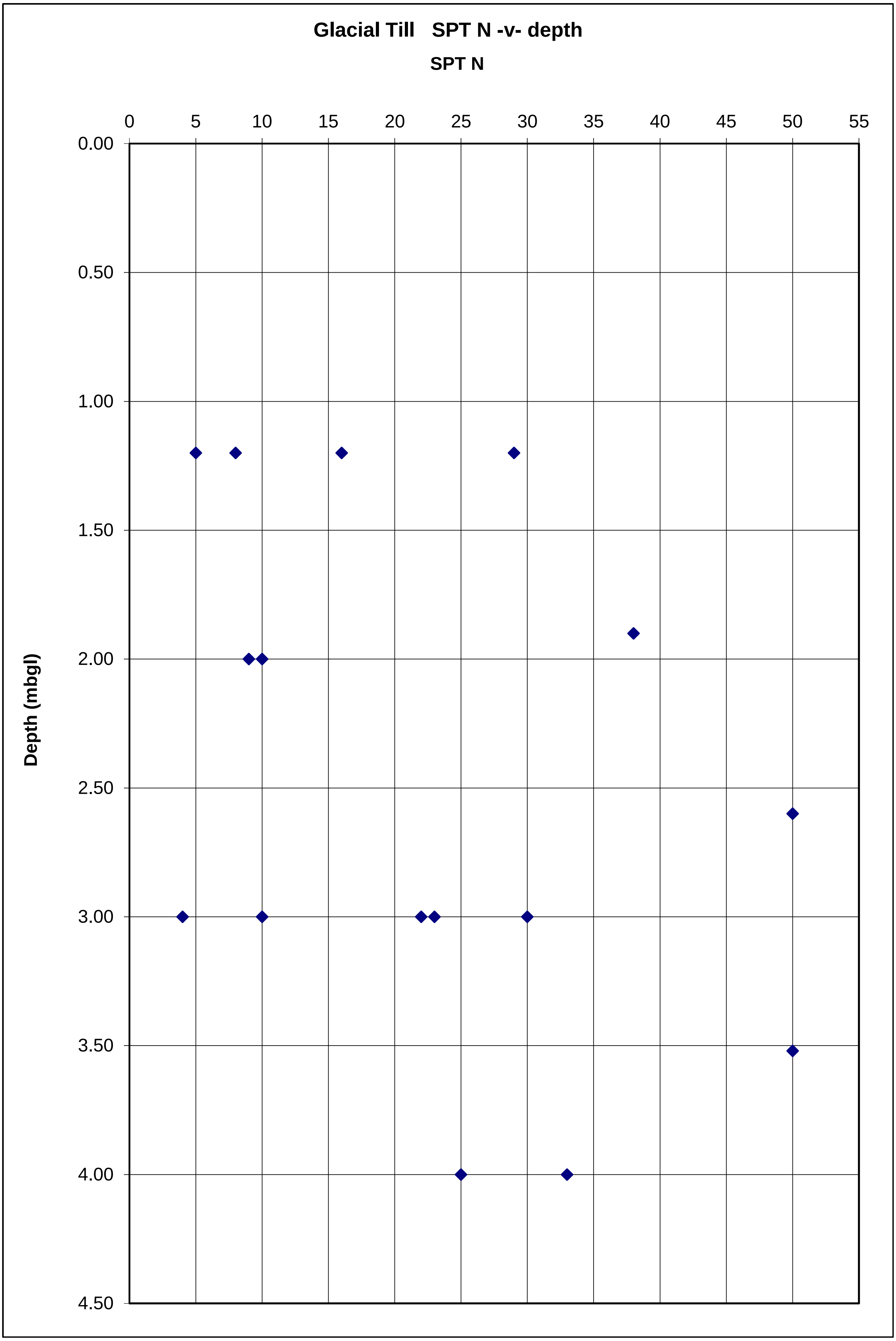
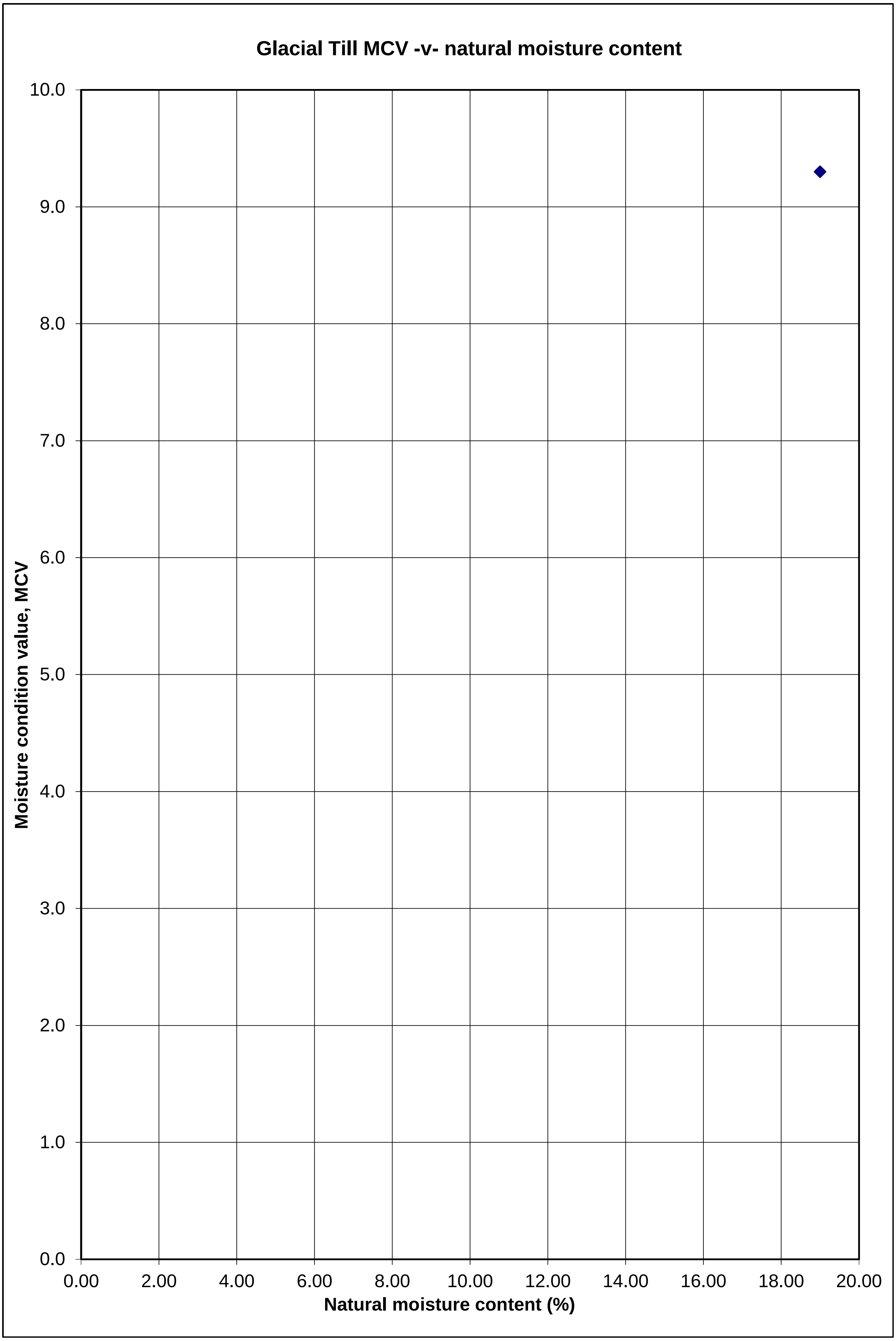
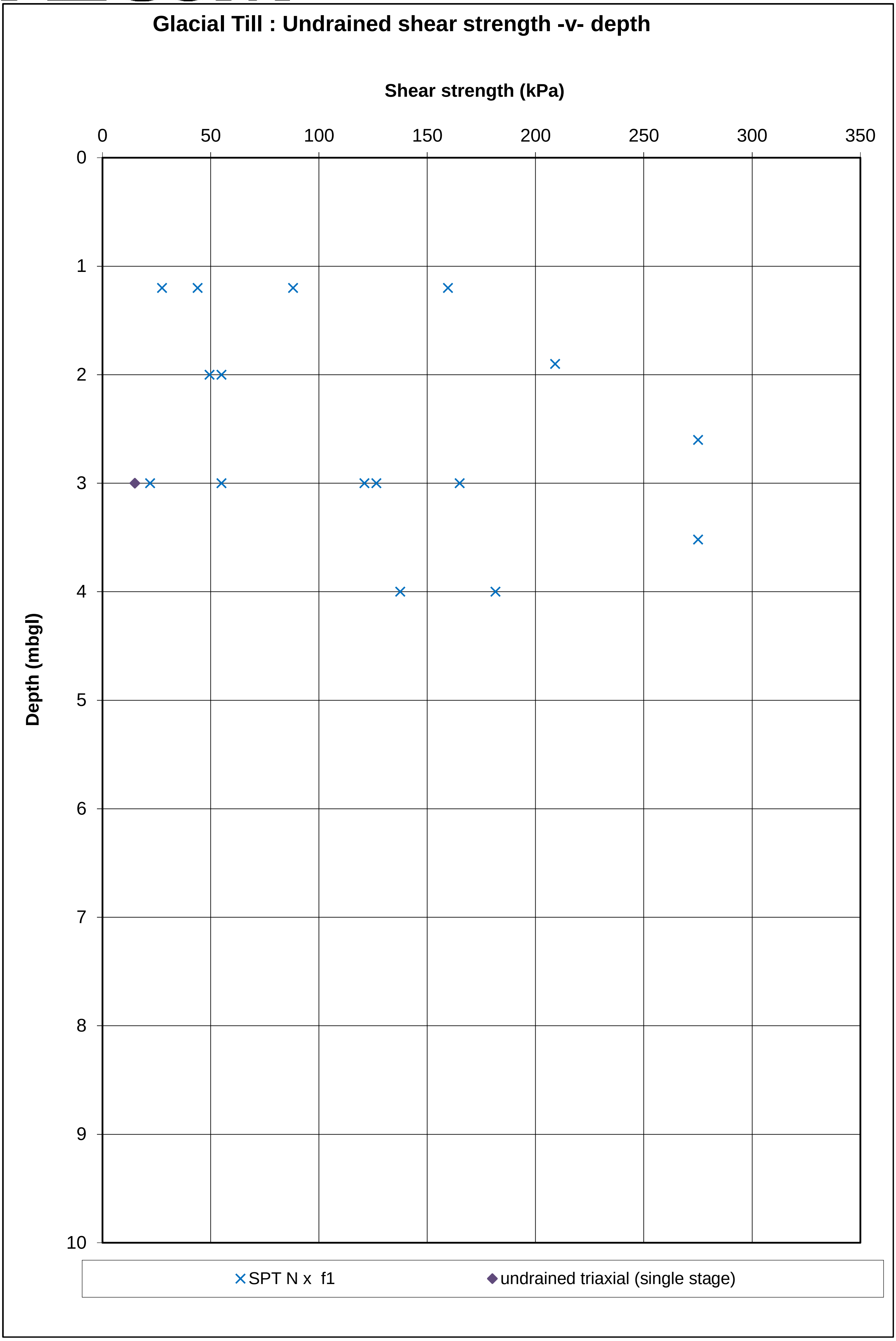


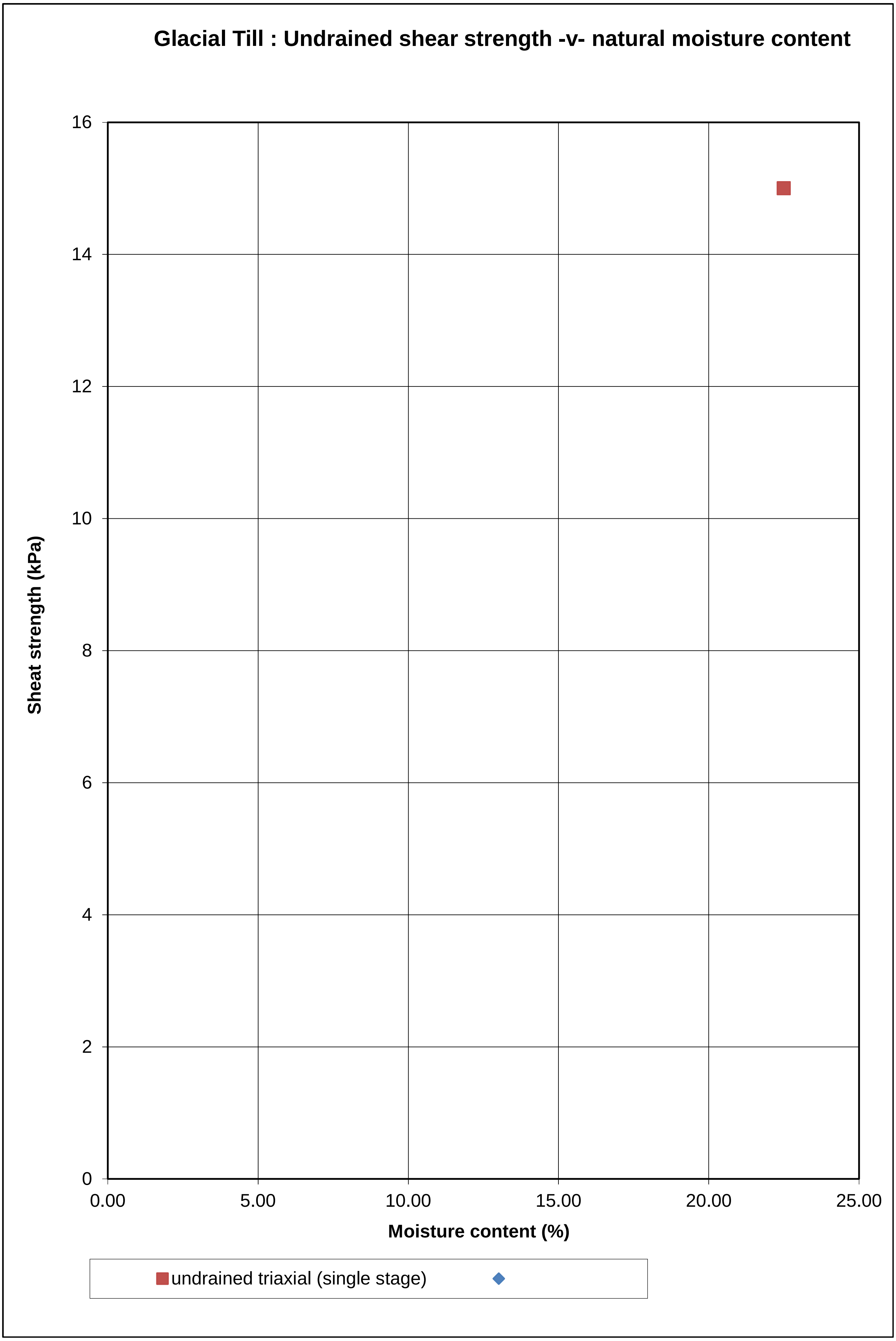
Figure R6.GT.5

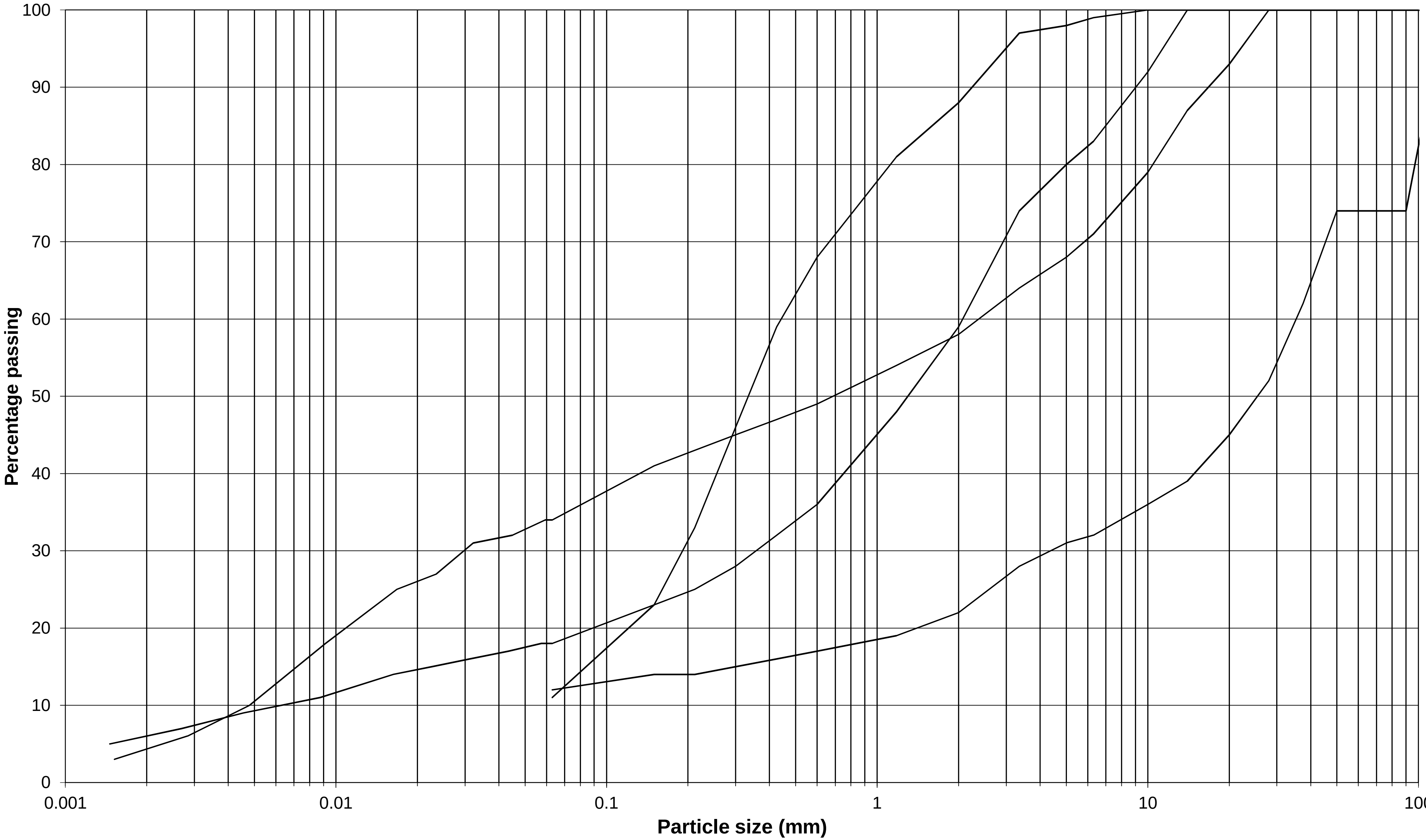

Glacial Till Plastic limit -v- depth
Plastic limit (%)
0
20
40
60
80
100
Depth (mbgl)
0
1
2
3
4
5
6


Glacial Till SPT N -v- depth
SPT N
0
5
10
15
20
25
30
35
40
45
50
55
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
Depth (mbgl)


Glacial Till MCV -v- natural moisture content
Moisture condition value, MCV
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
Natural moisture content (%)

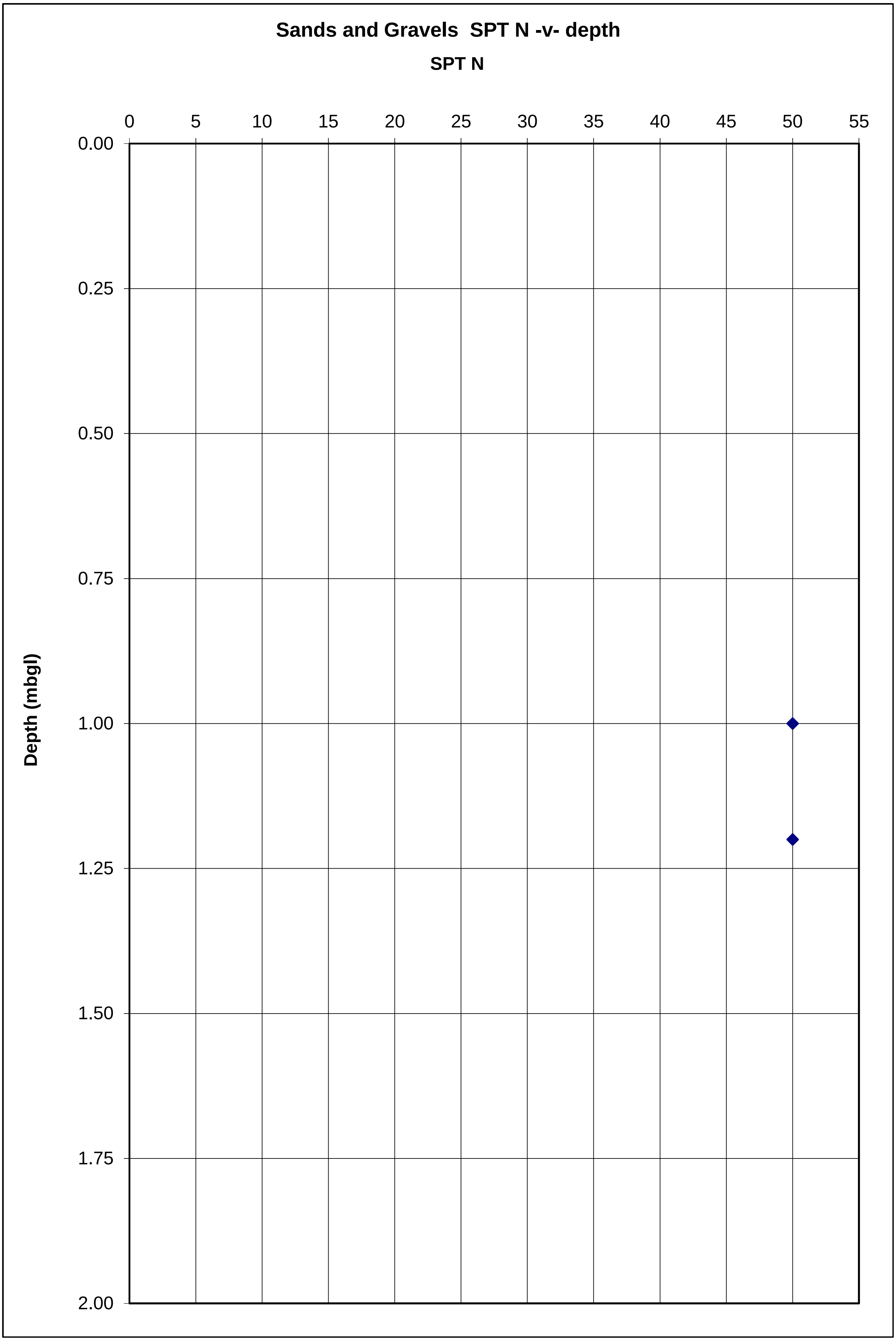

Glacial Till : Undrained shear strength -v- depth
Shear strength (kPa)
0
50
100
150
200
250
300
350
Depth (mbgl)
0
1
2
3
4
5
6
7
8
9
10
SPT N x f1
undrained triaxial (single stage)

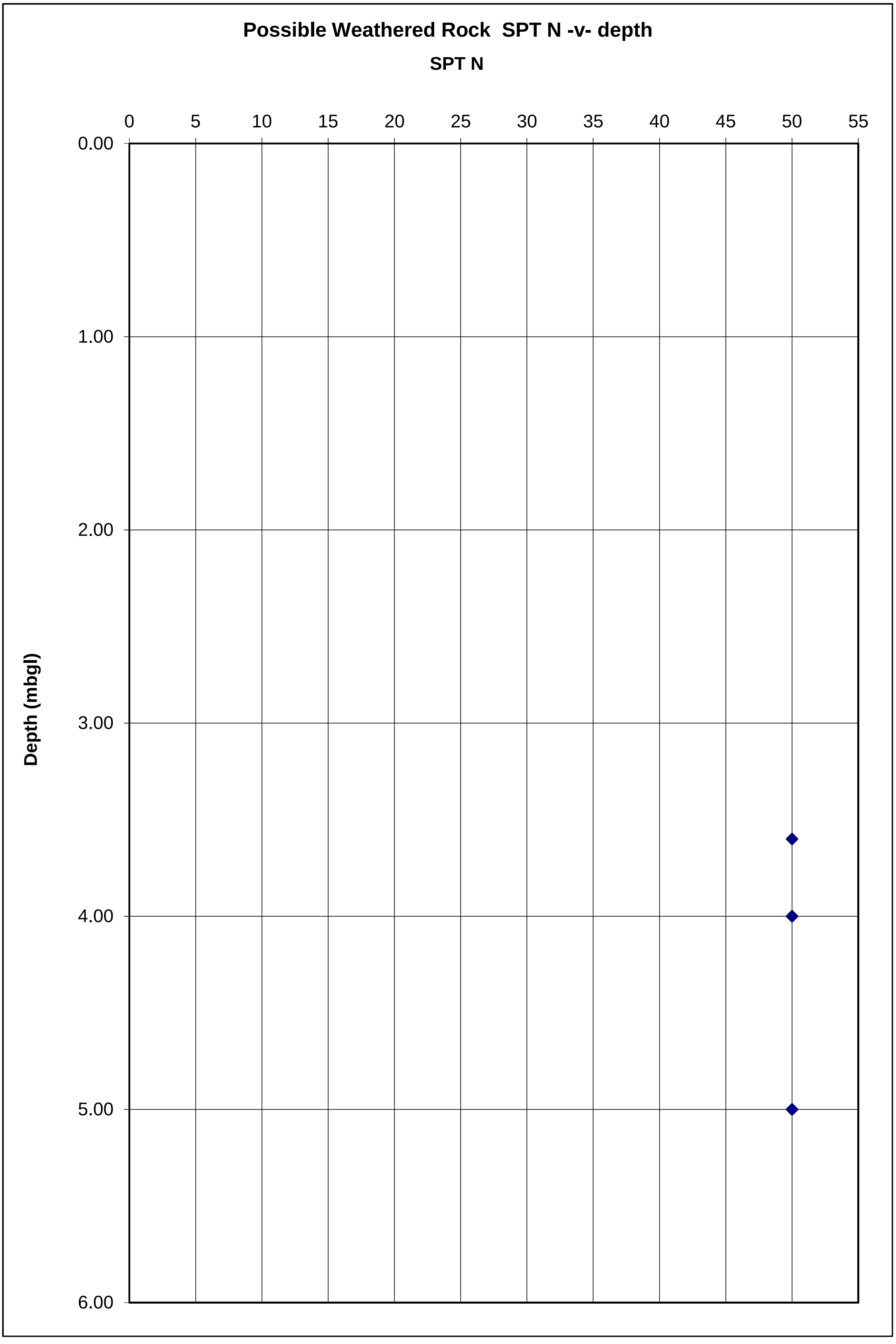

Glacial Till : Undrained shear strength -v- natural moisture content
Sheat strength (kPa)
16
14
12
10
8
6
4
2
0
0.00
5.00
10.00
15.00
20.00
25.00
Moisture content (%)
undrained triaxial (single stage)

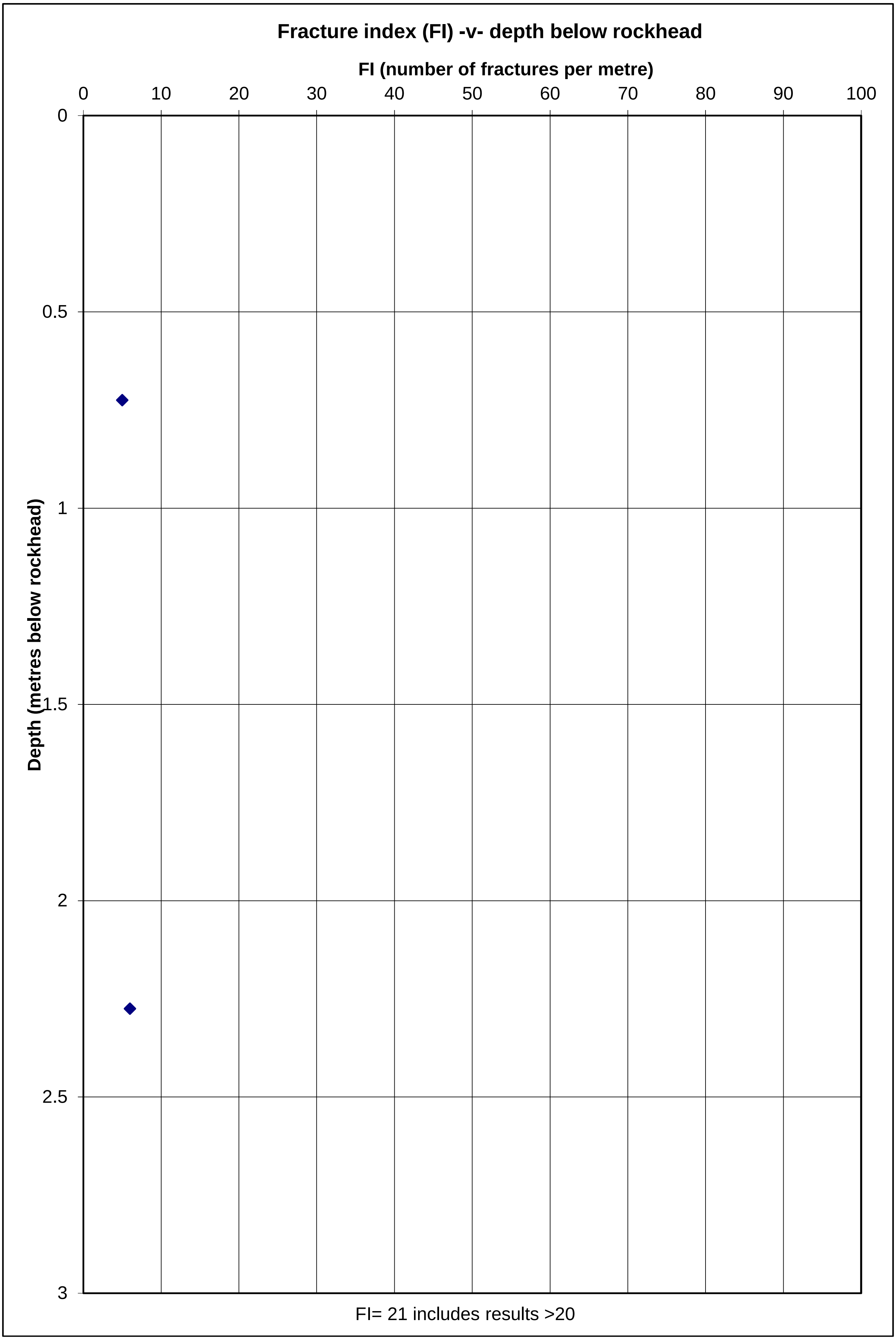


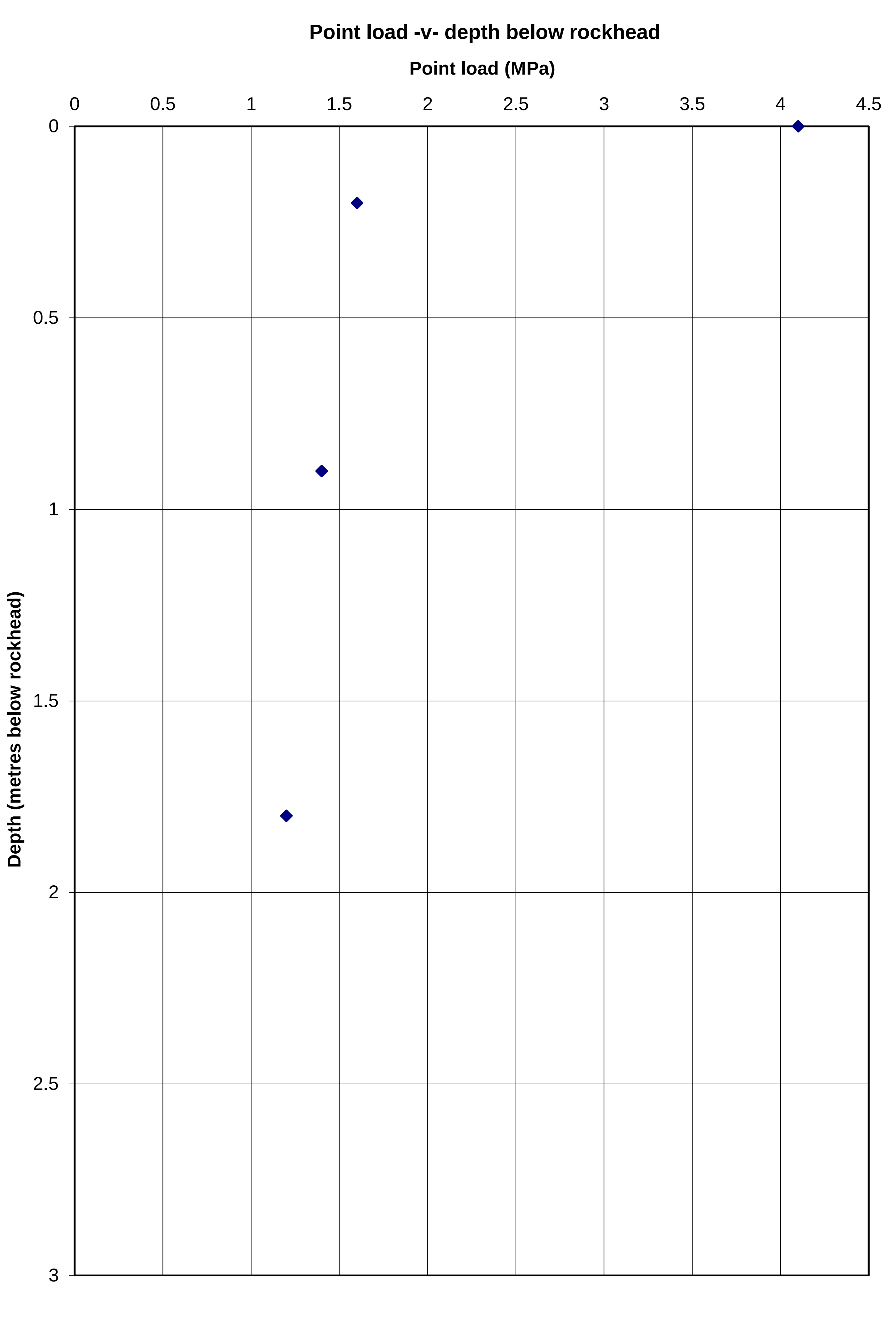
CLAY	SILT	SAND			GRAVEL			COBBLES
		Fine	Medium	Coarse	Fine	Medium	Coarse	

Sand and Gravels- particle size distribution


Sands and Gravels SPT N -v- depth
SPT N
0
5
10
15
20
25
30
35
40
45
50
55
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Depth (mbgl)


Possible Weathered Rock SPT N -v- depth
SPT N
0
5
10
15
20
25
30
35
40
45
50
55
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Depth (mbgl)


Fracture index (FI) -v- depth below rockhead
FI (number of fractures per metre)
0
10
20
30
40
50
60
70
80
90
100
0
0.5
1
1.5
2
2.5
3
Depth (metres below rockhead)
FI= 21 includes results >20


Point load -v- depth below rockhead
Point load (MPa)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Depth (metres below rockhead)
0
0.5
1
1.5
2
2.5
3

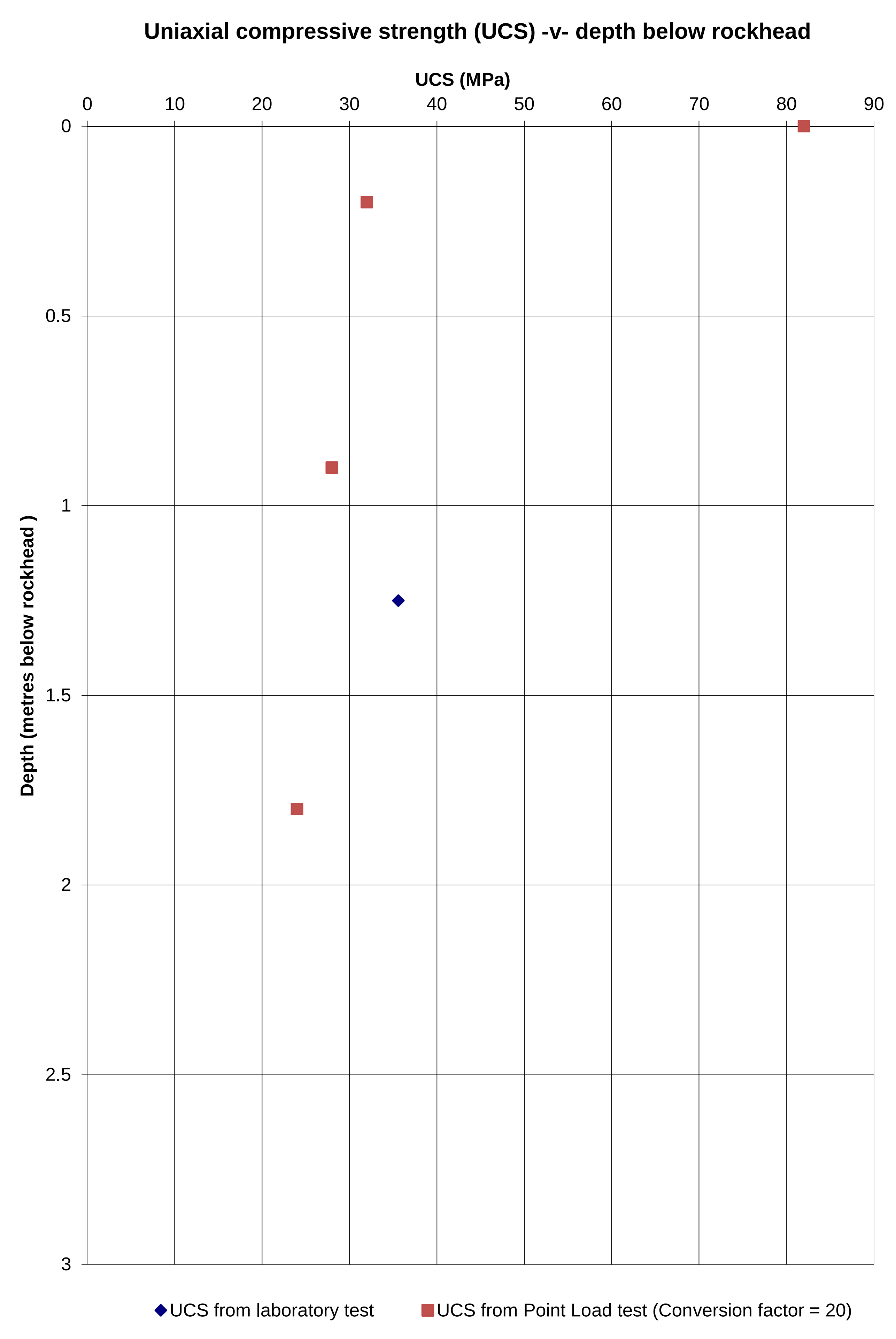


Figure R6.ROCK.3