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Quick clay – an investigation in South West Sweden

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ABSTRACT: In 2002, a project entitled "Mapping of quick clay" was started at the Swedish Geotechnical Institute, with funding from SRSA – Swedish Rescue Services Agency (Räddningsverket). The mapping included in situ investigations of different methods of sounding, an in-situ investigation of pore water chemistry of quick clays and electrical resistivity measurements from three locations in the Göta River area. Here the electrical resistivity and the pore water chemistry results are presented together with the results of summarizing present knowledge. The preliminary result of the "quick clay mapping in the Southwest of Sweden", i.e. the overall process of gathering present knowledge concerning quick clay, is that there are a number of main prerequisites for the formation of quick clay. In this part of the country these include clay is deposited in salt water, limited thickness of the clay deposit, large thickness (i.e. large water-conducting capacity) of the underlying coarse sediments, possibility for infiltration of water into the water-conducting layer. In the Southwest of Sweden quick clays are thus found mostly in areas close to valley sides where bare rock becomes visible, above (and below) thick and continuous deposits of coarse sediments (sometimes only in parts of the clay layers which are located close to the coarser layer) and close to outcropping (and buried) hillocks. In general the conclusion is that all unweathered clays which have been deposited in salt water may become quick as a result of leaching. According to the investigations using electrical resistivity and the pore water chemical investigations, the use of electrical resistivity measurements is very useful to estimate the distribution of quick clay in areas where quick clay is known to occur. The correlation between sensitivity and electrical resistivity can be used only for separation of soil volumes in marine clays, which have been leached sufficiently to possibly form quick clay, from those volumes where the salt content remains high enough to prevent this.

1 INTRODUCTION

Quick clay in Sweden is defined as clay with a sensitivity of 50 or more and fully remoulded shear strength of less than 0.4 kPa (Karlsson and Hansbo, 1989). The latter value corresponds to a penetration of 20 mm by the 60 g cone with 60° tip angle in the fall-cone test. The sensitivity is the relation between the undisturbed and the fully remoulded undrained shear strength.

The only reliable method for the detection of quick clay used so far in Sweden is to take undisturbed samples and to perform fall-cone tests on the clay in its undisturbed and remoulded states. This is also the method that has been used in practice. Mapping of quick clay formations in this way requires extensive sampling. For economic reasons, the method is therefore not practically applicable to a detailed mapping of the extent of a quick clay formation, but only at a few points in selected investigated sections.

In 2002, a project entitled "Mapping of quick clay" was started at the Swedish Geotechnical Institute, with funding from SRSA – Swedish Rescue Services Agency (Räddningsverket) – (Rankka et al., 2004). This was an interdisciplinary project aiming at gathering the knowledge of specialists in soil mechanics, geology, hydrogeology, geophysics and soil chemistry, and presenting this in a uniform way.

The mapping included in situ investigations of different methods of sounding and their abilities to be used to detect and estimate the extent of quick clay.

The investigation also included an in-situ investigation of pore water chemistry of quick clays and electrical conductivity measurements from three locations in the Göta River area.

This paper presents only the electrical resistivity and the pore water chemistry results. For more information and a detailed description of the full project, readers are referred to Rankka et al. (2004), Leroux and Dahlin (2003), and Andersson-Sköld et al. (2005).

In marine clays that have been leached by fresh water, there is often a link between the salt content and the sensitivity of the soil, as well as between the salt content and the electrical resistivity of the soil. However, a low salt content does not necessarily imply that the clay is quick but only that a precondition for this exists. Torrance (1974) found that the salt content had to be reduced below 2 g/litre (0.2%) before quick clay can be formed. The corresponding electrical resistivity varies somewhat with the porosity of the soil since it is mainly the pore water that is conductive (Penner, 1965). Laboratory studies on a typical Swedish clay have shown that a content of 0.2% NaCl corresponds to a resistivity of between approximately 6 and 13 Ωm for the range of bulk densities of interest for quick clay formation in Swedish clays. Clays with lower densities are normally organic and clays with higher densities normally have water contents well below their liquid limits. In both cases they are not quick.

During the 1950s, a special "salt probe" was developed (Söderblom, 1969). The probe as pushed down into the soil and the resistivity was measured throughout the profiles. The method appeared to work satisfactorily and certain relations were established. Söderblom found that the resistivity was higher than 5–10 Ωm in quick clays. However, when using the salt probe, data were only obtained at individual points and the method was not very rational with the measuring and data processing techniques of that time. An electrical resistivity higher than the given limit also only indicated that the clay could be quick, but a high resistivity could correspond to any sensitivity.

2 METHODOLOGY

The project was divided into the following parts:

1. Gathering of present knowledge concerning quick clay (literature survey, site surveys and personal communications).
2. Summarising the information obtained by the gathering of present knowledge to identify geological and hydrogeological conditions for quick clay formation.
3. Investigation of mapping quick clay by surface electrical resistivity measurements and penetration tests.
4. Geotechnical investigation of the presence of quick clay, its stratification and other properties by sampling.
5. Investigation of pore water chemistry of quick clays from three locations in the Göta River area.

2.1 *Surface electrical resistivity measurements*

The general principle for measuring electrical surface resistivity is to use electrodes pushed into the ground surface, most often along a measuring line. In a measurement, two electrodes are used for injecting electrical current into the ground, with the electrical potential being measured between another pair of electrodes, and possibly between several other pairs. The measured potentials are influenced by the magnitude of the current and of the conducting properties of the underlying soil. The depth and volume of the soil that influences a measurement are dependent on the spacing and position of the electrodes.By collecting measurements for a large number of electrode positions and spacings, a set of data is obtained that makes it possible to interpret and present an image of the electrical resistivity in the ground beneath the measuring line. In the present project the ABEM Lund Imaging System (Dahlin, 1996) was used for measuring the resistivity, and the Res2Dinv program was used for inverse modellings between the measured and the theoretical values are calculated, and the model is adjusted to obtain the best fit to the measured value to interpret the data as cross sections of the resistivity of the ground es. In this case, the (Loke et al., 2003) has been used.

The quality of the measured data depends greatly on the homogeneity of the ground and the contact between the electrodes and the ground. Natural ground, homogeneous clay profiles, thin dry crusts and fairly wet conditions are thus beneficial factors for the measurements. Fills, pavements, overlying layers of coarse soils with low ground water tables, thick dry crusts, buried objects in the ground such as cables, pipes, piles and walls, as well as a highly irregular ground surface, are factors that reduce the quality of the measurements.

Three different areas with known occurrence of quick clay were used to obtain data to evaluate the method of electrical resistivity as a method of quick-clay mapping.

The geotechnical mapping programme consisted of 9–10 static pressure soundings and 3–4 rotary pressure soundings, total soundings and CPT tests at each site. The static pressure soundings were located in both quick clay and non-quick clay, and were placed to verify the assumed border of the quick clay formation. Based on these results and the previous information, 3–4 of the investigation points were selected to cover the range quick clay – highly sensitive clay – normally sensitive clay. At these points undisturbed samples were taken.

3 RESULTS

A summary of the results is presented in this paper. For a more detailed description readers are referred to Rankka et al. (2004), Leroux and Dahlin (2003) and Andersson-Sköld et al. (2005).

The preliminary result of the "quick clay mapping in the Southwest of Sweden", i.e. the overall process of gathering present knowledge concerning quick clay, is that there are a number of main prerequisites for the formation of quick clay. In this part of the country they are (Rankka et al., 2004):

- the clay is deposited in salt water,
- limited thickness of the clay deposit,
- large thickness (i.e. large water-conducting capacity) of the underlying coarse sediments,
- possibility for infiltration of water into the water-conducting layer.

In the Southwest of Sweden quick clays are thus found mostly in areas:

- close to valley sides where bare rock becomes visible,
- above (and below) thick and continuous deposits of coarse sediments (sometimes only in parts of the clay layers which are located close to the coarser layer),
- close to outcropping (and buried) hillocks.

In general the conclusion is that all unweathered clays which have been deposited in salt water may become quick as a result of leaching. The main restrictions are the availability of water, the conditions governing water seepage through the clay, and the duration of leaching. In some cases, the ion composition of the leaching water is also a restriction. Moum et al. (1971 and 1972) presented an area in Drammen, Norway, where quick clay was found only in the central depths of the clay deposit. The explanation given by the authors was that the clay had probably been quick in the lower parts but had reverted to non-quick clay through release of Mg and K ions by mineral weathering.

The in-situ investigation of the pore water chemistry shows that extensive leaching has occurred at all three locations investigated. One location, Surte, was extensively studied. At this location the lowest salinity was found at the greatest depth (27 m) and the salinity increases with decreasing depth, inferring that the leaching by fresh water was accomplished by water movement upward and laterally through the sediment from the underlying bedrock. This is consistent with the local setting where bedrock hills rise sharply to over 100 m above the marine sediment surface. An artesian pressure would also be anticipated at this location. At all three locations a correlation (negative) between sensitivity and salinity. At Surte, however, there is an indication that the maximum salinity or electrical conductivity consistent with the quick clay behaviour is higher than reported elsewhere. Further work is needed to confirm this difference and to investigate the possible interplay of salinity and potential dispersing agents in this region.

At all three locations that have been investigated, high remoulded shear strengths and low sensitivity have been seen near the surface together with a decrease in pore-water cation concentrations. This is explained by that influences related to surface weathering in an oxidising environment and water extraction counteract the influence of salt removal in modifying the geotechnical properties of the soil. Such influences are observed in the surface crust (pedogenic weathering zone) of all other areas, where geochemical aspects

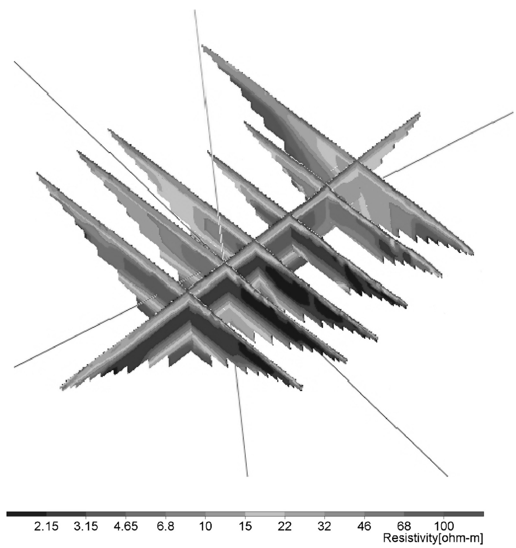

Figure 1. Resistivity model results from the Utby site.

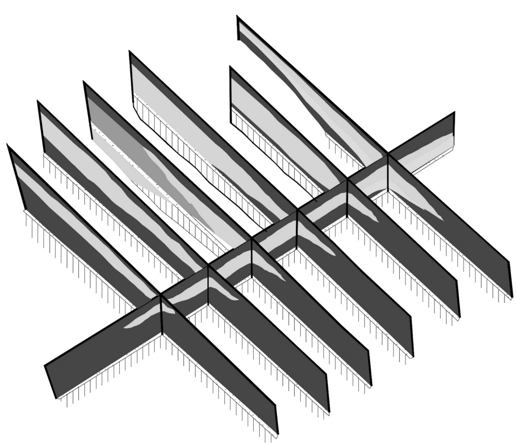

Figure 2. Composite interpretation result for the Utby site.

of quick clay development have been studied (Torrance, 1990; Berry and Torrance, 1998).

The correlation between sensitivity and electrical resistivity can be used only for separation of soil volumes in marine clays, which have been leached sufficiently to possibly form quick clay, from those volumes where the salt content remains high enough to prevent this. The actual sensitivity of the leached clay has to be determined by other methods, which can only provide sample tests. Certain general observations – for example, the soil in the dry crust and the weathered zone, as well as organic soils and heavily overconsolidated soils, are rarely quick – can also be used in the screening process.

4 CONCLUSIONS

According to the investigations using electrical conductivity and the pore water chemical investigations, the use of electrical resistivity measurements is very useful to estimate the distribution of possible quick clay in areas where quick clay is known to occur. The use of resistivity measurements is mainly applicable when large areas are to be investigated since these measurements provide continuous sections. The resistivity measurements are also mainly applicable in rural areas with a minimum of surface pavements and installations in the ground. Fills and thick overlying layers of unsaturated sand are also unfavourable for these measurements. A complex geology could also be a restriction for this type of measurement, but this is not normally the case in the Swedish areas of main interest. The results of resistivity measurements should always be supplemented by geotechnical investigations, but these do not need to be as extensive as those undertaken in a traditional geotechnical investigation.

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