



HBR NL Grondonderzoek Maasvlakte Distripark West

Report geotechnical site investigation | Maasvlakte Rotterdam

2422-210725 | 1 April 2022

Final

Port of Rotterdam

Document Control

Document Information

Project Title	HBR NL Grondonderzoek Maasvlakte Distripark West
Document Title	Report geotechnical site investigation
Fugro Project No.	2422-210725
Fugro Document No.	2422-210725-21-R01-v1.0-20220401
Issue Number	1.0
Issue Status	Final
Fugro Legal Entity	Fugro NL Land B.V.
Issuing Office Address	Prismastraat 2 Postbus 63 2260 AB Leidschendam T 070 31 11333

Client Information

Client	KIVI
Client Address	Prinsessegracht 23, 2514 AP, DEN HAAG
Client Contact	

Revision History

Issue	Date	Status	Comments on Content	Prepared By	Checked By	Approved By
1.0	01-04-2022	Final	Initial version	FDV	KKN	CVI

Project Team

Initials	Name	Role
CVI	drs. C. van Isselt	Senior Adviseur Geofysica

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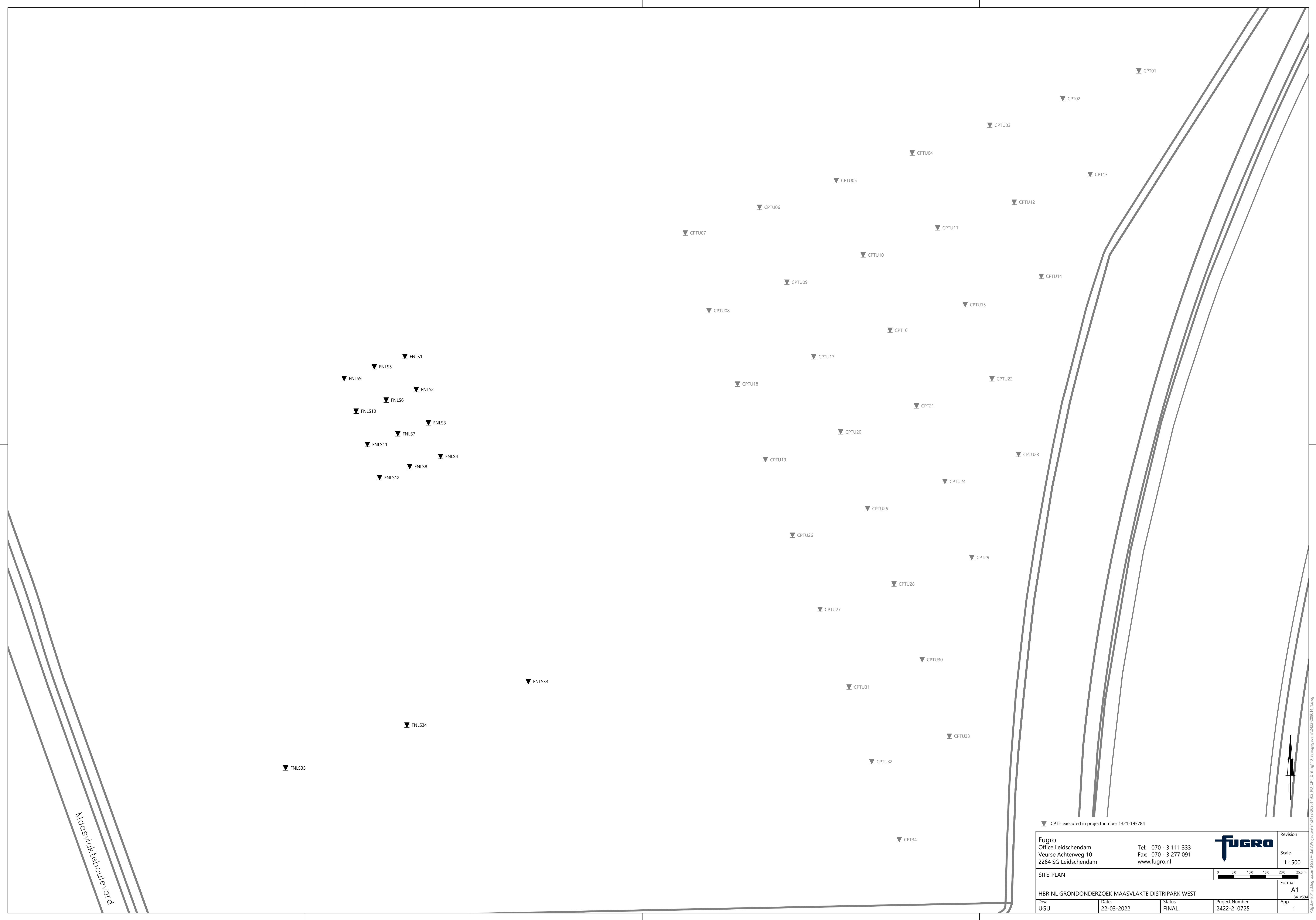
1. Report
2. Site plan
3. Survey data
4. Explanation geotechnical site investigation
5. Electrical cone penetration testing
6. Legend site investigation tests

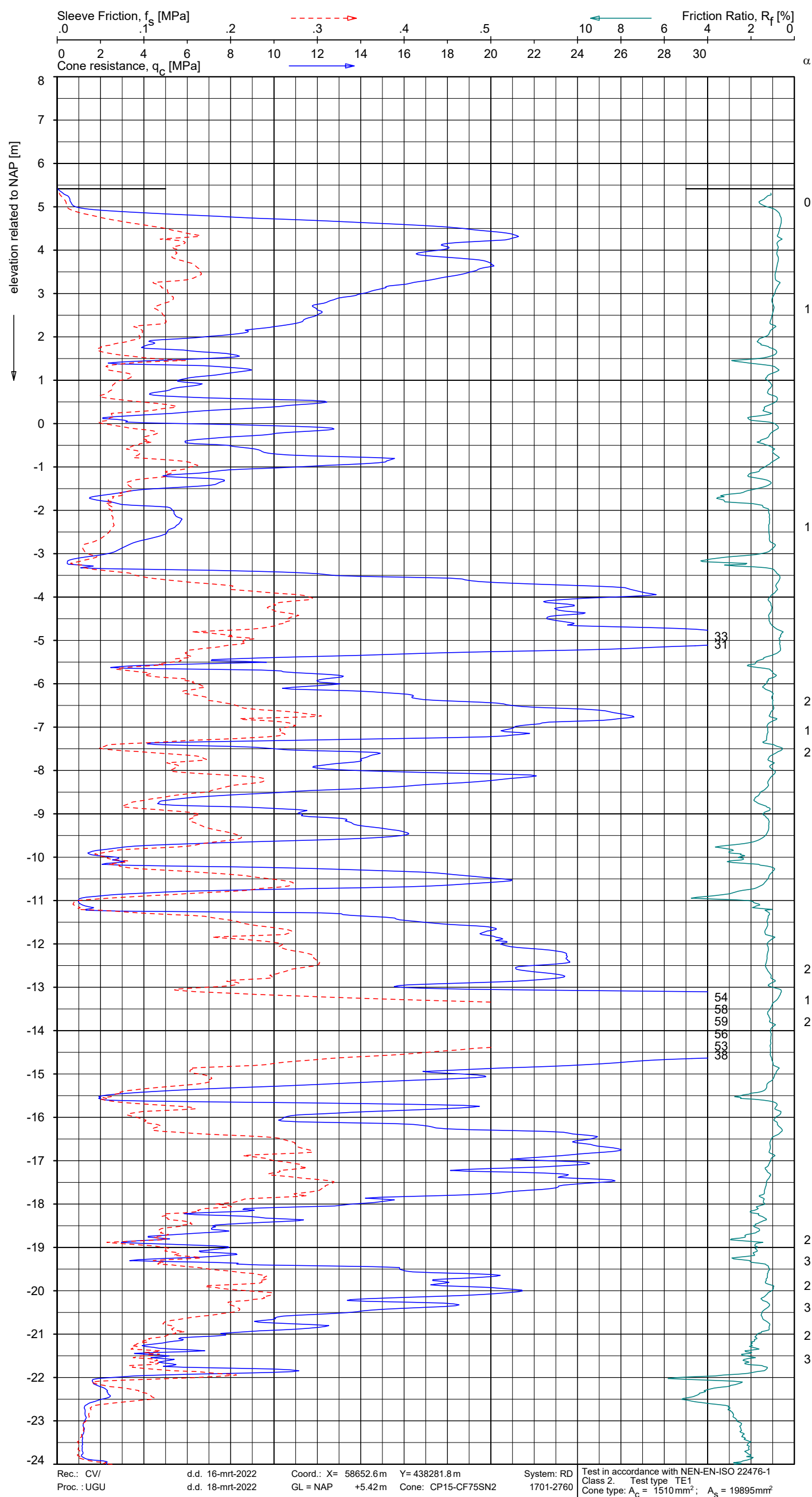
Reporting overview

Project Title: HBR NL Grondonderzoek Maasvlakte Distripark West
Fugro Project No.: 2422-210725

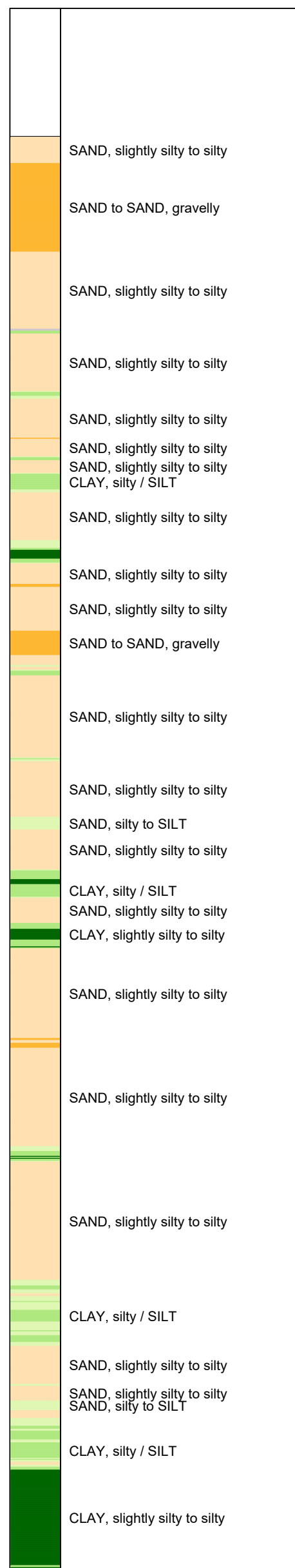
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	X	Y	NAP	NAP	
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FNLS4	58663.5	438250.9	58663.67		
FNLS5	58643.1	438278.5	58643.03		
FNLS6	58646.8	438268.2	58646.73		
FNLS7	58650.4	438257.9	58650.36		
FNLS8	58654.1	438247.6	58654.05		
FNLS9	58633.7	438275.2	58633.64		
FNLS10	58637.4	438264.9	58637.37		
FNLS11	58641.0	438254.6	58640.90		
FNLS12	58644.7	438244.2	58644.68		
FNLS33	58691.0	438180.5	58690.99		
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measured





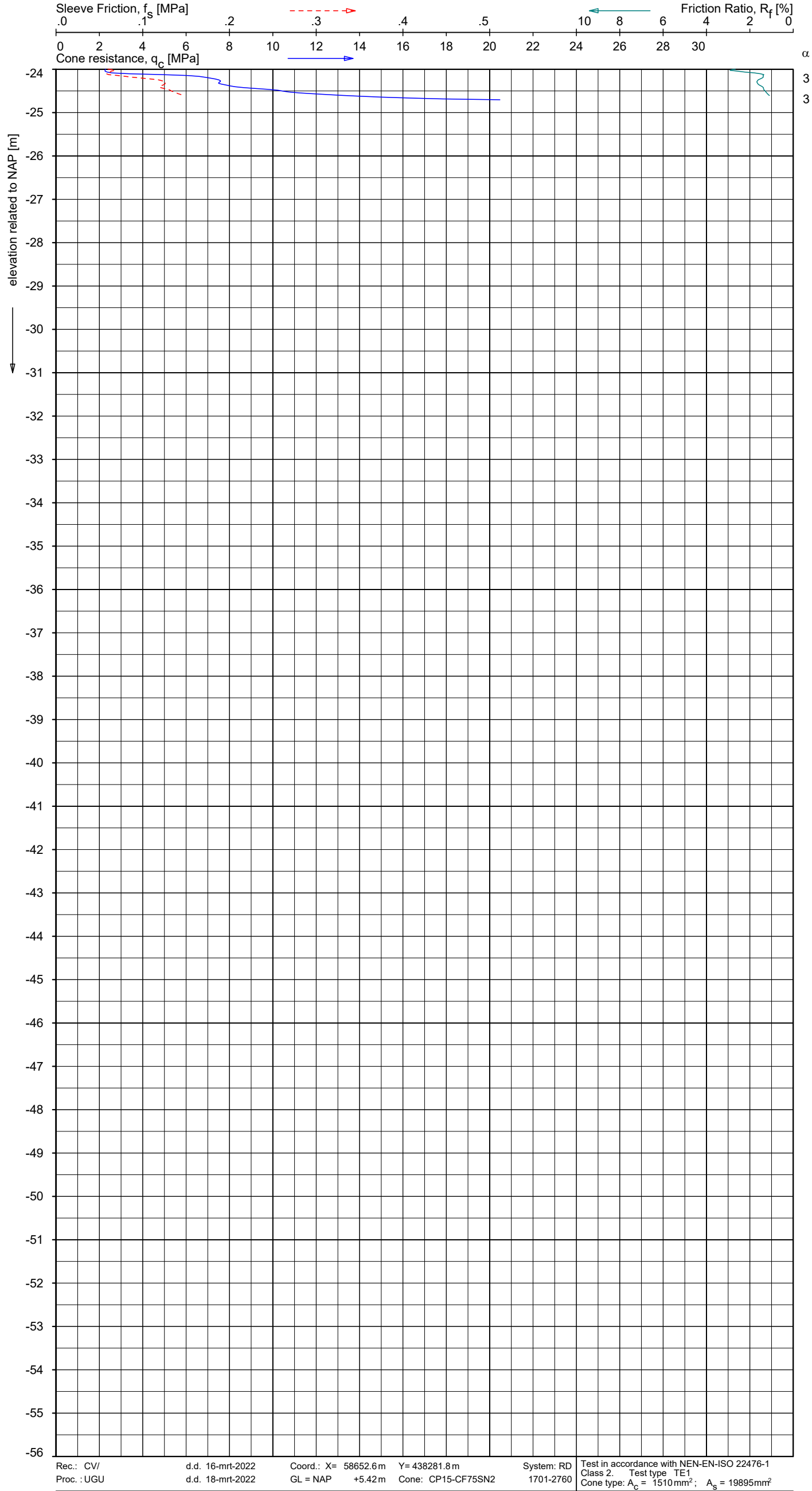
Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)



CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

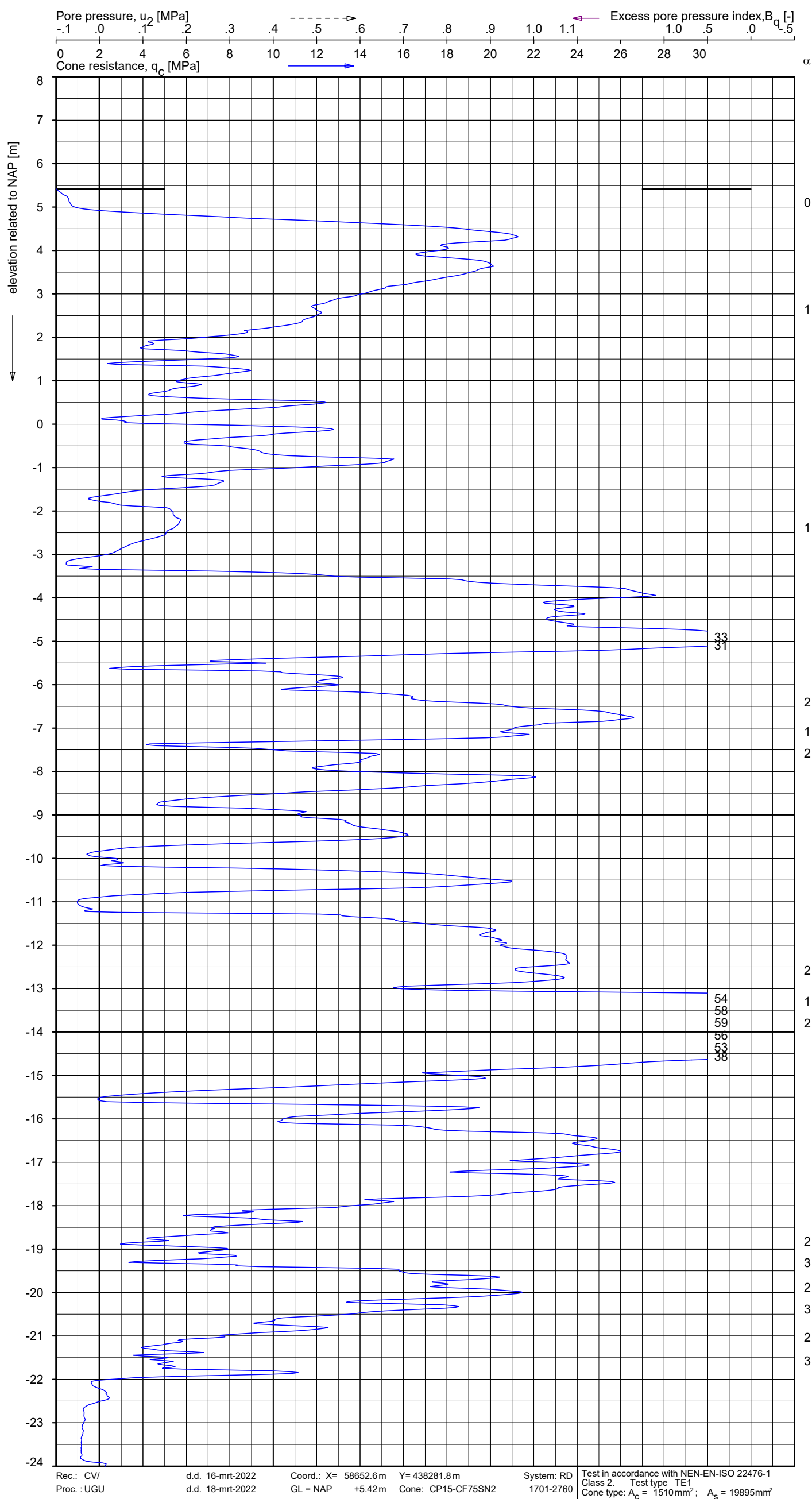
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Cpt	FNLS1



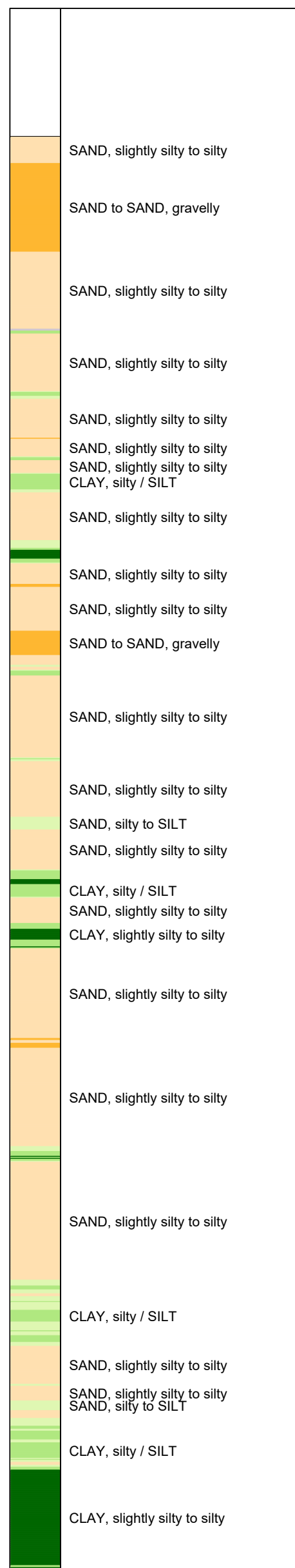
Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

	SAND, silty to SILT
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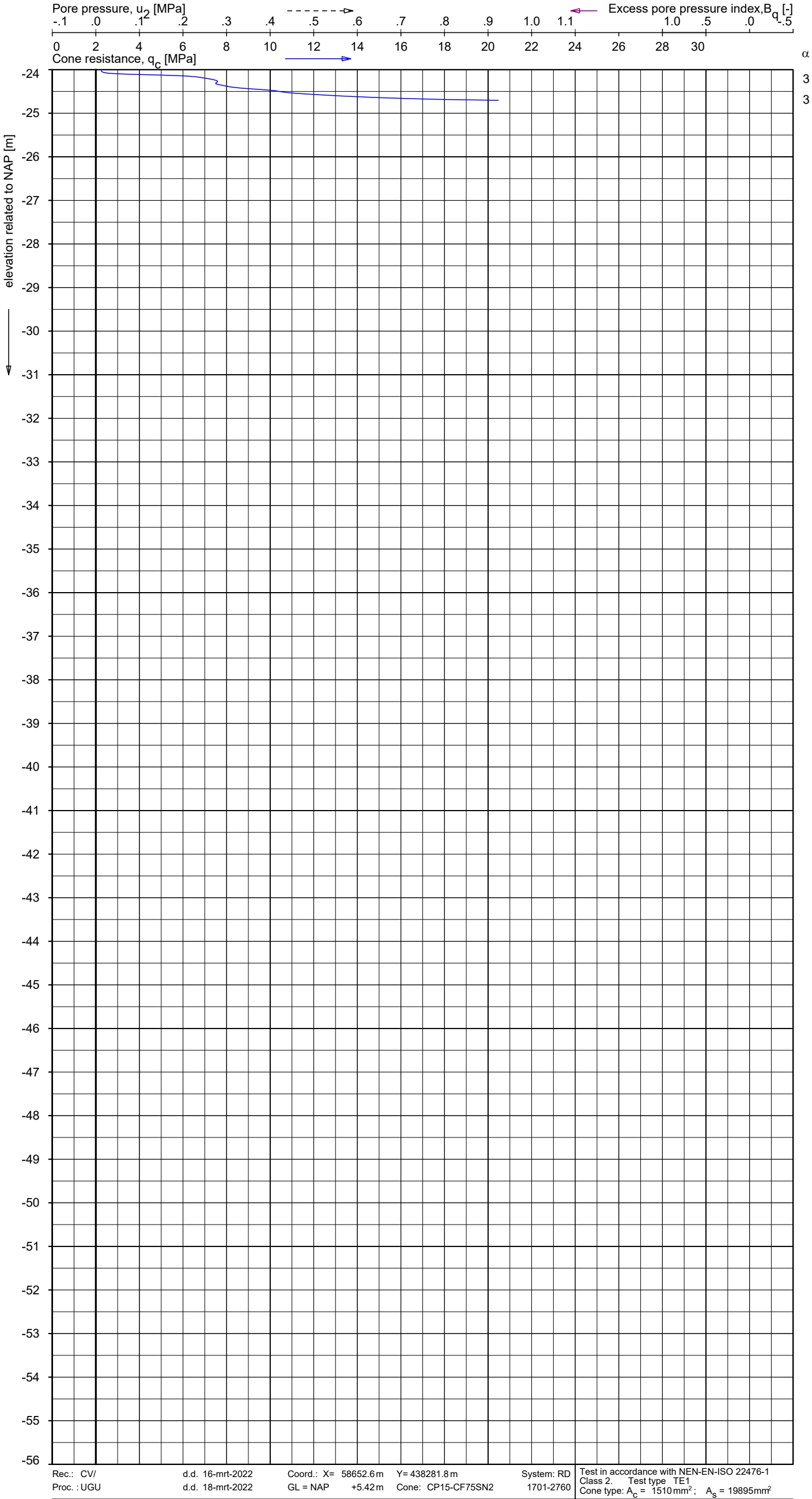
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Valid below groundwater level
(Robertson 1990, NL corr.)



PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIIPARK WEST

Proj.	2422-209014
Cpt	FNLS1



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

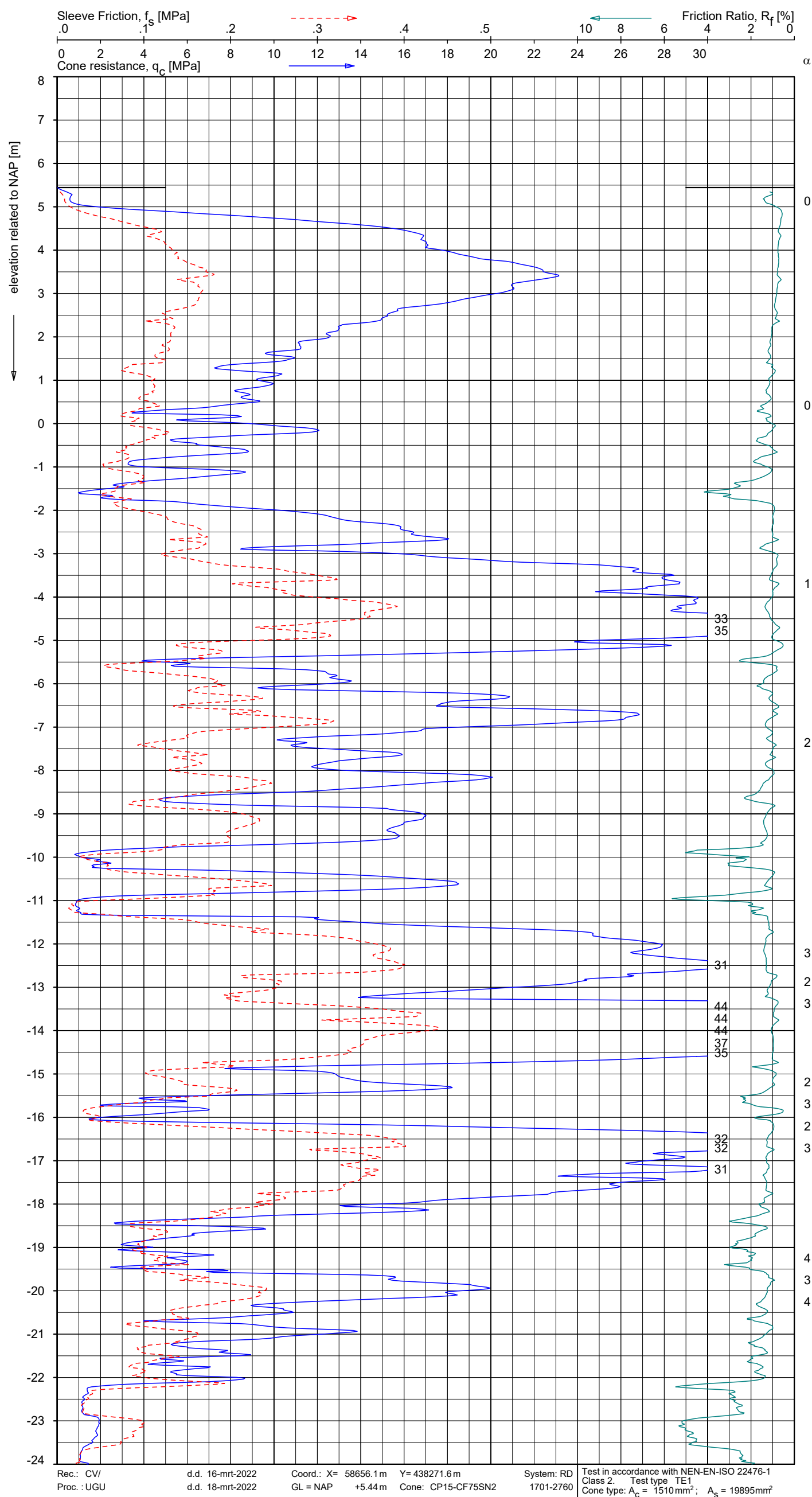
	SAND, silty to SILT
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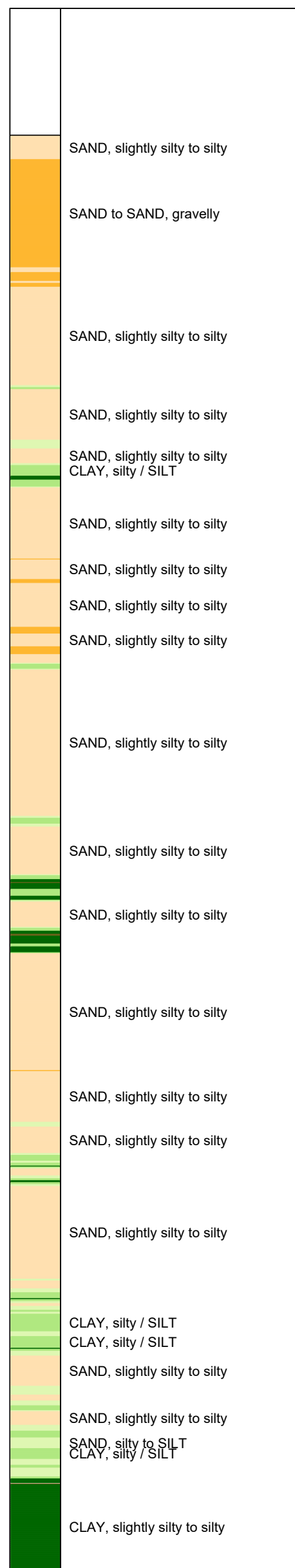
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS1





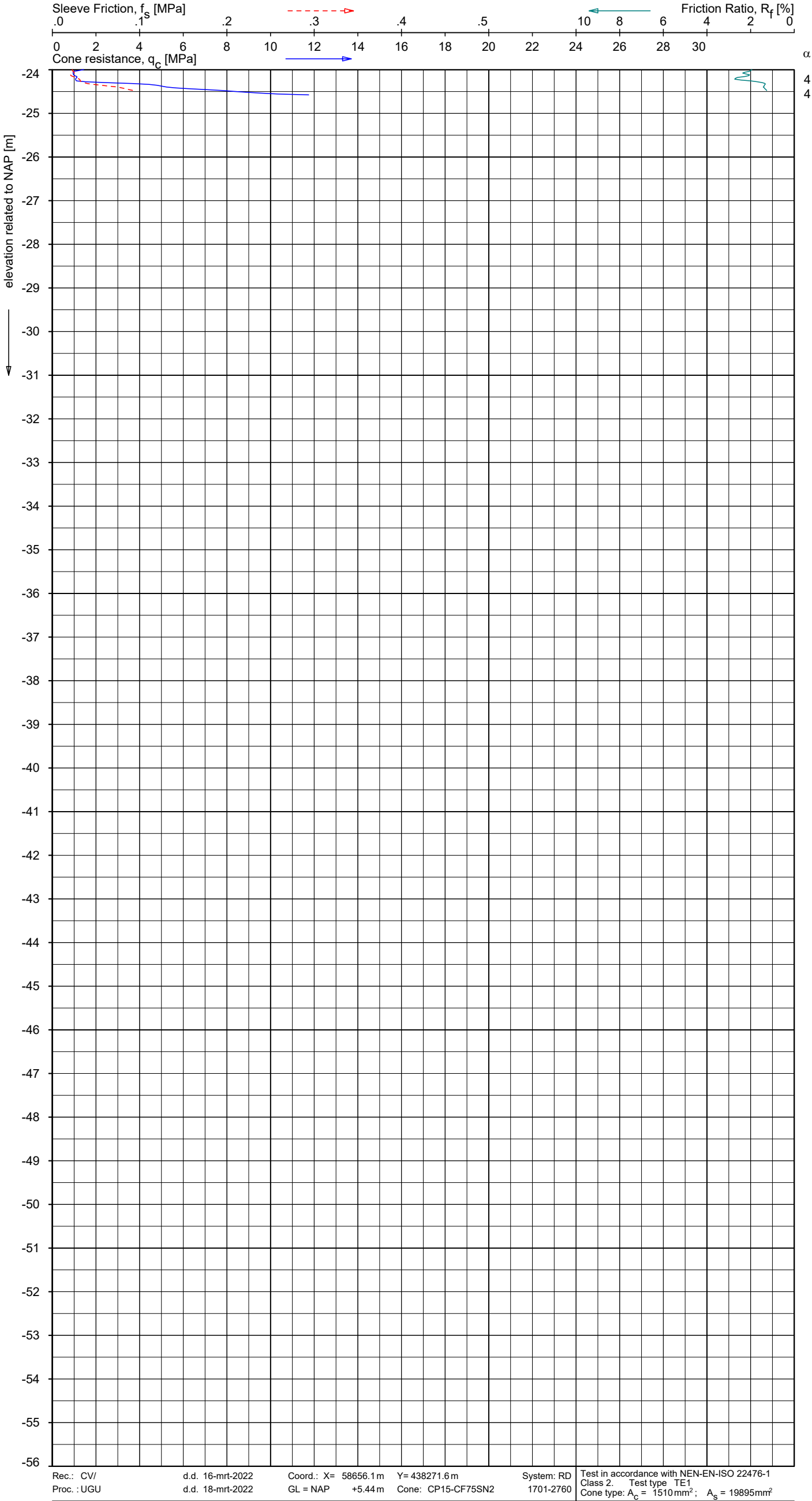
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Valid below groundwater level
(Robertson 1990, NL corr.)



CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj.	2422-209014
Cpt	FNLS2



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

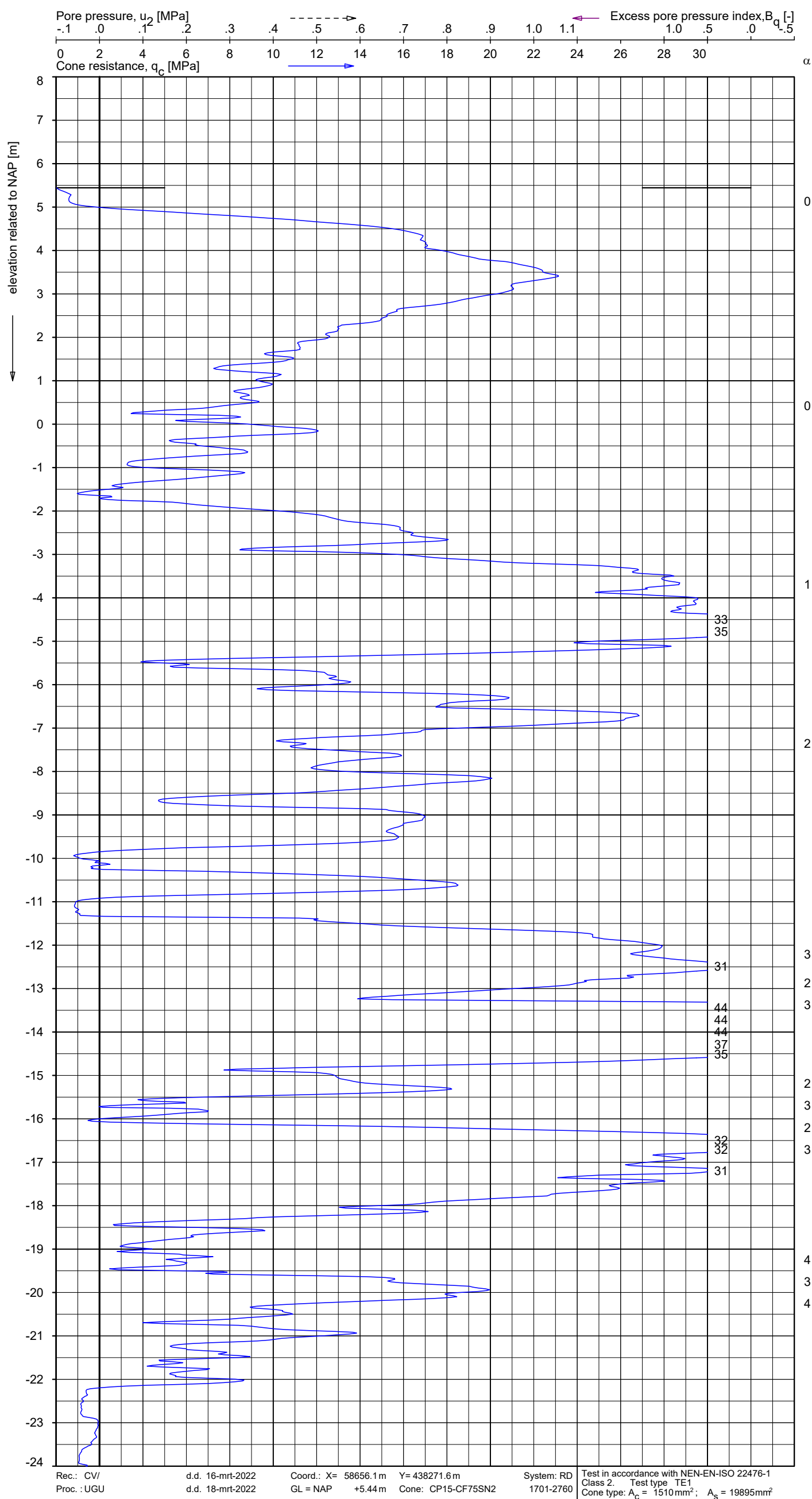
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	SAND, silty to SILT

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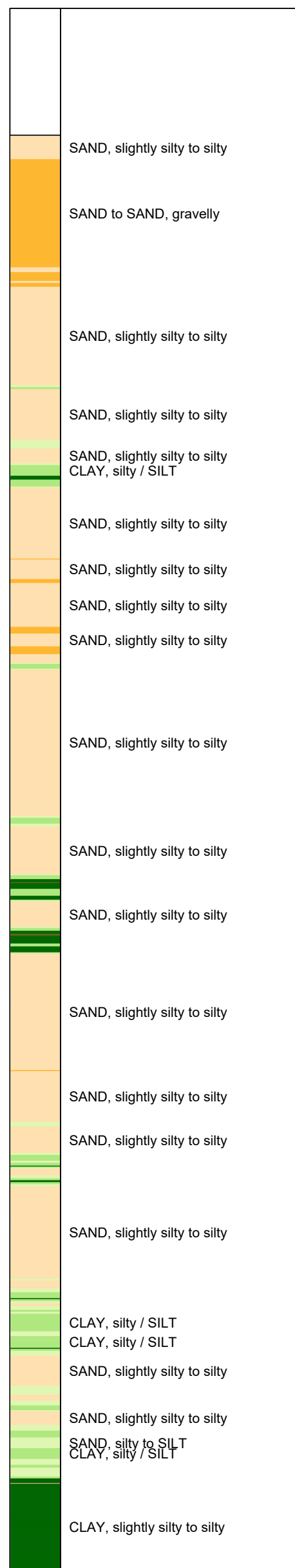
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Proj. 2422-209014
Cpt FNLS2





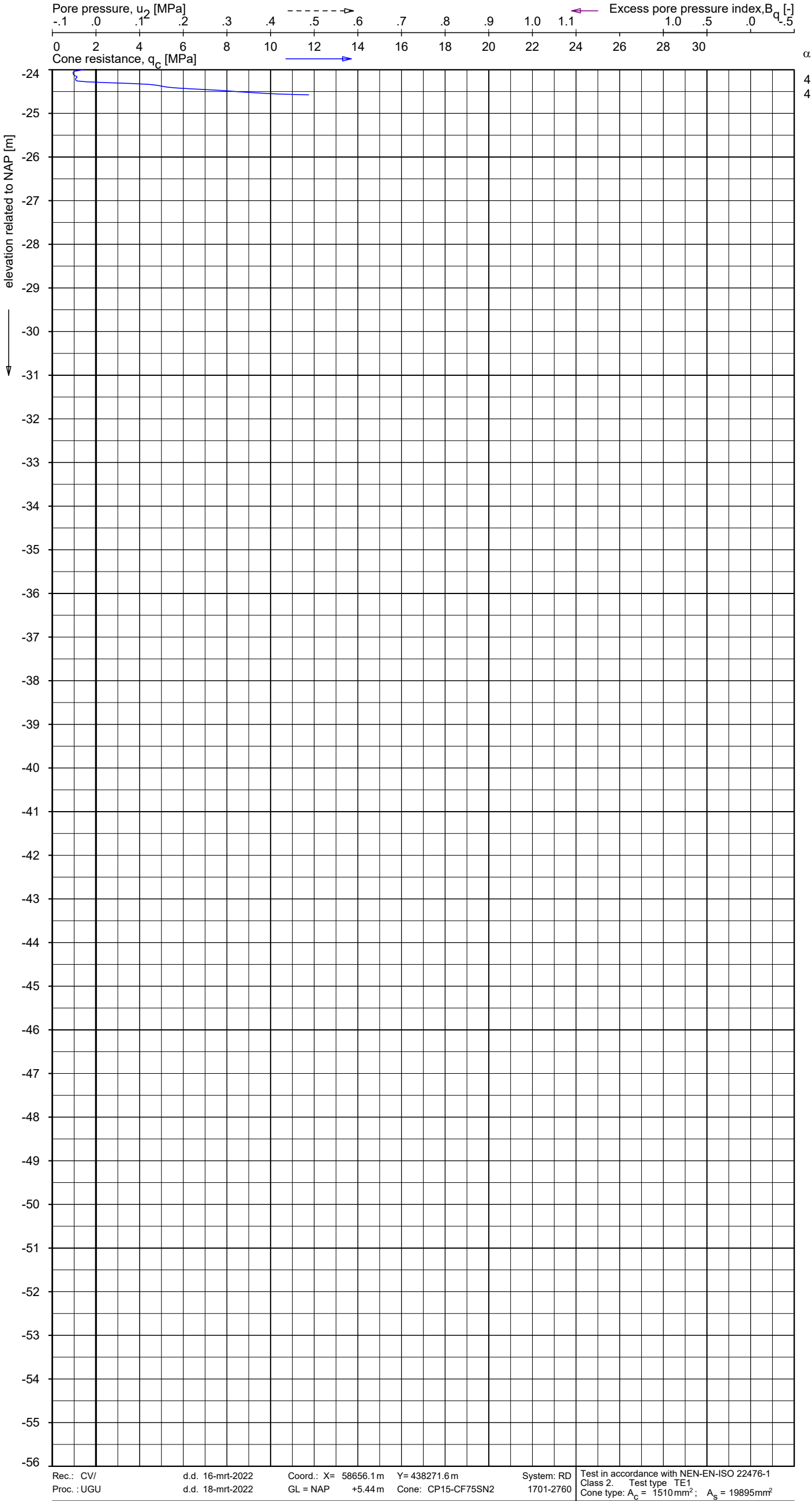
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Valid below groundwater level
(Robertson 1990, NL corr.)



PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj.	2422-209014
Cpt	FNLS2



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

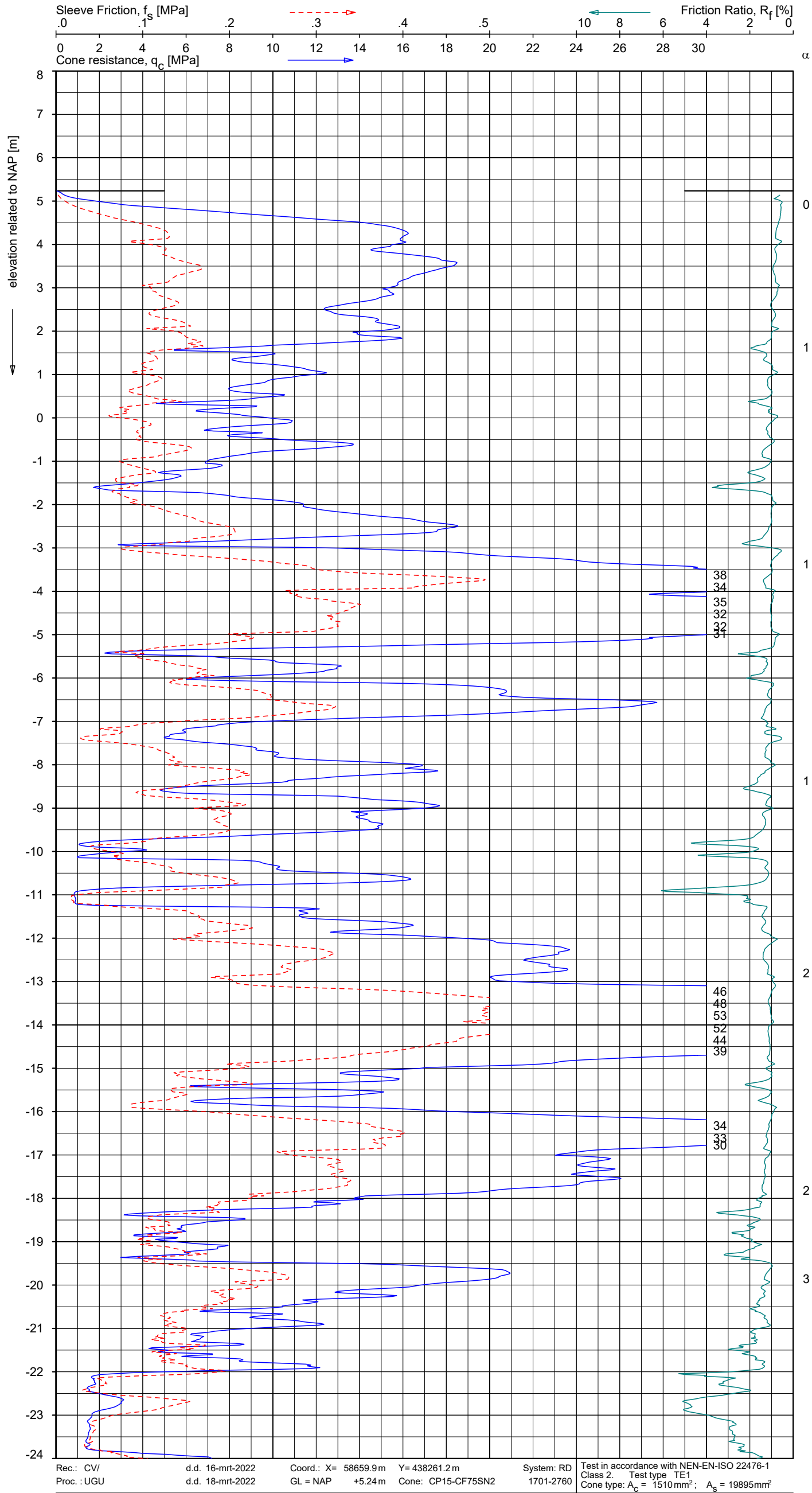
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	SAND, silty to SILT

PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS2





CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

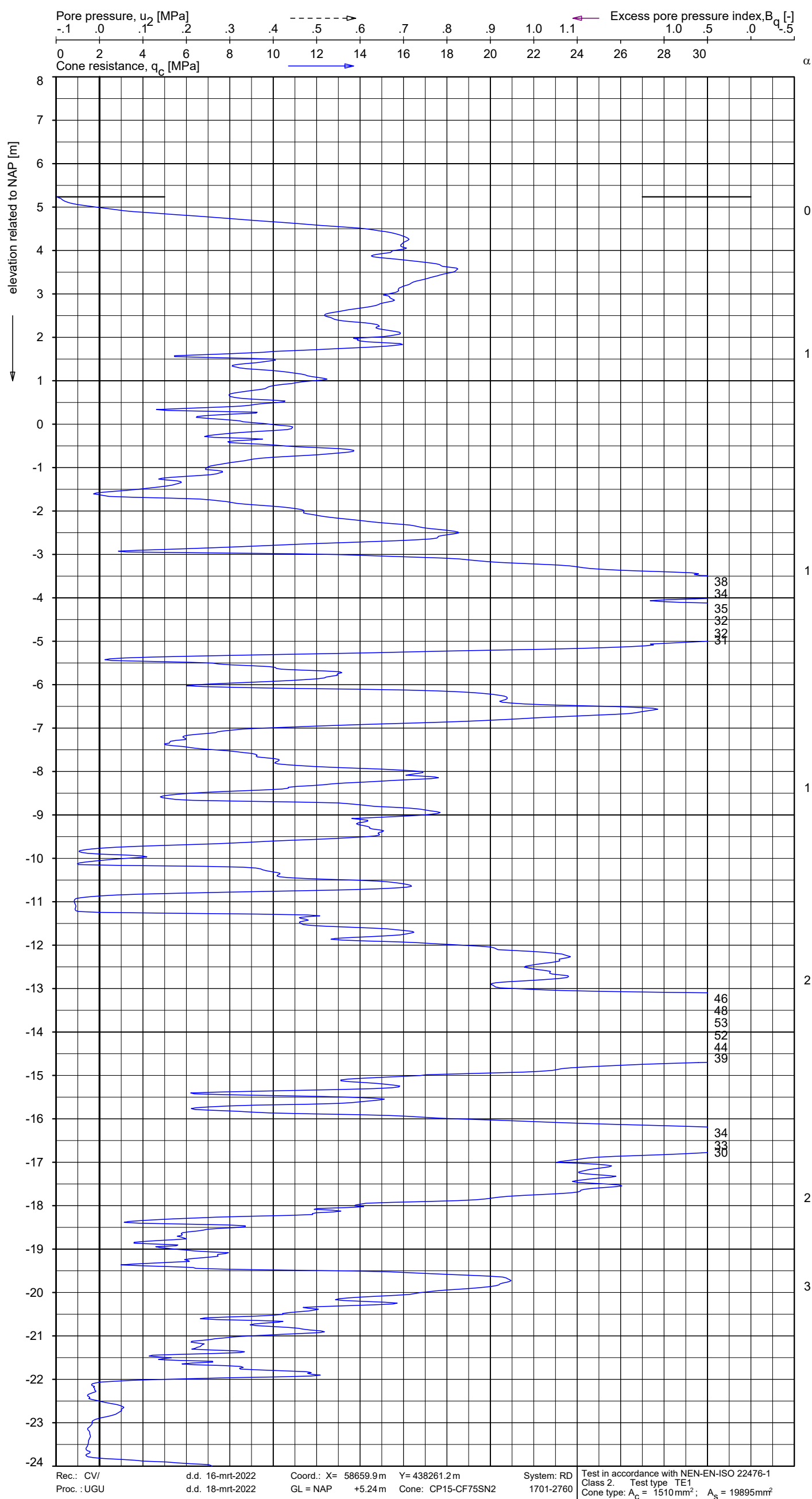
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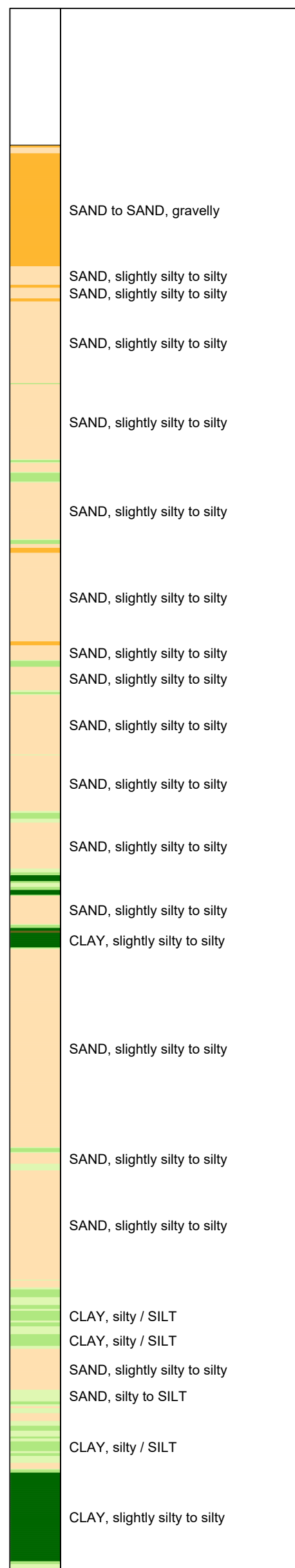


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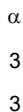
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Valid below groundwater level
(Robertson 1990, NL corr.)



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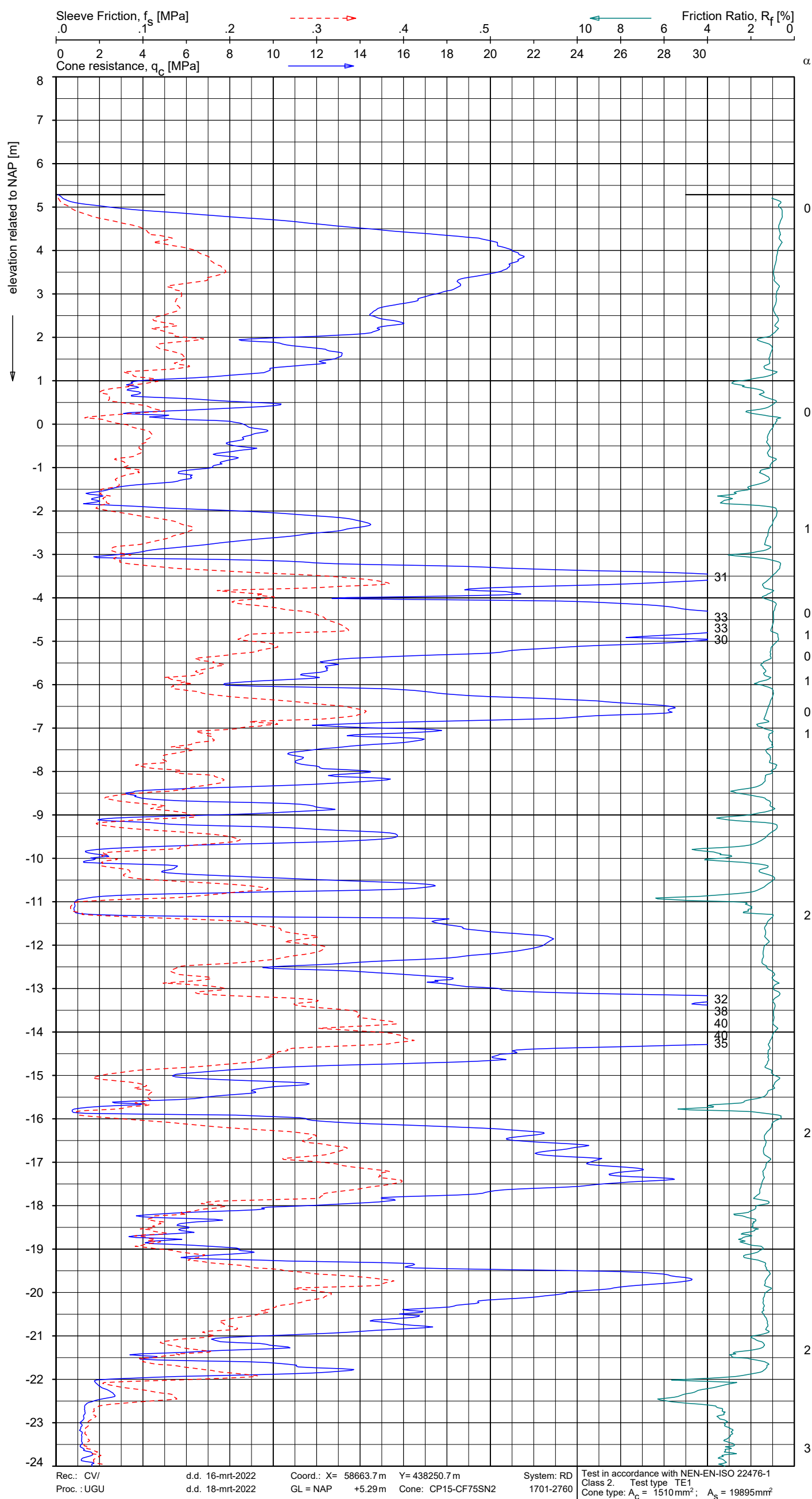
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

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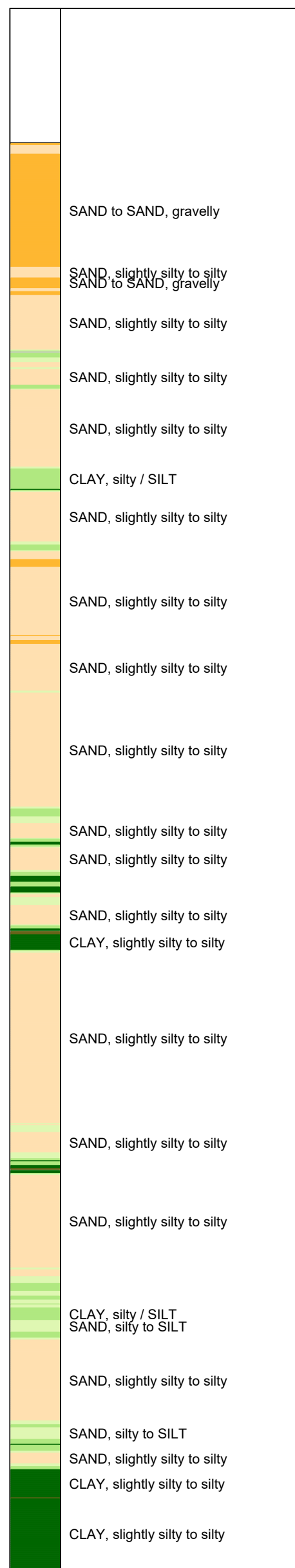


	SAND, slightly silty to silty
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Proj.	2422-209014
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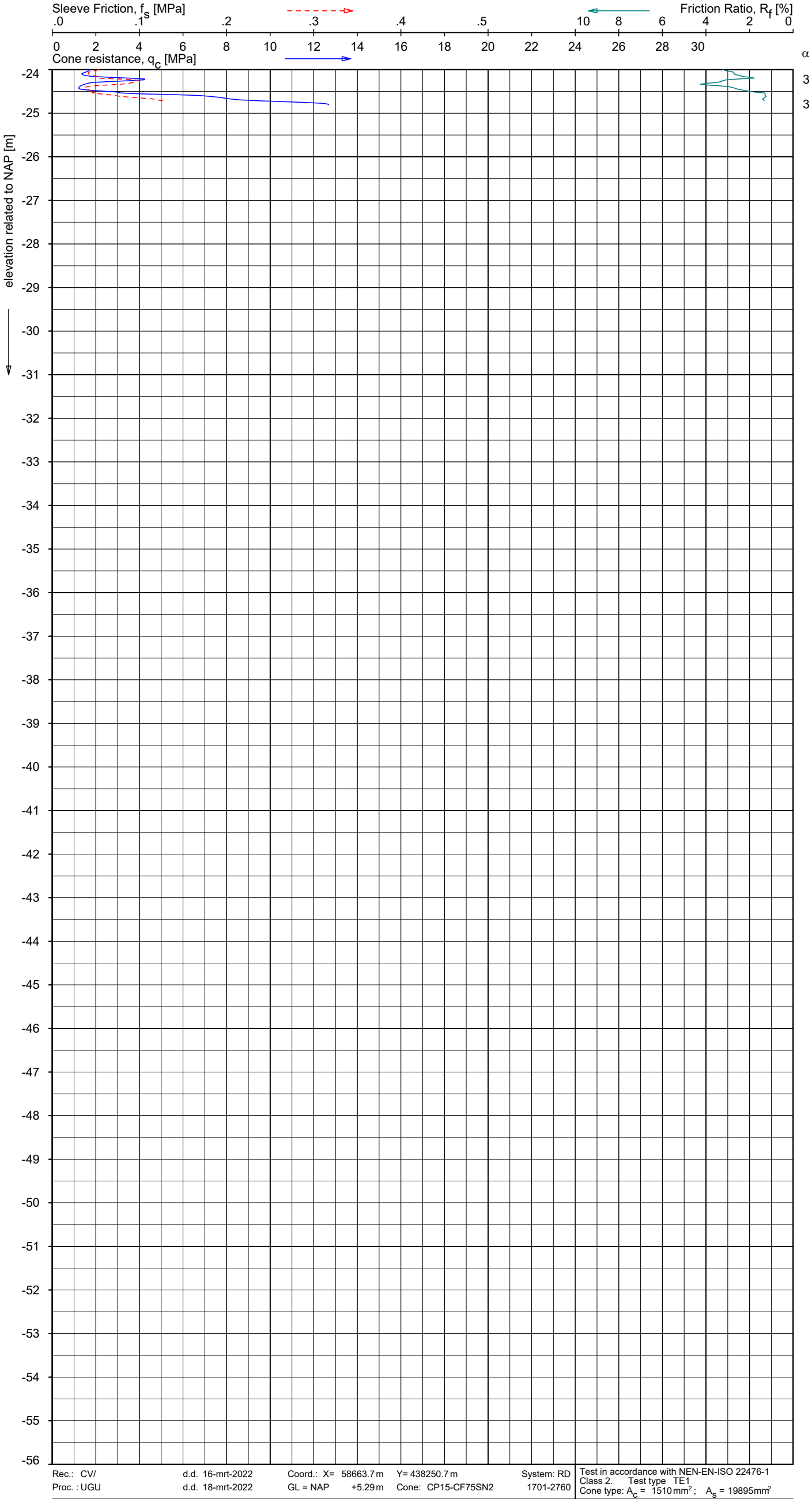
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Valid below groundwater level
(Robertson 1990, NL corr.)



CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIIPARK WEST

Proj.	2422-209014
Cpt	FNLS4



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

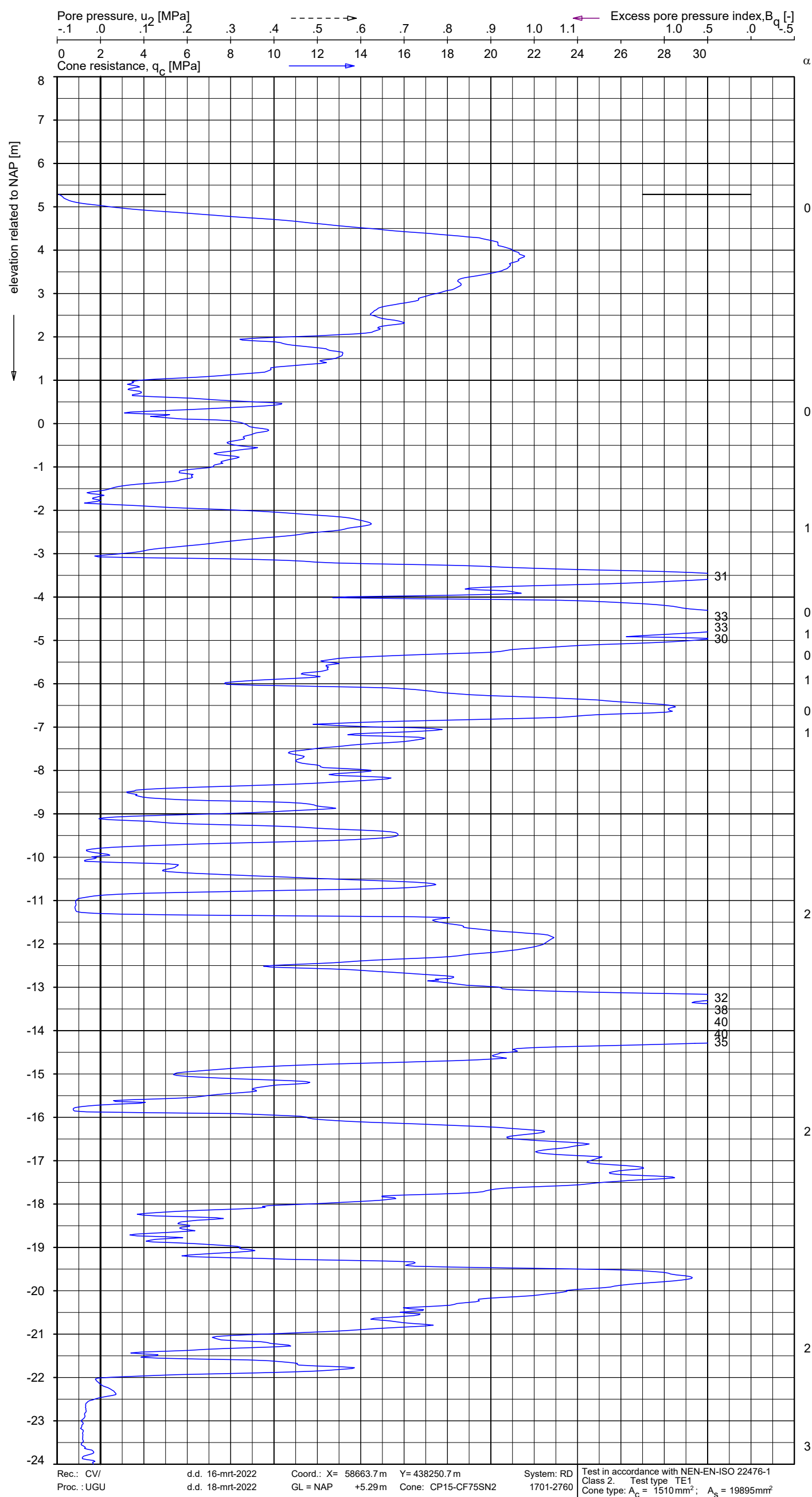
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	SAND, silty to SILT

CONE PENETRATION TEST WITH LOCAL FRICTION

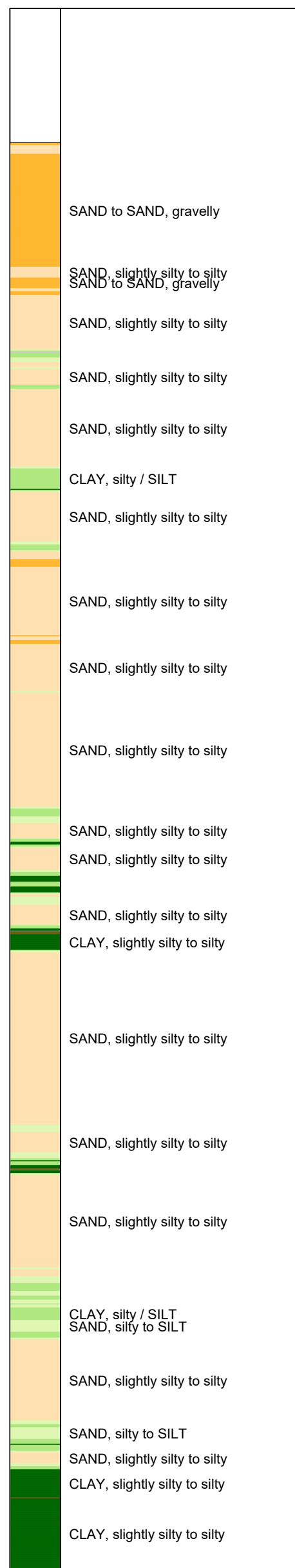
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS4





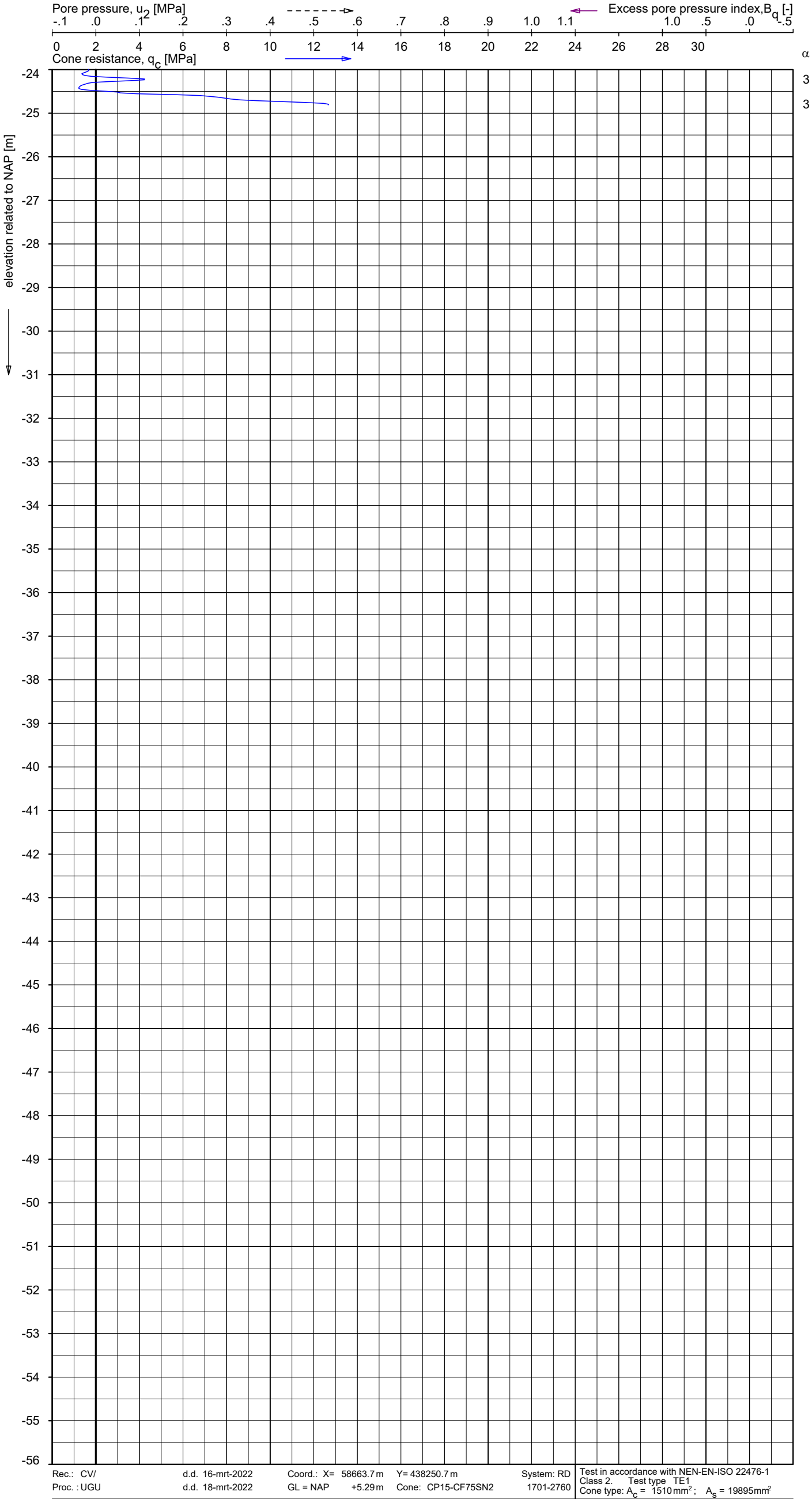
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Valid below groundwater level
(Robertson 1990, NL corr.)



PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj.	2422-209014
Cpt	FNLS4



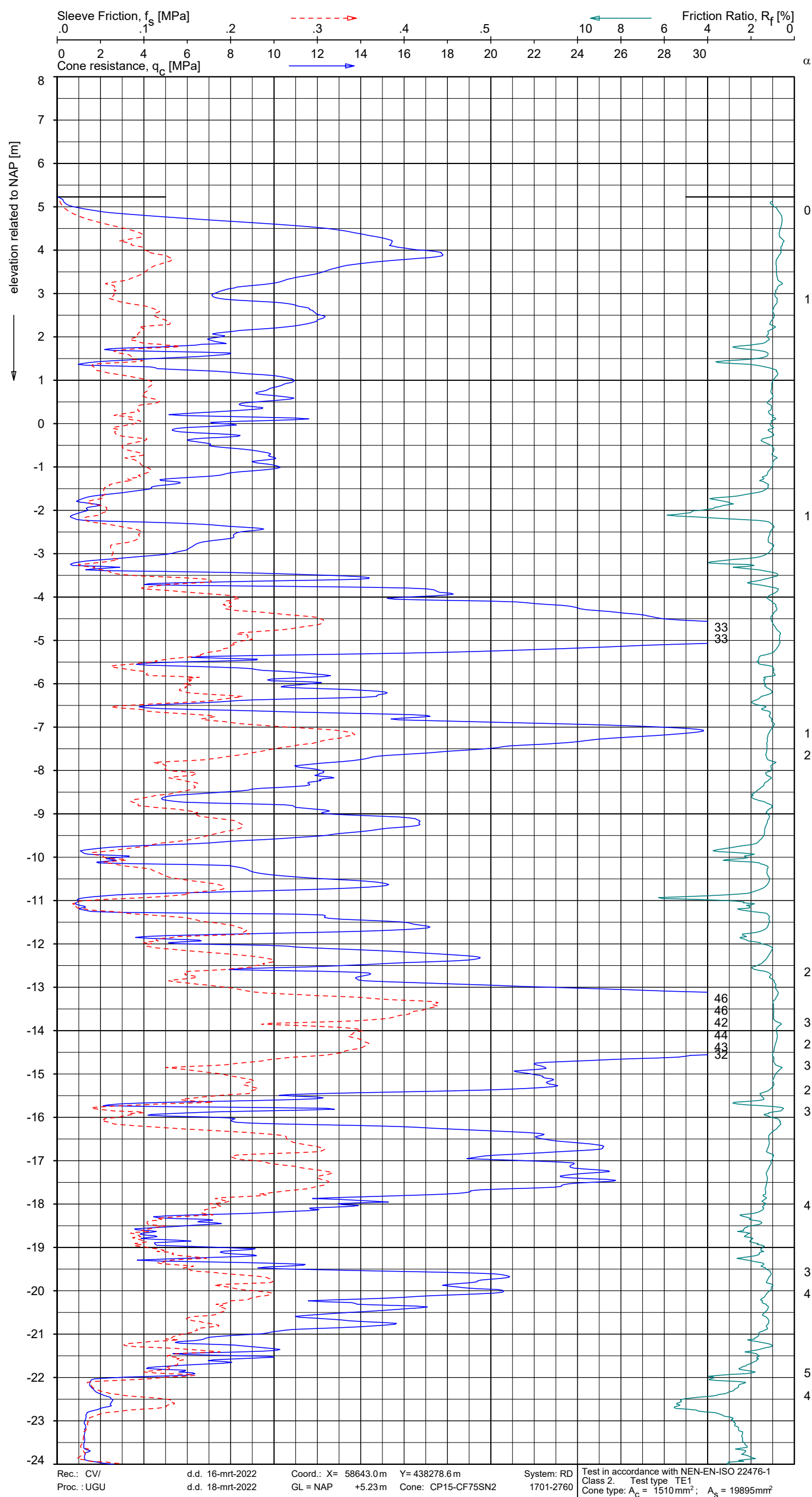
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HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

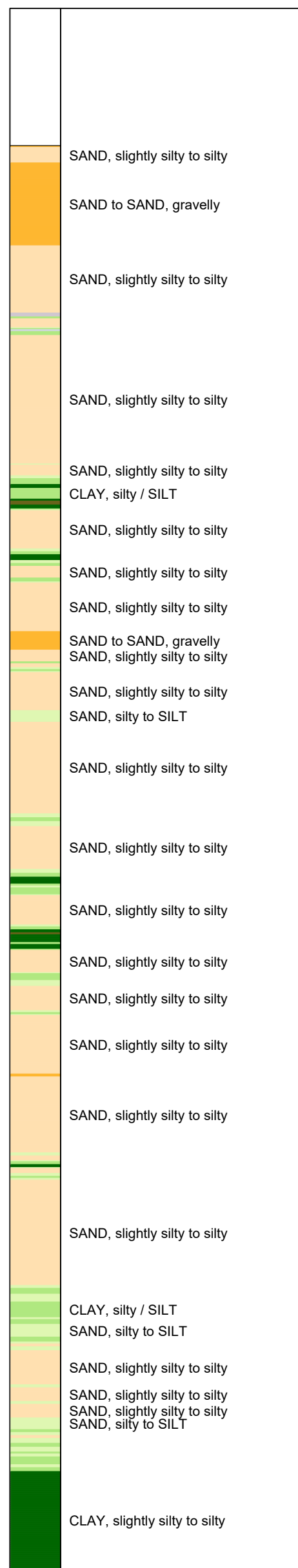
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Cpt FNLS4

Indicative soil classification
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Valid below groundwater level
(Robertson 1990, NL corr.)

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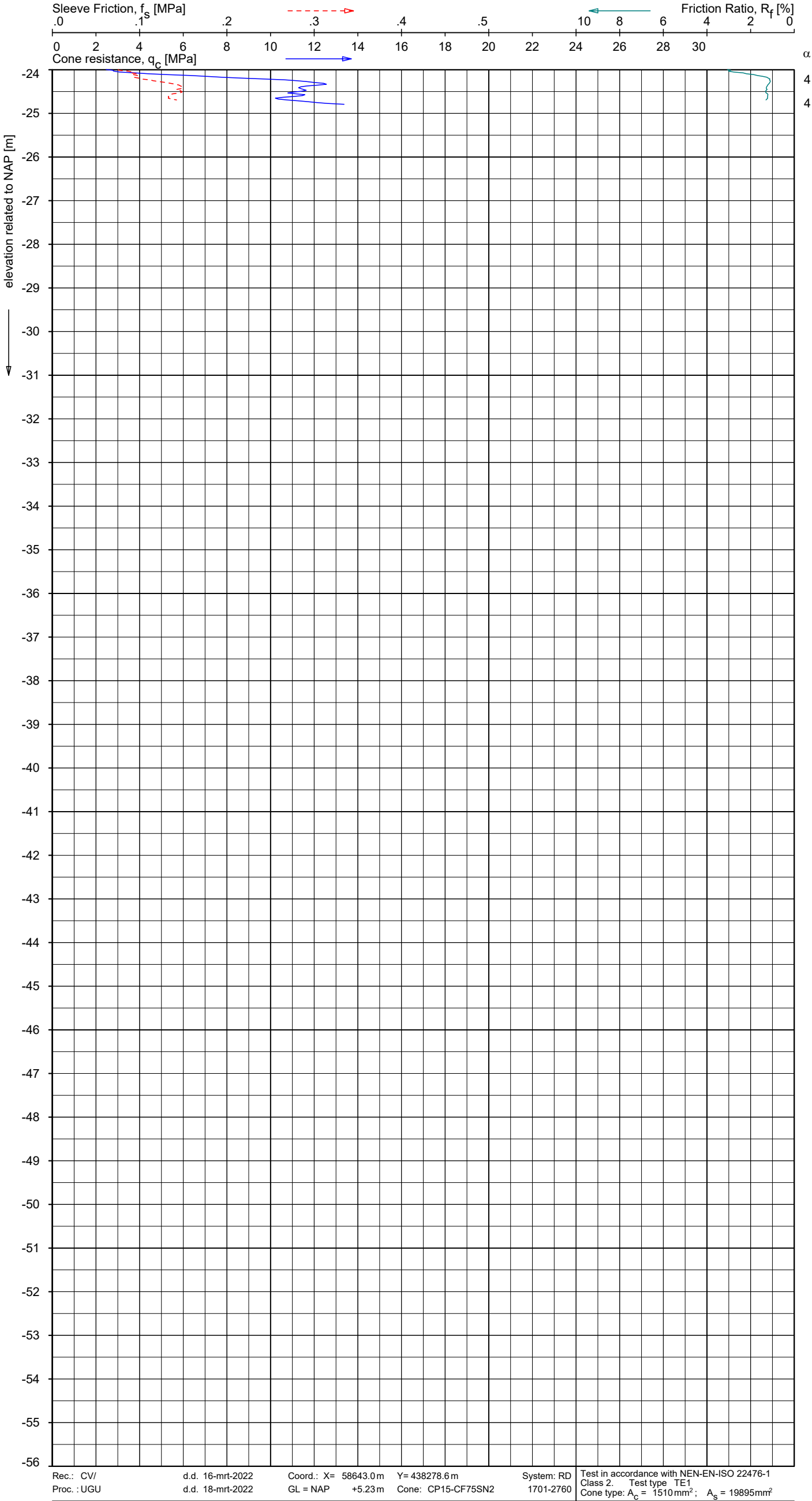
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(Robertson 1990, NL corr.)



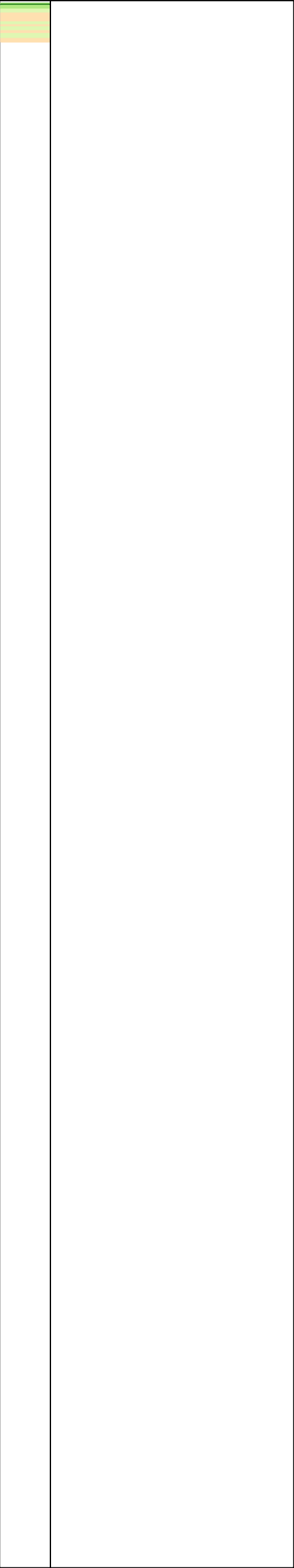
CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj. 2422-209014
Cpt FNLS5



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

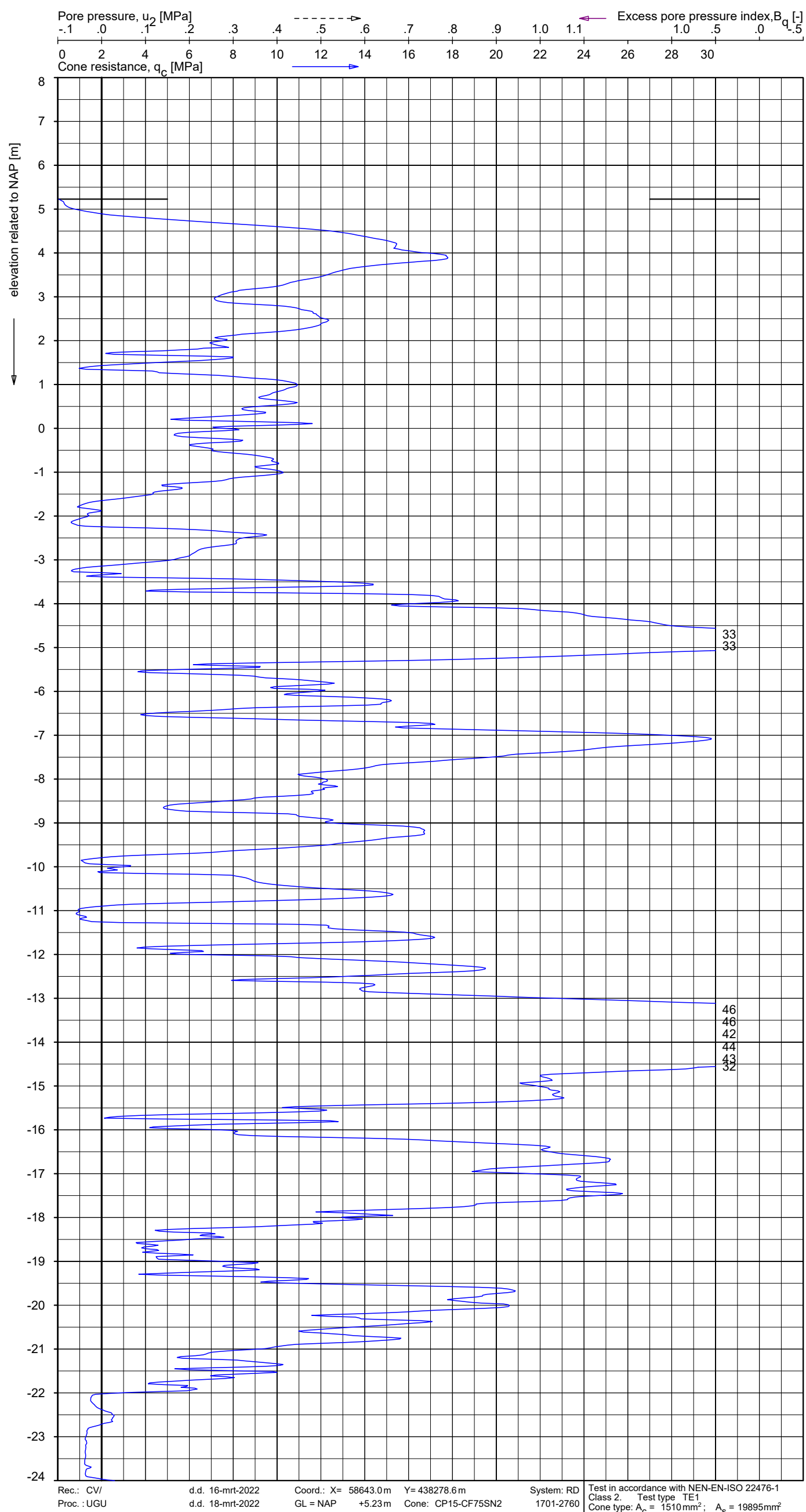


CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

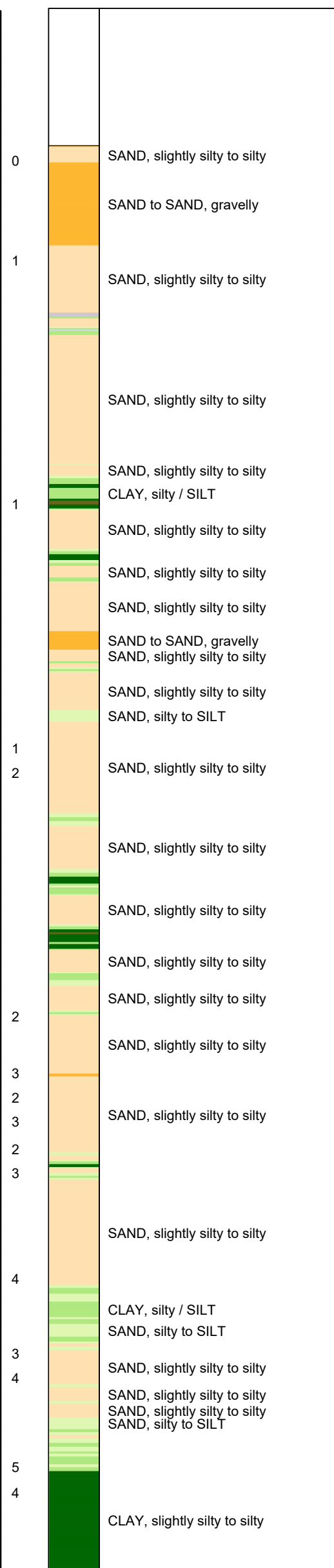
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Cpt FNL55





Indicative soil classification

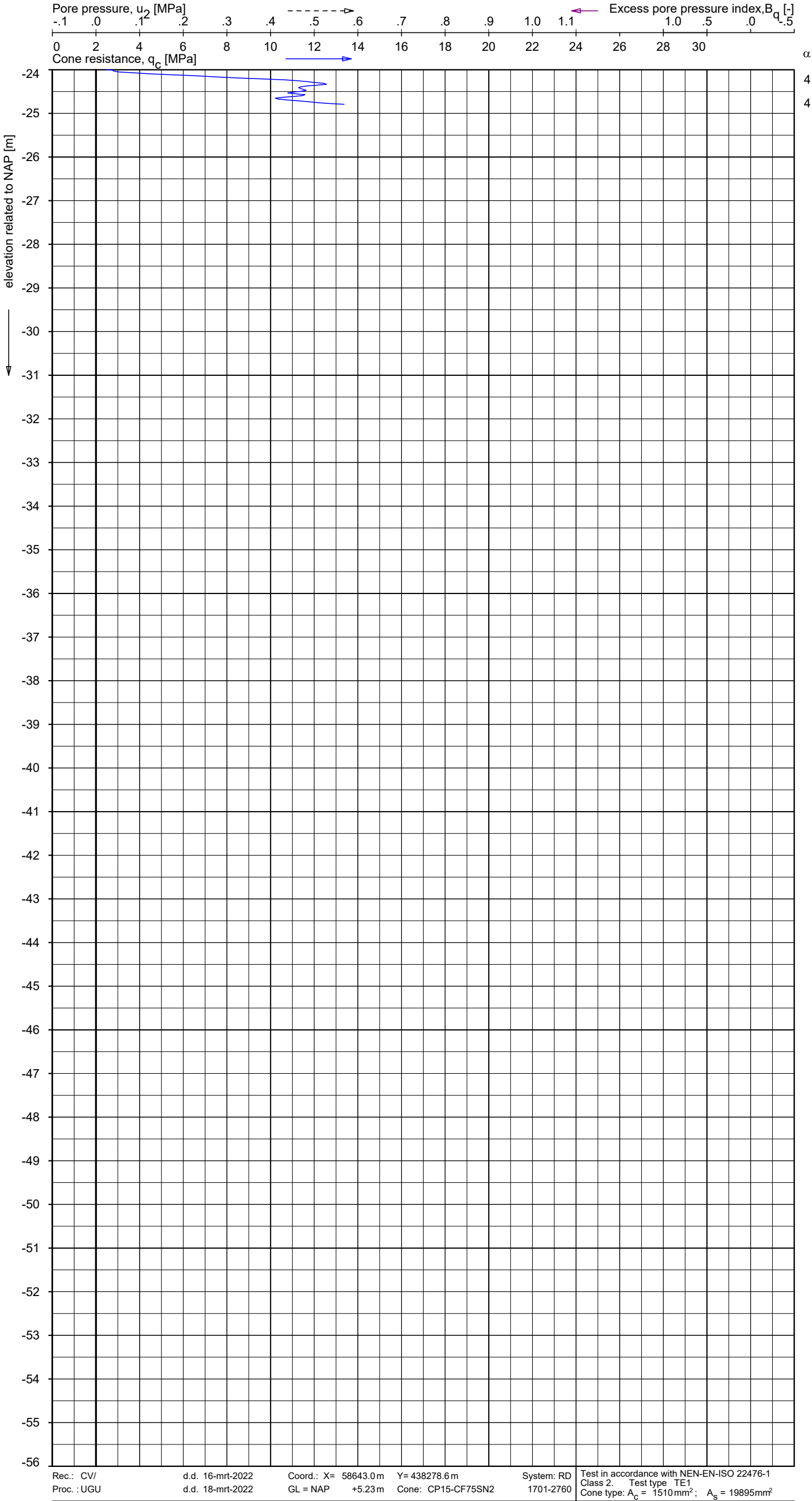
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(Robertson 1990, NL corr.)



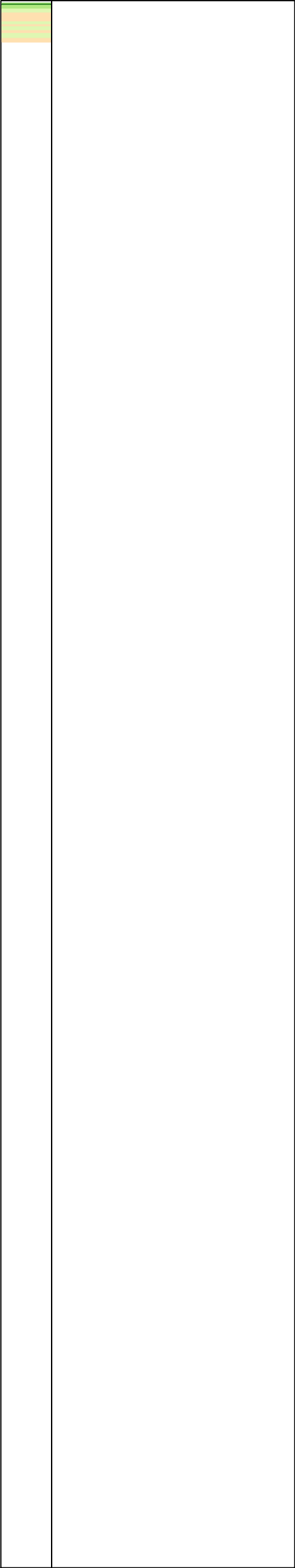
PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj. 2422-209014
Cpt FNLS5



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(Robertson 1990, NL corr.)

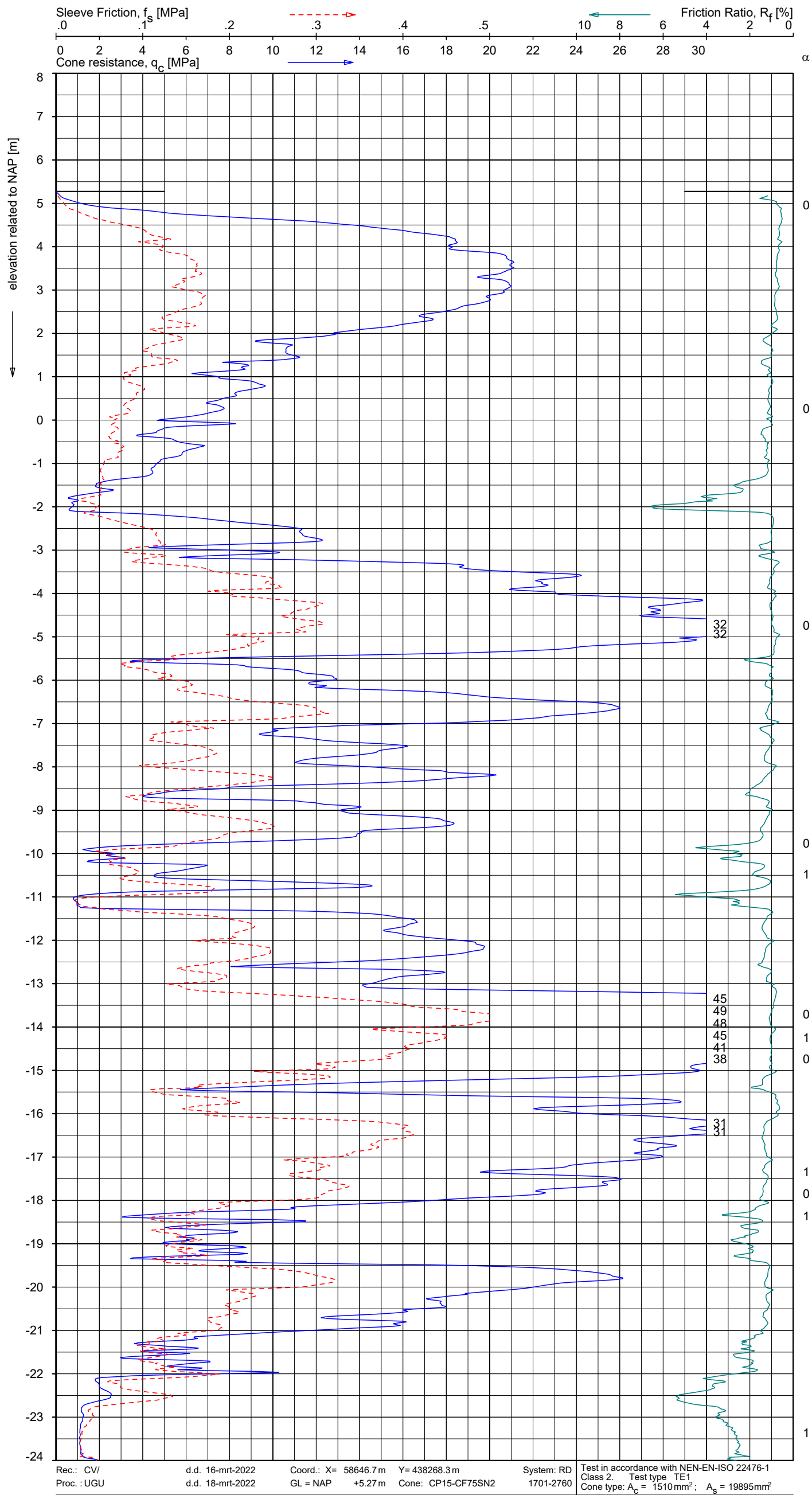


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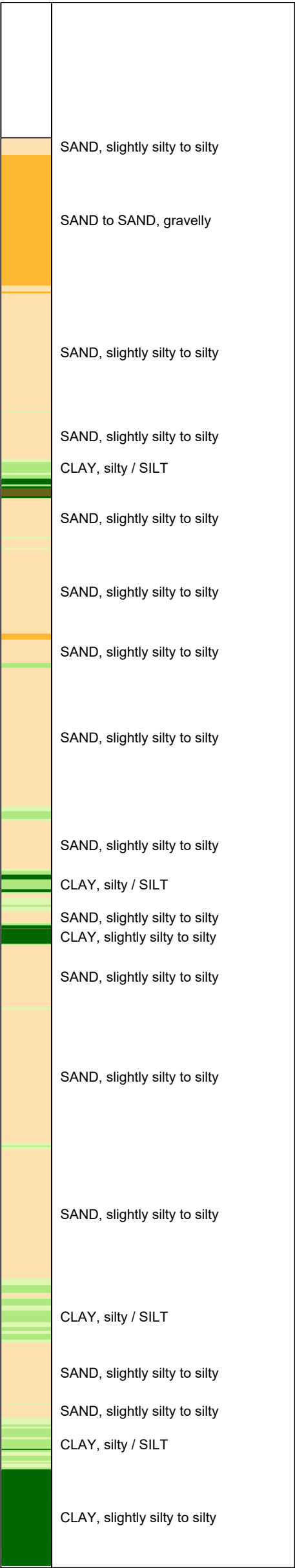
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS5





Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)



CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

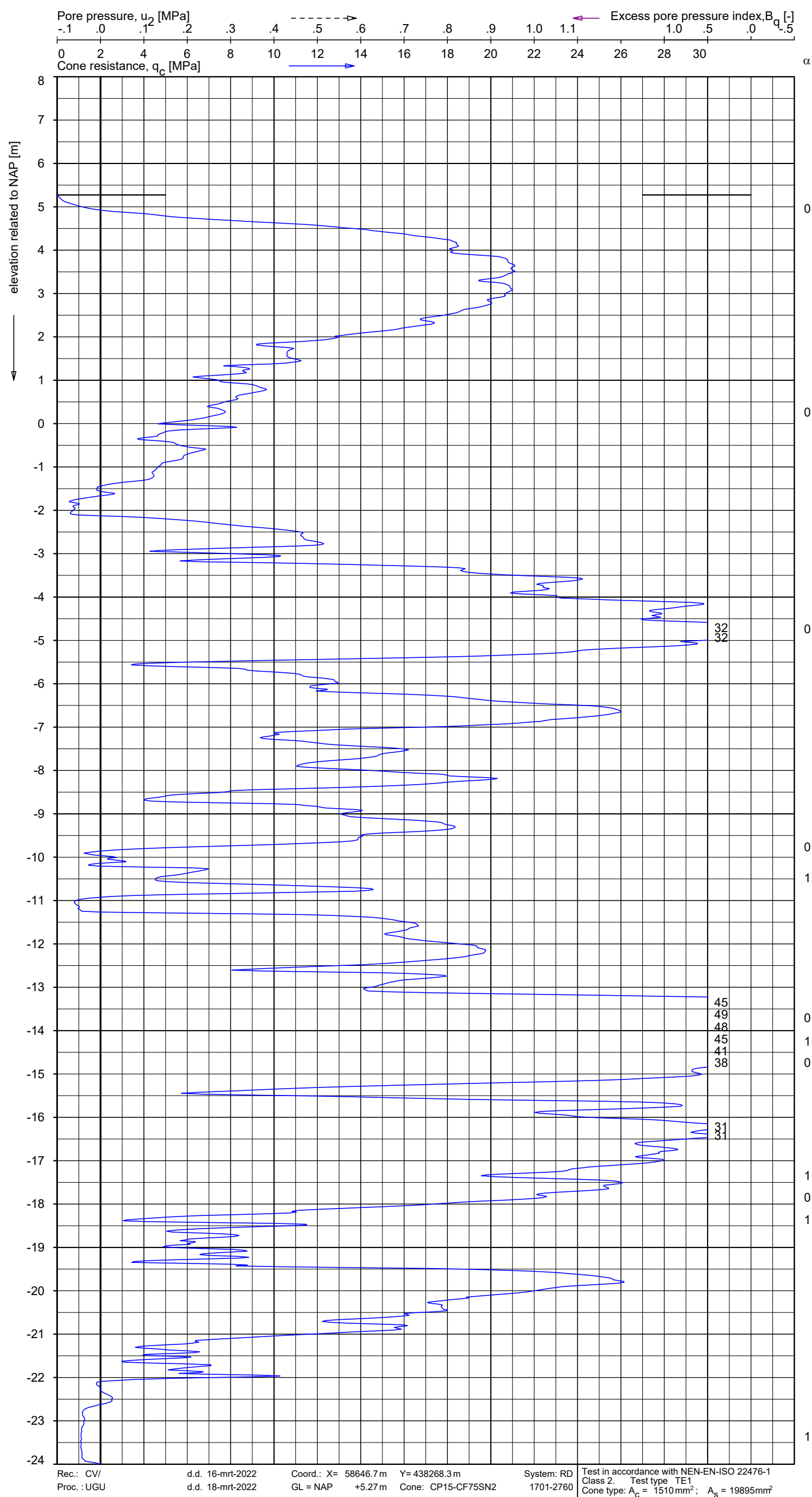
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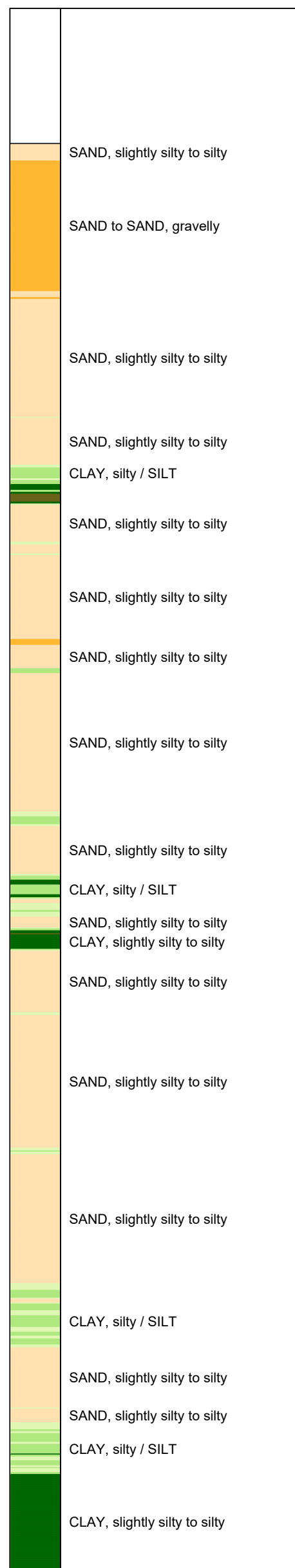


Proj. 2422-209014
Cpt FNLS6





Indicative soil classification
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(Robertson 1990, NL corr.)

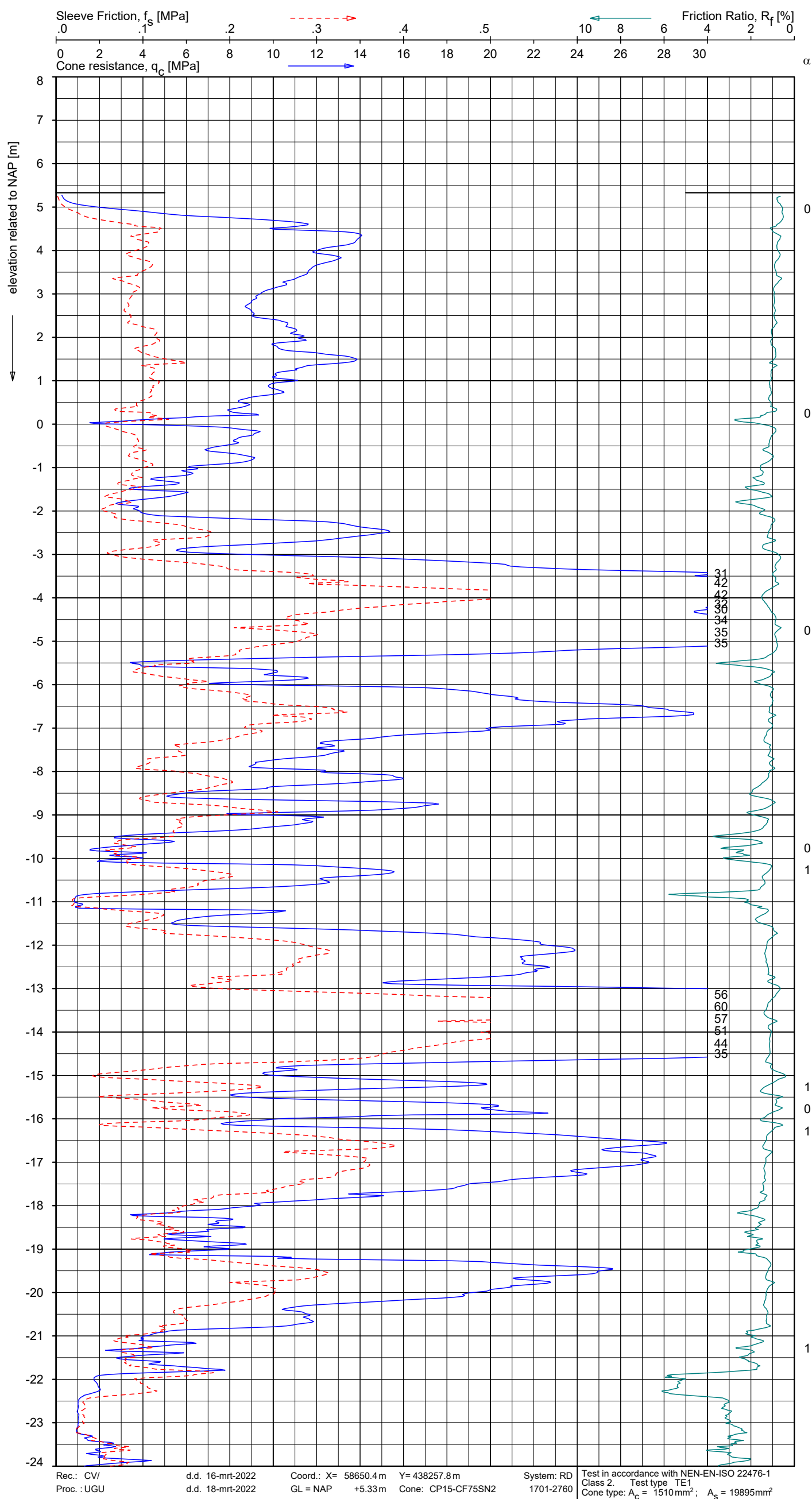


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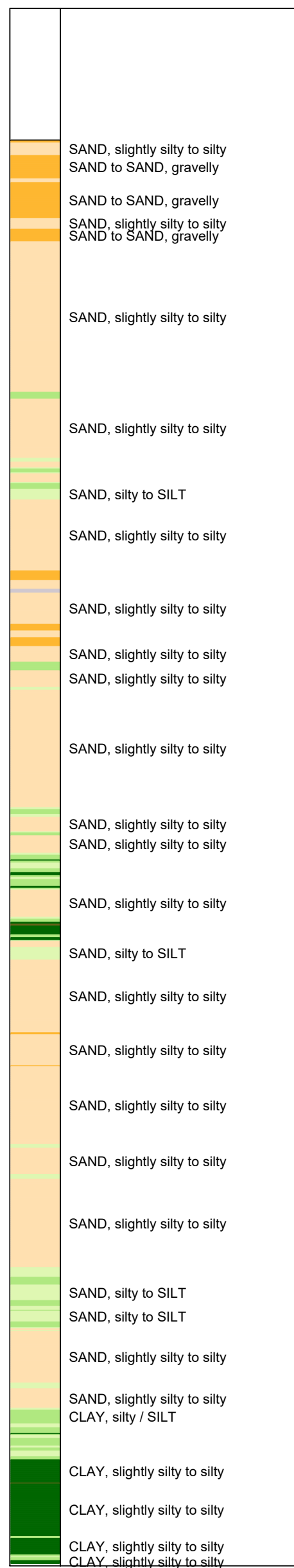
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj. 2422-209014
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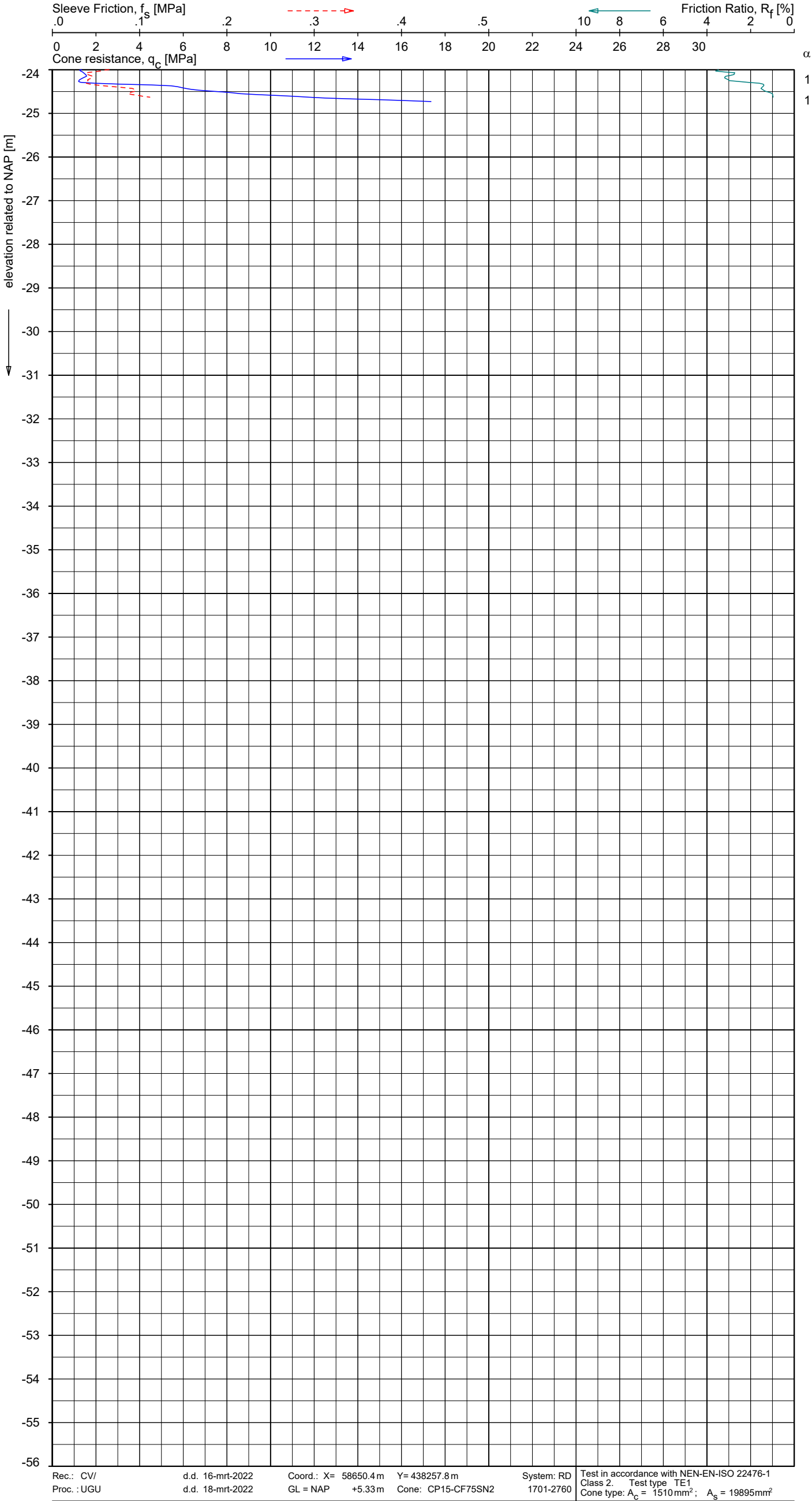
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Valid below groundwater level
(Robertson 1990, NL corr.)



CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj. 2422-209014
Cpt FNLS7



Indicative soil classification
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(Robertson 1990, NL corr.)

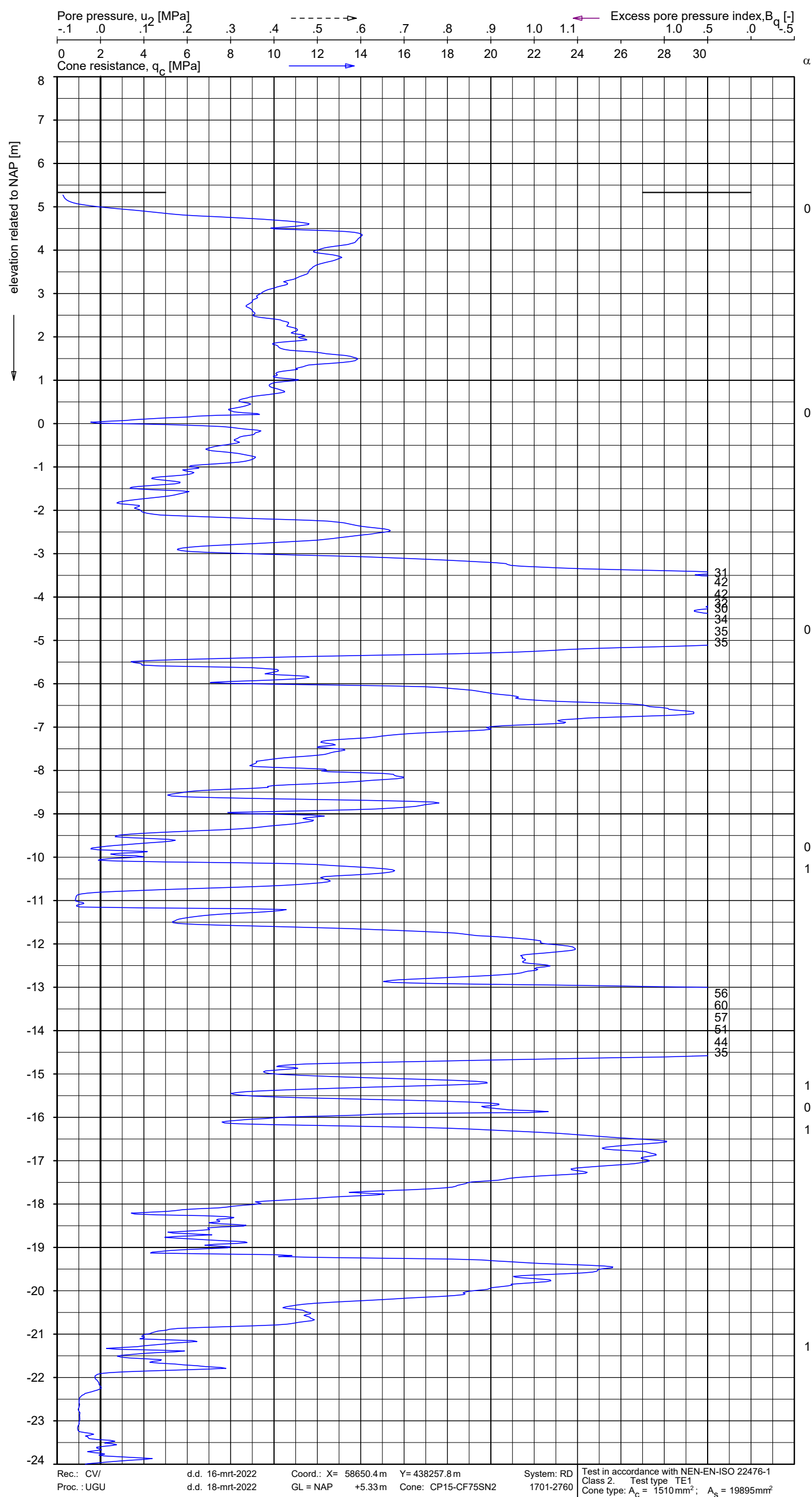
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	SAND, silty to SILT

CONE PENETRATION TEST WITH LOCAL FRICTION

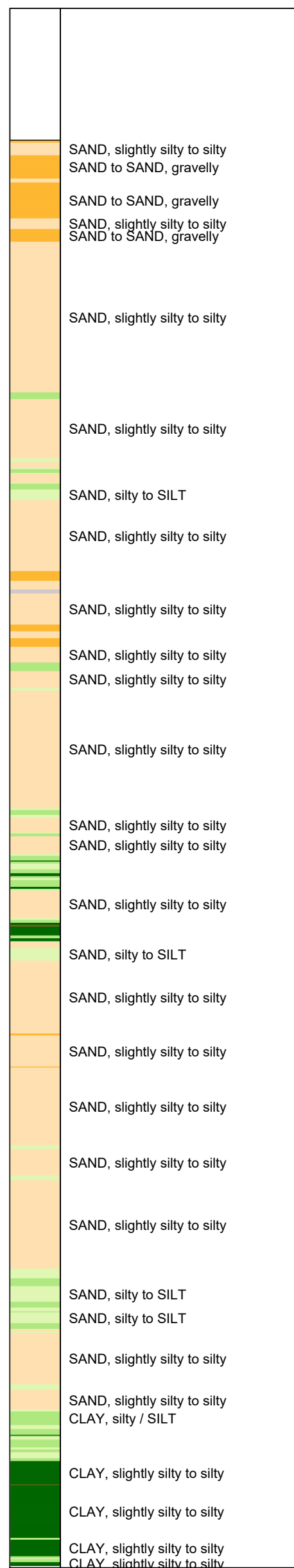
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
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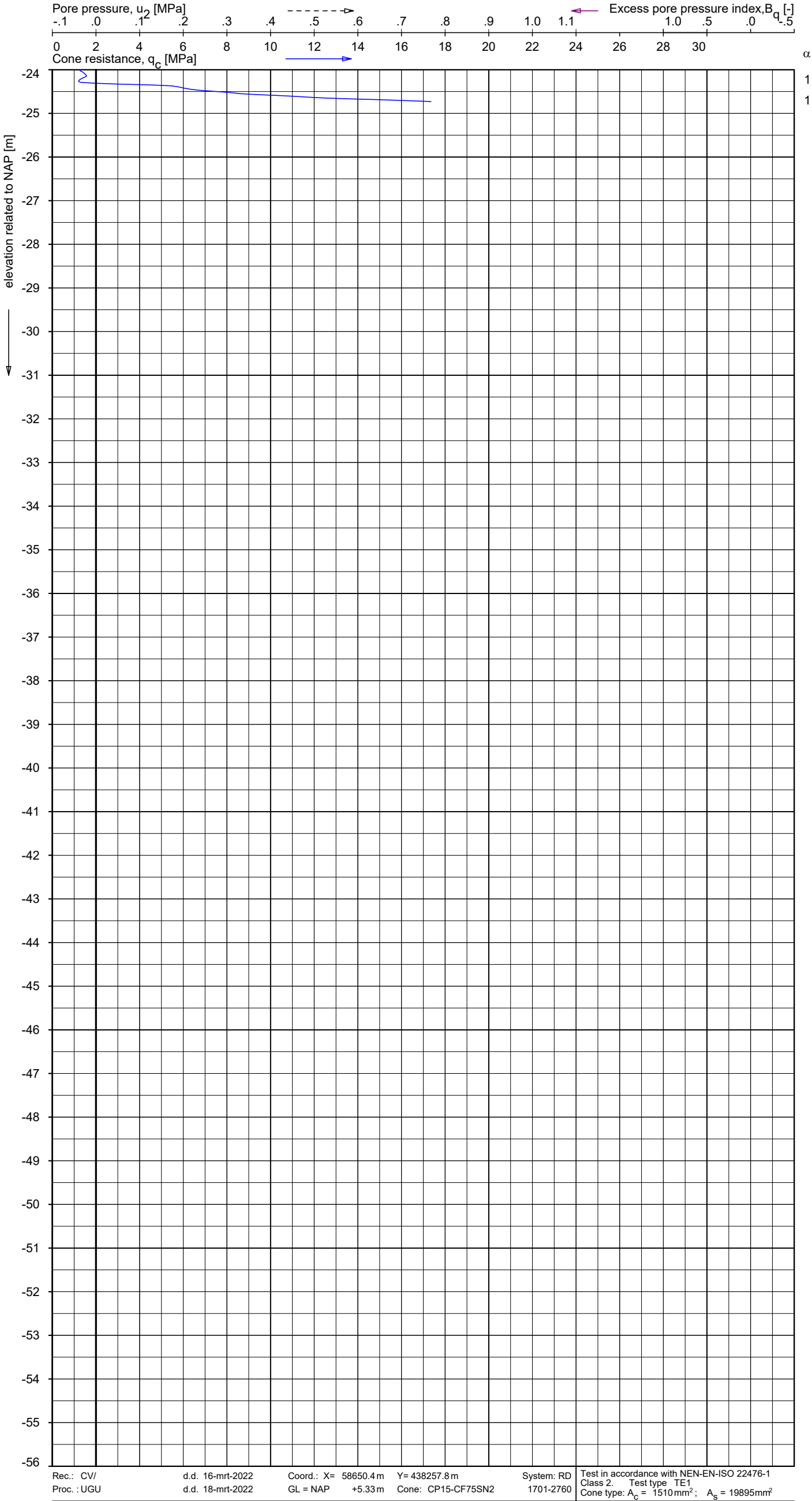
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Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)



PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj. 2422-209014
Cpt FNLS7

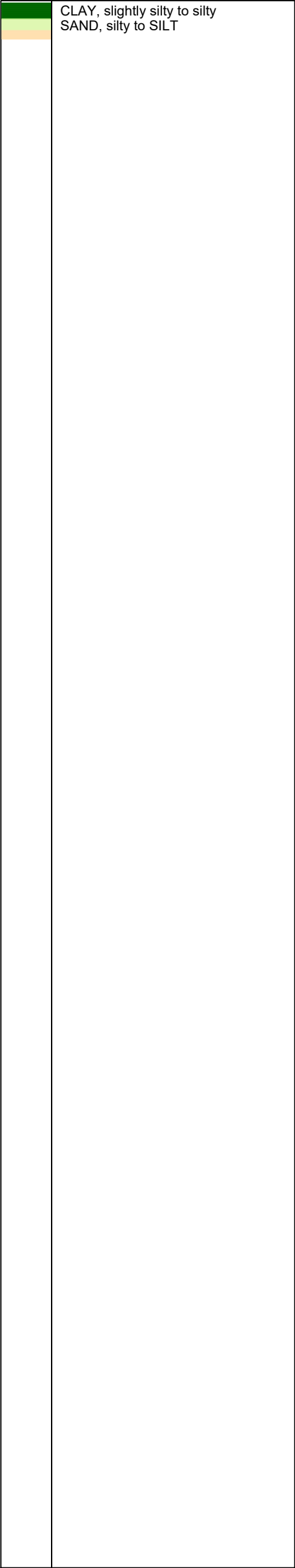


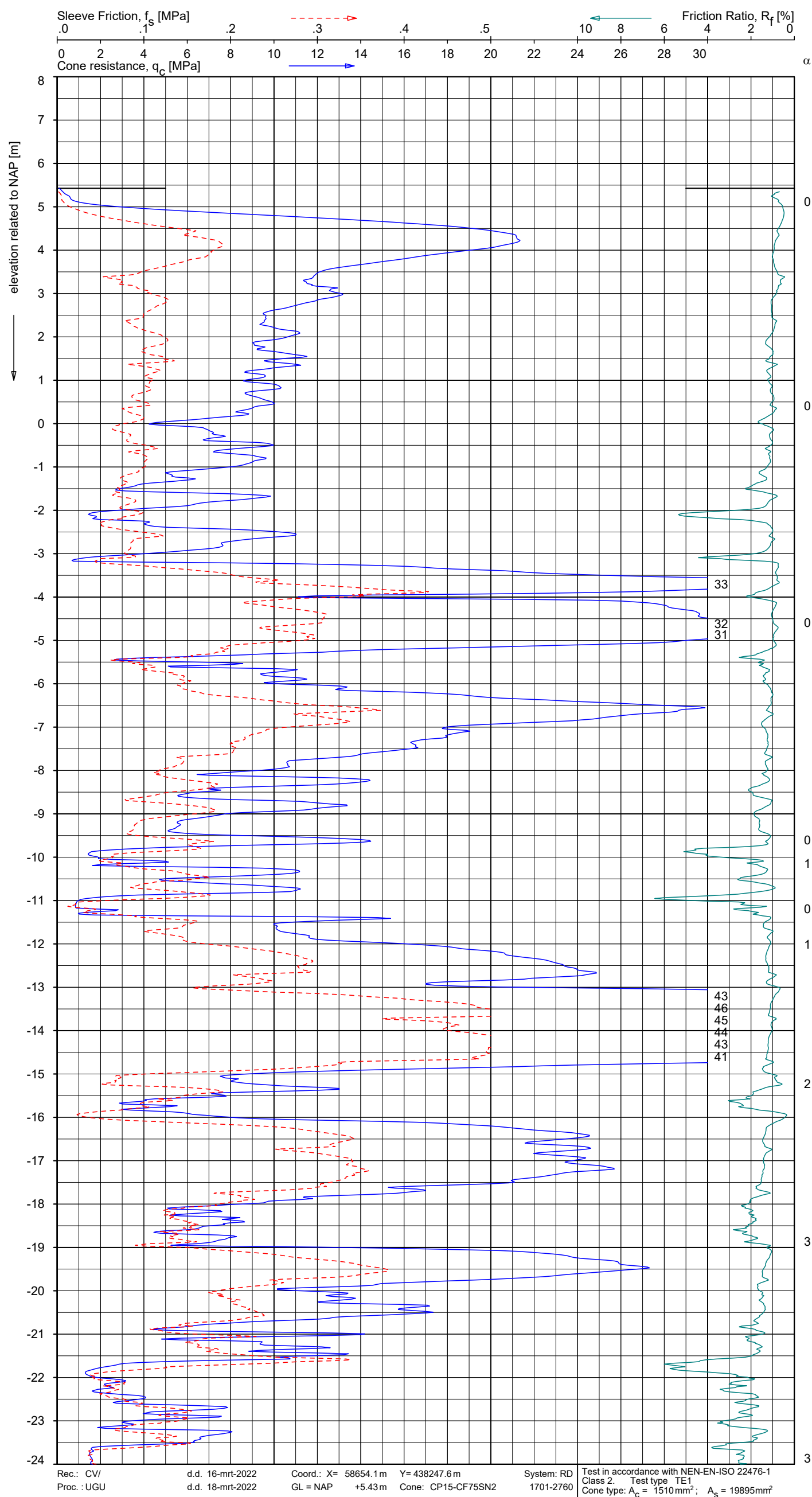
PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

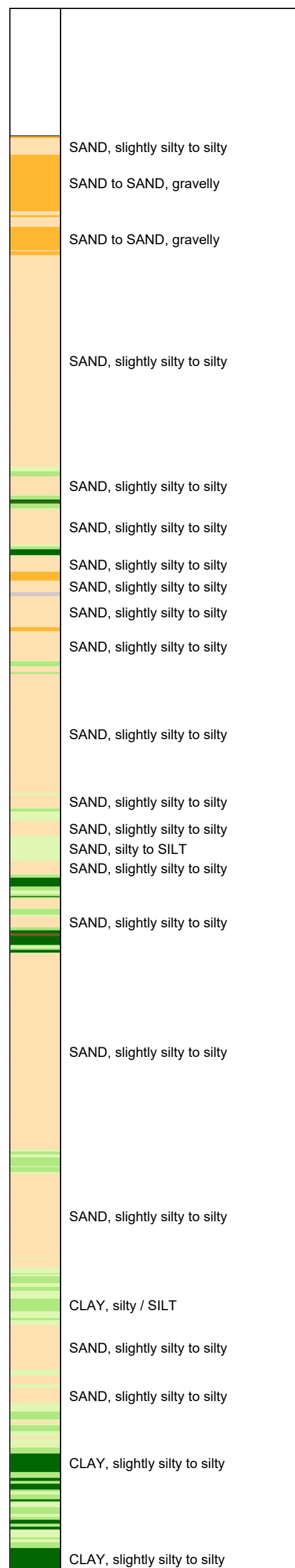
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Cpt FNLS7

Indicative soil classification
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Valid below groundwater level
(Robertson 1990, NL corr.)





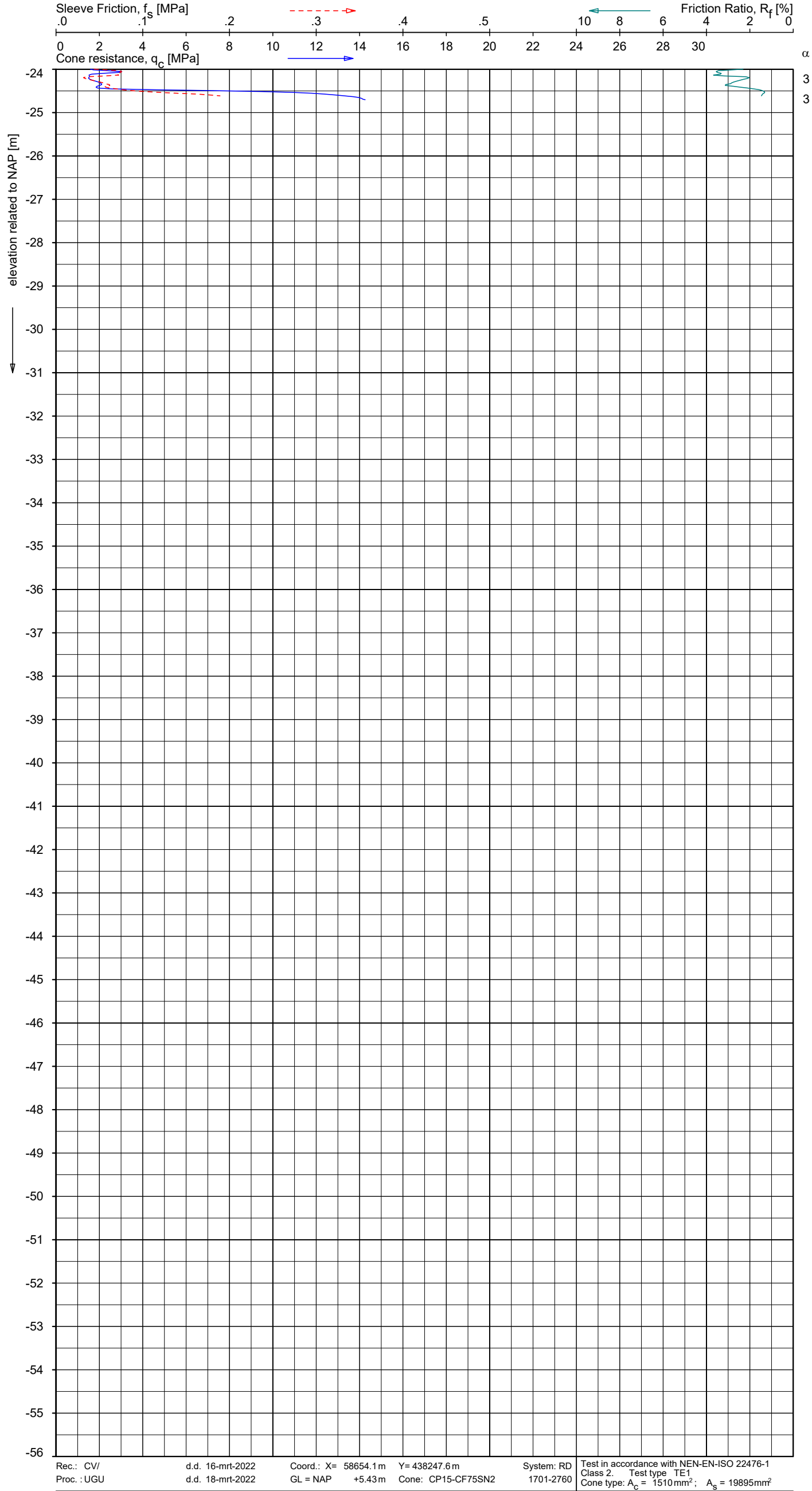
Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)



CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj.	2422-209014
Cpt	FNLS8



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

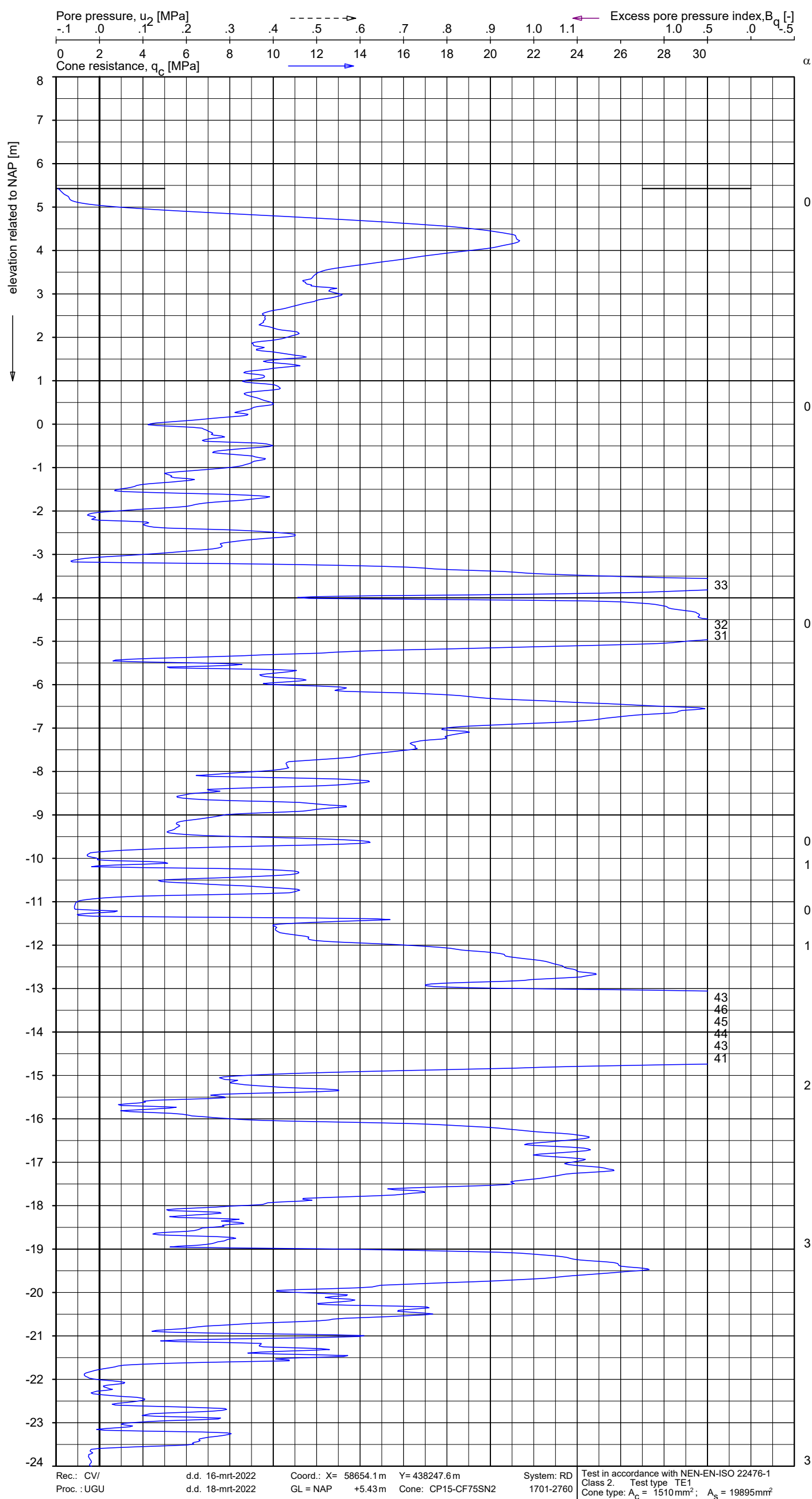
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CONE PENETRATION TEST WITH LOCAL FRICTION

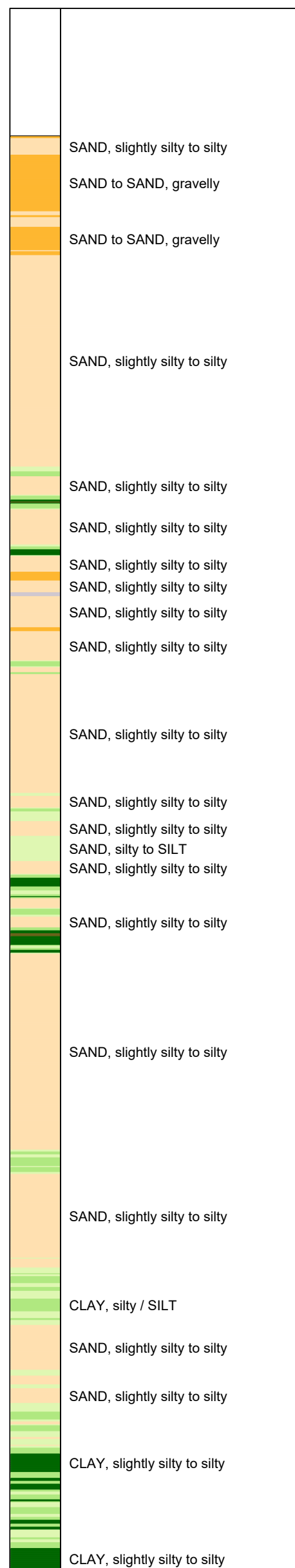
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS8





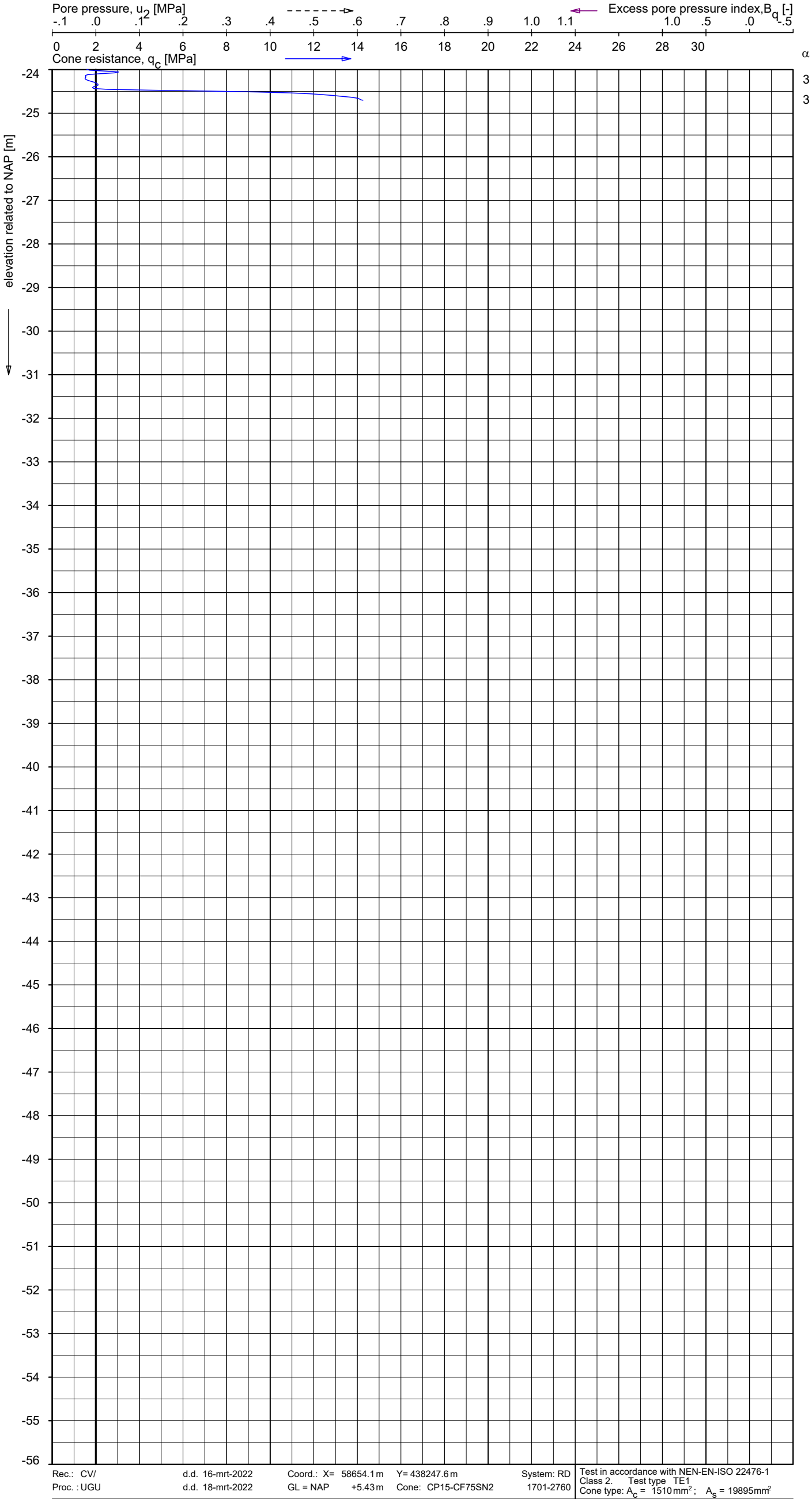
Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)



PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIIPARK WEST

Proj.	2422-209014
Cpt	FNLS8



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

	CLAY, slightly silty to silty
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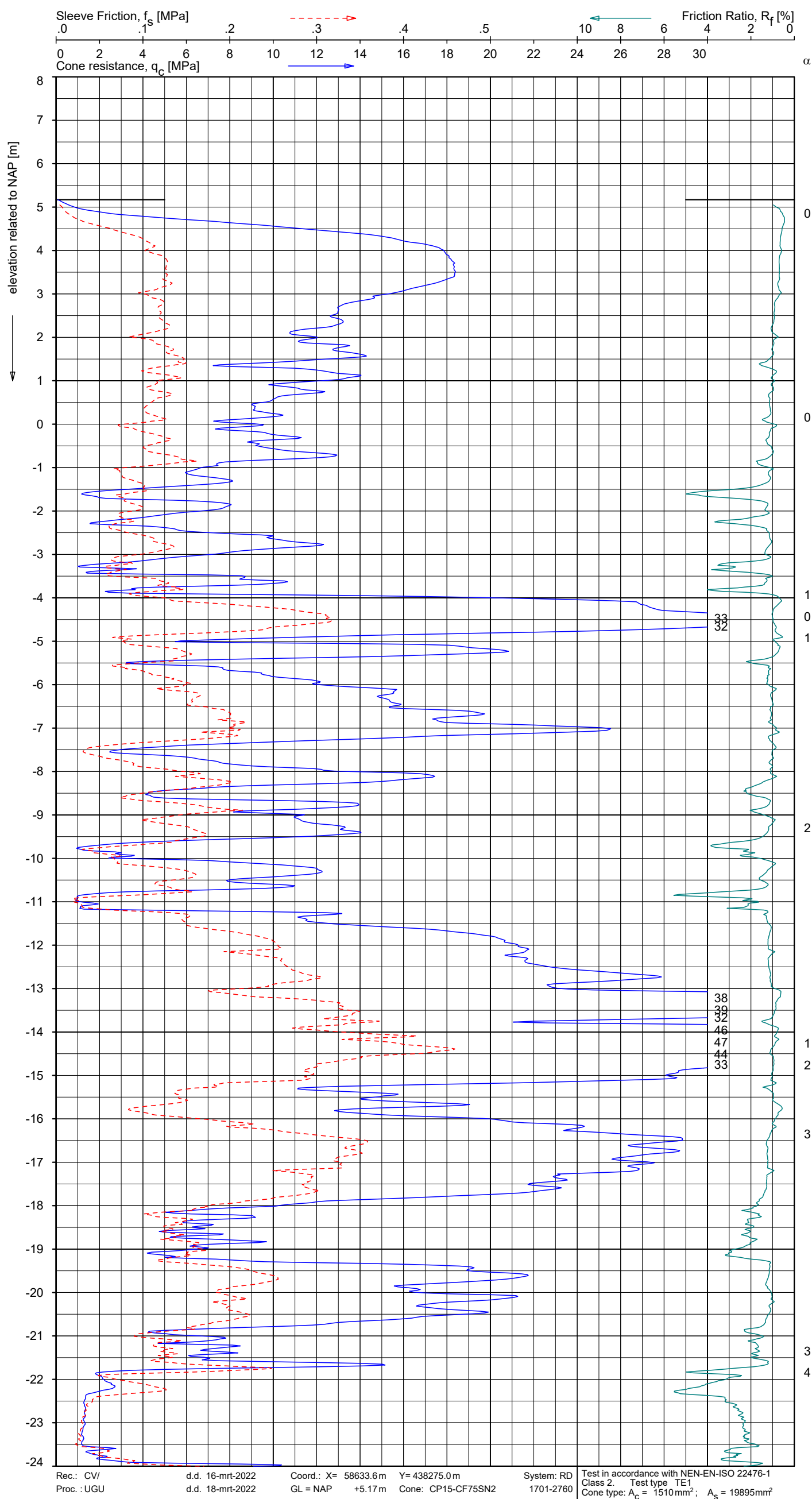
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PIEZO CONE PENETRATION TEST

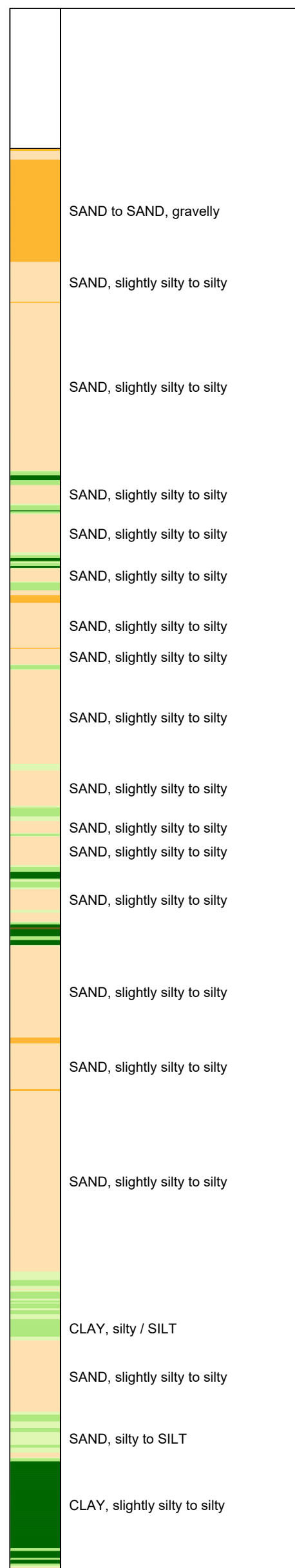
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS8





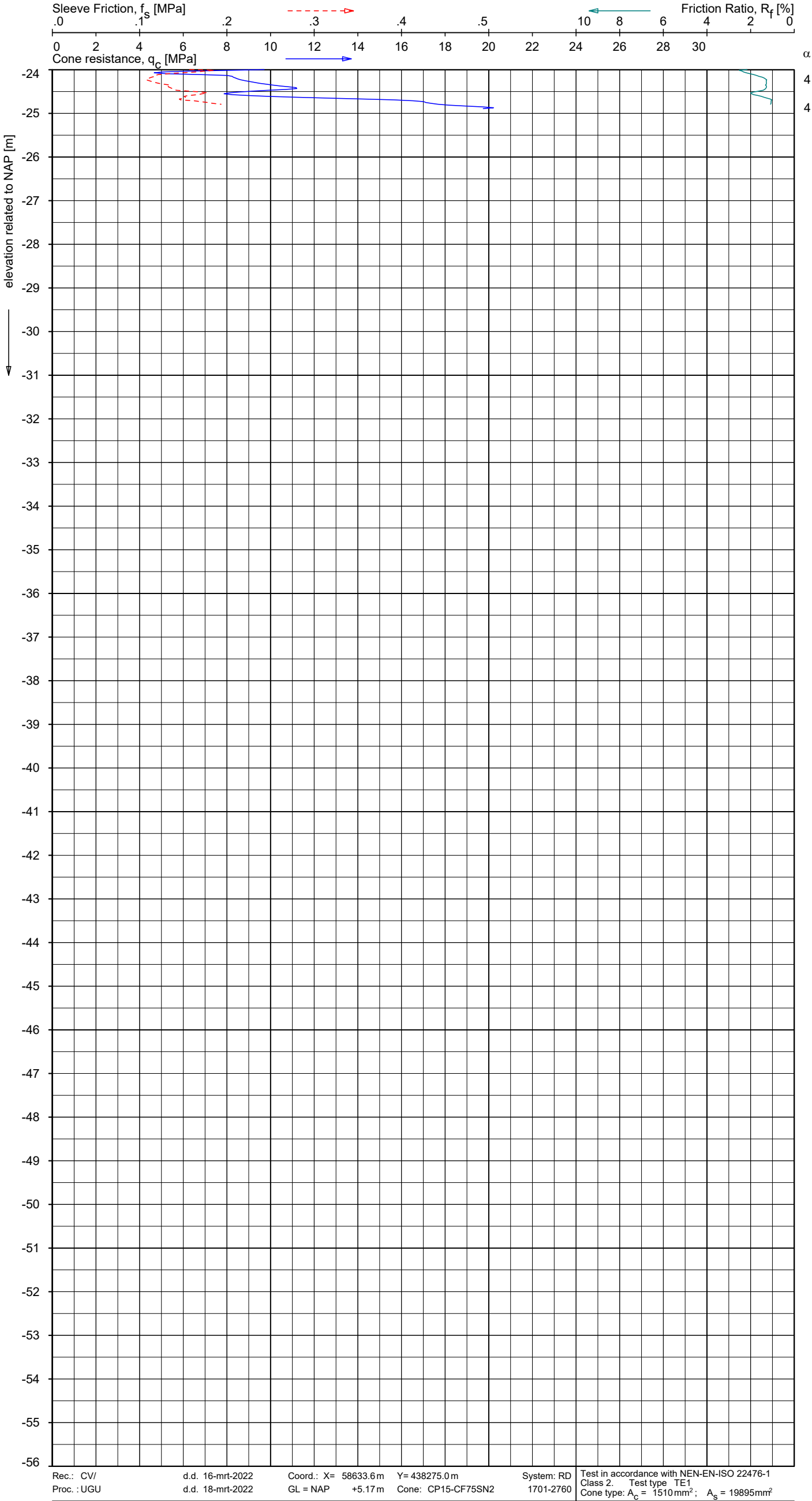
Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)



CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj. 2422-209014
Cpt FNLS9



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

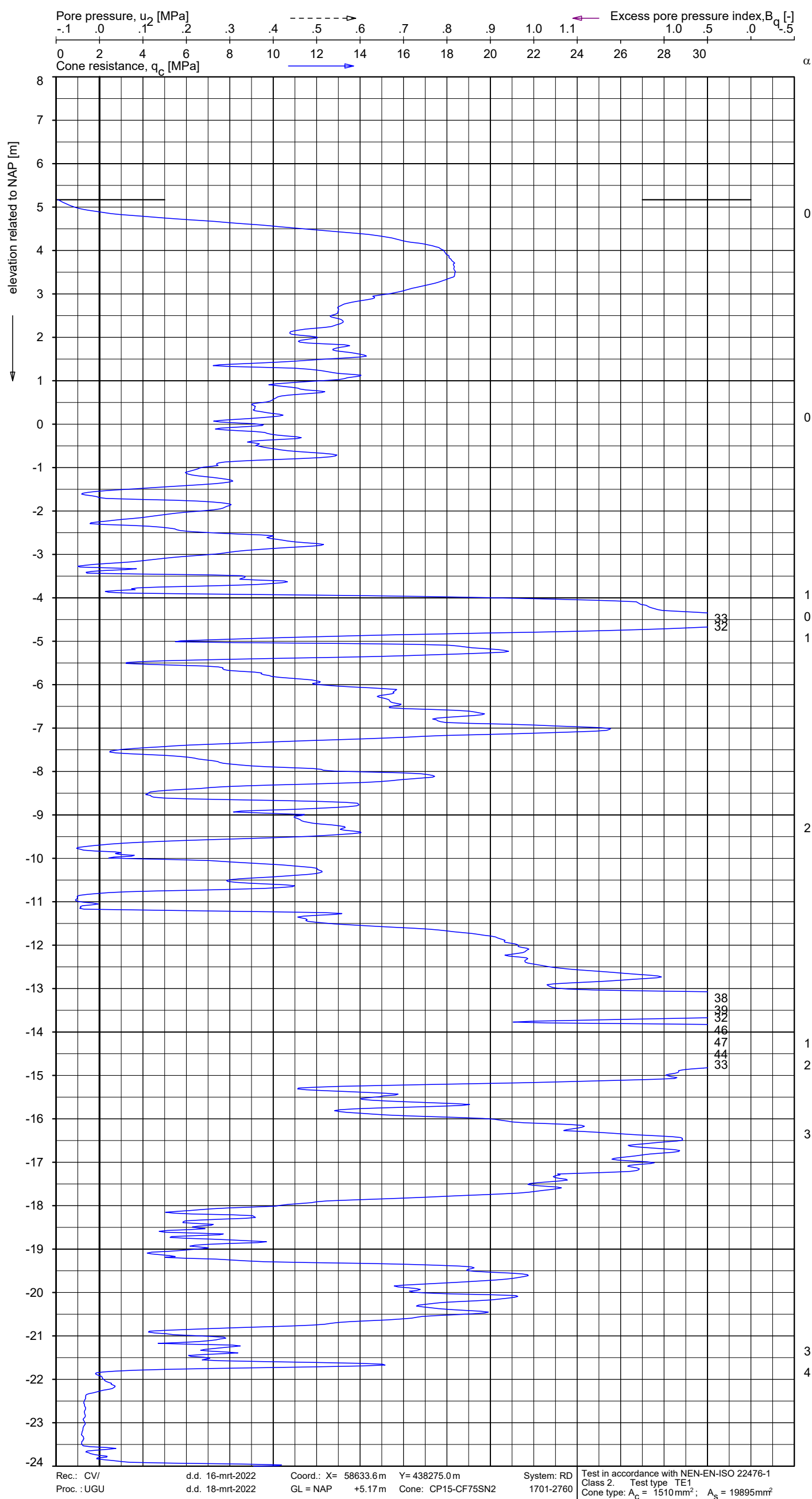
	SAND, silty to SILT
	SAND, slightly silty to silty

CONE PENETRATION TEST WITH LOCAL FRICTION

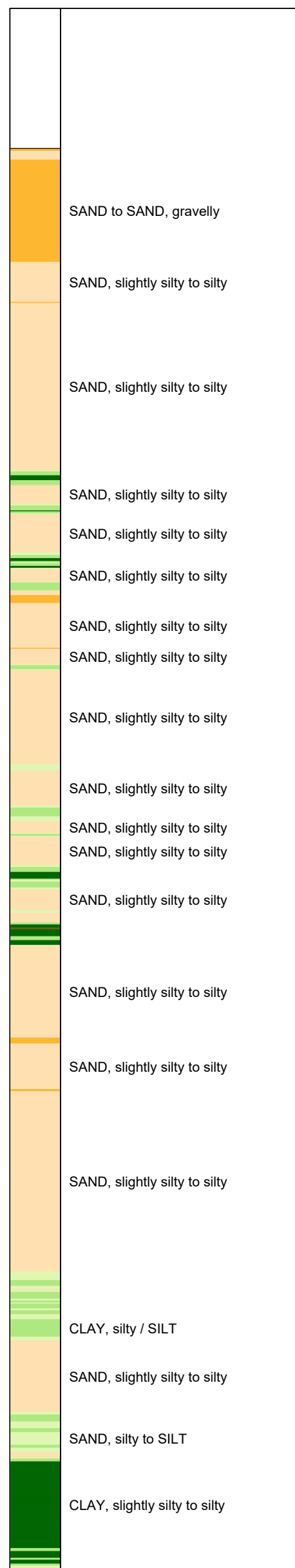
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS9





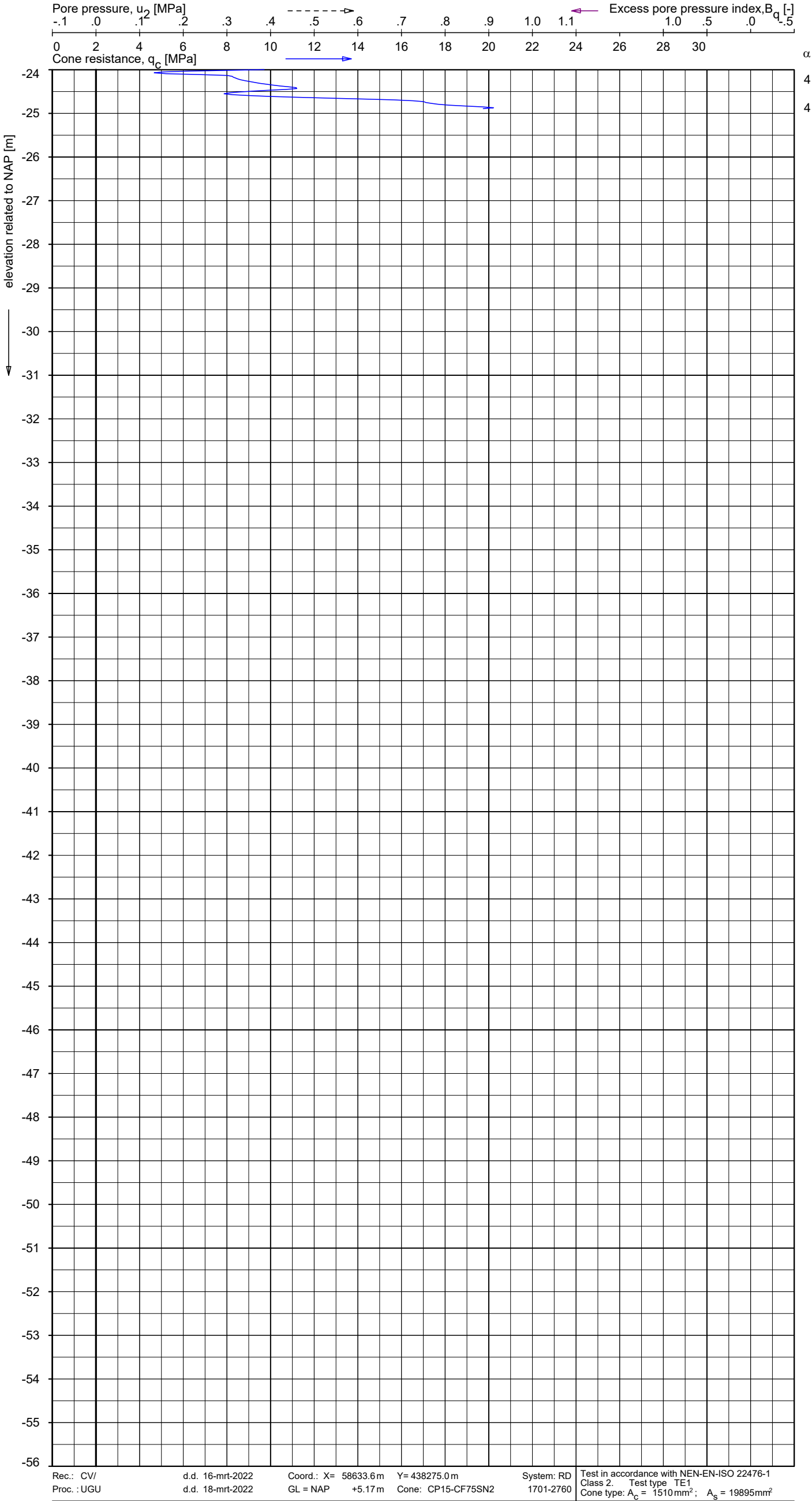
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Valid below groundwater level
(Robertson 1990, NL corr.)



PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIIPARK WEST

Proj. 2422-209014
Cpt FNLS9



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

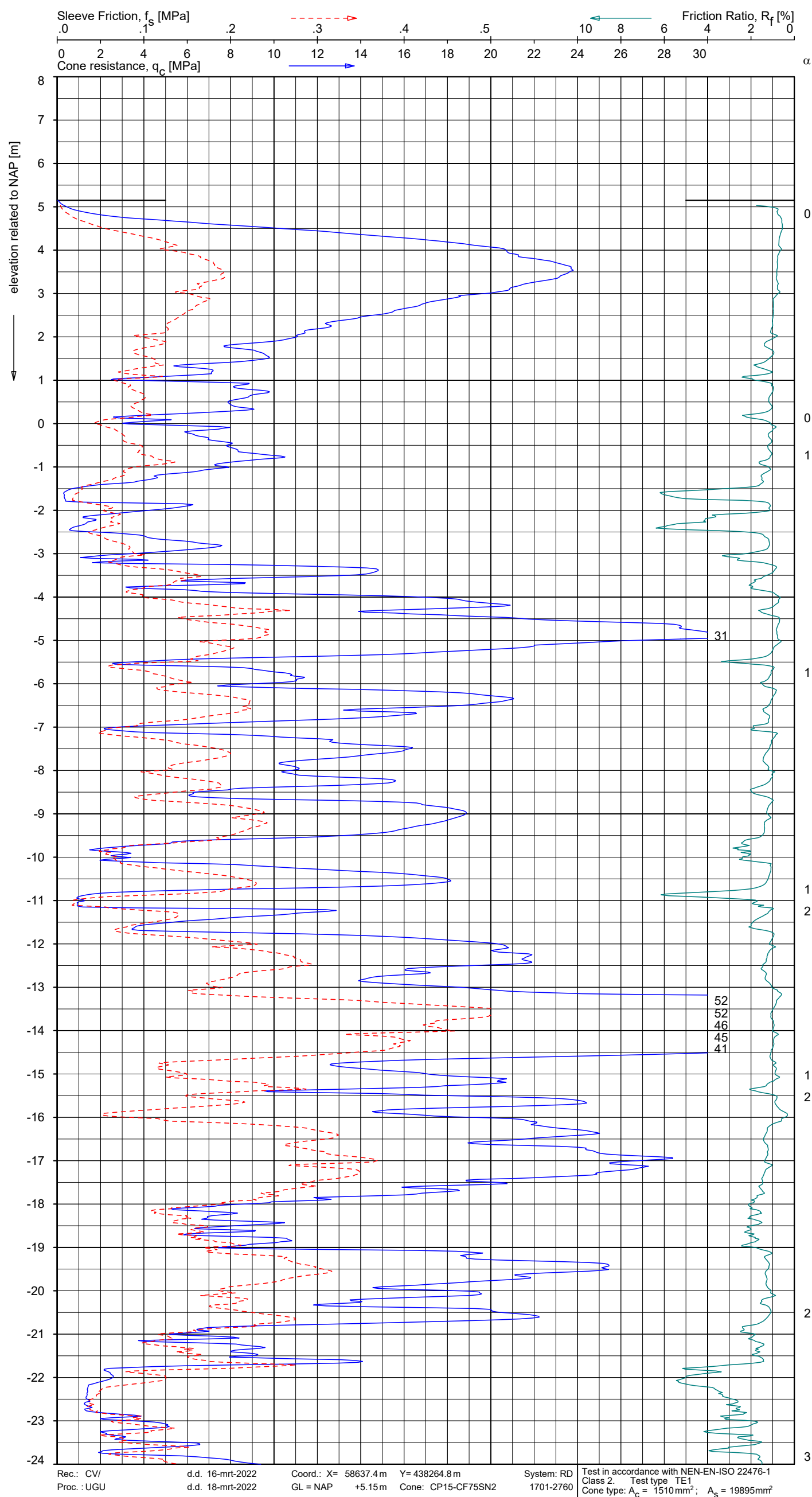
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PIEZO CONE PENETRATION TEST

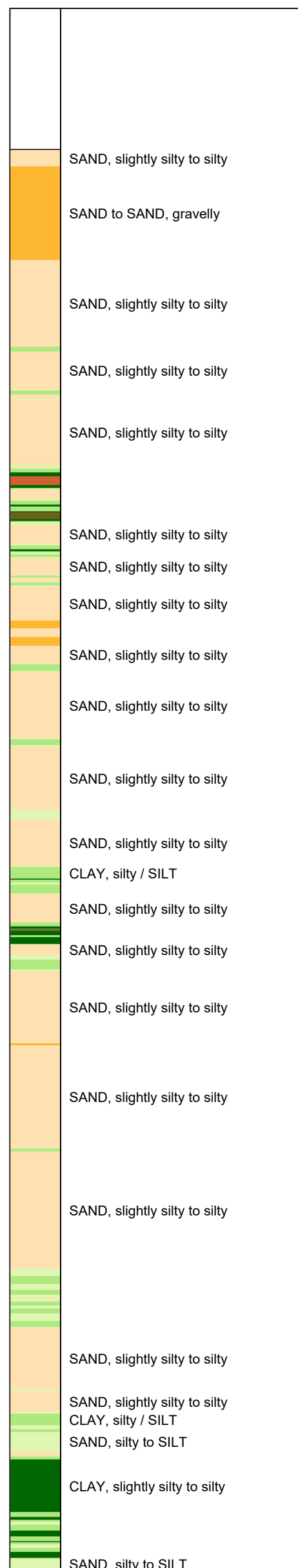
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Proj. 2422-209014
Cpt FNLS9





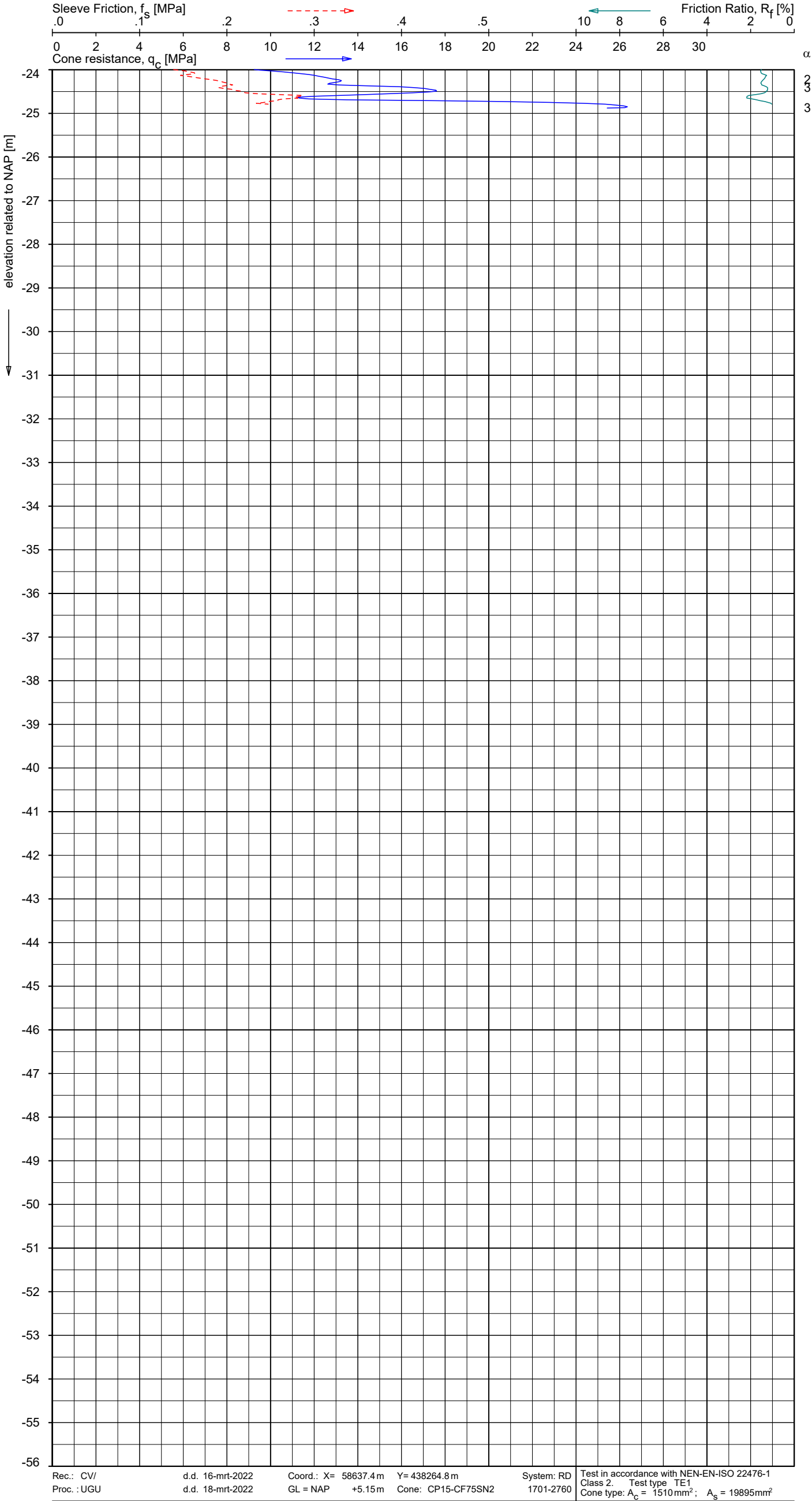
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Valid below groundwater level
(Robertson 1990, NL corr.)



CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj.	2422-209014
Cpt	FNLS10



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

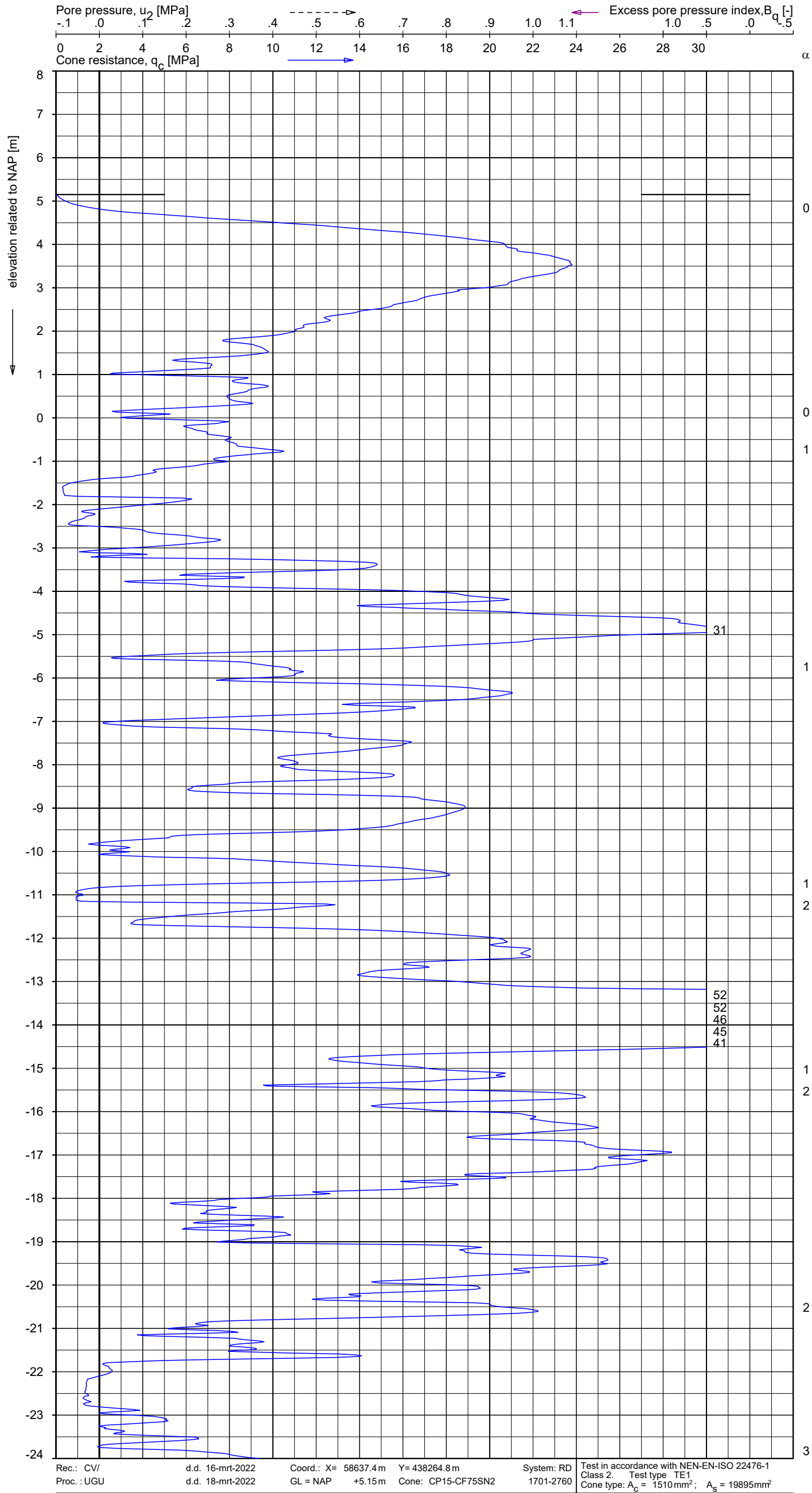
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CONE PENETRATION TEST WITH LOCAL FRICTION

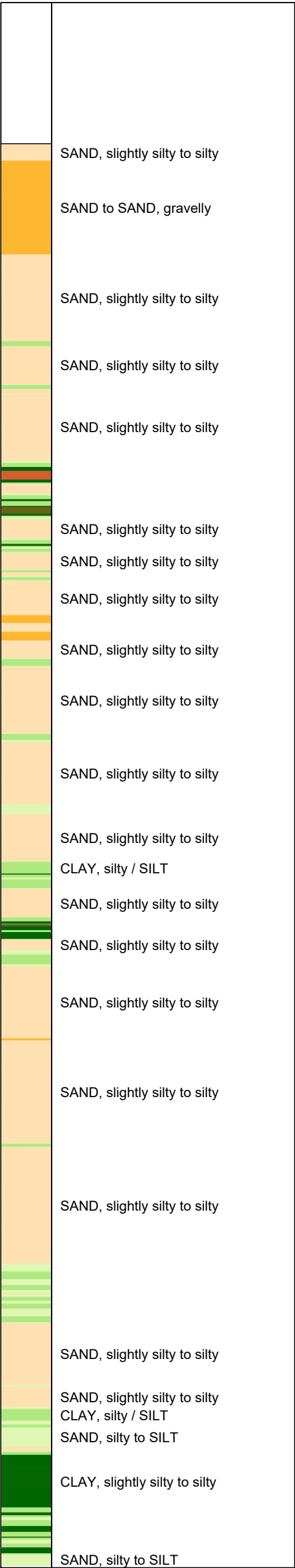
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS10





Indicative soil classification
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Valid below groundwater level
(Robertson 1990, NL corr.)

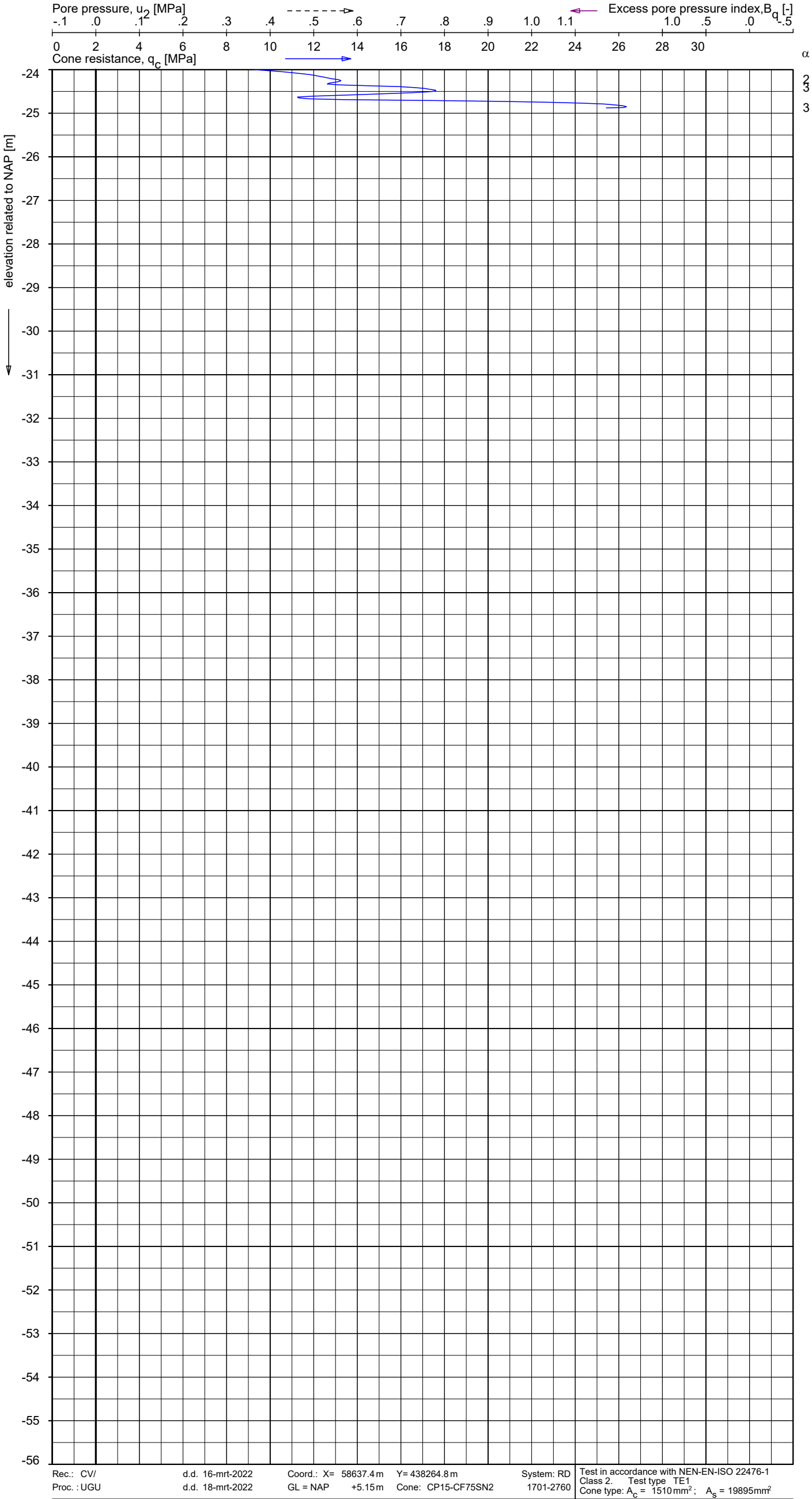


PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS10





Indicative soil classification
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(Robertson 1990, NL corr.)

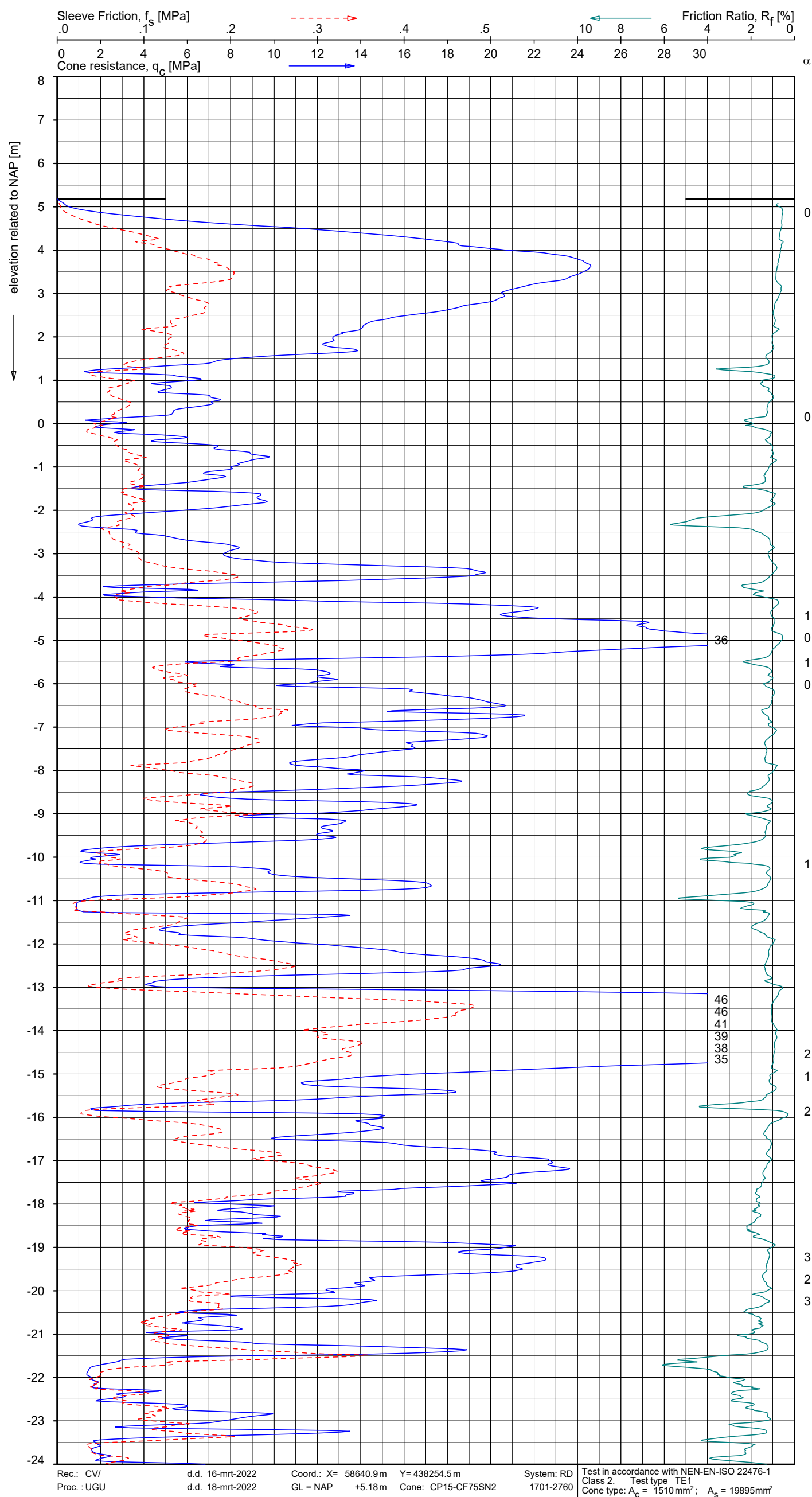
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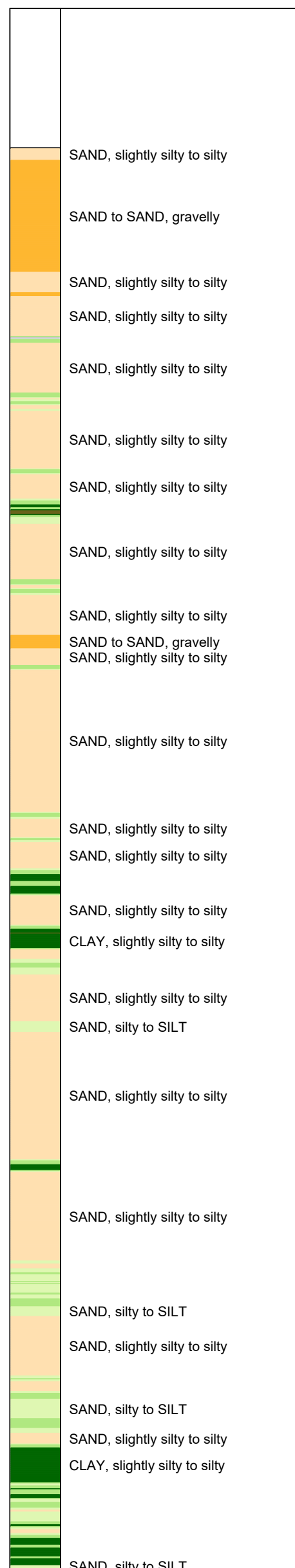
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Proj. 2422-209014
Cpt FNLS10





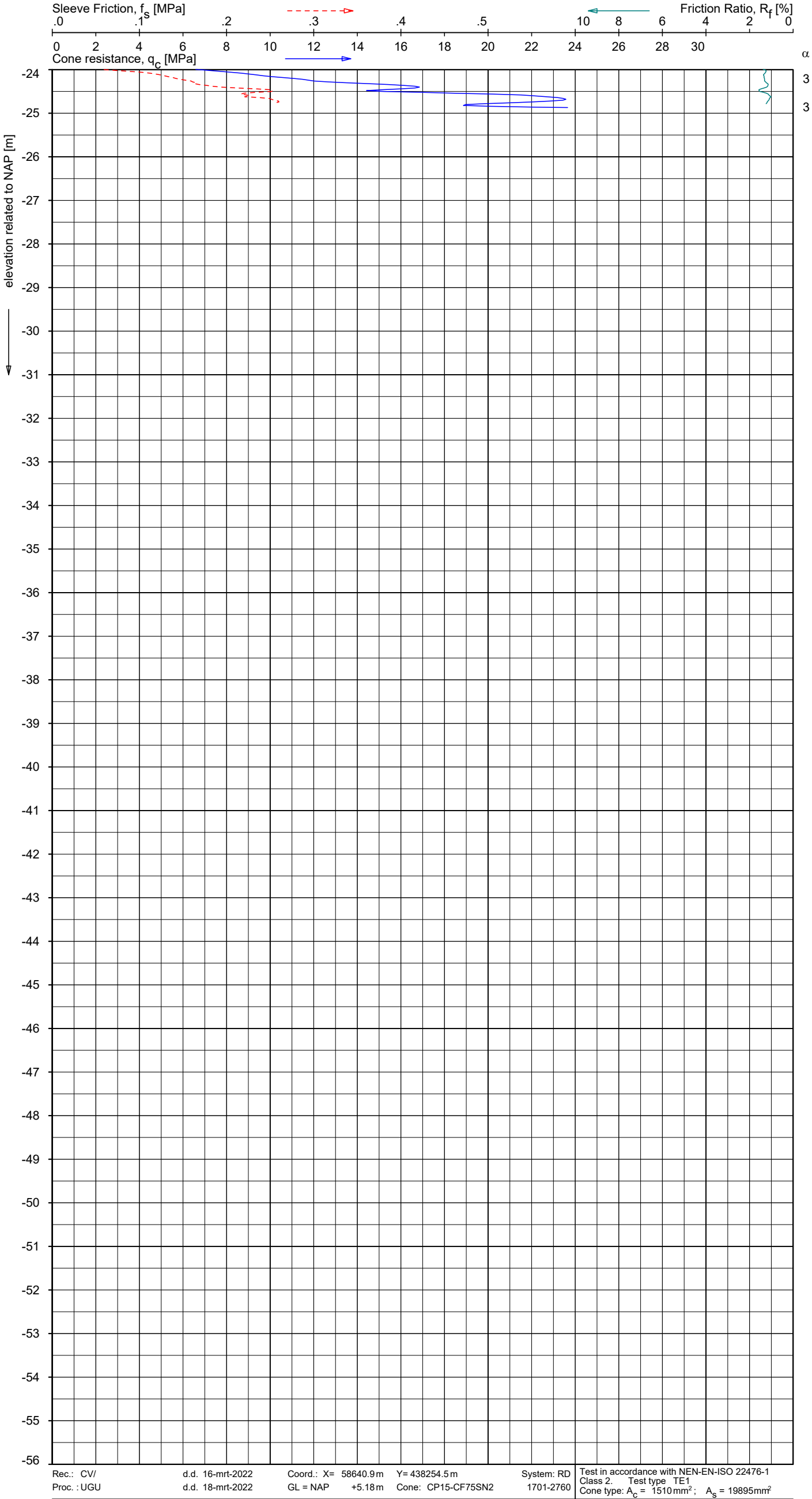
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(Robertson 1990, NL corr.)



CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj.	2422-209014
Cpt	FNLS11



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

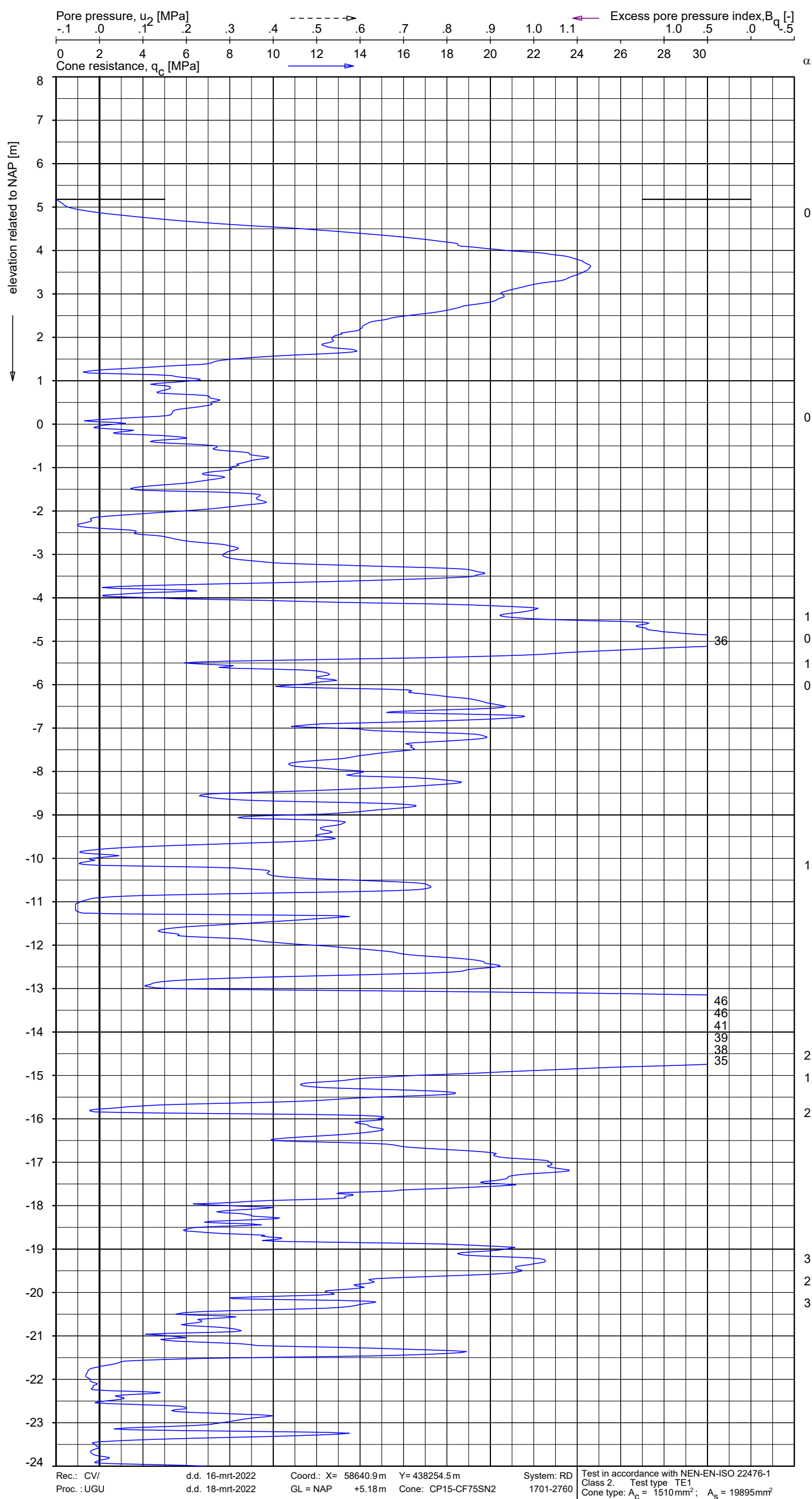
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CONE PENETRATION TEST WITH LOCAL FRICTION

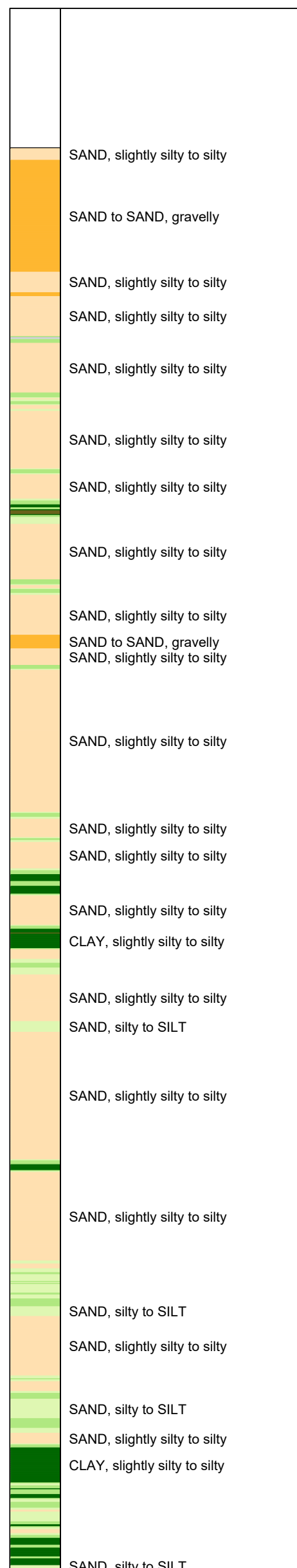
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS11





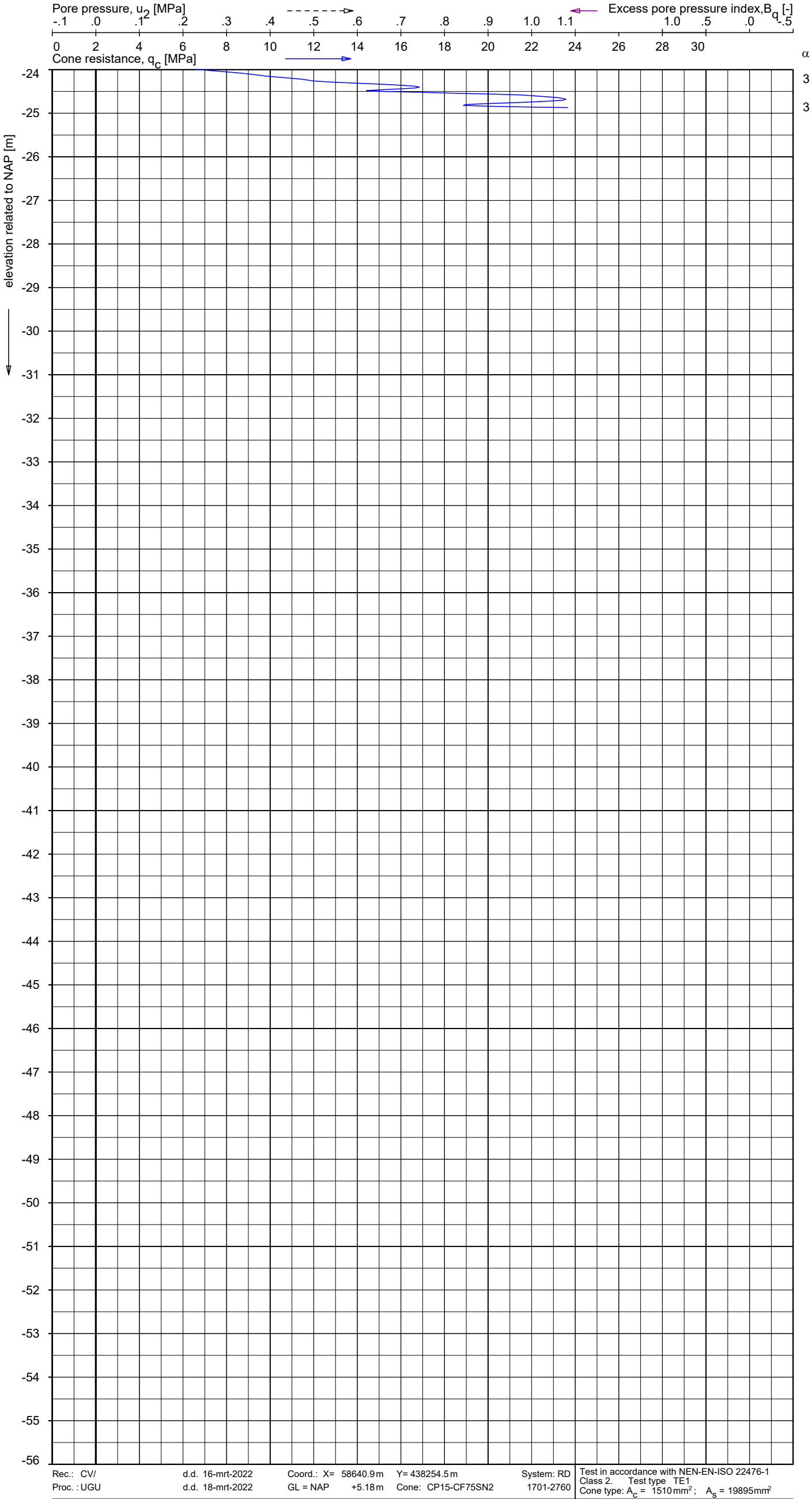
Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)



PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj.	2422-209014
Cpt	FNLS11



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

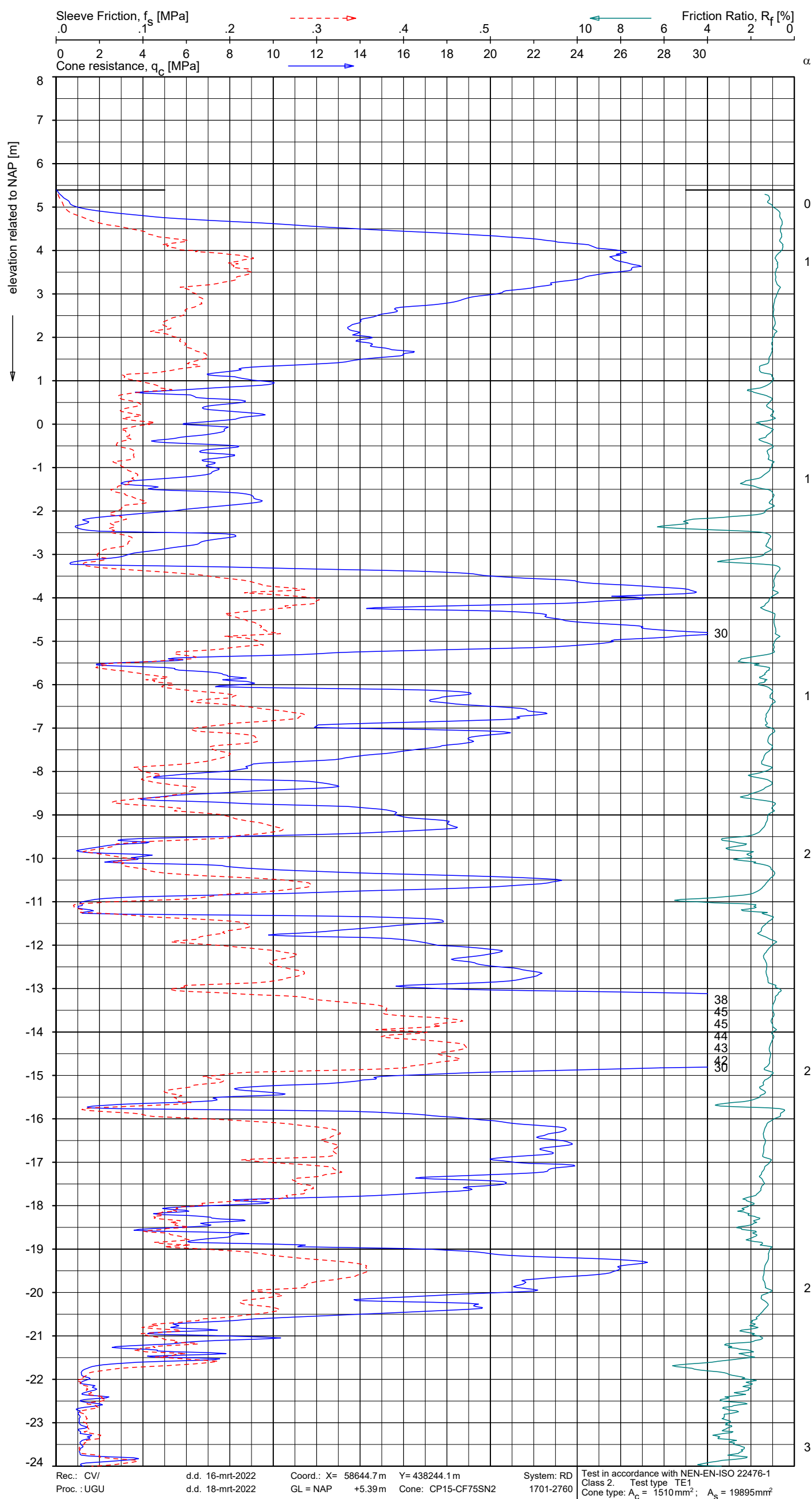
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PIEZO CONE PENETRATION TEST

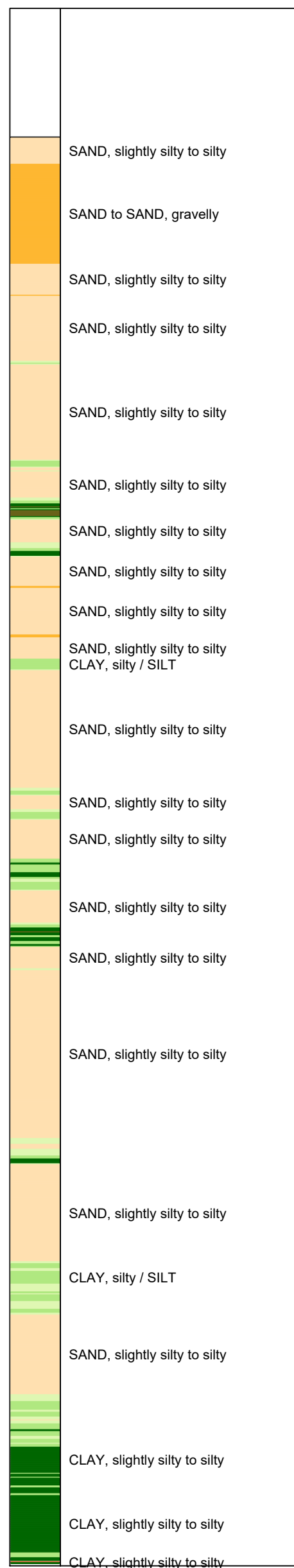
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS11





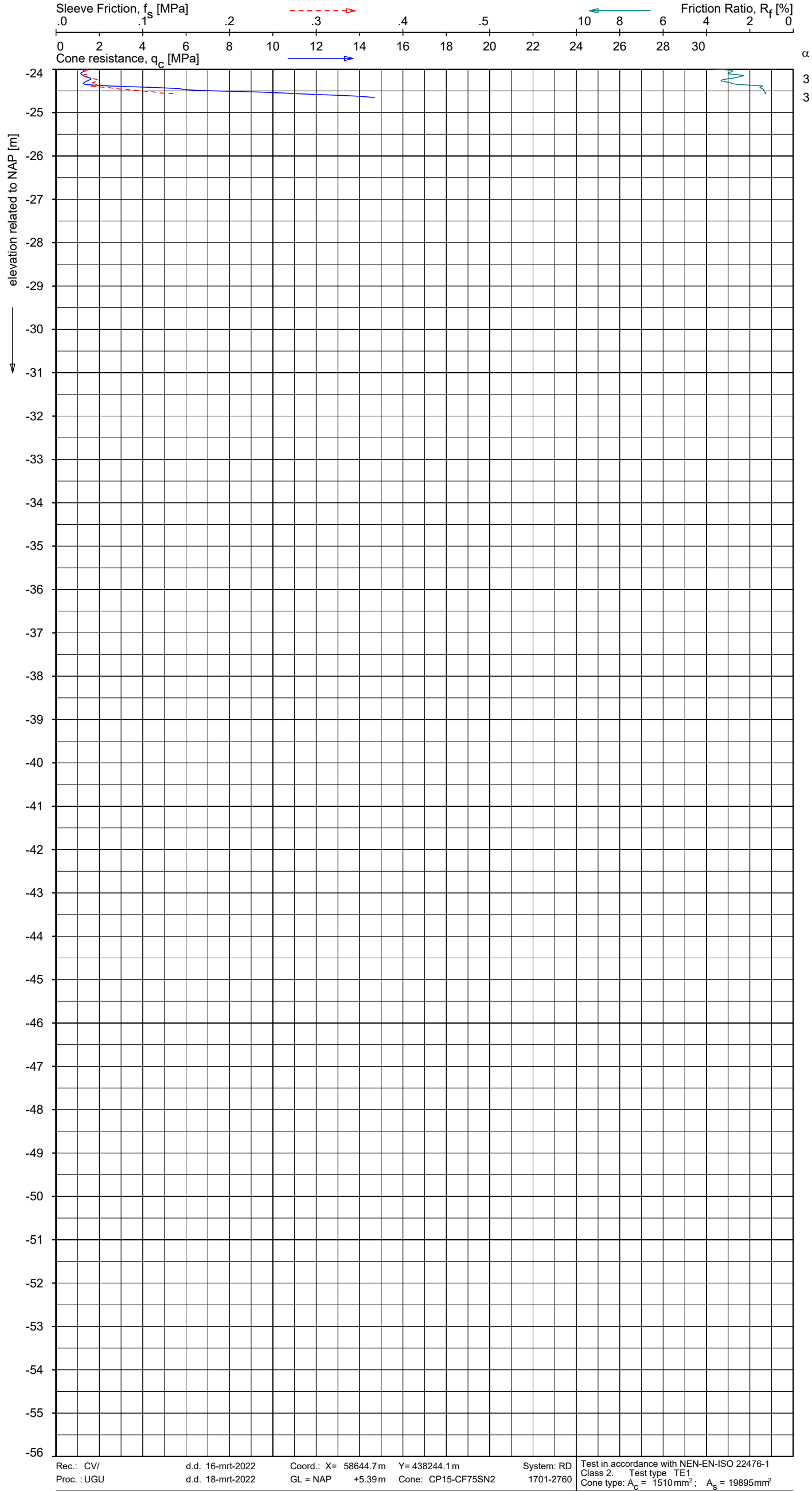
Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)



CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj.	2422-209014
Cpt	FNLS12



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

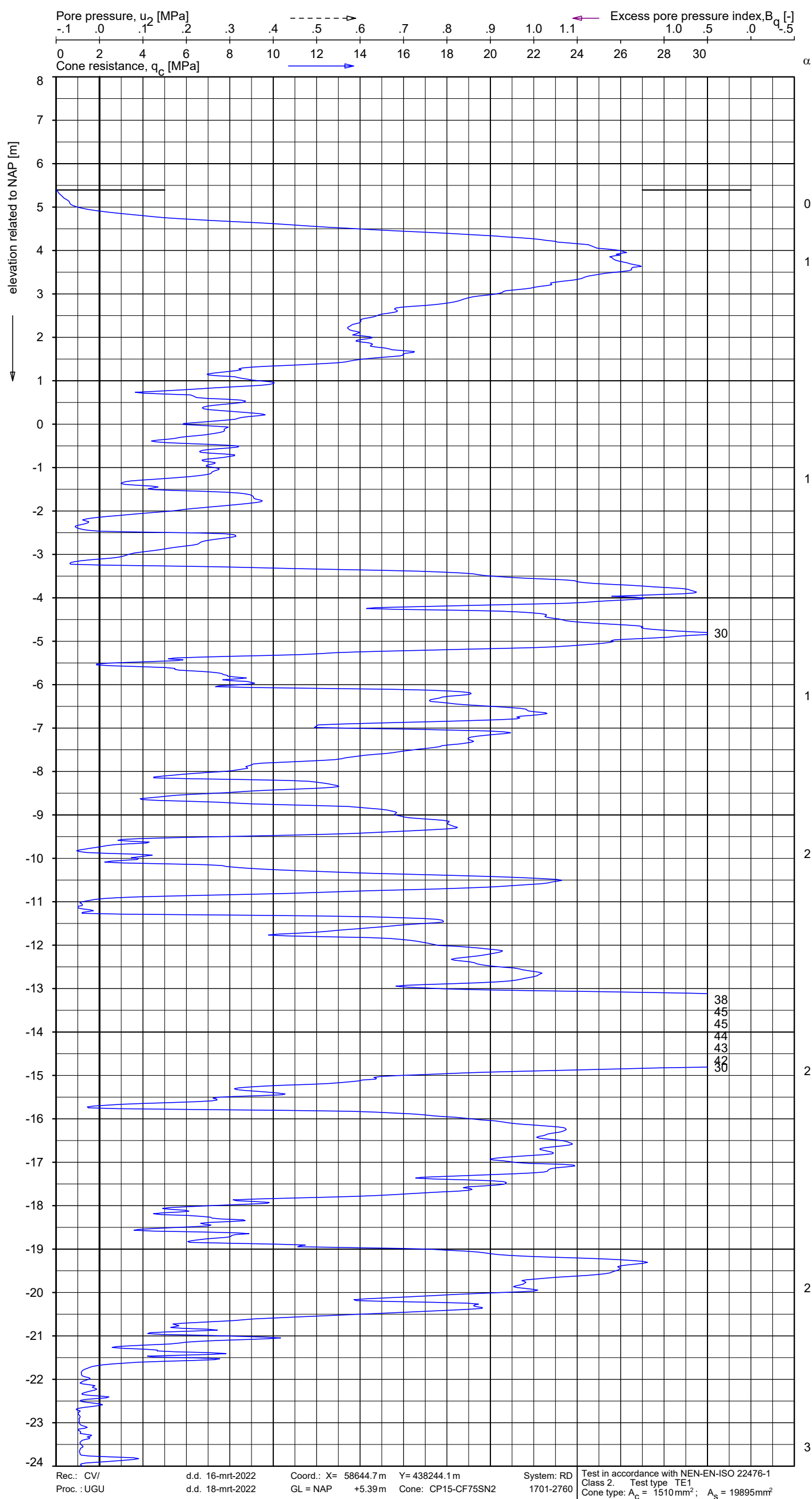
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CONE PENETRATION TEST WITH LOCAL FRICTION

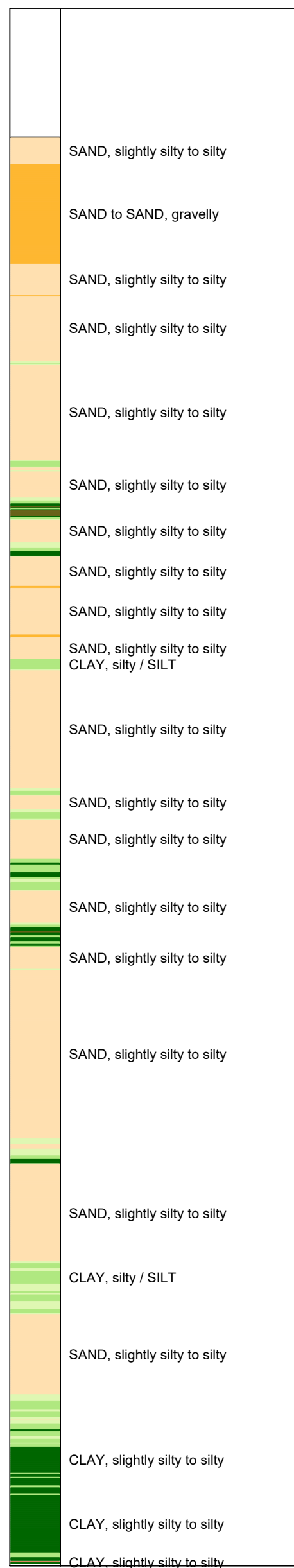
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Proj. 2422-209014
Cpt FNLS12





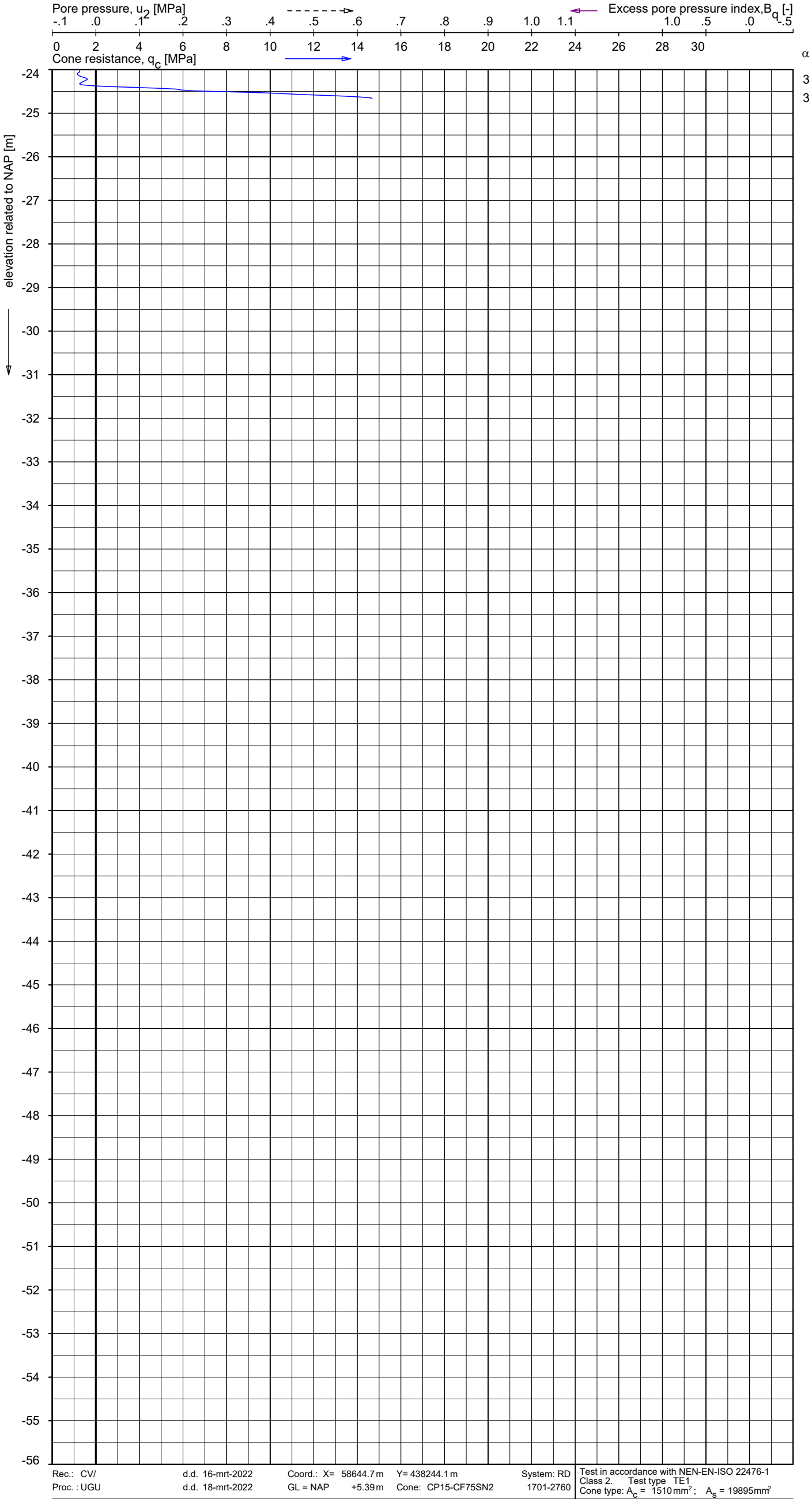
Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)



PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIIPARK WEST

Proj.	2422-209014
Cpt	FNLS12



PIEZO CONE PENETRATION TEST

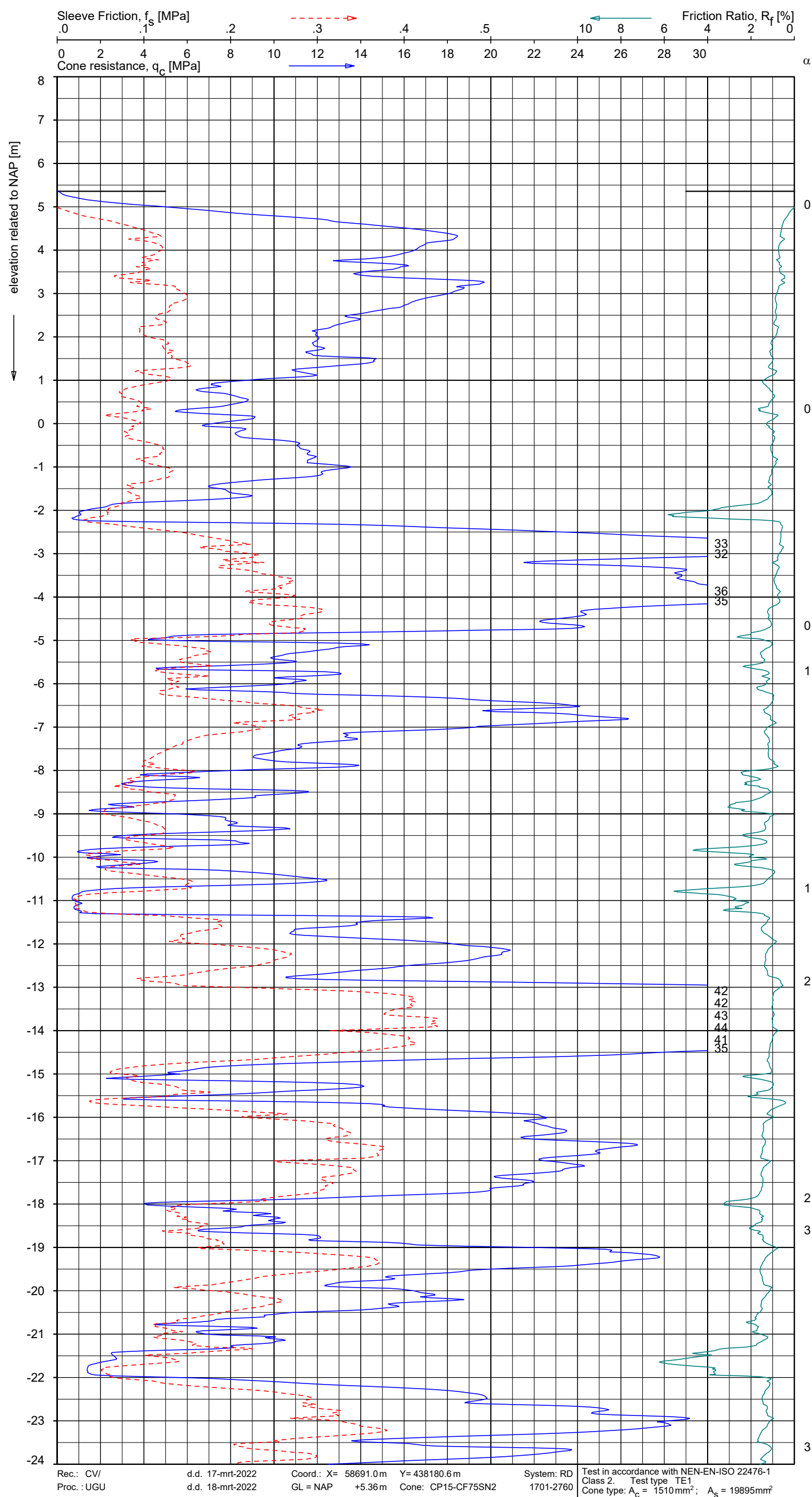
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Proj. 2422-209014
Cpt FNLS12

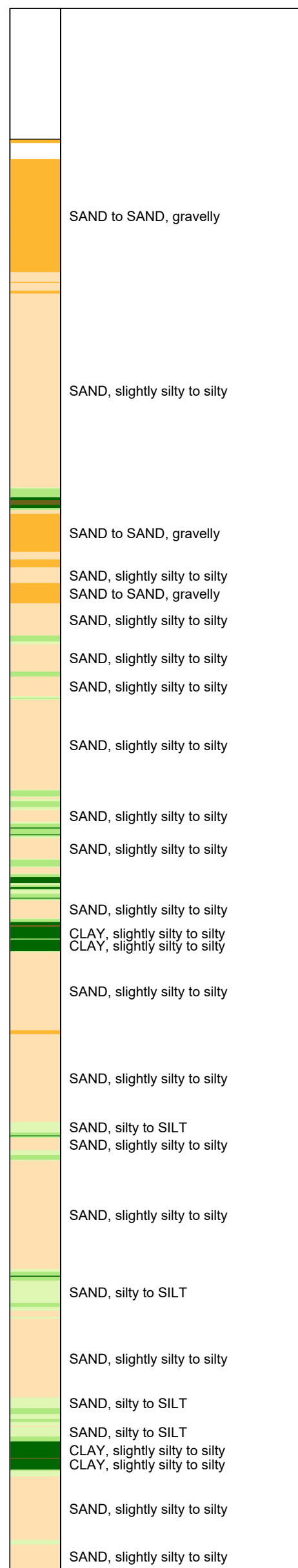
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Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

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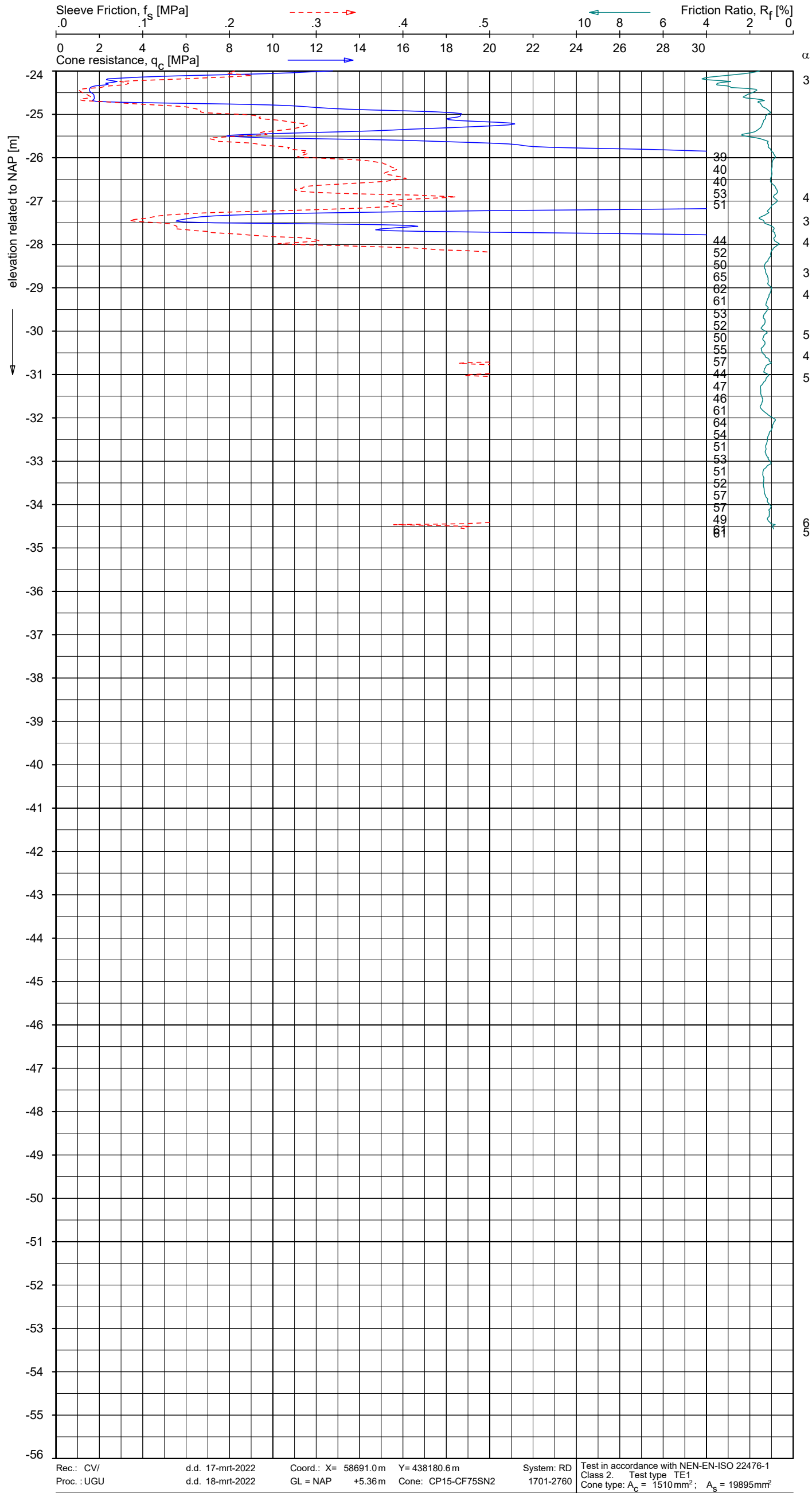
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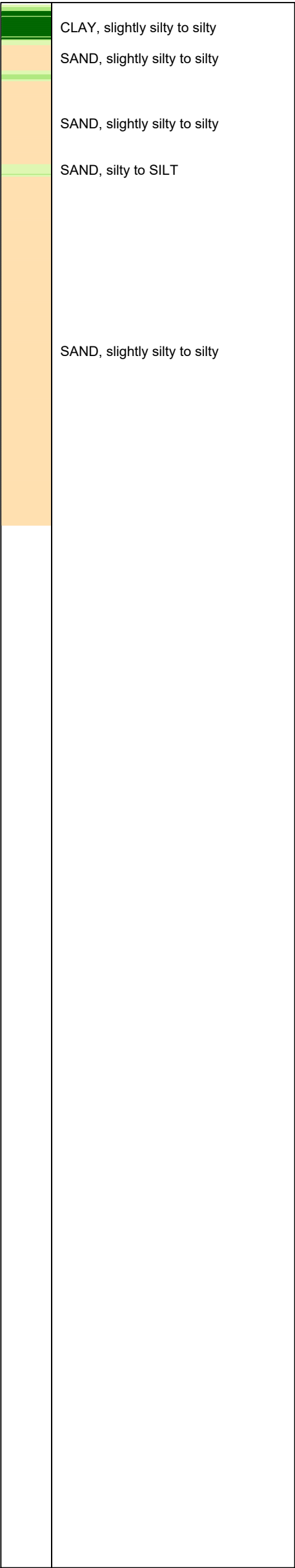
CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj. 2422-209014
Cpt FNLS33



Indicative soil classification
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Valid below groundwater level
(Robertson 1990, NL corr.)

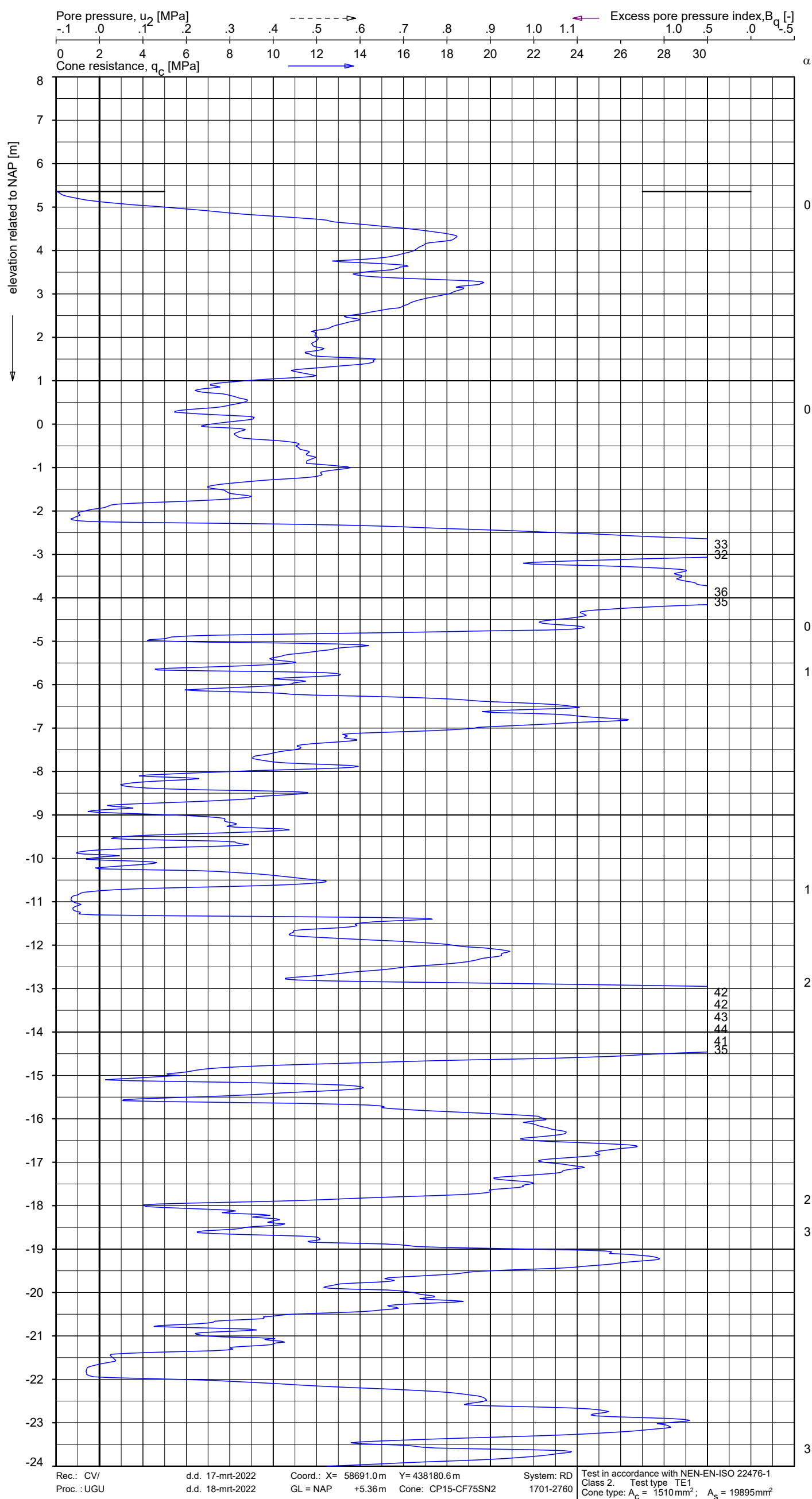


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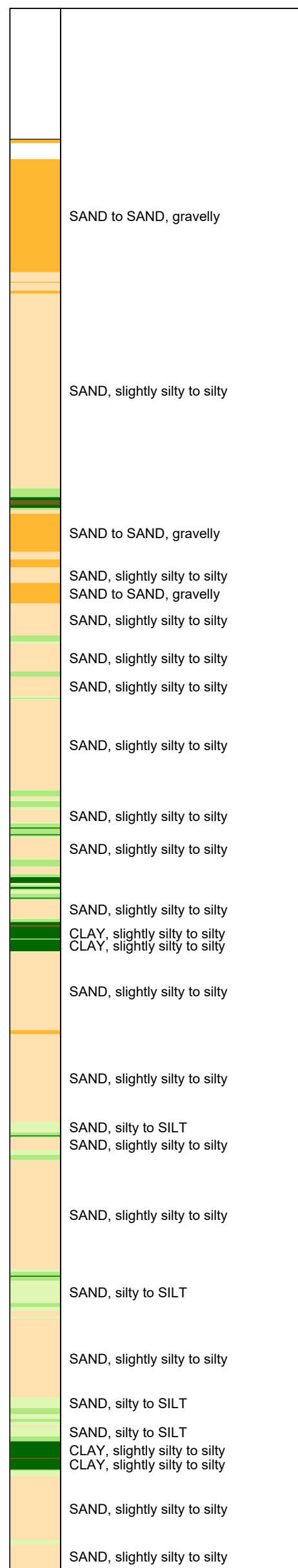
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Cpt FNLS33





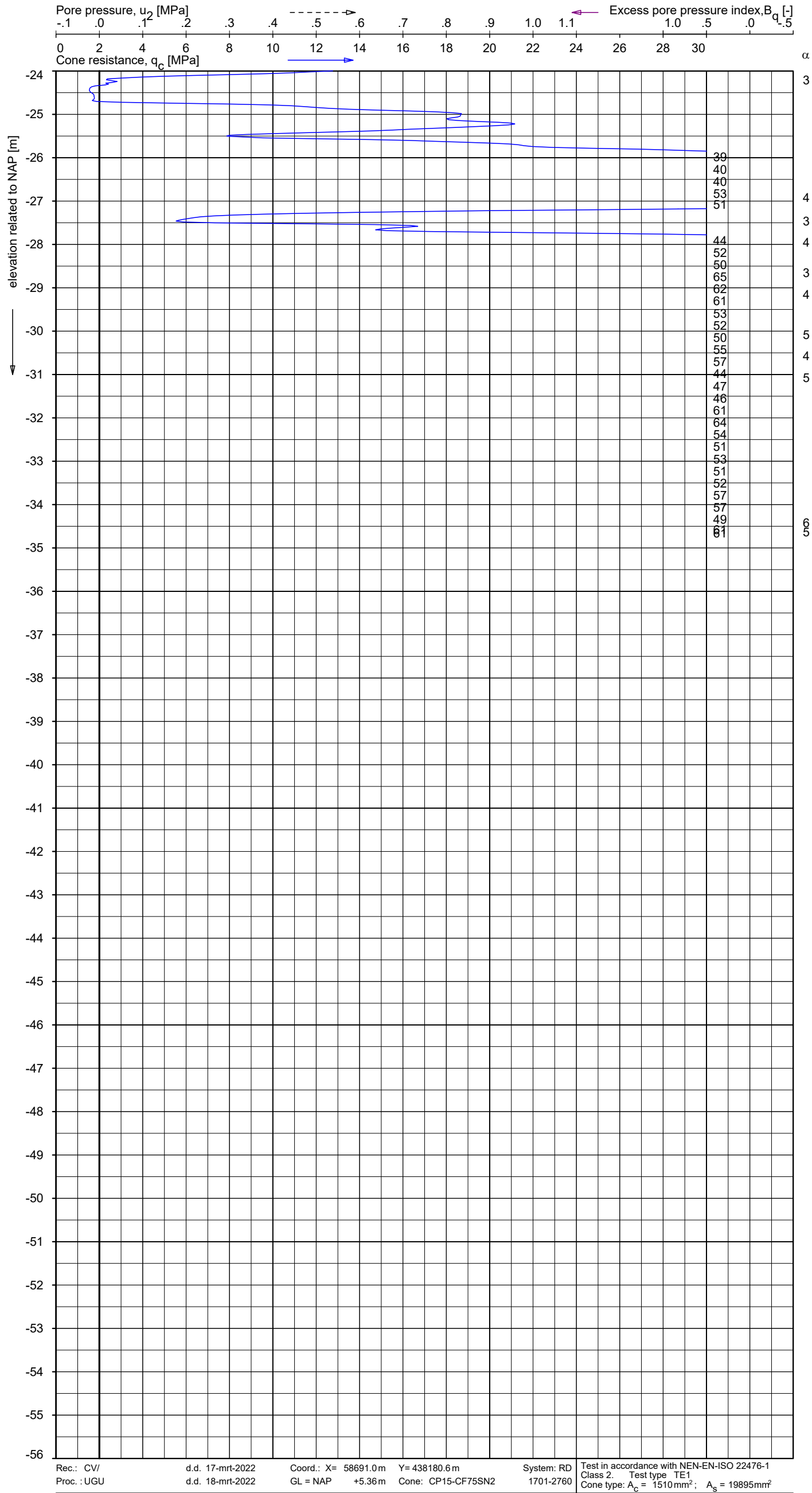
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(Robertson 1990, NL corr.)



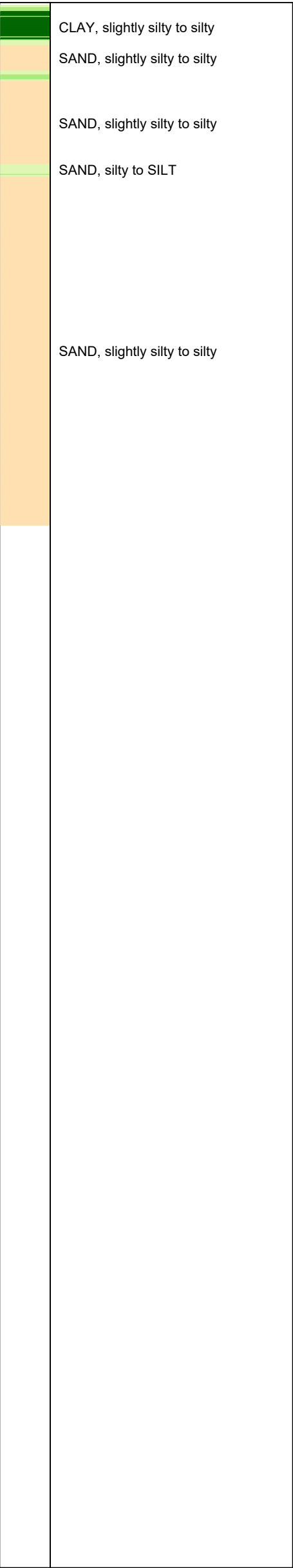
PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIIPARK WEST

Proj. 2422-209014
Cpt FNLS33



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

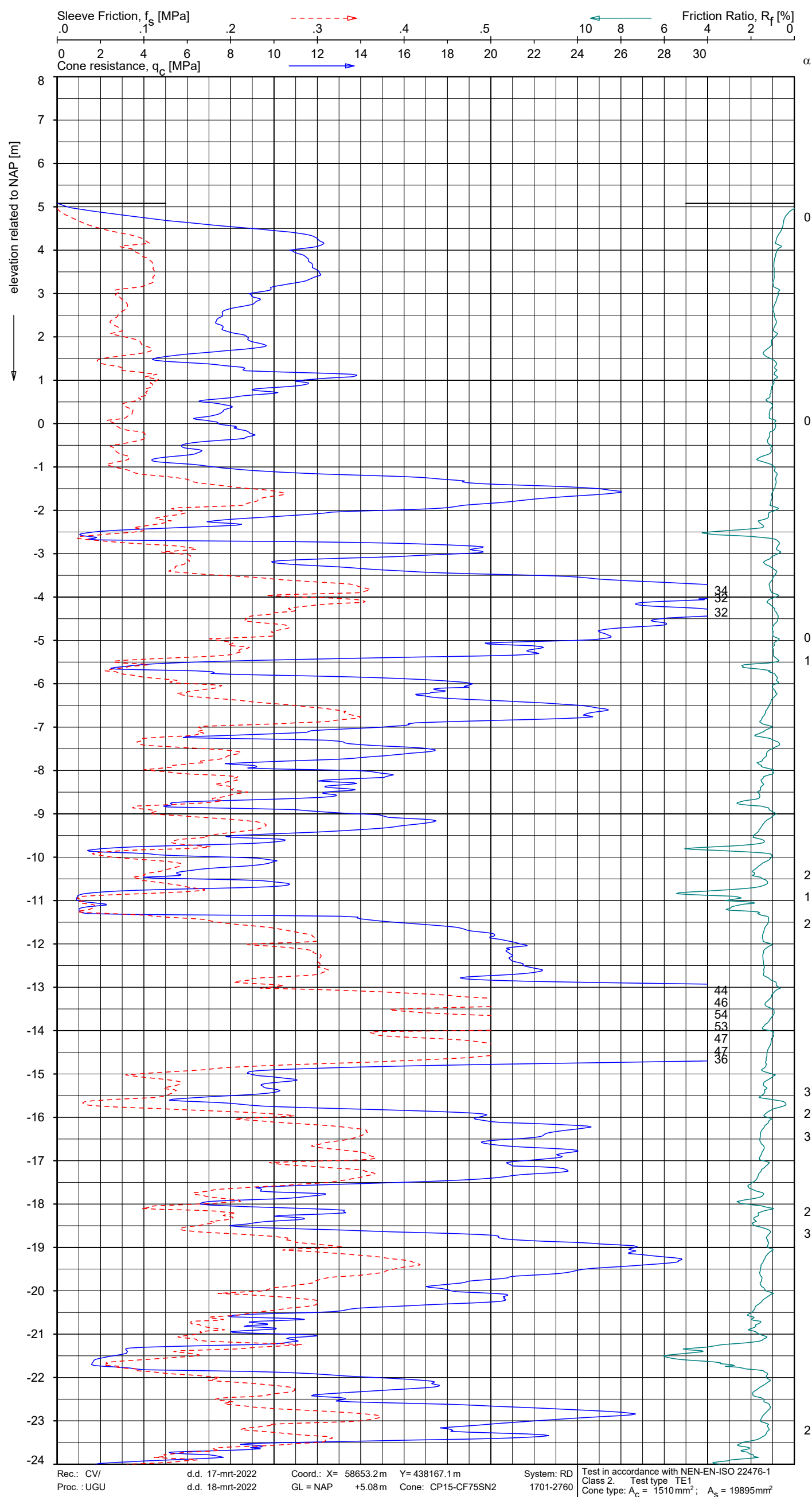


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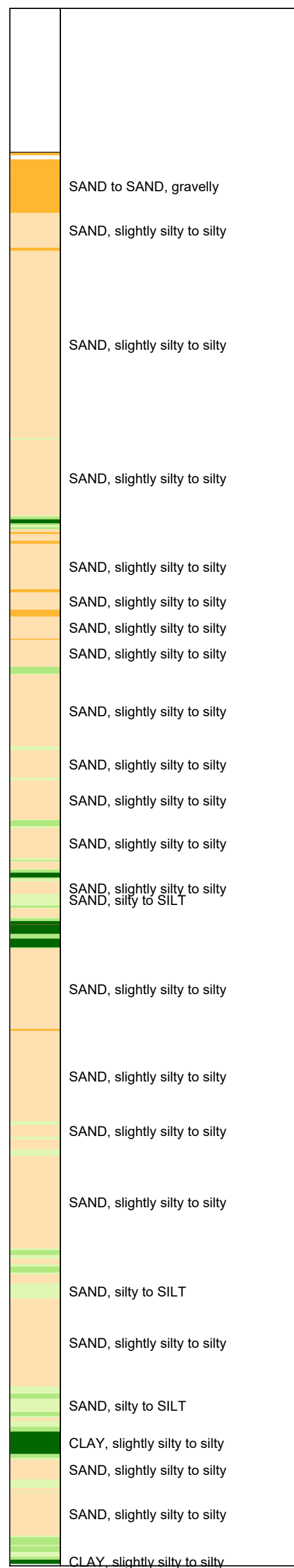
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Cpt FNLS33





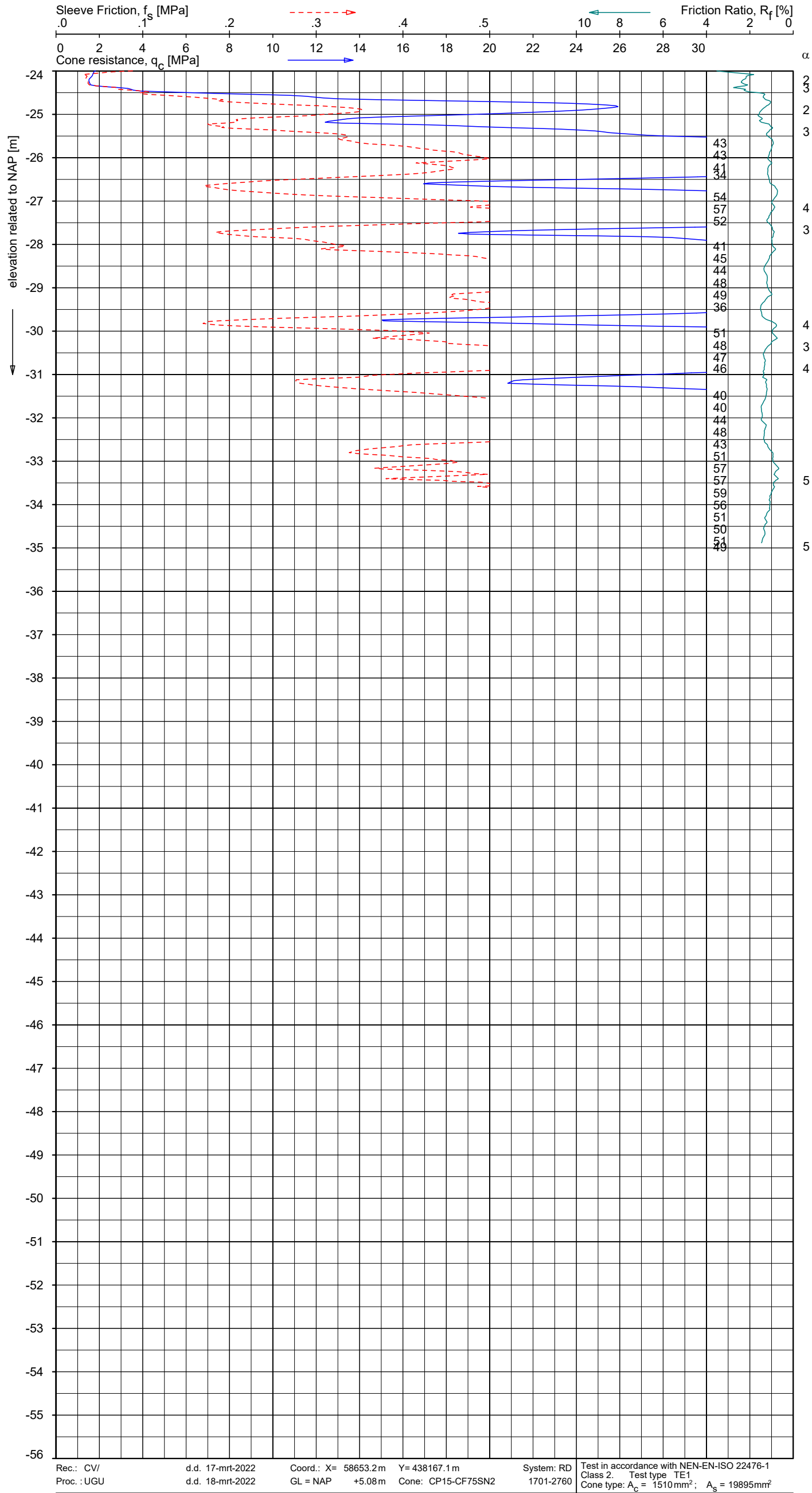
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(Robertson 1990, NL corr.)



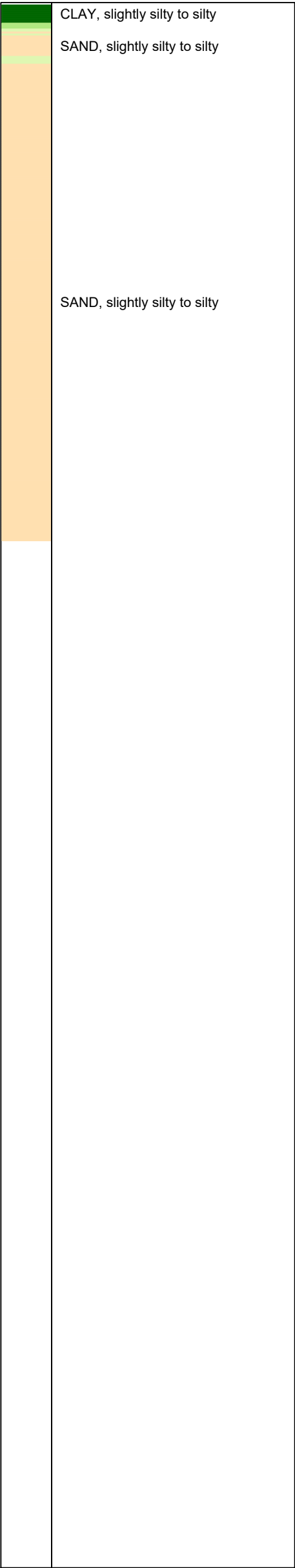
CONE PENETRATION TEST WITH LOCAL FRICTION

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj. 2422-209014
Cpt FNLS34



Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)

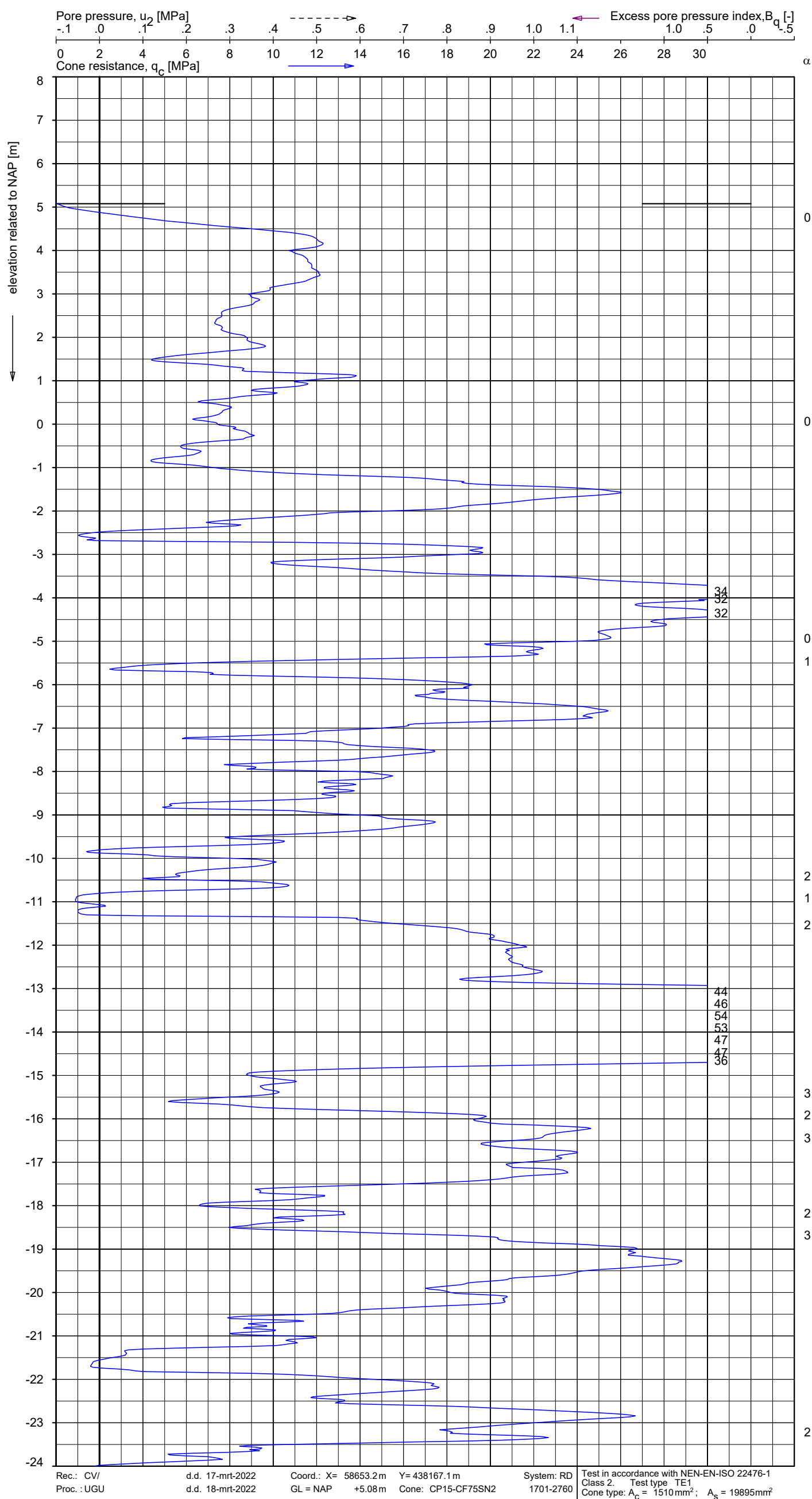


CONE PENETRATION TEST WITH LOCAL FRICTION

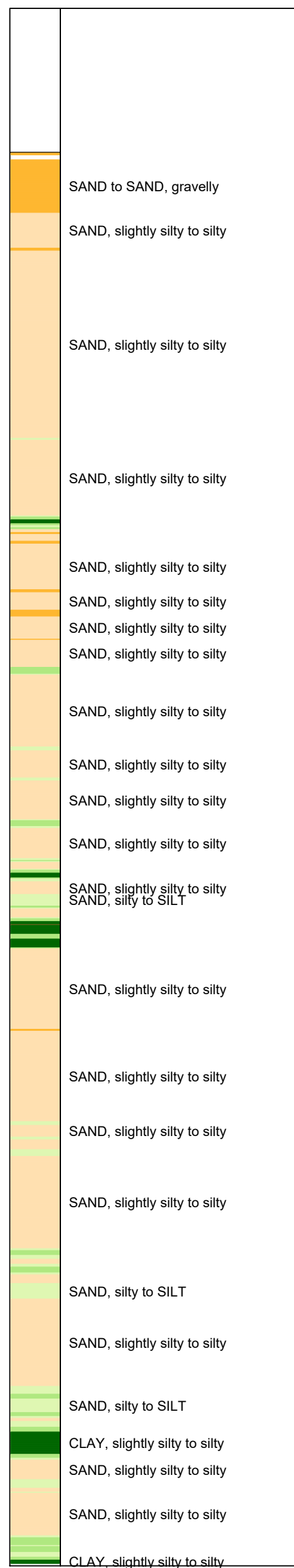
HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS34





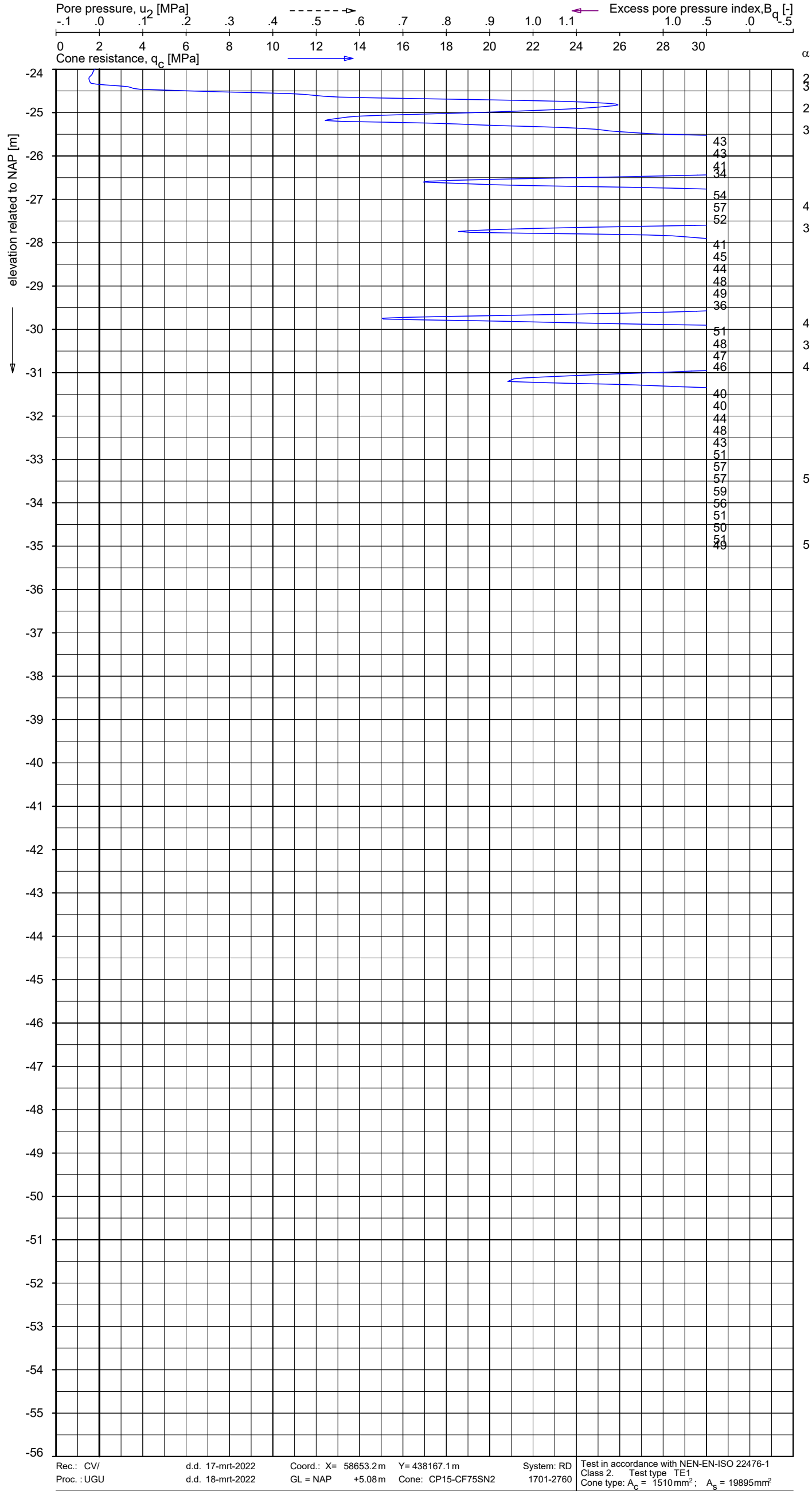
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(Robertson 1990, NL corr.)



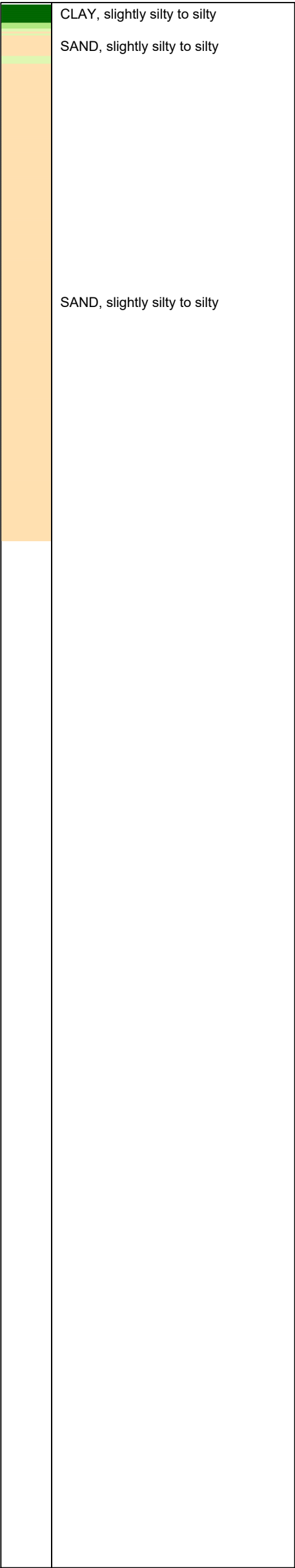
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HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIJPARK WEST

Proj. 2422-209014
Cpt FNLS34



Indicative soil classification
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Valid below groundwater level
(Robertson 1990, NL corr.)

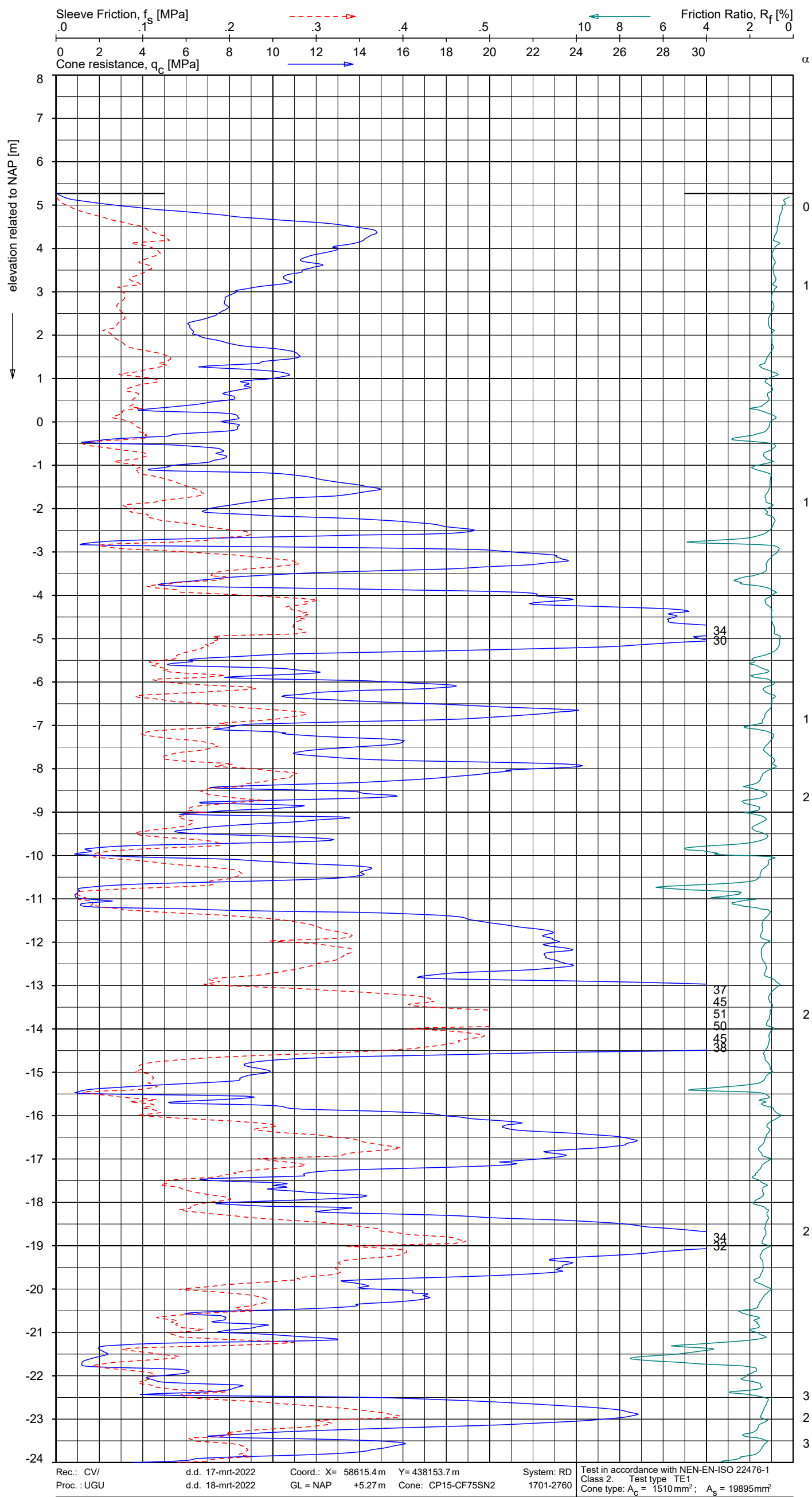


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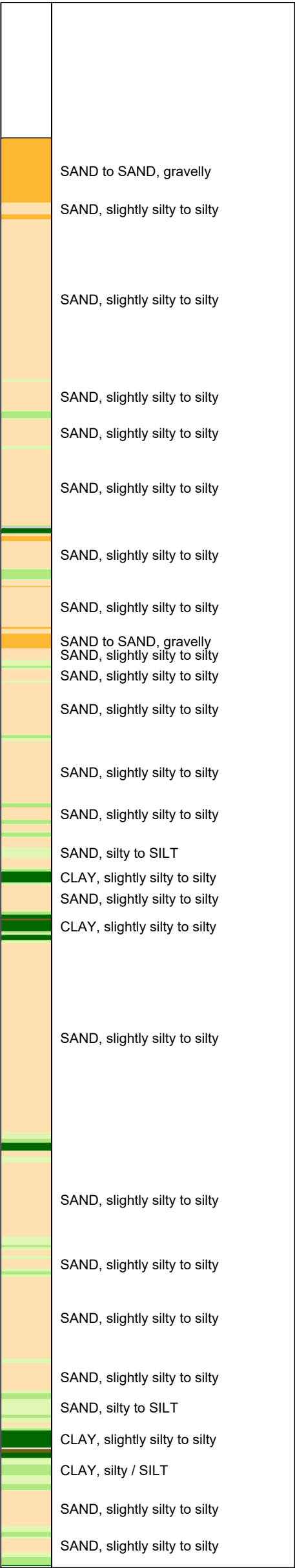
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Cpt FNLS34





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(Robertson 1990, NL corr.)

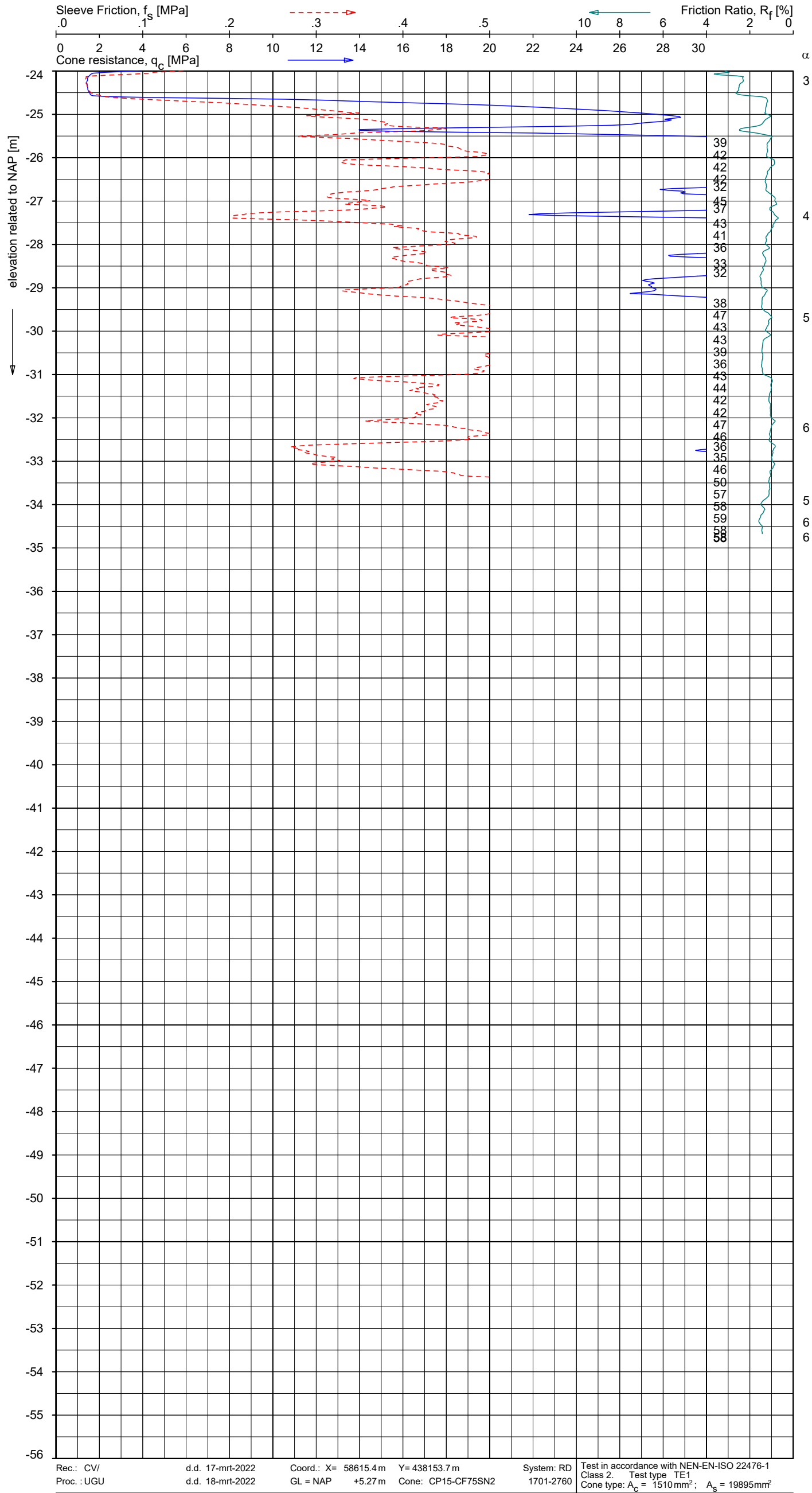


CONE PENETRATION TEST WITH LOCAL FRICTION

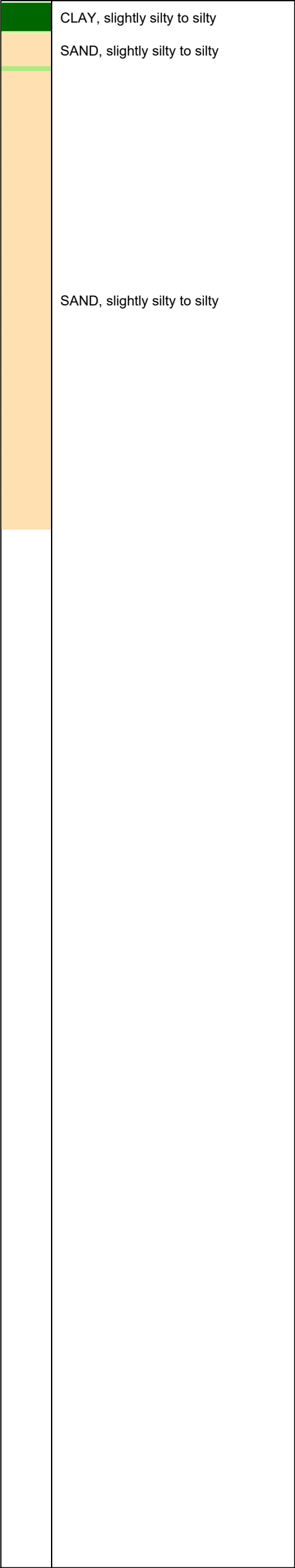
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Proj. 2422-209014
Cpt FNLS35





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(Robertson 1990, NL corr.)

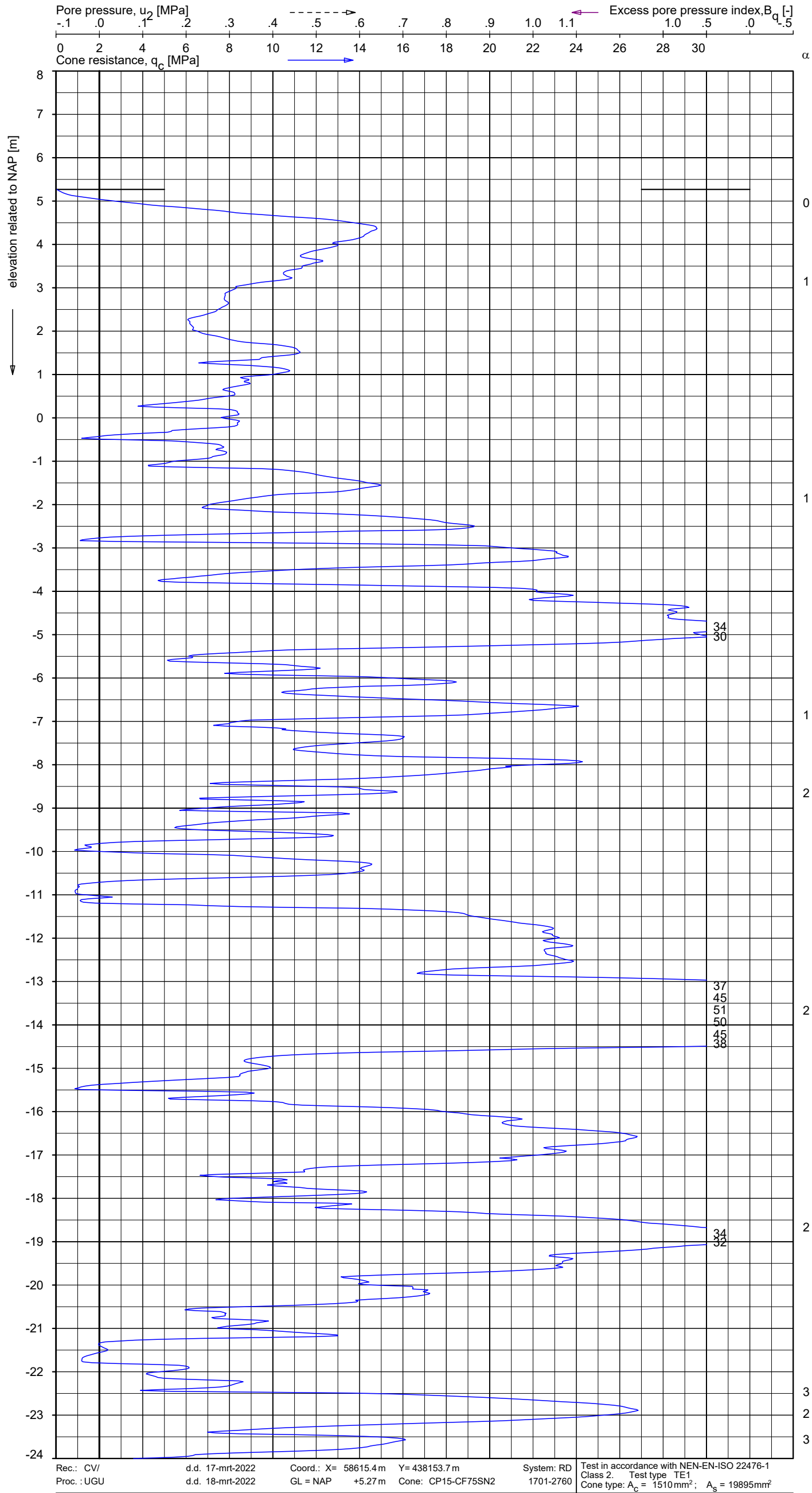


CONE PENETRATION TEST WITH LOCAL FRICTION

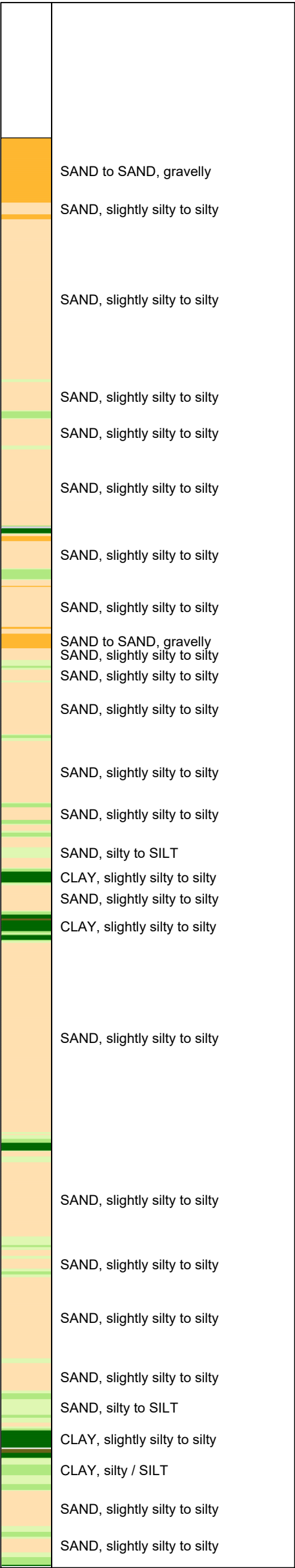
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Proj. 2422-209014
Cpt FNLS35





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(Robertson 1990, NL corr.)

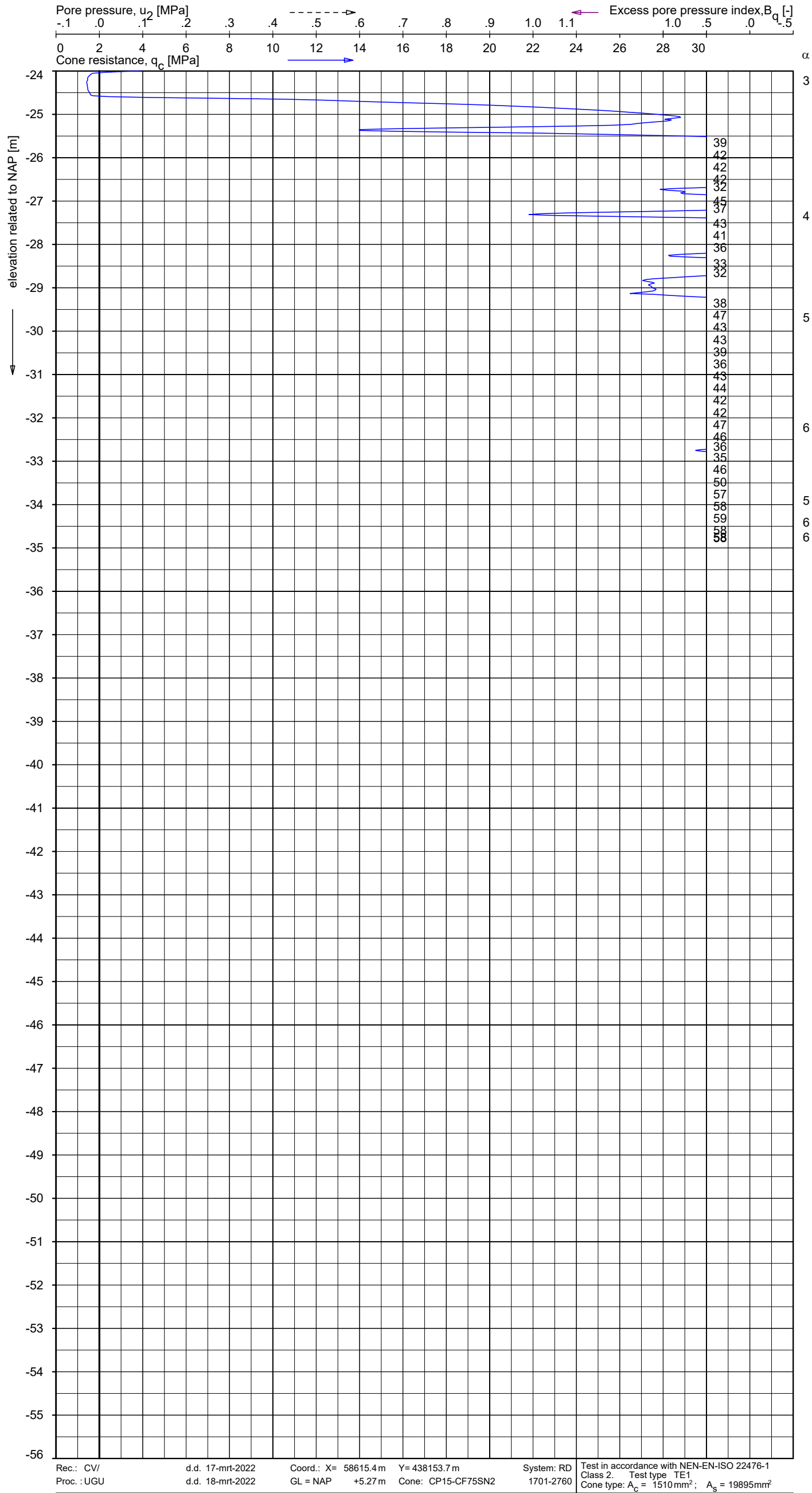


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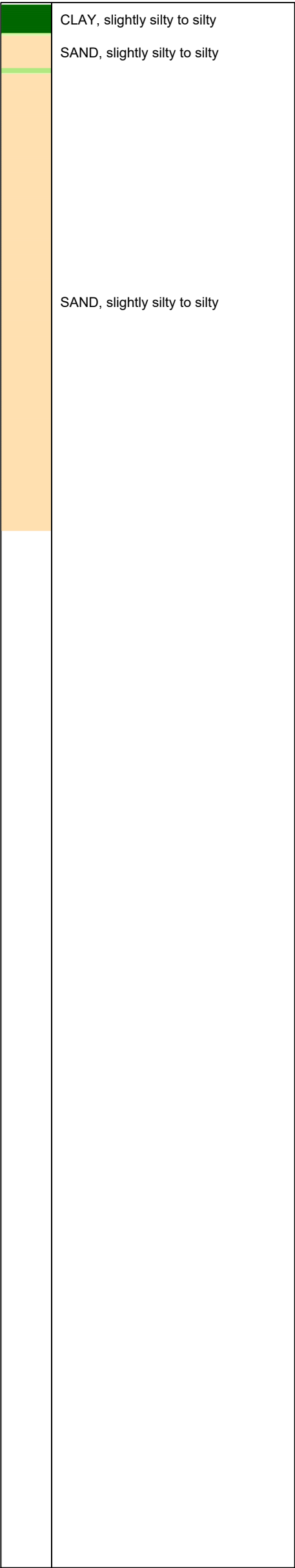
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Proj. 2422-209014
Cpt FNLS35





Indicative soil classification
Automatically generated from CPT data
Valid below groundwater level
(Robertson 1990, NL corr.)



PIEZO CONE PENETRATION TEST

HBR NL GRONDONDERZOEK MAASVLAKTE DISTRIK WEST

Proj. 2422-209014
Cpt FNLS35



Explanation geotechnical site investigation

Coordinates and height of research points

If the level and the coordinates of the Ground Investigation locations are surveyed in RD (X, Y) and NAP (Z) coordinates, the maximum deviation of the measurement of coordinates is 10 cm, the maximum deviation of the measurement of the level is 5 cm. For projects where Ground Investigation location(s) have been surveyed relative to a local fixed point, the maximum deviation of the measurement of the level is 5 cm, the maximum deviation of the measurement of coordinates is 25 cm.

If Ground Investigation sites are not referenced to a fixed reference, the investigation does not conform to requirements set in NEN-EN-ISO 22476-1.

The level determination of the investigation location(s) is to enable the soil and/or rock profile to a known reference level. The survey data is not suitable for any purposes other than this site investigation.

Cone penetration testing

The CPT's are performed in accordance with existing directives and the NEN-EN-ISO-22476-1. A description of the measurement and registration method is given in the appendix "Electrical cone penetration testing".

Drilling

Drilling of the boreholes (are) carried out using the standard tools and sinker bars and temporary threaded steel casing as the ground conditions dictate. All sampling and in-situ testing are performed in accordance with the work instruction or as directed by the (client) Engineer. Specific technical details of any equipment shall be held in the Fugro office and can be provided on request.

Manually drilling is performed by a hand auger.

The work is performed in accordance with the NEN-EN-ISO 22475-1.

The standpipe installed in the boreholes are performed in accordance with the NEN-EN-ISO 22475-1. The filter depth, gravel pack and bentonite are indicated on the drilling graphics. The boreholes with standpipes are with corresponding symbol shown on the site plan.

Undisturbed samples during mechanical drilling can be acquired by:

- Pressing or driving a liner (Ackermann) into the soil;
- Pressing a Piston liner;
- Pressing a Gelpush sample.

For manual drilling soil sampling is performed with a Van der Horst core sampler.

During drilling activities disturbed samples are taken and identified on site. If laboratory work is performed after the fieldwork, the samples will be classified and/or identified in additional detail in the laboratory. In case of differences between the field and laboratory identification, the laboratory identification is leading.

The description of the soil is carried out in accordance with NEN-EN-ISO-14688-1 or NEN 5104.

Groundwater levels

The (ground)water level(s) are a single measurement and intended as exploratory data. The groundwater level may fluctuate over time under influence of the weather and the seasons.

Quality assurance

All work is performed in accordance with the management system of Fugro NL Land B.V. that complies with the ISO 9001:2015 and SCC ** 2008/5.1. The calibration sheet(s) of used cone(s) can be acquired upon request.

Electrical cone penetration testing

Measurement

In 1965 Fugro developed an electrical cone penetrometer, of which the shape and dimensions formed the basis for the present cone penetrometer designs. During penetration measurements of the cone penetrometer: cone resistance, sleeve friction and inclination are recorded simultaneously. Since February 2013 the new standard NEN-EN-ISO 22476-1:2012/C1:2013 applies instead of the old Dutch NEN 5140. NEN-EN-ISO 22476-1:2012 deals with the accuracy requirements of measurement, the execution of and reporting on electrical cone and piezo cone penetration tests as part of geotechnical investigation and testing according to EN 1997 1 and EN 1997 2.

When performing a penetrometer test in accordance with NEN-EN-ISO 22476-1: 2012 / C1:2013, the cone penetration resistance will be measured, while pushing the cone penetrometer with a nominal apex angle of 60° and a cross-sectional area of 1,000 mm² with uniform penetration rate of about 20 mm/s (approximately 1 inch per second) into the ground. Hence, a 20 m CPT can be completed (start to finish) in about 30 minutes. The friction sleeve is situated directly above the cone tip with a nominal surface area of 15,000 mm² to allow measurement of the sleeve friction. The force on the cone (cone penetration resistance in MPa) and the local friction along the friction jacket (local sleeve friction in MPa) are continuously measured by strain gauges in the cone. According to NEN-EN-ISO 22476-1 no correction factors have to be applied when the base area of the cone varies between 5 (mini-cone) and 20 cm² (large cone). Fugro uses commonly a standard cone with a base area of 15 cm² and a friction sleeve area of 200 cm², which are more robust and can be applied in dense soil conditions.

The measurement signals are sent directly to an electrical measurement unit, and stored along with depth and time. Final processing is carried out in the office. Continuous recording of measured cone and sleeve friction is an accurate method to determine the stratification of the soil layers and resistance obtained from the soil. The cone penetrometer also includes an electrical inclinometer for measuring of deviations from the vertical. Depth measurements are usually corrected for inclination.

Interpretation of the cone penetration test with sleeve friction

With measurement of the cone penetration resistance q_c and the sleeve friction f_s it is possible to determine the friction ratio R_f . The friction ratio R_f is expressed as a percentage of the sleeve friction f_s , over the cone penetration resistance, q_c , at the same depth ($R_f = f_s/q_c$).

The friction ratio R_f together with the cone penetration resistance q_c gives a good indication of the soil stratigraphy and soil type below the ground water table. It is noted that the above interpretation applies to cylindrical cone penetrometers only and to soils permanently below the ground water table. The interpretation is indicative and should be verified, for example by correlation with boreholes or other locally available information as geology and/or experience.

Soil type	Friction ration in %	Soil type	Friction ration in %
Gravel, coarse sand	0.2 – 0.6	Clay; organic clay	3.0 – 5.0
Sand	0.6 – 1.2	Glacial clay; overconsolidated	5.0 – 7.0
Silt, loam, löss	1.2 – 4.0	Peat	5.0 – 10.0

In disturbed soil and soil above ground water table this correlation is less/not suitable.

Other types of penetrometers

In addition to the measurement of cone penetration resistance and sleeve friction, it is possible to carry out (combinations of) other measurements. In the table below some possibilities are indicated. Detailed information can be provided on request.

Type of sensor	Results	Application
Pore pressure u1 or u2	Pore pressure at the tip (u1) Pore pressure behind the tip (u2)	Detection low permeability soil layer indication of the piezometric head interpretation of statigraphy and geotechnical soil behaviour.
Magnetometer	Magnetic field in 3 orthogonal directions (X, Y,Z)	Investigation of unexploded shell, underground obstacles (steel pipes, ground anchors), pile tip elevation, battered piles, bottom sheet pile.
Electrical conductivity	Electrical conductivity of the ground and ground water	Identification water quality, investigation of fresh/brackish water boundary, dispersion of pollutants
Temperature	Measurement of temperature on different depths	Measurement of thermal conductivity of soil measurement of in-situ temperature gradient with depth.
Seismic	Dynamic soil parameters on different depths	Determination of low strain stiffness for machine or wind turbine foundations.
Acceleration	Acceleration on different depths	Measurement of vibrations resulting from pile driving or traffic
MIP (membrane interface probe)	Vertical dispersion of vaporized (chlorinated) hydrocarbons	Investigation of weak / sumps layers and/or vaporized (chlorinated) hydrocarbons.
ROST (rapid optical screening tool)	Vertical dispersion of (aromatic) hydrocarbons	Investigation of weak / sumps layers and/or (chlorinated) hydrocarbons.

CPTU Equipment

Fugro piezo-cone penetrometers give a continuous registration of the pore water pressure, the cone penetration resistance and also the sleeve friction. Included in the cone penetrometer is an internal sensor for measuring (pore) pressure either at the face of the cone (u_1) or at the cylindrical extension of the cone tip (u_2), see figure 1. The u_3 location immediately above the friction sleeve is exceptional. Fugro penetrometers are always equipped with a non-directional inclinometer.

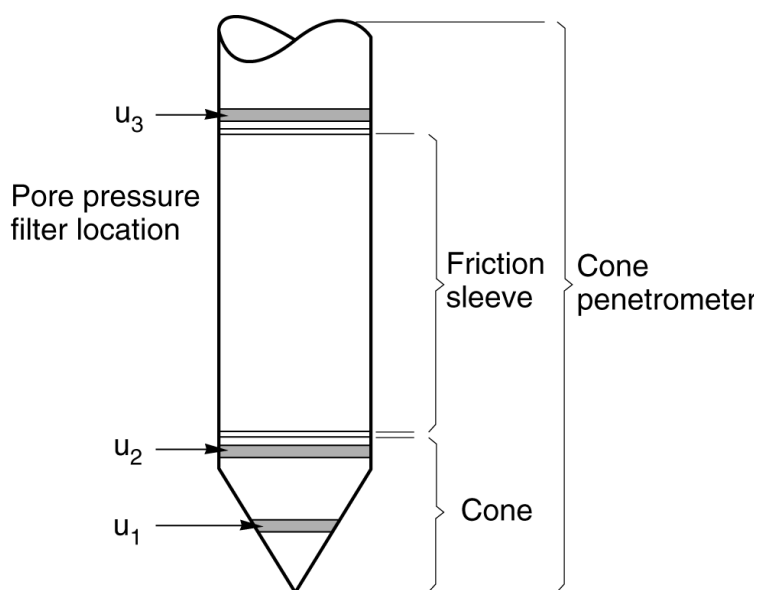


Figure 1: Piezo-cone penetrometer

The pressure sensor is located at the same level as the filter and has direct contact to the pore water. The construction of the penetrometer is such that no air is entrapped, that could possibly disturb the response of the pressure sensor. The pressure sensor used requires a minimum flow of water and provides a high output. Only a volume of 0.2 mm^3 is necessary for full scale output. The measuring range is chosen on basis of the expected excess pore water pressures during penetration. In stiff clays these values may exceed 3 MPa (300 m of water) or higher.

Procedure of the CPTU

The entire measuring system should be fully de-aired and filled with non-compressible liquid in order to measure pore water pressures correctly. Loss of saturation by leakage of liquid may occur when penetrating unsaturated zones above the groundwater table. For that reason, a high viscosity liquid is used for saturation of the filter (either ceramic or stainless steel) and the cone. Additionally, the cone is fitted with a rubber membrane.

In case of a relatively high ground water table the CPTU is executed preferably from a predrilled bore hole to avoid loss of saturation and problems with the rubber membrane. The (excess) pore water pressure and the cone penetration resistance are recorded continuously during cone penetration.

Interpretation of the CPTU

Results of electric PCPTs include cone penetration resistance (q_c), local sleeve friction (f_s), friction ratio (R_f), measured pore water pressure (u_1 in the cone or u_2 at the cylindrical extension of the cone) and the pore pressure ratio (B_q). With respect to the interpretation of the soil profile the measured pore water pressures during cone penetration provide important additional information in geotechnical and geohydrological point of view. Combining the measured cone penetration resistance and pore water pressure and, preferably, the sleeve friction, yields optimal use of the CPT methodology. Furthermore, it allows for efficient planning of additional soil investigation.

The excess pore water pressure (increase in pore water pressure due to penetration of the cone) plays an important role when interpreting CPTU results.

The (excess) pore water pressures during cone penetration allow for detection of thin cohesive layers interbedded in a sand layer or thin sand layers interbedded in a clay layer that cannot be detected from the friction ratio because of averaging the friction resistance over the height of the friction sleeve. These layers may have a large influence on the settlement of foundations and on the (vertical) permeability of the soil.

The piezo-cone, in particular with u_1 -measuring, provides additional information to be able to distinguish thin bedded soil layers from homogeneous soil layers. This refers to both sand and clay layers. In these soils friction ratio and cone penetration resistance alone often provides insufficient information. For this purpose, measuring u_1 is more suitable for identification of soils than measuring with u_2 .

Pore pressure ratio B_q

The pore pressure ratio B_q allows for a more reliable soil classification. This ratio is defined as the excess pore water pressure divided by the net cone penetration resistance q_{net} . Parameter q_{net} is the measured cone penetration resistance q_c including corrections for hydrostatic and transient pore pressures, in-situ stress, and cone construction, in formula:

$$B_q = \beta \cdot (u_1 - u_0/q_{net}) \text{ or } B_q = (u_2 - u_0)/q_{net}$$

Equation 1

where:

- β = adjustment factor for the ratio of pore pressure at the cylindrical extension above the base of the cone (u_2) to pore pressure on the cone face (u_1). Default value is 0.8 as for normally consolidated clay, see table below;
- q_{net} = $q_t - \sigma_{v0}$ = net cone penetration resistance;
- q_t = $q_c + (1-a) \cdot \{\beta \cdot (u_1 - u_0) + u_0\}$ filter at the face of the cone;
- = $q_c + (1-a) \cdot u_2$ filter at the cylindrical extension of the cone;
- σ_{v0} = in-situ vertical stress at the cone base, relative to ground surface or seabed. This is a calculated value, using bulk density of 14 kN/m³ and ground water table at 1 m below ground surface (estimated averages) for standard onshore processing;
- a = net area ratio of the cross sectional steel area (at the gap between cone and friction sleeve) to the cone base area.
- u_1 = pore pressure at the face of the cone, relative to the reference level of the test;
- u_2 = pore pressure at the cylindrical extension above the base of the cone, relative to the reference level of the test;
- u_0 = hydrostatic pore pressure at the cone, relative to the phreatic surface. This is a calculated value using a ground water table at 1 m below ground surface as default value.

The table below gives β -values for various types of soil.

Soil type	β -factor
Clay, normally consolidated	0.6 – 0.8
Clay, slightly over consolidated	0.5 – 0.7
Clay, heavily over consolidated	0 ¹ – 0.3
Silt, loose, compressible	0.5 – 0.6
Silt, dense, dilative	0 ¹ – 0.2
Sand, silty, loose	0.2 – 0.4
¹ Occasionally, negative pore pressures are measured at the cylindrical extension above the base of the cone. These values provide only information on the soil behaviour and hardly on the permeability.	

Pore pressure dissipation test

A penetration interruption may be used to perform a pore pressure dissipation test. With this test the dissipation of the excess pore water pressure as a function of time is measured. The penetration is continued after completion of the dissipation test.

In permeable soils the dissipation test is used to provide information on the hydrostatic pore water pressure and the piezometric head. Due to measuring uncertainties the accuracy is limited. More accurate evaluation is possible by executing a number of dissipation tests in the same soil layer and calculating the average value. From experience the inaccuracy is estimated at 0.5 m.

Recording the water table in standpipes during an extended period of time reveals more accurate values of piezometric head and its fluctuations.

In low permeable, cohesive soils the dissipation test is used to provide information on the coefficient of consolidation and on the coefficient of permeability in vertical direction. In this case, the duration of the dissipation test needs to be long enough to allow for a decrease in excess pore water pressure of at least 50%. In average a dissipation test in sand takes about 5 to 10 minutes to reach a constant value. In cohesive layers this process takes, depending on the consistency, usually 30 to 45 minutes or more. From calculations and qualitative comparisons of measuring results, information is obtained on the consolidation behavior of the soil.

In clayey soils the dissipation test is not suitable to determine the hydrostatic pore water pressure because of the long time to reach 100% dissipation and the inaccuracy.

Classification according to EN-ISO 22476-1

Before starting the execution of SPT-tests the required application class as described in the standard EN-ISO 22476-1 should be determined in order to select the appropriate equipment. The application class depends on the soil conditions and allowable minimum accuracy of the measured parameters and relates to the accuracy of the measured parameters. (Note: Not to the accuracy of the cone penetrometer instrument).

Application classes according to NEN-EN-ISO 22476-1:2012

Application class	Test type	Measured parameter	Allowable minimum accuracy ^a	Maximum length between measurements	Suggested use	
					Soil type ^b	Interpretation ^c
1	TE2	Cone resistance, q _c Sleeve friction, f _s Pore pressure, u Inclination, i Penetration depth, l	35 kPa of 5 % 5 kPa of 10 % 10kPa of 2 % 2° 0.1 m of 1%	20 mm	A	G, H
2	TE1 TE2	Cone resistance, q _c Sleeve friction, f _s Pore pressure, u Inclination, i Penetration depth, l	100 kPa of 5 % 15 kPa of 15 % 25 kPa of 3 % 2° 0.1 m of 1 %	20 mm	A B C D	G, H* G, H G, H G, H
3	TE1 TE2	Cone resistance, q _c Sleeve friction, f _s Pore pressure, u Inclination, i Penetration depth, l	200 kPa of 5 % 25 kPa of 15 % 50 kPa of 5 % 5° 0.2 m of 2 %	50 mm	A B C D	G G, H* G, H G, H
4	TE1	Cone resistance, q _c Sleeve friction, f _s Penetration depth, l	500 kPa of 5 % 50 kPa of 20 % 0.2 m of 1 %	50 mm	A B C D	G* G* G* G*
For extremely soft soils, even higher demands on the accuracy can be needed.						
a	The allowable minimum accuracy of the measured parameter is the larger value of the two quoted. The relative or % accuracy applies to the measurement rather than the measuring range or capacity.					
b	According to ISO 14688-2:					
	A	homogeneously bedded soils existing of very weak tot stiff clay (and silt) (typically q _c < 3 MPa)				
	B	mixed bedded soils with weak to stiff clays (q _c ≤ 3 MPa) and moderate to dense sand (typically 5 MPa ≤ q _c ≤ 10 MPa)				
	C	mixed bedded soils with stiff clays (typically 1.5 MPa ≤ q _c < 3 MPa) and very dense sand (typically q _c > 20 MPa)				
	D	very stiff to hard clays (typically q _c ≥ 3 MPa) and very dense to gravelly soil (q _c ≥ 20 MPa)				
c	G	profiling and material identification with low associated uncertainty level				
	G*	indicative profiling and material identification with high associated uncertainty level				
	H	interpretation in terms of design with low associated uncertainty level				
	H*	indicative interpretation in terms of design with high associated uncertainty level				
d	Pore pressure can only be measured if TE2 is used.					

For projects where the parameters are derived from table 2.b. NEN 9997-1, a higher accuracy is desired. However it is almost impossible to meet/fulfil the requirements for class 1 for soil profiles with both very weak soils and very dense sands with high cone resistance as shown in the table above.

Experiences have shown that Fugro's measurement for standard cone penetration testing is very accurate by using digital cones, strict quality control and regular calibrations.

In practice it is found that Fugro's standard penetration testing results for the greater part (> 95%) are within in the range for application Class 2.

Application class 1 penetration tests can only be performed by special sensitive cones with a limited range of measurement, a clay soil profile with $q_c < 3$ MPa and procedures to eliminate temperature effects as much as possible.

In soil profiles with both very weak soil layers as very dense sand layers, the highest measurement accuracy of Class 1 can only be approximated by additional measurements and procedures.


































Application class 2 penetration tests can only be used for soil profiles with both very weak soil layers and very dense sand layers with the use of digital cones and regular calibrations, additional execution measurements and quality control.

Application class 1 is not feasible in these types of soils.

The only practical indication of the achieved penetration class is checking the calibrations and zero-points between the start and end of the CPT.

Occasionally, the ground level is not measured relative to a reference point. These CPTs are not meeting the standard EN-ISO 22476-1.

Legend site investigation tests

Borings / monitoring wells		Cone Penetration Tests (CPT)	
	Hand auger boring not performed		CPT with sleeve friction measurement not performed
	Hand auger boring (BH)		CPT with sleeve friction measurement
	Hand auger boring with monitoring well		CPT not performed
	Hand auger boring with monitoring well, shallow and deep well screen		CPT
	Mechanical boring not performed		DPSH/SPT
	Mechanical boring (BH)		Manual/mechanical CPT
	Mechanical boring with monitoring well		Penetration test with push-in groundwater sampling probe not performed
	Mechanical boring with monitoring well, shallow and deep well screen		Penetration test with push-in groundwater sampling probe
	Mechanical boring with monitoring well, shallow, intermediate and deep well screen		Penetration test with ball probe not performed
	Boring third party		Penetration test with ball probe
	Boring third party with monitoring well		Electrical piezometer not performed
	Push-in monitoring well not performed		Electrical piezometer
	Push-in monitoring well, small diameter standpipe		CPT performed by third party
Other symbols			CPT with sleeve friction measurement performed by third party
	Measuring point		Inclinometer casing not installed
	Height		Inclinometer casing installed
	Electrical resistivity test		Valprobe
Type of test		Additional measurements	
SPT	Standard Penetration Test	HPT	Hydraulic Profiling Tool
CPT	Cone Penetration Test	U	Pore pressure
DPSH	Dynamic Probe Test, Super Heavy	M	Magnetic field strength
		E	Electrical conductivity
		S	Shear wave velocity (Seismic Down Hole Test)
		T	Temperature

Monitoring well

