An integrated approach to Geotechnics and Geophysics on the Electrification Programme in Denmark

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ABSTRACT
The Electrification Programme is a design and construct project involving the electrification of approximately 1500 km of railway line in Denmark. As a part of the geotechnical basis for the project, an integrated approach to geotechnics and geophysics was adopted, in order to provide the tenderers with sufficient information regarding the expected ground conditions and with due consideration to the time schedule for the project. A combination of traditional geotechnical site investigation including on track Cone Penetration Testing and geophysics using Electrical Resistivity Tomography was performed. The results of the fieldwork were combined with existing geotechnical data along the railway alignment in order to prepare tables presenting geotechnical parameters and design soil profiles. Furthermore, all existing and new geotechnical data - such as borehole profiles and geotechnical reports - were made easily accessible through a homepage containing a GIS platform with online access for the Tenderers. This approach enabled the vast amounts of geotechnical and geophysical data to be presented in an easily accessible and usable format. The integrated approach to the geotechnical and geophysical investigations proved to be an ideal solution for a project of this size and complexity.

Keywords: Site investigation, Cone Penetration Testing, Electrical Resistivity Tomography, GIS Platform.

1 INTRODUCTION

The Electrification Programme (EP) consists of electrifying existing and new railway lines for Banedanmark (Rail Net Denmark). It is one of the largest infrastructure projects, ever undertaken in Denmark. The project consists of electrifying approximately 1500 km of railway line on 15 separate sections (including 5 new railway lines) in the majority of the country.

As shown in Figure 1, only the green sections of the railway network in Denmark are electrified today. The red and yellow sections of the network are scheduled for electrification in the period 2015 – 2029. The total budget for the Electrification Programme is 12 billion Danish kroner (approximately 1.6 billion Euros).

Given the tight time schedule for preparation of the tender documents for the project, the challenge for the geotechnical team was to provide a sufficiently robust geotechnical and hydrogeological basis for tendering purposes. A strategy was developed by COWI-SYSTRA involving a combination of existing available data with new data from supplementary geotechnical investigations and geophysical surveys. In all 270 geotechnical boreholes and 140 km of ERT (Electrical Resistivity Tomography) were undertaken for the project. All the existing and new data was collated and presented in a single, easily accessible GIS database for all project users.

The database, known as EacoWeb, is accessible on-line through a homepage that was set up specifically for this purpose. As part of the data package in the tender documents a desktop version was provided making it possible to access the data also when off-line.

Figure 1, A map of Denmark showing the extent of the planned works with red and yellow lines. Green lines represent already electrified railway sections.

2 STRATEGY FOR INTEGRATING GEOTECHNICS AND GEOPHYSICS

As the project involves electrification of vast lengths of track, a methodology for covering these very large distances was thus required.

The strategy for geotechnics was based on a cost benefit principle, in which the greater the degree of geotechnical knowledge made available at tender stage, the greater the risk reduction in unforeseen ground conditions is achieved. However, at a given point in time, the incremental reduction in risk becomes minimal in relation to the time restraints and cost of performing the investigations. Thus a certain minimum of data had to be provided – a minimum that would still be enough to reduce the risk of unforeseen ground conditions significantly.

This could be achieved if enough data was available to form the basis for a rough model of the ground conditions. The model provides information on the geotechnical strength parameters along the railway lines. To reduce the risk for the client and the tenderers it should be provided in the tender documents and serve as the basis for the tenderers' design calculations. It was therefore decided to aim at a level of information high enough to set up a rough, but still realistic model for the geotechnical strength parameters in the uppermost 8 m below ground level along the ca. 1400 km of railway track.

This challenge was overcome by combining existing data from Banedanmark, GEUS (Geological Survey of Denmark and Greenland) via the Jupiter Database and COWI's own geotechnical database with a series of new geotechnical boreholes including CPT tests at selected locations as well as a series of geophysical surveys performed parallel to the track at selected locations.

The focus of the new supplementary data was to gain more information on the fill and intact geological deposits along the railway lines. This information was obtained by conducting geophysical surveys parallel to the railway combined with geotechnical boreholes off-track. Compared to conducting boreholes on-track at night during the limited available track possessions the off-track geotechnical investigations proved to be both faster, more flexible and significantly cheaper. Having the vast majority of supplementary geotechnical boreholes drilled off-track reduced the cost of the supplementary geotechnical investigations significantly.

The geophysical ERT surveys could further reduce the number of geotechnical boreholes needed and at the same time give continuous information along the survey lines parallel to the railway lines. As the geotechnical and geophysical methods are highly complementary, the combined use provided detailed information on the ground conditions along the alignment.

3 PLANNING OF SUPPLEMENTARY GEOTECHNICAL AND GEOPHYSICAL DATA

On the basis of 1:25.000 and 1:200.000 surface geological maps prepared by GEUS, existing boreholes from JUPITER, existing geophysical data from GERDA (Geophysical Relational Database), geomorphological maps, historical maps and existing data from Banedanmark consisting of existing geotechnical boreholes and reports, the supplementary geotechnical and geophysical investigations were planned.

The planning of supplementary investigations was based on existing data. The focus was primarily on the type and density of existing data as well as on the expected geological complexity at a specific location. However, also more practical considerations were taken into account, such as available railway possessions, time constraints and access conditions along the railway track.

Initially, a desk study of possible access roads to the railway or in the proximity of the railway was carried out. A combination of orto photos and topographical background maps was utilized to identify possible access points to the railway where off-track geotechnical investigations could be carried out. The result of the desk study was used in the planning of the supplementary geotechnical investigations and furthermore, provided for the tenderers as part of the tender material.

The supplementary geotechnical boreholes were drilled at carefully assessed locations, in order to provide supplementary geological and geotechnical information, including geotechnical properties of the soils and rocks encountered. In addition, standpipes were installed in all off track boreholes in order to provide information on groundwater levels.

The geophysical investigations were planned along selected sub-sections of the railway in order to supplement the geotechnical investigations. The ERT survey lines were planned in order to give 2D continuous information on the soil layers along the track. This was utilized directly in the geotechnical model for the soil layers. In addition it gave information on the geological complexity in a specific area and provided additional focus on prospective locations for boreholes. In some areas it even reduced the number of boreholes and thereby reduced the cost of the geotechnical investigations further.

4 FIELDWORK

4.1 Geotechnical Investigations

The geotechnical investigations for the project consisted of both on-track and off-track boreholes, supplemented with insitu testing consisting of CPTu (Cone Penetration Testing with pore pressure measurement) and SPT (Standard Penetration Test). Planning of the geotechnical investigations (i.e. type of investigation and location) was undertaken using the GIS software Mapinfo in order to collate all the existing information along the track regarding geology, geotechnical and geophysical investigations and reports, information on utilities, access and terrain conditions, property owners, etc.

Figure 2, Drilling rig mounted on wagon ready for on-track work

The on-track boreholes were performed by a drilling rig mounted on a wagon with a hole in the floor. The rig was transported to the drilling location by shunter. The drilling work was undertaken during track possessions at night. The boreholes were located between the sleepers and centrally between the rails. The challenge for the drilling teams was to perform the works within the tight duration (3 – 6 hours) of the track possessions, including transport to and from the drilling location. Depending on the duration of the track possession and distance to the drilling location from the siding, a borehole with a drilling depth up to 8 m below track level including recovery of disturbed and undisturbed soil samples, performing field vane shear tests in cohesive soils and undertaking 1 – 2 nos. CPTu to 8 m below track level could be performed in a single track possession. Due to time restraints and long term railway safety considerations, standpipes were not installed in on-track boreholes.

Concurrent to the on-track fieldwork, off-track geotechnical investigations were undertaken at selected locations where access was possible. Due to railway safety restrictions, the locations of these investigations were limited to a minimum safety distance of 8 m to the nearest rail. The off-track geotechnical investigations consisted primarily of geotechnical boreholes including recovery of disturbed and undisturbed samples, performing field vane shear tests in cohesive soils and undertaking SPT and CPTu in situ testing.

Figure 3 below shows a typical borehole log with in situ testing.

Standpipes were installed in all off-track geotechnical boreholes in order to monitor the groundwater levels along the railway.

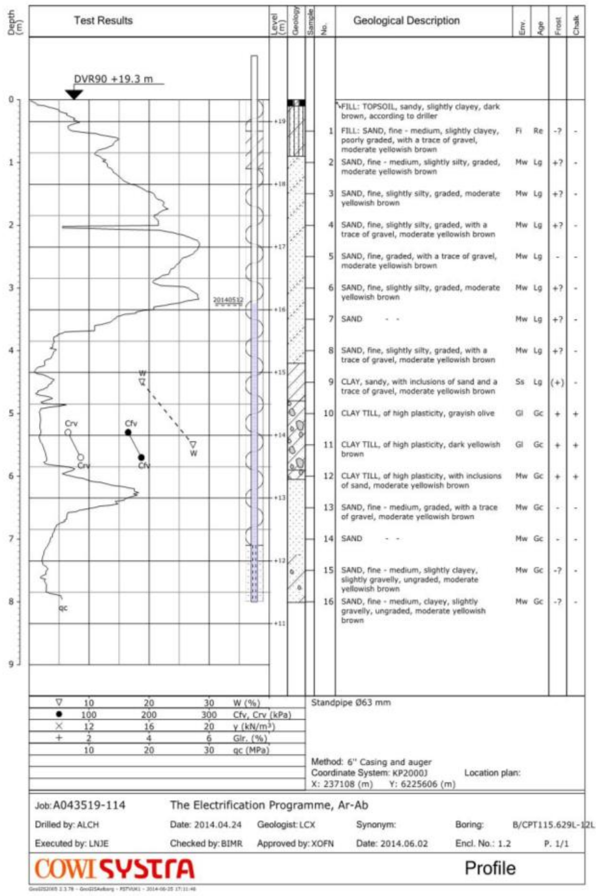

Figure 3, Off-track borehole log with CPTu and field shear vane testing

4.2 Geophysical Investigations

The geophysical investigations were conducted as ERT (Electrical Resistivity Tomography) using a minimum electrode distance of 5 m. An ABEM SAS4000 Terrameter was utilized transmitting a minimum current of 20 mA. The Gradient Array geometry was applied in a setup with 41 electrodes giving a maximum penetration depth of up to 60 meters.

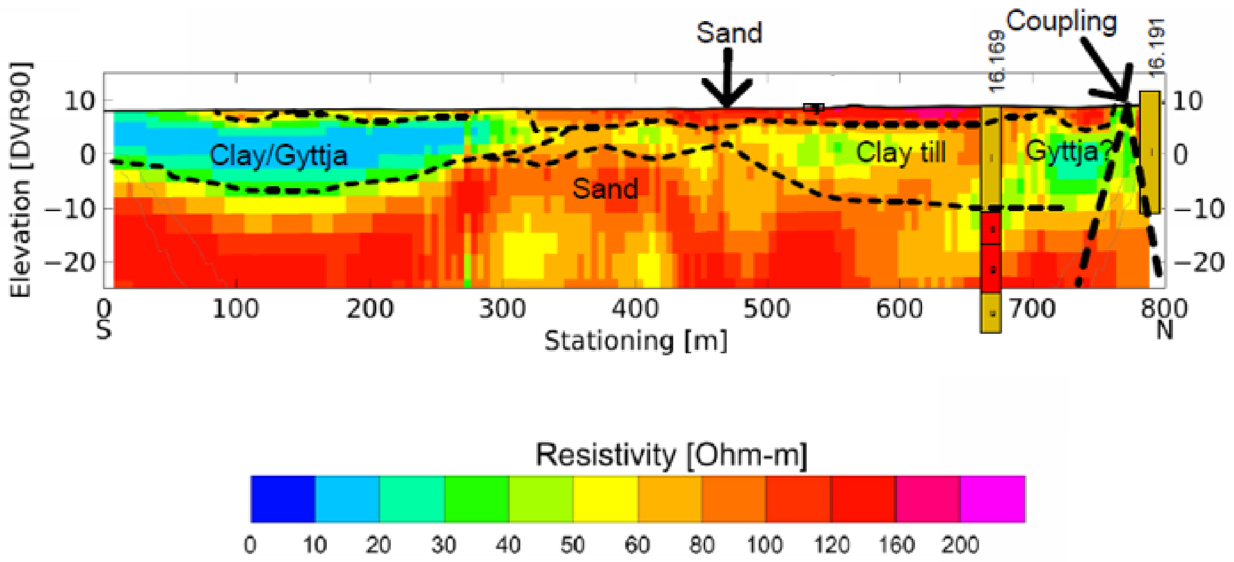

Figure 4, Example of interpreted model section of an 800 m long ERT profile along the railway line. Two existing boreholes have been projected onto the profile (at 670 m and 790 m).

The ERT survey lines were placed 50-75 m from the railway line in order to avoid electrical coupling to the railway tracks or underground utilities along the track. At some locations a short survey line was placed perpendicular to the line parallel to the railway in order to provide detailed spacial information on the soil layers.

The fieldwork was carried out by two operators. An ATV (All-Terrain Vehicle) was used to carry the equipment between the subsections.

5 GIS-PLATFORM AND EACOWEB

All geotechnical and geophysical data was collated together with relevant hydrogeological data gathered in a central database. The data was geocoded and made accessible through a GIS-platform displaying boreholes, geotechnical reports and relevant geophysical data along the railway lines. The geotechnical reports can be opened directly via a hyperlink to a pdf-version of the report. On the EacoWeb homepage borehole logs can be directly generated from the database from a selected borehole. Cross sections along a self-defined (crooked) line can be generated showing topography and boreholes within a selected distance from the profile alignment. This feature makes it possible to visualize and better understand the geological setting in a specific area.

The purpose of delivering the geo-data in a GIS-platform was to provide a clear overview and easy access to all geo-data, which in time will save time and money. Furthermore, the GIS-platform will also help to ensure that all available data are utilized in the project. The amount of existing data along the railway lines is extensive and represents a very high value for the client. Banedanmark's geotechnical archive was established at the beginning of the 19th century, however the geological and geotechnical data are still applicable regardless of age as this type of information remains almost unchanged over time.

The GIS-platform with all the geo-data was part of the data package in the tender documents. It was delivered both as a stand-alone desktop version to be used when off-line and as an on-line version. The latter is accessible through Banedanmark's EacoWeb homepage and, in contrast to the desktop version, interlinked with the national borehole database and EP's borehole database. This means, that Eacoweb is continuously updated with new boreholes. All boreholes drilled by the contractor will thus become available on EP's EacoWeb homepage throughout the project.

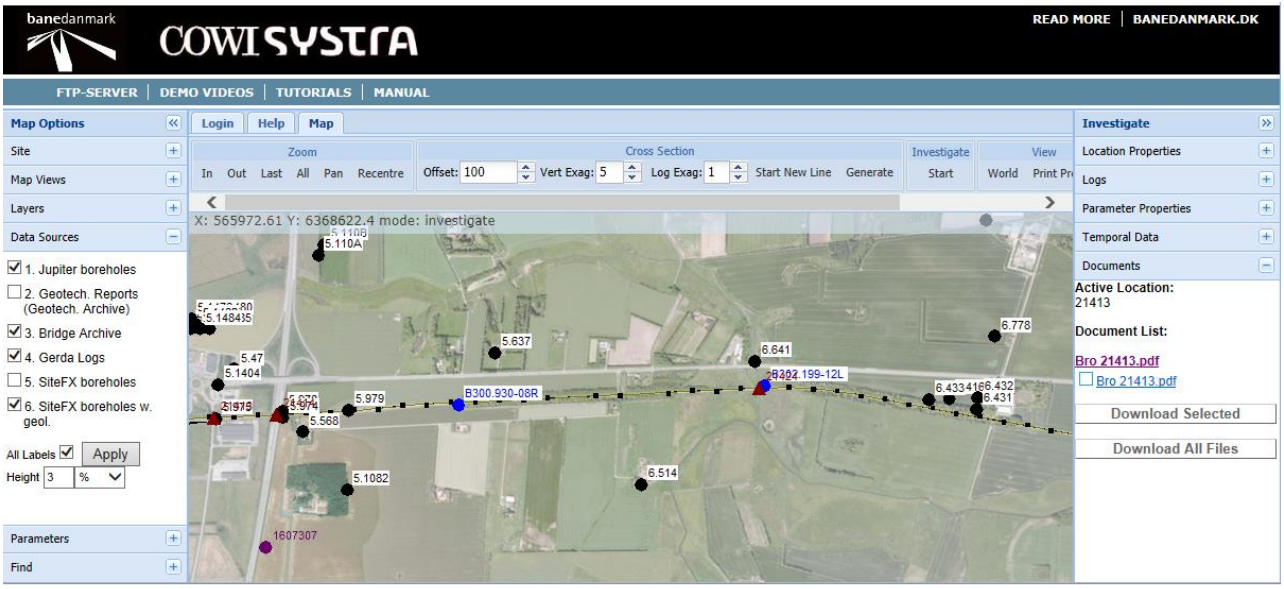

Figure 5, Example from Banedanmark's EacoWeb homepage for the Electrification Programme showing a close-up of the railway section Aalborg-Frederikshavn. Accessible data seen here are boreholes, borehole logs and geotechnical reports. Click on the link (purple text) in the right column to open the selected report as a pdf-file. Borehole logs can be generated directly from the database under the menu Logs and under the menu Cross Section you can generate cross sections with topography and boreholes projected from a selected offset distance.

6 ASSESSMENT OF SOIL AND ROCK PARAMETERS

In order to provide a uniform basis for tendering the project, a set of characteristic geotechnical parameters for the soils and rocks encountered down to 8 m below terrain and geotechnical profiles for all sections of track were provided for the tenderers. This required collation of all available data from existing sources (geological maps, historical maps, borehole logs, geophysical surveys, reports, memos, etc.) as well as the geotechnical and geophysical investigations performed for the project by COWI-SYSTRA for the client.

7 ADVANTAGES & RESERVATIONS

The combined approach in undertaking geotechnical and geophysical supplementary investigations in order to provide a sufficiently detailed and robust basis for the preparation of tenders has proven to be ideal for a project of this size. The methods are highly complementary and the integrated interpretation increases the achievable level of information.

On-track geotechnical boreholes can provide data very close to the location of a future mast foundation – but at a significant cost, whereas off-track boreholes are positioned at locations, where off-track access is available, and thus costs are less, however the off-track location may not correspond to the location of a proposed mast foundation. Due to the considerable extra costs involved in planning and drilling on-track geotechnical boreholes, as compared to off-track geotechnical boreholes, a well-considered balance between the numbers of these alternative types of boreholes in the drilling programme is required.

The interpreted model section from the geophysical ERT surveys have shown to be directly applicable to the model of the characteristic geotechnical parameters of the soil layers.

Where possible, the results of the geophysical ERT surveys have further been incorporated into the planning of the supplementary geotechnical investigations in order to optimize their location. In some instances, the geophysical information was not available in time for planning of the geotechnical investigations, typically due to weather or access issues. However, the geophysical ERT surveys give a solid geological basis in which the contractor can use in eventual planning of additional geotechnical investigations.

Similarly, the results of the geophysical surveys can also be used to assess the sections of railway in which the distance between the geotechnical investigations can be increased without compromising the overall quality of the basis geotechnical information for the project.

The geophysical surveys cannot be used directly to assess the characteristic geotechnical parameters for the soils and rocks encountered and as such, they cannot be used as a standalone investigation method for the purposes of this project. However, the ERT profiles provide continuous data which combined with boreholes can extrapolate the information from the borehole(s) along the ERT profile. This greatly enhances the value of nearby boreholes.

Due to electrical disturbances from the signaling cables that can affect the ERT data, the geophysical surveys were typically located 50 – 75 m from the railway. As such, the results of the geophysics need to be considered in this light when interpreting the geological longitudinal sections along the track.

In built up areas such as towns, in forests or in periods of frost or snow it was not always possible to perform the geophysical surveys.

The use of one single and easily accessible GIS platform to store and access all geotechnical, hydrogeological and geophysical project data is an enormous advantage compared to paper format, and not just with regards to presenting the information in the tender documents, but just as importantly, during the design and construction phases of such a large project. The fact that all users can access the same data simultaneously is an important factor in reducing the number of misunderstandings between the different parties working on the project.

The quality of the overall database is only as good as the quality of the individual input data. As such, stringent controls need to be in place in order to ensure that the quality of the input data is assured.

The use of the GIS tools Mapinfo and EacoWeb was a major factor in collating the vast amounts of data. Furthermore, these GIS tools were very efficient in facilitating the tasks of planning the supplementary geotechnical and geophysical investigations as well as assessing the characteristic values of the geotechnical parameters for soils and rocks encountered.

8 FUTURE APPLICATIONS

On major infrastructure projects such as roads, motorways, railways, as well as large utility projects, for example laying gas lines or electricity cables, the combination of geotechnical investigations and geophysical surveys can be used to optimize the number and location of investigation points, particularly over large distances, where scarce placement of geotechnical investigations is a necessity.

The complementarity of the two investigation methods raises the achievable level of information. This is possible when an integrated interpretation of the two data sets is made. Thus, it is strongly recommended that a geotechnical borehole is drilled along a geophysical survey line and vice versa.

The use of a single, easily accessible internet based GIS platform such as EacoWeb is a very efficient way of storing, maintaining, sharing and updating data for all project users.