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Mapping of heterogenic geological setting at a hospital construction site using geophysical surveying and NMR logging

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SUMMARY

NMR logging was employed as part of integrated geophysical and geotechnical site investigations for a new planned new hospital in Hillerød, Denmark. Due to the complex hydrogeological conditions, where localised discontinuous sand lenses can affect excavation during construction, NMR logging was integrated to supplement hydrological and geological investigations, in order to localise and describe local heterogeneities. NMR logging was carried out in 4 geotechnical boreholes using Javelin system indicated that increase mobile water was present at the bottom of the sand lense aquifer, corresponding to where borehole logs indicated more gravel composition. Not all sand lenses indicated the same degree of mobile water and permeability estimates, indicating hydraulic discontinuity of these sand lenses. Information gained from NMR logging at meter scale of variability in flow within aquifers mapped by logging are relevant to optimise design of excavation construction where meter scale is needed to design appropriate dewatering systems during construction.

Key words: NMR logging, Javelin, Excavations.

INTRODUCTION

The Capital Region of Denmark has initiated pre-investigations for a new hospital to be built as part of the hospital Nordsjællands Hospital. The planned location for the new hospital is just south of the town Hillerød in Zealand, Denmark. The new hospital will have a total area of 124,000 m^2 including an underground parking lot area. Thus excavation of 4-5 meters of soil is expected and geological and hydrogeological conditions are therefore of vital importance. To minimize the risks additional information has been collected using geophysical methods. The main purpose of the geophysical investigations was to get information on thicknesses and lateral extent of fill and soft soils (peat and gytja) as well as deeper lying sand/gravel lenses with relatively high permeability.

METHODS AND RESULTS

Methods

Geophysical data were collected using GEM-2, ERT (Electrical Resistivity Tomography) and NMR (Nuclear Magnetic Resonance). The GEM-2 (from Geophex) is an inductive method operating in the frequency domain. It was applied as an initial screening method used for planning of more detailed data collection using ERT. Indications of soft sediments were primarily based on the frequencies 62,525 Hz and 20,875 Hz.

The GEM-2 results were supplemented with 6 ERT profiles of approximately 500 m each. The Gradient configuration was applied with a minimum electrode spacing of 2.5 m and a maximum penetration depth of approximately 35 meters. A total of 3.000 m of ERT was collected covering an area of approximately 250,000 m^2.

Finally NMR was applied in 4 geotechnical boreholes using the Javelin NMR logging system by Vista Clara. The purpose of the NMR logging was to get specific information on the water content as well as estimations on the permeability in the different soil layers.

The NMR signal is generated by hydrogen nuclei excited in a background magnetic field provided by the logging tool. The vast majority of the signal originates from the hydrogen nuclei in the water molecules of the pore water in the soil. The received signal amplitude, S_0, is directly proportional to the water content whereas the relaxation time, T_2, reflects the pore size of the soil: Smaller pore size gives shorter relaxation time. This relationship makes it possible to estimate the amount of mobile and bound water in the matrix (deposits) as well as the permeability of the matrix.

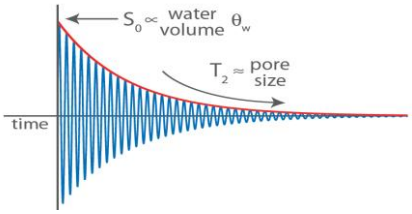

Figure 1 Received NMR signal during relaxation of the hydrogen nuclei in the porewater of the soil. Figure from Walsh *et al*. (2011).

Geophysical Mapping

The initial screening using the GEM-2 gave information on where to focus the following ERT investigations with respect to especially mapping of the soft sediments. The ERT gave detailed information on the thicknesses and lateral extent of layers of soft soil (peat/gytja) as well as on sand lenses/layers. The interpretations of the geophysical mapping where based on geological information from nearby boreholes (27 in total made on the project).

3D Geological Model

The interpreted layers were visualized in a 3D geological model using the software Rockworks making it possible to

generate any profile section and calculate volume estimates. The layers in the 3D model was based on an integrated interpretation utilizing all available information from geological, geotechnical, hydrogeological and geophysical investigations.

NMR Logging

The NMR logging was applied in 4 selected boreholes to give information on the specific water content of the different layers as well as estimations of the permeability. This information is important with respect to the hydrogeological evaluations e.g. in connection with groundwater lowering and risk of hydraulic failure.

Figure 2 shows the NMR results from the borehole G18. The water content and transverse relaxation time, T2, is presented in the left picture of the figure. Content of bound versus mobile water is presented in the centre picture whereas two different estimations of the permeability is presented in the picture to the right. The results show high water content in the top layers which mainly is found as bound water with short T2. This correlates with the soil sample description at this depth which is described as sand/silt/clay with limestone content. Low water content and permeability is observed at a depth from 5-7 meters and may be attributable to low porosity or to bound water signals that relax too quickly to be detected. The log indicates that the lower sand unit (6-12 m) becomes more permeable with depth, reflected with increasing mobile versus bound water content and increasing T2. The log shows the highest permeability estimates at the bottom of the log. Layers of elevated water content are distinguishable from 3-5 m and 9-12 m. Similar results were seen in borehole G19 and is in both boreholes in good agreement with the grain size being increasingly bigger with depth; turning from sand into gravel around 11 m below ground level.

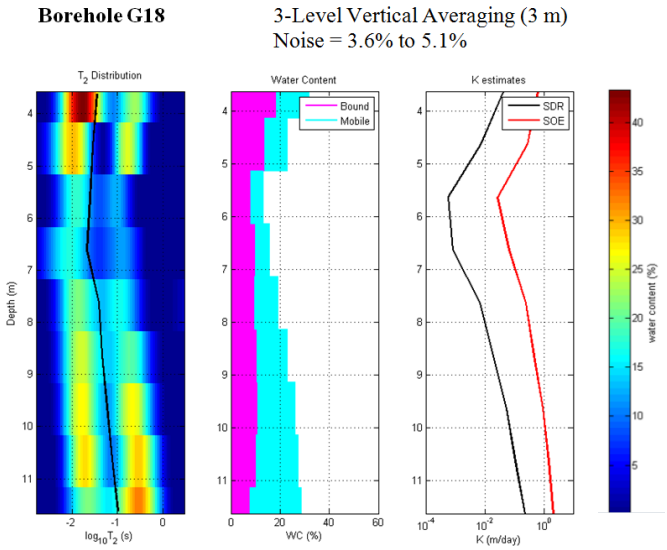

Figure 2 NMR results from borehole G18 (depth interval 3.5 – 11.5 m). Left: Water content (see colour scale) and T2 distribution (transverse relaxation time), Center: Bound versus Mobile water content, Right: Estimations of permeability using two different calculations.

Figure 3 The Javelin NMR logging tool after logging: Magnetic sediments have been captured and aligned by the strong magnets inside the tool. The tool has a diameter of 44 mm and a total length of 2.1 meters. The picture was taken after logging in the field.

CONCLUSIONS

The use of geophysical mapping combined with geotechnical investigations made it possible to carry out an integrated interpretation of the geological and geotechnical data. The result was a 3D geological model with detailed information on the thicknesses and lateral extend of the geological layers. NMR was applied in 4 selected boreholes giving new and specific information about the water content in the individual layers as well as estimations on the permeability. This made it possible to hydraulically distinguish between deposits of sand that initially could seem similar based on the geological descriptions, but which had different permeability. Furthermore the NMR results showed higher water content and permeability with depth in the lower sand layer. This could not necessarily have been achieved using results from hydraulic pump test as the sand lenses are unevenly distributed over the site and in some areas have no or little hydraulic contact. The integrated interpretation and use of NMR logging therefore gave a much better understanding of the hydrogeology and the hydraulic conditions.

ACKNOWLEDGMENTS

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