Influence of operator performance on quality of CPTu results

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ABSTRACT
Cone penetration tests (CPT) is one of the most sophisticated geotechnical field investigations methods. As for all test methods, the CPT is associated with many uncertainties. However, there are two main sources that have an influence on the quality of CPTu measurements. One is the choice of equipment since different equipment differs in design and functionality. The other source relates to operator performance and incorrect execution of the method as well as lack of competence to analyze the results. However, in order to achieve satisfying results, the operator should be skilled, competent and well-educated. Some countries don't have any formal education and in countries were formal education do exist, the achieved quality of results does quite frequently still come out unsatisfactory. This fact is seldom mentioned, but still a well-known fact amongst practicing geotechnicians. The objective of this paper is to discuss operator performance related factors and contribute to a better knowledge of how important every single procedure contributes to the outcome as well as quality of the results.

Keywords: CPT, operator performance, undrained shear strength

1. INTRODUCTION

Ground investigations form the basis for geotechnical analyses design and decisions at various phases in sustainable building. In a report presented by Rydell & Johansson (2001), it is stated that the quality of geotechnical investigations and the documentation have gradually deteriorated. This problem is by no means new (Magnusson et al. 1989). There are fortunately few occasions of geotechnical shortcomings that have lead to any serious consequences, but the loss expenses of these occasions are obvious (Lind 2012).
The cone penetration test (CPT) is one of the most used geotechnical in-situ testing field method in Sweden. However, due to the gradual deterioration of quality of CPT test results, geotechnical engineers in Sweden have lately displayed a tendency to choose alternative method for investigations of clay. Du to this, presented study aims to discuss operator performance related factors and their influence on the accuracy of CPT results. To mention previously studies with the same subject, see Gauer et al. (2002) and Sandven (2010).
The two common piezometer CPT probes (CPTu) used by commercial actors in Sweden are either made by Envi or Geotech. The equipments can either be equipped with a porous filter or a slot filter (Larsson 1995). One of the original intention with this study, inspired by the work of Gauer et al. (2002),

was to investigate the effect of mentioned equipment factors on the results when sounding in typical Stockholm/Mälar-dalen soft sediments, i.e. post-glacial clay on top of deposits of varved glacial clay. However, presented study instead ended up in documenting and analyzing how the effects of operator performance influenced the outcome of the quality of the results. The study has been performed as a MSc thesis project at KTH Royal Institute of Technology by Kardan (2015).

2. TEST SITE AND METHODS

The CPTs were conducted over a period of six week, from April 24th 2014 to May 22th 2014, in the vicinity of a recycling facility in Hagby, 25 km northwest of Stockholm. The geotechnical condition of the test site is typical for Stockholm/Mälardalen region. A short description of the soil stratigraphy can be found Table 1. The ground water level was approximately 0.7 m below the ground surface.

Before the investigations, a written invitation was sent to a number of commercial actors in Stockholm/Mälardalen region to ask for their interest to participate in the test. Five actors reported interest to participate, named A to E in this paper. There was no secret for each actor, as in the study presented in Magnusson et al. (1989), that other actors participated. No special instructions provided, other than the desire to get as many CPTu results as possible and that they should follow the ISO standard for Electrical cone and piezocone penetration test (SS-EN 2012) and the Swedish guidance for CPT tests (SGF 1993). The actors had thus the opportunity to perform as good as possible. A description of the equipment used by the participating actors can be found in Table 2. A total of 24 CPTu-tests were performed and the relative location of the bore holes is illustrated in Figure 1.

Table 2 Equipment used by the five actor's contributing to this study.

Actor	Cone penetrometer	Drill rig
A	Envi Memocone	GM 75 GT
B	Geotech Nova	GEORIG 604
C	Envi Memocone Geotech Nova	GM 65 GT
D	Geotech Nova	GEORIG 605
E	Envi Memocone	GM 75 GT

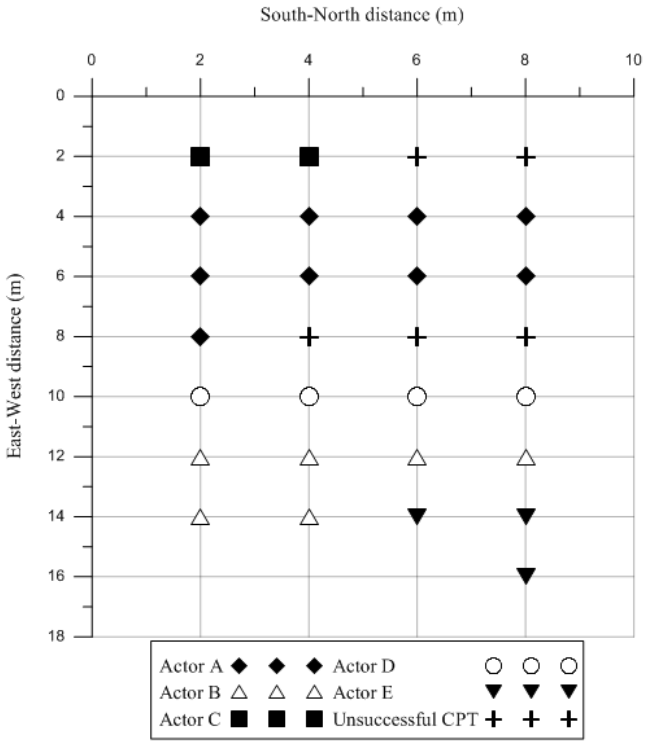

Figure 1 Relative location of the CPTs.

Table 1 Soil profile and soil properties at test site.

Layer	Depth (m)	ρ (t/m^3)	w_n (%)	w_l (%)	S_t (-)	OCR (-)	c_u (kPa)
Fill	0 – 0.3	1.75	-	45	-		
Dry crust	0.3 - 1	1.7	-	60	-		
Organic clay	1 – 2	1.4	115	110	12	(3)	14
Sulphide clay	2 – 6	1.5	65-85	50-65	18-30	1.2 – 1.3	9.5 - 12
Varved clay	6 - 12	1.65	60-75	50-65	17-25	1.0 – 1.2	11 - 19

3. PERFORMANCE RELATED FACTORS

According to the Swedish guideline (SGF 1993) and Sandven (2010), the following performance related factors are the most common to affects the results, see Figure 2:

- pre-drilling
- calibration of cone penetrometers
- saturation of pore pressure system
- control of inclination (verticality)
- reference measurements
- reading of zero values
- rate of penetration

For each mentioned factor, there is detailed instruction to be found in both the Swedish as well as International standards. If actors as well as operators followed these instructions, the impact of operator procedures on CPTu-results would decrease.
During the execution of the CPTs in this presented study, the used equipment as well as performance of each operator with respect to mentioned factors were noted and well documented.

Calibration

Three of the five cone penetrometers used in the study were not calibrated according to the standard. Due to the sensitivity of this method, use of uncalibrated equipment will affect the accuracy of the results.

Saturation

Full saturation of the pore pressure chamber and filter are required. Negligence of this process affects the result of the measured excess pore pressure (Δu). One actor used both porus stone and slot filter. Another operator used three liquids; oil, glycerin as well as water and took the initiative to perform a dissipation test.

Cleaning

Two of tree operators did not clean the probe from dirt and other particles properly using new and clean rugs. Carelessness in the cleaning process will affect the result of the recorded values.

Inclination

In the ISO standard (SS-EN 2012), there are five criteria for classification of CPTu. One of them relates to the maximal angle of inclination. However, one of the operators did not have an inclinometers installed in the cone used and it is thus not possible to classify the performed penetration.

Reference measurements

Registration of reference measurements can help the operator to check if the results are free from environmental impact such as differences in temperature. Not all of the operators were aware about it. Instead of invalidating the results and perform the penetration again when the differences where large in the reference measurements, some of them chose to consider the result as an approved result.

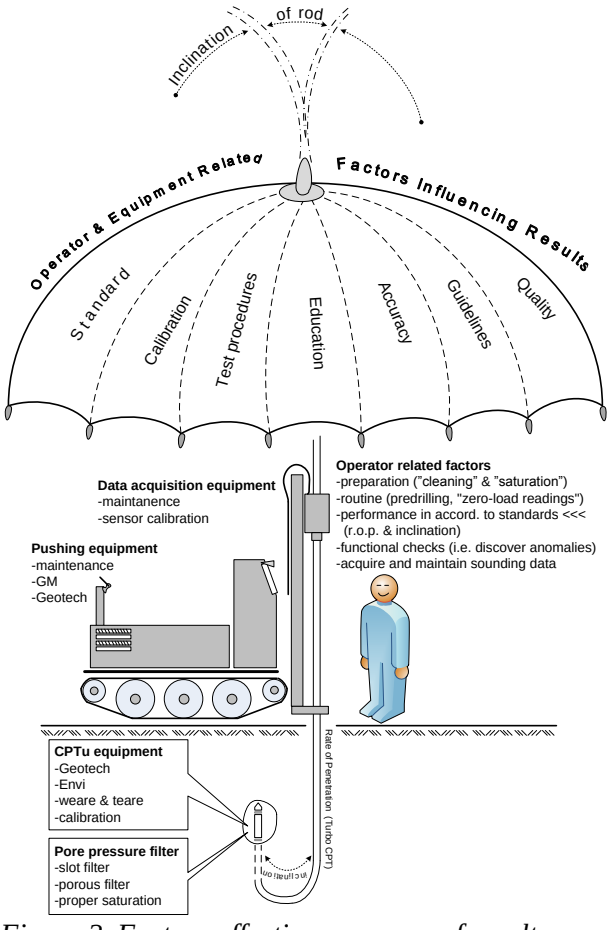

Figure 2 Factors affecting accuracy of results.

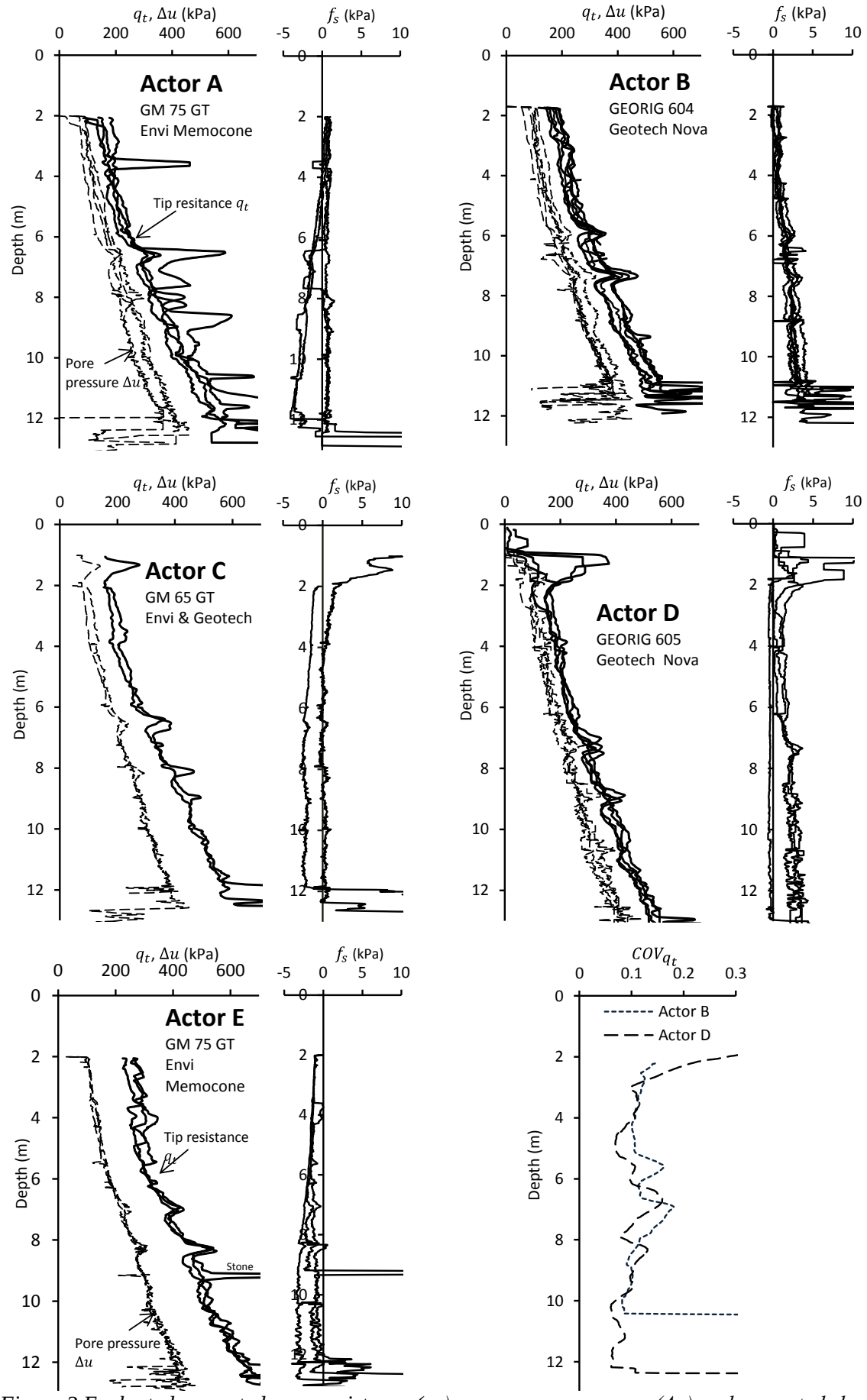

Figure 3 Evaluated corrected cone resistance (q_t), excess pore pressure (Δu) and corrected sleeve friction (f_t) for each actor A-E.

Pre-drilling

Pre-drilling of the fill and crust is normally always required in the Stockholm/Mälardalen region. However, one operator neglected to pre-drill which produced results that was obvious effected by this negligence. The most obvious affect were the negative value of recorded sleeve friction (f_s), see Figure 3.

Rate of penetration

Rate of penetration is perhaps the most important factor of performance. The rate of 20 mm/s with an allowed deviation of ±5 mm/s according to the ISO standard (SS-EN 2012). One operator neglected the rate of 20 mm/s and named these as turbo CPT. The results have for obvious reasons been omitted in this paper.

Other

Other factors observed during the conducted test that might not influence the outcome of results, but reflects the need to educate the field operators. One actor omitted to unsplice three sections of steel rods (totally 6 m) wile relocating from one spot to another (illustrated in Figure 2).

4. RESULTS

A representative part of obtained results of conducted field test by the five actors are presented Figure 3 and 4. The results are evaluated by the commercial program CONRAD (Larsson 2006). Figure 3 shows; the corrected cone resistance (q_t), the excess pore pressure (Δu), and the corrected sleeve friction (f_t), as well as evaluated coefficient of variation of q_t (COV_{q_t}) of actor B and D who performed sufficient number of tests. For reader interested of complete set of results are kindly referred to Kardan (2015). The variability expressed as COV_{q_t} is approximately 10% which can be considered relatively small for the evaluated q_t in soft clay. The variability includes both measurement errors and the natural variation in the soil. The evaluated COV_{q_t} is twice as high as the COV related to measurement errors for CPT around 5% as reported by Lunne et al. (1997). Somewhat unexpected, the variation of evaluated Δu for each actor were smaller than variation of evaluated q_t. The variation of evaluated f_s compared to q_t and Δu is much larger. Results of actors A and E displays consistently negative values of evaluated f_t, results that are obviously unreasonable.

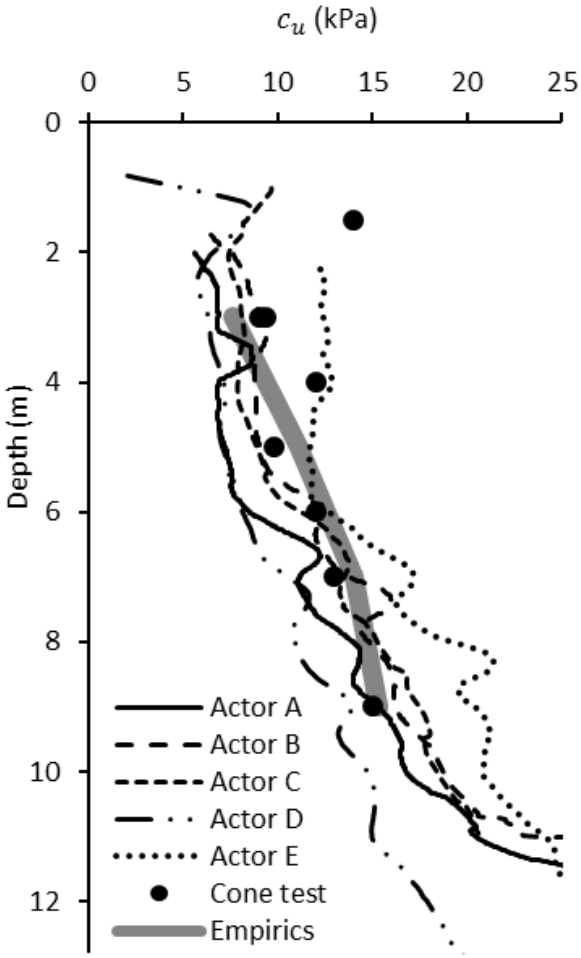

Figure 4 Evaluated undrained shear strength.

The interpretation of the undrained shear strength (c_u) in clays is probably one of the most important parameter evaluated from CPTu results. Figure 4 shows the evaluated c_u as a moving average over 1 m, for each commercial actor. The results can be compared with a simple empirical evaluation $c_u = 0.22\sigma_c'$ (Larsson 1980) based on results from CRS tests and results from fall cone tests on samples taken on the site.

Results of actor E show evaluated c_u 60 to 150% higher than results of actor E. It can also noted that results of actor E have the largest variation of evaluated c_u over the depth range analyzed. The largest difference

of evaluated c_u is found at depth level 2 to 4 m. This large variation is particularly troublesome in relation to estimates of stability of shallow excavations.
It has been possible to clarify reason related to the large variation of evaluated c_u. A probable reason is that the variation correlates to systematic errors due to the lack of calibration of the cone penetrometers. Another possible explanation could be the choice to use high-capacity CPT-probes in soft clay layers which reduces the resolution of the conducted measurements.

CONCLUSIONS

The results from the conducted study have provided valuable insight and proof of the correlation between poor quality in relation to routine performance of CPTu-tests. The poor performance correlates to operator performances as well as insufficient internal controls and lack of procedures to regularly calibrate the equipment. It´s clear that CPT results are highly operator-dependent.
And finally, it can be concluded that there is an immediate need to both increase the awareness amongst the geotechnical society as well as clients together with the need to increase the quality of CPTu tests and analysis of results. It's the authors' opinion that this is best accomplished with education of field operators, geotechnical engineers and not least clients. This will hopefully lead to improved internal controls, routines, calibrations and maintenance of equipment belonging to commercial actors.

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