Preface

This report describes the BSc thesis Integration of Shallow depth geophysics data. This thesis is the final course in the three year Bachelor program of the faculty Applied Earth Sciences at the Delft University of Technology.

The author of this report would like to thank Dominique Ngan-Tillard for her advice and guidance and Han Visser for his help during the measurements in the field.

Linneke vd Veeken
September 2009
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Summary

The purpose of this thesis is to integrate the geophysical data gathered along side a future road construction site.

The gathered data consists of: surface elevation data, CPT’s and several types of electrical and geoelectrical measurements. The data has been integrated both in a qualitative and in a quantitative way. For the qualitative integration the visibility of known geological features has been checked and compared for the different types of data. The quantitative integration involved the kriging of the cone resistance measured by several CPT’s.

While this thesis was carried out it became clear that visual correlation and integration was the only option to integrate the data.
Chapter 1  Introduction

The largest part of the surface geology of the Netherlands consists of soft soils, so the majority of the roads are constructed on soft soils. Soft soils cause specific problems for road construction. Problems stem from deformation of the road structure itself and from deformation of the underlying soft soils. (Munsterman et al)

Knowledge of the subsurface (in particular of the geometry of heterogeneities) helps to fulfill strict design criteria. It is important to know the geometries of soft and stiffer soil both in vertical and horizontal direction. Site investigation with the help of geophysics and CPT’s can provide this knowledge.

In the area under study over time many different geophysical measurements have been conducted. The purpose of this thesis is to integrate this data in order to develop a clearer and more accurate picture of the subsurface to provide the knowledge that is needed for the design of motorways.

The data will be qualitatively integrated by trying to find known geological features in the data and comparing these.

Several attempts have been made to integrate the data quantitatively. Most of these attempts have been unsuccessful. In chapter 6 a profile of the cone resistance is made with the help of kriging.

Chapter 2 gives a short introduction about the geology of the site where the measurements have been made. Chapter 3 and 4 describe the equipment used and the data gathered. Chapter 5 presents the actual qualitative integration. Chapter 6 presents the quantitative integration. Chapter 7 presents the conclusions and recommendations.
Chapter 2  Description of the site
This chapter gives a short introduction in the geology of the area. It also introduces architectural elements of the subsurface

2.1 Presentation of the project
The location where the measurements that are used in this thesis were made lies between Delft and Schiedam; between the oostvenseweg and the kerosene pipeline from Europoort to Schiphol. (Figure 2-1)

In the sixties and seventies a part of the A4 way was planned in this area A Sand embankment was placed in the seventies to serve as a foundation for the road. Due to environmental concerns and budget restrictions the road has never been build. The embankment however is still there and can be seen in Figure 2-1.

2.2 Geological history of the site

Importance of geological features for road construction
As mentioned in the previous part an embankment was placed for ground improvement in the seventies. From mapping this embankment its behaviour (settlement etc) can be derived giving information that can be used in case of widening of roads on other sides. Possible heterogeneities (soft and more stiff soils) in the subsurface are important for uneven settlement of the road.

Bridges are often founded on piles in the Pleistocene sand that is expected to be found around 20 metres. Localizing and mapping the Pleistocene can help improve these foundations. The Pleistocene is the oldest and deepest layer about which information is needed for road construction in the Netherlands; therefore our geological description will be limited to the quartaire.

The Pleistocene
The climate during the Pleistocene is characterized by glacial and interglacials. During the last ice age a large amount of fluvial sand known as the krefthenheyen formation has been sedimented in the
region. This layer is nowadays at about ten meters thick. It is present in the whole area and can therefore be used as a benchmark. The Pleistocene is expected to be present at 13 to 20 meters depth. (Berendsen 1996)

**The Holocene**

The region was during a large part of the Holocene a coastal area mainly formed by marshlands comparable to the area on the photo in Figure 2-2.

![Figure 2-2 An impression of how the fieldwork area at the beginning of the Holocene (Dolman)](image)

The Holocene started 10,000 years ago, when the last ice age ended. It is marked by an important increase in temperature, which led to the melting of the land ice. Since then the climate has been apart from some minor fluctuations relatively stable. (Berendsen 1996)

From the Atlanticum a large amount of peat has been sedimented in the Netherlands and also in the research area. The formation of peat has been attributed to a change in the watersystem. This change was caused by a changing in the evaporation rate, deforestation and sea level rise. These factors made the area more moist. (Berendsen 1996)

Relative sea level changes have had a profound impact on the geological development of our area during the Holocene. A rapid transgression has caused the sedimentation of marine clay in the area on top of the already deposited peat. Tidal basins were formed and sand was deposited in these tidal channels. (Berendsen 1996)

**Geological maps and sections**

The 1:50,000 geological map indicates a tidal channel in the fieldwork area. The tidal channel belongs to a large network of tidal channels.
The conceptual model of the geology in the fieldwork area shows the following features:

1. Tidal channel
2. Surrounding peat deposits
3. Pleistocene

Figure 2-3 Geological map of the fieldwork area scale 1:50,000 (presentation AES 1650 2005)

Figure 2-4 conceptual geological model of the region (presentation AES 1650 2005)
Chapter 3  CPT’s and surface elevation data

Both surface elevation data and CPT data are available. In this chapter will be explained how and where these measurements were made. The first part explains how the CPT’s were made, what they are where they were made and how they are interpreted. The second part of this chapter explains how the surface elevation data has been gathered and used.

3.1 CPT’s an introduction

A CPT (cone penetration test) is originally a Dutch invention and now a standard test in the parts of the world with soft soil. It consists of pushing continuously a metal cone into the ground while measuring two parameters: the sleeve friction and the cone resistance. These parameters give information about the physical and mechanical properties of the soil.

The cone resistance is derived by dividing the total force acting on the cone by the projected area of the cone. The sleeve friction is derived by dividing the total force acting on the friction sleeve divided by the surface area of the friction sleeve. The ratio between sleeve friction and cone resistance is called the friction ratio. (Lunne et al 1997)

CPT’s can be used for soil classification. Several soil classification charts have been derived over the years. An example can be seen in Figure 3-1. These classifications are based on the values of cone resistance and friction ratio. Sandy soils generally have low high cone resistance and low friction ratio, while clay usually has low cone resistance and high friction ratio. Organic soils like peat have often have very low cone resistance and high friction ratio. (Lunne et al 1997)

![Figure 3-1 CPT soil behaviour classification chart by Douglas and Olsen (1981) (Lunne et al 1997)](image)

3.2 CPT data gathered

The locations of the CPT measurements projected on the geometry of the fieldwork area can be seen in Figure 3-2. Several CPT’S were performed at close spacing for training purposes. For CPT Gt/m the sleeve friction was not recorded correctly. Therefore the friction ratio is also incorrect for these CPT’s and can therefore not be used.
In Figure 3-3 the cone resistance and sleeve friction for the CPT’s alongside the embankment can be seen. And Figure 3-4 shows this for the CPT’s made on top of the embankment. For more details CPT’s the reader is referred to Appendix A.
Figure 3-4 CPT’s made on the embankment
3.3 The surface elevation data

In 2004 a detailed digital elevation map of the Netherlands (AHN algemeen Nederlands hoogtebestand) has been published. The AHN was commissioned by the directorate general for public works and water management. (rijkswaterstaat) The AHN has been based on very accurate subdecimetre laser altimetry data with an average resolution of one measurement per 8 m. The vertical resolution is one centimeter. This data allows for fast mapping of the geomorphology of large area’s and can help to make these maps more accurate. (Berendsen 2007)

The vertical resolution is one centimeter; however the absolute vertical accuracy per point is less the standard deviation is 15 cm. This standard deviation is mainly due to stochastic laser errors. (Berendsen 2007)

The data was imported into the Matlab®, by means of manual adjustment of the color map the digital elevation map was enhanced to show more detail. Further in the report the data was used to make profiles of the area. To improve processing speed a smaller subset was made of the data only covering the fieldwork area was made. The data is displayed in Figure 3-5.

![Figure 3-5 the surface elevation data after processing](image)

It is still less common used in site investigations in the Netherlands than CPT’s, but it can be very helpful in identifying heterogeneities. In this case the former tidal channel appears as a light ridge in the landscape and is visible in the data.

This is because the sand in the tidal channel will show less settlement than the surrounding clay deposits, therefore a different in height between the tidal channel and its surroundings can be expected.

For further information about the processing of the data the reader is referred to Appendix B.
Chapter 4 Geophysical measurements and equipment

The geophysical methods can be divided into different categories of which seismics, electrical and electromagnetic methods are the main categories. In this thesis data was gathered with the electrical and the electromagnetical methods is used. These two methods are discussed below. (Burger 2006)

4.1 The Electric method

The basic idea of an electrical resistivity survey is to apply a direct current to the surface and to measure the resistivity between two points.

Supersting

Introduction

The Supersting is a time domain multi-channel DC resistivity method. It consists of 84 electrodes with 8 active electrodes in each measurement. It is manufactured by Advanced Geosciences. Inc. By increasing the distance between the electrodes which send the current, the penetration depth is also increased. (Burger 2006)

The data was processed with earthImager 2d, a software package from the same manufacturer.

Locations and description of the Supersting data

In Figure 4-1 the locations of the Supersting surveys data is shown projected on a surface elevation map. Figure 4-2 shows an example of the data itself after it has been processed with Earthimager 2d. The Schlumberger configuration with electrode spacing of 3 meters was used. (Kalamatas & Phiredj 2005)

Figure 4-1 Locations of supersting projected on surface elevation map
The upper picture of Figure 4-1 shows the measured apparent resistivity’s. After some iteration the earth imager software is able to distinguish different layers with respect to the resistivity (lowest figure).

4.2 Electromagnetic method

The second category is electromagnetic surveying. There are two basic ideas behind this method.

The first one is to produce an electromagnetic field by passing alternating currents through a coil. Conducting bodies beneath the surface generate a secondary magnetic field which is measured by a receiver. The differences between these fields are then used to determine the characteristics of these bodies. The Tem-fast, Gem2 belong to this category. The gem2 operates in the frequency domain and the tem-fast operates in the time domain.

The second one is to send electromagnetic (radar) waves into the surface. The GPR belongs to this category. (Burger 2006)

Tem-Fast

Introduction

TEM-FAST 48 HPC is a portable electromagnetic geophysical system. TEM-FAST 48 HPC operates by generating and sending short pulses of electromagnetic field in the earth and registers its response. This device applies a primary magnetic field on the surface that generates induction currents in the subsurface. These induction currents provoke a secondary magnetic field, which is recorded at the surface and which is also a measure of the resistivity of the subsurface. (www.aemr.net)
Locations and description of Tem-Fast data

The location of the measurements is shown in Figure 4-3. The interval between the measurements was 10 meters. A square of 12.5 by 12.5 and two loops were used. Figure 4-4 show an example of Tem-Fast measurements after processing (Brinkman et al, 2007). The tem fast measurements have been made during the shallow depth geophysics practical in 2007.

Figure 4-3 the locations of the Tem-Fast measurements

Gem 2

Introduction

The Gem2 is an electromagnetic method that operates in the frequency domain. It is manufactured by the company Geophex. The Gem2 has a source and a receiver for the electromagnetic waves. The large advantage of the GEM2 over the other geophysical methods is the fact that it is portable and can be operated by one person. Also the speed of with which a survey can be conducted is very high. Estimated is that 10,000 data points per acre can be gathered. The source receiver distance is fixed.

(www.geophex.com/product_page)
The source creates 5 different frequencies: 925, 2175, 8175, 12225 and 20025 Hertz. The frequency used is inversely proportional to the so-called ‘skin depth’ or depth of exploration. (www.geophex.com/product_page)

A low frequency travels deeper than a high frequency, so it can uncover deeper structures in the subsurface than higher frequencies. Scanning through a frequency window is therefore comparable to depth sounding. Unfortunately, a reliable and cost-effective inversion technique is yet to be discovered. (www.geophex.com/product_page)

The data used in this paper has been converted to apparent resistivity.

Locations and description of Gem2 data

The Gem2 measurements have been made on 2 different locations (Figure 4-5). Two lines in opposite direction have been measured at each location (Brinkmanetal 2007)

During processing it became clear that the higher frequencies were more accurate, because the measurements made the higher frequencies contain less noise. The measurements at the frequencies: 9825, 12025 and 20025 hz can be seen in Figure 4-6.

During processing it became clear that the lower frequencies contain too much noise to be used.
GPR

Introduction
The GPR uses EM waves in the frequency band or 10-1000 MHz (High Frequency EM Methods). The advantage of using EM waves is that signal wavelength is relatively small and that therefore the resolution high is. The EM waves detect variation in the dielectrical properties of the ground materials. Penetration is affected by the conductivity of the soil.

Locations and description of GPR data
One line of GPR measurements has been made, with a frequency of 100 Mhz. The location can be seen in Figure 4-7 and the results can be seen in Figure 4-8. (Brinkman et al 2007)

For further details on the processing of this data the reader is referred to Appendix E.
Figure 4-7 Location GPR

Figure 4-8 GPR measurements after processing and interpretation (Brinkman et al 2007)
Chapter 5 Qualitative data integration

5.1 Introduction
The goal of this chapter is to compare the different methods with each other and to come to a qualitative integration. This will be achieved by using several known geological features described in chapter 2: the bottom of the embankment, the ground water table, the tidal channel and the depth to the Pleistocene deposits.

For each of these features data integrations have been made. For each feature it is described if and how well it can be detected by each survey method (geophysics, AHN, CPT’s). This gives an overview how well the methods perform and how useful they are in a site investigation.

5.2 Data integration for the bottom of the embankment
Figure 5-1 shows the data integration for the bottom of the embankment.

From the CPT’s made on top of the embankment it is very easy to determine the bottom of the embankment. It corresponds to the first drop in cone resistance and sleeve friction. There the sand of the embankment ends and the clay of the original deposits begin. It is indicated by the black line in Figure 5-1.

From the air the embankment is very clearly visible. It is not possible to determine exactly the bottom of the embankment since the embankment has settled into the surrounding soft soil.

In the processed tem-fast data the bottom of the embankment is clearly visible. It was however used as a constraint for the inversion process of the data.

In the Supersting data a drop in resistivity is expected at the bottom of the embankment because under the sand there is probably clay. There are two drops in resistivity; one at approximately 2.5 meters and one between 4 and 6 meters. The first drop is probably the ground water table the second is the bottom of the embankment. The second drop in resistivity corresponds with the findings of the CPT’s.

For the GPR the embankment is indicated by the yellow line. It is not very clear from the GPR data and has been interpreted as the boundary between the reflections with reasonably high amplitudes and reflection with relatively low amplitudes. This should however not be taken as a very reliable estimate.

With the gem2 it is impossible to determine the depth of the bottom of the embankment, because the signals measured with different frequencies are too similar to be inverted. The Gem2 gives information about the wideness of the embankment.

On the west side the measured resistivity is higher than on the east side. This could mean that the embankment is thicker on the west side than on the east side.

Figure 5-1 gives a summary of the data integration for the bottom of the embankment.
Figure 5-1 Data integration for sand embankment

**SECTION # 4**

![Diagram of Section #4](image)

- **Elevation, m**
- **Distance, m**
- **POINT 000001**
- **POINT 000002**
- **POINT 000003**
- **POINT 000004**

**Tem Fast data**

Supersting data

CPT data

GPR data

GEM2 data

Surface elevation data

**Figure 5-1 Data integration for sand embankment**
### DATA INTEGRATION FOR THE BOTTOM OF THE EMBANKMENT

<table>
<thead>
<tr>
<th>METHOD</th>
<th>VISIBLE?</th>
<th>DEPTH?</th>
</tr>
</thead>
<tbody>
<tr>
<td>surface elevation data</td>
<td>no</td>
<td>Impossible to determine</td>
</tr>
<tr>
<td>CPT’S</td>
<td>yes</td>
<td>4 m</td>
</tr>
<tr>
<td>Tem-Fast</td>
<td>yes</td>
<td>3.5 m</td>
</tr>
<tr>
<td>Supersting</td>
<td>yes</td>
<td>5 m</td>
</tr>
<tr>
<td>GPR</td>
<td>Yes not very clearly</td>
<td>5 m</td>
</tr>
<tr>
<td>GEM2</td>
<td>no</td>
<td>Impossible to determine</td>
</tr>
</tbody>
</table>


5.3 The Tidal Channel

The surface elevation data and the tidal channel

The tidal channel is clearly visible in the surface elevation data. It can be seen as a slight elevation of the landscape of about 0.5 to a meter high (indicated by arrows in Figure 5-2). Other details like difference in settlement of the embankment and landscape features like ditches are also visible.

The global resemblance between surface elevation data with the geological map of the area on which the channel is indicated by a blue circle is quite striking.

![Figure 5-2 Comparison of the surface elevation data and the geological map](image)

Data integration for the tidal channel

The data integration for the tidal channel can be seen in Figure 5-3.

In the CPT data the tidal channel is not immediately visible. When comparing the surface elevation data to the CPT data, it becomes clear that cptb, cptg and cptf lie on the tidal channel. In cptb and cptg a sand body beneath the surface is indeed visible. In cptf the tidal channel isn’t visible, indicating that the tidal channel is smaller then would be presumed based on the surface elevation data.

For Supersting line A and line B in the middle of the measurement line an increase in resistivity is visible. This is probably the tidal channel. When the CPT’s are projected onto the Supersting data a correlation is visible between the CPT’s and Supersting data. CPTB is also a resistivity cone. When the resistivity is plotted on the Supersting data and next to the cone resistance a sharp increase of the resistivity is measured consistent with the tidal channel in the Supersting data. For the resistivity cone, line awas measured with an electrode spacing of 500mm line b with 100mm.

The Gem2 data shows first an increase in the resistivity and after that a decrease indicated with arrows’. This could indicate the presence of a sand body. It coincides with the surface elevation and the Supersting data. The tidal channel is neither visible in nor the Tem-Fast data and in the GPR data.
Figure 5-3 Data integration for tidal channel

- Supersting en CPT
- Resistivity cone
- Gen2
Table 5-1 gives a summary of the visibility of the tidal channel in the different methods.

<table>
<thead>
<tr>
<th>METHOD</th>
<th>VISIBLE?</th>
</tr>
</thead>
<tbody>
<tr>
<td>surface elevation data</td>
<td>yes</td>
</tr>
<tr>
<td>CPT’S</td>
<td>yes</td>
</tr>
<tr>
<td>Tem-Fast</td>
<td>no</td>
</tr>
<tr>
<td>Superstring</td>
<td>yes</td>
</tr>
<tr>
<td>GPR</td>
<td>no</td>
</tr>
<tr>
<td>GEM2</td>
<td>yes</td>
</tr>
</tbody>
</table>

Table 5-1 Summary for the data integration for the tidal channel
5.4 **Ground water table**

The ground water table is only visible in the Supersting data and in the GPR data as can be seen in Figure 5-4. In the supersting data it is visible as a reflection at 2 metres in the GPR data as reflection at 2 metres. Table 5-2 gives a summary for the visibility of the ground water table in the different types of measurements.

![Figure 5-4 Data integration for the ground water table](image)

### DATA INTEGRATION FOR GROUND WATER TABLE

<table>
<thead>
<tr>
<th>METHOD</th>
<th>VISIBLE?</th>
</tr>
</thead>
<tbody>
<tr>
<td>surface elevation data</td>
<td>no</td>
</tr>
<tr>
<td>CPT’S</td>
<td>no</td>
</tr>
<tr>
<td>Tem-fast</td>
<td>no</td>
</tr>
<tr>
<td>Supersting</td>
<td>yes</td>
</tr>
<tr>
<td>GPR</td>
<td>yes</td>
</tr>
<tr>
<td>GEM2</td>
<td>no</td>
</tr>
</tbody>
</table>

Table 5-2 Summary for the visibility of the ground water table
5.5 Data integration for the Pleistocene sand body

The data integration for the Pleistocene sand body can be seen in Figure 5-5.

The Pleistocene sand body is not directly visible in the surface elevation data. Differences in thickness of the Pleistocene may be visible as differences in surface elevation, however it is difficult to attribute differences in surface elevation directly to variations in Pleistocene thickness without other information.

The Pleistocene is quite well visible in the CPT’s it is indicated by the red line in Figure 5-5. For the Supersting data the Pleistocene is visible as an increase in resistivity. It is in the Supersting sections indicated with black arrows, again a strong correlation between Supersting data and the CPT’s is visible.

The pleistocene is not visible with the Gem2 that is used in this thesis. However the Pleistocene can possibly be found with the Gem2 using lower frequencies, which penetrate deeper into the subsurface. A higher average resistivity will be found than.

The Pleistocene is also not visible in the Temfast measurements, although it has been used as a constraint during data inversion.

In the GPR data the Pleistocene also cannot be seen, because the penetration depth isn’t deep enough, because of the high ground water table.
Figure 5-5 Data integration for the Pleistocene sand body
A summary is given in Table 5-3.

<table>
<thead>
<tr>
<th>METHOD</th>
<th>VISIBLE?</th>
<th>DEPTH?</th>
</tr>
</thead>
<tbody>
<tr>
<td>surface elevation data</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>CPT’S</td>
<td>yes</td>
<td>18 m</td>
</tr>
<tr>
<td>Tem-Fast</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>Supersting</td>
<td>yes</td>
<td>18 m</td>
</tr>
<tr>
<td>GPR</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>GEM2</td>
<td>no</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5-3 Summary for the data integration for the Pleistocene sand body
Chapter 6  Quantitative integration

6.1 Quantitative integration: a possible future of shallow geophysical data integration?

For this thesis visual correlation was used to integrate the data.

The previous chapter could have been somewhat expanded comparing the data on even more points, but that probably wouldn’t have added much to this thesis anymore. It would have been just more of the same.

The ultimate goal of engineering geology in the end is to build a model of the subsoil that contains the geotechnical parameters of the soil, not only at the measurement points, but also in between. With these types of models the response of the subsoil during the construction works, during construction and afterwards can be estimated. This requires a great deal of complex interpolation in between verticals.

During this thesis many attempts have been made, to take the integration a step further using geostatistics. The dataset however turned out to be unsuitable for this. In part an attempt will be made to integrate the data using a quantitative method.

It should be taken into account that if one wants to achieve a quantitative integration, the measurement methods used should measure the same type of the soil properties and the values of the measurements should be easily converted into one another. And that was one of the difficulties in applying geostatistics to this data set.

When building a model to assess the impact of road construction works on the soft subsoil knowledge of geotechnical parameters is necessary. The best measurement methods for such a model are CPT’s and shallow S-wave seismics. Both these methods give strength parameters of the soil, which can be converted into one another.

6.2 Integration using geostatistics

“Geostatistics is used to describe the autocorrelation of of one or more variables in 1D, 2D and 3D space or even in 4D time space to make predictions about the unobserved locations to give information about the accuracy of the prediction and to reproduce spatial variability.” (Trauth, 2006, page 173)

A basic assumption is that the spatial temporal process is a combination of deterministic and stochastic components. The deterministic component can be formed by local or global trends. The stochastic part consists of a purely random and an autocorrelated part. The autocorrelated part implies that on average, closer observations are more similar than more distant observations. This behaviour is described by a semivariogram. (Trauth 2006)

A technique called kriging which was introduced by the South African mining engineer Daniel G. Krige uses this variogram for interpolation. Over time other interpolation techniques have been developed. (Trauth 2006)

In the next part the cone resistance of the CPT’s is interpolated with the help of Kriging.

6.3 Integration of the depth of the Pleistocene using kriging

To test the possibilities of kriging the cone resistance of the CPT’s that were made alongside the embankment is made. To do this this easy krig was used. Easy krig is a free software package developed
by Dezhang Chu with funding from the National Science Foundation through the U.S. GLOBEC Georges Bank Project's Program Service and Data Management Office. (easykrig manual)

Easy krig works under Matlab and uses a GUI. The program has five processing stages:
1. data preparation
2. variogram
3. computation,
4. kriging,
5. visualization

Data analysis and preparation

Figure 6-1 shows the locations of the CPT’s used.

Figure 6-1 Locations of the CPT’s used for kriging

The Spacing of the CPT’s is much smaller than the size of the heterogeneities. The heterogeneities are therefore well sampled and easy to derive with manual interpolation, so geostatistics is not that useful here.

<table>
<thead>
<tr>
<th>Data characteristics</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum</td>
<td>-0.0813 (cone resistance)</td>
</tr>
<tr>
<td>maximum</td>
<td>34.0650 (cone resistance)</td>
</tr>
<tr>
<td>Skewness</td>
<td>5.8816</td>
</tr>
<tr>
<td>kurtosis</td>
<td>39.2921</td>
</tr>
</tbody>
</table>

Table 6-1 Characteristics of the data used
Kriging is a parametric method. This means that it is sensitive to outliers and to data that deviates from a normal distribution. Data that is used for kriging is assumed to have a normal distribution. The data is checked by visual inspection of a histogram of the data Figure 6-2. (Trauth 2006)

The data is negatively skewed and doesn’t satisfy the assumption that the data is normally distributed. This is very likely to affect the results of the kriging process. (Trauth 2006)

![Figure 6-2 A histogram of the cone resistance data set](image)

**The variogram**

“The variogram describes the spatial dependency of referenced observations in one or multidimensional space. While we usually do not know the true variogram of the spatial process have to estimate it from the observations this process is called variography. (Trauth 2006)

![Figure 6-3 The variogram](image)

“The variogram model is a parametric curve fitted to the variogram estimator”. Because of some theoretical reasons are only a certain amount of functions that can be used for this. (Trauth 2006)

In this case an exponential model was used and fitted through the data with the least squares method. Based on this model the Kriging is done.

![Figure 6-4 variogram with variogram model fitted](image)
**Kriging**

The next step in the process is to choose the theoretical model that fits the data the best. The type of kriging that will be used is ordinary kriging. “Ordinary kriging uses a weighted average to estimate the value of an unobserved point.” (Trauth, 2006)

Figure 6-5 shows the interpolation values. The Pleistocene is clearly visible in the higher cone resistance in the bottom of the picture. In the middle a slightly higher cone resistance is visible, which could be the tidal channel.

![Figure 6-5 Kriging estimate showing the interpolated values on a](image)

Figure 6-6 shows the kriging variance. The higher the kriging variance, the higher the uncertainty of the corresponding estimate.

![Figure 6-6 The kriging variance](image)
Chapter 7  Conclusions and recommendations

7.1 Summary of which geological feature is visible with which method

<table>
<thead>
<tr>
<th>Layer</th>
<th>Surface elevation data</th>
<th>CPT’s</th>
<th>Supersting</th>
<th>Gem2</th>
<th>Tem-Fast</th>
<th>GPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom embankment</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>maybe</td>
<td>Y</td>
</tr>
<tr>
<td>Tidal channel</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>-</td>
</tr>
<tr>
<td>Ground water table</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Pleistocene sand body</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>possibly</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

7.2 Conclusions for each method

Surface elevation data

The surface elevation data gives a clear overview of the location and the tidal channel is also clearly visible in the data. This makes surface elevation a relatively cheap method to map heterogeneities like tidal channels.

CPT’s

CPT’s are most often used in Dutch site investigation they are relatively cheap and processing is easy. The CPT’s give also direct information about the geotechnical parameters of the soil via empirical relationships; however the derivation of strength and compressibility for soft layers from CPT data is often not reliable. They were able to distinguish three geological features.

The Supersting

The Supersting was able to distinguish all four geological features. The Supersting gives a relative clear picture of the subsurface, but a little bit more validation of the data for instance with the help of boreholes might be necessary to confirm the exact position of the layers. CPT’s can also be used for this purpose. In this thesis the Supersting data is compared to the cone resistance of the CPT’s.

The Gem 2

The Gem2 is a very fast method of conducting measurements. By scanning through the frequency band different depths can be reached with it. However a fast way of inverting the data hasn’t been found yet.
The Tem-Fast
In the Tem-Fast data only the bottom of the embankment is visible and that was used as a constraint for data inversion. Probably more research is necessary to improve its performance. Many configurations are possible and for the measurements used in this thesis maybe not the best configuration was used or the measurements were simply too far apart.

A disadvantage of the Tem-Fast is that while processing you already need to use some geological knowledge.

The GPR
The GPR gives a good high resolution picture of the shallow subsurface. The groundwater table acts as a strong reflector. Therefore the penetration depth isn’t very high for the GPR.

7.3 General conclusion
The different methods all have their advantages and disadvantages. They can be integrated by visual correlation, but that has its limitations and these limitations have been met in this thesis. Therefore further research might focus on integration by means of interpolation and geostatistics among others.

It will then depend on the goal of the site investigation which methods will be chosen, because not all methods can be integrated by means of geostatistics with each other.

Several attempts to integrate the data with geostatistics were undertaken. There is one discussed in this thesis. An attempt was made to make an interpolation of observations of the cone resistance from CPT’S. The dataset proved unsuitable for this, because it wasn’t distributed normally.
Bibliography


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Munsterman W, Ngan-Tillard D, Venmans A,*Total engineering geological approach applied to motorway construction on soft soils*, www.delftcluster.nl


websites

www.aemr.net

www.geophex.com/product_page
Appendix A CPT data preparation
The CPT data has been processed with the following MATLAB® scripts.

The following functions were written

```matlab
CPTcoord
%De functie [B]=cptcoord(x,y,A) verbind de x en y coordinaten aan cpt's x
%is een scalar met de x coordinaten. y is een scalar
%met de y coordinaten A bevat in de eerste kolom de sondeerlengte.
function [B]=cptcoord(x,y,A)
c=size(A);
c=c(1,1);
Y=ones(c,1);
X=ones(c,1);
Y=y*Y;
X=x*X;
B=[X Y A];

Fugro determine the friction ratio
function [B c]=Fugro(A)
c=((A(:,5))./(A(:,4)).*100);
B=[A c];

Cptcolor determines whether there is clay, sand, silt or peat and attaches a color to it.
function [C]=cptcolor(A)
b=size(A);
c=b(1,1);
C=zeros(c,1);
C2=zeros(c,1);
C3=zeros(c,1);
for k=1:c
    if A(k,6)<=1; %zand is blauw
        C(k,1)=0;
        C(k,2)=0;
        C(k,3)=1;
    elseif (A(k,6)>1) && (A(k,6)<=2); % silt is cyaan
        C(k,1)=0;
        C(k,2)=1;
        C(k,3)=1;
    elseif (A(k,6)>2) && (A(k,6)<=4); % klei is groen
        C(k,1)=0;
        C(k,2)=1;
        C(k,3)=0;
    else (A(k,6)>4); % veen is rood
        C(k,1)=1;
        C(k,2)=0;
        C(k,3)=0;
    end
end
The CPT data was prepared in the following script
load cptaR;
A=cptaR;
```

The CPT data has been prepared with the following MATLAB® scripts.

The following functions were written

```matlab
function [B]=cptcoord(x,y,A)  % De functie [B]=cptcoord(x,y,A) verbind de x en y coordinaten aan cpt's
% x is een scalar met de x coordinaten. y is een scalar
% met de y coordinaten A bevat in de eerste kolom de sondeerlengte.
    c=size(A);
    c=c(1,1);
    Y=ones(c,1);
    X=ones(c,1);
    Y=y*Y;
    X=x*X;
    B=[X Y A];

function [B c]=Fugro(A)  % Fugro determine the friction ratio
    c=((A(:,5))./(A(:,4)).*100);
    B=[A c];

function [C]=cptcolor(A)  % Cptcolor determines whether there is clay, sand, silt or peat and attaches a color to it.
    b=size(A);
    c=b(1,1);
    C=zeros(c,1);
    C2=zeros(c,1);
    C3=zeros(c,1);
    for k=1:c
        if A(k,6)<=1; %zand is blauw
            C(k,1)=0;
            C(k,2)=0;
            C(k,3)=1;
        elseif (A(k,6)>1) && (A(k,6)<=2); % silt is cyaan
            C(k,1)=0;
            C(k,2)=1;
            C(k,3)=1;
        elseif (A(k,6)>2) && (A(k,6)<=4); % klei is groen
            C(k,1)=0;
            C(k,2)=1;
            C(k,3)=0;
        else (A(k,6)>4); % veen is rood
            C(k,1)=1;
            C(k,2)=0;
            C(k,3)=0;
        end
    end
The CPT data was prepared in the following script
load cptaR;
A=cptaR;
```
x1=83568.6; y1=441432; z1=-2.9; A=cptcoord(x1,y1,A); cptaB=Fugro(A); cptaB(:,3)=(-1*cptaB(:,3)+ z1); save  cptaB

load  cptaB A=cptaB; x2=83561.66616; y2=441450.7596; z2=-2.93; A=cptcoord(x2,y2,A); cptaB=Fugro(A); cptaB(:,3)=(-1*cptaB(:,3)+ z2); save  cptaB

load  cptaB A=cptaB; x3=83513.12929; y3=441582.0766; z3=-3.05; A=cptcoord(x3,y3,A); cpteB=Fugro(A); cpteB(:,3)=(-1*cpteB(:,3)+ z3); save  cpteB

load  cpteB A=cpteB; x4=83520.06313; y4=441563.3171; z4=-2.82; A=cptcoord(x4,y4,A); cptdB=Fugro(A); cptdB(:,3)=(-1*cptdB(:,3)+ z4); save  cptdB

load  cptdB A=cptdB; x5=83526.99697; y5=441544.5575; z5=-3.15; A=cptcoord(x5,y5,A); cpteB=Fugro(A); cpteB(:,3)=(-1*cpteB(:,3)+ z5); save  cpteB

load  cpteB A=cpteB; x6=83544.33156; y6=441497.6585; z6=-2.94; A=cptcoord(x6,y6,A);
cptfB=Fugro(A);
cptfB(:,3)=(-1*cptfB(:,3)+ z6);
save  cptfB

load  cptgR
A=cptgR;
x7=83552.99886;
y7=441474.2091;
z7=-2.71;
A=cptcoord(x7,y7,A);
cptgB=Fugro(A);
cptgB(:,3)=(-1*cptgB(:,3)+ z7);
save  cptgB

load  cpthR
A=cpthR;
x8=83585.9346;
y8=441385.101;
z8=-2.85;
A=cptcoord(x8,y8,A);
cpthB=Fugro(A);
cpthB(:,3)=(-1*cpthB(:,3)+ z8);
save  cpthB

load  cptiR
A=cptiR;
x9=83589.40152;
y9=441375.7213;
z9=-3.08;
A=cptcoord(x9,y9,A);
cptiB=Fugro(A);
cptiB(:,3)=(-1*cptiB(:,3)+ z9);
save  cptiB

load  cptjR  %tud01
A=cptjR;
x10=83620;
y10=441397.7;
z10=-0.71;
A=cptcoord(x10,y10,A);
cptjB=Fugro(A);
cptjB(:,3)=(-1*cptjB(:,3)+ z10);
save cptjB

load  cptkR  %tud02
A=cptkR;
x11=83608.30847;
y11=441430.7694;
z11=-0.50;
A=cptcoord(x11,y11,A);
cptkB=Fugro(A);
cptkB(:,3)=(-1*cptkB(:,3)+ z11);
save  cptkB

X=[x1  x2  x3  x4  x5  x6  x7  x8  x9  x10  x11]';
Y=[y1 y2 y3 y4 y5 y6 y7 y8 y9 y10 y11];
Z1=[z1 z2 z3 z4 z5 z6 z7 z8 z9 z10 z11];

save X
save Y
save Z1

clear cptaR
clear cptbR
clear cptcR
clear cptdR
clear cpteR
clear cptfR
clear cptgR
clear cpthR
clear cptiR
clear cptjR
clear cptkR

The final pictures were plotted with the following script.

eerste groep cpt's in plat vlak
clear all;clc;
run dataprepfinal

%creeren volledig figuur en creeren positievector

H=axes;
load X
x=X(1:9,1);
XX=[min(x) max(x)]+[-5 5];
load Z1
axis([min(XX) max(XX) -25 0])
xlabel('x coordinate')
ylabel('depth')
V=get(H,'position');
w=0.1;

hold on
%---------------------------------------------------------
%cpta
%sleeve friction
load cptaB
a=V(1,3)/(max(XX)-min(XX));
l=V(1,1)+a*((x(1,1)-min(XX)))-w;
b=V(1,2);

h=V(1,4);

va1=[l b w h];
ha1=axes('position',va1,'Xaxislocation','top','color', 'none','ylim',[-25 0],'ytick',[],'box', 'off', 'xlim',[0 0.2]);
gca
la1=line(cptaB(:,5),cptaB(:,3));

hold on
%ccone resistance
l=l+w;
va2=[l b w h];
ha2=axes('position',va2,'Xaxislocation','top','color', 'none', 'ylim',[-25 0],'xlim',[0 30]);

la2=line(cptaB(:,4),cptaB(:,3));
set(la2, 'color', 'r')

hold on
set(ha1,'Yaxislocation','right','Xdir','reverse', 'ytick',[], 'xtick',[]);
set(ha2,'xtick',[])
%set(ha2,'Yaxislocation','right')
%ylim,[min(cptaB(:,5)) max(cptaB(:,5))]
%
%cptb
%sleeve friction
load cptbB
a=V(1,3)/(max(XX)-min(XX));
l=V(1,1)+(a*((x(2,1)-min(XX))))-w;
b=V(1,2);

h=V(1,4);

vb1=[l b w h];
hb1=axes('position',vb1,'Xaxislocation','top','color', 'none', 'ylim',[-25 0], 'ytick',[], 'box', 'off', 'xlim',[0 0.2]);
gca lb1=line(cptbB(:,5),cptbB(:,3));
set(lb1, 'color', 'm')
hold on
%cone resistance
l=l+w;
vb2=[l b w h];
hb2=axes('position',vb2,'Xaxislocation','top','color', 'none', 'ylim',[-25 0], 'xlim',[0 30]);

lb2=line(cptbB(:,4),cptbB(:,3));
set(lb2, 'color', 'g')
hold on
set(hb1,'Yaxislocation','right','Xdir','reverse', 'ytick',[], 'xtick',[]);
set(hb2,'xtick',[])
%set(ha2,'Yaxislocation','right')
%ylim,[min(cptaB(:,5)) max(cptaB(:,5))]
%
%cptc
%sleeve friction
load cptcB
a=V(1,3)/(max(XX)-min(XX));
l=V(1,1)+a*((x(3,1)-min(XX)))w;
b=V(1,2);

h=V(1,4);

vc1=[l b w h];
hc1=axes('position',vc1,'Xaxislocation','top','color', 'none', 'ylim',[-25 0], 'ytick',[], 'box', 'off', 'xlim',[0 0.2]);
lc1=line(cptcB(:,5),cptcB(:,3));
%set(lc1, 'color', 'm')
% cone resistance
l = l + w;
vc2 = [l b w h];
hc2 = axes('position', vc2,'Xaxislocation', 'top', 'color', 'none', 'ylim', [-25 0], 'xlim', [0 30]);

lc2 = line(cptcB(:,4), cptcB(:,3));
set(lc2, 'color', 'r')
hold on
set(hc1, 'Yaxislocation', 'right', 'Xdir', 'reverse', 'ytick', [], 'xtick', []);
set(hc2, 'xtick', [])

% cone resistance
l = l + w;
ld1=axes('position', vd1,'Xaxislocation', 'top', 'color', 'none', 'ylim', [-25 0], 'ytick', [], 'box', 'off', 'xlim', [0 0.2]);

ld1 = line(cptdB(:,5), cptdB(:,3));
set(ld1, 'color', 'm')
hold on
% cone resistance
l = l + w;
hd1 = axes('position', vd1,'Xaxislocation', 'top', 'color', 'none', 'ylim', [-25 0], 'xlim', [0 30]);

hd1 = line(cptdB(:,5), cptdB(:,3));
set(hd1, 'color', 'g')
hold on
set(hc1, 'Yaxislocation', 'right', 'Xdir', 'reverse', 'ytick', [], 'xtick', []);
set(hc2, 'xtick', [])

% cone resistance
l = l + w;
hd2 = axes('position', vd2,'Xaxislocation', 'top', 'color', 'none', 'ylim', [-25 0], 'xlim', [0 30]);

hd2 = line(cptdB(:,5), cptdB(:,3));
set(hd2, 'color', 'g')
hold on
set(hc1, 'Yaxislocation', 'right', 'Xdir', 'reverse', 'ytick', [], 'xtick', []);
set(hc2, 'xtick', [])

% sleeve friction
load cpteB
a = V(1,3)/(max(XX)-min(XX));
l = l + a*(x(5,1)-min(XX))-w;
b = V(1,2);
h = V(1,4);

ve1 = [l b w h];
he1 = axes('position', ve1,'Xaxislocation', 'top', 'color', 'none', 'ylim', [-25 0], 'ytick', [], 'box', 'off', 'xlim', [0 0.2]);
le1=line(cpteB(:,5),cpteB(:,3));

hold on
%cone resistance
l=l+w;
ve2=[l b w h];
he2=axes(['position',ve2,'Xaxislocation','top','color', 'none','ylim',[-25
0],'xlim',[0 30]);

le2=line(cpteB(:,4),cpteB(:,3));
set(le2,'color','r')
hold on
set(he1,'Yaxislocation','right','Xdir','reverse', 'ytick',[], 'xtick',[]); set(he2,'xtick',[])
%set(ha2,'Yaxislocation',right)
%'xlim',[min(cptaB(:,5)) max(cptaB(:,5))]
-------------------------------------------------- ------------------------
%cptf %sleeve friction
load cptfB
a=V(1,3)/(max(XX)-min(XX));
l=V(1,1)+(a*((x(6,1)-min(XX))))-w;
b=V(1,2);
h=V(1,4);

vf1=[l b w h];
hf1=axes(['position',vf1,'Xaxislocation','top','color', 'none','ylim',[-25
0], 'ytick',[], 'box', 'off', 'xlim',[0 0.2]);

lf1=line(cptfB(:,5),cptfB(:,3));
%set(le1,'color','m')
hold on
%cone resistance
l=l+w;
vf2=[l b w h];
hf2=axes(['position',vf2,'Xaxislocation','top','color', 'none','ylim',[-25
0], 'xlim',[0 30]);

lf2=line(cptfB(:,4),cptfB(:,3));
set(lf2,'color','r')
hold on
set(hf1,'Yaxislocation','right','Xdir','reverse', 'ytick',[], 'xtick',[]); set(hf2,'xtick',[])
%set(ha2,'Yaxislocation',right)
%'xlim',[min(cptaB(:,5)) max(cptaB(:,5))]
-------------------------------------------------- ------------------------
%cptg %sleeve friction
load cptgB
a=V(1,3)/(max(XX)-min(XX));
l=V(1,1)+(a*((x(7,1)-min(XX))))-w;
b=V(1,2);
h=V(1,4);
vg1=[l b w h];
hg1=axes('position',vg1,'XAxisLocation','top','color','none','ylim',[-25 0],'ytick',[],'box','off','xlim',[0 0.2]);

lq1=line(cptgB(:,5),cptgB(:,3));
%set(le1,'color','m')
hold on
%cone resistance
l=l+w;
vq2=[l b w h];
hq2=axes('position',vq2,'XAxisLocation','top','color','none','ylim',[-25 0],'xlim',[0 30]);

lg2=line(cptgB(:,4),cptgB(:,3));
set(lg2,'color','r')
hold on
set(hq1,'YAxisLocation','right','XDir','reverse','ytick',[],'xtick',[]);
set(hq2,'xtick',[])
%set(ha2,'YAxisLocation',right)
%ylim,[min(cptaB(:,5)) max(cptaB(:,5))]
%cpt
%sleeve friction
load cpthB
a=V(1,3)/(max(XX)-min(XX));
l=V(1,1)+(a*((x(8,1)-min(XX))))-w;
b=V(1,2);
h=V(1,4);

vh1=[l b w h];
hh1=axes('position',vh1,'XAxisLocation','top','color','none','ylim',[-25 0],'ytick',[],'box','off','xlim',[0 0.2]);

lh1=line(cpthB(:,5),cpthB(:,3));
set(lh1,'color','m')
hold on
%cone resistance
l=l+w;
vh2=[l b w h];
hh2=axes('position',vh2,'XAxisLocation','top','color','none','ylim',[-25 0],'xlim',[0 30]);

lh2=line(cpthB(:,4),cpthB(:,3));
set(lh2,'color','g')
hold on
set(hh1,'YAxisLocation','right','XDir','reverse','ytick',[],'xtick',[]);
set(hh2,'xtick',[])
%set(ha2,'YAxisLocation',right)
%ylim,[min(cptaB(:,5)) max(cptaB(:,5))]
%cpti
%sleeve friction
load cptiB
a=V(1,3)/(max(XX)-min(XX));
l=V(1,1)+(a*((x(9,1)-min(XX))))-w;
b=V(1,2);
h=V(1,4);

vl=[l b w h];
hil=axes('position',vl,'Xaxislocation','top','color','none', 'ylim',[-25 0], 'ytick',[], 'box', 'off', 'xlim',[0 0.2]);

li1=line(cpteB(:,5),cpteB(:,3));
%set(le1,'color','m')
hold on
%cone resistance
l=l+w;
vi2=[l b w h];
ih2=axes('position',vi2,'Xaxislocation','top','color','none', 'ylim',[-25 0], 'xlim',[0 30]);

li2=line(cptiB(:,4),cptiB(:,3));
set(li2,'color','r')
hold on
set(hil,'Yaxislocation',right,'Xdir','reverse', 'ytick',[], 'xtick',[]);
set(hi2,'xtick',[])
%set(ha2,'Yaxislocation',right)
%xlim,[min(cptaB(:,5)) max(cptaB(:,5))]
%-------------------------------------------------- ------------------------
%insert labels and legend
axes(H)
load X
r=['cpta';'cptb';'cptc';'cptd';'cptf';'cpte';'cptg';'cpth';'cpti'];
labels=num2str(r);
depth=-3*ones(9,1);
text(X(1:9,:),depth,labels);
%-------------------------------------------------- ------------------------
axes(ha1)
axes(ha2)
axes(hb1)
axes(hb2)
axes(hc1)
axes(hc2)
axes(hd1)
axes(hd2)
axes(he1)
axes(he2)
axes(hf1)
axes(hf2)
axes(hg1)
axes(hg2)
legend('sleeve friction')
axes(hg2)
legend('cone resistance')
axes(hil)
axes(hi2)
axes(hh1)
legend('sleeve friction')
axes(hh2)
legend('cone resistance')
%---------------------------------------------------------------------
Appendix B  Surface elevation data preparation

The data has been converted from a Surfer® grid to an arcview® ASCII grid with the help of the following script in scripter® downloaded from the Golden software website, this in order to be able to load the data in MATLAB®.

'Grd2arc converts a Surfer GRD file to ArcView, ArcINFO,
' Spatial Analyst ASC format.
' Converted from srf7_2aiGRD.frm from Johan.Kabout@MI.DHV.NL - TB Jan 00.
' TB - 19 Mar 00.
Sub Main
  Set srf = CreateObject("Surfer.application")
  Set plot = srf.Documents.Add(srfDocPlot)
  srf.Visible = True
  TempFile = Srf.Path+"\samples\temp.dat"

  SurferGrid = GetFilePath(srf.Path+"\samples\demogrid.grd","grd", _
    srf.Path+"\samples\","Open GRD File")

  'Mirror Y in Surfer GRD file, save to ASCII format.
  ok = srf.GridTransform(SurferGrid, srfGridTransMirrorY, _
    OutGrid:=TempFile,OutFmt:=srfGridFmtAscii)

  lengthstr = Len(SurferGrid)
  ArcGrid = Mid(SurferGrid, 1, Len(SurferGrid)-3) + "ASC"
  Open TempFile For Input As #1
  Open ArcGrid For Output As #2

  'Skip the first line of the file.
  Line Input #1,a

  'Read number of columns and rows.
  Line Input #1,a
  nCol = Left(a,InStr(a," "))
  nRow = Right(a,Len(a)-InStr(a," "))

  'Read X min max.
  Line Input #1,a
  xMin = Left(a,InStr(a," "))
  xMax = Right(a,Len(a)-InStr(a," "))

  'Read Y min max.
  Line Input #1,a
  yMin = Left(a,InStr(a," "))
  yMax = Right(a,Len(a)-InStr(a," "))

  'Read Z min max (not used in Arc grid file).
  Line Input #1,a
  zMin = Left(a,InStr(a," "))
  zMax = Right(a,Len(a)-InStr(a," "))

  xCellSize = ((Val(xMax) - Val(xMin)) / (Val(nCol) - 1))
  yCellSize = ((Val(yMax) - Val(yMin)) / (Val(nRow) - 1))
Diff = 100*(xCellSize - yCellSize) / xCellSize
'Debug.Print "xCellSize, yCellSize, Diff =";xcellsize;" ";yCellsize;" ";diff
If (xCellSize - yCellSize) / xCellSize > 1e-3 Then
    MsgBox("Cell dimensions are not square. ("+Str(Diff)+ ")%.") + 
    "Creating Arc grid with xCellSize: " + Str(xCellSize) 
End If

Print #2, "ncols         "; nCol
Print #2, "nrows         "; nRow
Print #2, "xllcorner     "; xMin
Print #2, "yllcorner     "; yMin
Print #2, "cellsize      "; xCellSize
Print #2, "NODATA_value 1.70141e+038"
Print #2, " 
Do While Not EOF(1)
    Line Input #1, instring
    Print #2, instring
Loop
Close #1
Close #2

MsgBox ("The Arc grid file "+ArcGrid + " has been created.")
srf.Quit

End Sub

After that the data was plotted with the following commands.

clear all;clc;clf
[Z R]=arcgridread('37ez1-emb1.ASC');
Z=Z/100;
mapshow(Z, R, 'DisplayType', 'surface')
save Z
save R
hold on
ylabel('northings')
xlabel('eastings')
title('surface elavation in metres')
Appendix C Gem 2 data preparation

This appendix is derived from the fieldwork report for the aes1650 course by Brinkman et al.

Line 5= line A
Line 6= line B
Line 7= line C
Line 8= line D

Processing Data

Raw Data imported in Excel

The following data is obtained after the measurements in the field:

<table>
<thead>
<tr>
<th>Line</th>
<th>Sample</th>
<th>X</th>
<th>Y</th>
<th>Mark</th>
<th>Status</th>
<th>GPSStat</th>
<th>Time[ms]</th>
<th>Time[hh:mm:ss]</th>
<th>Powerin</th>
<th>I,50Hz</th>
<th>Q,50Hz</th>
<th>QSum</th>
<th>E[50Hz][nGSM]</th>
<th>TotalE[50Hz][nGSM]</th>
<th>MGauss[50Hz][10^2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>178.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>179.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>178.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>178.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
<tr>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>178.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
<tr>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>178.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
<tr>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>178.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
<tr>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>178.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
<tr>
<td>0</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>178.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
<tr>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>178.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
<tr>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>178.54</td>
<td>205.06</td>
<td>791</td>
<td>791</td>
<td>790</td>
<td>31572</td>
<td>31572</td>
<td>15.4077</td>
</tr>
</tbody>
</table>

- The first two columns contain the Line and Sample numbers identifying each sample.
- If the data contains GPS records, the interpolated X and Y (UTM) coordinates are listed in the final two columns. Otherwise, these columns contain zeros.
- The Mark column contains a number which changes for those samples flagged with an Event Marker.
- A non-zero value in the Status column indicates a problem with the data (e.g. ADC overload).
- The seventh column displays the GPS Status or quality parameter if a GPS unit is attached to the GEM-2.
- The eighth and ninth columns are time of day in two formats – milliseconds and hours, minutes, and seconds.
- The tenth column is the magnitude of power line noise (at the power line frequency) in a magnetic field unit of milli-Gauss. This data can be used to produce a map of power line contamination in the survey area.
- The inphase and quadrature data (in ppm) for each RX frequency are listed in the next columns.
- “QSum” is the sum of all the quadrature values.
- If the Compute conductivities option was selected, the apparent conductivity [milli-Siemen per meter] for each frequency is listed followed by the total apparent conductivity and the magnetic susceptibility [nondimensional, multiplied by 1000] calculated for each frequency.

Distance between measurements

The walked distance of line 5 and 6 was 78 meter. To approximate the distance between the measuring points 78m was just divided by the amount of measuring points and multiplied by the number of measuring point.

In line 7 and 8 also GPS coordinates were available. To calculate the distance between coordinates the Great Circle formula can be used.
Great Circle formula:

Distance [°] = \( A \cos[\sin(lat1) \cdot \sin(lat2) + \cos(lat1) \cdot \cos(lat2) \cdot \cos(lon1 - lon2)] \)

Distance [m] = 1852.60. Distance [°]

\( \text{[Coordinate 1} = (lat1;lon1) \text{ and coordinate 2} = (lat2;lon2)] \)

It is also possible to plot coordinates on Google Earth and measure the distance between them. I had same results as with the Great Circle method, with an accuracy of about 0.5m at 300m length.

Sometimes you want to have decimal degrees represent in degrees, minutes and seconds, for example Google Earth displaces coordinates in degrees, minutes and seconds. You can convert decimal degrees in Excel by creating a custom function.

Steps to create a custom conversion formula:
1. Start Excel and press ALT+F11 to start the Visual Basic editor.
2. On the Insert menu, click Module.
3. Enter the sample code for the Convert Degree custom function described beneath. (You can copy paste the code)
4. Press ALT+F11 to return to excel.
5. In cell A1 type 10.46.
6. In cell A2 type the following formula: "=Convert_Degree(A1)"
7. The formula returns in10°27'36"

Sample code for the Convert Degree:

Function Convert_Degree(Deci\al_Deg) As Variant
    With Application
        'Set degree to Integer of Argument Passed
        Degrees = Int(Deci\al_Deg)
        'Set minutes to 60 times the number to the right
        'of the decimal for the variable Deci\al_Deg
        Minutes = (Deci\al_Deg - Degrees) * 60
        'Set seconds to 60 times the number to the right of the
        'decimal for the variable Minute
        Seconds = Format(((Minutes - Int(Minutes)) * 60), "0")
        'Returns the Result of degree conversion
        '(for example, 10.46 = 10°27'36")
        Convert_Degree = " " & Degrees & "° " & Int(Minutes) & "' " & Seconds + Chr(34)
    End With
End Function

Phase and Amplitude

From the Inphase (I) and Quadrature (Q) components the Phase and Amplitude can be calculated.

\[ \alpha = a \tan \left( \frac{Q}{I} \right) \]

\[ A = \sqrt{I^2 + Q^2} \]
\( \alpha \) = phase [°]

\( Q \) = quadrature component [ppm]

\( I \) = inphase component [ppm]

\( A \) = amplitude [ppm]

### Skin Depth and Induction Number

From the measured electrical conductivity the skin depth can be calculated, the induction number depends on the skin depth and the coil separation. The coil separation of the Gem2 we used is 1.66 meter.

\[
\delta = \sqrt{\frac{1}{\pi f \mu \sigma}}
\]

\[
\theta = \sqrt{\frac{s}{\delta}}
\]

\( \delta \) = Skin Depth [m]

\( \mu \) = magnetic permeability \( (\mu_0 = 4\pi \times 10^{-7} \text{ for vacuum}) \) \( \frac{N}{m^2} \)

\( \sigma \) = electrical conductivity \( \frac{S}{m} \)

\( f \) = frequency [Hz]

\( \theta \) = Induction number [-]

\( s \) = Coil Separation [m]

### Correction for low induction number

If we can assume that the induction number is low, the measured conductivity will not be cored. We can use the quadrature component to calculate the corrected conductivity.

\[
\sigma = \frac{2Q}{\pi f \mu_0 s^2} \quad \text{if } \theta < 0.02
\]

\( Q \) in ppm*10^6

In following table the criteria for low induction number are mentioned.

<table>
<thead>
<tr>
<th>Low Induction Number ( \theta \leq 0.02 )</th>
<th>Middle Range ( \theta = 0.02 - 1 )</th>
<th>High Induction Number ( \theta &gt; 1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>In general, EM response is low and of little dependence of frequency. Not good for frequency sounding. This is an effect of small coil separation coupled with all limited bandwidth. IP response frequency</td>
<td>IP response steadily increases with frequency</td>
<td>Called the ‘Resistive Limit’ (in combination with the highest frequencies). No energy penetrates the earth. Not good for frequency sounding.</td>
</tr>
<tr>
<td></td>
<td>Q response is proportional to ( \theta )</td>
<td></td>
</tr>
</tbody>
</table>
To determine in what range the induction numbers of our measurements are, the inphase components are plotted, and the induction number versus the quadrature component.

(Source: "Testing the Gem-2 field response", Harmen Molenaar and Diego Vázquez, T&A Survey, August 2006)
We see for all lines that the inphase component response steadily increases with frequency and the quadrature component is proportional to the induction number. We can conclude that the induction numbers are in the middle range for all lines 5 to 8 and correction of the conductivities is not necessary.

For line 5 we find very low induction numbers ($\theta \leq 0.02$) at the lowest frequency of 925Hz. When applying the correction formula to calculate corrected inductions we obtain following result.

With the corrected inductions we can see the sand embankment, but is still not as clear as the measurements at the higher frequency’s. We also haven now negative conduction.
It is recommended to use only the higher frequency measurements for interpretation.
Electric resistivity for each line

Line 5 Electric Resistivity

Line 6 Electric Resistivity
Phase and amplitude graphs

Line 5 Phase

Line 5 Amplitude
Appendix D Temfast datapreparation

This appendix is derived from the fieldwork report of (Brinkman et al).

Interpretation of the temfast measurements.
Interpretation and processing of the tem-fast method consist of several steps.
  1) Editing and smoothing of the data
  2) Setting the first model
  3) Inversion
  4) Creating a profile

Editing and smoothing data
With editing you change the data points manually. You can for example remove outliers with this function. Editing is optional.
Smoothing makes as the name suggests the curve more smooth, but also the transformations, \textbf{Res(h)} and \textbf{S(h)} the distributions of specific resistivity and total conductivity versus apparent depth will be calculated.

Fig 1 (derived from tem-fast manual)
There are several parameters that can be changed
Limited: exponential spectrum is positive $E(s) > 0$
Free: any sign of exponential spectrum $E(s)$
Ignore errors: the procedure of smoothing does not take into account the weight factors determined by errors of measurements
Tension: factor of smoothing. The more value of parameter Tension, the more detailed is approximation of initial dependence $\rho_a(t)$.

For processing our data The limited option was used and the tension was about $\frac{3}{4}$.

Setting the first model
For this step you use the time depth transformed data from the last step. You set a first model manually. The program suggests borders between $l$ As help after activation of command Design, on diagrams recommended borders of layers which are determined using maximum of function $d^2\rho(h)/d\text{h}^2$ are marked. Thus, the user only more or less correctly should draw resistance of layers. Of course multiple solution are possible. It is also possible to include previous knowledge. Two models are made from our model. One following the suggestions of the programme and an other one also incorporating previous knowledge of the embankment and the Pleistocene. A disadvantage is that in this step of the process you are also already interpreting the data Also the amount of tension you have used to smooth the data plays an important role here.
Inversion
For this step the programme calculates a model with the help of the first model. When there is a model made, you can remove and change layers and run the inversion again until you are satisfied with the outcome. The problem with this step is that you manipulate the data according to your expectations which can lead to errors. Multiple solution are possible. I have added some pictures of final models that have been made. To show the match between measurements and final outcome. I tried for these model to include knowledge about the embankment and the Pleistocene although the pleistocene is not obvious visible in the measurements.
Creating a profile
From the different measurements the programme can create a profile. Three profiles have been made of the first four points including no prior knowledge. The second one of all the point including no prior knowledge. The last one is made with all the points using prior knowledge of the embankment and

Sectie 1

Sectie 2

Sectie 2
Appendix E  GPR data Preparation

This appendix is derived form the fieldwork report by Brinkman et al.

Orientation antennas
The Ground Penetrating Radar is used for 3 surveys during the fieldwork: one common offset, one common midpoint survey (CMP) with a stack of 32 and one common midpoint survey with a stack of 64. We have done the measurements 300m south from the concrete block, perpendicular to the orientation of the embankment. The survey started and ended respectively 1 m from the west and east canal. We used a step size of 0.1m, i.e. for the CMP 0.05 m increase of distance for source and receiver to the midpoint. The common offset is done using the yy-configuration, i.e. the antennas are aligned parallel to the acquisition line. The CMPs are done using the xx-configuration. See figure below. One can find the used Matlab commands in appendix F.

![Diagram of GPR configurations](image)

This has implications for the orientation of the E field and thus for the sensitivity of object in the subsurface with a particular orientation. Some examples that illustrate this effect for objects above the ground are displayed below. For the objects below the ground the same effects take place.
Reflection from a wall ($\varepsilon_r=40$)

Reflection from a wire ($\sigma=1000 \, S/m$)

Reflection from a tree ($\varepsilon_r=40$)

GPR SURVEY PARAMETERS

<table>
<thead>
<tr>
<th>COMMON OFFSET</th>
<th>COMMON MID POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antennas</td>
<td>100 MHz</td>
</tr>
<tr>
<td>Time window (ns)</td>
<td>199.2</td>
</tr>
<tr>
<td>Sampling interval (ns)</td>
<td>0.8</td>
</tr>
<tr>
<td>Number of stacks</td>
<td>16</td>
</tr>
<tr>
<td>Step size (m)</td>
<td>0.1</td>
</tr>
<tr>
<td>Antennas separation (m)</td>
<td>1.0</td>
</tr>
<tr>
<td>Delay time before start of survey (s)</td>
<td>3.0</td>
</tr>
<tr>
<td>Delay time between traces (s)</td>
<td>2.0</td>
</tr>
</tbody>
</table>

In this table we derived the time windows using Matlab and the following formula:
\[ dt(\text{nt}-1) \]
Where \( dt \) = sampling interval and \( \text{nt} \) = number of measurements taken.
In Matlab we import the data using “dt1load.m” and look at the size of the matrices using “whos”.
This leads to the following calculations:
CMP stack 32 and stack 64: \( 0.8 \times (500-1) = 399.2 \text{ ns} \)
Common offset: \( 0.8 \times (250-1) = 199.2 \text{ ns} \)

Processing GPR data

The data obtained at the fieldwork are files with a .dt1 extension, i.e. a pulseEKKO format. We use the function dt1load.m in Matlab to read the data.

This function produces the data, the position of the trace and the recording time. Now we are already able to plot the data:

Stack is 32. The x-axis displays distance [m] and the y-axis displays time [ns]
Stack is 64. The x-axis displays distance [m] and the y-axis displays time [ns]

We can see little difference between the two stacks, the survey with the higher stack is less noisy and has less anomalies (this is partly due to the higher stack because the S/n decreases with \sqrt{N}, but also because the survey was performed better).

x-axis is distance [m], y-axis is time [ns]. We recognize the direct waves as the linear events and the reflections as the hyperbolic events. We use the direct ground wave to pick the velocity: \( v = \frac{\Delta x}{\Delta t} = \frac{(6.4-2.3)}{(79.2-50.4)} = 0.14 \text{ m/ns} \).

Now when we read in the common offset data, we will get a crosssectional view of the embankment.
As can be observed quite clearly, there is no correction made yet for the topography. This is possible to do using the m-file convert1.m. In this file also time-depth conversion takes place, on basis of the earlier picked velocity. One has to be aware of the fact that the parameters used in this m-file are dependent on the local topography and the position of the line of the survey (i.e. an adjustment has to be made if the survey starts e.g. one meter more to the right).

We have not exactly measured the dimensions of the embankment. Therefore we base our parameters on basis of dimensions of the previous years, the measurements of dimensions we do have and on basis of satellite pictures (see below).

The geometry of the cross-section of the embankment is as follows from west to east (this is also the direction of measurement). Note that again this is only the part of the embankment that is measured during the GPR survey. The survey started and ended respectively 1 m from the west and east canal. The first 13m is flat and 2.5m below the top of the embankment. The next 3.1 m is a linear slope up to zero depth. Then 48.5 m is flat on the embankment at zero depth. The next 3.4 m is linear slope down to 2.5 depth. The remaining part is down at 2.5m depth. This is 7.9 m, because the total survey length is 75.9 meters.

Adjusting convert1.m with the above geometry parameters results in the following graph:
Figure 2 Data corrected for geometry

The above figure contains both the amplitude and the phase of the reflections. We are able to plot the phase and amplitudes separately as well using “hilbert.m”. This separation is useful, because the amplitude spectrum can be used to detect objects easily and the phase spectrum can be used to track layers in the deep subsurface (with low amplitude). The results are displayed below.

Figure. Amplitude spectrum

Figure. Amplitude spectrum in dB

Figure. Amplitude spectrum, only upper 60 dB displayed (similarity with the amplitude spectrum is expected)
Figure. Phase spectrum
Appendix F Matlab commands GPR data

This appendix is derived from the fieldwork report of Brinkman et al.

```matlab
>> [cmp300,x300,t] = dt1load('aes1650/cmp300e',10000);
>> imagesc(x300,t,cmp300);
>> colorimagesc(100,10);
```

![CMP300x-t.jpg](image)

```matlab
>> [cmp300,x300,t] = dt1load('aes1650/cmp3064e',10000);
>> imagesc(x300,t,cmp300);
>> colorimagesc(100,10);
```
\[
\text{CMP30064x-t.jpg}
\]

\[
>> \text{[xline300,x300,t] = dt1load('aes1650/xline30e',10000);} \nn\]
\[
>> \text{max(x300)}
\]
\[
\text{ans =}
\]
\[
75.9000
\]
\[
>> \text{imagesc(x300,t,xline300);} \nn\]
\[
>> \text{colorimagesc(100,10);} \n\]
>> [xline300,x300,t] = dt1load('aes1650/xline30e',10000);
>> [z,xzline]=convert1(xline300, t, x300, 15, 2.5,.14);
>> set(gca,'plotboxaspectratio',[10 1 1])
>> axis([0 76 0 6])
>> colorimagesc(100,1);

xline300corrected.jpg

>> [xline300,x300,t] = dt1load('aes1650/xline30e',10000);
>> [z,xzline]=convert1(xline300, t, x300, 15, 2.5,.14);
>> imagesc(x300,z,abs(hilbert(xzline)))
>> set(gca,'plotboxaspectratio',[10 1 1])
>> axis([0 76 0 6])
Amplitude plot.jpg

```matlab
>> figure(2)
>> imagesc(x300,z,20*log(abs(hilbert(xzline))))
>> set(gca,'plotboxaspectratio',[10 1 1])
>> axis([0 76 0 10])
```

Amplitude plot dB.jpg

```matlab
>> c=get(gca,'clim');
>> cmax=max(c);
>> cmin=cmax-60;
>> set(gca,'clim',[cmin cmax])
```

Amplitude plot dB 60 top.jpg

```matlab
>> imagesc(x300,z,angle(hilbert(xzline)))
```
convert1.m

function \([z,xzline] = convert1(filename, t, x, tzi, alt, v)\)

% converts the topography from flat to real. needs filename, time matrix, distance matrix, time zero, % altitude difference, velocity

\[xline=filename(tzi:end,1:length(x));\]

% time zero correction index
\[tzi=22;\]

\[dt=t(2);\]
% step size from data
\[dx=x(2);\]
\[xl=max(x);\]
% start topography correction
% first 13m is flat and 2.5m below top embankment
\[topo=zeros(1,length(x));\]
\[punt1=13;\]
\[nx1=1;\]
\[nx=floor(punt1/dx)+1;\]
\[topo(nx1:nx)=alt;\]
% next 3.1 m is linear slope up to zero depth.
\[punt2=punt1+3.1;\]
\[nx1=nx+1;\]
\[nx=floor(punt2/dx);\]
\[topo(nx1:nx)=alt - [0:nx-nx1]*alt/(nx-nx1);\]
% next 48.5 m is flat on the embankment at zero depth
\[punt3=punt2+48.5;\]
\[nx1=nx+1;\]
\[nx=floor(punt3/dx);\]
\[topo(nx1:nx)=0;\]
% next 3.4 m is linear slope down to 2.5 depth.
\[punt4=punt3+3.4;\]
\[nx1=nx+1;\]
\[nx=floor(punt4/dx);\]
\[topo(nx1:nx)=[0:nx-nx1]*alt/(nx-nx1);\]
% rest is down at 2.5m depth
\[punt5=xl;\]
\[nx1=nx+1;\]
\[nx=floor(punt5/dx)+1;\]
% change from depth to time-recording index
\[topo(nx1:length(x))=alt;\]
\[topo=floor(topo*2/v);\]

\[xzline=zeros(size(xline));\]
\textbf{for} \(k=1:(length(x)-1)\)
xzline(topo(k)+1:size(xline,1),k)=xline(1:end-topo(k),k);
\textbf{end}

\[z = t(1:end+1-tzi)*v/2;\]
\textbf{imagesc}(x,z,xzline)
\textbf{set}(gca, 'FontName', 'TimesNewRoman', 'FontSize', 14)
% colorimagesc(100,1)
colorbar
axis([1 76 0 8])
\textbf{xlabel}('distance [m]', 'FontName', 'TimesNewRoman', 'FontSize', 14)
\textbf{ylabel}('estimated depth [m]', 'FontName', 'TimesNewRoman', 'FontSize', 14)
**colorimage.m**

```matlab
function colorimage(C, scale);

% This function makes a colorbar
% for an imagesc plot with colorbar;
% 
% cm=[zeros(1,127-C) 0:1/C:1 ones(1,128)
%     zeros(1,128-C) 0:1/C:1-1/C 1:-1/C:0 zeros(1,127-C) ;
%     ones(1,128) 1:-1/C:0 zeros(1,127-C)];
colormap(cm');
c=get(gca, 'clim');
cmax=max(abs(c))/scale;
set(gca, 'clim', [-cmax cmax]);
%colorbar;
```

**hilbertt.m**

```matlab
function [hdata]=Hilbertt(data, len)
l=length(data);
fd=fft(data, len);
hdata=2*ifft(fd(1:len/2,:), len);
hdata=hdata(1:l,:)
```

function [dataout,pos,t] = dt1load(filename,maxtrace)

% reads in a dt1 file with pulseEKKO format and gives back the data,
% position of trace and recording time

% start definition of data
dataout = [];
fn=[filename,'.dt1'];
 fid=message = fopen(fn,'rb');
 if fid == -1
   disp(message)
   fn
 return 
end
 disp([ 'reading file:' fn]);
 for itrace=1:maxtrace
   Header = fread(fid,32,'float32');
   if feof(fid)
     disp([ 'maximum number of traces reached at number: ' int2str(itrace-1)]);
      %for ndummy=itrace:maxtrace % if you want to padd with zero traces
      %   dataout = [dataout Record];
      %   disp([ 'repeating trace: ' int2str(itrace-1) ' for trace: ' int2str(ndummy) ]); 
      %end
      %dataout = [dataout zeros(nsamp,maxtrace-itrace+1)];
      return 
 end
   pos(itrace) = Header(2);
       %
   if itrace==1
     nsamp=Header(3);
     tw=Header(9);
     t=[0:nsamp-1]*tw/nsamp;
   end
   Record = fread(fid,nsamp,'int16');
   % Record = Record/max(abs(Record)); % if you want normalized traces
dataout = [dataout Record];
 end