O3.3-604

Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method

Miriam Kristekova, Jozef Kristek, Peter Moczo

Comenius University Bratislava, Slovakia
Slovak Academy of Sciences, Slovakia

FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS
Comenius University Bratislava

Presentation Date: 11 September 2025

Miriam Kristekova, Jozef Kristek, Peter Moczo

Outline

Motivation

FISP – methodology

FISP – applications

Conclusions

FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS
Comenius University
Bratislava

Miriam Kristekova, Jozef Kristek, Peter Moczo

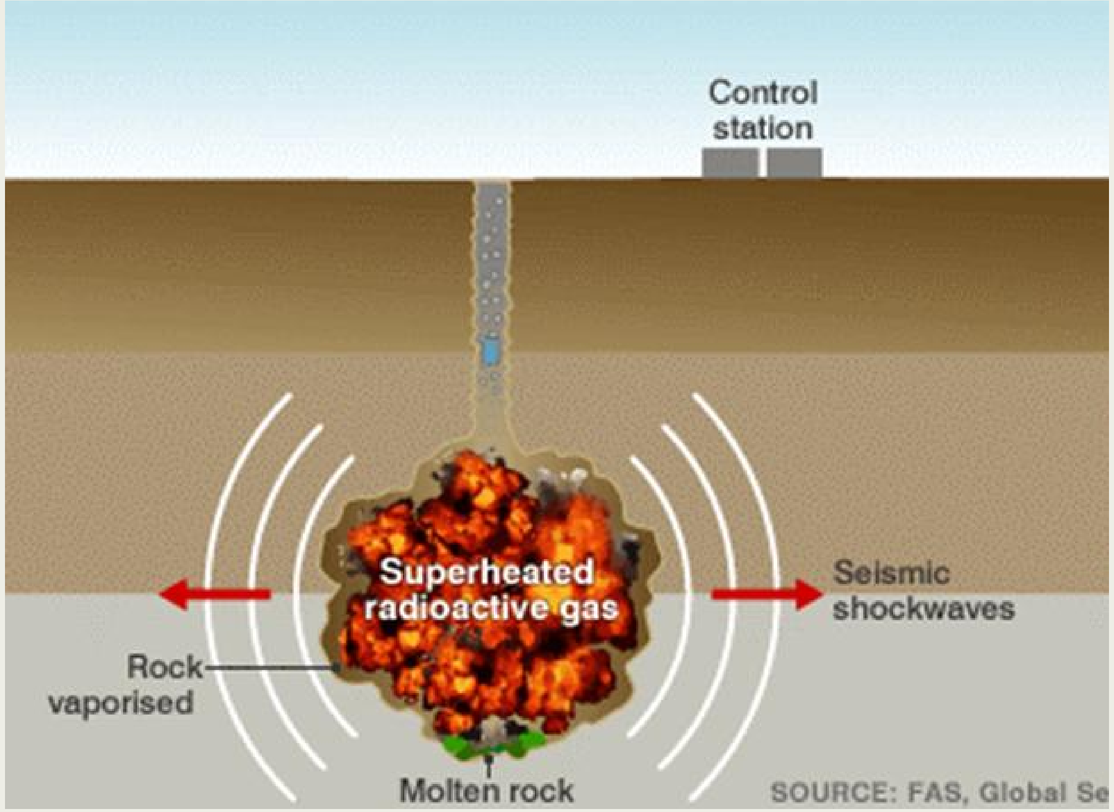
CTBTO on-site inspection team seeks cavities hundreds of meters underground

limited time for inspection

limited number of seismic stations

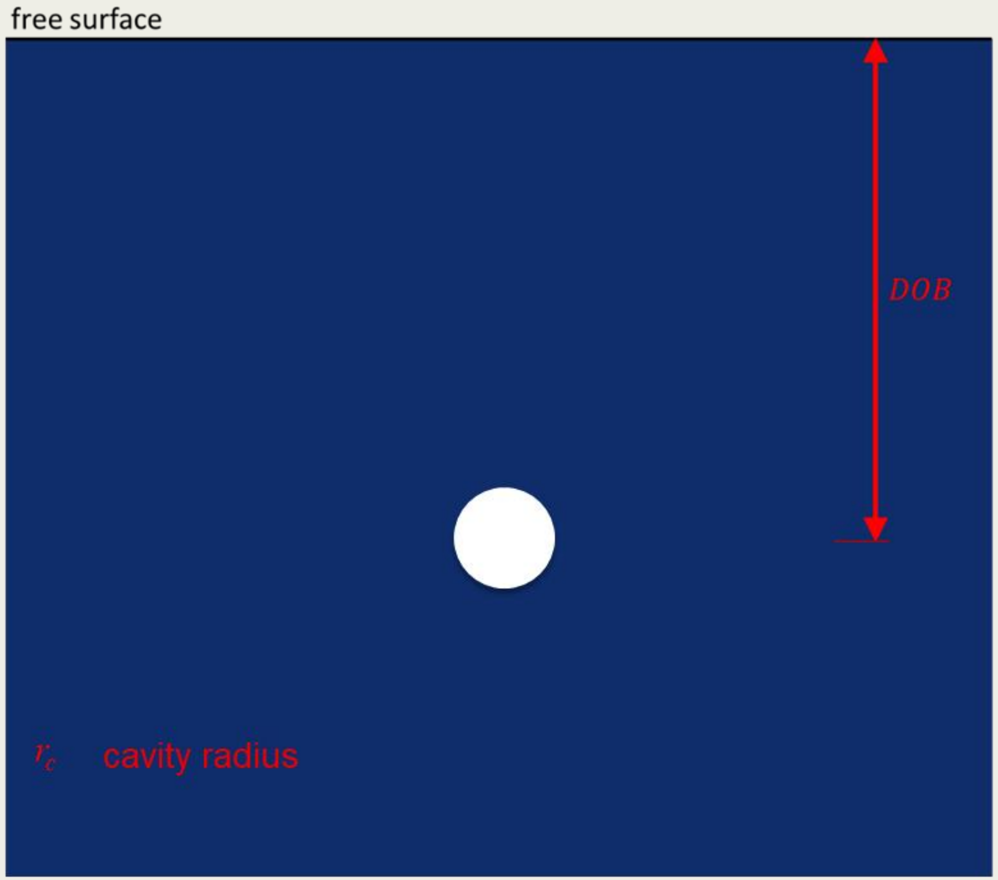
limited possibilities to deploy a large and dense array

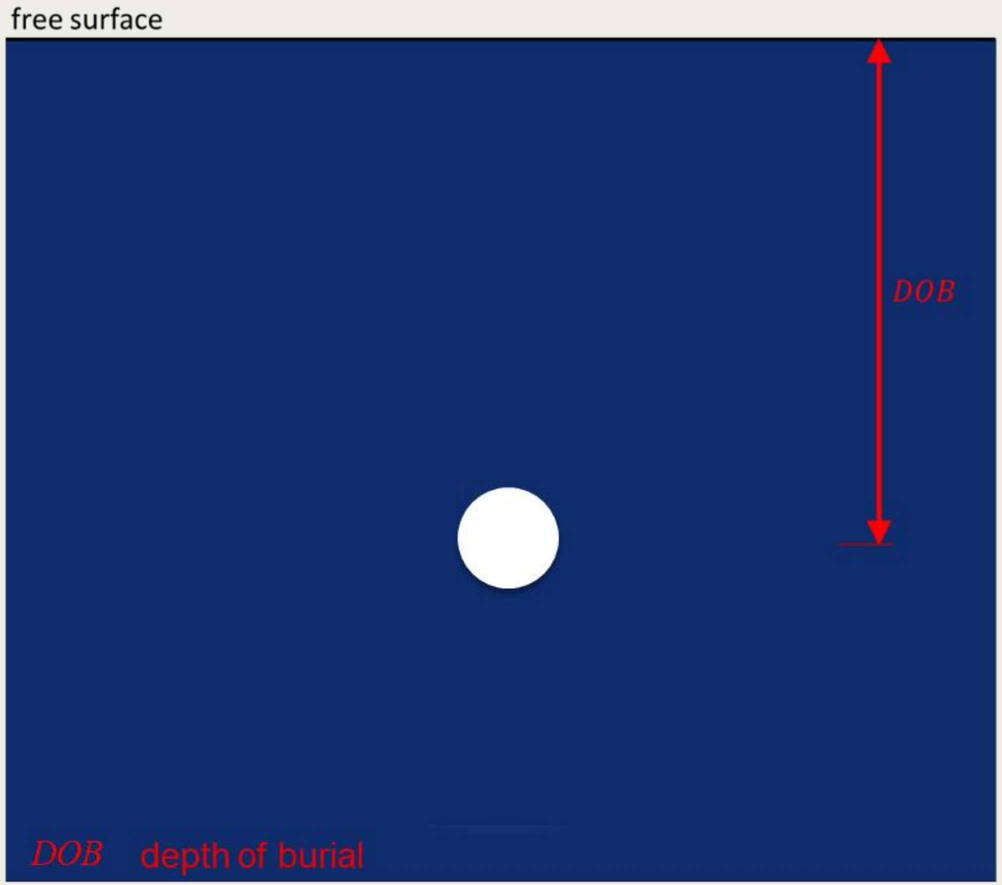
it is useful to have a robust method
utilizing seismic ambient noise
applicable to data from
single station (or a few stations) measurements



Miriam Kristekova, Jozef Kristek, Peter Moczo

Structural Models for the Vertical Emplacement

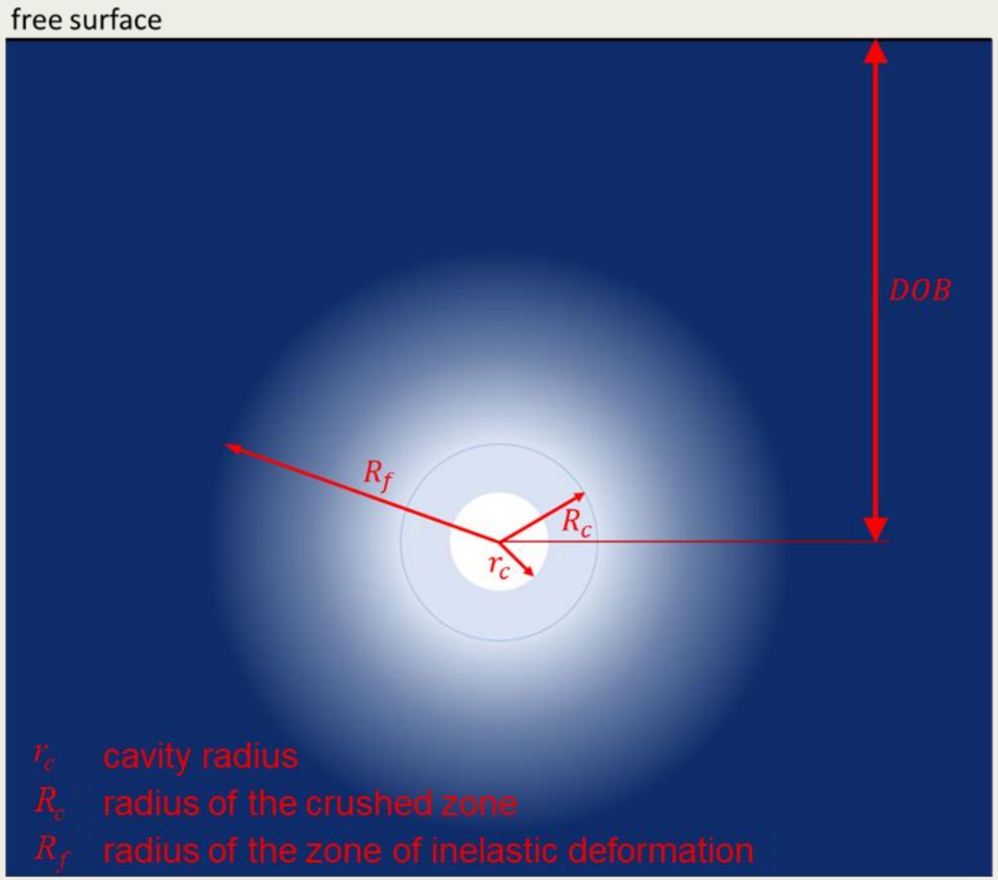




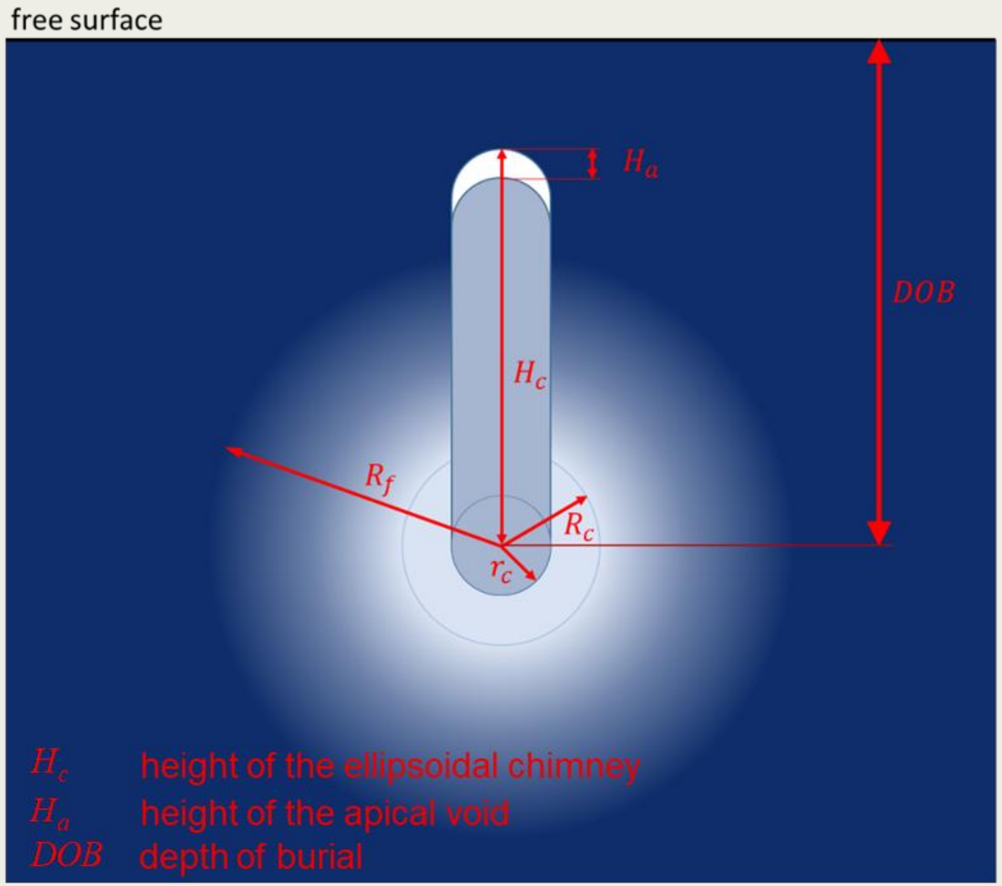
Miriam Kristekova, Jozef Kristek, Peter Moczo

Structural Models for the Vertical Emplacement

cavity without chimney (for plastic rock)



cavity with chimney filled with rubble + apical void



FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS
Comenius University
Bratislava

Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method

Miriam Kristekova, Jozef Kristek, Peter Moczo

O3.3-604

Result of Analysis of Synthetics

Amplitude Fourier spectra
averaged over
all 6400 receivers

tuff

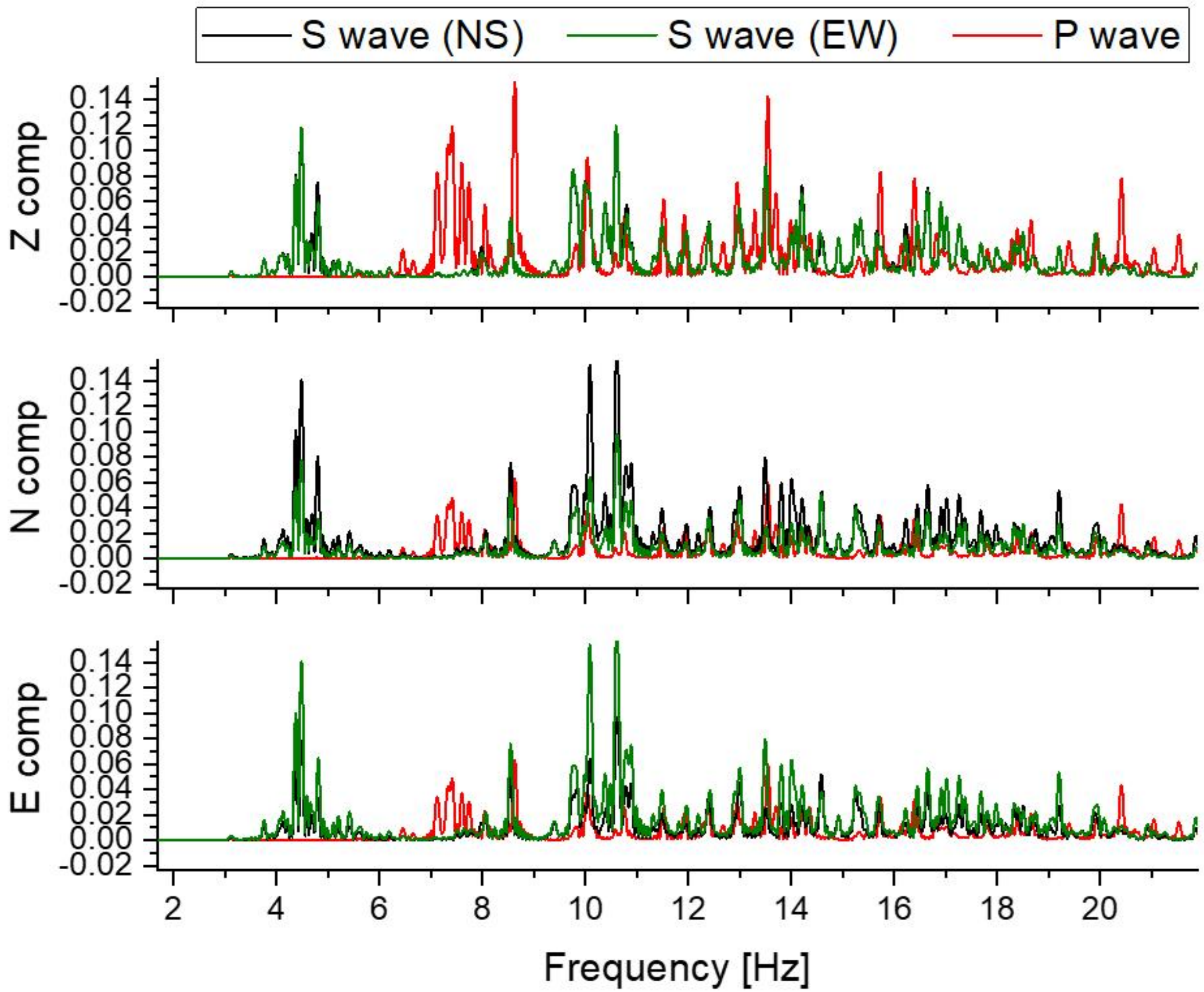
low yield (1kt)

GAS filling of apical void

minimal depth of burial
(180 m)

Select

Type of excitation
- ◉ plane waves
- ○ point double-couple sources



Miriam Kristekova, Jozef Kristek, Peter Moczo

The Finite-Interval Spectral Power Method (FISP)

instead of problematic identification
of individual weak peaks
and
calculation of the corresponding spectral characteristics,
the FISP is based **on evaluation**
of signal energy (spectral power)
within a finite-interval of frequencies

Kristekova et al. 2021. Geophys. J. Int., 945-960

Miriam Kristekova, Jozef Kristek, Peter Moczo

The Finite-Interval Spectral Power Method (FISP)

we proposed to evaluate spectral power
representing the entire reasonably selected frequency interval $[F_{min}, F_{max}]$

$$FISP_Z = \int_{F_{\min}}^{F_{\max}} \left| \tilde{X}^Z(f) \right|^2 df \qquad FISP_H = \int_{F_{\min}}^{F_{\max}} \left| \tilde{X}^E(f) \right| \left| \tilde{X}^N(f) \right| df \qquad \frac{FISP_H}{FISP_Z}$$

$\left| \tilde{X}^C(f) \right|^2$ is a smoothed power spectral density (PSD) of one component of noise

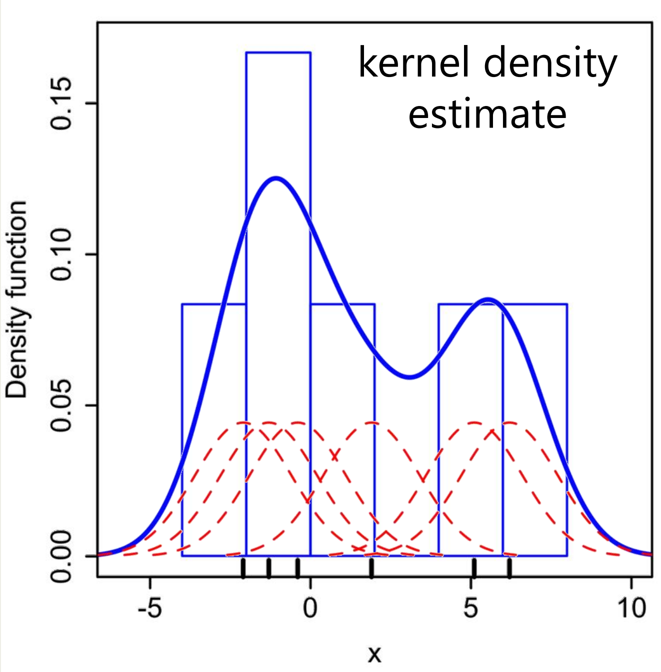
Miriam Kristekova, Jozef Kristek, Peter Moczo

The Finite-Interval Spectral Power Method (FISP)

we proposed to evaluate spectral power
representing the entire reasonably selected frequency interval $[F_{min}, F_{max}]$

? how to estimate power spectral density (PSD)
in case of non-unimodal distribution?

$PSD(f) =$ the maximum of kernel density estimate

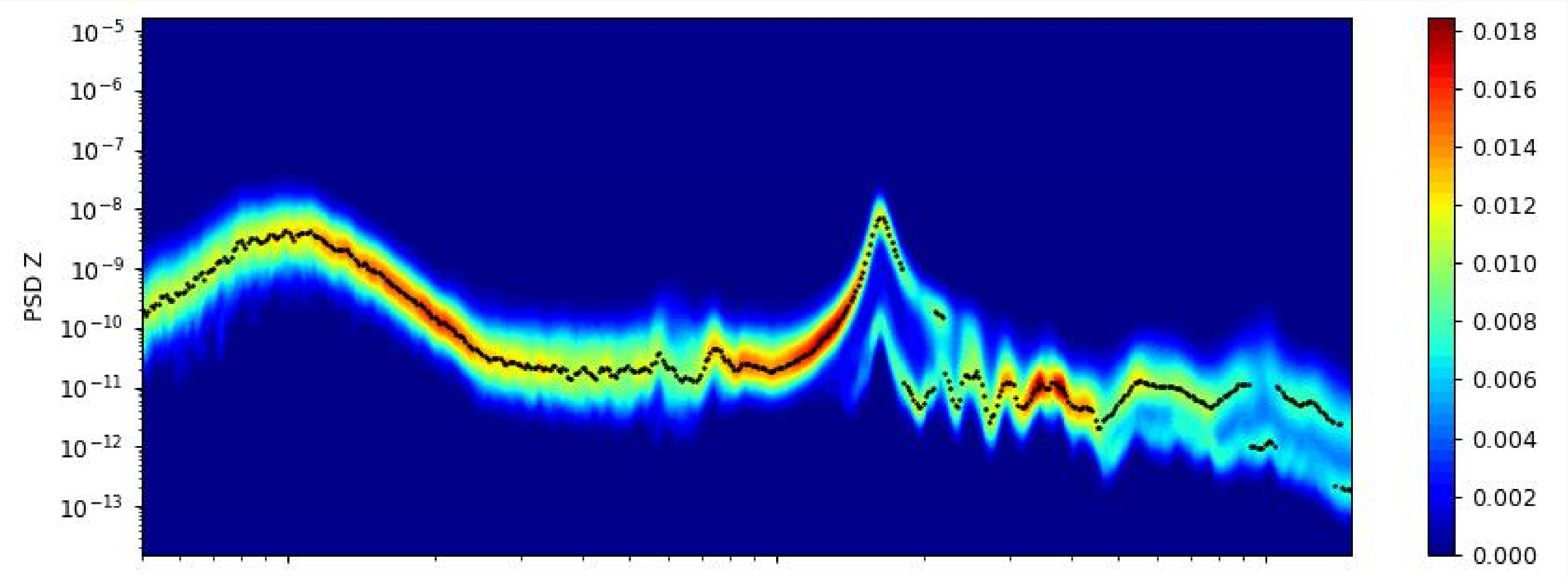


FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS
Comenius University
Bratislava

Miriam Kristekova, Jozef Kristek, Peter Moczo

The Finite-Interval Spectral Power Method (FISP)

we proposed to evaluate spectral power
representing the entire reasonably selected frequency interval $[F_{min}, F_{max}]$



Miriam Kristekova, Jozef Kristek, Peter Moczo

The Finite-Interval Spectral Power Method (FISP)

we proposed to evaluate spectral power
representing the entire reasonably selected frequency interval $[F_{min}, F_{max}]$

the **coefficient of variation**

$$CV(f) = \sqrt{\exp\left[\sigma^2(f)\right] - 1}$$

quantifies the differences
between the segments
regardless of the value of PSD

$$SNR(f) = -10\log_{10} CV(f)$$

is the **signal-to-noise ratio**
in decibels

the larger signal-to-noise ratio,
the smaller differences
between the segments
and therefore
more reliable measurement

FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS
Comenius University
Bratislava

Miriam Kristekova, Jozef Kristek, Peter Moczo

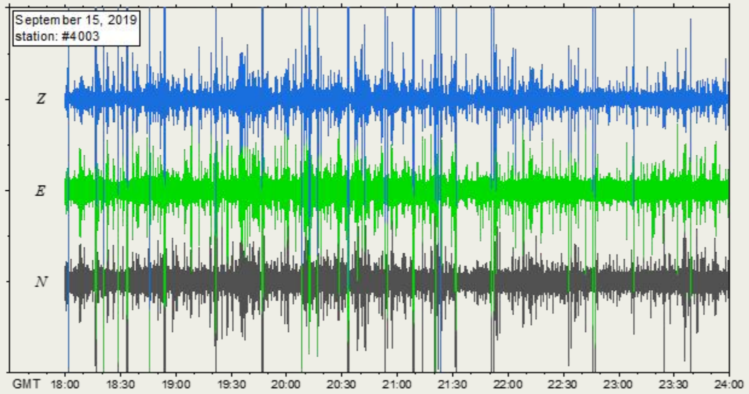
The Finite-Interval Spectral Power Method (FISP)

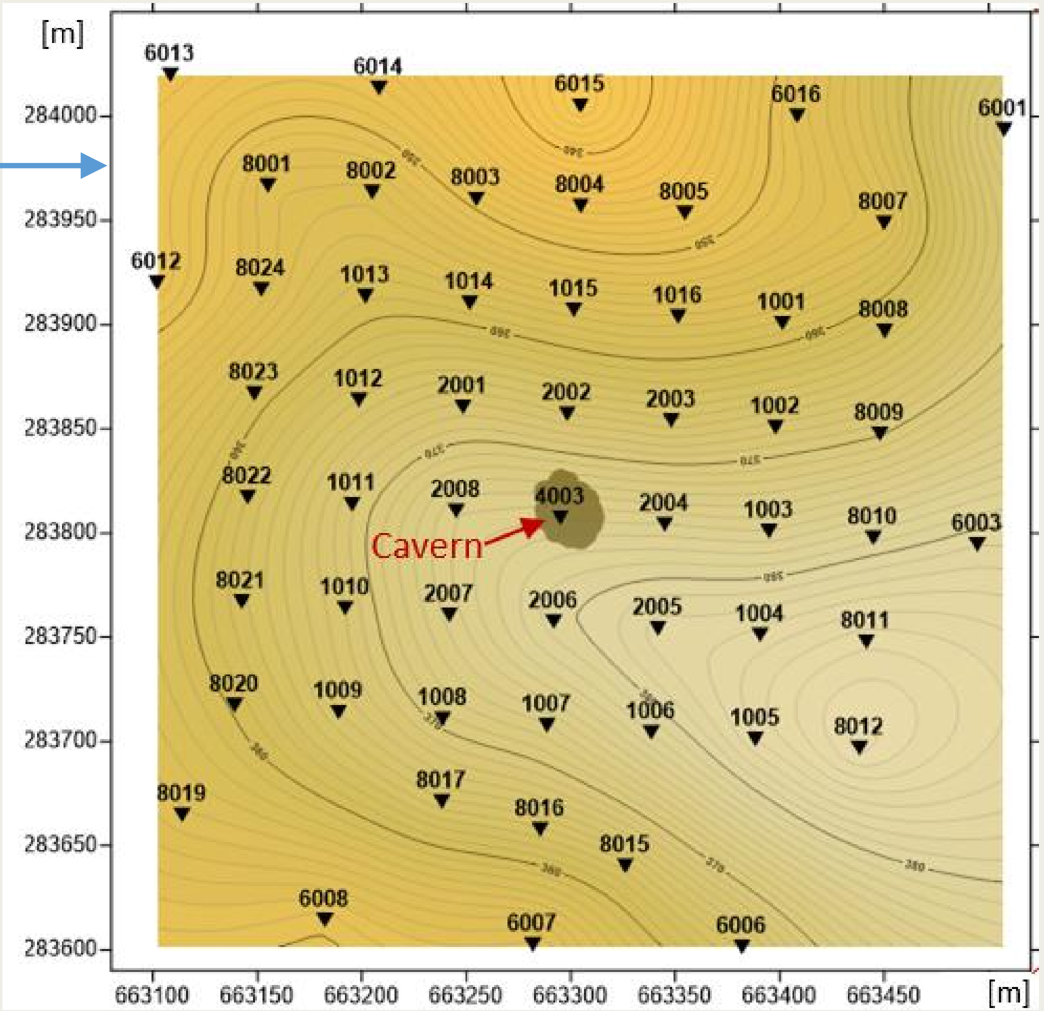
we assume

a set of measurement points
at the free surface
above a suspected cavity

and

sufficiently long
3-component records of noise
at all measurement points





Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method

Miriam Kristekova, Jozef Kristek, Peter Moczo

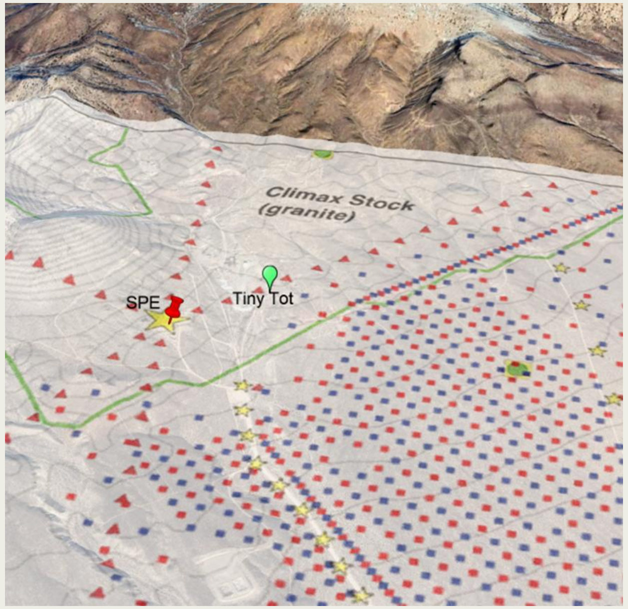
Real-site application of FISP

Great Cavern, Hungary

roughly oval shape
horizontal span: 28 - 30 m
height: 25 - 28 m
depth (ceiling): ~70 m

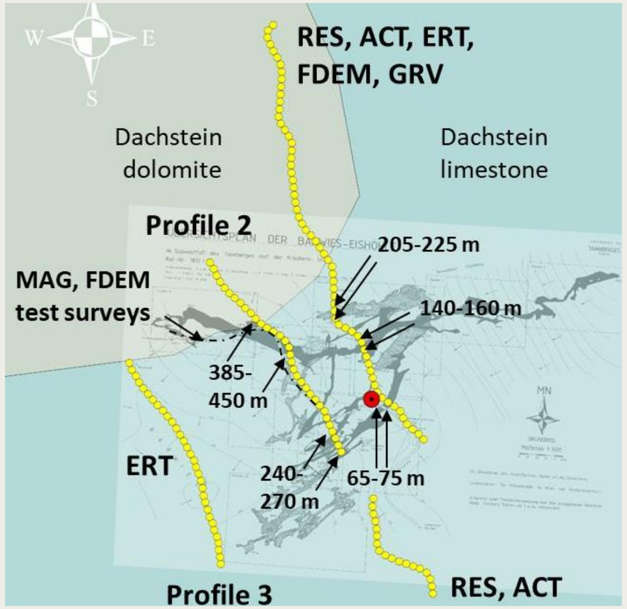
Tiny Tot, NNSS, Nevada

cavity from yield 20kT
horizontal span: ???
height: ???
depth: ~111 m



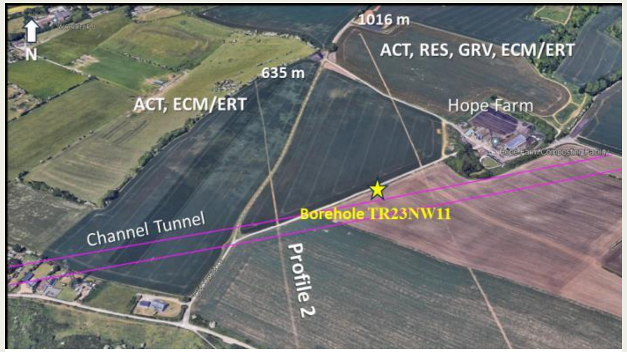
Rotmoos, Austria

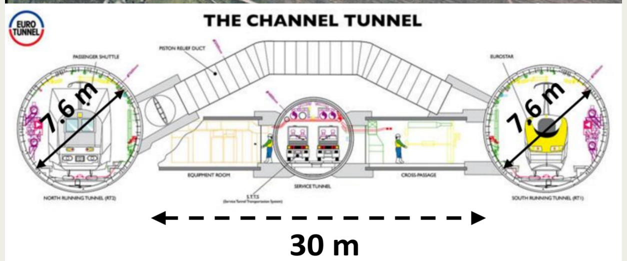
karst area
horizontal span: ???
height: ???
depth: 60 - 450 m



Channel Tunnel, UK

two tubes 30m appart
horizontal span: 46 m
height: 7.6 m
depth: ~90 m



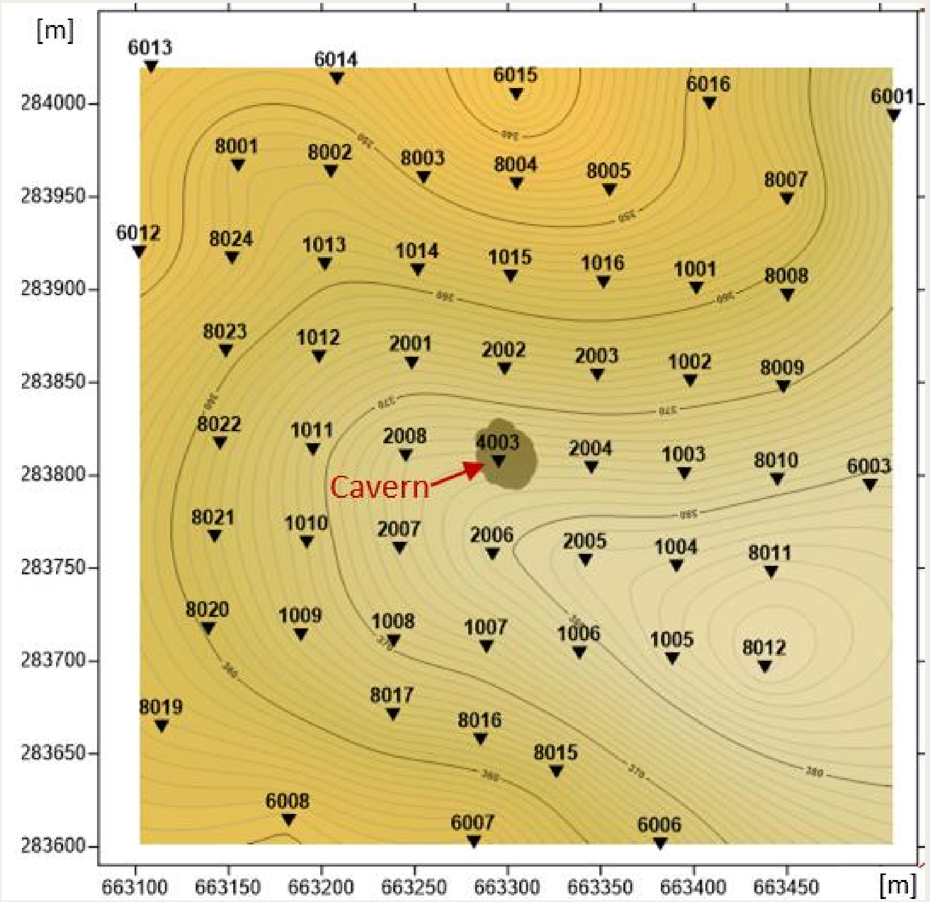


Miriam Kristekova, Jozef Kristek, Peter Moczo

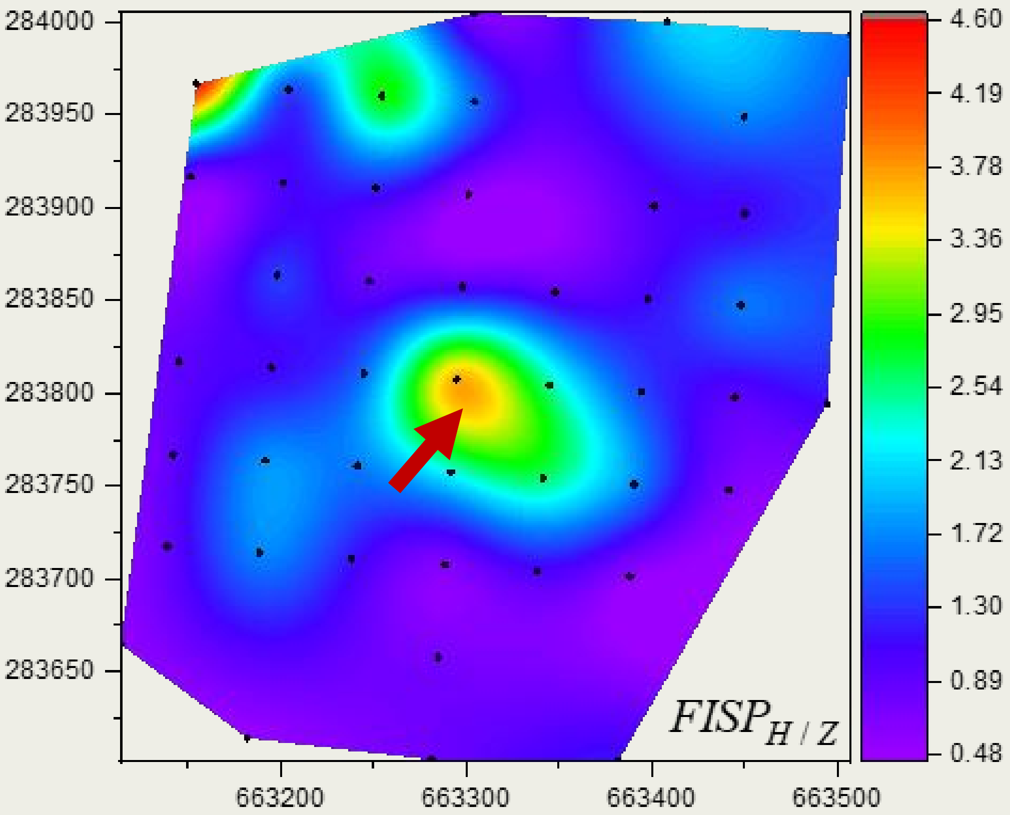
O3.3-604

Real-site application of FISP – Great Cavern, Hungary

3-component records of noise
at 50 measurement points (interstation distance ~50 m)



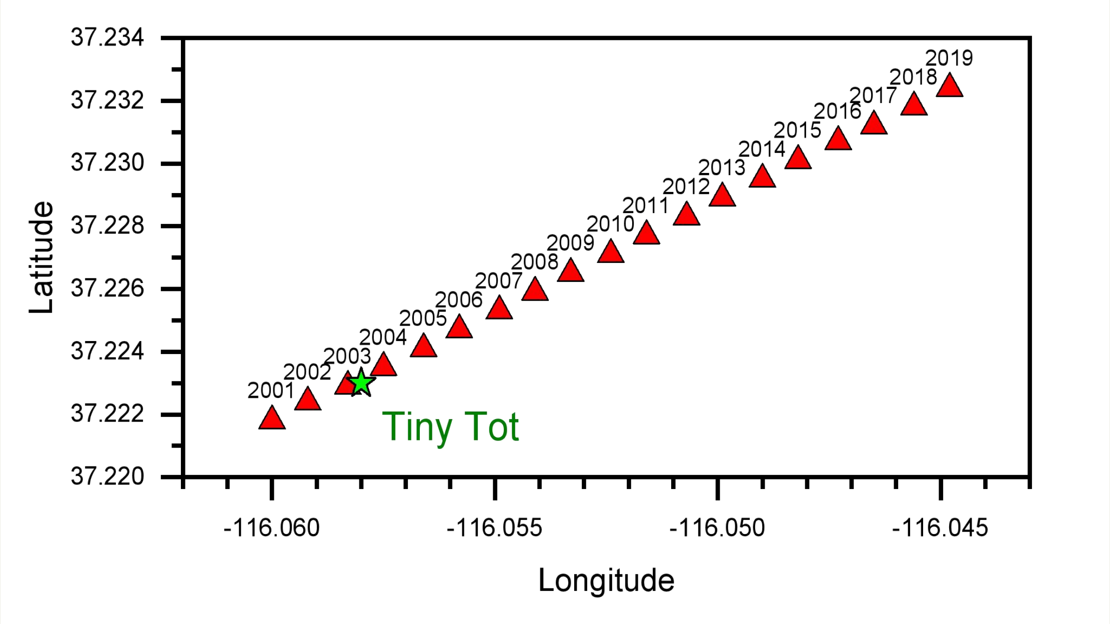
maps showing $FISP_{H/Z}$ computed
for frequency interval 5.5 - 30 Hz

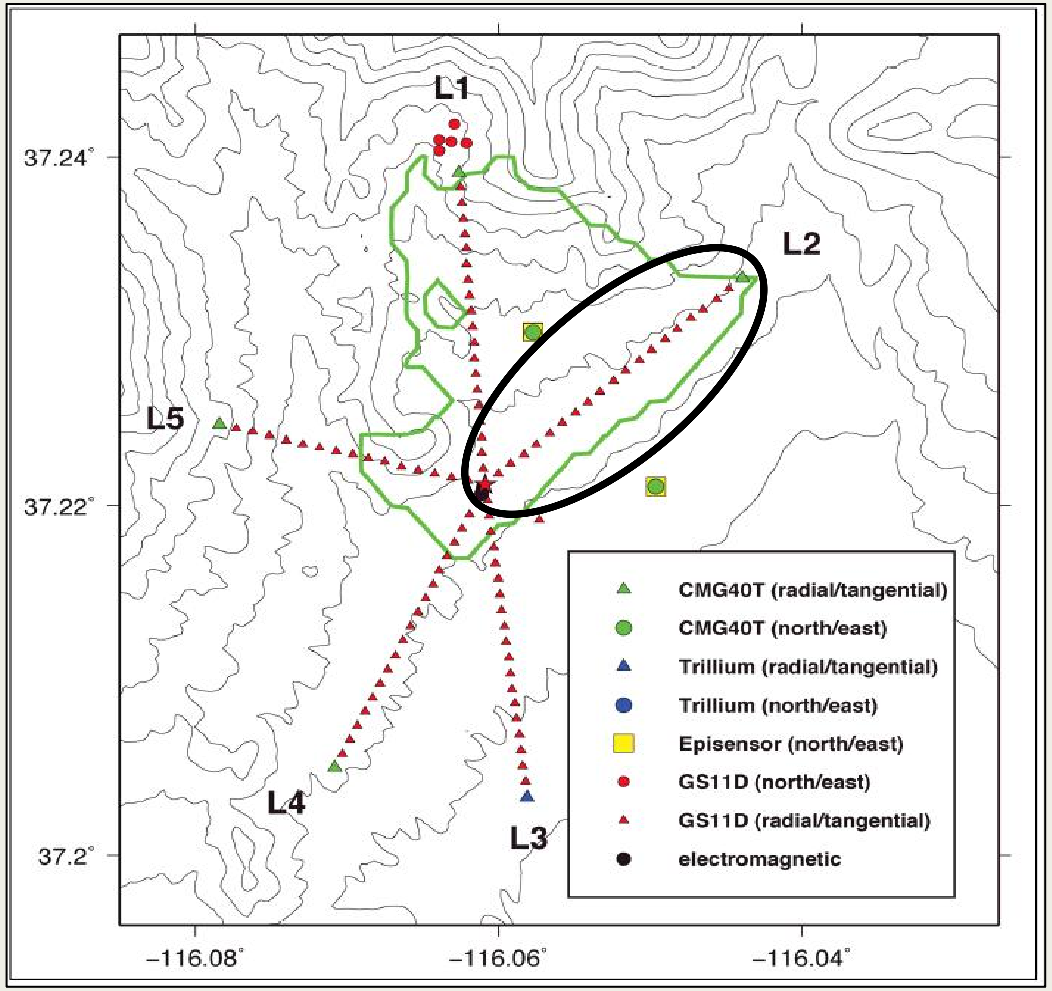


Miriam Kristekova, Jozef Kristek, Peter Moczo

Real-site application of FISP – Tiny Tot, NNSS, Nevada

3-component records of noise from SPE-5 and SPE-6



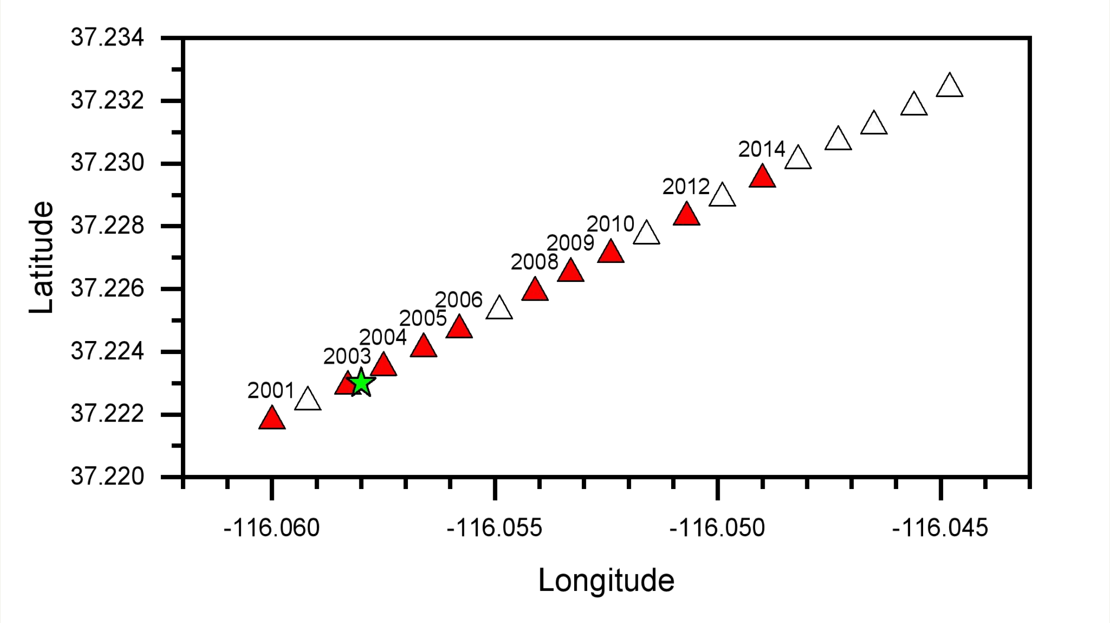


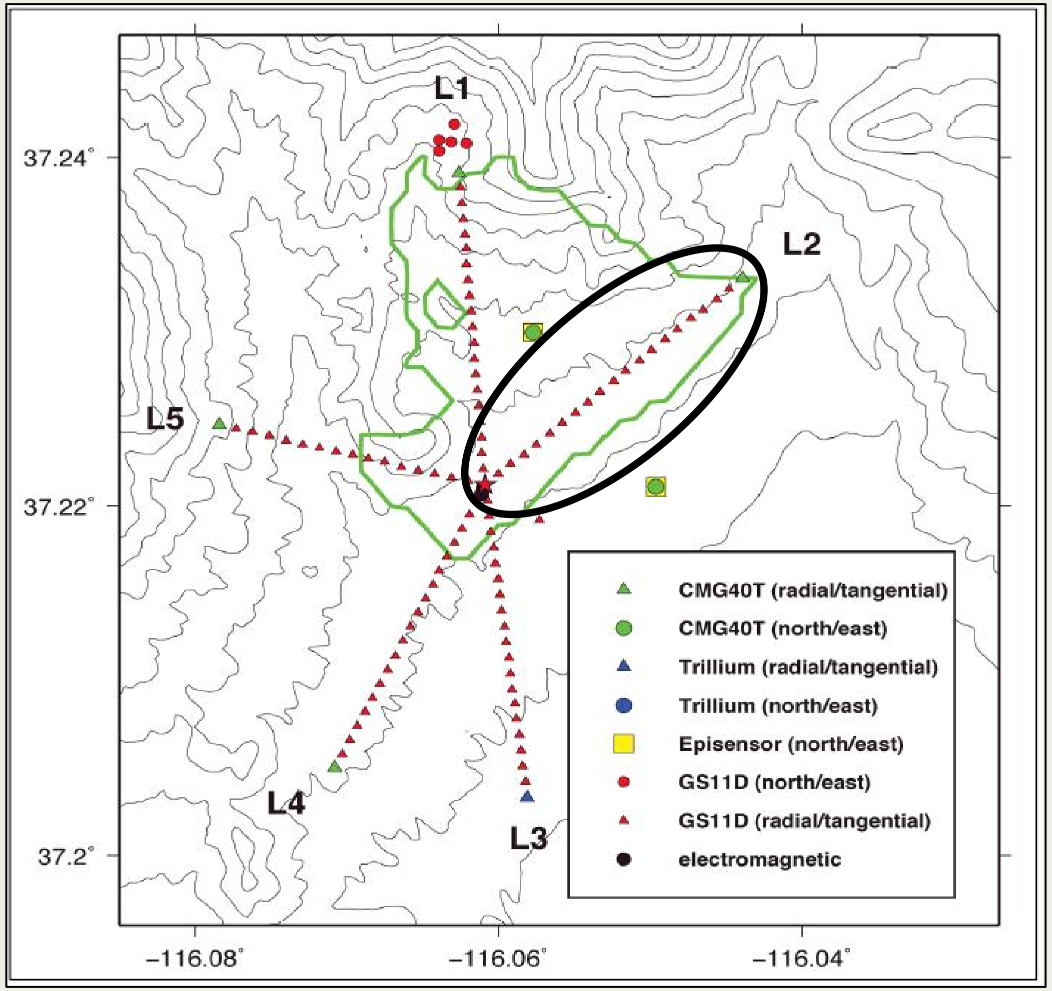
Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method

Miriam Kristekova, Jozef Kristek, Peter Moczo

Real-site application of FISP – Tiny Tot, NNSS, Nevada

3-component records of noise from SPE-5 and SPE-6





data from many receivers unusable either due to malfunction or due to strong interference at most frequencies

Analysis of Seismic Ambient Noise
for Resonance Seismometry OSI Technique – the FISP Method

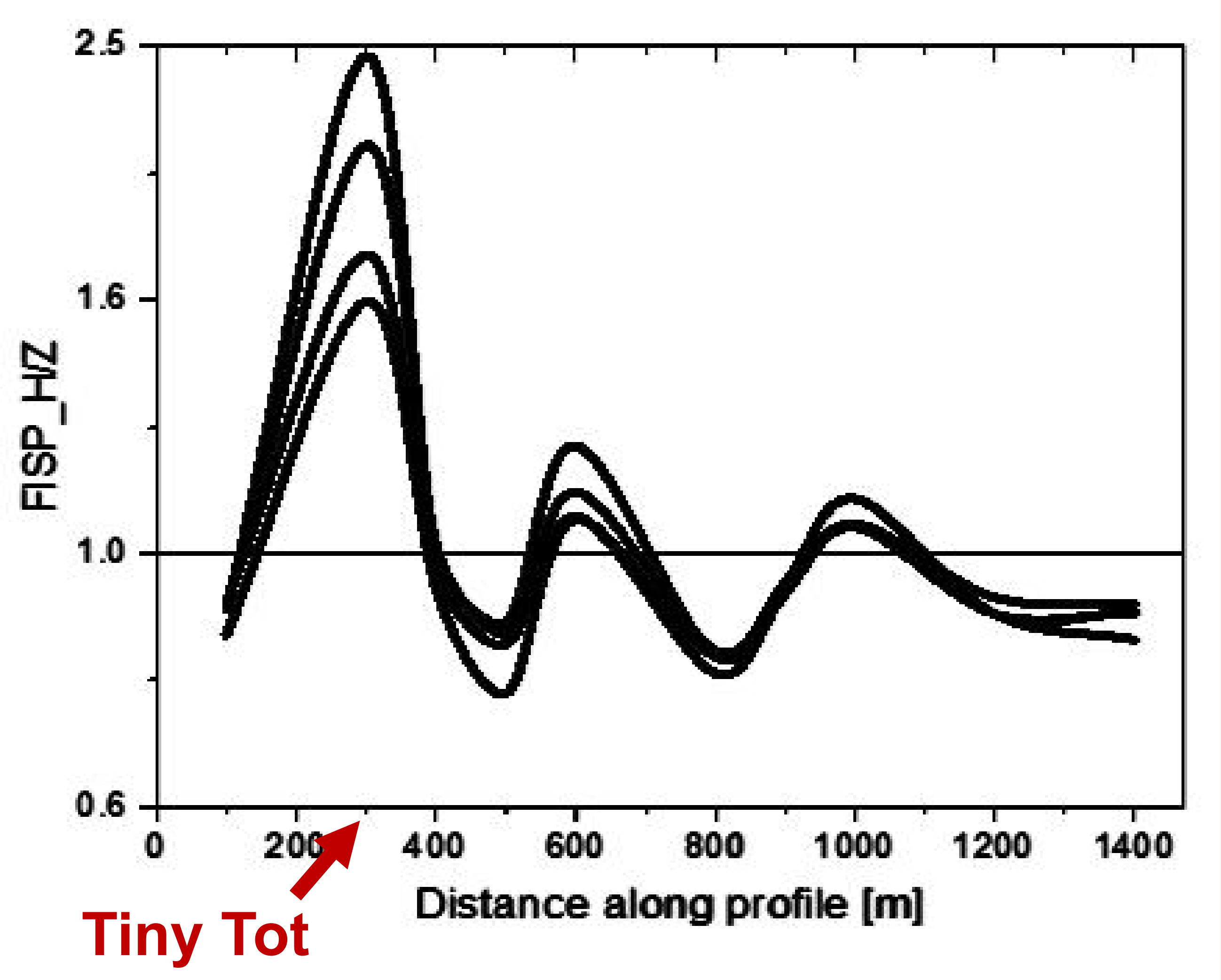
Miriam Kristekova, Jozef Kristek, Peter Moczo

Real-site application of FISP – Tiny Tot, NNSS, Nevada

$FISP_{H/Z}$ computed

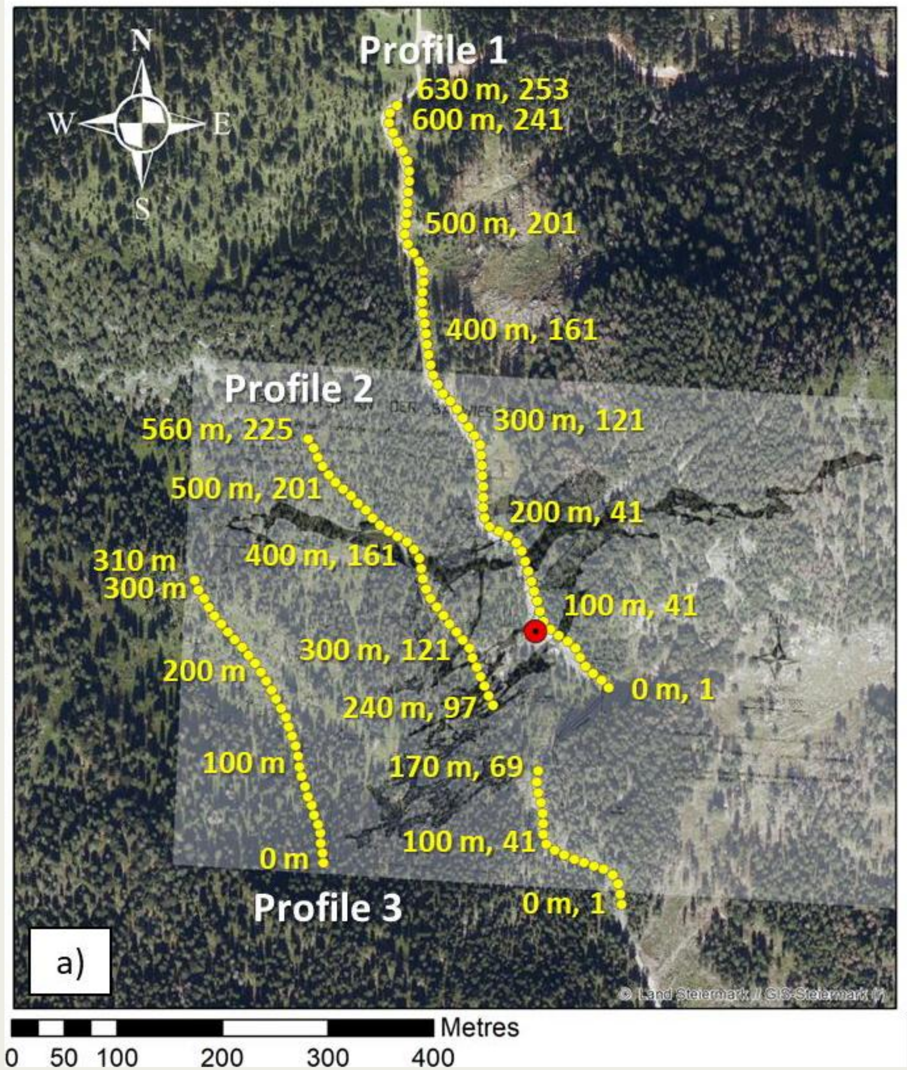
for frequency interval 17 - 24 Hz

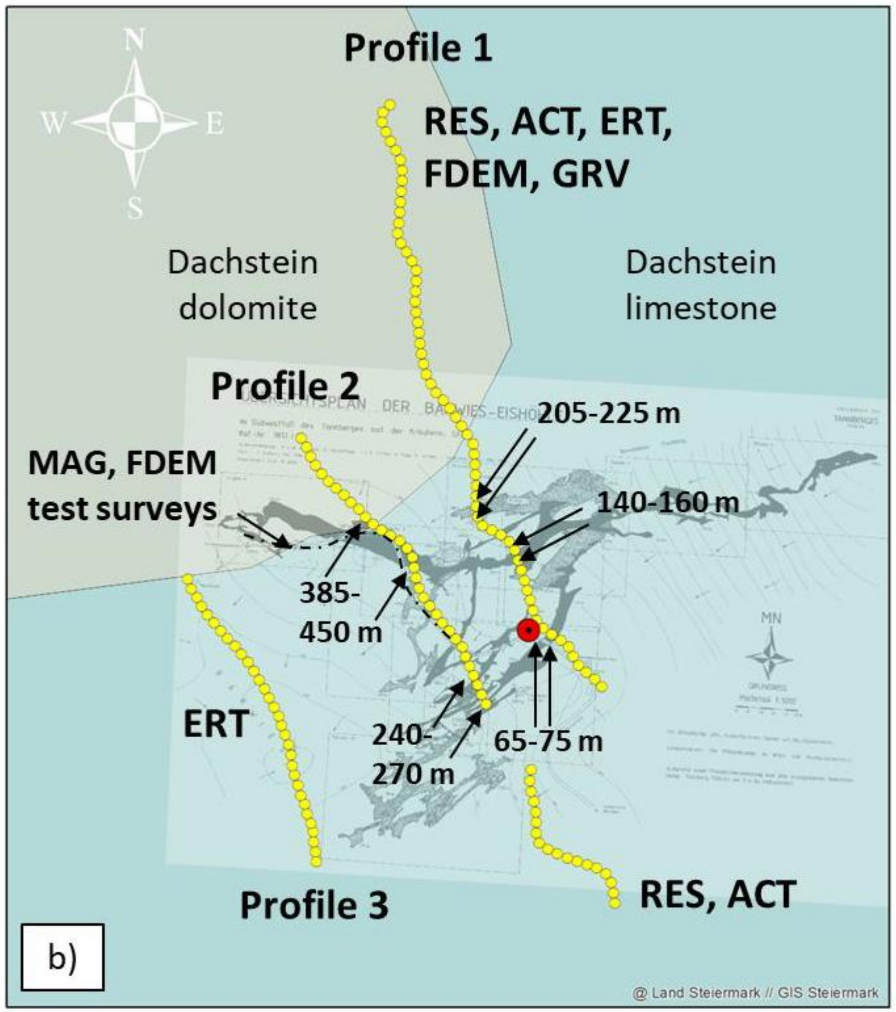
for 4 variations of FISP parameters



Miriam Kristekova, Jozef Kristek, Peter Moczo

Real-site application of FISP – Rotmoos, Austria

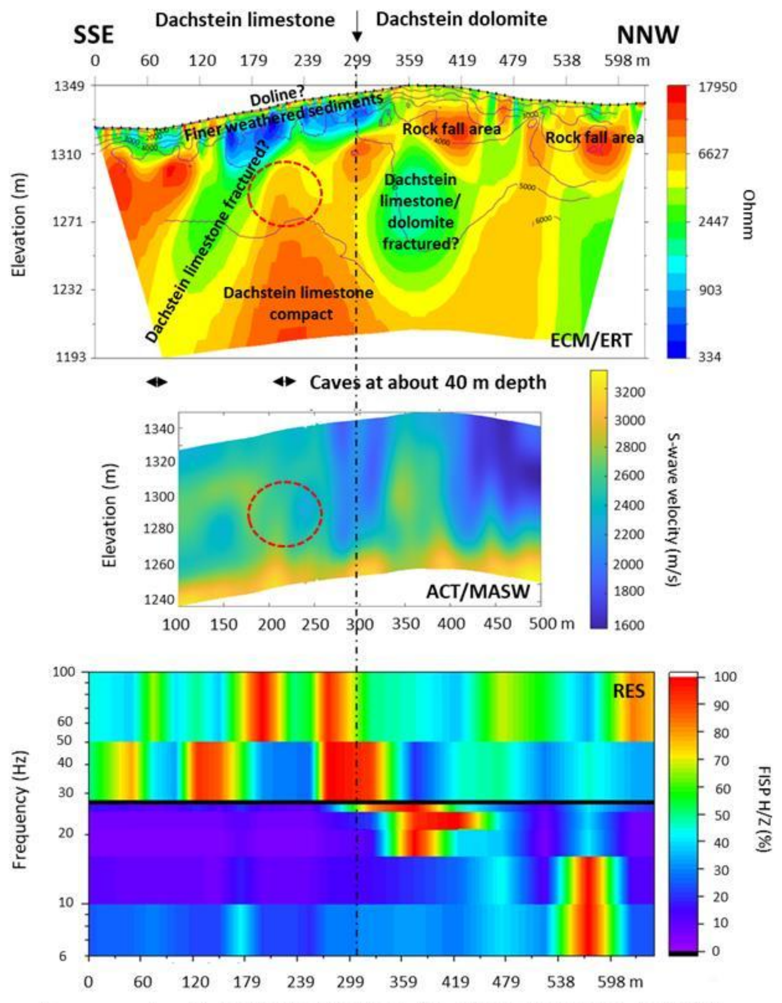




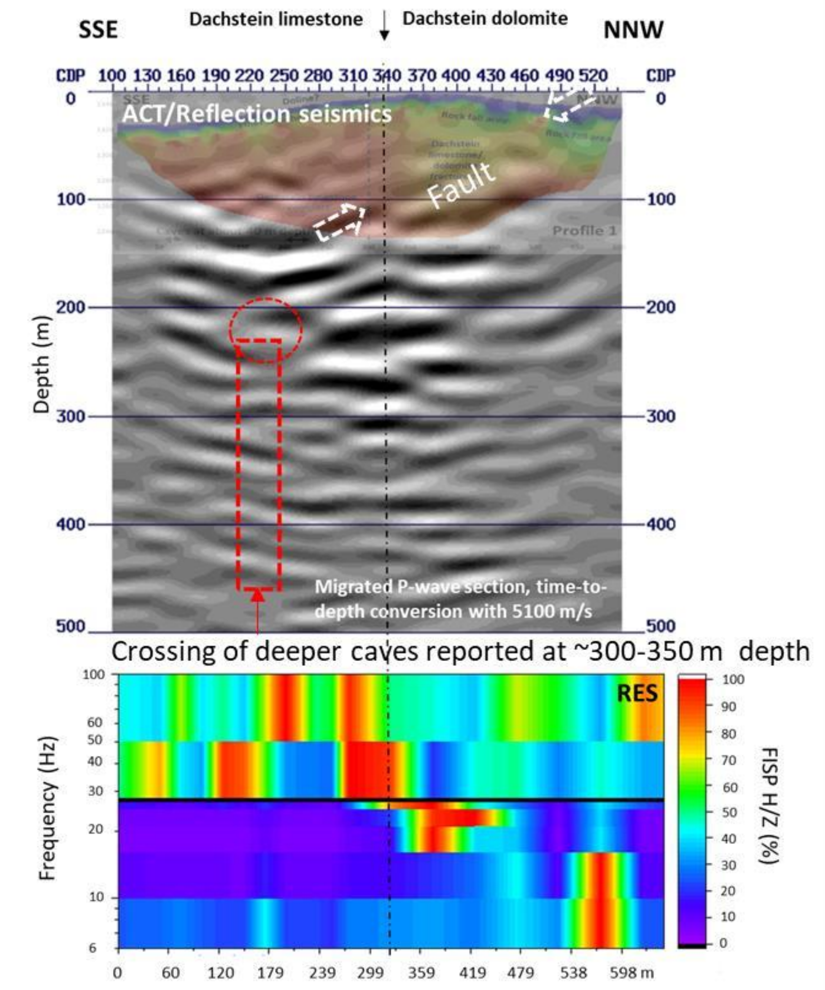
Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method

Miriam Kristekova, Jozef Kristek, Peter Moczo

Real-site application of FISP – Rotmoos, Austria



Frequency bands: 6-10, 10-15, 16-21, 21-25, 25-27, 28-50, 50-100 Hz



Frequency bands: 6-10, 10-15, 16-21, 21-25, 25-27, 28-50, 50-100 Hz

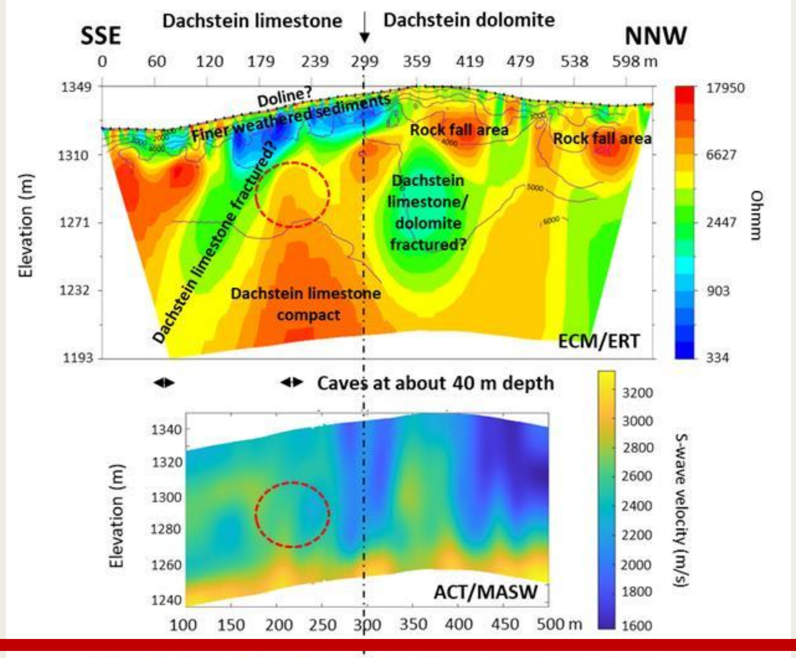
See: P3.3-556 Results of 2022 and 2023 OSI Field Tests for Seismic Techniques

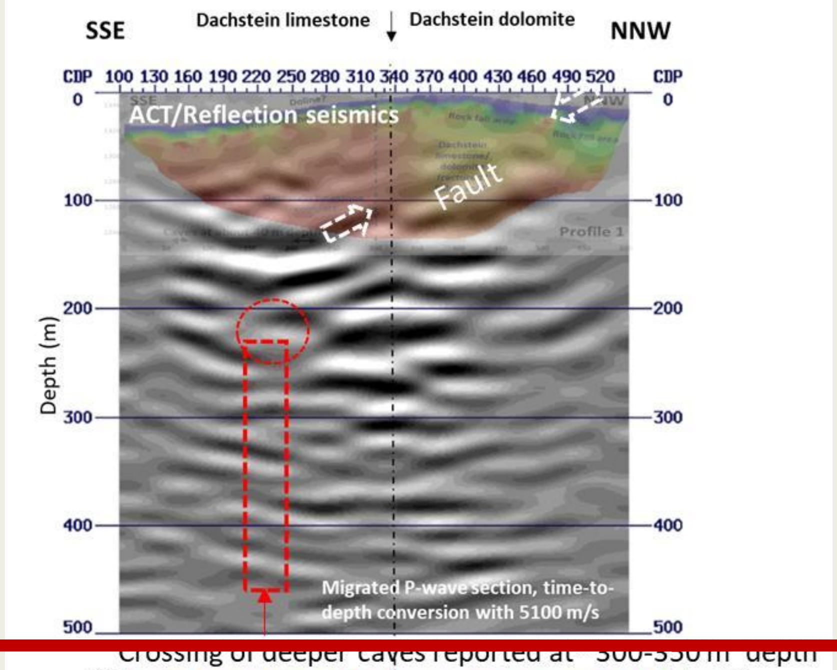
Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method

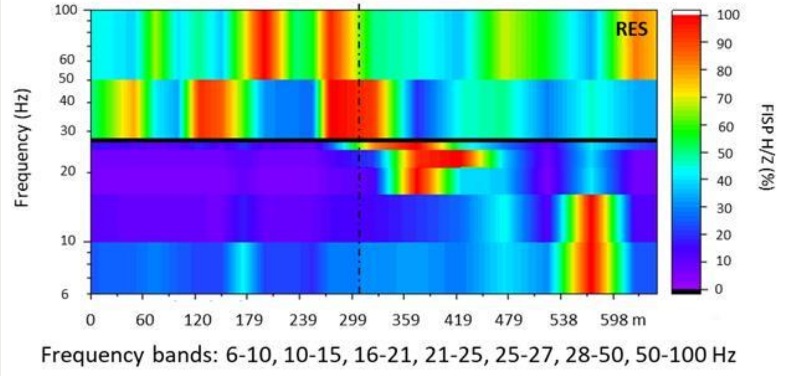
Miriam Kristekova, Jozef Kristek, Peter Moczo

O3.3-604

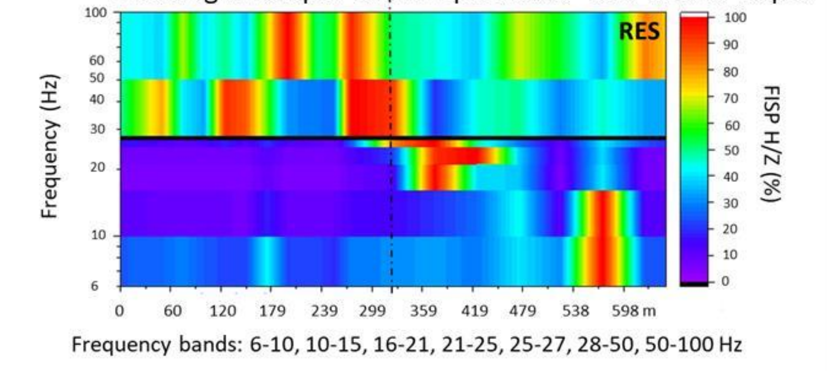
Real-site application of FISP – Rotmoos, Austria







FISP H/Z



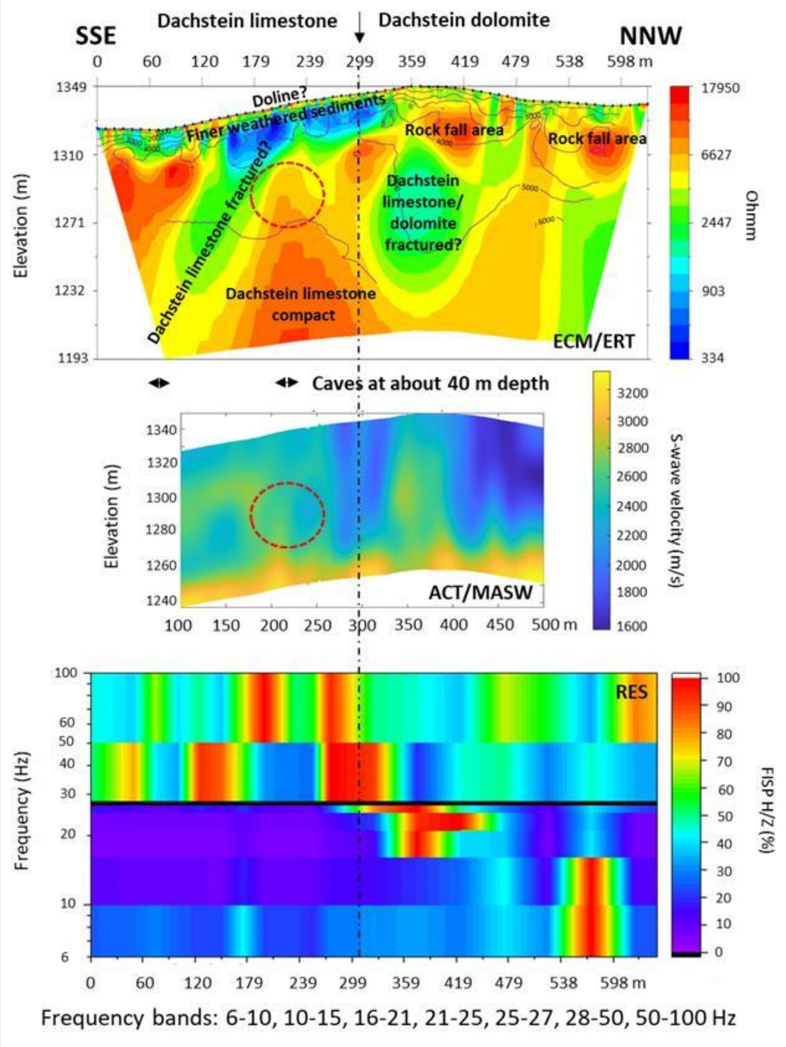
See: P3.3-556 Results of 2022 and 2023 OSI Field Tests for Seismic Techniques

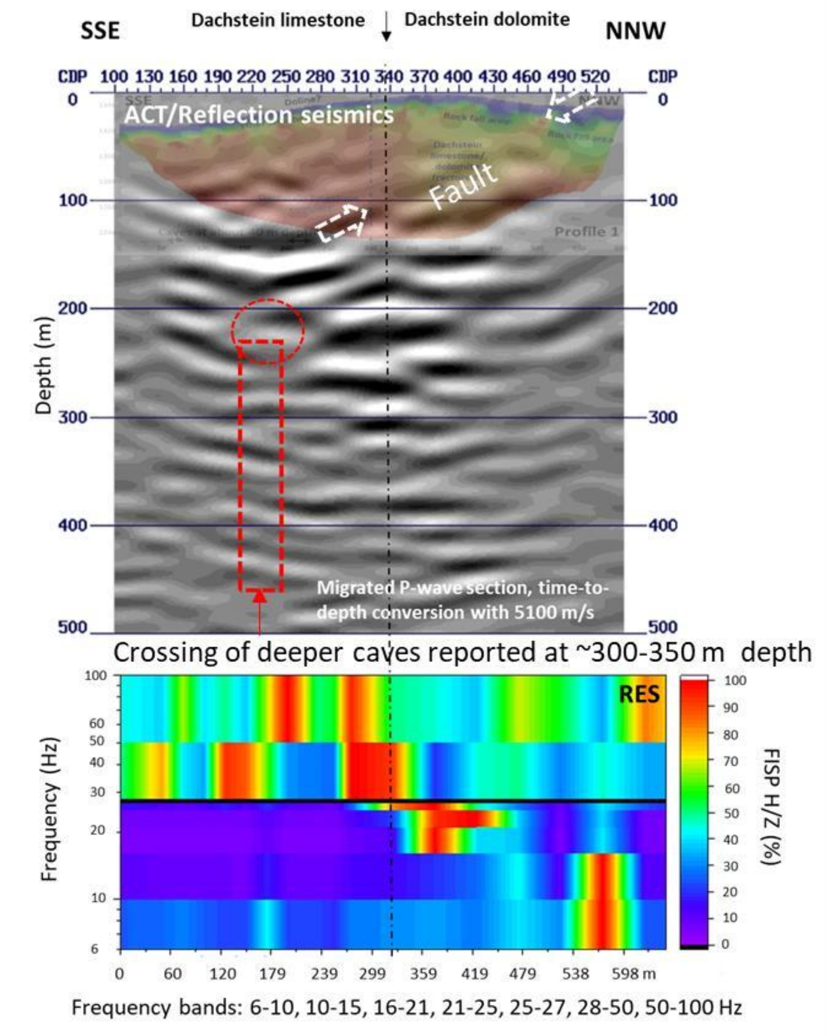
Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method

Miriam Kristekova, Jozef Kristek, Peter Moczo

O3.3-604

Real-site application of FISP – Rotmoos, Austria

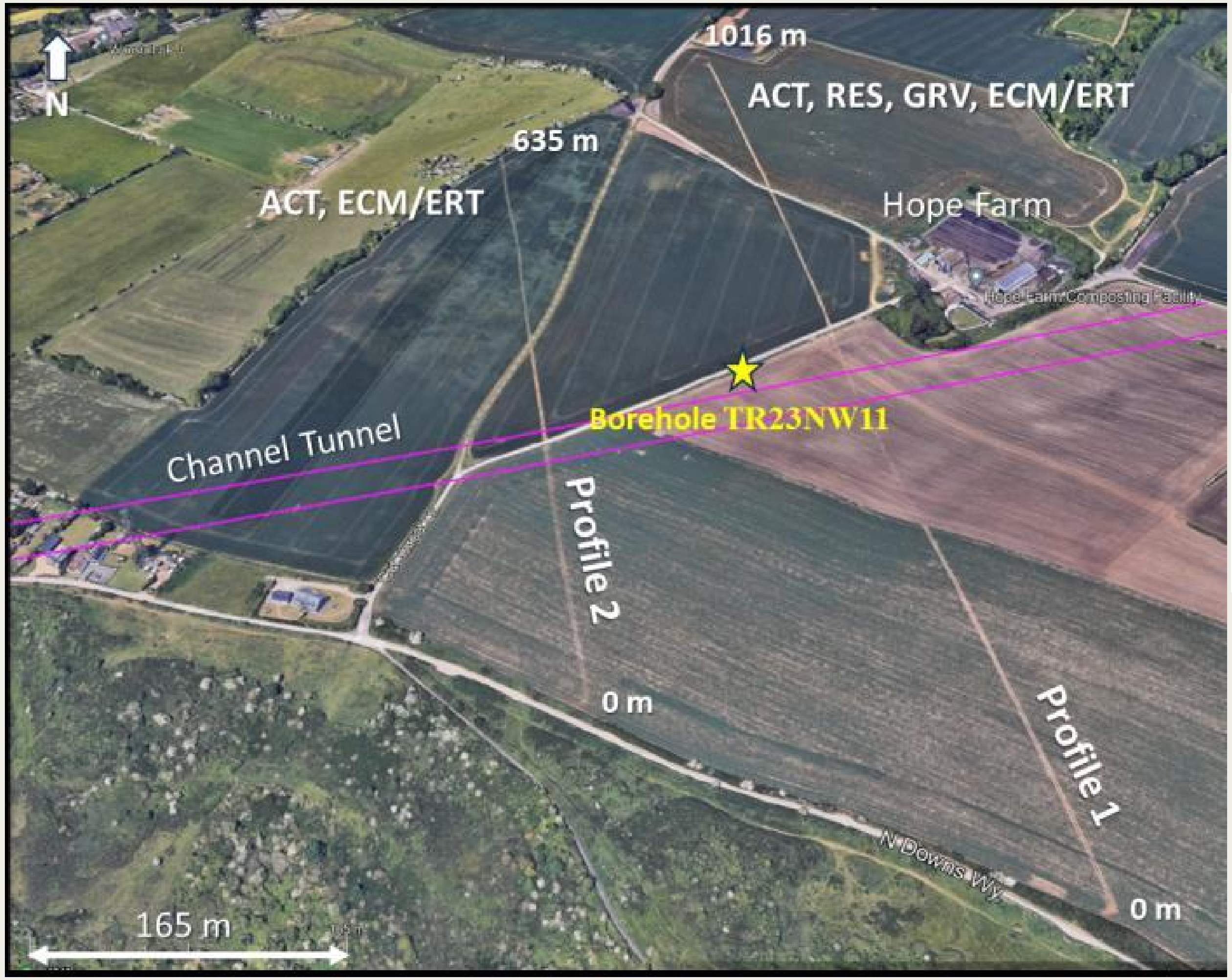


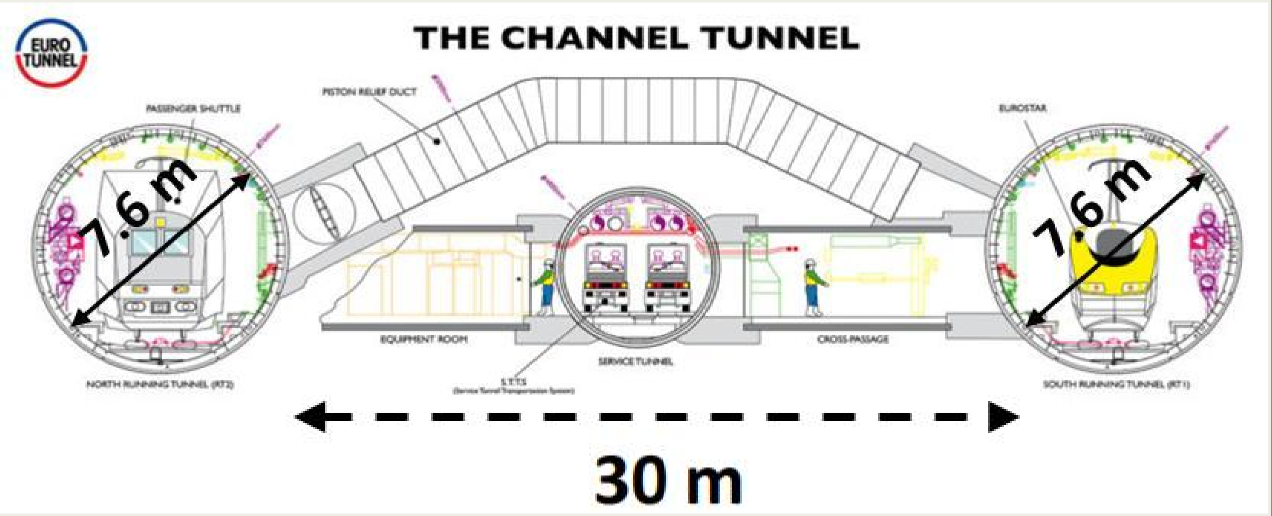


See: P3.3-556 Results of 2022 and 2023 OSI Field Tests for Seismic Techniques

Miriam Kristekova, Jozef Kristek, Peter Moczo

Real-site application of FISP – Channel Tunnel, UK

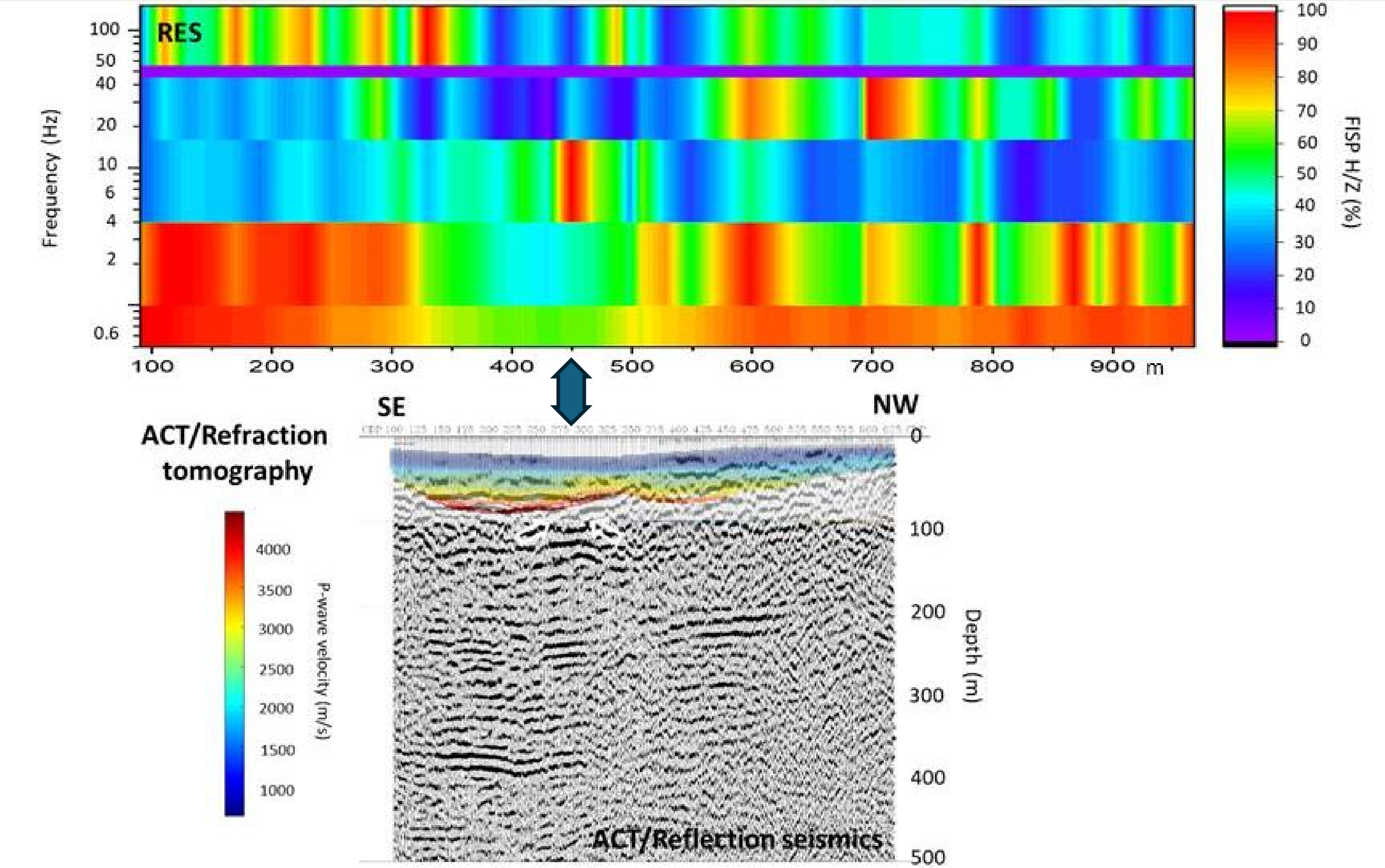




used data from Profile 1
across the Channel Tunnel
excavated in chalk marl at 90 m depth

Miriam Kristekova, Jozef Kristek, Peter Moczo

Real-site application of FISP – Channel Tunnel, UK



Unmigrated P-wave section, time-to-depth conversion with 2000 m/s

See: P3.3-556 Results of 2022 and 2023 OSI Field Tests for Seismic

Miriam Kristekova, Jozef Kristek, Peter Moczo

Conclusions

The application of FISP at various locations

has shown that

the method has the potential

to identify and locate underground cavities.

Miriam Kristekova, Jozef Kristek, Peter Moczo

Conclusions

Based on our experience in processing data we have the following recommendations for organizing future noise measurements for resonance seismometry:

- measuring instruments must be **sufficiently sensitive** to be able to record even the weakest level of seismic noise in the range of at least several hundred counts,
- if two or more measuring instruments are to be used, it is necessary to ensure and **test that the seismic noise recorded** by all instruments **at the same place is the same**,
- seismic noise should be measured at all locations in the **most similar conditions possible**,

Miriam Kristekova, Jozef Kristek, Peter Moczo

Conclusions

- measurements should be **disturbed as little as possible** by technogenic activities (including staff),
- after the initial measurement in the basic grid of measuring points and after the first analysis of FISP anomalies it is useful to perform **additional measurements in denser grid** around the places with anomalous values of FISP to verify and/or ensure the reliability of obtained of FISP anomaly,
- when selecting suitable frequency interval for FISP calculation, **avoid frequencies** containing an energy **from technogenic sources**,
- subject the obtained results to **sensitivity analysis** in relation to different time windows selection and different time segment selection.

FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS
Comenius University
Bratislava

Miriam Kristekova, Jozef Kristek, Peter Moczo

Many thanks

to the CTBTO team of experts who performed the measurements at all sites,
and
to the members of the CTBTO Expert Group for the fruitful discussions.

FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS
Comenius University
Bratislava

Miriam Kristekova, Jozef Kristek, Peter Moczo

Thank you !

See also: P3.3-556 Results of 2022 and 2023 OSI Field Tests for Seismic Techniques

FACULTY OF MATHEMATICS,
PHYSICS AND INFORMATICS
Comenius University
Bratislava