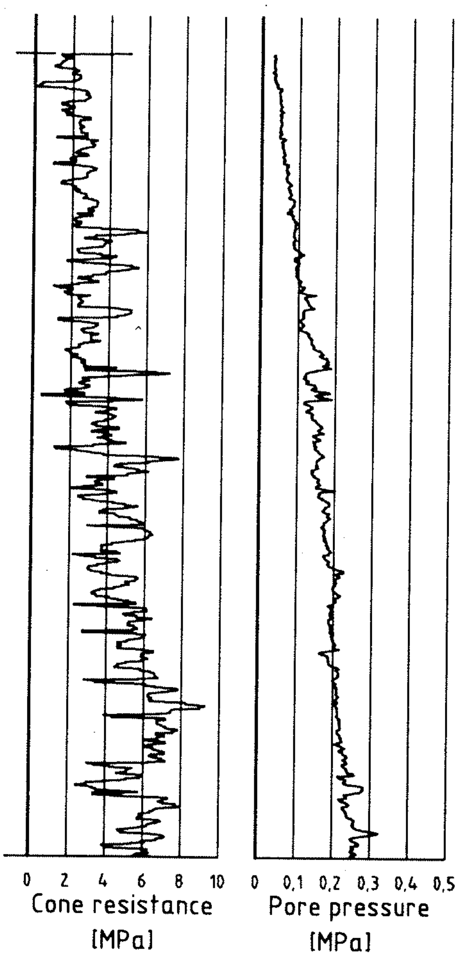
Intern rapport nr. 1788

CPT in bridge foundation and embankment design



August 1995

Veglaboratoriet

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Sammendrag

The cone penetration test (CPT) has proved to be a valuable tool in obtaining design parameters for foundations especially in silty and sandy soils, and even in clay.

This paper is submitted to the international symposium CPT'95 in Linkjøping, Sweden. It shows a few cases where CPT interpretations are compared with laboratory test results, and design calculations based on CPTs are compared with field observations and other design methods.

Emneord: *CPT, interpretation*

Seksjon: *Geoteknisk*
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Dato: *August 1995*

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Innhold

CPT IN BRIDGE FOUNDATION AND EMBANKMENT DESIGN

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SYNOPSIS: At the Norwegian Road Research Laboratory (NRRL) we have more than ten years of experience with the use of CPT in ground investigations for road and bridge projects.
The CPT equipment has proved to be a valuable tool in obtaining design parameters especially in silty and sandy soils, and even in clay. It can in many cases provide sufficient data to reduce the amount of more expensive piston sampling.
The article focuses on the interpretation of strength and deformation parameters with case histories including embankments and pile foundation design. CPT interpretations are compared with laboratory test results, and design calculations based on CPTs are compared with field observations and other design metods.

1. INTRODUCTION

The first CPT soundings for the Norwegian Public Roads Administration were performed with the site investigations for the bridge over the lake Mjøsa in 1973 and in 1980 - 82 (Rygg, 1983). The positive results from this project led to the purchase of our first CPT equipment in 1981, and later on to a more practically applicable equipment purchased in 1987.

Our present CPT equipment is an electronic 3 - channel ENVI-cone with cone resistance, pore pressure and friction measurement. The annual amount of CPT soundings is about 1000 metres.

Traditionally, rotary-pressure sounding has been our main tool obtaining information about the overall ground conditions, including the location of quick clay deposits (Rygg and Andresen, 1988). This method is cost-effective, and with its development into the so-called total sounding method during the last years it provides most of the basic information needed (Fredriksen et.al., 1992).

For more detailed information on soil layering, and for the assessment of strength and deformation parameters, CPT is a valuable supplement. In cases where it is difficult or very expensive to obtain good results from 54 mm piston sampling, CPTs can reduce the number of samples necessary. This has been the case both for on-land and sub-sea investigations, especially for projects in silty and sandy soils, but even in soft clay.

Penetration capability is a limitation for the CPT equipment due to rod friction, especially when compared to the sounding methods mentioned above. Penetration can be improved to some extent by rather simple means (Oset, 1989), and soundings have been performed to depths of more than 60 metres in clay.

In several projects CPT data have formed a major part of the design basis for:

* bearing capacity of piles
* stability and settlements of embankments
* detailed mapping of soil layering for wellpoints.

Most of the excisting interpretation methods are reviewed in the report by NGI (1992). The interpretation methods used by The Norwegian Road Research Laboratory are summarized by

Vaslestad (1993).

The interpretation of data from CPT soundings and their use in a number of cases is outlined in the following sections.

2. INTERPRETATION OF SOIL PARAMETERS

In the following section we will present a comparison between strength- and deformation parameters obtained by CPT - soundings and by other methods based on laboratory testing of soil samples like triaxial and oedometer tests. The same methods for interpretation are used in both cases (Sandven et.al. 1988 and Senneset et.al. 1988).

2.1 Verdalsøra bridge

Verdalsøra bridge is situated in Nord Trøndelag county, Norway, and is planned as a 178 m long steel beam bridge founded on steel pipe friction piles.

The ground mainly consists of silty sand / sandy silt to depths exceeding 70 m. In connection with the ground investigations CPT - soundings were performed, as well as soil sampling with 54 mm piston sampler. The soil conditions and design of bridge foundations are reported by Vaslestad (1995).

As shown on figure 2.1 there were good accordance, on this site, between parameters obtained by CPT and by triaxial / oedometer tests.

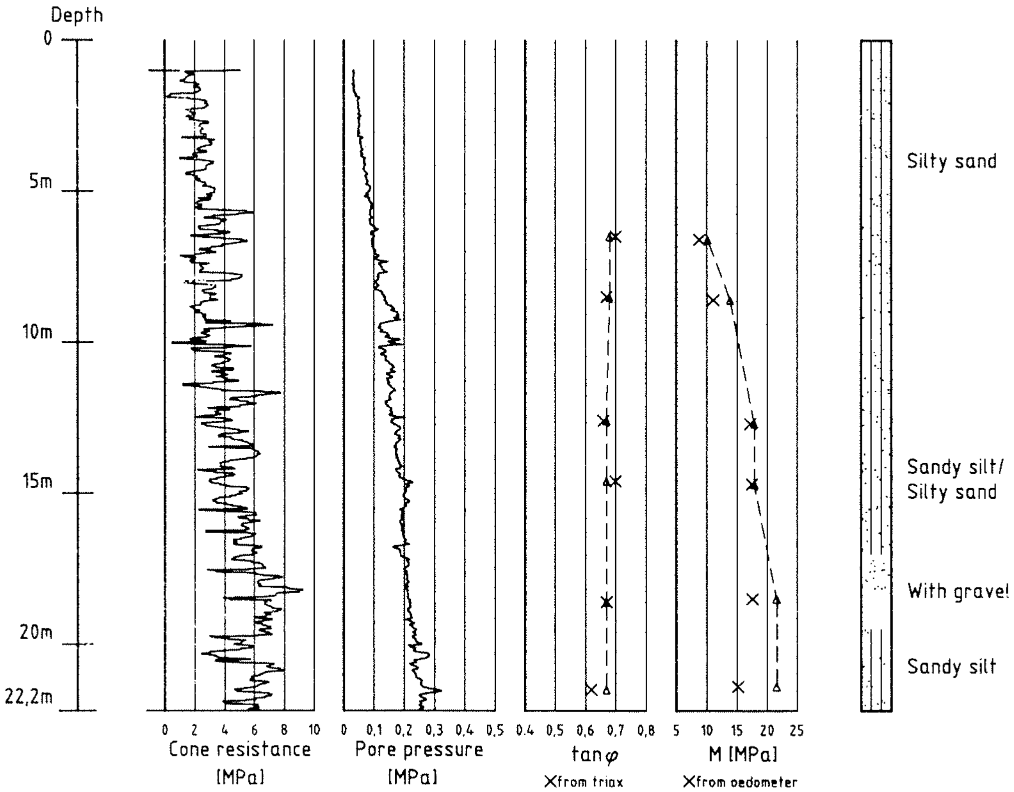

Figure 2.1 Results from Verdalsøra bridge.

2.2 Jungerveien bridge

Jungerveien bridge is situated in Buskerud county, Norway, and is a 69 m long bridge founded on end bearing piles.

The ground consists of soft clay. Depths to bedrock are from 25 m to 57 m along the bridge. Among other soil investigation methods there were performed CPT - soundings, triaxial tests and oedometer tests. The ground conditions are reported by Solberg (1994).

As shown on figure 2.2 there is a sligthly poorer accordance between parameteres obtained by CPT - soundings and by triaxial / oedometer tests for the clay material. The interpretation of the CPT - soundings gives higher values for the shear strength parameter, tan φ, and lower values for the deformation modulus , M.

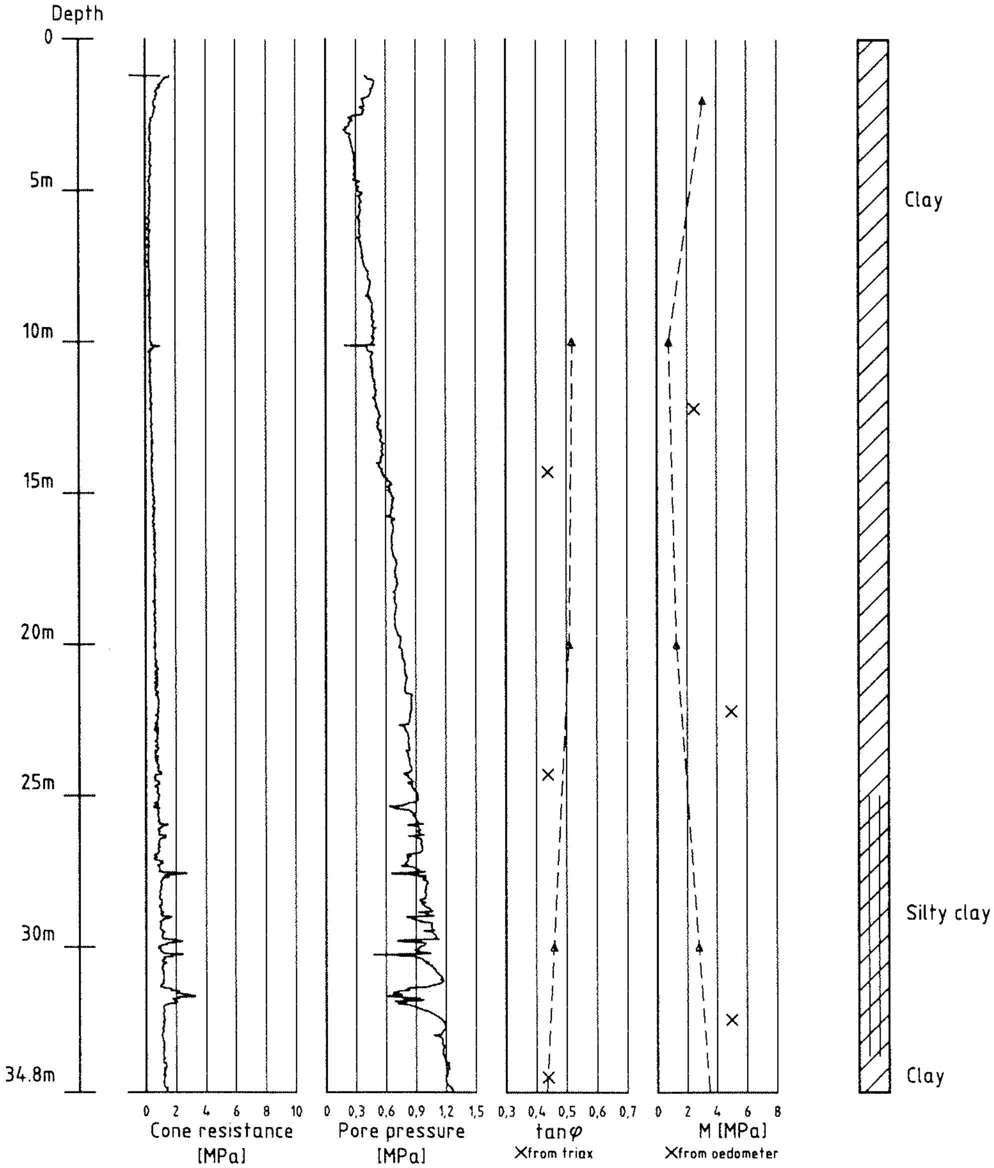

Figure 2.2 Results from Jungerveien bridge.

3. BEARING CAPACITY OF PILES

Large diameter driven steel pipe piles is a common method for the design of highway bridge foundations in Norway.

The most common method for predicting the bearing capacity of piles in bridges in Norway is the Janbu-method,(Janbu, 1976). The method of Flaate and Selnes (1977) are also used.

Both of these methods are theoretically based, and there is a need for a method based on in-situ investigations.

Bustamente and Gianeselli (1982) introduced a method based on results of in-situ investigations, namely CPT.

The method is based on 197 full scale static loading tests with different types of piles and ground conditions. Most of the static loading tests were carried out by the laboratory network of the French Highway Department (LCPC), and is called the LCPC-method.

The method is based on cone resistance from CPT directly (direct method) and there is no need for evaluating any intermediate values like effective shear strength parameters used in the Janbu-method (indirect method).

The LCPC-method does not directly require the CPT sleeve friction value. This is a desirable feature since the cone resistance is generally obtained with more accuracy and confidence than the sleeve friction.

Robertson et.al (1988) reported predictions from thirteen axial pile capacity methods compared with the results from eight full scale pile load tests on six different steel pipe piles. The direct methods, which incorporate CPT-pile scaling factors , provided the best predictions for the piles and methods evaluated. For the piles tested the LCPC-method was shown to be the best method.

The LCPC-method was used to predict the bearing capacity of steel pipe piles in the foundation of two bridges in Norway.

The first bridge was the Minnesund bridge, reported by Rygg (1991). The ground conditions consists of mainly overconsolidated silty clay with sand layers. CPTU testing were performed.

The steel pipe piles were open ended, 24 m long with diameter 916 mm and steel thickness 16 mm. Static load testing were performed on one of the piles.

The following characteristic bearing capacity Qk were predicted :

- The Janbu method : Qk = 4200 kN

- The LCPC-method : Qk = 3100 kN

Result from static load testing :
Q = 1900 kN

The reasons for the low bearing capacity obtained on the open ended steel pipe piles will be investigated further.

The second bridge is Finneidstraumen bridge, reported by Sleipnes (1993). The soil consists of silty clay with undrained shear strength between 40 and 80 kPa predicted from CPTU- testing down to 65 m depth.

Steel pipe piles with length 40 m, diameter 1000 mm had the following predicted bearing capacity :

- The Janbu method : Qk = 8000 kN

- The LCPC-method : Qk = 6500 kN

The predictions based on the LCPC-method were used in the final design.

4. SETTLEMENT OF EMBANKMENTS

In 1990 - 1991 there were performed ground investigations in connection with planning and building of the new main road E6, from Hommelvik to Værnes in Nord Trøndelag county, Norway. The new road consists of embankments, partly along the shore line, as well as a 330 m long bridge crossing the river Stjørdalselva and two smaller cross-over bridges. Settlement analysis was performed based on deformation parameters obtained from the CPT - soundings.

The ground in the area consists of loose sands, silty sands and silt. A clay layer at 25 - 30 m depth were also registrated. The results for one of the boreholes are shown on figure 4.1.

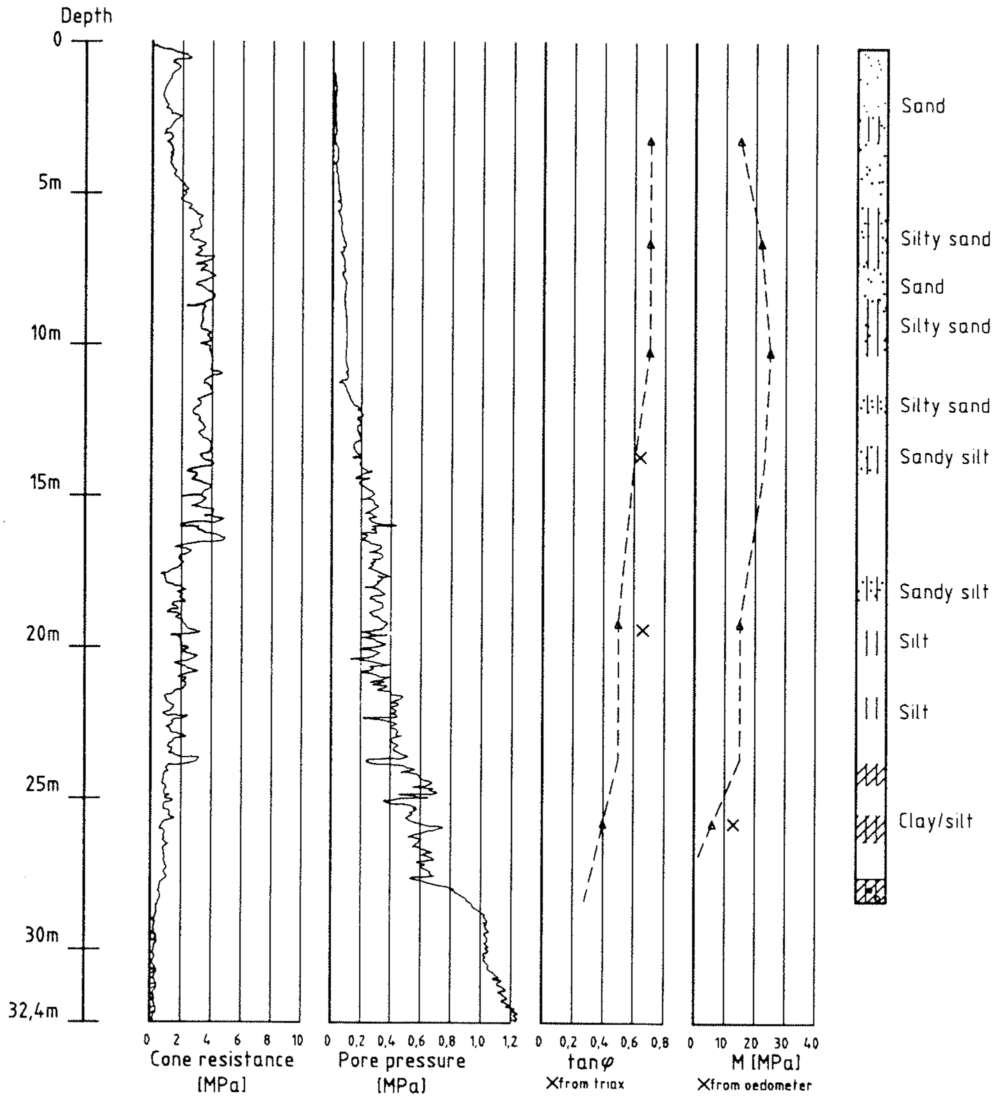

Figure 4.1 Results from Hellstranda.

Using deformation parameters from the CPT, the settlements for a 3 m high embankement was calculated to be 10 - 12 cm. The settlements were expected to be completed in short time due to the loose sand / silt. After the building of the embankment the settlements were measured with settlement plates at regular intervals. The measurements showed that the total settlements were only about 6 cm at this particular site. Settlements measured on other sites on this project (abutement fills) were also smaller than predicted by using the deformation modulus, M, interpreted from the CPT - soundings. As an average the measured settlements were about 50 % of the calculated settlements.

5. CONCLUSIONS

With its limitations on penetration, CPT is not likely to replace the rougher sounding methods like Rotary-pressure sounding and Total sounding, but it is a useful supplement where more detailed mapping of soil layers is needed. In addition, CPT can replace or reduce the amount of piston sampling in many cases.

CPT has proved to be an efficient tool providing soil data for design of bridge foundations, embankments etc. Interpretations of shear strength parameters on effective stress basis have proved to correspond well to laboratory results from triaxial testing.

Deriving deformation parameters from CPTs for use in settlement calculations seem to be a more uncertain task when the calculations are compared to actual observations.

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