Results of a comparative study on cone resistance measurements

V. Whenham, N. Huybrechts, M. De Vos
Belgian Building Research Institute (BBRI), Belgium

J. Maertens
Jan Maertens bvba & Catholic University of Leuven (KUL), Belgium

G. Simon
Ministry of Equipment and Transport of the Walloon Region, D421 Geotechnical Direction

G. Van Alboom
Ministry of Flanders, AOSO, Geotechnics Division, Belgium

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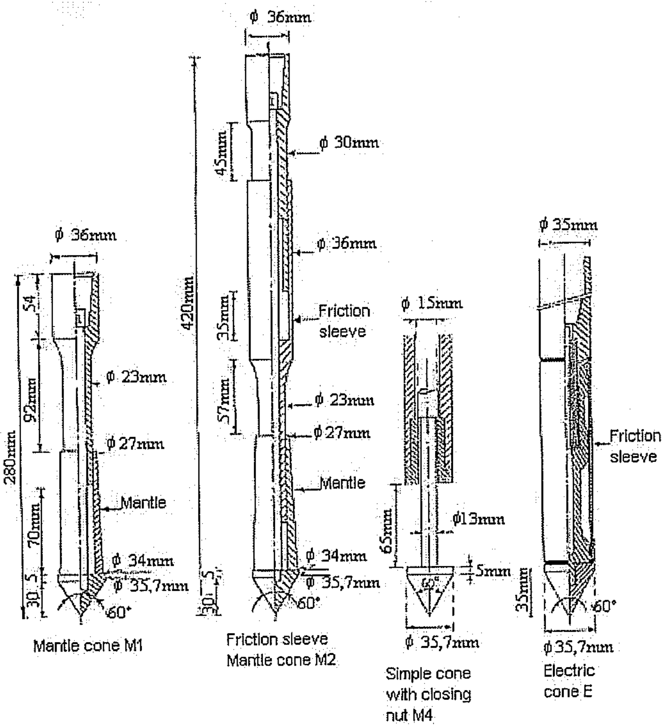
ABSTRACT: Cone penetration tests (CPT) can be performed using a mechanical or an electrical cone. Because the electronic tip is recommended as a standard by the Eurocode 7, and as in Belgian very commonly mechanical CPTs are performed, a study is currently performed at the BBRI to quantify the ratios between the cone resistances as measured with four types of CPT tips - three mechanical tips (M1, M2 and M4) for discontinuous penetration, and the standard electric tip for continuous penetration. The data comes from 20 test sites where comparative CPTs recently have been performed in Belgium and covers various soil types, in particular stiff clays in which it has been experienced that the differences on cone resistance between electrical and mechanical measurements are significant.

1 INTRODUCTION

The three mechanical cone types used in Belgium are illustrated below in Figure 1: the simple cone with closing nut (CPT-M4), the mantle cone (CPT-M1) and the friction sleeve mantle cone (CPT-M2). The electrical cone (CPT-E1) is also illustrated in Figure 1. Electrical cones give more accurate readings than mechanical cones, but their use in Belgium is not standard due to the regular occurrence of hard inclusions in the soil, and the presence of very dense or cemented layers, which can cause damage to the rather expensive electrical cone.



Mantle cone M1

Friction sleeve Mantle cone M2

Simple cone with closing nut M4

Electric cone E

Figure 1. Cone penetrometer tips.

Systematic comparisons between tests with mechanical (CPT-M1, CPT-M2 & CPT-M4) and electrical (CPT-E1) cones show that the measured cone resistance may be affected by the type of cone (see Joustra K., 1974, Rol A.H., 1982).

Because the electrical tip is recommended as a standard by the Eurocode 7 (expected year of publication 2006) and also by the current draft of the National Annex (see De Vos, Bauduin, Maertens, 2003), and as in Belgium mostly mechanical CPTs are performed due to the soil conditions, a study is being undertaken at the BBRI in collaboration with the Geotechnical Division of the Flemish & Walloon Regional Ministries in order to investigate the difference between mechanical and electrical cone measurements and to summarise the conclusions into pragmatic conversion rules.

2. THE COMPARATIVE STUDY

2.1. Collection of data

The cone penetration results from 20 test sites especially in the northern part of the country are gathered and analysed. The location of the test sites are represented in Figure 2.

2.2. Overview of the investigated sites and soil layer identification

For each investigated site, two approaches for soil classification are considered. The first one is based on the mechanical properties of the soil as deduced from the electrical CPTs (Robertson method, see Lunne & al., 1997), the second one is based on the nature of the soil as deduced from geological information and the results of borings performed on the test sites.

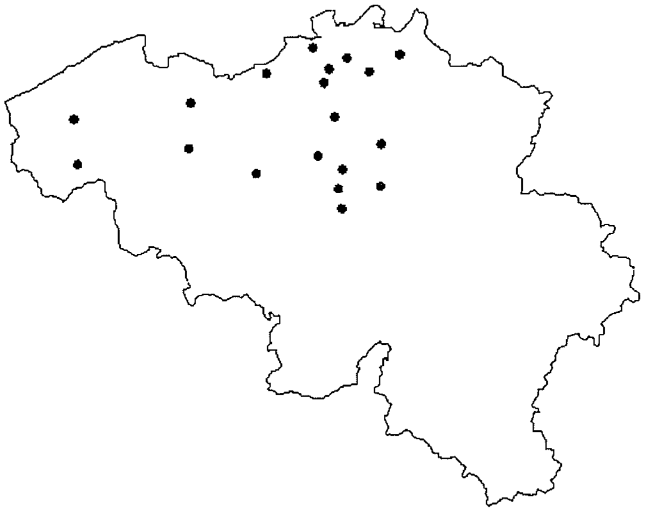


Figure 2. Location of the test sites in Belgium.

In Figures 3 to 8, typical electric and mechanical CPTs from some of the investigated sites together with the soil layer identifications based on the Robertson method (normal character) and the geologic informations (bold italic characters) are presented. Figures 3 and 4 correspond to sites where the subsoil consists of stiff tertiary clays (Rupelian clay or Boom clay and Ypresian clay). Because of the high cone resistance and the low friction ratio (which can be lower than 2% for the Ypresian clay) of the tertiary clays, they are often identified as silty or sandy soils when using soil classification methods based on CPT-E results. Based on the mechanical CPTs, the tertiary character of these soils is identifiable by an important increase in the total friction Q_{st}. The tertiary clays are also characterized by a regular increase in the cone resistance with depth.

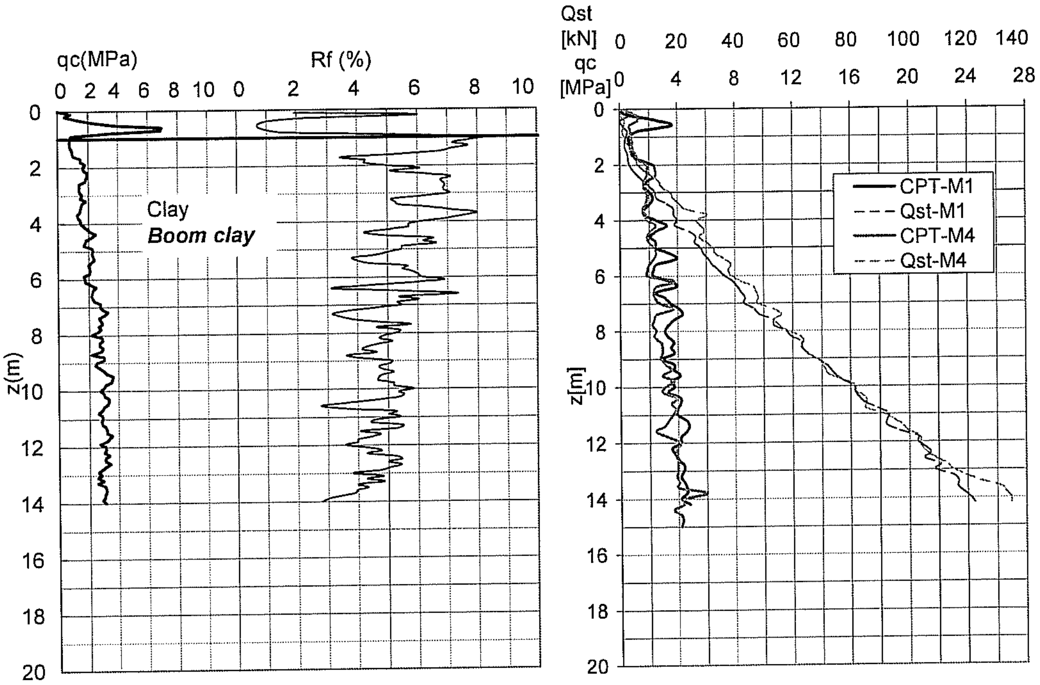


Fig 3. Sint-Katelijne Waver

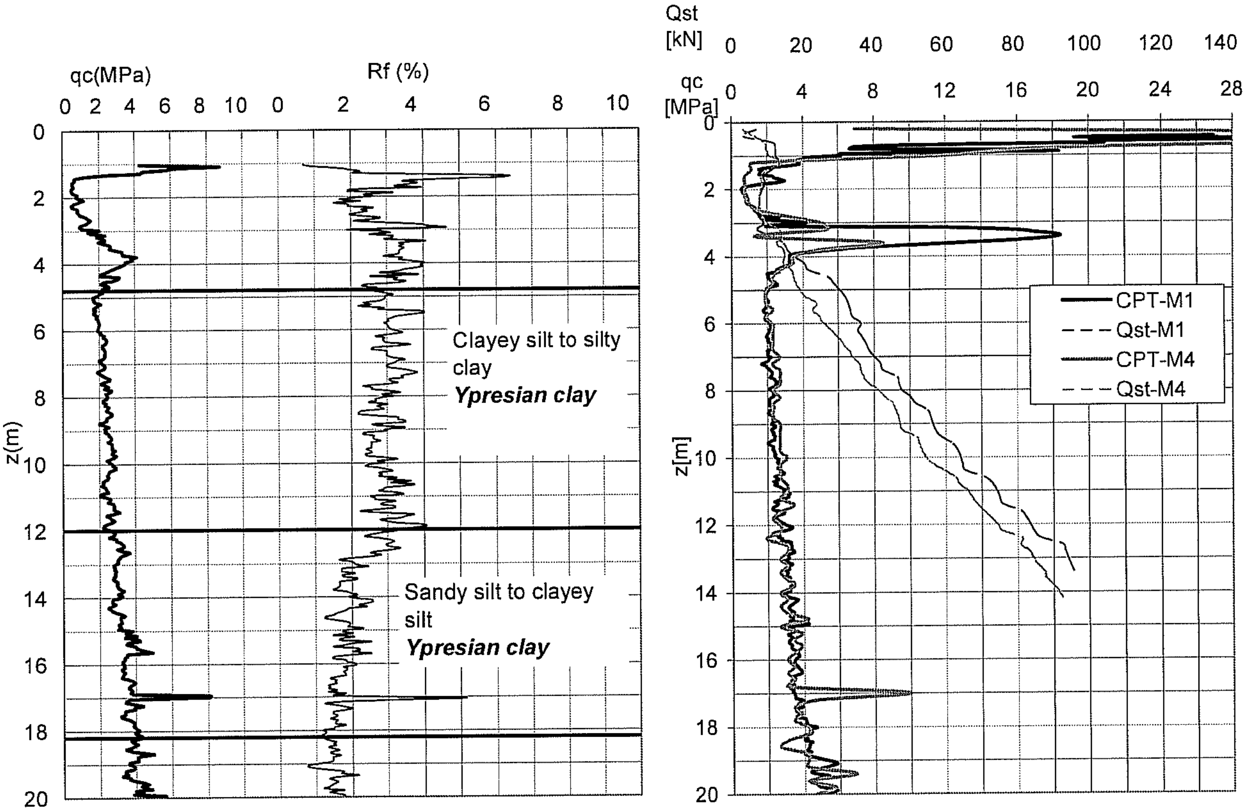


Fig 4. Koekelaere

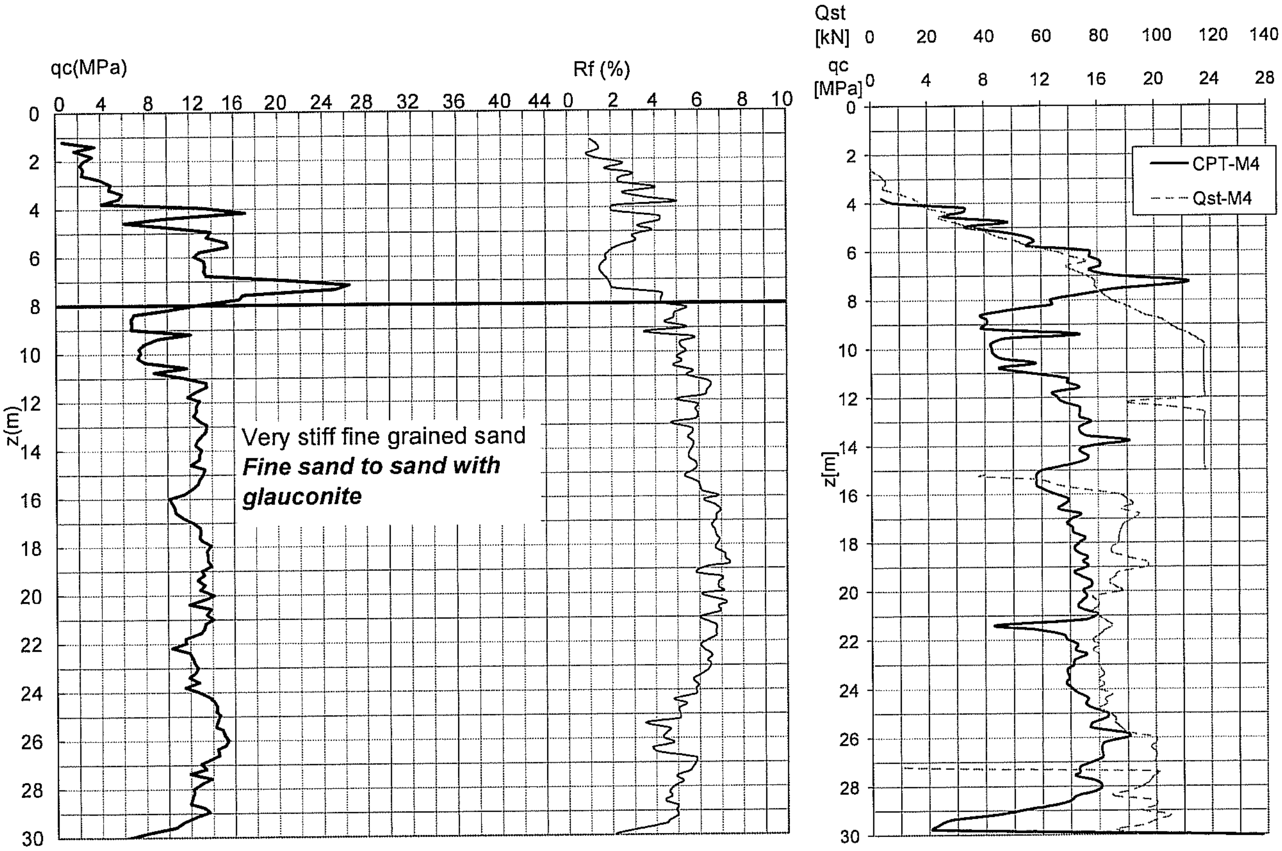


Fig 5. Antwerpen

In Figure 5, a site in Antwerpen where the subsoil consists of sand with a high content of glauconite is presented. As sands with a high content of glauconite have a high friction ratio, they are identified as clays or very fine grained soils following the CPT-E classification methods.

For the others types of soil (Fig.6 to 8), the classifications following both approaches are in good agreement. In Figure 6, the site of Loenhout is presented. The subsoil consists of tertiary sand covered by altering quaternary layers of silt, sand and clay.

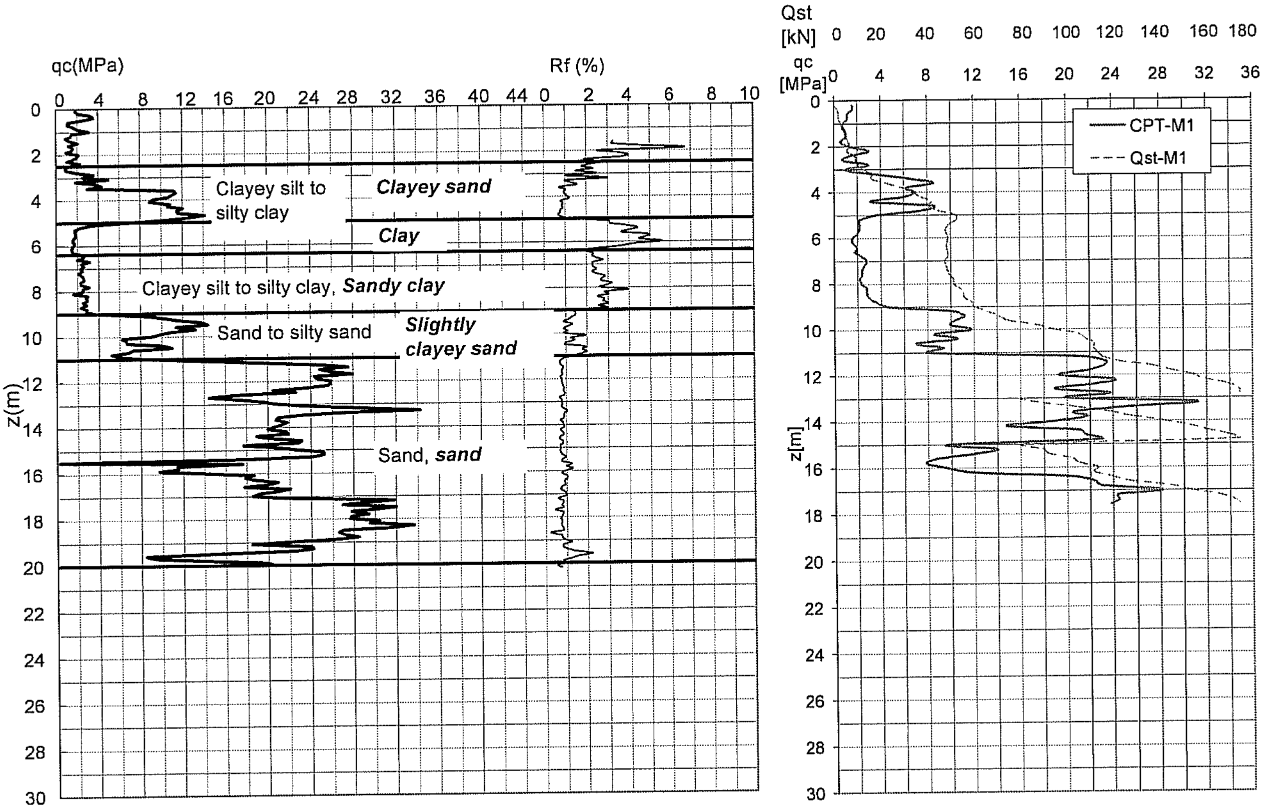


Fig 6. Loenhout

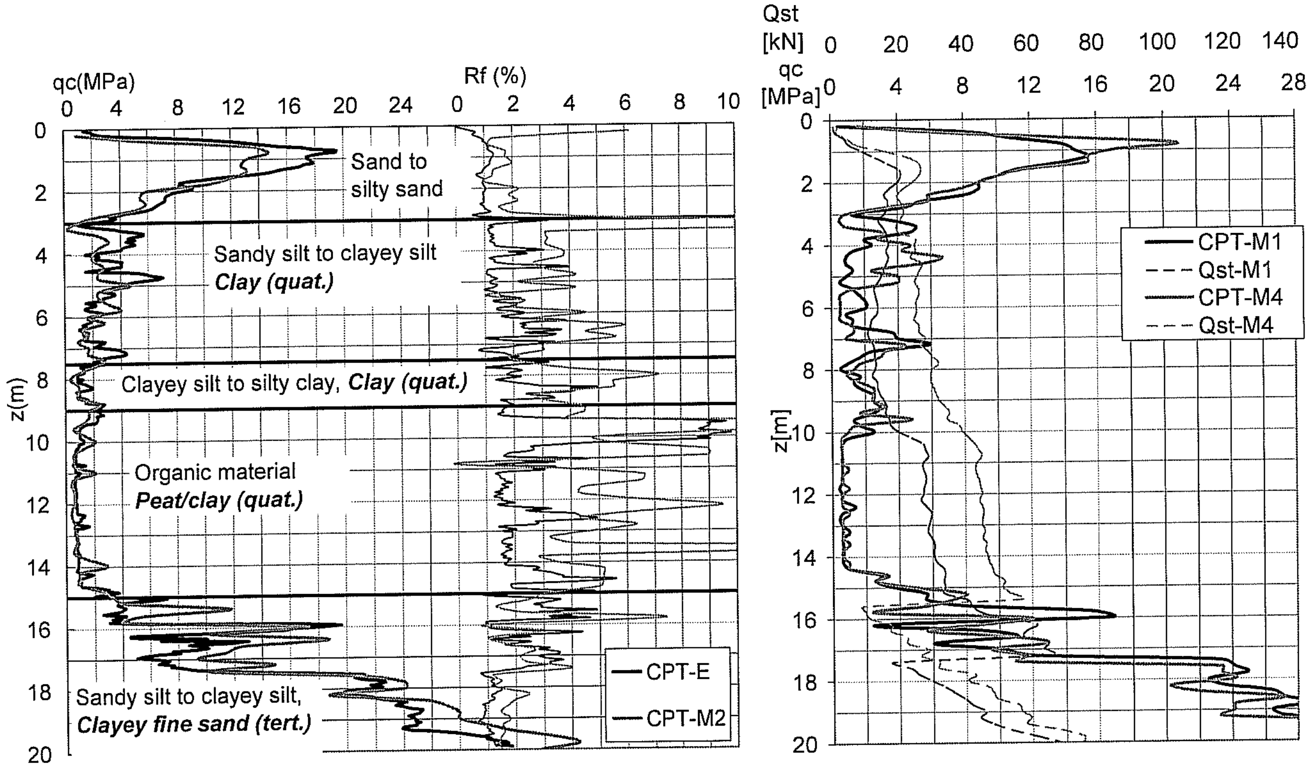


Fig 7. Beveren Doel

The subsoil in Beveren Doel (Figure 7) is characterized by weak soil conditions between 3 to 15m depth. For this site continuous CPT-M2 had been performed, from which it was possible to deduce a friction ratio as presented in Figure 7. It can be observed that the difference in friction ratio deduced from electric and mechanical CPTs is quite important. A general observation from the numerous CPTs performed in the framework of this study is that the repeatability and reliability of the mechanical friction measurements is quite not so good as for electrical CPTs. This is also the case for the discontinuous penetration measurements as can be seen by comparing the total side friction Q_{st} from the different types of cones.

The last example (Figure 8) is a loamy site in Ninove, which is representative for the quaternary subsurface of many sites in Belgium.

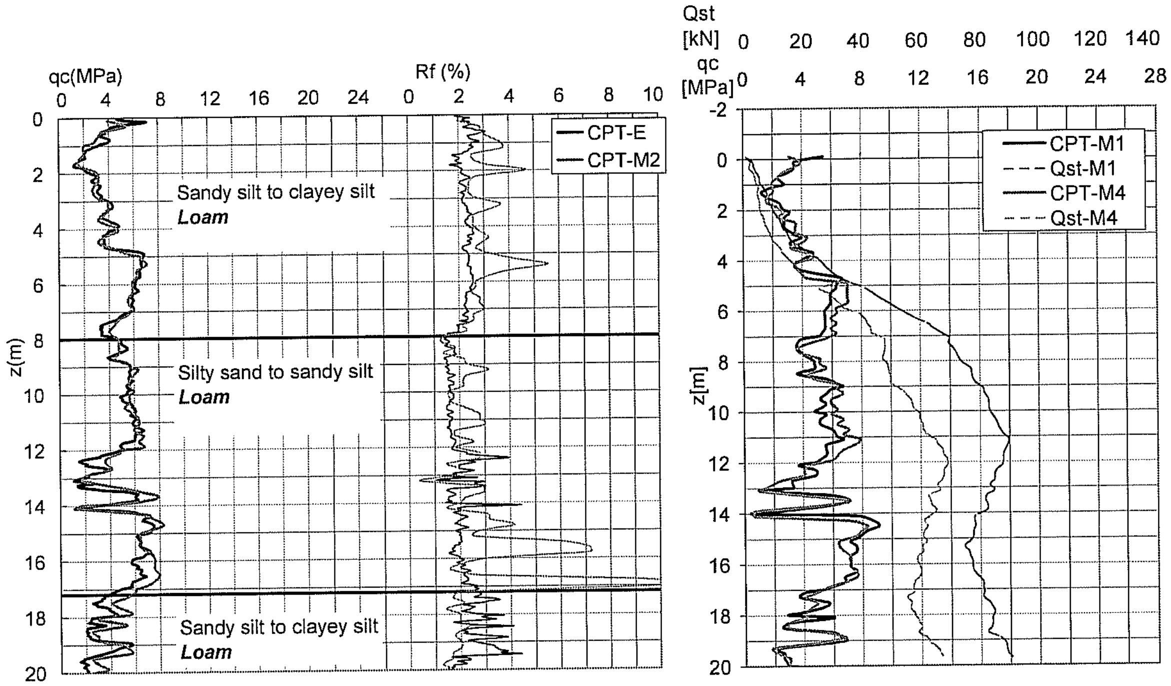


Fig 8. Ninove

2.3. *Comparative analysis of q_c-values measured with different CPT tips*

For comparing the influence of the different tips the mean values of cone resistance and friction ratio, calculated per meter of depth, are introduced. The cone resistances correspond to the 'q_c' value without any correction for the porewater pressure effects. Indeed the use of CPTU is not common in Belgium, and it is assumed that the influence of the porewater pressure on the ratio between electrical and mechanical cones is limited in most of the cases. Exception should be made for the soft clays, for which more investigation has to be performed. Based on these values, the ratios between the cone resistances obtained with the reference electrical cone and with the mechanical cones are compared. Examples are given in Figures 9 to 12 for different soil conditions.

2.4. *Global statistical analysis of the ratios between electrical and mechanical cone resistance*

For the global statistical analysis, four classes of soils are considered: "clay", "sand", "sand with glauconite" and "others". The "clay" soils cover the tertiary as well and the quaternary clays, as it has been observed by the analysis that for these soils the differences on cone resistance between electrical and mechanical measurements are quite similar. However the conversion factor for quaternary clays should be confirmed by more data for the whole range of very soft to stiff clays. Moreover the porewater pressure effects on the cone resistances and friction sleeve measurements have to be studied in more detail in the case of very soft clays. In the "sand" class the pure sand and the slightly clayey sands are gathered. A separated class is considered for the "sand with glauconite" because of the specific character of this sand (a.o. high Rf). Finally the "others" class covers all the types of soils between the clay and the slightly clayey sand.

Results are summarised in Table 1 and Figure 13. It can be observed that the average ratios between cone resistances as measured with various types of CPT tips are affected by the soil conditions. Clear trends are observable for clays; in particular the fact that measurements with the M1 and M2 mantle cones may give an increase of the cone resistance up to 30%, what can be explained by the friction of the soil on the mantle. For sands and intermediate soils, the results are more difficult to interpret. As a general rule, the ratios between the qc-values obtained with the mantle cones and the electrical cone are slightly below unity in the sand (0,97 and 0,90 respectively), and increase with the clay content. The ratio between the mechanical simple cone (M4) and the electrical cone is slightly above unity for all types of soils and is less influenced by the soil type. Statistically, for the other soils, the ratios are about one.

3 CONCLUSIONS

The difference between mechanical and electrical cone measurements is investigated in order to define conversion factors between the cone resistances as measured with various types of cones. Principal results are summarised in Table 1 and Figure 13. Because the ratios between cone resistances mainly depend on the soil types, the major difficulty is to define soil classification criteria for the choice of the conversion factors. In the "clay" class (Figure 13 & Table 1) the quaternary clay identified based on the CPT results (for example following the Robertson method) or based on the nature of the soil, and the tertiary clay identified based on the nature of the soil, are gathered. For these soils, the cone resistances measured with the mantle cones M1 and M2 are observed to be respectively 23 and 27% greater than the cone resistances measured with the electrical cone, especially for tertiary clays. For quaternary clays a same trend is observed, but should be confirmed by more data, covering the whole range of very soft to stiff clays. Also the porewater pressure effects have to be considered in the case of very soft clays. In the "sand" class, the sand, fine sand and slightly clayey sand as deduced from a CPT or boring identification are covered. In these soils, the mantle cones (M1 and M2) give cone resistances slightly below those obtained with the electrical cone, whereas the simple cone gives somewhat higher cone resistances, in particular in the sands with glauconite. The "others" class covers all the other types of soils. Statistically, the ratio between the cone resistances measured with mechanical and electrical cones are about the unity in these soils. This is the consequence of the averaging between soils with more or less sand or clay. As we can see in Figure 13 and Table 1, the uncertainty concerning the ratios for these soils is more important than for the pure clays or sands.

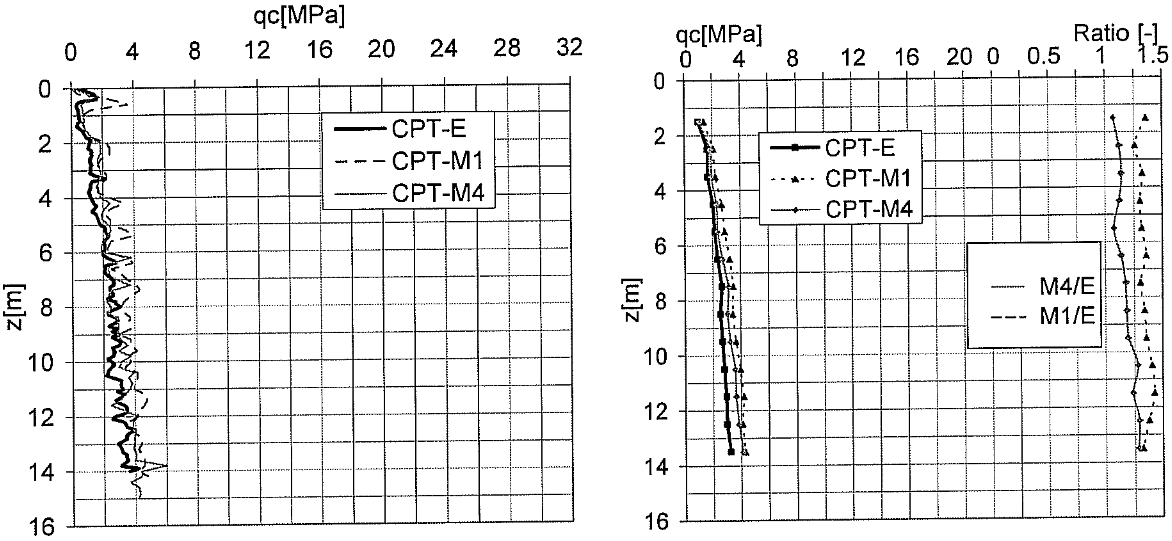


Fig 9. Clay example (Sint Katelijne Waver)

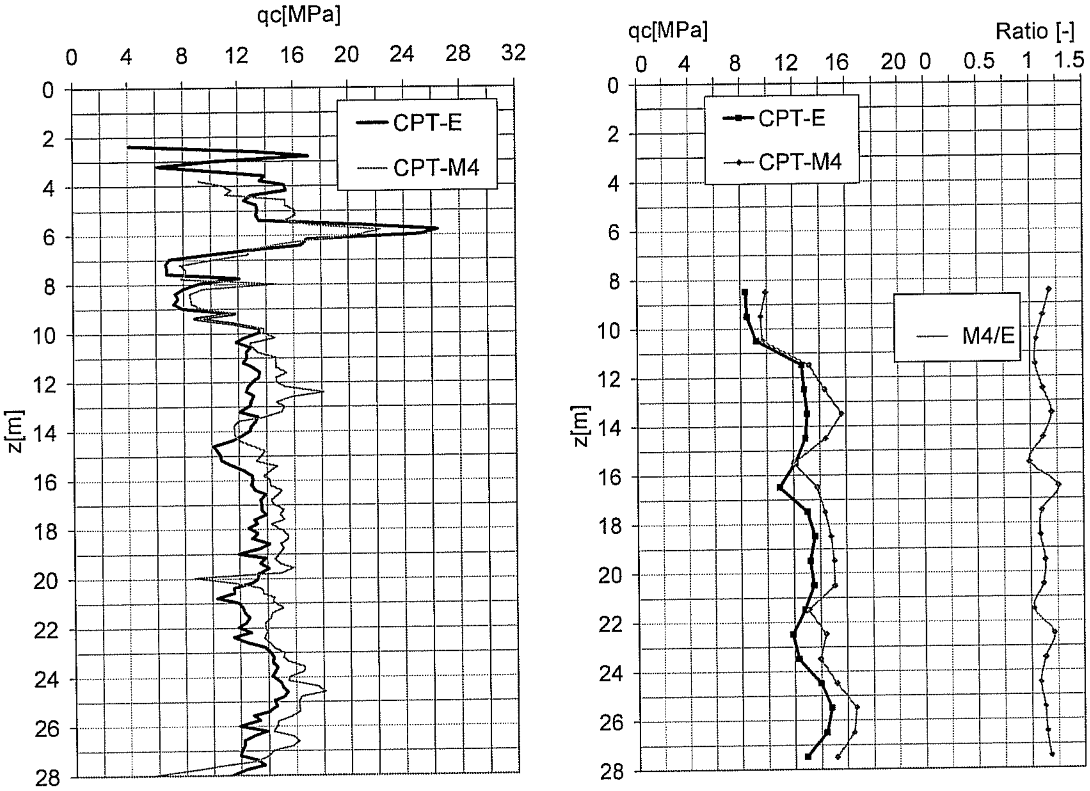


Fig 10. Sand with glauconite example (Antwerpen)

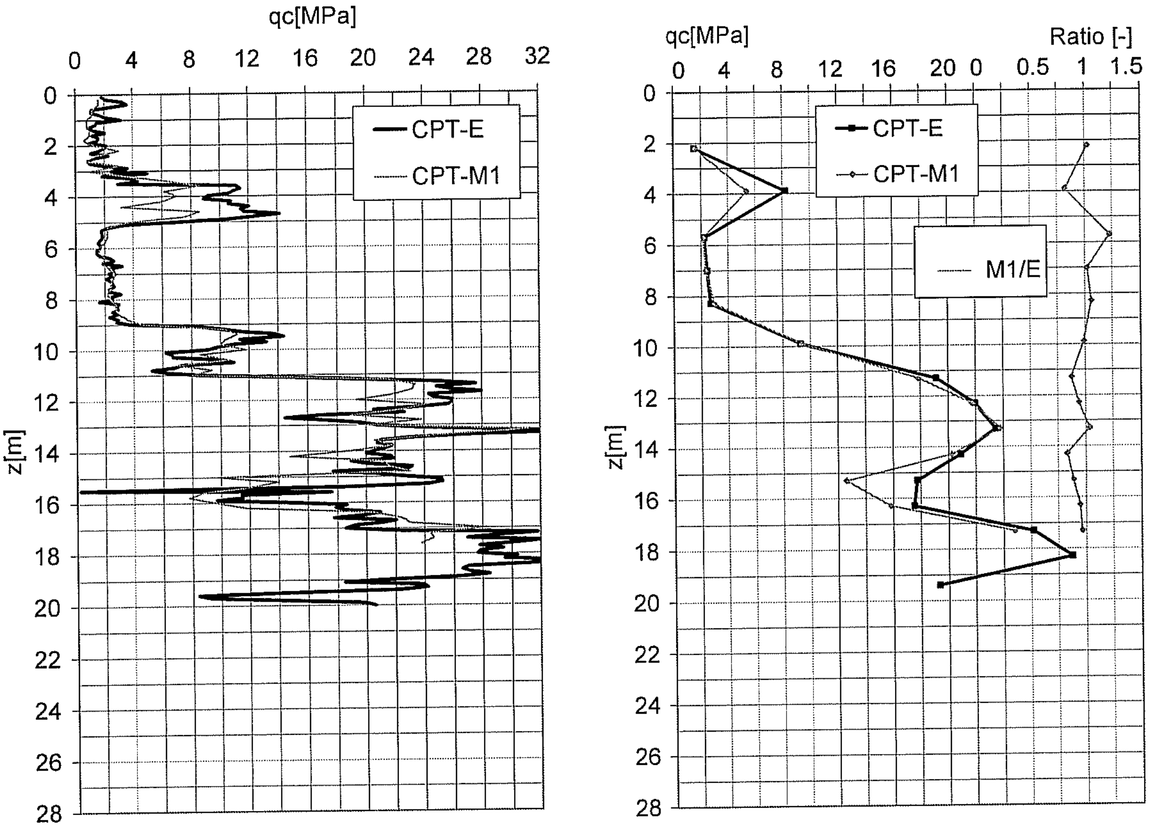


Fig. 11. Sand example (Loenhout)

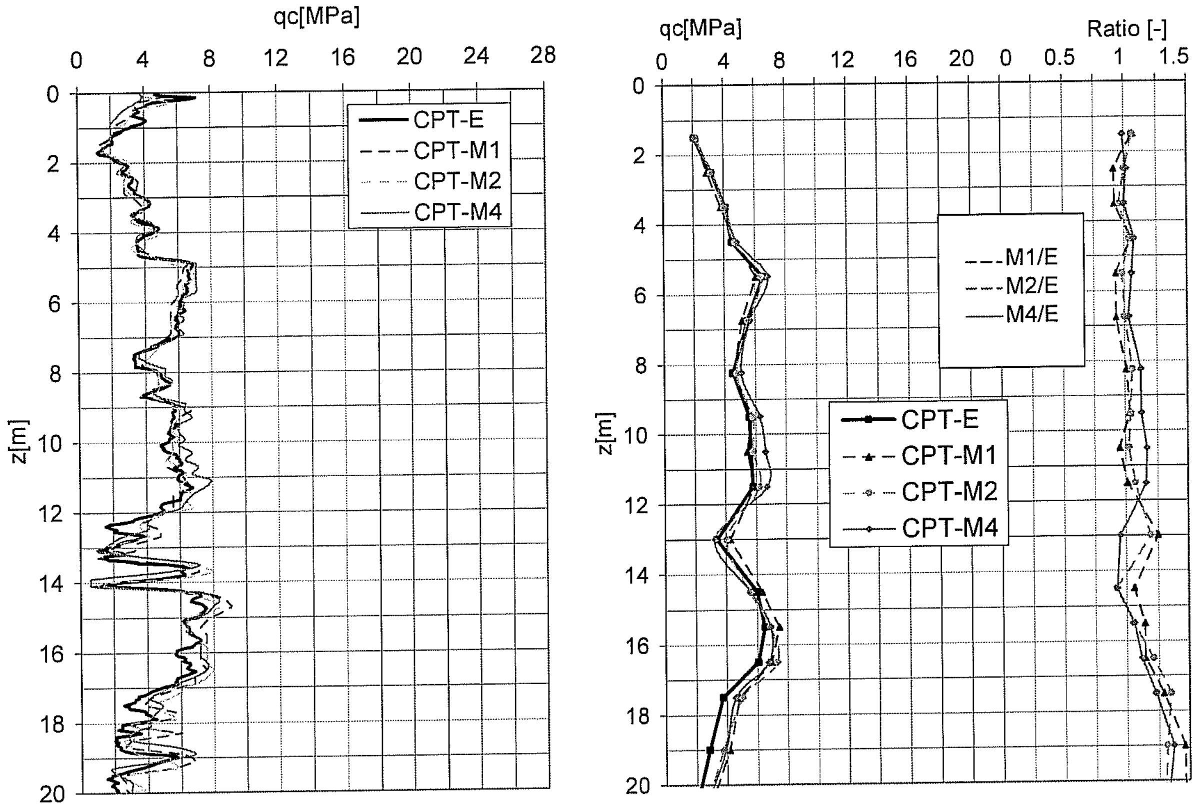


Fig. 12. Loam example (Ninove)

Table 1. Ratios between cone resistances as measured with mechanical and electrical cones.

Clay CPT-M1/CPT-E	Ratios	1,23
	Standard deviation	0,09
	Coefficient of variation	8%
Clay CPT-M2/CPT-E	Ratios	1,27
	Standard deviation	0,25
	Coefficient of variation	20%
Clay CPT-M4/CPT-E	Ratios	1,08
	Standard deviation	0,14
	Coefficient of variation	13%

Others CPT-M1/CPT-E	Ratios	0,99
	Standard deviation	0,18
	Coefficient of variation	19%
Others CPT-M2/CPT-E	Ratios	1,01
	Standard deviation	0,28
	Coefficient of variation	18%
Others CPT-M4/CPT-E	Ratios	1,01
	Standard deviation	0,18
	Coefficient of variation	18%

Sand CPT-M1/CPT-E	Ratios	0,97
	Standard deviation	0,11
	Coefficient of variation	12%
Sand CPT-M2/CPT-E	Ratios	0,90
	Standard deviation	0,10
	Coefficient of variation	11%
Sand CPT-M4/CPT-E	Ratios	1,07
	Standard deviation	0,13
	Coefficient of variation	12%
Sand with glauconite CPT-M4/CPT-E	Ratios	1,07
	Standard deviation	0,13
	Coefficient of variation	12%

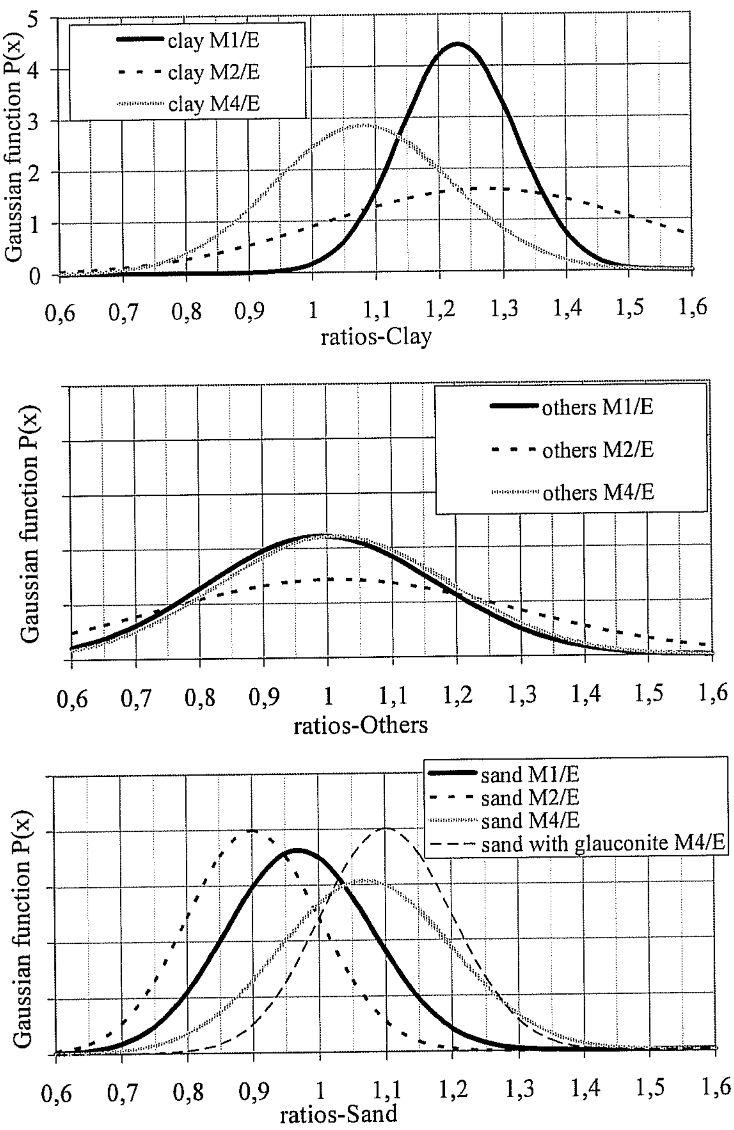


Fig 13. Ratios between cone resistances as measured with mechanical and electrical cones.

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