Wireline Logging Services

A powerful tool for ground investigation in traffic infrastructure projects

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Wireline Logging for Traffic Infrastructure Ground Investigation

Overview

Wireline logging – general

Koralrn railway tunnel

Wireline logging @ Koralrn railway tunnel

Wireline logging – selected methods
Wireline Logging - General
Why spend money on it?

Wireline Logging provides…

- …in-situ data of (nearly) undisturbed formation.
- …profiles with high depth sampling rate ("continuous")
- …small integration volume but higher resolution compared to surface geophysics
- …data with exact depth information
- …data widely independent from the "human factor"
- …cost-effective and reliable solutions that help to reduce construction risk
Wireline Logging - General
Why spend money on it?

But...

- ...WL data are no substitute but complementary to drill records, geologist’s logs or other available information

- ...there must be a suitable borehole. Drilling diameter, drilling fluid, inclination, casing material influence the set of applicable methods

- ...formation properties influence the set of applicable methods

- ...the measurements have to be done by qualified field engineers with properly calibrated instruments

- ...WL data have to be processed, interpreted and translated into the engineer’s language by experienced geophysicists/geologists

- ...this interpretation is partly based on models and assumptions
Koralm Railway Tunnel
The project

Baltic – Adriatic railway corridor

Koralm railway tunnel / Austria, OEBB Infrastruktur AG

Courtesy of OEBB Infrastruktur AG
Koralm Railway Tunnel

The project

Project status

- Start of ground investigation and groundwater monitoring in 1998
- Start of excavation in 2010, KAT1 finished (drill & blast), KAT2 active (2 TBM), KAT3 will start in 2014 (drill & blast + 1 TBM)
- Start of operation expected for 2023
- Target costs $ 2,500 mill

Courtesy of ÖBB Infrastruktur AG
Wireline Logging @ Koralm Railway Tunnel
Ground investigation phase

>130 vertical or inclined boreholes
max. depth 1,300m
Total drill length 21,400 m, 100% cored

WLS methods
- Acoustic / Optical Borehole Imager
- Oriented 4-Arm Caliper
- Full Wave Sonic
- Gamma Gamma Density
- Cavity Scanners

Solutions
- Structure analysis (discontinuity planes)
- Evaluation of elastic rock parameters
- Cavity survey (carbonate karst)
- Evaluation of groundwater parameters for modelling (Transmissivity, yield, etc.)
120 vertical or inclined monitoring wells
Uncased / partly cased / fully cased
max. depth 1,300m

WLS methods
- Flowmeter
- Tracer Logs
- Qualitative water parameters (temperature, conductivity, oxygen, pH)
- Water Sampler

Solutions
- Monitoring of groundwater regime (gw-table, quality, quantity) before / during excavation of tunnel
- Temperature monitoring
Wireline Logging @ Koralm Railway Tunnel

Excavation phase of exploratory tunnels

20 horizontal boreholes ahead of the face of the exploration tunnels (max. length 240m)

WLS methods

- Acoustic / Optical Borehole Imager
- Borehole Deviation (open or metal cased hole)
- Natural Gamma Ray

Solutions

- Structural and hydraulic investigation ahead of the tunnel face
Wireline Logging – Selected Methods
Structure analysis of discontinuity planes

**Acoustic Borehole Imager (ABI)**
- Rotating ultrasonic device
- Fluid filled borehole
- Amplitude and traveltime

**Optical Borehole Imager (OBI)**
- Fixed camera + conical mirror
- Clear water or air
- Optical image
Example of processed Optical Borehole Imager Log (OBI) in metamorphic rock (amphibolite, marble)
Wireline Logging – Selected Methods
Evaluation of elastic rock parameters

Velocity of elastic waves
\( V_p, V_s \)

Formation density
\( \rho_b \)

Full Wave Sonic Log
or
PS Suspension Log
or
Borehole Seismic

Gamma-Gamma Density Log

Young’s Modulus
\[ E_{dyn} = 2\rho^* V_s^2 (1 + \nu_{dyn}) \]

Poisson’s Ratio
\[ \nu_{dyn} = \frac{[(V_p/V_s)^2 - 2]}{2[(V_p/V_s)^2 - 1]} \]

Shear Modulus
\[ G_{dyn} = \rho^* V_s^2 \]

\( \rho \) … formation density [kg/m³]
\( V_p \) … velocity of compressional waves [m/s]
\( V_s \) … velocity of shear waves [m/s]
\( \nu \) … Poisson’s Ratio [1]
# Wireline Logging – Selected Methods

## Evaluation of elastic rock parameters

<table>
<thead>
<tr>
<th>CAL</th>
<th>T1-p</th>
<th>T2-p</th>
<th>vp</th>
<th>vs</th>
<th>CHROMODU</th>
<th>POISSON</th>
<th>COMPRSS</th>
<th>YOUNG (E)</th>
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<tbody>
<tr>
<td>125 [mm]</td>
<td>155 [µs]</td>
<td>1200 [µs]</td>
<td>0 [µs]</td>
<td>1200 [µs]</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

Elastic rock parameters from Full Wave Sonic and Gamma Gamma Density Log
Wireline Logging – Selected Methods

Evaporite lithology evaluation

\[ M = 0.01 \frac{\Delta t_f - \Delta t_{ma}}{\rho_{ma} - \rho_f} \]

\[ N = \frac{\phi N_f - \phi N_{ma}}{\rho_{ma} - \rho_f} \]

Schlumberger in Ellis 2006
Wireline Logging – Selected Methods
Cavity survey

Tech Specs
- Cavities filled with air (Cavity Laser Scanner CLS) or water (Cavity Sonar Scanner CSS)
- Tool diameter 50mm (CLS) or 80mm (CSS)
- Distance range 0,50 m - approx. 50 m
- Orientation by magnetic compass module or torsion-free push-pull-rods

Limitations
- Dust / fine particles
- Roughness of reflecting surface
- Impinging angle of beam
- Shadow zone behind objects
Wireline Logging – Selected Methods
Cavity survey

Results
- Oriented sections and plan views
- 3D images
- X-, Y-, Z-data for further processing
- Volume calculation
- Overlay on land register plans
Theory

- The stress field is defined by
  - $S_H$ maximum horizontal stress
  - $S_h$ minimum horizontal stress
  - $S_V$ vertical stress
- Borehole is vertical, i.e. parallel to $S_V$

Signs of the stress field on image logs

- Axial drilling induced tensile fractures in direction of $S_H$
- Axial borehole wall breakouts in the direction of $S_h$

Schmitt et al. 2012
Wireline Logging – Selected Methods
Rock stress evaluation from borehole imaging

ABI: Axial drilling induced fractures in direction of $S_h$

ABI: Borehole breakouts in direction of $S_h$
**Wireline Logging – Selected Methods**

**Hydraulics from reflected tube wave analysis**

**Principle**

- Besides p- and s-waves Full Wave Sonic downhole tools generate also Stoneley Waves (=Tube Waves), travelling vertically along the wall at the speed of the borehole fluid.
- When a Stoneley Wave passes a **permeable formation**, the direct wave is slowed down and its amplitude is attenuated due to energy loss into the voids.
- When a Stoneley Wave passes a **distinct open fracture**, the direct wave is slowed down, its amplitude is attenuated and a reflected tube wave is generated.

**Result**

- Tube wave analysis gives qualitative information, if formations or single fractures are hydraulically permeable or not.

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Wireline Logging – Selected Methods

Hydraulics from reflected tube wave analysis

Peaks in RTW analysis
Caliper Extensions
Strong Reflected Tube Waves

→ permeable fractures @402,2m and @404,0m

ABI shows open fracture
Thank You!