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WHAT IS AN APPROPRIATE CRITERIUM FOR THE TRANSITION FROM A WIDER PENETROMETER TO SMALLER PUSHING RODS?

Introduction

For Dutch practice, most commonly utilized cone penetrometers have a projected base area of 10 cm^2 or 15 cm^2. This corresponds to a diameter, D, of respectively 3.6 cm and 4.4 cm. However, Ø 3.6 cm pushing rods are used for both cone types. This implies the need for a transition from the wider penetrometer to the smaller pushing rods in case of a 15 cm^2 cone. According to NEN-EN-ISO 22476, the transition should be positioned at least 11.2D above the cone shoulder. In practice, however, we notice that companies prefer and use configurations in which the transition is only in between 5 to 7 times D above the cone shoulder. The main reason for this deviation from the standards seems reduction in required force to reach depth, as the configuration acts like a friction reducer. Further, smaller inclinations are observed with a 15 cm^2 cone compared to a 10 cm^2 cone. Therefore, less risks are involved when using 15 cm^2 cone with a reduced distance between the cone shoulder and the transition in diameter.

These observations have led to the following questions:

1. What are the effects of the penetrometer configuration on cone resistance, q_c, sleeve friction, f_s, and/or pore water pressure?
2. What was the basis for the requirements in the testing standards?

Some companies refer to Powell & Lunne (2005) and claim that the measured quantities are hardly affected by the shorter distance from shoulder to transition. Powell and Lunne discuss tests in UK clays, utilizing 15 cm^2 piezocones with sleeve areas of 200 and 300 cm^2 and conclude little difference in results between the different sleeve areas. The distances from shoulder to transition are not mentioned in their publication, however, the results indicate that the friction in clays is uniformly distributed over the sleeve. Heijnen (1972) presents extensive field research on the shape of the cone penetrometer (10 cm^2), as different results in q_c were observed from a "Dutch mantle cone" and a "straight electrical cone" in sands. Heijnen concluded that a reduction in diameter just behind the cone does influence q_c significantly, but that such effects also rapidly decrease with distance from the cone shoulder. Interestingly, no significant differences were observed between a "straight" cone (constant diameter over full length) and a cone with a reduced diameter from 10 cm above the cone "tip" (2.8D). Although we believe that such conclusions should treated with caution due to natural variability of the subsoil and measurement uncertainty, it is striking that the requirements in the standards are what they are.

Most likely, the basis for the requirements in NEN-EN-ISO 22476 are classical analytical solutions (Meyerhof, 1951; Van Mierlo & Koppejan, 1952; De Beer, 1963). In such approaches, the size of the failure wedge is typically a function of the friction angle of the soil and can extend to great distances from the cone shoulder. However, this basis seems to contradict with the pile base shape factors from NEN 9997-1+C2, see figure 1. For instance, in case of a 15 cm^2 cone with 10 cm2 rods (Deq / deq = 1.5), only H ≥ 2D is required to become comparable with a fully straight pile concerning the tip resistance in sands. However, the basis for figure 1 is not known to us.

From above findings it might be expected that the different configurations of the 15 cm^2 cone as we come across in the field will not significantly influence q_c. However, it is important to validate

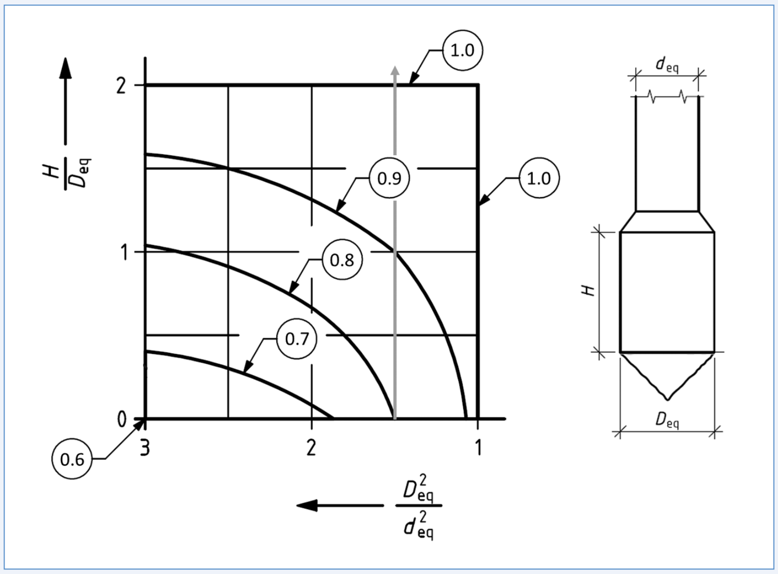

Figure 1 – Pile base shape factor β for piles in sand (NEN 9997-1+C).

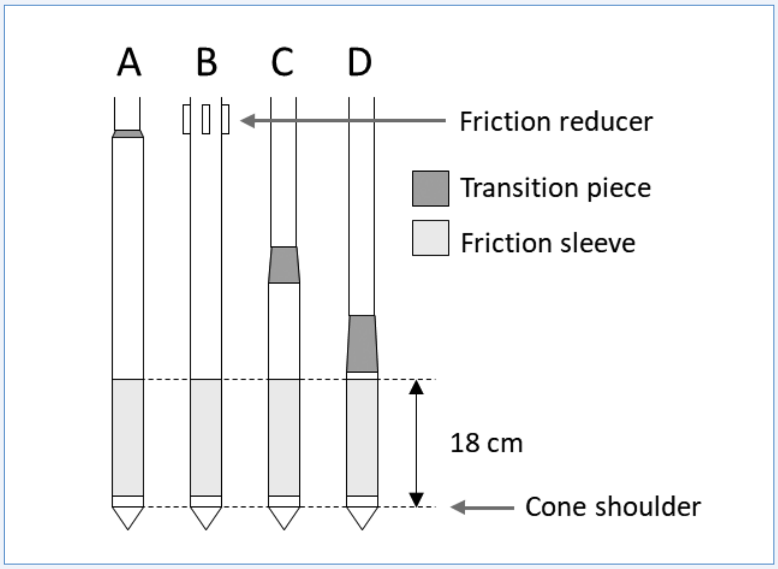

Figure 2 – Schematization of tested 15 cm2 penetrometers (De Lange et al, 2022).

SUMMARY

As 15 cm2 cone penetrometers are pushed by Ø 3.6 cm rods, a transition from the wider penetrometer to the smaller pushing rods is needed. It has been noticed in practice that CPT sounding companies prefer and use configurations in which the transition is in between 5 to 7 times the cone diameter, D, above the cone shoulder. However, according to NEN-EN-ISO 22476, the transition should be positioned at least 11.2D above the cone shoulder. In order to fuel discussion, a first step was made by performing two series of 9 CPTs with different penetrometer configurations. The results have been analysed and no systematic differences between the different penetrometers are found. Better understanding and validation is needed, but if all results point in the same directions, the standards can be updated.

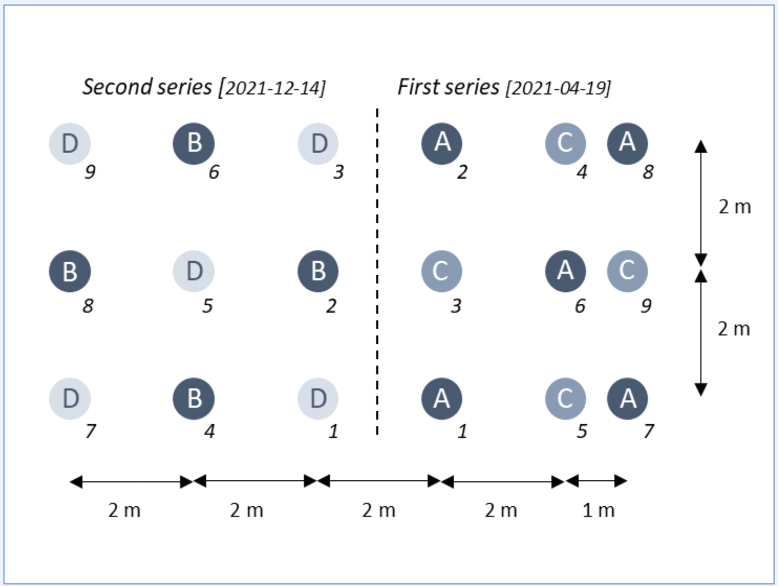

Figure 3 – CPT locations and order.

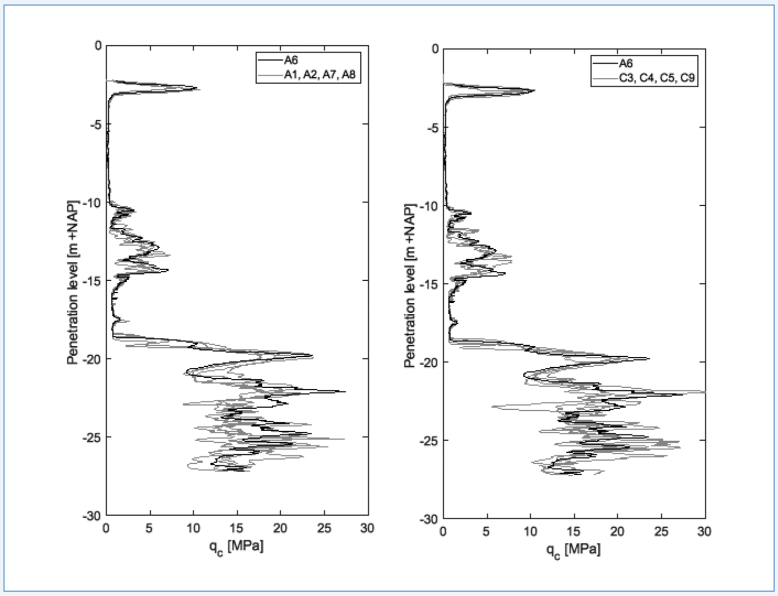

Figure 4 – Results from A6 with respect to results of (left) other type A tests and (right) type C tests (De Lange et al. 2022) .

this with (more) empirical evidence. Further, the potential influence on the friction readings is less clear so far, as the penetrometer configuration also might affect the horizontal soil stresses around the sleeve. Therefore, Deltares proposed a series of CPTs using 15 cm² cone penetrometers having the transition at different distances from the shoulder. This paper is a follow up of De Lange et al. (2022) and presents a further analysis of the test results.

Approach and results

Two test series, consisting of each 9 CPTs, were performed in 2021 (1st in April & 2nd in December). All tests were performed according class III (NEN-EN-ISO 22476-1). Tests were executed in a closely spaced grid at a green field owned by Delft University of Technology. The distance between two adjacent CPTs was 2 m and in some cases only 1 m. Four different 15 cm² penetrometer configurations have been used, see figure 2. Configurations A and B do meet the requirements of NEN-EN-ISO 22476 with respect to the location of the transition, while configurations C and D do not. Relevant cone dimensions are given in Table 1. All penetrometers were manufactured by the same company, having identical location and area of the friction sleeve. Further, both test series were executed by the same company. The test locations and the tests order are given in figure 3. E.g. "A2" refers to penetrometer type A and the second CPT of the test series. The target penetration level was 25 m below surface level, passing through Holocene clay and peat deposits and Pleistocene sand. Pore water pressures were not measured. The penetrometers were equipped with double inclinometers.

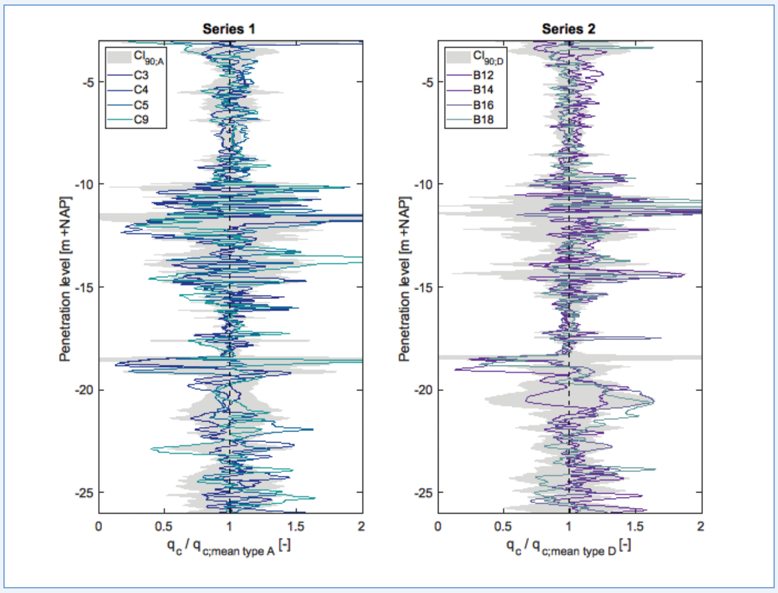

Figure 5 – Normalized q_c results of series 1 (left) and series 2 (right) .

Table 1 – Penetrometer characteristics

Penetrometer	A cm	B cm	C cm	D cm
Shoulder – transition distance	52	52.5*	31.5	19
Sleeve – transition distance	34	34.5*	13.5	1
Transition length	1	-	5	8

** Distance to friction reducers is given.*

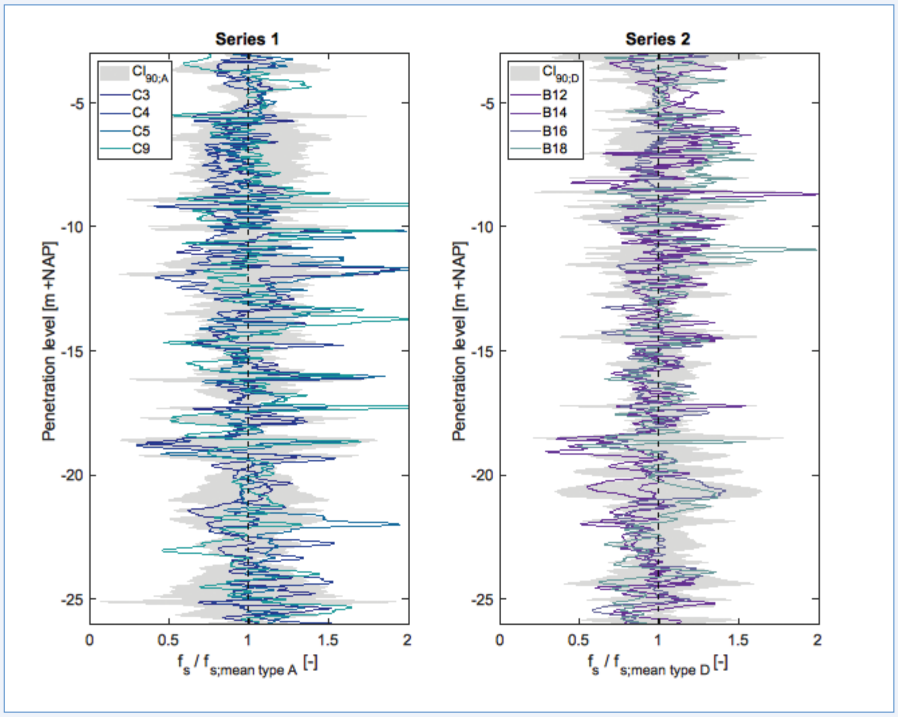

Figure 6 – Normalized f_s results of series 1 (left) and series 2 (right).

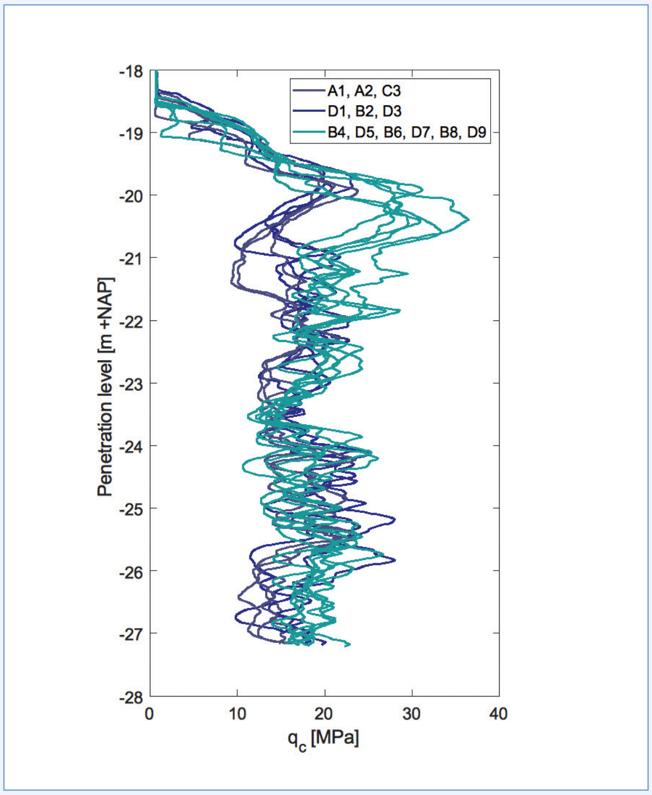

Figure 7 – q_c results of series 1 and 2 (zoomed in on the Pleistocene sand).

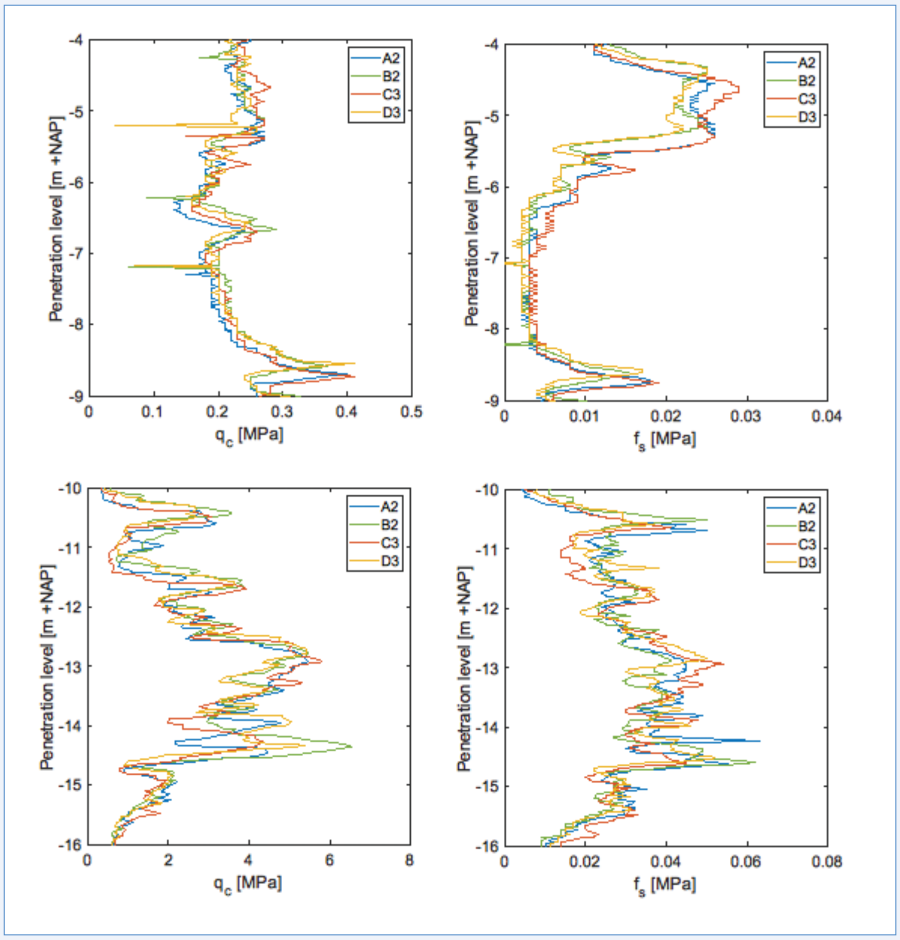

Figure 8 – Comparison of all types (4 adjacent CPTs).

All results (both q_c and f_s) can be found in De Lange et al. (2022). In order to give an impression of the subsoil and the variability in measurements, all q_c results of series 1 are presented in figure 4. The left subfigure shows all q_c-profiles from the type-A tests to indicate the inherent variability, with the results of the central CPT being emphasized. The right subfigure shows all q_c-profiles from the type-C tests, again with respect to the central type-A test. Total cone inclinations of about 1° to 3° were measured at final depth. Therefore, interference between the tests are excluded.

Analysis

In both series, a group of 4 and a group of 5 CPTs is present. To investigate possible differences in measured quantities, the group of 5 CPTs has been used as reference in both series. All results from this group have been used to determine a mean μ(z) and a standard deviation σ(z). Then, the results of the group of 4 CPTs have been normalized by μ(z). Figures 5 and 6 show the 90% confidence intervals, CI90, based on the reference group. The normalized results of the other group are also given. The confidence intervals are given as a measure of the inherent soil and/or measurement variability. For q_c, larger variability is observed in the sandy deposits and around "soil layer interfaces". The latter can be explained by fluctuation in level of the layer interfaces. For f_s, the variability is more constant over depth. In general, away from the layer interfaces, the results fall within the 90% confidence intervals. No systematic differences are noticed which can be directly related to the cone configuration. Striking deviations from the mean μ(z) can be explained by inherent variability. For example, the normalized q_c-measurements of type B seem to be structurally higher than type D in the upper part of the Pleistocene sand (around NAP -20 m). However, when having a closer look to the results itself, the northern CPTs (B4, B6, B8, D5, D7 and D9) show higher q_c-values than the southern CPTs, see figure 7. This natural variability has impact on the analysis as both D1 and D3 influence significantly the mean of type D. Therefore, the normalized results of B4, B6 and B8 are significantly higher than that mean value and only B2 shows lower values.

As test series 2 was performed at only 2 m from series 1, results from all 4 cone types can be compared as well. Figure 8 shows such a comparison. No systematic differences are observed from these graphs either. The sharp drops in q_c in the upper left subfigure are a result of tightening the 1 m pushing rods. These specific measurement values are deleted from the raw data in general, but probably not all spots were adequately identified by the provider of the data.

Concluding remarks

In practice 15 cm² cone penetrometers are used, several of which do not meet the requirements of the standards. A range has been tested in the field at one location. The location of the diameter transition ranged from 4.4 to 12 times D from the cone shoulder. During analysing the results no systematic differences were observed which can be related to the cone configuration (only). This is an important finding, that gives a preliminary answer to the first questions in the introduction. We foresee the need to consult archives and involved people to understand the background and motivation of the adopted standards in order to answer the second question in the introduction. In order to achieve a broader basis and have a better statistical support of present results, tests should be repeated at other locations (in other soil types and soil states). For better understanding of the mechanisms, a combination of numerical (e.g. MPM) and physical modelling can be applied. Lastly, should you want to contribute, any relevant information from your side is more than welcome! Please contact one of the corresponding authors.

Acknowledgements

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