

Seismic Borehole Methods for Engineers

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A short guide for
Tomography, Crosshole and Downhole methods
and their applications

1. Why using seismic borehole methods ?
2. Which seismic borehole methods are available?
3. Which information can be obtained from seismic borehole methods?

Situation: Underground structures are three-dimensional and heterogeneous



Limestone
compact

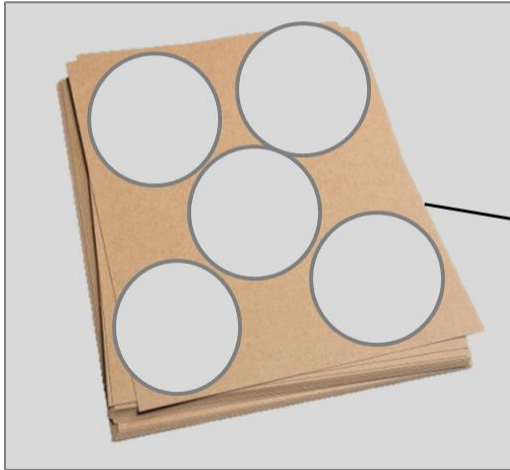
Limestone with
fracture filling

Clay

Limestone embedded
in clay

What is your knowledge base if you have five drillings to explore an area of the size of a football ground?

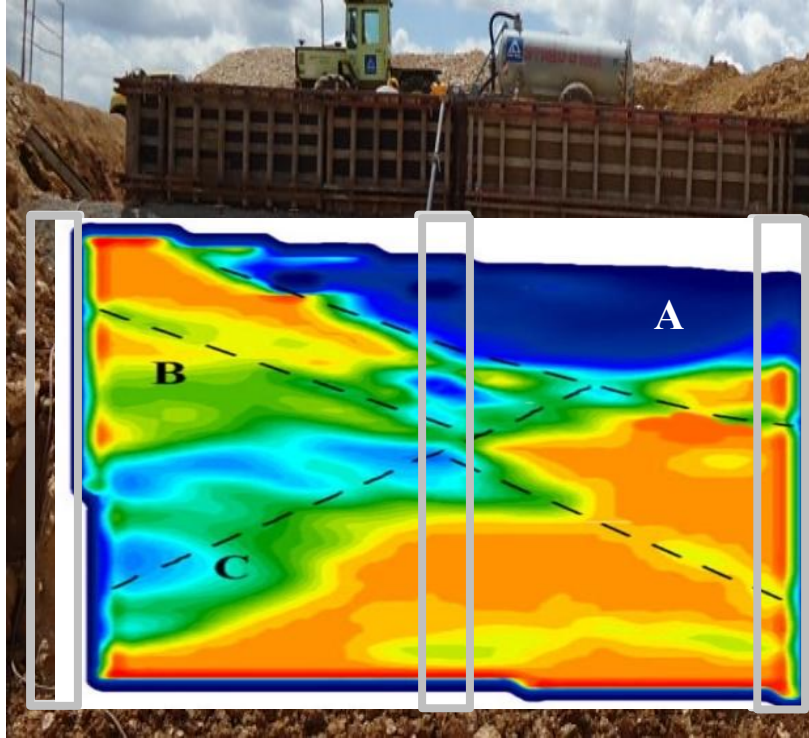
Five drillings of 5" size cover an area of an A4 sheet.



Boreholes can only be pinpricks in an unknown host rock.



Imagine if you could expand your knowledge by connecting the boreholes and analyse the space in between...



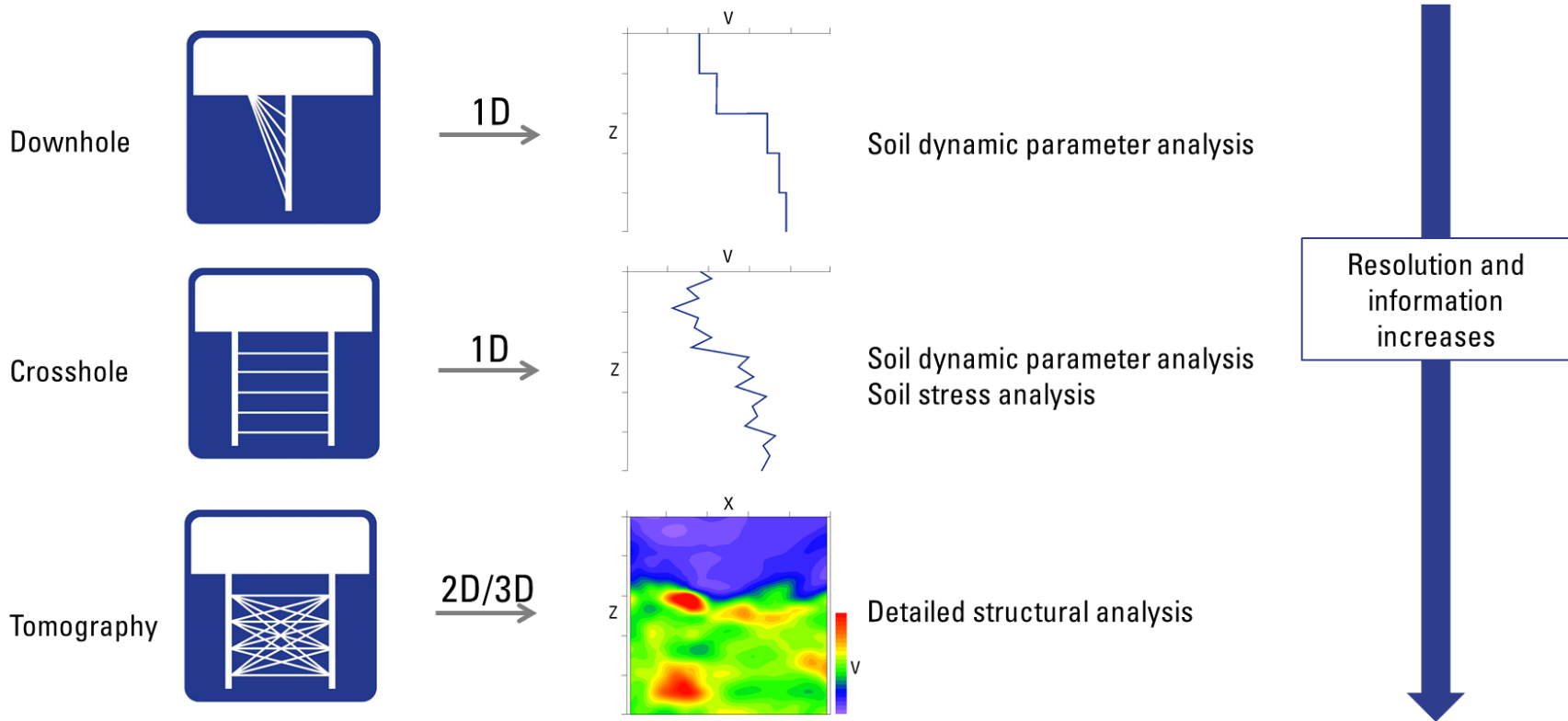
Borehole methods provide **more information** about the subsurface than available from drilling, sampling, or surface geophysics alone.

Borehole seismic can **fill the gap between boreholes** and provide even 3D images if more than two boreholes are used.

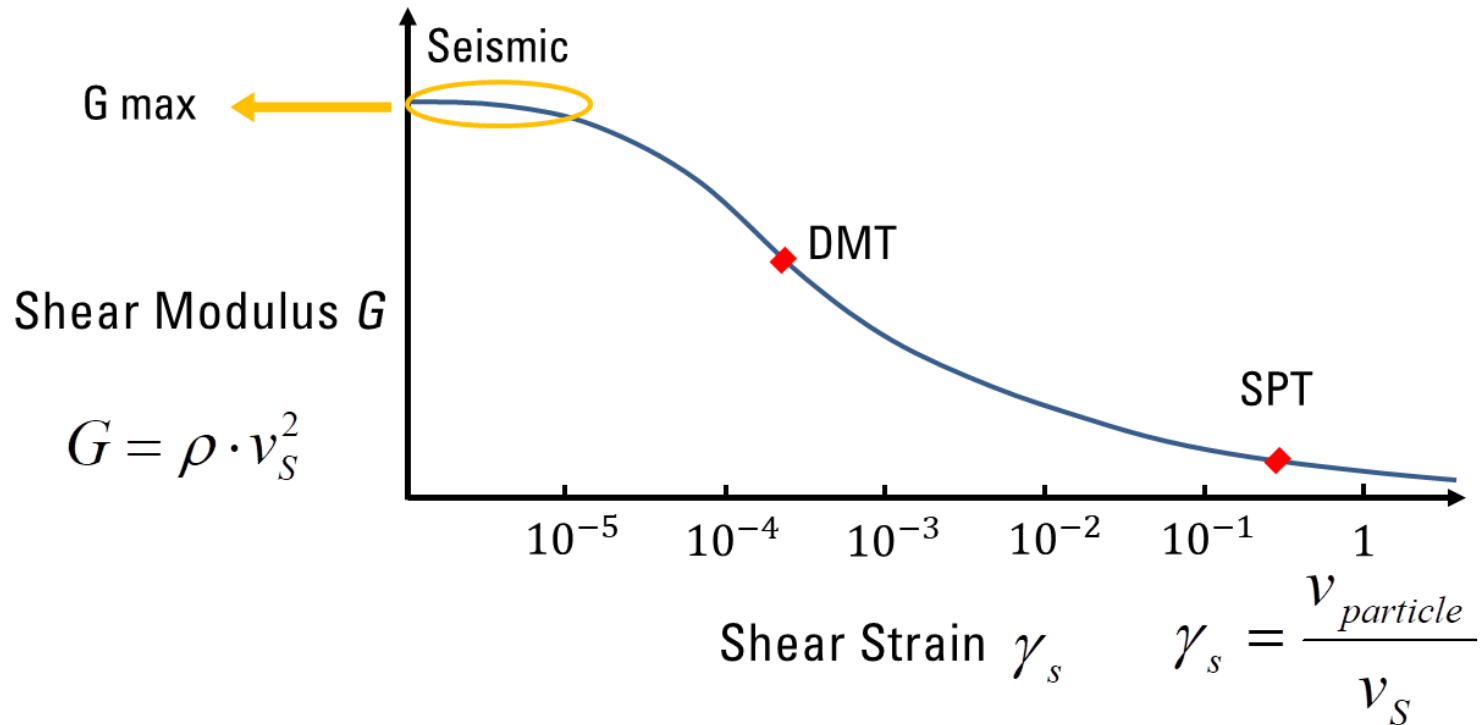
The advantage of seismic is that it is the only geophysical method that is **sensitive to rock mechanical parameters**.

Seismic Borehole Methods

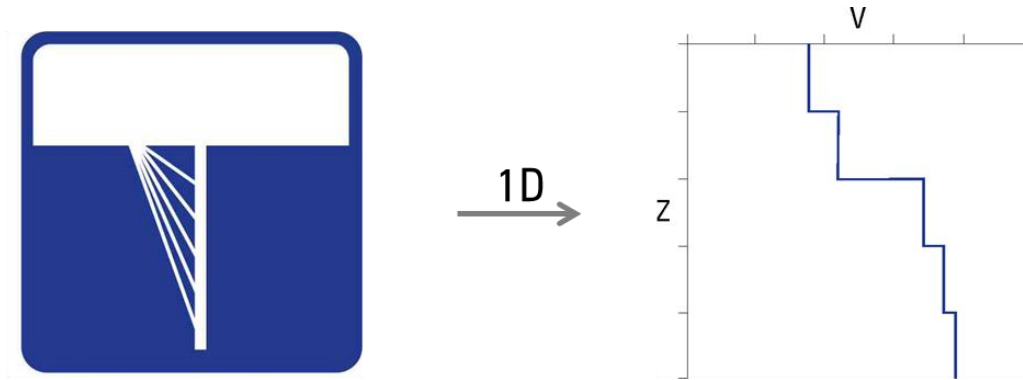
Soil Characterization



The most important parameter needed for soil characterization is the shear modulus.



Downhole-Test (DHT)



- One borehole needed for the downhole-test
- Borehole should be PVC cased with grouting for an optimal coupling
- Investigation possible to a depth of about 100 m
- Measurement interval is usually 1 or 2 m
- Horizontal offset between source and borehole should be max. 1-3 m

Downhole-Test is required

1

... where the calculation of the structure - soil interaction is required for dynamic loads:

Site characterisation

Ship locks/ship lifts

Power plants

Bridges

Wind turbines

2

... where the calculation of foundation settlements is required:

Buildings

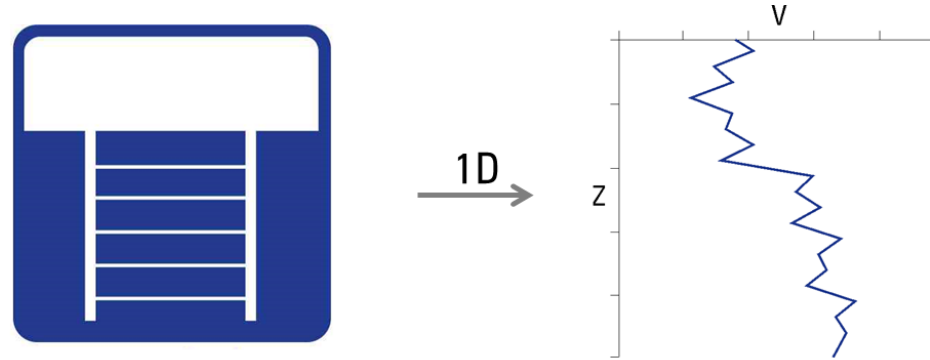
Infrastructure

Shear
Modulus
(G_0)

Poisson's
Ratio
(ν)

Young
Modulus
(E)

Cross-hole-Test



- Two boreholes are needed for the crosshole-test
- Boreholes should be PVC cased with grouting for an optimal coupling
- Investigation is possible to a depth of about 200 m
- Measurement interval is usually 1 or 2 m
- Borehole spacing should be between 3 and 10 m

Cross-hole-Test is required

1

... where the calculation of the structure - soil interaction is required for dynamic loads:

Ship locks/ship lifts

Power plants

Bridges

Wind turbines

2

... where the calculation of settlements and/or soil stress information (horizontal vs vertical) are required:

Buildings

Infrastructures

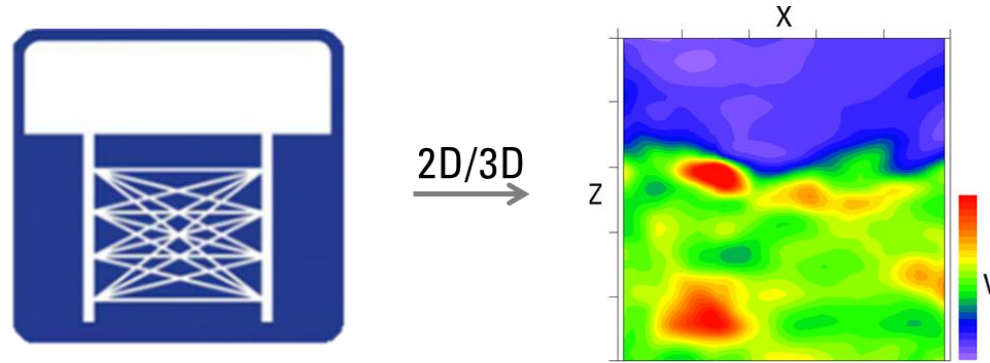
**Shear
Modulus
(G_0)**

**Poisson's
Ratio
(ν)**

**Young
Modulus
(E)**

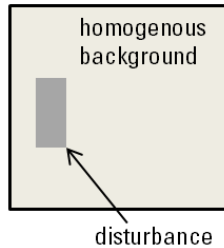
**Over-
Consolidation
(OCD)**

Seismic Tomography

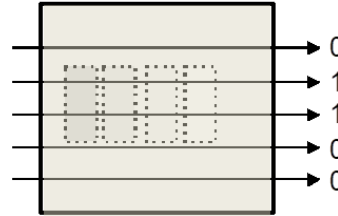


- At least 2 boreholes needed for seismic tomography
- Boreholes should be PVC cased with grouting for an optimal coupling
- Water-filled boreholes are required
- Investigation possible to a depth > 100 m
- Measurement interval is usually 1 or 2 m
- The borehole spacing should be between 5 and 100 m (depending on geology and required structural resolution)

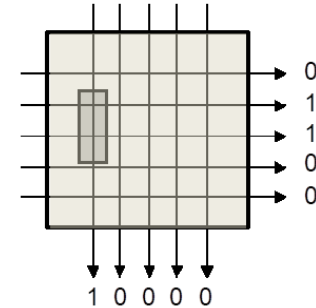
Seismic Tomography provides a high-resolution structural velocity image.



Homogenous background with one disturbance.



Rays crossing through the surface may show changes (1) from background (0).



The disturbance can be located if other directions are also considered.

With only one ray direction, the correct location of the disturbance can not be obtained.

Tomography is required

1

... where
(geological)
structures have to
be detected:

Natural cavities/
karst structures

Weak/
disaggregation zones

Man-made mining
shafts/tunnels

Sinkholes

2

...where
investigation of the
founding rock is
needed

Buildings

Infrastructures

3

...where time-
dependent
processes have to
be imaged

Gas/water injection

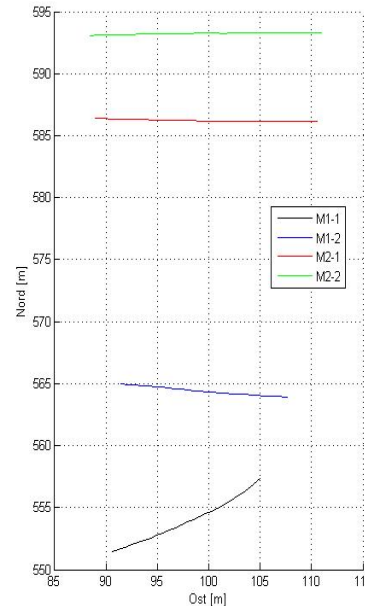
Grout injections

Geothermal

Equipment used in borehole seismics

	Power Supply	Sources	Receivers
 tomography			
 crosshole			
 downhole			

Tomography to detect soil improvement



In the immediate vicinity of a ship lock system, karst structures were identified through drilling. It is suspected that the karstification is affecting the stability and therefore the safety of the lock.

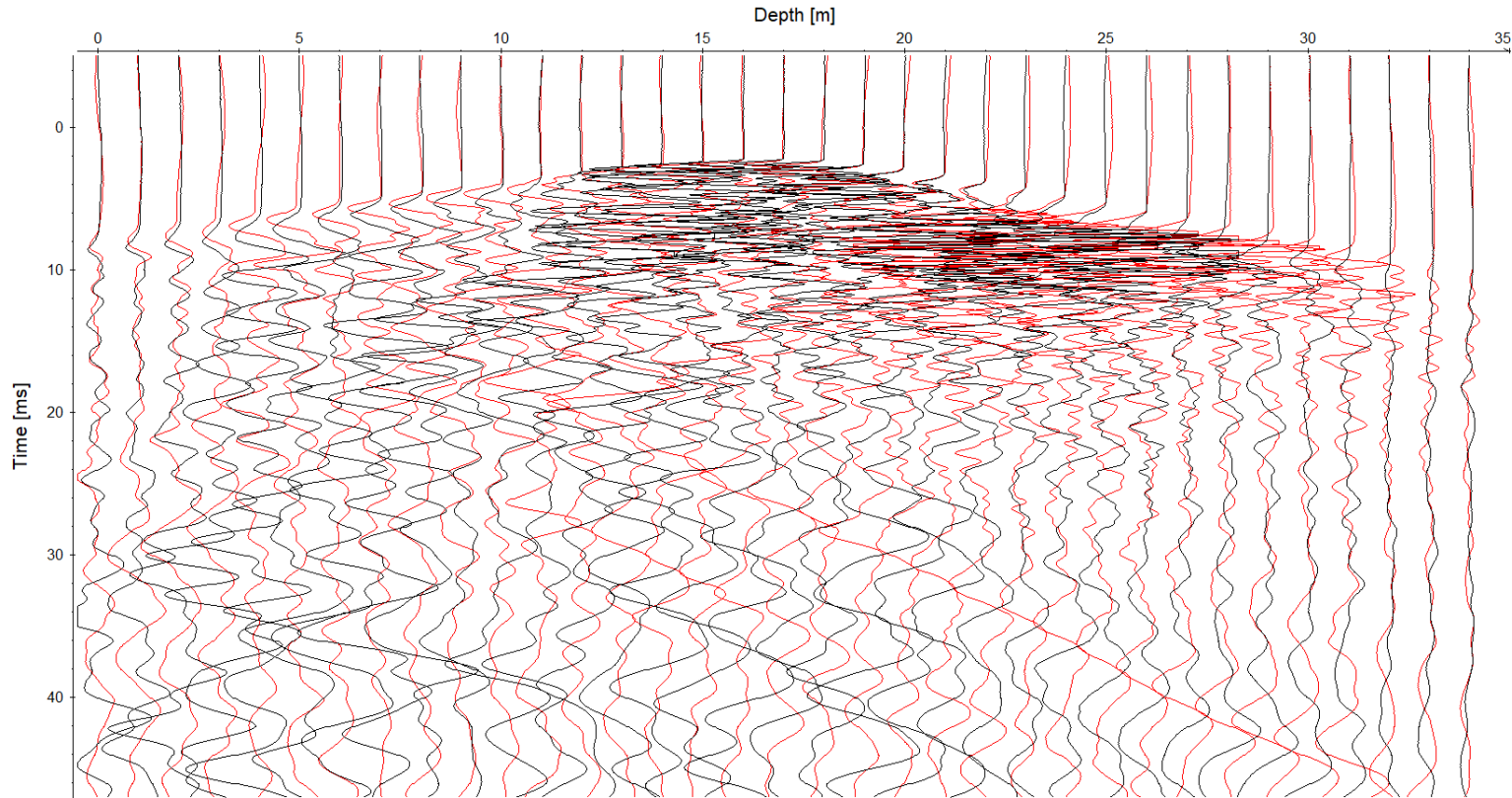
The cavity extent was already investigated in 2016 as part of seismic and tomographic investigations and crosshole tests.

Two test areas were defined in which concrete was to be injected via inclined boreholes.

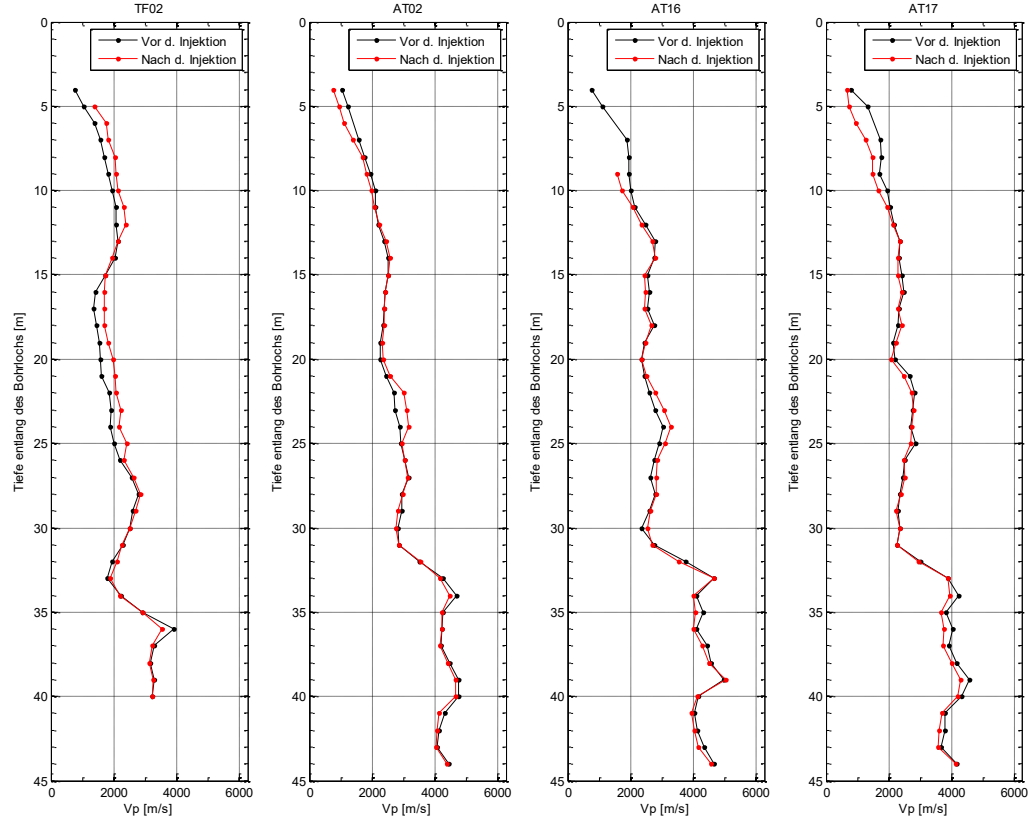
Seismic before-and-after tomography was to be used to determine the success of the injection measures.

It was expected that the injection of concrete would lead to a significant increase in seismic velocity in the karstified areas.

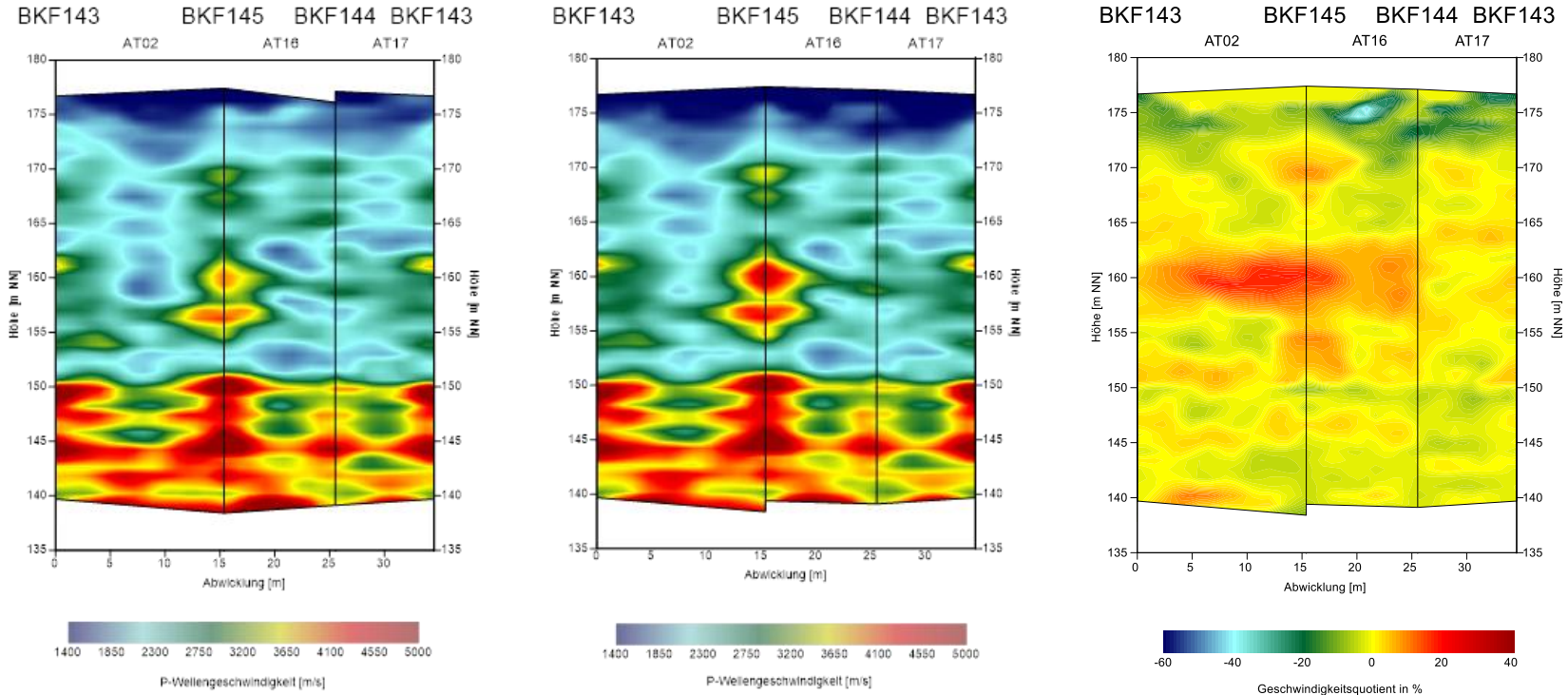
Seismic signals before (black) and after injection (red)



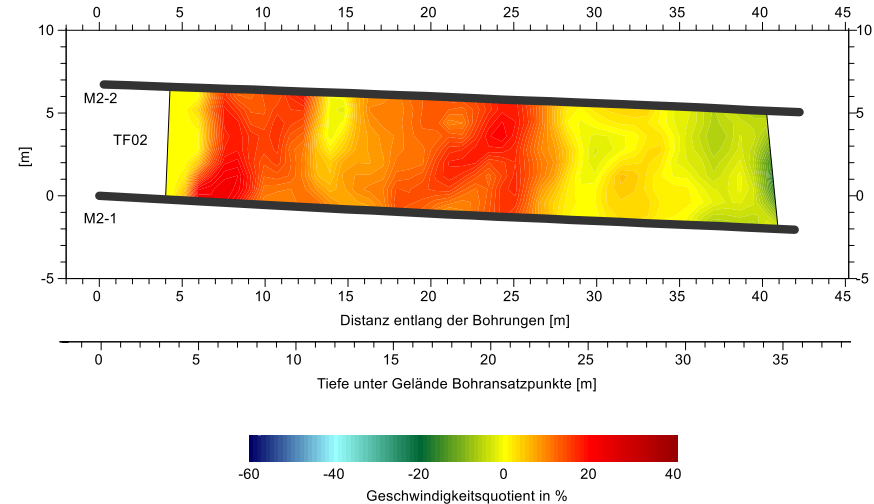
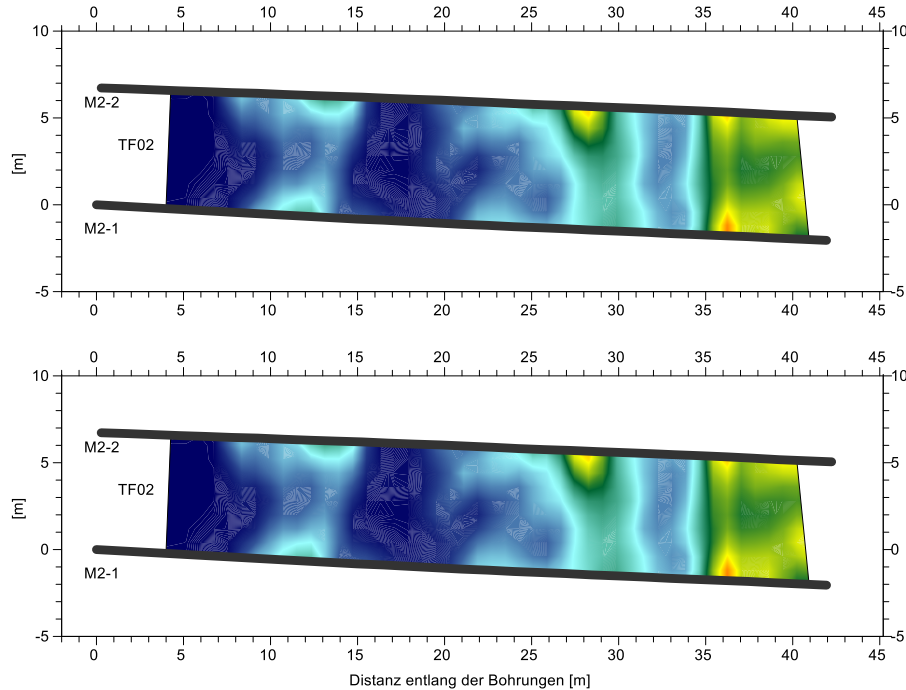
Seismic velocities before (black) and after injection (red)



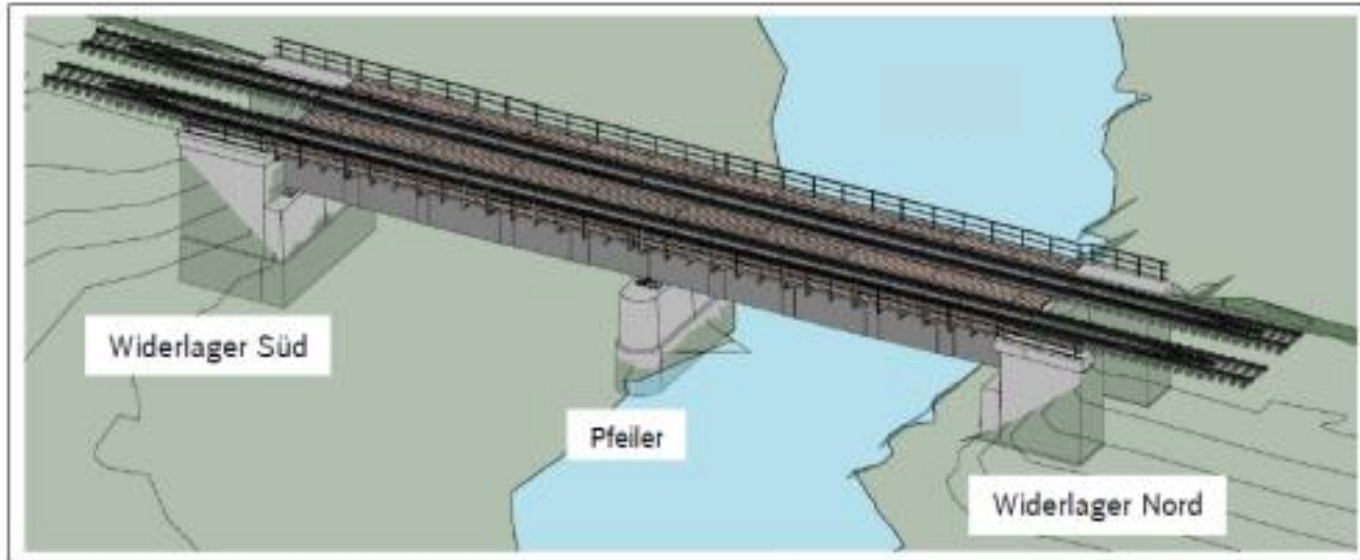
Seismic tomograms before and after injection and ratio



Seismic tomograms before and after injection and ratio



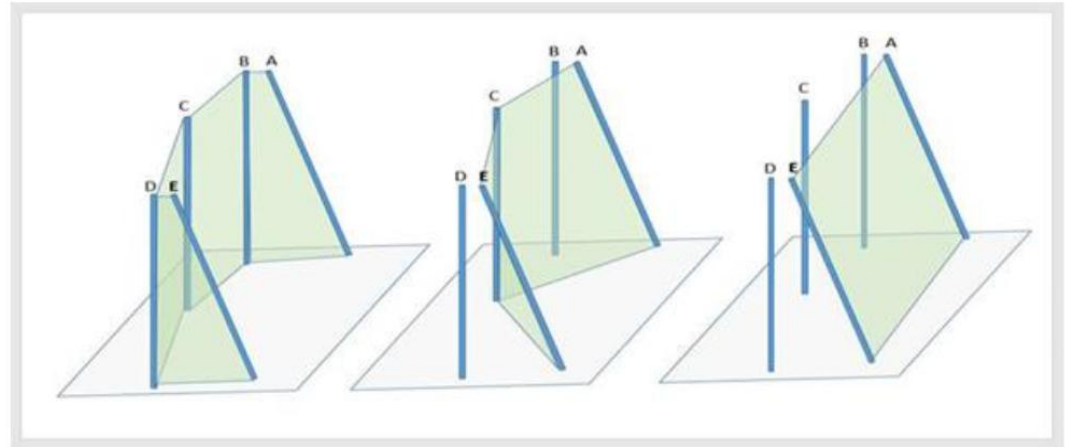
Seismic tomograms to detect cavities and weak zones



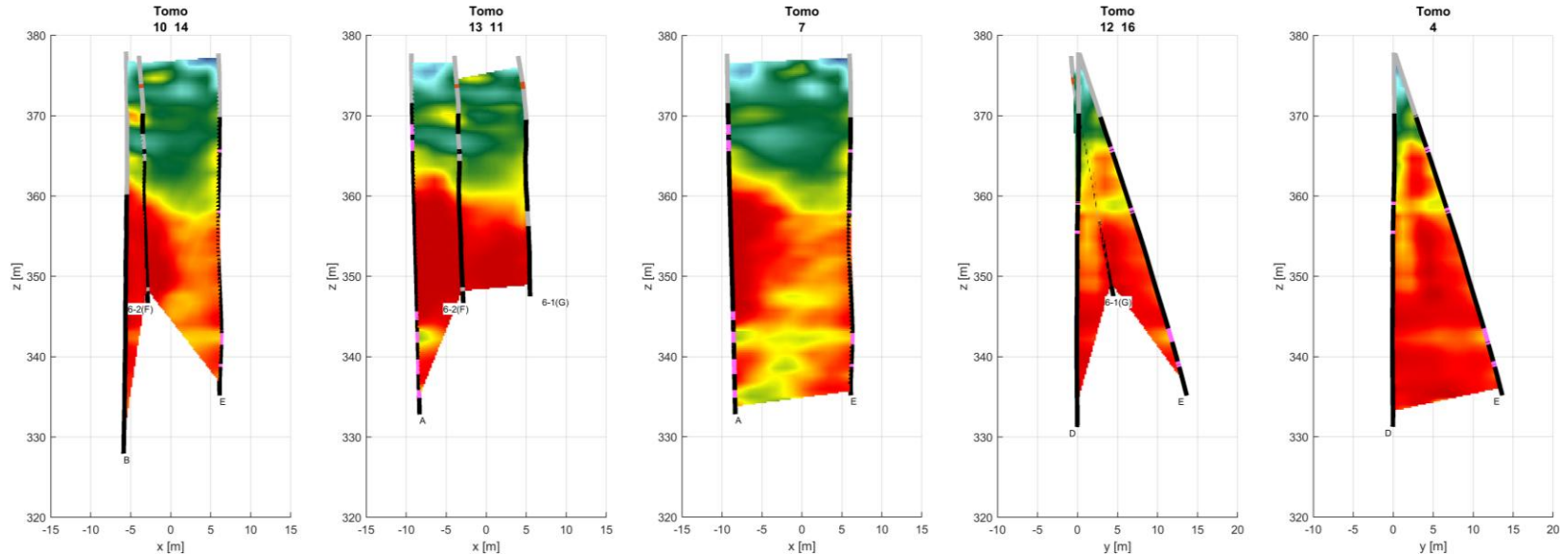
As part of the German Railway infrastructure project railway bridges are going to be investigated to check their current state and the potential need to strengthen the abutment of the bridges.

The seismic measurements were initiated in order to detect possible cavities or potential weak points .

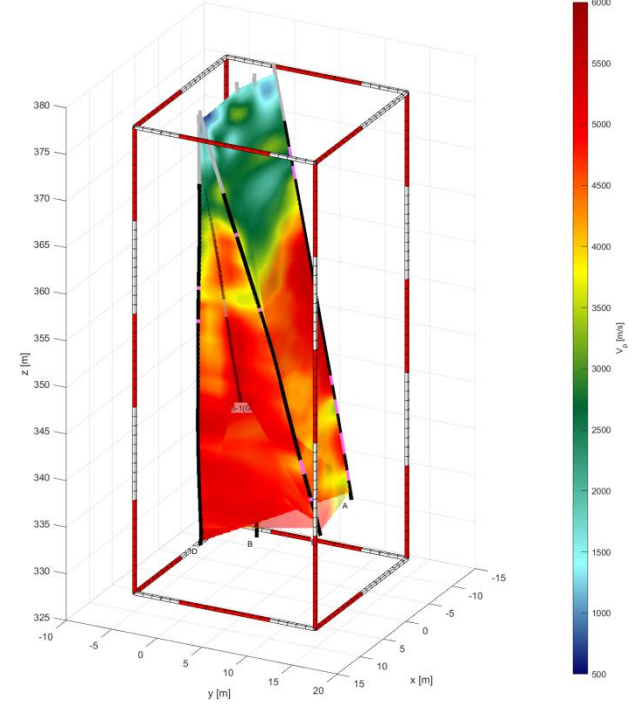
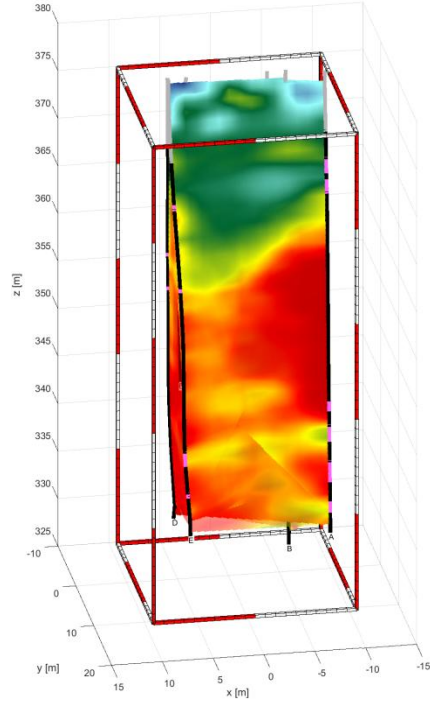
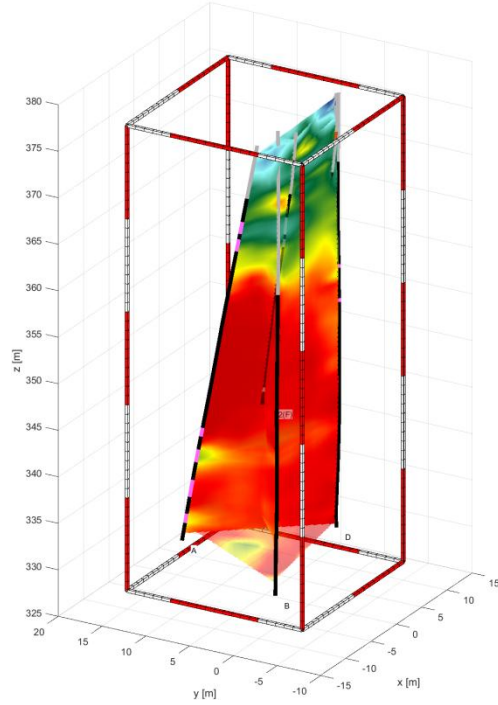
Borehole locations and tomogram slices



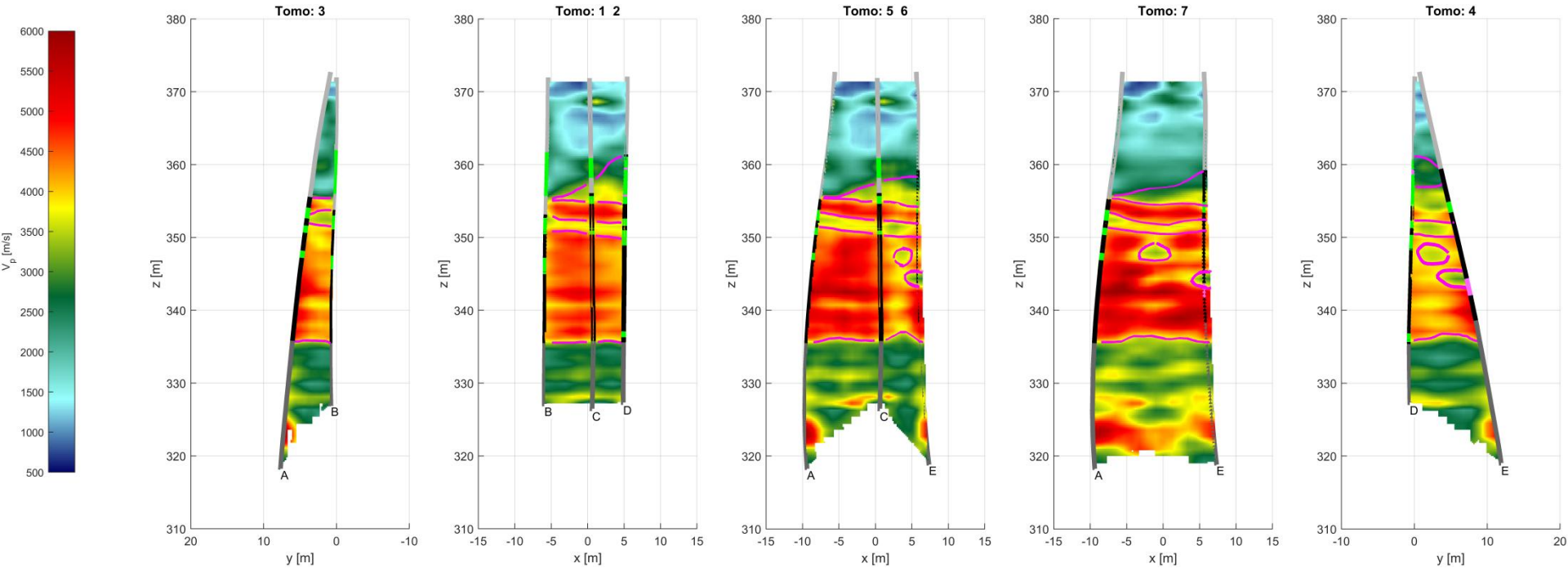
Tomograms in 2D



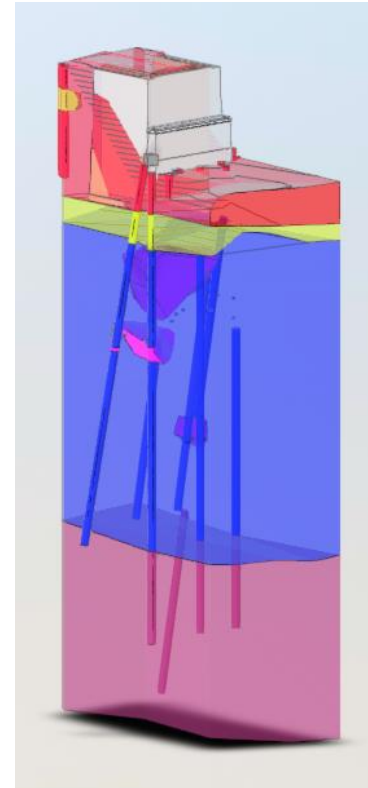
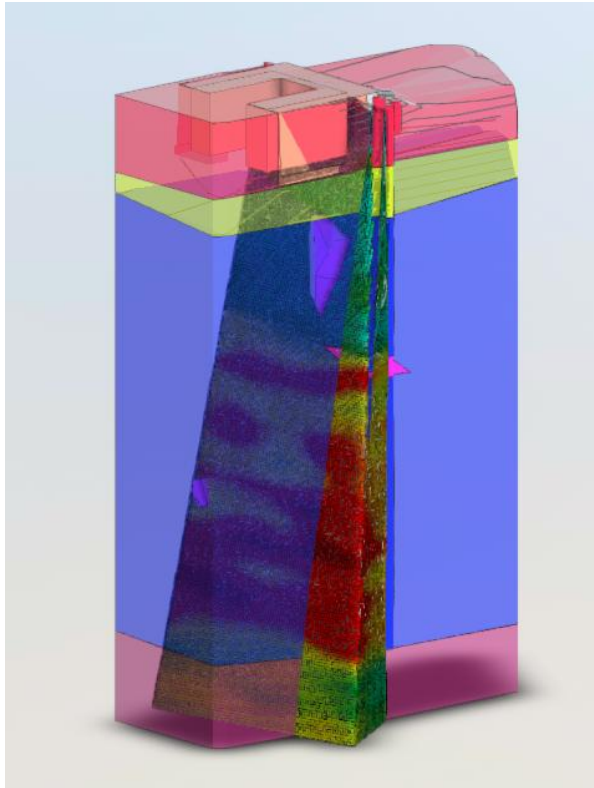
Tomograms in 3D



Tomograms to BIM



BIM – Building Information Model for customer



Summary

- Borehole seismic tests provide soil dynamic parameters (G, E, OCD)
- Borehole seismic tests provide structural information like cavities & weak zones
- Borehole seismic tests can monitor time dependant soil changes like cement injections
- Seismic information can be included into BIM
- Important part is that both sides speak to each other and that there is time and money allocated for this.



Thank you for your attention

