Evaluation of stress and saturation effects on seismic velocity and electrical resistivity – laboratory testing of rock samples

Jan Vilhelm, Jaroslav Jirků – Charles University in Prague, The Czech Republic

Lubomír Slavík – Technical University of Liberec

The Czech Republic

Jaroslav Bárta – G IMPULS Praha, Ltd., The Czech Republic

The measurement / monitoring

- Development of monitoring system for underground excavation in rock massif (e.g. nuclear waste repository)
- Active seismic measurement (monitoring of velocity changes over distance 1-3 meters by ultrasonic time-of-flight measurement)
- Electrical resistivity tomography (48 electrodes on profile with electrode distance 0.2 m)
- Continuous long-term monitoring

The measurement / monitoring

- Test site: underground gallery made by TBM (Tunnel Boring Machine)
- Coarse grained granite, measurement across macroscopically visible void
- Remote control – automatic data collection over internet

Laboratory experiments

- The effect of water saturation on seismic wave velocity
- The effect of stress state and deformation (fracturing) on seismic wave velocity

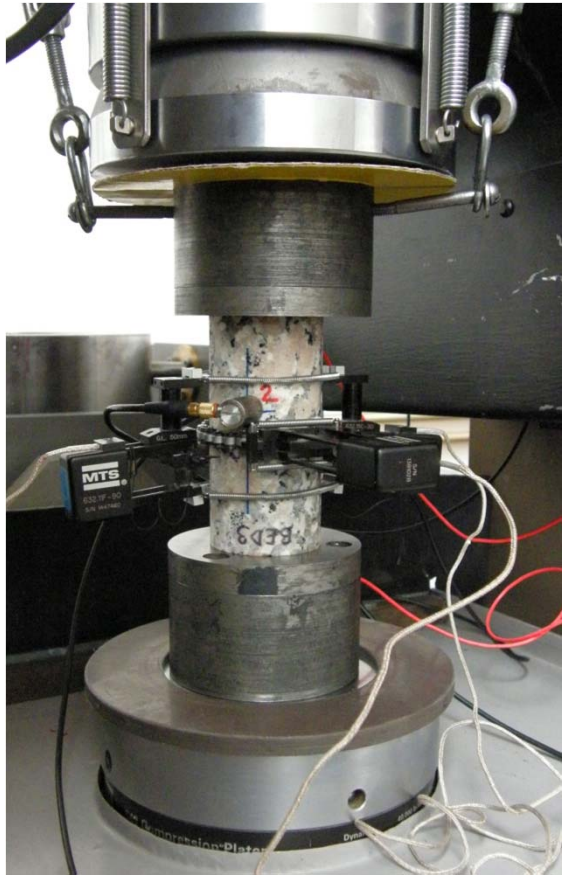
Liberec granit – Hraničná quarry

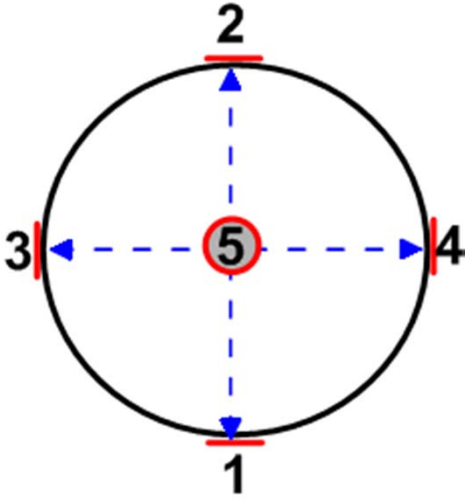
- Cylindrical samples: 5cm in diameter, length 10 cm
- Coarse grained biotitite granite, K-feldspar phenocrysts
- Total porosity 1.24 %
- Effective porosity 0.24 %
- In nearby quarry macroscopically visible three main joint systems

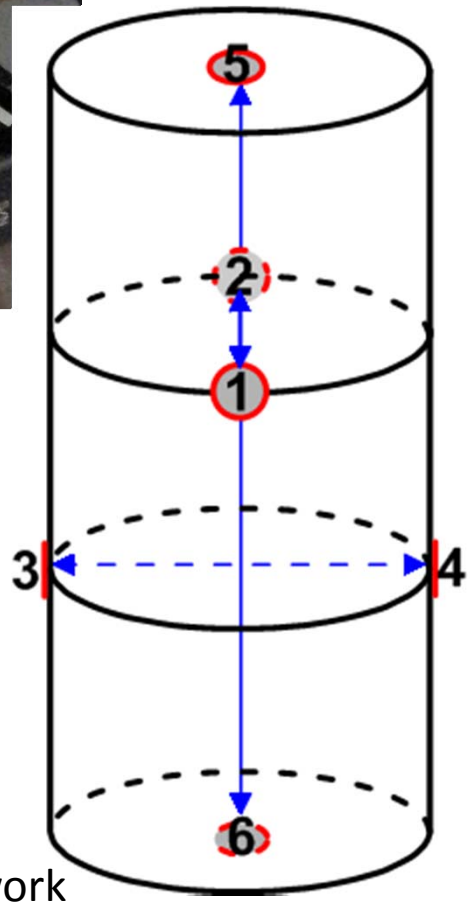
Experiment

- Loading frame MTS 815
  - Circumferential deformation extenzometr 632.12F–20
  - Relative longitudinal deformation 632.11F–90
  - Total longitudinal deformation
- Ultrasonic time of flight measurement
  - AE sensors – Fuji AE204A (Fuji, Japan, frequency range 100-1000 kHz, size 0.8 cm)
  - Recording and pulse generation by sixteen channel transient recorder Vallen Systeme AMSY-5, Germany
  - Sampling frequency 10 MHz
  - Averaging of 10 records

Loading and measurement setup

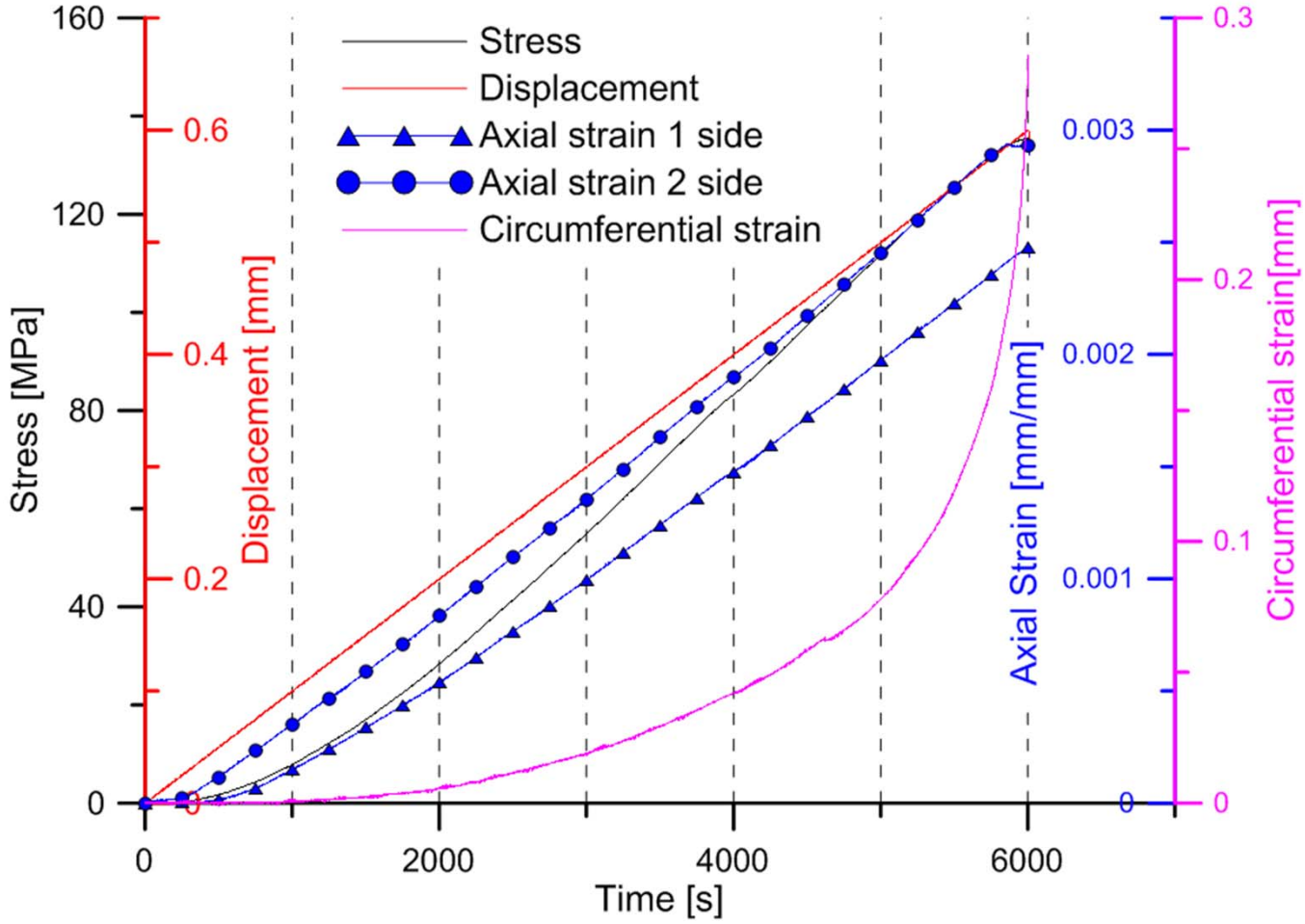






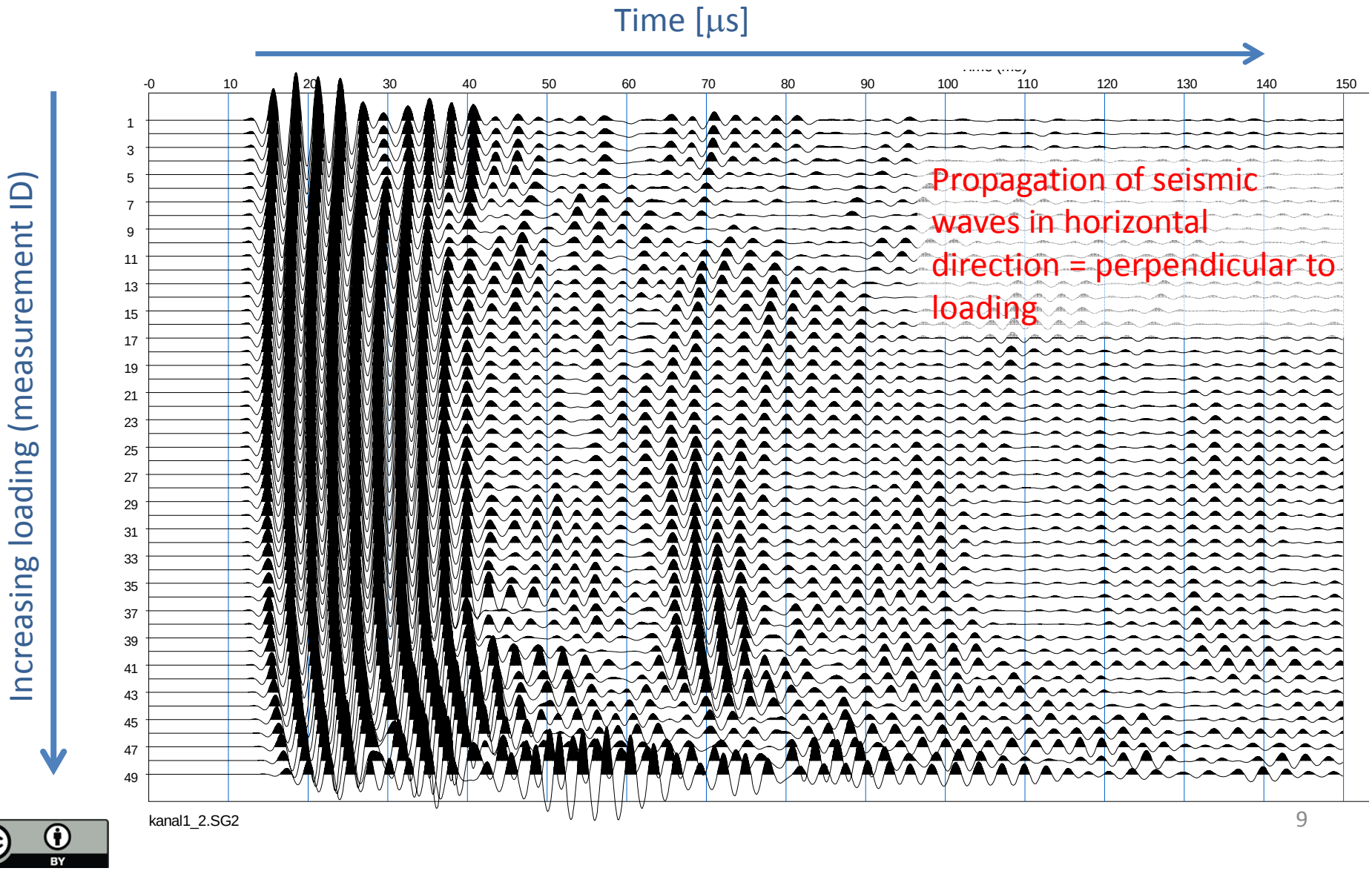
Ultrasonic transducers network

Loading test (saturated granite)

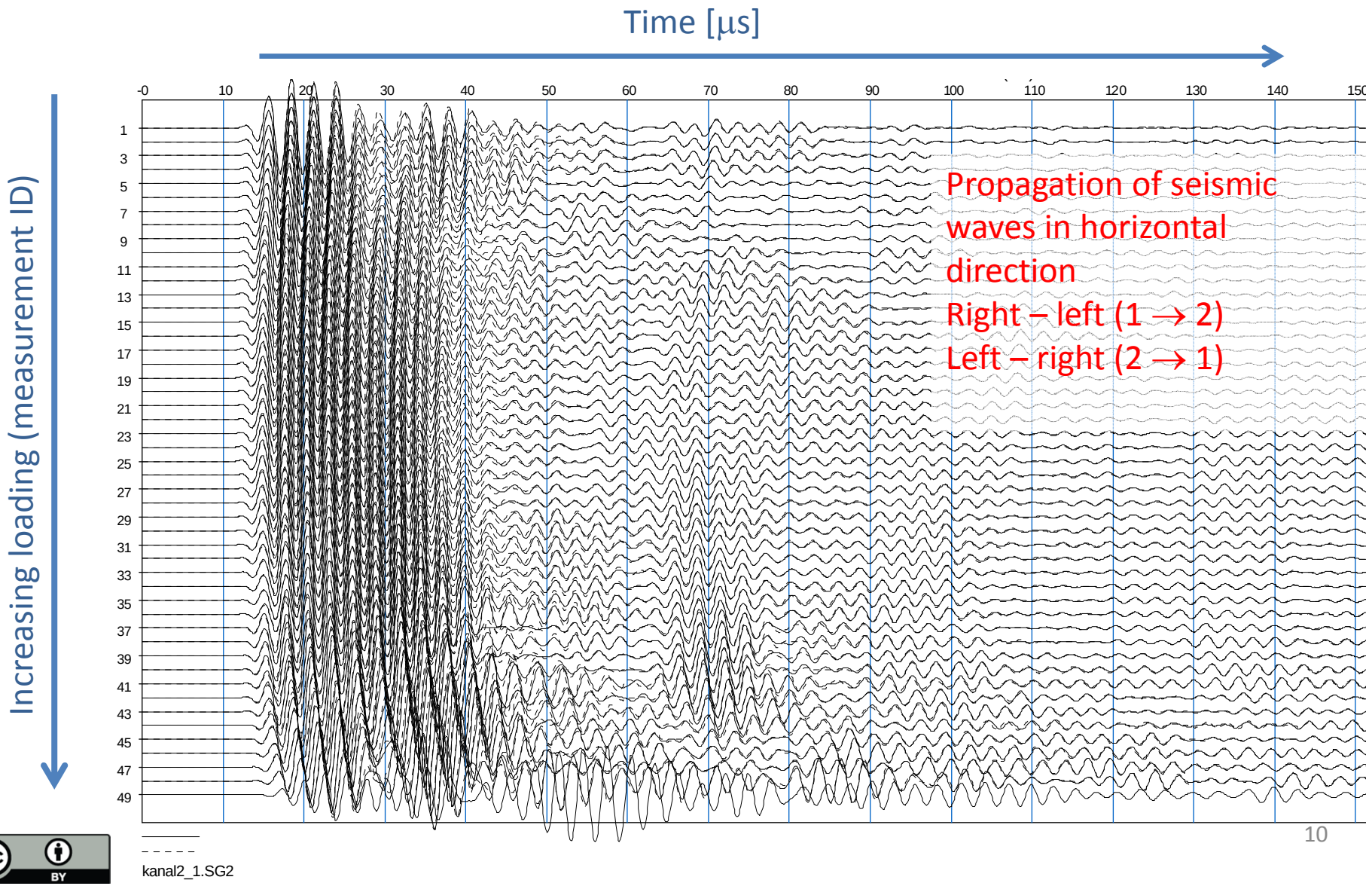


Loading with constant strain rate 0.006 mm/min

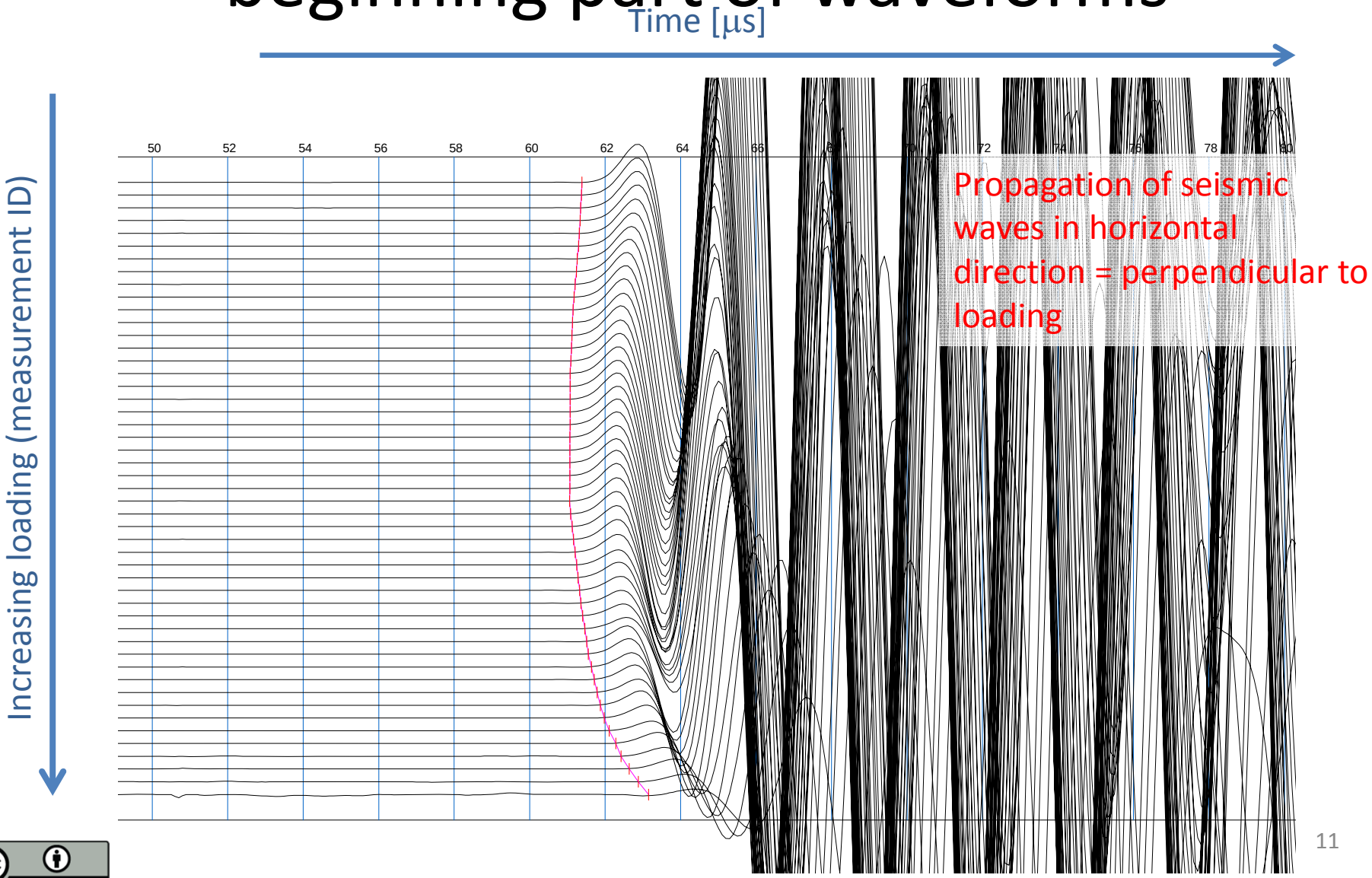
Active ultrasonic measurement



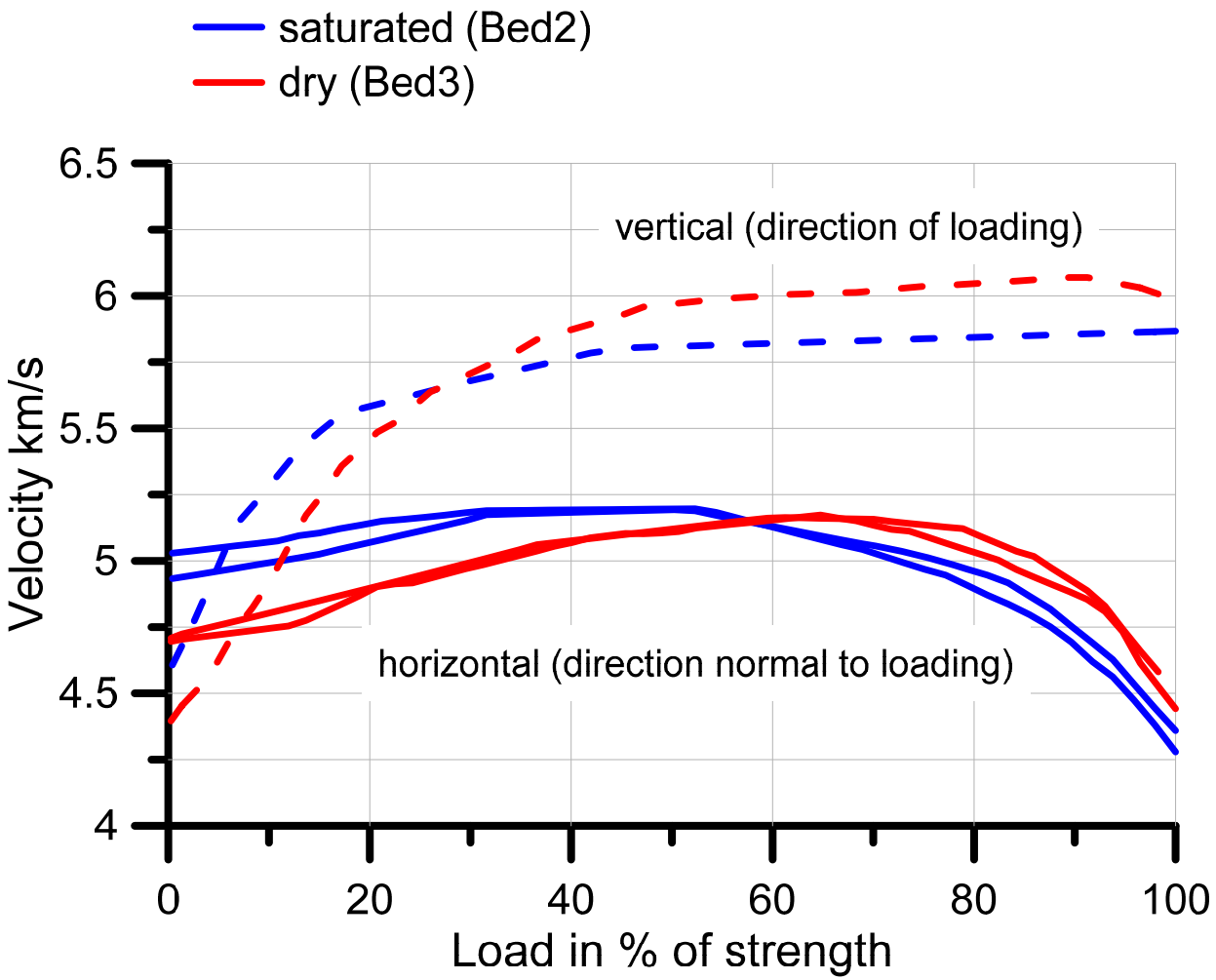
Active ultrasonic measurement

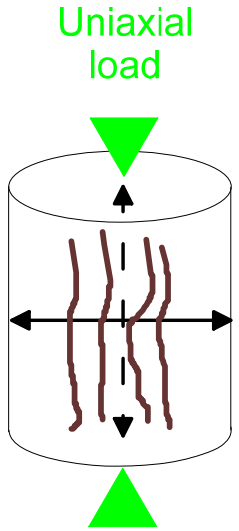


Active ultrasonic measurement beginning part of waveforms

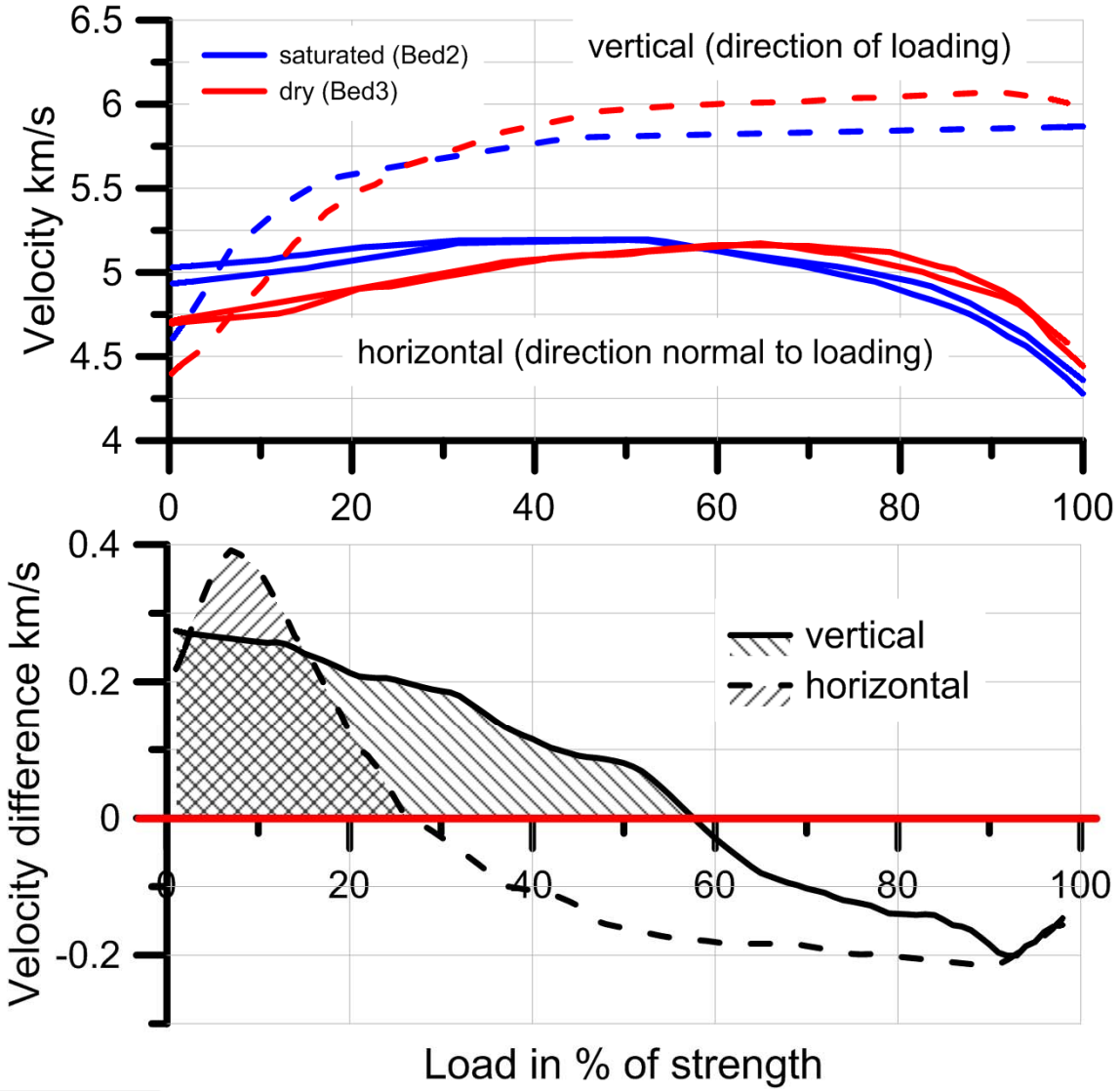


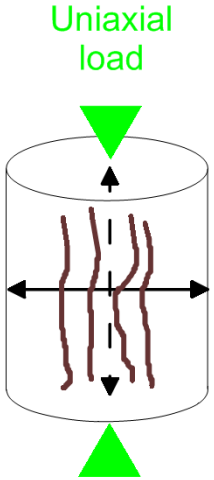
Results – velocities in dry and fully saturated samples





Velocity difference between dry and saturated samples





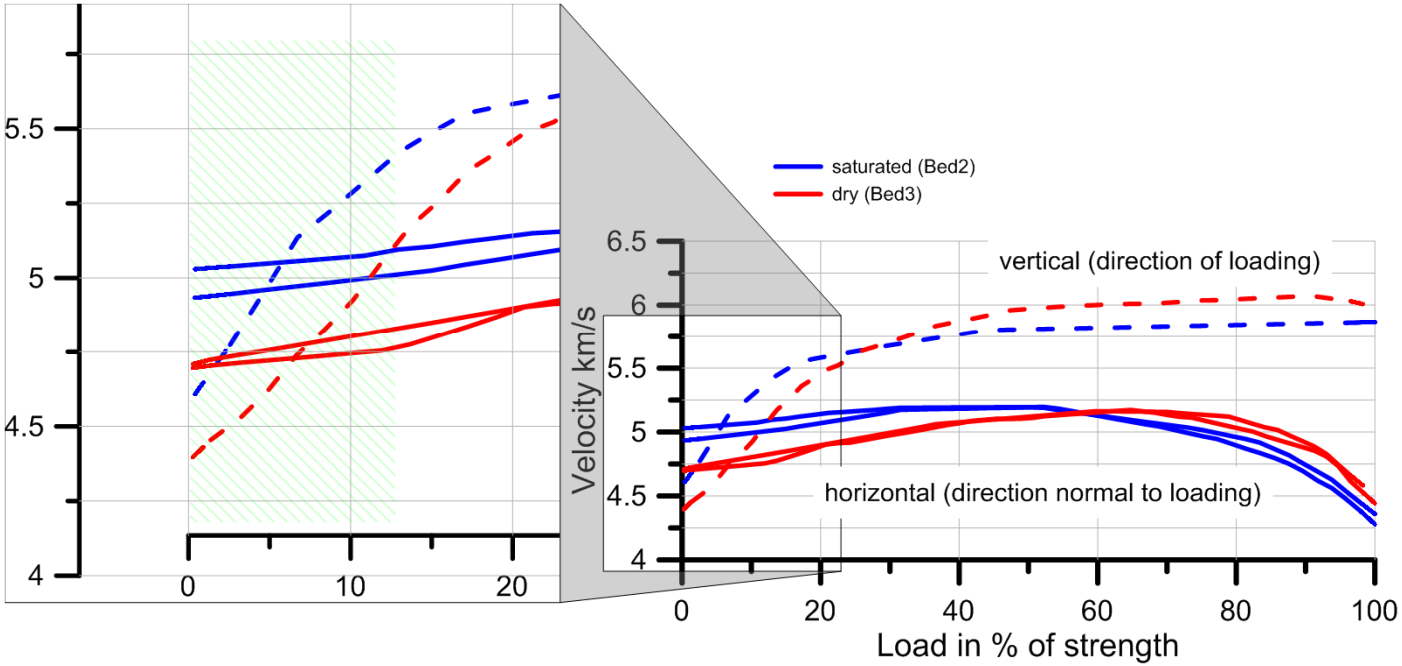
Velocity difference: saturated – dry granite

Stress state in the field conditions

- Gravitational loading
- Example:
  - depth 0 m - σ_z=0 MPa
  - depth 100 m - σ_z=2,6 MPa

P-wave velocity [m/s]	Saturated granite (Bed2)		Dry granite (Bed3)	
Load	0 MPa	2.6 MPa	0 MPa	2.6 MPa
Vertical direction (=in direction of loading)	4600	5320	4400	5050
Horizontal (=perpendicularly to loading direction)	5000	5035	4700	4790

Stress state in the field conditions



P-wave velocity [m/s]	Saturated granite		Difference Sat. - Dry	Dry granite	
Load	0 MPa	2.6 MPa	m/s	0 MPa	2.6 MPa
Vertical	4600	5320	200-300	4400	5050
Horizontal	5000	5035		4700	4790

Saturation and load effects on velocity value versus accuracy of field velocity determination

- Saturation: velocity increase about 200 – 300 m/s
- Loading (approx. gravitational load σ_z in depth 100 m):
  - Vertical direction (direction of loading) 450 – 700 m/s
  - Horizontal direction (perpendicular to loading) 35 – 90 m/s
- Velocity decrease due to rock fracturing: it is not easy to express it quantitatively

P – wave velocity	Sampling	Distance	Time of flight for P-wave	Velocity uncertainty per 1 sample
5300 m/s	1 μs	3 m	566 μs	9 m/s (0.17%)

Conclusions

- laboratory loading tests revealed:
  - The effect of saturation on seismic wave velocity is important even in granite with effective porosity 0.24%
  - The velocity increase in the filed can be result of increased load or increased saturation; ERT can be used to recognize increased saturation (electrical resistivity decrease)
  - The stress in the field depends on orientation of fractures, its more complicated than uniaxial loading of samples. However the accuracy of field measurements of velocity is very high and therefore even small change in the stress field can be evaluated
  - The effect of velocity decrease due to sample fracturing cannot be easily quantified