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Near-surface Geophysics as Used in Geotechnical Site Investigations

**Dr Simon Hughes FGS,
Commercial Manager,
TerraDat (UK) Limited**

Simon Hughes is the Commercial Manager of TerraDat (UK) Limited, a commercial geophysical survey company with offices in Cardiff, Glasgow and Spain. Simon is the Secretary of the Near-surface Geophysics Group of the Geological Society and is their representative on the Ground Forum, the "umbrella" body for the ground engineering sector. Near-surface is becoming a commonly used tool in a Ground Investigation (GI), and in November 2019 Simon spoke to members of the Institute and discussed what geophysics is, benefits of its use and, though a series of case studies, described several techniques. In this paper, three of those case studies are given.

What is Geophysics

Geophysical methodologies are often considered a magical black box that produces unintelligible pages of data, and the related surveys are sometimes thought to be too expensive, unreliable and inaccurate. The purpose of this paper is to reverse these thoughts by carefully considering the aims of individual surveys and proposing methodologies that match the survey requirements.

It should be remembered that near-surface geophysics comprises of a suite of measurement techniques that can be used to precisely measure geophysical properties of the ground. These properties include conductivity, resistivity, seismic velocity, magnetism, and so on. To be able to detect a target, there must be a geophysical contrast between the target and the surrounding ground.

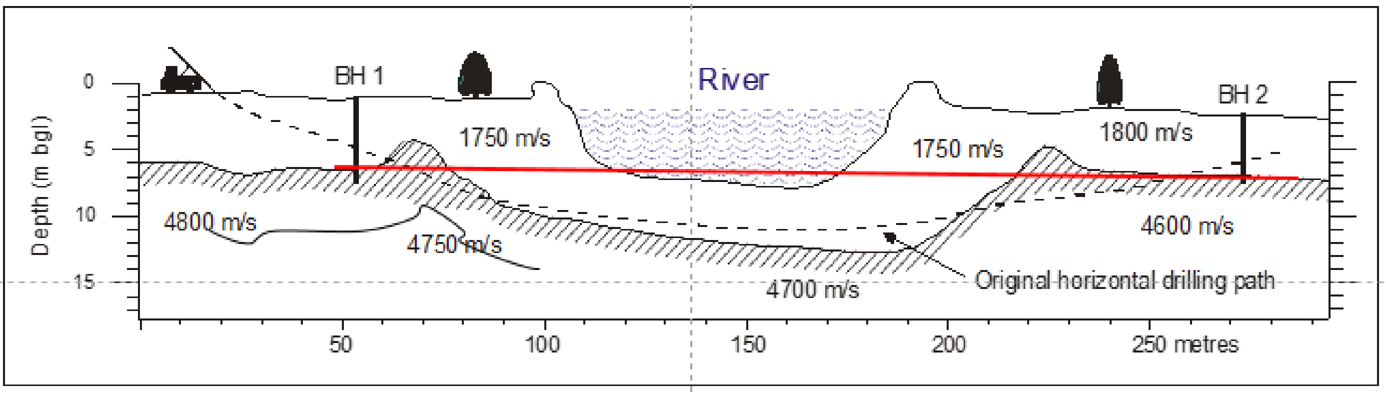

Figure 1: Schematic drawing of proposed Horizontal Directional Drilled (HDD) river crossing.

Benefits of Using Geophysics

The majority of surface geophysical methods are non-intrusive and so allow for the ability to measure subsurface properties without the need for excavation or drilling. This makes geophysical surveys ideal for sensitive sites (such as Sites of Special Scientific Interests or contaminated sites) and urban /developed sites. Given that most surveys are non-intrusive, there is also no requirement for reinstatement costs.

Areal geophysical surveys offer total site coverage using survey line spacings defined by the targets of interest. For instance, if there is a concern for any unexploded ordnance (UXO) or bell pits, 1 m spaced survey lines might be used across and area of interest. Locating mine shafts would usually require 2 m spaced survey lines while larger wavelength solution features could be detected using survey line spacings of 3-5m.

Linear geophysical techniques can produce continuous data along a profile and so overcome errors geological interpolation. In Fig. 1 boreholes on either side of the river indicate that bedrock is at approximately at the same depth below ground level and so it might be tempting to draw a (red) line between the boreholes indicating the depth to bedrock. However, the depth to bedrock between the two boreholes could be very variable (due to the suggested buried channel), and this can be detected by using geophysics.

When to Use Geophysics

Ideally, geophysical surveys should be carried out immediately after a desk study and site visit before any other site works. This will allow the survey to target any subsurface features that may be masked by the presence of trial pits and drills rigs. An early geophysical survey will also allow for the survey report to highlight targets of interest and to permit an optimal design of a campaign of boreholes and sampling to Dunston.

Case Studies

Case study 1 – Mineshaft Target

A primary school wanted to extend its building over an area where a mineshaft was thought to be present, and so a geophysical survey was carried out to try and detect the shaft. The survey area was approximately 100 x 50m, and a number of methods were deployed using 2 m (assuming a target > 2m) spaced survey lines.

Electromagnetic was used to measure subsurface conductivity as this allows for the mapping of subtle changes in shallow geology and foundations/infrastructure associated with the shaft. A magnetic survey was also carried out to map anomalies in the Earth's magnetic field caused by buried ferrous objects associated with a potential reinforced cap and shaft infrastructure. Finally, based on the results of the first two techniques, a targeted microgravity survey was carried out over any anomalies of interest. A microgravity survey measures subtle variations in the Earth's gravity due to subsurface density changes caused by a void (in this instance a mine shaft) or different geology.
Example survey results are shown in Fig. 2.

In Fig. 2a, the conductivity plot shows a large circular anomaly in the centre of the plot (mineshaft cap?) and linear anomalies that may be related to land drains. The magnetic plot (Fig. 2b) also shows a large central anomaly (mineshaft cap?) and two smaller anomalies that were related to buried goal post supports. The microgravity survey (Fig. 2c) was targeted over the central magnetic anomaly (blue outline) and indicates there is an off-centre gravity anomaly (mineshaft). Based on this, the client was encouraged to "ground-truth" the central anomaly by using intrusive methods, and the location of the mineshaft was confirmed.

Case study 2 – Road Realignment Survey

The second case study is associated with a proposed road realignment around an accident blackspot. The purpose of the survey was to map potential solution features along the suggested alignment using electrical resistivity tomography (ERT) to produce geophysical cross-sections. ERT measures ground resistance in relation to an induced DC electrical field and is measured using an electrode array. The array has to be straight and commonly uses electrode spacings of 2-5 m (the greater the electrode spacing, the greater the depth that can be imaged. In this instance, the technique is used to measure the depth to bedrock (limestone) and any lateral changes in the bedrock associated with potential faults or solution features. Fig. 3 illustrates one of the resulting cross-sections.

Fig. 3 shows limestone bedrock as being highly resistive (red) with one less distinct change in lithology (F4) to the west of the section and more obvious less resistive feature (F2) to the east. Feature F2 was in line with a suggested fault running across the site, and so it was recommended to the client that this feature should be “ground-truthed”.

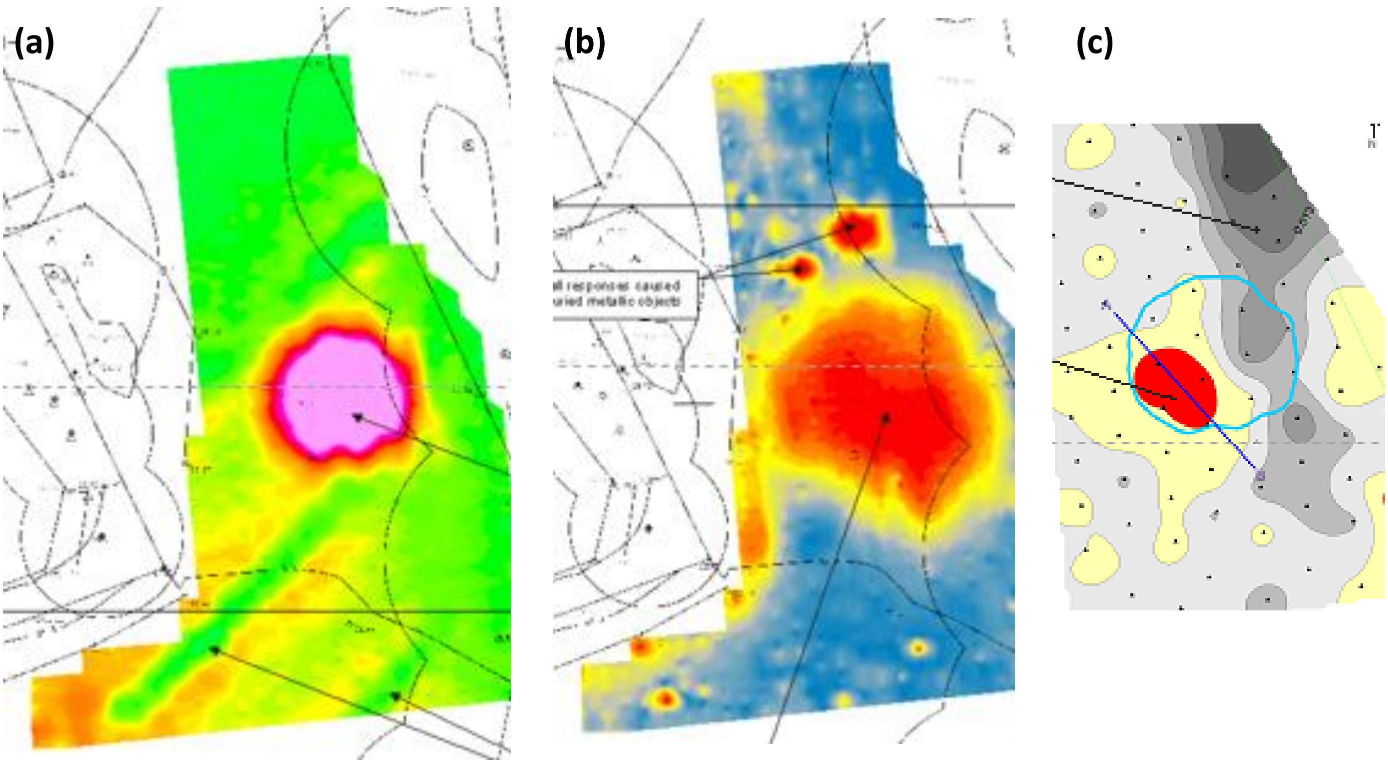

Figure 2: Example results of (a) conductivity, (b) magnetic and (c) microgravity surveys

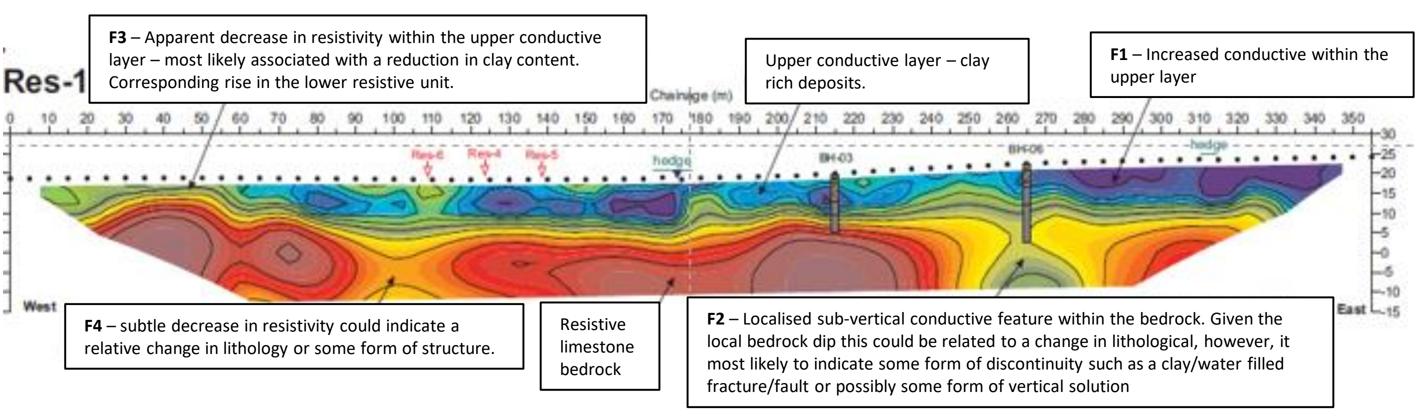

Figure 3: Resistivity cross-section

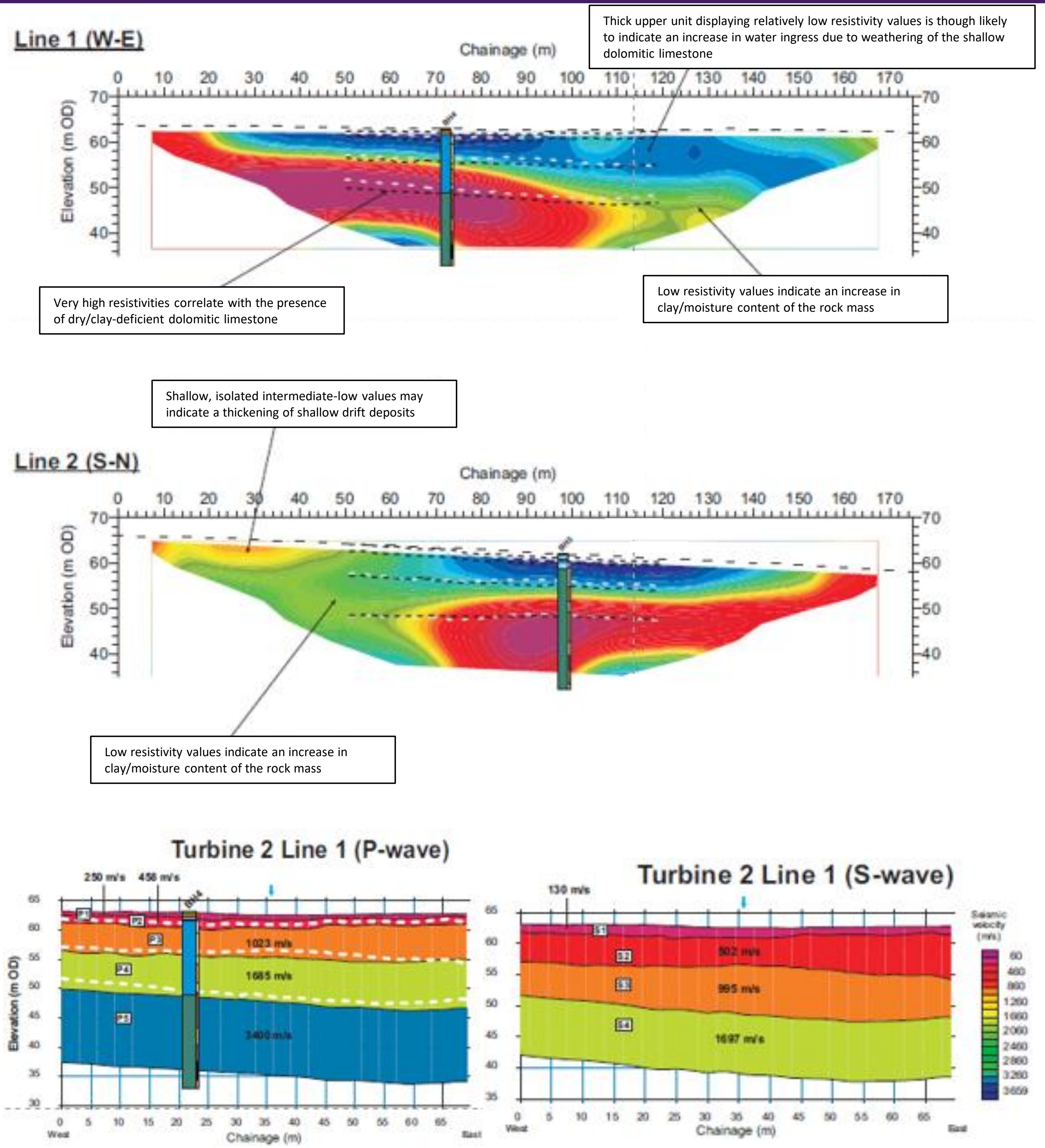

Figure 4: Geophysical results from one turbine location (Turbine 2) with (a) showing seismic refraction cross-section and (b) resistivity section

Case study 3 – Wind Farm

The final case study considered in this paper is a survey of a proposed wind farm. The aim of the survey was to map depth to bedrock, establish geotechnical properties for foundation design and to establish soil resistivity for earthing purposes. Depth to bedrock and geotechnical parameters were established using P-wave and S-wave seismic refraction. Seismic refraction measures subtle variations in the seismic velocity of subsurface materials and is commonly used to profile bedrock, establish rock rippability and, together with density information, can establish engineering properties such Young's modulus, shear modulus and Poisson's ratio. Soil resistivity is mapped using the ERT technique introduced above. In this instance, a suggested centre point for each turbine location was given with perpendicular seismic and resistivity profiles centred on the suggest location to allow micro-siting. A borehole was sunk at each location for ground-truthing. Table 1 shows some of the geophysically derived geotechnical properties at one turbine location. The P-wave and S-wave information was extracted at 1 m intervals from the seismic velocity profile. Density information was provided by the client and is assumed to be the density of bedrock.

Conclusions

Near-surface geophysical surveys have become a recognised tool as part of a suite of tools used for ground investigation. When considering geophysics, it is important that the right technique(s) is matched to the requires aims of a survey. It is also important to consider the make-up of the site, size and depth of the targets of interest, and the geology of the proposed survey area may influence the applicability of various geophysical methods. Let your favourite geophysical contractor/consultant be your guide – they will want to help get the best information out of the ground and promote geophysics. After a survey has been completed, reported, and ground-truthed, give feedback to your contractor/consultant as it will help refine future surveys.

Line 1

		Note 1	Note 2		Note 3			
Depth (mbgl)	P-velocity (m/s)	S-velocity (m/s)	density (kg/m3)	Vp/Vs (m/s)	Poisson's Ratio	Shear G_{max} (Mpa)	Young's E (Mpa)	Bulk K (Mpa)
0	-	-	-	-	-	-	-	-
1	458	130	-	3.52	0.46	-	-	-
2	458	502	-	0.91	-	-	-	-
3	1023	502	1900	2.04	0.34	479	1285	1350
4	1023	502	1900	2.04	0.34	479	1285	1350
5	1023	502	1900	2.04	0.34	479	1285	1350
6	1023	502	1900	2.04	0.34	479	1285	1350
7	1023	995	1900	1.03	-	1881	-	-
8	1685	995	1900	1.69	0.23	1881	4636	2886
9	1685	995	1900	1.69	0.23	1881	4636	2886
10	1685	995	1900	1.69	0.23	1881	4636	2886
11	1685	995	1900	1.69	0.23	1881	4636	2886
12	1685	995	1900	1.69	0.23	1881	4636	2886
13	1685	995	1900	1.69	0.23	1881	4636	2886
14	1685	995	1900	1.69	0.23	1881	4636	2886
15	3400	1697	1900	2.00	0.33	5472	14600	14668
16	3400	1697	1900	2.00	0.33	5472	14600	14668
17	3400	1697	1900	2.00	0.33	5472	14600	14668
18	3400	1697	1900	2.00	0.33	5472	14600	14668
19	3400	1697	1900	2.00	0.33	5472	14600	14668
20	3400	1697	1900	2.00	0.33	5472	14600	14668

Table 1: Table showing derived geotechnical properties for Turbine 2.