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CETANZ best practice for CPT testing in NZ

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ABSTRACT

Cone Penetration Testing (CPT) is commonly used in routine geotechnical investigations throughout NZ. It provides a valuable resource for the geotechnical profession. However, different contractors undertake CPT testing in slightly different ways, and they may not necessarily follow recognised international standards for the test. Consequently, the accuracy of the resulting data may vary, and it is difficult for users to understand what level of uncertainty there may be in the data. To address this issue, an industry group representing the CPT contractors has been formed within the Civil Engineering Testing Association of New Zealand (CETANZ). This group has been working collaboratively on a best practice guideline document to guide contractors to achieve consistent procedures aimed at providing good quality results. The guideline is based on ISO 22476-1, which provides application classes that allow users to recognise a level of certainty in the data. This paper gives an overview of the Best Practice Guideline and how it is intended to incorporate this into practice.

1 INTRODUCTION

CPT is a rapid and cost-effective test that provides a huge amount of data that can be used to profile the ground and be correlated to a wide range of soil parameters in a near continuous manner. The use of CPT in NZ has grown over the last decade and is now a common investigation tool used by geotechnical engineers. There are approximately twenty contractors providing CPT services with rigs located all over the country. The wide availability of CPT and the benefits that the test provides makes this a valuable resource. The use of CPT is likely to further continue and become more relied upon in geotechnical investigations in the future. This is positive as it will lead to improved soil characterisation and ground modelling.

CPT creates a huge amount of data. A typical CPT penetrometer will record data with depth every 10 mm from three sensors (cone resistance, q_c, sleeve friction, f_s and porewater pressure, u_2). This relates to 300 data points every metre, or 3,000 for a typical 10 m deep test. The data from a CPT is usually provided to the geotechnical engineer as a table, e.g. excel spreadsheet, containing thousands of numbers. The geotechnical engineer may then input this data into a computer program, such as CPeT-IT, which processes and interprets the data into graphs of various soil parameters with depth. They may then use this information in design. In this process, the geotechnical engineer may ask themselves; how reliable is the data that they got from their CPT contractor? That is, what is the level of uncertainty in the data and can derived correlations to soil parameters be relied upon in design? These are good questions that both the CPT contractor and the engineer should ask themselves and have an understanding about.

In general, CPT contractors operate in the manner that they were trained by the manufacturers of the equipment, or by in-house procedures developed over time. Although these procedures may follow along the lines of an international standard, CPT contractors generally do not strictly follow standards in the same way as, say, a laboratory technician would. Consequently, there is an inconsistency across the industry in the way the testing is carried out. This is a worldwide issue, not just a NZ one. The basic operation for conducting a CPT is straight forward. But it is the details of the test that may contribute to uncertainties in the results.

To address this issue for NZ, the CPT contractors have set up an industry group under the Civil Engineering Testing Association of New Zealand (CETANZ). The purpose of this CPT group is to establish a standardised practice for CPT operation so there is consistency in procedures and accuracy across the industry. At the time of writing this paper, all known CPT contractors in NZ have joined this CPT Group. This shows a level of commitment and desire for improving accuracy across the industry.

It has become common in NZ for clients procuring CPT services to specify the American international standard, ASTM D5778-12. The ASTM standard provides good procedural methodologies for conducting CPTs. There are no strong performance criteria, however, to allow users to understand the level of uncertainty that there may be in the test results. There is a criterion for checking baseline drift during a test, but the acceptance criteria are wide, meaning that significant errors in the test may not be detected or understood.

The CETANZ CPT Group have agreed to follow the ISO standard, ISO 22476-1: 2012, in preference to the ASTM standard. The ISO standard is similar to the ASTM standard in the basic operation of the test but classifies the test results into ‘application classes’ depending on the error in the test and the ground conditions. The application classes (classes 1 to 4) allow the user of the data to understand the level of uncertainty in the test and how reliable the test data is for profiling and soil parameter interpretation. The application class concept requires the CPT Operator to understand the level of error involved in the test. It also requires the geotechnical engineer to understand the implications of a particular application class for the application that the test is to be used for. The application class is also a useful criterion to include in specifications for procurement of CPT services.

The application class system essentially makes the ISO standard a performance-based standard. It requires the CPT contractor to quantify all possible sources of error. This is difficult to do as there are many possible sources of error, of which many are not easily quantifiable. The ISO standard does provide some guidance as to where the uncertainties may be, but how to measure the errors and what errors should be included is not clear. There are also some ambiguities elsewhere in the standard.

The CETANZ CPT Group is preparing a best practice guideline document to guide CPT operators so that they can apply the ISO standard in a practical and consistent manner. The Best Practice Guidelines are intended to compliment rather than replace the ISO standard. The purpose is to maintain the intent of the standard whilst simplifying the application class concept.

At the time of writing this paper, the Best Practice Guidelines are yet to be finalised. This paper provides an overview of what the Best Practice Guidelines are intended to cover.

2 ISO 22476-1:2012

As discussed above, the ISO standard uses an ‘application class’ system, which is the central concept of the standard. There are four application classes, 1 to 4, distinguished by the degree of accuracy and the soil type that is being tested. Application Class 1 has more stringent accuracy requirements and Class 4, the least. Table 1 below shows information from a table in ISO 22476-1 which sets out the application class criteria.

Table 1: Summary of ISO 22476-1 ‘Table 2 – Application Classes’.

Application Class	Measured Parameter	Allowable minimum accuracy[a]	Soil Type[b]	Interpretation[c]
1	Cone resistance, q_c	35 kPa or 5%	A	G, H
	Sleeve friction, f_s	5 kPa or 10%		
	Pore pressure, u_2	10 kPa or 2%		
2	Cone resistance, q_c	100 kPa or 5%	A	G, H*
	Sleeve friction, f_s	15 kPa or 15%	B, C, D	G, H
	Pore pressure, u_2	25 kPa or 3%		
3	Cone resistance, q_c	200 kPa or 5%	A	G
	Sleeve friction, f_s	25 kPa or 15%	B	G, H*
	Pore pressure, u_2	25 kPa or 3%	C, D	G, H
4	Cone resistance, q_c	500 kPa or 5%	A, B, C, D	G*
	Sleeve friction, f_s	50 kPa or 20%		
	Pore pressure, u_2	n/a		

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

[b]*Soil types are:*

A. *homogeneously bedded soils with very soft to stiff clays and silts (typically $q_c < 3$ MPa)*

B. *mixed bedded soils with soft to stiff clays (typically $q_c \leq 3$ MPa) and medium dense sands (typically 5 MPa $\leq q_c <$ 10 MPa)*

C. *mixed bedded soils with stiff clays (typically 1.5 MPa $\leq q_c <$ 3 MPa) and very dense sands (typically $q_c >$ 20 MPa)*

D. *very stiff to hard clays (typically $q_c \geq$ 3 MPa) and very dense coarse soils ($q_c \geq$ 20 MPa)*

[C]*Interpretation:*

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*

The application class system allows the user of the data to understand the degree of uncertainty there may be in the data and how reliable it may be in the interpretation to soil parameters. An error in a test may be insignificant when testing in dense sands whereas the same error in very soft clay may render the data useless. So, it is the error in relation to the measured values and the type of soil being tested that is important.

For example, when testing very soft clay (soil type A), the maximum allowable error for q_c is 35 kPa or 5% of the measured value (whichever is the higher) in order to meet the Application Class 1 criteria. If all parameters (q_c, f_s, u_2) meet their respective Class 1 criteria over the full depth of the sounding, then the test can be assigned as a Class 1 test. Interpretations from that data can then be considered to have a low uncertainty level (G, H). However, if the error exceeds the Class 1 criteria of any parameter, then the test is assigned a lower accuracy class (2, 3 or 4) depending on the magnitude of the error. If the error in q_c is, say, 50 kPa, that would put it into Application Class 2. The data from that CPT can be used for profiling with low uncertainty (G), but design interpretations would be at high uncertainty (H*). If the error is greater and it then falls into Class 3, the data can be used for profiling with low uncertainty (G), but interpretations to soil parameters for design cannot be relied on.

If on the other hand, the soil is stiff clay or dense sand (Soil Type C or D), then the data can be interpreted with low uncertainty (G, H) for Classes 2 and 3. In other words, for these harder soils, a higher error can be accepted whilst still being reliable for design purposes.

A geotechnical engineer procuring the services of a CPT contractor could specify a target application class depending on the anticipated ground conditions. There would be no point in specifying an Application Class 1 test in dense sand because a Class 2 or 3 test would still provide adequate accuracy for design purposes. Class 1 is only intended for very soft to soft soils. Class 1 is harder to achieve and requires additional procedures, which is likely to make testing to Class 1 more expensive. The soil type needs to be considered when specifying CPTs in the procurement stage and when interpreting the test results. CPT contractors in NZ have good quality modern piezocone penetrometers (CPTU) and Class 2 is a reasonably achievable target in most situations. Geotechnical engineers, however, should be open to accepting Class 3 tests in very stiff clays or dense sands. Class 4 tests are unlikely to be useful and so should generally not be specified. Any tests that show Class 4 accuracy are likely to be erroneous and should not be relied upon.

Some of the problems associated with the Application Class system of ISO 22476-1 along with how the Best Practice Guidelines will deal with these are discussed below.

3 PROBLEMS WITH APPLICATION CLASS

The application class is a useful concept that allows the user of the data to understand the levels of uncertainty that there may be in a CPT test. However, there are some problems or ambiguities associated with application class in the ISO standard. These are:

- How to determine soil type (A, B, C or D)
- How to determine errors in the test
- How to assign application class (1, 2, 3 or 4)

These issues are discussed below along with how the Best Practice Guideline is intending to deal with these.

3.1 How to determine soil type

There is some ambiguity in the soil types defined in the application class table of ISO 22476-1, summarised above in Table 1. Consequently, some subjectivity is required in selecting the soil type that is appropriate for the site. For example, stiff clay can fall into either A, B or C, with varying associated levels of uncertainty depending on Application Class. In the text of ISO 22476-1, it refers to Application Class 1 as intended only for soft to very soft soils, but in the application class table, Application Class 1 is shown to be applicable to type A soils, which are defined as very soft to stiff clays and silts. Soil types B and C refer only to mixed bedded soils, which makes it unclear as to where homogenously bedded soils will fall. For the sandy soils, there is discontinuity and ambiguity in their q_c criteria. Sandy soils of type B are $q_c < 10$ MPa, whereas for type C they are $q_c > 20$ MPa. Sands with q_c between 10 and 20, presumably fall either way. Very dense sands specified in type D have the same q_c criteria ($q_c > 20$ MPa).

In order to simplify the soil type definitions, a suggested alternative soil type classification is shown in Table 2, below.

Table 2: Proposed soil type definitions.

Soil Type:	**A**	**B**	**C**	**D**
General description	Very soft to firm clays and silts, sensitive soils and peat/organic soils	Stiff to hard clays and loose to medium dense sandy silts or silty sands	Medium dense to dense sands and overconsolidated or weakly cemented soils	Dense to very dense sands and gravels or cemented weak rocks
CPT q_c criteria (MPa)	$q_c < 1$	$1 < q_c < 5$	$5 < q_c < 20$	$q_c > 20$

3.2 How to determine errors in the test

ISO 22476-1 requires that the accuracy of a CPT test should be determined by considering ‘all possible sources of error’. There are many potential sources of error and uncertainties associated with CPT. To quantify all possible sources of error is a near impossibility. The ISO standard provides an annex, which lists some common sources of uncertainties, but provides very little guidance as to how to quantify those uncertainties. Some uncertainties, such as dimensional errors and errors determined from calibration in the laboratory have measurable quantities. Other uncertainties may, in part, be minimised by procedural means, such as cleaning the CPT probe to remove errors due to dirt in the instrument’s gaps. Beyond errors that are measurable or can be minimised by careful procedures, epistemic uncertainty remains, mostly relating to ambient and transient temperature effects.

Peuchen and Terwindt (2014) have undertaken a comprehensive analysis of CPT accuracy, which considers an imaginary analytical CPT probe as a reference for true values. Their detailed study illustrates the near impossibility of determining the uncertainties of the test and the difficulties in utilising the application class system in ISO 22476-1. Lunne, et al. (2014) also discuss the practical challenges of application class. Although that paper is in reference to ISO 19901-8: 2014, it is very similar to ISO 22476-1 with regards to the application class concept. They suggest a pragmatic approach where high quality laboratory calibrations are combined with detailed test records that illustrate good field practices. The uncertainty is assessed from measured values from the calibration and from measurable elements of the test records, along with assessment of the non-quantifiable information in the test records. This is a sensible approach and illustrates the need for good test practices and documentation. There remains, however, some subjectivity in the assessment of uncertainty with regard to qualitative descriptions in the test records.

The approach of the CETANZ Best Practice Guideline is also a pragmatic one; it seeks to:

- quantify uncertainties that are readily measurable
- provide clearer procedures where errors are not easily quantified but can be minimised by good practice
- provide clearer procedures for assigning application class

The intention is to resolve ambiguity and provide a basis for a consistent approach across the industry. Requirements are given for achieving Application Classes 2, 3 and 4 and additional requirements for Class 1.

It is considered that, by following good test procedures and using good quality equipment, Application Class 2 is generally achievable. This sets the benchmark for routine CPT testing. The Best Practice Guidelines will provide guidance over the ISO standard to clarify what it considers to be good practice. First, the cones must meet the calibration accuracy criteria given in ISO 22476-1 for Class 2. If not, they will be degraded to an appropriately corresponding class. Secondly, the test is undertaken in accordance with the specific guidance of the Best Practice Guidelines. On completion of the CPT test, the magnitude of uncertainty is determined by the drift in the before and after zero readings only. This puts the emphasis on good test practices and assumes that, provided these practices are followed, any error (beyond that indicated by the zero drift) will not be significant in terms of the assignment of application class. Although this may not be the case, it is a practical solution that allows routine CPT work to be conducted without the complications of detailed uncertainty analyses.

Application Class 1 is a different story. More stringent procedures are required and there is a need to consider more errors in determination of the accuracy of the test. The accuracy is determined from the zero drift, but other known and measurable errors must also be considered.

In effect, the Best Practice Guidelines provide two procedural and uncertainty assessment criteria; a standard one for Classes 2,3 and 4 (with target of Class 2); and a more stringent one for Class 1.

3.3 How to assign Application Class

Having assessed the accuracy of the test, the application class can be determined by using the Table in ISO 22476-1 (summarised in Table 1, above). ISO 22476-1 requires the whole CPT sounding to be assigned based on the lowest accuracy class determined at any measured depth point and for any of the three parameters (q_c, f_s, u_2). This is conservative as a test may be degraded due to not meeting the accuracy criteria in a thin soft layer whereas the remainder of the sounding does. If one of the parameters (e.g. f_s) does not meet the accuracy criteria, then the whole sounding is degraded even if the other parameters do meet the criteria.

The Best Practice Guidelines will aim to clarify how the application class is applied to the whole sounding. There are two options:

1. Determine application class by comparing the assessed error to the absolute minimum values given in Table 1. For example, if the assessed error for q_c is 90 kPa, that would meet the Class 2 criteria (100 kPa). The same would need to be checked for the other parameters (f_s, u_2) and the lowest accuracy application class selected. This is the simplest method and will result in one defined application class but may not be representative of the accuracy in terms of percentage of measured value throughout the sounding.

2. Determine the application class accuracy as a percentage of the measured value. This will vary with each measuring depth point and so this is best presented in a graphical form.

The paper by Peuchen and Terwindt (2014) illustrate the graphical representation of Application Class with depth for the three main parameters (q_c, f_s and u_2), as shown in Figure 1, below. The resulting Class, which is the worst of each of the three main parameters, is shown on the right-hand graph.

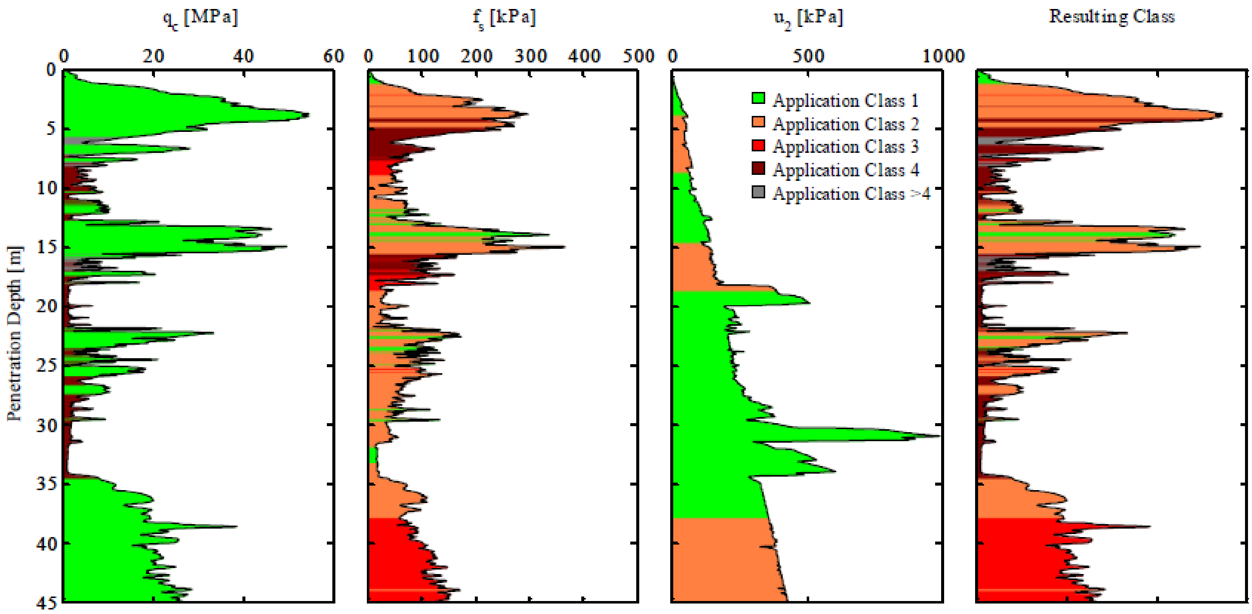

Figure 1: Graphs illustrating application class determination as percentage of measured value (after Peuchen and Terwindt 2014)

This method allows the user of the data to understand the level of uncertainties there are in each of the parameters and in the test in general. For example, the user may see that there is better accuracy in q_c in the dense layers and therefore have more confidence in interpretations from that parameter in those layers. They could see that f_s may be less reliable in those same layers, but more reliable in the softer layers where q_c is shown to be more erroneous. Further graphs could be generated that show high or low uncertainty depending on application class and soil type by utilising the q_c criteria given in Table 2, above.

It should be noted that the graphs in Figure 1 show Application Class 1 in dense sand layers, whereas Class 1 is strictly only applicable to very soft to soft soils. The graphs, however, do illustrate the concept.

4 BEST PRACTICE PROCEDURES

As discussed above, the Best Practice Guidelines are intending to clarify the ISO procedures so as to remove any ambiguity and provide clear procedures for Class 2 to 4 with additional requirements for Class 1. An overview of the main procedural aspects of the Best Practice Guidelines are summarised below. It should be noted that these are still to be finalised, so may vary from what appears in the final document.

4.1 Calibration

ISO 22476-1 provides only general guidance on laboratory calibration and refers the reader to ISO 10012: 2003, which is a generic standard for measurement management systems. There are little definitive requirements given specifically for CPT in ISO 22476-1 and when calibrations should be done is unclear.

The Best Practice Guidelines specify that a continuous record of before and after zero readings should be maintained with time (or meterage) starting from the last full-scale laboratory calibration.

For Classes 2 to 4, a new calibration should be carried out at least every 6 months from first use of the penetrometer. The calibration period can be extended, provided that the continuous record of zero readings shows a variation of less than 1% of the full scale output (FSO) for each of the sensors. In any case, the calibration period should not be longer than 12 months from the date of the last calibration. Calibrations should be carried out in load increments of 0, 2, 5, 10, 25, 50, 75 and 100% of FSO, in line with ASTM D5778-12.

For Application Class 1, a new calibration should be carried out at least every 3 months and preferably at the start of each project. A new calibration should also be carried out if the continuous record of zero readings shows a variation from the last calibration values of more than the allowable absolute accuracy values given in Table 1 for Class 1. In any case the calibration should be no more than 6 months old. The laboratory calibration should be focussed on the low end of the measuring range. The same calibration load increments given for Classes 2 to 4 apply, but with at least 2 load increments below 1 MPa for q_c and below 10 kPa for f_s. The calibration factor should favour the low end (e.g. 0 – 2 MPa for q_c).

The calibration should include an uncertainty analysis that includes a combined uncertainty for resolution, output stability, repeatability, linearity, hysteresis and zero drift, plus uncertainty regarding temperature and inclination. Based on the laboratory uncertainty analysis, a penetrometer class will be assigned to the penetrometer. This is based on the accuracy the penetrometer can achieve in laboratory conditions in relation to the accuracy criteria given in Table 2 of ISO 22476-1. The penetrometer class will be stated on the calibration report.

4.2 Penetrometer dimensions

The Best Practice Guidelines will specify when and with what equipment to carry out dimensional measurements and checks. For Classes 2 to 4, measurements using digital callipers will be taken at least once a day. In addition, checks can be done before and after each test using a wear indicator tool.

For Application Class 1, measurements are taken using a micrometre before and after each test.

4.3 Penetrometer preparation

The Best Practice Guidelines will emphasis the importance of cleaning the cone, checking the dirt seals and examining the components for wear and surface imperfections.

4.4 Penetrometer saturation

For piezocones, the Best Practice Guidelines will provide three options for saturation:

1 ‘Primary’ saturation, which is saturating the cone using a syringe or the funnel method

2 ‘Secondary’ saturation, where the assembled penetrometer is placed in a vacuum chamber under the saturation fluid and treated to full vacuum until no more air can be seen exiting the porous filter

3 Slot filter, where a silicon grease is used as the saturation fluid

Any of the above methods can be used for Application Classes 2 to 4 at the Client’s instruction, but only secondary saturation can be used for Application Class 1.

4.5 Temperature conditioning

The Best Practice Guidelines provide more guidance as to how the penetrometer should be conditioned so that it is at about the same temperature as the ground. Three methods are provided:

1 Placing the penetrometer in a bucket of water and waiting for the temperature to stabilise

2 Placing the penetrometer into a heating/cooler chamber or bath where the temperature is set to that close to what is expected in the ground and left to stabilise

3 Pushing the penetrometer into the ground by a few meters and left until the temperature has stabilised.

For Application Classes 2 to 4, any of the above methods can be used. For Class 1 only the last method can be used, unless the contractor can demonstrate an alternative method that provides a similar result. The piezocone must include a temperature sensor for testing to Application Class1.

4.6 Zero load readings

The Best Practice Guidelines clarify when and how the before and after zero load readings are taken, including the need for a second 'after' zero reading with the cone cleaned (for Application Class 1).

4.7 Pore water pressure problems during testing

For piezocone testing in on-shore applications, it is sometimes difficult to maintain full saturation, particularly when pushing through a desiccated crust above the water table, despite best endeavours. If the pore water pressure response is sluggish, it may suggest that the pore pressure measurements are erroneous due to loss of saturation and should then be discarded. However, the remaining measurements of the test (q_c and f_s) may still be valid. In these situations, the Best Practice Guidelines allows the acceptance of these tests with the pore water pressure component ignored, as if it were a non-piezocone test.

4.8 Reporting

ISO 22476-1 has somewhat onerous reporting requirements including two different reports and plots at specific graphical scales. The Best Practice Guidelines simplify the reporting requirements into one test report with required information clearly identified. Plots can be at any scale. The Best Practice Guidelines also define what is raw data, measured parameters, calculated parameters and interpreted parameters.

5 AUDITING AND ACCREDITATION

Once the Best Practice Guidelines have been agreed and finalised, all CPT contractors that are members of CETANZ will be audited on the guidelines. On successful completion of the audit, the contractor will be awarded some form of certification. The contractors will be subject to periodic audits to maintain their certification. The time between audits is yet to be agreed upon but is likely to be once a year or once every two years. The audits will be conducted by an independent auditor. In time, the industry will likely move towards IANZ accreditation as the benchmark certification.

In addition to the periodic audits for certification, the Best Practice Guidelines also provide a scaled down audit checklist for clients or engineers to conduct their own checks on CPT contractors.

6 CONCLUSIONS

The CPT industry supported by CETANZ is moving to adopt ISO 22476-1:2012 for CPT testing in NZ. The ISO standard uses an application class system that classifies CPT tests depending on assessed uncertainties so that users of the data can understand the reliability of the data for use in interpretation and design. The ISO standard, however, does pose challenges in terms of interpreting ambiguities and assessing uncertainties. The CETANZ CPT Group is developing a Best Practice Guideline to clarify these issues. A summary of the application class system and the Best Practice Guidelines are given in this paper. At the time of writing, the Best Practice Guidelines are yet to be finalised. Once adopted, the Best Practice Guidelines will standardise CPT testing in NZ and provide a baseline for accuracy. This will represent a major move forward in terms of quality and understanding of CPT testing in NZ. The Guidelines are not intended to be the perfect solution for addressing CPT accuracy but pragmatic approach to applying the concepts and intent of the ISO standard in a practical manner.

Both the CPT operator undertaking the test and the Engineer procuring and using the test results need to understand the ISO standard and the application class concept. The Best Practice Guidelines are aimed primarily at CPT operators, but will also be a useful reference document for Engineers.

7 REFERENCES

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