



Fig. 1. Examples of appropriately designed rock slopes

Rock Slope Stability

Accurate structural data collection for use in quarry slope design

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All hard rock slopes within any quarry excavation should have an appropriate geotechnical design that takes into account the in-situ rock mass strength and rock mass structure, with the level of geotechnical investigation and design required commensurate with the geological and geotechnical complexity of the deposit. However, quarry slope design can often rely on limited geotechnical data or poorly located boreholes that have been planned for resource definition purposes rather than the collection of geotechnical data for future slope design. Some slopes may be economically sensitive, where small changes in slope angle can have major consequences on project economics, or are located above or below critical plant or infrastructure, such as crushing stations, conveyors systems, quarry offices etc, or where failure may affect third party land (fig. 1).

Where exposed outcrops are not available for either photogrammetric or traditional mapping, geotechnical drilling can often be the only source of data collection. The use of down-hole televewers (both acoustic and optical) to capture structural geotechnical data for use in rock slope design is becoming increasingly routine. They provide rapid and accurate high-resolution oriented images of the borehole walls and are generally used as a replacement for manual core orientation techniques. SRK Consulting (UK) Ltd have successfully used down-hole televewer techniques on a number of slope design projects. This article considers several cases where orientator data has

been augmented with later televewer data, allowing comparison of the rock mass and structural characterization results. The article demonstrates the much improved accuracy of the televewer systems and identifies cases where data from traditional methods that were originally considered to be good, have actually contained serious systematic errors.

Manual core orientation techniques

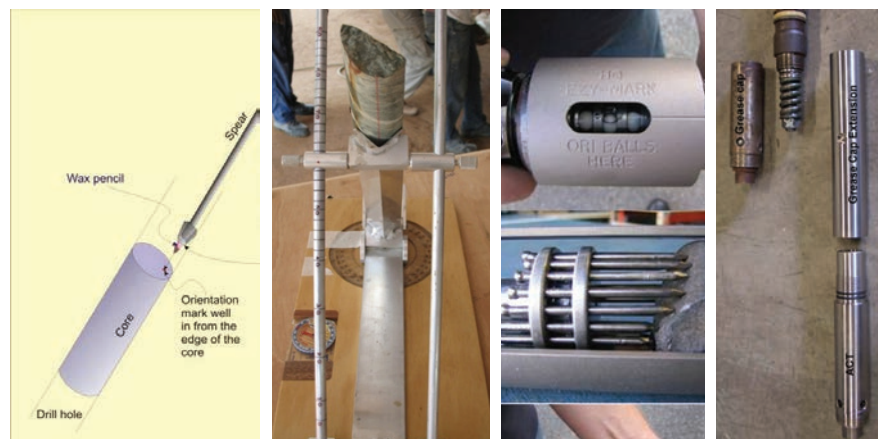
Manual core orientation techniques have traditionally been used to capture down-hole structural data, and whilst accurate data can be generated, there are a number of inherent

reliability issues that can occur, often leading to low confidence or errors in the structural data set. Such issues can be a result of low accuracy in the operating system (spear method), systematic error (rocket launcher), operator error (manual orientation tools) or logging errors. Figure 2 presents examples of a number of traditional core orientation methods.

Acoustic (ATV) and optical (OTV) televewer tools

The use of down-hole televewers can be considered a reliable, visual, fileable method for capturing structural data. ►

Fig. 2. Examples of traditional core orientation systems – left to right: spear tool, rocket launcher, Ezy-Mark and ACE Core Tool (ACT)



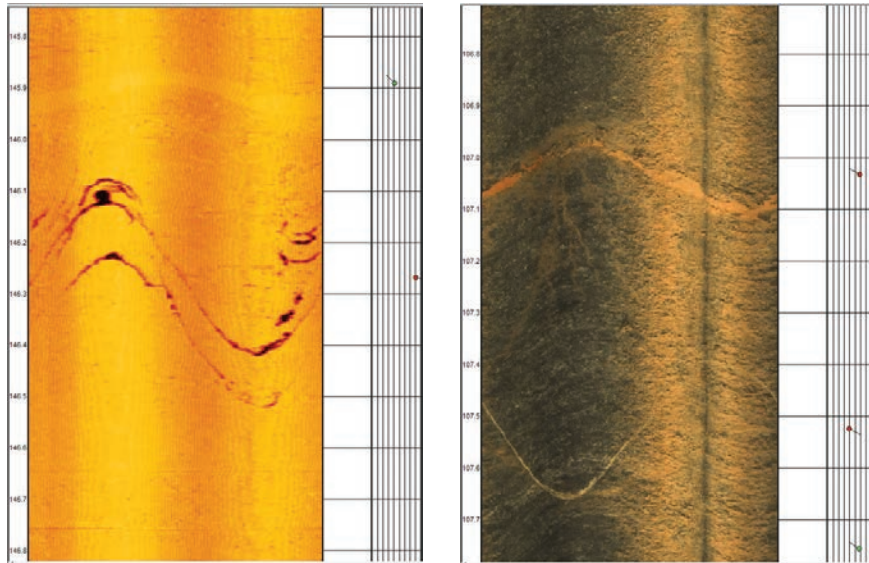


Fig. 3. Examples of acoustic (left) and optical (right) televiewer images

Although these systems were developed for use in the petroleum industry, within the last two decades their use has become more widespread within mining and quarrying. Both systems collect images of discontinuities in the drill hole using down-

hole geophysical survey equipment that can be orientated for structural logging. The acoustic televiewer transmits ultrasound pulses from a rotating sensor and records the amplitude and travel time of the signals reflected from the borehole wall, to provide

an image of the borehole wall. The acoustic probe can only be used when the borehole is filled with water. If the borehole is dry, or partly dry, an optical televiewer utilizes a down-hole digital camera and prism to obtain a continuous and oriented 360° image of the borehole wall. Optical televiewers can be used in water-filled boreholes although the water will need to be very clear and free from drilling fluid/mud. Figure 3 shows images of a borehole wall generated by an optical and an acoustic televiewer.

Whilst down-hole televiewers have previously been considered expensive, the costs are not necessarily adversely comparable to the use of traditional core orientation methods that require the daily hire of the orientation tool and geotechnicians, as well as geologists to supervise the logging (often 24h a day) at each working rig. The quality of data captured and the influence high-confidence structural data can have on a slope design can far outweigh the upfront costs of using the televiewer system. Importantly, in addition to the high-quality data capture, down-hole televiewer systems can be used on non-cored holes, very old open boreholes in good ground and/or old boreholes that can be reamed out at low cost. Thus, the system can often negate the need for new core drilling.

Examples of the benefits of using televiewer systems

Case Study 1 – Major fault interpretation

Situation

- Need to define fault orientations
- Spear tool was replaced with ATV
- Provided a structural data comparison in four drill holes with ATV and spear tool data

Issues

- Orientations and thicknesses of the major structures could not be recorded when using the spear data

- due to the fractured nature of the core
- Orientations, thicknesses and exact depth could be recorded using the ATV tool giving more confidence in the nature of the fault
- The exact depth of the fault coincided with the end of a core run, therefore logging the fault proved problematic

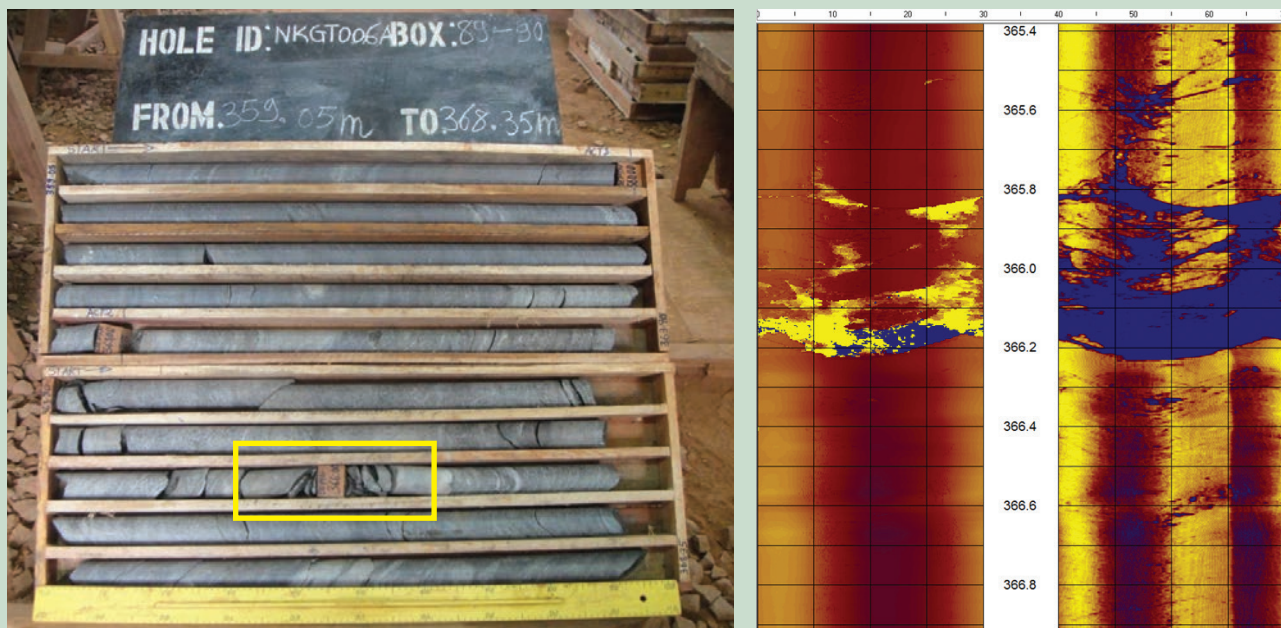
Result

- The confidence in the engineering

characterization of the fault was significantly increased using the ATV data. As a result, the pit slope design accommodated the location, geometry and engineering characteristics of the fault.

- Figure 4 shows an example of the recovered core (left) and the fault intersection as recorded on a down-hole ATV log (right).

Fig. 4. Recovered core (fault in yellow box) and fault intersection on a down-hole televiewer image



Case Study 2 – Quality of core orientation data in different drilling phases

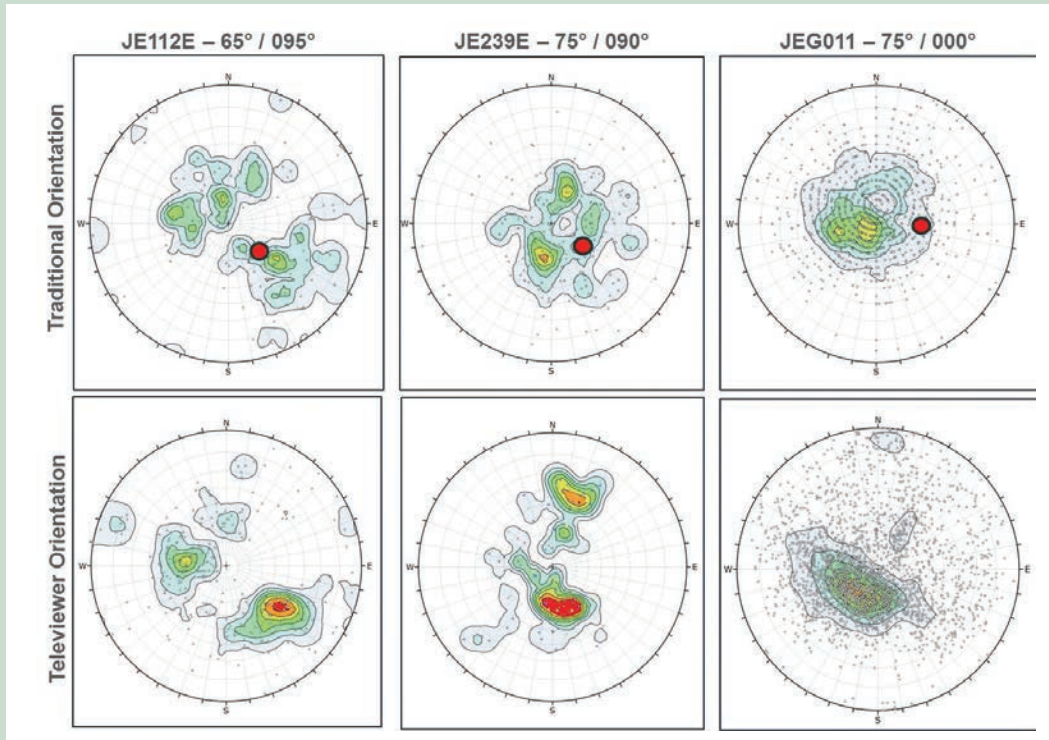


Fig. 5. Comparison of structural data from traditional (top row) and televiewer (bottom row) orientation methods

Situation

- Traditional core orientation tool was used to orientate drill core for up to 30 drill holes
- Slopes economically sensitive to changes in slope angle, so ATV and OTV were used

to define the actual structural joint sets in the rock mass for an updated slope design

Issue

- Fractured nature of the core resulted in low-confidence core orientation data for use in slope design (fig. 5)

Result

- Accurate data generated from the televiewer logging and an updated slope design with steeper, more confident slopes was provided to the client.

Case Study 3 – Improved rock mass classification (RMC) in foliated rock

Situation

- Slope design using RMC data
- Open joint count comparison between traditional orientation and ATV within foliated rock mass

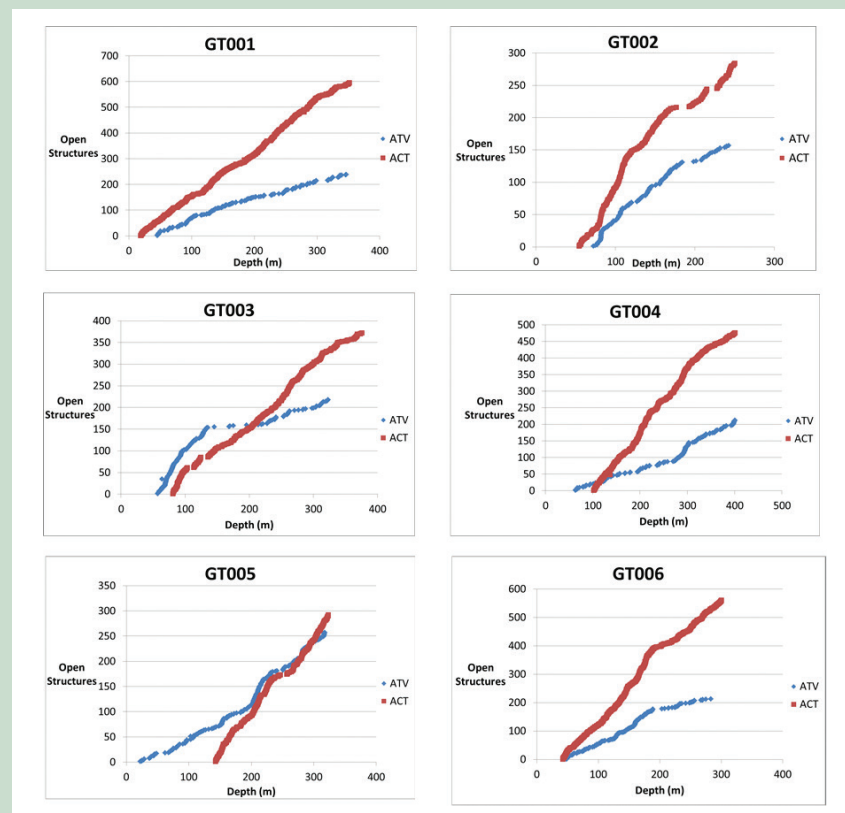
Issues

- Foliation was generally tight but core fracturing was suspected as a result of the drilling and core-handling procedures
- In five of the drill holes the number of open joints was 100–200% more when using traditional orientation as opposed to ATV (fig. 6)

Results

- Mechanical joints were included in the traditional logging but excluded when ATV logging
- The rock mass rating (RMR) ranged from 6–9% higher with ATV compared with traditional orientation
- The higher the RMR, the higher the rock mass strength (RMS), which can lead to an increase in overall slope angle (OSA) if the rock mass structure is favourable. ➤

Fig. 6. Comparison of open joint count per borehole between traditional core orientation (shown in red) and ATV (shown in blue)



Case Study 4 – Reduced catch berm requirement in design

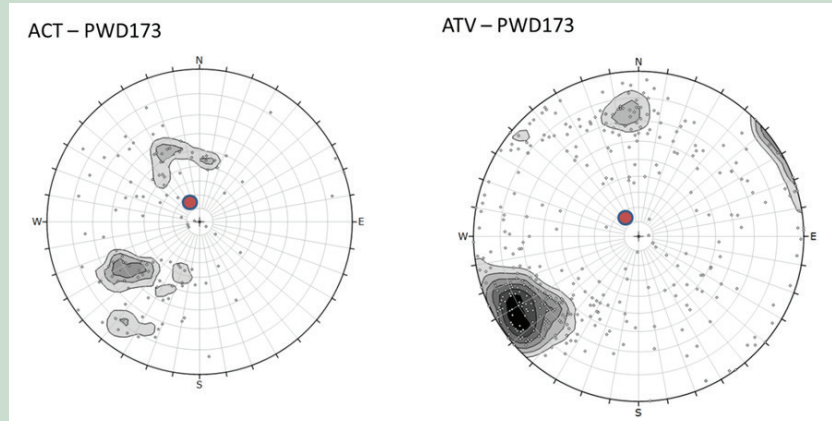


Fig. 7. Comparison between small-scale structural dip and azimuth variability from traditional orientation and ATV data sources. The image on the right, generated from ATV data, clearly shows more defined joint sets

Situation

- Structural data comparison in eight drill holes with traditional orientation and ATV data
- Lower orientation confidence meant reference lines did not join up or were missing for much of the core
- Significantly fewer orientated joints recorded using traditional methods in comparison with ATV

Issues

- Much greater variability in structure dip and azimuth from traditional orientation data set – can result in less confidence or inappropriate slope design

- Use of traditional data would have defined more joint sets
- This would require development of wider berms and shallow bench face angles to minimize and contain structural failures

Results

- ATV collected a greater volume of more accurate data which allowed greater confidence in slope designs
- Example shown in figure 7 resulted in higher confidence and steeper slope design when using ATV-generated data.

Conclusions

The use of down-hole televiewer methods can result in much improved confidence in rock mass conditions and structural data sets, which, in turn, can result in greater confidence in slope designs. Such systems can be used in all rock masses. Very heavily fractured rock masses can be lined with PVC to ensure borehole stability and orientation by ATV. The use of televiewer systems maximizes data from drill holes and represents a minimal cost in relation to a drilling programme – typically 10–20% of the total drilling cost, although it can be much less if using existing open holes or very deep boreholes.

The advantages of using the system are:

- Increased rock mass rating (only logging natural open structures)
- More accurate fracture frequency/joint spacing calculation
- Reduced variability in the orientation of major joint sets
- Higher confidence in small-scale structures within the rock mass
- Increased confidence in the orientation, locations and thickness/intensity of major structures
- Provides fileable data that can be reassessed if necessary
- Can be carried out on stable old boreholes and does not always require new drilling programmes.

The above benefits can manifest themselves in greater optimization of pit slopes, which, in turn, can lead to financial benefits when designing economically sensitive slopes and confidence in design when developing slopes near to critical quarry infrastructure. **QM**

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