A SURVEY STUDY OF THE ENGINEERING PRACTICE OF PIEZOCONE DEVICES WITH REGARDS TO SATURATION CONDITIONS

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KEYWORDS

piezocone, CPTU, saturation

ABSTRACT

For many projects, Cone Penetration Testing with pore-pressure measurements (CPTU) is the main source of information regarding stratigraphy, mechanical and hydraulic properties of soils. Uncertainty in measurements may arise from malfunctioning of the piezocone equipment, poor calibration and/or maintenance, but also a lack of complete saturation. While a correct measurement of the pore-pressure is key to reliable results, and lack of saturation in the piezocone has long been acknowledged as a large source of error, the issue remains unresolved in common engineering practice. The great variety of saturation methods and media encountered in engineering practice is a symptom of the uncertainties persisting on the topic. To mitigate the issue, the saturation process is often explicitly detailed in contractual terms. However, since the quality of saturation can only be assessed *a posteriori*, after the test is completed, unwanted outcomes cannot be entirely avoided. This paper collects information on current engineering practices related to the saturation of piezocone from the perspective of operators and geotechnical engineers. The results highlight the need to implement tools to measure the saturation degree of the pore-water pressure system of piezocones in engineering practice.

1. INTRODUCTION

Cone Penetration Test (CPT) is possibly the most employed field technique deployed to obtain information about soil stratigraphy and geotechnical properties. Piezocone testing (CPTu), which includes a sensor to measure the pore-water pressure, was proposed in 1974 and dates back half a century. Defects in the piezocone saturation have since been cited as a major source of uncertainty and the comparison of pore-water pressure profiles presented by Lunne et al. [1], which was obtained with instruments having different saturation degrees,

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has become the epitome of the problem. Yet in engineering practice there is still uncertainty on the best methods and materials to be used for saturation, as indicated by a relatively recent survey [2]. The most acute problem is that saturation is assessed based on data quality, and this cannot be done unequivocally and for obvious reasons cannot be performed beforehand. Because it is more typically done after the test is completed, rather than while it is running, unwanted outcomes cannot be entirely avoided. As a result, operators and clients (or their consultants) may enter into conflict when results are unsatisfactory both because of the economic implications and because the sources and reasons for pore or loss of saturation cannot be objectively established. At the same time, manufacturers tend to minimize the occurrence of poor saturation, which is not conducive to a solution to the problem.

This research presents the results of a survey aimed to estimate the use of piezocone compared to other techniques, the occurrence of poor saturation, its relative importance compared to other issues, and solutions currently adopted in practice. It continues to summarize some preliminary results that have been gathered following the development of a tool that is able to measure the saturation degree of the piezocone pore-water pressure measuring system, based on the same concept applied before performing triaxial test to verify saturation of the hydraulic system.

2. METHOD

The survey consists of 11 questions both provided as multiple-choice questionnaire and open questions (see Appendix for the questions and the participants for each). Answers were collected in the period from 01.10.2023 to 31.03.2024 using several channels: 1) Google Forms questionnaire posted on LinkedIn and follow-up after meetings (10 responses), 2) during online meetings (8-10 responses), 3) sending emails (3 responses out of 15 contacts), 4) private messaging to contacts on LinkedIn (2 responses out of 15 contacts). The survey was sent to 50 potential participants and resulted in 21 geotechnical firms/engineers answering (42% response rate), which in two cases they also own and operate a CPT truck. Google form responses were anonymous, while the answers obtained through other means were personal. The participants country of operation was varied and included: Norway, Sweden, Belgium, Netherlands, Italy, France, Switzerland, UK, and Australia. While all designers/consultancies performed work both nationally and internationally, no information about extended geography was collected. The results of multiple-choice questions are expressed as % based on the number of answers obtained for each question, since this latter value changes from question to question.

3. SURVEY RESULTS

Based on answers to questions 1 and 2 there is no difference in the type of tests used for ground investigation based on whether a project is or not abroad. Laboratory tests, CPT/CPTu tests and other field tests are all always employed (where the relative weighting was not required to be specified), except for one response where only CPT/CPTu tests were considered.

The soil types that participants mentioned being relevant to their projects were varied and included sands, normally and overconsolidated clays, boulder clays, alluvial soils, marine sediments, mine tailings, and also chalk and rocks.

A limitation of the results collected is that most participants interpreted less than 10 tests in the previous 2 months, based on the assumption that far away memories are more likely to be less reliable.

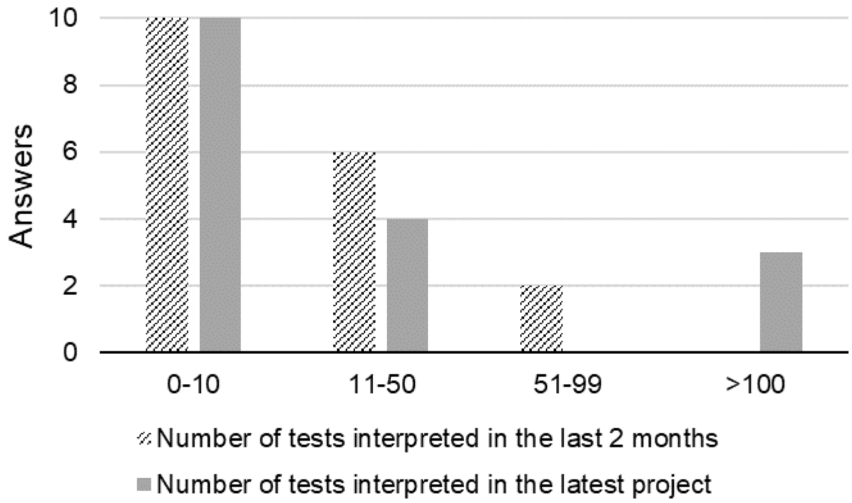

Figure 1 Representativeness of the survey response based on time proximity of the task and its volume, where the task is interpretation of CPT/CPTu profiles.

Based on question 6, CPT/CPTu results are the primary source for defining stratigraphy and measuring undrained shear strength (100%), followed by calculation of other mechanical parameters such as stiffness (64%) and angle of shearing resistance (55%), while they are used to a lesser extent to estimate hydraulic parameters (permeability and consolidation both scoring at 36%). The most employed quality check to assess reliability of results are comparison with stratigraphic description of boreholes (mentioned by 6 participants), checking pore-water pressure response with respect to hydrostatic values and its speed of response (mentioned by 10 participants). With regards to questions 8 and 9, Figure 2 shows from top to bottom the most reported issues and how many of the participants considered this to be a frequent issue, not so frequent or not an issue. Almost unanimously (20 responses out of 21) the most mentioned issue was reported to be pore-water pressure measurements, and associated issues such as occurrence of cavitation and unreliable dissipations, out of which 15 participants reported this to be encountered often. Sleeve friction and depth/inclination were also reported as frequent (4 responses) or not (1 response), alone (1) or combined with pore-water pressure measurements (4).

Finally, when it comes to ways to account for or mitigate the uncertainty linked to pore-water pressure measurements, the following strategies were adopted: test repetition, alternative sources (such as laboratory testing) and adopting conservative values, either together or in combination, the most common being to use laboratory testing as an alternative source (66% of participants adopting this strategy). In equal numbers, participants either repeated the test or adopted a conservative value (about 30% of responses).

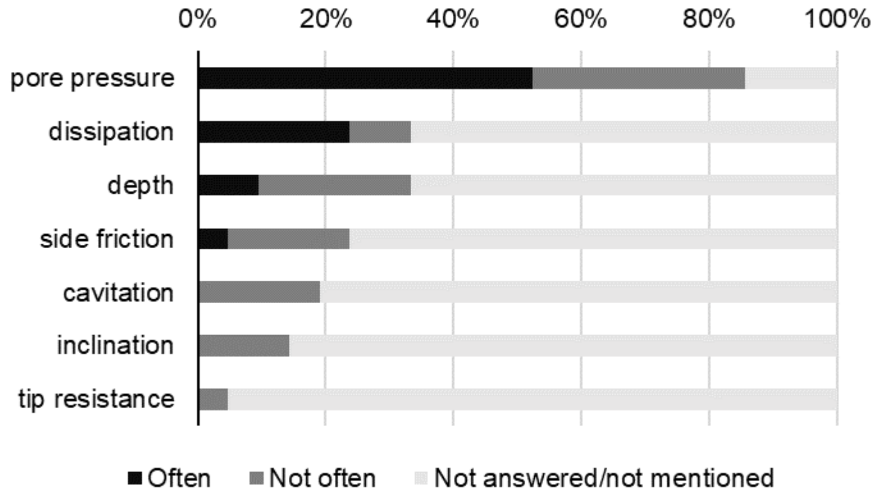

Figure 2 Main issues encountered and their frequency when performing and interpreting CPT/CPTu.

4. MEASUREMENT OF SATURATION CONDITIONS AND IMPACT

Figure 3(a) shows a summary of the results obtained when measuring the B^* value of the pore-water pressure measuring system of a piezocone in laboratory conditions, under different saturation conditions of the filter and the hydraulic system behind it [3,4], which are more extensively described in [5]. A clear link between the saturation degree of the filter and measured B^* is observed. Furthermore, it is observed that both procedures recommended by the standards are effective in saturating the instrument. Figure 3(b) compares the pore-water pressure profiles obtained from 2 CPTu soundings performed at the test site of Boretto (Italy), for which B^* was measured to be 1.0 and 0.84, respectively.

Despite the relatively small difference in B^*, which can only be attributed to poor saturation of the instrument, since the corrected tip resistance (q_t) and the sleeve friction (f_s) are virtually identical, the pore-water pressure response (u) is stunningly different. More detailed information about these field tests can be found in [7].

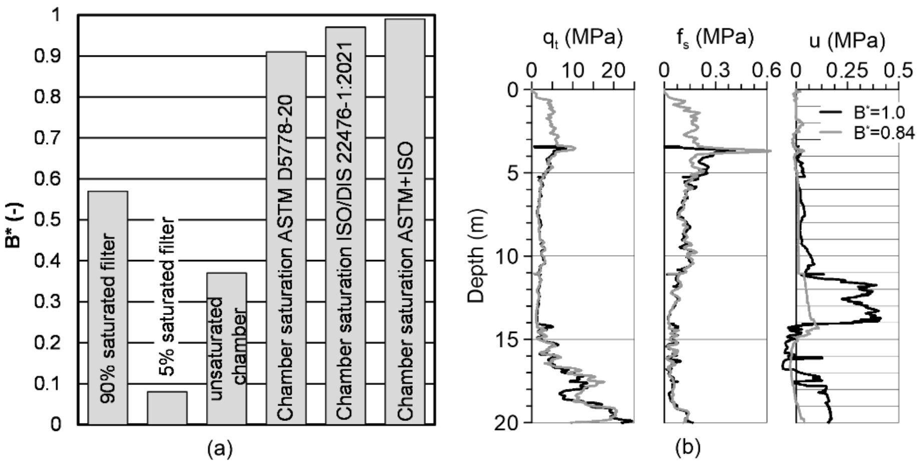

Figure 4 (a) Measurement of piezocone saturation by B^* and (b) Comparison of pore-water pressure measurement performance based on initial measured B^*.

5. CONCLUSIONS

Pore-water pressure measurements are commonly used as an a posteriori quality check for CPTu results, despite or perhaps because they are the main source of error in CPTu results. Survey results show that there is a need for proper quality control for piezocone saturation, such as provided by the tool developed by Rocchi et al. [8]. This tool, which has been proved to be effective at a laboratory scale, and preliminary validated in the field, allows to quantify the degree of saturation in piezocone tips prior to testing. The ultimate objective of the research is to introduce such tool as a benchmark for quality assessment of piezocone testing with regards to its saturation.

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APPENDIX

The survey contains 11 questions (6 multiple choices, with answers reported under the question) followed by the number of responses in brackets.

1. What ground investigations do you recommend to your clients in national projects? (16)

   a. Laboratory testing
   b. Cone penetration test (CPT/CPTu)
   c. Other field tests
   d. Other

2. What ground investigations do you recommend to your clients in international projects? (19)

   a. Laboratory testing
   b. Cone penetration test (CPT/CPTu)
   c. Other field tests
   d. Other

3. What types of soils do you mostly work with? (10)

4. How many CPT/CPTu did you interpret in the last 2 months? (18)

5. How many CPT/CPTu did your last project have? (18)

6. For which parameters do you rely most on CPT results? (19)

   a. Undrained shear strength
   b. Friction angle
   c. Stiffness modulus
   d. Permeability
   e. Consolidation parameters
   f. Stratigraphy
   g. Other…

7. How do you check if the results obtained are of good quality? (20)

8. How often do you encounter issues with CPTu? (21)

9. What are the main issues you encounter with CPTu? (21)

   a. tip resistance
   b. side friction
   c. pore pressure
   d. depth
   e. inclination
   f. dissipation
   g. cavitation

10. What do you usually do to fix/mitigate these issues? (20)

   a. ask for the CPTu to be repeated
   b. rely on input from a different test
   c. assume a conservative value
   d. Other…

11. With regards to filter saturation in CPTu (19)

a. Good saturation is critical in my typical design tasks
b. I do not have knowledge/preference about slot or porous filters being used
c. When possible I prescribe guidelines about filter saturation
d. Other…

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