



PROPOSED RESIDENTIAL DEVELOPMENT

**LAND AT TRUB FARM, MANCHESTER ROAD, ROCHDALE,
OL11 2XG**

MCI DEVELOPMENTS (NORTHWEST) LTD



A KEEPMOAT COMPANY

PHASE II FACTUAL SITE INVESTIGATION REPORT

Our Ref: 18112/FSIR

SEPTEMBER 2025



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DOCUMENT STATUS

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Title	Phase II Factual Site Investigation Report
Client	MCI Developments (Northwest) Ltd
Project No.	18112/FSIR
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DRAFT

EXECUTIVE SUMMARY

Site	<i>The site is irregular in shape and extends to an area of approximately 4.98 hectares. The site is located off Manchester Road, Rochdale off Marlborough Street, approximately 2km southwest of Rochdale's town centre.</i>
NGR	<i>SD 88226 10043</i>
Investigations	<i>The ground conditions present within the proposed bund area of the site have been investigated utilising a series of ten (10 No.) windowless sampled boreholes and five (5 No.) CPT's which were supervised by an experienced REFA engineer between the 3rd September and the 5th September 2025.</i> <i>The ground conditions present at the access road have been investigated utilising a series of three (3 No.) windowless sampled boreholes, one (1 No.) trial pit and one (1 No.) cable percussive borehole on the 3rd September 2025.</i>
Ground Conditions	<i>Ground conditions at the entrance road area of investigation generally comprised of made ground to significant depths of 5.00/5.45mbgl overlying a soft to firm greyish brown slightly gravelly sandy CLAY. Deeper ground conditions within this area were investigated with a cable percussive borehole, which encountered interbedded stratum of SAND and CLAY to a maximum depth of 13.0mbgl.</i> <i>Ground conditions within the area of the proposed bund consisted of limited made ground overlying natural deposits comprising mainly of orangish grey brown slightly gravelly SAND, light grey silty SAND and dark grey slightly gravelly slightly silty SAND, to a maximum depth of 5.45mbgl.</i> <i>Within the natural deposits, plastic brown slightly sandy pseudofibrous PEAT, extending to depths of 1.3 – 2.2mbgl, was encountered. Peat was not observed in WS07, WS08 or WS09.</i> <i>Further PEAT deposits were encountered in WS02, WS03, WS06 and WS13 at greater depths, from 2.65-3.2mbgl, extending to a maximum depth of 3.0 - 3.7mbgl.</i> <i>Cone penetration testing was undertaken by Lankelma Limited across the area of the proposed bund on the 3rd September 2025. A total of five (5 No.) tests were undertaken to a maximum depth of 10.26mbgl.</i>
Groundwater	<i>These intrusive investigations have identified confined groundwater within the natural SAND deposits near the entrance road. Water strikes were encountered at 6.1, 9.6 and 10.2mbgl.</i> <i>Furthermore, the intrusive investigations have identified perched groundwater within the proposed bund area, at 1.0mbgl.</i>
Further Works	<i>If any unusual or suspicious strata or ground conditions are encountered during the subsequent preparation work, it will be necessary for these areas to be brought to the attention of the appropriate authorities so that all necessary inspection may be undertaken. It is incumbent upon the site contractors to advise a responsible authority of any unusual findings within the site which may then be further investigated.</i>

This brief summary should not be assumed to represent a complete account of all the potential geo-environmental issues that may exist at the site. As such it is strongly recommended that the report be read in its entirety.

PHASE II SITE INVESTIGATION WORKS**LAND AT TRUB FARM, MANCHESTER ROAD, ROCHDALE****1.0 INTRODUCTION****1.1 Instructions**

- 1.1.1 We are instructed by MCI Developments (Northwest) Ltd, 15 Beecham Court, Wigan, WN3 6PR, to undertake a supplementary phase of ground investigation works at a site situated at Trub Farm, Manchester Road, Rochdale.

1.2 Object

- 1.2.1 The main objectives of the site investigation were:

- Investigate the ground conditions towards the southern end of the site where a proposed bund situated above varying thickness PEAT deposits.
- Investigation of the entrance road ground conditions.

1.3 Scope

- 1.3.1 The investigations considered within this report have comprised of the following elements:

- Undertake GI works by trial pits, windowless sample boreholes, cable percussive boreholes and cone penetration testing.
- Determine the thickness of peat deposits within the area of the proposed bund;
- Determine the ground conditions at the entrance road.

1.4 Development Proposals

- 1.4.1 The site has been proposed to be developed in a residential manner which will include the construction low rise residential dwellings and two multi-storey apartment blocks with associated gardens, estate roads and infrastructure. A copy of the Proposed Site Plan is attached to this report, reference: MCI-000-DR-A-500.

2.0 THE SITE**2.1 Location**

- 2.1.1 The site is irregular in shape and extends to an area of approximately 4.98 hectares. The site is located off Manchester Road, Rochdale off Marlborough Street, approximately 2km southwest of Rochdale's town centre with the approximate centre of the site is situated at approximate National Grid Reference SD 88226 10043. The site location is shown in figure 1 overleaf.

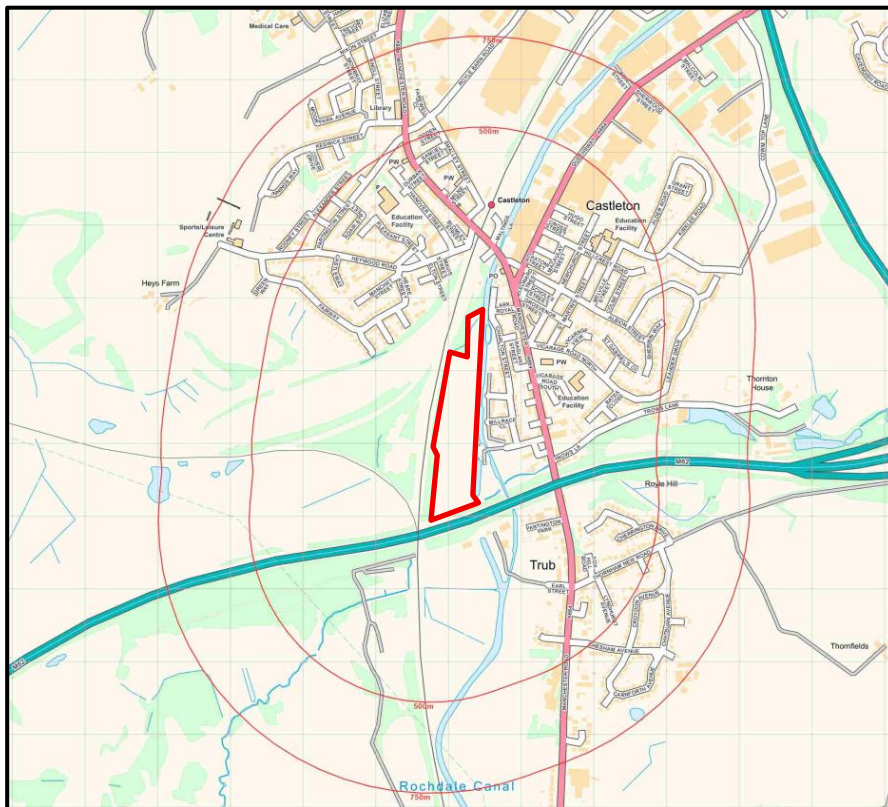


Figure 1 Site Location

3.0 SITE WORKS

3.1 Intrusive Works

- 3.1.1 The ground conditions present within the proposed bund area of the site have been investigated utilising a series of ten (10 No.) windowless sampled boreholes and five (5 No.) CPT's which were supervised by an experienced REFA engineer between the 3rd September and the 5th September 2025.
- 3.1.2 The ground conditions present at the access road have been investigated utilising a series of three (3 No.) windowless sampled boreholes, one (1 No.) trial pit and one (1 No.) cable percussive borehole on the 3rd September 2025.

3.2 Locations

- 3.2.1 The locations of the boreholes were chosen by REFA to target the areas requiring further information for design requirements. The locations were chosen in an effort to identify the representative ground conditions present in these areas.
- 3.2.2 The locations of each of the exploratory hole positions are indicated upon the appended Exploratory Hole Location Plan 218112/02. These locations are shown in relation to site features present at the time of the investigations.

3.3 Records

- 3.3.1 During the investigation, details of the stratum types, water entries, ground conditions and levels have been maintained by the site engineer. This information has been collated into a series of windowless sample, trial pit, and cable percussive logs. CPT results/logs are appended to this report also.

3.4 Targeting

- 3.4.1 The investigation locations were undertaken to identify the shallow and deeper superficial strata present over the whole site area, though it is acknowledged that ground conditions may vary between investigation locations.
- 3.4.2 The investigation locations have been spread across each investigation area in accordance with the recommendations laid down in BS10175:2011+A2:2017 "Investigation of Potentially Contaminated Sites". The initial ground investigation strategy is detailed within table 1 below.

Table 1 Initial Ground Investigation Strategy		
Exploratory Hole No.	Target	Purpose
WS10, 11 and 13 TP101 CP01	Entrance road	To determine the general nature of underlying soils and geology including: 1. Nature, distribution and thickness of made ground. 2. Content of unacceptable material e.g. peat and biodegradable matter etc. 3. Engineering properties of the ground.
WS01-09 and 13 CPT01 - 05	Proposed area of bund	To determine the general nature of underlying soils and geology including: 1. Nature, distribution and thickness of made ground. 2. Content of unacceptable material e.g. peat and biodegradable matter etc. 3. Engineering properties of the ground.

4.0 GROUND CONDITIONS – ENTRANCE ROAD

4.1 Made Ground

- 4.1.1 All exploratory hole locations encountered made ground to a depth of 0.30 to 5.45mbgl. WS10 and WS11 were able to establish the base of the made ground at 5.45mbgl.
- 4.1.2 WS12 was unable to be drilled due to the large volume of rebar and concrete in the made ground encountered. Various hand dug excavation were undertaken, but no variation in the ground was found that allowed the commencement of drilling. This hole was therefore terminated.
- 4.1.3 TP101 also found made ground with a high cobble content. This exploratory hole location was therefore terminated at 0.6mbgl.
- 4.1.4 Typically made ground comprised of a loose light greyish brown gravelly SAND, with gravel comprising fine to coarse angular to subangular of brick, concrete, ceramic and sandstone.
- 4.1.5 Standard Penetration Tests undertaken within the clay from 1.20m have produced 'N' values 9 to 32.

4.2 Natural Strata

- 4.2.1 Underlying the Made Ground, WS positions recorded soft to firm greyish brown slightly gravelly sandy CLAY from 5.0m to 5.45m, extending to final depths of 6.45mbgl.

4.2.2 CP01 recorded natural deposits from 0.8mbgl, consisting of varying deposits of yellowish-brown silty SAND, slightly gravelly COBBLE and slightly sandy slightly gravelly CLAY to a final depth of 13.00mbgl.

4.2.3 Standard Penetration Tests undertaken within the natural deposits from 5.00m have produced 'N' values 9 to 42.

4.2.4 Standard Penetration Tests undertaken within the natural deposits from 0.8m have produced 'N' values 12 to 43.

4.3 Bedrock

4.3.1 Bedrock has not been encountered in the investigations at the entrance road.

4.4 Groundwater

4.4.1 These intrusive investigations have identified confined groundwater within the natural SAND deposits near the entrance road. Water strikes were encountered at 6.1, 9.6 and 10.2mbgl. Groundwater is not considered to represent an important hazard to the development of the site but water entries into excavations cannot and should not be discounted. If this were to happen, a simple sump system should be used to remove accumulated water within the excavations.

5.0 GROUND CONDITIONS – PROPOSED BUND AREA

5.1 Made Ground

5.1.1 Exploratory hole locations WS04, WS07, WS08 and WS09 encountered made ground to a depth of 0.6 to 0.7mbgl.

5.1.2 Typically made ground comprised of a dark brown slightly gravelly fine and medium SAND with a low cobble. Gravel is angular to surround fine to coarse of mudstone, sandstone and brick. Cobbles are angular to subangular of sandstone and brick.

5.2 Natural Strata

5.2.1 Underlying the Made Ground described above, and from ground level elsewhere, the majority of positions recorded an orangish grey brown slightly gravelly SAND, light grey silty SAND and dark grey slightly gravelly slightly silty SAND, to a maximum depth of 5.45mbgl.

5.2.2 Within the natural deposits, plastic brown slightly sandy pseudofibrous PEAT, extending to depths of 1.3 – 2.2mbgl, was encountered. Peat was not observed in WS07, WS08 or WS09.

5.2.3 Further PEAT deposits were encountered in WS02, WS03, WS06 and WS13 at greater depths, from 2.65-3.2mbgl, extending to a maximum depth of 3.0 - 3.7mbgl.

5.2.4 Standard Penetration Tests undertaken within the natural strata from 1.20m have produced 'N' values 0 to 50.

5.3 Bedrock

5.3.1 Bedrock has not been encountered in the investigations at the proposed bund area.

5.4 Groundwater

- 5.4.1 These intrusive investigations have identified some perched groundwater within the deposits on site, at 1.0mbgl. Groundwater is not considered to represent an important hazard to the development of the site but water entries into excavations cannot and should not be discounted. If this were to happen, a simple sump system should be used to remove accumulated water within the excavations.

5.5 Cone Penetration Testing

- 5.5.1 Cone penetration testing was undertaken by Lankelma Limited across the area of the proposed bund on the 3rd September 2025. A total of five (5 No.) tests were undertaken to a maximum depth of 10.26mbgl.
- 5.5.2 CPT tests results can be found in full within the Appendices of this report.

6.0 Further Works

6.1 General

- 6.1.1 If any unusual or suspicious strata or ground conditions are encountered during the subsequent preparation work, it will be necessary for these areas to be brought to the attention of the appropriate authorities so that all necessary inspection may be undertaken. It is incumbent upon the site contractors to advise a responsible authority of any unusual findings within the site which may then be further investigated.

7.0 NOTES

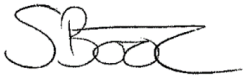
- 7.1 All reports are for advisory purposes only and all design decisions are the ultimate responsibility of others.
- 7.2 Unless stated otherwise the investigation has been undertaken in general accordance with the recommendations given in BS5930:2015+A1:2020 "A Code of Practice for site Investigations" and the laboratory testing has been carried out in accordance with BS1377-2:2022 "Methods of Test for Civil Engineering Purposes".
- 7.3 Soil and rock descriptions are generally based on the scales of strength and relative density within BS5930 although it should be noted that in certain circumstances descriptions are based on site records or a qualitative assessment without the benefit of in-situ or laboratory test results.
- 7.4 The assessment of ground conditions given in this report is based on the results of the fieldwork and laboratory testing carried out and there may be other conditions at the site not encountered by these works, which have not been taken into account.
- 7.5 The scope of the investigation and information provided may not necessarily reflect all the geotechnical and environmental aspects related to the site, and the omission of certain items does not mean that the site is unaffected by such problems.
- 7.6 It should be noted that groundwater levels can vary and may at times be significantly different to those recorded during the investigation and attention is drawn to BS5930 which indicates that measurements may be necessary over an extended period of time to investigate changes in groundwater pressures due to seasonal, tidal and other causes.
- 7.7 Any recommendations on construction methods within this report are for initial guidance only and all design proposals remain the responsibility of the appropriate contractor/consultant.

- 7.8** Further assessment, investigation, construction activities or time may reveal conditions that were not found during the period of investigation and, therefore, could not have been taken into account in the preparation of the report and where such information might impact upon the stated opinion R. E. Fry & Associates Ltd request the opportunity to review such information and modify the report if necessary.
- 7.9** Where information has been obtained from sources other than the direct findings of the investigation, R. E. Fry & Associates Ltd cannot and does not guarantee the authenticity or reliability of this information.
- 7.10** Where opinions expressed in this report are based on current available guidelines and legislation, no liability can be accepted by R. E. Fry & Associates Ltd for the effects of any future changes to such guidelines and legislation.
- 7.11** This report has been prepared on the instructions and to the requirements of the named client and any unauthorised party using this information for any purpose does so at his own risk and any duty of care to that party is excluded.

Signed for and on behalf of
REFA Geotechnical, Civils & Structural Engineers

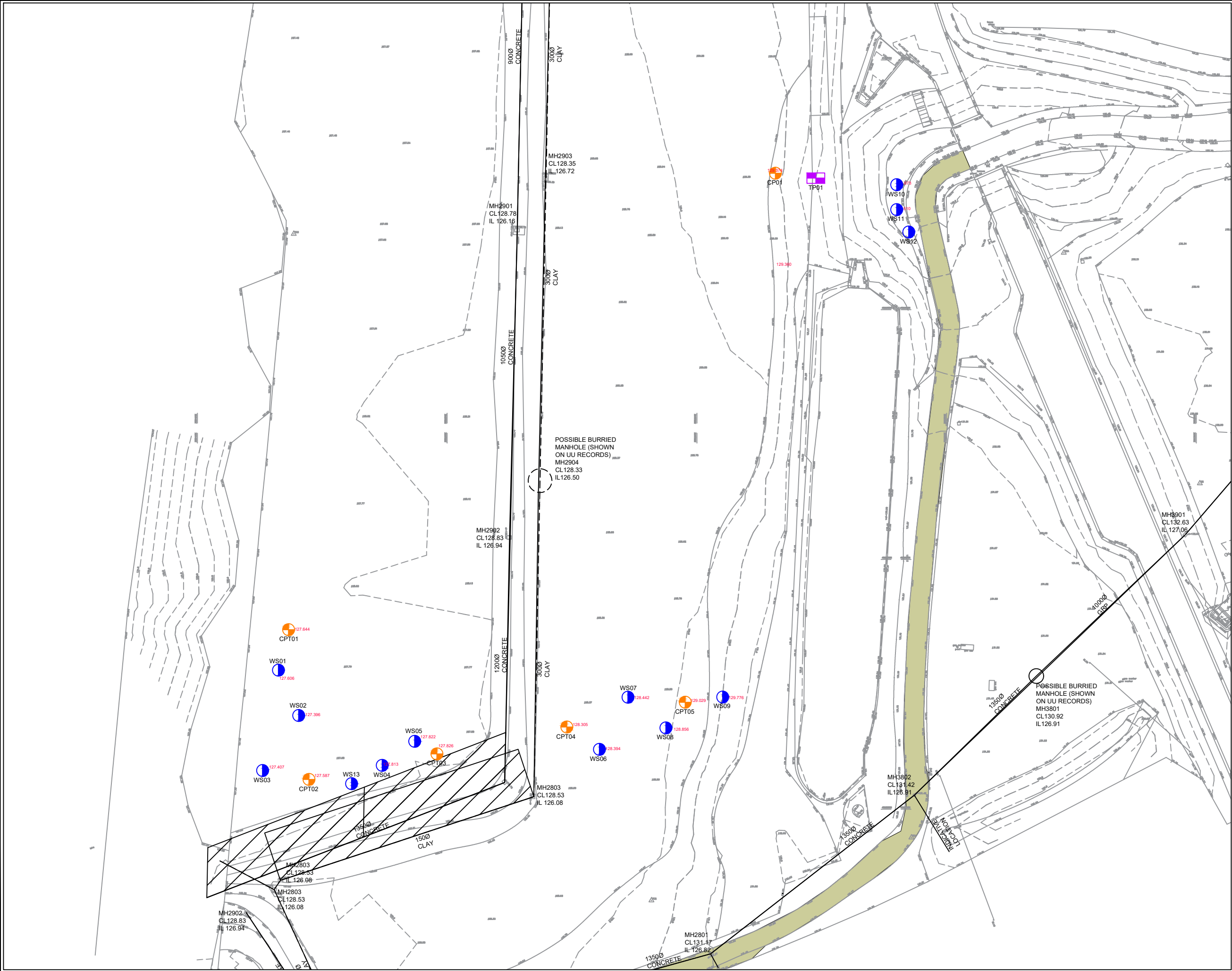


Chris Pilkington BSc. (Hons) FGS
Senior Geoenvironmental Engineer



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Senior Geoenvironmental Engineer

APPENDIX A



KEY

	Cone Penetration Test
	Windowless Sampling Borehole
	10m Easement around Existing Sewers

INFO

Rev	Description	By	Date	
Revision History				
 CONSULTING ENGINEERS worksafe designer SSIP 45 Bridgeman Terrace Wigan Lancashire WN1 1TT 01942 826020 info@refa.co.uk www.refa.co.uk				
Client				
Keepmoat Homes Ltd				
Trub Farm, Castleton				
Drawing				
Exploratory Hole Location Plan				
Sheet Size	Scale at Sheet Size	Date	Drawn By	Checked By
A3	nts	28/08/2025	AB	
Project Number		Drawing Number		Current Revision
18112		18112/02		*



CABLE PERCUSSION RECORD

Borehole Number

CP01

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 04/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: Lundy SI		Drilling Equipment: Dando 2000	
Log Status FINAL	Hole Type CP	Level	Approved By CP	Scale 1:50	Page Number Sheet 1 of 2

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.00	D		0.25			Loose dark brown sandy SILT. Sand is fine and medium. Frequent rootlets.	
					0.80			Soft reddish brown slightly gravelly silty CLAY. Gravel is fine subangular of sandstone. (Potentially reworked)	
		0.80	D		0.80			Medium dense to dense yellowish grey brown silty fine and medium SAND. Frequent pockets of SILT throughout (25-30mm dia.).	1
		1.20	D	12					
		1.20	SPT						
		2.00	D	20	1.90			Medium dense greyish brown slightly gravelly rounded COBBLE of mixed lithologies. Gravel is coarse rounded of mixed lithologies.	2
		2.00	SPT						
		3.00	D	27				Stiff dark brown slightly gravelly slightly sandy silty CLAY. Sand is fine. Gravel is medium and coarse angular to rounded of sandstone.	3
		3.00	SPT						
		3.50	D		3.50				
		4.00	U						4
		5.00	D	19					5
		5.00	SPT						
		6.00	D	18	6.10				6
		6.00	SPT						
					6.70				7
		7.50	D	19					8
		7.50	SPT						
		9.00	D	21					9
		9.00	SPT						
		9.60	D		9.60			Stiff brown slightly gravelly sandy SILT. Sand is fine and medium. Gravel is fine and medium subangular of sandstone.	10

Remarks: *Field description	Casing Diameter by Depth			Chiselling		
	Depth Top	Depth Base	Diameter	Depth Top	Depth Base	Duration

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Company Number: 02436911



CABLE PERCUSSION RECORD

Borehole Number
CP01

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 04/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: Lundy SI		Drilling Equipment: Dando 2000	
Log Status FINAL	Hole Type CP	Level	Approved By CP	Scale 1:50	Page Number Sheet 2 of 2

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
	▼	10.50 10.50	D SPT	32	10.20		XXXXX	Stiff brown slightly gravelly sandy SILT. Sand is fine and medium. Gravel is fine and medium subangular of sandstone. Dense reddish brown fine and medium SAND.	11
		12.00 12.00	D SPT	43	13.00				12
								End of Borehole at 13.00m	13
									14
									15
									16
									17
									18
									19
									20

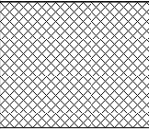
Remarks: *Field description	Casing Diameter by Depth			Chiselling		
	Depth Top	Depth Base	Diameter	Depth Top	Depth Base	Duration



TRIAL PIT RECORD

Pit ID
TP01

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 05/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by:			
Project No. : 18112		Crew Name:		Equipment: 3T Excavator	
Log Status FINAL	Location Type TP	Level	Approved By CP	Scale 1:37	Page Number Sheet 1 of 1

Legend	Water Strikes	Sample and In Situ Testing			Stratum Description	Depth (m)	Level (m)	
		Depth (m)	Type	Results				
					MADE GROUND: Grey gravelly sand with a low concrete cobble content. Gravel is angular to subangular fine to coarse concrete, brick, metal fragments, limestone, sandstone.	0.60		0.5
					End of Trial Pit at 0.60m			1.0
								1.5
								2.0
								2.5
								3.0
								3.5
								4.0
								4.5
								5.0
								5.5
								6.0
								6.5

Dimensions		Trench Support and Comment			Key: ES - Envriomental Sample D - Small Disturbed Sample B - Bulk Disturbed Sample PID - Photo-ionisation Detector
Pit Length	Pit Width	Pit Stability	Shoring Used	Remarks	

Remarks:



WINDOWLESS SAMPLER RECORD

Borehole Number

WS01

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 05/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 127.61m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.15	D		0.20	127.41		Grass over dark brown sandy SILT. Sand is fine. Fine rootlets throughout.	
		0.75	D					Very soft yellowish brown slightly silty fine and medium SAND. Occasional organic silt pockets throughout.	1
		1.20	D	0					
		1.20	SPT		1.40	126.21		Plastic dark brown slightly sandy pseudofibrous PEAT.	
		2.00	D	5					2
		2.00	SPT		2.10	125.51		Loose light grey slightly silty SAND.	
		3.00	D	12					3
		3.00	SPT		3.00	124.61		Firm yellowish grey brown slightly gravelly fine and medium SAND. Gravel is fine subangular to rounded of mudstone.	
		4.00	D	12					4
		4.00	SPT		4.40	123.21		Medium dense yellowish grey brown gravelly fine to coarse SAND. Gravel is fine to coarse subangular to subrounded of mixed lithologies.	
		4.70	D						5
		5.00	SPT	17					
					5.45	122.16		End of Borehole at 5.45m	6
									7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading



WINDOWLESS SAMPLER RECORD

Borehole Number

WS02

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 05/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 127.40m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.15	D		0.30	127.10		Grass over dark brown sandy SILT. Sand is fine. Fine rootlets throughout.	
					0.60	126.80		Light grey slightly gravelly silty fine and medium SAND. Gravel is fine and medium angular to subrounded of mixed lithologies.	
		0.75	D					Plastic brown slightly sandy pseudofibrous PEAT.	1
		1.20	D	0					
		1.20	SPT						
		1.90	D		1.85	125.55		Loose light grey slightly gravelly fine and medium SAND. Gravel is fine subrounded to rounded of mixed lithologies.	2
		2.00	SPT	5					
					2.65	124.75		Spongy brown pseudofibrous PEAT	
		3.00	D	9	3.00	124.40		Medium dense light grey slightly gravelly fine and medium SAND. Gravel is fine subrounded to rounded of mixed lithologies.	3
		3.00	SPT						
		4.00	SPT	5					4
		5.00	D	13	5.00	122.40		Medium dense yellowish brown slightly gravelly fine to coarse SAND. Gravel is fine and medium subangular to subrounded of mixed lithologies.	5
		5.00	SPT		5.20	122.20			
					5.45	121.95		Firm reddish brown slightly sandy slightly gravelly silty CLAY. Sand is fine. Gravel is fine subrounded of mudstone.	
								End of Borehole at 5.45m	6
									7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading



WINDOWLESS SAMPLER RECORD

Borehole Number

WS03

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 05/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 127.41m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.20	D		0.30	127.11		Grass over brown slightly gravelly fine to coarse SAND. Gravel is angular to subangular fine and medium of mudstone.	
		0.40	D		0.60	126.81		Light grey mottled brown slightly clayey fine and medium SAND.	
		0.90	D					Plastic brown slightly clayey slightly sandy pseudofibrous PEAT.	1
		1.20	D	4					
		1.20	SPT					<i>Between 1.4 and 1.55m bgl: band of fine to medium sand.</i>	
		2.00	D	4	1.90	125.51		Loose light grey slightly gravelly silty fine and medium SAND with a slight organic matter and odour. Gravel is fine to coarse subangular to rounded of quartzite and mudstone.	2
		2.00	SPT						
		3.00	D	12	2.85	124.56		Spongy brown slightly sandy pseudofibrous PEAT.	3
		3.00	SPT						
		4.00	D	8	3.70	123.71		Firm to stiff brown slightly gravelly medium and coarse SAND. Gravel is fine and medium subrounded of quartzite.	4
		4.00	SPT						
		5.00	D	17					5
		5.00	SPT						
					5.45	121.96		End of Borehole at 5.45m	6
									7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading

Robert E Fry & Associates Ltd
45 Bridgeman Terrace, Wigan, WN1 1TT
www.refa.co.uk 01942826020 info@refa.co.uk
Company Number: 02436911



WINDOWLESS SAMPLER RECORD

Borehole Number

WS04

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 04/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 127.81m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.20	D		0.60	127.21		MADE GROUND: Grass over dark brown slightly gravelly fine and medium SAND. Gravel is fine to coarse angular to subangular of mudstone and ceramic.	
		0.90	D					Light grey mottled brown slightly gravelly slightly silty fine and medium SAND. Gravel is fine to coarse subangular to subrounded of quartz.	1
		1.20 1.20	D SPT	0					
		2.00	SPT	8					2
		3.00 3.00	D SPT	9	3.00	124.81		Plastic brown pseudofibrous PEAT.	3
					3.50	124.31		Medium dense grey slightly gravelly slightly silty fine and medium SAND. Gravel is fine and medium angular to subrounded of quartzite.	4
		4.00	SPT	13					
		5.00	SPT	22					5
					5.45	122.36		End of Borehole at 5.45m	6
									7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading

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www.refa.co.uk 01942826020 info@refa.co.uk
Company Number: 02436911



WINDOWLESS SAMPLER RECORD

Borehole Number

WS05

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 04/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 127.82m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.10	D		0.20	127.62		Grass over brown slightly gravelly fine and medium SAND. Gravel is fine and medium angular to subangular of mudstone.	
		0.80	D					Light grey slightly clayey fine and medium SAND with slight organic content and odour.	1
		1.20	D	0	1.20	126.62		Plastic brown amorphous PEAT.	
		1.20	SPT		1.55	126.27		From 1.4m bgl: slightly clayey pseudofibrous. Light grey slightly silty fine and medium SAND with occasional organic material and slight organic odour.	
		2.00	D	9				At 3.4m bgl: band of subangular to subrounded fine to medium quartz gravel.	2
		2.00	SPT					From 5.0m bgl: Brown slightly gravelly coarse SAND.	
		3.00	D	8				End of Borehole at 5.45m	3
		3.00	SPT						
		4.00	SPT	1					4
		5.00	D	14	5.45	122.37			5
		5.00	SPT						
									6
									7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading



WINDOWLESS SAMPLER RECORD

Borehole Number

WS06

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 04/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 128.39m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.15	D		0.30	128.09		Grass over brown slightly gravelly fine and medium SAND. Gravel is fine and medium angular to subangular of mudstone.	
		0.50	D		0.60	127.79		Yellowish brown slightly gravelly fine and medium SAND. Gravel is fine and medium subangular to subrounded of sandstone.	
		0.80	D					Plastic brown clayey amorphous PEAT.	1
		1.20	D	9	1.30	127.09		Loose to medium dense light grey slightly gravelly silty fine and medium SAND. Gravel is subangular fine and medium subrounded of mudstone and sandstone.	
		1.20	SPT						
		2.00	D	11					2
		2.00	SPT						
		3.00	D	4	3.20	125.19			3
		3.00	SPT						
		3.50	D		3.60	124.79		Soft light grey sandy SILT with occasional organic matter. Sand is fine and medium.	
		3.80	D		3.90	124.49		Medium dense brown slightly gravelly fine and medium SAND. Gravel is fine to coarse angular to subrounded of mudstone and sandstone.	4
		4.00	D	13					
		4.00	SPT						
		5.00	D	23	5.45	122.94		End of Borehole at 5.45m	5
		5.00	SPT						
									6
									7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading



WINDOWLESS SAMPLER RECORD

Borehole Number

WS07

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 04/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 128.44m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.20	D					MADE GROUND: Grass over dark brown slightly gravelly SAND with low cobble content. Gravel is fine to coarse angular to subrounded of mudstone, sandstone and brick. Cobbles are subangular of sandstone and brick.	
		0.80	D		0.60	127.84		Soft light grey mottled dark brown sandy CLAY with high organic content and a strong organic odour. Sand is fine and medium.	1
		0.95	D		0.90	127.54			
		1.20	D	8				Medium dense to dense light grey slightly gravelly slightly clayey fine and medium SAND with a low organic content. Gravel is fine to coarse angular to subrounded of mudstone, sandstone and quartzite.	
		1.20	SPT						
		2.00	D	8					2
		2.00	SPT						
		2.90	D						
		3.00	SPT	9				<i>From 3.0m bgl: orangish brown gravelly sand. No recovery in 3m SPT.</i>	3
		4.00	D	20					4
		4.00	SPT						
		5.00	D	28					5
		5.00	SPT						
					5.45	122.99		End of Borehole at 5.45m	6
									7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading

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Company Number: 02436911



WINDOWLESS SAMPLER RECORD

Borehole Number
WS08

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 03/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 128.86m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.25	D		0.60	128.26		MADE GROUND: Grass over dark brown slightly gravelly SAND with low cobble content. Gravel is fine to coarse angular to subrounded of mudstone, sandstone and brick. Cobbles are subrounded of sandstone and brick.	
		0.75	D						
		1.20 1.20	D SPT	18					1
		2.00	SPT	50					2
		3.00	SPT	12					3
		4.00 4.00	D SPT	15	4.00	124.86		End of Borehole at 4.00m	4
									5
									6
									7
									8
									9
									10

Remarks: *Field description.	Key: ES - Environmental Sample D - Small Disturbed Sample B - Bulk Disturbed Sample PID - Photo-ionisation Detector Reading
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WINDOWLESS SAMPLER RECORD

Borehole Number

WS09

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 03/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 129.78m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.30	D		0.70	129.08		MADE GROUND: Grass over dark brown slightly gravelly SAND with low cobble content. Gravel is fine to coarse angular to subrounded of mudstone, sandstone and brick. Cobbles are subarounded of sandstone and brick.	
		0.80	D						1
		1.20 1.20	D SPT	18				Medium dense orangish brown slightly gravelly fine and medium SAND. Gravel is fine to coarse subrounded of quartzite and sandstone.	
		2.00 2.00	D SPT	15					2
		3.00 3.00	D SPT	8					3
		4.00 4.00	D SPT	13					4
		5.00 5.00	D SPT	14					5
					5.45	124.33		End of Borehole at 5.45m	6
									7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading

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Company Number: 02436911



WINDOWLESS SAMPLER RECORD

Borehole Number

WS10

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 03/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 129.37m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.10	D					MADE GROUND: Grass over light greyish brown gravelly fine and medium SAND. Gravel is fine to coarse angular to subangular of brick, concrete, ceramic, sandstone and quartzite.	
		0.75	D						1
		1.20	D	32					
		1.20	SPT						
		2.00	D	10					2
		2.00	SPT						
		3.00	D	20					3
		3.00	SPT						
		4.00	SPT	14					4
		5.00	D	14					5
		5.00	SPT						
		5.85	D	42	5.85	123.52		Firm to stiff greyish brown slightly gravelly sandy CLAY. Sand is fine and medium. Gravel is fine and medium angular to subrounded of mudstone.	6
		6.00	SPT		6.45	122.92			
								End of Borehole at 6.45m	7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading

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Company Number: 02436911



WINDOWLESS SAMPLER RECORD

Borehole Number

WS11

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 03/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 129.36m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.15	D					MADE GROUND: Grass over light greyish brown gravelly fine and medium SAND. Gravel is fine to coarse angular to subangular of brick, concrete, ceramic, sandstone and quartzite.	
		0.90	D						1
		1.20	D	25					
		1.20	SPT						
		2.00	D	21					2
		2.00	SPT						
		3.00	D	10					3
		3.00	SPT						
		4.00	D	9					4
		4.00	SPT						
		5.00	D	9	5.00	124.36			5
		5.00	SPT						
		6.00	D	15				Firm greyish brown slightly gravelly sandy CLAY. Sand is fine and medium. Gravel is fine and medium angular to subrounded of mudstone.	6
		6.00	SPT						
					6.45	122.91			
								End of Borehole at 6.45m	7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading

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Company Number: 02436911



WINDOWLESS SAMPLER RECORD

Borehole Number
WS12

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 03/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 136.67m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
					0.50	136.17		MADE GROUND: Grass over brown gravelly fine to coarse SAND with a high cobble content. Gravel is fine to coarse angular to subangular of brick, concrete and ceramic. Cobbles are subangular of concrete and brick. End of Borehole at 0.50m	1
									2
									3
									4
									5
									6
									7
									8
									9
									10

Remarks: *Field description.	Key: ES - Environmental Sample D - Small Disturbed Sample B - Bulk Disturbed Sample PID - Photo-ionisation Detector Reading
---------------------------------	---



WINDOWLESS SAMPLER RECORD

Borehole Number

WS13

Project Name: Trub Farm, Castleton		Client: MCI Developments Ltd		Date: 04/09/2025	
Location: Trub Farm, Manchester Road, Rochdale, OL11 2XG		Logged by: AB			
Project No. : 18112		Crew Name: PM Sampling Ltd		Drilling Equipment: Archway Dart	
Log Status FINAL	Hole Type WS	Level 136.51m AoD	Approved By CP	Scale 1:50	Page Number Sheet 1 of 1

Well	Water Strikes	Sample and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		0.15	D		0.30	136.21		Grass over brown slightly gravelly fine and medium SAND. Gravel is fine and medium angular to subangular of mudstone.	
		0.35	D		0.40	136.11		Soft orangish brown very sandy CLAY. Sand is fine and medium.	
	▼	0.85	D					Light grey slightly gravelly silty fine and medium SAND. Gravel is fine and medium angular to subrounded of mudstone and sandstone.	1
		1.20	D	0	1.20	135.31		Plastic brown slightly clayey slightly sandy amorphous PEAT.	
		1.20	SPT						
		2.00	D	8					2
		2.00	SPT		2.20	134.31		Medium light grey silty fine and medium SAND.	
		3.00	D	9	3.00	133.51		Plastic brown slightly sandy pseudofibrous PEAT.	3
		3.00	SPT						
					3.50	133.01		Dark grey slightly gravelly slightly silty fine and medium SAND. Gravel is subangular to subrounded fine to medium quartzite.	4
		4.00	D	13					
		4.00	SPT						
		5.00	D	22				At 4.8m bgl: band of soft grey silt.	5
		5.00	SPT		5.45	131.06		End of Borehole at 5.45m	6
									7
									8
									9
									10

Remarks:

*Field description.

Key:

ES - Environmental Sample

D - Small Disturbed Sample

B - Bulk Disturbed Sample

PID - Photo-ionisation Detector Reading

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Company Number: 02436911

APPENDIX B

ROCHDALE

SOIL INVESTIGATION

CPT REPORT

Cone penetration testing
Dissipation testing
Parameter derivation

Project Reference.: 25-32-30058-1

Report Issue No.: 01 30058_01

PROJECT:	Rochdale
----------	----------

CLIENT:	REFA
---------	------

FIELDWORK

CPT rig(s)	17.9-tonne track-truck mounted CPT unit (UK20)
Date fieldwork started	3 rd September 2025
Date fieldwork completed	3 rd September 2025
Lankelma's representative	Paul Dimelow
Client's representative	Stephen Boot

DOCUMENT CHECKING

Action	Date	Name
Completed	08/09/2025	Christopher Player
Checked	08/09/2025	Joseph Hobbs
Approved	08/09/2025	Joseph Hobbs

Issue	Date	Status
01_01	08/09/2025	Final

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1 INTRODUCTION

At the request of REFA, a soils investigation was carried out on project *Rochdale*.

Site location:

(In the general region of)

Trub Road
Castleton
Rochdale
OL11 2XG

2 DISCLAIMER

The information contained in this report and all other associated reporting deliverables supplied in digital data files and AGS format data files referenced within this report (collectively "Report") are for the sole benefit of Lankelma's client ("Client") identified at the front of this report.

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3 GLOSSARY OF SYMBOLS, TERMS AND ABBREIATIONS

SYMBOLS (excluding base units)

B_q	Pore pressure ratio. The net pore pressure normalized with respect to the net cone resistance: $B_q = (u_2 - u_0) / (q_t - \sigma_v)$
c_{vh}	Coefficient of consolidation. Subscript vh indicates some combination of horizontal and vertical flow when assessed from CPTu dissipation tests.
E	Young's modulus (generic, E' and E_u apply to drained and undrained deformation conditions respectively)
F_r	Normalised friction sleeve resistance: $F_r = f_s / (q_c - \sigma_v)$
f_s	Friction sleeve resistance: The total frictional force acting on the friction sleeve, F_s , divided by its surface area A_s : $f_s = F_s / A_s$
g	Gravitational field strength: $g = 9.81 \text{ N kg}^{-1}$

G	Shear modulus (generic, G_0 applies to small strain conditions, G_u applies to undrained shear (G at existing effective stress) and $G_{\%}$ applies to stress at variable % mobilised yield stress (e.g. G_{50}))
s	Specific gravity of solids
I_c & I_{SBT}	Soil Behaviour Type Index: Continuous numerical representations of Robertson soil behaviour type classification charts. I_c and I_{SBT} apply to the Robertson (1990) and Robertson and Cabal (2010) classification charts respectively. Soil Behaviour Type Index: Continuous numerical representation of Robertson & Cabal (2010) soil behaviour type classification chart based on dimensionless parameters.
I_R	Rigidity Index: Ratio of shear modulus to undrained shear strength, $I_R = G_u/s_u$
k	Coefficient of permeability with units of velocity
m_v	Coefficient of compressibility: $m_v = 1/M'$
m'	Pre-consolidation (yield) stress exponent (section 0).
M'	Constrained modulus
q_c	Cone resistance: The total force, Q_c , acting on the cone, divided by the projected area of the cone, A_c : $q_c = Q_c/A_c$
Q_t	Normalised cone resistance (method 1): $Q_t = (q_c - \sigma_v)/\sigma'_v$
Q_{tn}	Normalised cone resistance where normalisation varies with soil type. See section 6.4.
q_t	Corrected tip resistance: The cone tip resistance q_c corrected for pore water pressure effects on the cone shoulder
q_{t-net}	Net cone resistance: $q_{t-net} = q_t - \sigma_v$. Where q_t is unavailable q_c is applied
q_{t1}	Normalised cone resistance (method 2): $q_{t1} = (q_t)/(\sigma'_v)^{0.5}$
Dr	Relative density (percentage)
R_f	Friction ratio: The ratio, expressed as a percentage, of the sleeve friction, f_s , to the cone resistance, q_c : $R_f = (f_s/q_c) \cdot 100$
r	Radius
s_u	Undrained shear strength (generic)
t	Time
u_0	Equilibrium pore pressure
u_2	Measured pore pressure: Dynamic pore pressure measured at the shoulder position (u_2) during penetration and dissipation tests. $u_2 = \Delta u_2 + u_0$
Δu_2	Excess (or differential) pore pressure: $\Delta u_2 = u_2 - u_0$
V_s, V_p	Shear wave velocity, V_s , and pressure wave velocity, V_p . Measured with use of a seismic receiver

Greek

γ	Unit weight of soil
γ_w	Unit weight of water
ρ	Volumetric mass density (or specific mass) of soil: $\rho = \gamma/g$
σ_v	Total overburden stress
σ'_v	Effective overburden stress
σ_{atm}, P_a	Reference atmospheric stress: $\sigma_{atm} = 101.3 \text{ kPa}$

TERMS AND ABBREVIATIONS

Cone or 'tip': The conical tip of the cone penetrometer. This is sometimes referred to as the 'point' in other literature

CPT: Cone penetration test

CPTu: Cone penetration test using a penetrometer with pore pressure measurement (piezocone).
Friction sleeve: The section of the cone penetrometer upon which the sleeve friction is measured, located behind the conical tip.
HOC: Heavily overconsolidated
LOC: Lightly overconsolidated
mBGL: Meters below ground level
NC: Normally consolidated
OC: Overconsolidated
Penetration length: CPT test length without correction for inclination
Piezocone: A cone penetrometer with a pore pressure sensor (u_2 or u_1 position).
Seismic cone: A cone penetrometer with a seismic receiver incorporated.
Dynamic pore pressure: The pore pressure measured during penetration (u_2 or u_1)
Soil behaviour type, or 'SBT': A classified soil type according to a classification system based on CPT or CPTu measurements.
Rod string: The series of hollow tube push rods that transmit thrust force to the penetrometer.
Zero value(s) or baseline value(s): The analogue or digital output of a sensor (or set of sensors) with no load applied.

4 COMPLETED WORKS

- 5 nr. cone penetration tests with pore pressure measurement (CPTu)
- 3 nr. dissipation tests
- Factual report including point data interpretation of selected parameters

Several non-scheduled short QA/QC dissipation tests were undertaken during the works during penetration pauses, to verify drainage conditions, re-saturate or during temperature stabilisation pauses. Where these tests produced data suitable for interpretation, the results and interpretation are included in this report.

Appendix A contains tabulated details of the works completed together with analysis results where applicable.

5 FIELDWORK GENERAL

Fieldwork was performed with a 17.9-tonne track-truck mounted CPT unit (UK20) equipped with a 17.5-tonne capacity hydraulic ram set.

The Client was responsible for the positioning and re-survey of all investigative locations.

The target depth for the investigation was 10 m below ground level. Table 3 details the final test depths and reasons for test termination (*refusal factor*). Where required, each penetration refusal decision was verbally confirmed with the Client's on-site representative.

The depths of dissipation tests were advised by the Investigation Supervisor or Engineer's Representative.

6 CONE PENETRATION TESTS

Cone penetration testing was carried out in general accordance with BS ISO 22476-1:2022.

Penetrometer measurements included cone tip resistance, friction sleeve resistance and dynamic pore water pressure sampled at a 10 mm resolution.

Penetrometers were calibrated in accordance with BS ISO 22476-1:2022 and ISO 376:2011 within 6 months of the fieldwork completion. Copies of all calibration certificates for the cones used are provided in Appendix B.

The penetrometer used was a 150 kN axial capacity model with digital output (down-hole digitisation) and internal measurement of load cell temperature. The temperature data was used for QA during the test and QC during processing. The test operative aimed to keep the rate of temperature change to less than 0.5°/min in low strength soils to maintain acceptable measurement error. The temperature data can be used to assess ground temperature at depths where the cone has paused for more than 20-50 minutes with an accuracy of $\pm 0.5^\circ$, depending on the thermal properties of the soil.

The piezometer filter element was HDPE plastic with a nominal filtration of 40 to 60 microns. The filter was vacuum saturated in a $> 99.9\%$ vacuum under 1.5 Pa.s vegetable glycerine oil for > 7 days prior to mobilisation. The pore pressure system was vacuum saturated in the disassembled state under 0.042 Pa.s monopropylene glycol and assembled under oil prior to each test. The u_2 filter position was used for all piezocone tests.

At intervals during the fieldwork, the penetrometer was temperature stabilised in a water bath to obtain stabilised zero load baseline values (after extraction from the water). This was done prior to each test, or approximately every 30 m of testing where the final depths were relatively shallow, when larger zero drifts were observed, or when changing penetrometer. The purpose of this procedure is to prevent transient temperature effects from influencing the strain gauge sensors, so that representative baseline values may be subtracted from the data collected during penetration - where temperature is controlled, and temperature effects are corrected for based on the magnitude and rate of change in temperature. Additionally, it enables more reliable assessment of long-term shift in the baseline output of the sensors.

Penetrometer dimensional measurements and tolerance checks were obtained prior to each test, or following each 20-60 m of testing, depending on aggressiveness of ground conditions and closeness of prior measurements to tolerance limits. The tip measurement was based on the largest diameter portion of the tip (comprising the conical part, u_2 pore pressure filter and 'equal end area piece' adjacent to the friction sleeve), while the sleeve measurement was obtained at both ends of the sleeve and averaged for the purpose of determining the surface area.

6.1 CPT DATA REDUCTION AND PRESENTATION

Presentation

The CPT results are presented in Appendix C. The corrected cone resistance (q_t), local side friction (f_s), dynamic pore water pressure (u_2), friction ratio (R_f) and inclination are all presented against depth and elevation in accordance with BS ISO 22476-1:2012. CPT data and the associated derived geotechnical parameters are included in the 4.0 data file provided.

Derivation of pressure

The cone tip and sleeve force measurements were converted to pressure using the measured tip and sleeve diameters.

Zero load reference values

Zero load reference values were recorded before and after each test, and periodically these were obtained after temperature stabilisation in a water bath to remove the influence of transient temperature effects. When selecting the most representative baseline values (for subtraction from the raw data), priority was given to values obtained following temperature stabilisation. Depending on the frequency of baseline output stabilisation, the stabilised values applied to the raw data may be obtained prior to a previous test, or, following a subsequent test when the average of pre & post stabilised baseline values is applied to the data.

Temperature correction (post-processing algorithmic)

For standard high capacity cones the correction and/or control of temperature effects is critical to the production of results suitable for design purposes, particularly in lower strength fine soils where temperature error can become a large proportion of the measured values.

For tests with load cell temperature measurements the tip and pore pressure measurements are corrected for static and transient temperature effects using parameters obtained from temperature response tests. For each recorded value, the static and transient temperature error component (apparent sensor output due to change in temperature) were subtracted from the reading.

For subtraction type cones incorporating traditional temperature compensation wiring in the strain gauge circuit, the apparent cone tip resistance ($q_{c:a}$) and apparent pore pressure (u_a) due to static and transient temperature effects can be approximated by

$$q_{c:a} = a(\Delta T / \Delta t) + b(\Delta T),$$

$$u_a = b(\Delta T)$$

Where $q_{c:a}$ is the apparent tip resistance, a is the apparent resistance due to unit transient temperature change, and b is the change in apparent resistance per unit static temperature change relative to the temperature of the penetrometer at the time of zero load output measurement.

The temperature corrected tip ($q_{c:c}$), and pore pressure (u_c) are then found from

$$q_{c:c} = q_{c:m} - q_{c:a},$$

$$u_c = u_{:m} - u_{:a}$$

Where subscript ' $:m$ ', denotes the field measured resistance/pressure as recorded in the raw data files.

Notes:

1. Temperature correction of the sleeve data is possible but is often unwarranted as it does not substantially improve accuracy. This is because for subtraction type cones the errors in the sleeve force largely cancel with errors in the tip force when they have the same sign, which is expected when temperature change is the primary source of sensor drift.

2. To avoid confusion the parameter designation is kept unchanged in the logs and AGS data (q_c , q_t , f_s , and u_2) and unless stated otherwise, temperature correction has been applied.
3. The parameters and method applied are the same as those applied in the temperature verification section of the calibration certificate, which shows the uncorrected and corrected response of sensors during plunge tests between water baths of different temperature.

The effectiveness of the correction parameters is verified by the ISO 22476:2022 temperature verification procedure presented in the calibration certificate.

Correction for pore pressure effects

For piezocone tests the total cone resistance (or 'corrected cone resistance'), q_t , is calculated according to the formula

$$q_t = q_c + u_2 (1 - a)$$

Where a is the 'net area ratio' of projected shaft area divided by projected face area, and $1 - a$ is the proportion of cross-sectional area between the cone tip and penetrometer body where pore pressures (positive or negative) can act to add or subtract from the total external axial force on the tip. The difference between measured and corrected values is largest in low strength collapsible soils with large excess pore pressures. The percentage adjustment is described by the curves on the chart below for $a = 0.8$:

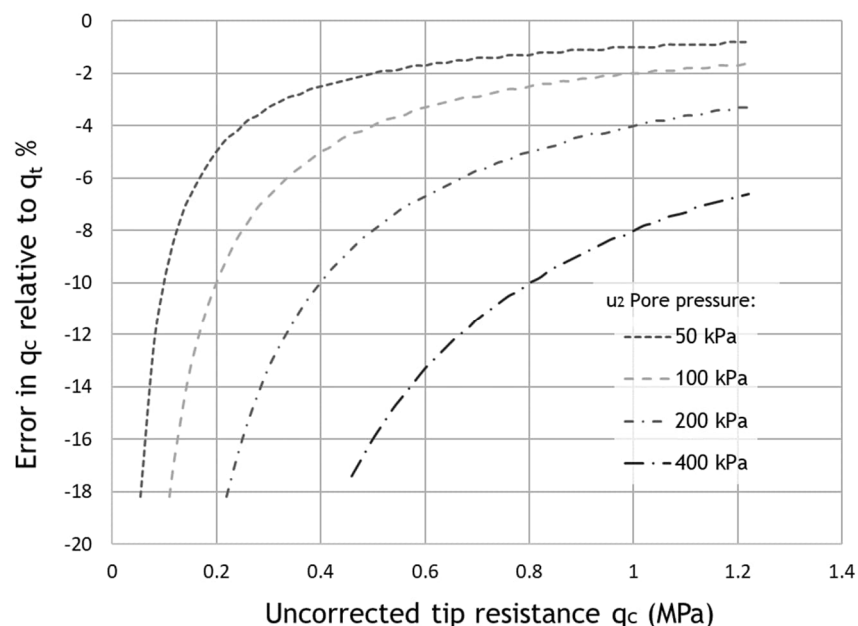


Figure 6-1 Uncorrected tip with % error for various pore pressure values

All penetrometers had equal sleeve end areas and no correction for pore pressure effects has been applied to the sleeve readings.

Depth corrections

Penetration length readings were corrected for inclination according to the procedure described in ISO-22476-1:2022. Sleeve readings were depth corrected for the dimensional offset between cone tip and sleeve and an additional 'effective' offset between the sleeve and focal point of bearing resistance within the soil below the conical tip.

Spike/ artefact removal and resampling

Rod spikes (artefacts of the pause for push rod addition) have been filtered from the cone tip and sleeve data and replaced with an interpolated value.

The data was re-sampled from 10 mm resolution to 20 mm to reduce the size of the data set to a more manageable size for end users. A 20 mm resolution is within the intrinsic influence zone of the cone tip measurement and the loss of meaningful resolution is negligible.

Parameter derivation and data deliverables

Raw data plots are presented in Appendix C and include the intermediate interpretation parameters friction ratio, R_f , and pore pressure ratio B_q . For piezocone tests q_t is reported on all logs, and q_c only appears in the digital AGS data. Dissipation test curves are plotted in Appendix H. Dissipation interpretation values are presented alongside CPT test results in Appendix G.

Geotechnical parameters appropriate for drained and undrained cone penetration conditions are derived for corresponding drained and undrained derived soil behaviour types (SBTs) respectively, however, to account for uncertainty in the SBT correlation with drainage behaviour, all parameters are derived over a range of transitional soils within the range $2.4 < I_c < 2.7$ (see section 6.5). Geotechnical parameter plots are presented in Appendix D onwards.

All raw and derived data are provided in the AGS 4.0 data file delivered alongside this report.

6.2 IN-SITU STRESS CONDITIONS

An estimate of the equilibrium pore pressure and total and effective vertical stress states is required for derivation of net and normalised readings required for interpretation of most soil parameters obtained from the CPT and dissipation test.

The total vertical stress with depth is calculated as the sum of the derived soil unit weight above a given depth:

$$\sigma_{v0} = \sum_{i=1}^n \gamma_i h_i$$

Where γ_i is the soil unit weight (kN/m^3) assigned to the depth increment i , h_i is the depth increment (m) and n is the total number of increments above the considered depth.

See section 6.3 for information on the applied empirical estimate of soil unit weight.

The depth of the phreatic surface applied in the calculation of effective stress was estimated for each location based on interpretation of piezocone measurements in drained soils and/or the final pressure of dissipation tests which proceeded to equilibrium pressure. The project average piezometric depth (or elevation if available) was applied to locations without direct measurements.

The in-situ pore pressure for specific dissipation test interpretation was assumed as above or, where possible, assessed directly from the dissipation plot.

Note: The term phreatic surface is used here, and it is assumed that the piezometric level measured by the piezometer, under hydrostatic conditions, coincides with the phreatic surface. The phreatic surface reported is intended to provide information about pore pressure distribution assumed for calculation purposes and may not represent the true position of the groundwater table or perched water bodies. Complex groundwater pressure distributions will be applied if they are observed from the measurements and are sufficiently well defined.

6.3 SOIL UNIT WEIGHT

The soil unit weight is estimated using the following method proposed by Robertson (2010b).

$$\frac{\gamma}{\gamma_w} = 0.27 \log(R_f) + 0.36 (\log(q_t/R_f)) + 1.236$$

Throughout pre-drilled zones (inspection pits or drill-out) the soil was assigned a nominal unit weight of 17 kN/m³.

For depths where the friction sleeve resistance measurement was less than zero due to measurement limitations, the friction sleeve resistance input parameter was substituted with a nominal 1.0 kPa resistance for the purpose of obtaining an approximate soil unit weight necessary for estimation of total vertical stress over the entire test profile.

6.4 SOIL BEHAVIOUR TYPE (SBT)

The data is interpreted using 4 soil behaviour type schemes: Robertson (1990, 2010, 2016) and Schneider et al, 2008. The Robertson (1990) scheme is very widely used and forms the bases of the layer analysis whereby the profile is split into approximate zones of common classification or classification variance. The Robertson (2010 & 2016) and Schneider et al methods are less widely used in general practice but can provide classification that is more relevant to the design problem in many instances and the reader is directed to the relevant references for additional information.

For all SBT classification systems discussed in this report, it should be noted that:

- The systems provide a general soil type that tends to show bias towards the soil fraction that dominates the mechanical behaviour in relation to the CPT parameters on which the system is based.
- Significant bonding/microstructure will influence derived soil type (Robertson 2022).
- If cohesive soils are dry and/or heavily overconsolidated, the classification tends to shift towards a coarser soil type (or lower I_c index).
- Strictly, all SBT systems are applicable to saturated or near saturated soils. If applicable, performance of SBT systems in dryer soils should receive due scrutiny.

- While the repeatability and behavioural bias of the SBT is often of practical benefit, the classification may not be an appropriate substitute for classification based on particle size grading and/or consistency (Atterberg indices).

A dedicated SBT comparison log is provided in Appendix D.

Robertson (1990, 2010)

The Robertson 1990 and 2010 SBT classification systems, based on the same chart shown in Figure 6-3, provides 9 classification zones as a function of q_t (or q_c) and f_s .

The 1990 system is based on dimensionless stress normalised parameters of cone resistance (Q_t) and friction ratio (F_r). Where:

$$Q_t = \left(\frac{q_t - \sigma_{v0}}{\sigma'_{v0}} \right)$$

$$F_r = \left(\frac{f_s}{q_t - \sigma_{v0}} \right)$$

Robertson (2009) recommended use of an improved stress normalisation method for tip resistance (Q_{tn}) that uses a stress exponent n that varies with the derived soil type and is found iteratively (starting with Q_t) from:

$$Q_{tn} = \left(\frac{q_t - \sigma_{v0}}{p_a} \right) \cdot \left(\frac{p_a}{\sigma'_{v0}} \right)^n$$

and

$$n = 0.318(I_c) + 0.05 \left(\frac{\sigma'_{v0}}{p_a} \right) - 0.15$$

where I_c is the SBT index discussed in section 6.5, and is continuous function of Q_{tn} and F_r .

Three iterations of Q_{tn} were performed during data processing, with the initial calculation based on an average of the non-normalised and normalised values of I_c for the upper 6 m to limit the effects of overconsolidation at shallow depth.

While the classification based on normalised parameters is more accurate, particularly for NC soils exceeding ~15 m depth, the classification is often significantly in error (artificially granular/drained) at shallow depth (< ~1-3 m). The error at shallow depth is largely associated with the potentially large difference between the estimated vertical effective stress (applied in normalisation of q_t and f_s) and the unknown horizontal stress influencing penetration resistance, especially at high OCR state.

Robertson (2010) proposed a non-normalised version of the 1990 chart which uses dimensionless cone resistance (q_c/Pa) and friction ratio (Rf). SBT classification according to this chart is generally more reliable at shallow depth in Lankelma's experience.

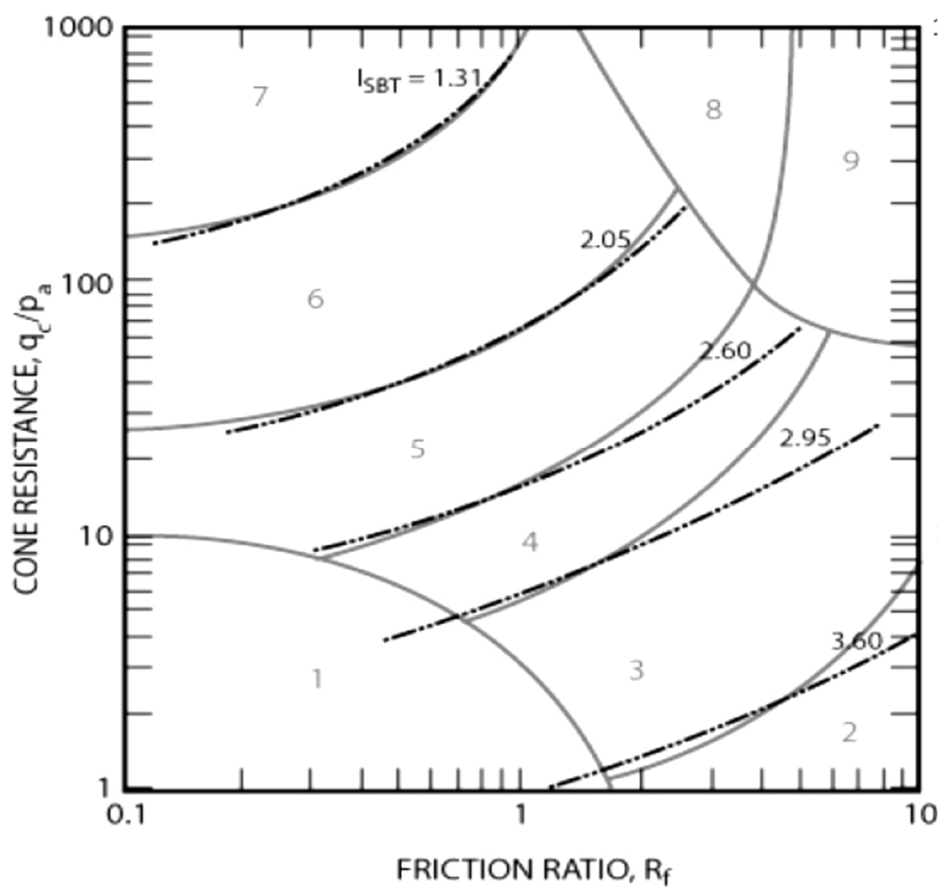


Figure 6-2 Non-normalised SBT chart by Robertson et al. (2010) based on dimensionless cone resistance (q_c/p_a) and friction ratio, R_f , showing contours of SBT index I_{SBT} (denoted I_c on the test plots). The chart is equally applicable to normalised tip resistance (Q_t , Q_{tn}) and normalised friction ratio (F_r) values using the same dimensionless scales.

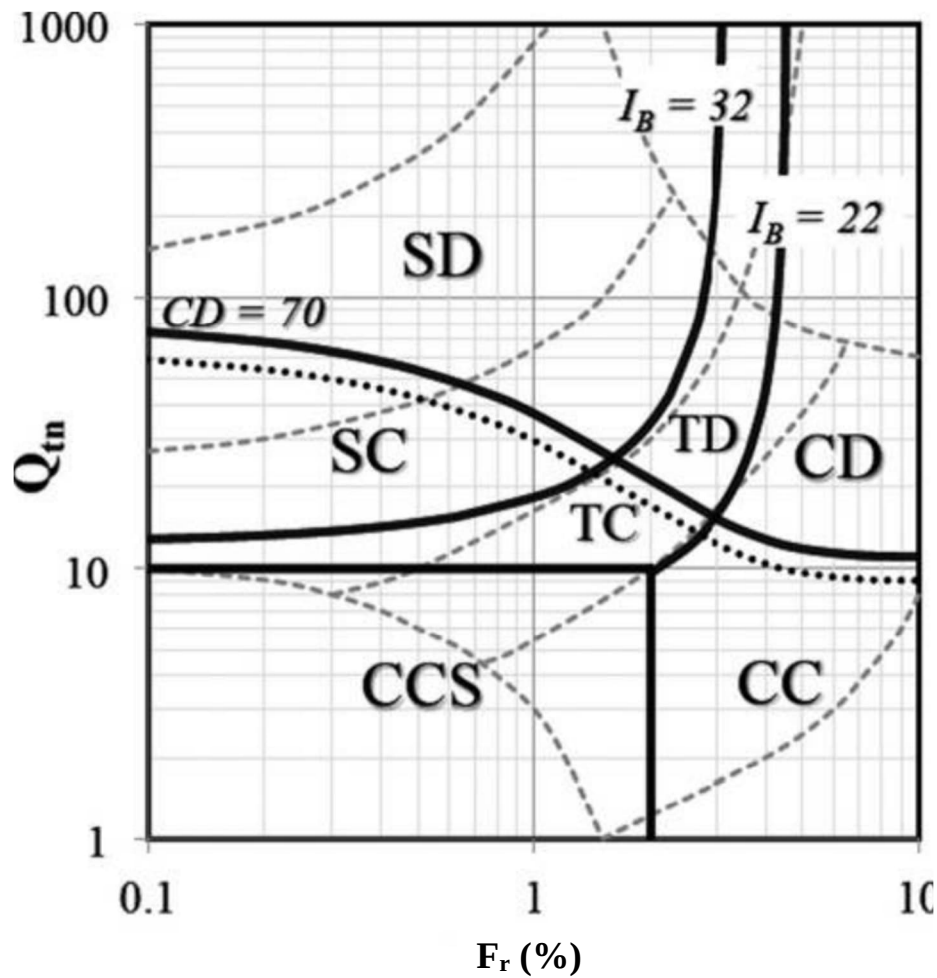
Table 1 Robertson (1990, 2010) soil behaviour type zone descriptions

Zone	Soil Behaviour Type (SBT)	
1	Sensitive fine-grained	6 Sands - clean sand to silty sand
2	Organic soils	7 Gravelly sand to sand
3	Clays – clay to silty clay	8* Very stiff/dense sand to clayey sand ¹
4	Silt mixtures - clayey silt to silty clay	9* Very stiff fine grained ¹
5	Sand mixtures – silty sand to sandy silt	*Heavily overconsolidated or cemented

¹Note zones 8 and 9 appear as 'Very stiff/dense sand to clayey sand - HOC or cemented' and 'Very stiff fine grained - HOC or cemented' within the soil unit descriptions of plots in Appendix D.

Robertson 2016

Using the same Q_{tn} - F_r space as the 1990 and 2010 charts, Robertson (2016) proposed an alternative purely behavioural classification system that places less emphasis on classification according to composition/textural properties and more emphasis on mechanical behaviour – namely the tendency of the soil to dilate or collapse during large strain shear, and sensitivity.



Zone	Soil Behaviour Type (SBT)
CCS	Clay-like – contractive - sensitive
CC	Clay-like – Contractive
CD	Clay-like – Dilative
TC	Transitional - Contractive
TD	Transitional - Dilative
SC	Sand-like - Contractive
SD	Sand-like - Dilative

Figure 6-3 Robertson 2016 soil behaviour type classification chart and zone descriptions

Schneider *et al.* (2008)

Schneider *et al.* (2008) proposed a classification system based on the normalised pore pressure B_q and normalised tip resistance Q_t . This system is particularly useful for fully saturated soils with a repeatable and dynamic pore pressure response.

A set of logs showing both the Robertson and Schneider *et al.* classification results are provided for comparison in Appendix D.

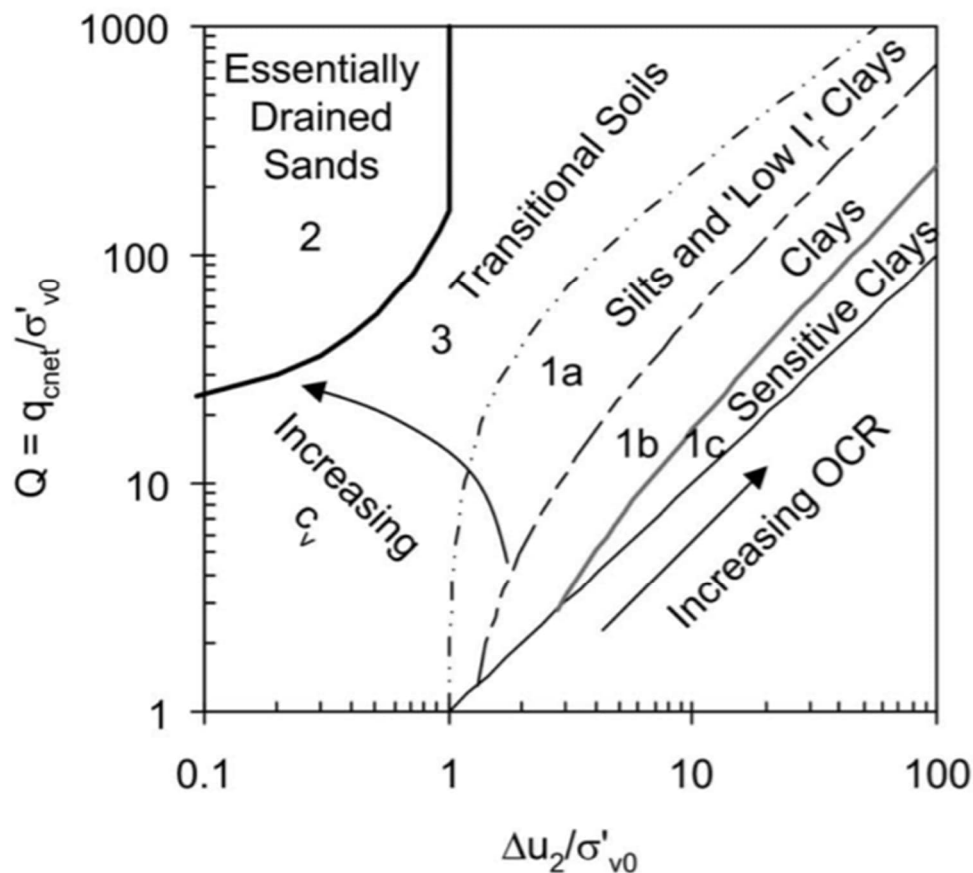


Figure 6-4 Schneider 2008 soil behaviour type classification chart

Layer Analysis

The layer boundaries are manually interpreted based on broad changes in Robertson's (1990) SBT classification or variance with depth. Once the layer boundaries are defined, the SBT zones within each layer are listed along with the corresponding percentage of data points, excluding null/filtered data. The modal classification is reported in full, while secondary zones are provided with abbreviated descriptions. For example: 'Clays – clay to silty clay [74%]; Silt mixtures [20%]', where the asterisk indicates an abbreviation of the full description 'Silt mixtures – clayey silt to silty clay'.

It is important to note that classification zone boundaries do not exist naturally, and minor variations in cone response can result in multiple classifications within layers of relatively uniform behaviour. This is particularly true when the data plot is near a zone boundary, contains spurious spikes, or includes very thin layers. Therefore, a system is necessary to limit the number of classified zones within each layer description. The following logic has been applied to retain only the most significant classifications:

For $LT \geq 1$, $C = 85$
For $0.5 \leq LT < 1$, $C = 75$
For $LT < 0.5$, $C = 65$

Where

C = Minimum % SBT zone classification coverage within the layer description text
 LT = Layer thickness (m)

For layers having a thickness of less than 1 m, 8% of data at the top and bottom of the layer (16% total) are excluded to limit the effect of transition zone data (measured resistance influenced by overlying or underlying strata of different stiffness) being included in the classification.

The continuous SBT index I_c can be used to assess the classification distribution and variation not accounted for by the layer description.

6.5 SOIL BEHAVIOUR TYPE INDEX – I_c

The principal trend in soil behaviour type (SBT) variation can be expressed by a continuous index, I_c , as proposed by Robertson and Wride (1998) based on a similar index proposed by Jefferies and Davies (1993). The index provides a continuous profile of SBT variation with depth for end-user analysis of soil units and variation within units. The equivalent non-normalised version proposed by Robertson (2010) is provided for comparison.

The basis of I_c and its approximation of the original chart classification zones may be seen from Figure 6-2. The method does not identify zones 1 (*sensitive fine grained*) or zones 8 & 9 (*heavily overconsolidated or cemented*).

Normalised SBT index I_c (Robertson and Wride, 1998), as updated by Robertson (2009) to use Q_{tn} :

$$I_c = [(3.47 - \log Q_{tn})^2 + (\log F_r + 1.22)^2]^{0.5}$$

Non-normalised SBT index I_c (Robertson, 2010):

$$I_c = \left[\left(3.47 - \log \left(\frac{q_c}{\sigma_{atm}} \right) \right)^2 + (\log R_f + 1.22)^2 \right]^{0.5}$$

The normalised version of I_c is generally more accurate, while the non-normalised version is intended for compatibility with the non-normalised Robertson's (2010) SBT chart and may be more accurate at shallow depths in overconsolidated soils.

I_c results are presented in Appendix D and are repeated alongside derived parameters on all plot sheets to provide SBT context.

6.6 RELATIVE DENSITY

The relative density of sands is calculated based on an empirical relationship proposed by Jamiolkowski *et al.* (2001) based on a large database of undisturbed frozen samples and calibration chamber tests on clean sands.

$$D_r = 100 \left[0.268 \cdot \ln \left(\frac{q_t / \sigma_{atm}}{\sqrt{\sigma_{vo}' / \sigma_{atm}}} \right) - k \right]$$

k = Compressibility dependant constant can be taken as -0.675 for medium compressibility (applied value in our interpretation), ≤ 1 for high compressibility and ≥ 2 for compressible sands.

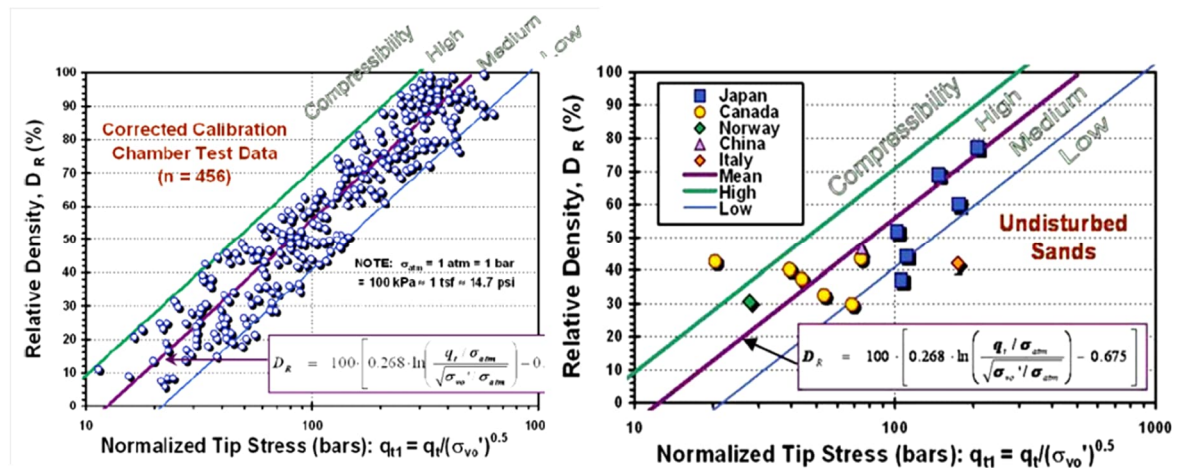


Figure 6-5 Relative density with normalised tip stress and sand compressibility from calibration chamber tests (left) and undisturbed frozen samples (right). Jamiolkowski *et al.* (2001). Reproduced from Mayne (2007).

The results are presented in Appendix F.

6.7 UNDRAINED SHEAR STRENGTH

The undrained shear strength s_u is usually estimated by dividing the net tip resistance by an empirical cone factor N_k (Lunne *et al.*, 1997):

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

Mayne and Peuchen (2018) performed an evaluation of 407 high-quality undrained anisotropically consolidated triaxial compression tests (CAUC) with net tip resistance data pairs, resulting in N_{kt} factors with regression analysis details for five categories of clays shown in Table 2.

Table 2 Summary of CAUC s_u versus q_{net} for various clays. Reproduced from Mayne and Peuchen (2018).

Clay Group	Number of sites	Nr Data	Correlation Coefficient r^2	Factor N_{kt}	Mean Pore Pressure Parameter B_q
1) Offshore NC-LOC	17	115	0.98	12.32	0.51
2) Onshore NC-LOC	30	191	0.867	12.00	0.53
3) Sensitive NC-LOC	5	43	0.507	10.33	0.84
4) OC Intact	5	36	0.862	13.57	0.49
5) OC Fissured	5	22	0.393	22.47	-0.01
All clays	62	407	0.923	13.33	0.55

The test plots of Appendix E provide profiles of s_u corresponding to the N_{kt} factors of groups 2, 4 and 5, with the applicable N_{kt} value and soil group name indicated in the header legend. ' $s_{u3...reference}$ ' on the logs corresponding to $N_{kt} = 15$ and has been included for comparison to data interpreted using the commonly adopted N_{kt} value of 15 for 'normal' clays.

A variable N_{kt} factor can be estimated with depth as a function of the pore pressure parameter B_q , applicable for B_q values of > -0.01 . The following equation proposed by Mayne and Peuchen is based on the same database evaluation:

$$N_{kt} = 10.5 - 4.6 \cdot \ln(B_q + 0.1)$$

Where the pore pressure parameter B_q is the ratio of excess pore pressure to net tip resistance:

$$B_q = \frac{u_2 - u_0}{q_t - \sigma_{v0}}$$

The estimate of N_{kt} has a standard error of 2.4 and correlation coefficient of 0.645.

When calculated, the s_u estimate based on B_q is presented as ' s_{u5} - Dynamic N_{kt} from B_q (CAUC)' on the plots and is only suitable for tests that have a high-quality pore pressure data, often indicated by a positive, repeatable, and dynamic response.

Note: N_{kt} (with subscript 'kt') indicates a N_k factor that has been established using the corrected (total) tip resistance q_t . N_{kt} can be applied to the uncorrected tip resistance q_c but results in a slightly lower estimate of s_u depending on the correction magnitude ($q_c - q_t$) in lower strength soils.

s_u results are presented in Appendix E.

6.8 OVERCONSOLIDATION RATIO

The preconsolidation stress σ'_p is calculated based on the method proposed by Mayne et al (2009):

$$\sigma'_p = k \cdot (q_t - \sigma_{v0})^{m'}$$

$$OCR = \sigma'_p / \sigma'_{v0}$$

Mayne *et al* found that the trend with mean grain size followed a power law through the addition of exponent m' and that its value can be estimated by relation to soil behaviour type index I_c :

$$m' = 1 - \frac{0.28}{1 + (I_c/2.65)^{25}}$$

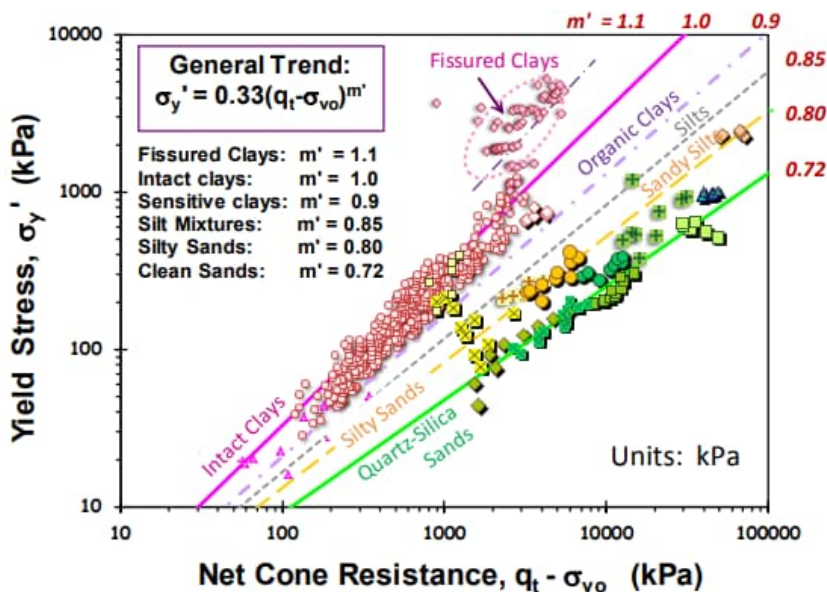


Figure 6-6 Preconsolidation stress with net cone resistance power law, reproduced from Mayne (2014).

An additional set of σ'_p and OCR values were calculated for $m' = 1.1$ to reflect the upper trend for over consolidated fissured clays not captured by the correlation with I_c .

The results are presented in Appendix E.

6.9 SPT N₆₀ VALUES

Equivalent SPT N₆₀ values, defined as the non-normalised SPT blow count over a 30 cm interval, with a reference hammer efficiency (energy transfer ratio, 'ETR' or 'ER') of 60%, is derived according to two correlations:

Method 1 - Jefferies and Davies (1993) cited in, and modified by, Lunne *et al.* (1997) to use I_c according to normalised Robertson 1990 SBT chart:

$$N_{60} = \frac{q_t}{8.5 \cdot \sigma_{atm} \cdot (1 - I_c/4.6)}$$

Method 2 - Robertson (2012):

$$\frac{\left(\frac{q_t}{p_a}\right)}{N_{60}} = 10^{(1.268 - 0.2817I_c)}$$

The correlations are intended for clays, silts and sands and not for carbonates or cemented geo-materials.

Conversion of N₆₀ values for comparison to other hammer efficiency values, or vice-versa, can be performed using the relationship:

$$N_{60} \cdot \frac{60}{ETR} = N_{ETR}$$

Where ETR is entered as a percentage.

The results are presented in Appendix F.

6.10 FRICTION ANGLE

Sands

The peak friction angle of granular materials is calculated using the Kulhawy and Mayne (1990) method. The relationship is based on a calibration chamber database from 24 sands (mainly sampled by freezing) of varying mineralogy and is found from:

$$\phi' = 17.6 + 11.0 \cdot \log(q_{t1})$$

Where:

ϕ' = Peak friction angle (degrees)

q_{t1} = stress normalised cone resistance:

$$q_{t1} = \left(\frac{q_t}{\sigma_{atm}} \right) / \left(\frac{\sigma_{v0'}}{\sigma_{atm}} \right)^{0.5}$$

The presence of compressible minerals or fines tends to reduce tip resistance resulting in lower estimate of friction angle, while very coarse (sand) or larger grain size tends to increase tip resistance resulting in higher estimate. Increased penetration resistance due to high k_0 conditions also results in an overestimate of friction angle.

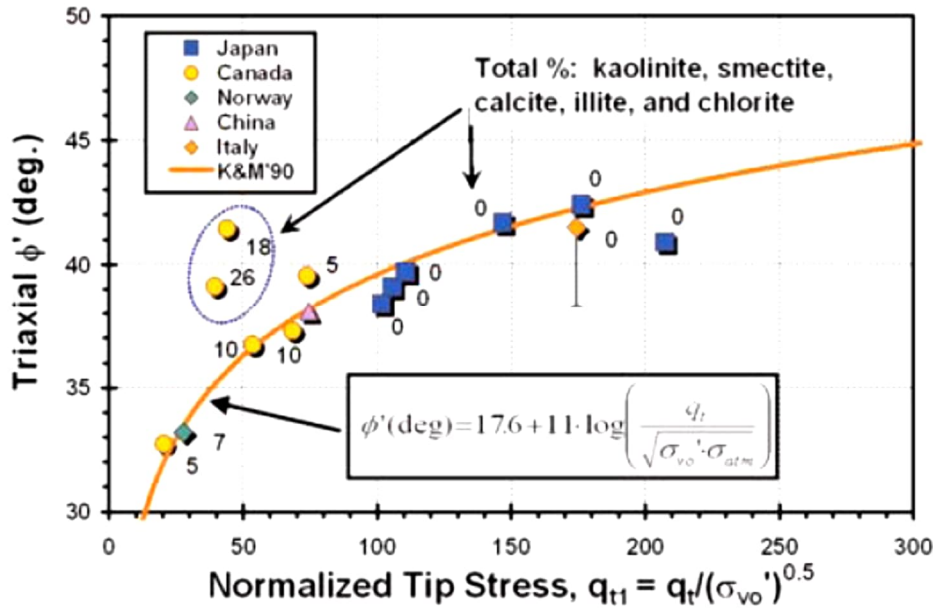


Figure 6-7 Peak triaxial friction angle from undisturbed sands with normalised cone resistance.

Fine grained soils

The effective friction angle for fine grained soils is calculated based on the Senneset *et al.* (1988, 1989) method, referred to as 'NTH' (Norwegian Institute of Technology) solution, using the modified and approximate closed form solution by Mayne & Campanella (2005) as a direct function of the pore pressure parameter B_q and normalised tip resistance Q_{tn} (referred to as Q in figure Figure 6-8 Triaxial ϕ' versus CPTu-evaluated value (NTH method) for 105 soft-firm clays with OCRs < 2.5 (Ouyang and Mayne 2018, cited in Mayne *et al* 2022). The method is generally applicable where $0.1 < B_q < 1.0$ and $20^\circ < \phi' < 45^\circ$ and is appropriate for non-cemented normally consolidated to lightly overconsolidated soils.

$$\phi' = 29.5^\circ B_q^{0.121} [0.256 + 0.336 B_q + \log Q]$$

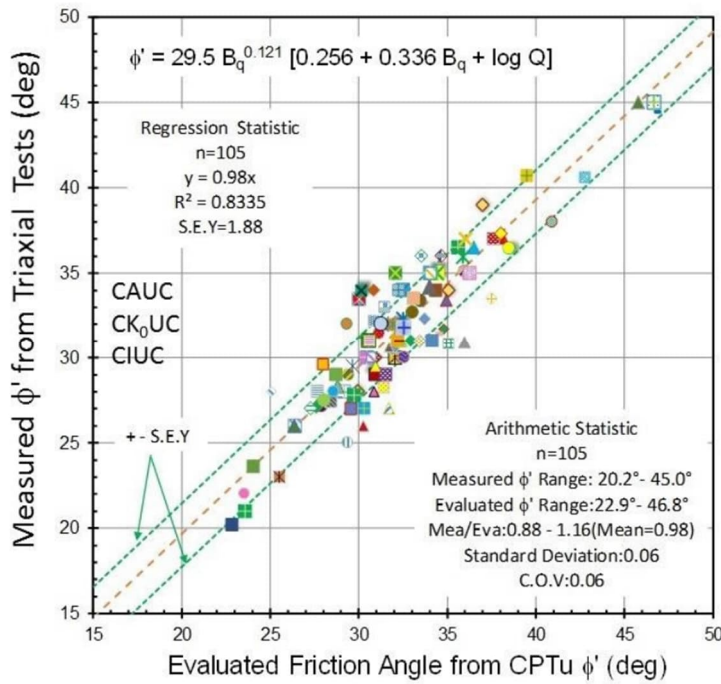


Figure 6-8 Triaxial ϕ' versus CPTu-evaluated value (NTH method) for 105 soft-firm clays with OCRs < 2.5 (Ouyang and Mayne 2018, cited in Mayne *et al* 2022).

The results are presented in Appendix F.

6.11 COEFFICIENT OF VOLUME CHANGE

Coefficient of volume change m_v , defined as the inverse of the constrained modulus M , is evaluated for all soil types using the constrained modulus method proposed by Mayne (2006) cited in Mayne (2007). The value may be used to predict settlement at the end of primary consolidation and is applicable to the present state of vertical effective stress up to the pre-consolidation stress for overconsolidated soils.

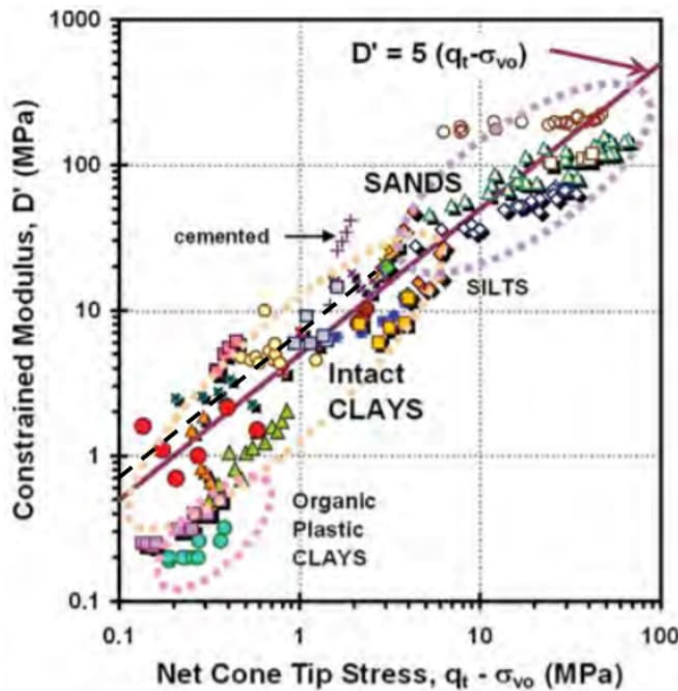
$$m_v = 1/M'$$

Where:

$$M' = \alpha \cdot (q_t - \sigma_v)$$

$$\alpha = 5$$

An alpha factor of 8.25 reported by Kulhawy & Mayne (1990) for fine grained soils appears to provide a better fit through the data for intact non-organic clays, reducing to around 1 to 2 for organic plastic clays.



Kulhawy & Mayne (1990) line
for inorganic clays; $8.25(q_t - \sigma_{vo})$

Figure 6-9 Constrained modulus of Mayne (2006). Annotated/redrawn from NCHRP Synthesis 368 (2007).

The results are presented in Appendix E.

6.12 YOUNG'S MODULUS

The secant Young's modulus E' at 25% mobilised shear strength (FOS = 4) is calculated according to the method proposed by Robertson (2009):

$$E' = \alpha(q_t - \sigma_v)$$

Where:

$$\alpha = 0.015(10^{0.55Ic+1.68})$$

The method described by Robertson may be adapted to estimate E' for loading at different percentages of mobilised shear strength.

The results are presented in Appendix F.

7 DISSIPATION TESTS

Dissipation tests were performed during the CPT at depths specified by the Client's representative or Investigation Supervisor on site.

The hydraulic clamp was on and maintained pressure for the duration of the test.

Pore pressures were sampled at 1 second resolution up to 300 seconds followed by a 10 second resolution thereafter.

7.1 COEFFICIENT OF CONSOLIDATION

Dissipation tests are interpreted according to Teh and Houlsby (1988), who determined modified dimensionless time factors T^* for various degrees of pore pressure dissipation due to consolidation around the stationary penetrometer. The solution for a given time factor is of the form:

$$T^* = \frac{c_{vh} \cdot t}{r^2 \cdot \sqrt{Ir}}$$

Where r = Radius of the cone, Ir = Rigidity Index ($= \frac{G_u}{s_u}$, assumed = 100), T^* = time factor (see table below for values), t = time to a given degree of pore pressure dissipation, c_{vh} = coefficient of consolidation.

Note:

- Ir is required in the analysis as it determines the length of the drainage path, but its true value is difficult to determine in practice.
- Whilst the direction of pore water flow is primarily horizontal, the coefficient of consolidation is denoted here with subscript vh to acknowledge uncertainty in relative magnitude of vertical and horizontal flow.

The solution of Teh and Houlsby was developed for monotonic dissipations with no initial rise due to dilatancy. For tests that displayed an initial rise, the corrected initial peak pressure at time t_0 is found using the Sully *et al* (1999) method of backwards extrapolation of the initial decay curve plotted in root time.

The saturated porous filter was in the shoulder (u_2) position in all cases. The results of the dissipation tests are presented in Appendix G.

Table 3 Modified time factors T^* from consolidation analysis (Teh and Houlsby, 1988)

Degree of dissipation (%)	u_2 measuring position
0	0.038
30	0.078
40	0.142
50	0.245

Where a test is of insufficient duration to perform the above analysis an upper-bound value of c_{vh} is calculated taking the time of the final value as equal to t_{50} . This should be treated with caution but is usually a safe assumption given that the peak measured pore pressure is very rarely less than 65% of the corrected initial pressure estimated by the Sully *et al*. method described above.

For dissipation tests with t_{50} values of less than ~40 seconds in NC-LOC soils, the estimate of coefficient of consolidation may be significantly influenced by partial consolidation during penetration prior to the test beginning. This results in a lower bound value of c_{vh} and is indicated as such in the results table (Table 4) of Appendix A.

7.2 PERMEABILITY

Method 1: Parez and Fauriel (1988) method based on t_{50} :

$$k = \left(\frac{1}{251 \cdot t_{50}} \right)^{1.25}$$

Where t_{50} is the time to 50% dissipation of excess pore pressure, and k is permeability (cm/s).

This method is based on monotonic dissipation results and should be cautiously applied to dissipations that exhibit dilative behaviour (showing initial rise to peak pressure) where t_{50} is calculated using a corrected initial pore pressure. Permeability values are multiplied by a factor of 1.5 for 15 cm² cones.

Method 2: Theoretical method, as discussed by Robertson (2014), which accounts for the effect of soil stiffness:

$$k = \frac{c_{vh} \cdot \gamma_w}{M}$$

Where c_{vh} is the coefficient of consolidation; γ_w is the specific weight of water and M is the constrained modulus. The derivations of c_{vh} and M are described separately within this report.

Robertson (2014) proposed an approximate relationship between permeability (k) and the soil behaviour type index (I_c) as follows:

$$\text{For } 1.0 < I_c \leq 3.27 \quad k = 10^{(0.952 - 3.04 I_c)}$$

$$\text{For } 3.27 < I_c < 4.0 \quad k = 10^{(-4.52 - 1.37 I_c)}$$

The values have been derived and are presented in Appendix G.

Where dissipation tests have been performed, it is possible to reverse calculate the 'equivalent' SBT index I_c from the calculated permeability based on dissipation tests. These values have been derived and plotted in the I_c log as K1 and K2 corresponding to permeability method 1 and 2 above. Permeability values for K2 are only evaluated for t_{50} values exceeding 35 seconds.

The equivalent I_c value is not intended as a correction nor a more accurate version of the index. The equivalent value based on permeability simply provides comparative insight into the soil type in terms of approximate drainage characteristics.

8 GENERAL INTERPRETATION NOTES

Provided below is a non-exhaustive set of notes on interpretation of the acquired CPT data with reference to examples within the dataset where appropriate.

DRAINED AND UNDRAINED SOIL BEHAVIOUR

Geotechnical parameters appropriate for drained and undrained cone penetration conditions are derived for drained and undrained soil behaviour types (SBTs) respectively, however, to help mitigate the uncertainty in the SBT correlation with drainage behaviour, all parameters are derived over the Soil Behaviour Type range $2.4 < I_c < 2.7$. For partially drained conditions, error will be introduced within derived parameters.

Piezocone dynamic pore pressure and dissipation tests may be used to identify drainage conditions. Dissipation t_{50} values exceeding 50 seconds indicate undrained penetration behaviour based on the findings of Kim *et al.* (2008).

In partially drained materials the friction sleeve resistance may rise significantly immediately following a pause in penetration due to consolidation and increased effective stress on the friction sleeve.

DYNAMIC PORE PRESSURE u_2 (CPTu)

While the piezo system is saturated before use, testing through unsaturated soils may result in some degree of desaturation leading to a less accurate and more 'sluggish' pore pressure response. Desaturation can also occur during penetration due to suction pressure causing cavitation during dilative shear at the cone shoulder. Dissipation tests that are undertaken following desaturation are likely to have a more pronounced initial rise and the results of analysis may have some degree of error.

If the piezometer system becomes desaturated it may re-saturate at higher excess pressures later in the test as gas dissolves under pressure. The pore pressure response in saturated contractive soils should normally have a dynamic 'peaky' appearance.

The tip resistance in lower strength contractive soils without pore pressure measurement in the u_2 position is likely to be significantly lower (up to 20%, typically ~10%) than the equivalent corrected tip resistance depending on the magnitude of excess pore pressure generated during penetration.

CONICAL TIP AND FRICTION SLEEVE OFFSET

The accuracy of the friction ratio (and derived SBT) over thin layers and at layer boundaries is sensitive to the offset between the focal point of shear in front of the conical tip and the centre of the friction sleeve, and the difference in the vertical extent of soil influencing the sensors. This often results in sharp peaks or troughs at boundaries when the sleeve rises or falls out of unison with tip resistance. More broadly, this error will be seen in any circumstances where the spacing between inclusions or discontinuities causes the cone tip and sleeve to experience heterogeneity, for example in disturbed fill or landslip material with a 'blocky' macro fabric or large inclusions. The figure below provides an example of the tip-sleeve offset and resulting (erroneous) friction ratio spike.

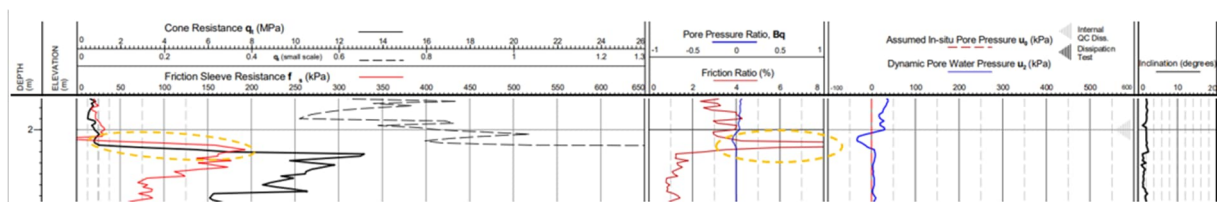


Figure 8-1 example of offset in tip and sleeve response at a strata boundary.

Note that the cone-sleeve offset results in the absence of friction ratio over the last ~14 cm of each test location, and therefore the SBT material description does not extend over this range.

FRICTION SLEEVE DATA

There are three common causes of friction sleeve measurement error; 1) unequal pore pressure acting on the sleeve end areas as the sleeve passes through materials of different permeability and hence excess pore pressure Δu_2 , often resulting in a negative/positive spike, 2) Accuracy limitations and temperature effects in very low strength or sensitive soils, and 3) error associated with bending strain that occurs while the cone inclination deviates rapidly. Temperature effects are generally mitigated by temperature stabilisation during the test and at the time of zero output measurement.

In sand, particularly loose to medium dense, the sleeve data may show a sudden drop following a penetration pause, followed by a much more gradual recovery over 15-30 cm. This is believed to be associated with relaxation of stress on the sleeve due to creep as stresses are redistributed further from the cone. The effect of this on SBT classification is generally very small.

CONE TYPE

The reference cone type has a 10 cm² projected cone tip area and 150 cm² friction sleeve area, however it is common to use a larger 15 cm² cone with a 225 cm² friction sleeve area for improved sensitivity, temperature stability, damage prevention and penetration depth potential due to the higher bending strength. Use of a 15 cm² cone does however require higher penetration force (reaction force) for a given penetration pressure and produces more pronounced transition zones and thin layer effects due to the larger influence zone.

TRANSITION ZONES AND THIN LAYER EFFECTS

During penetration at the boundary between soils of contrasting stiffness, a transition zone is often evident prior to mobilisation of the true soil stiffness. These should be cautiously ignored in assessment of soil behaviour type and parameter evaluation. Where the stiff layer is thin (<~1 m) mobilised resistance may be significantly less than that of an equivalent thick layer. The effect for thin low stiffness layers is less significant. Procedures for thin-layer effect correction are provided by Robertson and Wride (1998) and Boulanger & DeJong (2018).

GRAVELS

The presence of gravel or larger clasts in a soil is often characterised by short peaks in the CPT tip and sleeve readings, possibly with associated inclinometer 'shake' and/or short sharp reductions in pore water readings due to dilation effects. Frequent gravels in soft or loose soils may generate localised erroneous friction ratio values.

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APPENDICES

Appendix A	SUMMARY TABLES
Appendix B	GENERAL INFORMATION
Appendix C	CONE PENETRATION TEST RESULTS
Appendix D	SOIL BEHAVIOUR TYPE RESULTS
Appendix E	PARAMETER RESULTS 1 – s_u , m_v , OCR, SBT, I_c
Appendix F	PARAMETER RESULTS 2 – SPT N60, Φ , D_r , E , I_c
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APPENDIX A

SUMMARY TABLES

Table 3 CPT summary

Location ID	Stroke number	Final depth (m)	Cone ID	Piezocoone test	Pre-drilled (m)	Pre-drilling details	Rig	Primary refusal factor	Applied zero values	Tip zero drift (kPa)	Sleeve zero drift (subtraction) (kPa)	Piezo. zero drift (kPa)	Nr dissipation tests	Raw file name	X Coordinate	Y Coordinate	Z Coordinate	Date	Remarks
CPT01	1	10.22	S15-CFIPT.1852	YES			UK20	Target depth	pre	-26.20	-0.30	0.10	1	30058-V1-030925-UK20-LP113.L05				03/09/2025	
CPT02	1	10.26	S15-CFIPT.1852	YES			UK20	Target depth	pre	18.20	0.10	0.00	1	30058-V1-030925-UK20-LP113.L04				03/09/2025	
CPT03	1	10.26	S15-CFIPT.1852	YES			UK20	Target depth	pre	18.20	0.10	0.00		30058-V1-030925-UK20-LP113.L03				03/09/2025	
CPT04	1	10.26	S15-CFIPT.1852	YES			UK20	Target depth	pre	18.20	0.10	0.00	1	30058-V1-030925-UK20-LP113.L02				03/09/2025	
CPT05	1	10.22	S15-CFIPT.1852	YES			UK20	Target depth	pre	-9.60	1.20	0.20		30058-V1-030925-UK20-LP113.L01				03/09/2025	

CPT test plots are presented in Appendix C.

Table 4 Dissipation test interpretation summary

Location ID	Depth (mBGL)	Assumed piezometric level (mBGL)	In-situ pore pressure u_0 (kPa)	Piezometric level / u_0 origin	Final interpreted time value (s)	Final Interpreted degree dissipation (%)	Coefficient of consolidation C_{vh} (m^2/yr)	UB C_{vh} (m^2/yr) - incomplete diss., final time as t50	LB C_{vh} (m^2/yr) - Partial consolidation significant	Constrained modulus (MPa) - from CPT estimate	Permeability k_1 (m/s)	Permeability k_2 (m/s)	UB k_2 (m/s) based on UB C_{vh}	Remarks
CPT01	0.80	0.20	5.89	Piezocone response in drained soils		50	208.6			0.9	2.256E-08	7.210E-08		*CIP
CPT02	0.95	0.58	3.63	Piezocone response in drained soils		50	16.2			0.8	9.214E-10	6.280E-09		*CIP
CPT04	6.60	0.43	60.50	Piezocone response in drained soils, approx. ± 0.6 mbgl						78.3				*IEP, *NI

*Abbreviations:

- CIP: Corrected initial pressure
- DT: Disrupted test
- ID: Insufficient test duration - insufficient or no decay of excess pore pressure
- ICIP: Indicative corrected initial pressure
- IEP: Insufficient excess pressure generated
- LBI: Lower bound interpretation
- MD: Monotonic decay
- NEP: No excess pore pressure generated - excess pore pressure is required for interpretation of C_{vh}
- PC: Partial consolidation/drainage during penetration is significant ($t_{50} < 60$ s) - C_{vh} is lower bound
- NI: No interpretation
- UBI: Upper bound interpretation
- UR: Uncharacteristic response - uncharacteristic dissipation response precludes interpretation, for instance due to temperature effects of unidentified test disturbance.
- U0: Final dissipation pressure assessed to represent equilibrium pore pressure, u_0 , and has been used to establish effective stress in the normalisation of CPT data.

Graphical analysis of dissipation tests are presented in Appendix H

APPENDIX B GENERAL INFORMATION

LIST OF FIGURES

Cone calibration certificate: S15-CFIIP.1852

Data sheet: 17.9-tonne track-truck mounted CPT unit (UK20)

Site location plan: As built

Test Setup

Calibrated Instrument

Instrument type:	Subtraction	Number of sensors:	5
Serial number:	DS15-CFIPT.1852	Manufacturer:	Eijkelpamp Geopoint
Nominal cone area:	15 cm ²	Nominal sleeve area:	227 cm ²
Calibration standard:	BS EN ISO 22476-1:2023	Location:	Lankelma Calibration Laboratory
Calibration date:	09 June 2025	Calibration expiry:	09 December 2025

Sensor measurand	Calibration range	Maximum rating	Momentary overload	Sensor stability (60 sec)	Max drift before re-calibration
Cone resistance (qc)	66.67 MPa	100 MPa	100 MPa	± 0.29 kPa	4 bar
Sleeve friction (fs)	4.41 MPa	1.00 MPa*	1.00 MPa	± 0.05 kPa	0.04 bar
Pore pressure (u)	4 MPa	5 MPa	6.75 MPa	± 0.02 kPa	0.14 bar
Inclination (i)	20 °	90 °		± 0.03 °	
Temperature (t)	30 °C	90 °C		± 0.019 °C	
Magnetic field (m)					

* The maximum usable sleeve friction stress is limited by the physical strength of the sleeve.

ISO 22476-22 Cone Penetrometer Classification

Sensor measurand	Measurement uncertainty U _{qc: class} , U _{fs: class} , U _{u: class}	Ambient temperature stability			Transient temperature stability			Bending influence Δb _{qc} , Δb _{fs} , Δb _u	Overall classification (highest number represents penetrometer class)
		Uncorrected Δa _{qc} , Δa _{fs} , Δa _u	Corrected Δa _{qc} , Δa _{fs} , Δa _u		Uncorrected Δt _{qc} , Δt _{fs} , Δt _u	Corrected Δt _{qc} , Δt _{fs} , Δt _u			
Cone resistance	0	2	0		2	1		0	1
Sleeve friction	0	0	0		0	0		0	0
Pore pressure	0	2	0		0	0		0	0

Calibration signed by:

P Metcalf

Calibration checked by:

A Harman

Cone penetrometer, serial number: DS15-CFIPT.1852 was found to comply with the requirements of BS EN ISO 22476-1:2023 for the following classifications:
 Cone Resistance - Class 1 Sleeve Friction - Class 0 Pore Pressure - Class 0

Reference Instruments

Device	Serial number	Uncertainty of recorded value	Calibration date
AM DSCCHA-100 kN	66914	0.02 ±%	19/06/2023
AM DSCCHA-5 kN	61065	0.05 ±%	19/06/2023
Keithley 7.5 Digit DMM	4496826	12.00 PPM	02/07/2024
MMG750V1P1MC0T3A6CE	547961	0.02 ±%	02/09/2024
ETI Ref Thermometer	D24276054	0.04 °C	17/09/2024
Lankelma HV6 Rotary Table	INC-JIG 01	0.10 °	17/07/2023
10 kg Calibration Weight	H1-S1 10kg	0.001 %	02/08/2024
Mitutoyo 200mm Caliper	A23044194	0.02 ±mm	20/06/2024

Calibration Standard

The calibration was performed according to BS EN ISO 22476-1:2023 & BS EN ISO 17025:2017 for the calibration of cone penetrometers.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%. The uncertainty evaluation for each of the calibrated sensors has been carried out in accordance with BS EN ISO 22476-1:2023 requirements.

The report provides traceability of measurement to national standards and the SI system of units.

Clause 5.1.2 of BS EN ISO 22476-1:2023, states that the maximum period of validity of the calibration of the cone penetrometer shall not exceed 12 months. The cone penetrometer shall be recalibrated if the readings before a test show a zero baseline drift of over 2% of full scale output compared to the calibration zero load readings.

Cone Dimension Verification
Cone Tip
Cone shoulder diameter

Rotational position	d_c
0 °	43.90 mm
120 °	43.90 mm
240 °	43.90 mm

Height of the cylindrical extension of the cone

Rotational position	h_e
0 °	11.48 mm
120 °	11.48 mm
240 °	11.48 mm

Height of the conical section of the cone

Rotational position	h_c
0 °	36.22 mm
120 °	36.22 mm
240 °	36.22 mm

Filter element diameter

Rotational position	d_{fil}
0 °	43.63 mm
120 °	43.64 mm
240 °	43.64 mm

Friction Sleeve
Friction sleeve diameter

Rotational position	Upper section d_{2u}	Middle section d_{2m}	Lower section d_{2l}
0 °	43.95 mm	44.03 mm	43.96 mm
120 °	43.96 mm	44.04 mm	43.96 mm
240 °	43.98 mm	44.05 mm	43.96 mm

Friction sleeve length

Rotational position	l_s
0 °	164.97 mm
120 °	164.97 mm
240 °	164.97 mm

Gap between the cone and the lower end of the friction sleeve

Rotational position	l_{gl}
0 °	2.67 mm
120 °	2.67 mm
240 °	2.67 mm

Gap above the upper end of the friction sleeve

Rotational position	l_{gu}
0 °	2.41 mm
120 °	2.43 mm
240 °	2.43 mm

Cone Tip Dimension Uncertainty

Reference device uncertainty u_r	0.015 mm
Average diameter d_c	43.900 mm
Relative error b_c	0.000 %
Area A_c	1513.627 mm ²
Dimension uncertainty U_{dc}	0.015 mm
Area uncertainty u_{Ac}	1.034 mm ²
Expanded area uncertainty U_{Ac}	2.069 mm ²

Friction Sleeve Dimension Uncertainty

Reference device uncertainty u_r	0.015 mm
Average diameter d_2	43.988 mm
Relative error b_{c2}	0.141 %
Average length l_s	164.970 mm
Relative error b_{ls}	0.000 %
Area A_s	22797.481 mm ²
Dimension uncertainty diameter u_{d2}	0.039 mm
Dimension uncertainty length u_{ls}	0.015 mm
Area uncertainty u_{as}	20.282 mm ²
Expanded area uncertainty U_{as}	40.565 mm ²
Sleeve length to diameter ratio	3.750
Diameter difference, sleeve - tip	0.088 mm

Cone Resistance Calibration

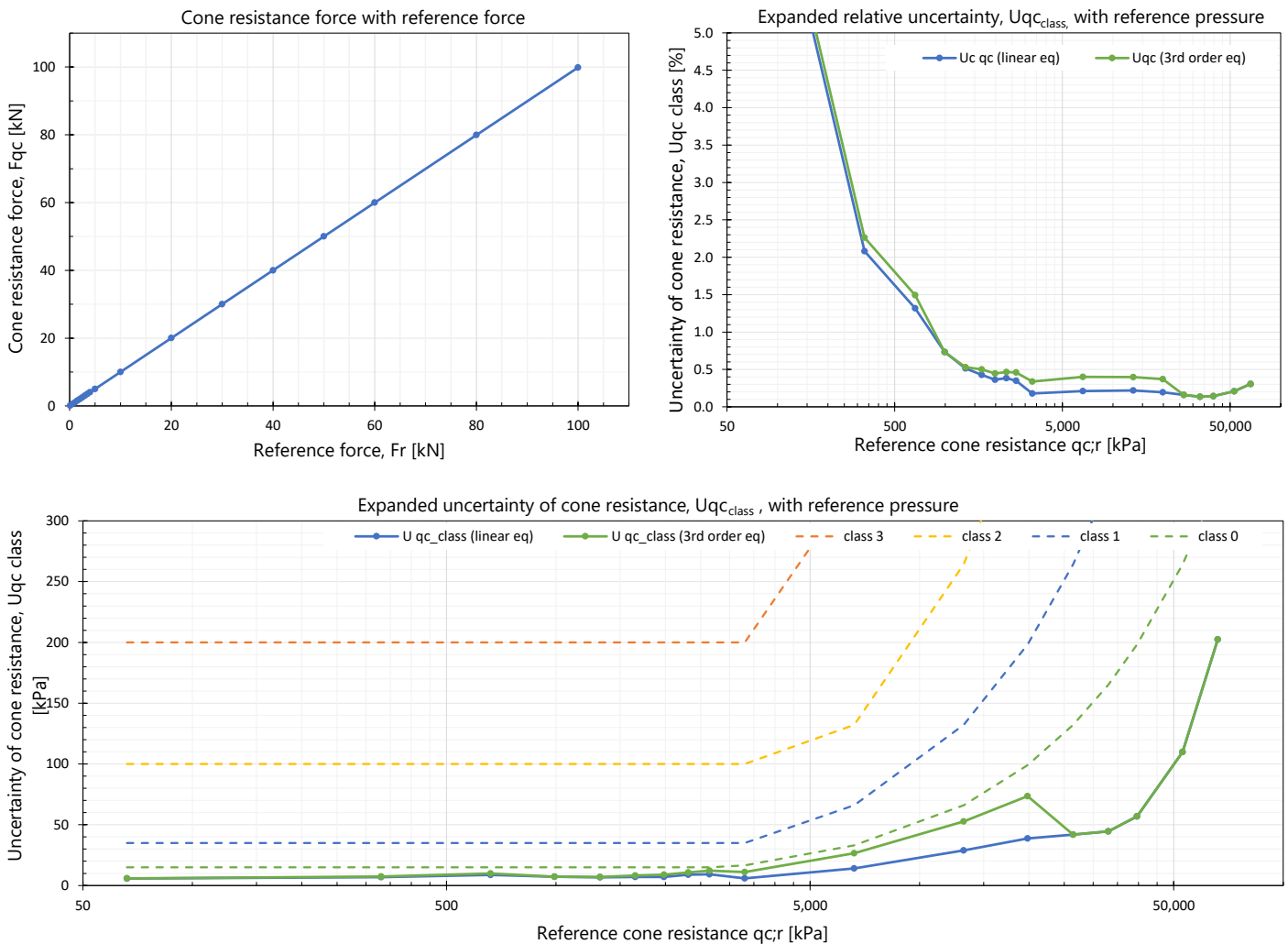
Calibration method

1. The cone was loaded to full range 3 times for no less than 1 minute before calibration.
2. The cone was calibrated with 4 sets of increasing forces and 2 sets of decreasing forces, with rotation before set 3 and 5.
3. The coefficients of a linear and third order equation relating the the estimate of applied force as a function of the deflection were calculated and are shown in Table 1.
4. The forces applied, and the resulting deflections are given in Tables 2. No corrections for temperature have been applied to these results.
5. The combined expanded uncertainty* of deflection U_{qc} and U_{qc_class} for each force is shown as a percentage of the recorded value and in units of pressure (kPa) as shown in Table 3.

* The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2$, providing a level of confidence of approximately 95%.

Cone Penetrometer		Calibration Conditions	
Cone penetrometer type	Subtraction	Ambient temperature	23.5 °C
Cone resistance capacity	150 kN	Ambient temperature variation	0.34 °C
Calibration range	100 kN	Instrument temperature variation	0.00 °C
Cone resistance effective resolution	0.0005 kN	Reference Load Cell Uncertainty	
Cone area	1,514 mm ²	AM DSCCHA-100 kN	0.02 ±%
Measured alpha factor cone area ratio	0.79	AM DSCCHA-5 kN	0.05 ±%
Historic drift between cone calibrations (u_{drift})	0.05774 %	Reference Indicator Uncertainty	
Apparent pore pressure (u_a) at full range	0.02 kPa	Keithley 7.5 Digit DMM	12 PPM
Cone resistance max zero drift	2.10 kPa		
Reference load cell max zero drift	3.47 kPa		

Cone Resistance Calibration - Graphical Results



Interpolation

Table - 1		
Linear Equation	The cone output in force units of D (0.1 N) is derived using a linear factor from the raw cone output. $D = \text{Factor} \times \text{RAW_Output}$	0.1 N Factor = 0.008976
Polynomial Equation	3rd order polynomial equation. For a given cone indicated output of D (in 0.1 N units), the corrected applied force, F (in 0.1 N units) is calculated from :	$a_0 = 0$ $a_1 = 1.000988775$ $a_2 = -6.93841E-09$ $a_3 = 1.76549E-14$ Polynomial calc. is only to be used when the cone load is under 30 kN

Cone Resistance Calibration - Tabular Results
Table - 2a Low range calibration results

	0°	0°	120°	120°	240°	240°
kN	kN	kN	kN	kN	kN	kN
Fr	X1	X2	X3	X4'	X5	X6'
0	0.0032	0.0029	0.0022		0.0011	
0.1	0.1056	0.1086	0.1038		0.1013	
0.5	0.5068	0.5094	0.5047		0.5032	
1	1.0079	1.0110	1.0062		1.0054	
1.5	1.5026	1.5058	1.4997		1.4982	
2	2.0026	2.0070	2.0016		1.9987	
2.5	2.5061	2.5098	2.5014		2.5004	
3	3.0052	3.0095	3.0044		3.0012	
3.5	3.5065	3.5127	3.5041		3.5019	
4	4.0084	4.0124	4.0057		4.0032	
5	5.0100	5.0149	5.0066		5.0035	
4				4.0052		4.0019
3.5				3.5075		3.5033
3				3.0081		3.0028
2.5				2.5072		2.5016
2				2.0034		1.9997
1.5				1.5022		1.4977
1				1.0030		0.9987
0.5				0.5034		0.4978
0.1				0.1004		0.0982

Table - 2b High range calibration results

	0°	0°	120°	120°	240°	240°
kN	kN	kN	kN	kN	kN	kN
Fr	X1	X2	X3	X4'	X5	X6'
10	10.0217	10.0245	10.0178		10.0154	
20	20.0398	20.0432	20.0352		20.0320	
30	30.0549	30.0530	30.0469		30.0460	
40	40.0213	40.0191	40.0108		40.0040	
50	50.0039	50.0055	49.9957		49.9910	
60	59.9809	59.9826	59.9723		59.9695	
80	79.9302	79.9293	79.9194		79.9154	
100	99.8657	99.8650	99.8547		99.8485	
80				79.9425		79.9353
60				60.0247		60.0182
50				50.0470		50.0420
40				40.0533		40.0500
30				30.0810		30.0773
20				20.0575		20.0539
10				10.0241		10.0217

Table - 3 Uncertainty assessment

Reference force	Reference tip resistance	Standard uncertainty u1 - u8								Combined standard calibration uncertainty		Expanded calibration uncertainty [k=2]				BS EN ISO 22476:2023 class	Tip calibration drift
kN	kPa	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN	kPa	%	kPa	%	Cone Class **	kPa
Fr	qc;r	u1*	u2	u3	u4	u5	u6	u7	u8	uc	uc;dim	Uc qc		Uqc class			Udrift ***
0	0	0.0000	0.0006	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0006	0.0006	0.8		0.8		0	0.0
0.1	66	0.0007	0.0013	0.0016	0.0002	0.0000	0.0034	0.0018	0.0000	0.0044	0.0044	5.9	8.90	5.9	8.90	0	0.0
0.5	330	0.0011	0.0012	0.0015	0.0002	0.0000	0.0048	0.0019	0.0000	0.0057	0.0057	7.5	2.27	7.5	2.26	0	0.2
1	661	0.0012	0.0011	0.0017	0.0002	0.0000	0.0065	0.0029	0.0000	0.0075	0.0075	9.9	1.50	9.9	1.49	0	0.4
1.5	991	0.0048	0.0018	0.0019	0.0002	0.0000	0.0002	0.0009	0.0000	0.0055	0.0056	7.4	0.75	7.3	0.73	0	0.6
2	1,321	0.0041	0.0018	0.0025	0.0002	0.0001	0.0010	0.0008	0.0000	0.0053	0.0055	7.2	0.55	7.0	0.53	0	0.8
2.5	1,652	0.0041	0.0026	0.0021	0.0002	0.0001	0.0026	0.0020	0.0000	0.0063	0.0065	8.6	0.52	8.3	0.50	0	1.0
3	1,982	0.0044	0.0021	0.0025	0.0002	0.0001	0.0036	0.0015	0.0000	0.0067	0.0070	9.3	0.47	8.9	0.45	0	1.1
3.5	2,312	0.0053	0.0025	0.0036	0.0002	0.0001	0.0042	0.0014	0.0000	0.0082	0.0085	11.2	0.49	10.8	0.47	0	1.3
4	2,643	0.0061	0.0029	0.0023	0.0002	0.0001	0.0057	0.0005	0.0000	0.0092	0.0096	12.7	0.48	12.2	0.46	0	1.5
5	3,303	0.0020	0.0036	0.0028	0.0002	0.0002	0.0067	0.0013	0.0000	0.0084	0.0091	12.0	0.36	11.2	0.34	0	1.9
10	6,607	0.0048	0.0056	0.0016	0.0002	0.0003	0.0183	0.0036	0.0000	0.0201	0.0212	28.0	0.42	26.5	0.40	0	3.8
20	13,213	0.0074	0.0099	0.0019	0.0002	0.0006	0.0356	0.0127	0.0000	0.0399	0.0421	55.7	0.42	52.7	0.40	0	7.6
30	19,820	0.0107	0.0145	0.0011	0.0002	0.0010	0.0492	0.0188	0.0000	0.0557	0.0594	78.4	0.40	73.6	0.37	0	11.4
40	26,427	0.0135	0.0051	0.0013	0.0002	0.0013	0.0120	0.0255	0.0000	0.0317	0.0419	55.3	0.21	41.9	0.16	0	15.3
50	33,033	0.0153	0.0038	0.0009	0.0002	0.0016	0.0031	0.0295	0.0000	0.0337	0.0480	63.4	0.19	44.5	0.13	0	19.1
60	39,640	0.0179	0.0034	0.0010	0.0002	0.0019	0.0258	0.0292	0.0000	0.0430	0.0594	78.5	0.20	56.8	0.14	0	22.9
80	52,853	0.0244	0.0044	0.0005	0.0002	0.0026	0.0784	0.0124	0.0000	0.0832	0.0995	131.5	0.25	109.9	0.21	0	30.5
100	66,066	0.0521	0.0050	0.0004	0.0002	0.0032	0.1439	0.0000	0.0000	0.1532	0.1677	221.6	0.34	202.4	0.31	0	38.1

The class of the penetrometer is determined from the measurement uncertainty at any deflection

At each given deflection the expanded measurement uncertainty Uqc_class is calculated from the readings obtained during calibration.

$$Uqc_{class} = \frac{2}{S} \times \sqrt{\sum_{i=1}^8 u_i^2}$$

where,

u1 is the standard uncertainty associated with the applied calibration force.

u2 is the standard uncertainty associated with the reproducibility of the calibration results.

u3 is the standard uncertainty associated with the repeatability of the calibration results.

u4 is the standard uncertainty associated with the resolution and noise of the system.

u5 is the standard uncertainty associated with the drift in zero output.

u6 is the standard uncertainty associated with interpolation.

u7 is the standard uncertainty associated with reversibility.

u8 is the standard uncertainty associated with apparent load transfer from other sensor.

* u1 is not a requirement for BS EN ISO 22476-1:2023 class uncertainty Uqc_class. We have included u1 for clarity and confidence in the result.

** If the classification is altered with the inclusion u1, then the lower classification will be given alongside a # symbol as identification.

*** udrift is the standard uncertainty associated with the drift in sensitivity between calibrations. This is an uncertainty associated with subsequent use and not a calibration uncertainty.

Sleeve Friction Calibration

Calibration method

1. The sleeve was loaded to full range 3 times for no less than 1 minute before calibration.
2. The sleeve was calibrated with 4 sets of increasing forces and 2 sets of decreasing forces, with rotation before set 3 and 5.
3. The coefficients of a linear and third order equation relating the estimate of applied force as a function of the deflection were calculated and are shown in Table 4.
4. The forces applied, and the resulting deflections are given in Tables 5. No corrections for temperature have been applied to these results.
5. The combined expanded uncertainty* of deflection U_{fs} and U_{fs_class} for each force is shown as a percentage of the recorded value and in units of pressure (kPa) as shown in Table 6.

*The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2$, providing a level of confidence of approximately 95%.

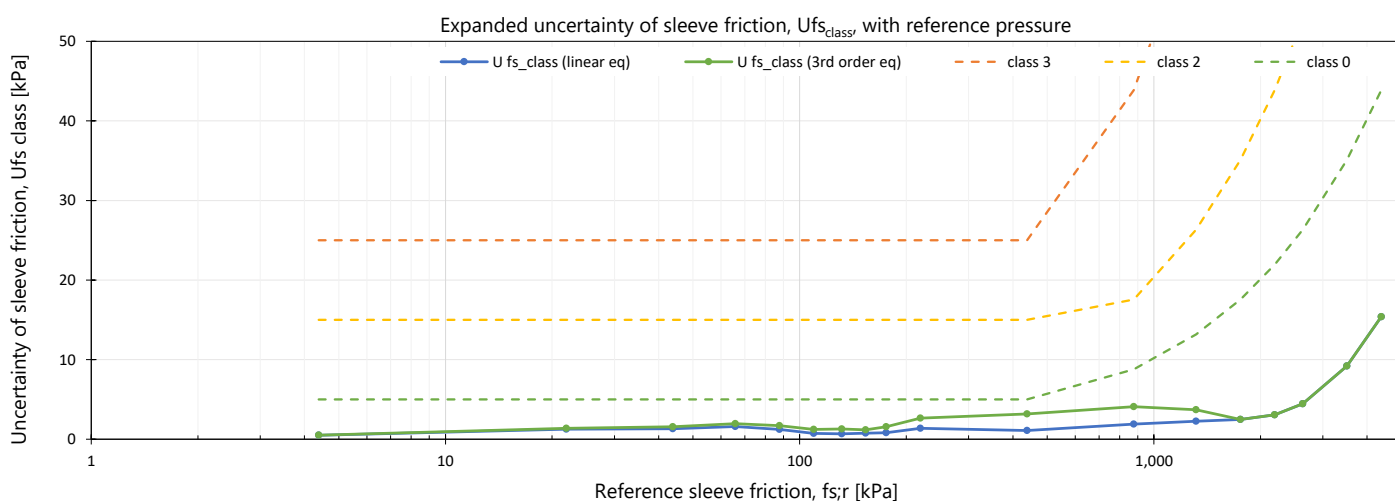
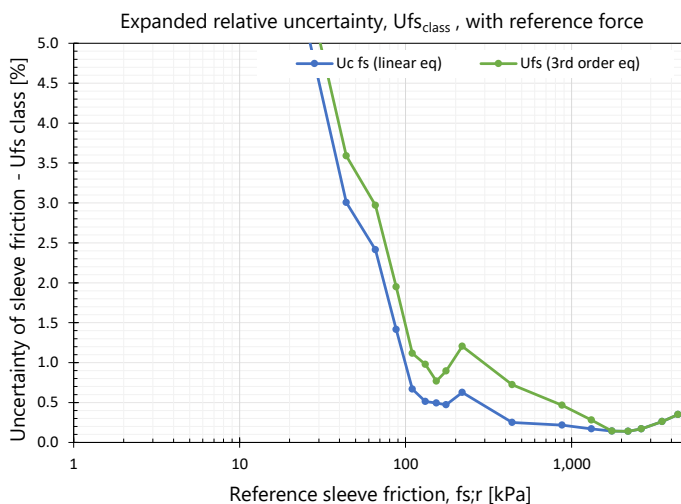
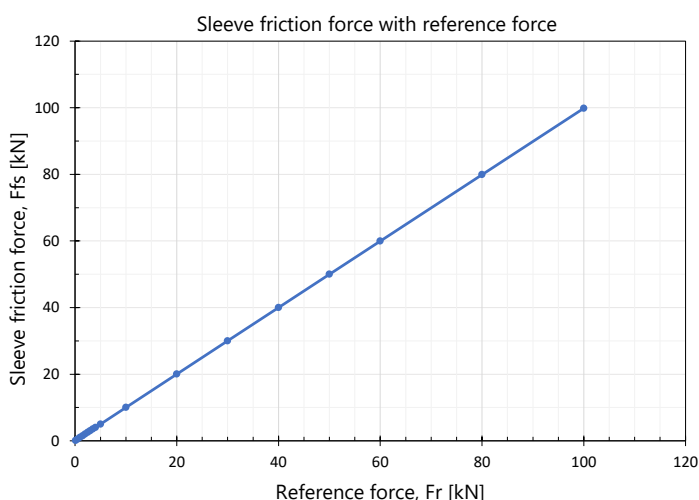
Cone Penetrometer	
Cone penetrometer type	Subtraction
Sleeve friction capacity	150 kN
Calibration range	100 kN
Sleeve friction effective resolution	0.005 kN
Sleeve area	22,797 mm ²
Measured beta factor sleeve area ratio	-0.002
Historic drift between sleeve calibrations (U_{drift})	0.01327 %
Apparent pore pressure (u_a) at full range	0.02 kPa
Sleeve friction max zero drift	0.40 kPa
Reference load cell max zero drift	0.23 kPa

Calibration Conditions	
Ambient temperature	23.5 °C
Ambient temperature variation	0.34 °C
Instrument temperature variation	0.00 °C

Reference Load Cell Uncertainty	
AM DSCCHA-100 kN	0.02 ±%
AM DSCCHA-5 kN	0.05 ±%

Reference Indicator Uncertainty	
Keithley 7.5 Digit DMM	12 PPM

Sleeve Friction Calibration - Graphical Results



Interpolation

Linear Equation	The sleeve output in force units D (0.1 N) is derived using a linear factor from the raw sleeve output. $D = \text{Factor} \times \text{RAW_Output}$	0.1 N Factor = 0.008699
Polynomial Equation	3rd order polynomial equation. For a given cone indicated output of D (0.1 N units), the corrected applied force, F (in 0.1 N units) is calculated from :	$a_0 = 0$ $a_1 = 0.997998047$ $a_2 = 4.74736E-09$ $a_3 = -1.04999E-15$ Polynomial calc. is only to be used when the sleeve load is under 30 kN

Sleeve Friction Calibration - Tabular Results

Table - 6a Low range calibration results

	0°	0°	120°	120°	240°	240°
kN	kN	kN	kN	kN	kN	kN
Fr	X1	X2	X3	X4'	X5	X6'
0	0.0092	0.0072	0.0064		0.0014	
0.1	0.1012	0.1091	0.1015		0.0998	
0.5	0.4966	0.5019	0.4938		0.4920	
1	0.9951	1.0003	0.9928		0.9906	
1.5	1.4886	1.4962	1.4867		1.4848	
2	1.9895	1.9998	1.9899		1.9868	
2.5	2.4959	2.5029	2.4931		2.4908	
3	2.9939	3.0025	2.9932		2.9920	
3.5	3.4961	3.5066	3.4964		3.4926	
4	3.9956	4.0061	3.9921		3.9896	
5	4.9869	4.9955	4.9833		4.9803	
4				3.9964		3.9896
3.5				3.4985		3.4914
3				2.9993		2.9906
2.5				2.5039		2.4958
2				2.0032		1.9964
1.5				1.5060		1.4977
1				1.0083		1.0031
0.5				0.5146		0.5020
0.1				0.1050		0.0992

Table - 6b High range calibration results

	0°	0°	120°	120°	240°	240°
kN	kN	kN	kN	kN	kN	kN
Fr	X1	X2	X3	X4'	X5	X6'
10	9.9889	9.9961	9.9871		9.9833	
20	19.9914	20.0051	19.9939		19.9921	
30	30.0186	30.0229	30.0182		30.0104	
40	40.0107	40.0122	40.0033		39.9928	
50	49.9947	50.0002	49.9856		49.9746	
60	59.9703	59.9768	59.9601		59.9507	
80	79.9146	79.9150	79.8988		79.8890	
100	99.8503	99.8506	99.8323		99.8211	
80				79.9007		79.8885
60				59.9960		59.9843
50				50.0259		50.0149
40				40.0404		40.0309
30				30.0452		30.0391
20				20.0159		20.0101
10				10.0021		9.9955

Table - 6 Uncertainty assessment

Reference force	Reference sleeve friction	Standard uncertainty u1 - u8								Combined standard calibration uncertainty		Expanded calibration uncertainty [k=2]				BS EN ISO 22476:2023 Class	Sleeve calibration drift
kN	kPa	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN	kPa	%	kPa	%	Cone Class **	kPa
Fr	fs;r	u1*	u2	u3	u4	u5	u6	u7	u8	uc	uc;dim	Ucfs		Ufsclass			Udrift ***
0	0	0.0000	0.0023	0.0000	0.0020	0.0000	0.0000	0.0000	0.0000	0.0031	0.0031	0.27		0.27		0	0.00
0.1	4	0.0007	0.0005	0.0043	0.0020	0.0000	0.0008	0.0012	-0.0027	0.0058	0.0058	0.51	11.55	0.51	11.55	0	0.00
0.5	22	0.0011	0.0014	0.0030	0.0020	0.0000	0.0059	0.0090	-0.0108	0.0158	0.0158	1.38	6.31	1.38	6.31	0	0.00
1	44	0.0012	0.0013	0.0030	0.0020	0.0001	0.0072	0.0081	-0.0137	0.0180	0.0180	1.58	3.60	1.58	3.60	0	0.01
1.5	66	0.0048	0.0011	0.0044	0.0020	0.0001	0.0134	0.0094	-0.0135	0.0223	0.0223	1.96	2.98	1.95	2.98	0	0.01
2	88	0.0041	0.0010	0.0059	0.0020	0.0002	0.0113	0.0067	-0.0122	0.0195	0.0196	1.72	1.96	1.71	1.96	0	0.01
2.5	110	0.0041	0.0015	0.0041	0.0020	0.0002	0.0068	0.0046	-0.0094	0.0139	0.0141	1.24	1.13	1.22	1.13	0	0.01
3	132	0.0044	0.0005	0.0050	0.0020	0.0003	0.0070	0.0022	-0.0106	0.0147	0.0149	1.31	0.99	1.29	0.99	0	0.02
3.5	154	0.0053	0.0012	0.0061	0.0020	0.0003	0.0050	0.0010	-0.0092	0.0135	0.0138	1.21	0.79	1.18	0.79	0	0.02
4	175	0.0061	0.0017	0.0061	0.0020	0.0004	0.0076	0.0013	-0.0134	0.0179	0.0182	1.60	0.91	1.57	0.91	0	0.02
5	219	0.0020	0.0019	0.0050	0.0020	0.0005	0.0165	0.0078	-0.0232	0.0301	0.0305	2.67	1.22	2.64	1.22	0	0.03
10	439	0.0048	0.0017	0.0042	0.0020	0.0009	0.0136	0.0078	-0.0319	0.0362	0.0372	3.27	0.74	3.17	0.74	0	0.06
20	877	0.0074	0.0008	0.0079	0.0020	0.0018	0.0075	0.0115	-0.0432	0.0467	0.0500	4.39	0.50	4.10	0.50	0	0.12
30	1,316	0.0107	0.0027	0.0025	0.0020	0.0028	0.0157	0.0161	-0.0336	0.0421	0.0498	4.37	0.33	3.69	0.33	0	0.17
40	1,755	0.0135	0.0052	0.0009	0.0020	0.0037	0.0023	0.0217	-0.0098	0.0282	0.0454	3.99	0.23	2.48	0.23	0	0.23
50	2,193	0.0153	0.0058	0.0031	0.0020	0.0046	0.0150	0.0233	-0.0119	0.0348	0.0565	4.95	0.23	3.05	0.23	0	0.29
60	2,632	0.0179	0.0057	0.0038	0.0020	0.0055	0.0397	0.0201	-0.0139	0.0507	0.0736	6.46	0.25	4.45	0.25	0	0.35
80	3,509	0.0244	0.0075	0.0002	0.0020	0.0074	0.0993	0.0007	-0.0209	0.1049	0.1268	11.12	0.32	9.21	0.32	0	0.47
100	4,386	0.0521	0.0085	0.0002	0.0020	0.0092	0.1657	0.0000	-0.0217	0.1755	0.1968	17.26	0.39	15.40	0.39	0	0.58

The class of the penetrometer is determined from the measurement uncertainty at any deflection.

At each given deflection the expanded measurement uncertainty U_{fs_class} is calculated from the readings obtained during calibration.

$$U_{fs_class} = \frac{2}{S} \times \sqrt{\sum_{i=1}^8 u_i^2}$$

where,

u_1 is the standard uncertainty associated with the applied calibration force.

u_2 is the standard uncertainty associated with the reproducibility of the calibration results.

u_3 is the standard uncertainty associated with the repeatability of the calibration results.

u_4 is the standard uncertainty associated with the resolution and noise of the system.

u_5 is the standard uncertainty associated with the drift in zero output.

u_6 is the standard uncertainty associated with interpolation.

u_7 is the standard uncertainty associated with reversibility.

u_8 is the standard uncertainty associated with apparent load transfer from other sensor. Includes subtraction error where: $F_{r;qC} = F_{r;fs}$.

* u_1 is not a requirement for BS EN ISO 22476-1:2023 class uncertainty U_{fs_class} . We have included u_1 for clarity and confidence in the result.

** If the classification is altered with the inclusion u_1 , then the lower classification will be given alongside a # symbol as identification.

*** u_{drift} is the standard uncertainty associated with the drift in sensitivity between calibrations. This is an uncertainty associated with subsequent use and not a calibration uncertainty.

Sleeve Friction Calibration - Subtraction Error

In use, the forces acting on the sleeve load cell element are a combination of tip resistance and sleeve friction, with the tip resistance force value from the tip load cell element being subtracted to give the sleeve friction value. The resultant error values for differing tip and sleeve values are shown in Table 7.

The highlighted cell results in Table 7, show a direct reading of the subtraction error from the calibration results.

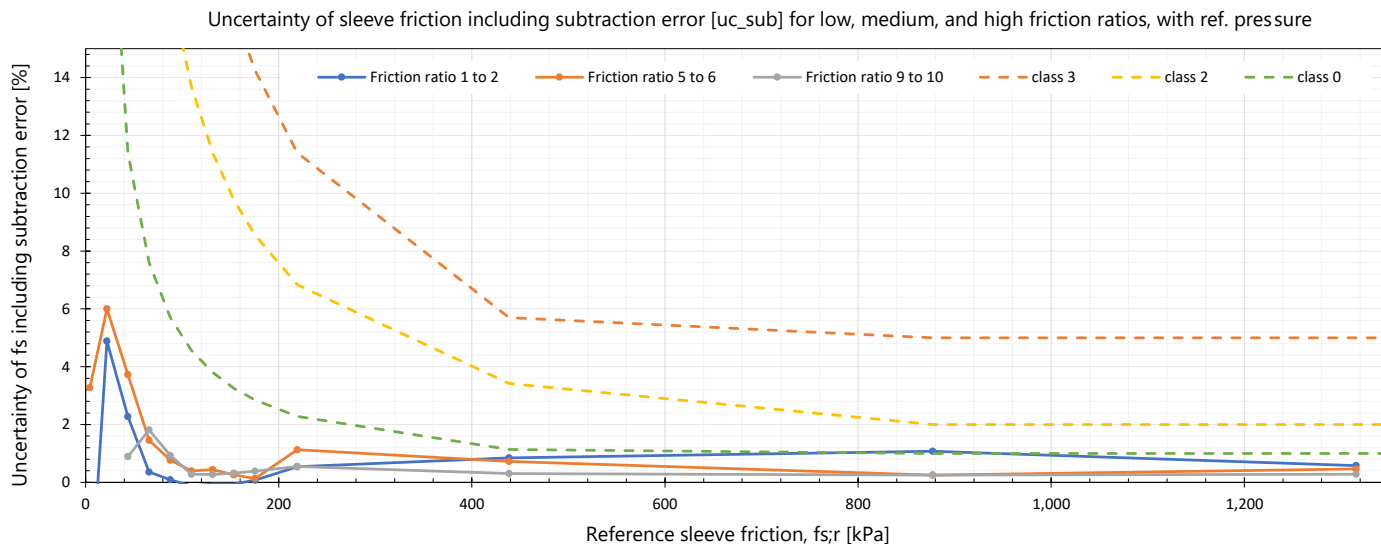
The non-highlighted cells in Table 7, show an interpolated subtraction error from the calibration results.

Sleeve friction - tip subtraction combined standard uncertainty uc_{sub} , where friction ratio is between 0.1% and 10%.

Table - 7

		Sleeve friction combined standard uncertainty including subtraction error (%)												
		Sleeve friction kPa →												
		4	22	44	66	88	110	132	154	175	219	439	877	1,316
Tip resistance kPa ↓	66	3.28	-	-	-	-	-	-	-	-	-	-	-	-
	330	-4.28	6.00	-	-	-	-	-	-	-	-	-	-	-
	661	-6.62	8.42	3.73	1.81	-	-	-	-	-	-	-	-	-
	991	-5.80	6.19	2.09	1.46	0.93	-	-	-	-	-	-	-	-
	1,321	-3.99	4.33	2.26	1.30	1.32	0.28	0.28	-	-	-	-	-	-
	1,652	-0.53	4.86	2.11	1.17	0.77	0.42	0.39	0.32	-	-	-	-	-
	1,982	-1.17	4.41	2.91	1.13	2.51	0.39	0.37	0.30	0.39	-	-	-	-
	2,312	0.85	5.93	1.41	1.27	0.84	0.47	0.44	0.36	0.44	0.62	-	-	-
	2,643	-2.73	1.55	5.24	1.03	0.66	0.33	0.32	0.26	0.35	0.55	-	-	-
	3,303	-11.39	-0.19	0.19	0.45	0.23	-0.02	0.03	0.01	0.13	1.13	-	-	-
	6,607	-	-0.74	-0.09	0.27	0.09	-0.13	-0.06	-0.07	0.06	0.32	0.73	-	-
	13,213	-	-0.64	-0.04	0.30	0.11	-0.11	-0.05	-0.06	0.08	0.33	0.62	0.22	0.29
	19,820	-	3.65	2.10	1.73	1.19	0.75	0.67	0.56	0.61	0.76	0.75	0.31	0.47
	26,427	-	-	5.66	4.10	2.97	2.18	1.86	1.57	1.50	1.47	0.62	0.50	0.38
	33,033	-	-	6.63	4.75	3.45	2.56	2.18	1.85	1.75	1.66	0.87	0.59	0.67
	39,640	-	-	7.61	5.40	3.94	2.96	2.51	2.13	1.99	1.86	1.05	0.89	0.45
52,853	-	-	-	6.51	4.77	3.62	3.06	2.61	2.41	2.19	1.22	1.31	0.50	
66,066	-	-	-	-	5.91	4.53	3.82	3.26	2.98	2.65	1.44	0.83	0.58	
		Friction ratio (for a given row) →												

Friction ratio (for a given column) ↑



Pore Pressure Calibration

Calibration method

1. The cone penetrometer was placed in a pressure vessel and was pressurised to full range 3 times for no less than 1 minute before calibration.
2. The pore pressure was calibrated with 2 sets of increasing pressures and 2 sets of decreasing pressures.
3. The coefficients of a linear and third order equation relating the estimate of applied pressure as a function of deflection were calculated and are shown in Table 8.
4. The pressures applied, and the resulting deflections are given in Tables 9. No corrections for temperature have been applied to these results.
5. The combined expanded uncertainty* of deflection U_u and U_{u_class} for each force is shown as a percentage of the recorded value and in units of pressure kPa as shown in Table 10.

* The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2$, providing a level of confidence of approximately 95%.

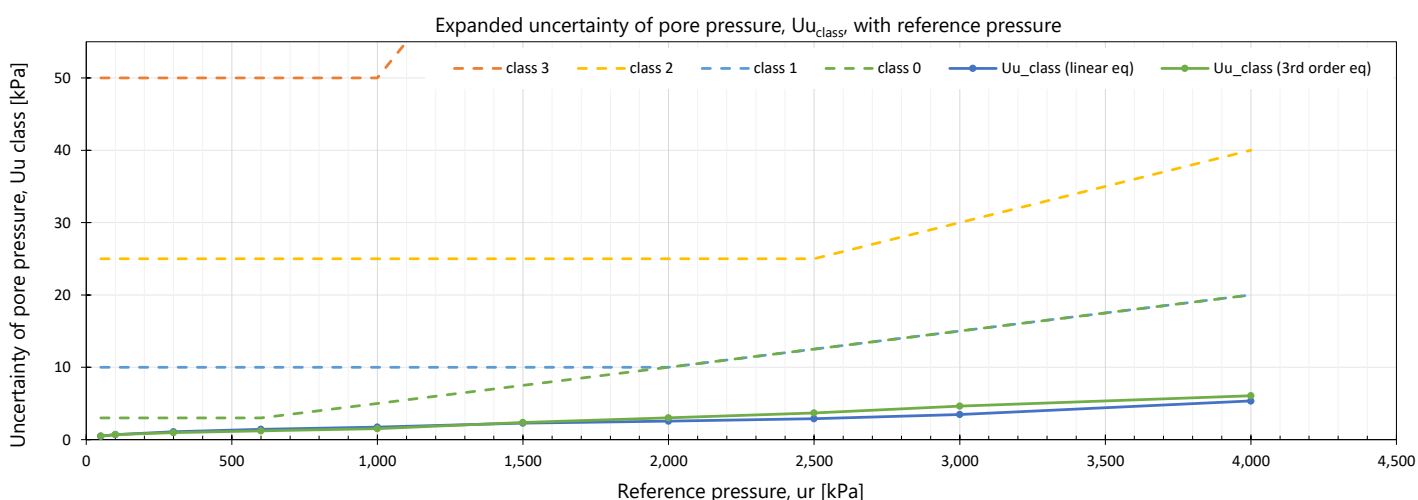
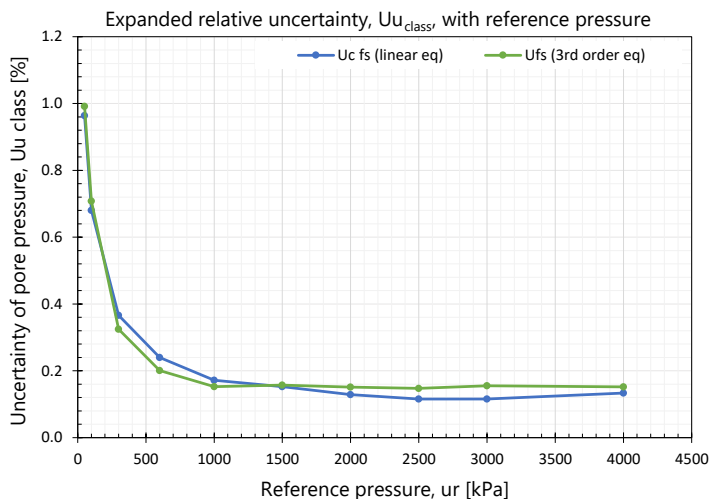
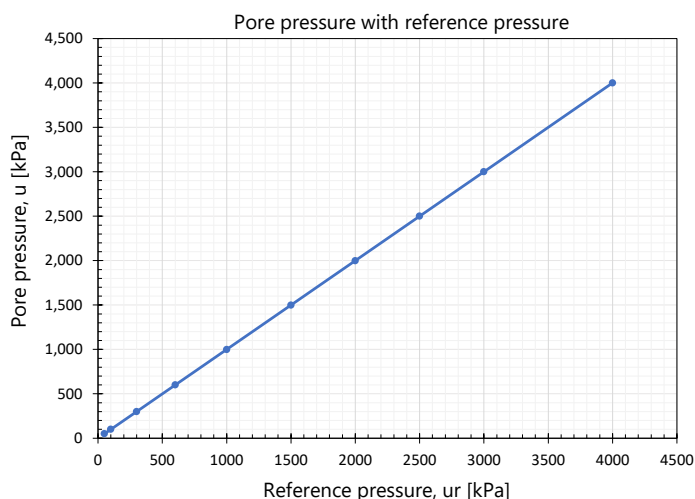
Cone Penetrometer	
Pore pressure sensor capacity	5 MPa
Calibration range	4 MPa
Pore pressure resolution	0.005 kPa
Historic drift between pore calibrations (u_{drift})	0.05774 %
Pore pressure sensor max zero drift	0.12 kPa
Reference pressure sensor max zero drift	0.11 kPa

Calibration Conditions	
Ambient temperature	23.7 °C
Pressure chamber temperature variation	0.18 °C
Instrument temperature variation	0.00 °C

Reference Pressure Sensor Uncertainty	
MMG750V1P1MC0T3A6CE	0.02 ±%

Reference Indicator Uncertainty	
Keithley 7.5 Digit DMM	12 PPM

Pore Pressure Calibration - Graphical Results



Interpolation

Table - 8		
Linear Equation	The pore pressure output in pressure units D (0.1 Pa) is derived using a linear factor from the raw pore pressure output. $D = \text{Factor} \times \text{RAW_Output}$	0.1 Pa Factor = 0.050793
Polynomial Equation	3rd order polynomial equation. For a given cone indicated output of D (0.1 Pa units), the corrected applied pressure, P (in 0.1 Pa units) is calculated from : $P = (a3 \times D^3) + (a2 \times D^2) + (a1 \times D) + a0$	$a0 = -1188.654135$ $a1 = 1.000864436$ $a2 = -6.24149E-11$ $a3 = 5.10479E-19$

Pore Pressure Calibration - Tabular Results

Table - 9 Calibration results

kPa ur	kPa X1	kPa X2'	kPa X3	kPa X4'
0	0.12		0.04	
50	49.84		50.04	
100	99.65		100.06	
300	299.72		299.61	
600	599.80		599.55	
1000	999.71		999.56	
1500	1499.36		1499.15	
2000	1999.41		1998.77	
2500	2499.17		2498.53	
3000	2998.89		2997.99	
4000	3998.71		3997.30	
3000		2999.06		2997.98
2500		2499.19		2498.40
2000		1999.09		1998.70
1500		1499.33		1498.85
1000		999.51		999.30
600		599.71		600.04
300		300.00		299.93
100		99.94		100.06
50		50.11		49.92

Table - 10 Uncertainty assessment

Reference pressure ur	Standard uncertainty u1 to u6						Combined standard calibration uncertainty		Expanded calibration uncertainty [k=2]				BS EN ISO 22476:2023 class	Pore calibration drift
	kPa u1*	kPa u2	kPa u3	kPa u4	kPa u5	kPa u6	kPa u _i	%	kPa U _u	%	kPa U _u class	%		
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00		0.00		0	0.00
50	0.18	0.11	0.00	0.00	0.06	0.11	0.25	0.50	0.50	0.99	0.50	0.99	0	0.03
100	0.21	0.24	0.00	0.00	0.14	0.08	0.35	0.35	0.71	0.71	0.71	0.71	0	0.06
300	0.31	0.06	0.00	0.01	0.33	0.17	0.49	0.16	0.97	0.32	0.97	0.32	0	0.17
600	0.45	0.15	0.00	0.02	0.33	0.17	0.60	0.10	1.20	0.20	1.20	0.20	0	0.35
1000	0.65	0.08	0.00	0.03	0.37	0.13	0.76	0.08	1.53	0.15	1.53	0.15	0	0.58
1500	0.90	0.12	0.00	0.05	0.75	0.09	1.18	0.08	2.36	0.16	2.36	0.16	0	0.87
2000	1.15	0.37	0.00	0.06	0.91	0.11	1.51	0.08	3.03	0.15	3.03	0.15	0	1.15
2500	1.39	0.37	0.00	0.08	1.15	0.05	1.84	0.07	3.69	0.15	3.69	0.15	0	1.44
3000	1.64	0.52	0.00	0.09	1.56	0.05	2.32	0.08	4.65	0.15	4.65	0.15	0	1.73
4000	2.13	0.81	0.00	0.12	1.99	0.00	3.03	0.08	6.07	0.15	6.07	0.15	0	2.31

The class of the penetrometer is determined from the measurement uncertainty at any deflection

At each given deflection the expanded measurement uncertainty U_{u_class} is calculated from the readings obtained during calibration.

$$U_{u_class} = 2 \times \sqrt{\sum_{i=1}^6 u_i^2}$$

where,

u_1 is the standard uncertainty associated with the applied calibration pressure.

u_2 is the standard uncertainty associated with the repeatability of the calibration results.

u_3 is the standard uncertainty associated with the resolution and noise of the system.

u_4 is the standard uncertainty associated with the drift in zero output.

u_5 is the standard uncertainty associated with interpolation.

u_6 is the standard uncertainty associated with reversibility.

* u_1 is not a requirement for BS EN ISO 22476-1:2023 class uncertainty U_{u_class} . We have included u_1 for clarity and confidence in the result.

** If the classification is altered with the inclusion u_1 , then the lower classification will be given alongside a # symbol as identification.

*** u_{drift} is the standard uncertainty associated with the drift in sensitivity between calibrations. This is an uncertainty associated with subsequent use and not a calibration uncertainty.

Pore Pressure Calibration - Measured Area Ratios

Calibration method

1. The apparent cone resistance $q_{c;a}$ and apparent sleeve friction $f_{s;a}$ are recorded for all pore pressure calibration intervals, and shown in Table 11a and 11b.
2. The resulting net area ratios of the cone a and net area ratios of the sleeve b are computed and shown in Table 11a and 11b.
3. The final recorded cone net area ratio a and sleeve net area ratio b are shown in Table 12, where reference pressure $u_r = 2000\text{kPa}$

Table - 11a Cone net area ratio assessment

kPa u_r	Apparent cone resistance [$q_{c;a}$]					Alpha factor
	kPa X1	kPa X2'	kPa X3	kPa X4'	kPa Mean	
50	41.8		41.7		41.8	0.84
100	82.6		82.6		82.6	0.83
300	245.5		244.1		244.8	0.82
600	479.7		479.8		479.8	0.80
1000	794.3		794.2		794.2	0.79
1500	1191.2		1191.8		1191.5	0.79
2000	1589.9		1590.1		1590.0	0.79
2500	1988.8		1990.2		1989.5	0.80
3000	2387.5		2388.2		2387.8	0.80
4000	3186.8		3188.0		3187.4	0.80
3000		2392.0		2392.8	2392.4	0.80
2500		1995.78		1996.34	1996.1	0.80
2000		1598.31		1598.82	1598.6	0.80
1500		1200.77		1201.18	1201.0	0.80
1000		801.723		802.07	801.9	0.80
600		482.347		482.275	482.3	0.80
300		242.163		242.441	242.3	0.81
100		81.1913		81.5995	81.4	0.81
50		40.976		41.649	41.3	0.83

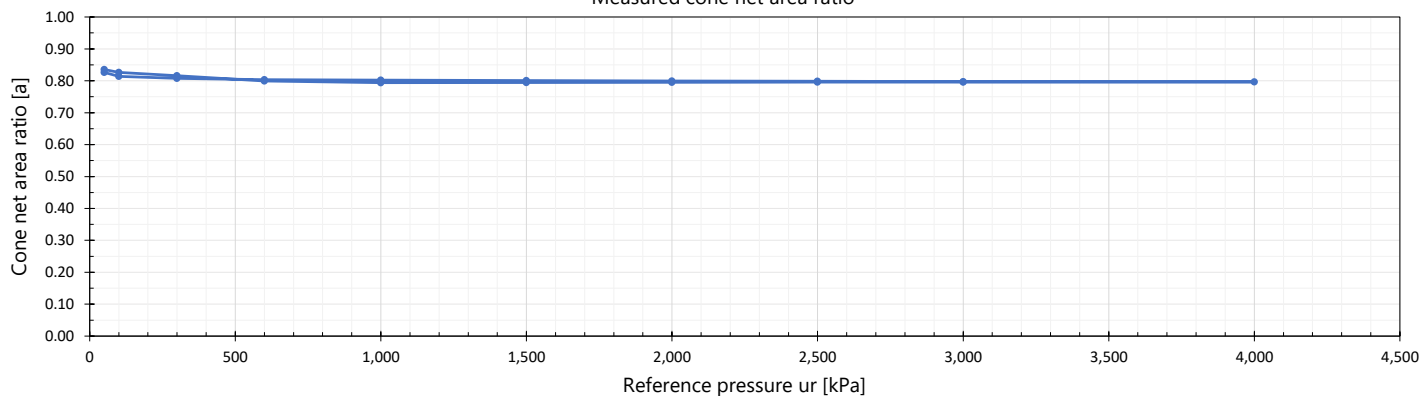
Table - 11b Sleeve friction net area ratio assessment

kPa u_r	Apparent sleeve friction [$f_{s;a}$]					Beta factor
	kPa X1	kPa X2'	kPa X3	kPa X4'	kPa Mean	
50	-0.54		-0.53		-0.54	-0.011
100	-0.98		-1.00		-0.99	-0.010
300	-2.16		-2.32		-2.24	-0.007
600	-2.71		-2.97		-2.84	-0.005
1000	-3.44		-3.57		-3.50	-0.004
1500	-4.14		-4.39		-4.26	-0.003
2000	-4.83		-5.13		-4.98	-0.002
2500	-5.77		-6.10		-5.94	-0.002
3000	-7.26		-7.35		-7.31	-0.002
4000	-9.28		-9.55		-9.41	-0.002
3000		-6.97		-7.08	-7.03	-0.002
2500		-6.07		-6.32	-6.20	-0.002
2000		-5.35		-5.45	-5.40	-0.003
1500		-3.92		-3.97	-3.94	-0.003
1000		-2.50		-2.52	-2.51	-0.003
600		-1.43		-1.44	-1.43	-0.002
300		-0.79		-0.83	-0.81	-0.003
100		-0.29		-0.38	-0.34	-0.003
50		-0.14		-0.23	-0.19	-0.004

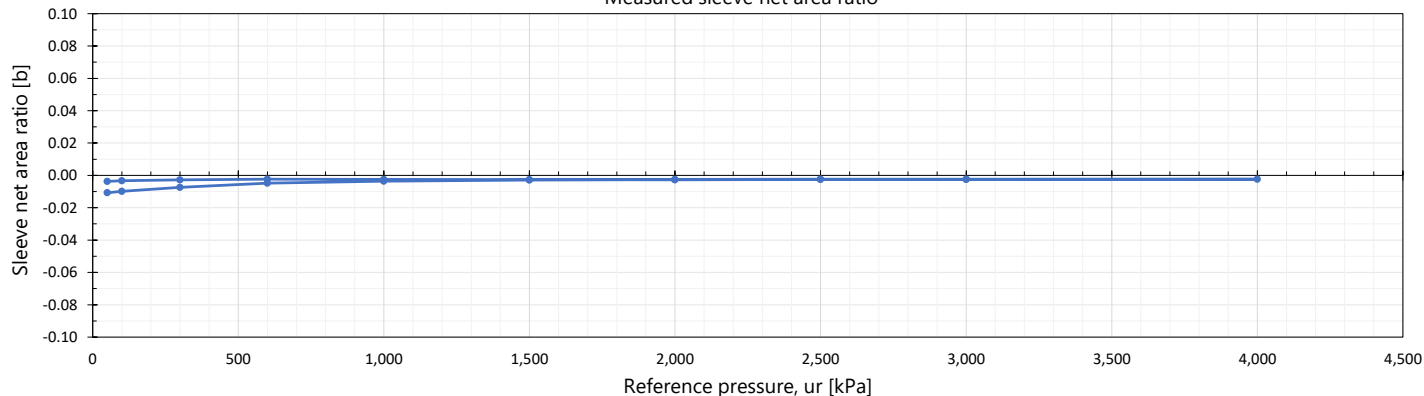
Table - 12

Cone net area ratio [a]	0.79
Sleeve friction net area ratio [b]	-0.002

Measured cone net area ratio



Measured sleeve net area ratio



Inclination Calibration

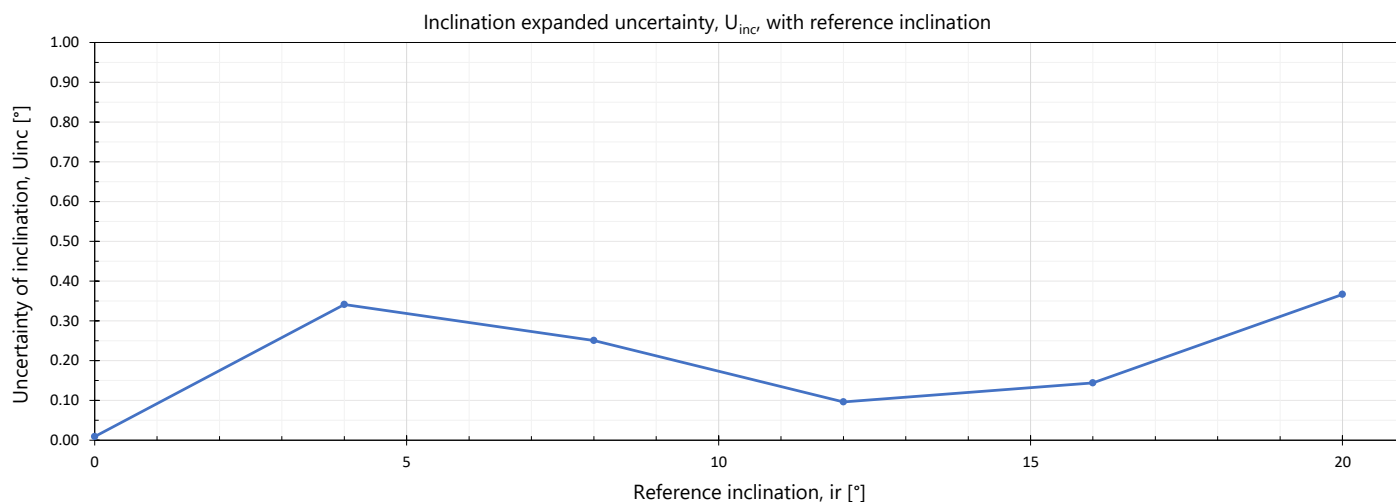
Calibration method

1. The cone penetrometer was placed in the inclination calibration frame and set to a vertical reference inclination of $i_r = 0^\circ$.
2. The inclination was calibrated from $i_r = 0^\circ$ to $i_r = 20^\circ$. This was conducted twice, once with the cone at 0° rotation and once with the cone at 90° rotation.
3. The coefficients of a linear equation relating the estimate of the inclination as a function of raw sensor deflection were calculated and are shown in Table 13.
4. The inclination angle applied, and the resulting measurements are given in Table 14.
5. The combined expanded uncertainty* of measurement U_{inc} for each inclination angle is shown as a percentage of the recorded value and in units of arc degrees $^\circ$, as shown in Table 15.

* The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2$, providing a level of confidence of approximately 95%.

Cone Penetrometer		Reference Inclination Rotary Table Uncertainty	
Inclination sensor range	90 $^\circ$	Lankelma HV6 Rotary Table	0.10 $^\circ$
Calibration range	20 $^\circ$		
Inclination resolution	0.005 $^\circ$		
Inclinometer number of axis	2		

Inclination - Graphical Results



Interpolation

Table - 13

Linear Equation	The Inclination output in angular units ($0.1^\circ \times 10^{-3}$) is derived using a linear factor from the raw inclination output.	X axis Factor =	9.828961
		Y axis Factor =	10.062654

Inclination Calibration - Tabular Results

Table - 14

Inclination calibration		
i_r	θ_0	θ_{90}
0	0.00	0.00
4	3.82	3.86
8	7.88	7.88
12	12.07	11.99
16	15.88	16.01
20	20.17	20.20

Table - 15 Uncertainty assessment

Reference Inclination	Standard calibration uncertainty u_1 to u_4				Combined standard calibration uncertainty u_i		Expanded calibration uncertainty U_{inc} [$k=2$]	
	i_r	u_1	u_2	u_3	u_4	u_i	U_{inc}	%
0	0	0.00	0.00	0.00	0.00	0.00	0.01	
4	4	0.01	0.01	0.00	-0.17	0.17	0.34	8.52
8	8	0.02	0.00	0.00	-0.12	0.13	0.25	3.14
12	12	0.02	0.03	0.00	0.03	0.05	0.10	0.80
16	16	0.02	0.04	0.00	-0.05	0.07	0.14	0.90
20	20	0.02	0.01	0.00	0.18	0.18	0.37	1.83

At each given deflection the expanded measurement uncertainty U_{inc} is calculated from the readings obtained during calibration.

$$U_{inc} = 2 \times \sqrt{\sum_{i=1}^4 u_i^2}$$

where,

u_1 is the standard uncertainty associated with the applied calibration inclination.

u_2 is the standard uncertainty associated with the reproducibility of the calibration results.

u_3 is the standard uncertainty associated with the resolution and noise of the system.

u_4 is the standard uncertainty associated with interpolation.

Temperature Calibration
Calibration method

1. The cone penetrometer was placed in the thermostatic temperature calibration bath with the temperature set to 0°C.
2. The temperature was calibrated from Tr = 0°C to Tr = 30°C.
3. The coefficients of a linear equation relating the estimate of temperature as a function of raw temperature sensor deflection were calculated and are shown in Table 16.
4. The applied temperature, and the resulting measurements are given in Table 17.
5. The combined expanded uncertainty* of measurement Utemp for each temperature is shown as a percentage of the recorded value and in units of Celsius °C, as shown in Table 18.

* The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.

Cone Penetrometer		Reference Thermometer Uncertainty	
Temperature sensor range	90 °	ETI Ref Thermometer	0.04 °
Calibration range	30 °		
Temperature resolution	0.005 °	Temperature Datalogger Uncertainty	
Temperature number of axis	1	ETI ThermoData	0.4 °

Temperature Calibration - Graphical Results

Expanded uncertainty of temperature, Utemp [°C], with reference temperature

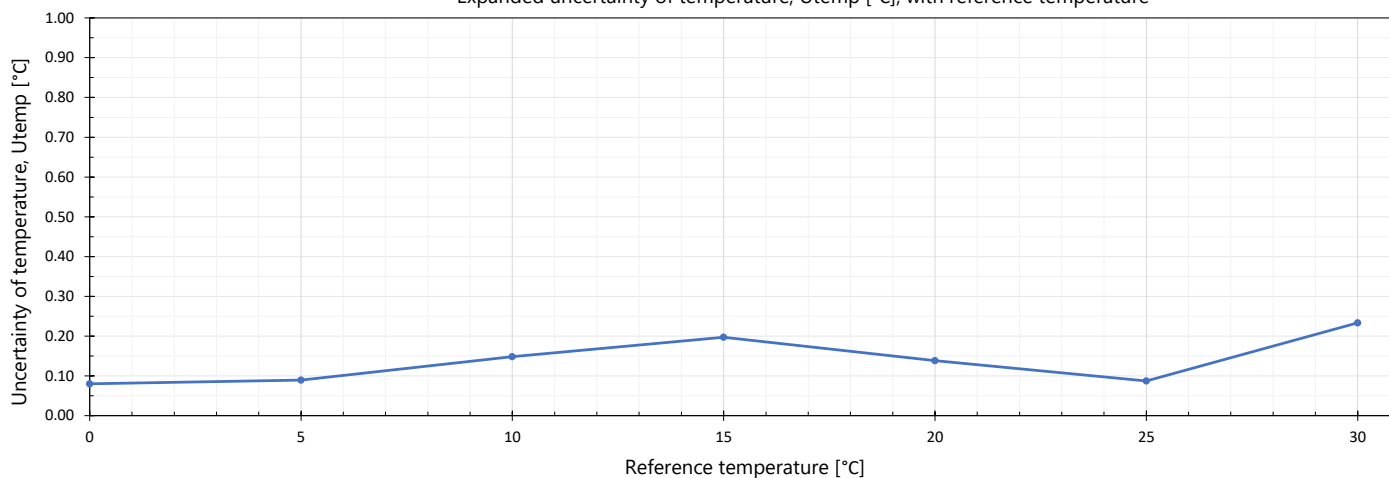

Interpolation

Table - 16

Linear Equation	The temperature sensor output in temperature units ($0.1^{\circ}\text{C} \times 10^{-3}$) is derived using a linear factor from the raw temperature output.	Temperature sensor factor =	0.000784
		-	0.000784

Temperature Calibration - Tabular Results

Table - 17
Temperature calibration

°C	°C
Tr	Ta
0	0.00
5	5.02
10	9.94
15	14.91
20	19.94
25	24.98
30	30.11

Table - 18 **Uncertainty assessment**

Reference temp	Standard calibration uncertainty u1 to u3			Combined standard calibration uncertainty ut		Expanded calibration uncertainty Utemp [k=2]	
	°C	°C	°C	°C	%	°C	%
Tr	u1	u2	u3	ut		Utemp	
0	0.04	0.00	0.00	0.04		0.08	
5	0.04	0.00	0.02	0.04	0.89	0.09	1.79
10	0.04	0.00	-0.06	0.07	0.74	0.15	1.49
15	0.04	0.00	-0.09	0.10	0.66	0.20	1.31
20	0.04	0.00	-0.06	0.07	0.35	0.14	0.69
25	0.04	0.00	-0.02	0.04	0.17	0.09	0.35
30	0.04	0.00	0.11	0.12	0.39	0.23	0.78

At each given deflection the expanded measurement uncertainty Utemp is calculated from the readings obtained during calibration.

$$U_{temp} = 2 \times \sqrt{\sum_{i=1}^3 u_i^2}$$

where,

u1 is the standard uncertainty associated with the applied calibration temperature.

u2 is the standard uncertainty associated with the resolution and noise of the system.

u3 is the standard uncertainty associated with interpolation.

Temperature Influence Verification
Verification method

1. The cone penetrometer was placed in the thermostatic temperature calibration bath with the temperature set to 30 °C, the second bath temperature was set to 0 °C.
2. The test method for verification of a cone penetrometer for temperature influence was followed as set out in BS EN ISO 224 76-1:2023, clause B.2.7.2.
3. The bath temperatures, apparent cone resistance, apparent sleeve friction, apparent pore pressure, and apparent cone temperature were recorded for the duration of the test.
4. The correction factors for q_c , corrected apparent cone resistance, corrected sleeve friction, and corrected pore pressure were applied in post processing.
5. The start and end apparent readings are shown in Table 19. The maximum and minimum apparent readings are shown in Table 20.
6. The ambient stability, transient stability, and resulting penetrometer class were calculated and are shown in Table 21.

Table - 19 Start and end apparent readings

	°C	°C	kPa	kPa	kPa	kPa	kPa	kPa
	Ta _{qc}	Ta _{fs}	q _c ;a	q _c ;ac	fs;a	fs;ac	u;a	u;ac
T30	30.1	30.1	-0.5	-0.6	0.0	0.0	0.0	0.0
T0	0.2	0.2	-72.4	0.4	-0.7	2.4	5.6	-0.6

Table - 20 Maximum / minimum apparent readings

	kPa	kPa	kPa	kPa	kPa	kPa
	q _c ;a	q _c ;ac	fs;a	fs;ac	u;a	u;ac
max	361.2	81.5	7.2	7.6	7.9	2.3
min	-411.5	-86.4	-7.2	-3.6	-2.5	-4.0

Maximum rate of change

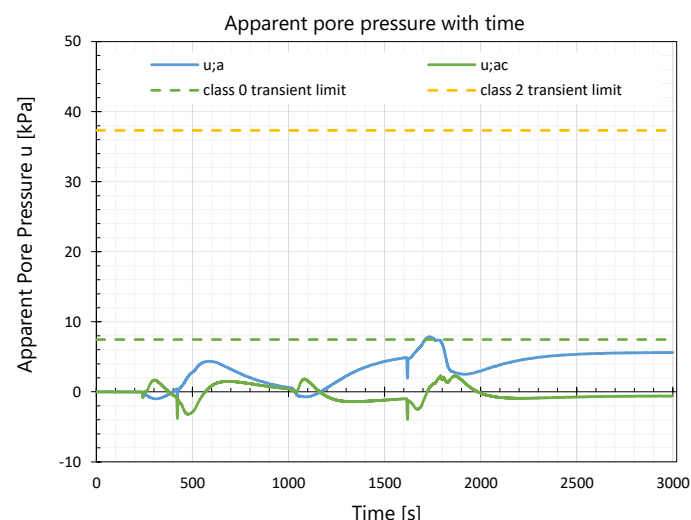
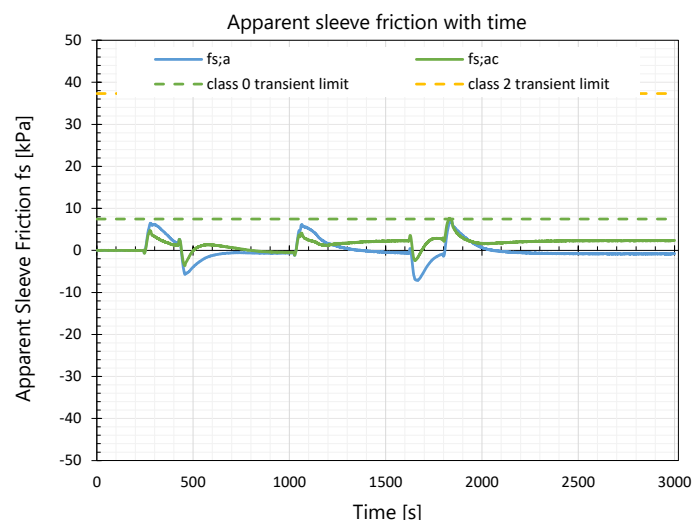
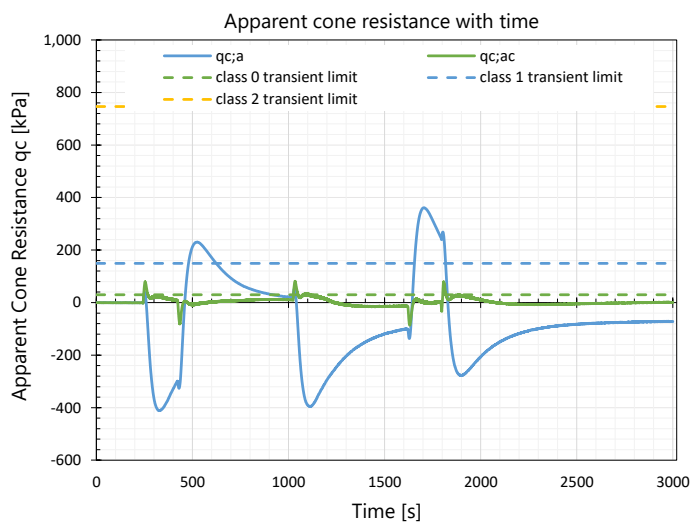
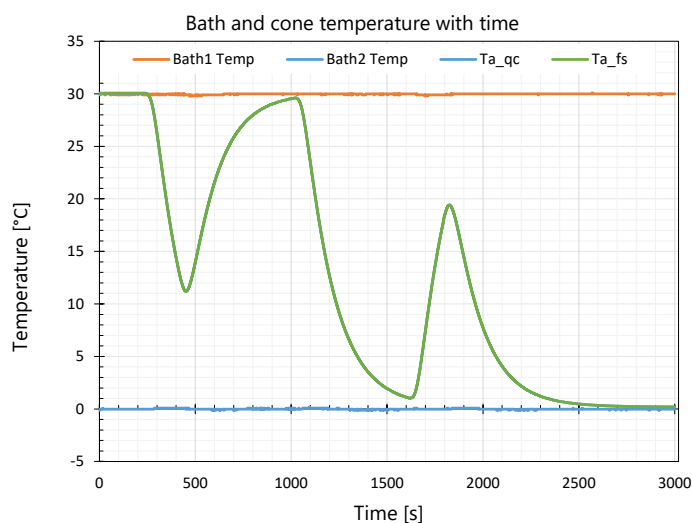
kPa/s	kPa/s	kPa/s	kPa/s	kPa/s	kPa/s
Δfg _{qc}	Δfg _{qcc}	Δfg _{fs}	Δfg _{fsc}	Δfg _u	Δfg _{uc}
13.25	4.59	0.36	0.29	0.16	0.17

Table - 21a Ambient temperature stability and classification

Ambient temperature stability		kPa/°C	Class
Uncorrected	Δa _{qc}	2.41	2
	Δa _{fs}	0.02	0
	Δa _u	-0.19	2
Corrected	Δa _{qcc}	-0.03	0
	Δa _{fsc}	-0.08	0
	Δa _{uc}	0.02	0

Table - 21b Transient temperature stability and classification

Transient temperature stability		kPa/°C	Class
Uncorrected	Δt _{qc}	25.88	2
	Δt _{fs}	0.48	0
	Δt _u	0.35	0
Corrected	Δt _{qcc}	5.62	1
	Δt _{fsc}	0.38	0
	Δt _{uc}	0.21	0



Bending Influence Verification

Verification Method

1. The cone penetrometer was placed in the bending influence frame, clamping the cone horizontally.
2. The test method for verification of a cone penetrometer for bending influence was followed as set out in BS EN ISO 22476-1:2023, clause B.2.8.2.
3. The air temperature, apparent cone resistance, apparent sleeve friction, and apparent pore pressure were recorded for the duration of each test. In total 8 tests were performed from 0° rotation to 315° rotation, evenly spaced with 45° rotation between tests.
4. The bending influence results and resulting cone penetrometer classification was calculated and are shown in Table 22.

Table - 22 Bending Influence results

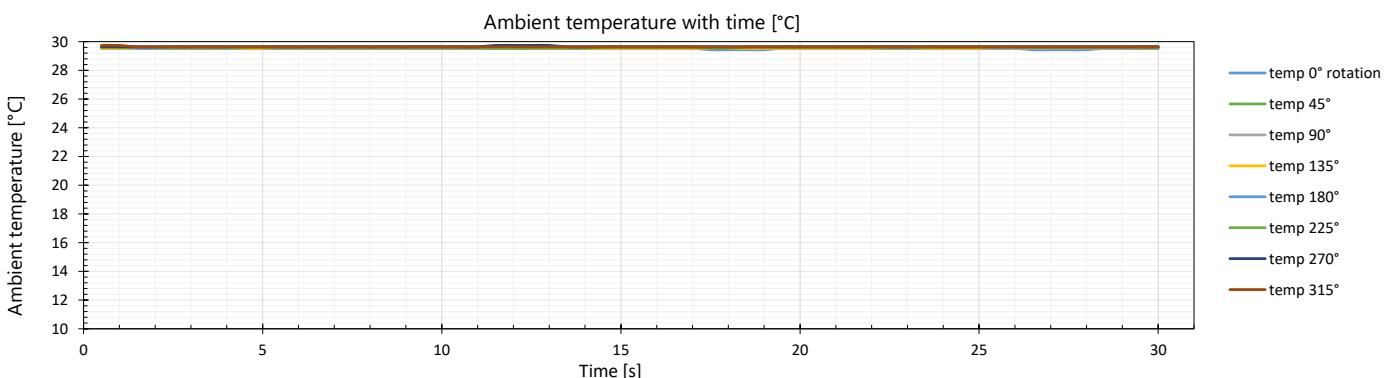
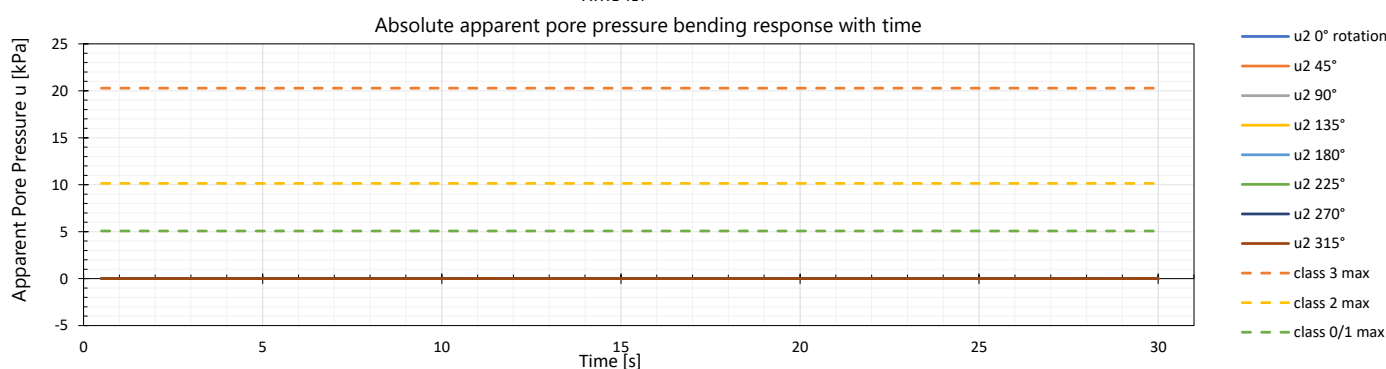
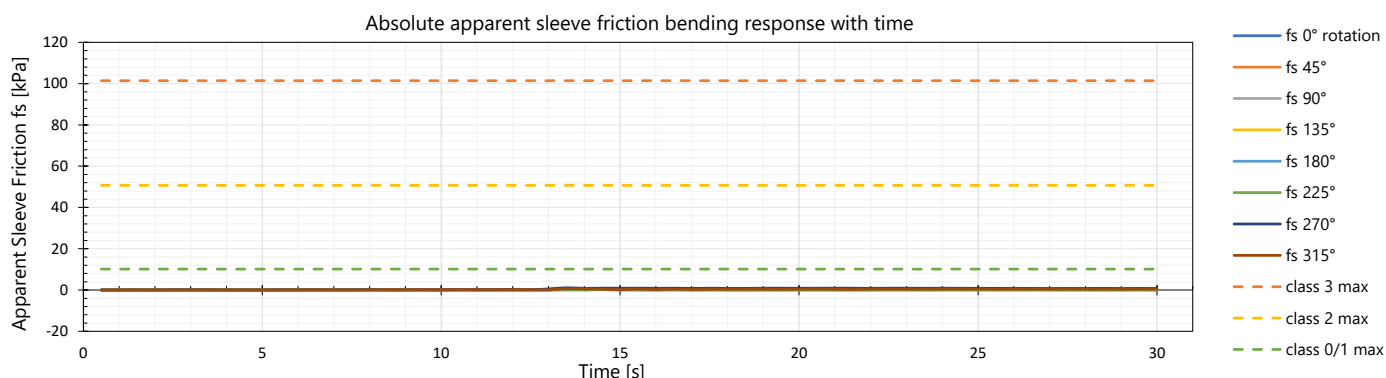
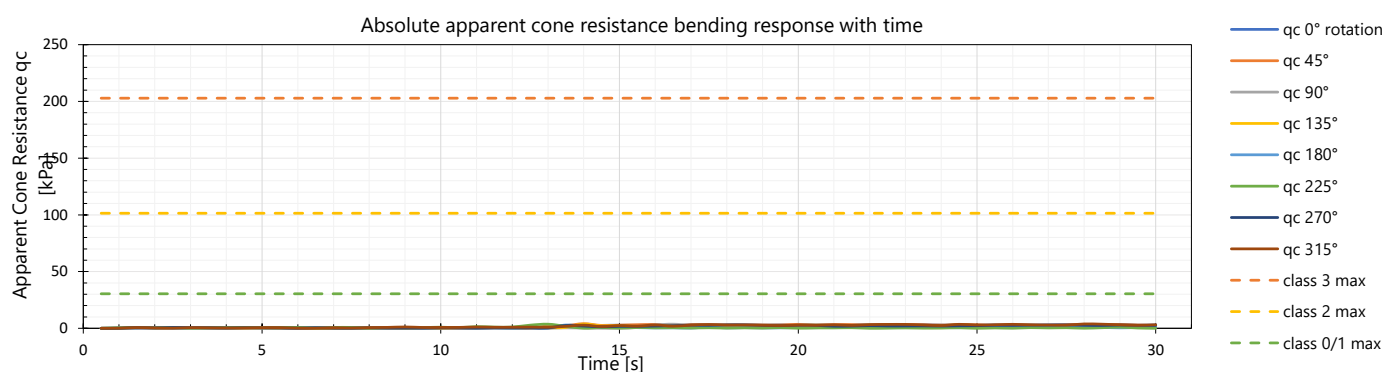
	qc;a [kPa/N]	fs;a [kPa/N]	u2;a [kPa/N]	Ambient Temp [°C]
max	0.028	0.002	0.000	29.5
min	-0.038	-0.011	0.000	29.4
max test Δb, Δt	0.066	0.013	0.000	0.1
class	0	0	0	

10 kg Calibration Weight Uncertainty

10 kg Calibration Weight 0.001 %

10 kg Calibration Weight

Reference weight 10.341 kg
Reference force 101.411 N



Sensor Stability Verification

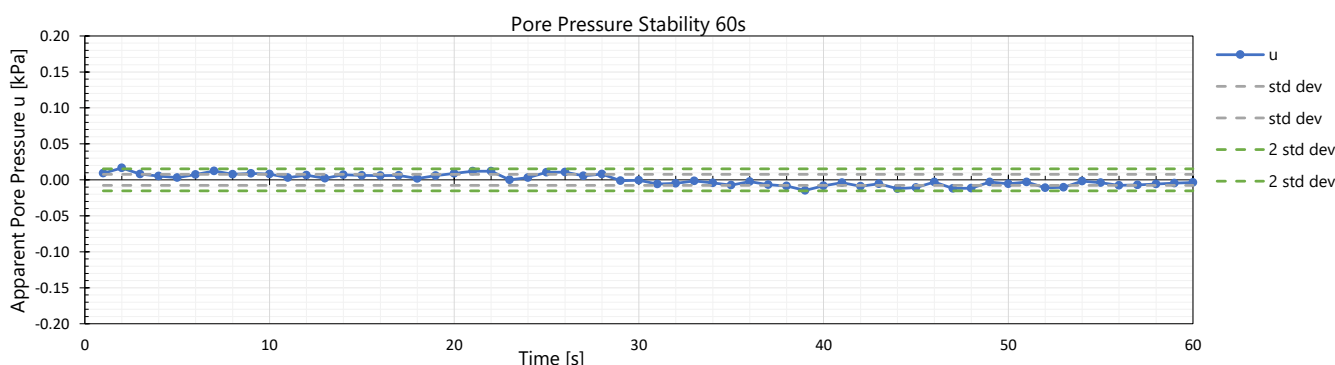
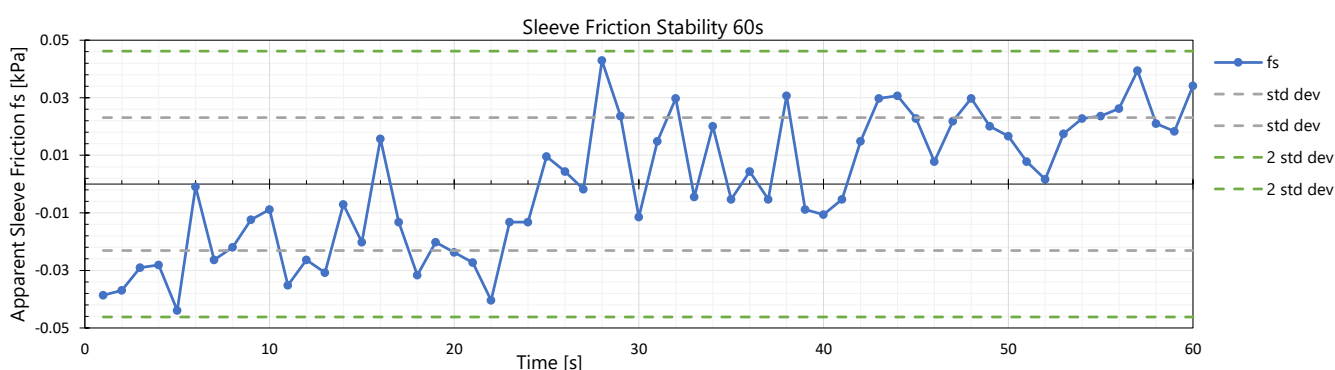
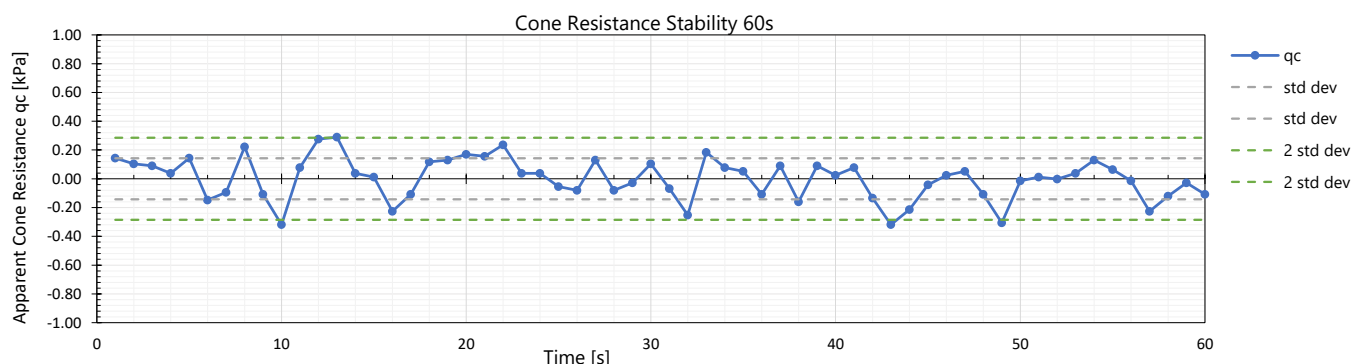
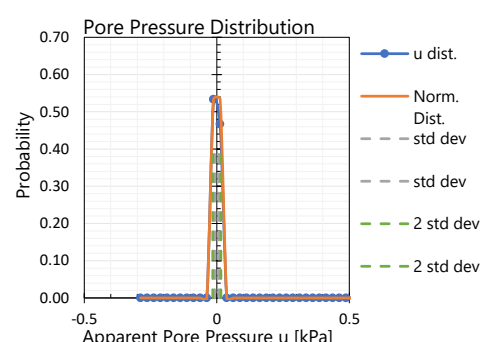
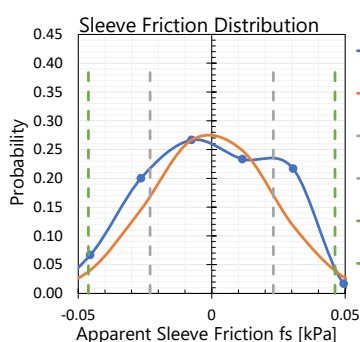
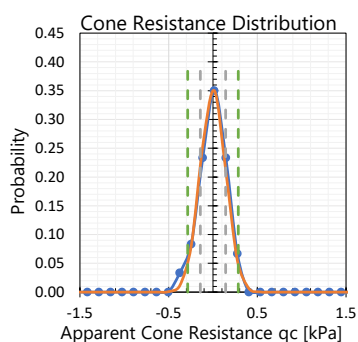
The purpose of this section is to quantify the stability of the geotechnical sensors (q_c , f_s , u) and demonstrate validity of applying a normal distribution, described by standard deviation and mean, when assessing probability of noise magnitude. The sampling duration has been limited to 60 seconds to allow direct comparison to the field verification data required under BS EN ISO 22476-1: 2023.

Verification method

1. The cone penetrometer was placed in the thermostatic temperature calibration bath at ambient temperature.
2. The cone penetrometer was left for no less than 30 minutes or until the output was stable.
3. The output was recorded for 60 seconds at a frequency of 1Hz. The maximum change and standard deviation are shown in Table 23.

Table - 23 Sensor stability results

	q_c (kPa)	f_s (kPa)	u (kPa)	Inc (°)	Temp (°C)
Max	0.289	0.043	0.016	0.038	0.016
Min	-0.319	-0.044	-0.015	-0.035	-0.016
Δ (Max - Min)	0.608	0.087	0.031	0.080	0.032
Standard deviation (68% coverage)	± 0.143	± 0.023	± 0.008	± 0.017	± 0.009
2 standard deviations (95% coverage)	± 0.285	± 0.046	± 0.015	± 0.035	± 0.019





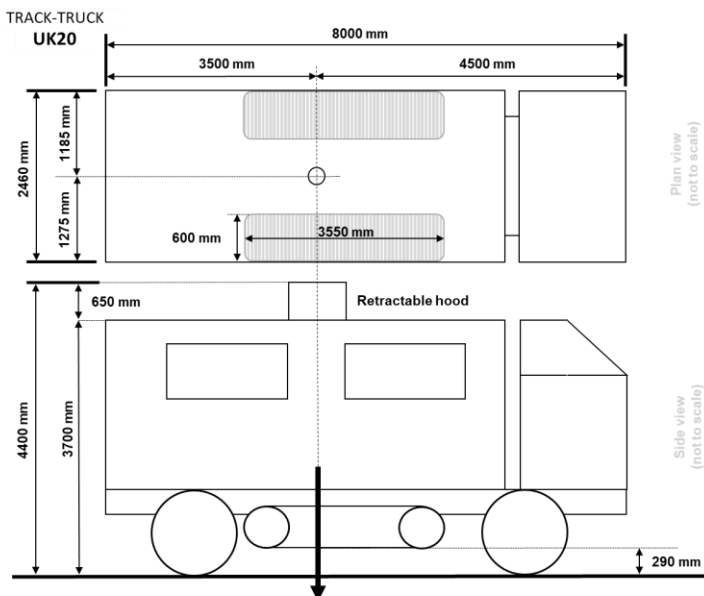
UK20 Track-truck

The versatile track-truck is suitable for most geotechnical sites. The rig is driven to site as a self-contained HGV with tracks that can be deployed to cope with soft or uneven terrain.

Fitted with a chawl valve and spark arrestor.

Remote-controlled tracking to assist with manoeuvring onto location.

Complies with Euro 6 emission standards for use in London's low emissions zones (LEZ).

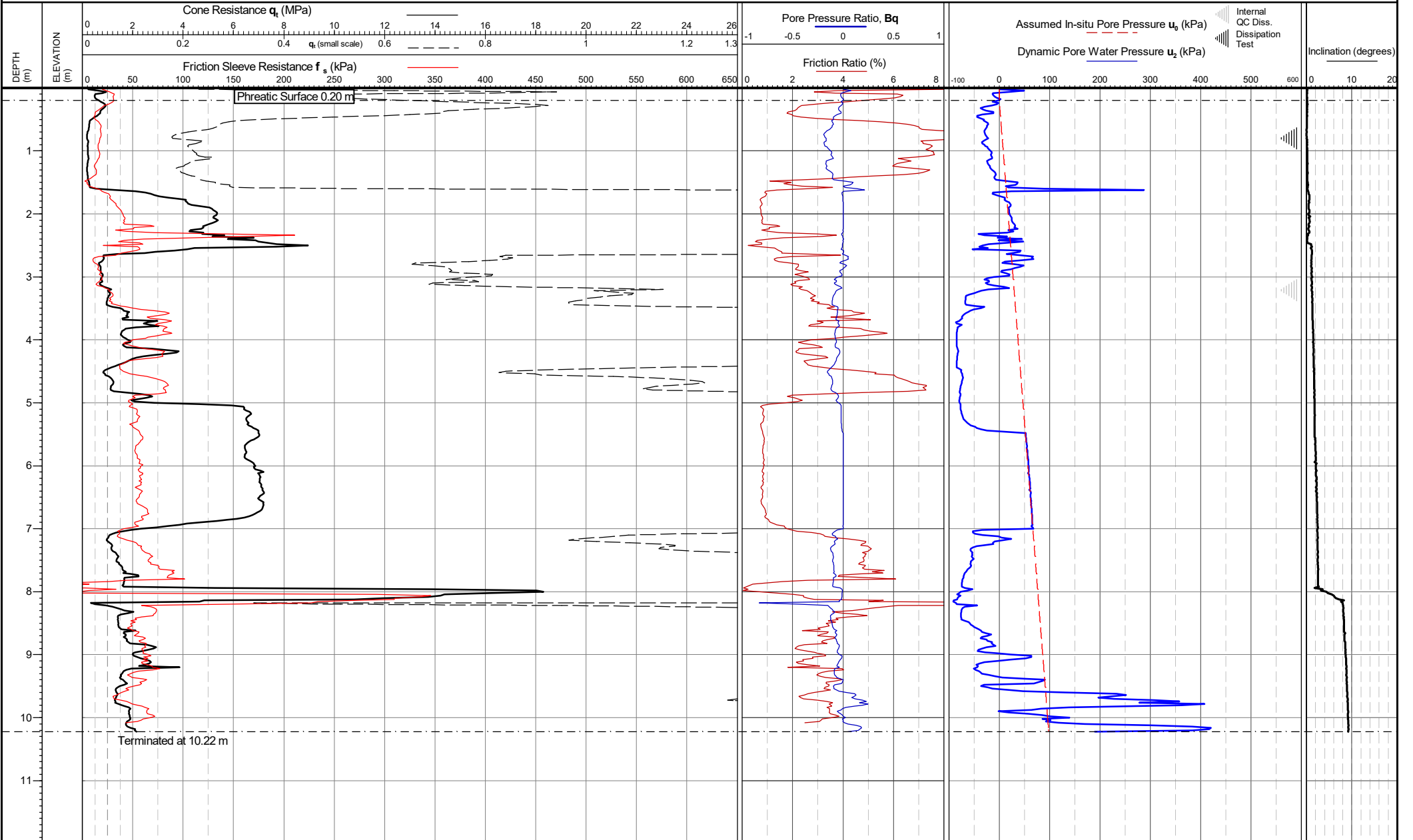


Rig weight	19. T
Max. operating ram capacity	20. T
Max. travelling speed	86 km/h
Track material	Steel
Track length	3550 mm
Track width	600 mm
Jack plate dimensions	Tracks act as jacks
Jack arrangements	1nr. on each side
Max. ground clearance on jacks	290 mm
Max. ground bearing pressure	Wheels – 300 kPa Tracks – 48 kPa
Max. testing gradient	10 degrees
Max. traversing gradient	20 degrees (operator assessed)
Noise output at 2 m	Testing - 69.5 dBA Driving – 78.7 dBA
Clamp arrangement	Hydraulic catching – semi automatic
Ram stroke	1.2 m
Max. casing size	55 mm
Typical production	100 m+ of standard CPTu testing per day (depending on conditions and access)

APPENDIX C CONE PENETRATION TEST RESULTS

Measured CPT parameters

intermediate parameters R_f and B_q



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 12:56:39

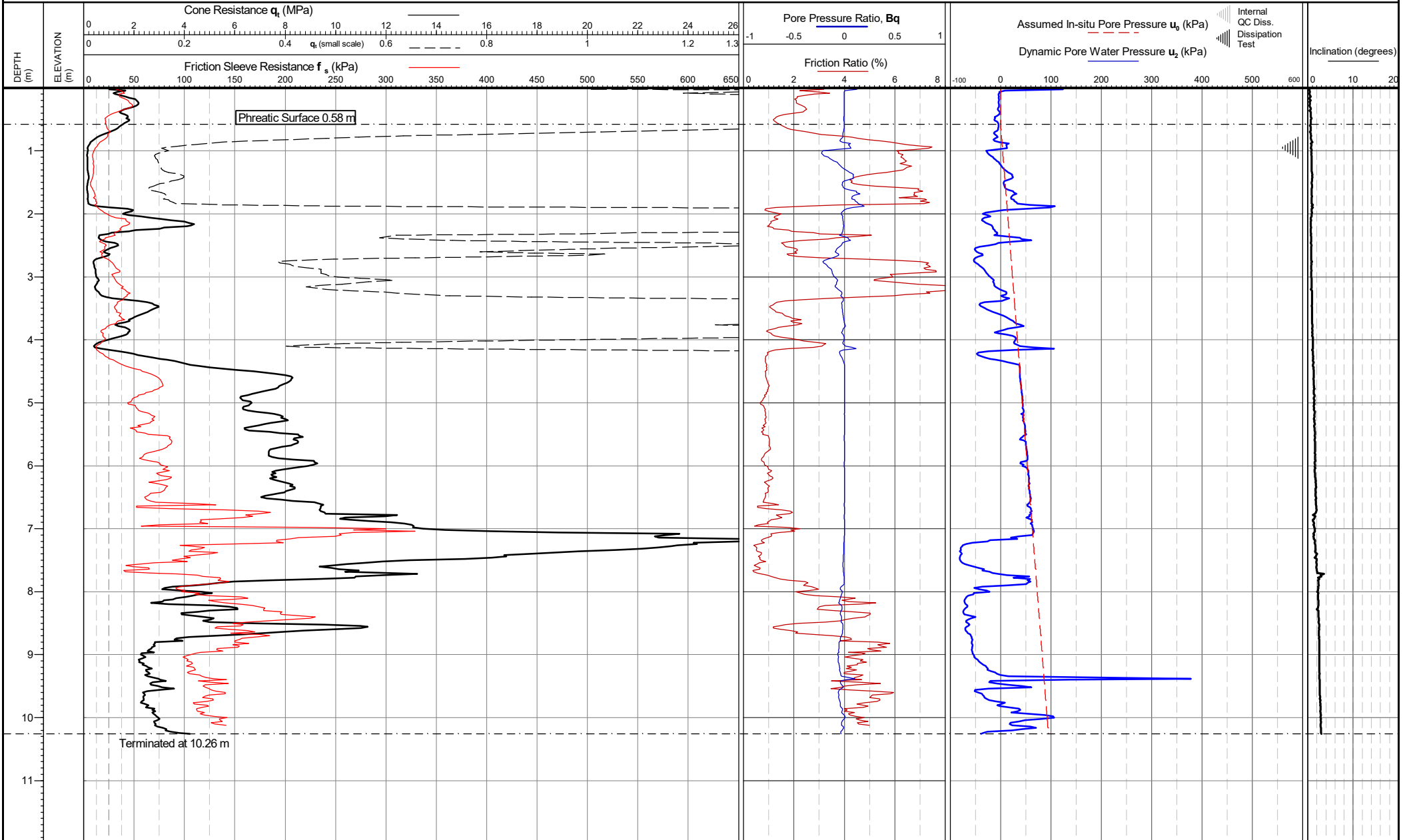
Zero drift (Pre/post test)
 q_0 (kPa): -26.2
 f_0 (kPa): -0.3
 u_2 (kPa): 0.1

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks:
*Phreatic surface origin: Piezocone response in drained soils
Termination Remark: Target depth

Date of plot: 03-09-25
Lankelma Project Ref: 25-32-30058-1
Checked by: Chris Player

TEST ID: CPT01



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 10:59:05

Zero drift (Pre/post test)
 q_0 (kPa): 18.2
 f_0 (kPa): 0.1
 u_2 (kPa): 0.0

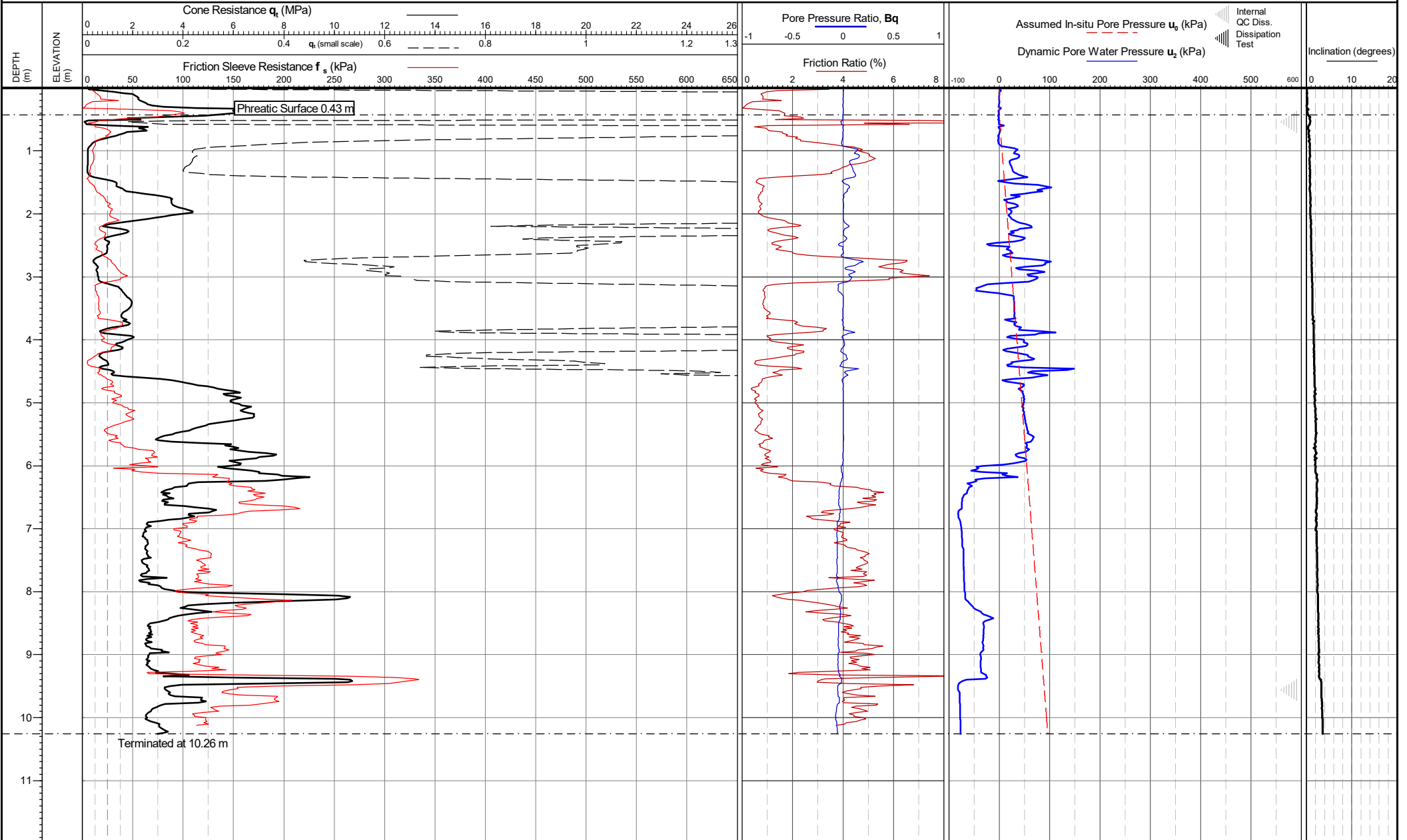
Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks:
*Phreatic surface origin: Piezocone response in drained soils
Termination Remark: Target depth

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT02



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 10:17:42

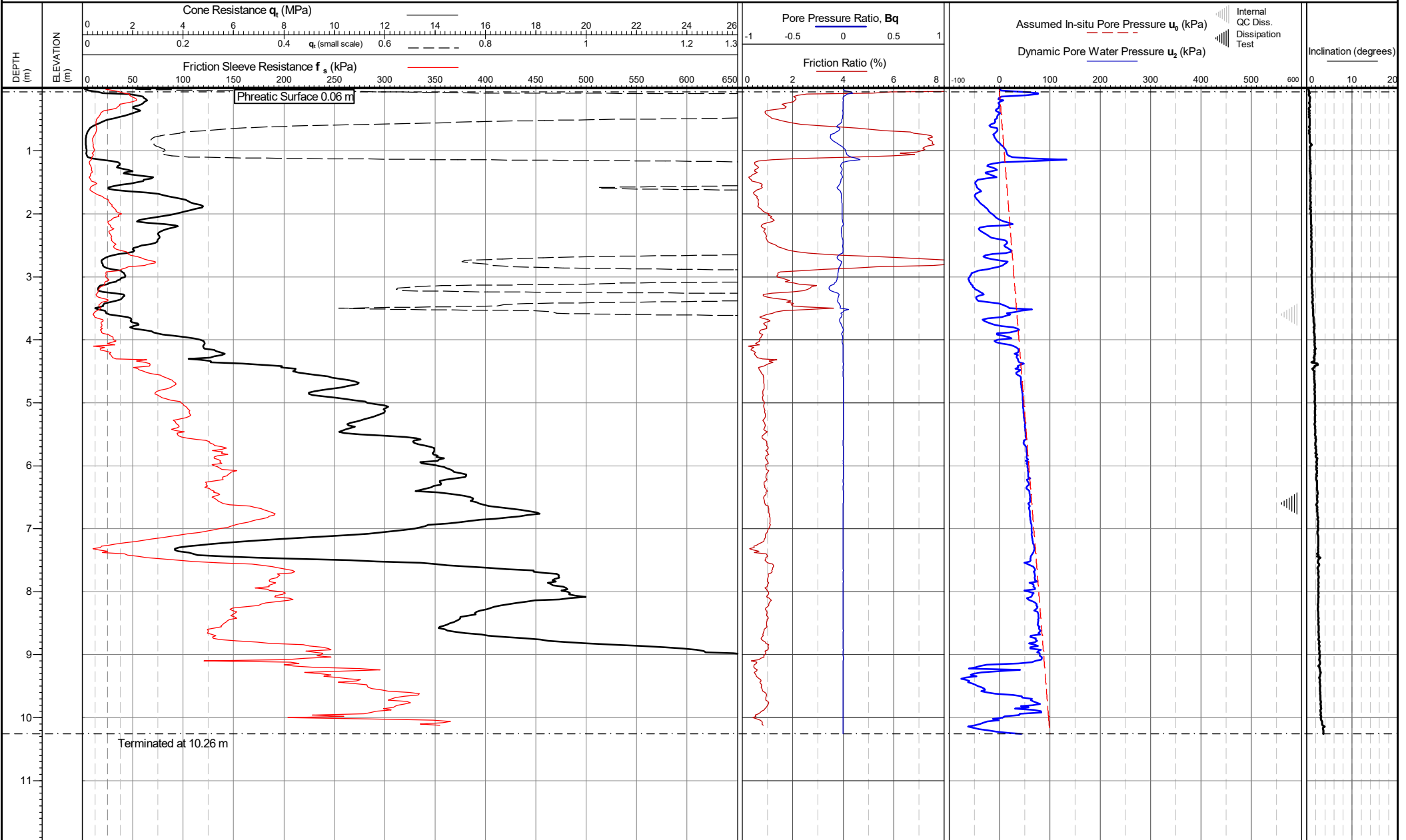
Zero drift (Pre/post test)
 q_0 (kPa): 18.2
 f_0 (kPa): 0.1
 u_2 (kPa): 0.0

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks:
*Phreatic surface origin: Average measured piezometric depth from other location(s)
Termination Remark: Target depth

Date of plot: 03-09-25
Lankelma Project Ref: 25-32-30058-1
Checked by: Chris Player

TEST ID: CPT03



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 09:33:42

Zero drift (Pre/post test)
 q_0 (kPa): 18.2
 f_0 (kPa): 0.1
 u_2 (kPa): 0.0

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks:
*Phreatic surface origin: Piezocene response in drained soils, approx. ± 0.6 mbgl
Termination Remark: Target depth

Date of plot:
03-09-25
Checked by:
Chris Player

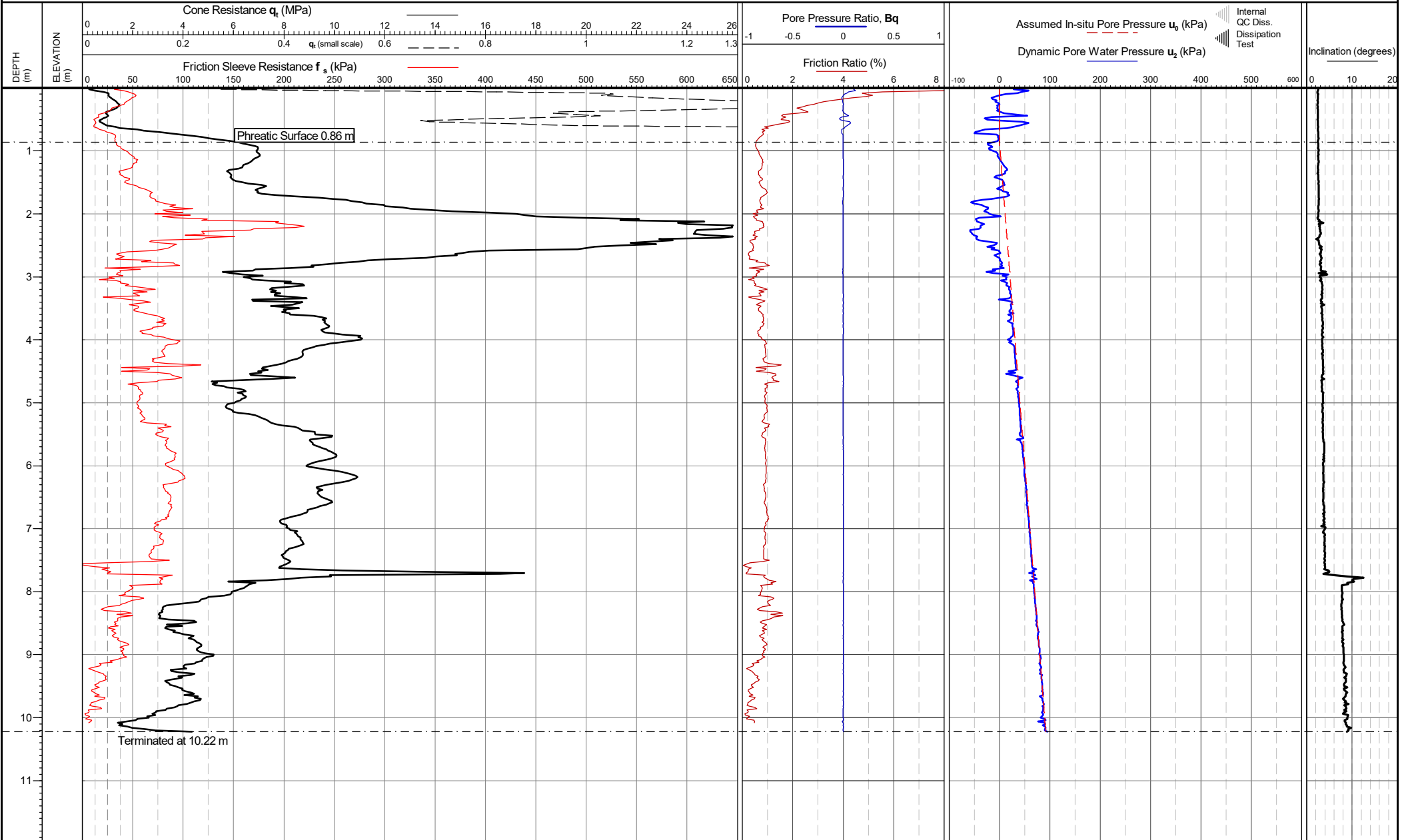
Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT04



Project: ROCHDALE

Client: REFA



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 08:44:24

Zero drift (Pre/post test)
 q_0 (kPa): -9.6
 f_0 (kPa): 1.2
 u_2 (kPa): 0.2

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks:
*Phreatic surface origin: Piezocone response in drained soils
Termination Remark: Target depth

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT05

Page 1 of 1

APPENDIX D SOIL BEHAVIOUR TYPE RESULTS

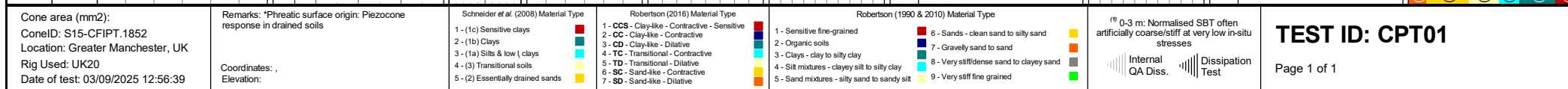
Soil behaviour type (SBT) point data evaluation according to:

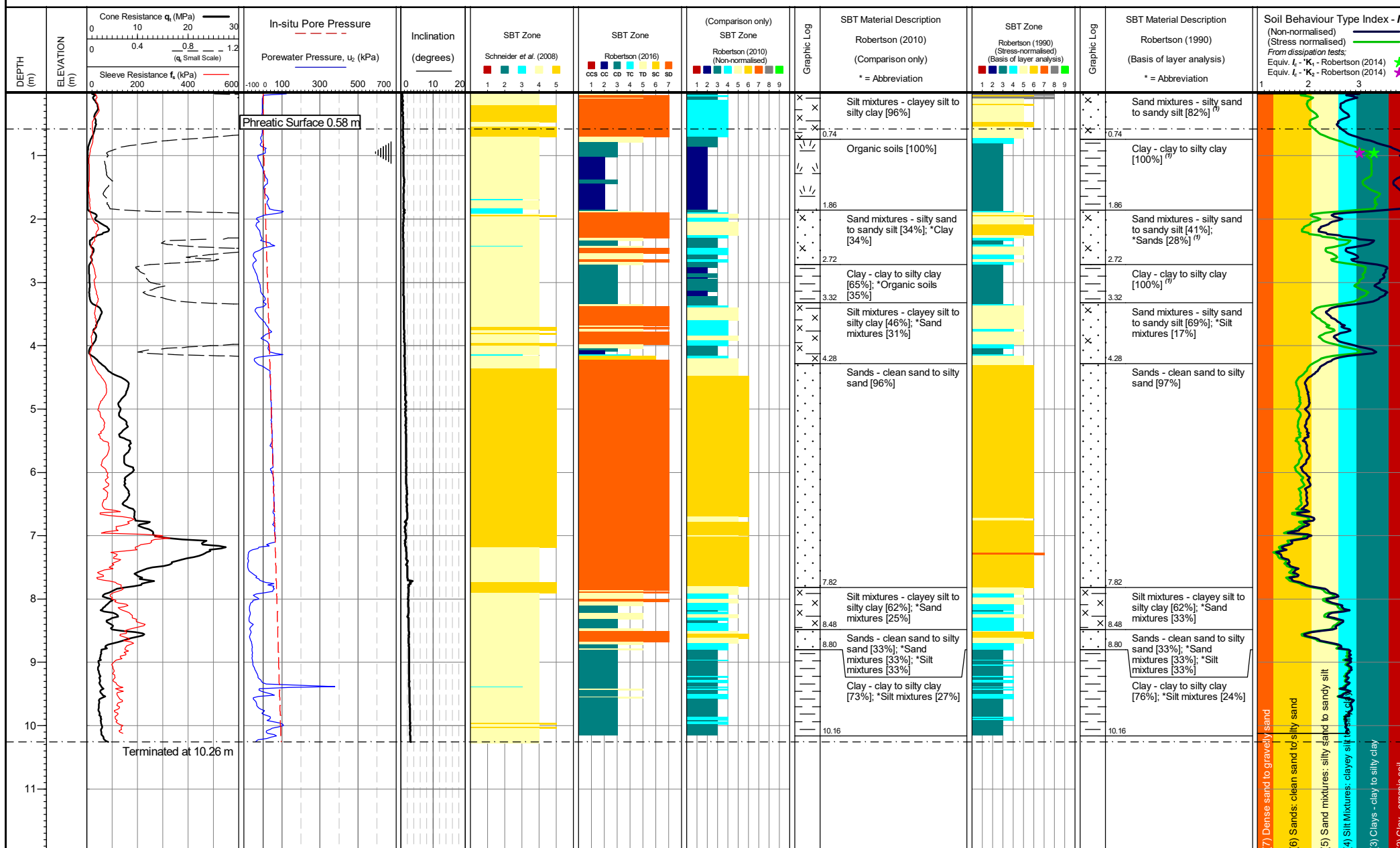
Schneider et al (2008)

Robertson (2016)

Robertson (2010) with aggregate layer descriptions

Robertson (1990) with aggregate layer descriptions





Cone area (mm2):
ConeID: S15-CFIPT.1852
Location: Greater Manchester, UK
Rig Used: UK20
Date of test: 03/09/2025 10:59:05

Remarks: *Phreatic surface origin: Piezocone response in drained soils

Coordinates: _____
Elevation: _____

Schneider *et al.* (2008) Material Type

- 1 - (1c) Sensitive clays
- 2 - (1b) Clays
- 3 - (1a) Silts & low I_p clays
- 4 - (3) Transitional soils
- 5 - (2) Essentially drained sands

Robertson (2016) Material Type

- 1 - **CCS** - Clay-like - Contractive -
- 2 - **CC** - Clay-like - Contractive
- 3 - **CD** - Clay-like - Dilative
- 4 - **TC** - Transitional - Contractive
- 5 - **TD** - Transitional - Dilative
- 6 - **SC** - Sand-like - Contractive
- 7 - **SD** - Sand-like - Dilative

Robertson (1990 & 2010) Material Type

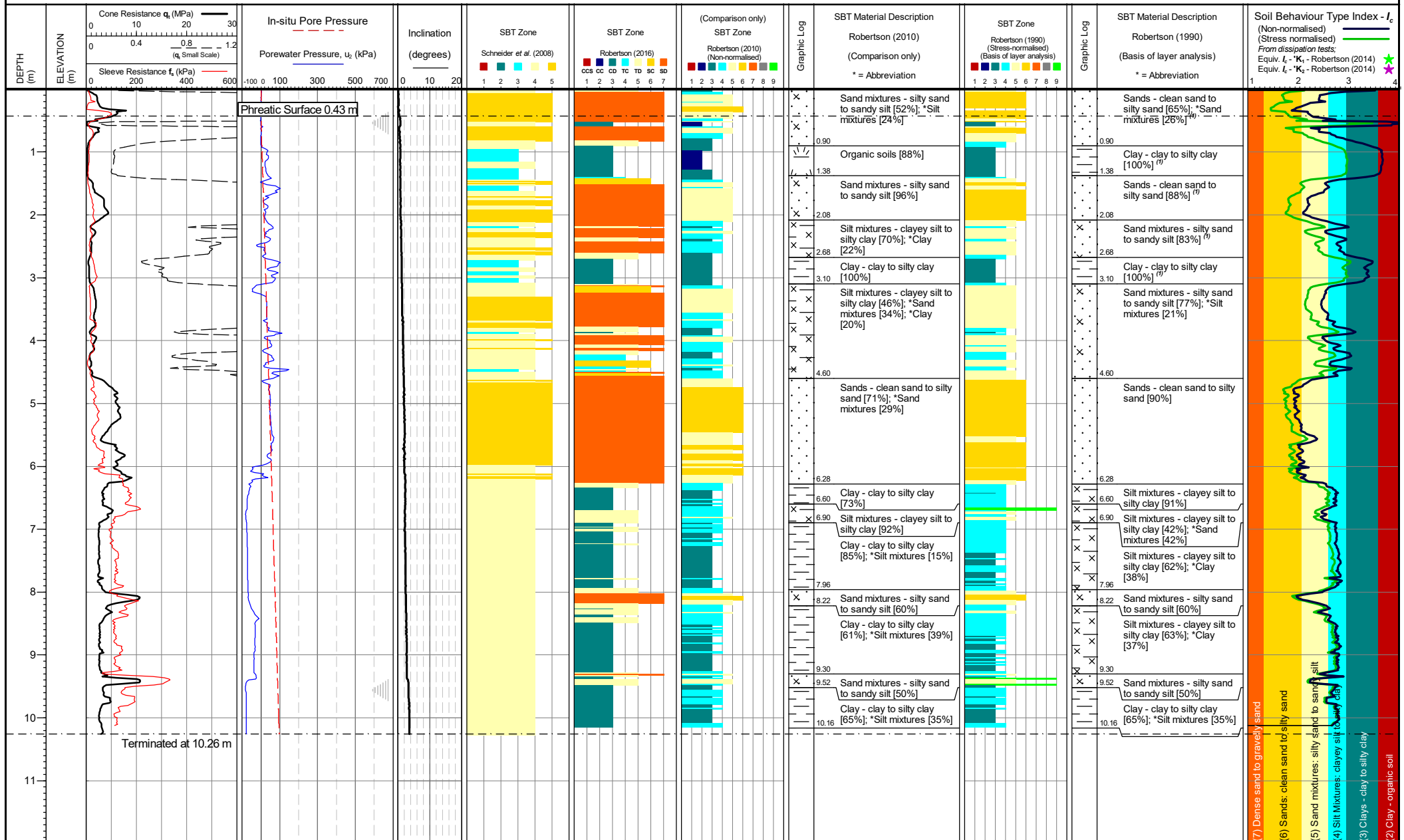
1 - Sensitive fine-grained	6 - Sands - clean sand to
2 - Organic soils	7 - Gravelly sand to sand
3 - Clays - clay to silty clay	8 - Very stiff/dense sand
4 - Silt mixtures - clayey silt to silty clay	9 - Very stiff fine grained
5 - Sand mixtures - silty sand to sandy silt	

⁽¹⁾ 0-3 m: Normalised SBT often artificially coarse/stiff at very low in-situ stresses

Internal
QA Diss.

TEST ID: CPT02

Page 1 of 1



Cone area (mm²):
ConeID: S15-CFPT.1852
Location: Greater Manchester, UK
Rig Used: UK20
Date of test: 03/09/2025 10:17:42

Remarks: *Phreatic surface origin: Average measured piezometric depth from other location(s)

Coordinates: ,
Elevation:

Schneider *et al.* (2008) Material Type

- 1 - (1c) Sensitive clays
- 2 - (1b) Clays
- 3 - (1a) Silts & low l. clays
- 4 - (3) Transitional soils
- 5 - (2) Essentially drained sands

Robertson (2016) Material Type

- 1 - CC - Clay-like - Contractive - Sensitive
- 2 - CC - Clay-like - Contractive
- 3 - CD - Clay-like - Dilative
- 4 - TC - Transitional - Contractive
- 5 - TD - Transitional - Dilative
- 6 - SC - Sand-like - Contractive
- 7 - SD - Sand-like - Dilative

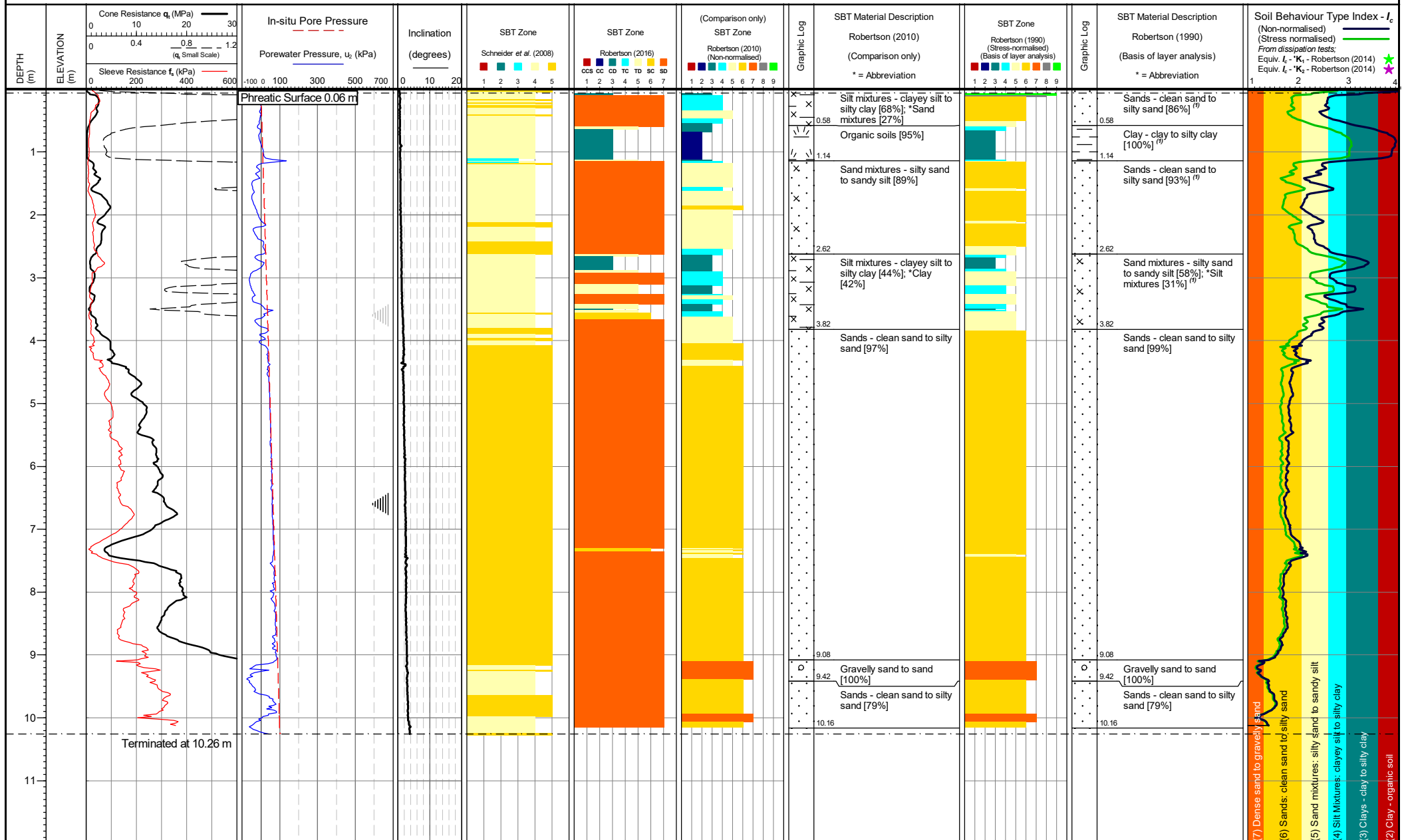
Robertson (1990 & 2010) Material Type

- 1 - Sensitive fine-grained
- 2 - Organic soils
- 3 - Clays - clay to silty clay
- 4 - Silt mixtures - clayey silt to silty clay
- 5 - Sand mixtures - silty sand to sandy silt
- 6 - Sands - clean sand to silty sand
- 7 - Gravelly sand to sand
- 8 - Very stiff/dense sand to clayey sand
- 9 - Very stiff fine grained

⁽⁹⁾ 0-3 m: Normalised SBT often artificially coarse/stiff at very low in-situ stresses

Internal QA Diss. Dissipation Test

TEST ID: CPT03



Cone area (mm2):
ConeID: S15-CFIPT.1852
Location: Greater Manchester, UK
Rig Used: UK20
Date of test: 03/09/2025 09:33:42

Remarks: *Phreatic surface origin: Piezocone response in drained soils, approx. ± 0.6 mbgl

Coordinates: ,
Elevation:

Schneider et al. (2008) Material Type

- 1 - (1c) Sensitive clays
- 2 - (1b) Clays
- 3 - (1a) Silts & low l_c clays
- 4 - (3) Transitional soils
- 5 - (2) Essentially drained sands

Robertson (2016) Material Type

- ☐ CS - Clay-like - Contractive -
- ☐ C - Clay-like - Contractive
- ☐ D - Clay-like - Dilative
- ☐ C - Transitional - Contractive
- ☐ D - Transitional - Dilative
- ☐ C - Sand-like - Contractive
- ☐ D - Sand-like - Dilative

Robertson (1990 & 2010) Material Type

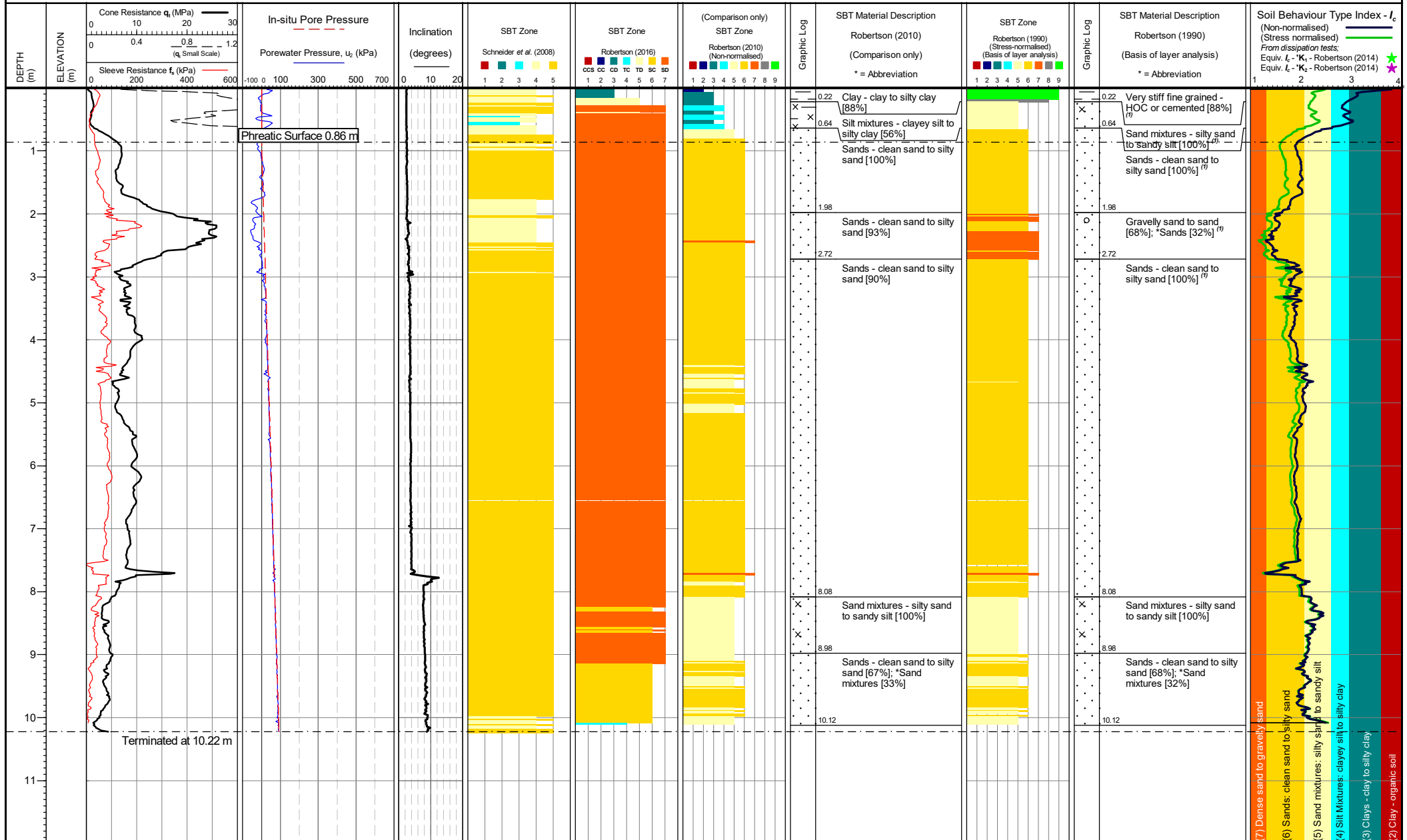
1 - Sensitive fine-grained	6 - Sands - clean sand to
2 - Organic soils	7 - Gravelly sand to sand
3 - Clays - clay to silty clay	8 - Very stiff/dense sand
4 - Silt mixtures - clayey silt to silty clay	9 - Very stiff fine grained
5 - Sand mixtures - silty sand to sandy silt	

⁽¹⁾ 0-3 m: Normalised SBT often artificially coarse/stiff at very low in-situ stresses

Internal
QA Diss. Dissipation
Test

TEST ID: CPT04

Page 1 of 1



Cone area (mm²):
ConeID: S15-CFIPT.1852
Location: Greater Manchester, UK
Rig Used: UK20
Date of test: 03/09/2025 08:44:24

Remarks: *Phreatic surface origin: Piezocone response in drained soils

Coordinates: ,
Elevation:

Schneider *et al.* (2008) Material Type

- 1 - (1c) Sensitive clays
- 2 - (1b) Clays
- 3 - (1a) Silts & low l. clays
- 4 - (3) Transitional soils
- 5 - (2) Essentially drained sands

Robertson (2016) Material Type

- 1 - CC - Clay-like - Contractive - Sensitive
- 2 - CC - Clay-like - Contractive
- 3 - CD - Clay-like - Dilative
- 4 - TC - Transitional - Contractive
- 5 - TD - Transitional - Dilative
- 6 - SC - Sand-like - Contractive
- 7 - SD - Sand-like - Dilative

Robertson (1990 & 2010) Material Type

- 1 - Sensitive fine-grained
- 2 - Organic soils
- 3 - Clays - clay to silty clay
- 4 - Silt mixtures - clayey silt to silty clay
- 5 - Sand mixtures - silty sand to sandy silt
- 6 - Sands - clean sand to silty sand
- 7 - Gravelly sand to sand
- 8 - Very stiff/dense sand to clayey sand
- 9 - Very stiff fine grained

⁽¹⁾ 0-3 m: Normalised SBT often artificially coarse/stiff at very low in-situ stresses

Internal QA Diss. Dissipation Test

TEST ID: CPT05

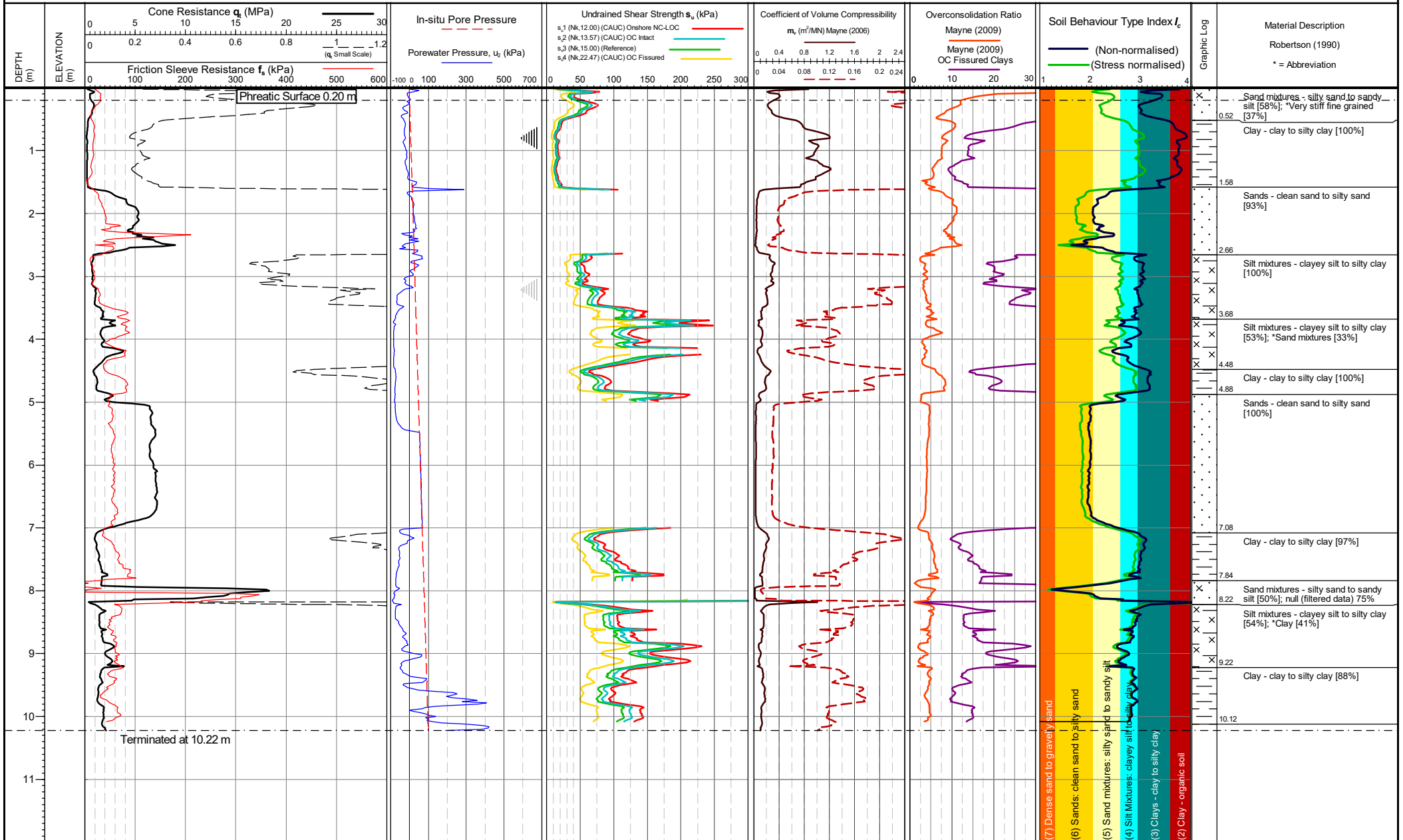
APPENDIX E PARAMETER RESULTS 1 – S_u , M_v , OCR, SBT, I_c

Undrained shear strength

Coefficient of volume change

Overconsolidation ratio

Robertson 1990 SBT descriptions & SBT index I_c



Cone area (mm²):
ConeID: S15-CFPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 12:56:39

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks: *Phreatic surface origin: Piezocone response in drained soils
Termination Remark: Target depth

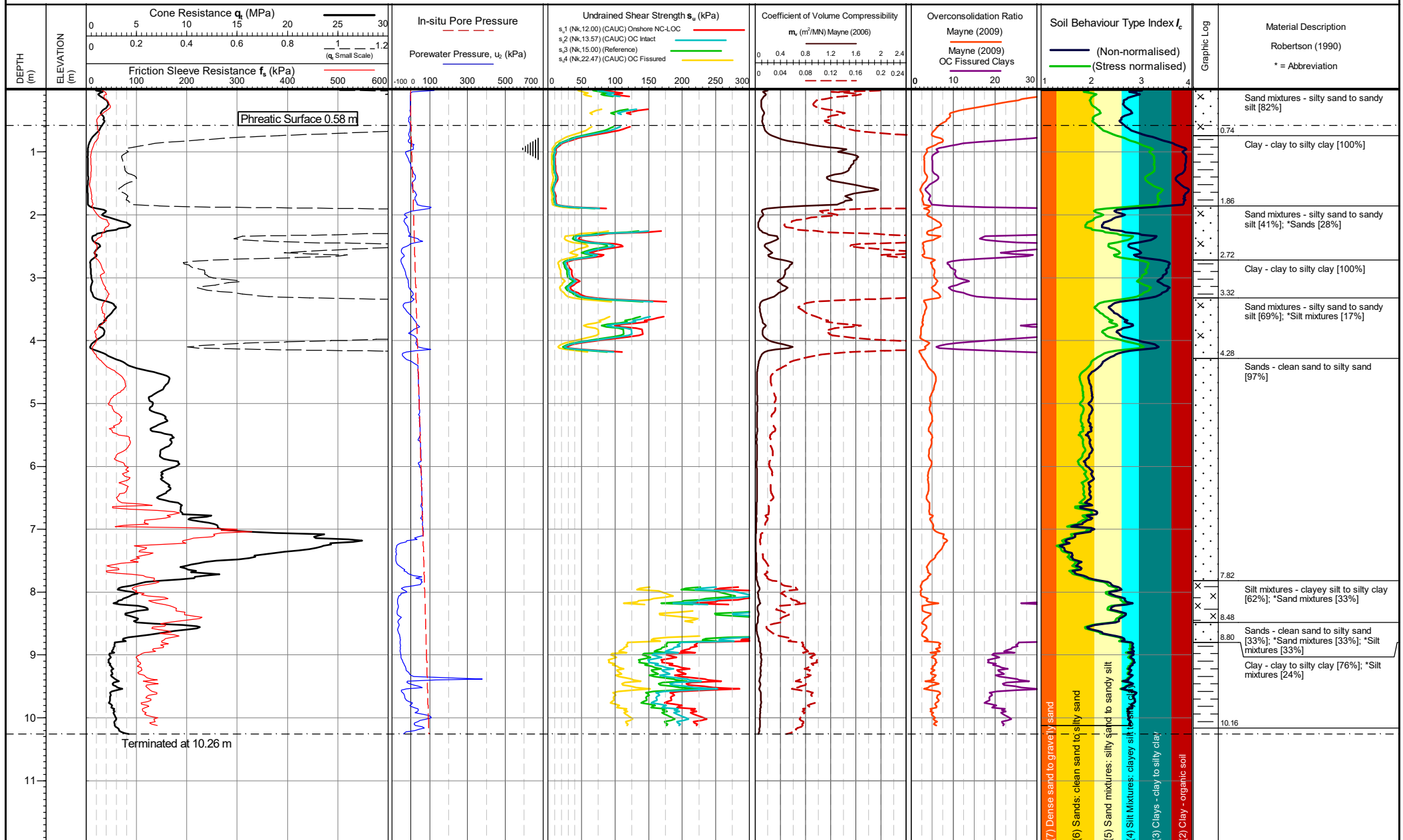
Internal QA Diss.
Dissipation Test
Penetration Pause (<1cm/s)

Both drained and undrained parameters are calculated for mixed SBTs = I_c 2.40-2.70. See report text for methods and discussion of parameter evaluation.

Date of plot: 03-09-25
Checked by: Chris Player

Lankelma Project Ref: 25-32-30058-1

TEST ID: CPT01



Cone area (mm²):
 ConeID: S15-CFIPT.1852
 Operator: Jamie Butterworth
 Rig Used: UK20
 Date of test: 03/09/2025 10:59:05

Location: Greater Manchester, UK
 Coordinates: ,
 Elevation:
 Coordinate system:

Remarks: *Phreatic surface origin: Piezocone response in drained soils

Termination Remark:
 Target depth

Internal QA Diss.
 Dissipation Test
 Penetration
 Pause (<1cm/s)

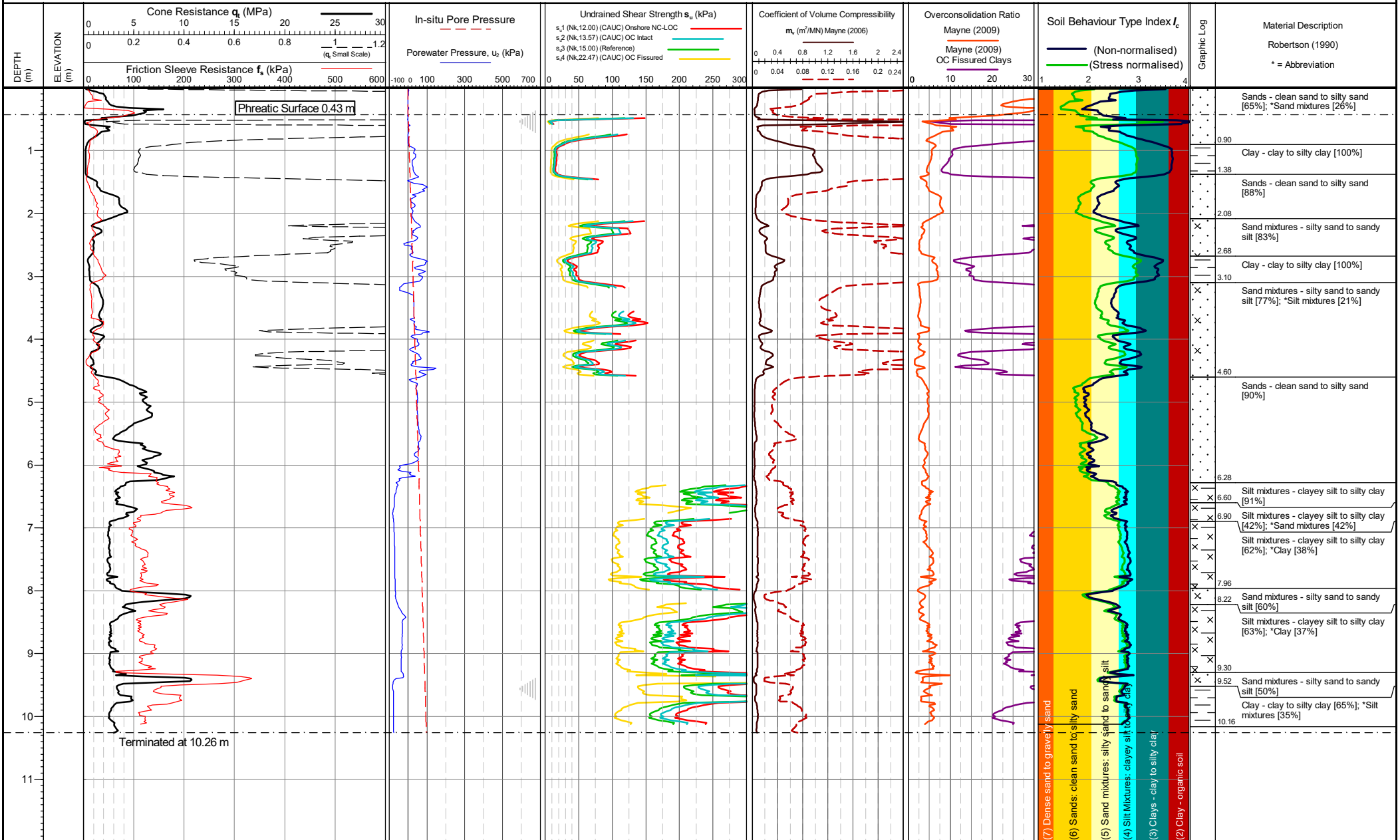
Both drained and undrained parameters are calculated for mixed SBTs = Ic 2.40-2.70. See report text for methods and discussion of parameter evaluation.

Date of plot:
 03-09-25

Checked by:
 Chris Player

Lankelma Project Ref:
 25-32-30058-1

TEST ID: CPT02



Cone area (mm²):
ConeID: S15-CFIPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 10:17:42

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks: *Phreatic surface origin: Average measured piezometric depth from other location(s)

Termination Remark:
Target depth

Internal
QA Diss.
Dissipation
Test
Penetration
Pause (<1cm/s)

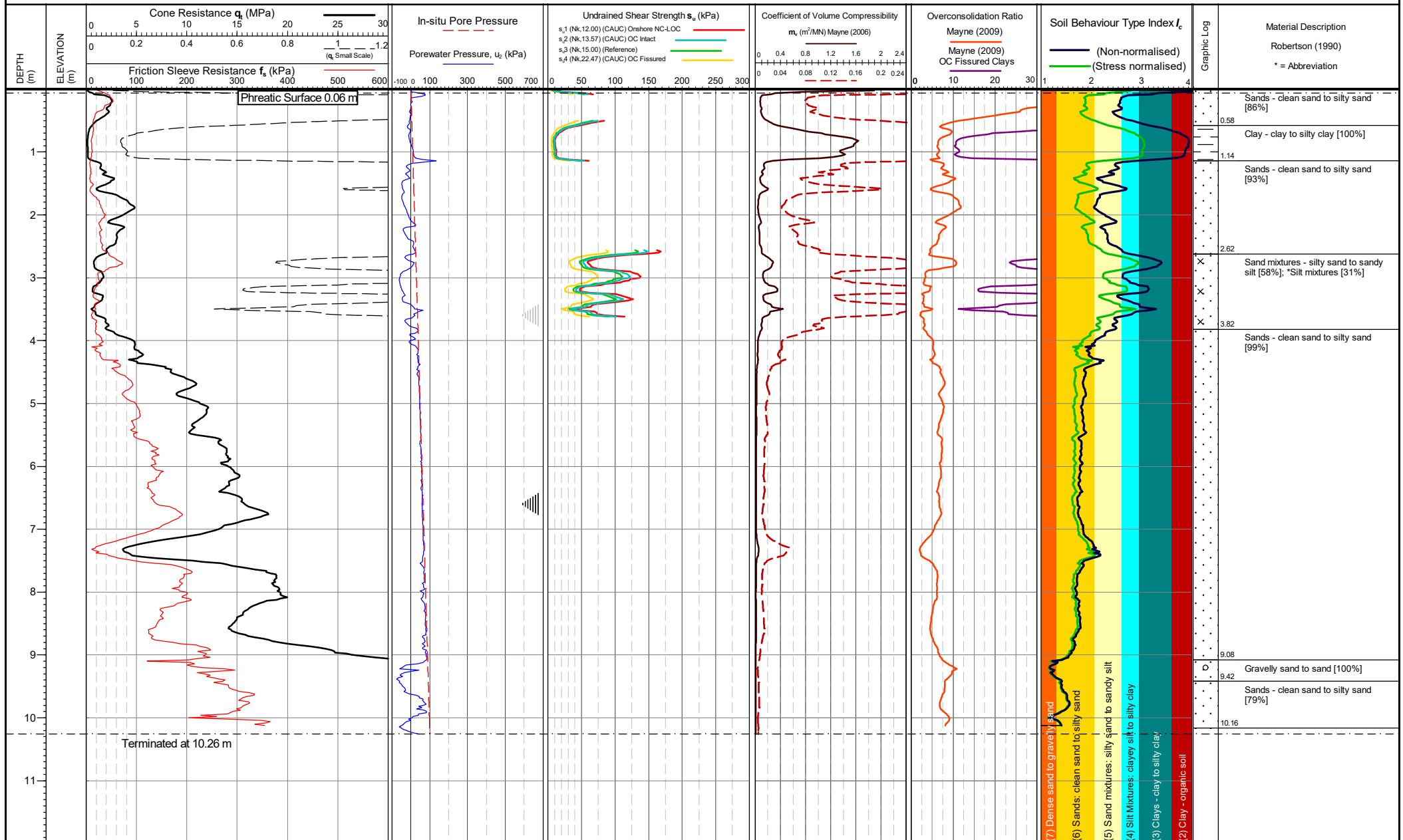
Both drained and undrained parameters are calculated for mixed SBTs = I_c 2.40-2.70. See report text for methods and discussion of parameter evaluation.

Date of plot:
03-09-25

Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT03



Cone area (mm²):
ConeID: S15-CFIPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 09:33:42

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks: *Phreatic surface origin: Piezocone response in drained soils, approx. ± 0.6 mbgl
Termination Remark:
Target depth

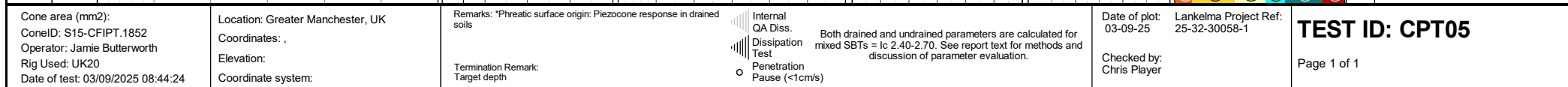
Internal
QA Diss.
Dissipation
Test
Penetration
Pause (<1cm/s)

Both drained and undrained parameters are calculated for mixed SBTs = I_c 2.40-2.70. See report text for methods and discussion of parameter evaluation.

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT04



APPENDIX F PARAMETER RESULTS 2 – SPT N60, ϕ , D_R , E , I_c

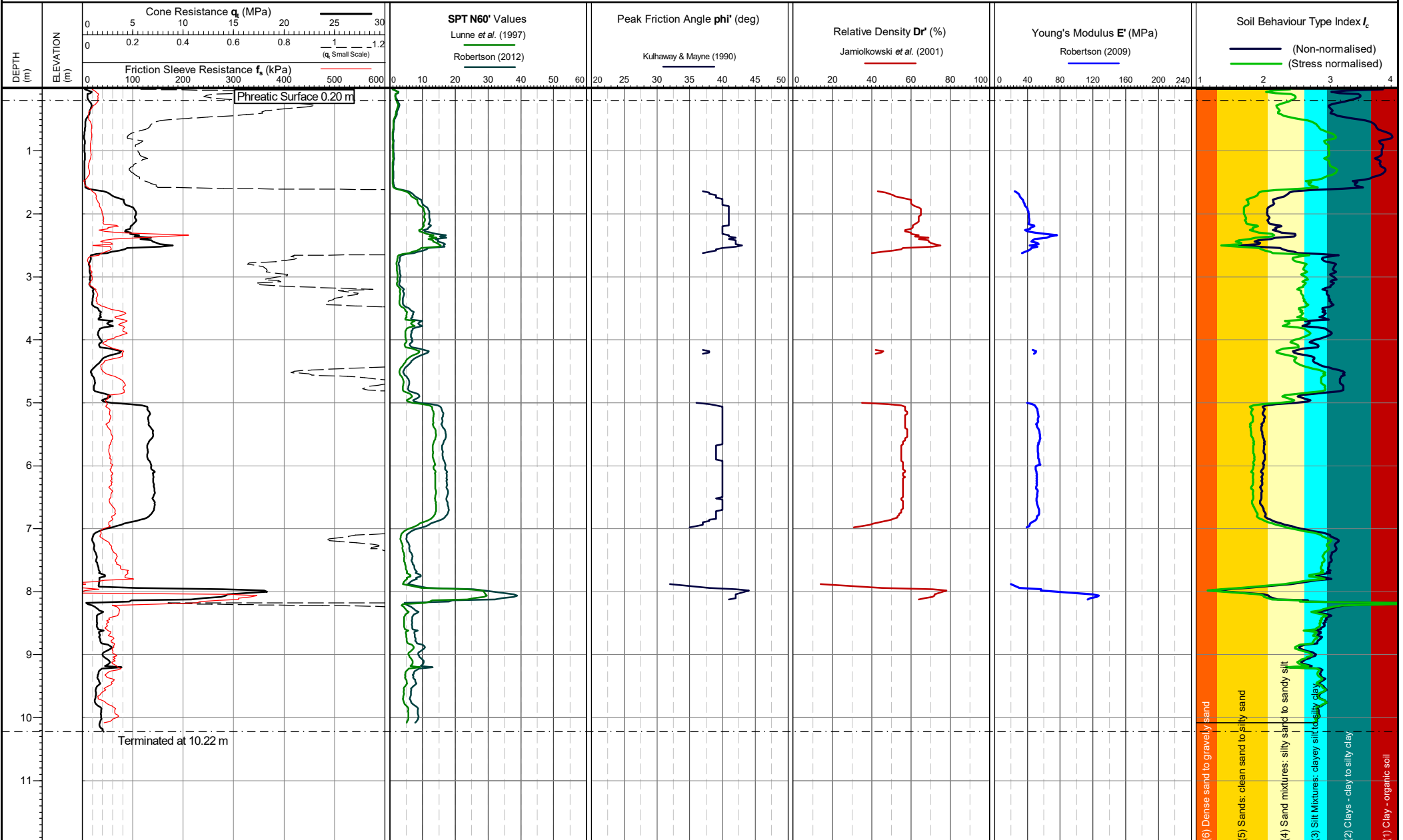
Equivalent SPT N60

Peak friction angle

Relative density

Young's modulus

SBT index I_c



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Date of test: 03/09/2025 12:56:39

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

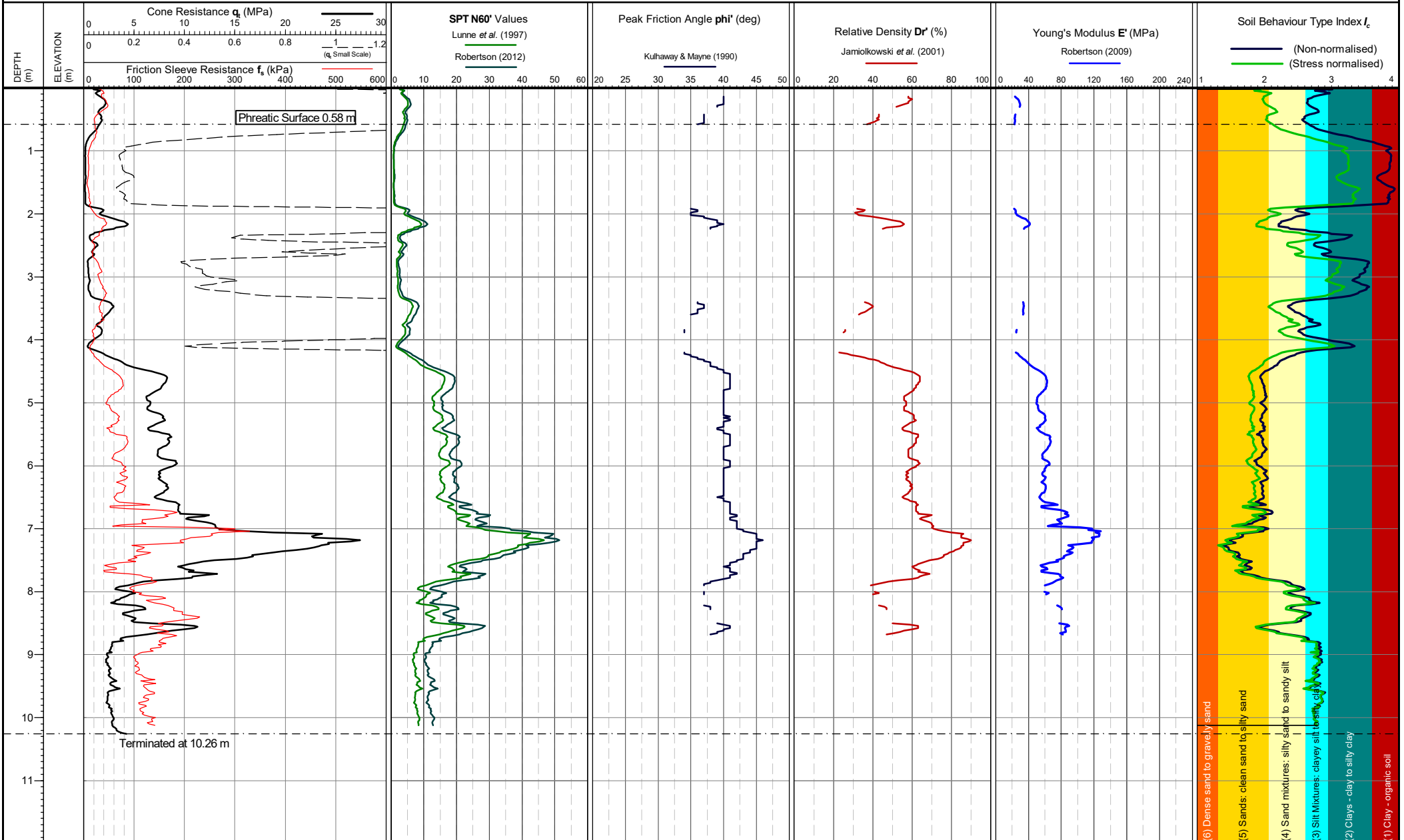
Both drained and undrained
parameters are calculated for mixed
SBTs = I_c 2.40-2.70. See report text
for methods and discussion of
parameter evaluation.

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT01

Page 1 of 1



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Date of test: 03/09/2025 10:59:05

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

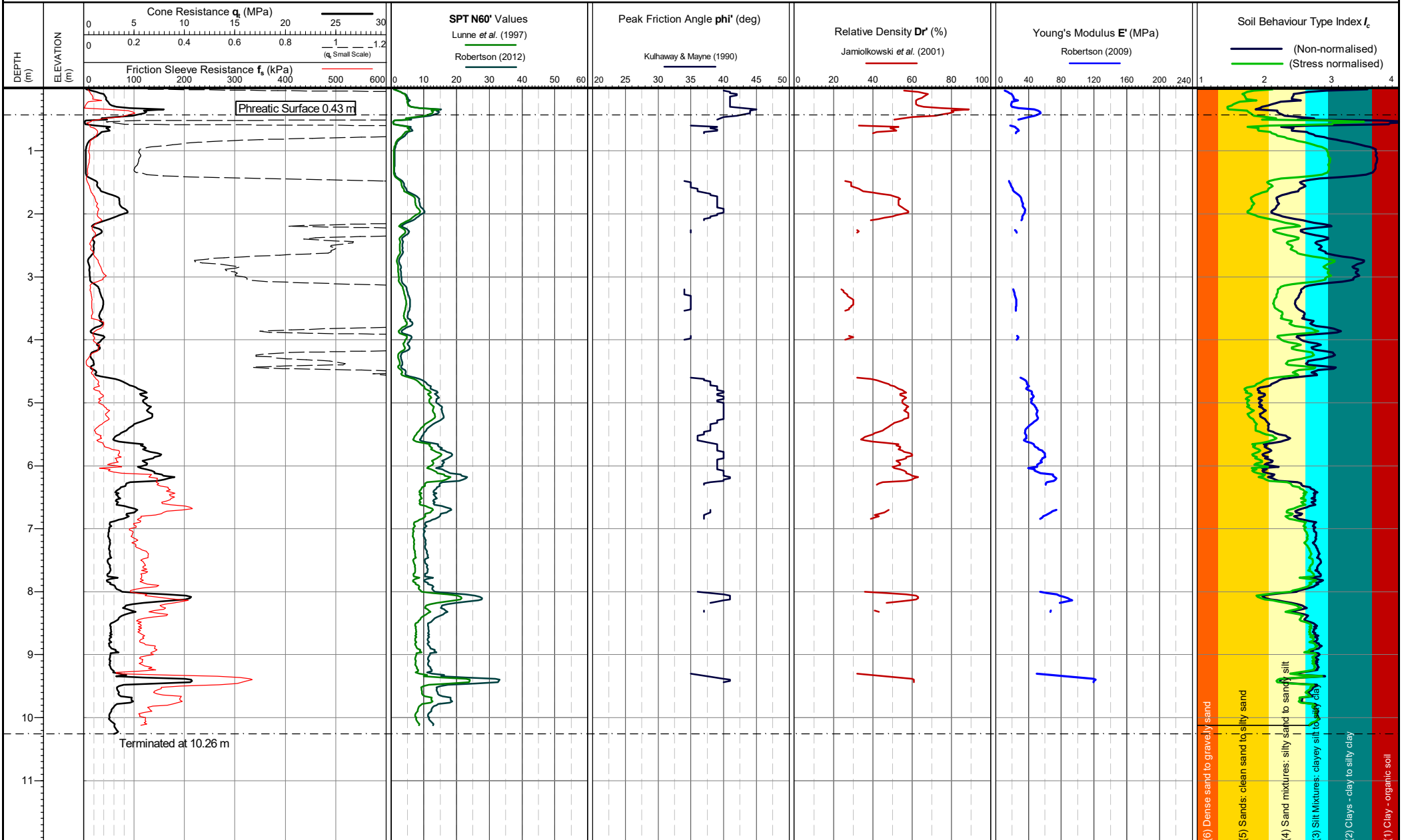
Both drained and undrained
parameters are calculated for mixed
SBTs = I_c 2.40-2.70. See report text
for methods and discussion of
parameter evaluation.

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT02

Page 1 of 1



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Date of test: 03/09/2025 10:17:42

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

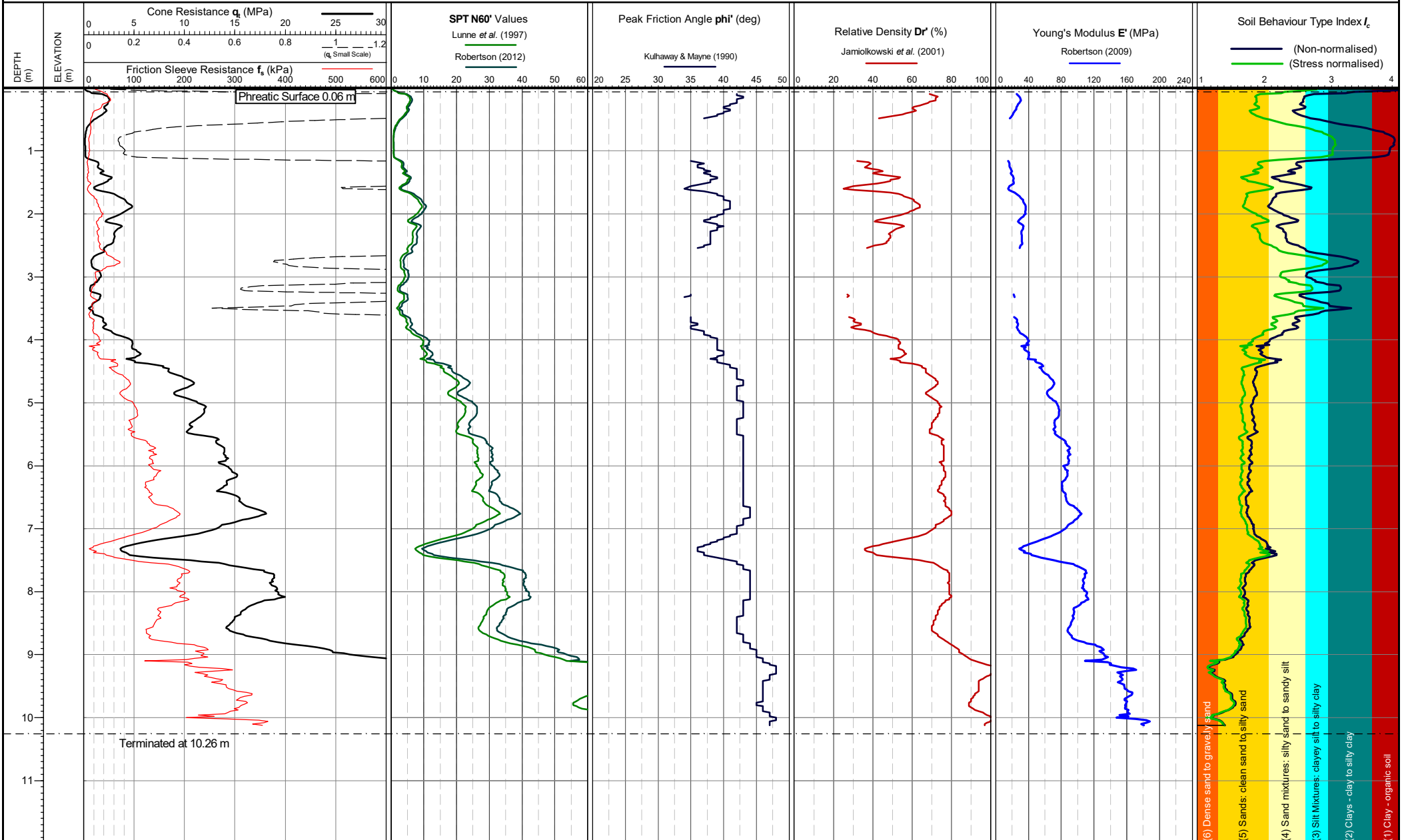
Both drained and undrained
parameters are calculated for mixed
SBTs = I_c 2.40-2.70. See report text
for methods and discussion of
parameter evaluation.

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT03

Page 1 of 1



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Date of test: 03/09/2025 09:33:42

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

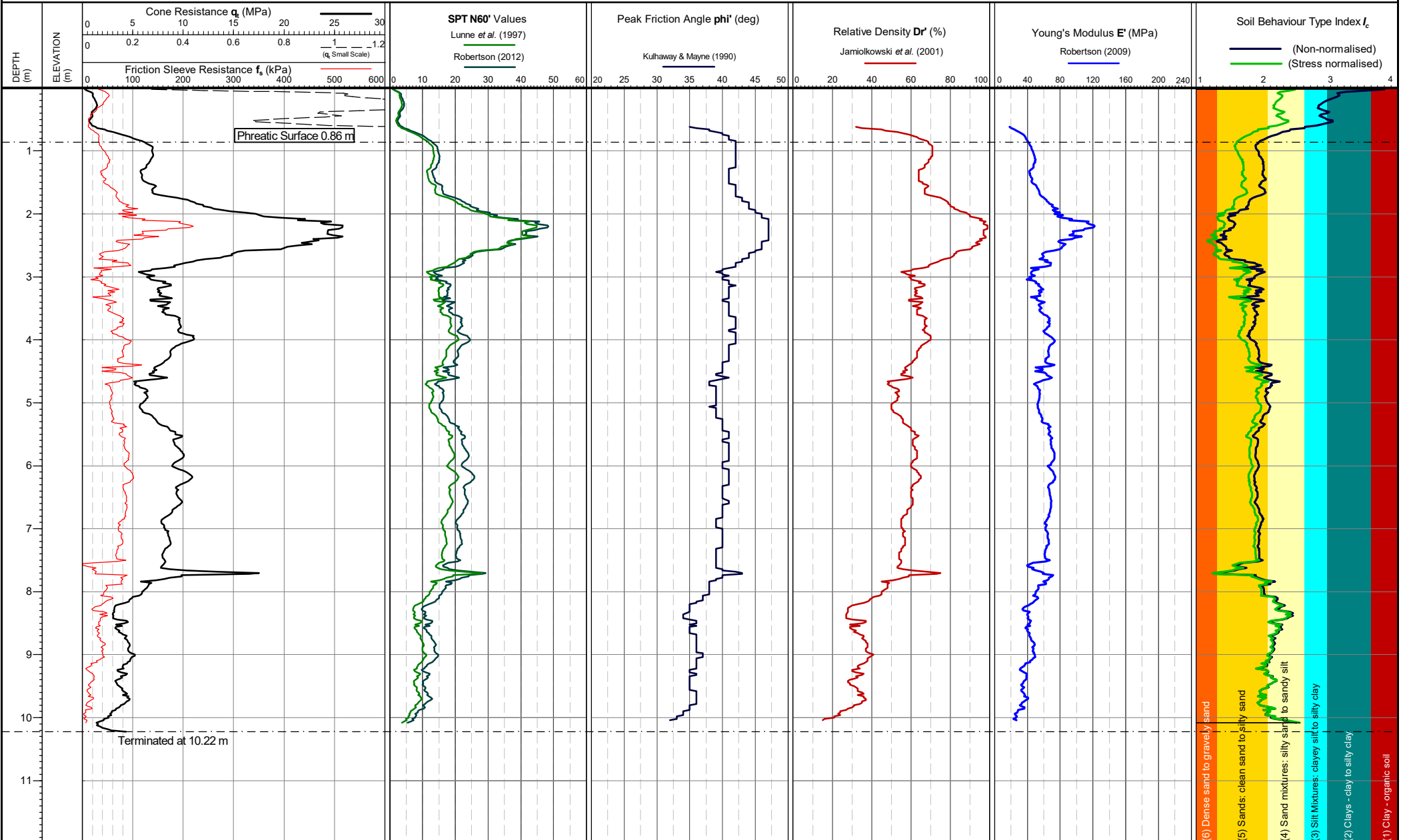
Both drained and undrained
parameters are calculated for mixed
SBTs = I_c 2.40-2.70. See report text
for methods and discussion of
parameter evaluation.

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT04

Page 1 of 1



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Date of test: 03/09/2025 08:44:24

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Both drained and undrained
parameters are calculated for mixed
SBTs = I_c 2.40-2.70. See report text
for methods and discussion of
parameter evaluation.

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT05

Page 1 of 1

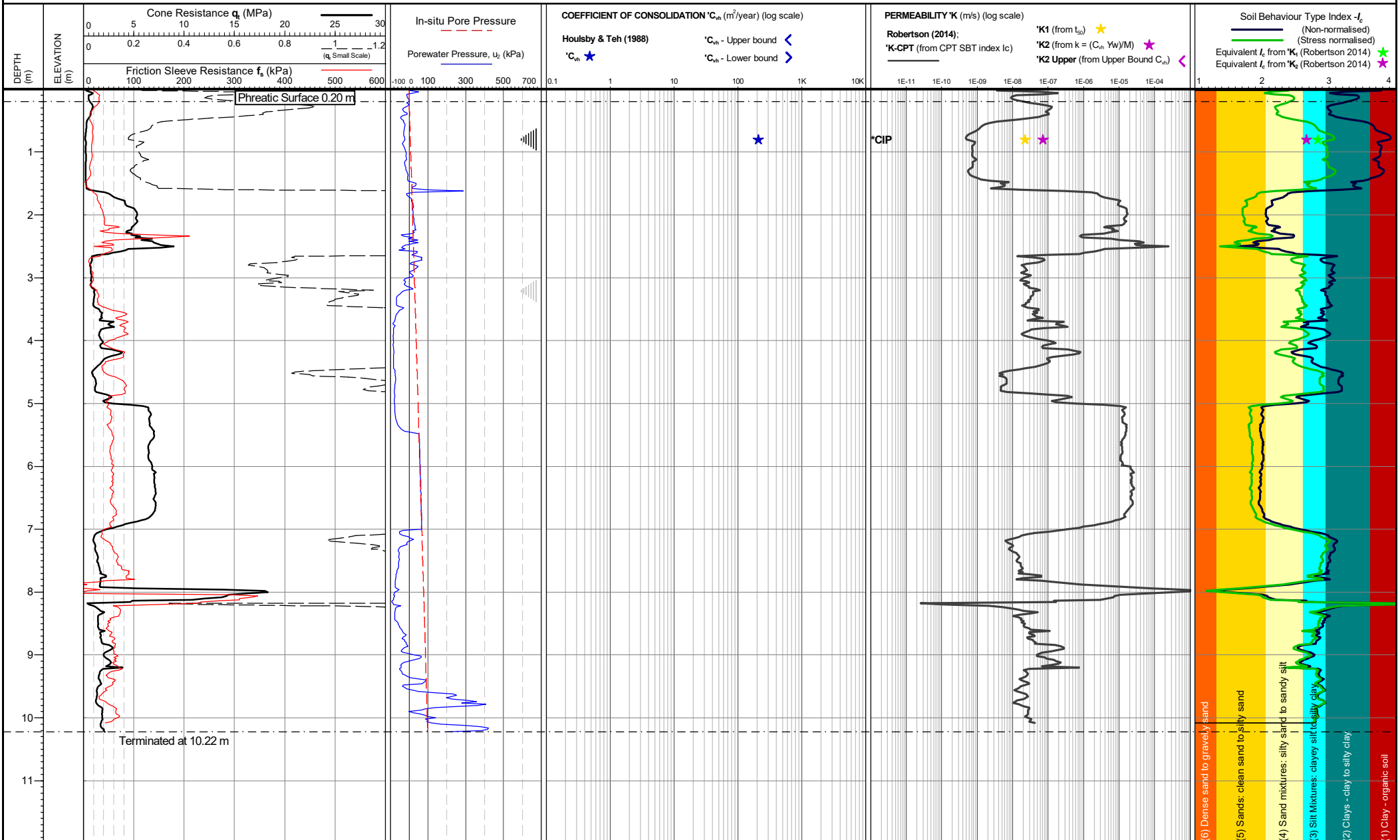
APPENDIX G INTERPRETED DISSIPATION TEST RESULTS

Permeability

Coefficient of consolidation

SBT index (I_c) derived from permeability

Plots are provided for all locations. Interpreted values are only provided for specified dissipation tests or QC dissipation data deemed to be suitable for interpretation.



Cone area (mm²):
 Cone ID: S15-CFIPT.1852
 Operator: Jamie Butterworth
 Date of test: 03/09/2025 12:56:39

Location: Greater Manchester, UK
 Coordinates: ,
 Elevation:
 Coordinate system:

Abbreviations:

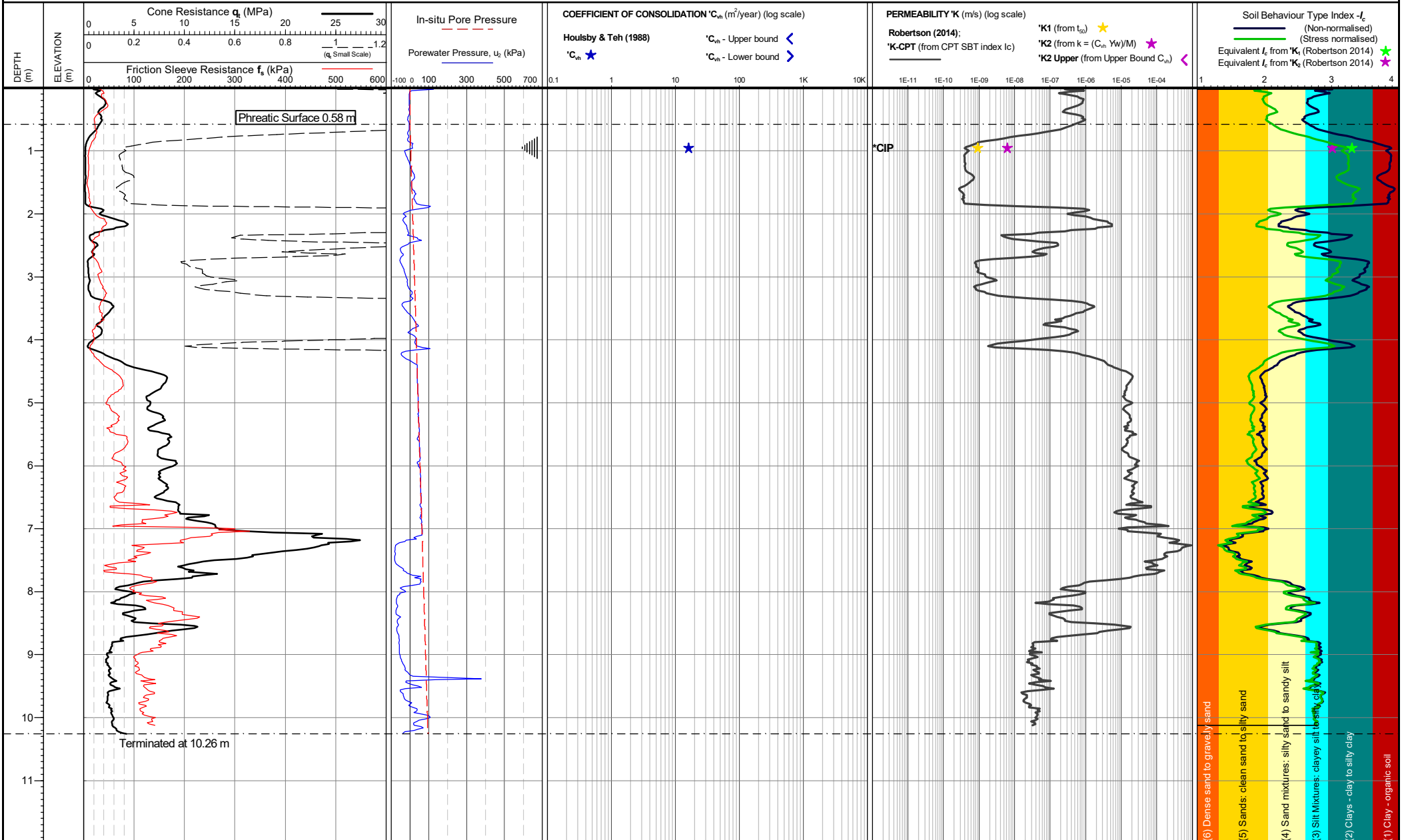
- NEP: No excess pore pressures generated
- ID: Insufficient test duration
- UR: Uncharacteristic response
- DR: Drained or partially drained response
- A: Estimated/measured in-situ pore pressure corresponds to artesian conditions.
- PUS: Potentially unsaturated soil.
- MD: Monotonic decay.
- IEP: Insufficient excess pressure generated.
- LB: Lower bound interpretation.
- DT: Disrupted test.
- NI: No interpretation.
- u_e : Reached equilibrium pressure u_e

Date of plot:
 03-09-25
 Checked by:
 Chris Player

Lankelma Project Ref:
 25-32-30058-1

TEST ID: CPT01

Page 1 of 1



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Date of test: 03/09/2025 10:59:05

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Abbreviations:
NEP: No excess pore pressures generated
ID: Insufficient test duration
UR: Uncharacteristic response
DR: Drained or partially drained response
A: Estimated/measured in-situ pore pressure corresponds to artesian conditions.
PUS: Potentially unsaturated soil.

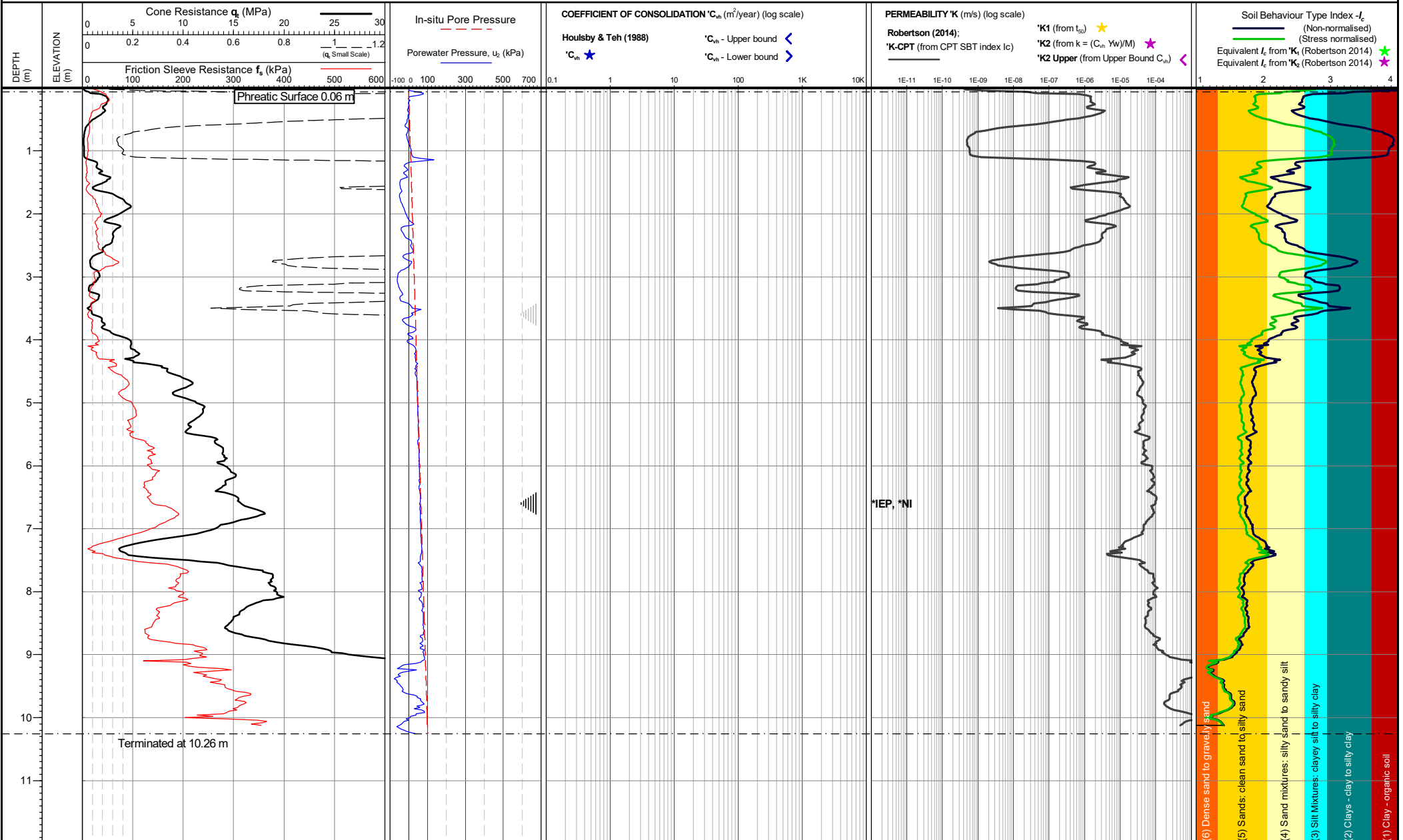
MD: Monotonic decay.
IEP: Insufficient excess pressure generated.
LB: Lower bound interpretation.
DT: Disrupted test.
NI: No interpretation.
 u_e : Reached equilibrium pressure u_e

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT02

Page 1 of 1



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Date of test: 03/09/2025 09:33:42

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Abbreviations:
NEP: No excess pore pressures generated
ID: Insufficient test duration
UR: Uncharacteristic response
DR: Drained or partially drained response
A: Estimated/measured in-situ pore pressure corresponds to artesian conditions.
PUS: Potentially unsaturated soil.

MD: Monotonic decay.
IEP: Insufficient excess pressure generated.
LB: Lower bound interpretation.
DT: Disrupted test.
NI: No interpretation.
 u_e : Reached equilibrium pressure u_e

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT04

Page 1 of 1

APPENDIX H DISSIPATION TEST CURVES & GRAPHICAL ANALYSIS

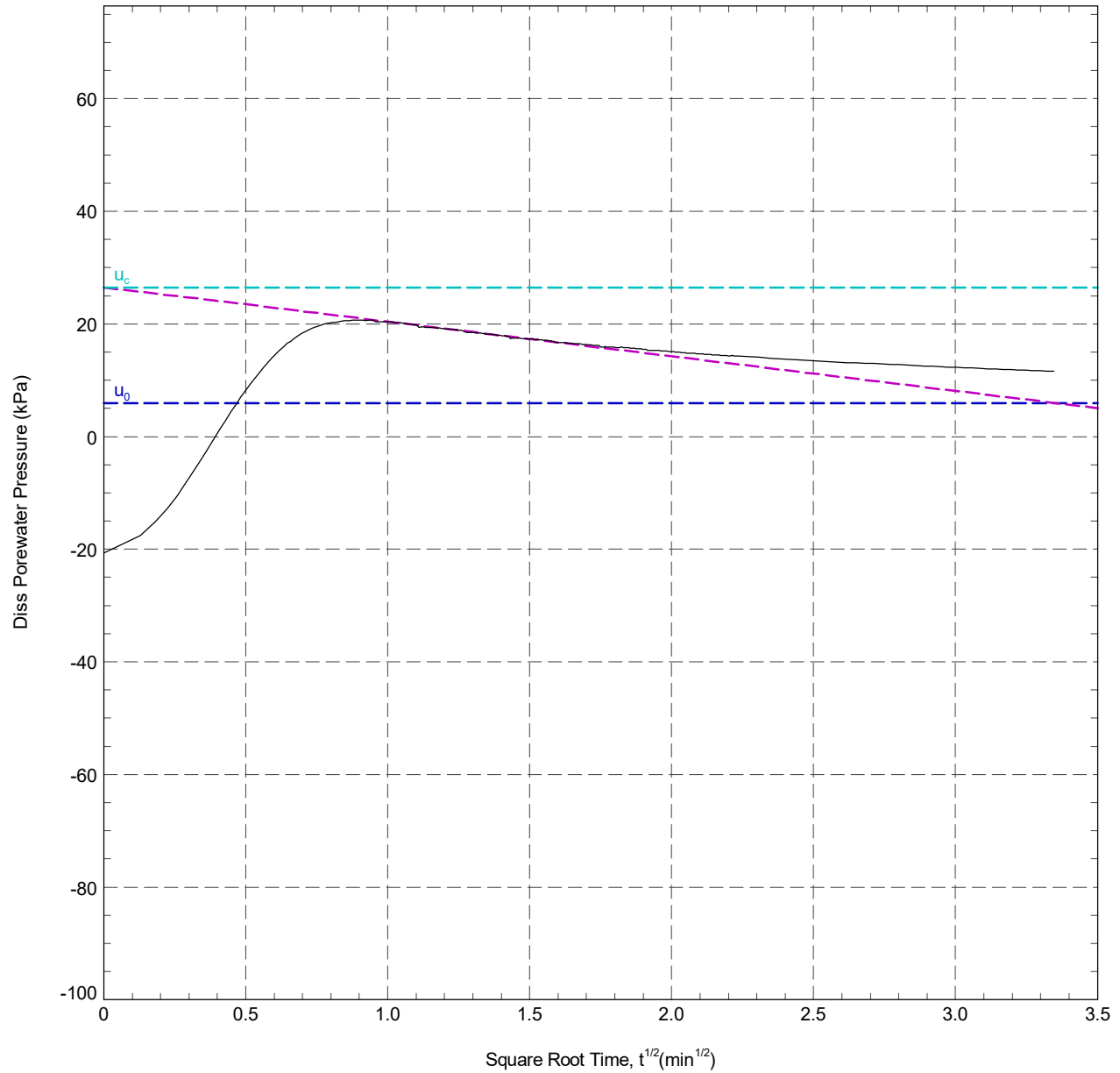
Test ID

CPT01 - 0.80 m

CLIENT : REFA
 PROJECT : ROCHDALE
 LOCATION : Greater Manchester, UK
 PROJECT No. : 25-32-30058-1

EASTING :
 NORTHING :
 COORD. SYS.:
 ELEVATION :

SHEET : 1 OF 1
 DATE : 03/09/25



RIG : UK20_
 CONE ID : S15-CFIPT.1852
 OPERATOR : Jamie Butterworth

REMARK
 *CIP

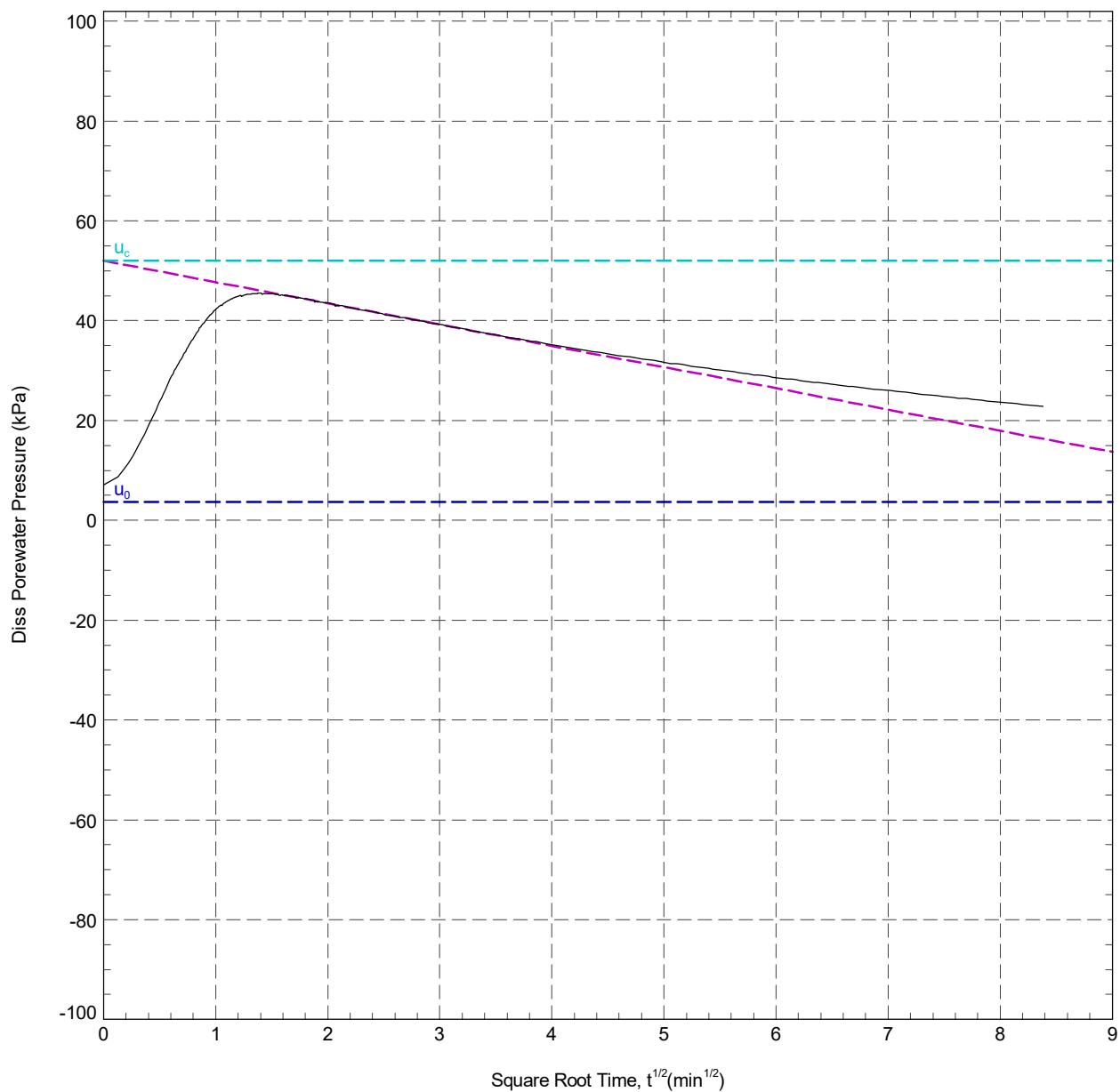
Test ID

CPT02 - 0.95 m

CLIENT : REFA
 PROJECT : ROCHDALE
 LOCATION : Greater Manchester, UK
 PROJECT No. : 25-32-30058-1

EASTING :
 NORTHING :
 COORD. SYS.:
 ELEVATION :

SHEET : 1 OF 1
 DATE : 03/09/25



RIG : UK20_
 CONE ID : S15-CFIPT.1852
 OPERATOR : Jamie Butterworth

REMARK
 *CIP

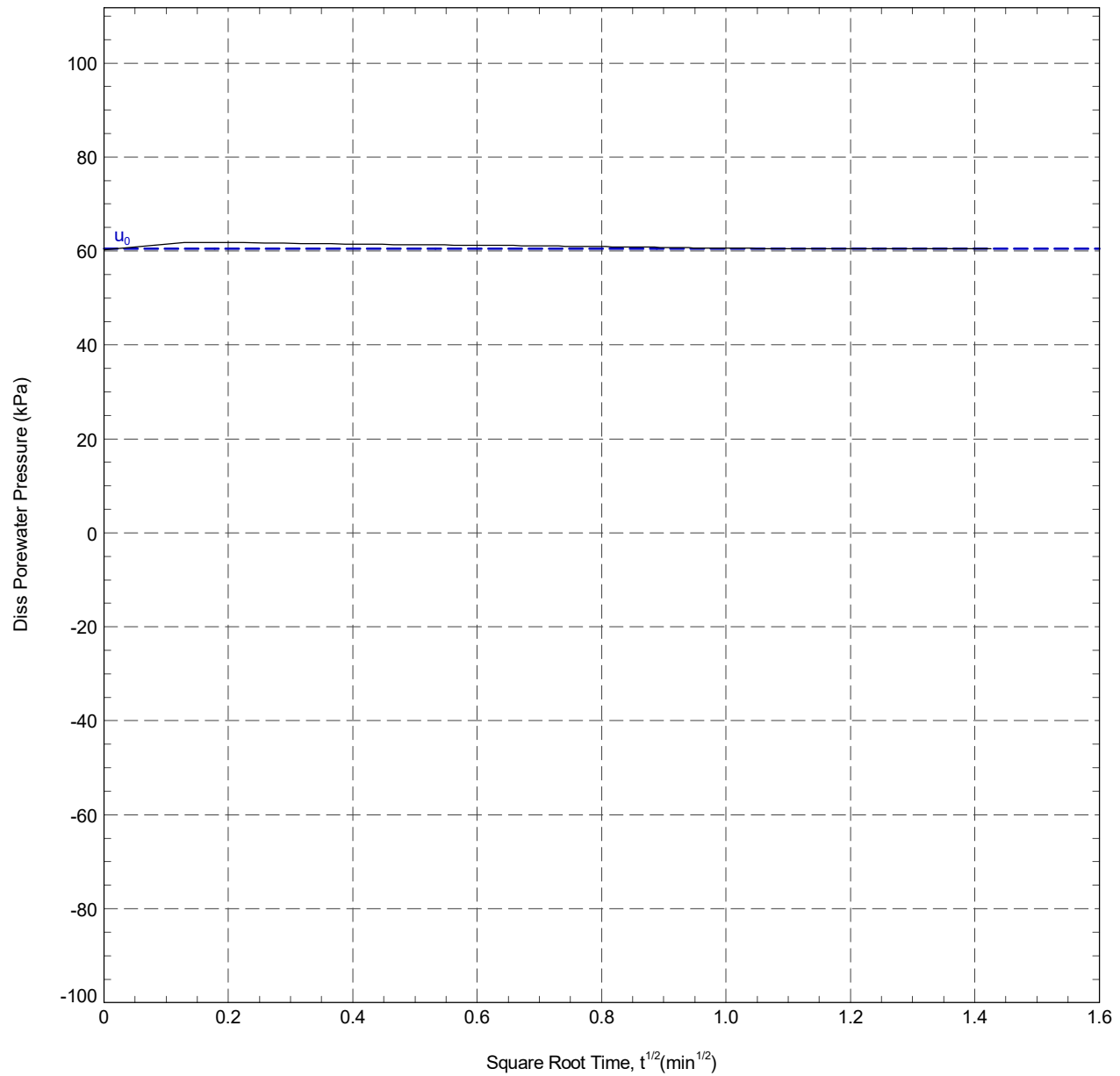
Test ID

CPT04 - 6.60 m

CLIENT : REFA
 PROJECT : ROCHDALE
 LOCATION : Greater Manchester, UK
 PROJECT No. : 25-32-30058-1

EASTING :
 NORTHING :
 COORD. SYS.:
 ELEVATION :

SHEET : 1 OF 1
 DATE : 03/09/25



In Situ Pore Pressure, u_0 : 60.50

RIG : UK20_
 CONE ID : S15-CFIPT.1852
 OPERATOR : Jamie Butterworth

REMARK
 *IEP, *NI

APPENDIX I PENETROMETER TEMPERATURE RESULTS

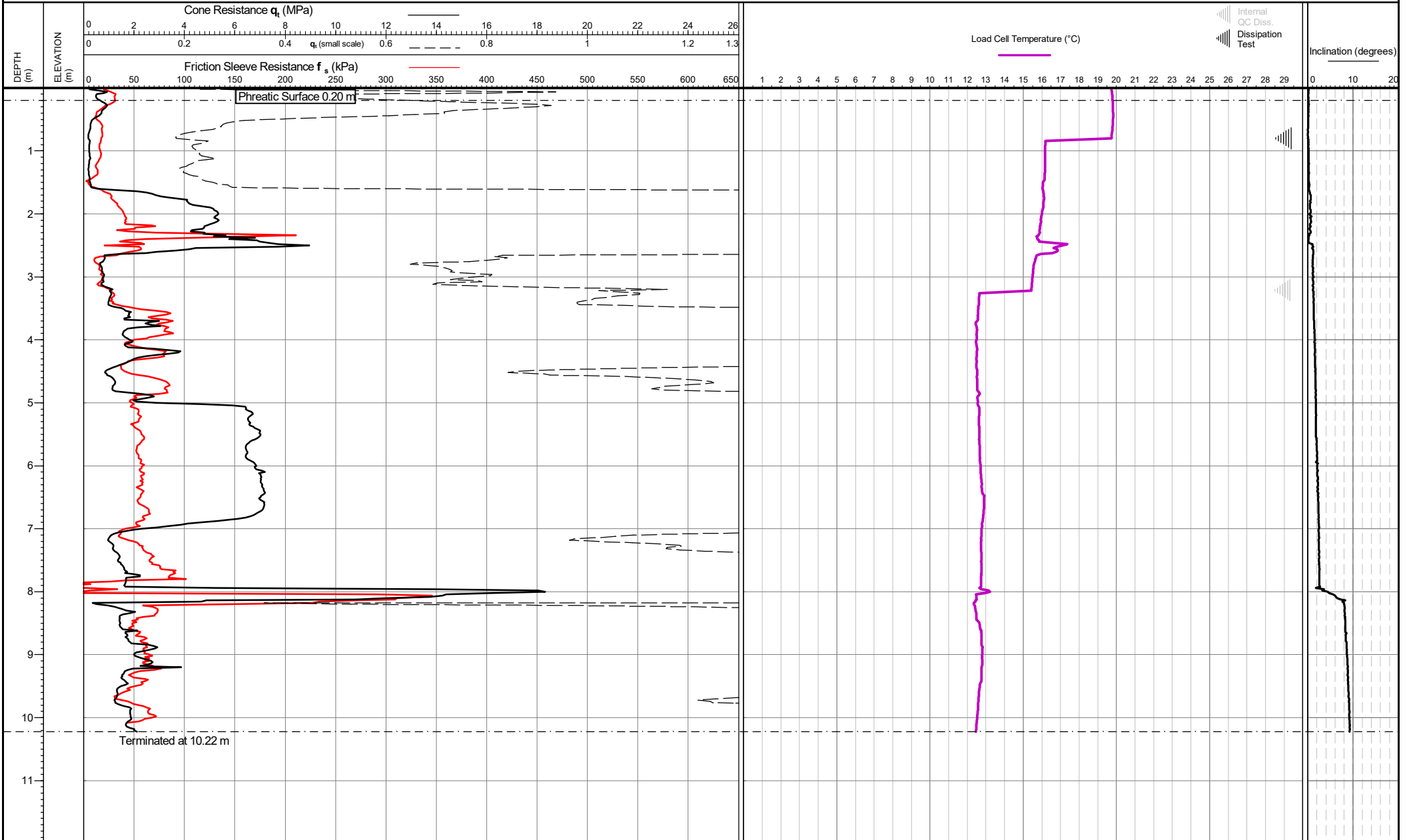
The logs of this Appendix present the recorded temperature of the penetrometer tip load cell. The data is used for QC purposes during fieldwork and post processing, and the reader may compare the data to the temperature verification section of the corresponding calibration certificate. The data has been used during post processing to correct the tip and pore pressure results for transient and static temperature effects.

Note:

Ground temperature is only represented within 0.5 degrees of the true value following a penetration pause of 20-50 minutes, depending on the thermal properties of the soil.

Plots will not be provided for tests performed with magnetometer readings.

Near horizontal lines (steps) in the temperature plots indicate change in temperature during a pause in penetration.



Cone area (mm²):
Cone ID: S15-CFPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 12:56:39

Zero drift (Pre/post test)
 q_e (kPa): -26.2
 f_s (kPa): -0.3
 u_z (kPa): 0.1

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks:
*Phreatic surface origin: Piezocone response in drained soils
Termination Remark: Target depth

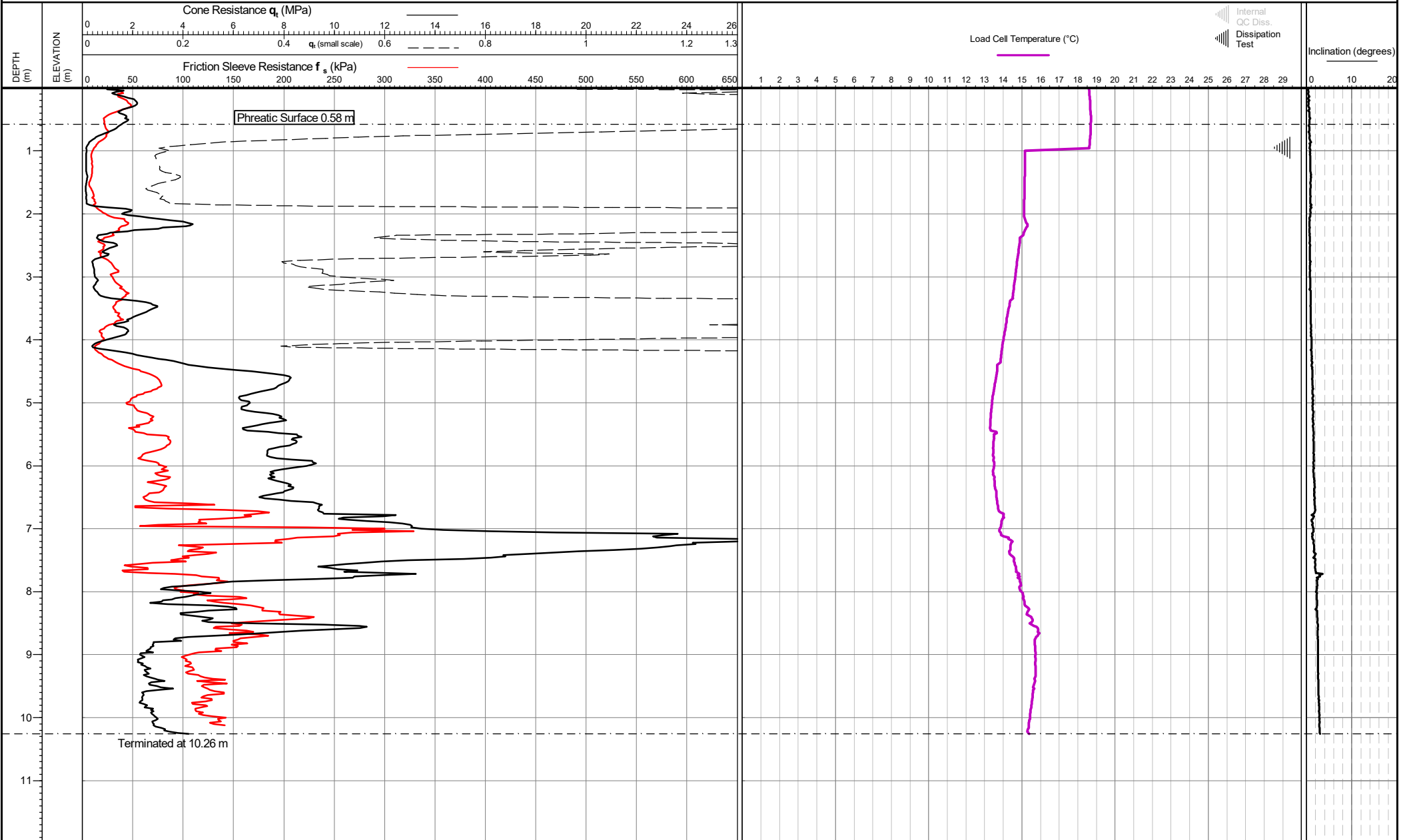
Date of plot: 03-09-25
Lankelma Project Ref: 25-32-30058-1
Checked by: Chris Player

TEST ID: CPT01



Project: ROCHDALE

Client: REFA



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 10:59:05

Zero drift (Pre/post test)
 q_t (kPa): 18.2
 f_s (kPa): 0.1
 u_z (kPa): 0.0

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

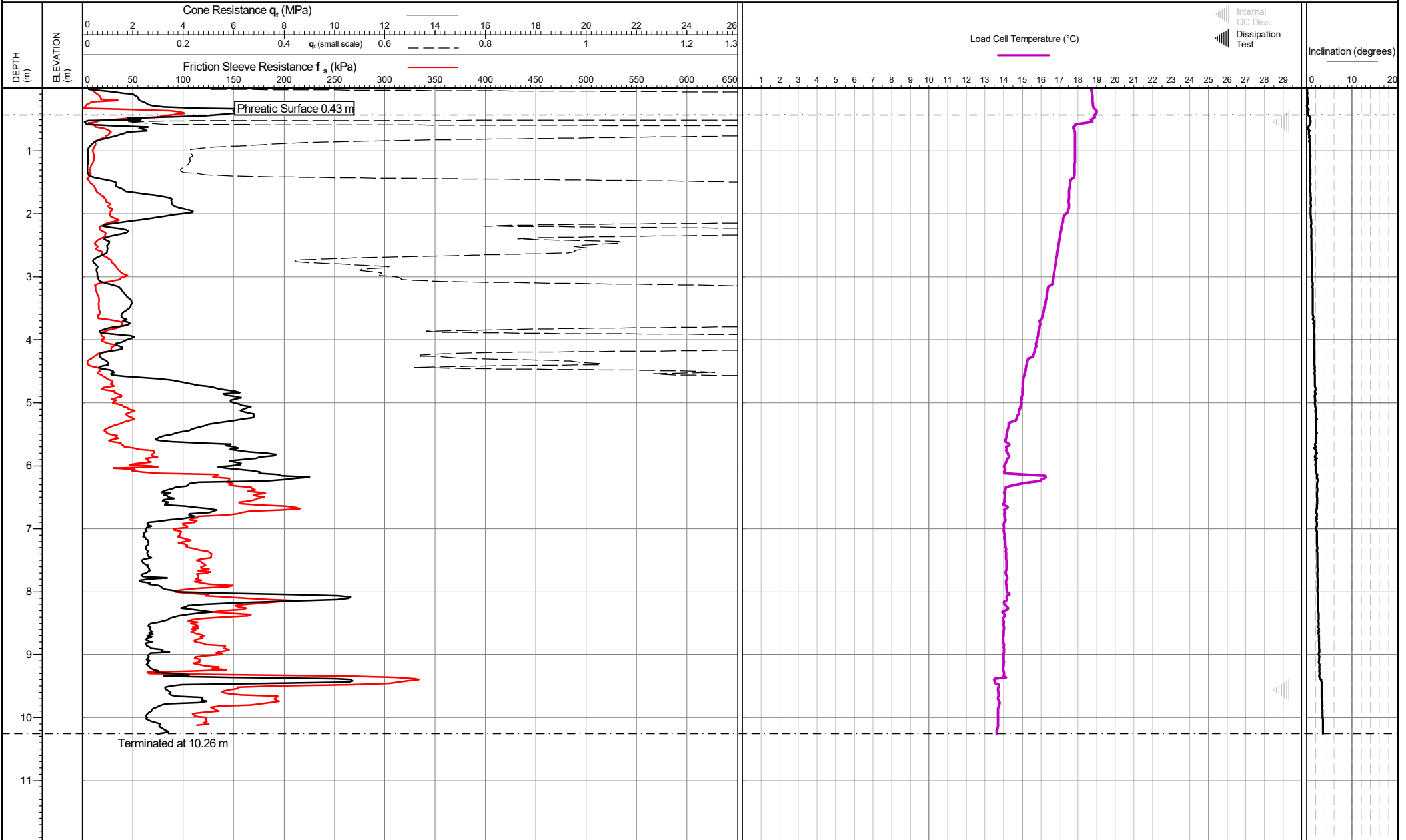
Remarks:
*Phreatic surface origin: Piezocone response in drained soils
Termination Remark: Target depth

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT02

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Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 10:17:42

Zero drift (Pre/post test)
 q_e (kPa): 18.2
 f_s (kPa): 0.1
 u_z (kPa): 0.0

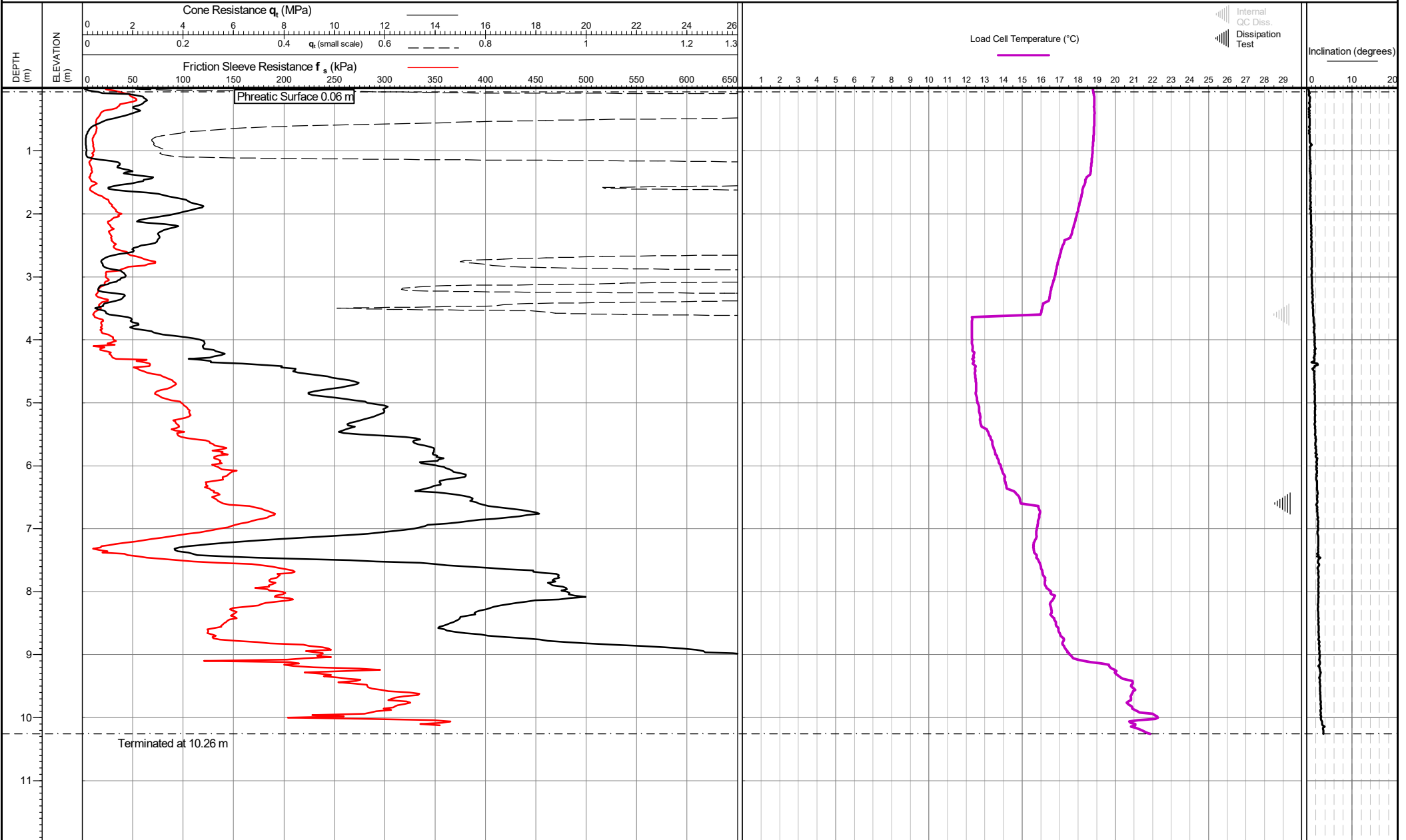
Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks:
*Phreatic surface origin: Average measured piezometric depth from other location(s)
Termination Remark: Target depth

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT03



Cone area (mm²):
Cone ID: S15-CFPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 09:33:42

Zero drift (Pre/post test)
 q_e (kPa): 18.2
 f_s (kPa): 0.1
 u_z (kPa): 0.0

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks:
*Phreatic surface origin: Piezocone response in drained soils, approx. ± 0.6 mbgl
Termination Remark: Target depth

Date of plot:
03-09-25
Checked by:
Chris Player

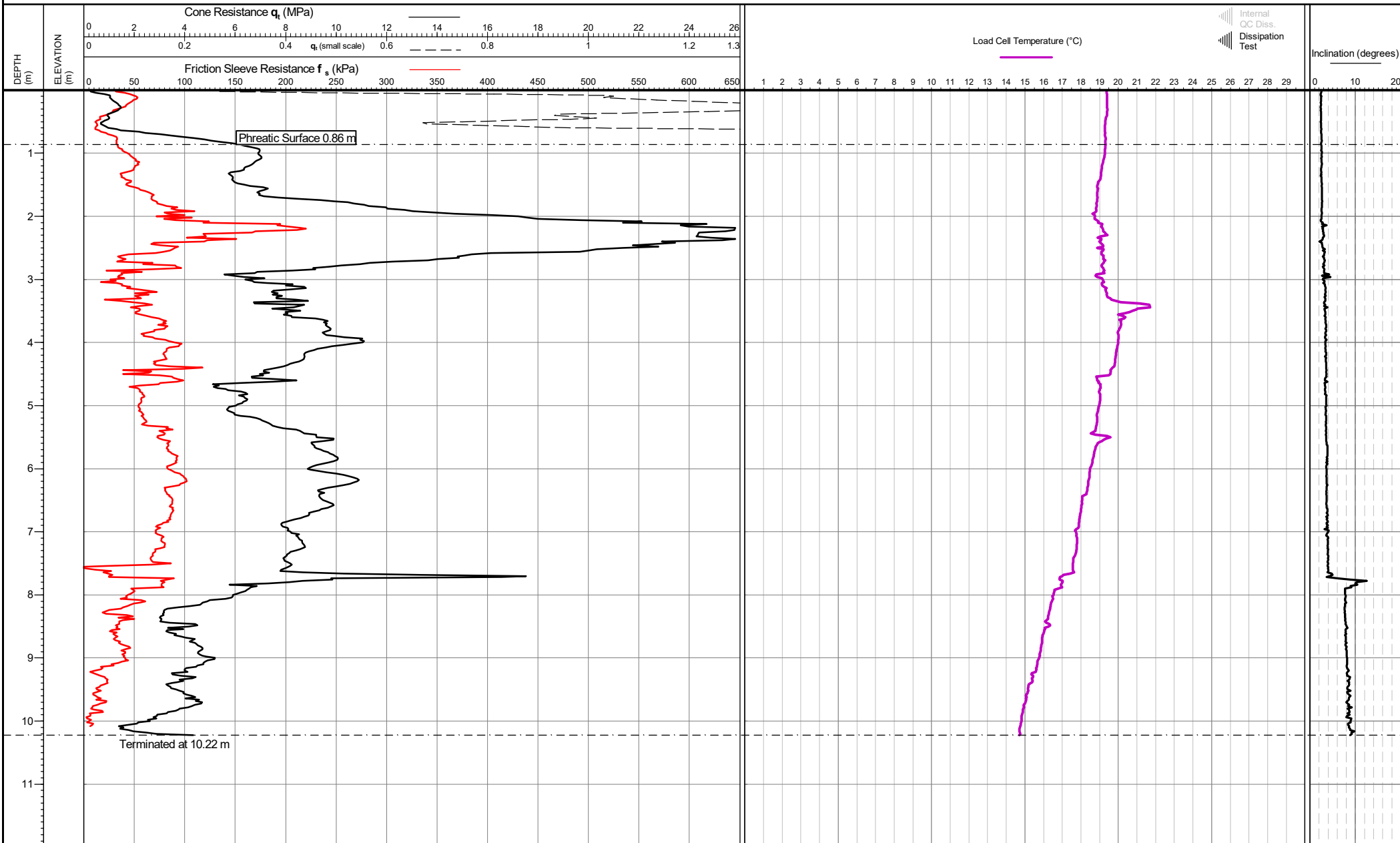
Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT04



Project: ROCHDALE

Client: REFA



Cone area (mm²):
Cone ID: S15-CFIPT.1852
Operator: Jamie Butterworth
Rig Used: UK20
Date of test: 03/09/2025 08:44:24

Zero drift (Pre/post test)
 q_0 (kPa): -9.6
 f_0 (kPa): 1.2
 u_z (kPa): 0.2

Location: Greater Manchester, UK
Coordinates: ,
Elevation:
Coordinate system:

Remarks:
*Phreatic surface origin: Piezocone response in drained soils
Termination Remark: Target depth

Date of plot:
03-09-25
Checked by:
Chris Player

Lankelma Project Ref:
25-32-30058-1

TEST ID: CPT05

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