Experimental S-wave data acquisition and processing above a tunnel

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CTBT: SCIENCE AND TECHNOLOGY 2017 CONFERENCE

T3.4-P5

CTBTO PREPARATORY COMMISSION

MFGI MAGYAR FÖLDTANI ÉS GEOFIZIKAI INTÉZET

Introduction

One of the most important steps of an On-Site Inspection is to apply different types of geophysical methods during the Continuation Period. For example to search for and locate underground anomalies with active seismic techniques, including tunnels, cavities and rubble zones.

In 2010 the Provisional Technical Secretariat of the Preparatory Commission for the Comprehensive Nuclear Test-Ban Treaty Organization carried out activities of Continuation Period Techniques (CPT) at a Tunnel Test Site in order to allow for a comparison between already existing geoscientific information and newly generated information from the CPT surveys.

Six years later - in 2016 - S-wave active seismic measurement was conducted at the same area.

In both cases the aim was to detect the location of the tunnel from the surface, and to get to know the physical parameters of the soil layers.

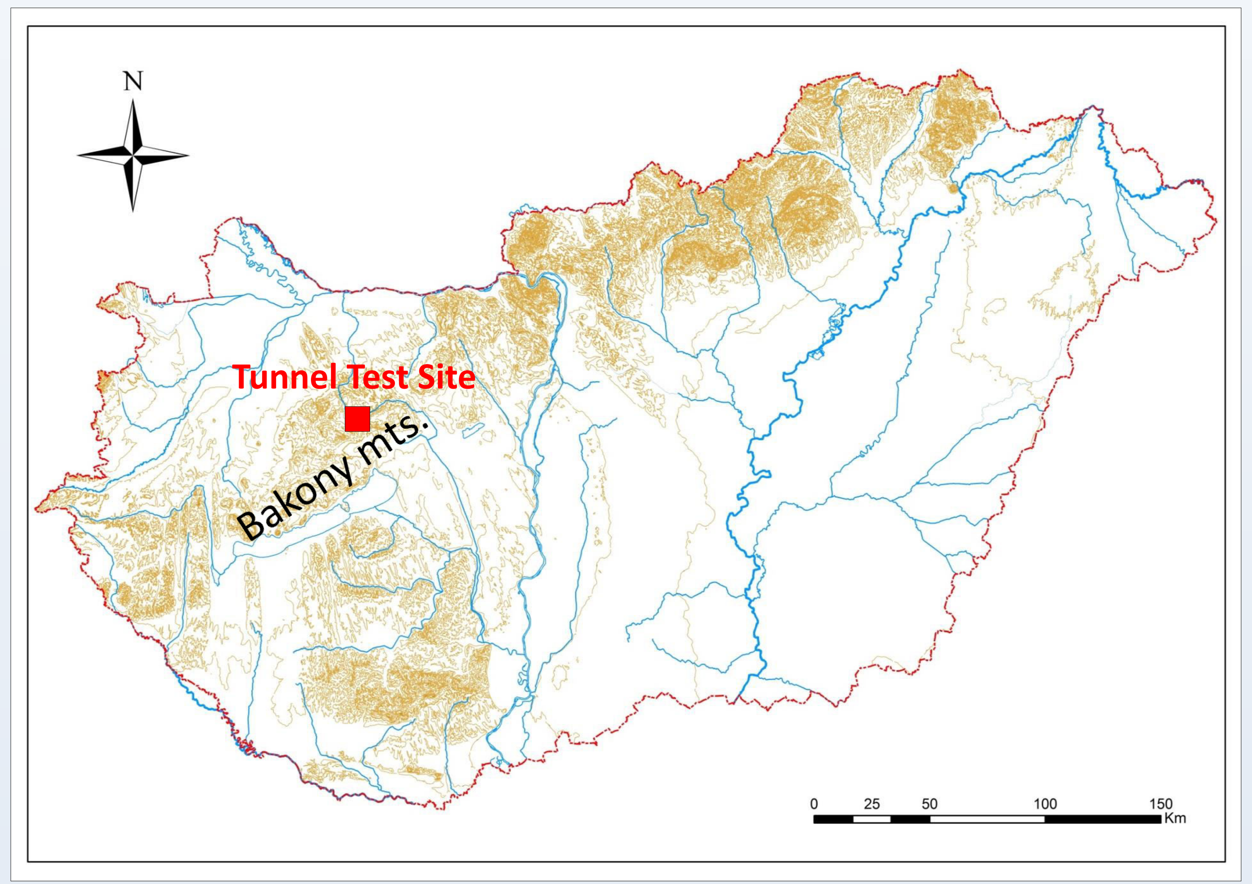

Figure 1. Location of the measured area (with red square)

Geological settings

The railway tunnel is in the Bakony Mountains, near Veszprém city in Hungary (Fig. 1). The basement is Lower Jurassic limestone formation. The overlying formation is an Oligo-Miocene marl with some limestone beds. The formations are faulted along a zone, mainly parallel with the tunnel.

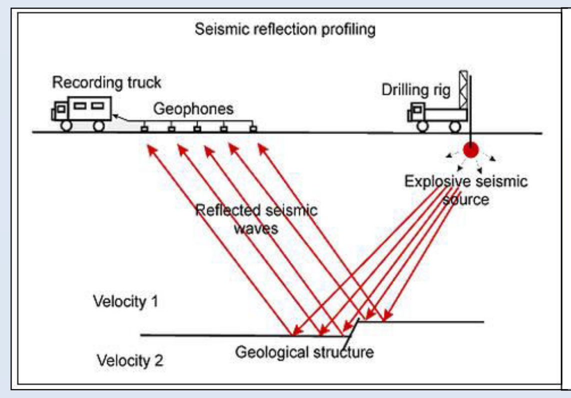

Figure 2. Reflection method

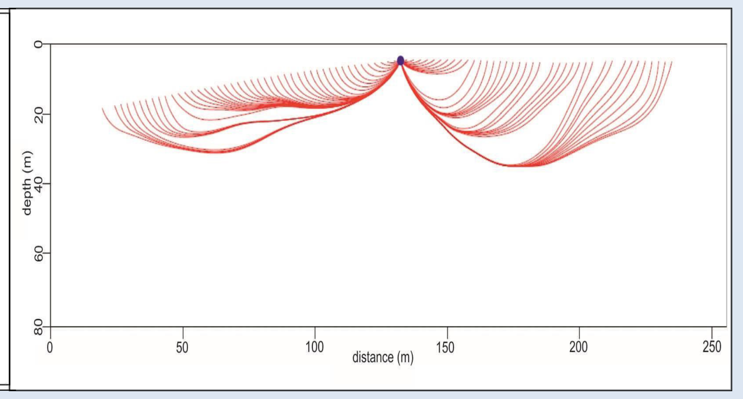

Figure 3. Seismic tomography

Basic Principles

When a seismic wave hits an interface with normal incidence, some energy is reflected, while the rest is passed through into the lower boundary.
On the boundary of the compact rock and an air filled space, large acoustic impedance can be observed. Acoustic impedance depends on the velocity and the density of the bounding space.

S-waves are characterized by lower velocity than the P-waves therefore they provide more detailed images of the subsurface. The geologic and man-made structures can be detected more precisely on the S-wave sections than on the P-wave ones. However, the attenuation for the S-waves is higher than the P-waves, but the signal-to-noise ratio is lower. That is why the S-wave data acquisition and processing is more challenging than the P-wave procedures. (Fig. 2)

Seismic tomography is a methodology for estimating the Earth's properties. Tomography is a process of obtaining 2D and 3D images within the interior of a 3-dimensional object by passing rays of some sort through the object and observing how rays are affected (attenuated or delayed in time) by passing through the soil material. The propagating velocities of compressional waves (P-wave) and shear waves (S-wave) were estimated by tomographic processing. (Fig. 3)

Field measurements

<u>P-wave data collection:</u>
- It was implemented in SW-NE direction, almost perpendicular to the tunnel (Fig. 4)
- Reference zero was the vertical projection of the tunnel
- The depth of the tunnel arch was 10 m under the surface
- Vertical geophones were deployed to observe the P-wave arrivals (48 pcs, distance was 2 m)

<u>S-wave data collection:</u>
- It was implemented along a straight and flat road, in SW-NE direction , perpendicular to the tunnel (Fig. 4)
- The depth of the tunnel arch was 14 m under the surface
- ELVIS-III type horizontal vibrator was utilized as a seismic source
- Horizontal geophones were deployed to observe the S-wave arrivals in SH mode when the source and sensor movement is perpendicular to the line direction. (96 pcs, distance was 1 m)

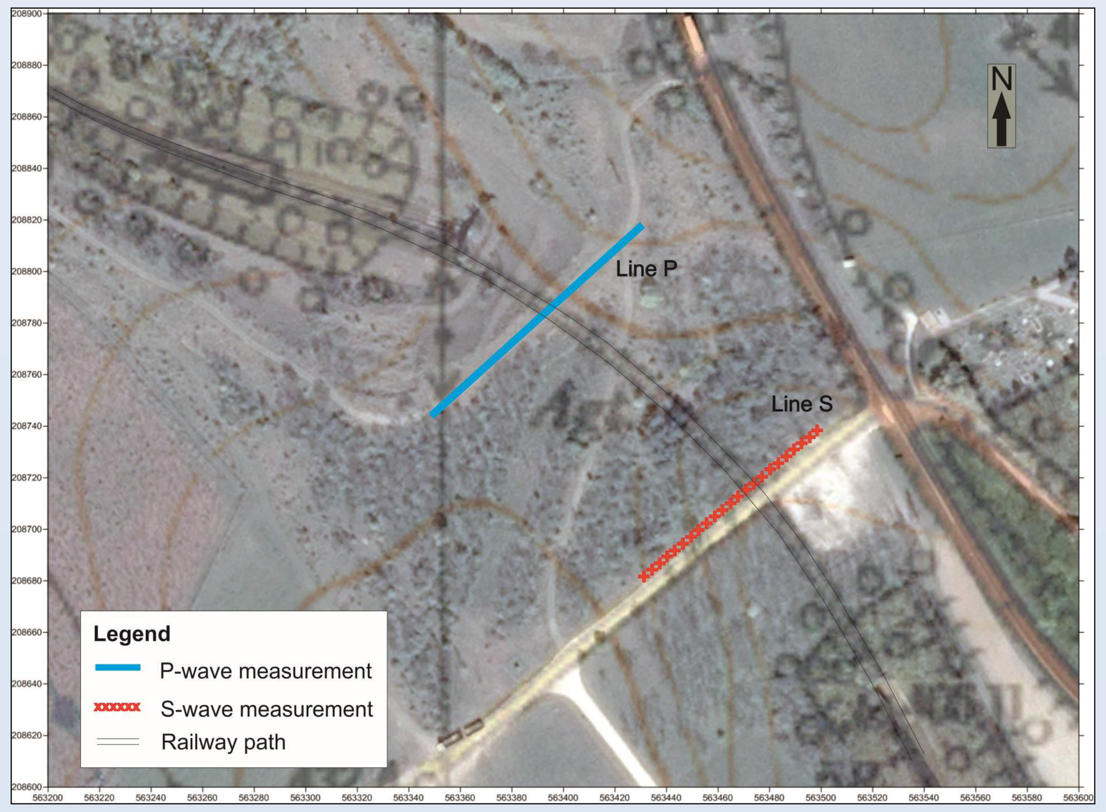

Figure 4. Map of the seismic measurements above the tunnel

Data Processing

The seismic processing was done with ProMax (Landmark Graphics Corp.) software.
<u>Reflection method:</u>
- True amplitude recovery
  - → spherical divergence correction
  - → surface consistent amplitude correction
- Surface consistent deconvolution
- Static correction
- Velocity analysis → NMO correction → Stacking
- 2D prestack time and depth migration

<u>Seismic Tomography:</u>
- utilizes the travel time oriented evaluation of the onset (first arrival) times
- the velocity field of the examined area can be defined by tomographic technique

Figure 5. Southern tunnel arch

Results

P-wave:
The result of the velocity tomography is presented (Fig. 6). The velocity anomalies reveal the tunnel (A) a deep fault throw below the tunnel (B) and a mechanically weak zone (C).

S-wave:
During the S-wave reflection data processing we aimed to get the highest possible signal-to-noise ratio and resolution on the final migrated section (Fig. 7); while refraction tomography provided an independent S-wave velocity model. On both sections, slide-like structures were detected; in addition, the tunnel can be recognized only as a disturbed zone on the reflection section (Fig. 8). The explanation is that the diameter of the tunnel is on the limit of horizontal resolution (7 m).

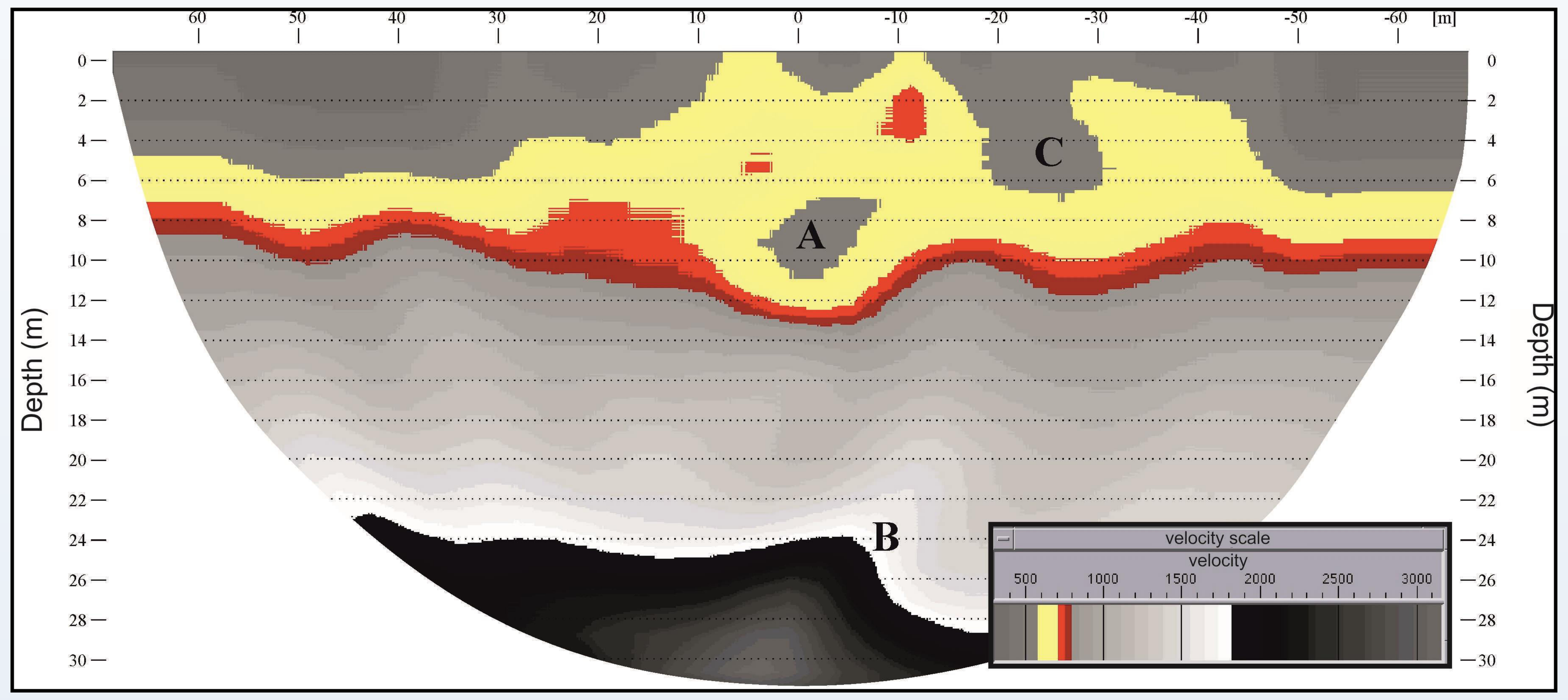

Figure 6. P-wave tomography section

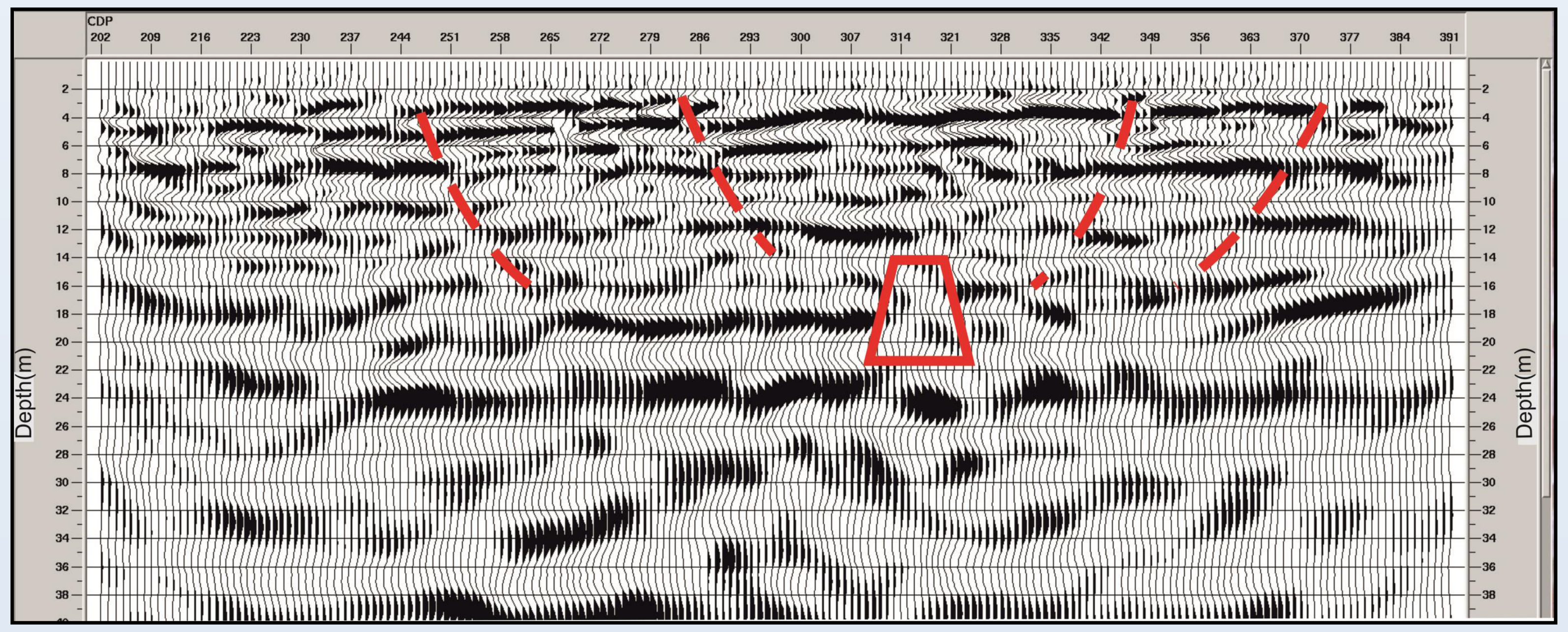

Figure 7. Result of S-wave reflection processing; (red polygon shows the known location of the tunnel)

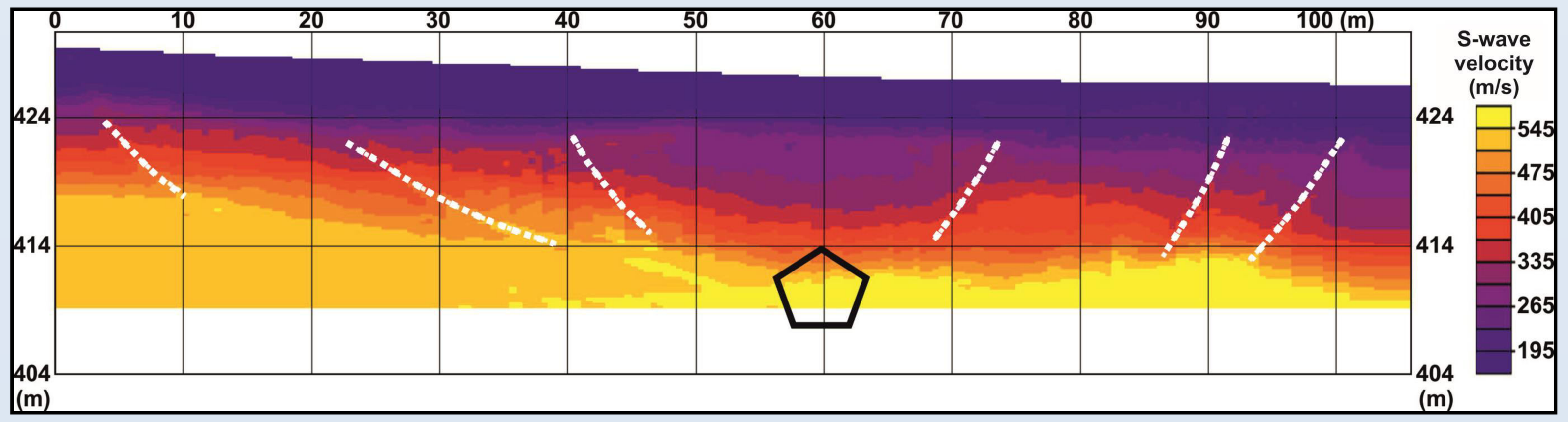

Figure 8. S-wave tomography section (depth in meters above sea level)

Conclusions

- The P-wave velocity tomography is provided a detailed image from the tunnel and it's surroundings.
- The S-wave reflections are provided 1 meter vertical resolution from below 4 meters under the surface.
- The diameter of the tunnel (5 m) is on the limit of the horizontal resolution (7 m).
- Finding tunnels by surface geophysical methods is a complex task that has not have a simple solution: „There is no silver bullet".

References

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