USING ACSW FOR MINING INVESTIGATIONS

Guidance Note SSGN023

Background

Advanced Continuous Surface Wave (ACSW) testing permits geotechnical profiles to be determined non-intrusively by measurement of the velocity of surface Rayleigh waves (Vr) over a range of frequencies (f). Inversion of the Vr versus f data (the 'dispersion curve') provides a shear-wave velocity (V_s) profile which can be simply converted to a stiffness (G_0) against depth profile along with a number of other geotechnical parameters including undrained shear strength (C_u) and Rock Quality Designation (RQD).

This Guidance Note outlines how the ACSW technique utilised by SoilSafe may be used to located abandoned and buried Mineworkings, shafts and associated disturbed ground. As for all test data, appropriate professional engineering judgement in the context of a suitable range of ground investigation information must be applied in using ACSW data.

Investigation Methodology

Mineworkings are often associated with zones of loosened ground due to crown collapse and bulking of soils or areas of surface backfilling around shafts. These loosened materials typically have lower V_s and G_0 values than undisturbed material permitting their detection by ACSW profiles where the stiffness contrasts presented are sufficient and their depth of burial not excessive. Where voids are present then ACSW profiles identify a deterioration in data quality below the crown of the void due to the complicated seismic interactions generated at this free surface.

The ACSW testing methodology provides a vertical profile which measures the bulk soil and rock properties beneath a 3m test line (roughly analogous to a borehole of 3m diameter) to typical depths of 6-10m in superficial soils and significantly deeper (up to 20m or more) where rock is encountered within this depth range.

A minimum grid spacing of 5m is normally recommended for mineworkings investigation. Where the anticipated width of Mineworkings disturbance is less than 2m then a reduced grid spacing may be required.

There are inevitably some limitations in using ACSW testing for profiling which should be considered when specifying testing. The key limitations with reference to Mineworkings investigation are listed below:

- ACSW testing profiles measure seismic velocity and stiffness variation with depth, which may not necessarily reflect variations in stratigraphy. Weathered rock for example may be of similar stiffness to overlying soils. Other ground investigation information (such as historic boreholes) is

recommended to provide control over correlation of stiffness profiles with stratigraphy

- ACSW testing profiles will not provide the same degree of accuracy as intrusive investigation if precise depths are required. ACSW profile resolution reduces with depth from about 0.5m at shallow depth to around 1 to 2m at depth
- Lateral resolution is limited by the extent of the test array (normally around 3m) and the lateral spacing of tests. Lateral variations in ground conditions within distances close to the array length may not be identified even with a very tight grid spacing
- Lateral variations in stiffness across distances less than the test array length will affect the quality of data since analysis assumes a constant velocity along the array.

Mineworkings Assessment Criteria Using ACSW Data

The following aspects of ACSW data can be indicative of possible shafts or mineworkings:

- Consistent sharp boundaries depth or otherwise unexplained very stiff layers which may be indicative of shaft caps
- Consistently poor data, significantly multimodal and/or highly variable dispersion curves indicative of highly variable ground conditions
- Highly variable simple inversion profiles to depth
- Locally significantly different simple inversion profiles to depth indicating a local change in ground conditions

For shaft and mineworkings assessment it should be noted that:

- The presence of shafts or mine features very close to or just within the test arrays cannot be discounted
- Very small or treated shafts/mine features may not be identified in the data and areas of ground disturbance for reasons other than shafts may be identified by testing.
- No assessment of the condition of shafts or workings or the risk posed from them can be made from the ACSW data.
- An evaluation of other available information will be required to assess the overall probability of shafts or mineworkings being present.
- Intrusive investigation will be required to prove the existence or otherwise of shafts or mineworkings and their condition.

Case Studies

Rockhead Identification

Figure 1 below shows a CSW stiffness profile (presented as a softened Young's Modulus, E(0.1%), against depth) for a site with rockhead at 7m depth. The CSW profile and adjacent borehole log demonstrates that a good agreement with stratigraphy can be expected where sufficient stiffness contrasts exist between adjacent strata. Testing over a shaft or where crown collapse had occurred at this site would be expected to reduce the stiffness contrast at rockhead level.

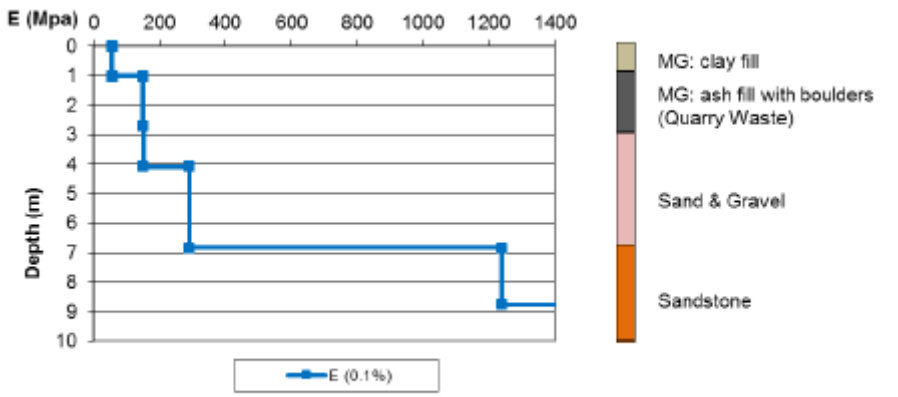

Figure 1: *Correlations between borehole stratigraphy and CSW stiffness profile*

Shallow Metalliferous Mineworkings

Figure 2 below shows the results of two tests undertaken in an area of mine workings located beneath a railway. Figure 2a shows a typical result obtained away from mineworkings. Figure 2b shows a profile obtained in an area subsequently shown via dynamic probing to be an area of disturbed ground associated with mineworkings. Due to the close spacing of tests at this site it was possible to generate a 2D (figure 2c) and 3D model (figure 2d) for the site to assist in interpretation.

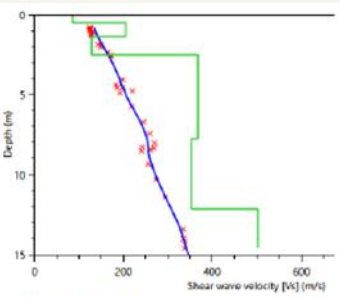

Figure 2a *Test located away from mine workings showing shallow rock head at around 2.5m depth*

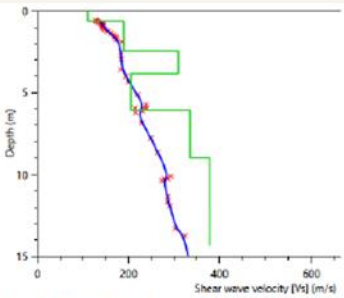

Figure 2b *Test located in area of mine workings showing disturbed ground to approximately 6m*

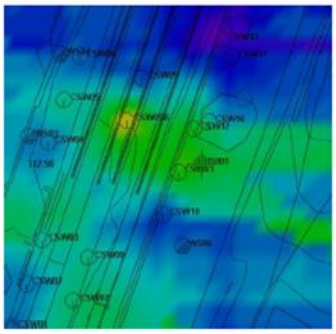

Figure 2c *Contoured model of ground stiffness at 6m depth showing low stiffness areas in green subsequently shown to correspond to disturbed ground associated with mine workings*

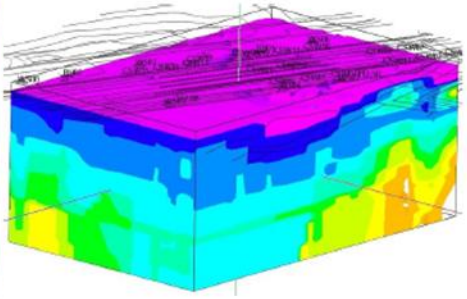

Figure 2d *3D model of ACSW to assist in interpretation of areas affected by mine workings*

Chalk Workings

Figure 3 below shows the results of two ACSW tests at the same location undertaken prior to and after compaction grouting to stabilise disturbed ground associated with mineworkings in the Chalk. Superficial clay extended down to a depth of approximately 8m below which disturbed ground was widely present across the site due to the collapse of ancient chalk adits located at a typical depth of 15-20m. Following a program of compaction grouting at close centres ACSW testing demonstrated improvement in the stiffness in the Chalk over the treated zone.

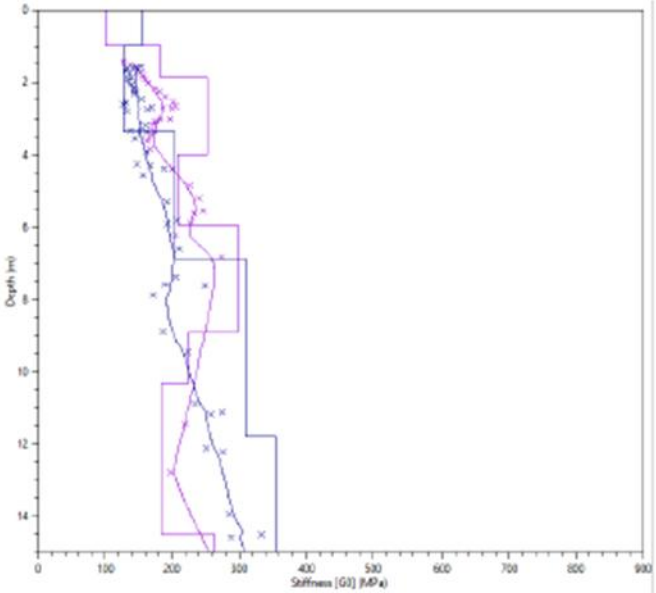

Figure 3: *Before (magenta) and after (blue) ground stiffness profiles in an area of collapsed chalk mineworkings showing the improvement in stiffness effected below 9m through compaction grouting.*

Shafts

Field ACSW outputs in Figures 4 & 5 below show potential shaft from testing on top of a major highway (testing undertaken over 3m grid centred on assumed shaft location). The ability to assess profiles in the field allowed the test grid to be adjusted necessary to define shaft locations. The speed and non-intrusive nature of testing minimised the extent and duration of lane closure (data was unaffected by highway traffic on open lanes).

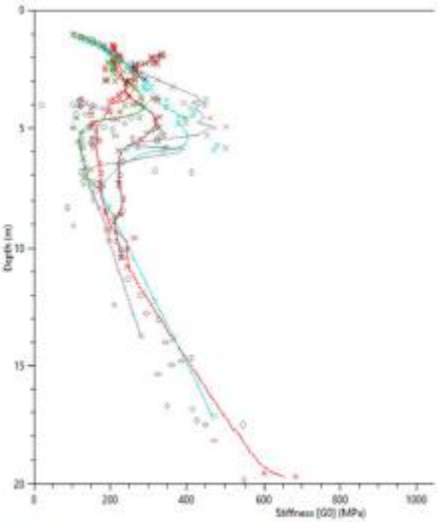

Figure 4 *Possible shaft cap at 4-5m depth indicated by local very stiff horizon*

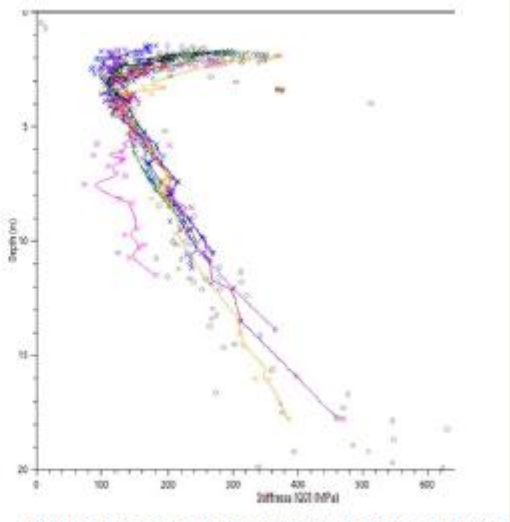

Figure 5 *Local significantly lower stiffness profile (in pink) in otherwise very inform profiles suggesting potential shaft location*

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Limitations

This document is intended to indicate potential approaches for the use of ACSW data by suitably qualified geotechnical engineers as part of a general design review. It may be subject to periodic review and change. No guarantees as to accuracy are made and where necessary original references and relevant design guidance should be reviewed.

ACSW test data should be reviewed against all available information on ground conditions as part of an appropriately scoped ground investigation.

References

- **CIRIA C562 (2002) Geophysics in engineering investigations**
- **Kearey P and Brooks M (1991) An introduction to geophysical exploration, 2nd Edition, Blackwell**
- **Wood E, Milne C & O'Donovan A (2018) Continuous surface wave testing as a new addition to the holistic approach of treating abandoned chalk mines and collapse features in chalk in *Proceedings of the Chalk 2018 Conference* Ed J.A. Lawrence; M. Preene; U.L. Lawrence; R. Buckley**