Advanced methodology for **geotechnical televiewer interpretation**

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An advanced Geotechnical Televiewer Interpretation (GTI) methodology has been developed that accurately interprets the full suite of geotechnical properties and structural characteristics of a rockmass utilising downhole televiewer survey data from diamond drill holes and percussion holes.

INTRODUCTION

This article describes how televiewer survey data is used to interpret the structural and geotechnical properties of a rock mass accurately.

Downhole televiewer surveys provide continuous orientated images of the internal drill hole surface, which is recorded using optical (OTV) and acoustic (ATV) televiewer tools. Traditionally, these surveys are used as a complementary source of structural orientation data and have not been applied in a manner that enables the comprehensive assessment of the geotechnical environment.

Significant geotechnical zones, such as faults, shears and highly fractured zones, are typically recovered in drill core as broken core, or the core is not recovered. These zones cannot be orientated and frequently cannot be accurately logged geotechnically, or logged at all in the case of core loss. Conversely, where televiewer data is available, rock mass properties for these geotechnically significant zones can be accurately assessed and the dominant structures can be identified.

An advanced methodology, Geotechnical Televiewer Interpretation (GTI), has been developed that accurately interprets the full suite of geotechnical properties of a rock mass from televiewer survey data. The methodology facilitates the identification and classification of relevant geotechnical defects, including joint condition (surface roughness and infill), joint orientation, rock quality designation (RQD), quality strength index (QSI), fracture frequency (FF) and joint set number (Jn).

The data collected from televiewer surveys is sufficient to enable the independent determination of all the major rock mass classification systems, including:

- Rock mass rating (RMR), after Bieniawski (1976, 1989) and Laubscher (1990)
- Norwegian Geotechnical Institute Tunnelling Quality Index (Q) (Barton *et al* 1974)
- Geological Strength Index (GSI) (Hoek *et al* 1995).

PROCESS AND METHODOLOGY

Data acquisition

Optical televiewer (OTV) data consists of a continuous high-resolution true-colour image, up to 1 800 pixels, or one pixel for every 0.2° over the circumference of the drill hole, generated via a rotating prism and camera housed with an internal lighting unit in a downhole tool. OTV tools can be used in dry holes or under clear water conditions.

The acoustic televiewer (ATV) tool transmits and records the amplitude and travel time of successive ultrasound pulses reflected off the borehole wall, with samples up to 360 points, or one sample point in every 1° over the circumference of the drill hole and caliper (hole diameter) resolution up to 0.08 mm.

Both tools have built-in magnetometers and accelerometers, allowing the orientation of images and the determination of the borehole azimuth and inclination. The tools commonly used can accommodate borehole sizes ranging in diameter from 50 mm to 500 mm.

Data validation/calibration

To generate a reliable geotechnical dataset, televiewer survey data is validated and calibrated using geotechnical logging of diamond drill core for the identified lithological units in the area of interest.

Data interpretation

The process of interpreting televiewer data is the same as that used to record geotechnical logs from drill hole core. Typically, the following parameters are logged:

- Core >10 cm: the total length of all core >10 cm (RQD to be calculated from it)
- Geotechnical interval: the length from the depth for each geotechnical interval

- Matrix type: discing, fault, intense fracturing, sheared rock, etc
- Hardness: the estimated rock strength index
- Number of fractures per interval
- Joint sets: degree of jointing (number of joint sets present)
- Joint roughness: the nature of the discontinuity
- Fracture infill: the type of joint infill and its alteration
- Joint wall alteration
- Weathering
- Rock type
- Fracture type: type of discontinuity
- Depth: depth at which fracture occurs
- Fracture thickness: the thickness of open fractures or the infill mineral in the fractures
- Orientation of each structure
- Major structure type: fault, shears, etc.

High-resolution true-colour OTV images and travel time and amplitude ATV images are processed, and the parameters that would normally be recorded during traditional core logging are interpreted from the processed televiewer data.

Table 1 Structure codes

	Code	Tadpole	Sine wave	
1	#10			Water table
2	#11			Casing
3	#12			Lithology contact
4	#13			Low confidence
5	#14			Bedding/foliation
6	#15			Open bedding/foliation
7	#16			Minor closed fracture
8	#17			Vein/sealed fracture
9	#18			Random/non-continuous
10	#19			Partial open fracture
11	#20			Minor open fracture
12	#21			Major open fracture
13	#22			Broken zone
14	#23			Micro fault
15	#24			Fault zone

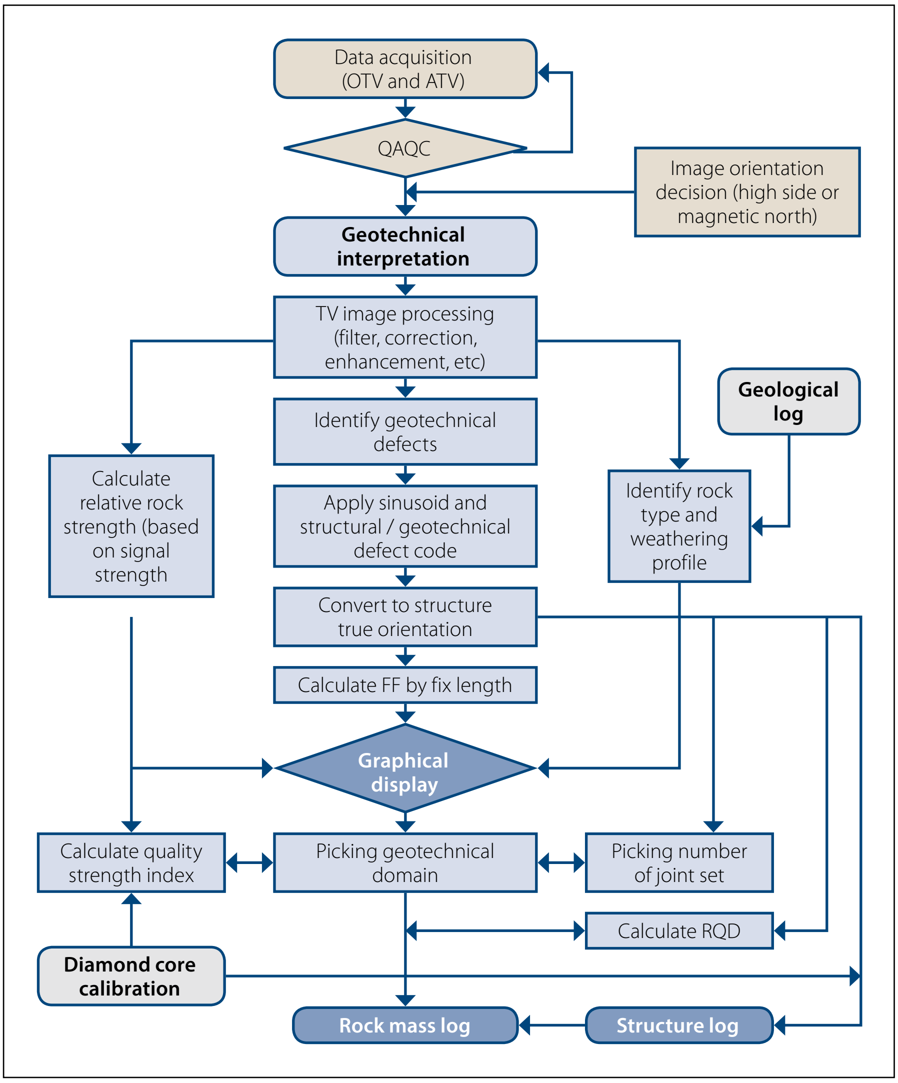

Figure 1 Flowchart of geotechnical interpretation data

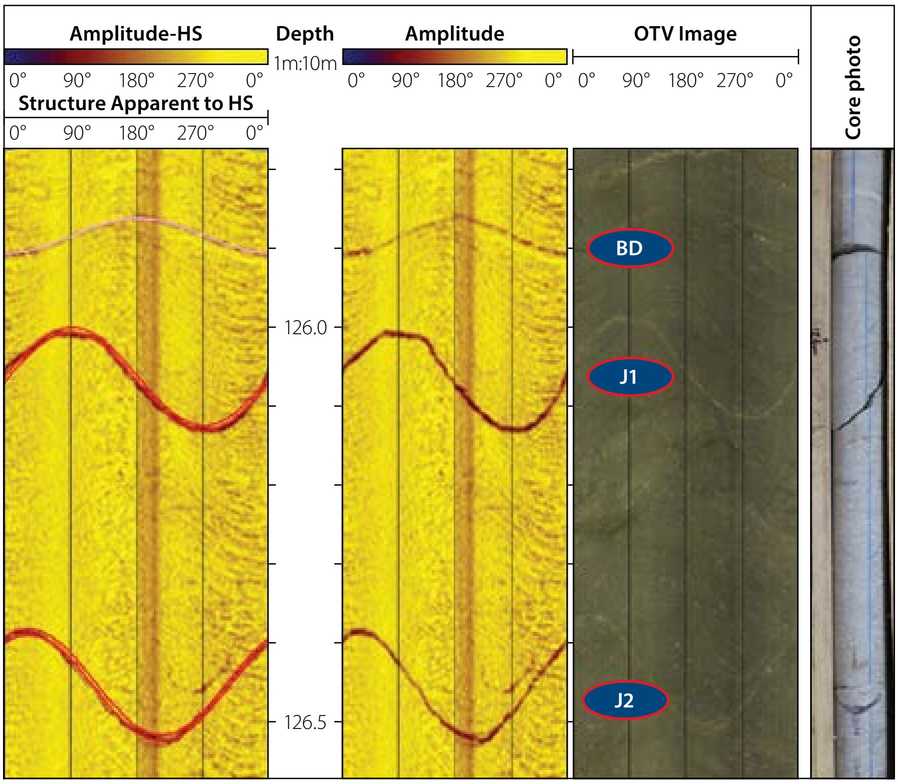

Figure 2 Examples of geotechnical defects: BD – open bedding planar rough, no infill; J1 and J2 – open joint rough undulating, hard infill

Televiewer data processing

Raw televiewer survey data is processed using downhole geophysical image processing software (WellCAD, Techlog Geology, Geolog, LogIC, RockDoc, etc). Televiewer images can be oriented to the high side of the drill hole or to magnetic north, with zero degrees at the start of the unrolled images. The images are filtered, enhanced and adjusted using different viewing scales and varying contrast, brightness and colour scales to improve visualisation of geotechnical defects and structural features.

The GTI process includes the following steps:

- Picking geotechnical defect: A sine wave is fitted on the identified structure and then assigned structural codes, in accordance with the structure classification scheme, which have been converted to tadpole dictionaries as presented in Table 1 (page 37). Structures coded as #15 – Open Bedding/Foliation, #20 – Minor Open Fracture, #21 – Major Open Fracture, #22 – Broken Zone, #23 – Micro Fault and #24 – Fault Zone are classified as geotechnical defects and are used for structural assessment and determination of the rock mass rating. Each identified geotechnical defect is further coded with separate structural codes, including structure type and descriptions with micro roughness and infill codes, as detailed by Dempers *et al* (2010).
- Calculate the structural orientation: The dip and dip direction for each defect are calculated from the sine wave amplitude, wave length, the crest locations and drill hole calliper, and are recorded as the Apparent Structure dataset. This dataset is then converted to true orientation using the borehole orientation tilt and magnetic azimuth, which have been determined by the televiewer associate tools or from other downhole survey tools, including gyro survey data in magnetic rocks, recorded as the True Structure dataset.
- Calculate the fracture frequency (FF) based on a fixed interval (e.g. 0.5 m or 1 m) to see the variation in occurrence of the identified geotechnical defects along the borehole length.
- Calculate the rock strength (UCS) based on the signal strength amplitude along the borehole length.

- Domaining: Geotechnical domains are determined based on weathering, rock type, rock strength and fracture frequency.
- Calculate the QSI-based domain interval and the relative rock strength calibrated with diamond drill core logs.
- Determine the number of defect sets: The number of defect sets is identified using a stereographical plot based on the geotechnical domain interval and the geotechnical defect orientations.
- Calculate the core >10 cm or RQD: The core >10 cm is calculated based on the distance between the identified geotechnical defects per geotechnical domain.
- The processed survey data is exported in text file format (.csv) and integrated into formatted rock mass logs and structure logs.

The process flowchart is shown in Figure 1. Examples of televiewer data of different geotechnical defects identified from drilling projects are shown in Figures 2 to 4.

Assessment of structural data

Figure 5 presents examples of two defects identified from ATV images:

- A major open joint with a rough and planar surface, and hard infill (non-softening coarse material) joint shown as J1 (red ellipse)
- A minor open joint with a rough and undulating surface, and hard infill (non-softening coarse material) shown as J2 (orange ellipse).

The aperture of open defects such as these can be measured directly from the ATV data.

The GTI provides the orientation of each structure which can subsequently be used in rigorous structural analyses. The nature of the survey data allows for a more accurate appraisal of highly fractured or drilling-induced broken zones where significant core loss intervals may occur. These intervals cannot be characterised accurately by traditional core logging. An example of the ability to identify and measure dominant structural controls accurately in fractured ground is presented in Figure 6. A large-scale structural feature can subsequently be modelled in 3D based on the dominant structure's orientation.

Following the identification of structures, the FF and RQD can then

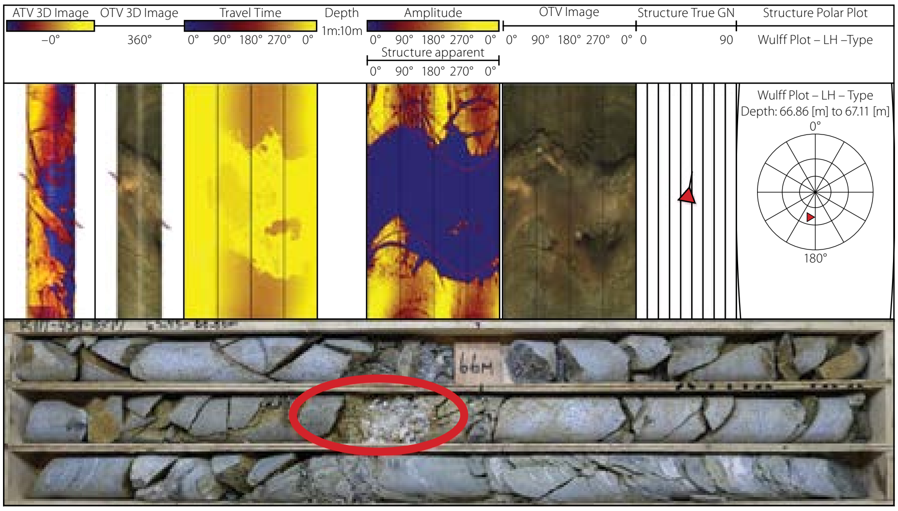

Figure 3 Example of geotechnical defect – broken zone/fault zone (red ellipse) identified with its orientation

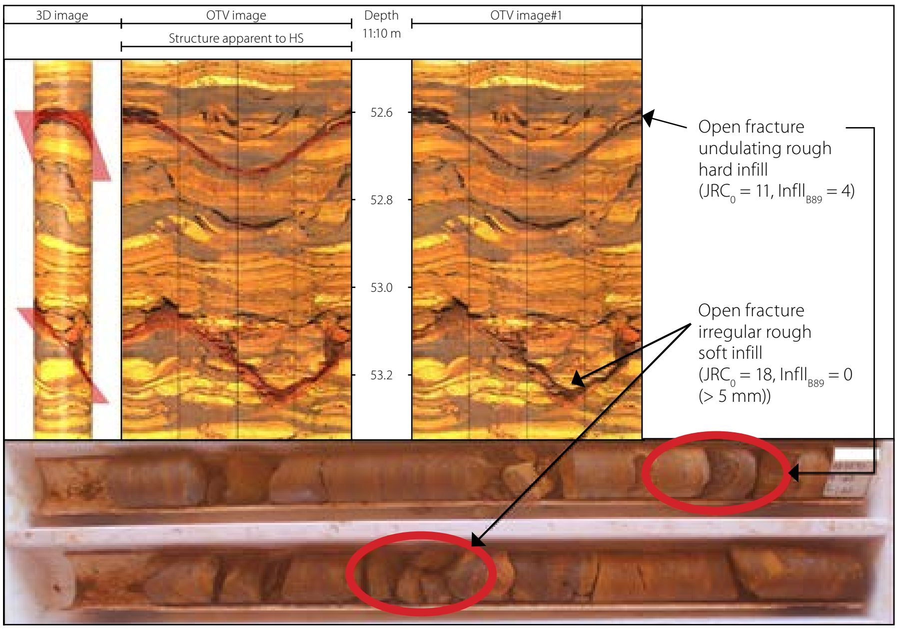

Figure 4 Examples of geotechnical defects – open fractures

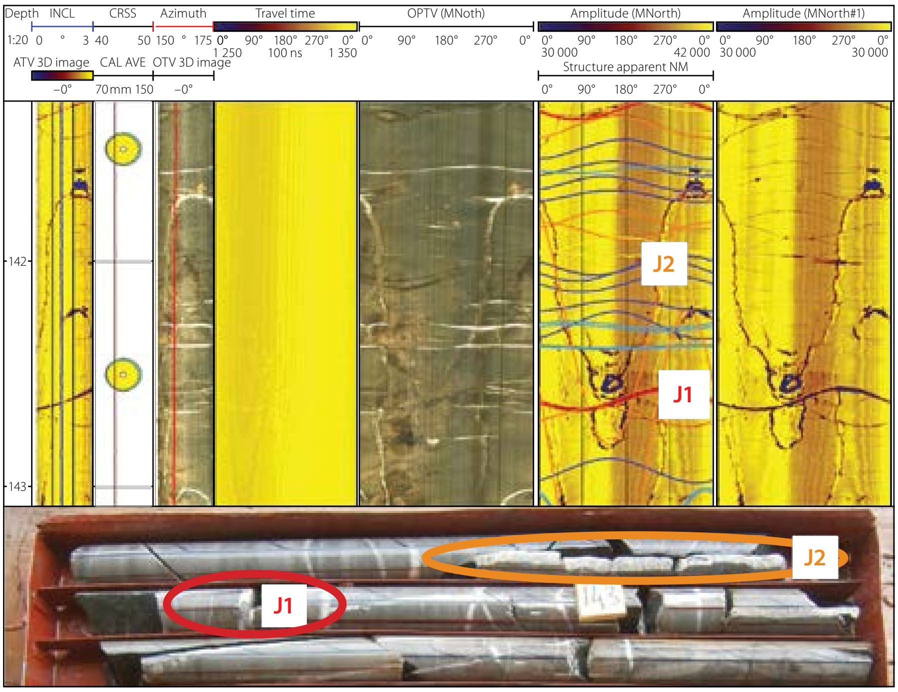

Figure 5 Examples of typical defects as presented in televiewer image and drill core

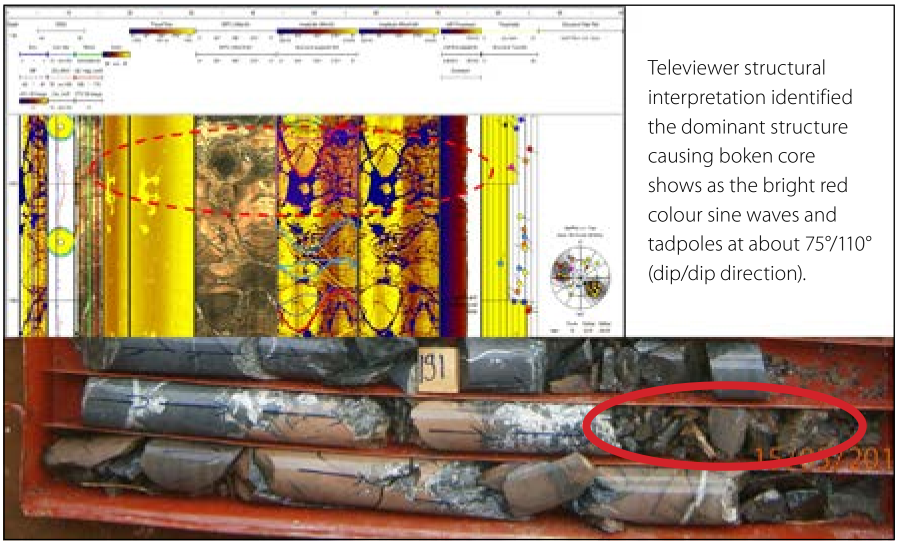

Figure 6 Dominant structure is identified from televiewer interpretation which could not be measured in broken drill cores

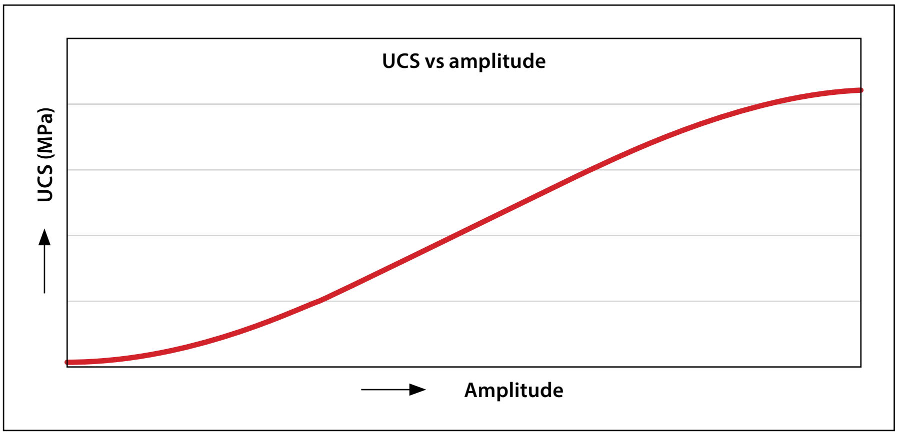

Figure 7 Sigmoidal curve relationship between UCS and amplitude of reflected signal

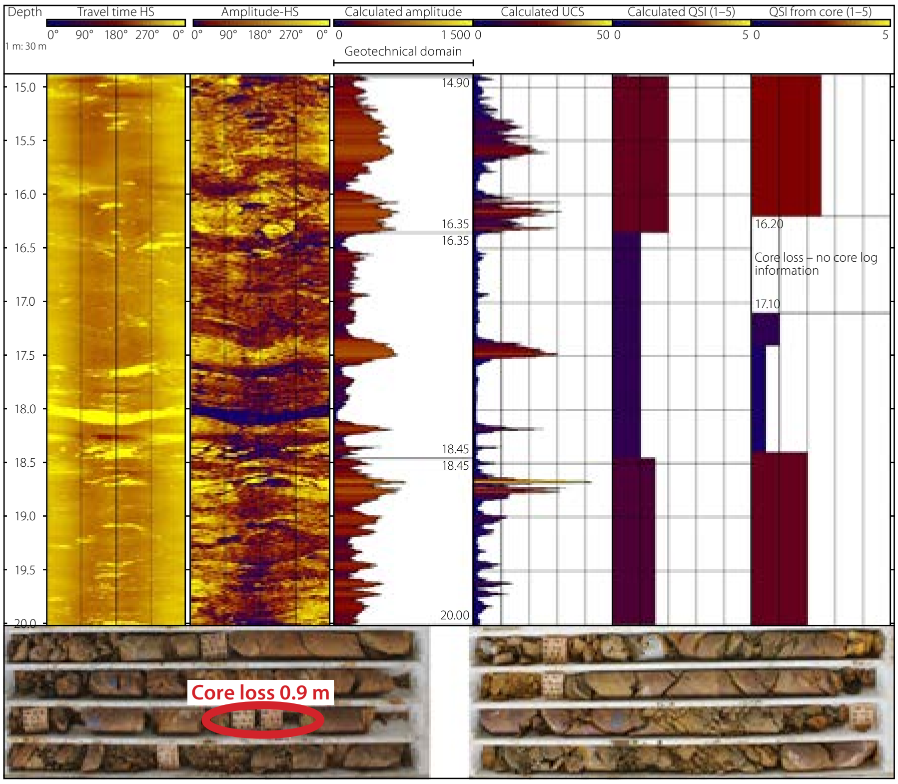

Figure 8 Image from acoustic televiewer tool and calculated rock strength compared with drill core log

be directly calculated using the given depths.

Assessment of rock strength

Rock strength is assessed from ATV data by interpreting the amplitude of the reflected acoustic signal (Schepers 1996). Figure 7 presents a sigmoidal curve showing the relationship between intact rock strength (as measured by UCS) and signal amplitude, which has been established from empirical data across several projects.

As with the identification of structures, the UCS calculated from the acoustic response should be calibrated for particular rock types within a project area, preferably in conjunction with the use of laboratory testing.

This value set produced by the ATV tool has been found to be sufficiently accurate to indicate a range on a strength scale such as the QSI, and is generally considered to provide more consistent strength data than that produced from tactile assessment by personnel during the logging of drill core.

Figure 8 shows an example of relevant data components used in the estimation of rock strength from televiewer data and comparison with drill core logging and drill core photographs. These are:

- Acoustic travel time log
- Acoustic amplitude log
- Calculated acoustic response/geotechnical domain
- Calculated rock strength in MPa
- Calculated QSI on a of 1–5 scale based on geotechnical domain
- QSI from the core log and core from the same depth.

It can also be seen in Figure 8 that 0.9 m of core loss has been marked by drillers on the core blocks within two pieces of competent rock (16.2–17.1 m), preventing the assessment of the geotechnical properties for that interval. However, the televiewer image indicates that the second competent piece of core is contiguous with the first, making the previous interval end at a depth of 16.35 m. In this instance the televiewer image demonstrates that the interval of core loss was incorrectly allocated.

Identification of geotechnical domains

Once relevant structural features have been identified (thus FF and RQD can be calculated) and where possible rock strengths have been estimated, the work-flow then involves the selection of geotechnical domains in much the same way as for the geotechnical logging of diamond drill core, as detailed by Dempers *et al* (2010). Figure 9 shows an example of interpreted geotechnical domains and a number of joint sets from OTV and ATV data.

Outputting rock mass and structure logs

Data interpreted from downhole geophysical image processing software can be exported to text file (.csv) and be converted and formatted to structure log and rock mass log in Microsoft Excel.

Each geotechnical defect has been interpreted and assigned a unique character code which is combined from structure type, micro roughness and infill. The code then needs to be converted into a numerical rating (detailed by Dempers *et al* 2010) for the convenience of rock mass rating (RMR) calculation and structural evaluations, and calibrated with drill core logs. An example of the outputting structure log format is shown in Table 2.

RMR is calculated for individual geotechnical domains based on the rock mass logging data. This data combines

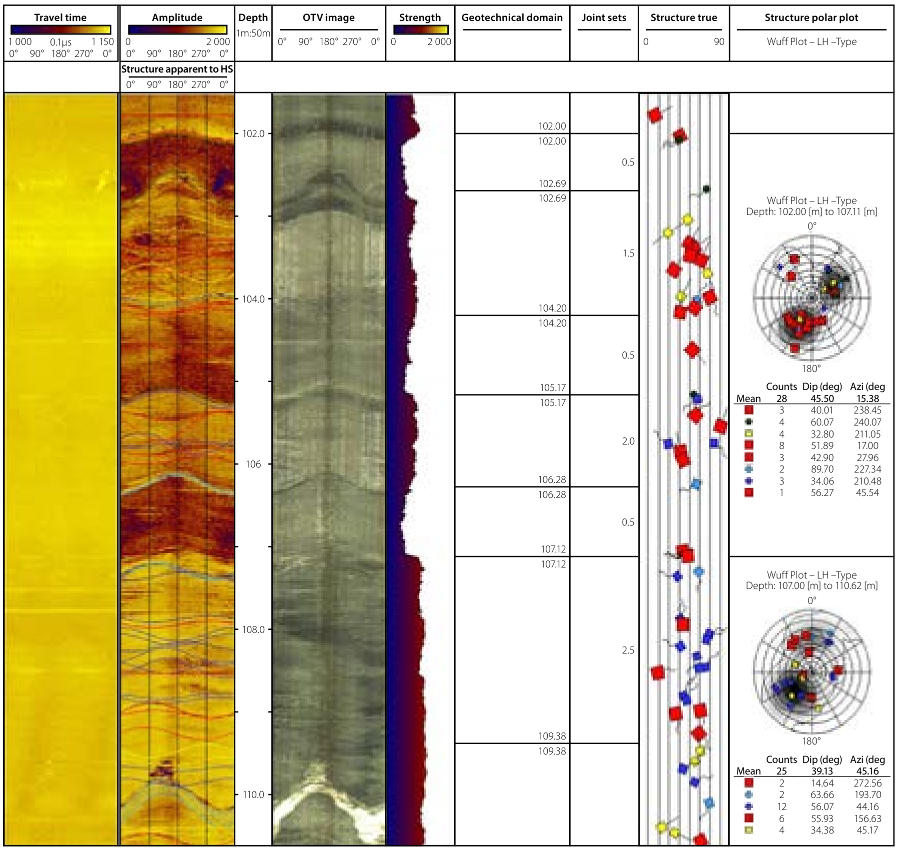

Figure 9 Example showing interpreted geotechnical domains and number of joint sets and images from acoustic and optical televiewers

Table 2 Structure log format

Project	Hole_ ID	Str_ No	Depth	Str_ Code	Structure_Type	Dip_ HS	DD_HS	Alpha	Beta	Beta ref	Thickness_ mm	Micro	Infill	Infill thick	Comments
Televiewer	GT001	496	114.19	#21	Major Open Fracture	78.2	323.3	11.8	143.3	BOH	0	6	8	1	
Televiewer	GT001	497	114.22	#21	Major Open Fracture	72.29	319.87	17.71	139.87	BOH	0	6	8	1	
Televiewer	GT001	498	114.33	#21	Major Open Fracture	73.57	326.46	16.43	146.46	BOH	0	3	8	1	
Televiewer	GT001	499	115.14	#21	Major Open Fracture	27.98	158.76	62.02	338.76	BOH	0	6	8	1	
Televiewer	GT001	500	115.29	#21	Major Open Fracture	33.9	169.94	56.1	349.94	BOH	7.47	6	8	3	
Televiewer	GT001	501	116.13	#21	Major Open Fracture	35.98	105.52	54.02	285.52	BOH	2.43	6	8	2	
Televiewer	GT001	502	116.25	#21	Major Open Fracture	38.95	206.87	51.05	26.87	BOH	2.33	3	8	2	
Televiewer	GT001	503	116.29	#21	Major Open Fracture	43.47	195.81	46.53	15.81	BOH	0	6	8	1	
Televiewer	GT001	504	116.53	#21	Major Open Fracture	12.81	132.86	77.19	312.86	BOH	0	6	8	1	
Televiewer	GT001	505	116.6	#24	Fault Zone	42.18	210.46	47.82	30.46	BOH	83.67	4	3	4	
Televiewer	GT001	506	117.43	#21	Major Open Fracture	67.64	113.43	22.36	293.43	BOH	1.71	3	8	2	
Televiewer	GT001	507	117.45	#21	Major Open Fracture	22.96	354.3	67.04	174.3	BOH	4.14	3	8	2	
Televiewer	GT001	508	117.73	#21	Major Open Fracture	46.74	106.21	43.26	286.21	BOH	2.05	3	8	2	
Televiewer	GT001	509	118.68	#21	Major Open Fracture	10.64	14.36	79.36	194.36	BOH	5.89	6	8	3	
Televiewer	GT001	510	119.79	#21	Major Open Fracture	43.15	126.42	46.85	306.42	BOH	4.49	6	8	2	
Televiewer	GT001	511	119.89	#21	Major Open Fracture	59.81	106.21	30.19	286.21	BOH	12.87	6	8	4	
Televiewer	GT001	512	120.21	#21	Major Open Fracture	13.19	112.92	76.81	292.92	BOH	0	6	8	1	
Televiewer	GT001	513	121.22	#21	Major Open Fracture	41.06	336.75	48.94	156.75	BOH	0	6	8	1	
Televiewer	GT001	514	121.22	#21	Major Open Fracture	47.44	128.75	42.56	308.75	BOH	3.04	6	8	2	
Televiewer	GT001	515	121.81	#21	Major Open Fracture	64.96	126.34	25.04	306.34	BOH	1.9	6	8	2	
Televiewer	GT001	516	121.95	#21	Major Open Fracture	38	82.73	52	262.73	BOH	4.73	3	8	2	
Televiewer	GT001	517	122.04	#21	Major Open Fracture	40.67	138.63	49.33	318.63	BOH	2.27	3	8	2	
Televiewer	GT001	518	122.48	#21	Major Open Fracture	42.67	147.58	47.33	327.58	BOH	7.72	6	5	3	
Televiewer	GT001	519	123.26	#21	Major Open Fracture	35.97	92.35	54.03	272.35	BOH	6.07	6	8	3	
Televiewer	GT001	520	123.28	#21	Major Open Fracture	25.11	153.17	64.89	333.17	BOH	8.14	6	8	3	
Televiewer	GT001	521	123.57	#21	Major Open Fracture	58.88	133.04	31.12	313.04	BOH	6.2	6	8	3	
Televiewer	GT001	522	124.19	#21	Major Open Fracture	66.04	291.8	23.96	111.8	BOH	3.05	6	8	2	
Televiewer	GT001	523	124.87	#21	Major Open Fracture	29.36	191.09	60.64	11.09	BOH	5.18	3	8	3	

Table 3 Rock mass log format (note 30° – 60° and 60° – 90° log not shown)

Project	Hole_ID	From	To	Domain no	Rock type	Weath (1–5)	QSI (1–5)	RQD (m)	RQD %	Matrix struct type	No joint sets	Fract 0–30	Micro (1–9) 0–30	Macro (1–5) 0–30	Infill (1–9) 0–30	Infill type	Infill thick	JWA	…	Fract 0-90	Micro (1-9) 0-90	Macro (1-5) 0-90	Infill (1-9) 0-90	Infill type	Infill thick	JWA	Comments
Televiewer	GT001	113.5	116.53	58	GAB	1	3.5	2.96	98		2.5	3	5	2	8		1	1		0							
Televiewer	GT001	116.53	116.7	59	GAB	1	0.5	0.00	0	M1	5	0								1000	5	2	6		3	1	Very strong broken
Televiewer	GT001	116.7	118.17	60	GAB	1	3	1.45	99		2.5	1	3	2	8		2	1		0							
Televiewer	GT001	118.17	123.2	61	GAB	1	3.5	4.86	97		2.5	1	6	2	8		2	1		0							
Televiewer	GT001	123.2	126.16	62	GAB	1	3	2.71	92		3	1	6	2	8		2	1		0							
Televiewer	GT001	126.16	128	63	GAB	1	3.5	1.84	100		2.5	0								0							
Televiewer	GT001	128	129.05	64	GAB	1	3	0.90	86		3	3	5	2	8		3	1		0							
Televiewer	GT001	129.05	134.81	65	GAB	1	4	5.69	99		2.5	0								0							
Televiewer	GT001	134.81	137.01	66	GAB	1	3.5	2.08	95		2.5	0								0							
Televiewer	GT001	137.01	138.82	67	GAB	1	3.5	1.66	92		2.5	1	6	2	8		2	1		0							
Televiewer	GT001	138.82	141.37	68	GAB	1	3.5	2.55	100		2.5	0								0							
Televiewer	GT001	141.37	143.64	69	GAB	1	2.5	2.27	100		2.5	0								0							
Televiewer	GT001	143.64	144.78	70	SAR	2	2	1.04	91		2.5	4	5	2	4		1	1		0							
Televiewer	GT001	144.78	145.79	71	SAR	2	2	0.91	90		2.5	1	3	2	4		2	1		0							
Televiewer	GT001	145.79	146.84	72	SAR	2	2	0.00	0	M1	5	0								500	5	2	4		4	1	Strong broken
Televiewer	GT001	146.84	147.64	73	SAR	2	2	0.00	0	M1	4									250	5	2	4		2	1	Broken
Televiewer	GT001	147.64	148.59	74	SAR	2	2.5	0.26	28		3	2	3	2	4		1	1		0							
Televiewer	GT001	148.59	151.16	75	GAB	1	4	2.40	93		2.5	0								0							
Televiewer	GT001	151.16	153.46	76	GAB	1	3.5	2.28	99		2.5	0								0							
Televiewer	GT001	153.46	155.13	77	GAB	1	4	1.64	98		2.5	0								0							
Televiewer	GT001	155.13	155.8	78	GAB	1	3.5	0.46	68		2.5	0								0							
Televiewer	GT001	155.8	160.5	79	GAB	1	4.5	4.59	98		2.5	7	5	2	8		2	1		0							
Televiewer	GT001	160.5	164.2	80	GAB	1	4	3.49	94		3	10	6	2	7		2	1		0							
Televiewer	GT001	164.2	169.29	81	GAB	2	3.5	4.22	83		3.5	21	6	2	6		2	1		0							
Televiewer	GT001	169.29	174.8	82	GAB	1	4	5.36	97		3	6	5	2	8		2	1		0							
Televiewer	GT001	174.8	175	83	GAB	1	3	0.14	71		2.5	0								0							
Televiewer	GT001	175	184.82	84	GAB	1	4.5	9.46	96		2.5	8	5	2	8		2	1		0							

geotechnical characteristics from rock type, weathering, number of defects, defect conditions (micro roughness and infill), number of joint sets, RQD, etc, which have been interpreted from televiewer surveys using Microsoft Excel. An example of the rock mass log format is shown in Table 3.

CONCLUSIONS

Acoustic and optical televiewer surveys can be used to interpret accurately the geotechnical properties of a rock mass. The GTI methodology outlined can be applied to diamond and percussion drill holes, as well as to existing open holes and, as such, may be used to optimise geotechnical drilling programmes by:

- ensuring high levels of accurate geotechnical data and improved data acquisition
- reducing the amount of diamond core drilling and geotechnical logging required, and the time required for data acquisition.

It is also important to note the significance of the need to calibrate the interpreted televiewer data with logged diamond core for each particular project. □

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