Seismic anisotropy analysis at the Low-noise underground Laboratory (LSBB) of Rustrel (France)

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ABSTRACT

Seismic data acquired at the LSBB site have been analyzed in terms of angular anisotropy. Preliminary results are presented. We found a strong anisotropy of nearly ±10%. The high velocity is oriented at N30°E, low velocity at N120°E (40° inclined with respect to the main gallery). The direction of the high velocity is approximately parallel to the local direction of the main fractures. An isotropic standard cross-hole tomography shows artifacts coherent with this anisotropy direction.

INTRODUCTION

In May 2005, seismic data were acquired between the main and the anti-blast galleries. In both directions, 120 sledge hammer blasts carried out in one gallery were recorded by 120 geophones in the opposite gallery. Shot and station separation was 1m. We picked some 22500 first arrival times from the shots done in the anti-blast gallery and recorded in the main gallery with the aim of doing a cross-hole tomography (Fig. 1).

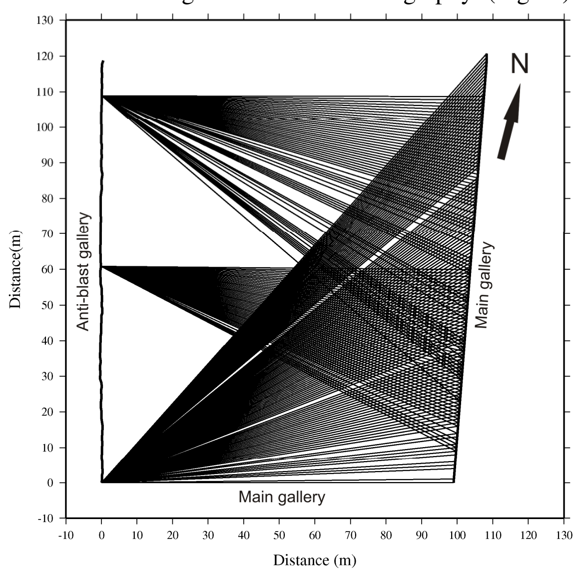

Fig. 1: Example of rays from 3 shot points. Missing rays are due to strong noise at the corresponding receiver.

DATA ANALYSIS

Fig. 2 shows the arrival times of all picks as function of offset. For an isotropic and homogeneous velocity distribution, one should expect all points lying on a straight line. However, two branches are well distinguished, indicating two different velocities. If these different velocities were due to laterally varying materials, one would expect the two branches to point towards a fictitious crossing point at offset and travel time zero. The fact that they are curved and join near the shortest observed offset can only be explained by anisotropy.

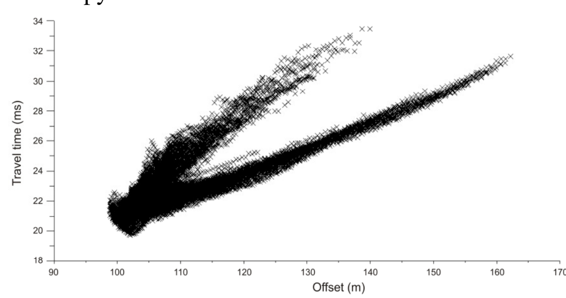

Fig. 2: Travel times vs. offset of all measured arrival times

At the actual state of data analysis, we fitted the observed travel times to a simple cosine function:

$$t(d,a) = \frac{d}{v_0 + dv \cdot \cos[2(a - a_0)]}$$

where t is travel time [ms], d offset [m], a the angle of ray departure (a=0 is perpendicular to the wall of the anti-blast gallery), v_0 the average velocity [km/s], dv the amplitude of anisotropy [km/s] and a_0 the direction of the high velocity direction with respect to the direction perpendicular to the anti-blast gallery.

The resulting parameters are:

- $v_0 = 4.72$ km/s
- dv = 0.42 km/s
- $a_0 = 45°$ (i.e. N30°E in absolute coordinates))

Fig. 3 shows the resulting theoretical travel time curves for the average distance between anti-blast and main gallery.

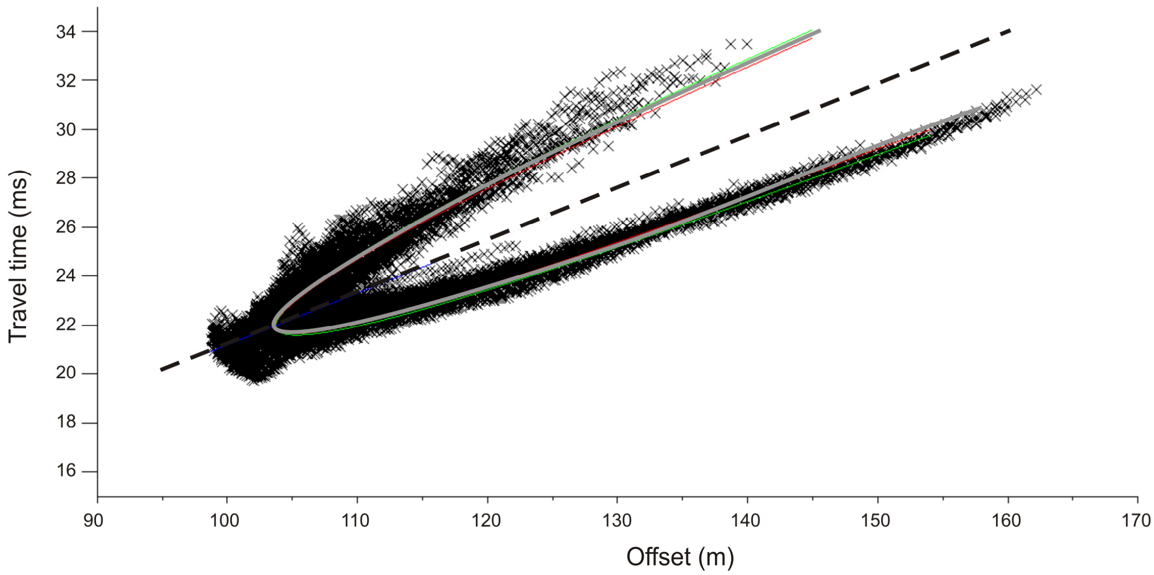

Fig. 3: Synthetic travel times superposed on measured data. Dashed straight line: travel times corresponding to an isotropic medium with velocity v_0 = 4.72 km/s; Continuous gray line: travel times corresponding to the anisotropic medium described in the text.

CROSS HOLE TOMOGRAPHY

The scatter of the arrival times around the synthetic line shows that the rocks are inhomogeneous in the area. As a first step, we did standard isotropic cross hole tomography using the code pstomo_eq by A. Tryggvason [1]. The resulting image (Fig. 4) shows clear artifacts that correlate well with the anisotropy:

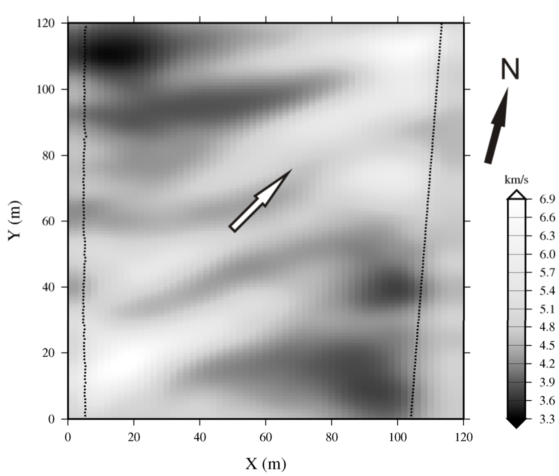

Fig. 4: P-wave velocity distribution obtained from isotropic cross-hole tomography. The very high velocities in the upper right and lower left corners and the low velocities in the opposite corners are artifacts due to neglecting anisotropy. The black dots correspond to the positions of shots (left) and receivers. White arrow: direction of high velocity.

Very high velocities were obtained in the NE and SW corner, very low ones in the NW and SE corners, resulting in a relatively good fit of the data.

DISCUSSION AND OUTLOOK

The direction of the high velocity corresponds well to the one of the main fractures observed between the two galleries. This is to be expected, since the seismic waves propagate faster parallel to fractures in sane rock than perpendicular to the fractures, where they have to cross fast hard rock as well as slow fluid or gas filled fractures. The amount of anisotropy depends on the fracturing of the rocks (pore space) as well as on the filling of the fractures: the anisotropy should be stronger in dry periods (gas-filled fractures) than in wet periods (water filled fractures).

We expect to find anisotropy also in electrical resistivity. However, here the anisotropy should be strongest during the wet period, since the most effective electrical conductor in this environment is water, whereas gas and sane limestone are both relatively good electric insulators. Therefore, resistivity tomography will be done and joint anisotropic tomography of seismic and resistivity data will be developed. The combined time lapse analysis should give information on the amount of fracturing and pore space in this karstic massif.

REFERENCE

[1] Tryggvason, A. et al.: 2002: *Geophys. J. Int.*, **151**, (2002) 848.