TECHNISCHE UNIVERSITÄT
BERGAKADEMIE FREIBERG
Die Ressourcenuniversität. Seit 1765.

A Conceptual Study of Mining Subsidence Analysis

Dr. N.Tamaskovics

TU Bergakademie Freiberg, Institut für Geotechnik

Chair of Soil Mechanics, Ground Engineering and Mining Geotechnics

Chair of Engineering Geology, Disposal Facilities and Geotechnical Securing Methods

Mining Subsidence Analysis:

Scientific field in the cross section between Geodesy and Geotechnics

The observation of deformations in the ground massive under mining exposure delivers extensive information quantity

Classical methods of mining subsidence analysis

Classical methods of mining subsidence analysis:

Verified empirical and stochastic hypothetical ground deformation models of mining induced displacements

Calibration on geodetic deformation measurements leads to a solid basis for displacement prediction with synthetic forward models

Advanced methods of mining subsidence analysis

Advanced mining subsidence analysis:

Deformation prediction for the mining influenced region is a difficult soil and rock mechanics (geotechnic) problem

Advanced analysis methods of Geotechnics offer the opportunity to solve the time independent or time dependent initial and boundary value problem

Mining subsidence analysis and deformation prediction with advanced analysis methods of Geotechnics

Modell formulation for geotechnic mining subsidence analysis:

Geological, hydrogeolgical and geotechnical model

Profound characterization of the initial (geostatic) stress state and stress history

Sequence of primary and secondary deformation processes due to mining

Conceptual study of a classical problem in mining subsidence analysis with advanced analysis methods of Geotechnics

(Qualitative analysis)

Geotechnic mine subsidence analysis:

Axialsymmetric model

Model radius: 50m

Radius of primary displacement: 10m

Amplitude of primary displacement: 1m

Model height: 30m und 50m

Geotechnic mine subsidence analysis:

Material model: Drucker-Prager without hardening or softening

Stiffness formulation: depending on the initial stress state but constant at loading

No volume change during shear failure

Drucker-Prager strength parameters:

$$\mathrm{ALFA} = \mathrm{ETA} = \frac{2\,\sin(\varphi)}{\sqrt{3}\,(\,3+\sin(\varphi)\,)}\ ,\quad \mathrm{BETA} = \mathrm{MU} = \sqrt{\frac{2}{3}}\ ,$$

$$\mathrm{K} = \mathrm{KL} = \frac{6\,c\,\cos(\varphi)}{\sqrt{3}\,(\,3+\sin(\varphi)\,)}\ ,$$

$$\mathrm{GAMM} = \frac{2\,\sin(\psi)}{\sqrt{3}\,(\,3+\sin(\psi)\,)}\ ,\quad \mathrm{DELT} = \sqrt{\frac{2}{3}}$$

Drucker-Prager stress dependent (but constant) stiffness parameters:

$$YOUN = E = E_{ref} \left(\frac{p'}{p'_{ref}} \right)^m$$

$$p' = \frac{1}{3} tr(\sigma')$$

Geotechnic mining subsidence analysis:

No layering (here)

No anisotropy (here)

No fluid influence (here)

No time dependent behaviour (creep)

Geotechnic mining subsidence analysis:

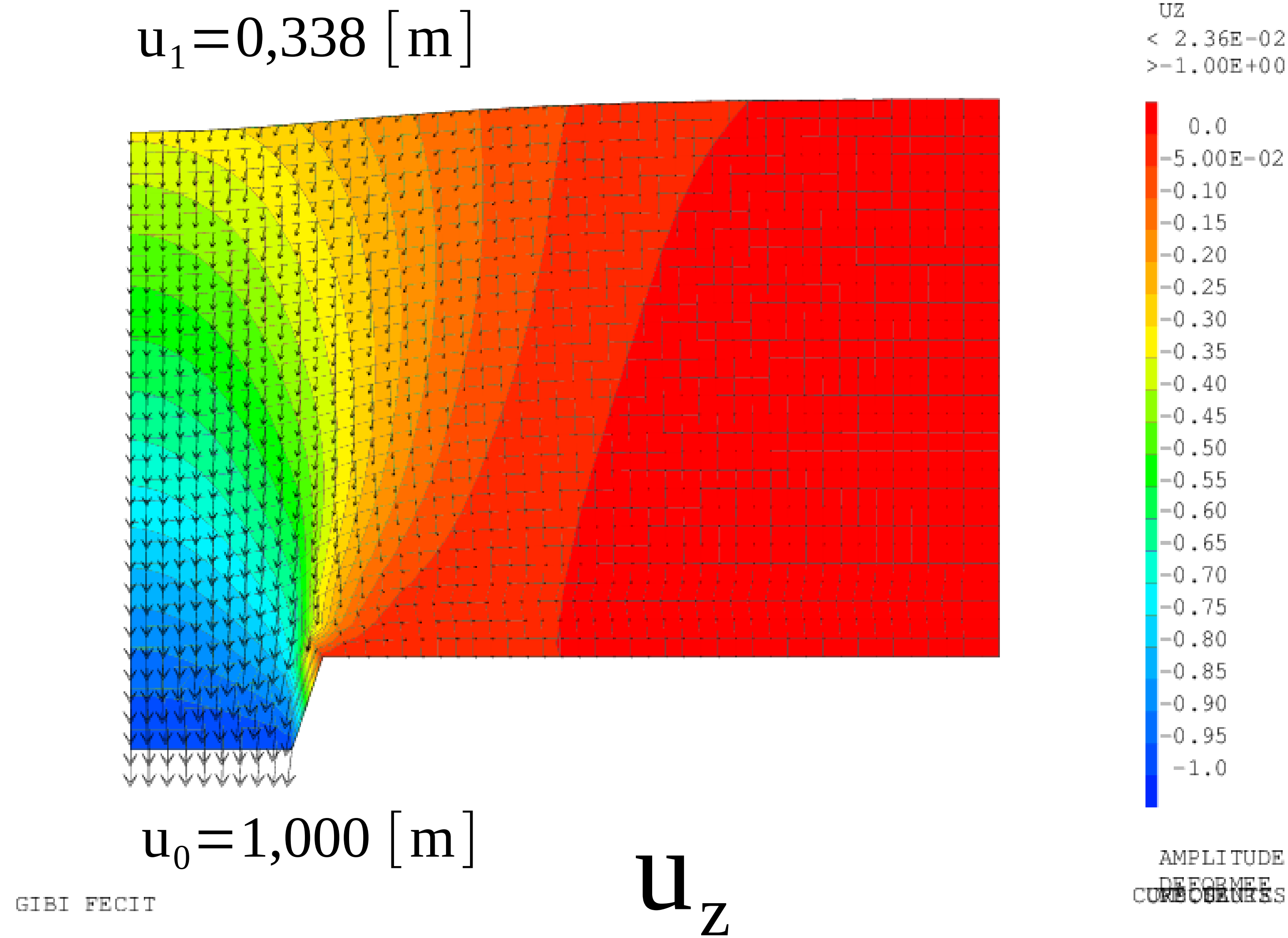
Model height: 30m

Stiffness: low

Material: cohesive (clay)

Mining subsidence – Vertical displacement:

$u_1 = 0{,}338\ [m]$



$u_0 = 1{,}000\ [m]$

u_z

Drucker-Prager:

$\varrho = 2000\ [kg/m^3]$

$\varphi = 10{,}00\ [°]$

$c = 10{,}00\ [kN/m^2]$

$\psi = 0{,}00\ [°]$

$E_{ref} = 10^6\ [kN/m^2]$

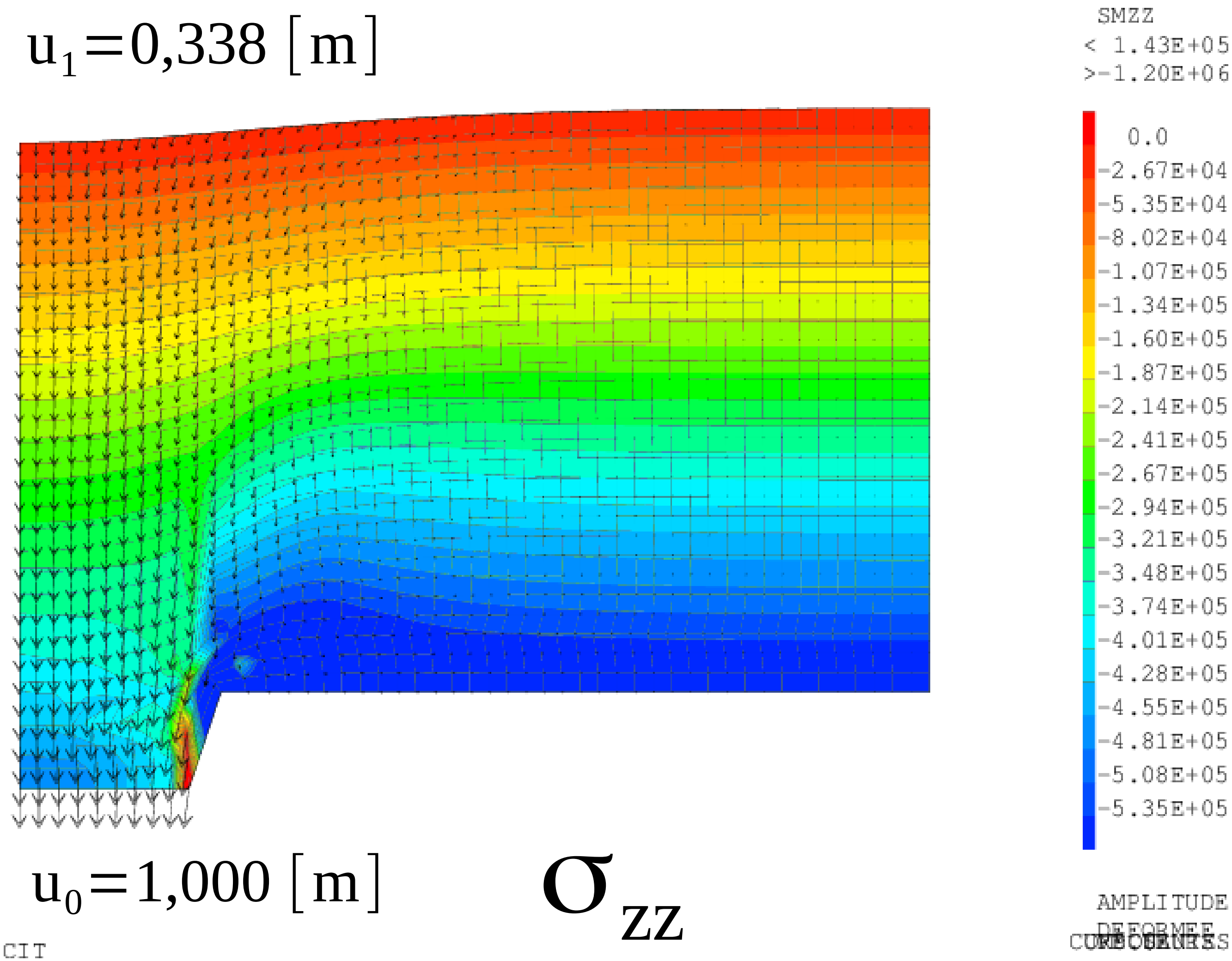
$p_{ref} = 10^5\ [kN/m^2]$

$m = 0{,}75\ [1]$

$\nu = 0{,}45\ [1]$

$K_0 = 0{,}826\ [1]$

Mining subsidence – Vertical stress:



Drucker-Prager:

$\varrho = 2000\ [kg/m^3]$

$\varphi = 10,00\ [°]$

$c = 10,00\ [kN/m^2]$

$\psi = 0,00\ [°]$

$E_{ref} = 10^6\ [kN/m^2]$

$p_{ref} = 10^5\ [kN/m^2]$

$m = 0,75\ [1]$

$\nu = 0,45\ [1]$

$K_0 = 0,826\ [1]$

Geotechnic mining subsidence analysis:

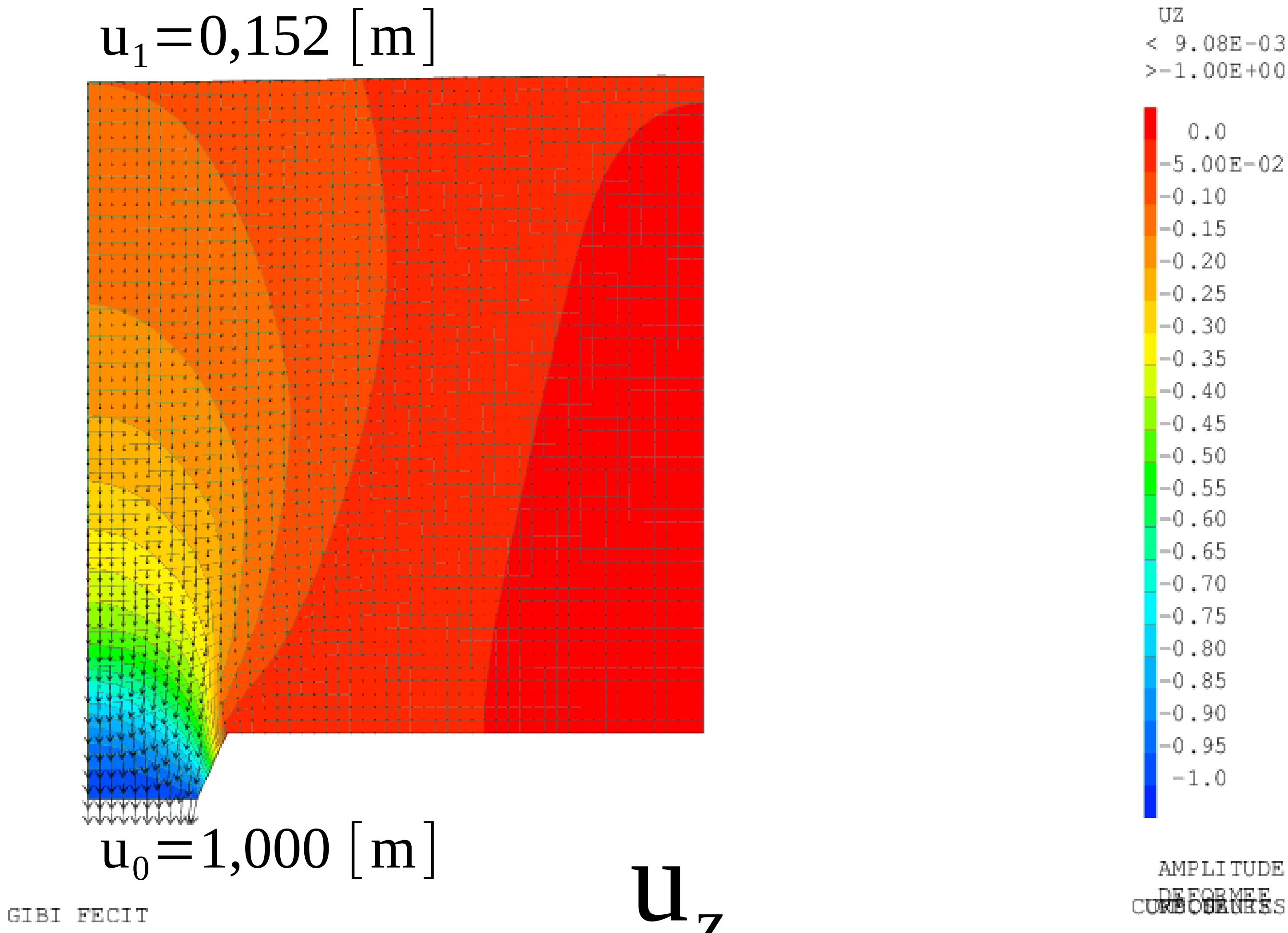
Model height: 50m

Stiffness: high

Material: frictional, non cohesive (sand)

Mining subsidence – Vertical displacement:

$u_1 = 0{,}152\ [m]$



$u_0 = 1{,}000\ [m]$

u_z

Drucker-Prager:

$\varrho = 2000\ [kg/m^3]$

$\varphi = 30{,}00\ [°]$

$c = 1{,}00\ [kN/m^2]$

$\psi = 0{,}00\ [°]$

$E_{ref} = 10^7\ [kN/m^2]$

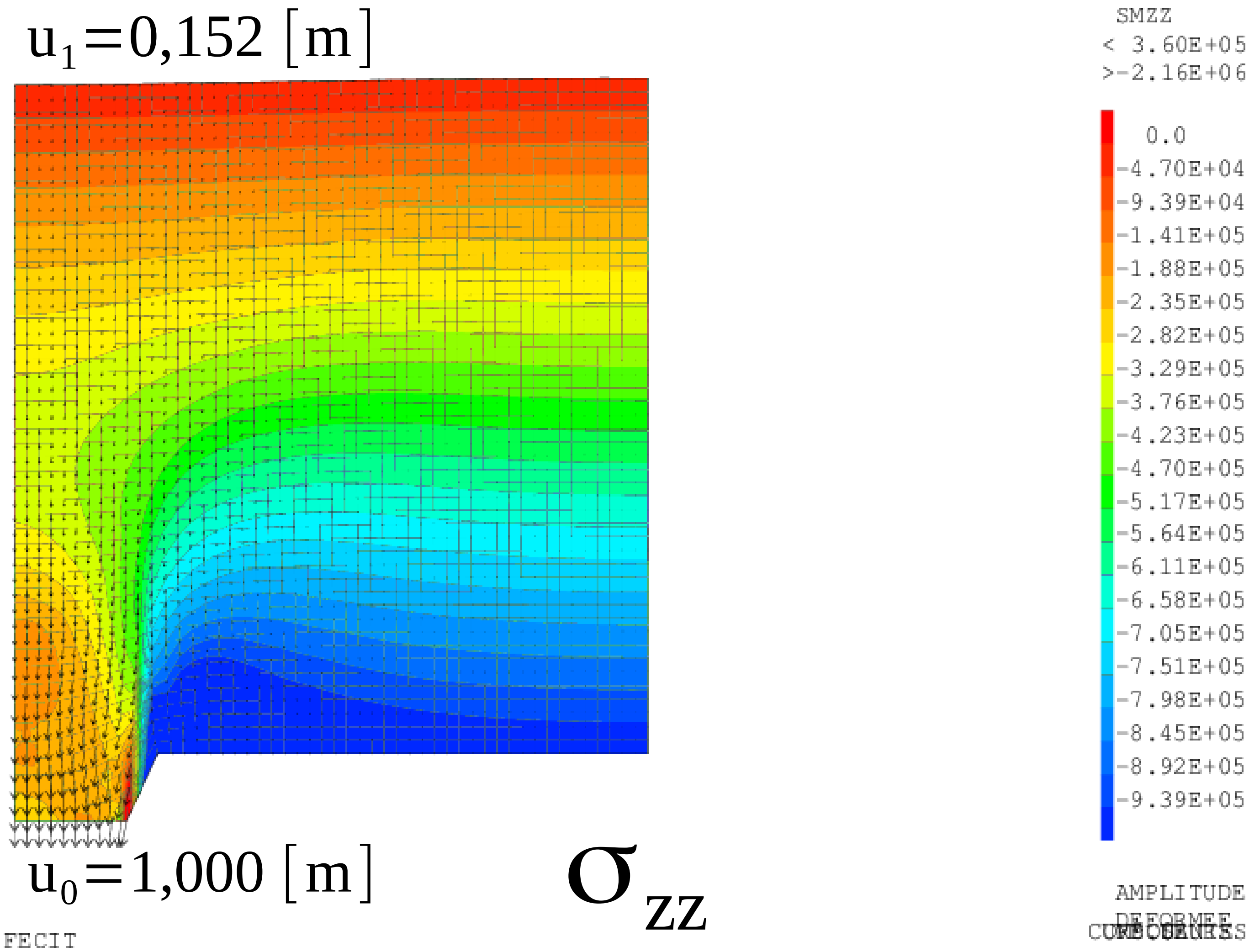
$p_{ref} = 10^5\ [kN/m^2]$

$m = 0{,}50\ [1]$

$\nu = 0{,}33\ [1]$

$K_0 = 0{,}500\ [1]$

Mining subsidence – Vertical stress:



Drucker-Prager:

$\varrho = 2000\ [kg/m^3]$

$\varphi = 30,00\ [°]$

$c = 1,00\ [kN/m^2]$

$\psi = 0,00\ [°]$

$E_{ref} = 10^7\ [kN/m^2]$

$p_{ref} = 10^5\ [kN/m^2]$

$m = 0,50\ [1]$

$\nu = 0,33\ [1]$

$K_0 = 0,500\ [1]$

Geotechnic mining subsidence analysis:

Program system Cast3M-2015-1 (fr)

Open Source (Esope, Fortran77-derivate)

Project oriented extension possible

Free license for research and education

(http://www-cast3m.cea.fr)

Future developments in mining subsidence analysis

Future developments in mining subsidence analysis:

Geotechnical analysis methods will be more intensely applied

Cooperation between Geodesy and Geotechnics will be more profound (coupling of GIS and simulation codes)

Integration of laboratory test results

Future developments in mining subsidence analysis:

Improvement of the prediction performance and quality of material behaviour models for geomaterials

Application of inverse methods in combination with sensitivity analyses and extensive modelling campaigns

Future developments in mining subsidence analysis:

Use of parallel computational resources (fat nodes are increasingly available)

Computation of large models in the framework of true mine scale modelling

Consideration of coupled thermic, mechanic and hydraulic problems

Geotechnic mining subsidence analysis:

"Green" HPC-Cluster:

35 x VIA-C3-1GB
4 x iATOM-4GB

Software:

openSuSE Linux Tumbleweed

SLURM Resource Manager

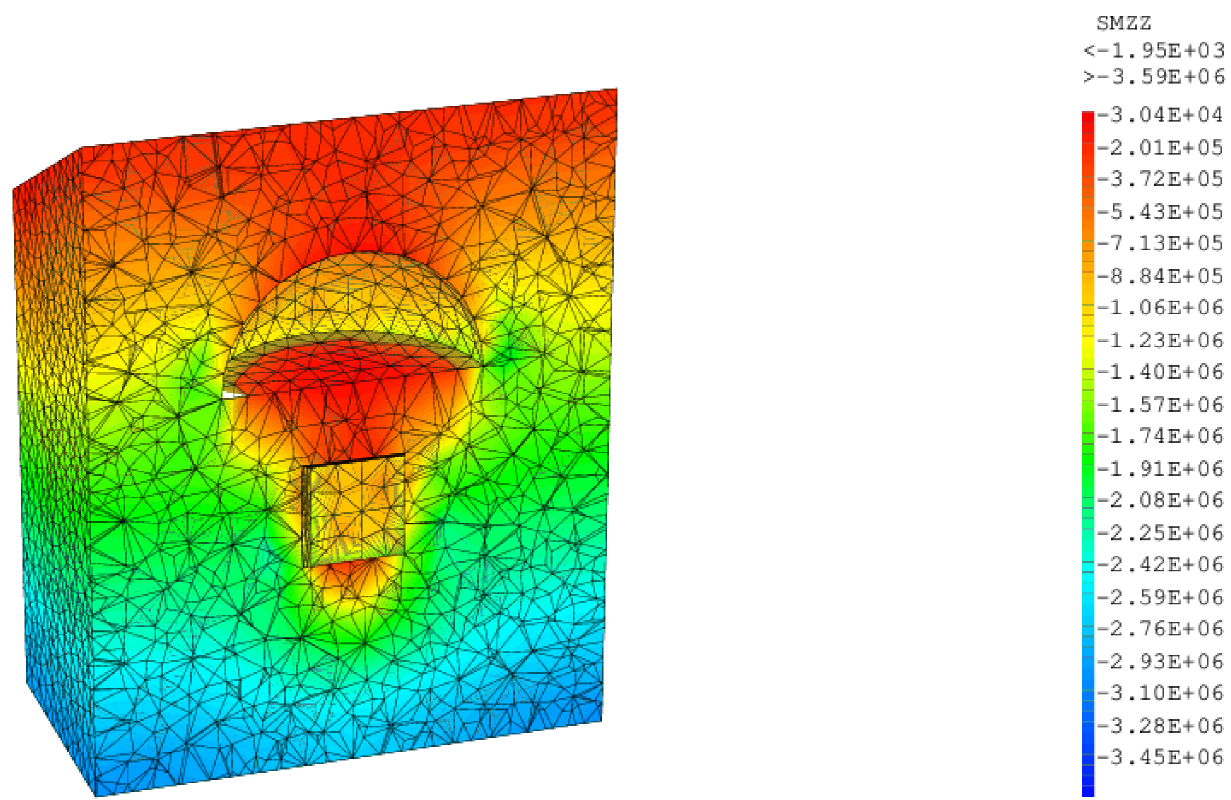
Python Scripting
+
Cast3M-2015-1 FEM Toolbox

Additional conceptual studies for diverse typical geotechnical applications of the Cast3M FEM analysis framework

Mine scale modelling

(Qualitative study)

Mine scale modelling (small scale here):



GIBI FECIT

NBEL=42k

Excavation procedure in Cast3M:

Efficient excavation procedure is available with virtual “time dependent” formulation of the material model parameters

From a stable initial state under external and self weight load, the stiffness and density parameters of the cavern are stepwise reduced to a very small value

Cast3M as solver module:

The MED (V3.2.0) library is available for data transfer between codes

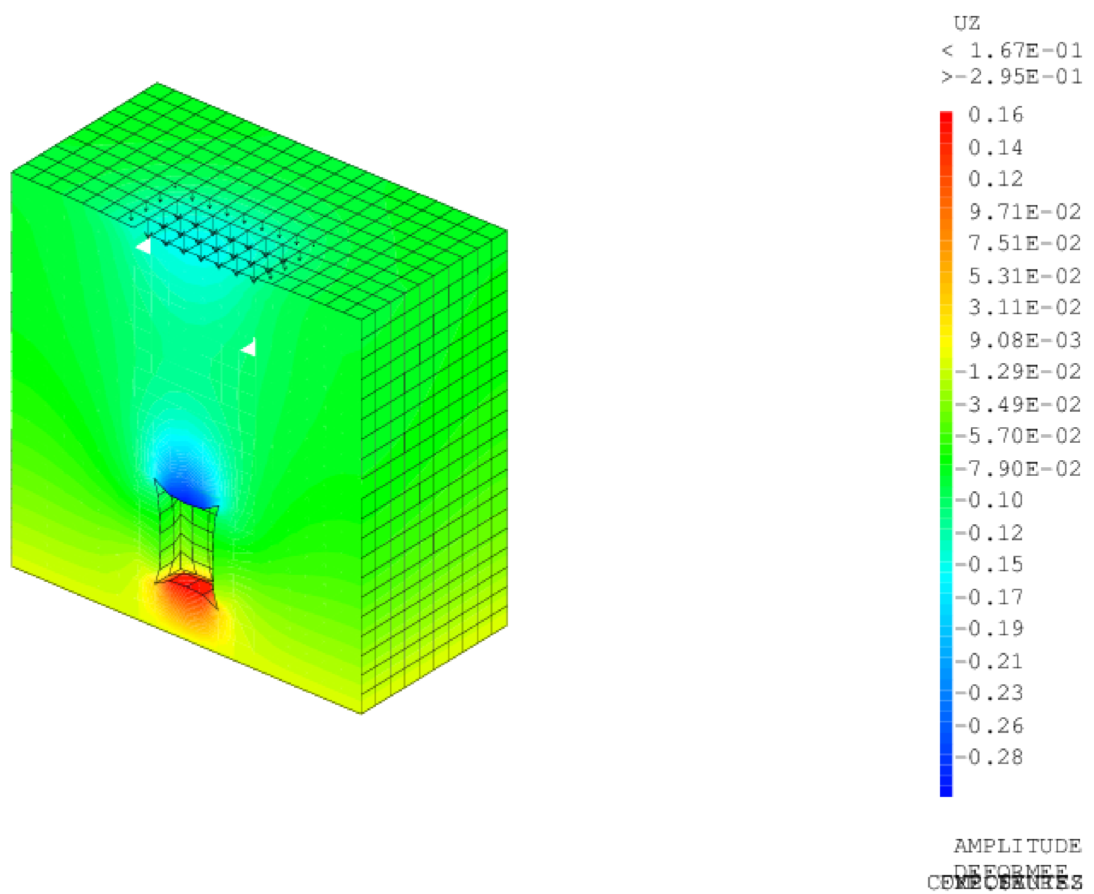
Coupling to GMSH is straightforward but post processing in Cast3M can be more powerful and advantageous

Additional coupling to SALOME through data transfer with the .sauv file format

Ground and structure interaction induced by underground openings such as caverns, tunnels or void spaces

(Qualitative study and patch test for excavation procedure)

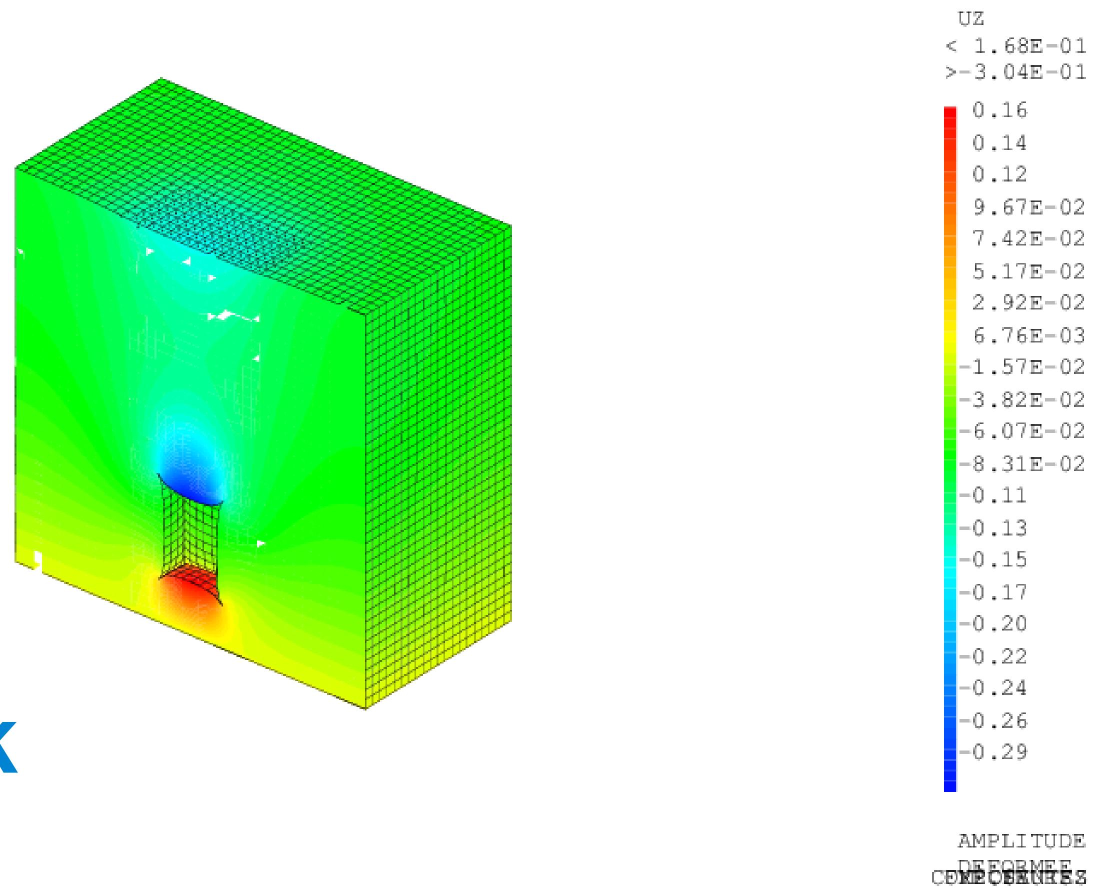
Ground and structure interaction:



NBEL=8k

GIBI FECIT

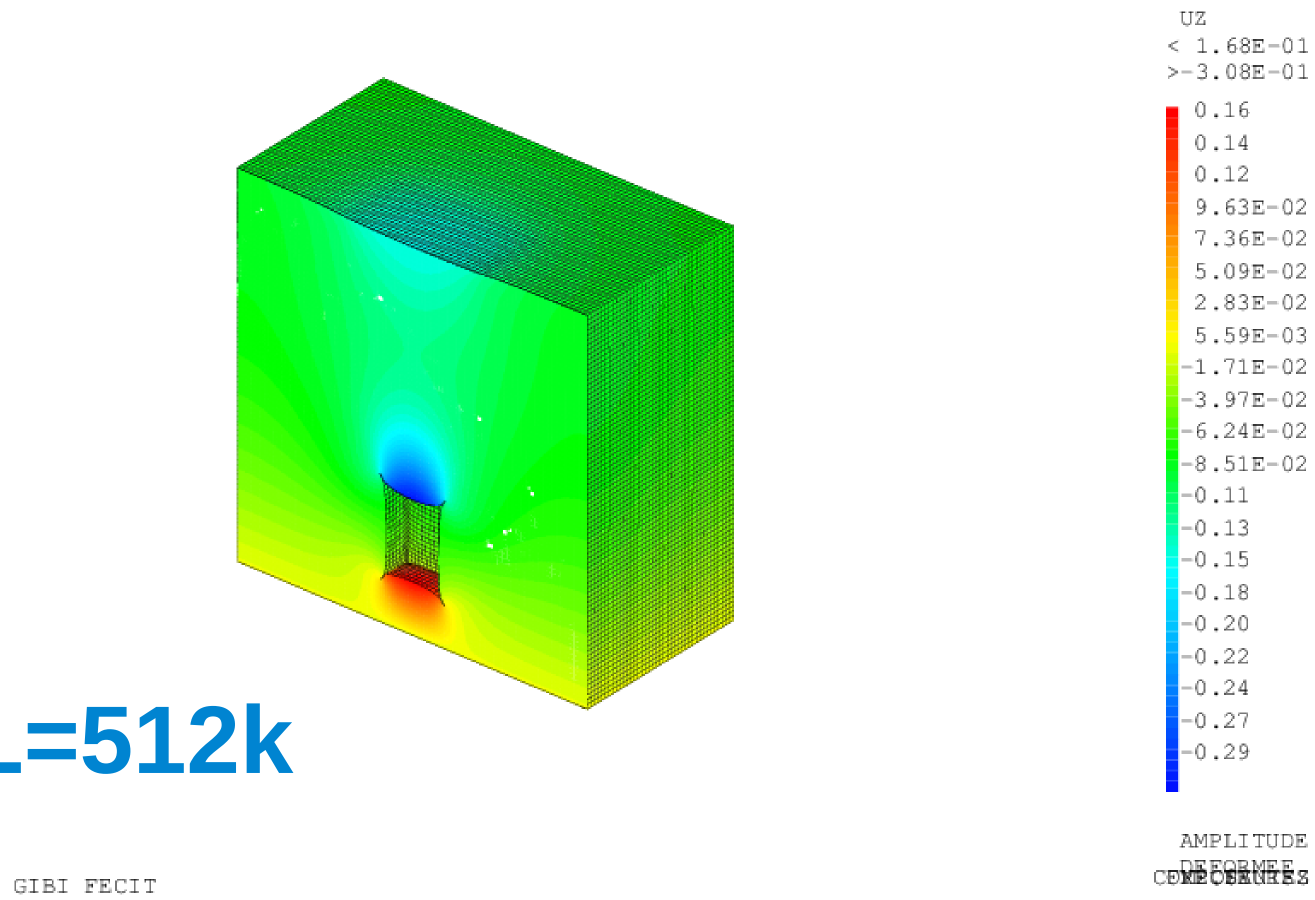
Ground and structure interaction:



NBEL=64k

GIBI FECIT

Ground and structure interaction:

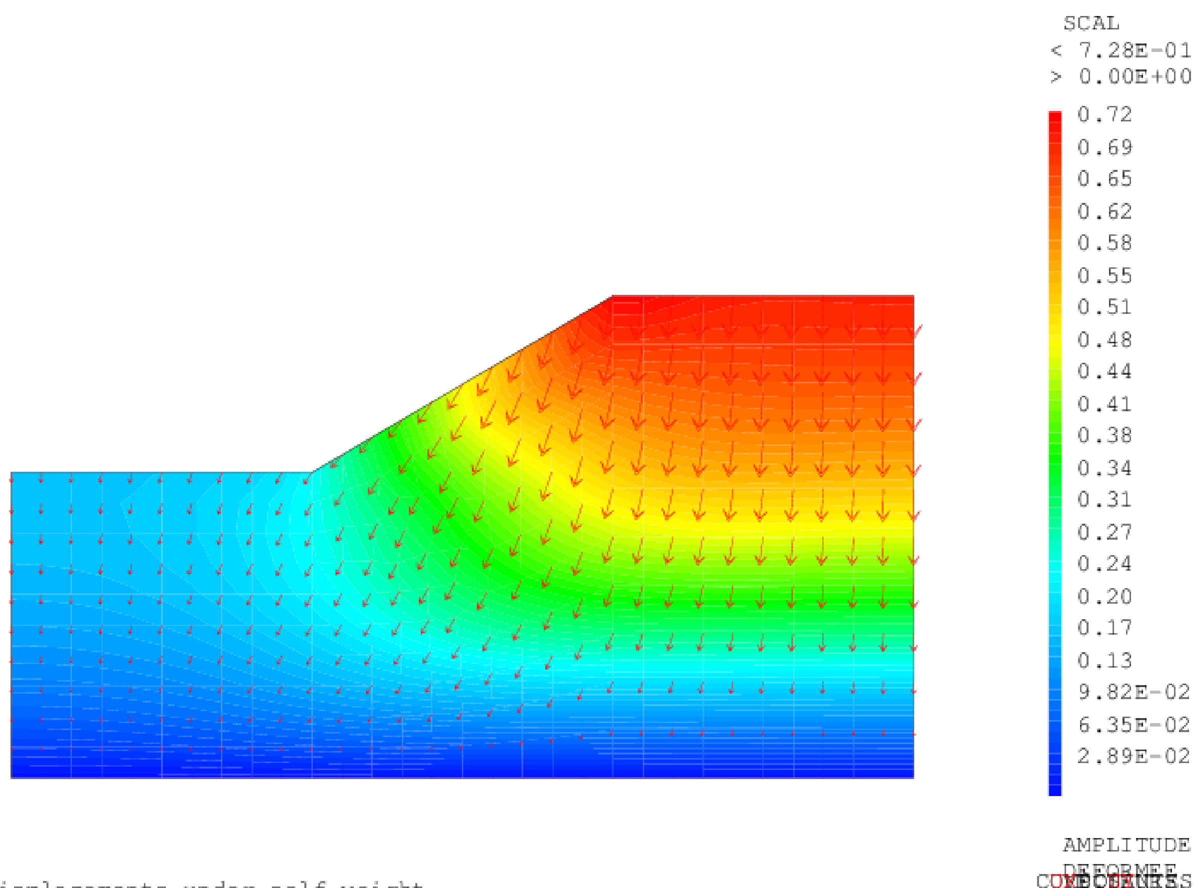


NBEL=512k

Slope stability analysis for the proof of the overall stability of a geotechnical system

(Qualitative study)

Slope stability – self weight deformations:



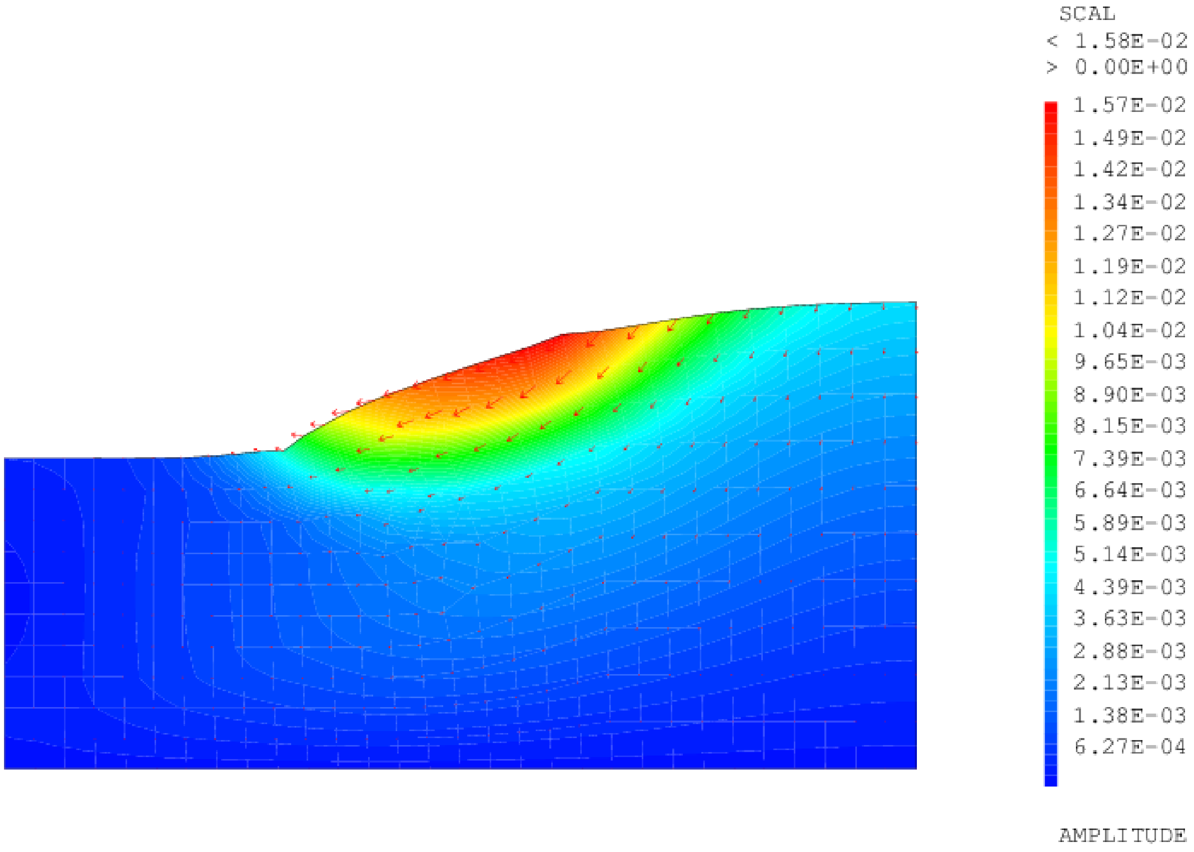
Slope displacements under self weight

Factor of safety or Utilisation factor calculation procedure:

Calculation of a stable initial stress and corresponding deformation state

Recursive reduction of the shear and tensile strength until a convergence to a prescribed tolerance is still obtainable

Slope stability – deformations in limit state:

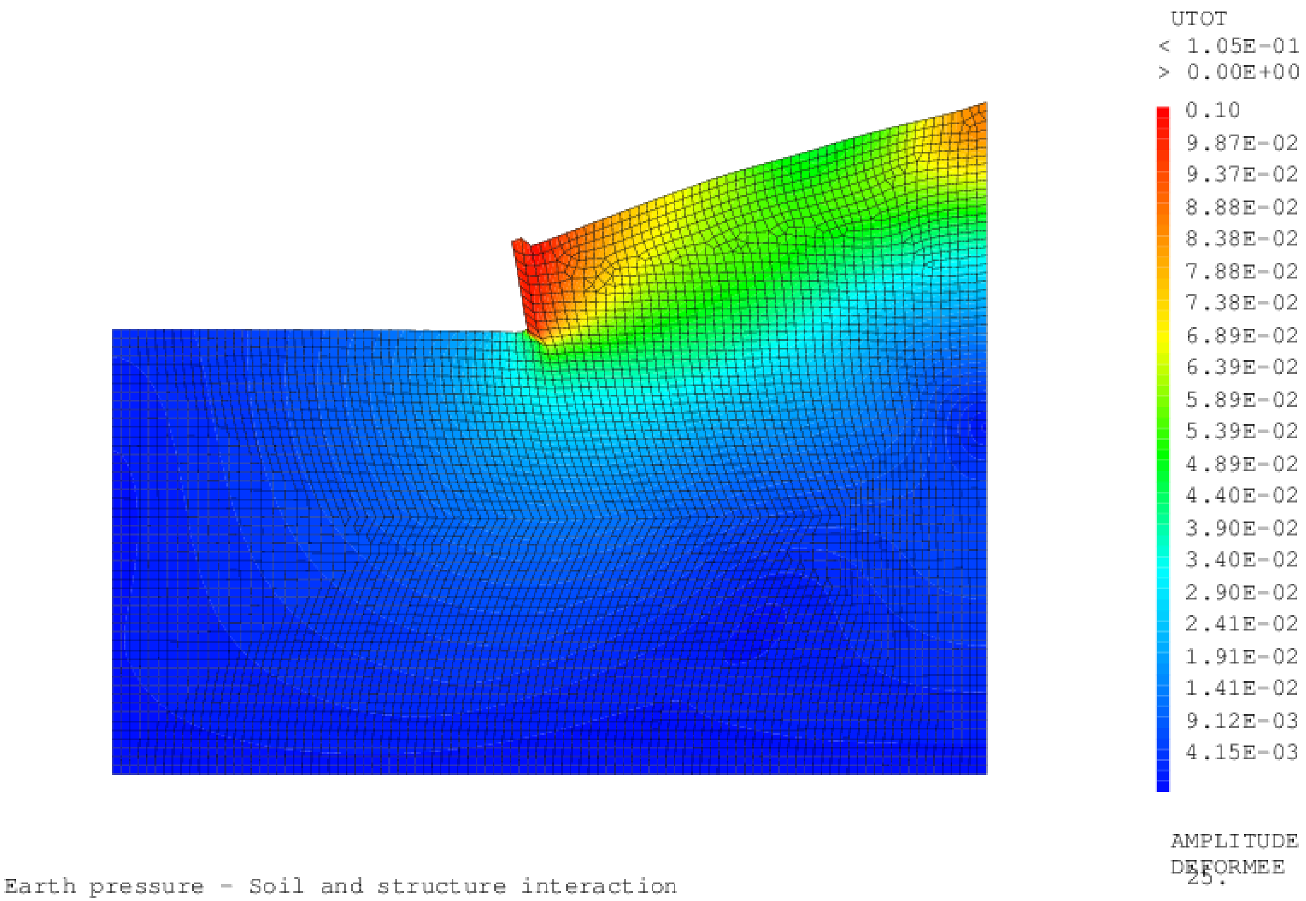


Slope displacements and deformations in limit state

Supporting construction design

(Qualitative study)

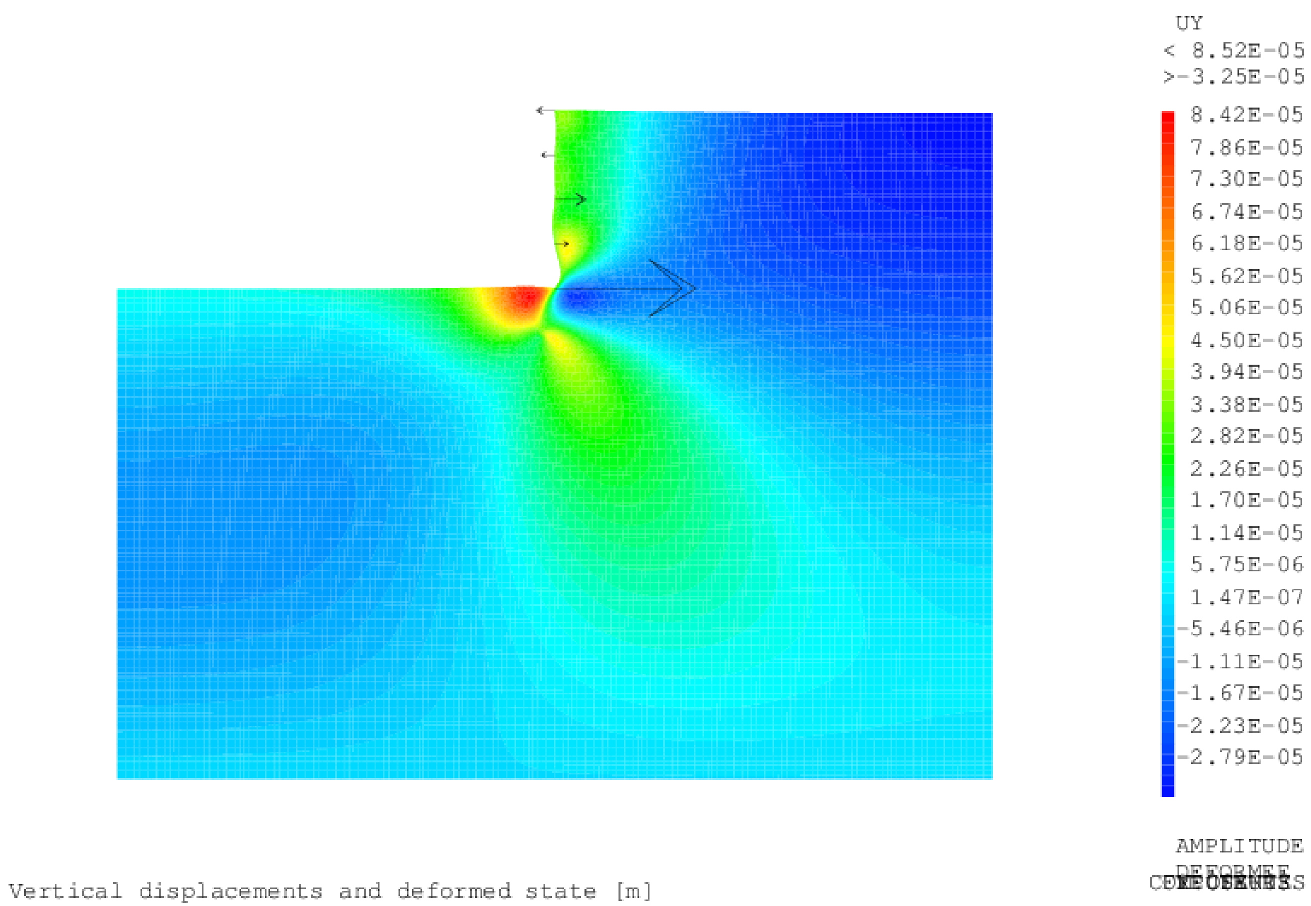
Supporting construction design:



Construction trench wall design

(Qualitative study)

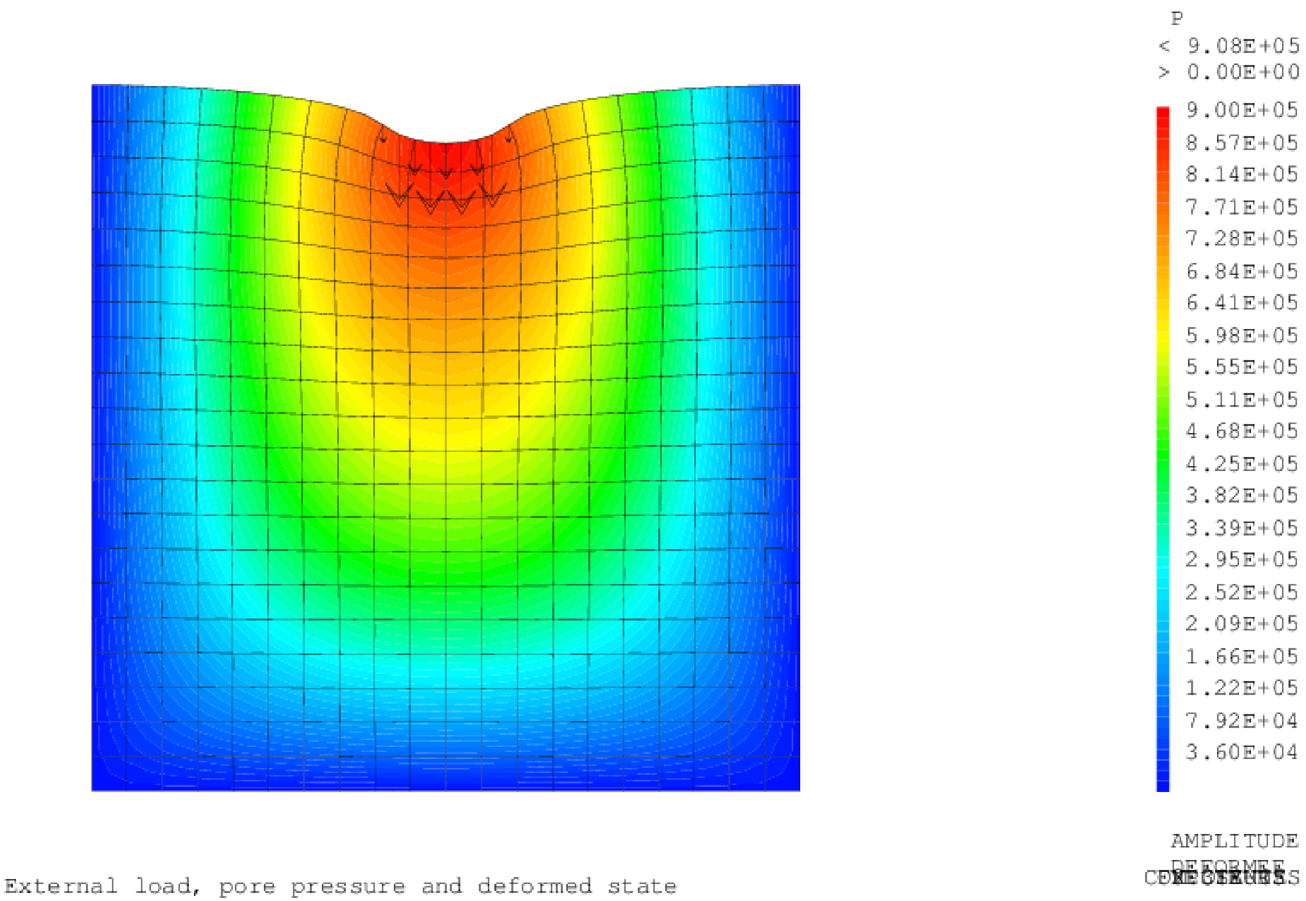
Construction trench wall design:



Spatial consolidation problem

(Qualitative study)

Spatial consolidation problem:



Further application fields:

Dynamic loading of structures in time and frequency domain

Soil and structure interaction

Groundwater flow and contamination transport modelling

Geothermal applications

Conclusions

Summary:

Cast3M is an excellent and unique open source programme for education, research and commercial use in Geotechnics

With minor extensions and adjustments, Cast3M can also compete with known commercial geotechnical codes on the market with WORLDWIDE HIGH DEMAND

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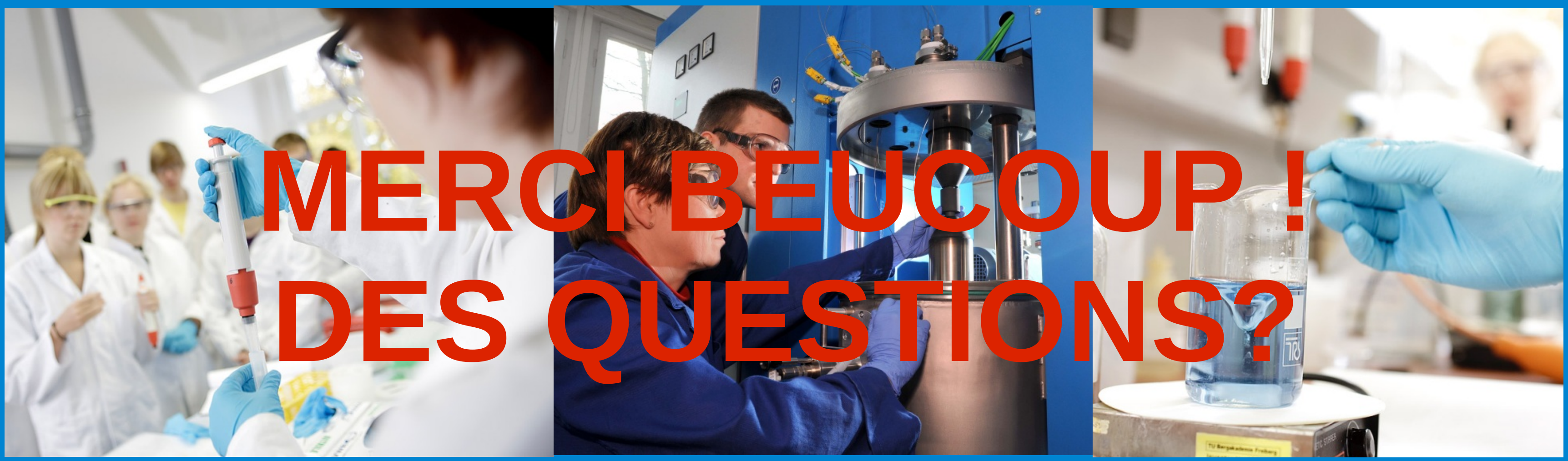

MERCI BEUCOUP !
DES QUESTIONS?

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