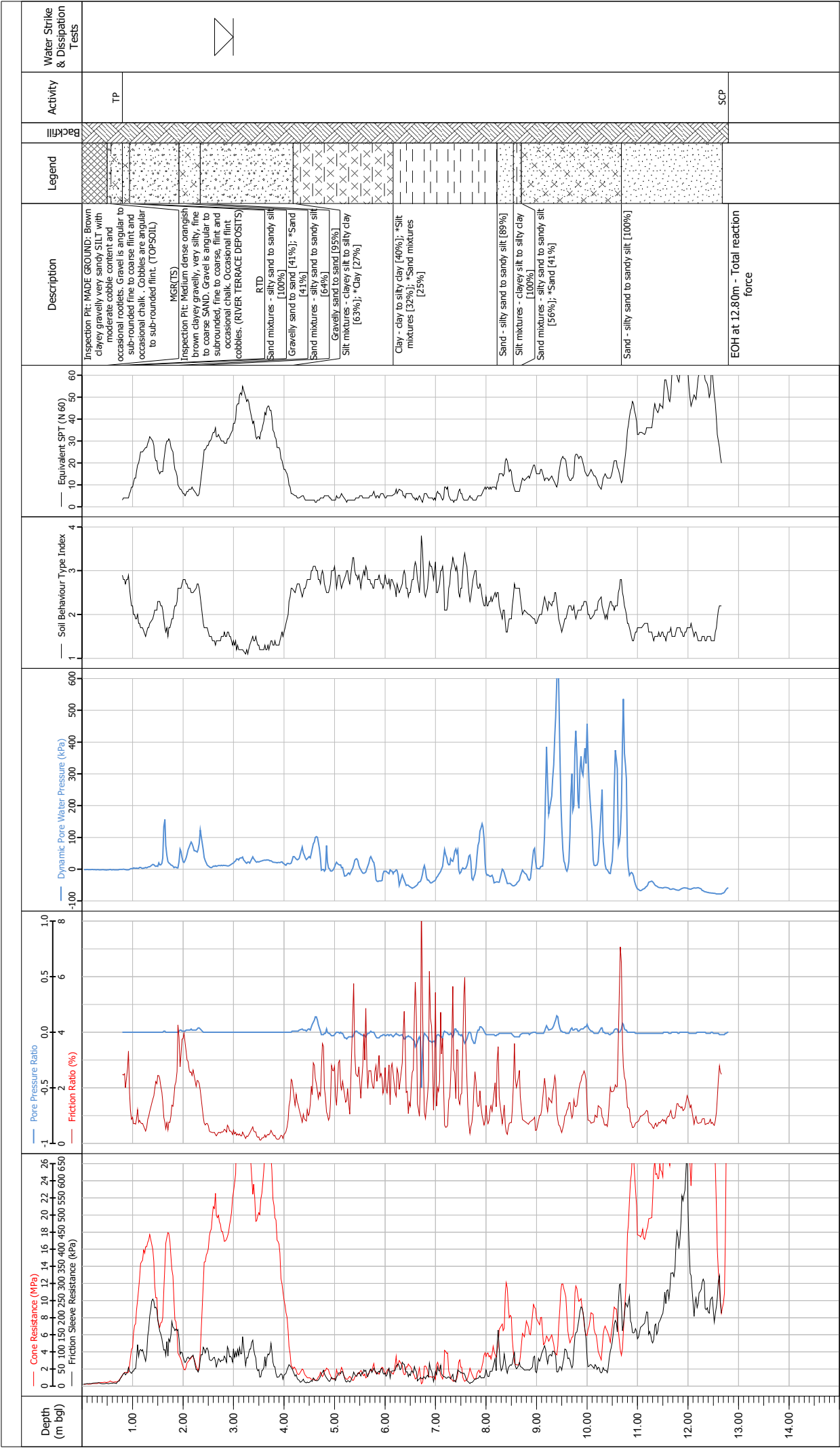


APPENDIX D: CPT LOGS AND REPORT



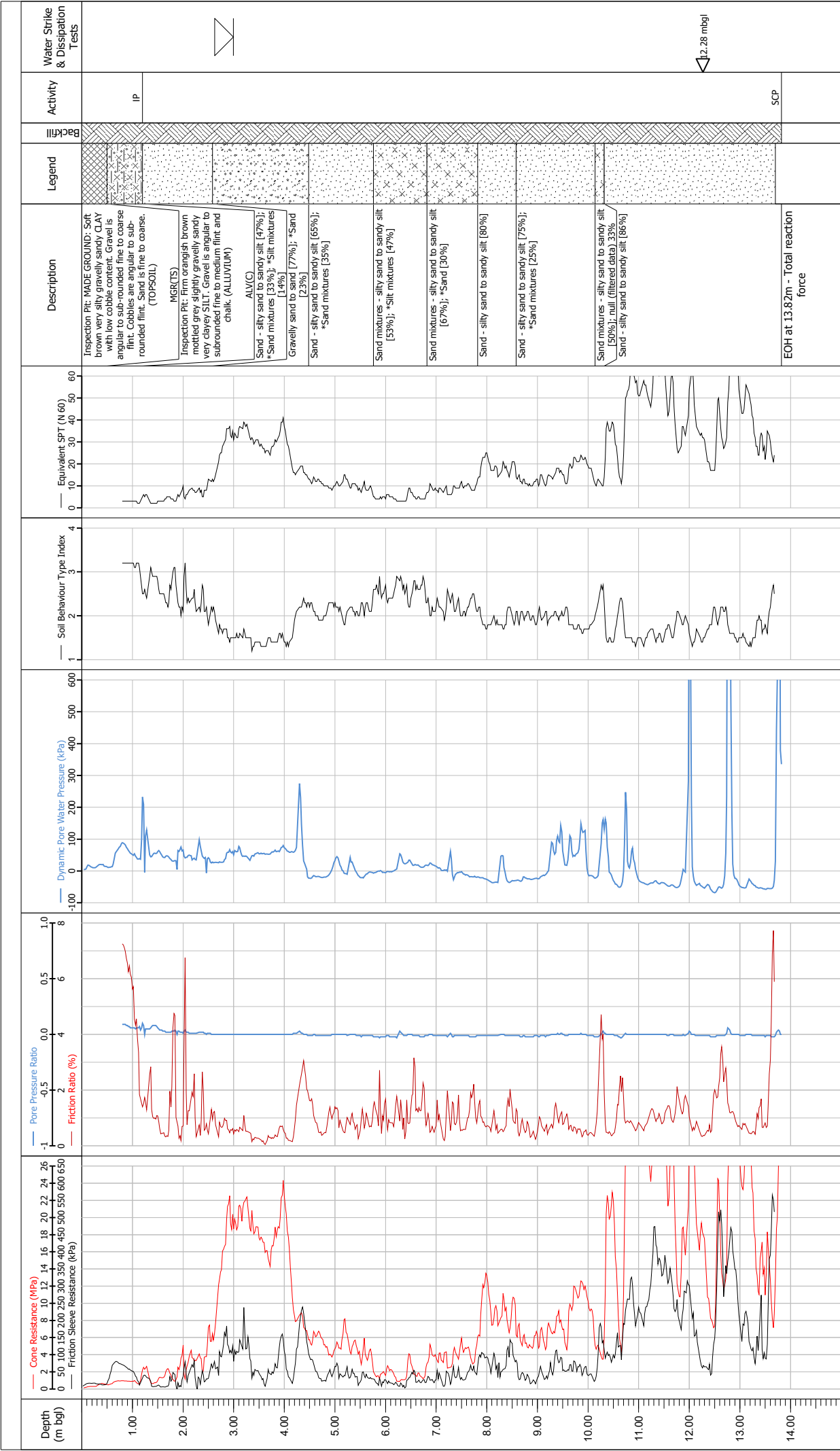
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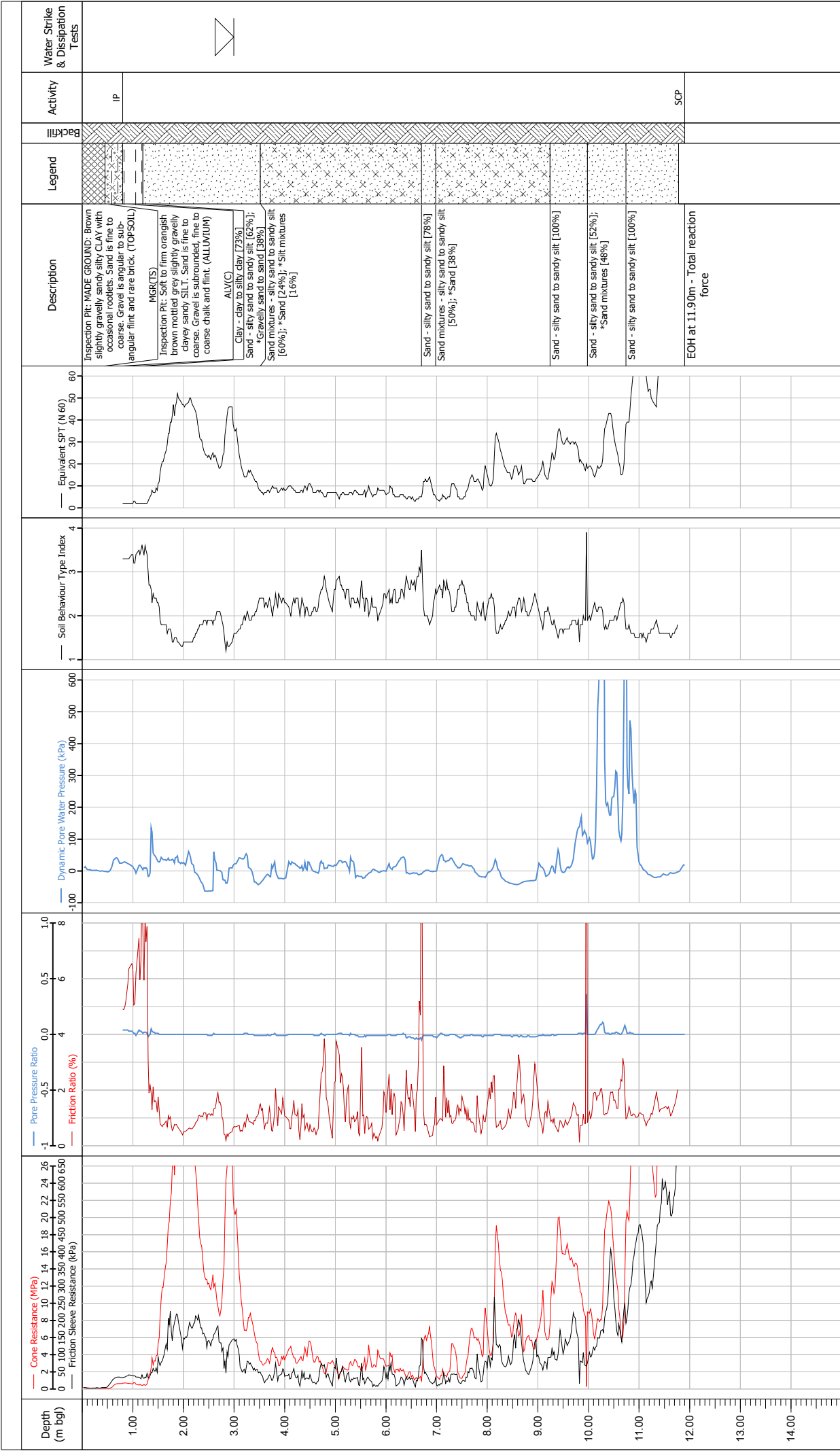
TETRA TECH

01623 684550

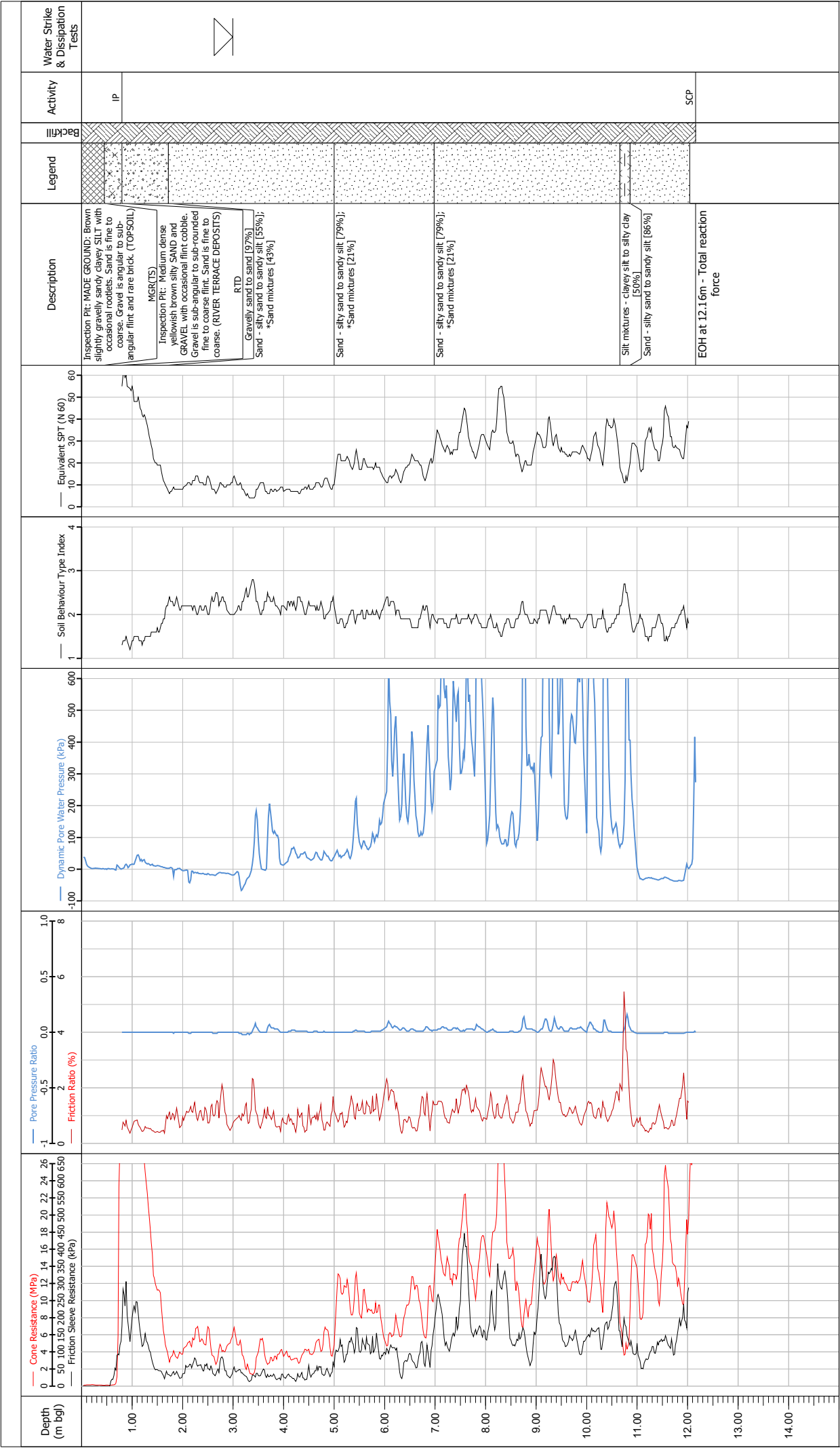
www.tetrateteurope.com



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		Date Finish:											



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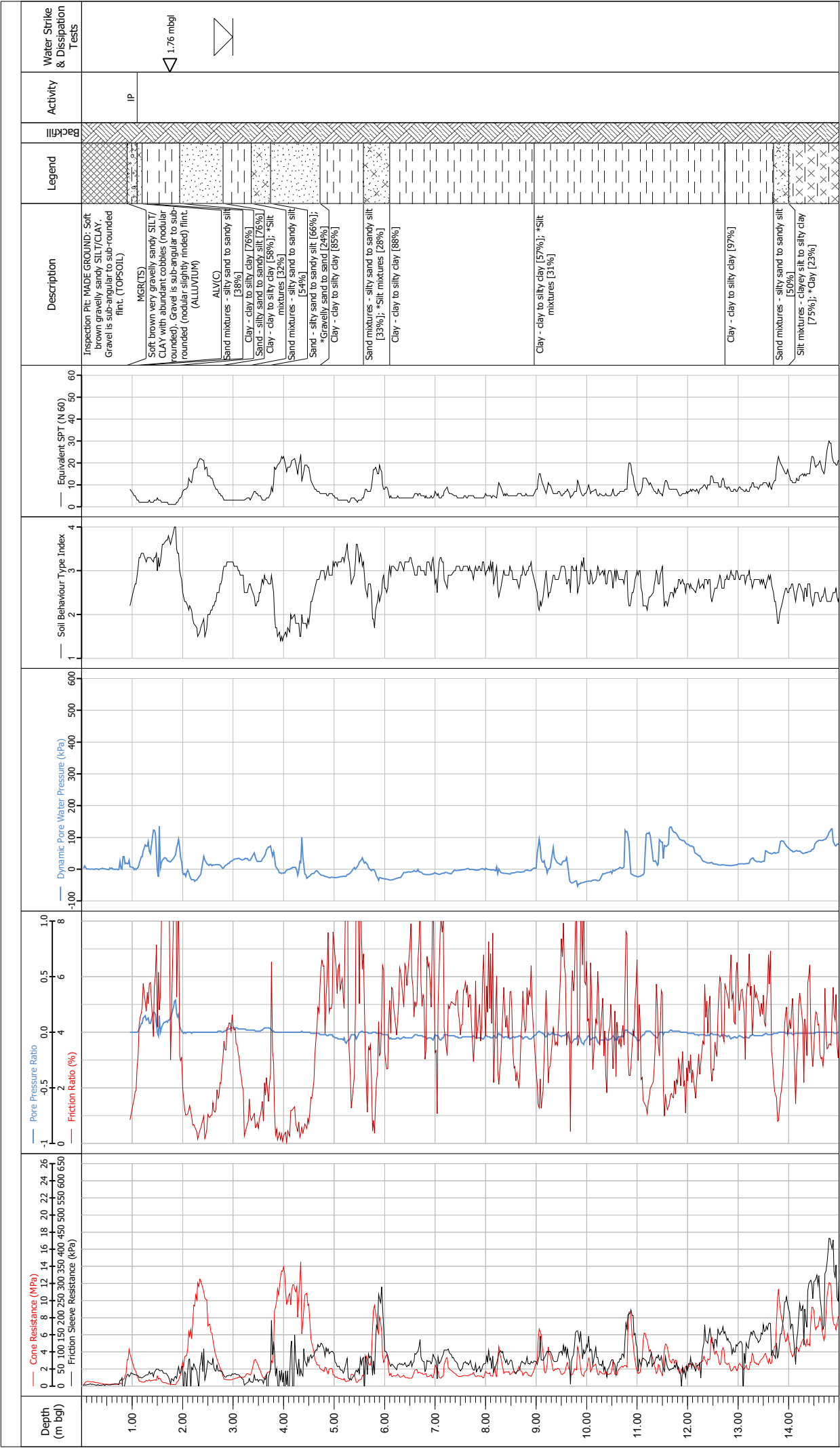


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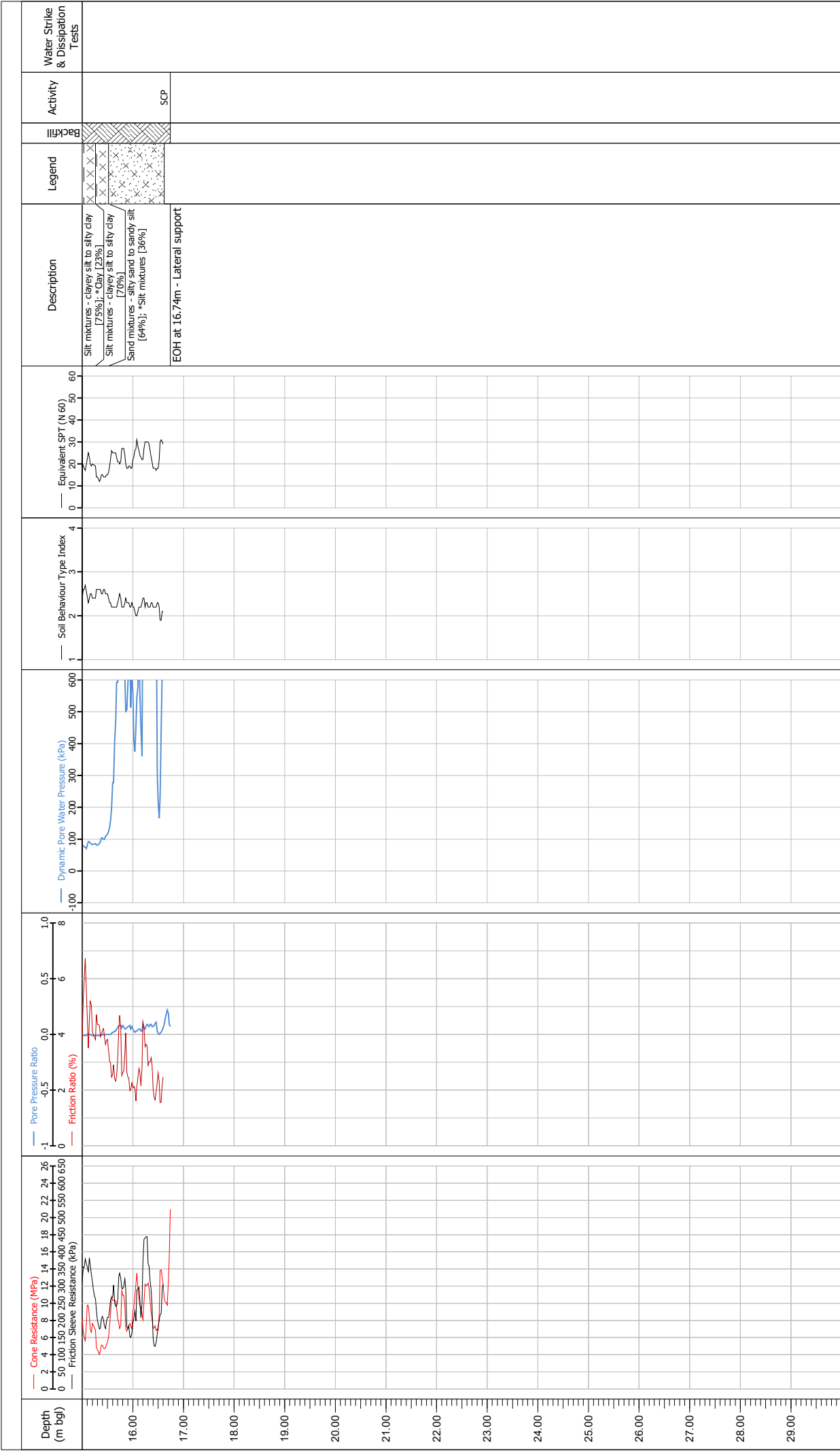


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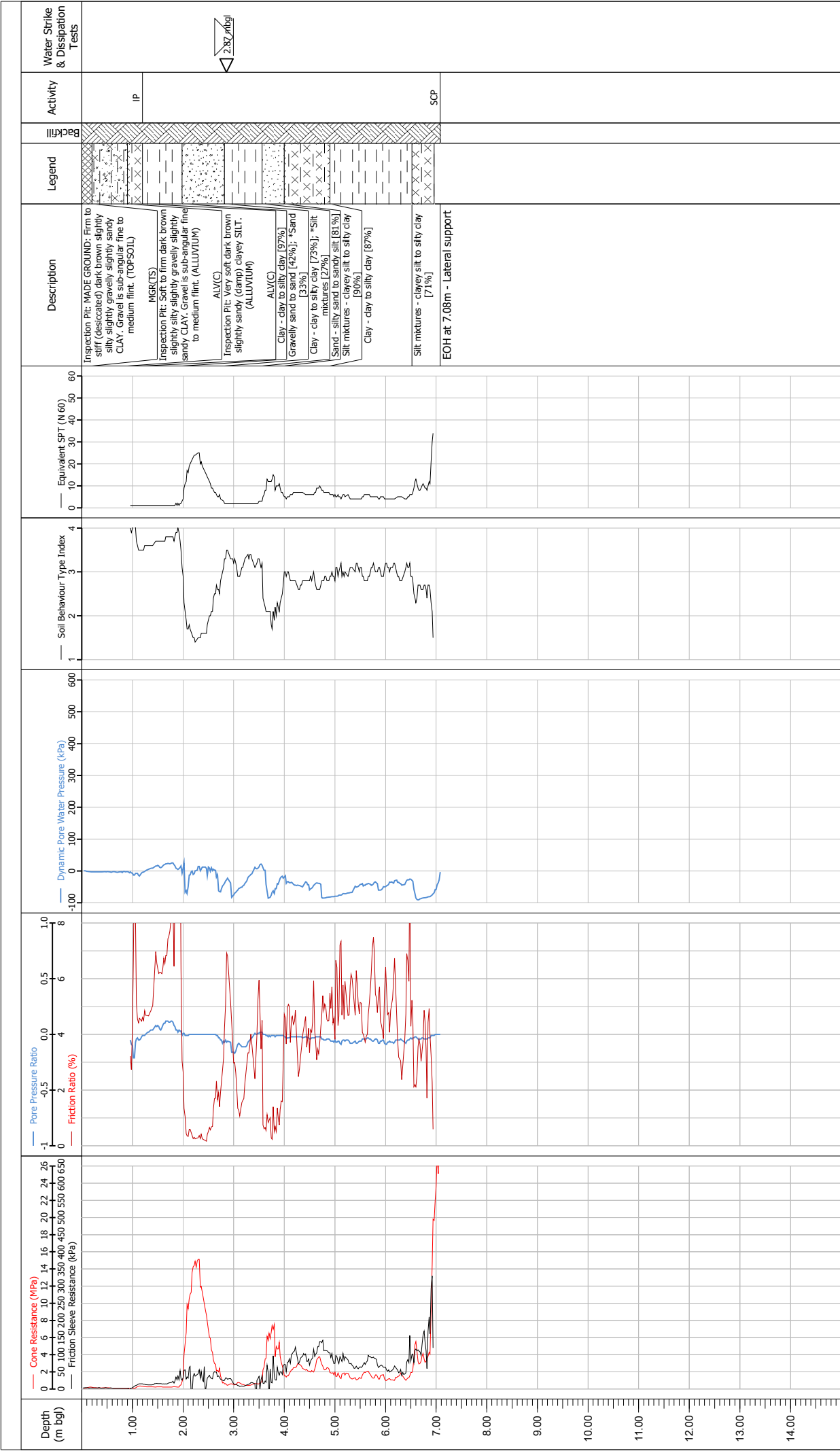




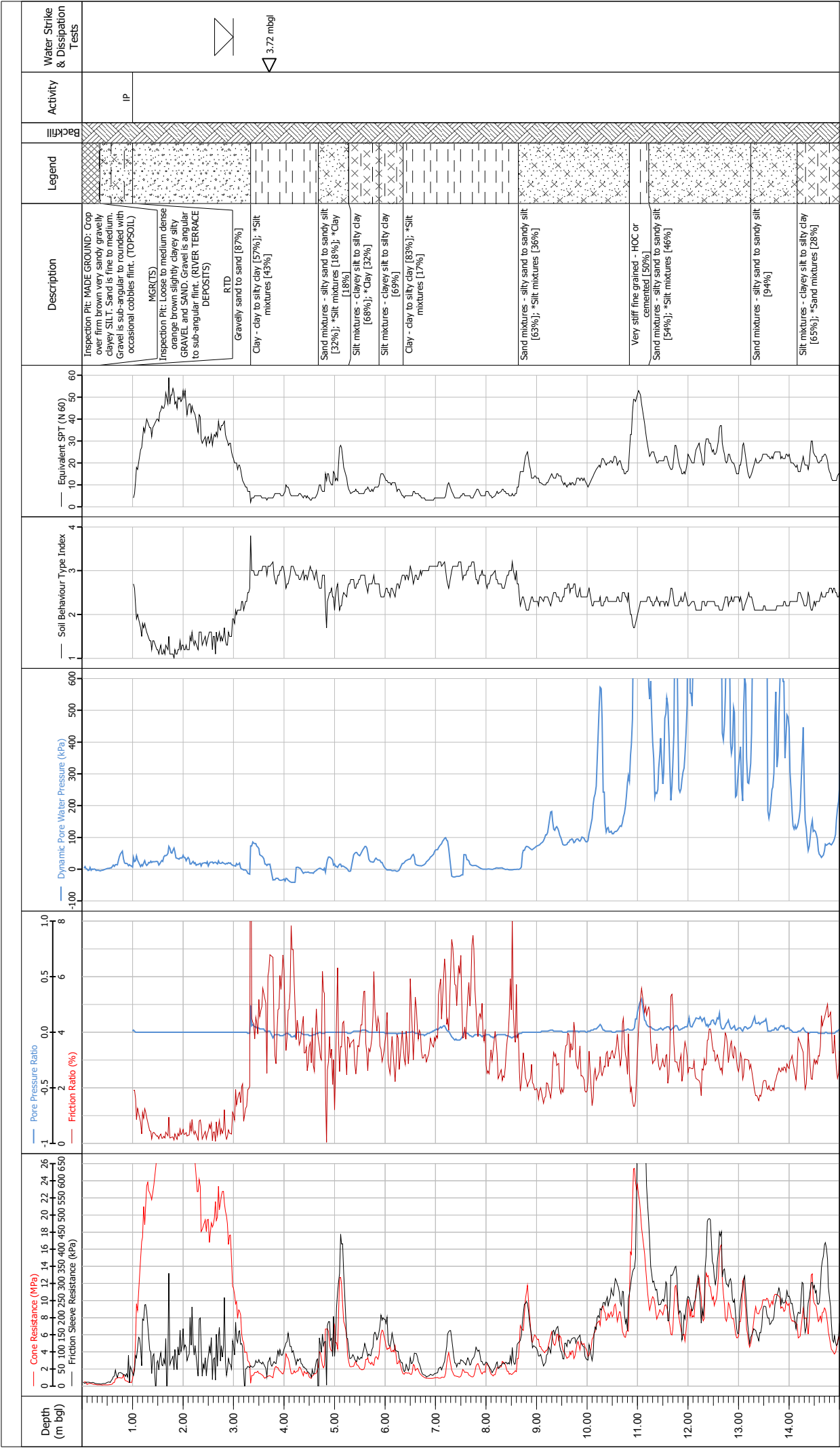
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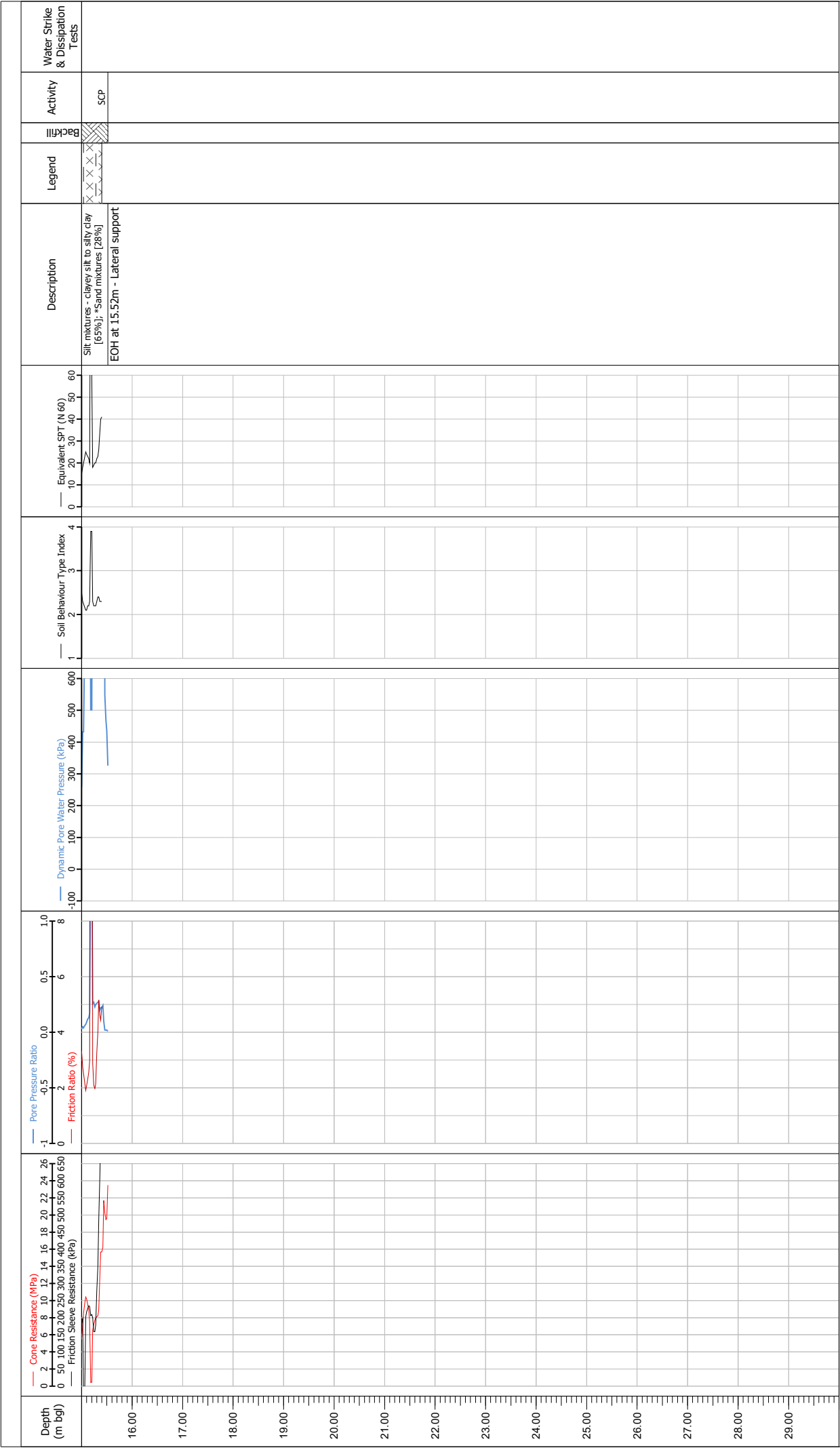


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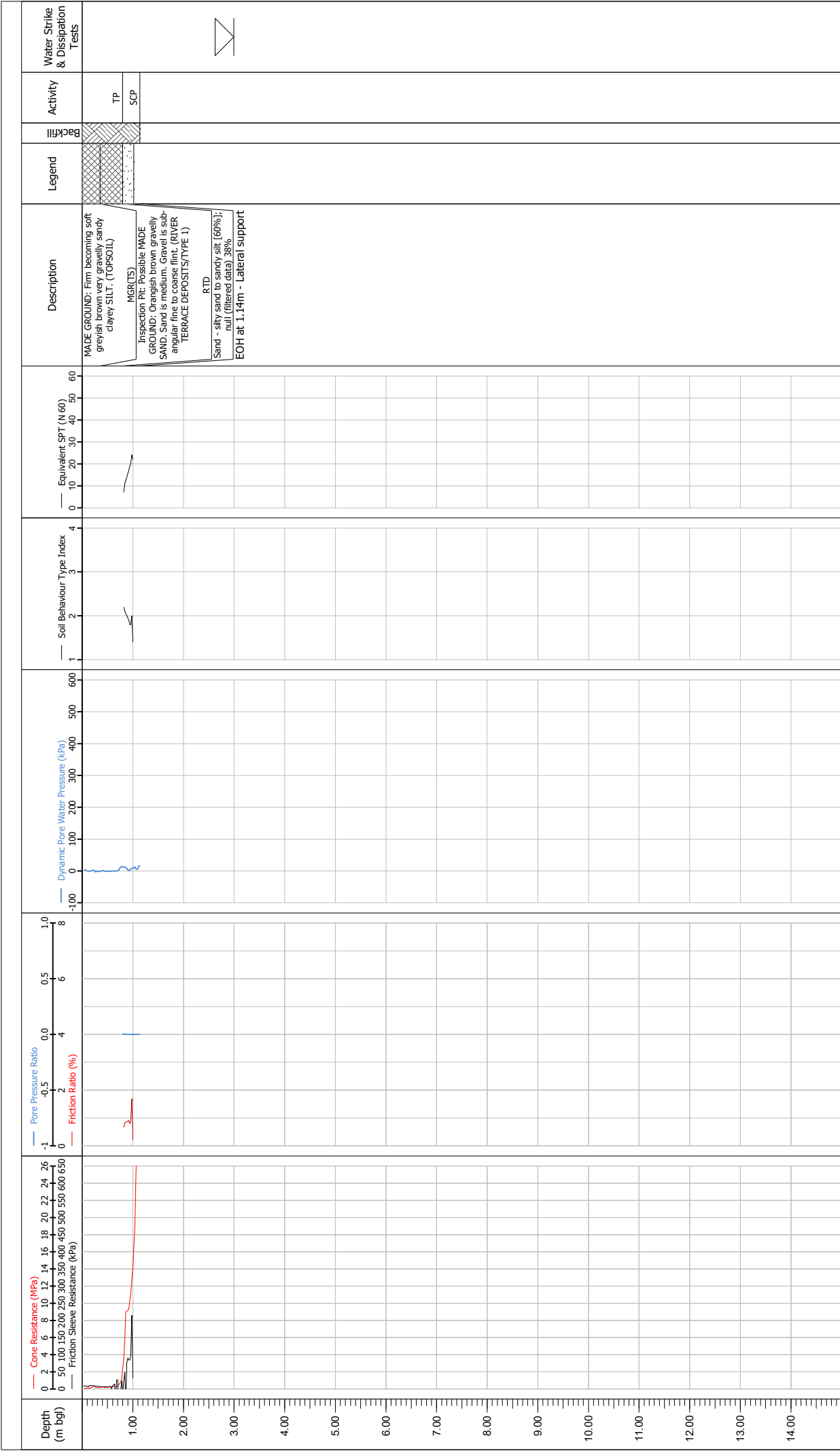


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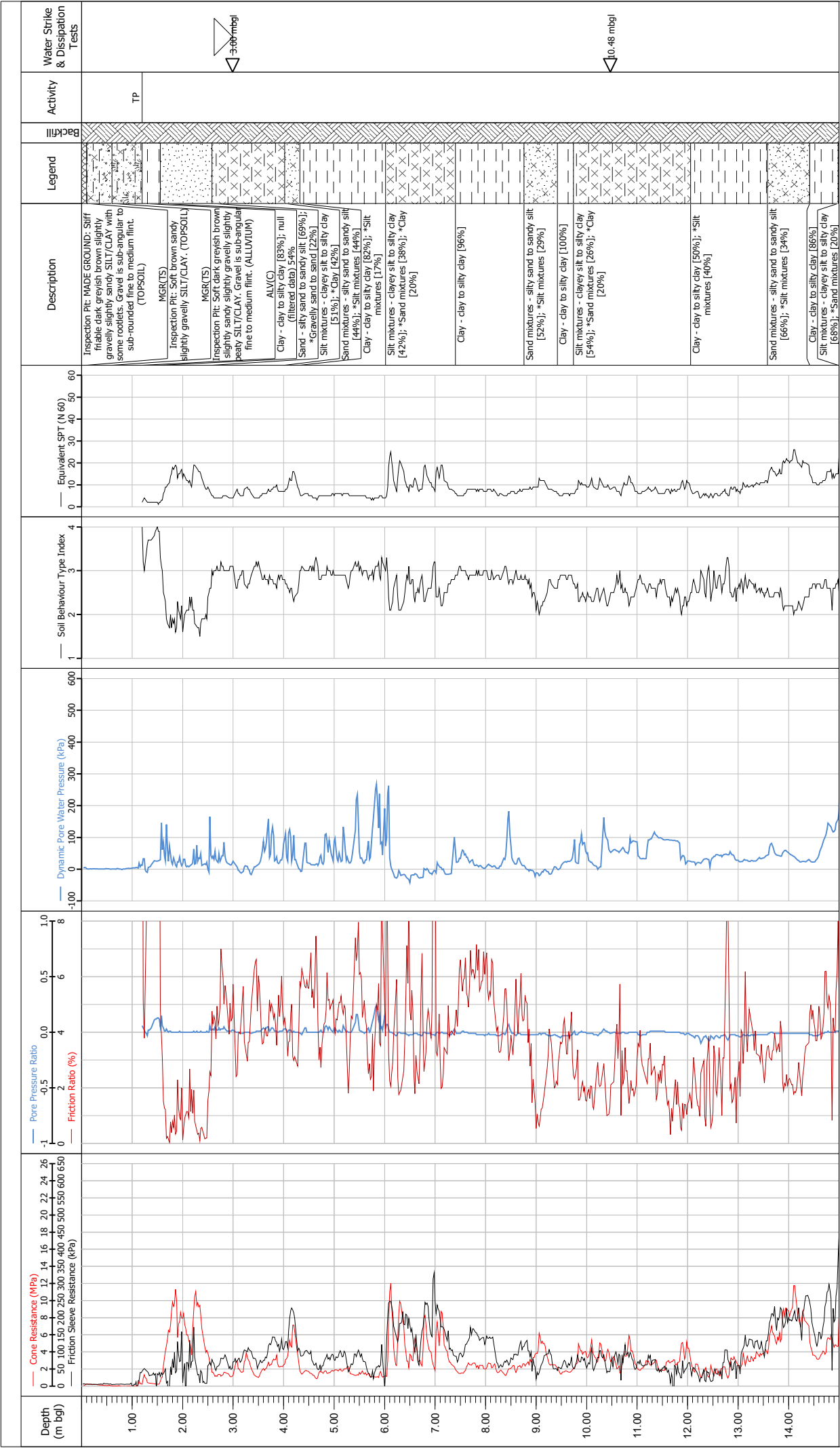


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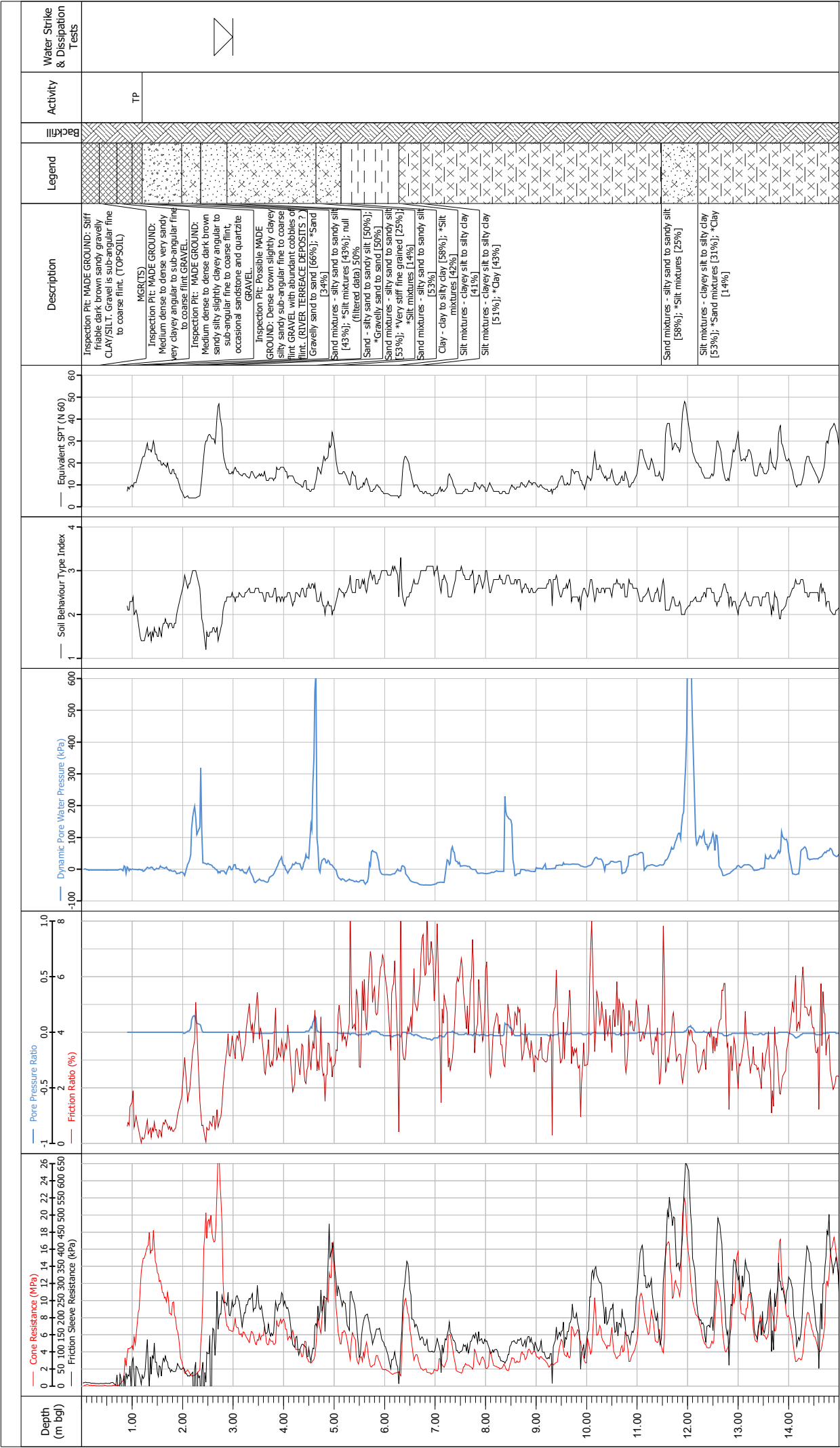


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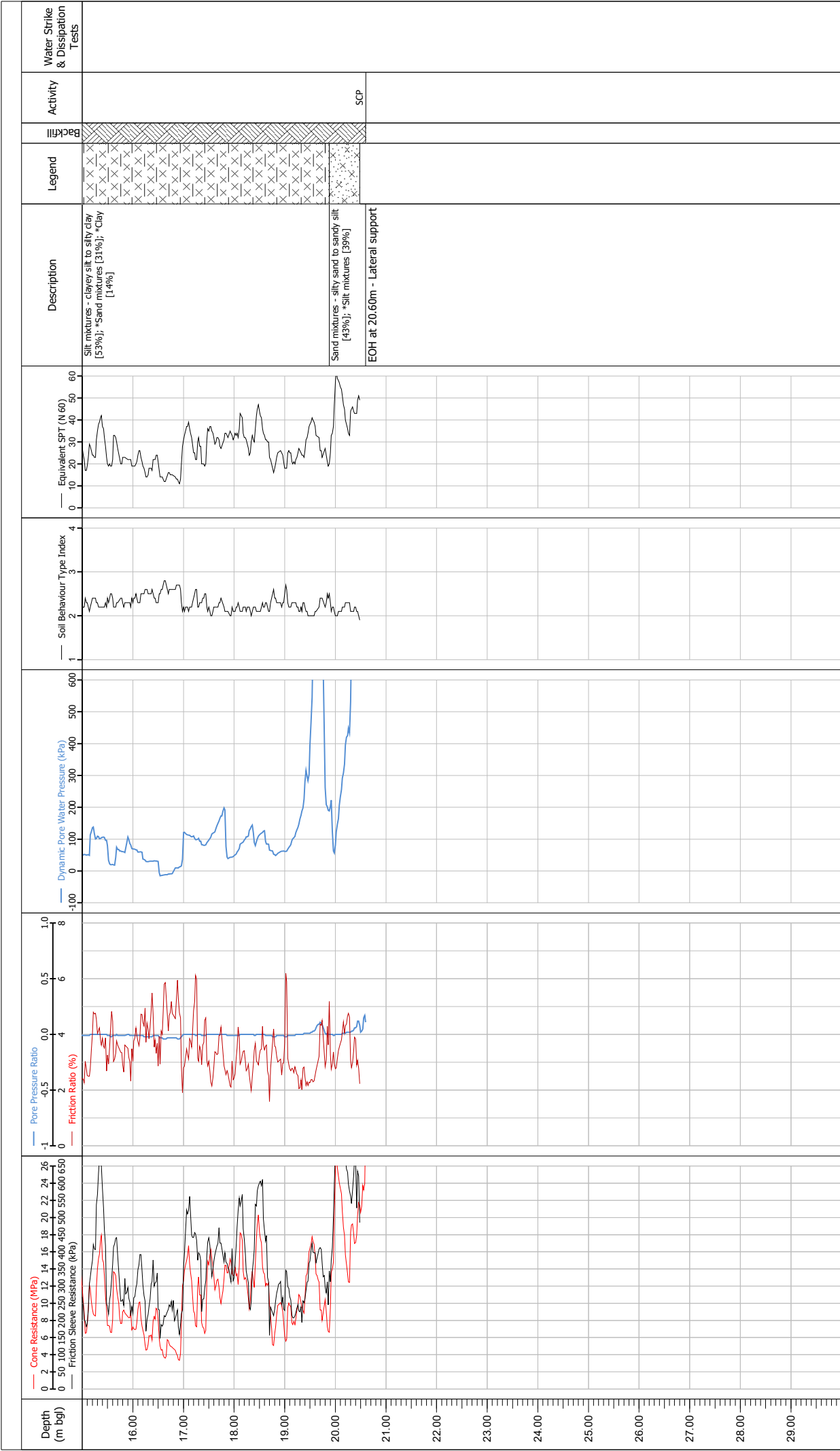


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Static Cone Penetration Testing	Sheet 1 of 2				Borehole Number		Status		Office Address	
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Static Cone Penetration Testing	Sheet 2 of 2				Borehole Number		Status		Office Address	
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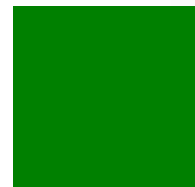
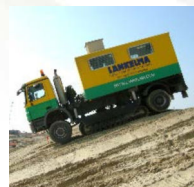
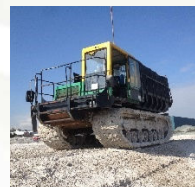
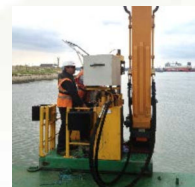
CAMBRIDGE

SOIL INVESTIGATION

CPT REPORT

Cone penetration testing
Parameter interpretation

Project ref.: P-107692-1



PROJECT:	Cambridge
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CLIENT:	Tetra Tech
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FIELDWORK

CPT rig(s)	20.5-tonne track-truck mounted CPT unit (UK3); 20.5-tonne track-truck mounted CPT unit (UK15)
Date fieldwork started	5 th March 2021
Date fieldwork completed	22 nd April 2021
Lankelma's representative	Paul Dimelow
Client's representative	Richard Tonge

REPORT

Status	Revision	Action	Date	Name
Revised	00	Completed	12/03/21	Chris Player
		Checked	16/03/21	Joseph Hobbs
		Approved	16/03/21	Joseph Hobbs
Revised	01	Completed	29/04/21	Chris Player
		Checked	29/04/21	Joseph Hobbs
		Approved	29/04/21	Joseph Hobbs
Final	02	Completed	04/10/21	Chris Player
		Checked	04/10/21	Joseph Hobbs
		Approved	04/10/21	Joseph Hobbs

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1 INTRODUCTION

At the request of Tetra Tech, a soils investigation was carried out on project *Cambridge*.

Site location:

(In the general region of)

Home Farm
High Street
Babraham
Cambridge
CB22 3AG

2 DISCLAIMER

The investigation information, raw data and interpretations provided in this report are for the sole benefit of the Client identified at the front of the report.

Lankelma has exercised reasonable skill and care in the fieldwork and preparation of this report. This report has been completed based on information available to Lankelma at the time of preparation. The measurement and interpreted data in this report do not constitute recommendations for design purposes. An appropriately qualified person must review and interpret the data given in this report, together with any assumptions we have made that affect the data, before using the data for design or recommendation. Lankelma accepts no responsibility for the accuracy or suitability of any assumptions, derived soil parameters, soil classification descriptions or soil layer boundaries contained in this report.

3 COMPLETED WORKS

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

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

4 FIELDWORK GENERAL

Fieldwork was performed with 20.5-tonne track-truck mounted CPT units (UK3 & UK15) equipped with 17-tonne capacity hydraulic ram sets.

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

The target depth for the investigation was 30 m below ground level. Table 1 details the final test depths and reasons for test termination (*refusal factor*). Where penetration refusal was encountered the termination depth was advised to, and agreed with, the Client's on-site representative.

5 CONE PENETRATION TESTS

Cone penetration testing was carried out in general accordance with BS ISO 22476-1:2012.

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

The penetrometer used was a digital model (down-hole digitisation) with 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 10 minutes with an accuracy of $\pm 0.5^\circ$.

Penetrometers were calibrated in accordance with BS8422:2003 and ASTM E74-13a, and penetrometers with down-hole digitisation and incorporating load cell temperature sensors were calibrated in accordance with ISO 376:2011. The BS8422:2003 calibration provides a single calibration uncertainty value as a percentage of full-scale output (FSO), while ISO 376:2011 calibrations provide an uncertainty value for each calibration force or pressure and extends to the very low range (tip pressure ≥ 0.06 MPa) required to quantify uncertainty in low strength soils. The management of calibration records is in accordance with ISO 10012. Copies of all calibration certificates for the cones used are provided in Appendix B.

The piezometer filter element was in the u_2 position and was vacuum saturated. The pore pressure system was saturated with de-aired 1000 cSt glycerine oil.

5.1 GLOSSARY OF CPT TERMS AND SYMBOLS

SYMBOLS & ABBREVIATIONS

B_q	Pore pressure ratio. The net pore pressure normalized with respect to the net cone resistance: $B_q = (u_2 - u_0) / (q_t - \sigma_v)$
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	Shear modulus
g	Gravitational constant: $g = 9.81 \text{ m/s}^2$
G_0	Small strain shear modulus
G_s	Specific gravity of solids

HOC	Heavily overconsolidated
I_c	Soil Behaviour Type Index: Continuous numerical representation of Robertson (1990) soil behaviour type classification chart.
LOC	Lightly overconsolidated
NC	Normally consolidated
OC	Overconsolidated
q_c	Cone resistance: The total force acting on the cone Q_c , 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_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): $q_{t1} = (q_t) / (\sigma'_v)^{0.5}$
R_f	Friction ratio: The ratio, expressed as a percentage, of the sleeve friction, f_s , to the cone resistance, q_c , at a given depth: $R_f = (f_s / q_c) \cdot 100$
SBT or SBTn	Soil behaviour type classification
u_0	Equilibrium pore pressure
u_2	Pore pressure: Dynamic pore pressure measured at the shoulder position (u_2) during penetration dissipation tests. $u_2 = \Delta u_2 + u_0$
Δu_2	Excess 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.
z	Depth below ground level: Depth as penetration length without correction for inclination, or true depth after correction for inclination.

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} , or, P_a	Reference atmospheric stress: $\sigma_{atm} = 101.3 \text{ kPa}$

TERMS

Cone or 'tip': The conical tip of the cone penetrometer.

Friction sleeve: The section of the cone penetrometer upon which the sleeve friction is measured, located behind the cone tip.

Piezocone: A cone penetrometer with a pore pressure sensor (u_2 / u_1)

Seismic cone: A cone penetrometer with a seismic receiver incorporated inside or behind.

Dynamic pore pressure: The pore pressure measured during penetration (u_2 / u_1).

Soil behaviour type, or ‘SBT’: Soil classification scheme or classified soil type according to Robertson (1990, 2016) often abbreviated to SBT or according to normalised cone parameters SBTn.

Rod string: The series of hollow tube push rods that transmit force to the penetrometer.

5.2 CPT DATA REDUCTION AND 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 BS ISO 22476-1:2012. CPT data and the associated derived geotechnical parameters are included in the 4.0 data file provided.

The cone tip and sleeve force measurements were converted to pressure using the nominal dimensions of the penetrometer.

Zero load output values were recorded before and after each test. The set of zero values applied to the measurements (subtracted from the raw output measurement) were those deemed to be obtained at a temperature closest to ground temperature, or the average of the two sets where appropriate.

For tests performed with digital cones, the tip sleeve and pore pressure measurements were corrected for static and transient temperature effects using parameters obtained from the *TEMPERATURE EFFECTS* section of the calibration certificate. For each CPT, the dataset was first grouped into penetration strokes (max 1.2 m) and then locally sub-grouped by tip resistance above and below 2 MPa. For each sub-group of $q_c < 2$ MPa, the slope of the temperature (T) profile with time (t) was determined by regression to obtain the rate of temperature change $\Delta T/\Delta t$. For each recorded value, the static and transient temperature error component (apparent sensor output due to change in temperature) was subtracted from the reading.

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

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

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

and

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

Where $q_{c:a}$ is the apparent tip resistance, $f_{s:a}$ is the apparent sleeve resistance, a is the apparent resistance due to unit transient temperature change $\Delta T/\Delta t$, and b is the change in apparent resistance per unit static temperature change relative to the temperature of the instrument at the time of zero load output measurement. Note that for the piezometer sensor only the static

temperature component is considered and is only applied to piezometer sensors without temperature compensation circuitry.

Parameter a is established by subjecting the cone to a positive and negative nominal temperature change ($\Delta T \sim \pm 9^\circ$) in water and measuring the apparent output corresponding to the maximum rate of temperature change at the load cells. Parameter b is established by measuring the apparent output after the cone has temperature stabilised.

The temperature corrected tip ($q_{c:c}$), sleeve resistance ($f_{s:c}$) and pore pressure ($u_{:c}$) are then found from

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

$$f_{s:c} = f_{s:m} - f_{s:a}$$

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

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

Notes:

1. Depending on the temperature performance of the individual cone, temperature correction of the sleeve is often not warranted 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.
2. There is currently no recognised nomenclature for CPT parameters with temperature correction applied during post processing. To avoid confusion the nomenclature 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 using the parameters reported in the calibration certificate.

For piezocone tests the total cone resistance (or ‘corrected cone resistance’) was calculated according to the formula

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

Where a is the ‘area ratio’ 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 $a = 0.8$:

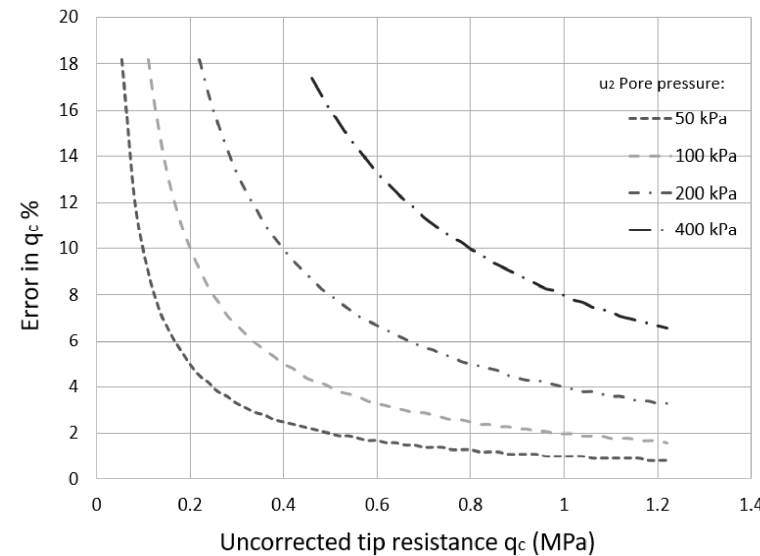


Figure 5-1 Uncorrected tip with measured tip resistance

Penetration length readings were corrected for inclination and sleeve readings were depth corrected for the dimensional offset between cone tip and sleeve during post processing. Rod spikes (artefacts of the pause for push rod addition) were filtered from the cone tip and sleeve data. 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 well within the intrinsic influence zone of the cone tip measurement and the loss of meaningful resolution is negligible.

The raw data are presented in Appendix C. For piezocone tests q_t is reported on all logs, and q_c only appears in the digital AGS data.

Geotechnical parameters appropriate for drained and undrained cone penetration conditions were 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 were derived over a range of transitional soils within the range $2.4 < I_c < 2.7$ (see section 6.3).

In general, the engineering parameters derived for fine grain soils (undrained) are suitable for soils of both silicate and carbonate composition, whereas parameters derived for coarse soils are intended for non-cemented predominantly silicate composition.

5.3 IN-SITU STRESS CONDITIONS

An estimate of the equilibrium pore pressure and total and effective vertical stress states is required for derivation of many parameters obtained from the CPT and dissipation test.

The total vertical stress with depth was calculated as the sum of the calculated soil unit weight above a given depth. See section 5.4 for information on the empirical estimate of soil unit weight.

An arbitrary phreatic surface of 3.00 mBGL was applied in the calculation of effective stress.

Note: The term phreatic surface is used here, however when it is based on piezocone measurements it is assumed that the piezometric level (under hydrostatic conditions) and phreatic surface coincide. The phreatic or piezometric surface reported is intended to provide information about the assumed pore pressure distribution 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.

5.4 SOIL UNIT WEIGHT

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

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

Throughout pre-drilled zones (inspection pits or drill-out) the soil unit weight was assumed as 17 kN/m³.

For depths where the friction sleeve measurement falls below zero, the friction sleeve was substituted with an artificial 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 profile.

5.5 SOIL BEHAVIOUR TYPE

The soil behaviour type (SBT) was interpreted using the Robertson (1990) classification system based on the normalised cone resistance (Q_t) and normalised friction sleeve resistance (F_r) for silicate soils.

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

Robertson (2010) proposed a non-normalised version of the 1990 chart which uses dimensionless cone resistance (q_c/Pa) and friction ratio, R_f . The classification according to this chart can be more reliable at shallow depth and has been plotted as an approximate SBT index (discussed below) for comparison to the normalised classification.

The SBT chart is provided in Appendix B - *General Information*, titled 'CPT Soil Behaviour Type Chart'.

It should be noted that:

- The SBT classification provides a general soil type and tends to show biased towards the soil fraction that dominates the mechanical behaviour.

- If fine cohesive soils are dry and overconsolidated, the classification tends to shift towards a coarser soil type (or lower I_c index)

Therefore, while the repeatability and behavioural bias of the SBT is usually beneficial, the classification is not always an appropriate substitute for classification based on particle size and plasticity.

The layer boundaries are manually interpreted based on broad changes in SBT classification or variance with depth. Once layer boundaries are defined, the SBT zones classified within each layer are listed together with the corresponding percentage of data points within the layer (excluding null/filtered data). The modal classification is reported in full, with abbreviated short descriptions for all secondary zones, for example - 'Clays - clay to silty clay [74%]; *Silt mixtures [20%]', where the asterisk represents an abbreviation of the full description 'Silt mixtures - clayey silt to silty clay'. It is important to consider that the classification zone boundaries do not exist in nature and small shifts in the cone response can lead multiple classifications within layers of relatively uniform behaviour; especially were the layer data plot close to a triple junction and/or has spurious spikes or very thin layers. Therefore, some system to limit the number of classified zones is usually necessary for clarity in the plot. The logic used by Lankelma for each layer is:

For $LT \geq 1$, $C = 85$
 For $0.5 \leq LT < 1$, $C = 75$
 For $0 < LT < 0.5$, $C = 65$

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

For layers having a thickness of less than 1 m then 10% of data at the top and bottom of the layer are excluded to limit the effect of transition zone data (mobilised resistance influenced by overlying or underlying strata) being included in the classification.

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

An alternative to this system is to classify each data point using coloured bars. However, the zones where the classification is known to be incorrect (e.g. very thin layers, transition zones) are left included and may be misinterpreted.

The results are presented in Appendix D.

5.6 SOIL BEHAVIOUR TYPE INDEX - I_c

The main trend in soil behaviour type (SBT) variation can be expressed by a continuous index, I_c , 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, as 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 Appendix B figure 'CPT Soil Behaviour Type Chart'. The method does not identify zones 1 (*sensitive fine grained*) or zones 8 & 9 (*overconsolidated or cemented*).

Normalised SBT index I_c (Robertson and Wride, 1998):

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

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 if 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.

The results are presented in Appendix D.

5.7 RELATIVE DENSITY

The relative density of sands was 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. The expected accuracy may be evaluated from the figures presented below.

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

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.

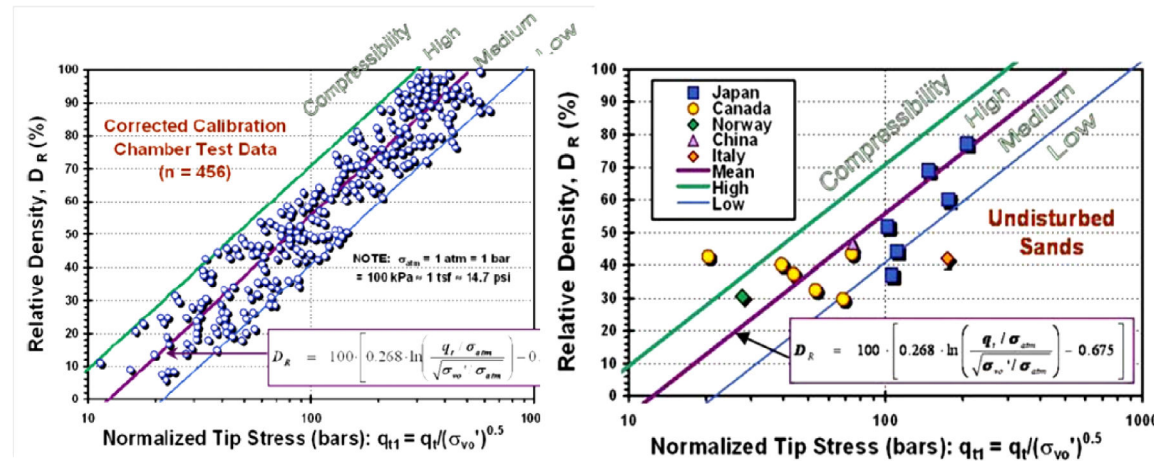


Figure 5-2 Relative density with normalised tip stress and sand compressibility from calibration chamber tests (left) and undisturbed frozen samples (right). Jamiolkowski *et al.* (2001). Reproduced from Mayne (2007).

The results are presented in Appendix E- *Standard interpretation results (set 2)*.

5.8 UNDRAINED SHEAR STRENGTH

The undrained shear strength s_u is usually estimated as a factor of net tip resistance (Lunne *et al.*, 1981):

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

Where N_k is an empirical cone factor which varies with soil type, stress history, structure/fabric, plasticity, and the mode of shear.

Mayne and Peuchen (2018) performed an evaluation of 407 high-quality triaxial compression tests with net tip resistance to proposed N_{kt} factors with regression analysis details for five categories of clays shown in Table 1.

Table 1 Summary of CAUC s_u versus q_{net} for 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
Offshore NC-LOC	17	115	0.98	12.32	0.51
Onshore NC-LOC	30	191	0.867	12	0.53
Sensitive NC-LOC	5	43	0.507	10.33	0.84
OC Intact	5	36	0.862	13.57	0.49
OC Fissured	5	22	0.393	22.47	-0.01
All clays	62	407	0.923	13.33	0.55

Alternatively, a variable N_{kt} factor can be estimated for the profile 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 N_{kt} estimate has a standard error of 2.4 N_k and correlation coefficient of 0.645.

The estimate based on B_q is presented as ' s_{u5} ' on the parameter 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 't') indicates a N_k factor that has been established using the corrected tip resistance q_t . N_{kt} can be applied to the uncorrected tip resistance q_c (non-piezcone tests) but results in a slightly lower estimate of s_u depending on the correction magnitude ($q_c - q_t$) in lower strength soils.

Undrained shear strengths corresponding to selected values of N_k are presented on the plots of Appendix D. ' s_{u3} ' on the logs ($N_k = 15$) has been included as a reference for comparison to traditionally reported N_k values of 15 and 20.

5.9 OVERCONSOLIDATION RATIO

The preconsolidation stress σ_p' was 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 :

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

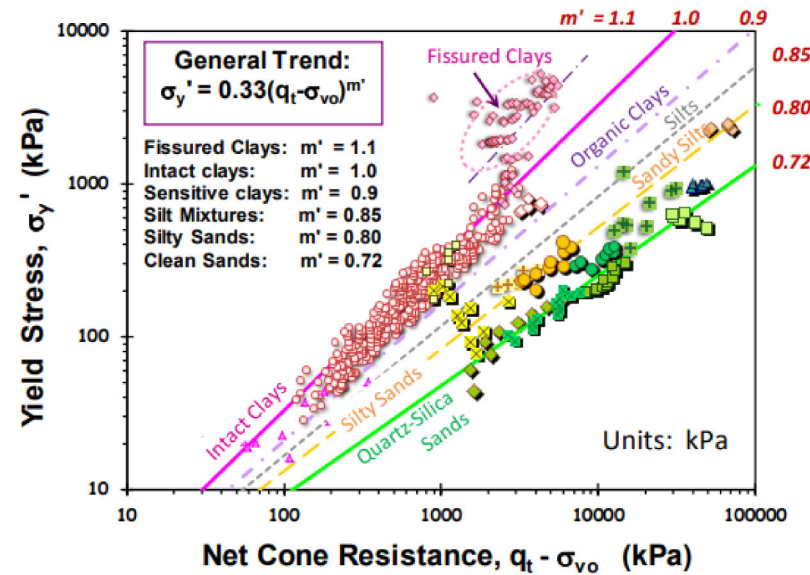


Figure 5-3 Preconsolidation stress with net cone resistance power law, reproduced from Mayne (2014).

An additional σ_p' and OCR was calculated for $m' = 1.1$ to reflect the upper trend for over consolidated fissured clays not captured by the correlation with I_c .

5.10 SPT N60 VALUES

Equivalent SPT N60 values, defined as the non-normalised SPT blow count over a 30 cm interval, were derived for two correlations.

Method 1 - Jefferies and Davies (1993) cited in Lunne *et al.* (1997)

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

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.

The results are presented in Appendix D.

5.11 FRICTION ANGLE

Sands

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

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

Where:

ϕ' = Peak friction angle (degrees)

q_{t1} = stress normalised cone resistance =

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

The presence of compressible minerals 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. High k_0 conditions also result in an overestimate of friction angle.

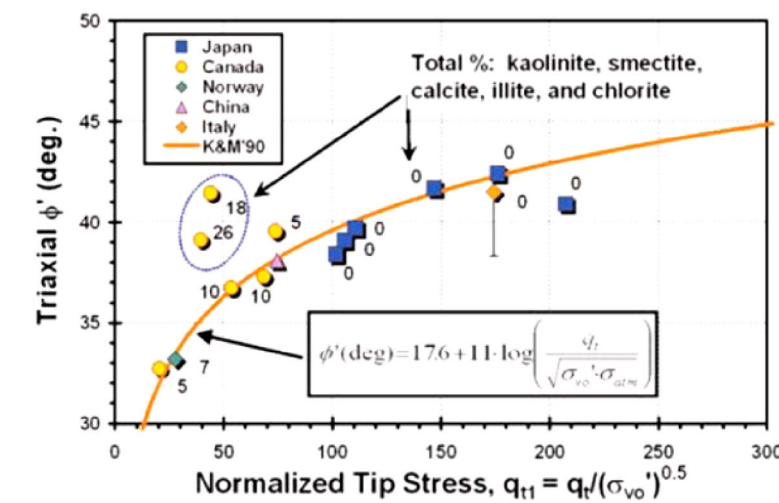
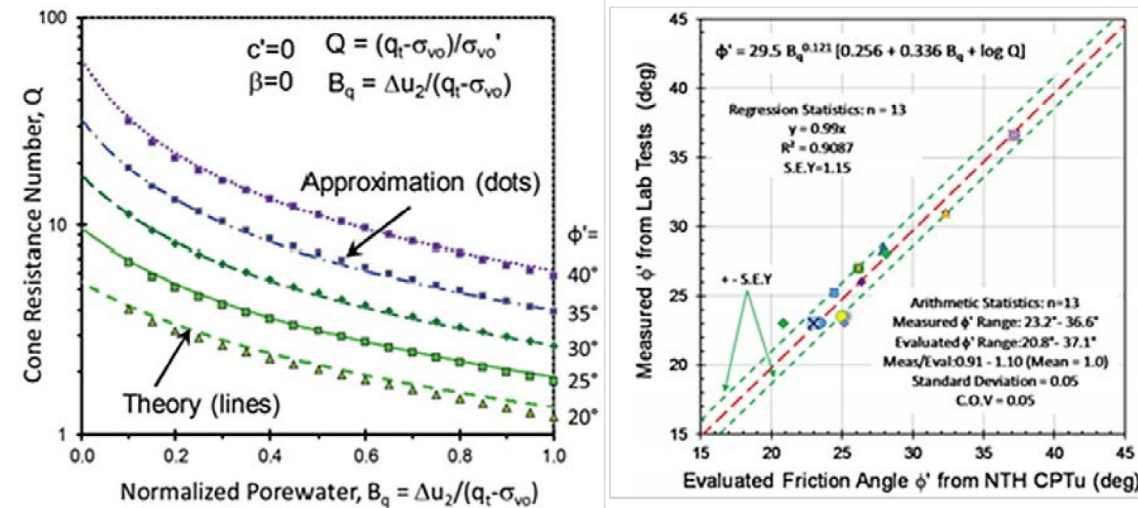


Figure 5-4 Peak triaxial friction angle from undisturbed sands with normalised cone resistance.

Fine grained soils

The effective friction angle for fine grained soils was calculated based on the Senneset *et al.* (1988, 1989) method by applying the approximate closed form solution by Mayne & Campanella (2005) as a direct function of the pore pressure parameter B_q and normalised tip resistance Q . The method is applicable where $0.1 < B_q < 1.0$ and $20^\circ < \phi' < 45^\circ$ and generally appropriate for non-cemented normally consolidated to lightly overconsolidated soils.

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



The results are presented in Appendix E.

5.12 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) applicable to the present state of vertical effective stress up to the pre-consolidation stress.

$$m_v = \frac{1}{M}$$

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.

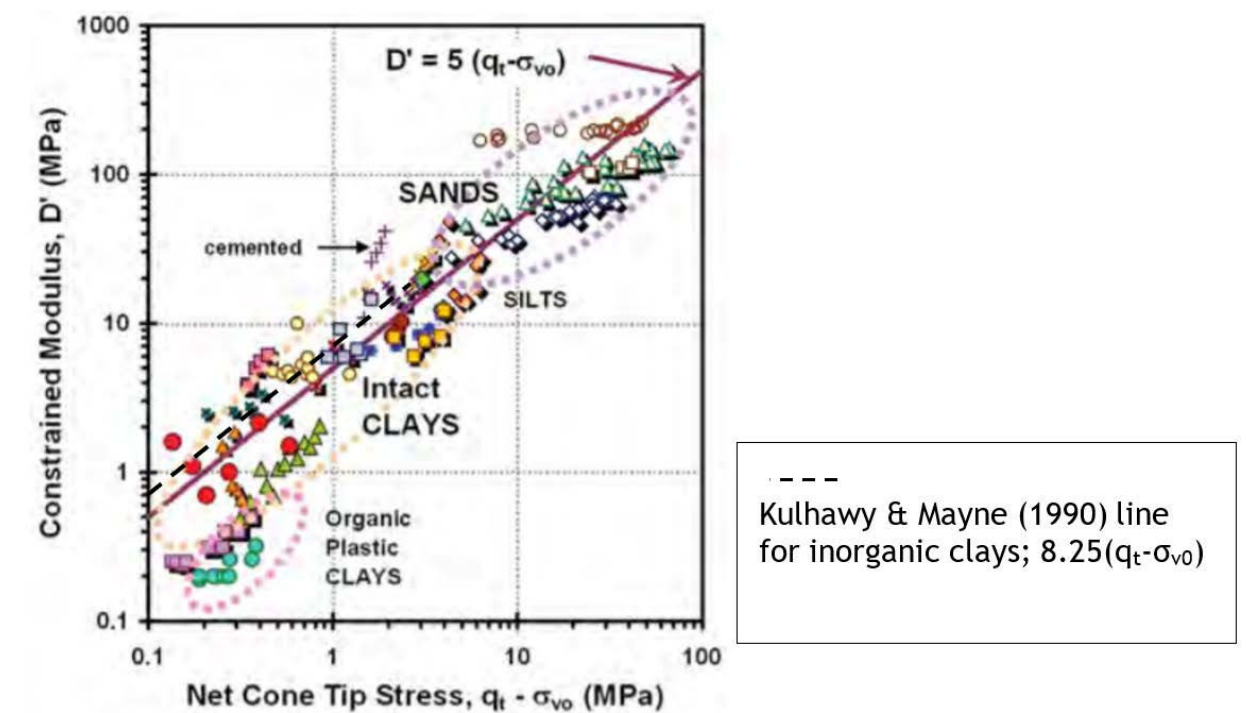


Figure 5-6 Constrained modulus of Mayne (2006). Annotated/redrawn from NCHRP Synthesis 368 (2007).

The results are presented in Appendix D.

5.13 YOUNG'S MODULUS

The Young's modulus E' at 25% mobilised shear strength ($FOS = 4$) was 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 yield stress.

The results are presented in Appendix E.

6 CPT 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.

Piezcone 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 (CPT u)

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 during dilative shear at the cone shoulder. Dissipation tests that are undertaken following desaturation are likely to have a more pronounced initial rise and some degree of error will be present in the analysis.

If the 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.

CONE TIP AND SLEEVE OFFSET

The accuracy of the SBT over thin layers and at layer boundaries is sensitive to offset error in the friction ratio often resulting in sharp peaks or troughs at boundaries. The friction ratio is often inaccurate in heavily disturbed soils with a ‘blocky’ macro fabric. The last ~8 cm of data is also not included in the SBT material description as no friction sleeve measurements are recorded.

FRICTION SLEEVE DATA

There are two common causes of friction sleeve measurement issues; 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, and 2) Accuracy limitations and temperature effects in very low strength or sensitive soils. The latter can often be mitigated by temperature stabilisation during the test and at the time of zero output measurement.

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 (larger failure 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 (<~0.75 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).

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

Table 2 CPT summary

Location ID	Stroke number	Final depth (m)	Cone ID	Piezocone test	Pre-drilled (m)	Pre-drilling details	Rig	Primary refusal factor	Applied zero values: q_c , f_s , u_2	Tip zero drift (kPa)	Sleeve zero drift (subtraction) (kPa)	Piezo zero drift (kPa)	Mr dissipation tests	Raw File Name	Easting (m)	Northing (m)	Elevation (m)	Date	Remarks
CPT-OBC-01	1	12.80	S15-CFPT.1778	YES	0.80	IP-BF	UK15	Total reaction force	pre, pre, pre	-5.60	0.50	-0.50		107692-V1.05032021-UK15.L05				05/03/2021	
CPT-OBC-02	1	13.82	S15-CFPT.1778	YES	0.80	IP-BF	UK15	Total reaction force	pre, pre, pre	-4.00	-0.30	4.80		107692-V1.05032021-UK15.L04				05/03/2021	
CPT-OBC-03	1	11.90	S15-CFPT.1778	YES	0.80	IP-BF	UK15	Total reaction force	pre, pre, pre	-3.60	-0.50	0.10		107692-V1.05032021-UK15.L03				05/03/2021	
CPT-OBC-04	1	12.16	S15-CFPT.1778	YES	0.80	IP-BF	UK15	Total reaction force	pre, pre, pre	-5.80	0.00	0.10		107692-V1.05032021-UK15.L02				05/03/2021	
CPT-OBC-05	1	12.74	S15-CFPT.1778	YES	0.80	IP-BF	UK15	Total reaction force	pre, pre, pre	-7.20	-0.50	-4.20		107692-V1.05032021-UK15.L01				05/03/2021	
CPT-PTR-01	1	16.74	S15-CFIP.1839	YES	0.95	IP-BF	UK15	Lateral support	pre, pre, pre	-65.20	0.80	2.80		107692-V2.220421-UK03-IPF4.L2001				22/04/2021	
CPT-PTR-02	1	7.08	S15-CFIP.1839	YES	0.95	IP-BF	UK15	Lateral support	pre, pre, pre	-10.90	0.70	-4.40		107692-V2.220421-UK03-IPF4.L2002				22/04/2021	
CPT-PTR-03	1	15.52	S15-CFIP.1839	YES	1.00	IP-BF	UK15	Lateral support	pre, pre, pre	32.60	1.30	1.10		107692-V2.220421-UK03-IPF4.L2004				22/04/2021	
CPT-PTR-04	1	1.14	S15-CFIP.1839	YES	0.80	IP-BF	UK15	Lateral support	pre, pre, pre	10.90	0.70	-0.60		107692-V2.220421-UK03-IPF4.L2005				22/04/2021	
CPT-PTR-05	1	17.96	S15-CFIP.1839	YES	1.20	IP-BF	UK15	Lateral support	pre, pre, pre	-32.60	0.10	3.30		107692-V2.220421-UK03-IPF4.L2003				22/04/2021	
CPT-PTR-06	1	20.60	S15-CFIP.1839	YES	0.90	IP-BF	UK15	Lateral support	pre, pre, pre	-32.60	-1.30	1.60		107692-V2.220421-UK03-IPF4.L2006				22/04/2021	

CPT test plots are presented in Appendix C.

APPENDIX B GENERAL INFORMATION

LIST OF FIGURES

Cone calibration certificate: S15-CFIIP.1778

Cone calibration certificate: S15-CFIIP.1839

Data sheet: 20.5-tonne track-truck mounted CPT unit (UK3)

Data sheet: 20.5-tonne track-truck mounted CPT unit (UK15)

CPT soil behaviour type chart

		CERTIFICATE OF CALIBRATION		Cone Serial Number: DS15-CFIPT.1778	
		Certificate Number: 1324			
Instrument:		Digital-Geopoint-S15-150kN-2MPa		Location:	
Serial number:		DS15-CFIPT.1778		Temperature (°C):	
Manufacturer:		Geopoint		Temperature change (°C):	
Calibration standard:		Conforms to ISO 376:2011 & ISO 22476-1:2012		Calibration engineer:	
ISO 22476-1:2012 application class:		Class 1		Calibration re-verification date:	
Date of calibration:		20/11/2020		Calibration verification completed:	
Calibration expiry:		20/03/2021			

This calibration certificate is valid for 6 months, with a verification of the calibration being performed between 2 and 4 months from the date of calibration.

Calibration signed and dated by:

P Metcalf

Calibration checked and dated by:

A N Harman

Calibration verification signed and dated by:

REFERENCE INSTRUMENTS	SERIAL NUMBER	UNCERTAINTY OF RECORDED VALUE	CALIBRATION DATE
AM DSCC-100kN Load Cell	51998	0.02%	12/07/2019
AM DSCCHA-5kN Load Cell	61065	0.05%	12/07/2019
Omega MMG750V	502273	0.01%	14/08/2020
Keithley 3706A Multimeter	4067652	10ppm	21/08/2020
LD Solar2-45	105775	0.04°	02/09/2020
ETI Ref Thermometer	D20345255	0.01°C	24/08/2020

The calibration tests were made in the Lankelma force standards machine. The applied forces of which are within an uncertainty of:
 ± 0.050 % of nominal value from 0.5kN up to 10kN, then 0.02% of nominal from 10kN up to 100kN.

MEASUREMENTS

- The forces applied, and the resulting deflections are given in Tables 1. No corrections for temperature have been applied to these results.
 - The cone was loaded to full range 3 times for no less than 1 minute before calibration and after each rotation.
 - The cone was calibrated in low and high range using two reference load cells. The low range calibration consisted of a maximum load of 5kN with 4 sets of increasing forces and 2 sets of decreasing forces. The high range calibration consisted of a maximum load of 100kN with 3 sets of increasing forces and 2 sets of decreasing forces.
 - The difference in deflection for each applied force with rotation is the relative reproducibility error b, shown as a percentage of the recorded value and in units of pressure MPa. The uncertainty relating to the difference in deflection for increasing forces against degreasing forces is the reversibility uncertainty U_rev, shown as a percentage of the recorded value and in units of pressure MPa.
 - For each application of force, the coefficients of a linear and third order equation relating the estimate of the mean deflection as a function of the applied calibration force were calculated. Table 2.
 - The combined expanded uncertainty of deflection U for each force is shown as a percentage of the recorded value and in units of pressure MPa.
 - The coefficients of a third order equation relating a given applied force to the estimate of the mean deflection were also calculated. The coefficients are given in Table 3.
 - In use the forces acting on the sleeve load cell element are a combination of tip resistance and sleeve friction, with the tip resistance 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 4.
- * The combined expanded uncertainties shown are to k=2 with a 95% coverage factor.

The calibration uncertainty is the uncertainty in the force value calculated from the interpolation equation at any deflection.

At each calibration point a combined standard uncertainty uc is calculated from the readings obtained during the calibration.

$$uc = \sqrt{\sum_{i=1}^8 ui^2}$$

and

$$U = k \times uc$$

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 creep of the instrument.
 $u6$ is the standard uncertainty associated with the drift in zero output.
 $u7$ is the standard uncertainty associated with temperature of the instrument.
 $u8$ is the standard uncertainty associated with interpolation best fit of the linear or 3rd order polynomial equation.

Symbol	Symbols and their designations
Ref LC	Reference load cell with calibration force in kN
cts	Counts. Base digital cone units.
0.1N	Interpolated digital cone units from counts
b	Relative reproducibility error
U_rev	Reversibility uncertainty
Uc	Combined standard uncertainty
Uc_sub	Combined standard uncertainty including sleeve subtraction
U	Combined expanded uncertainty
k=2	95% uncertainty coverage factor



CERTIFICATE OF CALIBRATION

Certificate Number: 1324

Cone Serial Number:
DS15-CFIPT.1778

CONE END RESISTANCE CALIBRATION

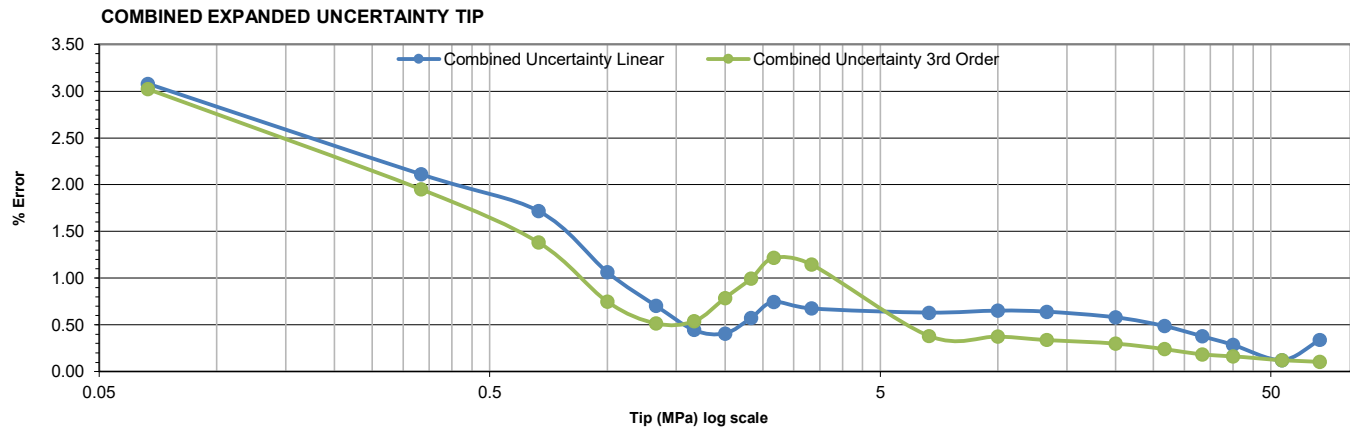
Table 1-a.

Low range calibration										High range calibration									
Ref LC (kN)	Tip change In output (cts)				Reproducibility error <i>b</i>		Reversibility error <i>U</i> _{rev}		Ref LC (kN)	Tip change in output (cts)				Reproducibility error <i>b</i>		Reversibility error <i>U</i> _{rev}			
	1 0°	2 120°	3 240°	4 240°	MPa	%	MPa	%		1 0°	2 120°	3 240°	MPa	%	MPa	%			
0.100	1.197E+05	1.179E+05	1.164E+05	1.164E+05	0.002	2.83			5.000	5.831E+06	5.848E+06	5.838E+06	0.009	0.28					
0.500	5.942E+05	5.899E+05	5.909E+05	5.873E+05	0.002	0.72			10.000	1.167E+07	1.170E+07	1.168E+07	0.019	0.28					
1.000	1.180E+06	1.171E+06	1.175E+06	1.173E+06	0.005	0.82			15.000	1.750E+07	1.755E+07	1.753E+07	0.026	0.26					
1.500	1.764E+06	1.747E+06	1.757E+06	1.755E+06	0.009	0.94			20.000	2.334E+07	2.340E+07	2.338E+07	0.036	0.27					
2.000	2.344E+06	2.326E+06	2.338E+06	2.336E+06	0.010	0.75			30.000	3.501E+07	3.509E+07	3.506E+07	0.045	0.23					
2.500	2.921E+06	2.904E+06	2.917E+06	2.917E+06	0.010	0.59			40.000	4.669E+07	4.677E+07	4.674E+07	0.049	0.18					
3.000	3.498E+06	3.480E+06	3.497E+06	3.496E+06	0.010	0.50			50.000	5.835E+07	5.844E+07	5.841E+07	0.052	0.16					
3.500	4.075E+06	4.059E+06	4.078E+06	4.076E+06	0.011	0.46			60.000	7.001E+07	7.010E+07	7.006E+07	0.054	0.13					
4.000	4.654E+06	4.638E+06	4.660E+06	4.659E+06	0.013	0.48			80.000	9.325E+07	9.337E+07	9.333E+07	0.070	0.13					
5.000	5.817E+06	5.800E+06	5.828E+06	5.822E+06	0.016	0.49			100.000	1.164E+08	1.165E+08	1.165E+08	0.068	0.10					
4.000	4.655E+06	4.642E+06			0.007	0.28	-0.001	-0.04	80.000	9.330E+07	9.341E+07		0.062	0.12	-0.014	-0.03			
3.500	4.087E+06	4.067E+06			0.011	0.48	-0.003	-0.13	60.000	7.008E+07	7.018E+07		0.058	0.14	-0.027	-0.07			
3.000	3.504E+06	3.494E+06			0.005	0.27	-0.003	-0.17	50.000	5.844E+07	5.852E+07		0.046	0.14	-0.027	-0.08			
2.500	2.927E+06	2.917E+06			0.006	0.36	-0.003	-0.19	40.000	4.678E+07	4.686E+07		0.048	0.18	-0.031	-0.11			
2.000	2.347E+06	2.339E+06			0.005	0.36	-0.003	-0.20	30.000	3.511E+07	3.518E+07		0.036	0.18	-0.030	-0.15			
1.500	1.764E+06	1.758E+06			0.003	0.31	-0.002	-0.19	20.000	2.341E+07	2.347E+07		0.033	0.24	-0.021	-0.16			
1.000	1.179E+06	1.177E+06			0.002	0.25	-0.001	-0.12	15.000	1.756E+07	1.761E+07		0.028	0.28	-0.019	-0.19			
0.500	5.861E+05	5.894E+05			0.002	0.56	0.001	0.42	10.000	1.170E+07	1.174E+07		0.019	0.29	-0.012	-0.19			
0.100	1.146E+05	1.159E+05			0.001	1.13	0.001	1.75	5.000	5.846E+06	5.861E+06		0.008	0.25	-0.005	-0.14			

Table 2-a.

Low range calibration								High range calibration							
Reference output		Linear equation			3rd order equation			Reference output		Linear equation			3rd order equation		
Ref Load Cell Nom. (MPa)	Ref Load Cell (0.1N)	Cone output (0.1N)	Expanded uncertainty <i>U</i> [*] MPa	%	Equation output (0.1N)	Expanded uncertainty <i>U</i> [*] MPa	%	Ref Load Cell Nom. (MPa)	Ref Load Cell (0.1N)	Cone output (0.1N)	Expanded uncertainty <i>U</i> [*] MPa	%	Equation output (0.1N)	Expanded uncertainty <i>U</i> [*] MPa	%
0.067	1000	1011	0.002	3.08	1012	0.002	3.17	3.333	50000	50045	0.009	0.26	49931	0.011	0.34
0.333	5000	5071	0.009	2.61	5063	0.009	2.63	6.667	100000	100133	0.022	0.33	99898	0.019	0.28
0.667	10000	10075	0.010	1.48	10055	0.008	1.22	10.000	150000	150225	0.035	0.35	149870	0.025	0.25
1.000	15000	15048	0.008	0.85	15016	0.006	0.63	13.333	200000	200335	0.051	0.38	199865	0.030	0.22
1.333	20000	20021	0.007	0.54	19977	0.007	0.54	20.000	300000	300457	0.068	0.34	299787	0.042	0.21
1.667	25000	24974	0.007	0.43	24919	0.013	0.76	26.667	400000	400541	0.081	0.30	399741	0.050	0.19
2.000	30000	29926	0.011	0.57	29859	0.020	1.01	33.333	500000	500543	0.083	0.25	499713	0.056	0.17
2.333	35000	34890	0.015	0.65	34812	0.026	1.13	40.000	600000	600442	0.074	0.19	599716	0.059	0.15
2.667	40000	39861	0.018	0.69	39771	0.032	1.19	53.333	800000	799816	0.067	0.12	799827	0.066	0.12
3.333	50000	49840	0.022	0.67	49726	0.038	1.15	66.667	1000000	998388	0.226	0.34	1000049	0.070	0.10
2.667	40000	39844	0.022	0.81	39755	0.033	1.25	53.333	800000	800112	0.065	0.12	800125	0.065	0.12
2.333	35000	34941	0.012	0.50	34862	0.020	0.87	40.000	600000	601096	0.155	0.39	600371	0.072	0.18
2.000	30000	29990	0.005	0.25	29923	0.011	0.57	33.333	500000	501224	0.169	0.51	500394	0.067	0.20
1.667	25000	25043	0.008	0.46	24988	0.005	0.32	26.667	400000	401309	0.179	0.67	400508	0.079	0.30
1.333	20000	20081	0.012	0.87	20037	0.007	0.49	20.000	300000	301212	0.164	0.82	300541	0.078	0.39
1.000	15000	15094	0.013	1.28	15062	0.009	0.87	13.333	200000	200882	0.120	0.90	200411	0.060	0.45
0.667	10000	10096	0.013	1.95	10076	0.010	1.54	10.000	150000	150694	0.095	0.95	150338	0.050	0.50
0.333	5000	5037	0.005	1.61	5029	0.004	1.27	6.667	100000	100448	0.062	0.93	100213	0.032	0.48
0.067	1000	987	0.002	3.07	988	0.002	2.88	3.333	50000	50170	0.024	0.72	50055	0.010	0.30

Table 3-a. Third order equation									
For a given cone indicated output of D (0.1N units), the corrected applied force				a0 =	2.86364	Maximum tip zero drift during the calibration (MPa) =			
F (in 0.1N units) is calculated from :				a1 =	0.99772	Maximum load cell zero drift during the calibration (MPa) =			
F = (a3 x D ³) + (a2 x D ²) + (a1 x D) + a0				a2 =	-1.51125E-09	Factor used to convert from counts to 0.1N units =			
				a3 =	5.46340E-15	Maximum tip full scale reading (MPa) =			
								Tip resolution (Pa) =	
								Tip area (cm ²) =	
								Tip area ratio =	



* The combined expanded uncertainties shown are to k=2 with a 95% coverage factor.



CERTIFICATE OF CALIBRATION

Certificate Number: 1324

Cone Serial Number:
DS15-CFIPT.1778

SLEEVE FRICTION CALIBRATION

Table1-b.																
Low range calibration								High range calibration								
Ref LC (kN)	Sleeve change In output (cts)				Reproducibility error <i>b</i>		Reversibility error <i>U</i> _{rev}		Ref LC (kN)	Tip change in output (cts)			Reproducibility error <i>b</i>		Reversibility error <i>U</i> _{rev}	
	1 0°	2 120°	3 240°	4 240°	kPa	%	kPa	%		1 0°	2 120°	3 240°	kPa	%	kPa	%
0.100	1.218E+05	1.220E+05	1.213E+05	1.213E+05	0.024	0.55			5.000	6.013E+06	6.036E+06	6.015E+06	0.862	0.39		
0.500	6.122E+05	6.102E+05	6.129E+05	6.084E+05	0.098	0.44			10.000	1.203E+07	1.207E+07	1.204E+07	1.719	0.39		
1.000	1.216E+06	1.208E+06	1.217E+06	1.215E+06	0.330	0.75			15.000	1.804E+07	1.811E+07	1.806E+07	2.279	0.34		
1.500	1.816E+06	1.803E+06	1.818E+06	1.817E+06	0.558	0.84			20.000	2.406E+07	2.414E+07	2.408E+07	2.925	0.33		
2.000	2.414E+06	2.399E+06	2.419E+06	2.418E+06	0.723	0.82			30.000	3.610E+07	3.619E+07	3.611E+07	3.575	0.27		
2.500	3.009E+06	2.995E+06	3.019E+06	3.017E+06	0.895	0.81			40.000	4.813E+07	4.824E+07	4.814E+07	4.018	0.23		
3.000	3.604E+06	3.588E+06	3.618E+06	3.616E+06	1.097	0.83			50.000	6.014E+07	6.026E+07	6.016E+07	4.426	0.20		
3.500	4.197E+06	4.185E+06	4.218E+06	4.215E+06	1.206	0.78			60.000	7.214E+07	7.227E+07	7.217E+07	4.733	0.18		
4.000	4.793E+06	4.781E+06	4.819E+06	4.817E+06	1.420	0.81			80.000	9.610E+07	9.624E+07	9.614E+07	5.373	0.15		
5.000	5.989E+06	5.977E+06	6.024E+06	6.019E+06	1.734	0.79			100.000	1.200E+08	1.201E+08	1.200E+08	5.886	0.13		
4.000	4.791E+06	4.782E+06			0.348	0.20	0.006	0.00	80.000	9.613E+07	9.628E+07		5.320	0.15	-0.710	-0.02
3.500	4.208E+06	4.190E+06			0.676	0.44	-0.170	-0.11	60.000	7.220E+07	7.234E+07		4.852	0.18	-1.325	-0.05
3.000	3.607E+06	3.600E+06			0.258	0.19	-0.160	-0.12	50.000	6.021E+07	6.033E+07		4.505	0.20	-1.464	-0.07
2.500	3.012E+06	3.003E+06			0.346	0.31	-0.125	-0.11	40.000	4.820E+07	4.831E+07		4.194	0.24	-1.594	-0.09
2.000	2.416E+06	2.408E+06			0.267	0.30	-0.116	-0.13	30.000	3.617E+07	3.627E+07		3.847	0.29	-1.530	-0.12
1.500	1.814E+06	1.811E+06			0.116	0.18	-0.056	-0.08	20.000	2.412E+07	2.420E+07		3.217	0.37	-1.230	-0.14
1.000	1.212E+06	1.211E+06			0.017	0.04	0.007	0.02	15.000	1.809E+07	1.816E+07		2.760	0.42	-1.073	-0.16
0.500	6.016E+05	6.061E+05			0.163	0.74	0.153	0.69	10.000	1.206E+07	1.211E+07		2.023	0.46	-0.721	-0.16
0.100	1.179E+05	1.178E+05			0.002	0.04	0.085	1.92	5.000	6.023E+06	6.047E+06		0.879	0.40	-0.215	-0.10

Table 2-b.																			
Low range calibration								High range calibration											
Reference output		Linear factor output				3rd order equation				Reference output		Linear factor output				3rd order equation			
Ref Load Cell Nom. (kPa)	Ref Load Cell (0.1N)	Cone output (0.1N)	Expanded uncertainty U^*			Equation output (0.1N)	Expanded uncertainty U^*			Ref Load Cell Nom. (kPa)	Ref Load Cell (0.1N)	Cone output (0.1N)	Expanded uncertainty U^*			Equation output (0.1N)	Expanded uncertainty U^*		
4	1000	1012	0.122	2.77		1016	0.153	3.47		220	50000	50082	0.930	0.42		49940	0.790	0.36	
22	5000	5088	0.804	3.65		5080	0.733	3.33		441	100000	100189	2.019	0.46		99903	1.428	0.16	
44	10000	10092	0.837	1.90		10068	0.641	1.45		661	150000	150286	2.951	0.45		149865	1.938	0.15	
66	15000	15075	0.754	1.14		15036	0.488	0.74		881	200000	200397	4.004	0.45		199852	2.339	0.13	
88	20000	20049	0.629	0.71		19996	0.461	0.52		1322	300000	300536	5.321	0.40		299791	3.061	0.12	
110	25000	25015	0.570	0.52		24947	0.722	0.66		1762	400000	400623	6.178	0.35		399763	3.519	0.10	
132	30000	29969	0.721	0.55		29886	1.204	0.91		2203	500000	500602	6.204	0.28		499737	3.963	0.09	
154	35000	34930	0.967	0.63		34833	1.653	1.07		2643	600000	600460	5.364	0.20		599724	4.271	0.08	
176	40000	39902	1.220	0.69		39790	2.043	1.16		3524	800000	799780	4.578	0.13		799800	4.505	0.06	
220	50000	49874	1.549	0.70		49732	2.594	1.18		4405	1000000	998453	14.435	0.33		1000055	4.779	0.05	
176	40000	39810	1.700	0.96		39698	2.679	1.52		3524	800000	800137	4.719	0.13		800160	4.773	0.07	
154	35000	34922	0.852	0.55		34825	1.625	1.05		2643	600000	601088	10.364	0.39		600353	5.016	0.09	
132	30000	29970	0.353	0.27		29887	1.021	0.77		2203	500000	501295	11.957	0.54		500431	5.209	0.12	
110	25000	25016	0.313	0.28		24948	0.539	0.49		1762	400000	401359	12.406	0.70		400499	5.469	0.16	
88	20000	20060	0.576	0.65		20007	0.238	0.27		1322	300000	301234	11.251	0.85		300488	5.189	0.20	
66	15000	15072	0.645	0.98		15034	0.316	0.48		881	200000	200949	8.691	0.99		200402	4.267	0.24	
44	10000	10074	0.657	1.49		10051	0.452	1.03		661	150000	150758	6.975	1.06		150335	3.578	0.27	
22	5000	5023	0.256	1.16		5014	0.205	0.93		441	100000	100505	4.689	1.06		100218	2.423	0.28	
4	1000	980	0.187	4.24		984	0.154	3.50		220	50000	50193	1.820	0.83		50050	0.788	0.18	



CERTIFICATE OF CALIBRATION

Certificate Number: 1324

Cone Serial Number:
DS15-CFIPT.1778Table 4-b Sleeve friction - tip subtraction combined standard uncertainty U_{c_sub}

Sleeve linear equation subtraction error (%)								
Sleeve kPa →								
	4	22	44	66	110	154	220	661
Tip MPa ↓								
0.07	5.0	1.9	1.2	0.7	0.3	0.4	0.4	0.4
0.33	13.0	3.5	2.0	1.3	0.7	0.6	0.7	0.5
0.67	18.8	4.6	2.6	1.7	0.9	0.8	0.7	0.5
1.00	17.7	4.4	2.4	1.6	0.8	0.7	0.7	0.4
1.67	12.3	3.3	1.9	1.2	0.6	0.6	0.6	0.4
2.33	22.1	5.3	2.9	1.9	1.0	0.9	0.8	0.5
3.33	36.2	8.1	4.3	2.8	1.6	1.3	1.0	0.5
10.00	107.0	22.3	11.4	7.5	4.4	3.3	2.5	0.9
13.33	138.0	28.4	14.5	12.6	5.6	4.2	4.0	1.3

Sleeve 3rd order equation subtraction error (%)								
Sleeve kPa →								
	4	22	44	66	110	154	220	661
Tip MPa ↓								
0.07	5.0	1.7	0.9	0.5	0.4	0.6	0.7	0.2
0.33	11.9	3.1	1.6	1.0	0.7	0.8	0.8	0.3
0.67	14.8	3.7	1.9	1.2	0.8	0.9	0.9	0.3
1.00	11.9	3.1	1.6	1.0	0.7	0.8	0.8	0.3
1.67	15.6	3.8	2.0	1.2	0.8	0.9	0.9	0.3
2.33	37.8	8.3	4.2	2.7	1.7	1.6	1.3	0.4
3.33	59.8	12.7	6.4	4.2	2.6	2.2	1.8	0.6
10.00	61.2	13.0	6.6	4.3	2.7	2.2	1.8	0.6
13.33	73.1	15.3	7.8	6.4	3.1	2.6	2.0	0.7

PORE PRESSURE CALIBRATION

Table1-c.

Ref PR (kPa)	PWP change in output (cts)			Reproducibility error b		Reversibility error U _{rev}	
	1 0°	2 120°	3 240°	kPa	%	kPa	%
50	2.296E+07	2.298E+07	2.303E+07	0.2	0.31		
100	4.603E+07	4.594E+07	4.612E+07	0.4	0.39		
200	9.212E+07	9.228E+07	9.216E+07	0.4	0.18		
300	1.382E+08	1.383E+08	1.382E+08	0.3	0.10		
400	1.842E+08	1.842E+08	1.842E+08	0.1	0.02		
500	2.302E+08	2.303E+08	2.303E+08	0.2	0.04		
600	2.762E+08	2.762E+08	2.762E+08	0.1	0.01		
800	3.681E+08	3.679E+08	3.679E+08	0.4	0.05		
1000	4.595E+08	4.597E+08	4.596E+08	0.3	0.03		
1200	5.510E+08	5.511E+08	5.511E+08	0.4	0.03		
1000	4.597E+08	4.597E+08		0.0	0.00	-0.1	-0.01
800	3.679E+08	3.679E+08		0.0	0.01	0.1	0.01
600	2.763E+08	2.763E+08		0.0	0.00	-0.2	-0.03
500	2.303E+08	2.304E+08		0.1	0.02	-0.1	-0.02
400	1.843E+08	1.844E+08		0.2	0.05	-0.1	-0.03
300	1.384E+08	1.384E+08		0.1	0.03	-0.1	-0.04
200	9.226E+07	9.241E+07		0.3	0.16	-0.2	-0.08
100	4.616E+07	4.616E+07		0.0	0.01	-0.2	-0.23
50	2.296E+07	2.304E+07		0.2	0.34	0.0	-0.08

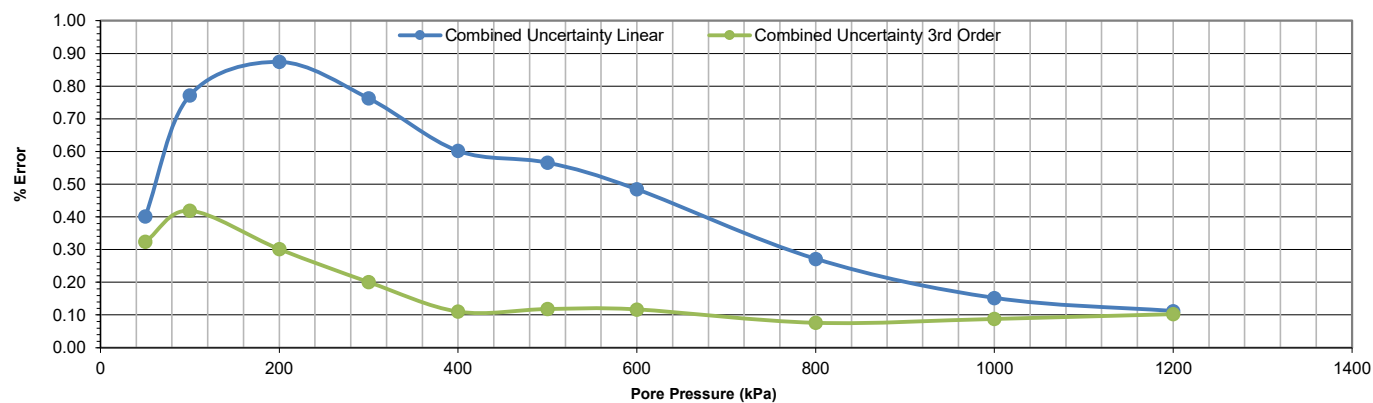
Table 2-c.

Reference output		Linear factor output		3rd order equation		
Ref Pressure (kPa)	Ref Pressure (0.1Pa)	Cone output (0.1Pa)	Expanded uncertainty U*	Equation output (0.1N)	Expanded uncertainty U*	
			kPa		kPa	%
50	500000	500465	0.178 0.36	499868	0.153 0.31	
100	1000000	1002032	0.511 0.51	999402	0.327 0.33	
200	2000000	2006996	1.437 0.72	2000892	0.344 0.17	
300	3000000	3009865	2.001 0.67	3001096	0.370 0.12	
400	4000000	4010764	2.179 0.54	4000140	0.298 0.07	
500	5000000	5013348	2.706 0.54	5001683	0.498 0.10	
600	6000000	6012613	2.566 0.43	6000730	0.459 0.08	
800	8000000	8011175	2.215 0.28	8001347	0.665 0.08	
1000	10000000	10005682	1.369 0.14	10001267	0.800 0.08	
1200	12000000	11996957	1.346 0.11	12001361	1.230 0.10	
1000	10000000	10007521	1.677 0.17	10003112	0.964 0.10	
800	8000000	8010265	2.132 0.27	8000436	0.559 0.07	
600	6000000	6016075	3.251 0.54	6004194	0.944 0.16	
500	5000000	5014618	2.952 0.59	5002953	0.688 0.14	
400	4000000	4013041	2.636 0.66	4002414	0.585 0.15	
300	3000000	3012756	2.576 0.86	3003980	0.833 0.28	
200	2000000	2010146	2.058 1.03	2004032	0.861 0.43	
100	1000000	1004985	1.032 1.03	1002343	0.511 0.51	
50	500000	500731	0.224 0.45	500132	0.171 0.34	

Table 3-c. Third order equation

For a given cone indicated output of D (0.1N units), the corrected applied force	a0 = 1626.32727	Maximum PWP zero drift during the calibration (kPa) =	0.17
	a1 = 0.99536	Maximum reference zero drift during the calibration (kPa) =	0.041
F (in 0.1N units) is calculated from :	a2 = 3.89883E-10	Factor used to convert from counts to 0.1Pa units =	0.0217707
F = (a3 x D³) + (a2 x D²) + (a1 x D) + a0	a3 = 1.34537E-18	Maximum PWP full scale reading (kPa) =	2000
		PWP resolution (Pa) =	0.1

COMBINED EXPANDED UNCERTAINTY PORE PRESSURE



* The combined expanded uncertainties shown are to k=2 with a 95% coverage factor.



CERTIFICATE OF CALIBRATION

Certificate Number: 1324

Cone Serial Number:
DS15-CFIPT.1778

INCLINATION CALIBRATION

Ref Inclination (°C)	Cone inclination output	
	X Inc (cts)	Y Inc (cts)
-25	-24776	-24150
0	1026	1197
25	27316	26676

Ref Inclination (°)	Cone inclination output	
	X Inc (°)	Y Inc (°)
-25	-24.8	-24.9
0	0.0	0.0
25	25.2	25.1

Factor used to convert from counts to 0.1m° units =	X inc	Y inc
	9.59812205	9.83746263
Inclination error (°) =		0.2 0.1

TEMPERATURE CALIBRATION

Recorded temp (°C)	Cone output (cts)
7.76	-223368277
10.67	-187212304
15.26	-129569124
20.42	-64139716
25.82	5578244

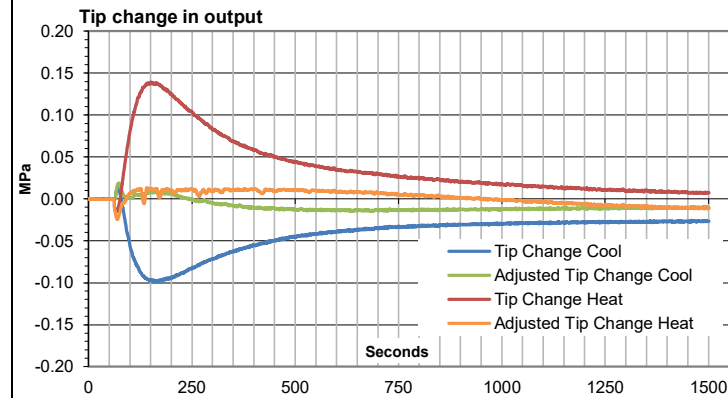
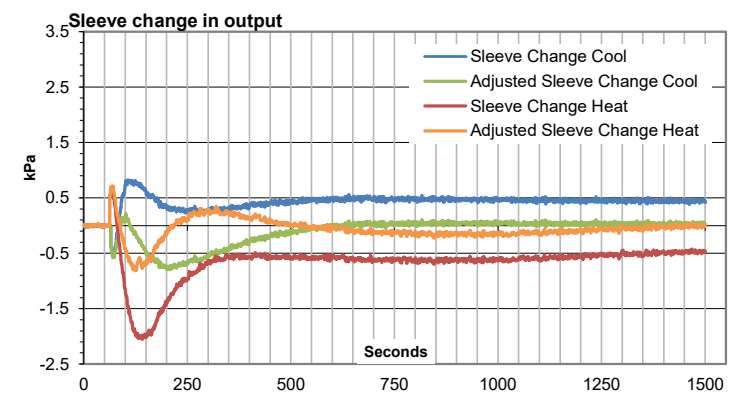
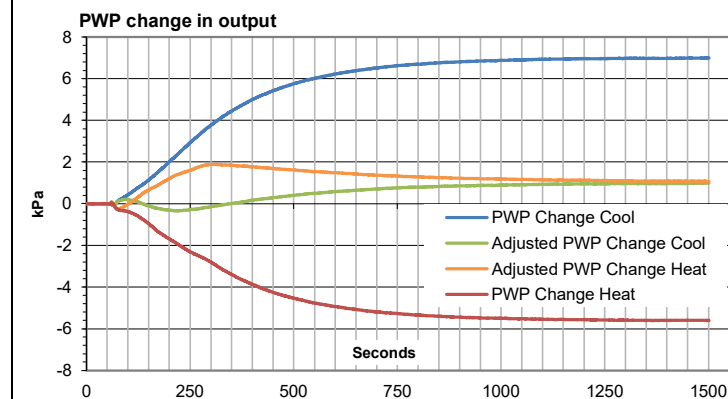
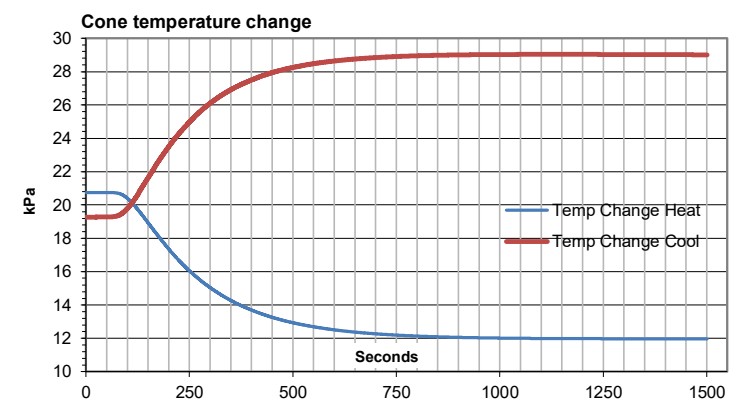
Recorded temp (°C)	Cone output (°C)
7.76	7.81
10.67	10.66
15.26	15.21
20.42	20.37
25.82	25.88

Factor used to convert from counts to 0.00001°C units =		0.0007892
Temperature error (°C) =		0.05

CONE TEMPERATURE EFFECT

	Cooling	Heating
Start temperature =	20.75	19.27
End temperature =	11.97	29.03
Temperature change =	-8.77	9.76

	Cooling	Heating
Tip maximum rate of change (MPa/°C/min) =	0.050	0.053
Tip end change (MPa/°C) =	0.003	0.001
Adjusted tip end change (MPa/°C) =	0.001	0.001
Sleeve maximum rate of change (kPa/°C/min) =	3.07	2.75
Sleeve end change (kPa/°C) =	0.05	0.05
Adjusted sleeve end change (kPa/°C) =	0.00	0.00
PWP end change (kPa/°C) =	0.80	0.57
Adjusted PWP end change (kPa/°C) =	0.01	0.01





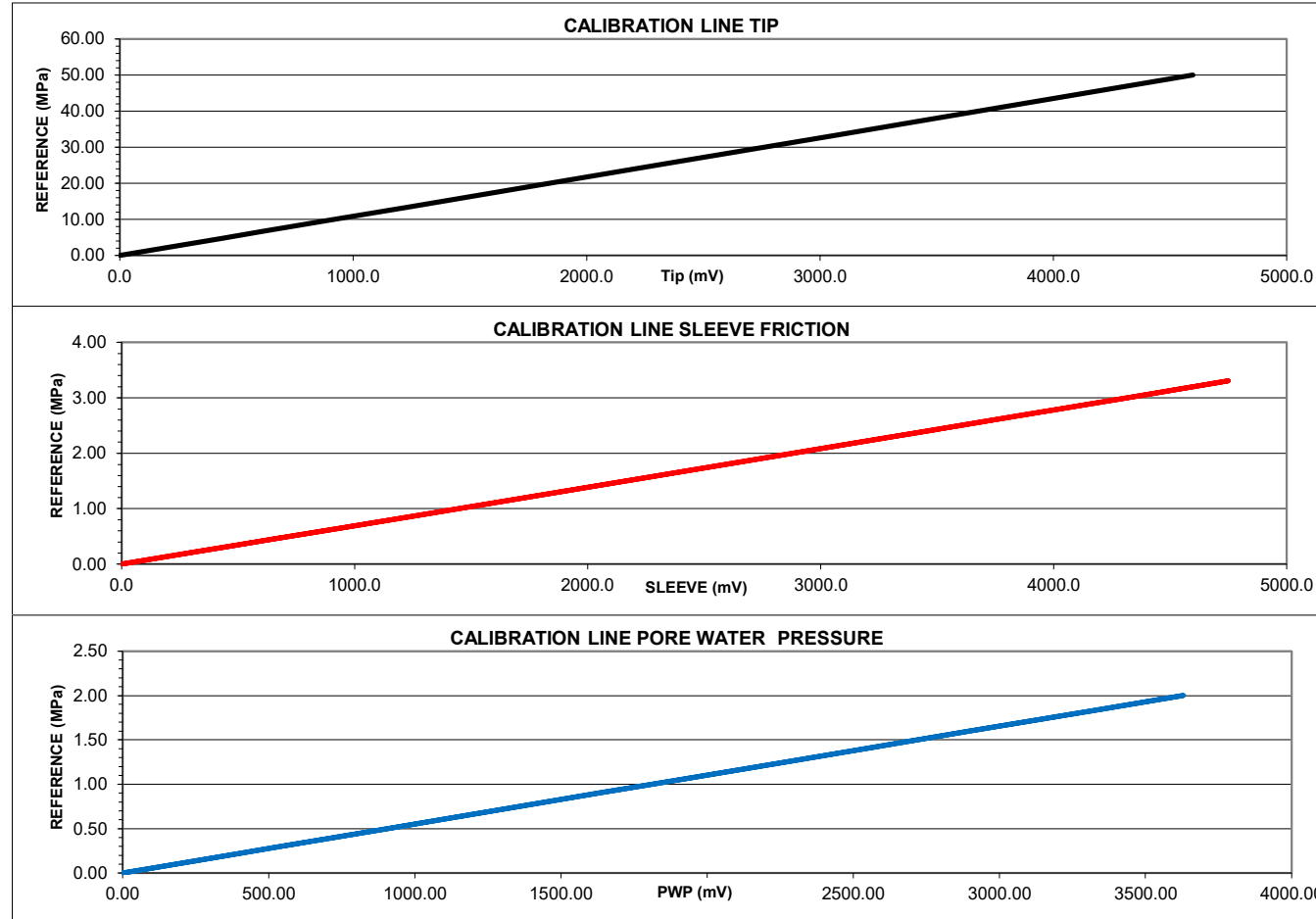
CALIBRATION CERTIFICATE

Geopoint-S15-150kN-5MPa

Cone Serial Number:
S15-CFIIP.1839

REFERENCE INSTRUMENTS:

	CONE END RESISTANCE	SLEEVE FRICTION	PORE WATER PRESSURE
ID	51998	51998	502273
TYPE	AM DSCC-100kN	AM DSCC-100kN	Omega MMG750V1
UNCERTAINTY (±%)	0.01	0.01	0.01
Nominal pressure (MPa,MPa,MPa)	50.00	3.30	3.00
Maximum pressure (MPa,MPa,MPa)	100.00	6.61	5.00
Area (cm ²)	15	227	N/A
Sensitivity (mV/MPa)	91.95	1437.12	1814.60
Calibration file scaling factor:			
Nominal cal force (kN, kN, BAR)	75	75	20
Calibration number (mV)	4598	4748	3629
Zero point (mV)	232	125	89
Sensitivity (mV/kN, mV/kN, mV/BAR)	61.303	63.309	181.460
Inclination factors (mV)	X -20°= 397, 0°= 2479, 20°= 4540 / Y -20°= 649, 0°= 2631, 20°= 4634		
Measured alpha factor:	0.80		
Uncertainty (%):			
Reproducibility	0.08	0.04	0.03
Linearity	0.06	0.08	0.11
Hysteresis	0.10	0.10	0.11
Combined expanded (k=2)	0.26	0.48	0.24
Application class	1	1	1



Instrument:	S15-150kN	Location:	Lankelma Calibration Laboratory
Serial Number:	S15-CFIIP.1839	Temperature(° C)	18.6
Manufacturer:	Geopoint	Calibration Engineer	P Metcalf
Date of calibration:	20/01/2021	Calibration Expiry	19/05/2021
Calibration signed and dated by:		Calibration checked and dated by:	
<i>P Metcalf</i>		<i>A N Harman</i>	



UK3 Track-truck

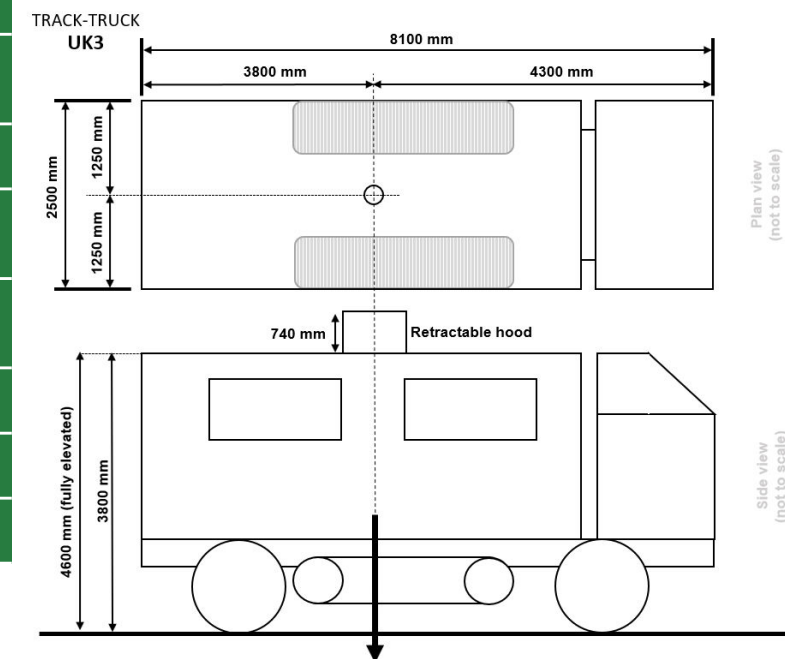
Rig weight	20.5 T
Max. operating ram capacity	17 T
Max. travelling speed	86 km/h
Track material	Steel
Track length	3300 mm
Track width	650 mm
Jack plate dimensions	Tracks act as jacks
Jack arrangements	1nr. on each side
Max. ground clearance on jacks	210 mm
Max. ground bearing pressure	Tracking/pushing – 47 kPa Pulling – 88 kPa
Max. testing gradient	10 degrees
Max. traversing gradient	20 degrees (operator assessed)
Noise output at 2 m	Testing - 74 dBA Driving – 87 dBA
Clamp arrangement	36/55 push-pull clamp
Ram stroke	1.2 m
Max. casing size	55 mm

Lankelma's 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 chalwyn valve and spark arrestor.

Typical production

An expected 100m+ of standard CPTu testing can be executed in a day (depending on conditions and access).

Specialist testing	Installations	Sampling
Seismic	VWP	MOSTAP
Pressuremeter	Piezometer	Shelby
Magnetometer	Inclinometer	
Video cone		
Wing cone		
Push-in shear vane		





UK15 Track-truck



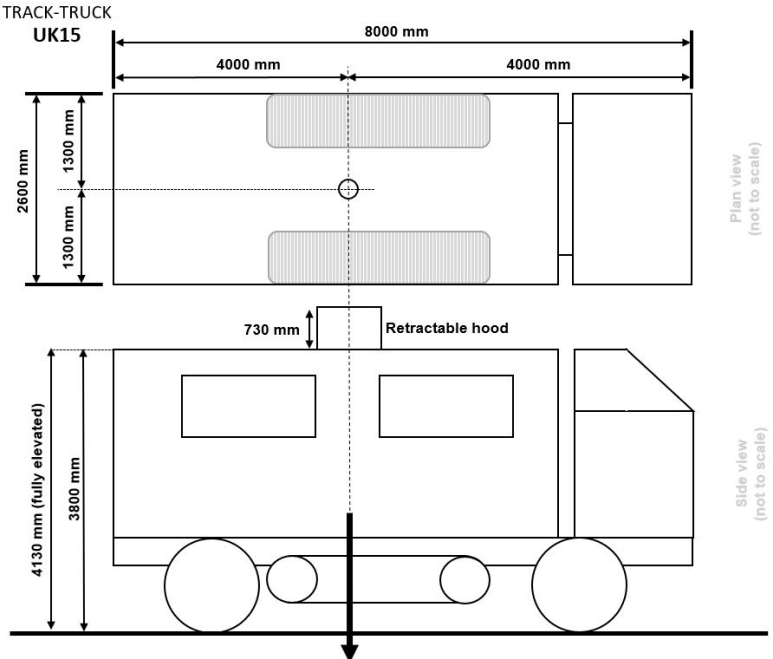
Rig weight	20.5 T
Max. operating ram capacity	17 T
Max. travelling speed	86 km/h
Track material	Steel
Track length	3300 mm
Track width	650 mm
Jack plate dimensions	Tracks act as jacks
Jack arrangements	1nr. on each side
Max. ground clearance on jacks	210 mm
Max. ground bearing pressure	Tracking/pushing – 51 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

Lankelma's 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.

Typical production

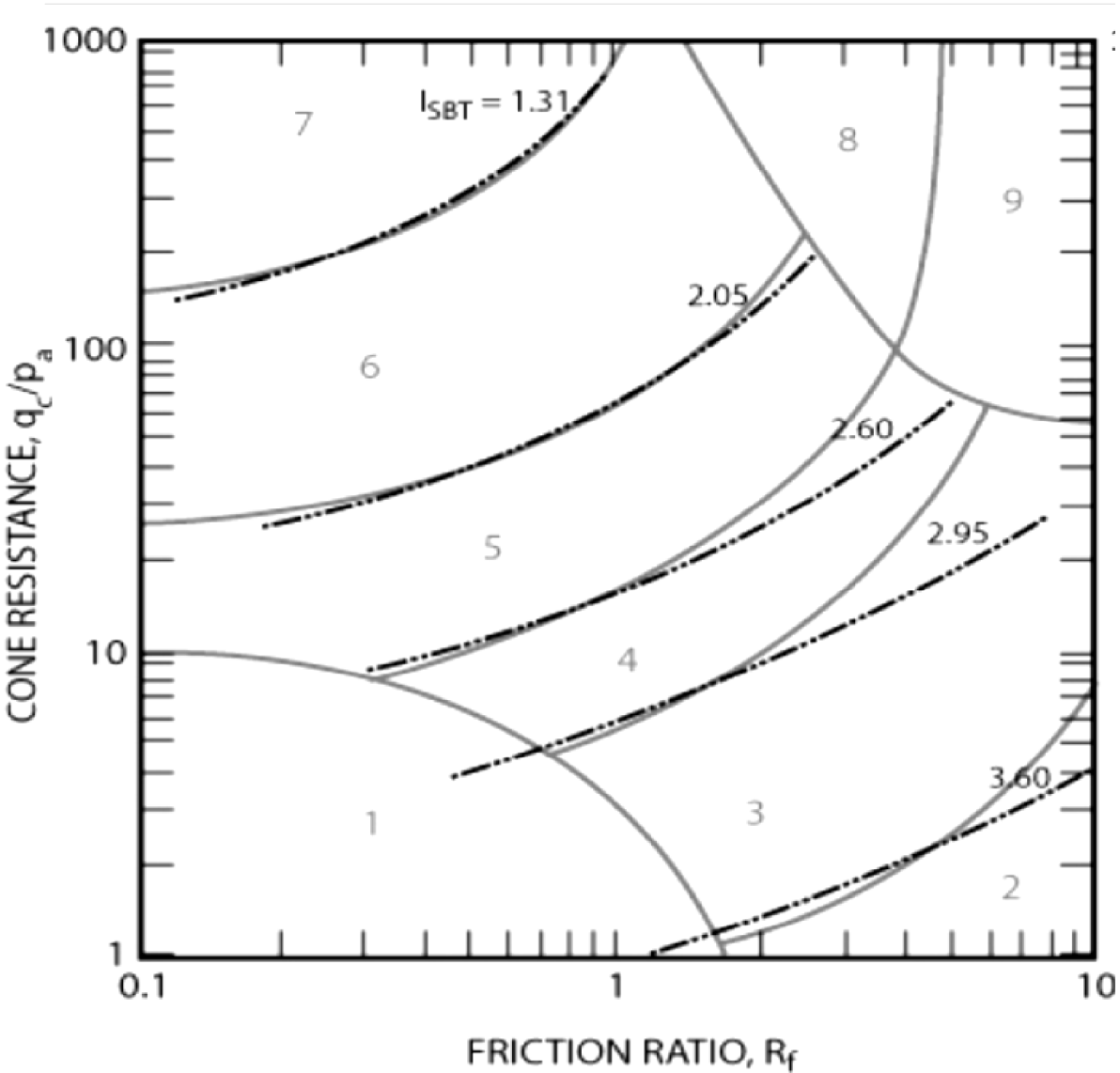
An expected 100m+ of standard CPTu testing can be executed in a day (depending on conditions and access).

Specialist testing	Installations	Sampling
Seismic	VWP	MOSTAP
Pressuremeter	Piezometer	Shelby
Magnetometer	Inclinometer	
Video cone		
Wing cone		
Push-in shear vane		



CAMBRIDGE

CPT SOIL BEHAVIOUR TYPE CHART



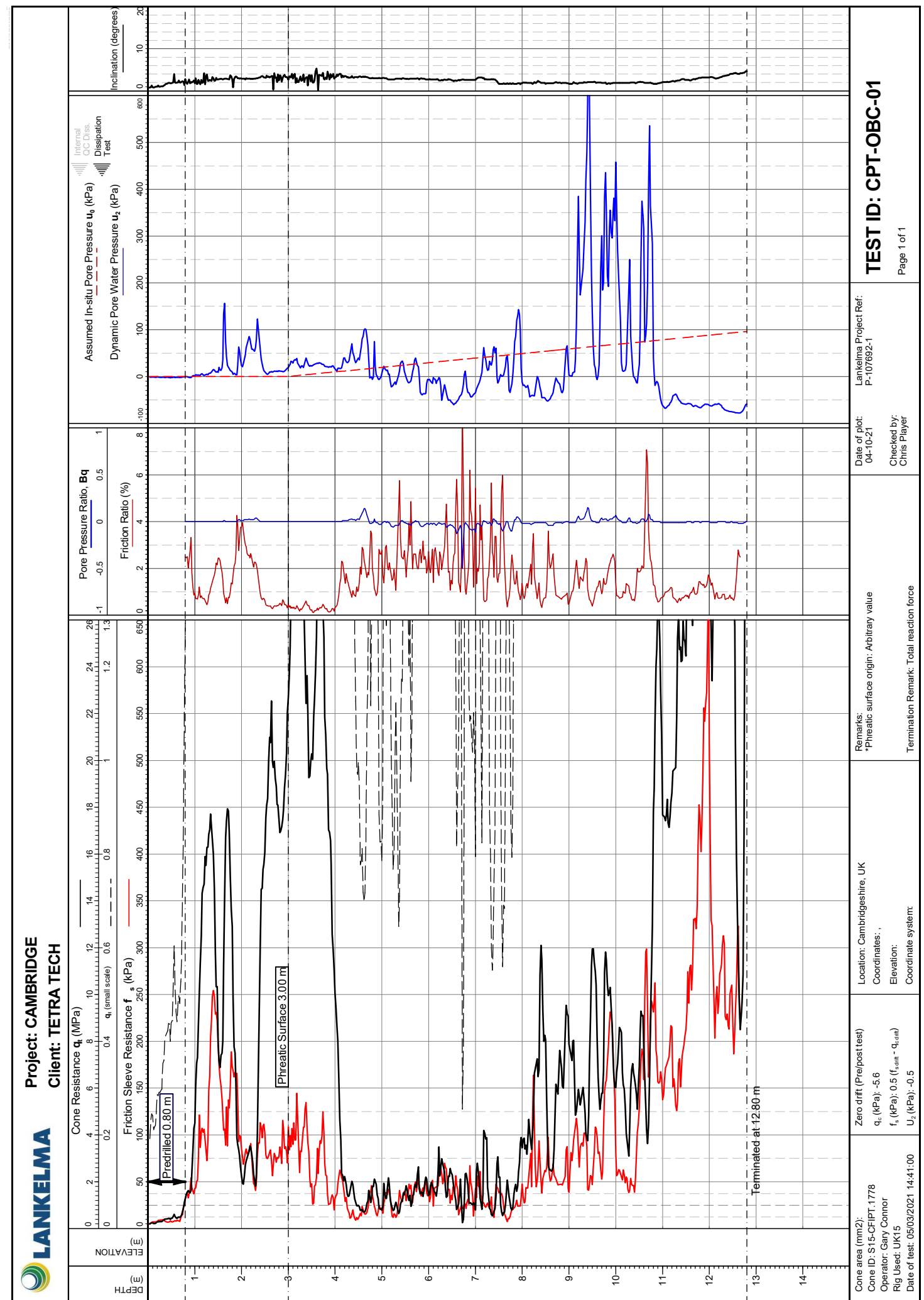
Non-normalised SBT chart by Robertson *et al.* (2010) based on dimensionless cone resistance (q_c/p_a) and friction ratio, R_f , showing contours of SBT index I_{SBT} (denoted I_c on the test plots). The chart is also applicable to normalised tip and sleeve values Q_t and F_r .

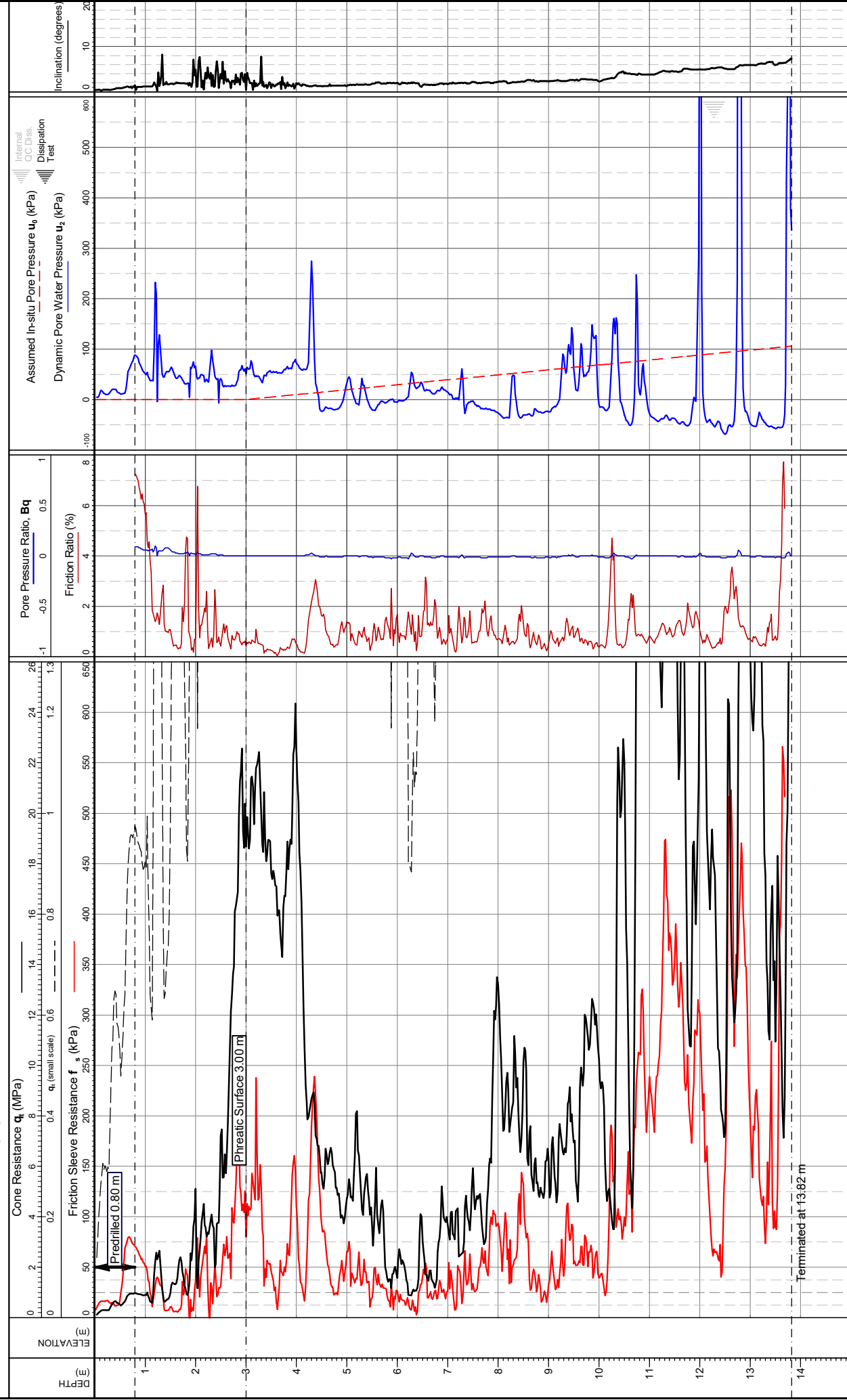
Zone	Soil Behaviour Type (SBT)	
1	Sensitive fine-grained	6 Sands - clean sand to silty sand
2	Organic soils	7 Gravelly sand to sand
3	Clays – clay to silty clay	8 Very stiff/dense sand to clayey sand*
4	Silt mixtures - clayey silt to silty clay	9 Very stiff fine grained*
5	Sand mixtures – silty sand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

Note 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.

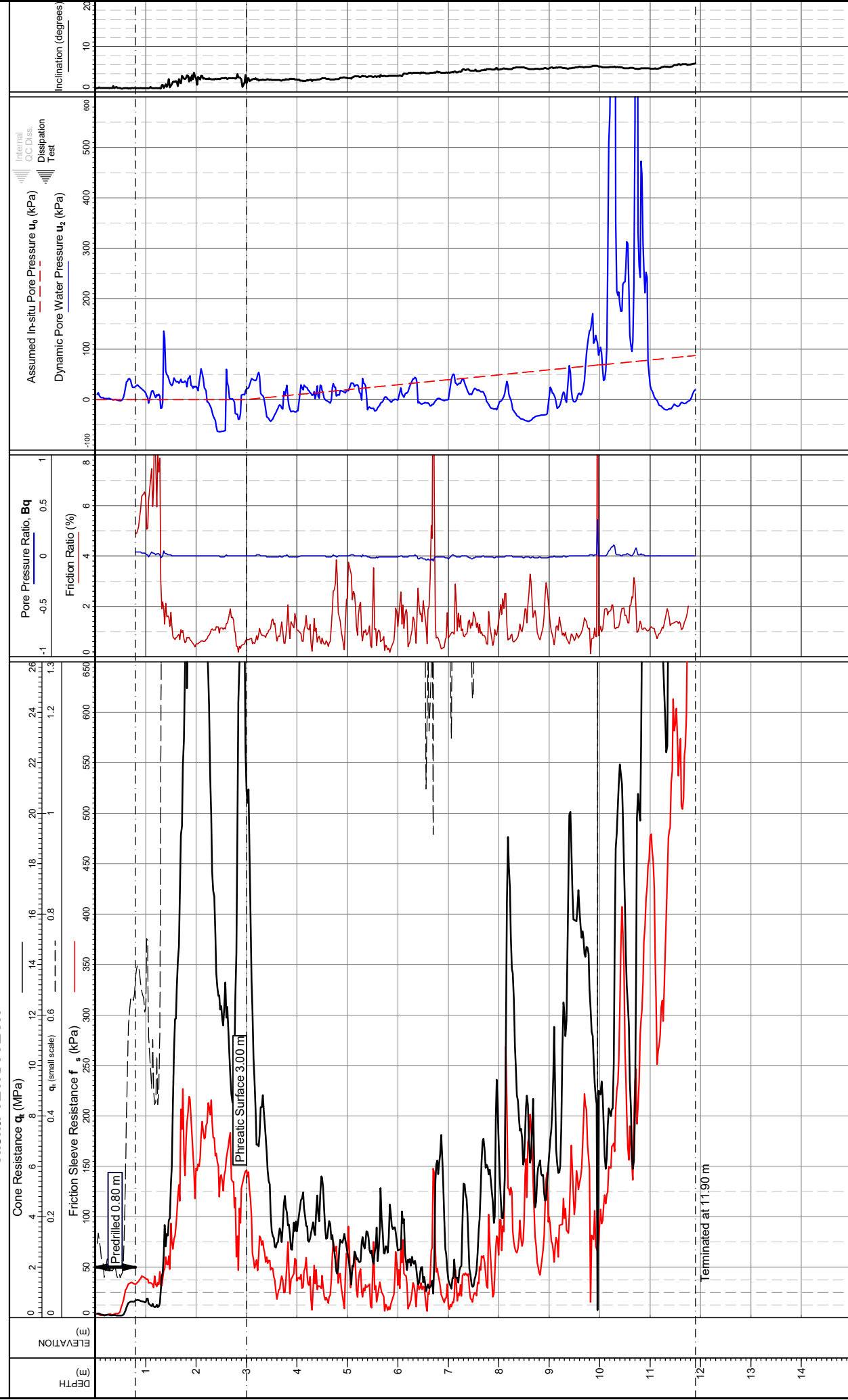
RAW DATA PLOTS

Plots are provided for all locations



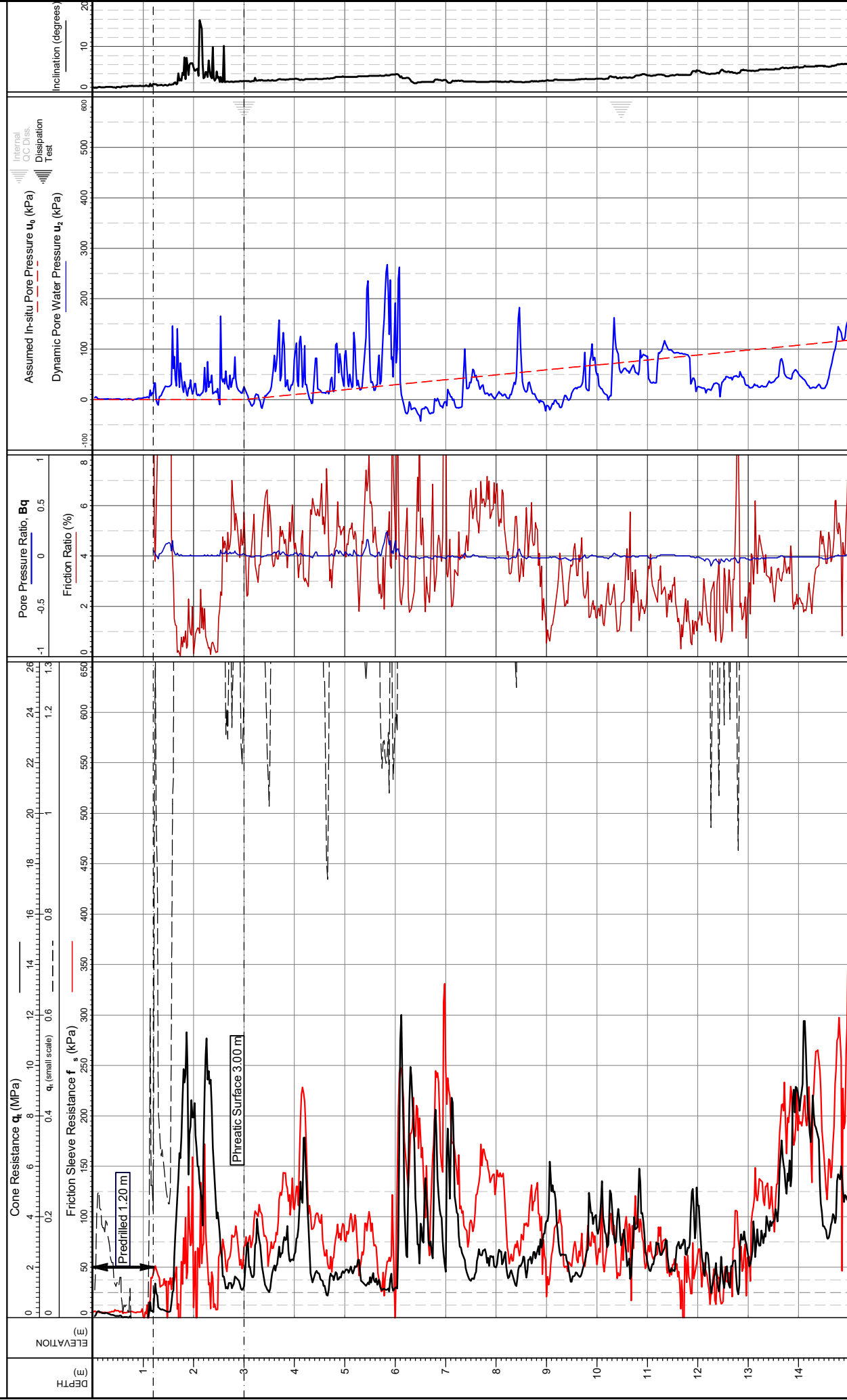
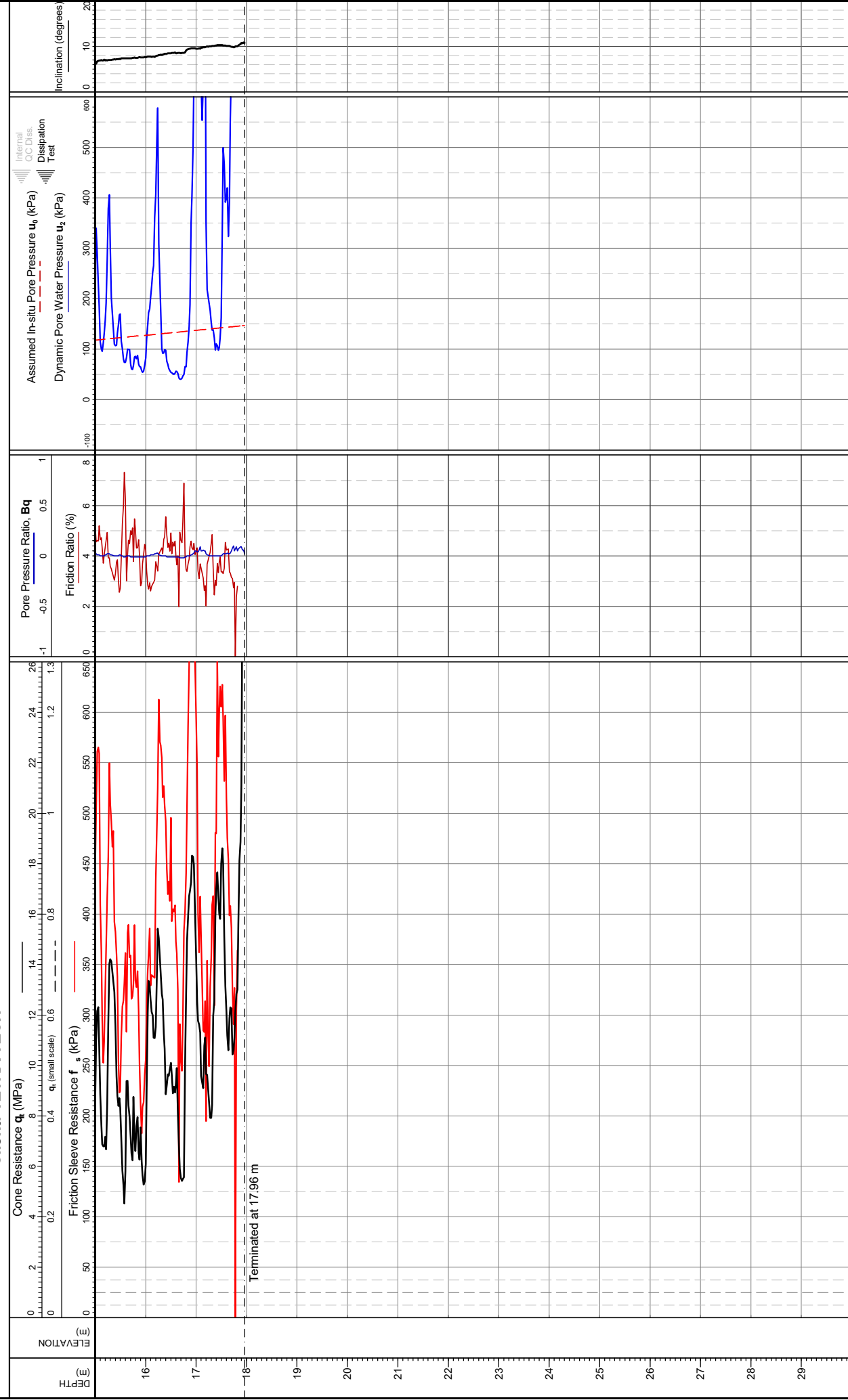


TEST ID: CPT-OBC-02		Lankelma Project Ref: P-107692-1	
Page 1 of 1			
Date of plot: 04-10-21		Checked by: Chris Player	
Remarks: -Pneatic surface origin: Arbitrary value			
Termination Remark: Total reaction force			
Location: Cambridgeshire, UK			
Coordinates: ,			
Elevation:			
Coordinate system:			
Zero drift (Pre/post test)			
q _c (kPa): -4.0			
f _s (kPa): -0.3 (f _{s,off} - q _{c,off})			
U ₂ (kPa): 4.8			
Cone area (mm ²):			
Cone ID: S15-CFPT-1778			
Operator: Gary Connor			
Rig Used: UK15			
Date of test: 05/03/2021 12:52:00			



TEST ID: CPT-OBC-03		Page 1 of 1	
Lankelma Project Ref: P-107892-1		Date of plot: 04-10-21	
Checked by: Chris Player		Remarks: -Pneatic surface origin. Arbitrary value	
Termination Remark: Total reaction force		Location: Cambridgeshire, UK Coordinates: , Elevation: Coordinate system:	
Zero drift (Pre/post test) q_z (kPa): -3.6 f_s (kPa): -0.5 ($f_{s, drift} - q_{z, drift}$) U_2 (kPa): 0.1		Cone area (mm2): Cone ID: S15-CF1PT-1778 Operator: Gary Connor Rig Used: UK15 Date of test: 05/03/2021 11:36:00	

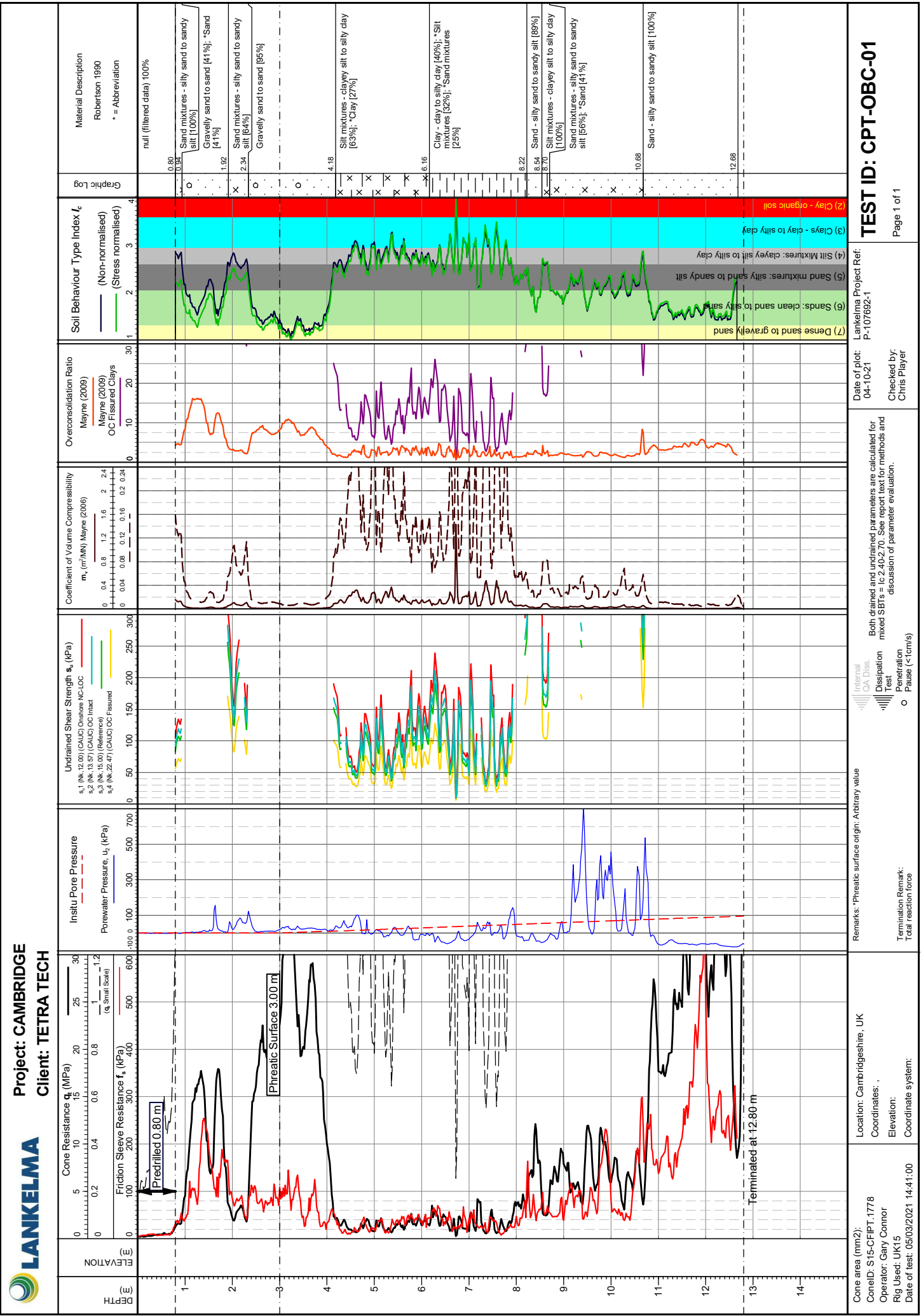
TEST ID: CPT-OBC-03



APPENDIX D INTERPRETATION RESULTS - SET 1

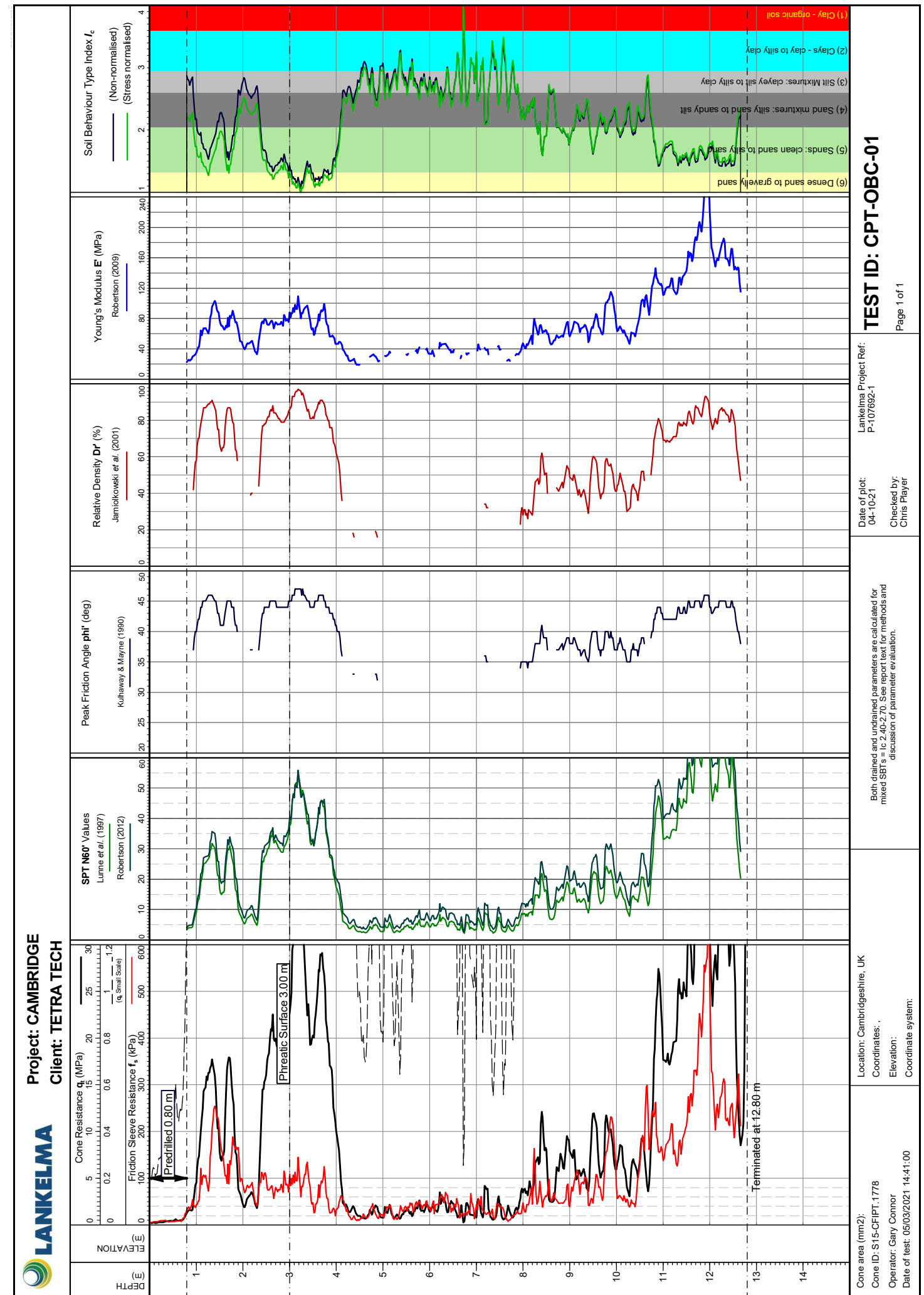
UNDRAINED SHEAR STRENGTH
COEFFICIENT OF VOLUME CHANGE
OVERCONSOLIDATION RATIO
SOIL BEHAVIOUR TYPE (SBT) DESCRIPTIONS

Plots are provided for all locations



EQUIVALENT SPT N60
PEAK FRICTION ANGLE
RELATIVE DENSITY
YOUNG'S MODULUS

Report no. P-107692-1R02CP

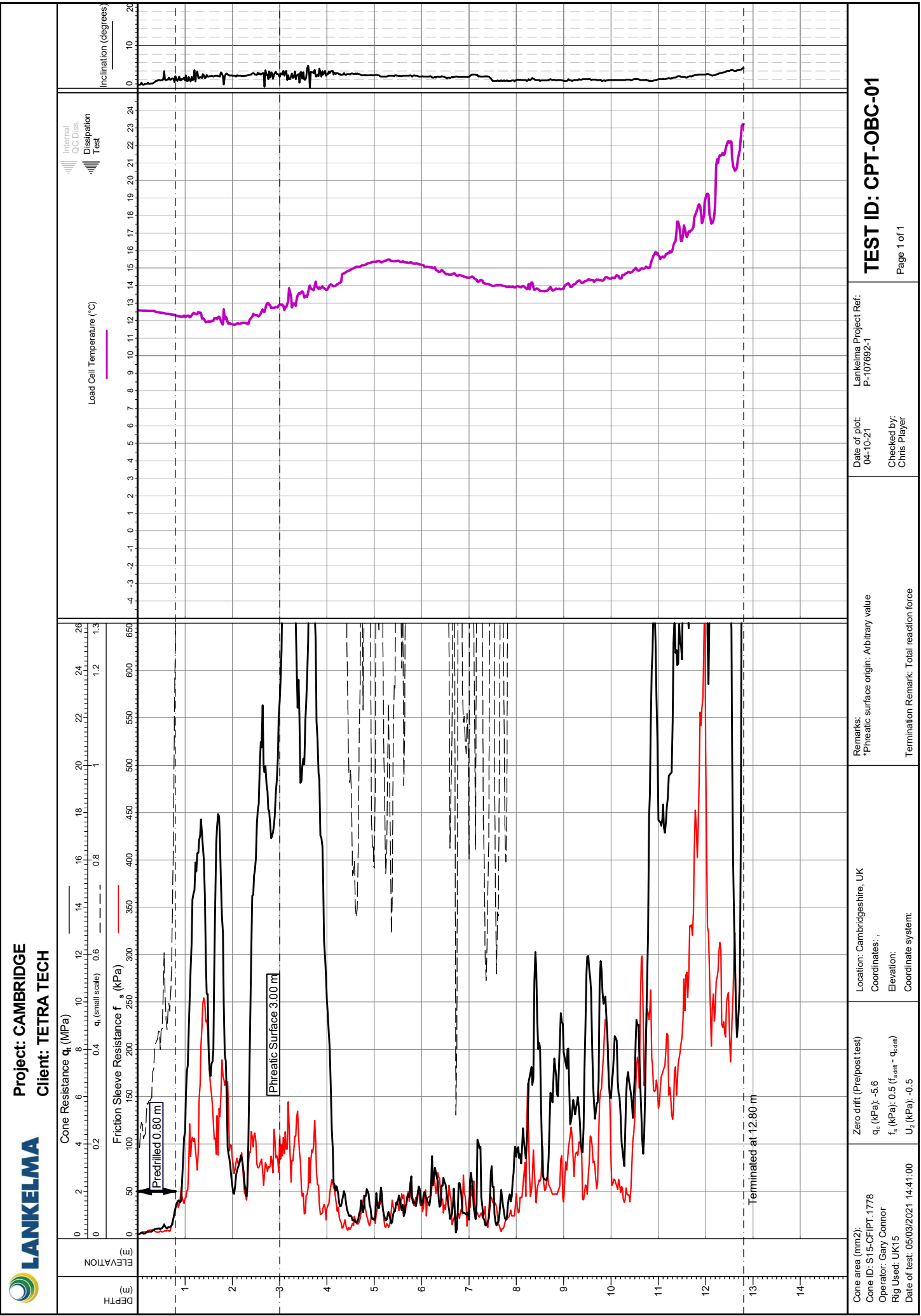


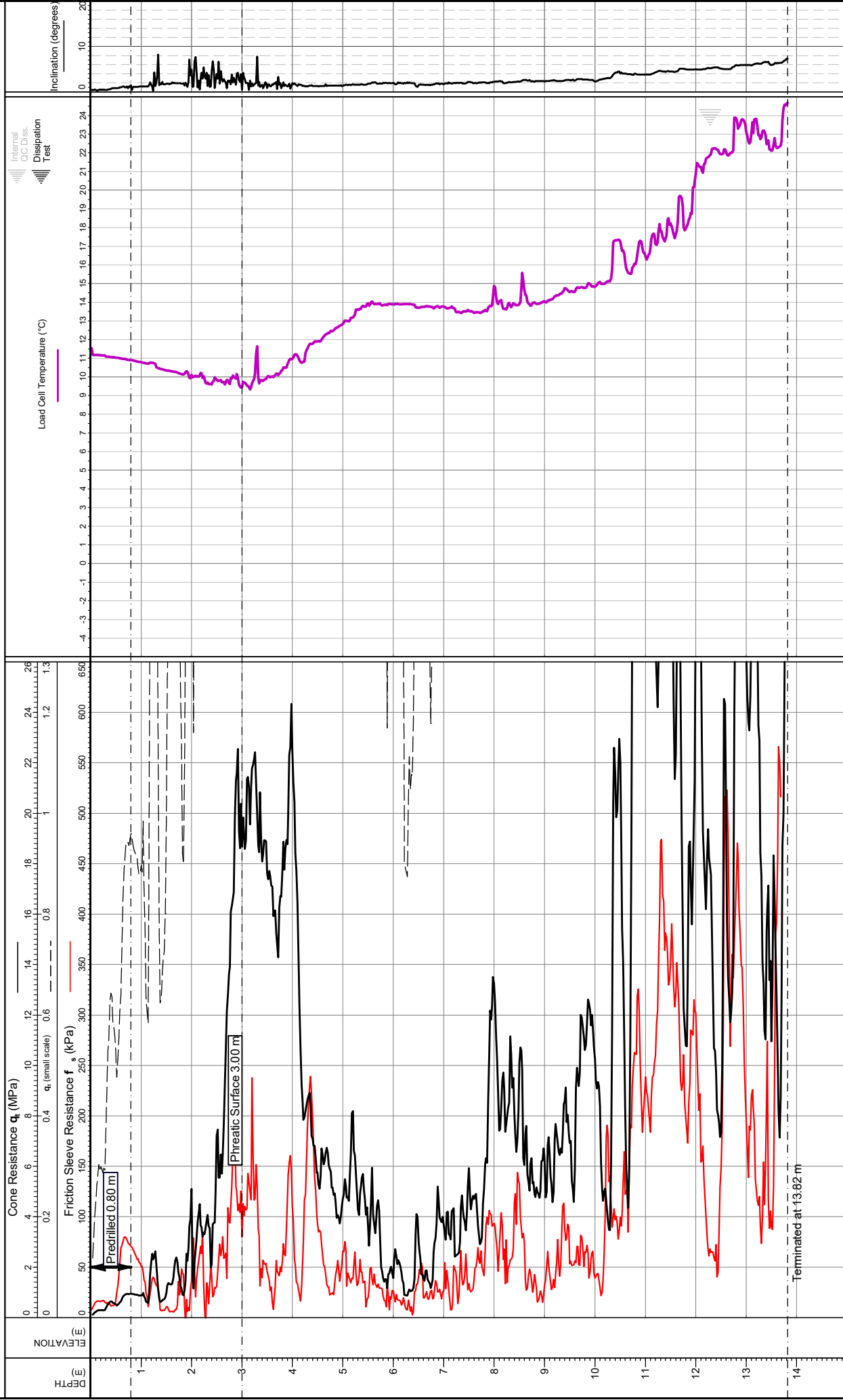
APPENDIX F PENETROMETER TEMPERATURE RESULTS

The temperature values in these logs represent the internal load cell temperature of the penetrometer and are used for QC purposes by comparison to the measured temperature response indicated on the calibration certificate. The CPT results have been corrected for transient temperature effects during post processing.

Ground temperature is only represented following a penetration pause of > 11 minutes.

Plots are only provided for locations performed with digital penetrometer(s) measuring internal load cell temperature





TEST ID: CPT-OBC-02

Page 1 of 1

Date of plot:
04-10-21

Checked by:
Chris Player

Remarks:
*Phreatic surface origin: Arbitrary value

Termination Remark: Total reaction force

Location: Cambridgeshire, UK

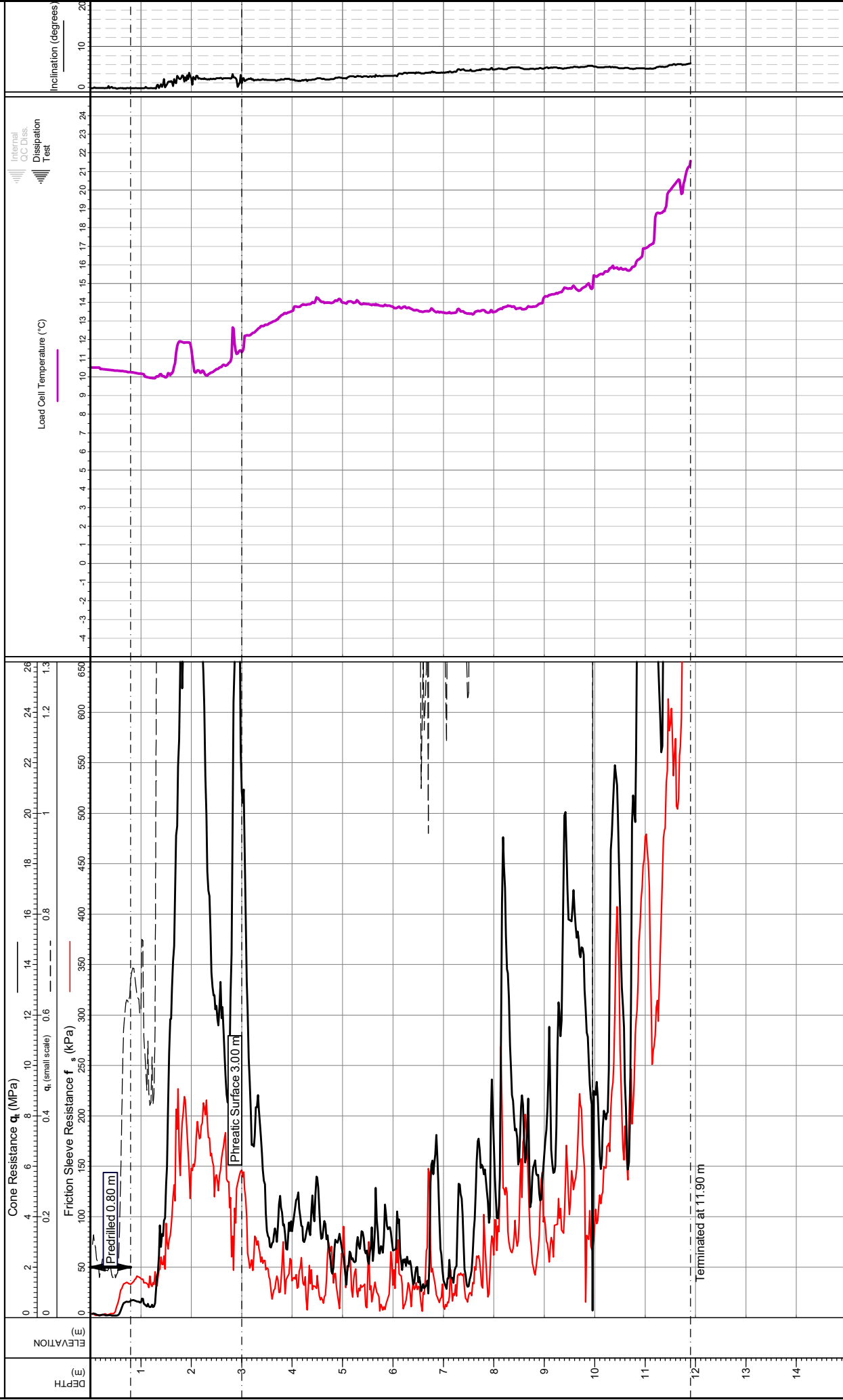
Elevation:

Coordinate system:

Zero drift (Pre/post test)

 $f_s \text{ (kPa): } -0.3 (f_{s \text{ drift}} - q_{\text{cdrift}})$ U_2 (kPa): 4.8

Cone area (mm2):
Cone ID: S15-CFIPT.1778
Operator: Gary Connor
Rig Used: UK15
Date of test: 05/03/2021 12:52:00



TEST ID: CPT-OBC-03

Page 1 of 1

Date of plot:
04-10-21

Checked by:
Chris Player

Remarks:
*Phreatic surface origin: Arbitrary value

Termination Remark: Total reaction force

Location: Cambridgeshire, UK

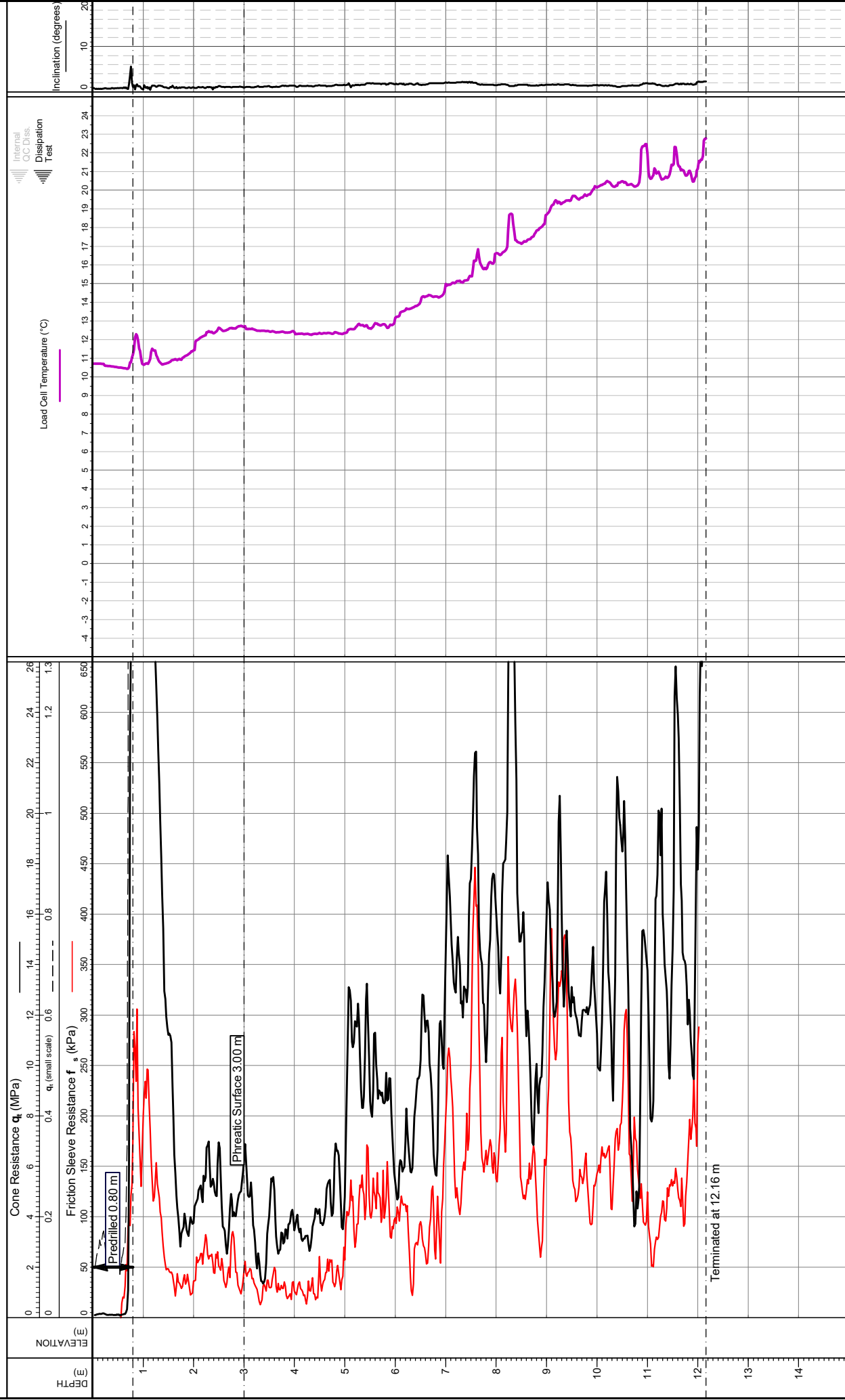
Elevation:

Coordinate system:

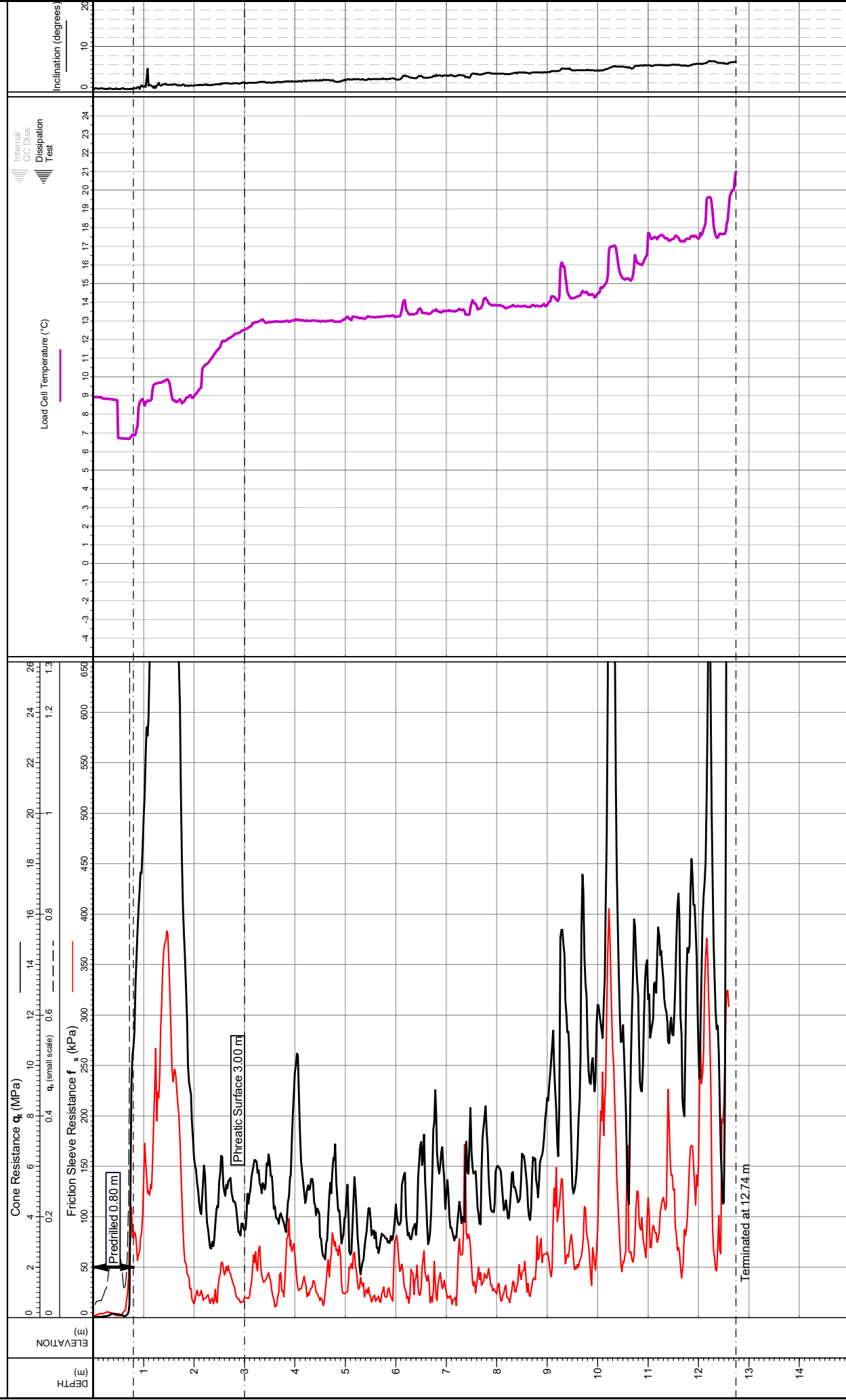
Zero drift (Pre/post test)

f_s (kPa): -0.5 ($f_{s\text{ drift}} - q_{\text{cdrift}}$)
 U_2 (kPa): 0.1

Cone area (mm2):
Cone ID: S15-CFIPT.1778
Operator: Gary Connor
Rig Used: UK15
Date of test: 05/03/2021 11:36:00



TEST ID: CPT-OBC-04		Lankelma Project Ref: P-107892-1	
Page 1 of 1			
Date of plot: 04-10-21		Checked by: Chris Player	
Remarks: -Pneatic surface origin. Arbitrary value			
Termination Remark: Total reaction force			
Location: Cambridgeshire, UK			
Coordinates: ,			
Elevation:			
Coordinate system:			
Zero drift (Pre/post test)			
q_c (kPa): -5.8			
f_s (kPa): 0.0 ($f_{s,diff} - q_{c,diff}$)			
U_z (kPa): 0.1			
Cone area (mm2):			
Cone ID: S15-CFPT-1778			
Operator: Gary Connor			
Rig Used: UK15			
Date of test: 05/03/2021 10:44:00			



TEST ID: CPT-OBC-05		Lankelma Project Ref: P-107692-1	
Date of plot: 04-10-21		Checked by: Chris Player	
Remarks: -Pneatic surface origin. Arbitrary value		Termination Remark: Total reaction force	
Location: Cambridgeshire, UK Coordinates: , Elevation: Coordinate system:		Zero drift (Pre/post test) q_c (kPa): -7.2 f_s (kPa): -0.5 ($f_{s,off} - q_{c,off}$) U_z (kPa): -4.2	
Cone area (mm2): Cone ID: S15-CFPT-1778 Operator: Gary Connor Rig Used: UK15 Date of test: 05/03/2021 09:40:00			

TEST ID: CPT-OBC-05