SEISMIC TOMOGRAPHY MEASUREMENTS IN THE RADIOACTIVE WASTE DISPOSAL SITE IN BÁTAAPÁTI

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1. Introduction

As a part of the underground investigations of intermediate and low-level radioactive waste disposal site in Bátaapáti, seismic and DC tomographic measurements were carried out to obtain a better understanding of the geological setting and structure and of the hydrogeological situation of the rock mass. The measurements were conducted in an underground space fully surrounded by galleries, which means almost optimal survey geometry. The large number of other investigations carried out in the tunnels made it possible to compare the tomography map with the widely used rock mass qualification parameters (Rock Quality Designation — RQD [1], and Quality of the rock mass — Q-value [2]), and the hydrogeological properties of the rock.

2. Data acquisition and processing

Due to the physical dimensions of the investigated rock mass we had to carry out the field work in 5 stages, using 24 2-component mining geophones, and 120-125 source points (9 kg sledgehammer) at each (Figure 1a).

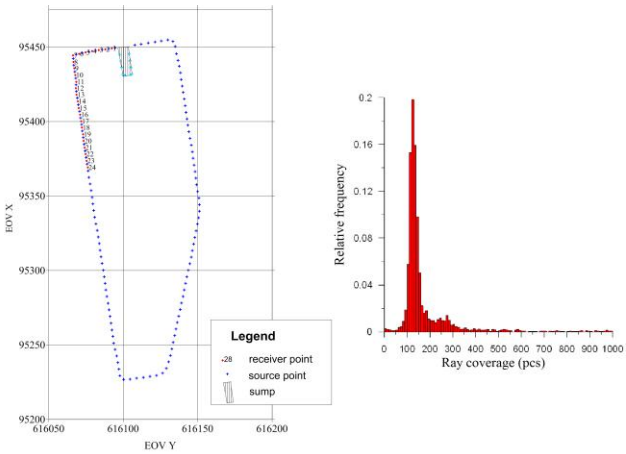

Figure 1. a) Measurement layout of the 5 measurement steps; b) ray coverage frequency of the tomography processing

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The survey was designed to achieve the best possible image taking into consideration the characteristic wavelength (about 10 m for the 4000–5500 m/s P-wave velocity and 400 Hz dominant frequency). Based on these properties the source and receiver spacing was 4.5 m. The relative frequency of ray coverage (the number of ray paths crossing the unit cell) can be seen in Figure 1b.

The tomography reconstruction technique applied was the simultaneous iterative reconstruction technique (SIRT) [3]; wave propagation was modelled by the "expanding time field" algorithm [4].

3. Tomography maps and geology

Generally seismic velocities are a function of the rock type, the fracturing, the fluid or gas content and the rock stresses. Based on laboratory measurements carried out on rock samples from the area of investigation, the geomechanical properties of different igneous and volcanic rocks – i.e. the matrix properties – are similar. However, seismic velocities of different rock types show differences (Figure 2). The main cause of these differences is the different background fracture system of the different rock bodies.

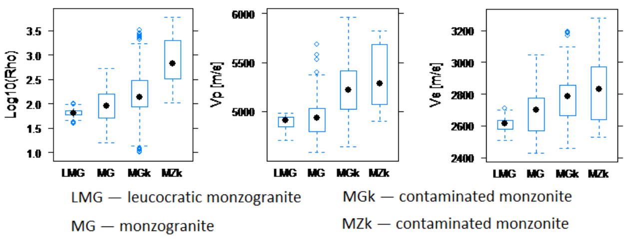

Figure 2.Physical properties of different rock types

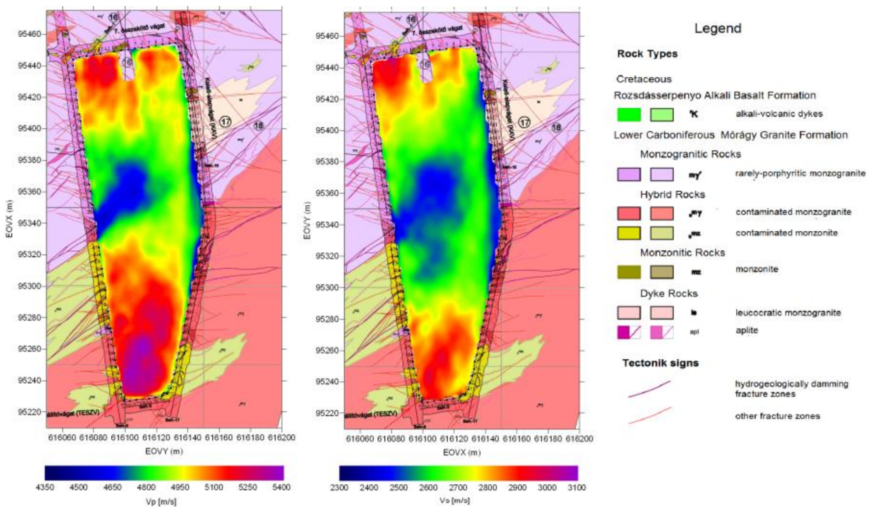

Figure 3. P- and S-wave tomography map inserted in the geologic map

The main fracture zone penetrating the investigated area (indicated by the red arrow) can be clearly seen in Figure 3. The most interesting feature of its tomographic image is the strong horizontal variability. Notwithstanding that this zone can be identified in both shafts, this kind of variability along the strike is definitely new information, and should be taken into account for any future activity here.

4. Comparison of seismic and rock mass properties

Rock mass properties are used for various engineering design and stability analysis. The classification is usually based on empirical parameters like a RQD parameter or a set of them, as in case of rock quality (Q-value). RQD is a rough measure of the degree of jointing in a rock mass, measured as a percentage of the drill core in lengths of 10 cm or more. High-quality rock has an RQD of more than 75%, low quality of less than 50%. The Q-value is based on RQD, but the shear strength and stress environment of the rock are also involved in the determination of the value. It can range between 0.00006 (for an exceptionally poor rock mass) and 2666 (exceptionally good).

The special location made it possible to compare the seismic velocity tomography maps with the rock mass property data obtained from the tunnels — i.e. from the perimeter of the investigated area. However, these comparisons have some limitations from various aspects.

General limitations:

- Offset: rock mass was observed on the tunnel wall during tunnel construction, while seismic parameters originate from the internal area behind the wall.
- Time gap: seismic measurements were carried out several months after the tunnelling. The aquifer system was disturbed and weak zones were injected.

Limitations related to seismic tomography:

- Limited resolution. The resolution is determined by the velocity and the frequency of seismic waves in the rocks (wavelength).
- Errors are swept out to the boundaries by tomographic algorithms where the ray coverage is uneven and less than average.
- Smoothing/averaging effect of long ray-paths. Seismic arrival times are integrated over long distances.

Geotechnical data related limitations:

- Estimated and discrete values expressed in one scale to calculate RMR and Q-value, direction and scale dependence of parameters.

The cell-by-cell correlation of the successive values in the galleries is shown in Table I.

Table I. Correlations between velocities and rock mass properties (rock mass properties are obtained from [5])

	RQD	**RMR**	**LOG(Q)**	**$RQD_{smoothed}$**	**$RMR_{smoothed}$**	**$LOG(Q)_{smoothed}$**
Vs	78.4%	74.0%	58.1%			
Vp	63.8%	60.8%	42.1%			
$Vs_{smoothed}$				91.1%	89.6%	87.8%
$Vp_{smoothed}$				76.9%	76.4%	80.0%

The similar character of RQD and V_s can be seen in Figure 4 for real (black) and smoothed (red) data sets. This means that the trend of RQD can be forecast from seismic velocities with an accuracy of around 90%.

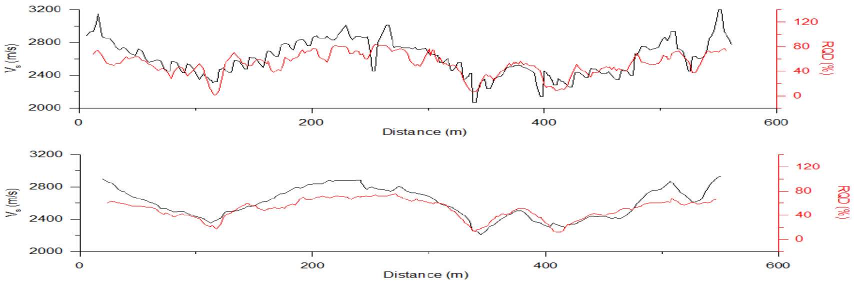

Figure 4. Comparison of RQD values and S-wave velocity alongside the perimeter of galleries: plots of real (above) and smoothed (below) data sets

5. Estimation of support categories from seismic velocities

The support requirements of underground excavations are generally determined from the rock mass classification parameters, especially from RMR or Q-value. The connection between the seismic velocity distribution along the tunnels and the support categories applied to these sections was also investigated. The results show that the estimation of support categories from the S–wave velocities is no less reliable than that from any other current method.

Based on the above comparison, the seismic velocity values can be scaled and transformed to rock mass properties, or directly to support categories (Table II,, Figure 5).

Table II. Support categories in Vs ranges

Support Category	$V_{s,\,min}$ (m/s)	$V_{s,\,max}$ (m/s)
II	2550	2750
III	2400	2550
IV	2000	2400
V		2000

The similarity of the applied and calculated support categories is excellent along the tunnels (Figure 5a), but of course the estimation for the rock mass is limited by the accuracy of the tomographic image reconstruction (non-uniqueness problems, resolution limits, etc.) so the most straightforward evaluation of the results can be comparison of the data set for the sumps which were driven after the measurements (Figure 5b). However, comparison of the data sets for the stumps is even more complicated than for the tunnels, because of the greater distance (the sumps are located at greater depth, outside the plane of the head tunnels), and the different (more strict) principles of support category selection due to the more complicated excavation geometry. The latter problem can be handled by a small modification: the calculated support categories should be compared with the categories determined from the rock mass classification parameter (Q value), yetrather than the applied support.

Calculated and Q-value based support categories at the sumps are less similar than those at the head tunnels, but taking into account that the differences increase with greater offset (the deeper location of stumps) and, that the size of the fracture zone which penetrate the sumps is limited, one can conclude that the differences can be caused by the vertical changes of geomechanical properties of the rock mass.

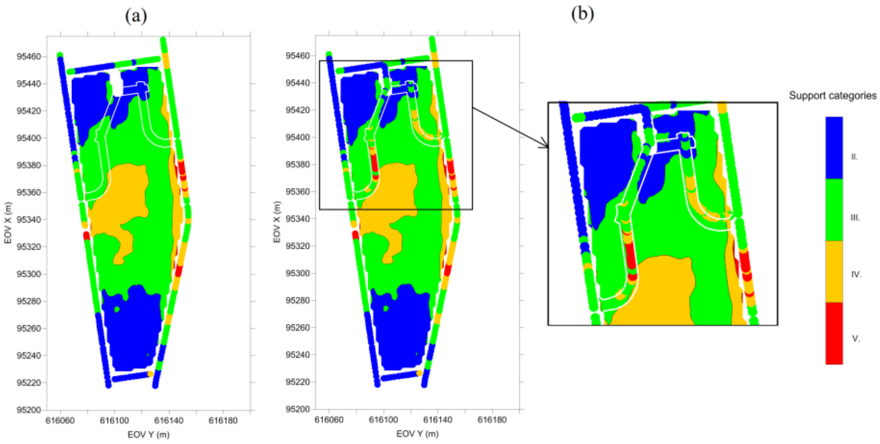

Figure 5. Calculated and applied support categories at the head tunnels (a) and sumps (b)

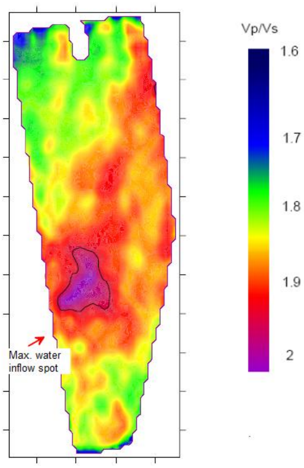

Figure 6. V_p/V_s and the hydrogeological connections (red arrow shows max. water inflow)

Vp/Vs – estimation of hydrogeological properties of rock mass

The investigated rocks can be considered as fractured reservoirs, so it was expected that the propagation of P-waves and S-waves would be different, since the latter does not propagate in liquid. The ratio of S- to P-wave velocities is sensitive to lithology and interstitial fluid – i.e. to the hydraulic properties of the rock on the perimeter of the transmitted area. This expectation was confirmed (Figure 6). The strong Vp/Vs anomalies correlate well with the great water inflows.

Conclusions

The patterns of P- and S-wave velocity maps show the strong vertical and lateral variability of the tectonic and lithological elements and help us to understand the structure of the investigated fractured rock mass. P-wave and especially S-wave velocities are in good correlation with RQD, RMR and Q-value, since their values are influenced by similar effects. The transversal velocities correlate better with rock mass classification than had been expected. Furthermore, the hydrogeological correspondence of rock masses could be predicted by Vs/Vp ratios.

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References

[1] Deere, D.U. and Deere, D.W.: The RQD index in practice, In: Rock classification systems for engineering purposes, (L. Kirkaldie, ed.), ASTM Special Technical Publications 984, Philadelphia, 1988, pp. 91-101.

[2] Barton, N.R.: Rock Mass Classification and Tunnel Reinforcement Selection using the Q-system". In: Rock classification systems for engineering purposes, (L. Kirkaldie, ed.), ASTM Special Technical Publications 984, Philadelphia, 1988, pp. 59-88.

[3] Vidale, J.: Finite Difference Calculation of Travel Times. Bulletin of Seismological Society of America, 1988, Vol. 78, pp. 2062–2076.

[4] McMechan, G.A., Harris J. M., Anderson, L. M.: Cross-hole tomography for strongly variable media. Bulletin of Seismological Society of America, 1987, Vol. 77, pp. 1945-1960

[5] Jakab A., Deák F., Kovács L., Maracsik Z., Máté K., Németh L., Rátkai O. András E. Szamos I., Szebényi G., Török P., Gyalog L., Borsody. J, Füri J., Gulácsi Z., Király E., Maros Gy., Rálisch E., Szabadosné Sallay E.: Tunnel interior design and construction of access tunnels of National Radioactive Waste Repository at Bátaapáti 1st stage. Geotechnical documentation of tunnels — “Small Loop”, RHK-K040/09, Mecsekérc Zrt 2009, Pécs (in Hungarian)