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Research on strength and deformation properties of Swedish fine-grained sulphide soils

La recherche sur la force et la déformation des propriétés de la terre sulphide Suédois au fin grain

B. Westerberg & D. Albing
Department of Civil and Environmental Engineering, Division of Soil Mechanics and Foundation Engineering, Luleå University of Technology, Sweden

R. Larsson
Swedish Geotechnical Institute, Sweden

ABSTRACT

A recently started research project concerning strength and deformation properties of Swedish fine-grained sulphide soils is presented. The scope of study is outlined. The overall purpose of the project is to find suitable testing methods in field and laboratory to determine reliably the mechanical properties of fine-grained sulphide soils. In this paper, some test results of undrained shear strength of sulphide soils, determined with different test methods at two test sites, is presented. The results confirm that there is a need for calibration of the different evaluation methods in order to obtain relevant values in fine-grained sulphide soils.

RÉSUMÉ

Un nouveau projet de recherche concernant la force et la déformation des propriétés de la terre sulphide Suédois au fin grain est présenté. L'étendue du projet est brièvement en revue. L'objectif général de ce projet est de trouver des mesures appropriées dans le champ et au laboratoire afin de déterminer d'une façon fiable les propriétés mécaniques de la terre sulphide au fin grain. Dans cet article, certains essais des épreuves de la force des terres sulphide sont présentés, étant déterminés par deux essais à deux endroits différents. Les résultats confirment le besoin de calibrer les différents moyens d'évaluations afin d'obtenir des valeurs relevantes pour les terres sulphide.

1 INTRODUCTION

1.1 *Determination of strength and deformation properties of sulphide soils*

Previous research concerning strength and deformation properties of Swedish fine-grained soils has only to a small extent included sulphide soil. Common field and laboratory methods used to determine mechanical properties of other fine-grained soils are therefore often not relevant for sulphide soil. The parameter values evaluated with these methods are often unexpectedly high or low and most likely not representative of the sulphide soil in question. This is due to the fact that the employed semi-empirical evaluation methods are developed for other types of soils and have not been tested and calibrated for sulphide soils.

A parameter of major engineering interest in fine-grained sulphide soils is the undrained shear strength. In Sweden, this parameter is most often determined by field vane tests and by fall-cone tests in laboratory. Values obtained by these methods are corrected empirically. However, experience shows that the two methods may yield significantly different values for sulphide soils. Apart from the field vane test, the CPT is a commonly used field method in Sweden to determine the undrained shear strength. Results of CPTs in sulphide soils sometimes show unexplained and unexpected high or low values of undrained shear strength when compared to other tests and empirical relations. Similar inconsistencies are found in results from dilatometer tests.

There are other examples of remarkable results when testing sulphide soils. In undrained triaxial tests with pore pressure measurements, unlikely high values of friction angle are often evaluated. In fall-cone tests, about 20% higher values of undrained shear strength are often obtained when using the 100 g cone compared to tests with the 400 g cone, although both cones are expected to give the same shear strength. An ocular inspection using common and simple index tests, like rolling the soil into a thin thread, to determine type of fine-grained soil, may lead to a sulphide soil being classified as a clay while the grain size distribution indicates a silt.

Sulphide soils are in general very compressible and susceptible to creep and these properties are more pronounced when the soil temperature is raised. The effects on evaluated parameter values, especially strength parameters, when performing laboratory tests in room temperature compared to the lower ground temperature, need to be further investigated.

Research in the area of strength and deformation behaviour of sulphide soils was carried out about 30 years ago by Schwab (1976), and the need for further research was strongly pointed out, especially to obtain representative values of undrained shear strength. Eriksson (1992) studied effects on compression properties of time and temperatures in laboratory tests and concluded that testing at room temperature, as compared to in situ temperature, affects the magnitude of some compression parameters. Yu (1993) conducted experimental tests on sulphide soil, related to constitutive modelling work, and found unrealistically high values of friction angle in undrained triaxial tests. Some other contributions to the research on sulphide soils have been made by Slunga and Helander (1985) and Larsson (1990).

The uncertainties in evaluated values and properties of sulphide soils often lead to a choice of values on "the safe side" in geotechnical design and thus probably more expensive foundation solutions. On the other hand, an overestimation of soil properties may lead to stability problems or large settlements. The need for further research is large in order to increase the reliability of the evaluated soil parameters used in geotechnical design and thus increase the possibility for a safer and more economic construction work.

1.2 *Sulphide soils*

Sulphide soil is the dominating fine-grained soil type in the coastal regions of northern Sweden where it can be found from the city of Gävle in the south to the city of Haparanda in the north, a distance of about 900 km. In the coastal regions, the main part of industry, communities and infrastructure in northern Sweden are situated. The geotechnical and chemical properties of sulphide soils vary along the coastal area both in east-west and north-south direction, depending on different composition of minerals, grain size distribution and amount of organic content (Eriksson et al., 2000).

Along the northern Swedish coast, the sulphide soil has been formed as sediments at river mouths and outside the coast in the special environment at the time for sedimentation, Mácsik (1994). The environment was typically deficient in oxygen, and the water in which the sulphide soil was sedimented was brackish/sweet. The environment prevented a complete decomposition of the organic material in the sediments. Also today, new sulphide soil sediments are being formed.

"Sulphide soil" may be described as an overall designation for fine-grained soils containing iron, sulphur, having an organic content less than 10%, a clay content between about 10–40%, a silt content between about 60–90%, and having a black colour when not oxidised. A suitable and generally accepted definition of (Swedish) sulphide soil has not yet come forward.

The sulphide soil in northern Sweden normally contains relatively high contents of iron and sulphur, iron typically 3–5% of dry soil mass and sulphur typically 0.5–2%. The loss on ignition is up to about 10–20% with about 30–40% of the loss corresponding to organic content (Eriksson et al., 2000). Based on grain size distribution, the most common designation is silty sulphide clay or clayey sulphide silt. The soil is normally coloured black or varved with black bands and has a special odour of hydrogen sulphide (H_2S). The black colour comes from the iron sulphide (FeS). Deposits of sulphide soil may be found with depths over 20 m and are typically normally consolidated or only slightly overconsolidated. In most sulphide soils, the undrained shear strength is between 5 and 40 kPa and typically 10–30 kPa. The bulk density is relatively low and varies normally between 1.2 and 1.8 t/m^3 and the natural water content is typically between 40 and 150%.

The structure of a sulphide soil is often relatively porous and the voids between the mineral grains and clay particles are filled with pore water, organic material and iron sulphide (Pusch, 1973; Eriksson et al., 2000). The matter in the voids results in a lower permeability compared to a non-sulphide soil with a corresponding grain size distribution (Eriksson et al., 2000). The iron sulphide and the organic material are believed to contribute to the open structure, low bulk density and high water content. In general a fine-grained sulphide soil shows low strength, high compressibility and significant secondary compression.

If a sulphide soil gets in contact with oxygen (air), it will gradually change colour from black to grey. Oxidation of iron sulphide (FeS) and pyrite (FeS_2) takes place. Sulphates, iron ions and other metal ions are released and the pH value of the pore water is lowered. As a result, acid pore water, ground water, drainage water and surface water conditions can occur, which might be the case when excavation or lowering of the ground water table takes place. Other possible negative environmental effects after oxidation are precipitation of iron hydroxides and clogging of drainage systems. For these reasons it is desired, if possible, to avoid excavation and instead use the natural or reinforced sulphide soil as foundation. Furthermore, an evaluation of chemical soil conditions is of importance in order to avoid negative environmental and/or geotechnical effects, Mácsik (1999).

Different types of sulphide soils can be found in other parts of the world, e.g. in coastal regions of northern Finland, Japan, Australia and Vietnam.

2 RESEARCH PROJECT

2.1 *Scope of study*

The research project presented in this paper is planned to continue for at least five years. The overall purpose of the project is to find suitable testing methods in field and laboratory to determine reliably the mechanical properties of fine-grained sulphide soils. This includes how the results should be interpreted and evaluated and how samples should be handled and tested. Furthermore, soil chemical properties will be determined in order to investigate possible relations between geotechnical and chemical soil properties and parameters. In the laboratory, testing is carried out at room temperature as well as in situ soil temperature, in order to identify any temperature effects on the mechanical properties.

One aim is to increase the general knowledge about sulphide soils and thus improve the possibility to predict properties and behaviour based on a few tests and to form a basis for future investigations. The main purpose of the project is to improve the interpretation tools and the relevance and accuracy of evaluated geotechnical soil parameters. The research is a collaboration project between Luleå University of Technology and the Swedish Geotechnical Institute.

2.2 *Testing program*

In the project, field and laboratory tests will be performed on soils from four or five test sites along the coastal region in northern Sweden, with different types of fine-grained sulphide soils. In the field, field vane tests, CPTs, dilatometer tests, seismic CPTs and undisturbed sampling are performed. In the laboratory, triaxial tests, direct simple shear tests, incrementally loaded oedometer tests, CRS-oedometer tests, routine tests of basic geotechnical properties and tests to determine chemical properties are carried out.

The results obtained from the field and laboratory tests will be compared. Strength and deformation properties and parameters and stress-strain behaviour will be investigated. Special emphasis will be put on the undrained shear strength. Other parameters to be studied are preconsolidation pressure, compression modulus, shear modulus and friction angle. The undrained shear strength is determined by different field and laboratory tests, CPT, field vane test, dilatometer test, fall-cone test, triaxial test, and direct simple shear test. By comparing the same parameter determined and evaluated from different tests, the aim is to establish possible relations between the tests and how these vary with basic geotechnical and chemical soil properties.

Chemical soil properties to be determined are mainly contents of sulphur, iron and organic matter, loss on ignition, pH, redox potential and conductivity.

The tests will, in the first part of the study, be conducted and evaluated according to existing standards and recommendations, apart from testing at two different temperatures. Depending on the outcome of the tests, modification of the test procedures with regard to sulphide soil may be proposed.

3 RESULTS

3.1 *Introduction*

There are only a few results presented in this paper since the research project started shortly before this paper was written.

3.2 *Undrained shear strength*

The evaluated undrained shear strength, c_u, is presented as a function of depth for the two test sites at Västerslätt and Gammelgården in Figures 1 and 2 respectively. Both test sites are situated along the northern coast of Sweden. Results are presented for the three field methods dilatometer test, CPT and field vane test and, for Västerslätt, also the fall-cone test in the laboratory. The field test results are average values from two test points. The field vane tests were performed in two points with tests at every meter depth but with a 0.5 m difference in test elevations between the two points. The results from these tests are put together in a single curve.

Testing and evaluation of the undrained shear strength has been performed according to Swedish standards and recommendations and with standard correction factors (SGF (1993 a); SGF (1993 b); SGF (1995); SS027125 (1991)).

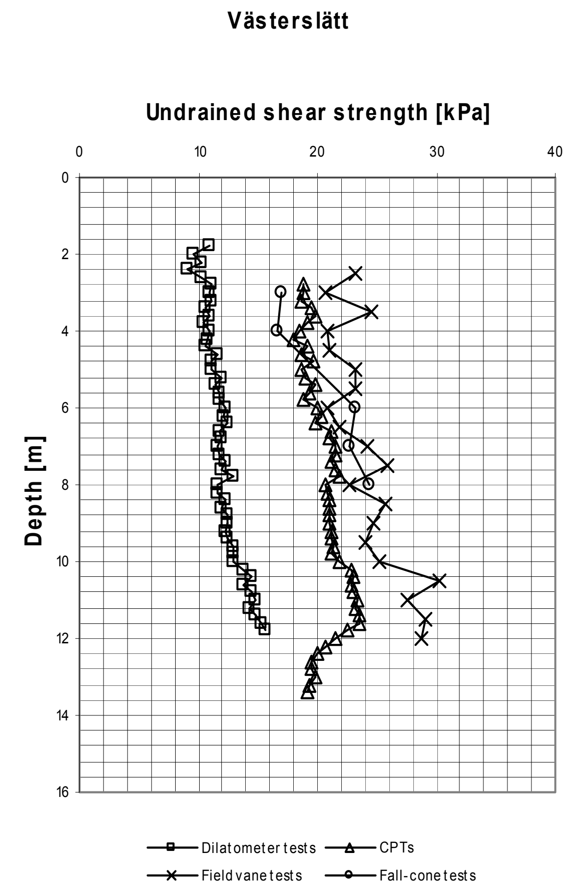

Figure 1. Undrained shear strength versus depth for sulphide soil at Västerslätt evaluated from dilatometer tests, CPTs, field vane tests and fall-cone tests.

The results from Västerslätt show that the variation of evaluated undrained shear strength with depth is similar for the three field methods, Figure 1. However, there is a significant difference in the values of evaluated undrained shear strength between the three methods. At 3 m depth the difference is about 8 kPa between the dilatometer test and the CPT and another about 3 kPa between the CPT and the field vane test, and the corresponding differences at 10 m depth are about 8 kPa and 5 kPa respectively. The relation between the undrained shear strengths evaluated from the three methods is about the same at different depths, which indicates a possible constant relation between values obtained from the three types of tests. The few test results from fall-cone tests show a larger variation of undrained shear strength with depth as compared to the field test results.

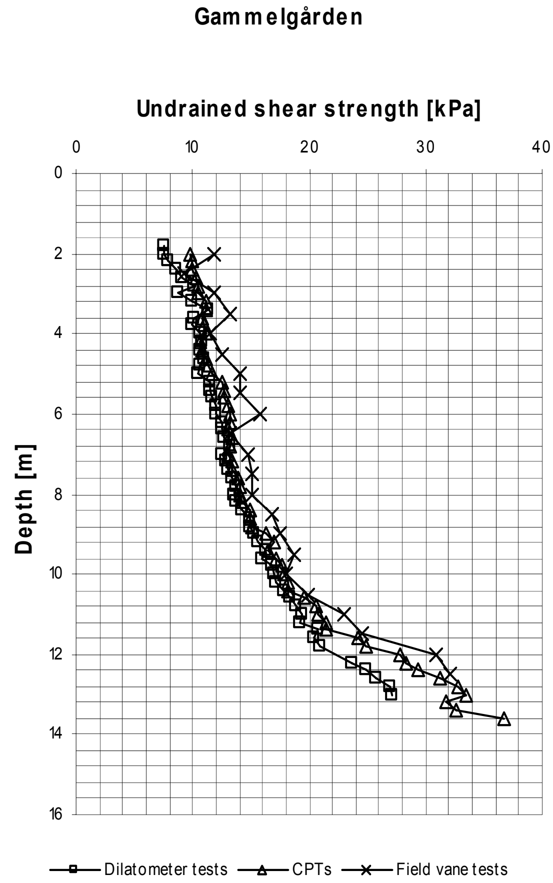

Figure 2. Undrained shear strength versus depth for sulphide soil at Gammelgården evaluated from dilatometer tests, CPTs and field vane tests.

The results from Gammelgården yield a similar relation in evaluated undrained shear strength when comparing the three field methods, Figure 2. However, the difference in undrained shear strength between the methods is much smaller compared to the results from Västerslätt. The values evaluated from the field vane tests are 1–2 kPa larger than those from the CPTs, which in turn are only marginally larger than those from the dilatometer tests.

The variation in evaluated undrained shear strength with depth for the results from Västerslätt implies, in comparison to the results from Gammelgården, that there is a larger relative variation in basic soil properties with depth. The soil at Västerslätt is also more layered with depth. At both sites, the lowest shear strength values are obtained from the dilatometer test and the highest from the field vane test.

However, the question remains which, if any, of the three field methods provides values that are representative of the undrained shear strength of the soil. This will be investigated when the laboratory tests (direct simple shear tests, active and passive triaxial tests) have been performed and reference (calibration) values are available. The normal procedure is to calibrate the field test results against the average value of the three different laboratory tests, or in a simpler way just against the results of the direct simple shear tests.

It should be observed that the parameter undrained shear strength is determined with different laboratory and field test methods with different deformation and failure modes in the soil and different theories are used to describe failure and evaluate the parameter. Fine-grained sulphide soils are observed to have structural anisotropy, are subjected to anisotropic stress conditions and most often have a varved stratigraphy. Furthermore, for the results shown in Figures 1 and 2 empirical formulas and constants used for Swedish fine-grained soils in general have been applied. For the above mentioned reasons it may be expected to obtain different values of undrained shear strength with the different test methods. In general, in order to find the most representative value of undrained shear strength in a specific geotechnical design situation, the most relevant deformation and failure mode for the problem at hand should decide the type/types of test method/methods to be used. This variation in test method is not possible in the field but can within certain limits be made in the laboratory.

4 SUMMARY AND CONCLUSIONS

In this paper, some test results of undrained shear strength of sulphide soils, determined with different test methods at two test sites have been presented. When using existing semi-empirical evaluation methods developed for other fine-grained soils, different values of undrained shear strength are often obtained. However, the three field methods show approximately the same variation of undrained shear strength with depth and fairly constant relations between the strength values obtained by the different methods. There is a need for calibration of the different evaluation methods in order to obtain relevant values also in sulphide soils. Further work and field and laboratory tests in the present research project will give guidance on how to do this.

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