Discrete vs. smeared modelling of rock slopes or where are the application limits of the Hoek-Brown strength criterion.

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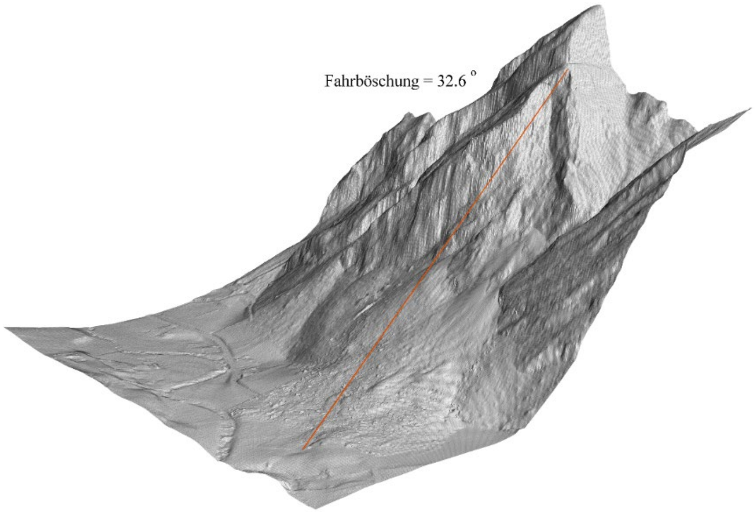
Example Rock Fall Vals



Geology Valsertal: Part of the Tauern window; mostly hard and firm calcareous marbles and calcareous mica schists (UCS > 100 MPa, class R5 according to ISRM 1981), subordinate also low-strength calcareous phyllites and graphite pyhllites.

Research Project

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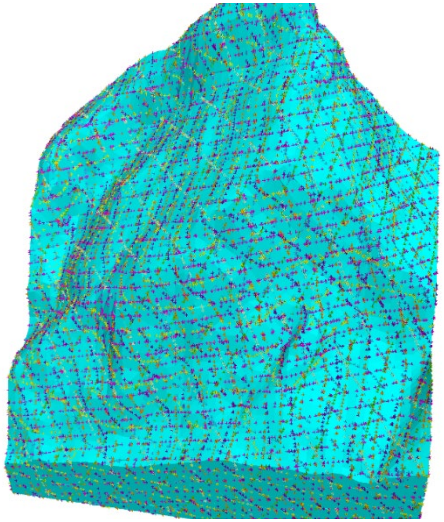
die.wildbach und lawinenverbauung

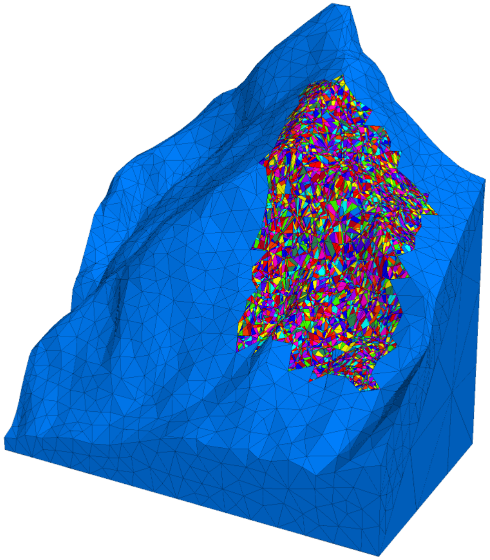
Continuum vs. Discontinuum mechanics

FEM or FDM

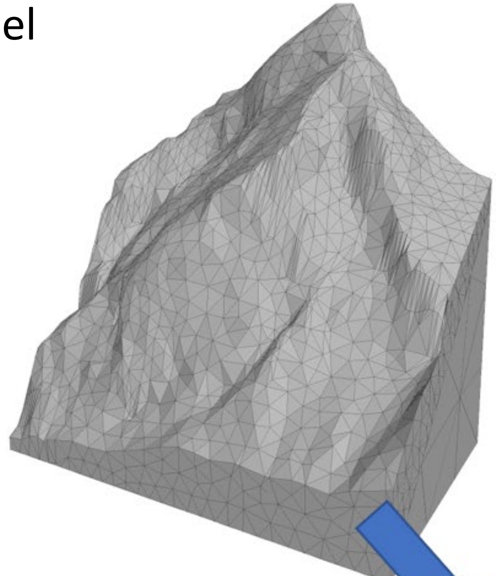
Conventional DEM



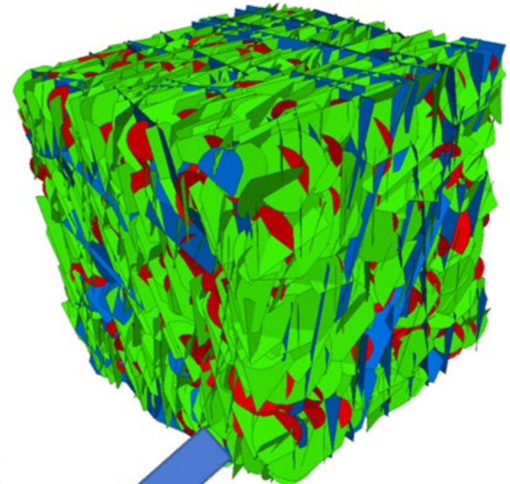
DEM using a Synthetic Rock Mass (SRM)



Solid model

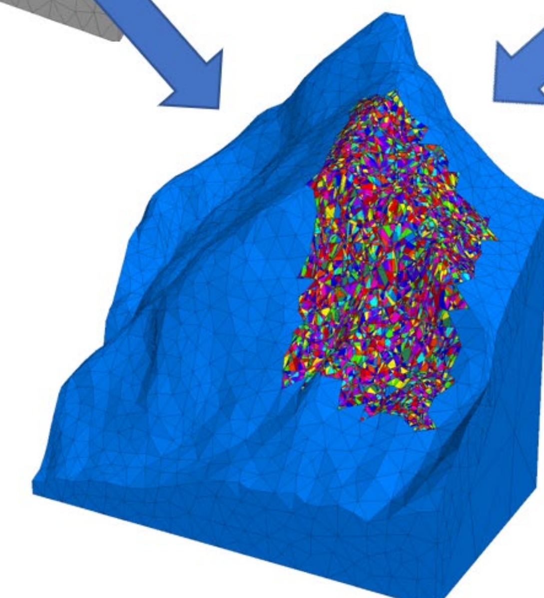


Discrete Fracture Network (DFN)



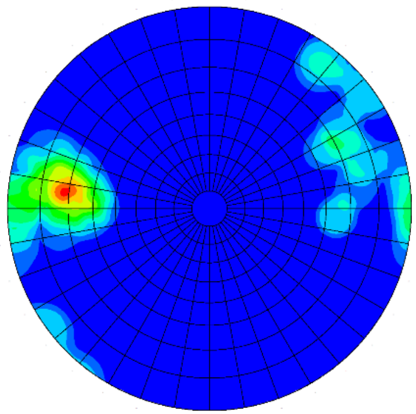
- Position
- Orientation
- Fracture Size Distribution
- Density or Fracture Intensity

SRM



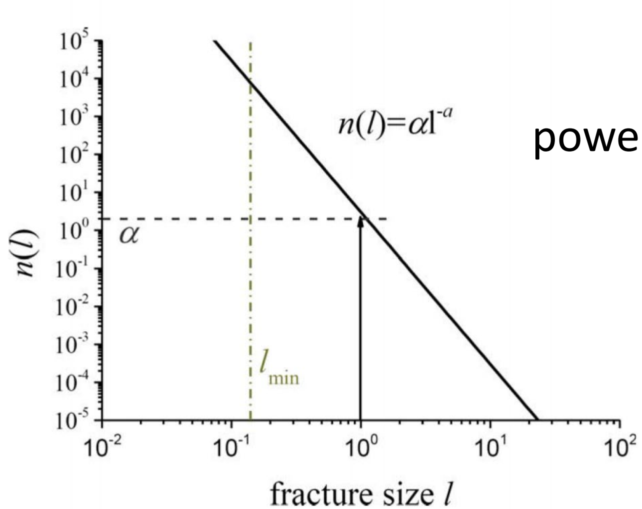
Discrete Fracture Network (DFN)

Orientation



e.g. Fisher

Fracture Size Distribution

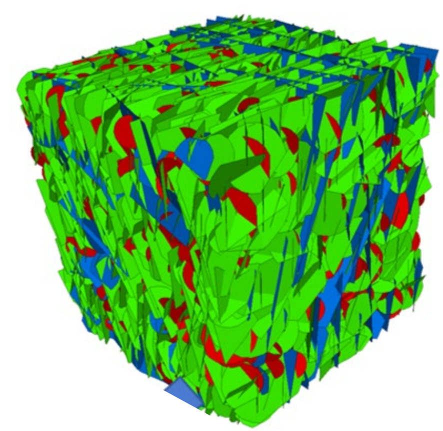


power law

fracture density

Dimension of Sample			Dimension of Feature: 0	1	2	3	
Dimension of Sample	Line	1	P_{10} Number of fractures per unit lenght [m^{-1}]	P_{11} Fracture aperture per unit lenght [-]			Linear Measures
	Area	2	P_{20} Number of fractures per unit area [m^{-2}]	P_{21} Lenght of fractures per unit area [m^{-1}]	P_{22} Area of fractures per unit area [-]		Areal Measures
	Volume	3	P_{30} Number of fractures per unit volume [m^{-3}]		P_{32} Area of fractures per unit volume [m^{-1}]	P_{33} Volume of fractures per unit volume [-]	Volumetric Measures
			Density		Intensity	Porosity	

DFN



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Parameters necessary for each joint set

Table 6.1 Summary of parameters used to generate the three fracture sets

Fracture set	Property	Distribution	Parameters
set 1:	positions	uniform	positions generated in all of space
subvertical	orientations	Fisher	dip 90°, dip direction: 120°, $\kappa = 200$
	lengths	power law	scaling exponent: $a = 4$, $l_{min} = 10$, $l_{max} = 500$
	density		$P_{32} = 0.33$ in the model domain extent
set 2:	positions	uniform	positions generated in all of space
subhorizontal	orientations	Fisher	dip 20°, dip direction: 30°, $\kappa = 500$
	lengths	power law	scaling exponent: $a = 4$, $l_{min} = 10$, $l_{max} = 500$
	density		number of observed fractures on the vertical outcrop: 39
set 3:	positions	uniform	positions generated in all of space
background	orientations	bootstrapped	from file
	lengths	power law	scaling exponent: $a = 3.2$, $l_{min} = 2$, $l_{max} = 10$
	density		P_{10} measured on the vertical borehole of length 85 m: 0.5

Intact rock parameters from laboratory tests

Intact rock

Density
Young's modulus
Poisson's ratio

Friction angle
Cohesion
Tensile strength

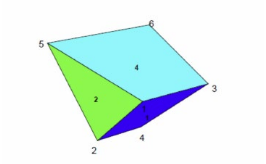
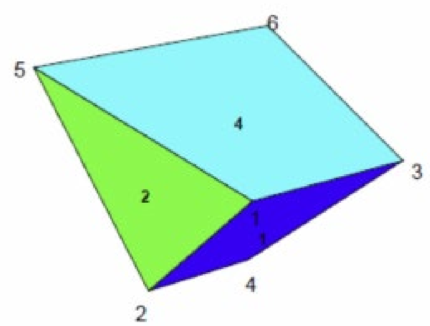
Joints

Normal stiffness
Shear stiffness

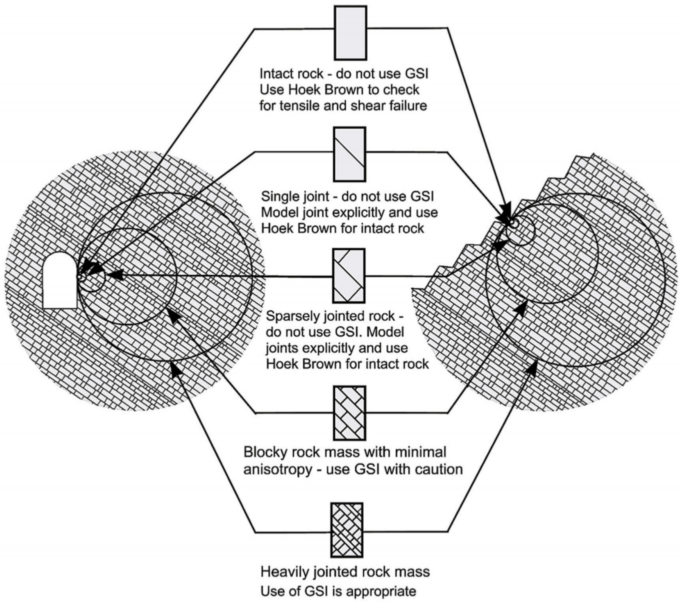
Friction angle
Cohesion
Tensile strength

Upscaling

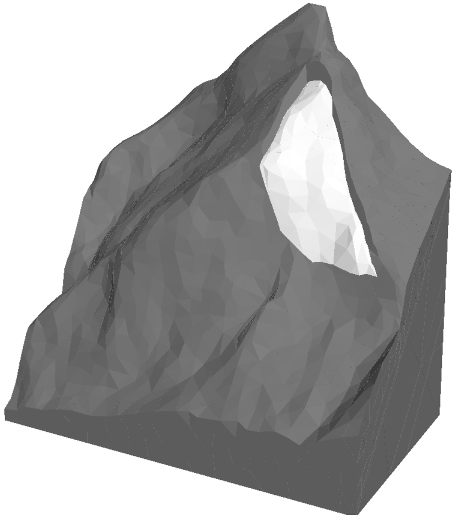
Due to the high computation times, density upsacling is required.

Laboratory scale   Model scale

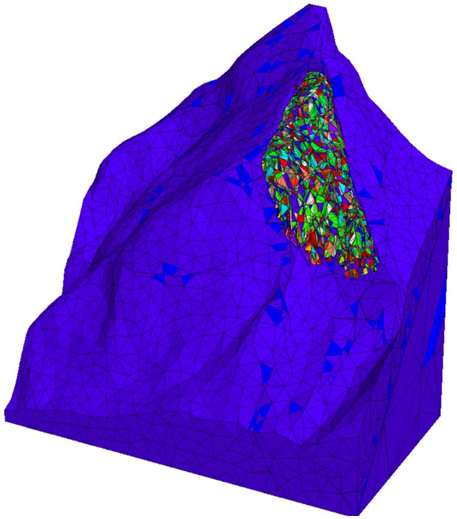
The blocks become larger than they are in situ!



Back-calculating the failure



Model A: Rigid Wedge

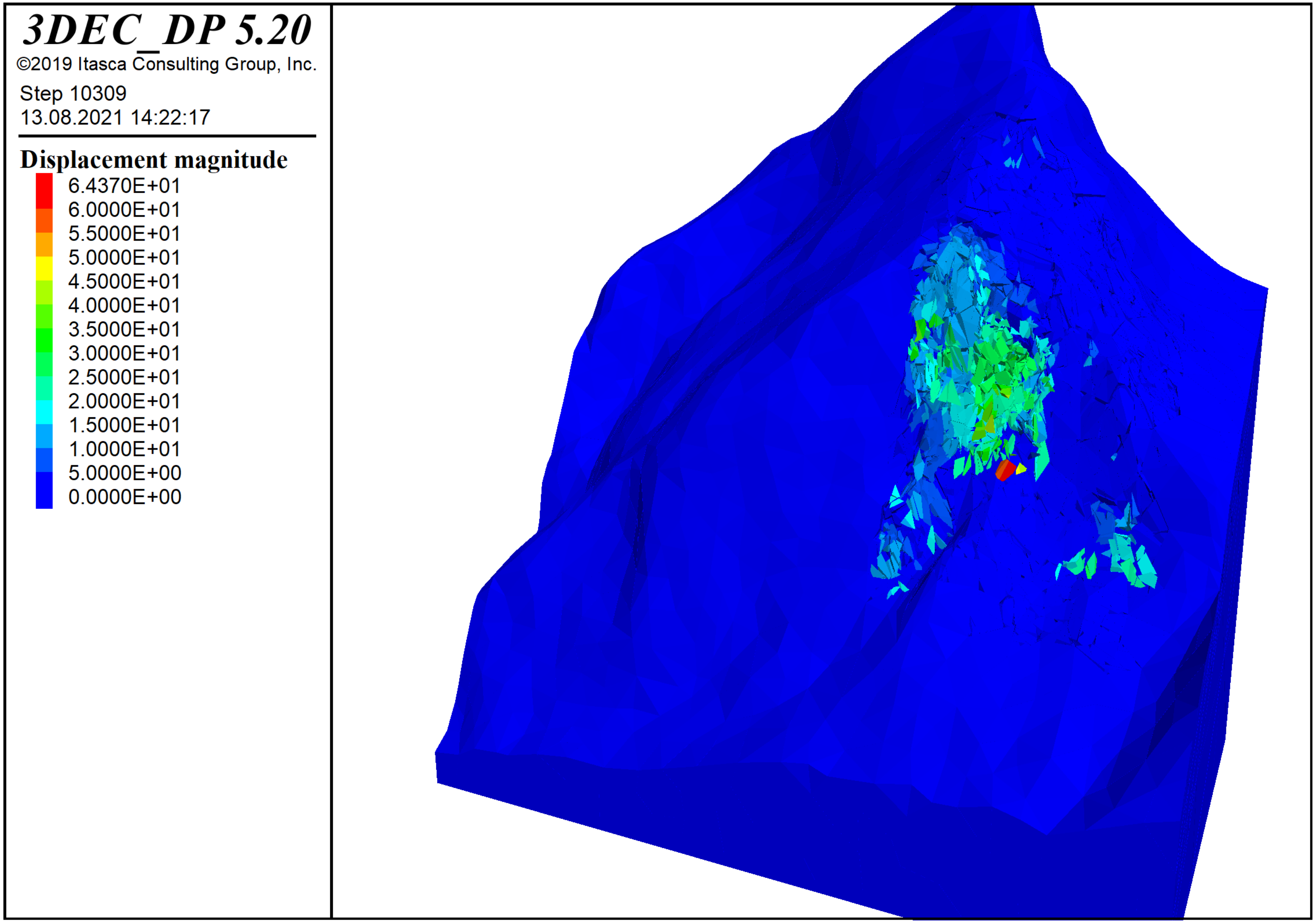


Model C: Wedge discretized via SRM

Fracture Intensity vs. Factor of Safety

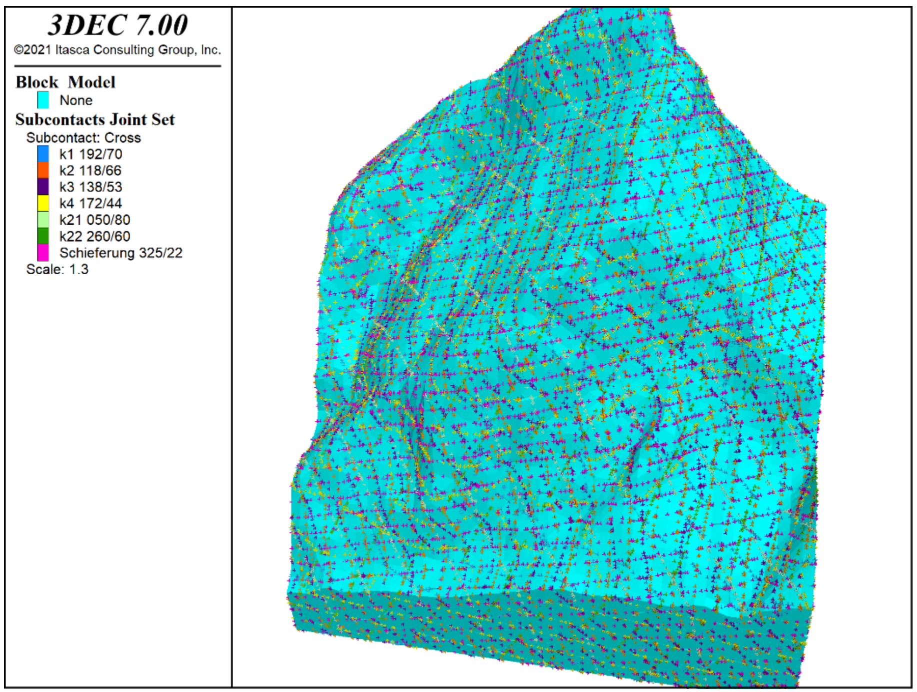
Versuch Nr.	I_{new}/I_{start}	FoS
Versuch_1b_1	1/20	0,4
Versuch_1b_2	1/40	0,4
Versuch_1b_3	1/80	0,6
Versuch_1b_4	1/100	0,8

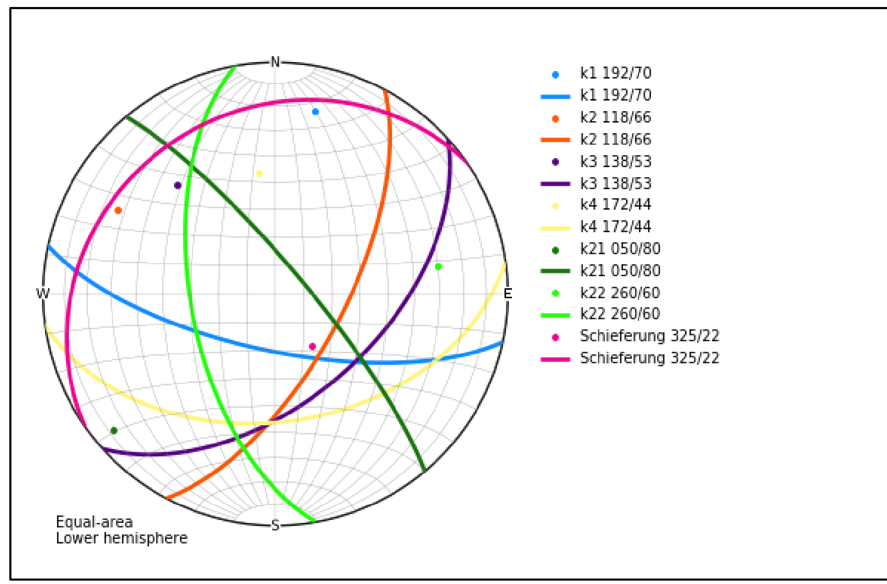
Deplacements - rigid block model



Conventional DEM- rigid block model

Conventional DEM: taking into account the mean orientations of the discontinuities.

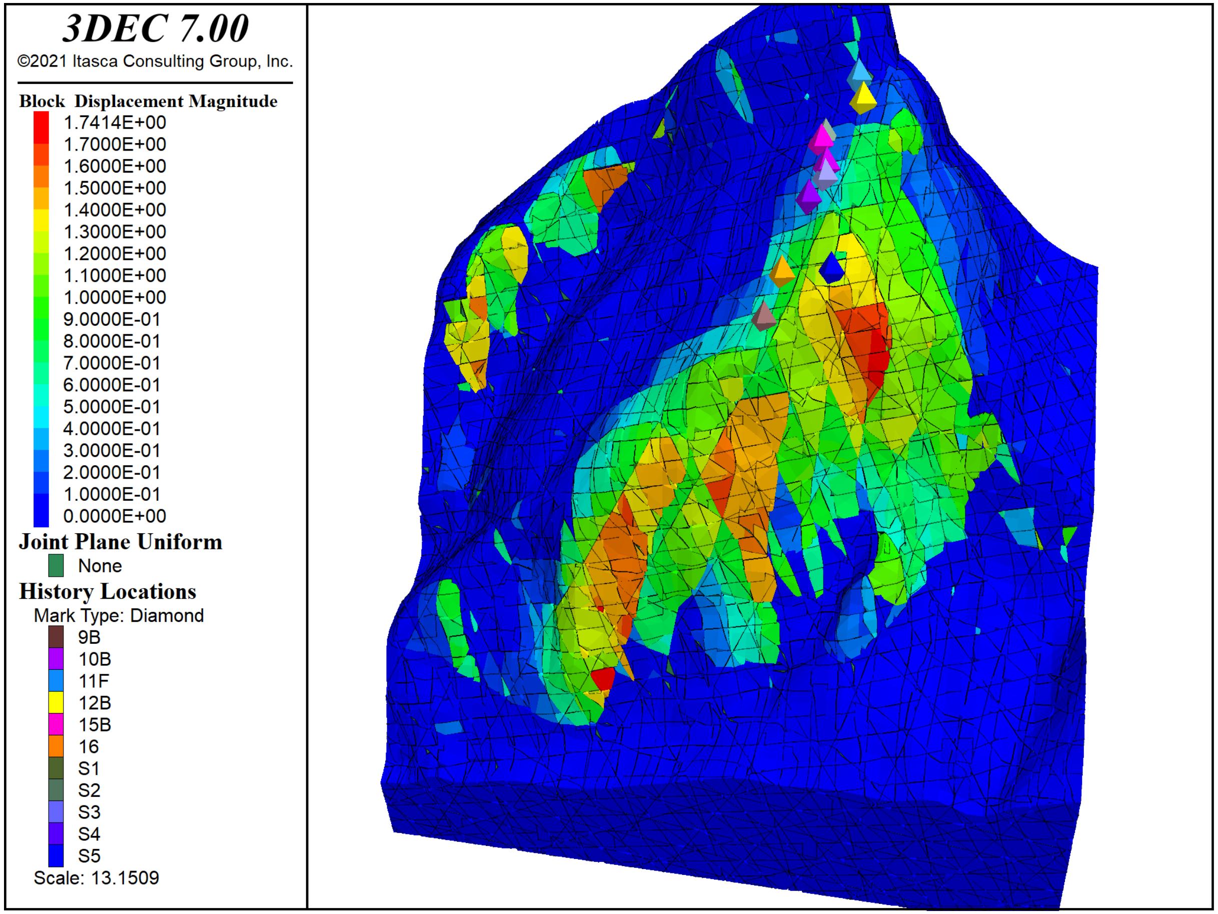




Conventional DEM- rigid block model

Interface strengths from wedge analysis

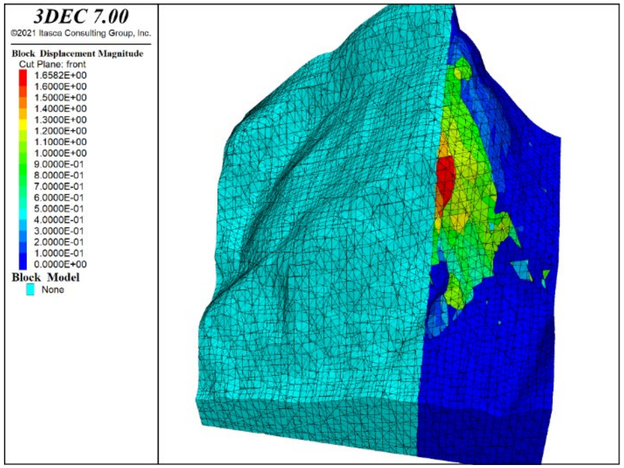
φ_{grenz} = 42,3°, c_{grenz} = 0,5 MPa.

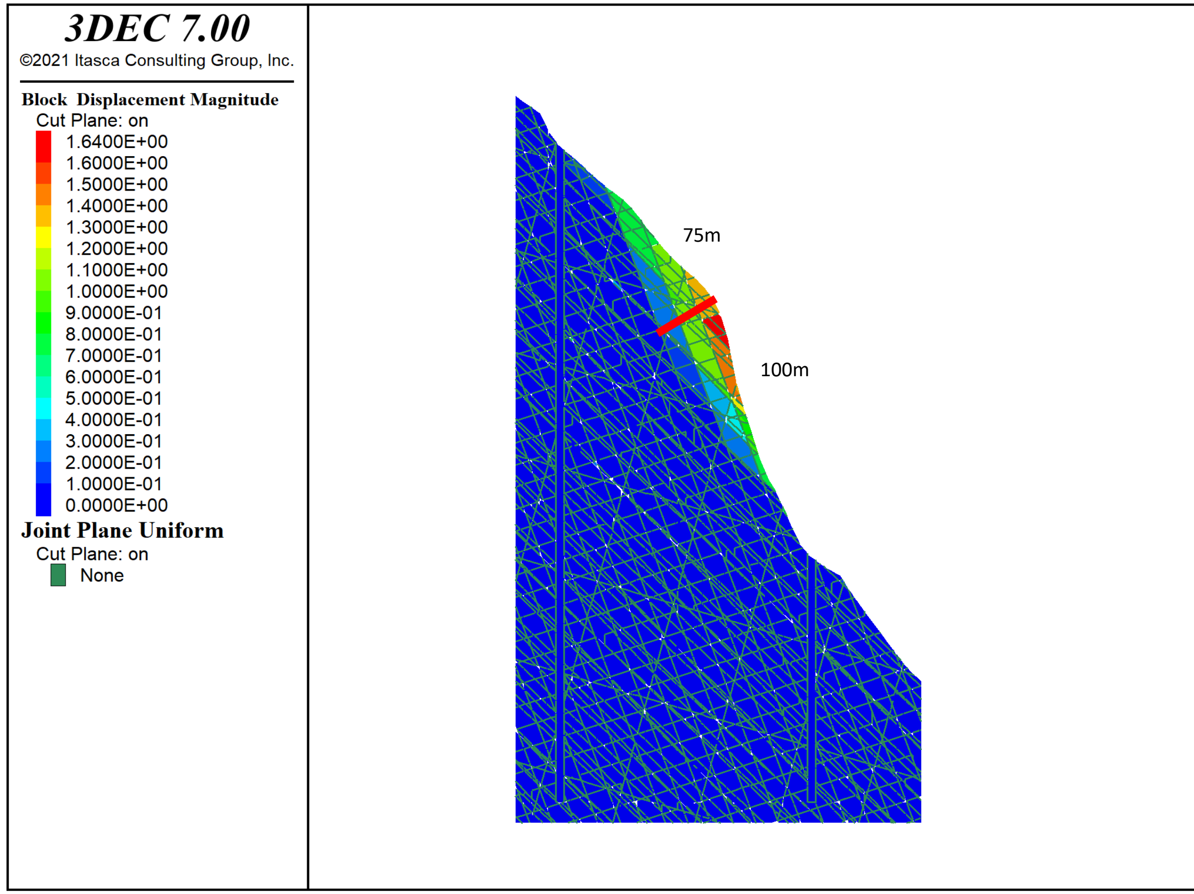


Contour plot of displacement magnitudes [m], 20,000 calculation steps

Rigid block model

Depth of movement: ca. 30m

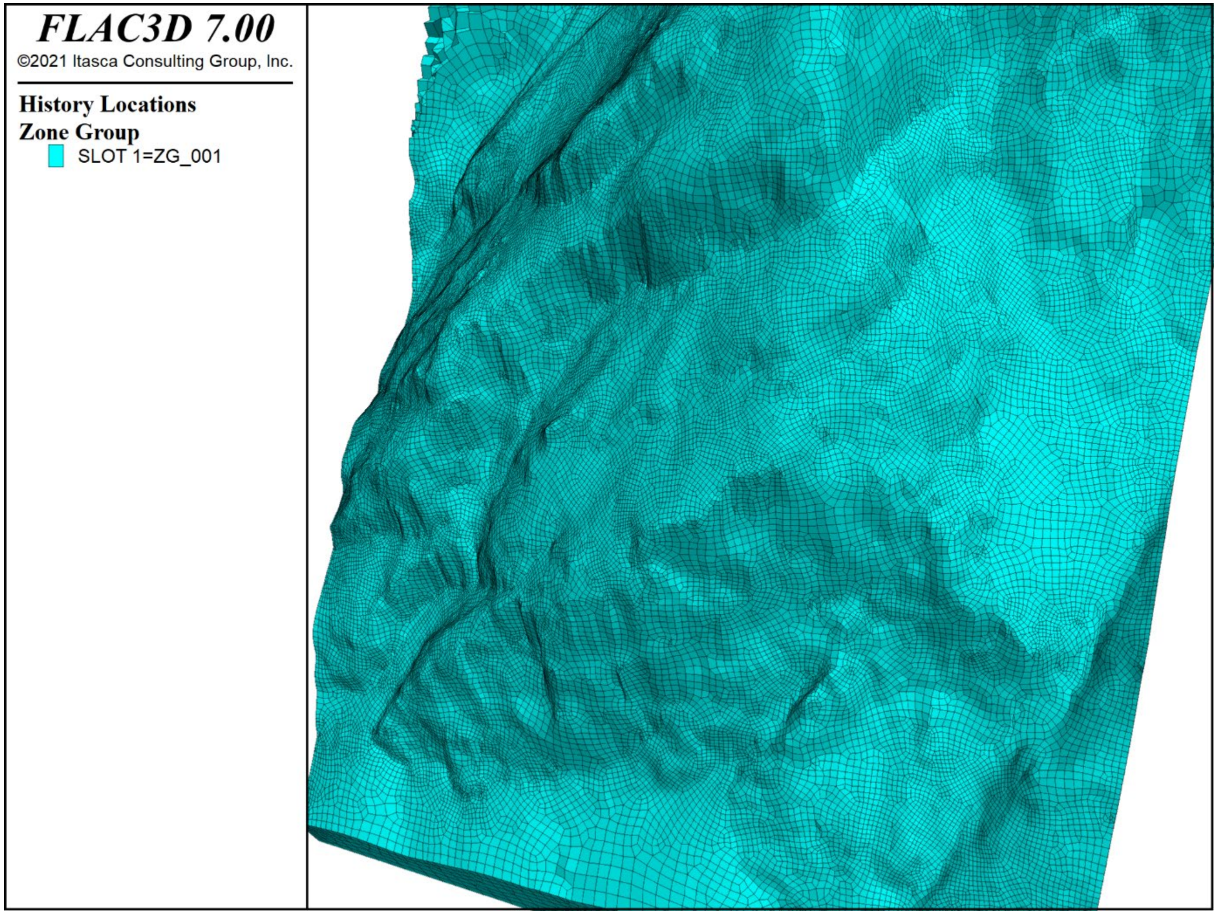




Contour plot of displacement magnitudes [m], 20,000 calculation steps

Number of continuum elements (zones): „ before“: 776.620

„after“: 652.463

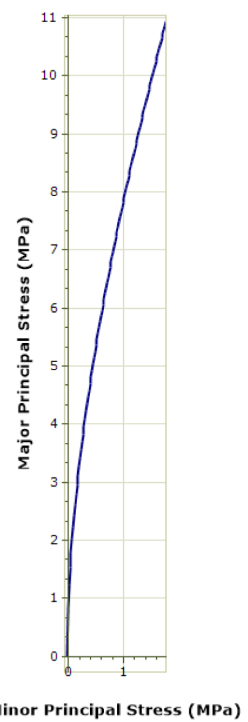


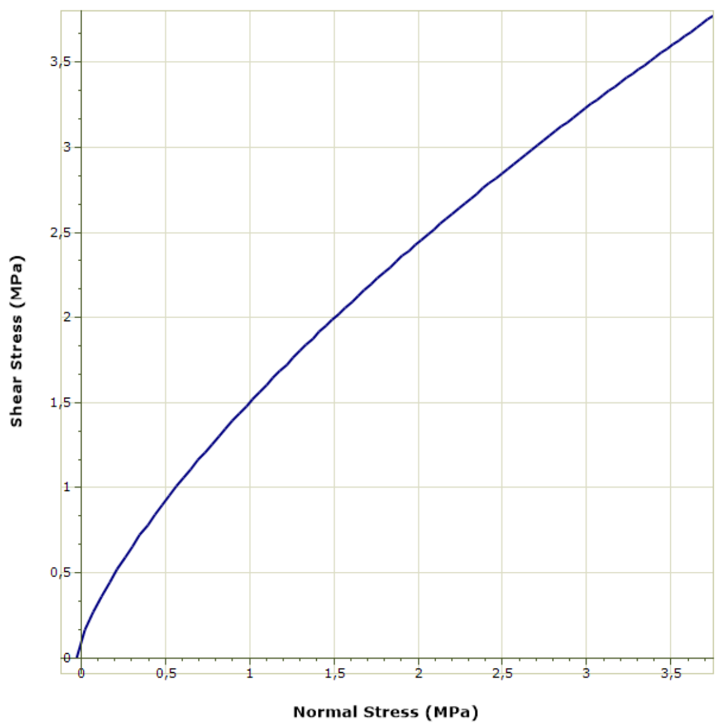
Used material models

1) Mohr-Coulomb (with equivalent parameters)
2) Hoek-Brown

Failure Criterion

	σ_{ci} (MPa)	GSI	mi	D	Ei (MPa)	modulus ratio	-	mb	a	s	-	application	sig3max (MPa)	unit weight (MN/m3)	tunnel depth (m)	slope height (m)	-	ϕ (°)	cohesion (MPa)	-	σ_t (MPa)	σ_c (MPa)	σ_{cm} (MPa)	E_m (MPa)
Material 1	45.8	34	12	0	30000	655.022		1.14	0.52	6.53e-004		slopes	1.72	0.02728	N/A	80		42.64	0.53		-0.03	1.03	6.1	3179.64

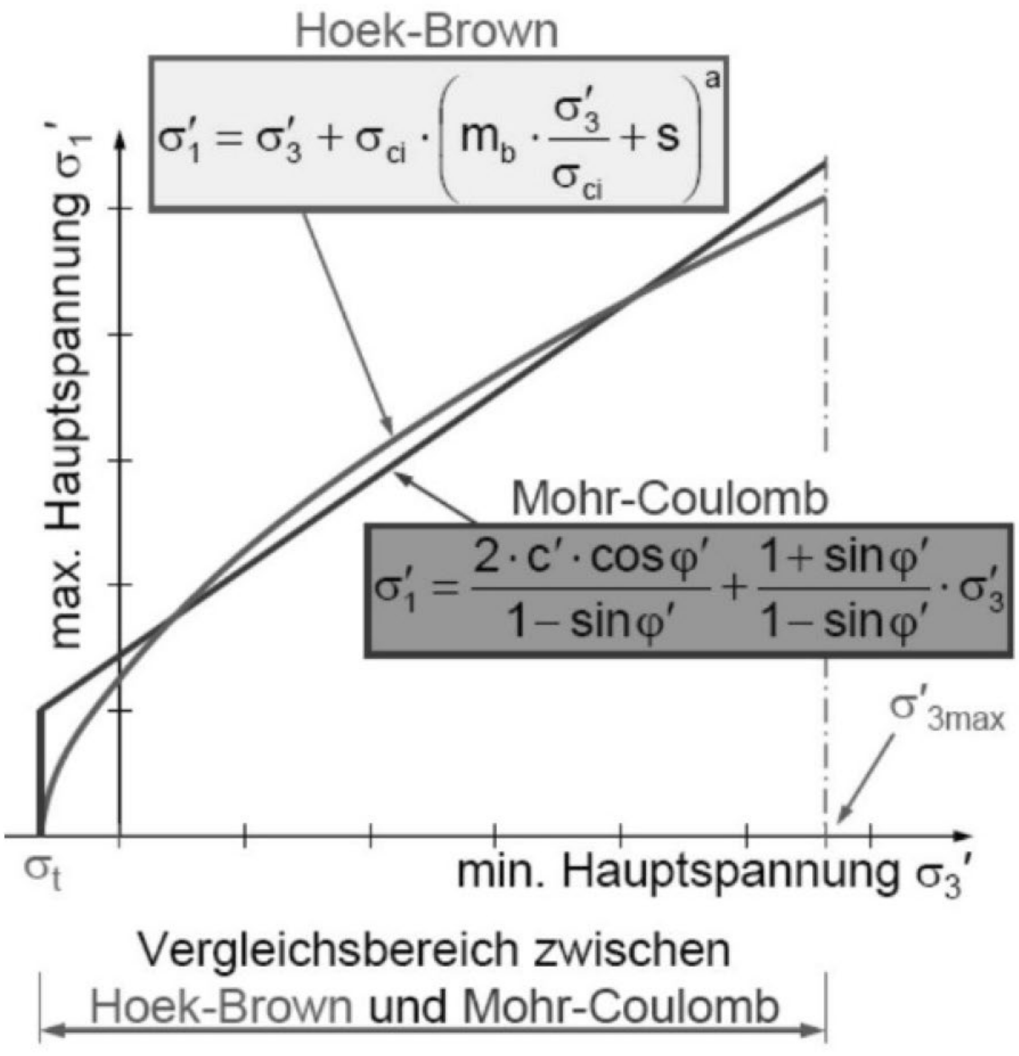




Input parameters :
σ_{ci} = 45,8 MPa
E_i = 30.000 MPa
GSI = 34 (Category D)
m_i = 12
D = 0
Slope height = 80 m

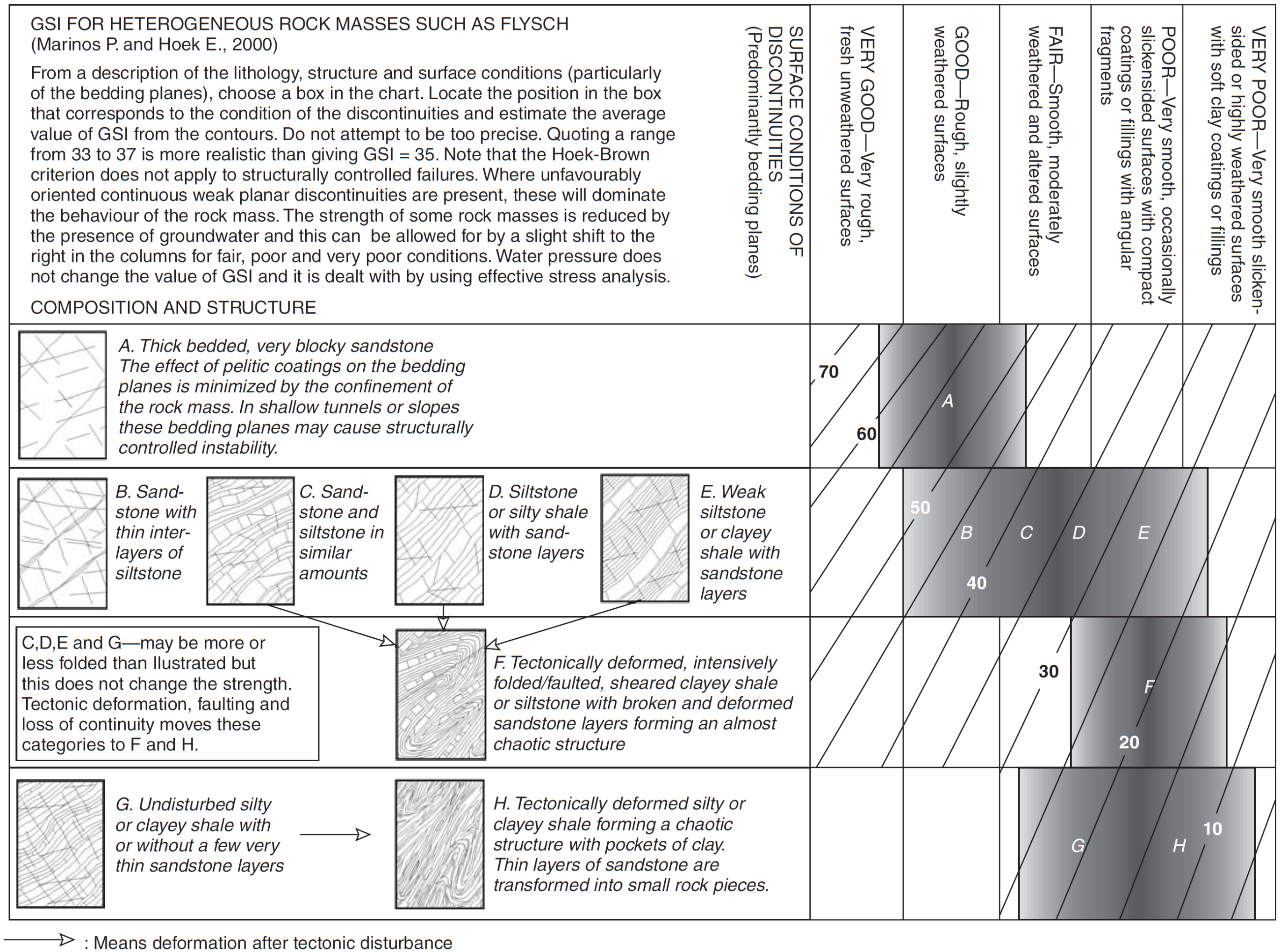
Equivalent parameters :
φ = 42°
c = 0,5 MPa
σ_t = 0,03 MPa

Equivalent MC-parameters



GSI

Table 4.4 GSI values characterizing schistose metamorphic rock masses on the basis of foliation and discontinuity condition



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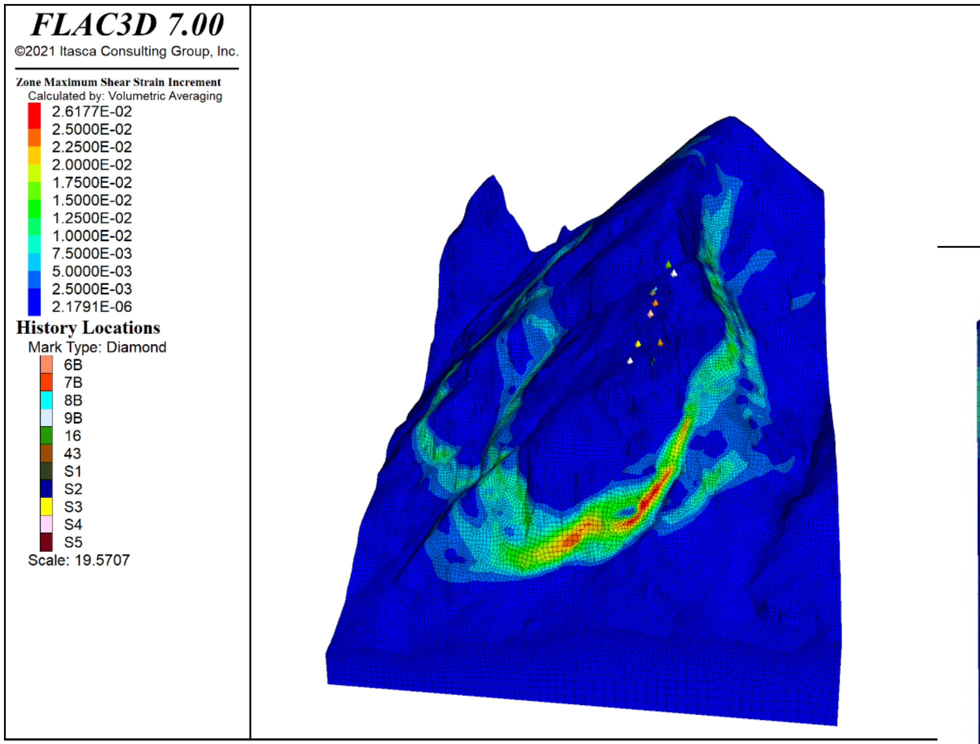
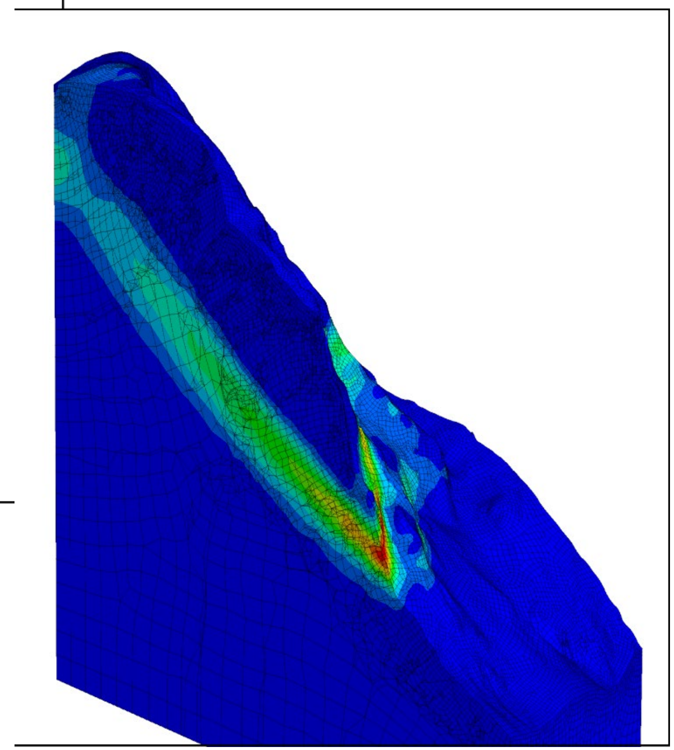
1) Mohr-Coulomb (with equivalent parameters) - model "after“ (η = 1,47)

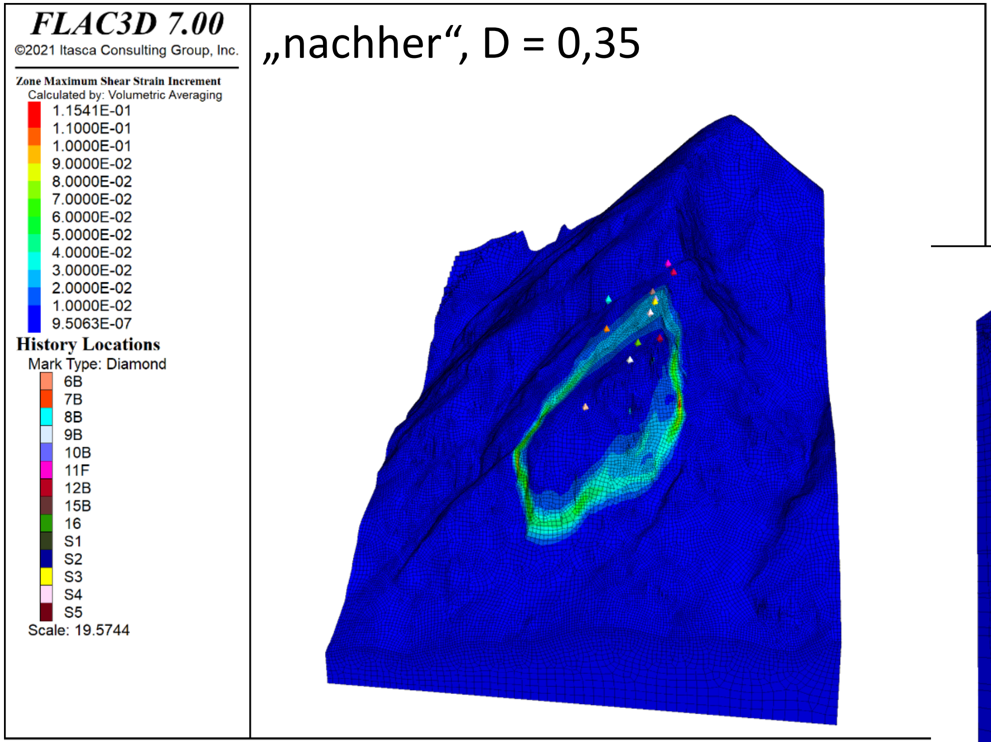


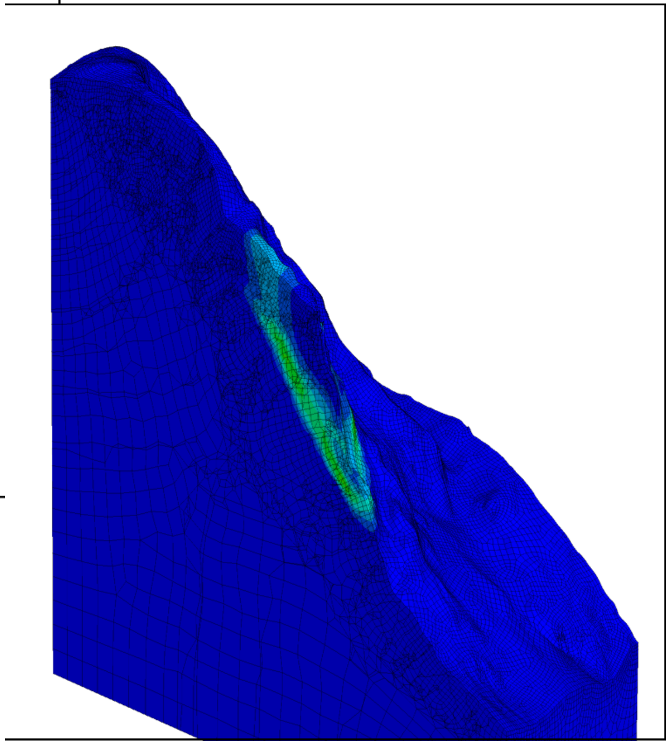


Shear Strain Increments

Model calculation after model calibration

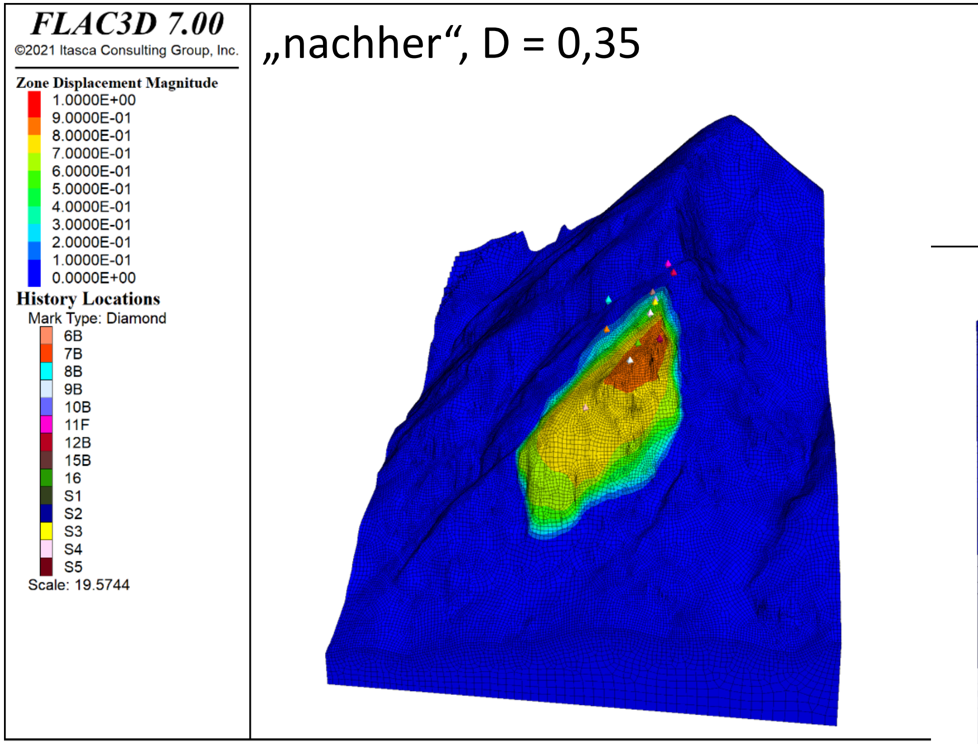
η = ca. 1,2

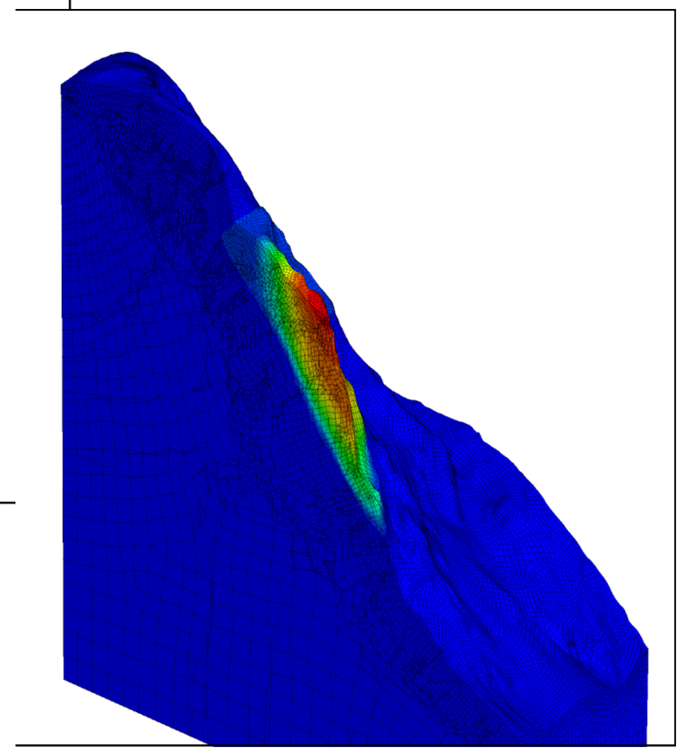




Shear Strain Increments

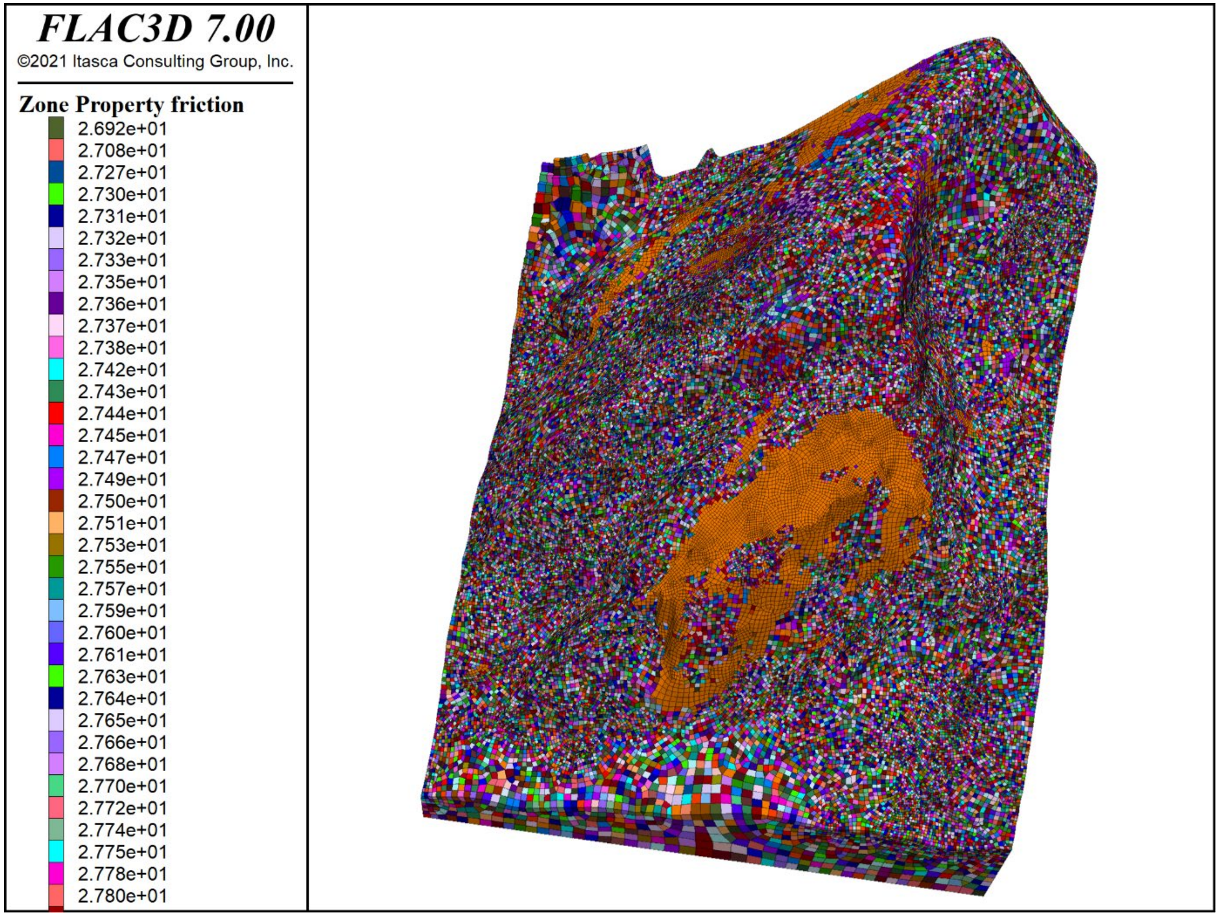
Model calculation after model calibration





Displacement magnitudes [m]

Apperent cohesion and apparent friction



Summary and conclusions

- Every DEM model (including the SRM) requires back-calculations to determine the model parameters.
- Conventional DEM rigid body models shows the best results in discontinuum mechanical models using the back-calculated strengths.
- Continuum mechanics approaches (such as FLAC3D) in combination with the HB material model can provide realistic results.
- Continuum mechanical approaches (such as FLAC3D) in combination with the MC material model are problematic, since the equivalent MC parameters require the estimation of the depth location of the fracture surface.
- Due to the many uncertainties, a combined use of continuum mechanics and discontinuum mechanics is recommended.