Selected case studies in Engineering Geophysics

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BIOGRAPHY

Michael van Schoor holds a PhD in Geophysics from Lancaster University in the UK and has more than 25 years' experience in research geophysics – mostly in the field of applied mining geophysics Other research topics/fields of interest include hydrogeophysics, forensic geophysics, heritage studies and engineering geophysics. Terence Turnbull is a Geomatics Officer at the Defence Works Formation and has lots of practical experience in the application of synthetic aperture radar, GPR and light detection and ranging (LIDAR).

SUMMARY

All geophysical methods have a specific niche application(s); however, some methods are more versatile than others and are applicable to a wider range of earth science problems. This is particularly true in the case of the GPR method, which is known to provide technical solutions in a diverse range of fields that include mining, hydrogeophysics, and engineering. This paper provides selected case study examples that illustrate the versatility and value of GPR within the field of engineering. Examples of specific applications of GPR in the engineering field include:

- Mapping reinforcing steel structures in concrete,
- Locating old foundations and building structures,
- Locating/tracking utilities,
- Mapping tree roots that threaten infrastructure,
- Characterising sinkholes, voids and subsidence, and
- Studying the integrity of concrete structures

Key words: ground penetrating radar, engineering geophysics.

INTRODUCTION

GPR is an extremely versatile geophysical method and is widely applied in the general field of engineering (this includes sub-fields such as civil engineering, construction, engineering geology and rock engineering/mechanics). It has, for example, previously been estimated that the vast majority (almost two thirds) of all GPR applications relate to applications such as utility and/or concrete and infrastructure mapping (pers. comms., Greg Johnston, 2016). The fact that GPR has been recognised as an affordable and effective tool for detecting and mapping underground features and structures in engineering-related settings, can be attributed to the favourable physical property contrast, geometry and shallow depths of typical targets. A further advantage provided by GPR is that it is non-destructive, non-invasive and does not damage buried targets (Ghozzi, et al., 2018). Ghozzi et al. (2018) noted that when compared to various non-destructive technologies, results generated by GPR are more accurate due to its high-resolution images. Additionally, it enables one to acquire data quickly and map large areas in an affordable way. Another attractive advantage of GPR technology is the ability to produce real-time results that facilitate on-site decision-making (Barone et al., 2016).

The purpose of this research paper is to disseminate some interesting case study results involving the application of GPR to engineering problems; it also aims to highlight some of the technological advancements that have been made in recent years that have further enhanced the applicability of GPR in engineering geophysics. Some noteworthy advances include the shift to three-dimensional (3D) GPR and the joint/integrated use with light detection and ranging (LIDAR) data.

CASE STUDIES

GPR can be applied using a 2D or 3D approach, with the latter offering a significant advantage in terms of spatial mapping. A 3D or grid survey approach is commonly used to cover large areas for the purpose of depth slice extraction and 3D data visualisation. 3D GPR surveys typically involve a grid of equidistant parallel profiles acquired in two perpendicular directions to optimise spatial resolution. In cases where survey productivity is important, a single survey direction with a slightly smaller profile spacing can also be used.

Data acquisition is usually done using a single operating frequency, in the frequency range of 100-1000 MHz, and the resulting depth of investigation is typically limited to the first 5-8 m of the near-surface. In GPR there is a trade-off between range and resolution: increasing the operating frequency implies a higher resolution, but at the cost of a decreasing range, associated with the corresponding increase in attenuation; similarly, a lower operating frequency will enable a greater depth of investigation, but at a reduced mapping accuracy.

The first case study example is a fairly common problem in civil engineering and construction; that is, to determine where existing reinforcing steel is located within concrete floors and slabs. The need for this information is usually driven by construction activities in areas where infrastructure already exists and where accurate/detailed historic building plans are not available. In this case study, the concrete floor of a building that previously housed heavy machinery was scanned to determine the extent of existing heavy-duty reinforcing steel. This information was required as modifications to the building were planned. A 3D grid GPR survey was conducted using a system operating at 500 MHz. Profiles were acquired along two perpendicular directions, using a profile spacing of 10 cm. The data profiles were processed as a 3D volume and the depth slices were extracted. The depth slice in Figure 1, equating to a depth below surface of approximately 25 cm, clearly reveals the presence and extent of the heavy-duty steel mesh. The depth slice also shows the location of a linear utility (water pipe).

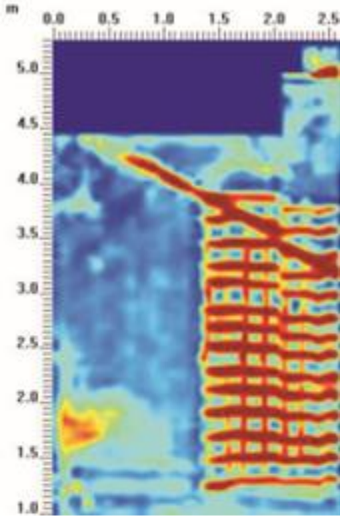

Figure 1. GPR depth slice showing the extent of a reinforced section of a concrete floor. A diagonally cross-cutting utility (water pipe) is also evident.

The second case study is an example of how GPR can be used to identify historic building structures/foundations that are buried in the subsurface. In this case, a large paved courtyard surrounded by old government buildings were surveyed as part of an investigation into localised subsidence observed around parts of the buildings. It was suspected that leaking water pipes might be the causal factor. For this particular area, a 250 MHz GPR was used with a profile spacing of 20 cm. Two perpendicular profiling directions were used.

Several of the resulting depth slices extracted from the 3D data set produced unexpected results; depth slices between approximately 30 cm and 90 cm below surface revealed a rectangular subsurface structure that was clearly man-made. It was discovered through post-survey follow-up enquiries that the unusual anomaly was an old, backfilled swimming pool structure that had since been covered with paving.

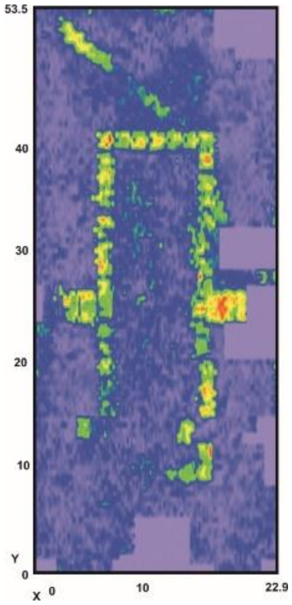

Figure 2. GPR depth slice revealing the presence of an old swimming pool structure buried beneath paving.

The third case study example relates to arguably the most popular use case for GPR in engineering, namely that of utility detection. Usually, linear utilities are very good GPR targets due to the distinct physical property contrast between the man-made materials and surrounding soil; however, it does sometimes happen that the contrast between the target and surroundings is such that it results in relatively subtle anomalies. Furthermore, if the linear target also has a gradient – as is the case with drain lines – it further complicates the detection and detailed spatial tracking of the target. Under such challenging conditions it is advisable to jointly consider the sequence of depth slices as well as 2D cross-sectional radargrams in order to assist with target identification and characterisation.

In this particular case, the location of a drain inspection eye associated with a blocked drain line on an overgrown and neglected residential property needed to be determined. Little or no information was available that could shed light on the likely strike direction of the drain line or the location of the inspection eye. A 3D GPR survey using a 500 MHz system was conducted. Profiles were only acquired in one direction (perpendicular to the anticipated strike of the drain line) and a profile spacing of 10 cm was used.

Selected depth slices from the survey (Figure 3) show how the drain line anomaly is not as prominent and easy to identify and track unless one considers multiple depth slices. The GPR survey was successful in that it enabled the plumbing team to uncover the ‘lost’ inspection eye, which was buried below more than 20 cm of soil at the location indicated in Figure 3.

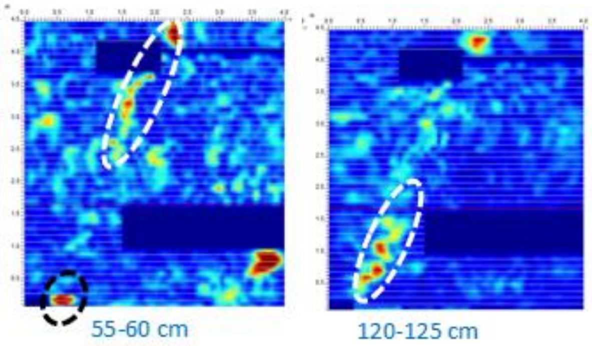

Figure 3. GPR depth slices used to infer the strike of a drain line. Evidence of the drain pipe are highlighted with the white-dashed ellipses. The black ellipse indicates the buried drain inspection eye.

The final case study included in this extended abstract relates to one of the most pertinent problems – not just in the engineering space, but also in some mining environments – namely that of detecting and characterising subsurface voids and sinkhole structures. The cause of these sinkholes and voids can in certain environments be related to soil and rock type; for example, sinkhole occurrences are quite common in dolomitic areas, especially after heavy rains. In some cases, human factors can also play a role in the formation of hazardous subsurface voids and sinkholes; for example, leaking water pipes, old mine workings and poor construction practices are all known to contribute to sinkhole and void formation.

Sometimes, early warning signs of a developing sinkhole may be evident as in this case study where other sources of information indicated that a warehouse had shown signs of vertical movement (possible subsidence). As part of the follow-up investigation, a 3D GPR grid survey was conducted outside the warehouse, over a concrete covered area that provides access to the warehouse. Even though there was no surface evidence of a sinkhole (e.g., tension cracks), the GPR results indicated the presence of a developing sinkhole below the concrete surface. A 3D view of the structure is shown in Figure 4.

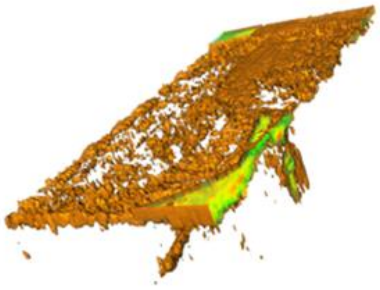

Figure 4. A 3D visualisation of a developing sinkhole structure below a concrete surface outside a warehouse.

The integration and supplementary potential of LIDAR data should also be noted. For example, where GPR data is acquired over a surface of varying topography, LIDAR data can be used to apply geometric corrections to the 3D GPR data volume before displaying or interpreting the data. LIDAR also provides a way of translating local survey coordinates to global coordinates; for example, if the end-user wanted to add context by overlaying selected results on a map (Figure 5).

Figure 5. Georeferenced GPR depth slice overlain on a Google Earth image

CONCLUSIONS

The case studies presented in this paper provide evidence of the versatility of the GPR method and demonstrate its applicability to a range of diverse, but common problems encountered by professionals in the broad field of engineering. GPR is capable of providing cm-scale mapping accuracy of anomalous features in the near-surface – typically in the upper 5-8 m.

Some noteworthy advances in the application of GPR were also demonstrated through case studies. For example, the shift to conducting 3D surveys has enabled powerful interpretation options that include depth slice analysis and 3D visualisation of GPR data. The integration with LIDAR data also provides enhanced georeferencing capabilities and potentially, supplementary structural information.

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