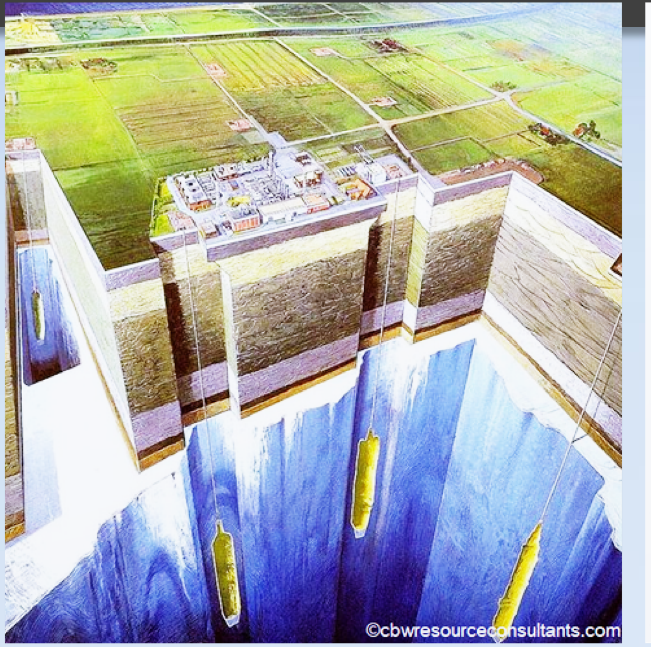
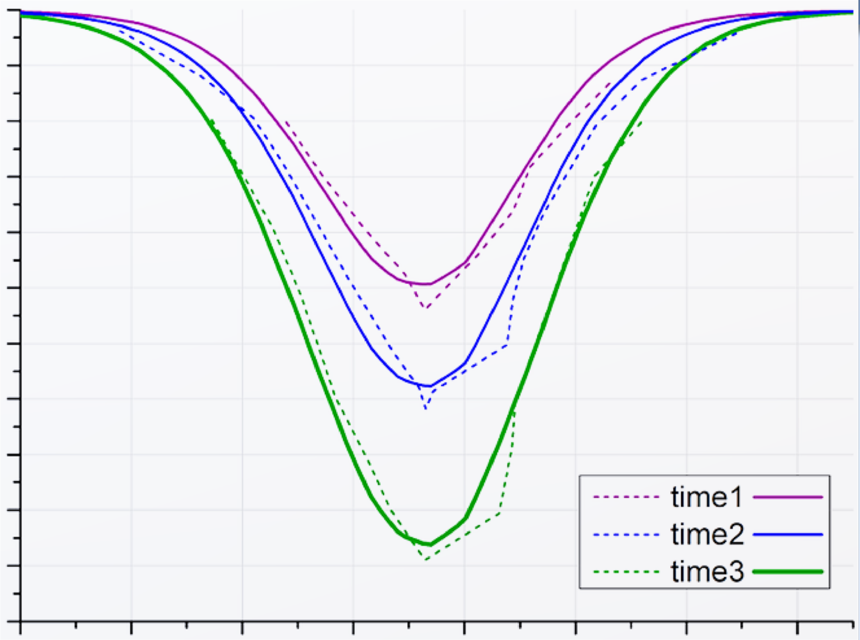
Large-scale 3D modeling of a realistic cavern field within a salt dome

Combined application of Griddle, FLAC3D & Python

Institut für Gebirgsmechanik GmbH
Untersuchung·Prüfung·Beratung·Begutachtung

Objectives





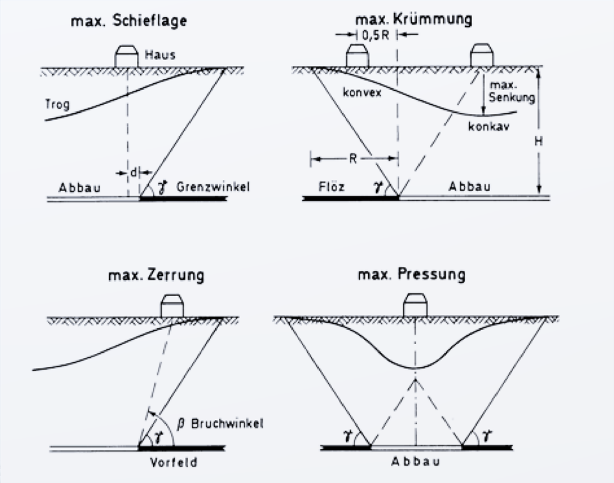
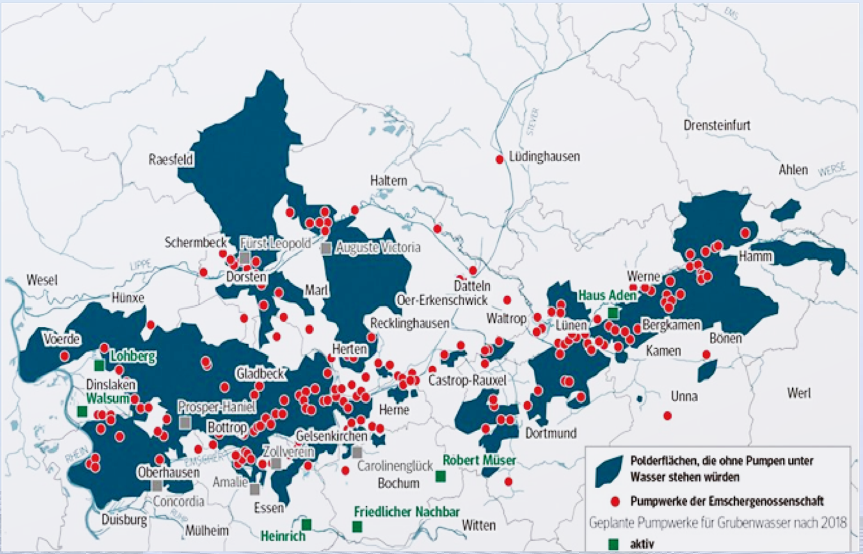
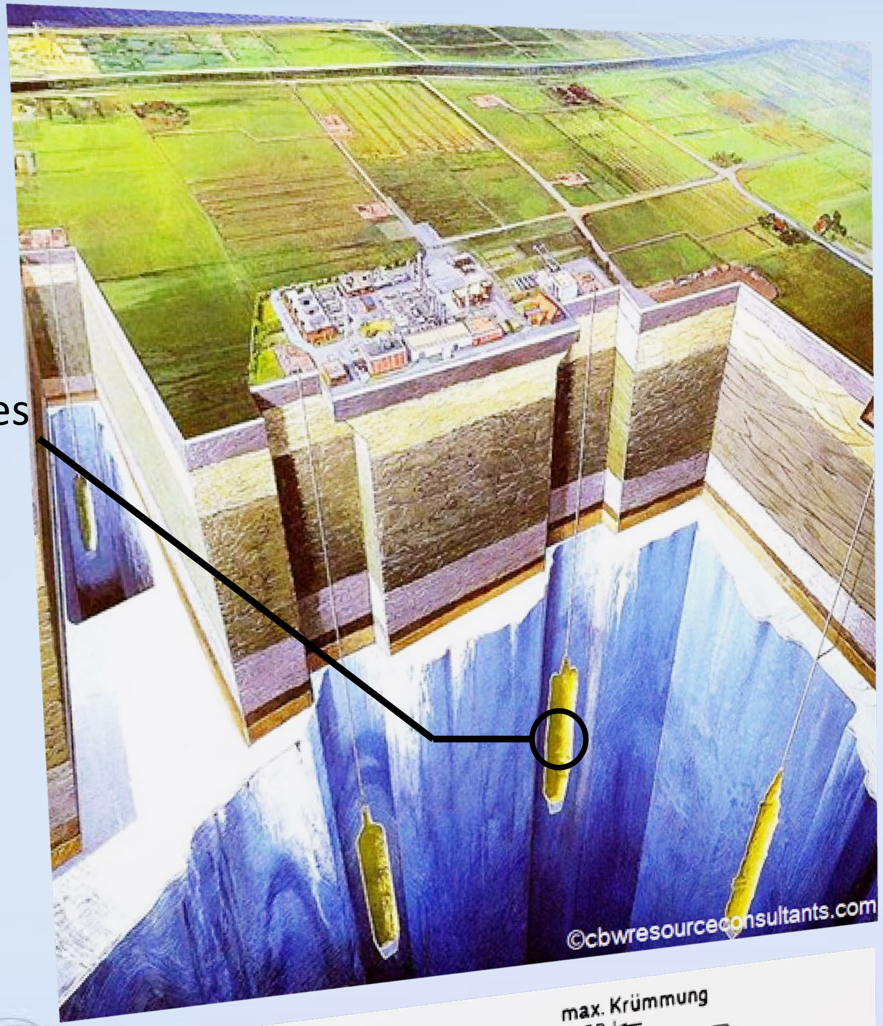
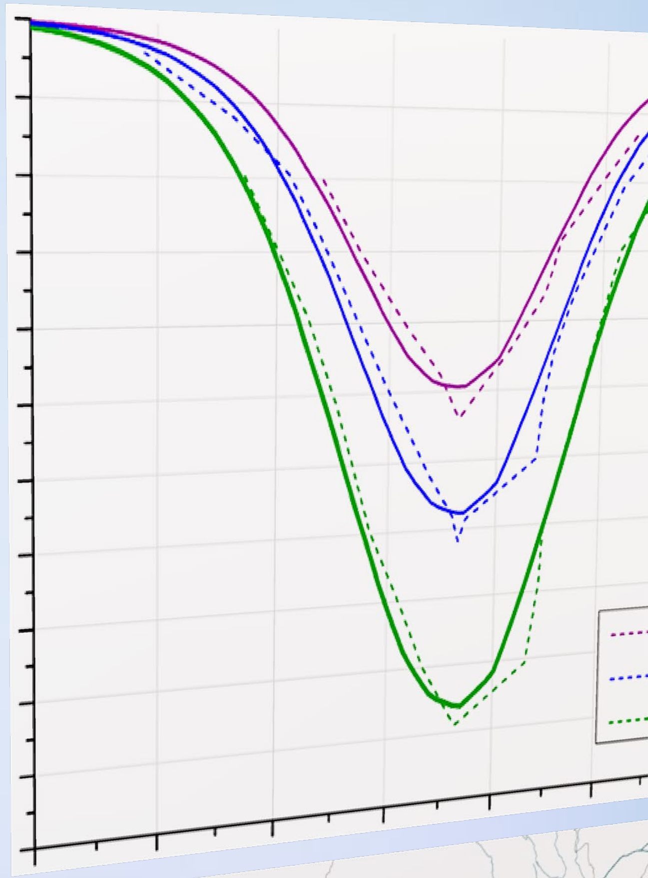


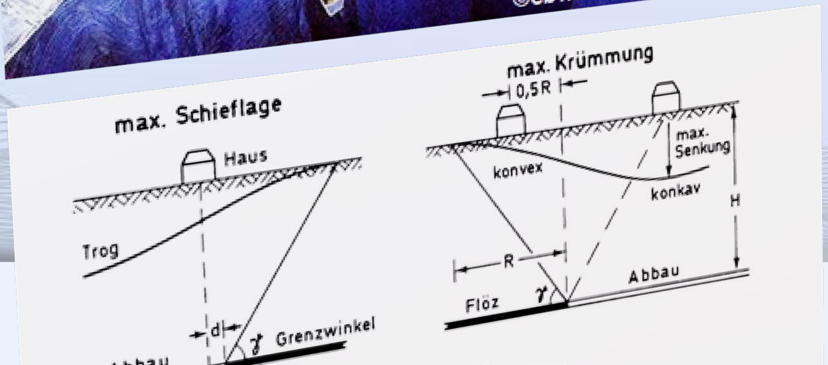
Abb. 236. Die Ortslagen maximaler Bodenbewegung oder -verformung über einem Abbaufeld in der Teufe H (Schnittriß)

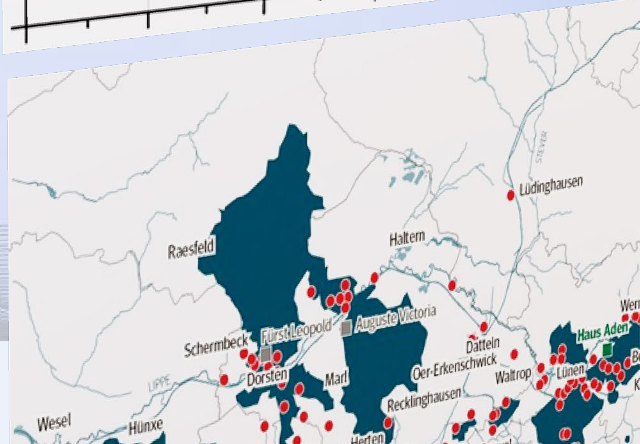


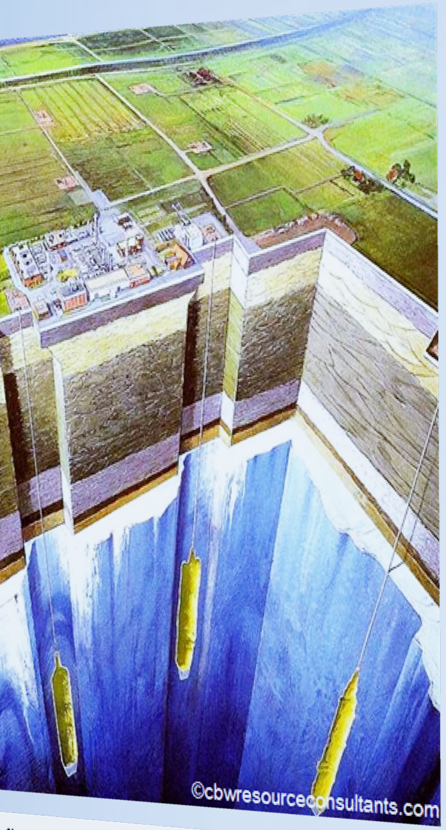
Sub-surface convergence of caverns / mined cavities induces subsidence at surface

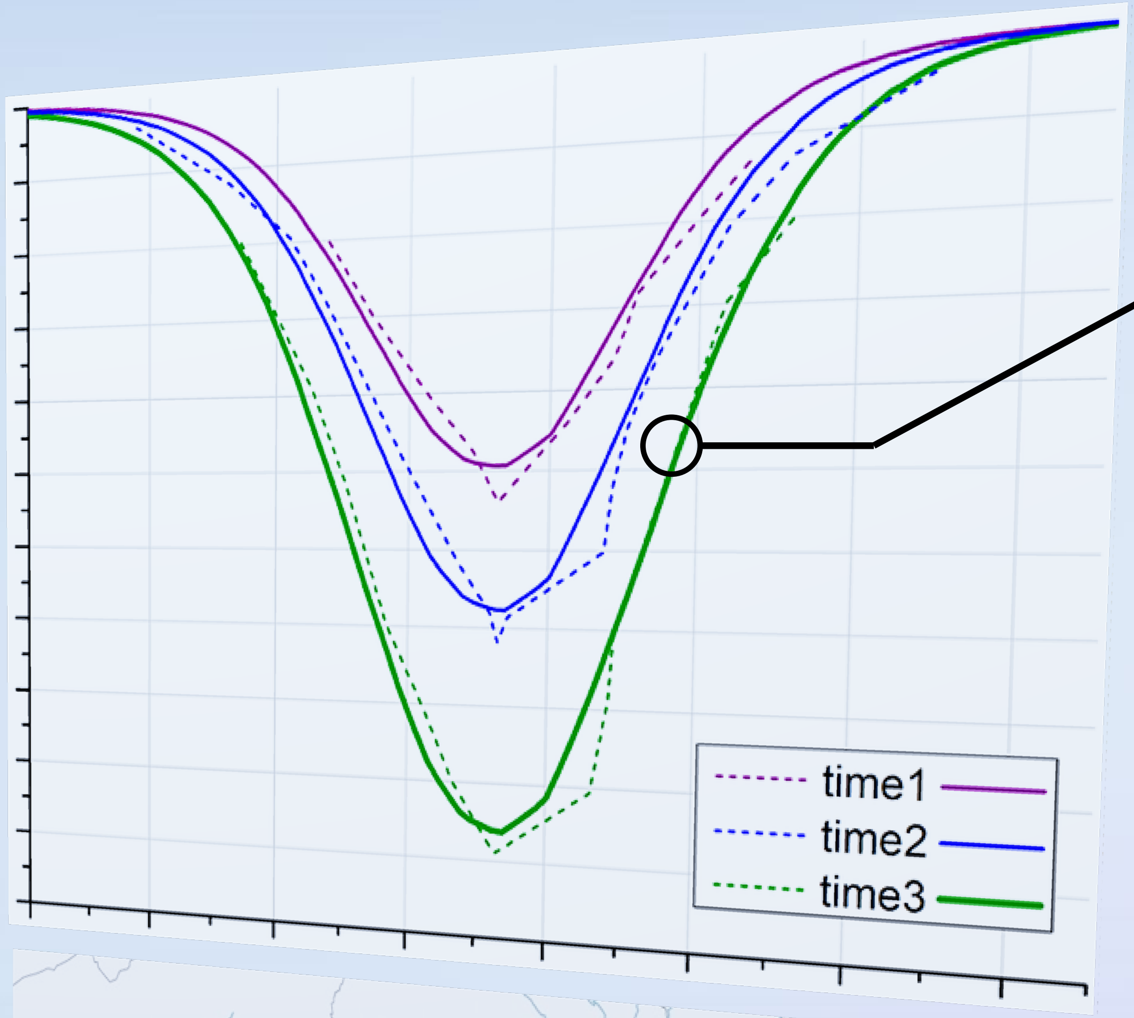




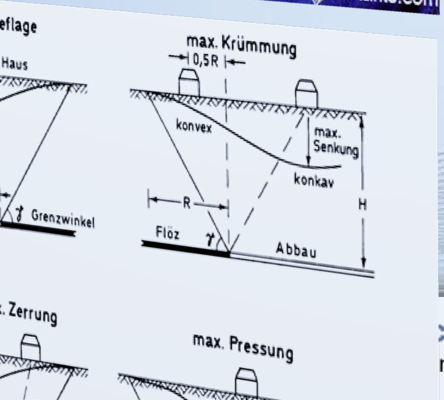


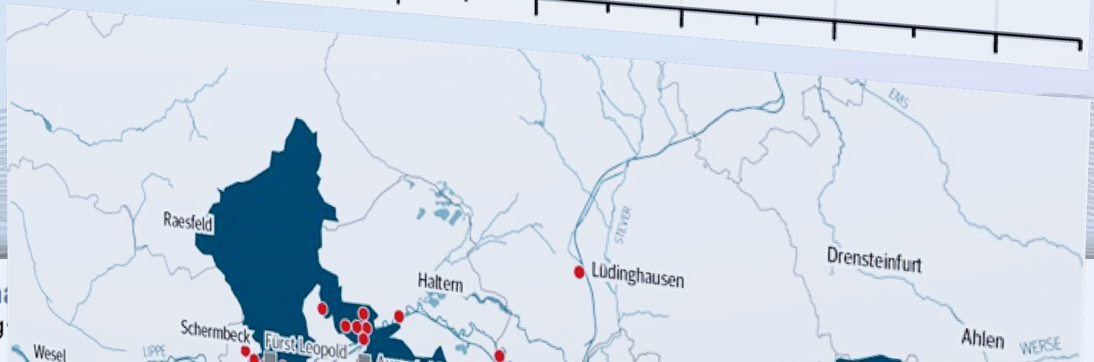






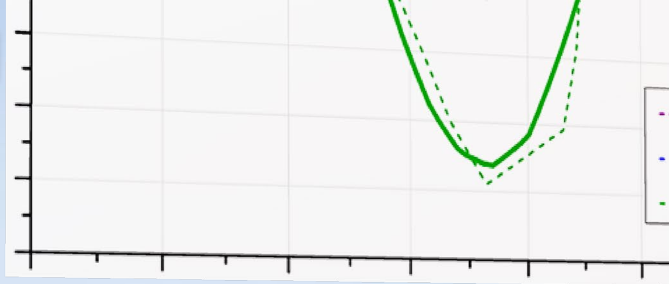
Prediction of subsidence as necessary tool for the assessment of the impact on protective goods

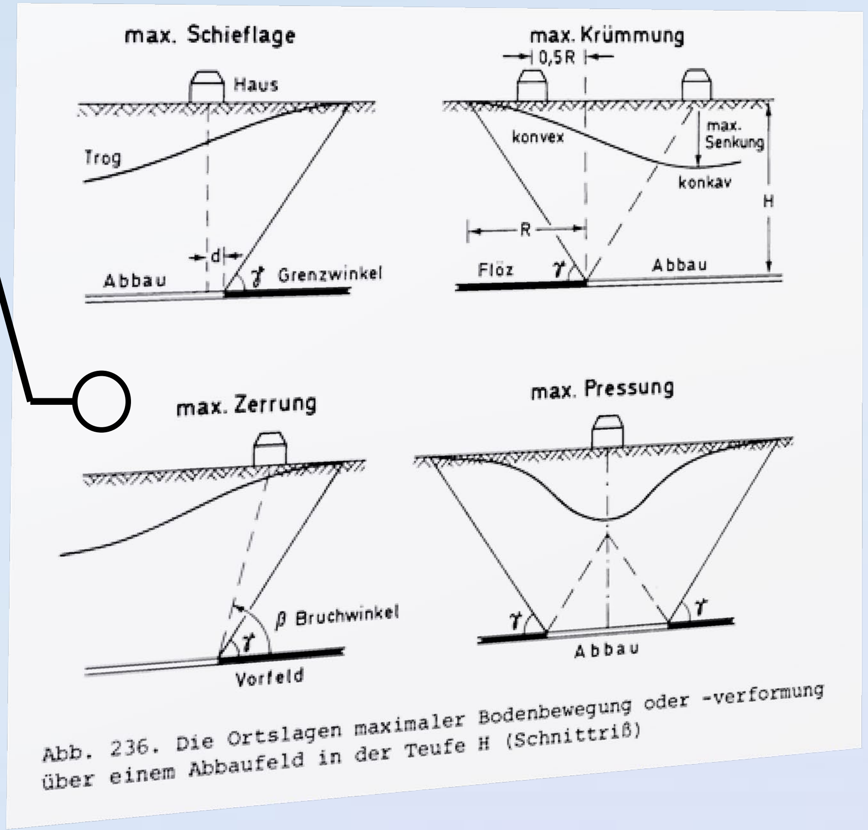


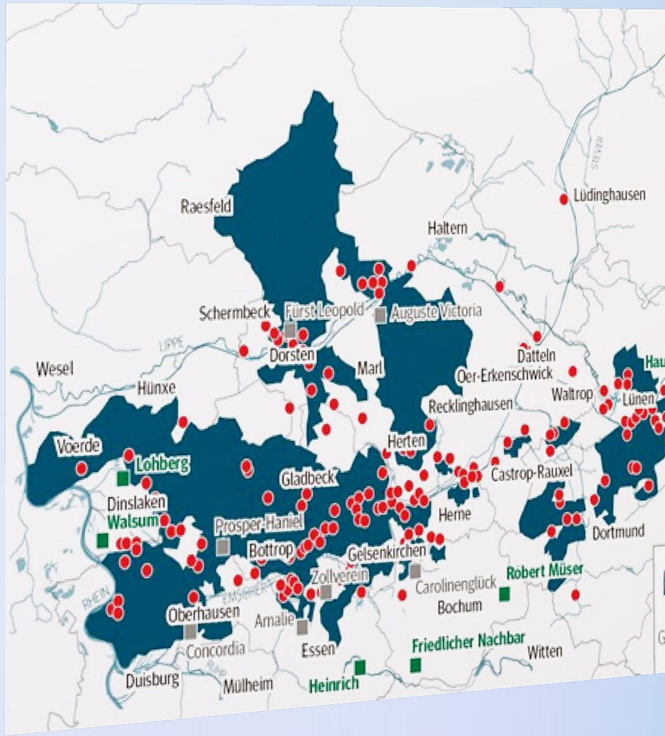


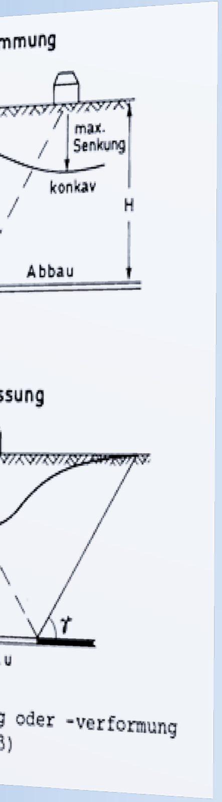
e.g. assessment of surface deformations relevant for evaluation/exclusion of damage resulting from mining activities

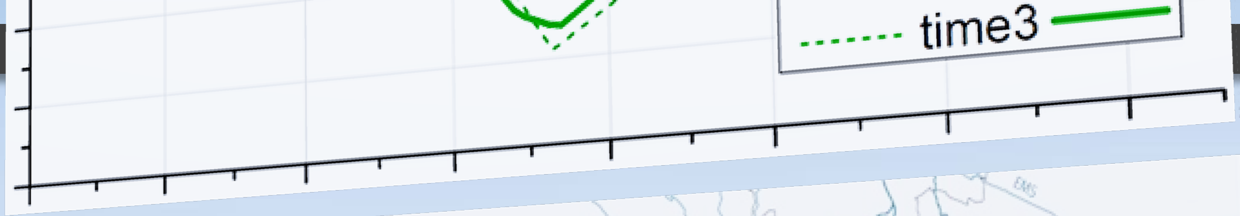
(Fig. According to Kratzsch, 2004)

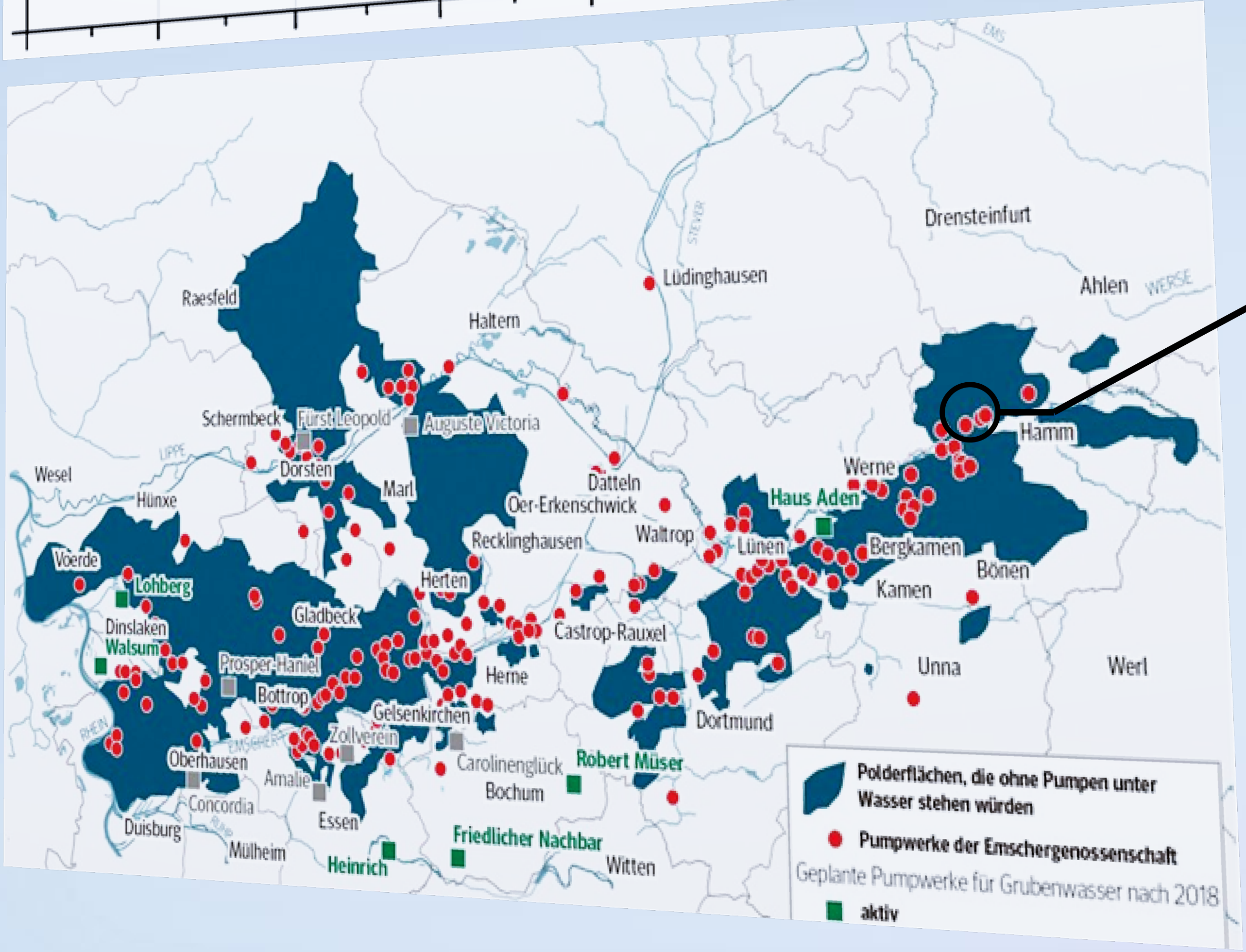












Basis for further analysis and countermeasures, e.g. groundwater management

https://www.waz.de/region/rhein-und-ruhr/wenn-die-pumpen-stillstaenden-id12358775.html

Method

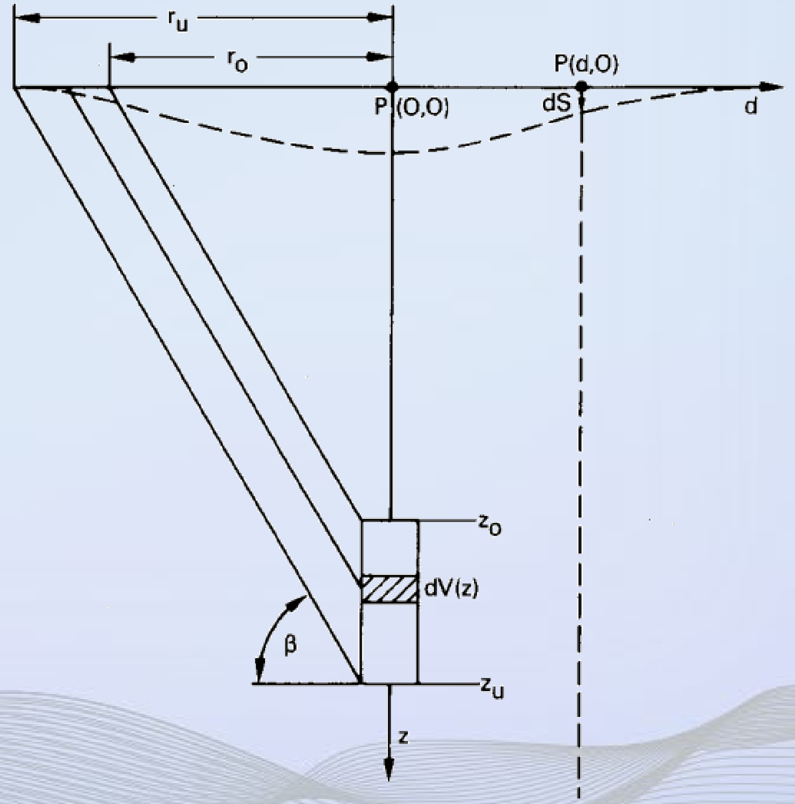
Conventional: Subsidence prediction via transfer function

- Convergence of volume elements is transfered to surface subsidence via mathematical relation

- Often isotropic Gaussian, e.g. Schober/Sroka 1982:

$$S\,(x,y,z,t) = \frac{a \cdot k \cdot V}{r^2(z)} \cdot \exp\left(-\pi \frac{d^2}{r^2(z)}\right)$$

$$r(z=0) = \sqrt{z^o z^u} \cdot \cot\beta$$



Advantage:

- Simple concept
- Quick calculation
- flexible

Disadvantages:

- No real description of rock mechanics / properties
- Result depends on transfer function
- Parameters in general not constant in space & time:

In Gleichung 1 wurde eine allgemeine Teufenabhängigkeit für den Einflußradius r(z) eingeführt, die es an dieser Stelle zu spezifizieren gilt. Da der Winkel β der eigentliche Gebirgsparameter ist, müßte auch dessen Änderung mit zunehmender Teufe beschrieben werden.

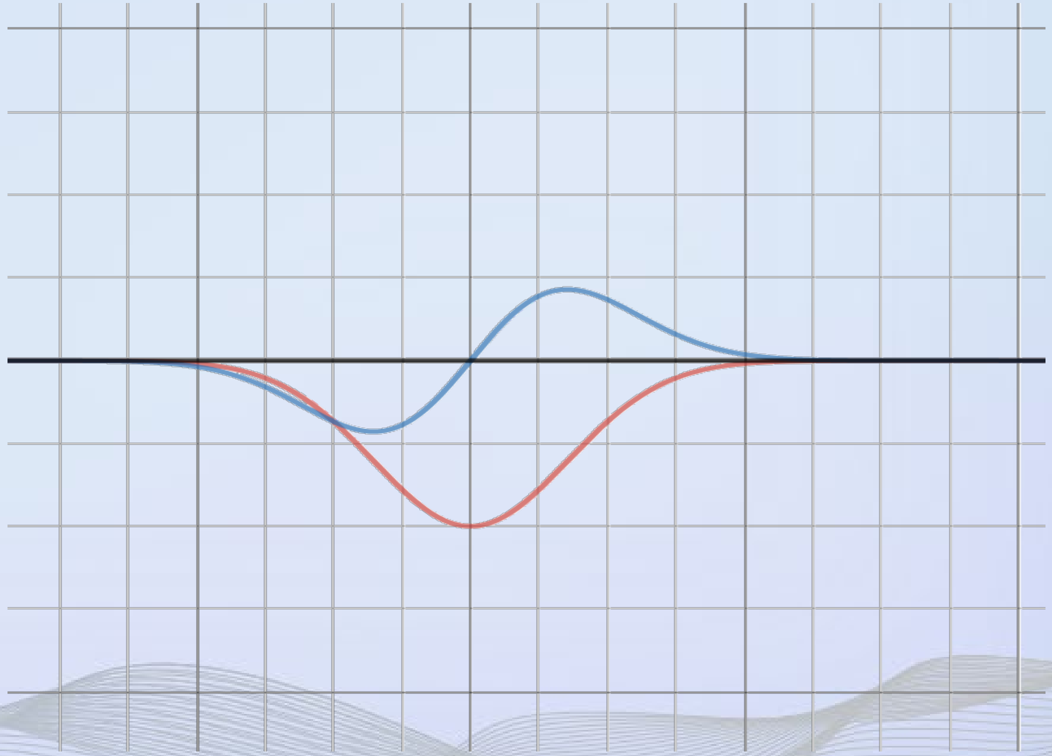
Disadvantages:

- Horizontal displacement (und therefore the compressive/tensile strains relevant for mining damage) are proposed as proportional to the tilt

$$u_x = B \cdot \frac{\partial s}{\partial x}$$

- What is B?

- Really proportional in nature?



Alternative : Subsidence prediction via geomechanical modeling

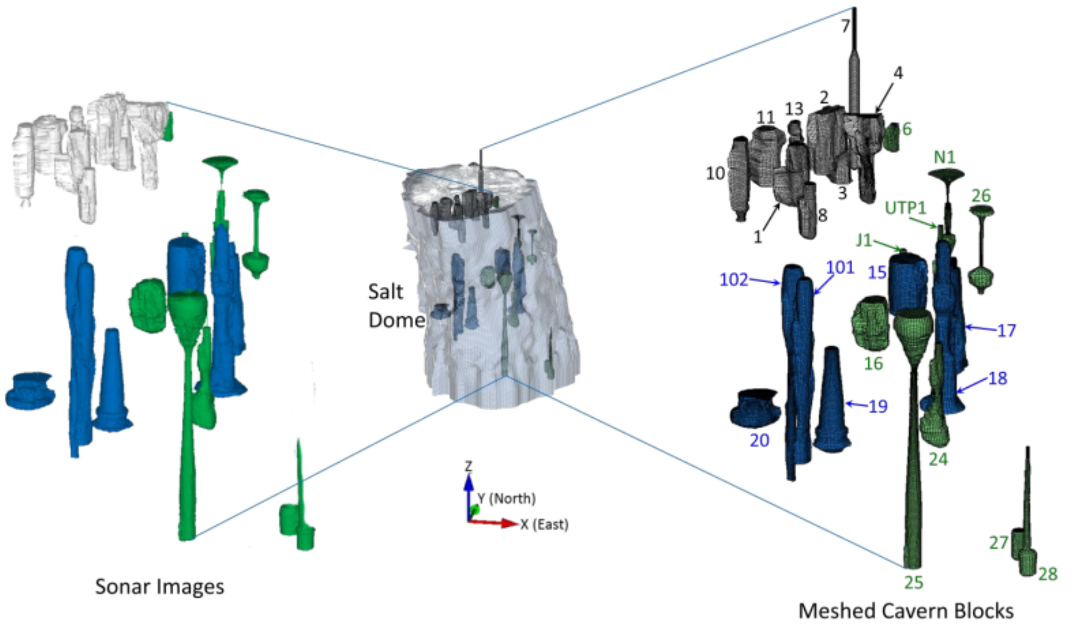


Figure 10 Sonar Images and hexahedral finite element meshed block of 26 caverns in the Bayou Choctaw salt dome. Caverns in gray, green, and blue indicate the abandoned, Boardwalk, and DOE SPR caverns, respectively. The cavern ID numbers are also shown.

(Park, 2017)

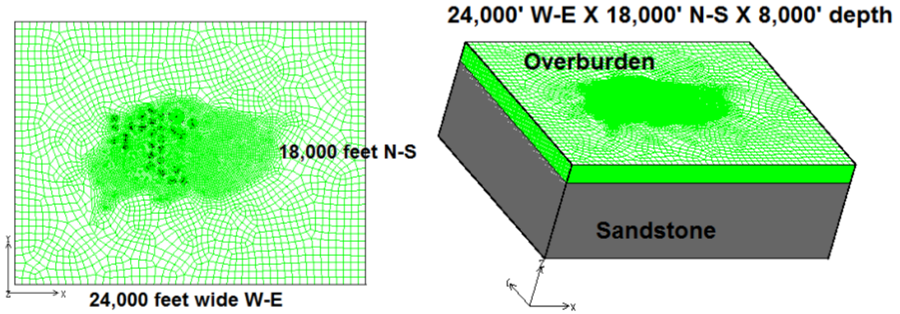


Figure 17. Computational mesh for the full-dome West Hackberry model.

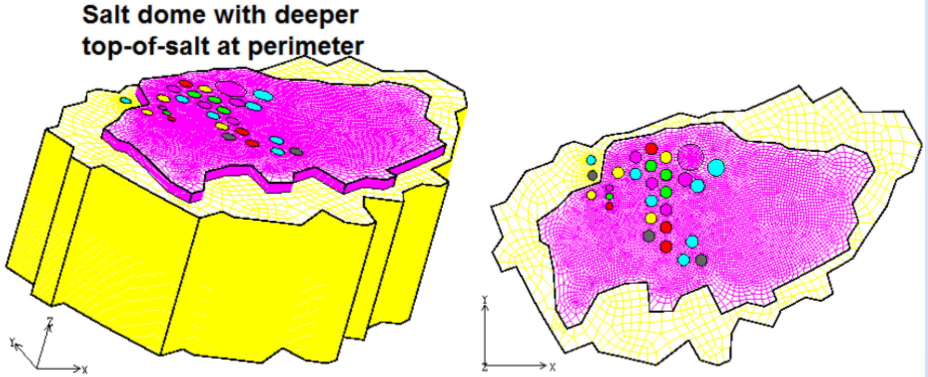


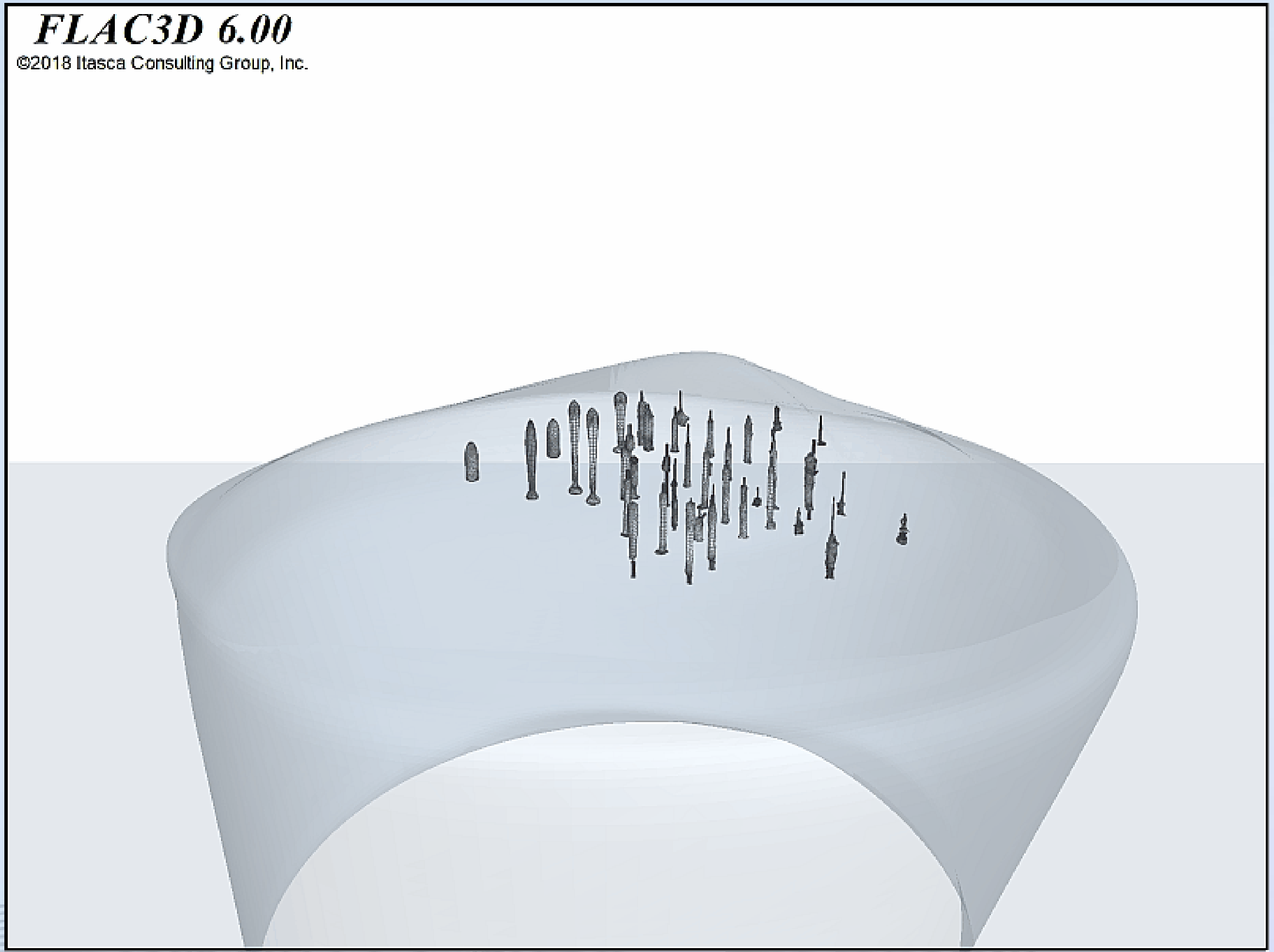
Figure 18. Computational mesh showing the salt dome and cavern locations.

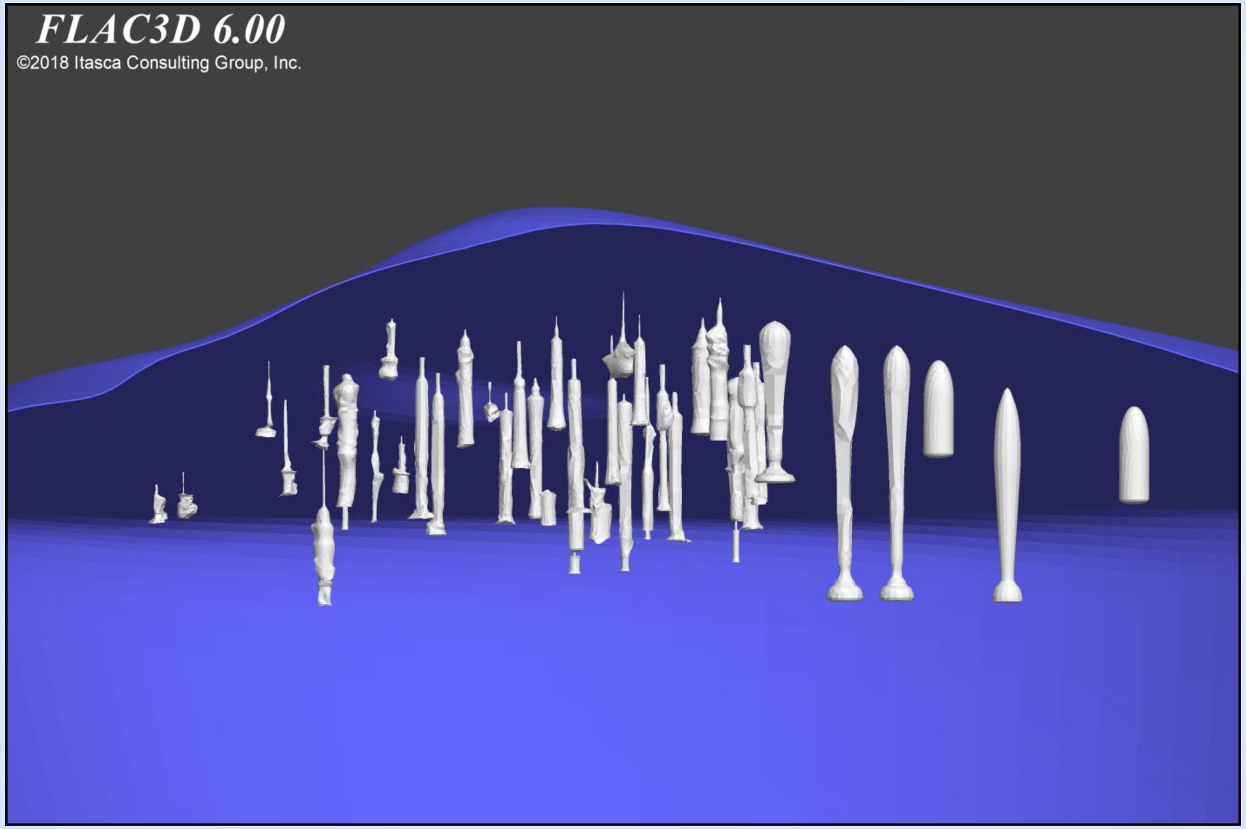
(Sobolik, 2015)

Disclaimer:

- Currently running project, all site-specific data anonymized
- Background maps of random city in France
- Graphs either normalized or without axis numbering

→ Focus on methods


FLAC3D 6.00
©2018 Itasca Consulting Group, Inc.


FLAC3D 6.00
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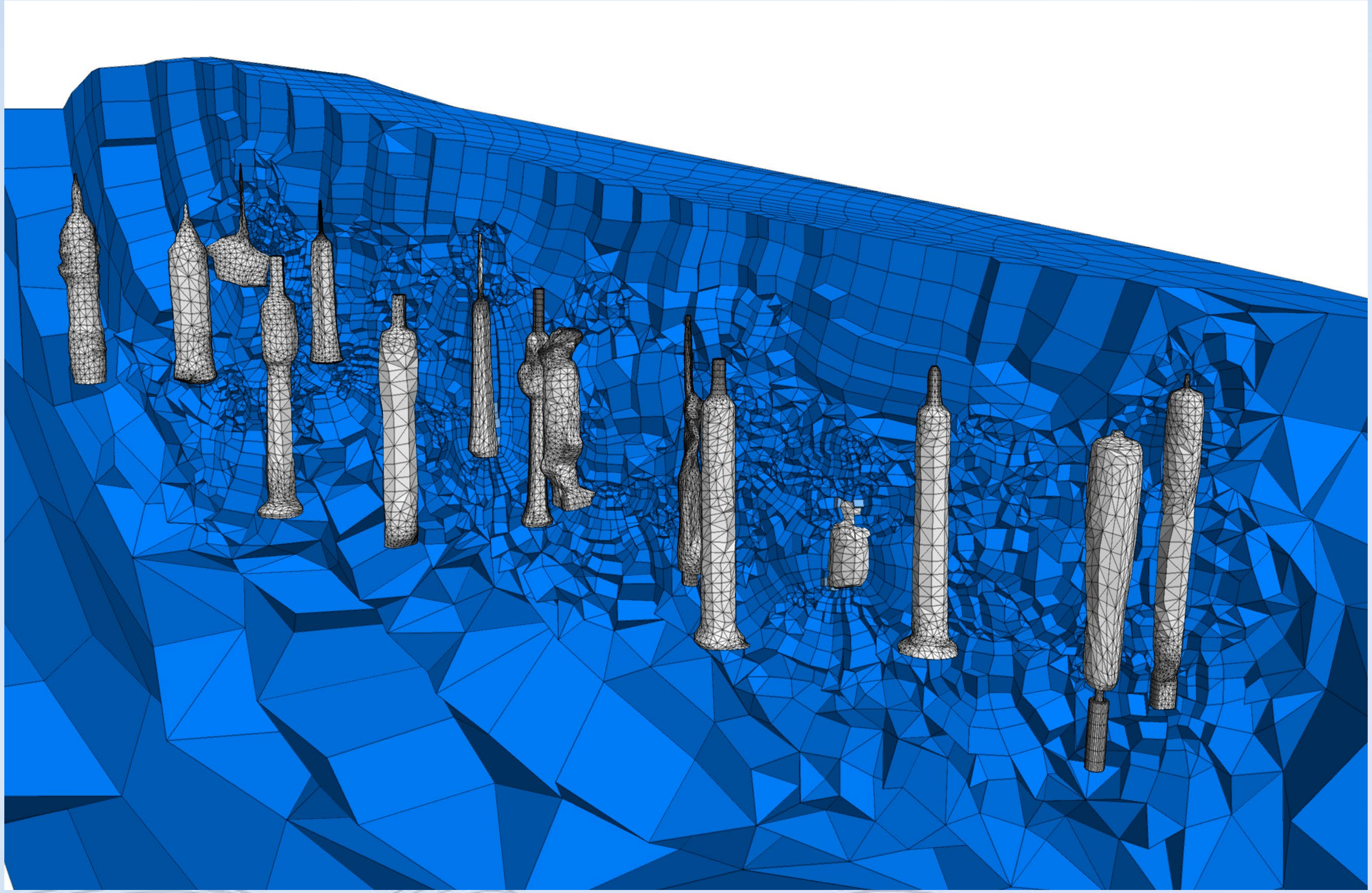
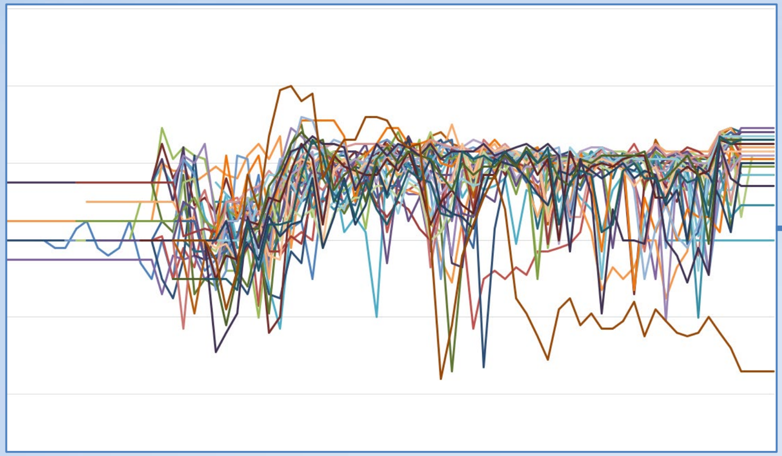
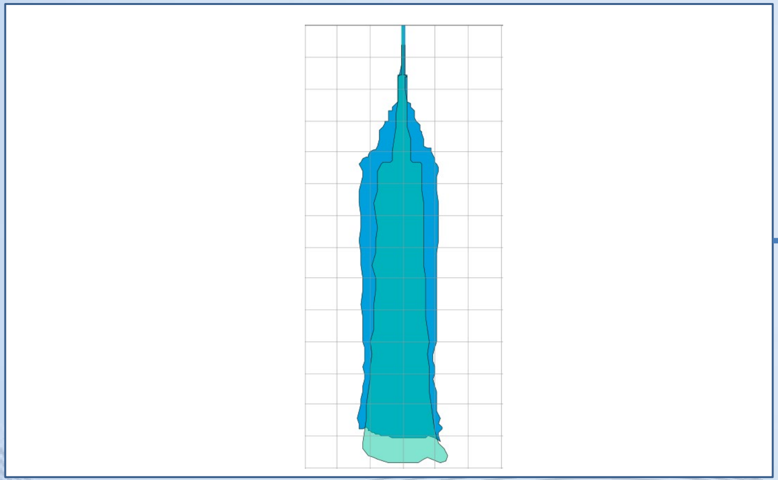




Real cavern pressure

Subsidence measurements

Input for model calibration

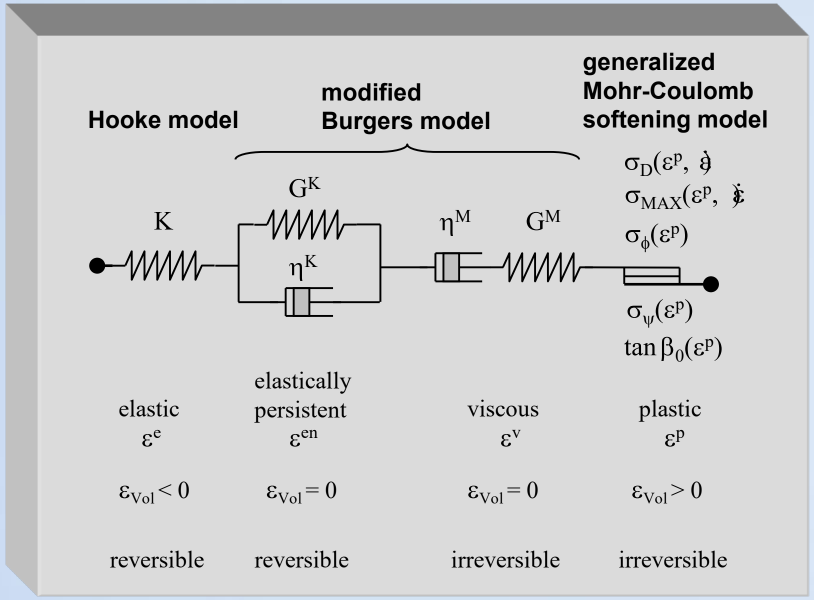


Sonar-based cavern measurements

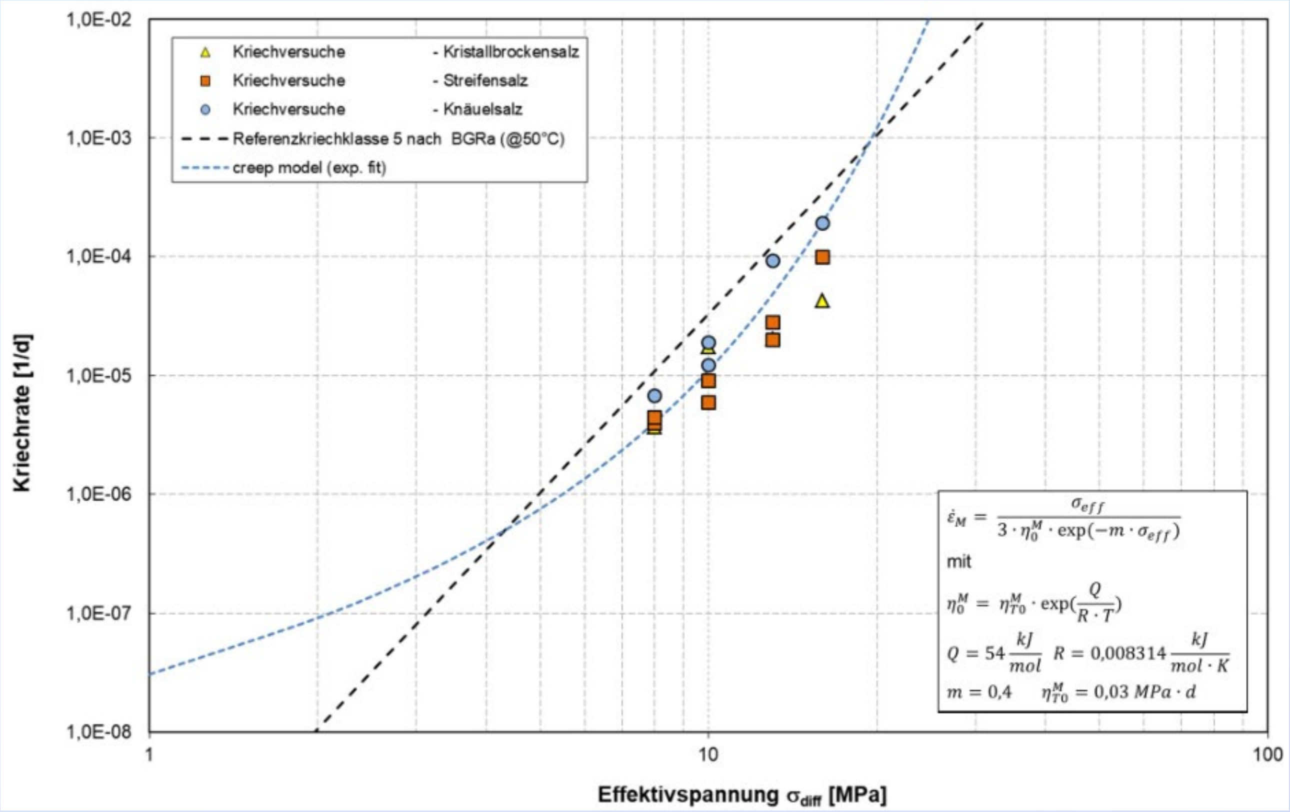
Additional operative measures (additional solution mining activities etc.)

Visco-elasto-plastic constitutive model for salt rocks

- ***non-Norton creep law***
- ***nonlinear strength boundary***



Lab-test creep behavior as starting point for calibration

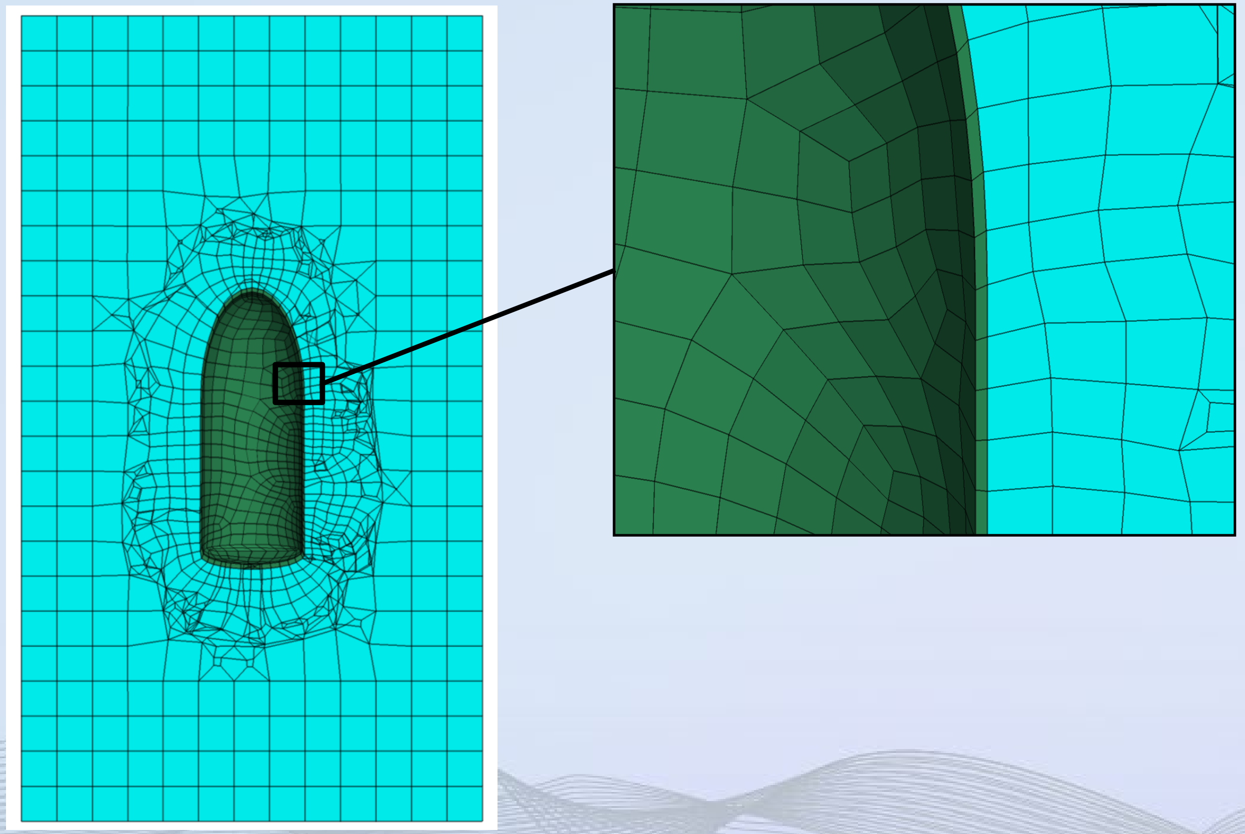


In reality, caverns experienced frequent small increases in volume due to oil being displaced by fresh water for retrieval

→Adds up to significant volume and cannot be ignored

But how to model many small increases in volume effectively and flexibly?

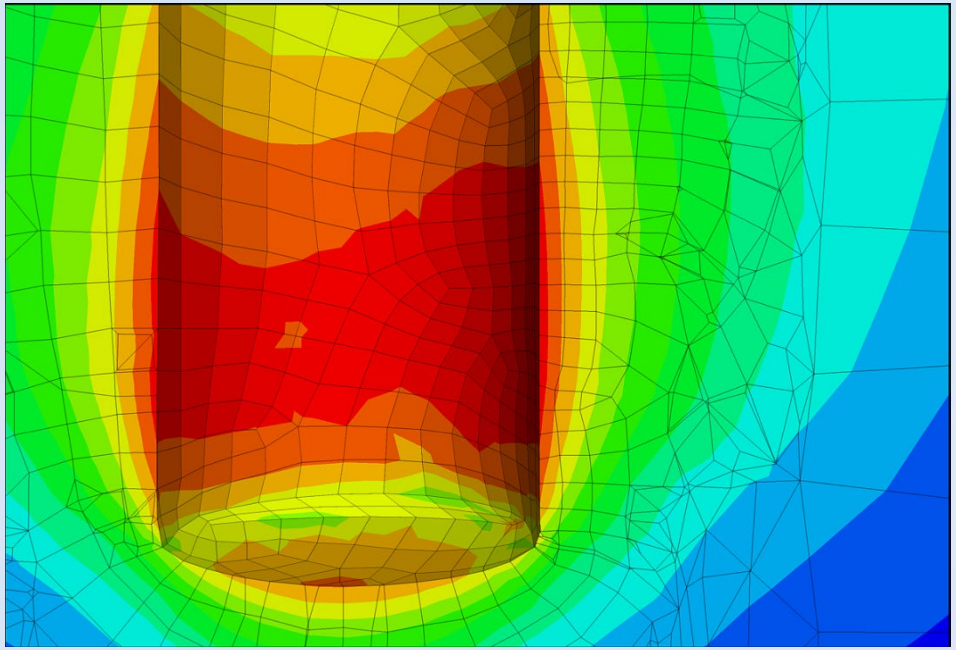
Typically for different stages of excavation: prepare these steps as small layers already in mesh creation



- **Inflexible (cannot be changed e.g. after changes by contractor)**
- **Instable (creates thin elements, prone to illegal geometry errors)**
- **Ineffecient (lots of labor in pre-processing/mesh generation)**

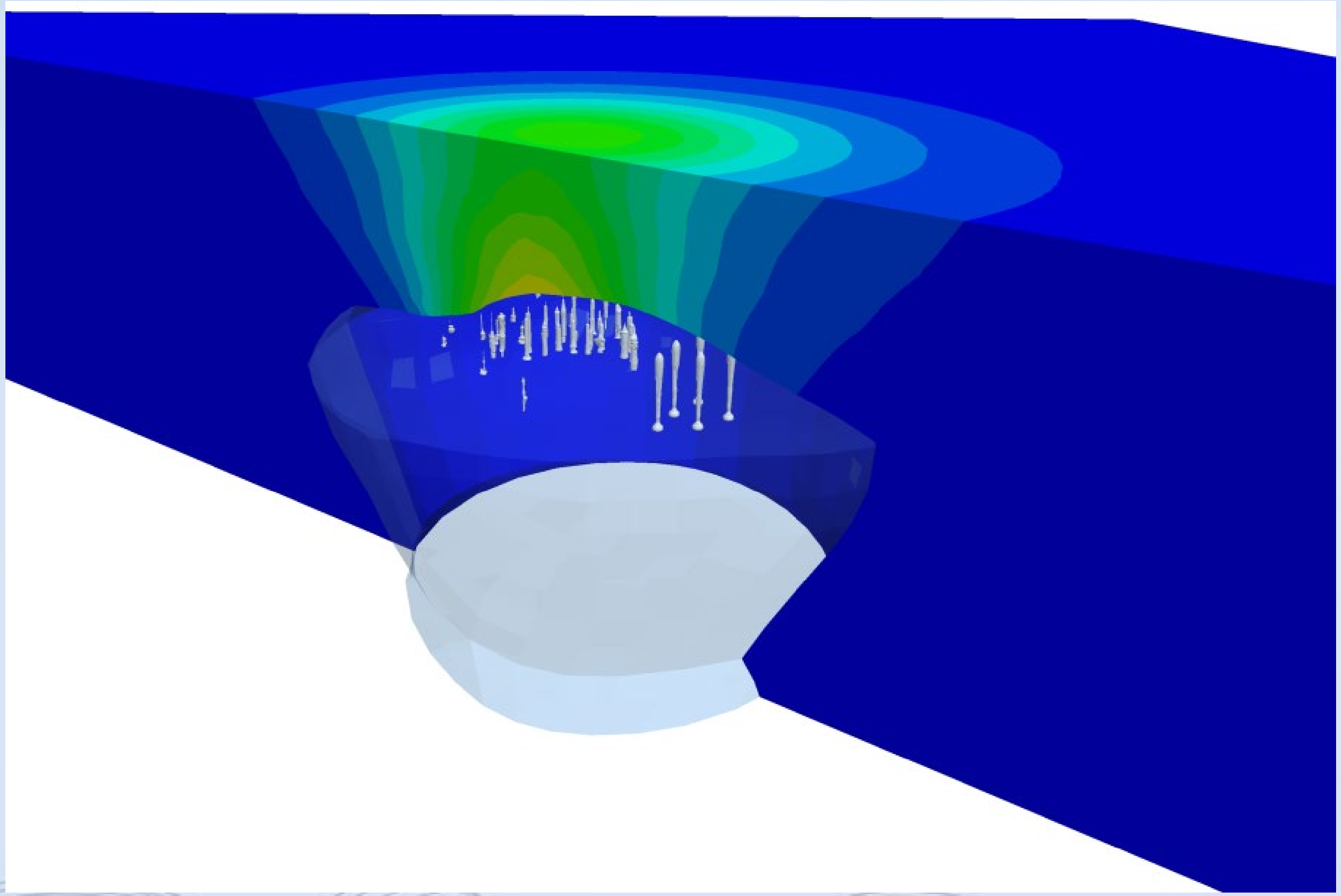
- Therefore approch in this model:

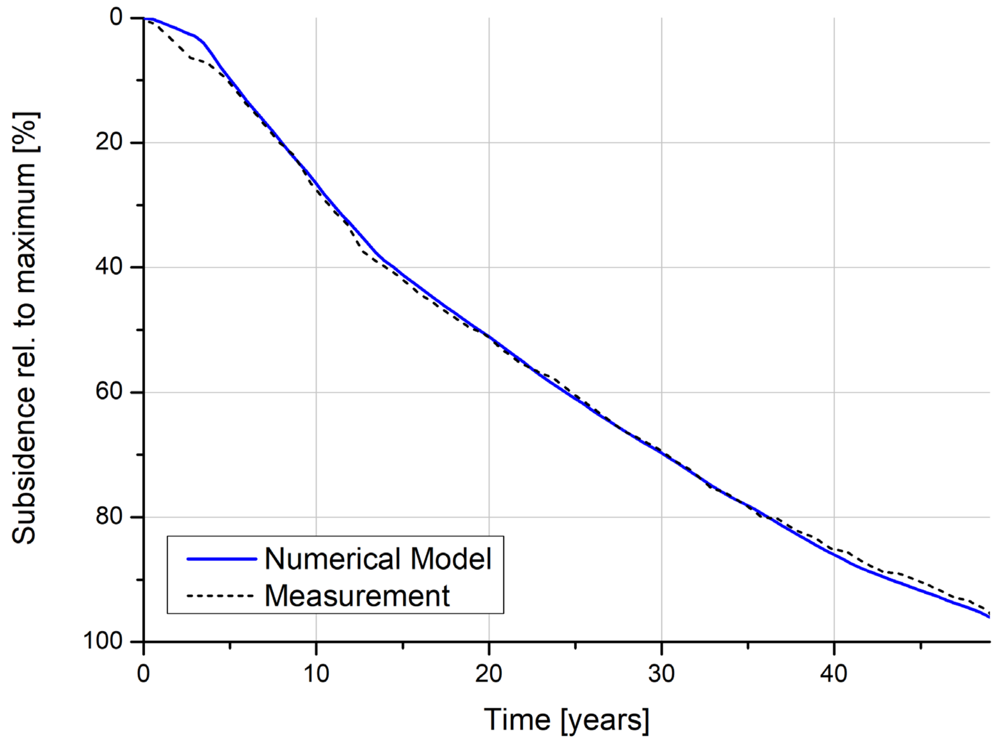
„Nudging“ of contour gridpoints opposite to displacement direction



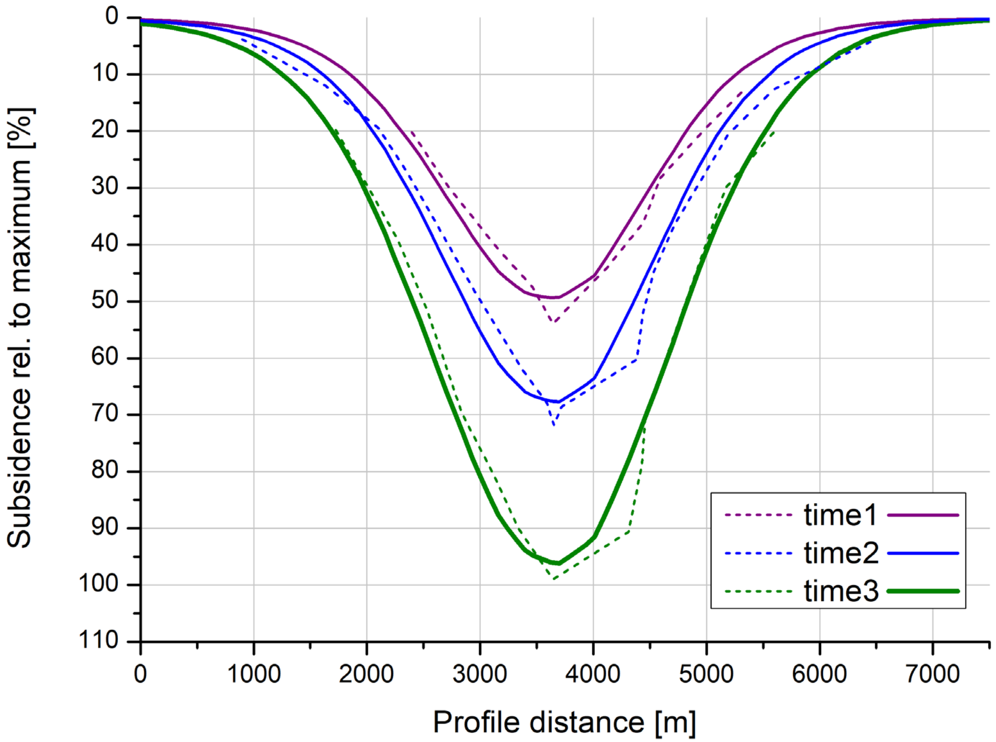
- Small impact on contour stresses and cavern convergence
- Takes a long time in FISH, significantly faster in Python

Excerpt of results

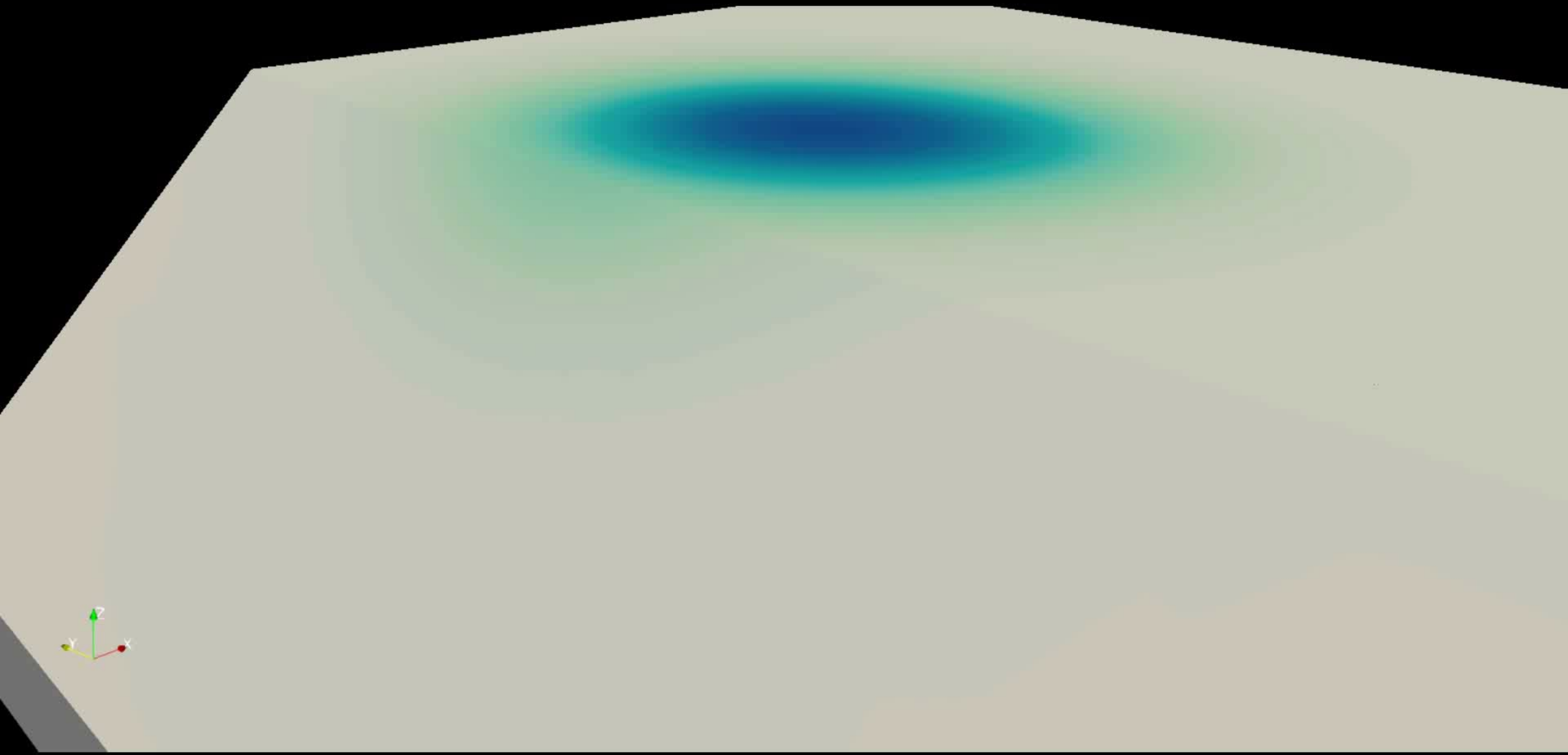


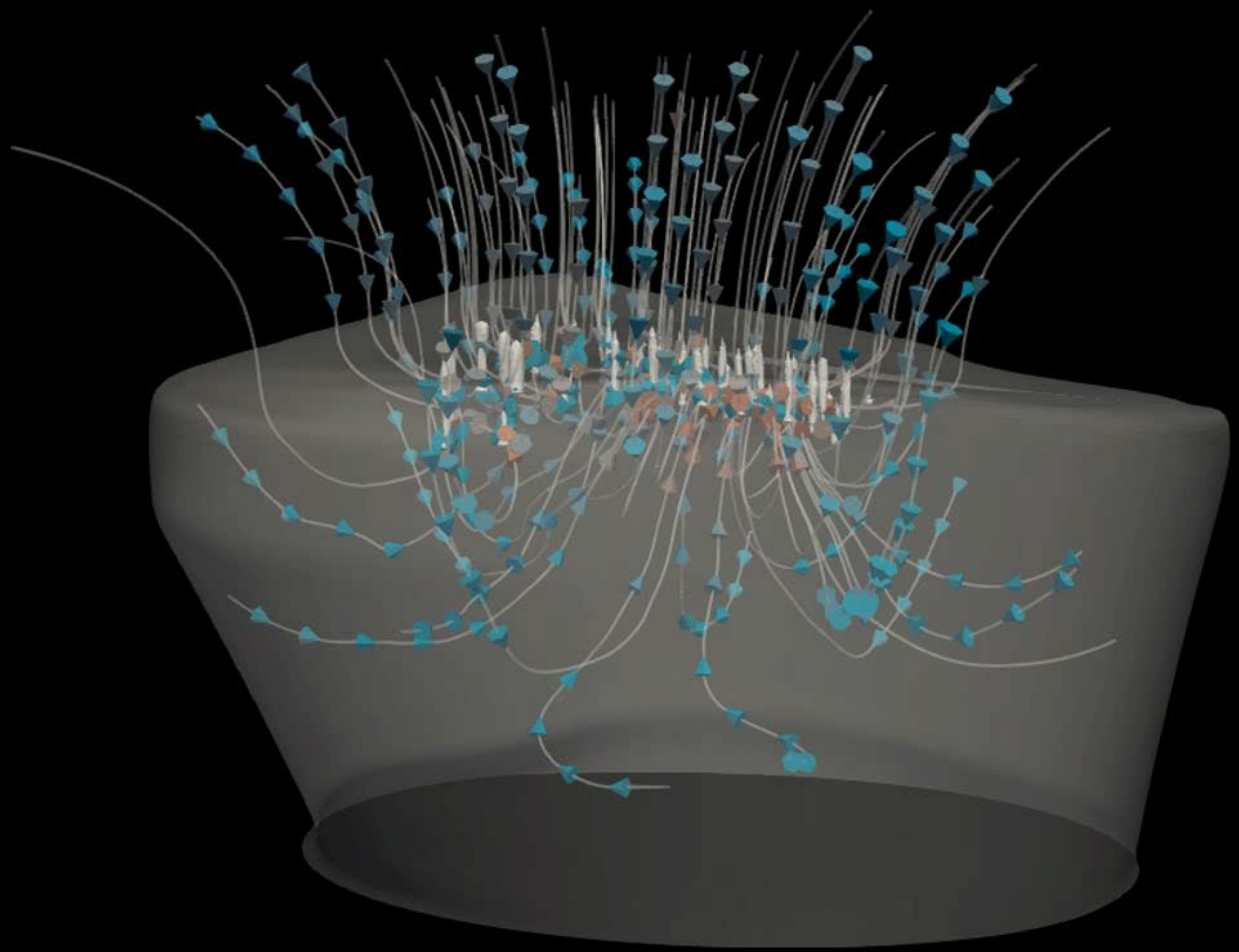


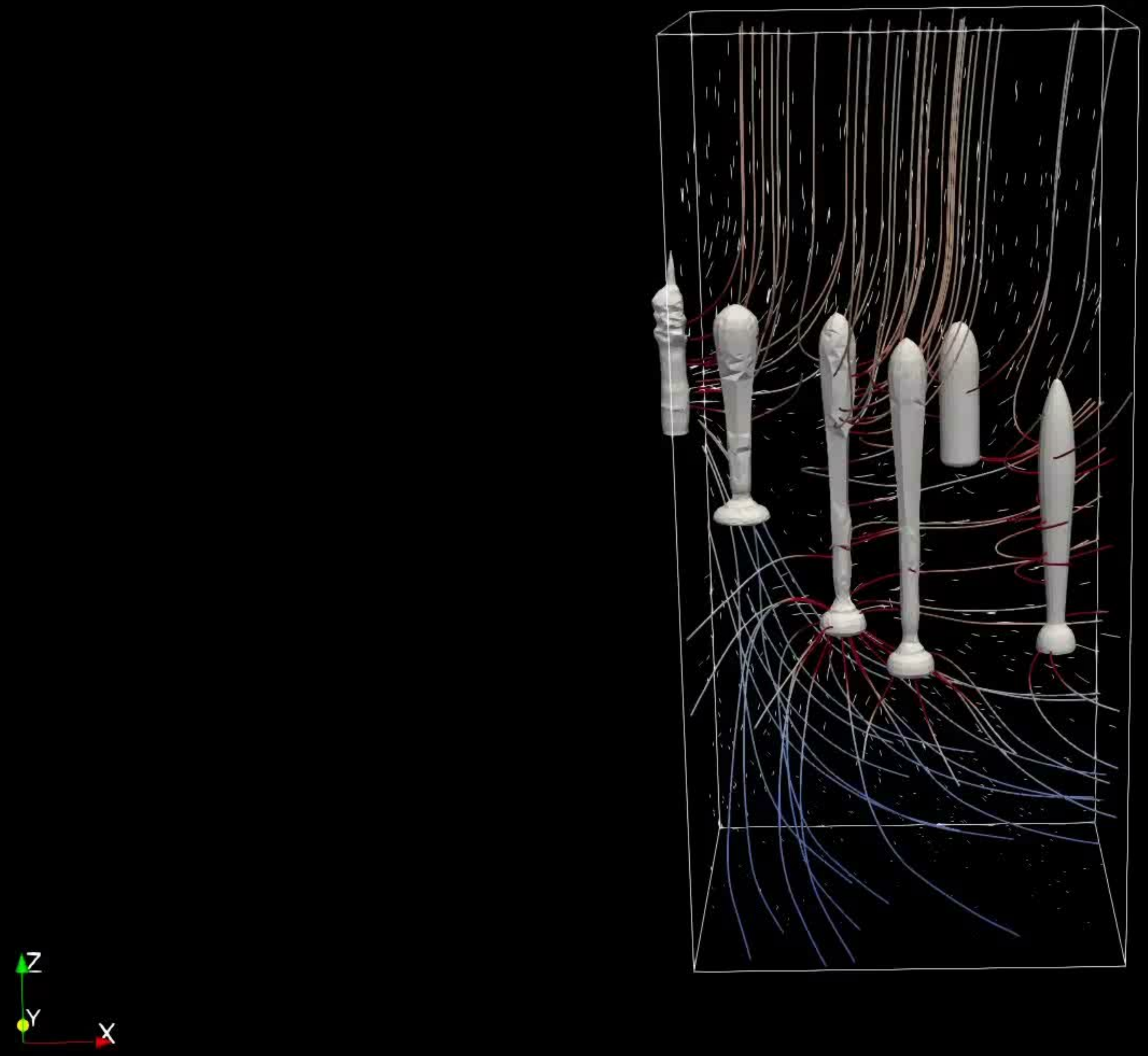
Subsidence over time at the surface



Subsidence along profiles for different times


Z
Y
X

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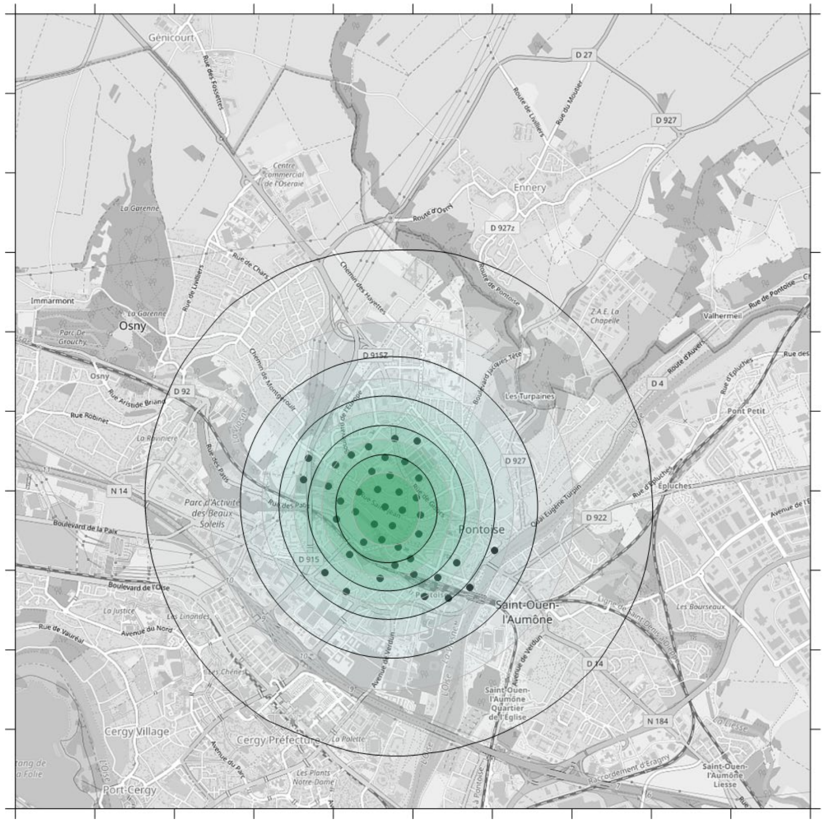
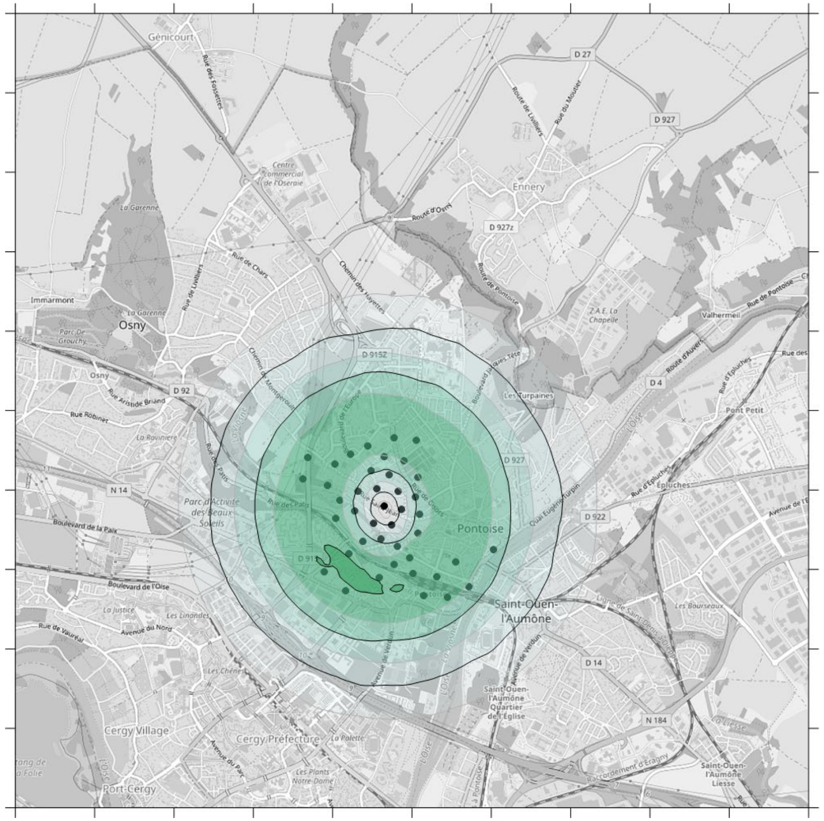
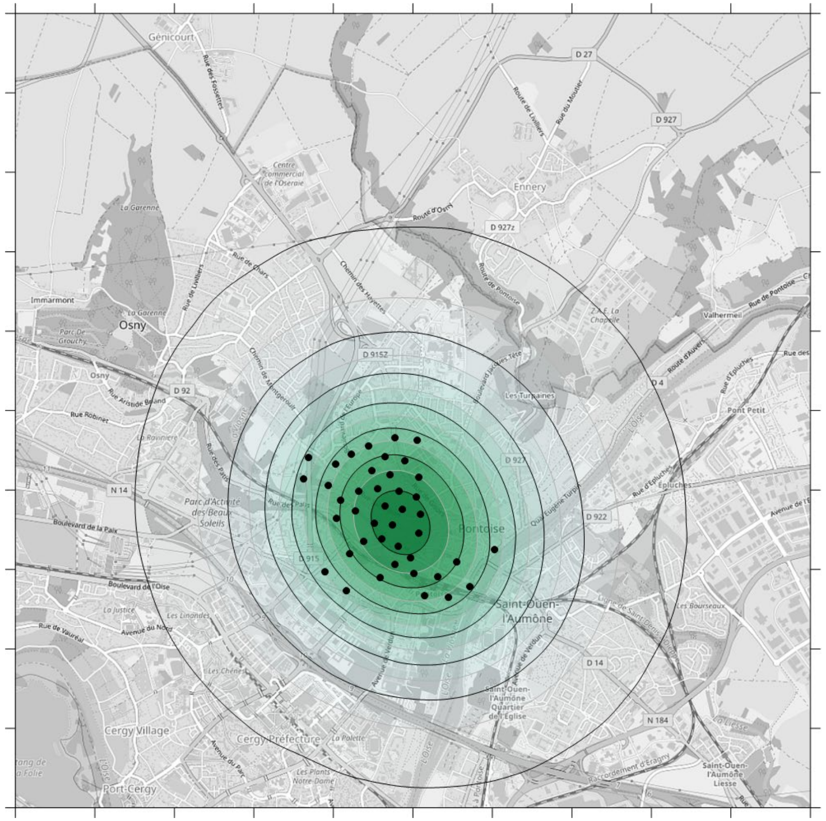


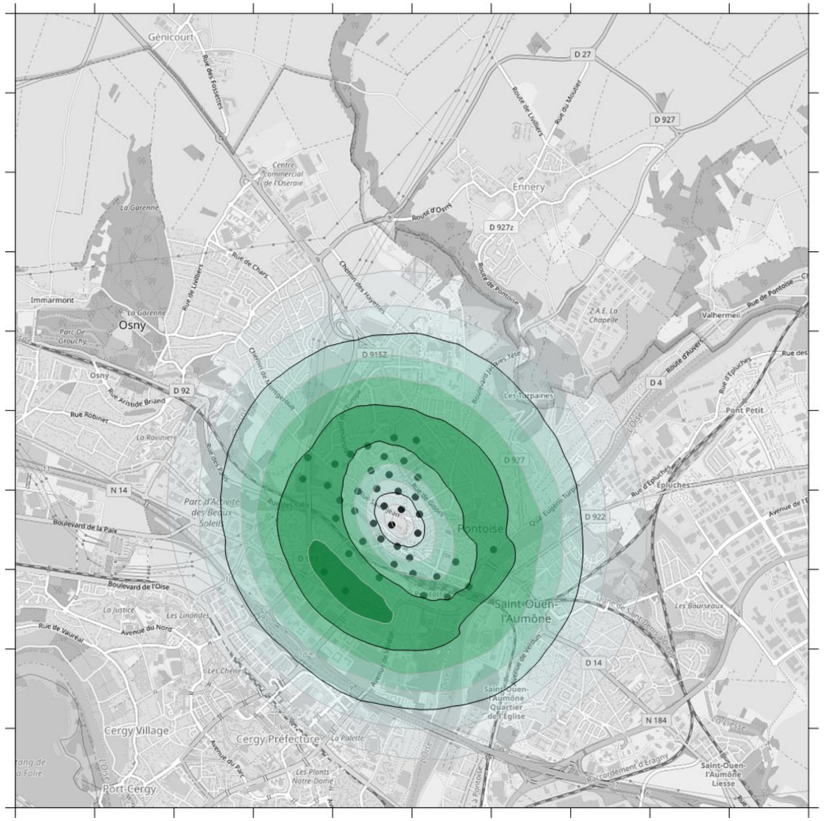
Modelled subsidence (current)



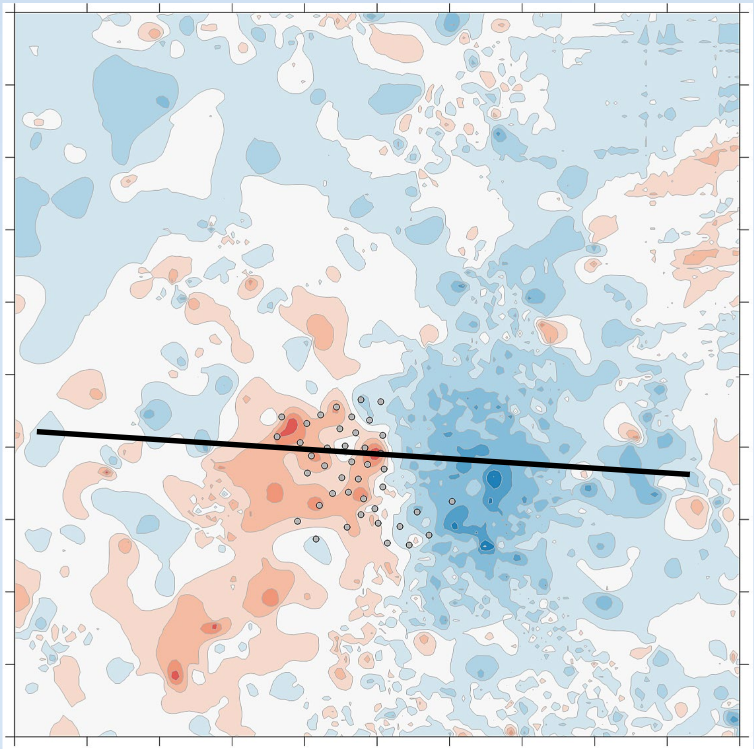
Modelled tilt (current)

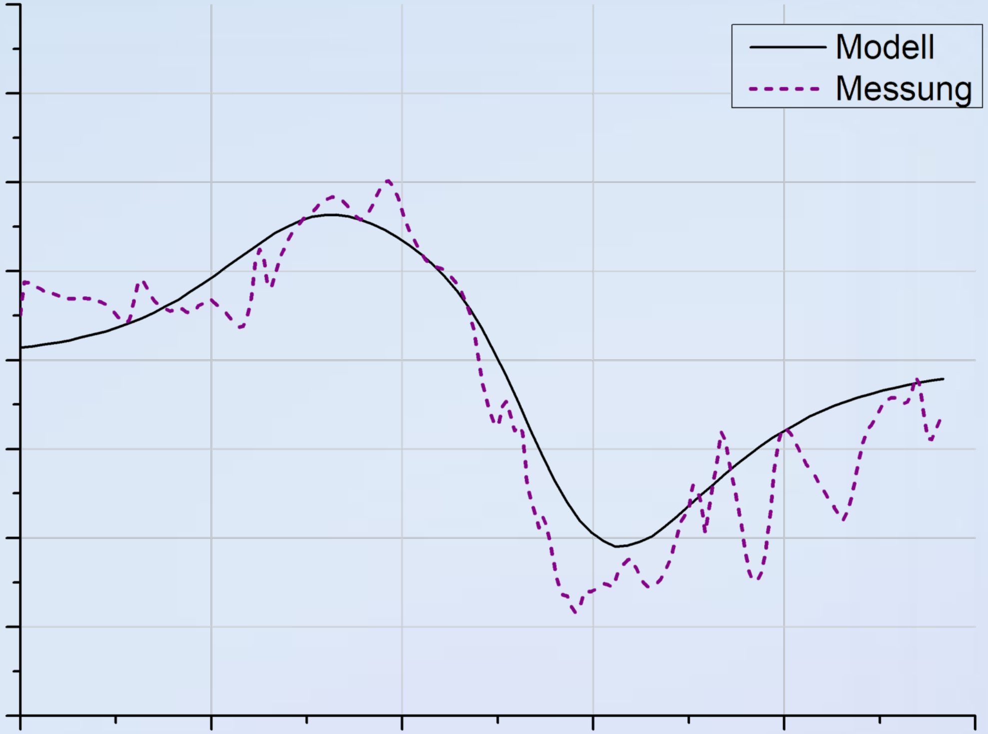


Modelled subsidence (predicted)

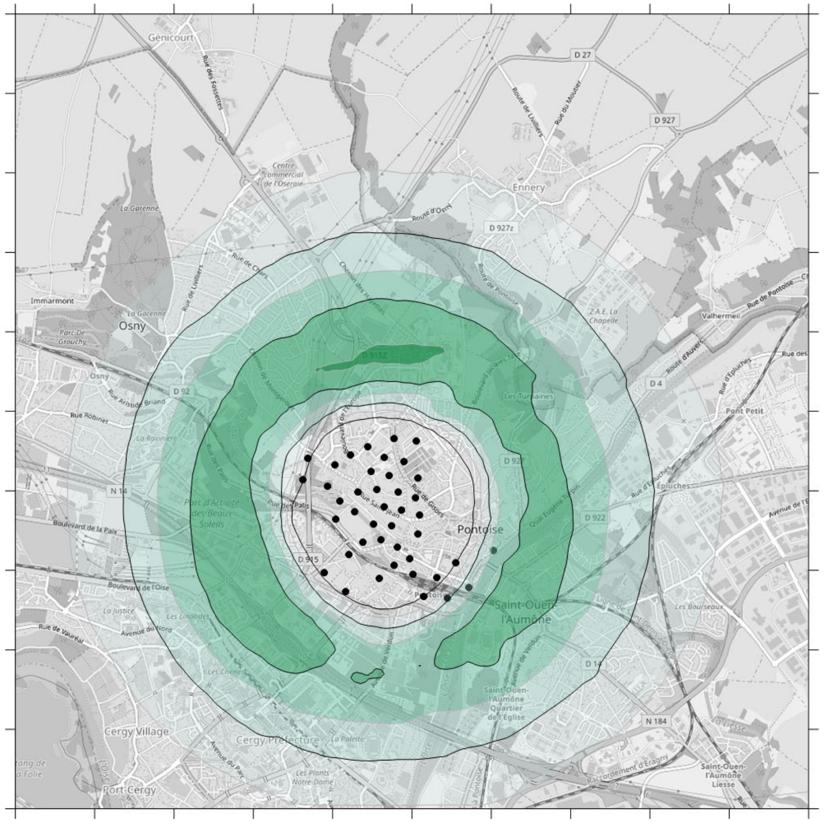


Modelled tilt (predicted)



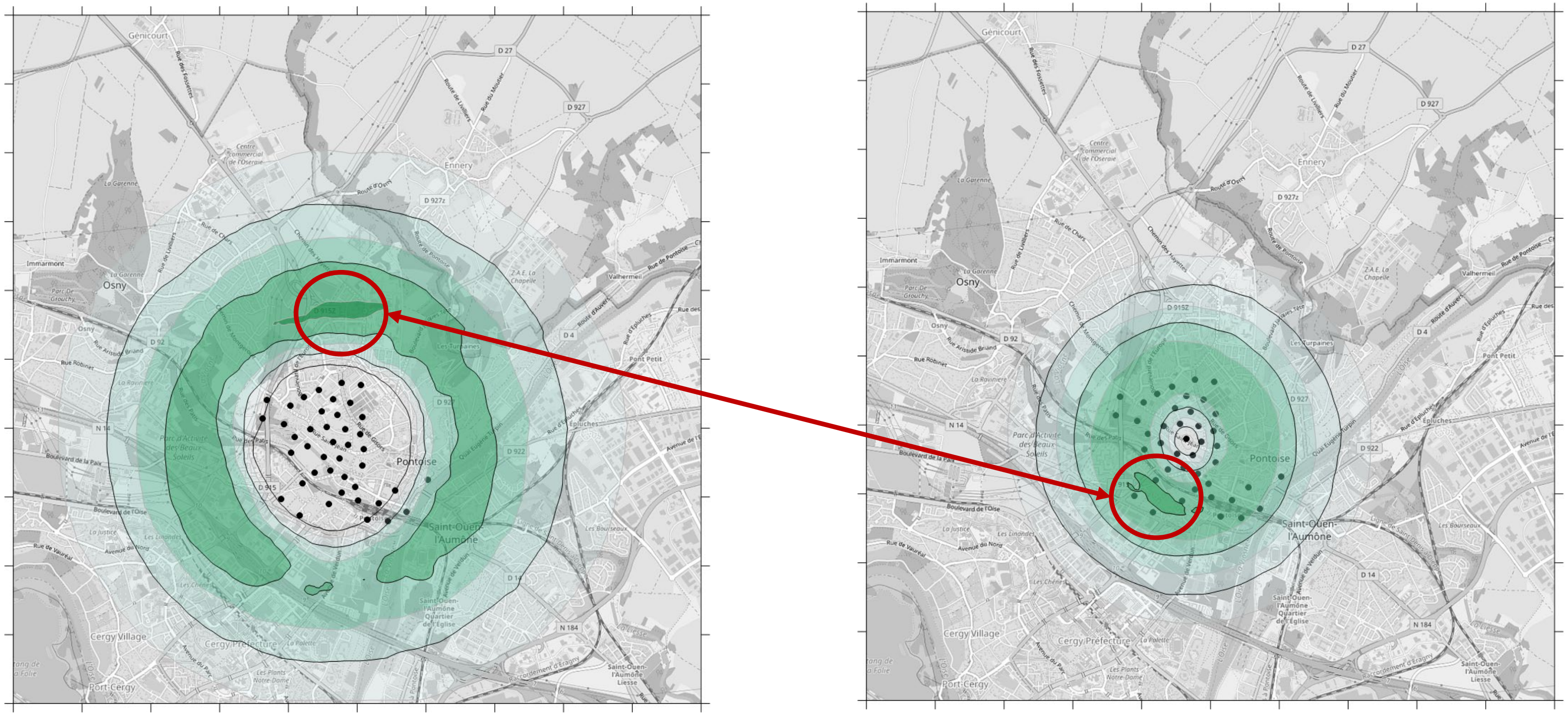


Measured vs. modeled east-to-west displacements



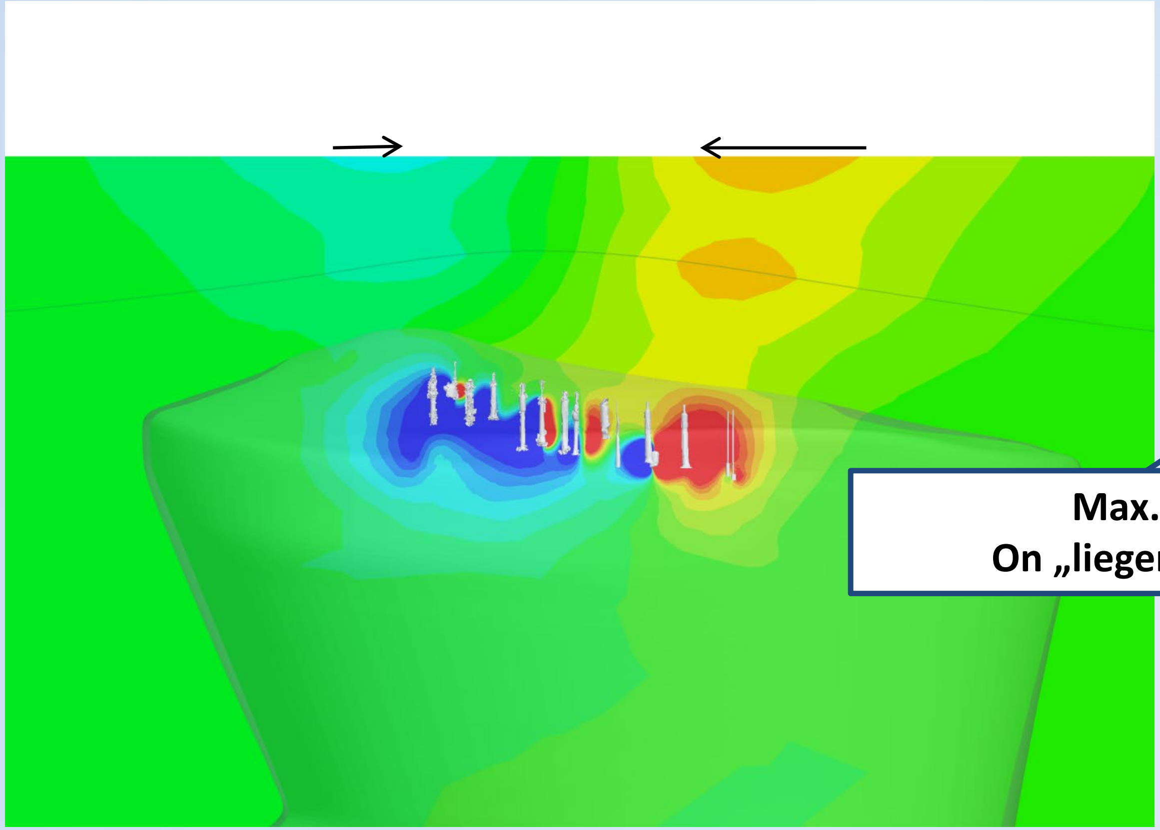
Modelled max. tensile strains (current)

Modelled max. compressive strains (current)



Modelled max. tensile strains (predicted)

Modelled max. compressive strains (predicted)



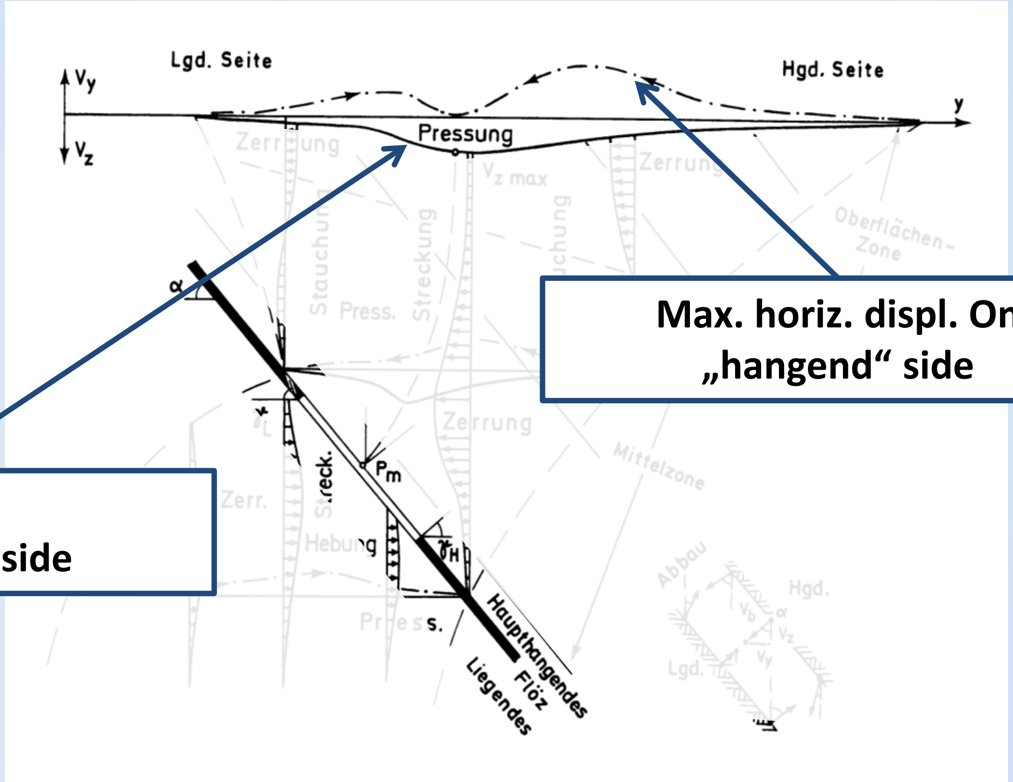


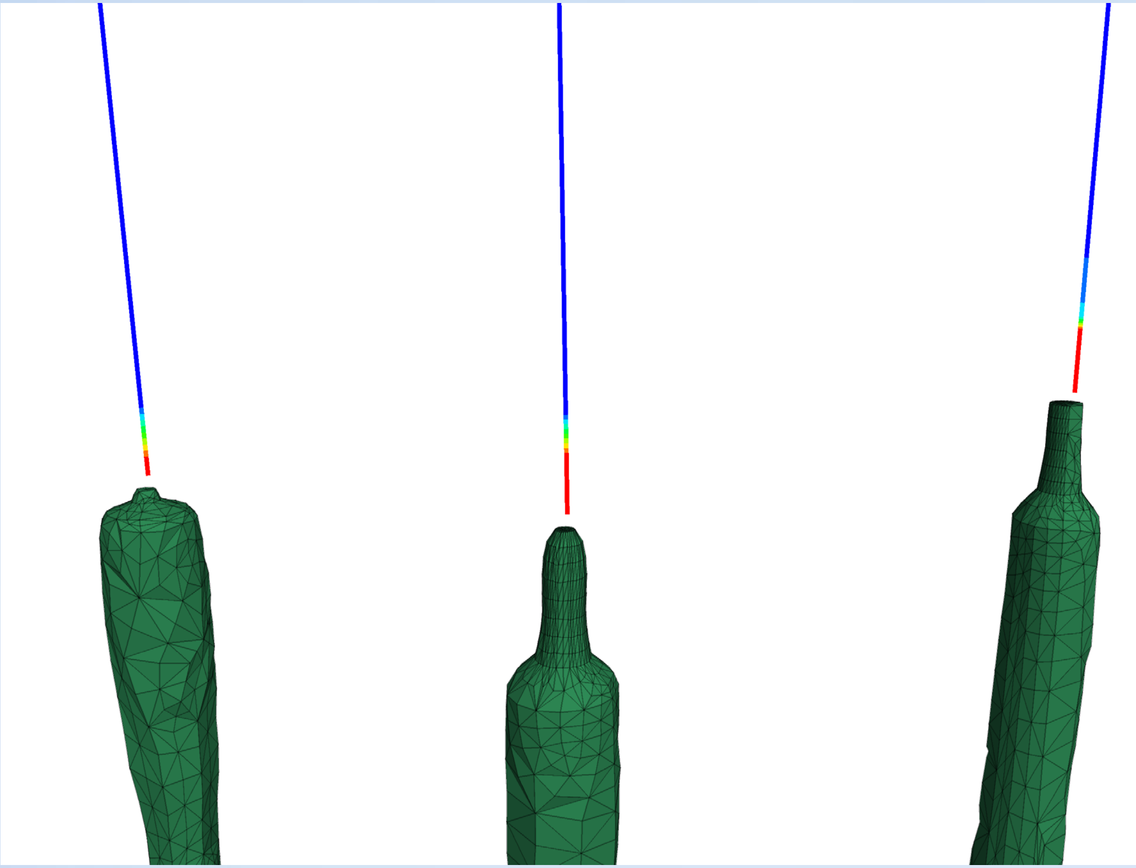
Abb. 25. Die Gebirgsbewegung und -verformung in steiler Lagerung

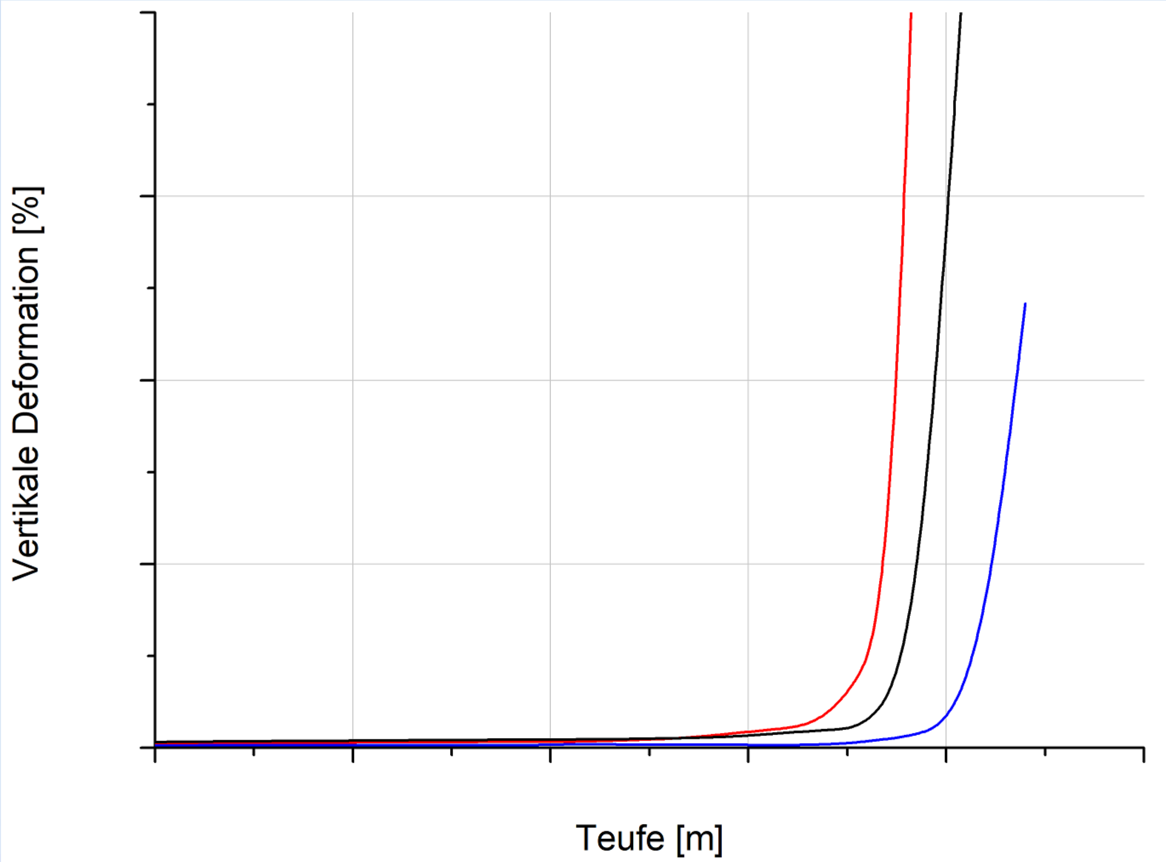
Max. tilt
On „liegend“ side

Max. horiz. displ. On „hangend“ side

(Kratzsch, 2004)

Deformation along borehole axis

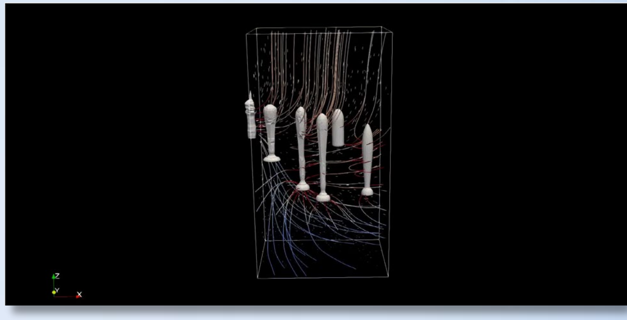




Conclusion:

- Current modeling tools & meshing algorithms allow for large-scale 3D-models of cavern fields using complex constitutive models
- Good agreement with results of conventional leveling, InSar-measurement and cavern convergence measurements
- Mesh may be locally refined for further cavern specific tasks (or model may yield boundary conditions for local models)
- Improved understanding of the cavern system‘s behavior and rock-mechanically based modeling of convergence-induced surface deformations

Thank you very much!



Questions?