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GeoSurf - The development of a new measuring tool for an efficient planning of shallow geothermal systems

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ABSTRACT

Within the GeoSurf project it is intended to develop a measuring tool, which measures the electrical resistivity to derive soil properties (e.g. grain size, moisture content) for a precise estimation of its geothermal capability. The tool should enable a more efficient planning of very shallow horizontal geothermal collector systems and their special forms like heat baskets.

In the course of this project the electrical resistivity of particular soil types were measured with the geoelectrical device *4point light* from *(L-GM) Lippmann - Geophysikalische Messgeräte* (http://www.l-gm.de/en/en_resistivity.html). These measurements were realised in the first field survey 2015 to define a range of electrical resistivity for different types of soil and their distinct properties to check if a clear and accurate differentiation of soil types is possible by electrical resistivity measurements. Therefor different transects of electrical resistivity tomography (ERT) were performed on a sandy soil body in Eltersdorf/Erlangen and additionally in a clay pit near Buttenheim. Both test areas are located in the northern part of Bavaria (Germany). For the geoelectrical investigation up to 75 electrodes with an electrode spacing of 1 m were used and the Wenner array was selected. To get more detailed information about the measured soil, two 2 m deep test pits were excavated (Fig. 1).

1. INTRODUCTION

Due to the prospective shortage of resources and the decentralisation of power plants renewable energy sources will play a crucial role within all energy supplying systems. Currently sustainable renewable energy systems are an important topic within the energy supply especially after the reactor accident in Fukushima.

Shallow geothermal systems are used as efficient energy storages and suppliers of thermal energy and they also help to reduce CO_2 emissions (Dickinson et al 2009; Blum et al 2010). The most common form of a horizontal ground source heat exchanger (GSHE) is the collector system. It has enormous advantages compared to other types of GSHE in terms of financial and planning aspects. There are also less legal requirements installers have taken into account during the installation process (e.g. areas with restrictions in the drilling depth).

Figure 1: Dredging a test pit at one point of the line the ERT transect was measured on. In Eltersdorf/Erlangen the survey was performed upon sandy soil.

However a horizontal collector system requires much space and this space has to be adapted to the existent needs of the building project. In principle there are uncertainties within soil properties as well as climate conditions in order to determine the required space for very shallow geothermal systems. Therefore the GeoSurf project wants to provide all systemically parameters for a sustainable and economic planning to avoid over- or under sizing of horizontal geothermal systems and there special forms (e.g. heat baskets).

Some international activities have been realised to provide more different information on the grain size and other relevant parameters (e.g. moisture content, protection zones) for an effective planning of very shallow geothermal systems on European level like the MapViewer within the ThermoMap project http://geoweb2.sbg.ac.at/thermomap/ (Bertermann et al 2013; Bertermann et al 2015). But there is still a lack of getting detailed local information for a sustainable planning.

The main focus now within the GeoSurf project is the reduction of this uncertainty factor by providing detailed information in each individual case for a more efficient and space-saving planning of these very shallow geothermal systems. A new measurement tool should be developed to analyse soil properties which are influencing the performance of horizontal geothermal systems. With these results the heat extraction rate could be defined more precisely. This enables the opportunity to make clear and customised recommendations about the size of the required area for installing a very shallow horizontal geothermal system.

One of the key parameters for the performance of horizontal geothermal systems is the thermal conductivity. This parameter has huge impact on the economic efficiency of the installed geothermal system. Within the uppermost meters of the ground thermal conductivity is mainly driven by the texture respectively the structure of the soil body and its mineralogy (Logsdon et al 2010). Therefore the most relevant parameters are bulk density, soil moisture and grain size distribution (Farouki 1981; Abu-Hamdeh and Reeder 2000; Abu-Hamdeh 2003). The new tool should measure the electric conductivity to make reliable statements on the existing soil properties and the thermal conductivity.

2. METHODLOGY

2.1 Geoelectrical measurements

ERT transects were performed on two contrary soil types (clay and sand). Therefor up to 75 electrodes in one line with a spacing of one meter (Fig. 3) were used as a multi-electrode system (Samouelian et al 2006; Loke et al 2013). Thus the maximum penetration depth was 13.6 m. For this survey the Wenner array was used (Fig. 2) (Dahlin and Loke 1998, Dahlin and Zhou 2004; Aizebeokhai 2010; Okpoli 2013). The electrical conductivity, respectively the electrical resistivity was gained by the the geoelectrical measurement device “4point light”. The measured apparent resistivities were inverted with *Res2Dinv*, the commercial software from *Geotomo Software* http://geotomosoft.com/downloads.php (Loke 2016).

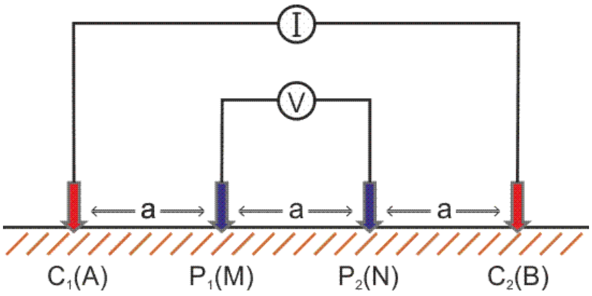

Figure 2: Wenner array which was selected for the geoelectrical investigations (C=current electrode, P=potential electrode).

Because of the better resolution for noisy data and a more accurate mapping of sharp boundaries the robust inversion settings were chosen (Loke et al 2003; Dahlin and Zhou 2004). Furthermore the effect of side blocks is reduced by using this inversion method. There was, besides the normal damping factors, no damping for the least-squares constraint method included but a reference model using the value of the average resistivity was applied with a damping factor of 0.05. The robust inversion equation was solved with the standard Gauss-Newton operation. The ERT transects are displayed on a defined logarithmic scale (Figure 6 and 7).

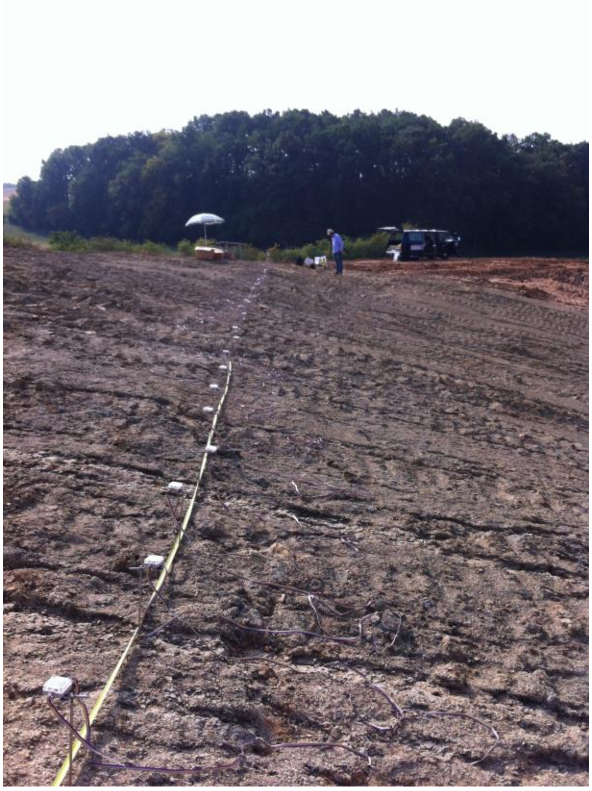

Figure 3: Measuring an ERT transect with the device of L-GM in the open clay pit near Buttenheim.

2.2 Determining of soil properties

To determine the relevant soil properties along the ERT transect in Eltersdorf two approx. 2 m deep test pits were dredged (Fig. 1). In each of these excavated pits 5 samples were taken about each 25 - 50 cm depth. Per layer one sample for the grain size analyses and one cylindrical probe for the bulk density were picked up. In the clay pit no test pit was carried out because the measurement was performed on the spoil heap of the clay pit, so the pedological conditions were well known.

The sampling and the determination of the bulk density was performed according to DIN 18125_2 with the cutter cylinder. Within the bulk density measurements the moisture content was defined in conformity with DIN 18121. Under the assumption that the soil particle density (ρ_0) is around 2.65 g/cm³, the porosity (Φ)[1] and the amount of saturated pore volume (Φ_w)[2] can be determined by including the measured bulk density (ρ) as well as the volumetric water content (θ).

$$\Phi = 1 - (\rho / \rho_0) \qquad [1]$$

$$\Phi_w = \theta / (\Phi / 100) \qquad [2]$$

For the sample fraction bigger than 63 µm the grain size distribution has been defined after DIN 18123 by wet sieving. In the course of the sieving sieves with mesh sizes of 63, 125, 250, 400, 500, 1000 and 2000 µm were used.

Table 1: Profile of soil properties of the first test pit performed on the ERT transect line in Eltersdorf/Erlangen.

Depth in m	Vol. water content in vol- %	Bulk density in g/cm³	Porosity in %
0.25	6.72	1.53	42.12
0.70	9.03	1.64	38.01
0.95	5.55	1.61	39.22
1.40	5.62	1.54	41.89
2.00	24.70	1.55	41.35

3. RESULTS

The test pits for defining the soil properties were dredged on the testfield in Eltersdorf until a depth of 2.1 m and 1.6 m into the sand body, so the deepest samples were collected right above the test pit bottom (Table 1 and 2). The grain size distribution (Fig. 4 and 5) shows that major parts of the particle size of all samples are located in the sand fraction. In any sample the total sand proportion is above 95 % (Table 3). The percentage for coarse sand is except for one sample (38.09 %) always beyond 40 %. Only two respectively three samples near the ground surface of the profile reveal a percentage of fine sand proportion over 10 %. This is similar for both in Eltersdorf examined test pits. But there is a difference between the amount of medium and course sand in the lower parts of the test pits. In the first pit the amount of medium and coarse sand is about equal distributed but within the second pit the proportion of course sand is around two thirds.

Within the first test pit the bulk density varies between 1.53 and 1.64 g/cm³ (Table 1). The average bulk density of the second pit is 0.12 g/cm³ higher, more precisely between 1.62 and 1.76 g/cm³ (Table 2). At the same time the porosity shows the same tendency in fact that there are higher porosities in the first test pit (38.01 % - 42.12 %) and lower porosity values within the second test pit (33.46 % - 38.69 %). It appears that there are similar patterns regarding the volumetric water content in both excavations. The upper four samples show values below 10 % and the sample at the bottom of each test pit points out with 24.70 and 16.74 % of volumetric water content.

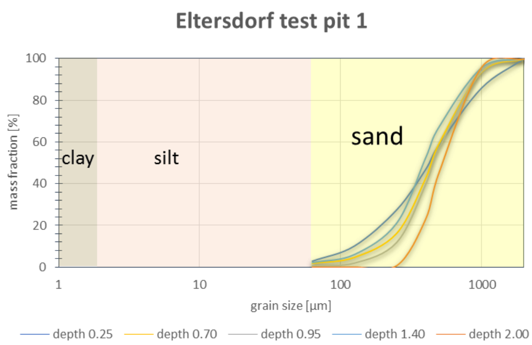

Figure 4: Results of the grain size distribution analysis of test pit 1 on the test site in Eltersdorf.

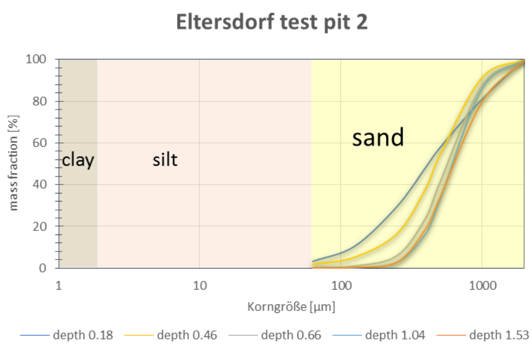

Figure 5: Results of the grain size distribution analysis of test pit 2 on the test site in Eltersdorf.

Table 2: Profile of soil properties of the second test pit performed on the ERT transect line in Eltersdorf/Erlangen.

Depth in m	Vol. water content in vol- %	Bulk density in g/cm³	Porosity in %
0.18	6.91	1.69	36.15
0.46	5.98	1.70	35.84
0.66	6.27	1.76	33.46
1.04	4.59	1.70	33.88
1.53	16.74	1.62	38.69

As expected the samples of the Buttenheim clay pit provides a very high amount of clay (> 92 %) but due to the missing of test pits these values couldn't be related to a certain depth of the measured ERT transect.

The inverted resistivity values of the ERT transect carried out in Buttenheim are almost between 10 and 20 Ω*m (Fig. 6). This transact was performed with 40 electrodes and a spacing of 1 m. Thus a calculated depth of nearly 8 m is reached. Within the first meter the resistivity is about 10 Ω*m. Below the first meter down to 5 meters depth there is a section with slight lateral varieties. These varieties are proceeding between 13 and 21 Ω*m. Underneath this section electrical resistivity is increasing up to values of approx. 30 - 40 Ω*m.

In Eltersdorf 75 electrodes with a spacing of 1 m were used. So there the measurement reached a calculated depth of more than 13 m (Fig. 7). In general there are two zones regarding the inverted electrical resistivity. An upper zone from the surface up to a depth range of around 2 - 3 m and a lower zone beneath. The lower zone indicates resistivity values from 30 up to 50 Ω*m, whereas the upper zone deals with values between approx. 150 and over 1000 Ω*m. There are two areas within around 1.5 m depth, where these high resistivity values are concentrated. One area stretches from 30 to 40 meter and the other between 49 m and the 68 m within the ERT transect. The remaining part of the upper zone do not show electrical resistivities beyond 400 Ω*m.

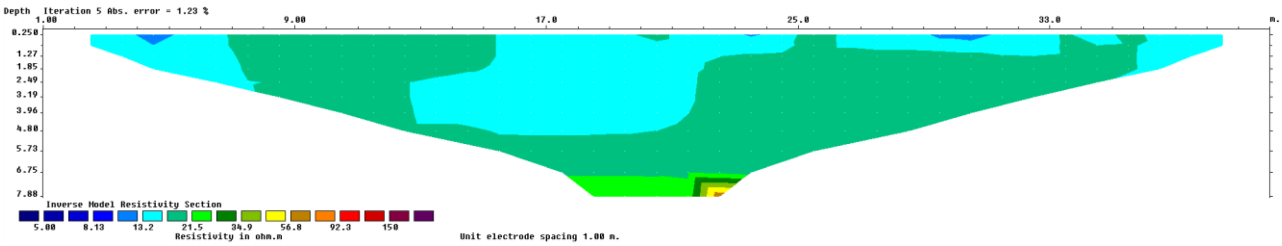

Figure 6: Inverse model of the electrical resistivity of the clay transect measured in the clay pit near Buttenheim. The 5. Iteration is displayed with a logarithmic scale from 5 Ohm*m up to 200 Ohm*m.

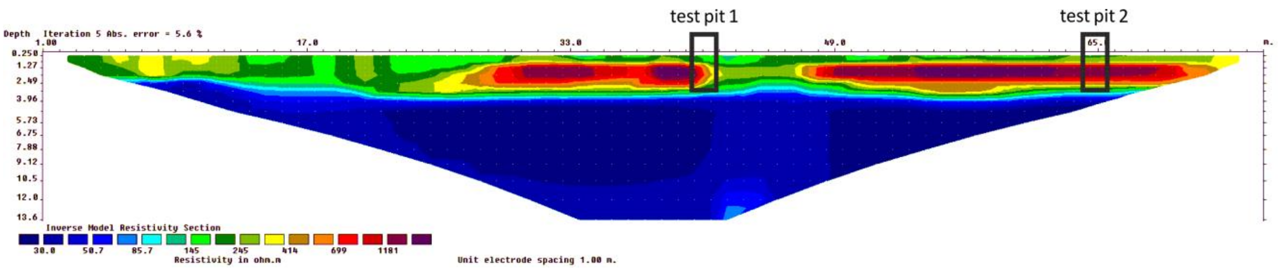

Figure 7: Inverse model of the electrical resistivity of the sand transect with highlighted test pits measured in Eltersdorf. The 5. Iteration is displayed with a logarithmic scale from 30 Ohm*m up to 1500 Ohm*m.

3. CONCLUSIONS

3.1 Overview

In general the analysis of the soil properties derived from the samples taken in Eltersdorf shows a grain size range from medium right up to coarse sands with a volumetric water content around 6 % (Table 1, 2 and 3). Only the lowest sample of each test pit contains an unusual high moisture content, which means that the capillary space or rather the transition zone between the phreatic and the vadose zone is more or less in a depth of 2 m. This interpretation is consisting with the results of the ERT transect of Eltersdorf (Fig. 7) and also with the experiences, which were made in the test pit in fact that there was an ingress of water at the bottom of the test pits (Fig. 8). Within the ERT transect a sharp horizontal line, which represents the water table and divides the transect in an upper vadose zone and a lower phreatic zone, is displayed more or less at the same depth range (between 2 m and 3 m) as the significant change of moisture content in the pits.

The lateral differences within the upper vadose zone of the ERT transect in Eltersdorf could occur because of very slight differences affecting the bulk density, the moisture content and the grain size distribution of the soil. In this case no crucial changes of the water content besides the transition zone are recorded. Such minor differences regarding the bulk density and the porosity of both test pits (Table 1 and 2) could be relevant for these lateral resistivity varieties.

Furthermore the percentage of fine grain material (clay, silt and fine sand) within these pure sands has big impact on the electrical resistivity. In the uppermost centimetres of the test pits there are slight percentages of silt and clay as well as a higher proportions of fine sand (Table 3). But below 0.7 m or rather 0.95 m there are even less fine particles included. This matches with the 2D-image of the ERT measurements in which these areas of high resistivity values set in below the first meter of the profile (Fig. 7).

The values gained by the ERT measurements performed on the two test fields in Eltersdorf/Erlangen and in the clay pit near Buttenheim regarding the electrical resistivity are significantly different.

Figure 8: Ingress of water in one of the testing pits in Eltersdorf/Erlangen as indicator for the vadose-phreatic transition zone at the bottom of the test pit.

The measured clay soil in Buttenheim shows very slight varieties. Thus it is a relatively homogenous mass featured with very low resistivities between 10 and 20 Ω*m. On the contrary the electrical resistivities measured on the sand body are all beyond 140 Ω*m, as long as these measurements take place in the vadose zone. Retrospectively it seems possible to identify two of the main grainsize classes (sand and clay) by using resistivity imaging.

3.2 Summary

Thus it seems possible to evaluate the relevant parameters regarding the thermal conductivity like soil moisture content and grain size distribution just by performing the ERT. Little variations within measured results can be caused by other system relevant soil properties (e.g. bulk density, porosity). Besides the localisation of sand respectively clay it seems also feasible to determine the water level.

All the mentioned parameters will be analysed in detail within the GeoSurf project due to their impact on the thermal conductivity potential. Additionally these effects are also compared to their influence on the electric conductivity. A laboratory measuring campaign should provide more specified data.

Finally the developed measuring tool should deliver relevant information to planners and landowners if their ground is feasible for a very shallow horizontal geothermal installation. As a result the planning process becomes more effective and economic. Over- and underestimations of very shallow geothermal installations will be reduced.

Table 3: Further parameters including the grain size distribution and the saturated pore volume taken in the two test pits of Eltersdorf.

	depth in m	*amount of silt and clay in %*	*total sand content in %*	*fine sand in %*	*medium sand in %*	*course sand in %*	*saturated pore volume in %*
Test pit 1.1	0.25	3.03	96.97	24.62	31.21	41.14	15.96
Test pit 1.2	0.70	1.72	98.28	14.48	43.20	40.60	23.75
Test pit 1.3	0.95	0.71	99.29	11.16	45.22	42.91	14.14
Test pit 1.4	1.40	0.01	99.99	7.34	54.58	38.09	13.42
Test pit 1.5	2.00	0.01	99.99	0.81	44.85	54.34	59.45
Test pit 2.1	0.18	3.07	96.93	26.47	27.95	42.50	19.10
Test pit 2.2	0.46	1.81	98.19	14.75	37.28	46.15	16.67
Test pit 2.3	0.66	0.25	99.75	5.76	34.66	59.33	18.73
Test pit 2.4	1.04	0.04	99.96	2.93	29.40	67.63	12.78
Test pit 2.5	1.53	0.04	99.96	2.83	30.57	66.56	43.26

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