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A STUDY OF LATE-PLEISTOCENE RIVER DEPOSITS OF THE RHINE SYSTEM BASED ON STATIC PENETROMETER SOUNDINGS[1]

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ABSTRACT

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Penetration testing is basically aimed at the assessment of soil mechanical properties, especially the bearing capacity of the soil. It can, however, be applied to determine the dimensions and composition of lithological units as well.

A short description of the method is given and a case study presented. This case concerns the survey of a horizon with fluviatile clay and silt and peat deposits overlain and underlain by sands. It was found that 85% of the sounding graphs could be adequately interpreted and that the geometry of the deposit could be established with reasonable accuracy.

The paper concludes with a brief discussion of the expenditure involved, showing the relatively low cost of soundings compared with bailer drillings.

INTRODUCTION

A wide variety of methods can be employed at present to explore sub-surface geological phenomena. The choice must be based upon quality requirements, time frame, financial considerations, technical know-how, and the available facilities. When the survey under discussion was planned, the Geological Survey of the Netherlands had had little experience with the use of penetrometer testing as a tool in geological exploration. To explore the area preference was given to the use of geo-electrical resistivity measurements supported by drilling. Analysis of geological data revealed an unfavourable depth/thickness ratio for the deposit to be studied, and this set-up was abandoned. On further consideration, the geology of the area and terrain conditions seemed to favour the use of penetrometer soundings.

The paper opens with some short introductory remarks on penetrometer testing. Then the case itself is presented with special attention to the methods employed. Although the geological outcome of the survey is of great interest for a better understanding of the deposits, space limitations made it impossible te deal with this subject at length in this paper.

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PENETROMETER TESTING

Static penetrometers were developed in the Thirties to assist in establishing a quantitative basis for soil mechanical calculations, especially for foundation and piling. A static penetrometer basically consists of a series of steel rods which are pushed vertically into the soil at a constant velocity of 2 cm/s. During this process the resistance of the soil layers is measured as the resistance encountered at the tip of the rod, which is called the tip of cone resistance. When required, the local friction at the sides can be measured as well; this is called local side or mantle friction. Originally, the equipment was fully hand-operated, the rods having a load capacity of 2,500-10,000 kg. Although this type is still in use, the modern penetrometers are completely mechanized and often employ electrical cones.

The static penetrometer that was used for the survey under discussion consists of a truck-mounted hydraulic apparatus with a mechanical cone and with continuous registration of the resistance to penetration (Figs 1 and 2). It was not fitted with a friction sleeve to measure the side friction. It could exert a maximum load on the rods of about 13-15 000 kg without anchoring and 20 000 kg with the use of ground anchors, in this survey area resulting in maximum cone pressures of around 30 MN/m^2.

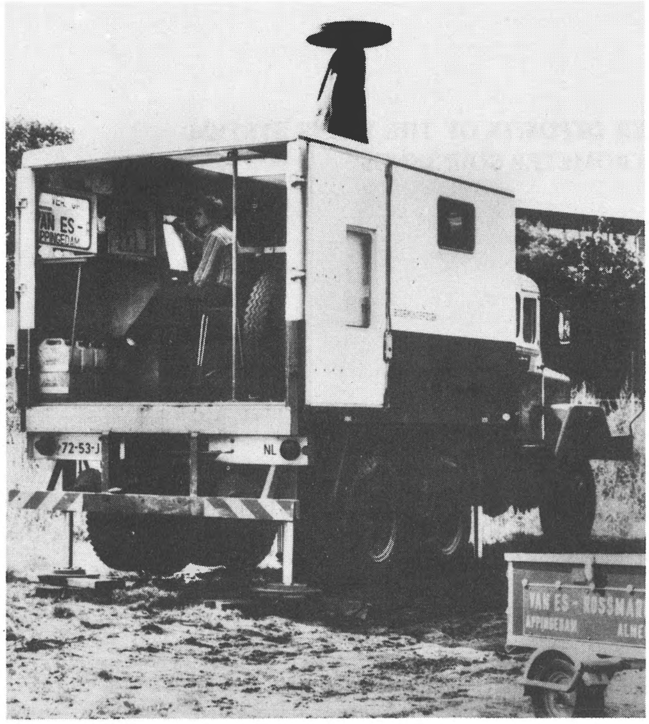

Fig. 1
Truck-mounted heavy penetration testing equipment. The hydraulic jacks at the four corners of the truck-body can be used to bring the work floor into a horizontal position, thus keeping the penetrometer rods in a vertical position, at least initially. The hood on the roof covers part of the sounding apparatus proper (see also Fig. 2). (Photo: Verenigde Grondboorbedrijven Van Es & Rossmark).

The interpretation of resistance logs for soil mechanical calculations is not always straightforward. Furthermore, geological studies of the type described here do not depend strongly on quantitative data but are based on the visual discrimination of units on the logs. Therefore, preference was given to continuous registration of cone resistance without measurement of the mantle friction, rather than discontinuous registration including mantle friction. Continuous registration reflects small variations in resistance better, thus facilitating a sedimentological interpretation of the deposit under study.

For a comprehensive discussion of the penetrometer, reference can be made to SANGLERAT (1972). The publications by BEGEMANN (1977) and BEGEMANN ET AL (1982) offer clear and useful information on the subject with special attention to applied aspects.

CASE STUDY

Geological background

Throughout late-Saalian, Eemian, and early and middle Weichselian times, the main course of the river Rhine ran through the present IJssel valley (Fig. 3). Especially during the Eemian, extensive clay and peat deposits were formed. Figure 4 shows a schematic cross-section depicting the main stratigraphic and lithologic units, which clearly indicates the variation in thickness of the clay-peat deposits and their absence in parts of the section. The causes of this variability are not yet fully understood, but it is assumed that the clay-peat deposit represents partly fossil back-swamp deposits and partly channel fills of the Rhine.

The presence or absence of the clay-peat deposits is of great importance from both geotechnical and hydrogeological points of view. The founding of heavy structures often encounters considerable problems, as is clearly illustrated by the very distinct depression in the road surface over one of the piers that supports the highway bridge spanning the IJssel near Deventer. The same applies to the highway bridge near Zwolle.

Hydrogeologically, a thick and extensive clay-peat deposit is of great interest because it protects the underlying aquifer from direct contamination by surface water. It also flattens out the depression cone that is generated when ground water is extracted by pumping. The study discussed here was undertaken for hydrogeological purposes.

The project

The regional water supply company (Waterleidingmaatschappij Overijssel) was interested in developing the aquifer in the coarse lower part of the Kreftenheye Formation (Fig. 4),

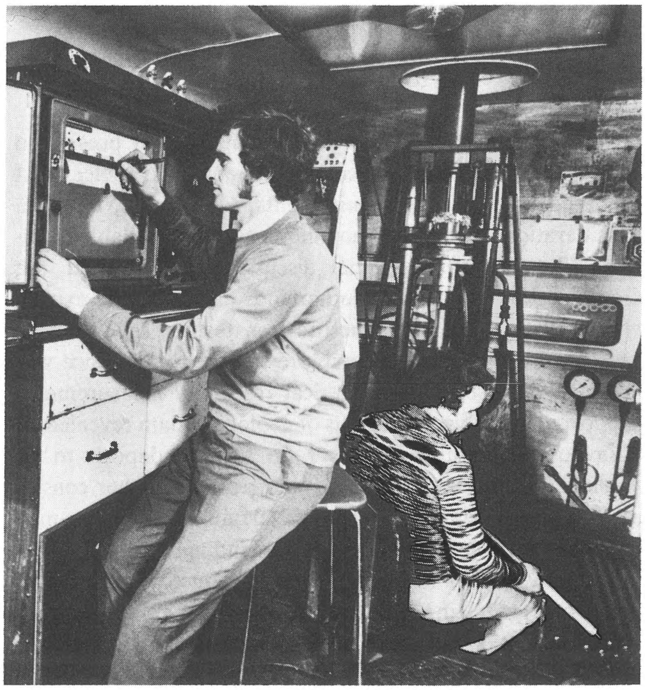

Fig. 2
Interior of truck shown in Fig. 1. In the middle at the back the hydraulic penetrometer machinery can be seen. The man on the floor holds an extension rod for the string of sounding rods. The technician on the left is working at the graphic recorder. (Photo: Verenigde Grondboorbedrijven Van Es & Rossmark).

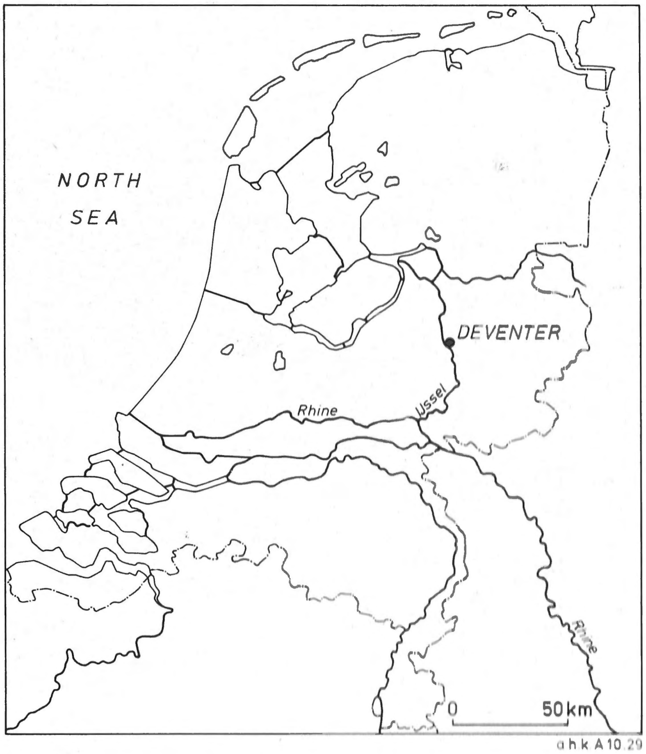

Fig. 3
Map of The Netherlands. The project area is located just north of the town of Deventer.

which made a good understanding of the distribution, thickness, and other characteristics of the clay-peat deposit necessary. The Geological Survey of The Netherlands was asked to undertake the required studies. The area in which the investigations took place is situated north and northeast of the town of Deventer (Fig. 3) and measures almost 30 km^2. Analysis of existing drilling logs and soundings graphs revealed the variability in thickness, depth, and occurrence of the clay-peat layer, which made extensive additional observations necessary. For these investigations, static penetrometer testing was chosen.

In the first stage of the survey, 123 soundings were made. This was followed by a series of 11 drillings to obtain reference data for the interpretation and checking of the soundings, to assess the transmissivity for water in samples, and to place standpipes with filters. Because the results proved to be very satisfactory another 99 soundings were performed, thus bringing the total number to 222. Of this number, 15% were not deep enough due to unsurmountable resistance or friction, or led to problems in interpretation. Since these shortcomings were already observed during the fieldwork, additional soundings could be performed immediately, thus avoiding gaps in the pattern of observation points.

The sites of the soundings were not arranged in a systematic grid but were chosen during the fieldwork. This was feasible because the soundings results could be read directly from the data provided by the self-registering recording equipment. Furthermore, because the truck-mounted apparatus is very mobile, it was almost always possible to make soundings at sites where information was needed the most.

Interpretation of soundings

The field programme was started with a series of soundings beside boreholes for which a lithological description was available. It became clear that both the value of the cone resistance and the shape of the sounding curve should be considered when the presence or absence of a clay-peat deposit must be established. A cone resistance of less than 4 MN/m^2 and an abrupt upper and lower boundary of the range with low resistance proved to be diagnostic for the presence of a clay-peat deposit. These rather simple criteria formed the basis for the interpretation.

However, zones with a resistance of less than 4 MN/m^2 are not always related to the occurrence of clay-peat layers. Compare, for instance, the depth range 0-5 m in Fig. 5a, the range 0-5.5 m in Fig 5c, the ranges 5-7 and 10-11 m in Fig 5d. Although the resistance values are in the range of clay-peat, the shape of the curves is distinctly divergent. In general,

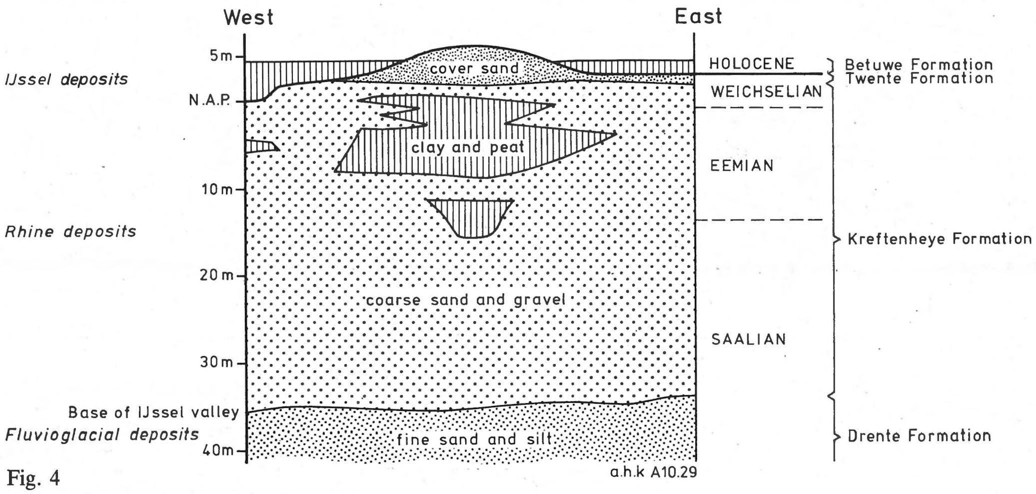

Fig. 4
Schematic cross-section near Deventer.

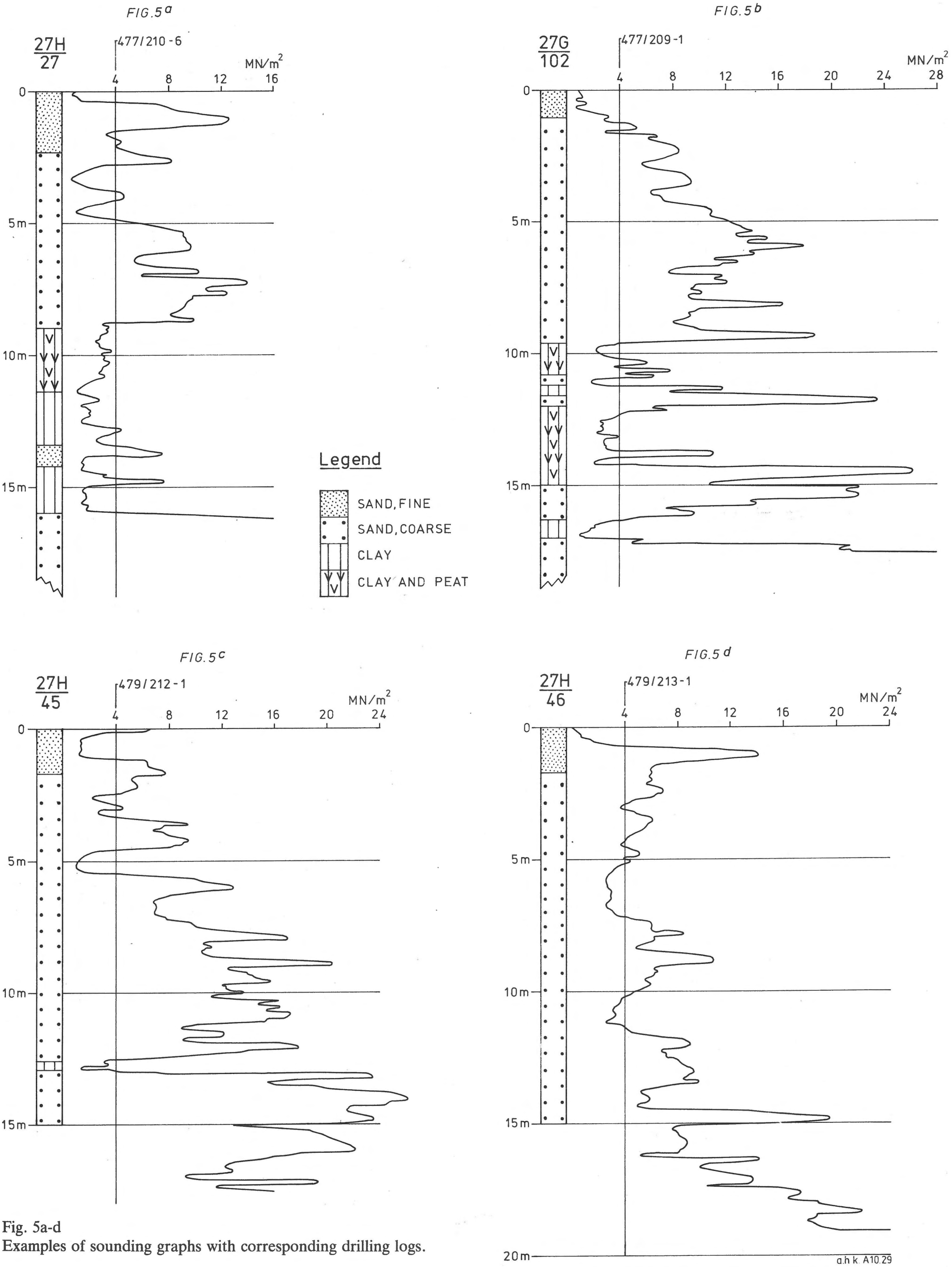

Fig. 5a-d
Examples of sounding graphs with corresponding drilling logs.

zones of low resistance due to clay-peat can be distinguished from those due to other factors, although curves like the one around 5 m in Fig. 5c are treacherous. Complementary measurement of the mantle friction greatly facilitates the discrimination, but the extra costs involved in the use of a special cone prohibited application of this method in the project under discussion. Furthermore the curve at the base of Fig. 5b is not typical for a clay-peat layer.

It should be mentioned here, that 4 MN/m² was taken as the boundary value between clay-peat and other deposits simply as a matter of convenience, because it had been found to be a workable criterion. With the methods described here, however, the numerical value is less important than it is in soil-mechanical investigations. Useful observations can also be made during the execution of the soundings. For example, penetration of gravel layers is signalled by the noise and sudden variations in resistance.

The 11 reference drillings were performed at the sites of the soundings considered to indicate the presence or absence of the clay-peat layer or whose interpretation created problems. Most of them could be brought down within 10 metres of the sounding but avoiding the same spot. The clay-peat layers were cored and described, and their depth was painstakingly recorded. The original soundings graphs from the recorder were not available; instead, the redrawn copies made by the contractor had to be used.

Four examples of sounding graphs and the corresponding drilling logs will be discussed. Figure 5a shows the comparison between the drilling log and the sounding graph of a clay-peat layer more than 7 m thick. There is a perfect match of log and graph for the upper and lower boundaries. The upper two metres of the sounding show a generally higher cone resistance than the lower part, which coincides with a high content of organic matter in the drilling log. This tendency is, however, not always noticeable. The two peaks with high resistance in the lower part appear to be of a comparable nature but have a different explanation. The upper one can easily be matched with the fine sand layer in the drilling log. This is not possible for the lower one. On the basis of the lithological description, the higher resistance can be explained either by the occurence of a shell layer or the presence of a sand layer.

Figure 5b shows a series of four clay-peat layers intercalated in sand. The lowermost (around 16.5 m) layer shows a good match between the drilling log and the sounding graph. This layer is overlain by 1.20 m of sand in the drilling log and a 2.00 m zone of > 4MN/m² in the sounding graph. In the drilling log this is followed by a sequence consisting of 3.00 m of sandy clay, 0.3 m of coarse gravelly sand, 0.4 m of clay, 0.3 m of coarse sand, and 1.30 m of sandy clay with peat. In the sounding graph a lower and an upper part can be distinguished divided by a peak of high resistance that coincides with the gravelly sand layer. The upper part shows a more variable cone resistance than the lower one. This is interpreted as a zone with sand layers alternating with clay and peat, contrasting with a more uniform sandy clay in the lower part.

In Figure 5c a 40 cm thick zone with a resistance of less than 4 MN/m² is present in the sounding graph. This matches perfectly with a 30 cm thick clay layer at the same depth in the drilling log.

Figure 5d shows a graph with a zone of low resistance around a depth of 10 m, but the curve does not show the abrupt changes that characterize a transition from clay-peat to sand (see Fig. 5a-c). The control drilling made at this spot does not reveal any clay or peat at this depth. Between 9 and 12 m, only coarse sand with dispersed fine gravel is present.

These four examples were selected to demonstrate the agreement between drilling logs and sounding graphs, ranging from excellent (Fig. 5a and c) via good (Fig. 5b), to no match at all (Fig. 5d).

Results

On the basis of the results of soundings and drillings, the pattern of the occurrence of the clay-peat layer could be mapped and variations in its thickness and lithology established. The results were presented in a report including a distribution map and 24 sections (RIJKS GEOLOGISCHE DIENST, 1973, unpublished report).

Although the aim of the project was to collect data for hydrogeological purposes, the results could also be used for studies of a more scientific character. Palynological studies on samples or organic layers encountered during the drilling programme and careful interpretation of drillings and soundings led to a better understanding of the development of the Rhine system since late Saalian times (VAN DE MEENE & ZAGWIJN, 1978, VAN DE MEENE, 1979).

Expenditure

Based on the price level for 1982, 222 soundings with an average depth of 18 metres, as made for the project, would cost about Dfl. 40 000 (approximately US $ 15 000). Such a project would require about 25 working days. Eleven bailer drillings with an average depth of 18 m, each including 3 m of continuous coring, would cost about Dfl. 20 000 (approx. US $ 7 500) and take 22 working days. These figures indicate the relatively low cost of soundings compared with bailer drillings.

CONCLUDING REMARKS

Static penetrometer sounding can be very useful for geological investigations. Continuous registration of the cone resistance produces a record that nicely displays lithological variations thus permitting rather detailed sedimentological studies. Combination with continuous registration of the mantle friction and determination of the friction ratio (ratio between cone resistance and mantle friction) leads to a better understanding of the lithological composition of the layers encountered. Nevertheless, carefully sampled reference drillings are still necessary for the proper interpretation of soundings (VAN DE MEENE, 1974; KRAJICEK & DE LANG, 1982).

In the project discussed here, the study of soundings graphs present in various files proved to be very rewarding. In this connection it may be mentioned that in The Netherlands alone about 80 000 soundings are performed each year (BEGEMANN ET AL., 1982) thus creating a largeley untapped reservoir of geologically uninterpreted data. However, it need hardly be said that optimal results can only be expected from the combination of soundings and drillings made to study a well-defined problem. In 1982, in another area, the regional water supply company undertook a survey to determine the distribution, thickness and composition of clay-peat deposits of Eemian age and for this survey an electrical cone equipped with a friction sleeve was used. Determination of the friction ratio proved to provide a very sensitive indicator of lithological variations (TH. P. R. SMIT, 1983, pers. comm.). This survey was modelled after a geological project based on penetrometer soundings which had been undertaken by the Geological Survey in 1981.

Penetrometer testing can be also useful for geomorphological investigations. An example of this application is given by KOSTER (1978), who used this method to discriminate between Late Glacial and Holocene dune sands.

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