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QUALITY IMPROVEMENT BY APPLICATION OF A REVISED STANDARD – FEASIBILITY STUDIES ON 2500 SOUNDINGS

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Abstract. CPT is a geotechnical investigation method that, depending on the geology, has been proved to be an essential tool to establish the Geotechnical Design Model. However, doubt has been raised about the quality of the data. Hence, the feasibility to use data from CPT to evaluate reliable parameters for the Geotechnical Design Model also needs investigation. Currently, the international standard EN ISO 22476-1 [1] is being revised, and the revised version will be published in winter 2022. It will include new requirements related to quality parameters such as zero stability, zero-shift, temperature, and pore pressure response. In addition, there will be updated requirements related to the calibration of the cone penetrometer. All this is to improve the quality of the CPT data, thereby increasing the reliability of parameters evaluated from CPT. This paper presents a feasibility study. It compares the zero-shift variation depending on the type of cone penetrometer, the operator, and the geology. More than 2 500 soundings from Sweden, Norway and Finland were the basis for this comparison. The results indicate that the data quality is strongly linked to the type of cone penetrometer, its calibration, and the management of the cone penetrometer in the field.

Keywords: CPT, quality, zero-shift.

1. Introduction

CPT (Cone Penetration Test) is a geotechnical investigation method that, depending on the geology, has proved to be an essential tool to establish the Geotechnical Design Model. However, doubt has been raised about the quality of the data and the investigation methods applicability in different types of geological conditions. Thus, the feasibility to use data from CPT to evaluate reliable parameters for the Geotechnical Design Model has been questioned.

Currently, the CPT-standard EN ISO 22476-1 [2] is under revision and the aim is to ensure high-quality data if the soundings are performed according to the standard. This paper gives an overview of some main revisions in the standard and presents some of the background material for the revision. The analyses in this paper indicate some of the key parameters for the user to consider if reliable data from the CPT is to be obtained.

The history of CPT is illustrated in Figure 1. It started, as in all sounding methods, as a handheld one that was further developed to include loading and then in the 1970s the first complete electric investigation equipment was developed. Today, there are multiple different ground investigation rigs carrying the CPT equipment, from full-scale field labs to multi-purpose hydraulic field rigs.

The applicability of the CPT in different ground conditions depends on the maximum resistance of the cone penetrometer utilized. For clay till and firm sand, a cone penetrometer with higher cone resistance should be used, while for clay, silt and fine sand a cone penetrometer with lower maximum cone resistance is preferred. CPT can be used in most ground conditions including organic soils as long as there are no boulders or extremely stiff layers to penetrate. The latter might cause damage to the cone penetrometer.

2. Revised version of EN ISO 22476-1

The first version of EN ISO 22476-1 Geotechnical investigation and testing – Field testing – Electrical cone and the piezocone penetration test, was published in 2012. A need for clarifications and improvements was identified in relation to several issues including confidence levels, dimensions of the cone penetrometer and calibration. Hence, the process of revision was initiated, and the aim is that the revised EN ISO 22476-1 will be published in late 2022 or early 2023.

2.1. Confidence levels

In the 2012 version of EN ISO 22476-1 information on confidence levels with requirements in the field and the information needed for calibration of the cone penetrometer in the lab is mixed together in one table. This causes unnecessary confusion for the user. Therefore, the table has been divided into three different tables in the revised version of the CPT standard.

The three tables that are used in the revised standard are illustrated in Figures 2, 3, 4.

Depending on the site conditions different test categories will be applied and hence the maximum cone penetrometer resistance will be in one of the three application classes shown in Figure 2 – Table A1. The

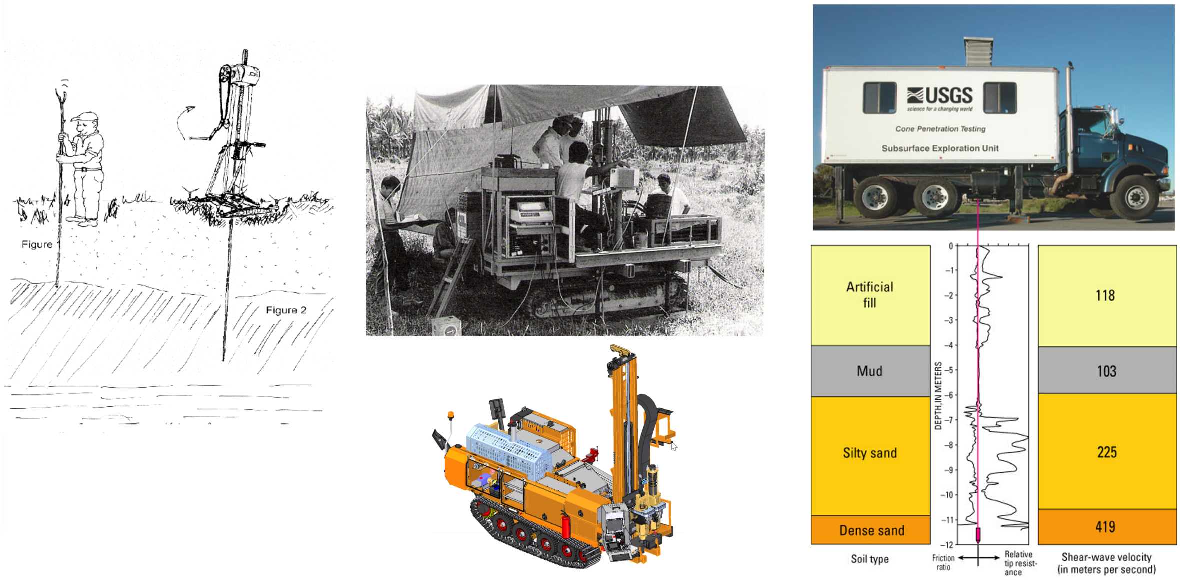


Figure 1. Illustration of the history of CPT.

Table A.1 — Confidence levels of measurements for the characterisation of geotechnical properties depending on the cone type and test category

<table>
<tr><th rowspan="2">Application</th><th rowspan="2">Confidence level</th><th colspan="4">Cone penetrometer class</th></tr>
<tr><th>0</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td rowspan="3">Characterisations of geotechnical proprieties of soil deposits with $q_{c;max} \leq 1$ MPa</td><td>High</td><td>A</td><td></td><td></td><td></td></tr>
<tr><td>Medium</td><td colspan="2">B</td><td></td><td></td></tr>
<tr><td>Low</td><td colspan="3">C</td><td></td></tr>
<tr><td rowspan="3">Characterisations of geotechnical proprieties of soil deposits with 1 MPa < $q_{c;max} \leq 3$ MPa</td><td>High</td><td colspan="2">B</td><td></td><td></td></tr>
<tr><td>Medium</td><td colspan="3">C</td><td></td></tr>
<tr><td>Low</td><td colspan="4">D</td></tr>
<tr><td rowspan="2">Characterisations of geotechnical proprieties of soil deposits with $q_{c;max} > 3$ MPa</td><td>High</td><td rowspan="2">Not recommended</td><td colspan="2">B and C</td><td></td></tr>
<tr><td>Medium</td><td colspan="3">D</td></tr>
<tr><td colspan="6">NOTE A, B, C and D are the test categories according to Table 3.</td></tr>
</table>

Figure 2. New tables in EN ISO 22476-9 – Confidence levels of measurements for the characterisation of geotechnical properties depending on the cone type and test category.

confidence level of the data (high, medium, low) in each application class depends on the test category (field) and cone penetrometer class (laboratory calibration).

The requirement on the cone penetrometer that shall be shown in laboratory calibration for the different penetrometer classes is given in Figure 3 – Table 2. This includes measurement uncertainty, temperature stability and bending influence.

In Figure 4 – Table 3 the requirements to achieve specific test categories in the field are given. There are requirements on the cone penetrometer to fulfil a given cone penetrometer class according to the latest calibration documentation. In addition to that, at every sounding, checks should be made that the zero readings (before and after soundings) and the variation in output stability fulfil the given requirements. A cone penetrometer calibrated for cone penetrometer class 1, might not be sufficient to achieve test category B due to its performance in the field.

The accuracy of the cone penetrometer is important for the interpretation of the results. It can be shown that uncertainty of the cone resistance of 15 kPa, results in an uncertainty in the measured undrained shear strength of 1 kPa. Likewise, the uncertainty of the pore pressure, u_2, of 75 kPa, results in an uncertainty in the measured undrained shear strength of 1 kPa. Therefore, the pore pressure system must be fully saturated, or errors in pore pressure measurement, u_2, up to 500–1 000 kPa may arise, depending on the geological properties. This is an error that may introduce significant uncertainty.

2.2. Calibration

In the version from the 2012 standard, it was stated simply that the calibration will be performed. However, no detailed requirements on the calibration were included. Therefore, it was up to each provider to

Table 2 — Classification of cone penetrometers under laboratory conditions

Cone penetrometer class	Measurand	Allowable maximum measurement uncertainty[a]	Ambient temperature stability[b]	Transient temperature stability[c]	Bending influence[d]
		$U_{qc:class}$ $U_{fs:class}$ $U_{u:class}$	Δa_{qc} or Δa_{qcc} $\Delta a_{fs,}$ or Δa_{fsc} Δa_{u} or Δa_{uc}	Δt_{qc} or Δt_{qcc} Δt_{fs} or Δt_{fsc} Δt or Δt_{uc}	Δb_{qc} Δb_{fs} Δb_{u}
0	Cone resistance	15 kPa or 0,5 %	0,5 kPa/°C	2 kPa/°C	0,3 kPa/N
	Sleeve friction	5 kPa or 1 %	0,1 kPa/°C	0,5 kPa/°C	0,1 kPa/N
	Pore pressure	3 kPa or 0,5 %	0,1 kPa/°C	0,5 kPa/°C	0,05 kPa/N
1	Cone resistance	35 kPa or 1 %	2 kPa/°C	10 kPa/°C	0,3 kPa/N
	Sleeve friction	5 kPa or 1 %	0,1 kPa/°C	0,5 kPa/°C	0,1 kPa/N
	Pore pressure	10 kPa or 0,5 %	0,1 kPa/°C	0,5 kPa/°C	0,05 kPa/N
2	Cone resistance	100 kPa or 2 %	10 kPa/°C	50 kPa/°C	1 kPa/N
	Sleeve friction	15 kPa or 2 %	0,5 kPa/°C	2,5 kPa/°C	0,5 kPa/N
	Pore pressure[e]	25 kPa or 1 %	1 kPa/°C	2,5 kPa/°C	0,1 kPa/N
3	Cone resistance	200 kPa or 5 %	10 kPa/°C	100 kPa/°C	2 kPa/N
	Sleeve friction	25 kPa or 10 %	1 kPa/°C	5 kPa/°C	1 kPa/N
	Pore pressure[e]	50 kPa or 5 %	1 kPa/°C	5 kPa/°C	0,2 kPa/N

[a] The maximum allowable uncertainty of the measured parameter is the larger value of the two quoted. The relative uncertainty applies to the measured value and not the measuring range.

[b] The values of ambient temperature stability represents the maximum allowable for each class.

[c] The values of transient temperature stability represents the maximum allowable for each class.

[d] The values of bending influence represents the maximum allowable for each class.

[e] Pore pressure applies only to CPTU.

Figure 3. New tables in EN ISO 22476-9 – Classification of cone penetrometers under laboratory conditions.

Table 3 — Test categories of CPT/CPTU

Test category	Cone penetrometer class	Reference reading checks		
		Parameter	Maximum allowable difference of reference values before and after test	Maximum variation in output stability
A	0	Cone resistance	15 kPa	1 kPa
		Sleeve friction	5 kPa	0,5 kPa
		Pore pressure	3 kPa	0,5 kPa
B	0, 1	Cone resistance	35 kPa	5 kPa
		Sleeve friction	5 kPa	1,5 kPa
		Pore pressure	10 kPa	3 kPa
C	0, 1, 2	Cone resistance	100 kPa	11 kPa
		Sleeve friction	15 kPa	3 kPa
		Pore pressure[a]	25 kPa	8 kPa
D	0, 1, 2, 3	Cone resistance	200 kPa	33 kPa
		Sleeve friction	25 kPa	5 kPa
		Pore pressure[a]	50 kPa	16 kPa

[a] Pore pressure applies only to CPTU.

Figure 4. New tables in EN ISO 22476-9 – Test categories of CPT/CPTU.

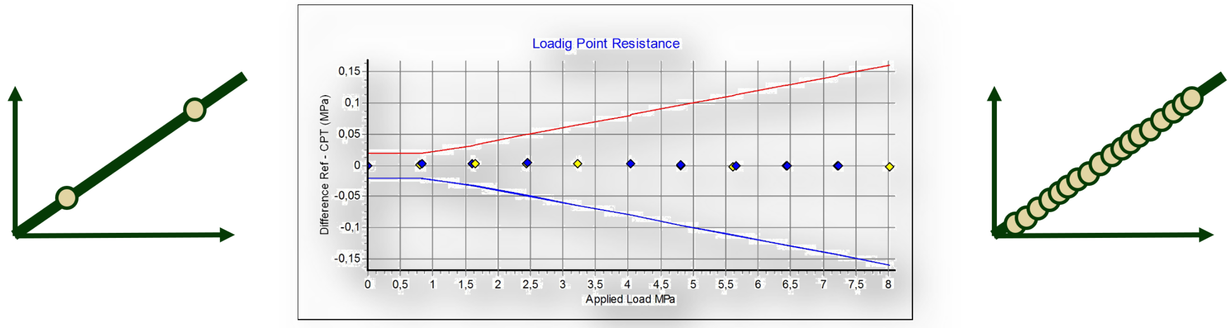


Figure 5. Illustration of the difference between calibration requirements between EN ISO 22476-1:2012 and ISO/FDIS 22476-1:202.

# 2369	qc	fs	U
A	44%	98%	56%
B	27%	0%	22%
C	18%	1%	12%
D	5%	0%	5%
E	5%	0%	5%

a) all 2500 soundings

# 1289	qc	fs	U
A	48%	99%	58%
B	26%	0%	22%
C	16%	1%	12%
D	5%	0%	4%
E	5%	0%	4%

b) cones with a $q_{c,max}$< 2MPa

Figure 6. Results of achieved test category.

perform the calibration based on their best practice. The calibration should be performed every six months.

In the revised version the interval has been extended to every twelfth month and there is a requirement that the calibration should be performed in a laboratory that fulfils the requirements of ISO/IEC 17025. The number of calibration points has been defined as 100 points in three directions of the cone penetrometer. The work needed to perform a complete calibration of the cone penetrometer is significantly extended.

Figure 5 illustrates the difference in principle between calibration according to the 2012 and 2022 versions.

3. Assessment of the 2500 soundings

3.1. Background

This assessment of the quality of CPT is based on 2500 soundings, collected during 2019 and 2020 in Norway and Sweden. Thirteen different ground investigation contractors were represented and more than 100 individual field engineers. Two different manufacturers (Geotech and Envi) provided 134 CPT-cones. The raw data were collected and, important for a simple database, involved the following information:

- Cone penetrometer#,
- operator,
- date,
- maximum depth,
- zero-readings before,
- zero-readings afterwards,
- temperature (start/min/max/end if recorded),
- Q_c-max,
- F_s-max,
- U-max.

The analyses focus on the following comparisons.

1) Achieved field performance test class considering all cone penetrometers and whether only those with a law maximum $q_{c,max}$ are used,
2) differences between different set-ups of the cone penetrometer (manufacturers),
3) the importance of long-term stability,
4) difference in zero-readings.

3.2. Achieved test category

The achieved test category was determined for all soundings (see Figure 6a). If only the cone penetrometers with a maximum $q_{c,max} < 2$ MPa are included, the results are slightly different (see Figure 6b), but this difference is not significant.

The results indicate that 98 % of the soundings fulfil the requirement of category B for friction sleeve, 73 % for the cone and 78 % for pore pressure.

The friction sleeve, which seldom is used for the evaluation of ground properties, seems easier to obtain with high confidence than cone and pore pressure. It should be recognized that one-fourth of the soundings did not fulfil the requirement of test category B.

# 1824	qc	fs	U
A	51%	97%	61%
B	29%	0%	19%
C	14%	2%	9%
D	2%	0%	5%
E	4%	0%	6%

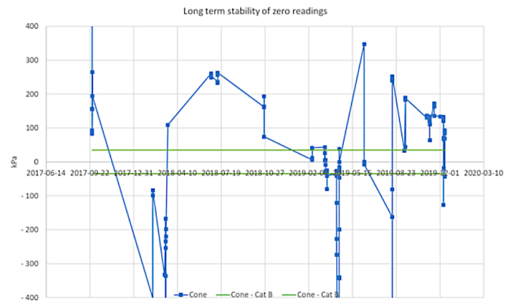
a) manufacturer A 1184 soundings

# 519	qc	fs	U
A	23%	99%	37%
B	21%	0%	32%
C	32%	0%	23%
D	14%	0%	5%
E	10%	0%	4%

b) manufacturer B 519 soundings

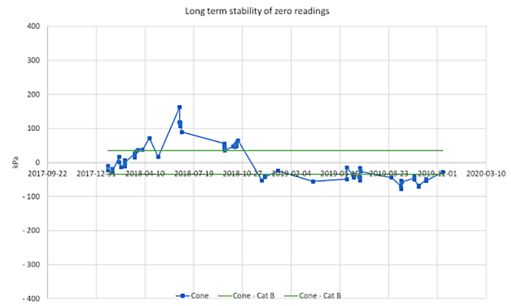
Figure 7. Results of achieved test category for different manufacturers.

# 107	qc	fs	U
A	34%	79%	33%
B	21%	0%	22%
C	17%	13%	19%
D	12%	4%	12%
E	16%	4%	14%



a) cone penetrometer #4996

# 70	qc	fs	U
A	77%	100%	70%
B	21%	0%	26%
C	1%	0%	3%
D	0%	0%	1%
E	0%	0%	0%



b) cone penetrometer #4315

Figure 8. Results of long-term stability.

3.3. Different set-ups of the cone penetrometer (manufacturers)

For manufacturer A 1184 soundings were available and for manufacturer B 519 soundings were. The results presented in Figure 7, show that for manufacturer A the test category B is achieved for about 80 % of the soundings, considering cone and pore pressure. For manufacturer B the corresponding values are 44 and 69 % for cone and pore pressure.

Even though both manufacturers follow the requirement of the standard in relation to dimensions, there are differences in how the cone penetrometer is assembled that give differences in confidence in the results.

3.4. Long-term stability

Two identical cone penetrometers from the same manufacturer that have been calibrated, might give a significantly different confidence in the data. In Figure 8 two cone penetrometers are compared. For cone penetrometer #4996 there are 107 soundings available and for cone penetrometer #4315 there are 70 soundings available. For both cone penetrometers, the long-term stability of zero readings for qc is also presented.

For cone penetrometer #4996 test category B is only achieved in 55 % of the soundings with regards to cone and pore pressure. In addition, the zero readings indicate very high variation. For cone penetrometer #4315 test category B is achieved in 98 % and 96 % of the soundings for cone and pore pressure. The zero readings show low variation.

This check of the field results is essential to determine if the data obtained is reliable to use in the Geotechnical Ground Model. In this case, the results from cone penetrometer #4996 do not have a sufficient confidence.

3.5. Concluding remarks

The following list indicates some of the items that will influence the achieved test category and confidence level:

- Each cone penetrometer is an individual one and therefore it is necessary to get information on calibration and field reference readings checks for the individual cone penetrometer with regards to:
  - ▹ Long-term stability of the zero readings before
  - ▹ Difference in zero readings (before – after)
- The result depends on the cone penetrometers' internal structure/sensors (Manufacturer) and model.
- Performance and handling (human error).
- Temperature (before vs. during sounding).

4. Recommendations

The revised standard will give the engineers the tools to ensure that the data obtained from the field have sufficient confidence to be included in the Geotechnical

Design Model. However, to obtain quality there has to be teamwork between the field engineer and the engineer evaluating the results.

The field engineer needs to be aware of how the performance of the sounding (including treatment of the cone penetrometer) will influence the test category and confidence. Any deviation from the normal test procedure or other factors that might influence the results should be documented and forwarded to the engineer evaluating the data.

The engineering evaluation of the data needs to know how the test was performed, site conditions and specific information for each sounding. The field reference readings should be evaluated to confirm the quality of the data before the parameters are evaluated.

It is the considered opinion of the authors that CPT testing, if applied with required knowledge and within its limitation, will be an essential tool for the engineer to prepare, select and verify data, based upon CPT, for the Geotechnical Design Model.

Acknowledgements

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References

[1] EN ISO 22476-1:2012 Geotechnical investigation and testing - Field testing - Electrical cone and piezocone penetration test.

[2] ISO/FDIS 22476-:2022 Geotechnical investigation and testing - Field testing - Electrical cone and piezocone penetration test.