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Televiewer imaging of boreholes; benefits and considerations for interpretation in the absence of physical rock core

G.T.C.McKenna & S.L.Roberts-Kelly
Coffey Corporate Services Pty Ltd: A Tetratech Company, Australia

ABSTRACT: A common occurrence in geotechnical assessment during geological and geotechnical modelling is the lack of readily accessible physical core. Defect characterisation can therefore be based only on borehole logs, core photographs and remote imaging data (if available). Previous experience indicates that interpretation of remote imaging data by data acquisition companies can differ from the actual rock core. This paper highlights that remote imaging data can be a useful resource especially where access to the physical core is limited or not possible. Two Australian cases are considered, where remote imaging data show discrepancies in ground conditions to those apparent in the rock core; these discrepancies were subsequently exposed during construction. A final recommendation interpretation of Televiewer data be reviewed by trained geotechnical professionals for consistency with core photographs and other sources, as data acquisition companies may not have access to all sources for correlation during their interpretation.

1 INTRODUCTION

All civil engineering projects benefit from an accurate geotechnical ground model, typically conceived from desk study assessment supported with a targeted site investigation and engineering geological review. Projects with deep or long cuttings in rock require a thorough understanding of the materials that are to be excavated to allow accurate estimation of rippability, support requirements and (if applicable) material reuse characteristics. Cored boreholes are the most common intrusive form of deep geotechnical investigation, but due to the staged procurement process on many larger projects the core may not be readily accessible during- or may have deteriorated prior to- the design period, and geotechnical design may have to rely on logs, photographs and Televiewer data.

In the authors' experience Televiewer data is beneficial but, as with most sources of data, requires careful analysis to ensure consistency with other available sources and the actual ground conditions, otherwise additional design and construction costs can result. This paper aims to provide a comparison of Televiewer data against the rock core, borehole logs and core photographs so the reader can make an educated assessment of the likely defect conditions in the absence of rock core during the design period.

It is noted that in some cases the Televiewer data can actually provide better information than the rock core, if the core has been mistreated, poorly handled or is damaged due to drilling. For an extensive bibliography regarding use of Televiewers the reader is referred to Prensky (1999).

2 BRIEF OVERVIEW OF GEOTECHNICAL CUTTING DESIGN

2.1 *Components of geotechnical cutting design*

Geotechnical design of cuttings involves assessment of:

Rippability – specifically what method is required to remove the material with minimal disturbance to the final cut slopes?

Support requirements – what will be required to maintain the final cut slopes at a required factor of safety for the design life?

Material reuse – is the excavated material suitable for reuse elsewhere on the project? What processing will be required so that it can be placed in accordance with the construction specification?

3 HISTORICAL/TYPICAL SOURCES OF GEOTECHNICAL INFORMATION

A good understanding of rock defects and strength is vital for every component of design. Rock defects or structural geology can be assessed using mapping of surface rock outcrops but will typically be supported by intrusive investigation in the form of cored boreholes. The strength of in situ materials can be assessed based on seismic studies, but is typically (and arguably more accurately) ascertained from point load or uniaxial compression testing of recovered rock core. Therefore cuttings usually have a number of cored boreholes that extend beyond the final cutting design depth. Variation of the orientation of the boreholes increases both the likelihood of encountering variably orientated strata, and recording of their structural geology data accurately (Versteeg & Morris, 1994).

Information from the boreholes is presented as a borehole log and core photograph. During logging a trained geotechnical professional will measure the structural geology data for each defect observable in the recovered core. If there are areas of core loss or core samples are disturbed during drilling and acquisition, then gaps or errors in the geological profile can occur.

Other sources of data that can corroborate Televiewer findings include published geological maps (and associated publications), local knowledge, past experience and a thorough understanding of geological processes.

Partially due to the receptiveness of the petroleum industry, there has been a rise in the use of borehole geophysical logging methods since the 1960's (Prensky 1999), specifically down the hole viewers or 'Televiewers' being used for geotechnical data acquisition. Televiewers used for geotechnical applications are separated into two types: optical and acoustic. Optical viewers take a 360° continuous 'true colour' image using a rotating prism and onboard light of the entire inner borehole wall. Acoustic Televiewers operate by firing ultrasound beams at the borehole walls and record the resultant travel time and amplitude. Both methods record inclination and magnetic orientation so that images can be located in three dimensional space for quantification and calibration of the structural geology data.

3.1 *Types of geotechnical information*

Table 1 provides a summary of the sources outlined in Section 3.

Table 1. Sources of geotechnical information for cutting design.

Source	**Factual / Interpretation**	**Ease of reinterpretation**
Rock core	Factual	Quality and access dependent, source for reinterpretation of other sources listed in this table
Laboratory results	Factual	-
Core photographs	Factual	Quality dependent, source for reinterpretation of other sources listed in this table.
Optical Televiewer	Factual and Interpretation	Images can be reinterpreted easily, particularly if compared with other sources. Reinterpretation can be undertaken (Li et al. 2013).
Acoustic Televiewer	Interpretation	Specific software used to assess raw input is typically not available during reassessment. Reinterpretation of outputs typically not reliable unless undertaken by specialists (Li et al. 2013).
Borehole log	Interpretation	Trained geotechnical professionals are able to assess interpreted information, correlate with other sources listed in this table and make educated reinterpretation if required.
Professional Knowledge	Factual and Interpretation	Can be difficult due to professionals having different experience levels.
Published Geological Maps	Factual and Interpretation	Maps may have additional notes or prior revisions which can be assessed and reinterpreted if required.

4 CASE STUDIES

Literature confirms that Televiewer data should be validated or calibrated with rock core (de Frederick et al. 2014). This section illustrates two examples of Televiewer data compared with data sources for the same borehole. The examples have been selected to highlight potential issues that should be considered when assessing Televiewer data. Note that rock core photographs in the figures have been scaled for ease of comparison and correlation has been undertaken based on the original photographs. The rock core was logged to AS1726-1993 standard; in which an extremely weathered material (XW) is defined as a rock weathered to such an extent that it has soil properties (ie, it either disintegrates or can be remoulded in air or water).

4.1 *Case Study One – optical Televiewer*

Case Study One is from an igneous source located in Queensland, Australia. Figure 1 illustrates a section where the defects identified in the interpreted Televiewer data do not align wholly with the other data sources. This can be seen immediately as defect 333/70 is absent from the Televiewer result.

The borehole log shows two defects with a 20° and 35° dip at 15.45m and 15.65m respectively and a drill break at 15.38m; aligning exactly with the rock core photograph. Optical output from the Televiewer shows two defects in this area; the first is a clearly visible open defect interpreted with the dip direction and dip of 114/24, the second is closed and less obvious in Figure 1 but it aligns with the interpreted

100/29 defect. The latter two interpreted defects (333/70 and 094/31) are not visible in the optical output or other data sources. The depth of Televiewer data also appears to be slightly inconsistent, as the 114/24 defect is shown at the same depth as the drill break. Depth data can be amended easily in this borehole; note however that in heavily fractured boreholes or where strata are more homogeneous this process can be quite difficult.

Close examination of the optical output indicates that there are artefacts on the image. Misinterpretation of the artefacts may account for the anomalous defects. [Artefacts are non-geological features that can blur, distort or otherwise reduce the quality and accuracy of the Televiewer output. Sources of artefacts are numerous and varied; for more information the reader is referred to Lofts & Bourke (1999) who provide a comprehensive review.] For example, the presentation of the Televiewer data can also create issues due to scaling exaggeration; the unfolded sine traces for the defects are horizontally exaggerated due to the relatively skinny core circumference versus the borehole depth; the sine trace can therefore vary significantly during interpretation and this can significantly affect the final dip direction and dip.

In this case the two anomalous defects appear to be due to misinterpretation of the optical output due to artefacts. It is noted that the data acquisition company did not have access to borehole logs or rock core at the time of their interpretation, highlighting the requirement for independent geotechnical review and correlation between data sources.

Although Figure 1 shows only two metres of the entire borehole the errors constitutes half of the defects in this area and if unchecked these errors can accumulate, creating enough scatter on summary stereonet plots to affect design.

During the construction of this project the igneous rocks displayed a preferential orientation that aligned with other data sources (including field mapping and the other defects shown on Figure 1). The structural geology data imported directly from the Televiewers contained a wide spread of data that did not readily align with other data sources. It was only after significant reinterpretation and correlation with the rock core, core photographs and borehole logs that an accurate structural geology representation was achieved.

4.2 *Case Study Two – acoustic and optical Televiewer*

Case study two is from a sedimentary source, located in Queensland, Australia. Figure 2 illustrates a section where the defects again do not wholly correlate between the data sources.

The borehole log shows defects that align with interpreted Televiewer data (DIPA and DIPT column on Figure 2) between 32.00m and 33.25m. The generalised defect description in the borehole log also correlates with the findings of the Televiewer. The borehole log indicates an XW zone between 33.25m and 33.65m which aligns with the Televiewer imagery and rock core. However the defects within the XW zone have been interpreted as open/partially open/closed fractures and foliation/banding/bedding in the Televiewer data and, arguably, should be classified as a weak zone. The defect description is critical when assessing design parameters and directly affects design.

Televiewer data here confirms the XW description in the log (possibly indicating a larger grain size for the gravel component) and provides structural information that is not measurable in the rock core. The representation of the core photograph on Figure 2 is distorted but original photographs correlate with the borehole log well. Bedding within the sedimentary rocks has been identified in the interpreted Televiewer data but not overrepresented (noting that overrepresentation of bedding can be a concern when stereographic modelling if not identified and considered probabilistically by the geotechnical professional).

A major omission from the Televiewer data occurs below the XW zone where an artefact precludes the observation of the defects shown between 34.00m and 34.50m depth in the borehole log.

5 ADVANTAGES AND LIMITATIONS OF TELEVIEWER DATA

5.1 *Advantages of Televiewers*

In the authors' experience the main advantages of Televiewers are:

Continuous measurement of the ground.

Invaluable in 'filling the gaps' where core loss or core disturbance has occurred. The in situ nature of data acquisition means that even the weakest and hardest to recover geological units can be accurately assessed.

When rock core is not available for physical assessment, it provides a valuable resource for correlation against borehole logs and core photographs.

Provides oriented defects; this can be achieved with inclined and/or oriented drilling methods but is typically quite time consuming and requires an appropriately skilled geotechnical professional.

Provides an additional visual record that can be relied upon if core is misplaced or damaged.

Is a valuable tool even if not correlated but offers a more accurate ground model when calibrated.

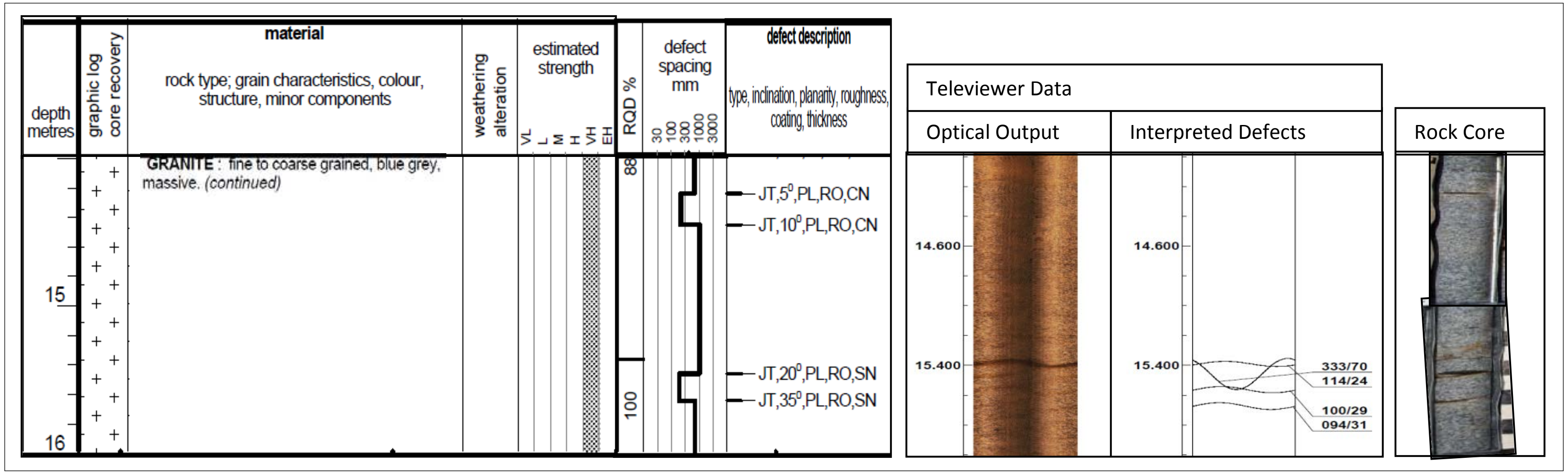

Figure 1 – Case Study 1 information; borehole log, optical Televiewer and rock core photograph. Refer Appendix A for definitions of abbreviations.

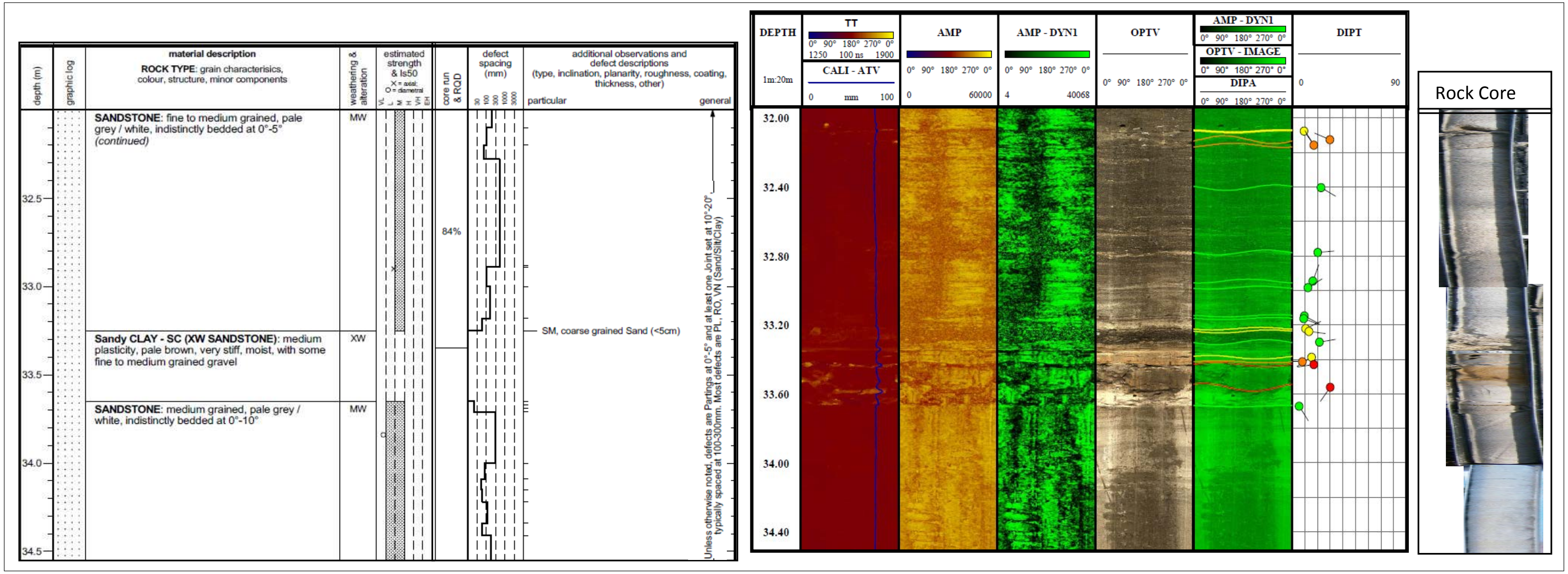

Figure 2 – Case Study 2 information; borehole log, optical and acoustic Televiewer and rock core photograph. Refer Appendix A for definitions of abbreviations

5.2 *Potential issues/limitations with Televiewers*

The main questions that should be considered by a geologist (as highlighted in the case studies) are therefore:

Are defects shown on the interpreted Televiewer artefacts or genuine defects?

The strength of materials. As these are not quantitatively assessed this can affect defect characterisation and description. Are the defects correctly classified in the Televiewer interpretation?

Statistical representation of the data. Are more visible defects such as bedding overrepresented?

Scaling issues. Is the data distorted or stretched? Are the sine waves correctly located or is there additional variance in the dip direction and dip?

Do the depths between the different sources align? Other considerations include:

Closed vs. open defects, although these are sometimes correctly separated in interpreted Televiewer data, open defects are easily identified when logging physical rock core and may be missed in Televiewer data. Due to this these defects may be overrepresented in the borehole logs and closed defects may be missed. For engineering however, open defects are more relevant than closed defects.

Similar to borehole logs, Televiewer data is provided to the geotechnical professional as an interpreted source; the main difference between the sources is the ease of re-interpretation. Most geotechnical professionals will have experience logging boreholes and reviewing and interpreting borehole logs and can therefore make informed judgements as to the validity of provided data. Fewer geotechnical professionals have formal training in understanding Televiewer outputs and therefore the accuracy of the data is harder to validate. This is not the subject of this paper but the authors believe it is of note.

Televiewer data is typically provided as a visual output (pdf) and the defects listed in a spreadsheet. This allows easy input in stereographic modelling software and with tight time constraints correlation of data between sources does not always occur. Unfortunately when the data is in the software it can be even harder to identify errors (due to natural variation in structural geology measurements) and may jeopardise the evaluation of preferential defect orientations. The sheer quantity of data provided for assessment can also be an issue, if bedding is dominant then it can easily be overrepresented in the data set and if not clearly understood or misinterpreted then may be presented as a dominant joint set.

Smearing of the lens or suspended particles in the groundwater can create artefacts or reduce the visual acuity and the acoustic accuracy of the data. Therefore flocculating the borehole prior to carrying out Televiewer investigation is critical.

Some of the interpretation by the data acquisition company can be automated (Al-Sit et al. 2015) and may have systematic errors. Also the background knowledge in engineering geology of the data acquisition company can be unknown.

For the reasons listed above, reinterpretation of Televiewer should be undertaken by sufficiently trained professionals.

6 CONCLUSION

Our experience indicates that calibration with physical rock core is vital in interpreting Televiewer data accurately. It is noted that defects in the rock core can be drilling induced, so it is also vital to use the logs as personnel in the field have assessed whether the fractures are in situ or just drilling induced. In the absence of physical rock core, logs and photographs have to be used extensively to corroborate the Televiewer interpretation, and this can be successful. Televiewer data provides a powerful tool for understanding ground conditions and structural geology data. Understanding the limitations of Televiewer imaging is critical and reliance on the information without geotechnical interpretation can cause inaccuracies in the geological model and additional design and construction costs.

The advantage of undertaking optical and acoustic Televiewer on the same hole allows for better interpretation even in the absence of borehole logs and rock core.

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