Identifying structural damage with ground penetrating radar

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Ground penetrating radar (GPR) and electrical resistance tomography (ERT) surveys were conducted in an urban environment in an attempt to identify the cause of severe structural damage to a historically significant residential property in Johannesburg, South Africa.

The CSIR's Applied Geosciences Group was presented with a fairly unusual problem: owner and editor of DeKat magazine, Elzilda Becker, was an interested buyer of an upmarket residential property located in 13th Avenue, Houghton, Johannesburg (see Fig. 1). The property also has historic significance in that former president Nelson Mandela lived in the house for some time after his release from prison in 1994. The house also appears on a list of 200 historic sites published by the Nelson Mandela Foundation. In recent years, the house developed severe cracks and signs of subsidence became apparent (Fig. 2).

The uncertainty around the exact cause and extent of the observed damage was an obvious concern to all interested parties during the property sale negotiations. Long term leaking of subsurface water and drain pipes were cited as a probable cause for the observed structural damage.

A site investigation revealed that the problem area was concentrated along the back or southern side of the house. The fact that this was where most of the water-related utilities and known plumbing problems occurred corroborated the theory of water related damage. It was therefore decided to conduct 2D GPR and ERT surveys along the back of house.

Access was limited to a paved pathway that extends from the south east (SE) corner of the house towards a courtyard outside the kitchen and then leading onto the paved section in front of the double garage that can be seen in the background of Fig 1. A schematic plan view of the site is also shown in Fig. 3. The position of the ERT profile is also shown in Fig. 3. GPR profiles were acquired along the same line, with a few additional, shorter profiles acquired at selected locations in a direction perpendicular to the main profile.

Method and results

GPR data were acquired using a Rock Noggin 500 MHz system. Various profiles using different acquisition parameters were run across the perceived problem area, which is located in, or just to the east of the kitchen courtyard. Range settings of between 2 m and 8 m were employed during GPR data acquisition. The ERT survey was done using a total of 22 electrodes spaced 1,5 m apart. Permission was granted to make holes through the paving and concrete in order to establish galvanic contact with the subsurface by means of conventional metal stake electrodes. The ERT survey approach involved a dipole-dipole measurement scheme and a circulating nearest-neighbour or `skip 0´ protocol (Slater *et al*. 2000). Due to the reconnaissance nature of the survey it was decided to restrict the survey to `skip 0´ measurements.

The radargram acquired along the main profile is presented in Fig. 4. Various utility responses can be observed in the upper near-surface (orange arrows). At greater depths, between approximately 2 m and 3 m, anomalies characterised by broad hyperbolic reflection patterns (magenta arrows) can be seen. Unfortunately the radargrams are characterised by poor signal-to-noise beyond about 70 ns (3 m depth at an assumed radar velocity of 0,08 m/ns). These radar results, however, do not provide sufficient proof to make interpretations about possible subsurface cavities or other subsurface features that may have resulted in the structural damage to the building.

The corresponding ERT result however clearly reveals the presence of prominent high resistivity zones that may be attributed to air filled cavities. Note that even though the image pixel values in such ERT sections are not absolute, the high relative contrast observed here is consistent with the expected response of such cavities.

Fig. 1: Front view of the house in 13th Avenue, Houghton, former home to Nelson Mandela.

Fig. 2: Some evidence of the structural damage that can be observed at the 13th Avenue property.

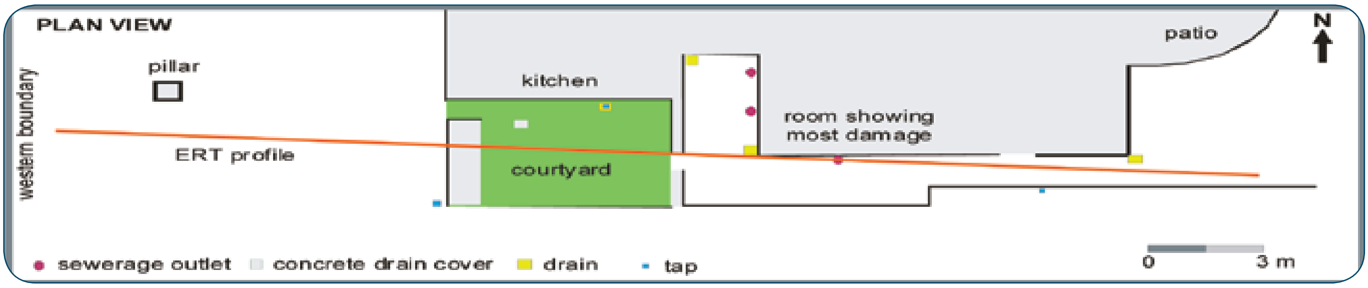

Fig. 3: Schematic view of the test site depicting the southern side (back) of the house, the surface positions of known utilities and the position of the main ERT and GPR profile.

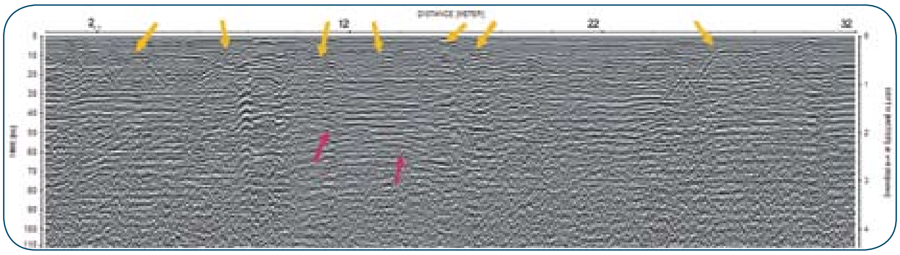

Fig. 4: Output radargram acquired along the southern side of the house. The orange arrows indicate utility responses; the magenta arrows show broad hyperbolic reflectors at depths of 2 - 3 m.

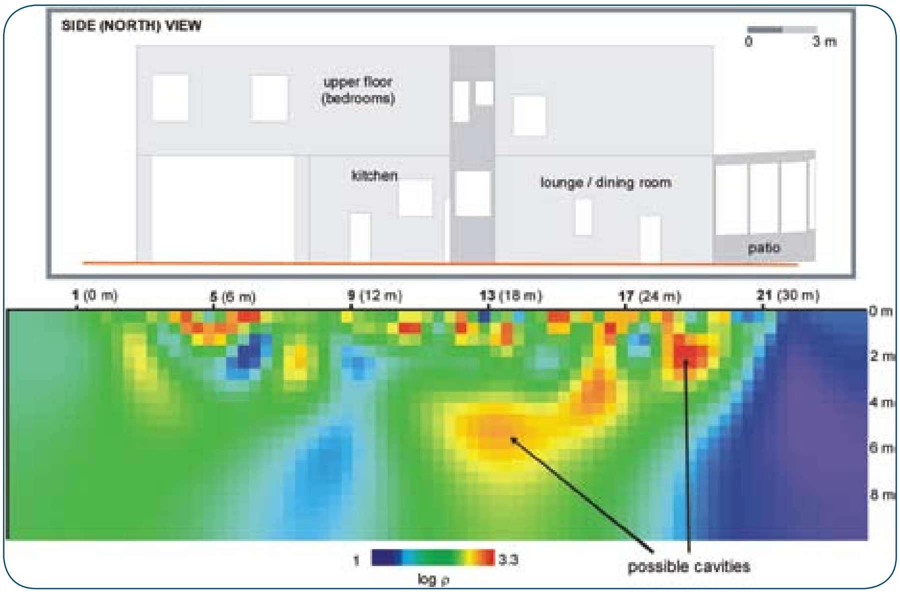

Fig. 5: ERT output image shows in relation to a schematic side view of the house. Electrode numbers are shown in bold and the relative in-line position in brackets. The most prominent high-resistivity anomaly occurs directly below the section of the house showing the most structural damage.

The deepest, most prominent apparent cavity also occurs just to the east of the previously mentioned broad hyperbolic GPR reflectors. However, the correlation between the observed ERT and GPR anomalies is not clear.

The resistivity anomalies occurring in the upper near surface (0-1,5 m) can mostly be attributed to known utilities and infrastructure features such as foundation structures. The reason for the sudden change in background resistivity towards the end of the profile between electrodes 21 and 22 is thought to be an inversion artefact associated with the local boundary between high-sensitivity and low-sensitivity grid elements resulting from the restricted measurement scheme.

Conclusions

This case study demonstrates the value of applying integrated geophysics to civil engineering problems in urban areas. GPR and ERT were used to investigate the possible cause of severe structural damage to a residential house, a location not usually associated with the application of geophysics.

ERT succeeded in mapping what is interpreted to be an unnatural cavity – probably caused by rapid subsurface erosion. Even though the ERT technique was not applied non-invasively, the potential value of the result arguably justified the means in this case; however, the use of appropriate non-invasive electrode technologies for concrete and paved / tarred surfaces deserves further investigation.

Although the GPR data showed some evidence of anomalies that could be related to the high-resistivity ERT anomalies, the value of GPR as a utility mapping tool was more obvious. In cases where the exact location of utilities might not be accurately known, GPR would be extremely useful for discrimination purposes. For example, by considering both ERT and GPR datasets it is in principle possible to discriminate between cavities and utilities and between different filling materials i.e. water, air or unconsolidated sediment. A follow-up GPR survey with a lower antenna frequency (greater depth of investigation) is recommended and will be proposed to the interested parties. Such a GPR survey might reveal subsurface anomalies that correlate with the prominent ERT anomalies described earlier.

The applicability of ERT to cavity detection and of GPR to utility detection is, respectively, well documented. This case study nevertheless represents an interesting and useful case study, since this type of engineering problem might be expected to become more prevalent in urban areas characterised by ageing houses and utilities.

Acknowledgements

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References

[1] L Slater, A Binley, and R Johnson: Cross hole electrical imaging of a controlled saline tracer injection: *Journal of Applied Geophysics*, Vol. 44, pp. 85-102, 2000.

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