Use of the Acoustic Scanner for Geotechnical Investigations

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SUMMARY

The acoustic scanner (or acoustic televiewer) is a geophysical tool capable of providing oriented acoustic images of a drillhole wall. It is being increasingly used in geotechnical investigations to determine the orientation of rock mass defects. Acoustic scanning was recently carried out at Roxburgh Dam, New Zealand, where two 60 m deep cored holes were drilled in schist rock. The holes were scanned and the data processed using proprietary software. A detailed comparison was made between the drill core and scanner images. The images produced clearly showed the major rock mass defects present, enabling their true dip, azimuth, and approximate thickness to be determined. Acoustic scanning was subsequently used at the site to rapidly and cost effectively determine the presence and orientation of defects in 37 non-cored foundation drainholes.

Acoustic scanning has considerable potential for use on geotechnical projects where defect orientation is a prime objective. It may be used in conjunction with core drilling to provide high quality geotechnical data and with non-core drilling to provide cost effective spatial coverage or data "infill" between cored holes. In some situations the scanner may also be used to estimate in situ stress orientations from analysis of drillhole breakout.

1. INTRODUCTION

Acoustic scanning is a relatively new technique for obtaining *in situ* geotechnical information from acoustic images of a drillhole wall. This paper introduces the technique and presents an example of its use in schist terrain at Roxburgh Dam in New Zealand's South Island. This is followed by a more general discussion of the geotechnical applications and practical limitations of the scanner based on the author's experience at Roxburgh and several other sites.

2. THE ACOUSTIC SCANNER

The acoustic scanner (also known as the acoustic televiewer) is a wireline geophysical tool incorporating a rapidly rotating transducer, which emits short bursts of sound energy[1]. Originally developed for the petroleum industry, the scanner is now used increasingly in geotechnical investigations.

Each acoustic pulse is reflected off the borehole wall and its amplitude and travel time recorded as it returns to the tool. The amplitude (or strength) of the reflected signal provides an indication of the reflective properties of the wall rock, which in turn can be related to the strength and hardness of the rock. Defects containing crushed rock or gouge that is softer than the surrounding rock are thus readily identified, as are boundaries between lithologies of contrasting strength. The acoustic travel time, when suitably corrected for the sonic velocity of the drillhole fluid, provides a measure of the drillhole diameter, thereby allowing open joints, voids, caving and breakout to be determined. As the tool traverses the drillhole a continuous helical scan is formed. The basic operation of the tool is shown in Figure 1.

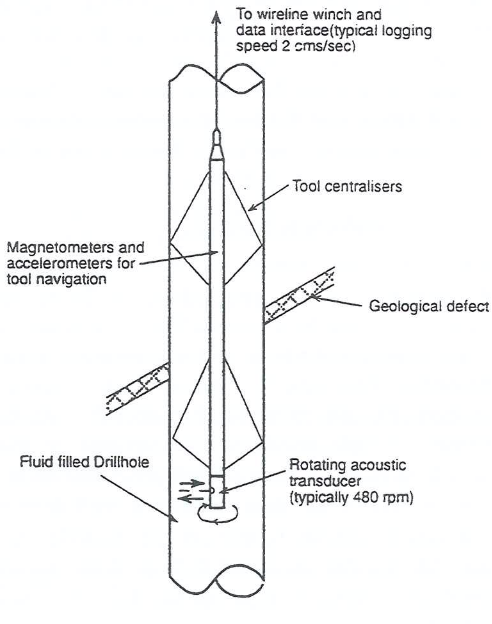

Figure 1: Operation of the acoustic scanner

The three dimensional orientation of the tool is recorded by a series of on-board magnetometers and accelerometers. In this manner the tool always knows exactly where it is in relation to the base of the hole. The amplitude and travel time data may therefore be imaged and presented in their correct orientations for later computer-based interpretation.

Data interpretation is carried out using various proprietary software packages, which allow the orientation (dip, dip direction) to be determined for each identified defect. The amplitude and travel time data are "imaged" using a gradational colour palette.

Interpretation is carried out on "unwrapped" 360° displays of the imaged drillhole wall. Planar features encountered in the drillhole appear as sinusoidal traces. A "best fit" sine curve is manually fitted to each defect trace and the orientation automatically calculated. The interpretation software also allows defect orientations to be exported as ASCII files for tabulation and presentation using stereoplotting software.

3. CASE STUDY– ROXBURGH DAM

3.1 Background

Roxburgh Dam is a concrete gravity structure located on the Clutha River in New Zealand's South Island. The dam has an annual power output of 320 MW from 8 turbines and was completed in 1956. Although comprehensive as-built geological logs of the foundation exposure were made, further information on the engineering geology of the schist rock on which the dam is founded was recently considered desirable. To this end a staged investigation programme including cored drilling, groundwater instrumentation and downhole geophysics was carried out. A feature of the investigation was the use of acoustic scanning to obtain orientated data on rock mass defects from drillholes.

3.2 Geological Setting

Roxburgh Dam is situated in a broad northwest trending belt of the Otago Schist. The schist originates from quartzofeldspathic and volcanogenic sediments of Mesozoic-Paleozoic age, that have been metamorphosed to textural zone IV. At least four phases of deformation are recognised in the region, which remains seismically active. The rock mass in the vicinity of the dam exhibits a well-developed sub horizontal foliation and is moderately to widely jointed. It contains shears both parallel and oblique to foliation. Intact rock strengths of 50 to 200 MPa are typical.

3.3 Field Investigations and Results

Two diamond cored PQ/HQ size (122/95 mm diameter) drilholes were drilled on the left abutment of the dam in mid 1997 to install additional piezometers. The acoustic scanner was trialed in these holes and the results compared with the drill core and conventional density, sonic and caliper logs[2]. A typical section of scanner image from one of these holes is presented in Figure 2. Following data processing, the acoustic images were interpreted to determine the type and orientation of all planar features identified. The trial concluded:

- The scanner clearly identified all the major shears (both sub-horizontal and steeply dipping) present in the core.
- The scanner identified the majority of joints present in the core. Those joints identified in the drill core but not revealed by the scanner may have been tight *in situ* and therefore not differentiable from the adjacent wall rock.
- The orientation of all defects identified could be readily determined during subsequent data processing.
- Due to the geometric considerations the dip angle determined for steeply dipping defects is generally of greater precision than that for shallow dipping features.

Following the success of the trial, 37 foundation drainholes located within the lower dam inspection gallery were scanned during 1998[3]. These holes had originally been drilled during construction by diamond coring, although the cores were not retained.

Immediately prior to scanning, the holes were flushed with high-pressure water jets and several of them reamed and deepened using a small percussive rig. A "dummy" probe of the same dimensions as the scanner was used to determine the "scannable" depth of each hole, allowing an optimum investigation schedule to be developed. The scanning operation took place over 5 days during which 466 m of drillhole were scanned. Data interpretation was carried out on site in tandem with the data acquisition. This had the major advantage of allowing the investigation to be modified as it progressed. Additional holes were scanned in areas where data quality was poor or where features of particular interest were identified. The scanner equipment used for the drainholes was different from that used for the surface holes, primarily due to the headroom restrictions in the dam galleries.

In spite of the holes having been drilled over 40 years previously, a large number of rock defects were identified from the scanner images, and their orientation determined. As with the earlier trial, defect classification from the scanner images was somewhat subjective, and difficulty was occasionally experienced in differentiating open or infilled joints from thin foliation shears and crushed zones on the scanner images (i.e. it was not always possible to determine whether or not shear displacement had occurred along the defect). "Major" shears (i.e. greater than 20 mm thickness) were readily identifiable.

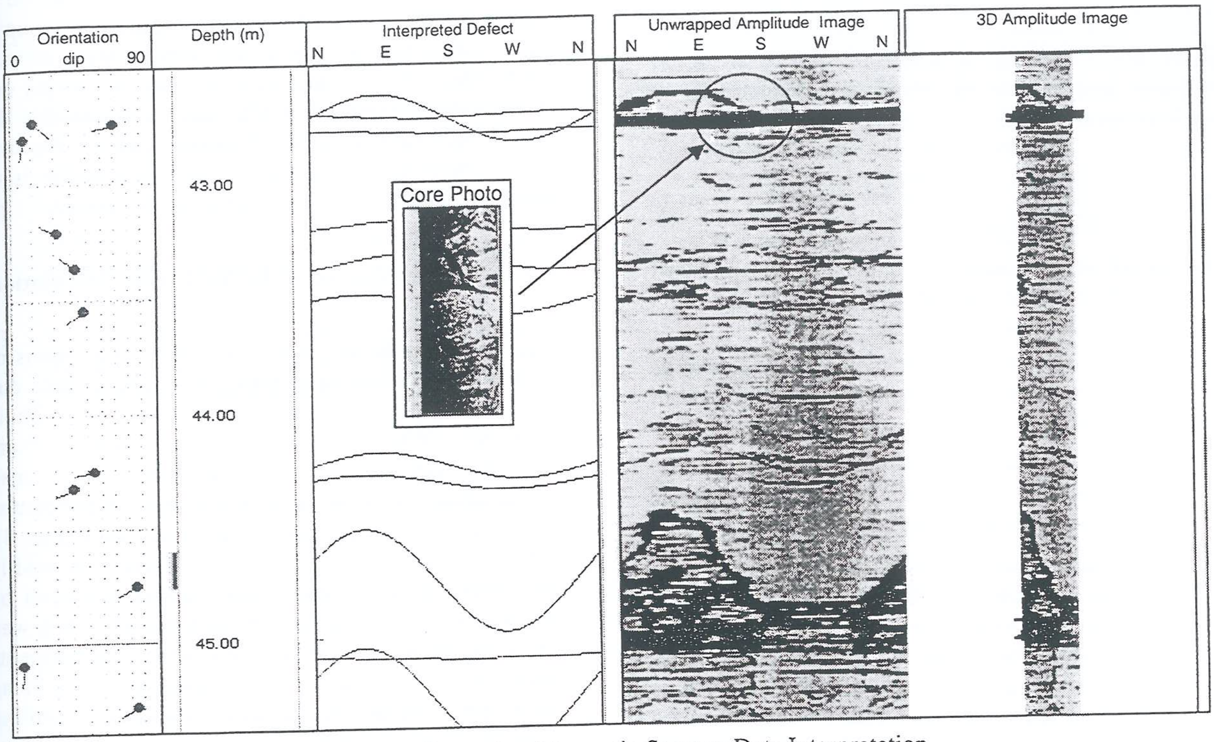

Figure 2: Example of Acoustic Scanner Data Interpretation

High quality, orientated data on rock defects were obtained from most of the drainholes. The quality of the acoustic scanner data appeared to be influenced by the condition of the drillhole wall. Overall, better results were obtained in diamond cored holes than holes redrilled by percussive means. Although different scanning equipment was used, data quality from drainholes that were not reamed was generally comparable with that of the cored surface holes.

The interpretation software allowed logs to be compiled for each drainhole showing the acoustic amplitude and travel time images, interpreted features and their classification and orientation, and drillhole azimuth and inclination. Consideration of the large amount of additional data gained from acoustic scanning at Roxburgh has contributed to a far more detailed understanding of rock mass properties at the dam site. It is unlikely that any other investigation tool would have given such detail and spatial coverage for the same cost.

4. ISSUES ASSOCIATED WITH USE OF THE ACOUSTIC SCANNER

4.1 Cored versus Non-Cored Drillholes

By providing orientated data the scanner represents a major advance over most conventional downhole geophysical methods.

The scanner is not regarded as a replacement for core investigation drilling. It does however have the potential to enhance the quality of geotechnical data obtained from both cored and non-cored holes.

Where highest quality orientated data is required the scanner may be used in conjunction with cored drilling. The two techniques are complementary and data from both may be combined on a single interpretive drillhole log for subsequent interpretation. The drillcore allows direct inspection and sampling of the strata encountered whilst the scanner provides defect orientations, 3D drillhole deviation data and additional information in zones of poor core recovery. The use of the scanner in this manner is more appropriate for projects where the orientation of rock mass defects can have major design and contractual implications. Examples include tunnels, cut slopes, deep excavations and landslide investigations.

The scanner may also be used to gain geotechnical information from non-cored holes drilled for other purposes. Examples include resource definition drilling in quarrying and mining, grouting holes, ground anchor holes, or as in the case of Roxburgh, drainage holes. Typically a large number of these holes are drilled rapidly and cheaply by open hole methods. Whilst the scanner data quality may be poorer than for cored holes, a wide spatial coverage of information on defect orientations and stratigraphy may be acquired at relatively low additional cost. Some "control" in the form of occasional cored holes is still desirable.

4.2 Drillhole Environment

There are a number of physical limitations on the drillhole environment in which the scanner may be used. These include:

- Drillhole fluid – the scanner requires a water or mud filled drillhole
- Drillhole diameter – the 75-mm diameter drainholes at Roxburgh were close to the lower limit of the equipment used.
- Headroom – the shortest tool used at Roxburgh was 2.6 m long. This precluded its use in some of the galleries
- Artesian groundwater/gassing - Data quality may be adversely affected by strong artesian groundwater flows or gas bubbles.
- Hole inclination - Vertical or steep downwardly inclined drillholes may be readily scanned using a conventional wireline winch. Lower angle and subhorizontal holes can be scanned in some cases, with the tool pushed into the hole with flexible fibreglass rods. Problems with tool centralisation may also be experienced. Upwardly inclined holes cannot be scanned due to the requirement for a drillhole fluid.
- Drilling method - Diamond cored holes provide a smoother drillhole wall than do percussive or wash bored holes. Data quality may be adversely affected by excess rugosity of the drillhole wall.
- Hole conditions - In softer rocks, excessive caving or smearing on removal of casing may effect data quality. Poor hole stability may also place the tool at risk of jamming or other damage.
- Casing - The scanner will not work through drillhole casing, screens or liners.

Specific requirements differ slightly between geophysical contractors and will no doubt change as new equipment is developed.

4.3 Cost Effectiveness

Depending on the site location, mobilisation costs may be significant, but the actual data acquisition is relatively quick. Cost effectiveness therefore increases with the number of holes scanned in one visit. This, however requires holes to be left open and uncased. In some situations this may not be possible, or may involve additional drilling costs to re-visit each hole after scanning to complete installations. The timing of investigation drilling must be carefully considered to maximise the cost effectiveness of a scanning programme.

Data interpretation and presentation costs can be a significant component of the overall investigation cost. Some contractors provide a data interpretation service while others do not. Interpretation may be carried out by the client's engineering geologist, in which case the cost of software purchase, training, and a "learning curve", must be considered. A third alternative is to make use of a "third party" interpretation service.

4.4 Determination of In Situ Stress Orientation

The scanner is being increasingly used as a means of estimating the direction of principal *in situ* stresses due to its ability to determine the orientation of drillhole breakout. When *in situ* deviatoric stress is high, breakout (spalling of the drillhole wall) may preferentially occur in the drillhole wall perpendicular to the axis of principal horizontal stress (see Figure 3). The occurrence and orientation of breakout is readily determined from the travel time images produced by the scanner. Stress orientation determined in this way has been shown to correlate well with measurements using other techniques[4]. Techniques are also being developed to deduce *in situ* stress directions for drilling induced fracture patterns[5]. These techniques have application in the design of underground mines, caverns and tunnels where *in situ* stress directions have the potential to influence excavation and stability.

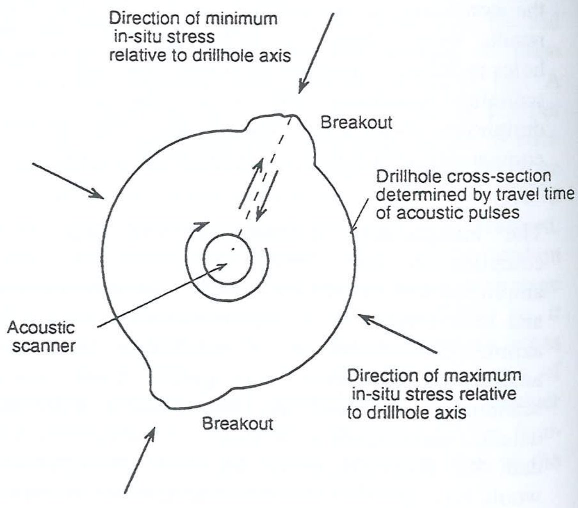

Figure 3: Determination of *in situ* stress orientation from drillhole breakout

Acknowledgements

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REFERENCES

1. Elkington, P., 1990: "The Acquisition and Analysis of Slim Acoustic Scanner Data" BPB Slimline Services, UK
2. Riddolls & Grocott Ltd., 1997: "Roxburgh Power Station. Review of Geophysical Logging techniques, Drillholes OW 12 and OW 13. Unpublished Consultants Report
3. Riddolls & Grocott Ltd., 1998: "Drainhole Acoustic Scanner Logs, Roxburgh Dam" Unpublished Consultants Report
4. Lamb, P.D. & Titheridge, D., 1989: "The Use of Borehole Breakout for Estimating Regional Changes in Horizontal Stress Directions" in Underground Coal Mining Exploration Techniques, Australian Coal Association
5. Aadnoy, B.S. & Bell, Sebastian J., 1998: "Classification of Drilling Induced Fractures and their Relationship to *In situ* Stress Directions". The Log Analyst, Nov-Dec 1999-11-02.