Resistivity imaging for mapping of quick clays

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A046 Resistivity Imaging for Mapping of Quick Clays for Landslide Risk Assessment

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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 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 has been to take undisturbed samples and to perform fall-cone tests on the clay in its undisturbed and remoulded states, and 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 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 the electrical resistivity results only. For more information and a detailed description of the full project, readers are referred to Rankka et al. (2004).

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 the pore water is conductive. Laboratory studies on 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 (closely related to porosities) 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 was 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.

Method description

Resistivity imaging was carried out as a number of 2D sections at each site. The ABEM Lund Imaging System was used for measuring the resistivity (Dahlin 1996), and the Res2Dinv program was used for inverse modelling to interpret the data as cross sections of the resistivity of the ground (Loke et al. 2003). The resulting inverted sections were presented as fence diagrams in addition to normal presentation as cross sections.

The geotechnical mapping programme was based on the resistivity imaging results and 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.

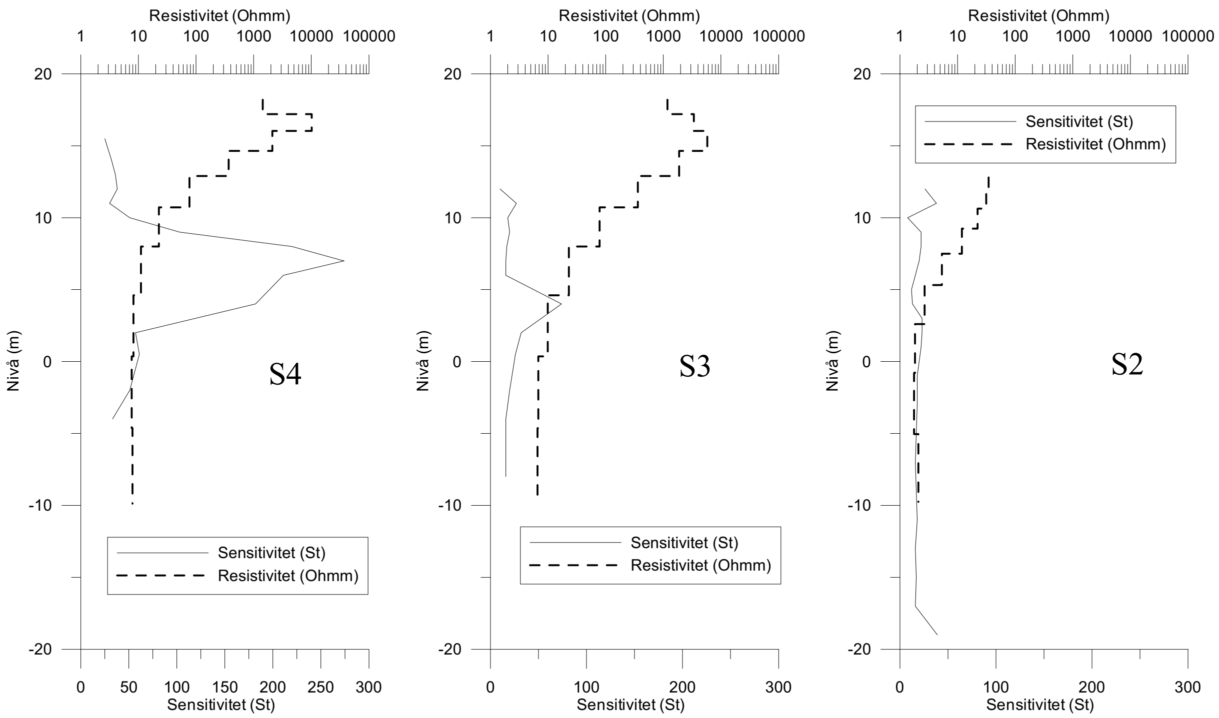

Figure 1. Comparison of inverted resistivity model and sensitivity for 3 sounding points at the Torp site.

Results

Two sites (Skepplanda and Utby) were dominated by fields used for farming, exhibiting homogeneous clay profiles, thin dry crusts and fairly wet conditions, were beneficial for the measurements and resulted in high data quality. The third site (Torp) had a rather large amount of coarse grained fill material, pavements, overlying layers of coarse soils with low ground water tables, thick dry crusts, buried objects in the ground such as cables, pipes etc, which reduced the quality of the measurements at that site.

The resulting inverted resistivity sections were very consistent, apart for noise affected parts at Torp. Results from previous studies were confirmed, as illustrated by Figure 1 where clay resistivity around 10 Ωm correspond to high sensitivity, and clay resistivity of few Ωm occur for low sensitivity clay.

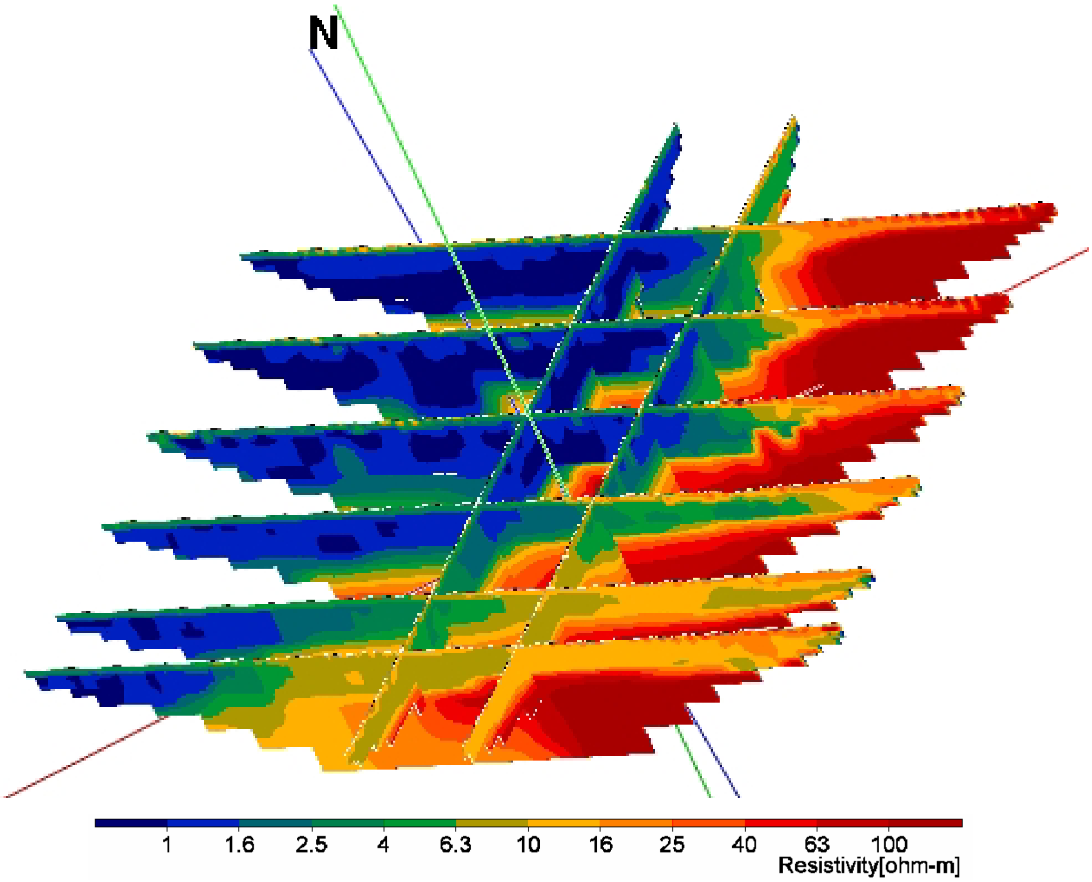

Figure 2. *Fence diagram visualisation of inverted resistivity models from the Skepplanda site.*

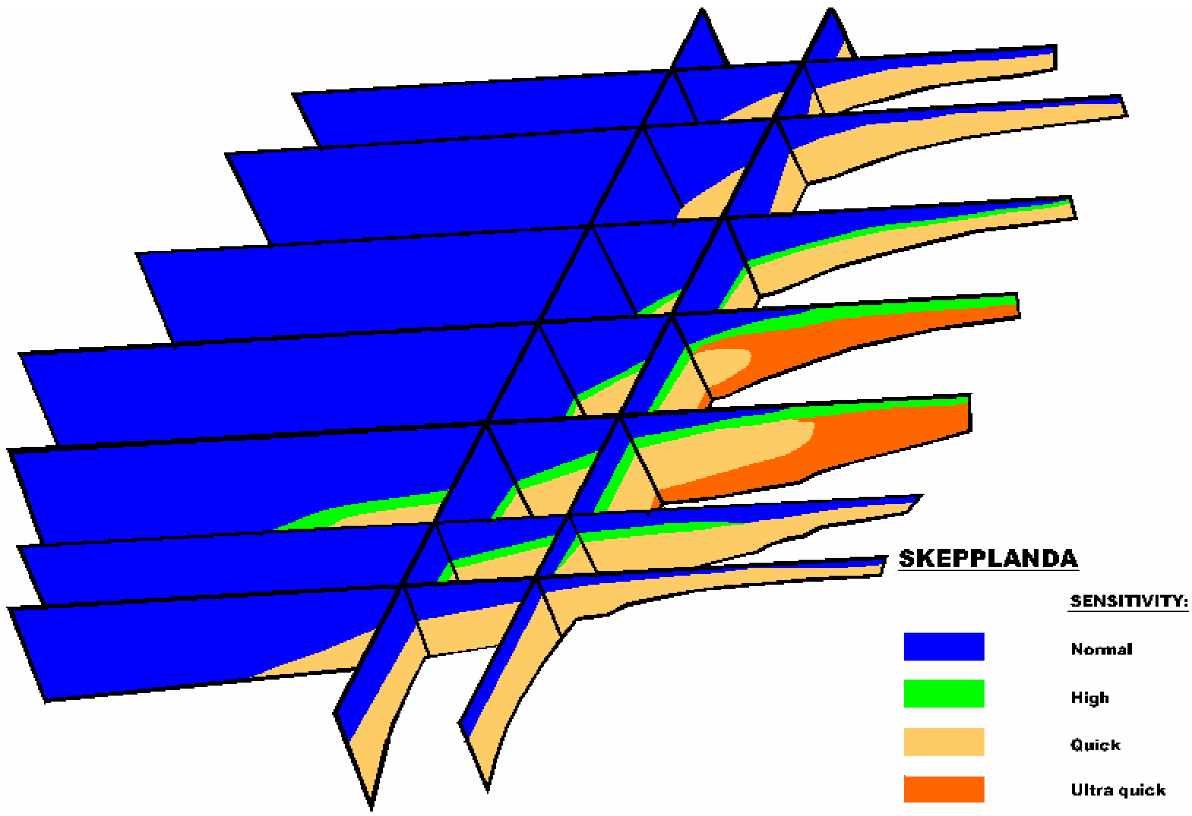

Figure 3. *Fence diagram visualisation of composite geotechnical interpretation from the Skepplanda site.*

The inverted resistivity section were plotted and analysed individually, and also visualised as fence diagrams (see example in Figure 2). The fence diagrams show that the inverted sections are consistent and fit each other quite well at the intersections. The geotechnical field and laboratory results were used together with the resistivity sections to generate interpreted geotechnical sections of the occurrence of quick clay at the sites, as shown by the example in Figure 3.

Conclusions

According to the investigations electrical resistivity imaging 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.

The correlation's 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 soils 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.

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