Rockfall and Landslides, UNAM Ongwediva - 03.12.2025 – www.aberle.biz

Rock Falls and Landslides

04.12.2025, Ongwediva
a lecture for the UNAM-JEDS

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Structure

01 Introduction

02 technical terms

03 mass movement in rock

04 mass movement in soil

05 debris flows

06 tasks of an engineer
06a structural analysis
06b design and planning
06c finding technical solutions
06d monitoring and control

07 what comes next



https://www.youtube.com/watch?v=uOJfcTZME0U
https://www.youtube.com/watch?v=LmiVb_XrjqM



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Godzilla

https://www.youtube.com/watch?v=uOJfcTZME0U



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Disaster of Vajont 09.10.1963

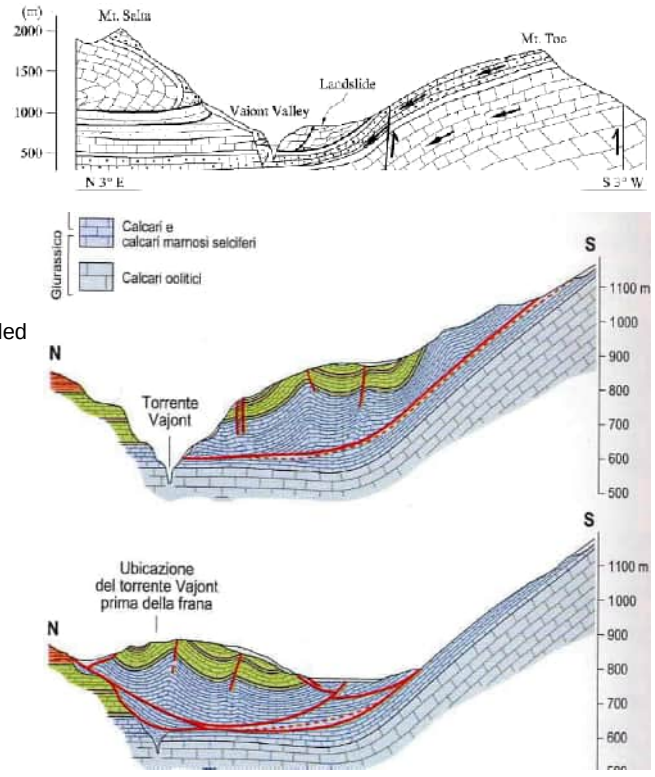


The dam was built in 1956, approx. 100 km north of Venice. The damming led to the Monte Toc landslide with a flood wave over the dam. The wave destroyed 9 towns and villages and more than 2,000 people lost their lives.

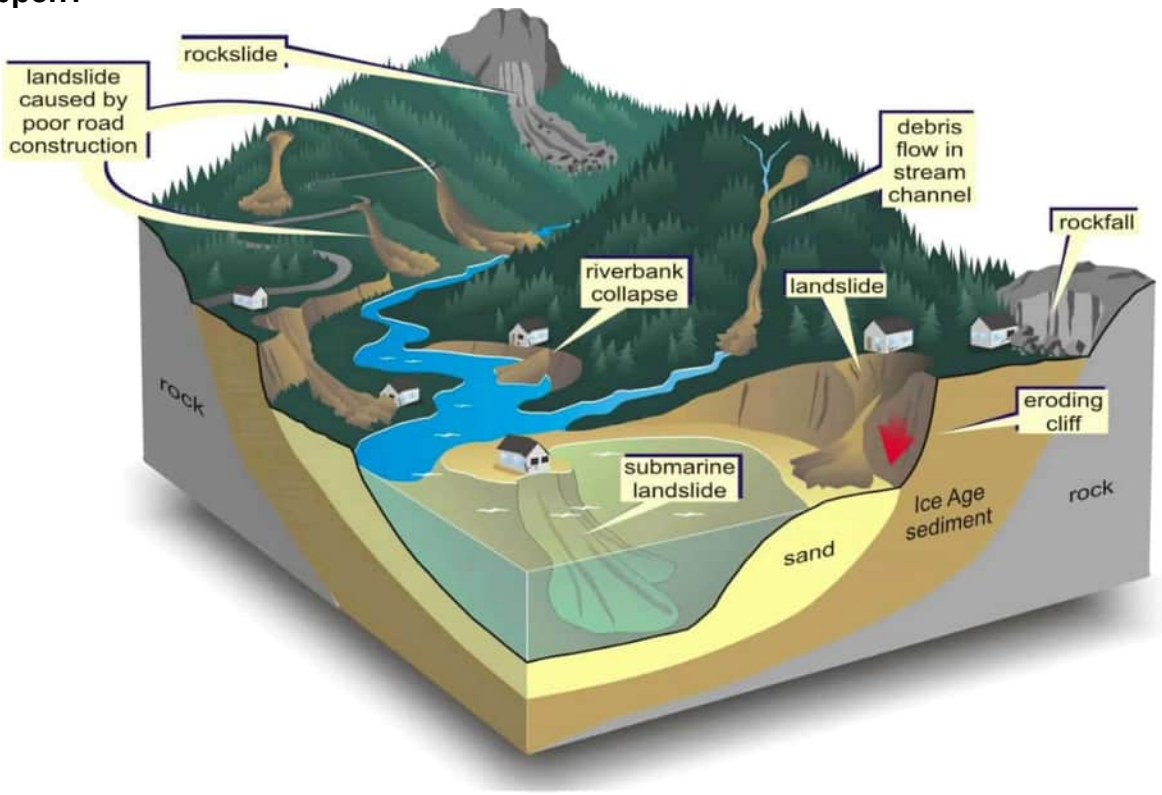


The wall remained almost intact, but was not dammed up again.

[Vortrag von Franco Cucchi, Università degli Studi di Trieste]



Where can it happen?



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The emergence of mass movements – causes in Germany



1) Climate change with more intense and frequent heavy rainfall events

2) Bark bettle (Borkenkäfer)

3) We build in locations that are not necessarily suitable



Soil vs Rock







Namibia, Dorob National Park



Namibia, Soutgat, death sea swim hole



Soil (continuum [= continuous])
pile of small and very small grains of rock, approximately isotropic in terms of its mechanical properties (deformability, strength, permeability)

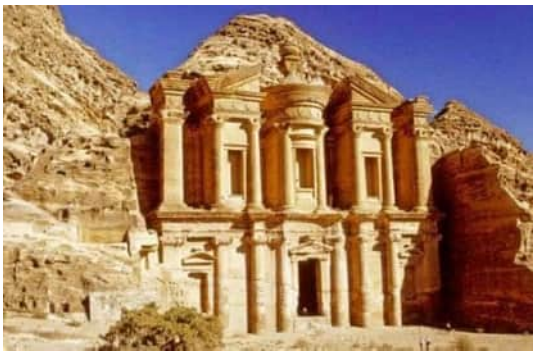
Rock (discontinuum)
naturally occurring assemblage or aggregate of mineral grains, crystals or mineral based particles compacted, cemented or otherwise bound together and which cannot be disaggregated by hand in water

Note to entry: rocks are generally of greater strength than soils

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Soil and Rock

solid rock	**soft ground**	
Discontinuum	Continuum *[= seamless coherence]*	
The decisive factor is the structure of the discontinuities	friction angle (φ) and cohesion (c')	
often inhomogeneous and anisotropic	nearly isotrop	
In general water only in discontinuities	pore volume	
sliding, overturning, bearing failure	Sliding, soil flow, settlement, slope failure	
Rockfall	Landslide	
Rock mechanics, special engineering	Soil mechanics, earthworks, foundation engineering	
rock matrix: cohesion = very high discontinuity: cohesion = nearly zero	cohesive ground: c' = 0 – 60 kN/m²	non-cohesive ground: c' = 0



sandstone –
Petra, Jordanien



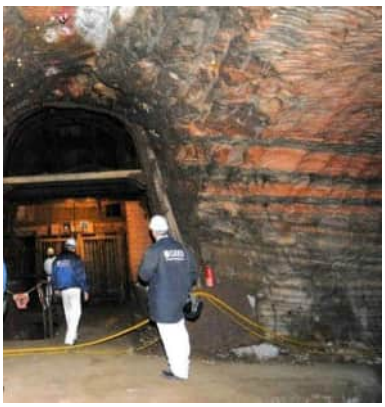
sand –
Namib, Namibia

structures of rock

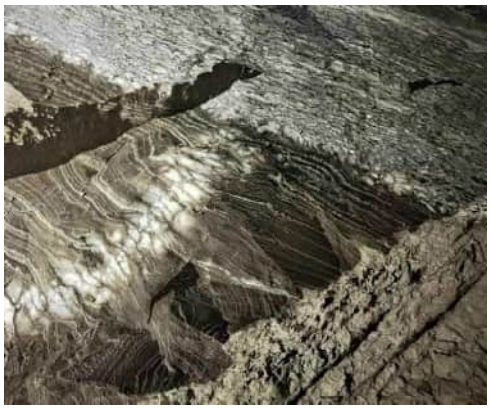
- **bedding (stratification)**
- **foliation (schistosity)**
- **fault**
- **Discontinuities**
- **fissures**







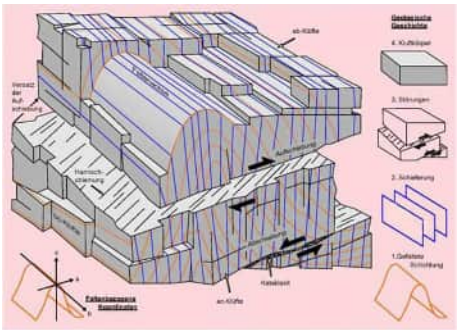




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Signs of movement on a joint surface

Sebastian U. (2018) Festgesteine (Fels). In:
Gesteinskunde. Springer Spektrum, Berlin, Heidelberg



Sign for movement of a joint body:
+ Harness surfaces
+ Mylonitic areas
+ Offset/inclination of a bedding









left and right side: the same rock

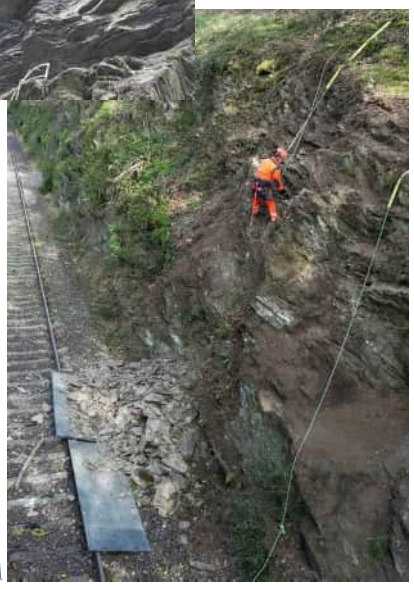


the orientation of dip and strike makes the difference

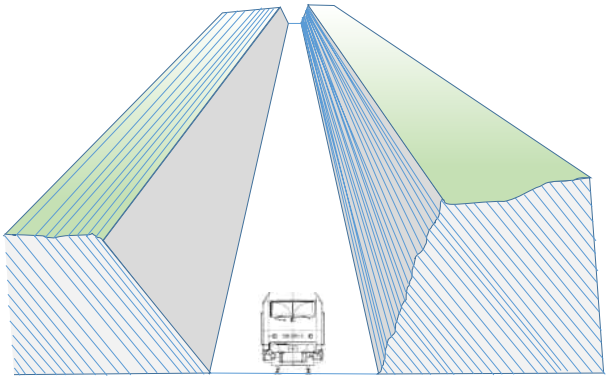
A railway line in Germany. Only one embankment is endangered by falling stones.
The other side is not a hazard.

Why?









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Slope stabilization, regardless of the rock structure







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03 mass movements in rock

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Borcka, Turkey 2001



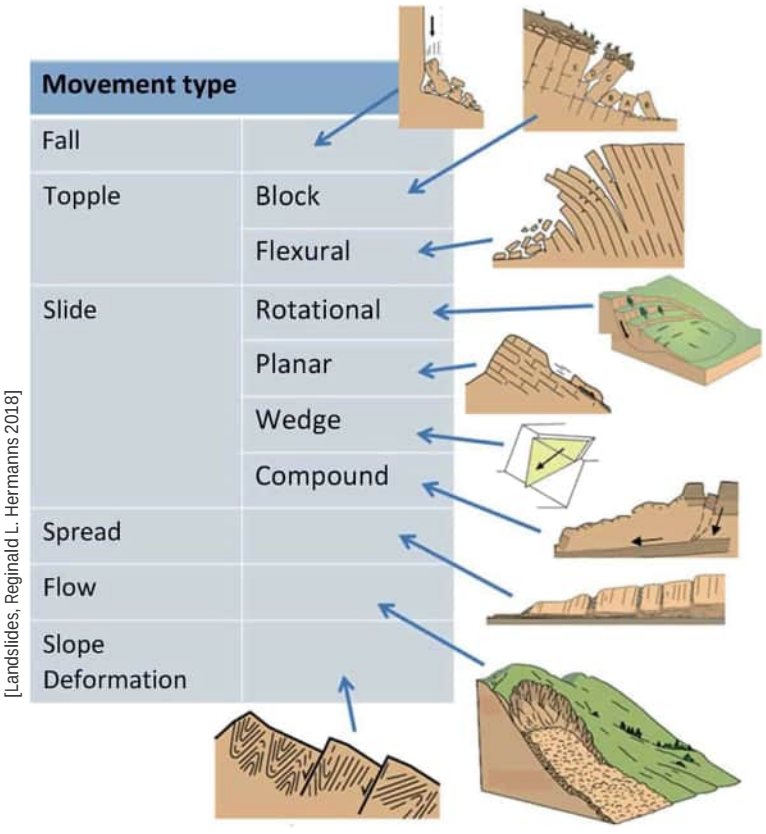
Rock fall Switzerland



https://www.youtube.com/watch?v=wmuXKPcHJ00

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Type of movements



[Landslides, Reginald L. Hermanns 2018]

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Falling processes according to the volume of the fallen rock material



Waldhotel Am Ilsestein



Bild: DPA

Stone impact:
Total cubage <10 m³,
components with a volume of less than 0.25 m³

Rock impact:
Total volume <10 m³
minimum volume of the relevant fallen components of 0.25 m³

Rockfall:
larger rock package > 10 m³ volume from the slope or rock face.
Rockfalls can be announced in advance by the falling of smaller components - e.g. by rockfall events - and can sometimes reach greater ranges than rockfall events.

Fall masses:
with a volume of > 1 million m³

Massive landslides:
are rare and, due to their mass, highly dynamic landslide events that can cover distances of several kilometers. Particularly in narrow valleys, the landslide masses can cause the damming of watercourses, which can lead to catastrophic flooding after a breakthrough. Landslides usually announce themselves through preliminary movements, such as increased rockfall or the opening of crevices.

Individual rock bodies often break away from the rock formation due to weathering (especially along dividing surfaces). The fall path of the rolling or jumping components is influenced by the trees and the subsoil. The components usually come to a standstill at a slope angle of < 30°. Forests also have a particularly dampening effect, as the tree population can slow down or even stop falling rocks. (AD-HOC Geology Working Group, 2016)

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Triggers for mass movements

+ Water
accumulation in open fissures
(fissure water pressure, hydrostatic pressure)
Washing away of already loosened stones/boulders during heavy rainfall
rainfall, especially in steep terrain
softening of the contact/support surfaces of rock sections

+ Temperature changes
freezing fissure water with volume increase of 9 %
(ice pressure, frost blasting)
loosening of the structure due to freeze thaw cycles

+ Vegetation
root blasting (thickness growth of root strands growing into separating surfaces)
dynamic load application by trees (leverage effect under wind load)
bees or wasps drilling holes in sandstone (e.g. Wiperti cemetery Quedlinburg)

+ Vibrations
loosening of stones/blocks by humans and animals

+ Changes in volume swelling and shrinking
clay stone, Calcium sulphate such as gypsum and anhydrite reacts with water

+ Earthquakes



Triggers for fall events

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The stone/block sizes are mostly determined by the interface structure (layering, cleavage, fracturing) of the rocks and the weathering that progresses along the interface structure. Fall events are often triggered by impacts along the interfaces.

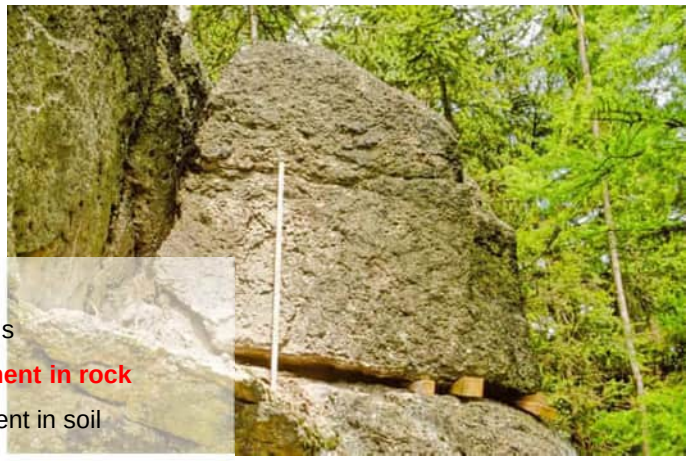
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Combination of landslide and rockfall



Hopa, Osttürkei 2002

Methods for rock



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Sosatalsperre 1996 and 2024

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Methods: a) cleaning

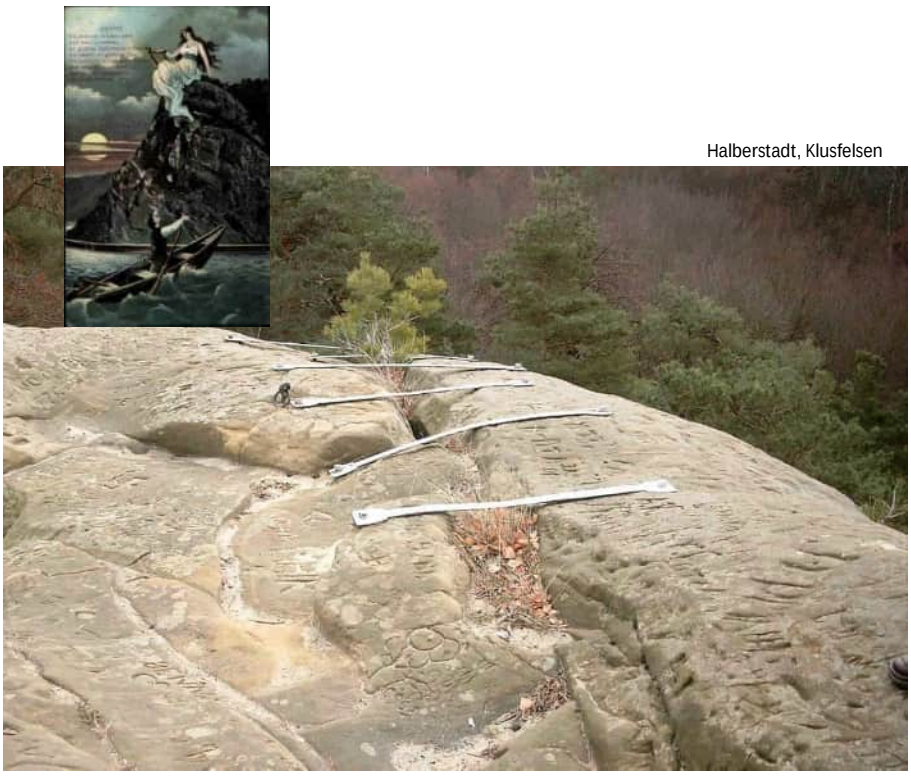




b) straps and ropes



Sankt Goarshausen, Rabenackfelsen



Halberstadt, Klusfelsen

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Methods: c) anchoring



Sosatalsperre 1996

Flexible shoring with wire mesh nets





Schraplau 2009

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Flexible shoring with wire mesh nets



Dunlace Castle, Irland, 2022

Methode: Rock barrier



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Rock barrier while it is working



Brake ring before – after





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Video Geobrugg, Fieldtest

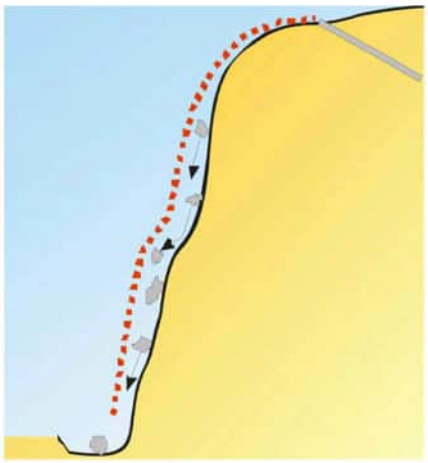


Curtain

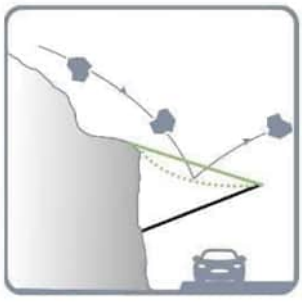
Controlled rockfall events by covering the embankment

Like a curtain = passive system
Mesh is rolled out over an embankment
And fixed at the top with suspension ropes and rope anchors





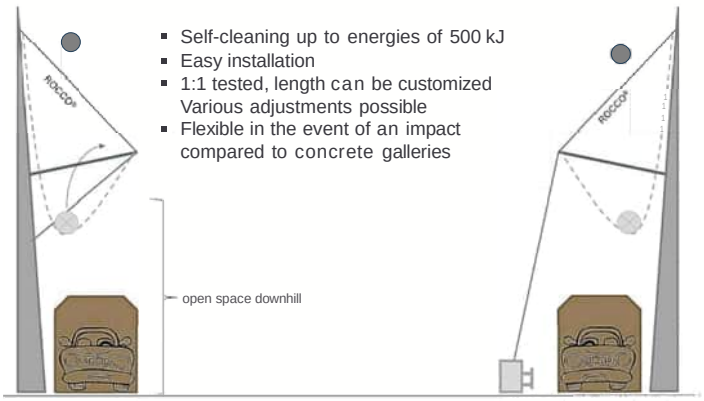
Special solution – Gallery



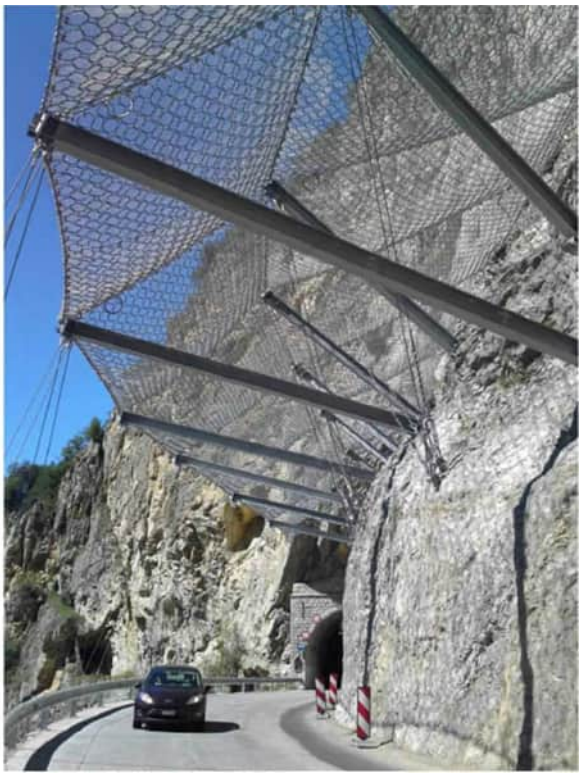
Self cleaning barrier – CANOPY SC-500



Special solution – Gallery

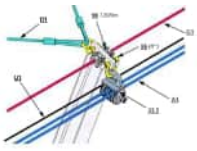


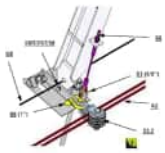
- Self-cleaning up to energies of 500 kJ
- Easy installation
- 1:1 tested, length can be customized
  Various adjustments possible
- Flexible in the event of an impact
  compared to concrete galleries



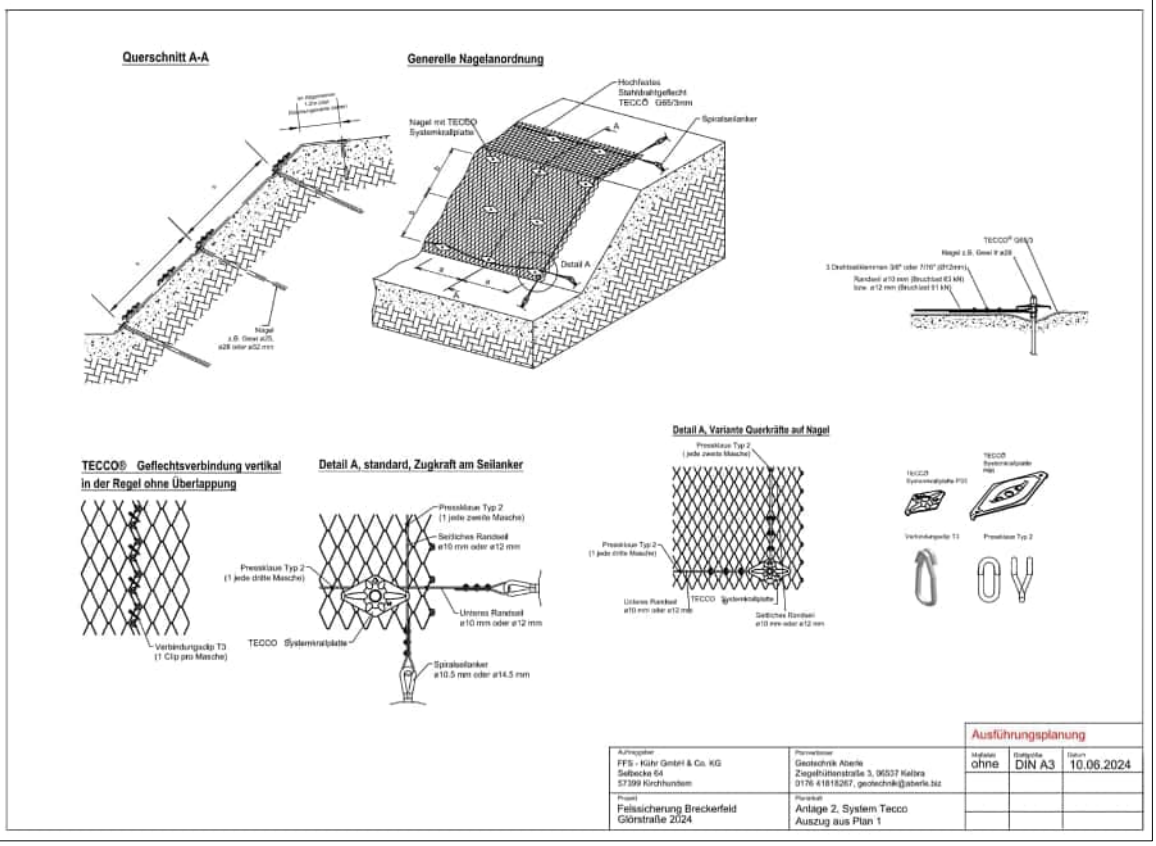
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system tecco



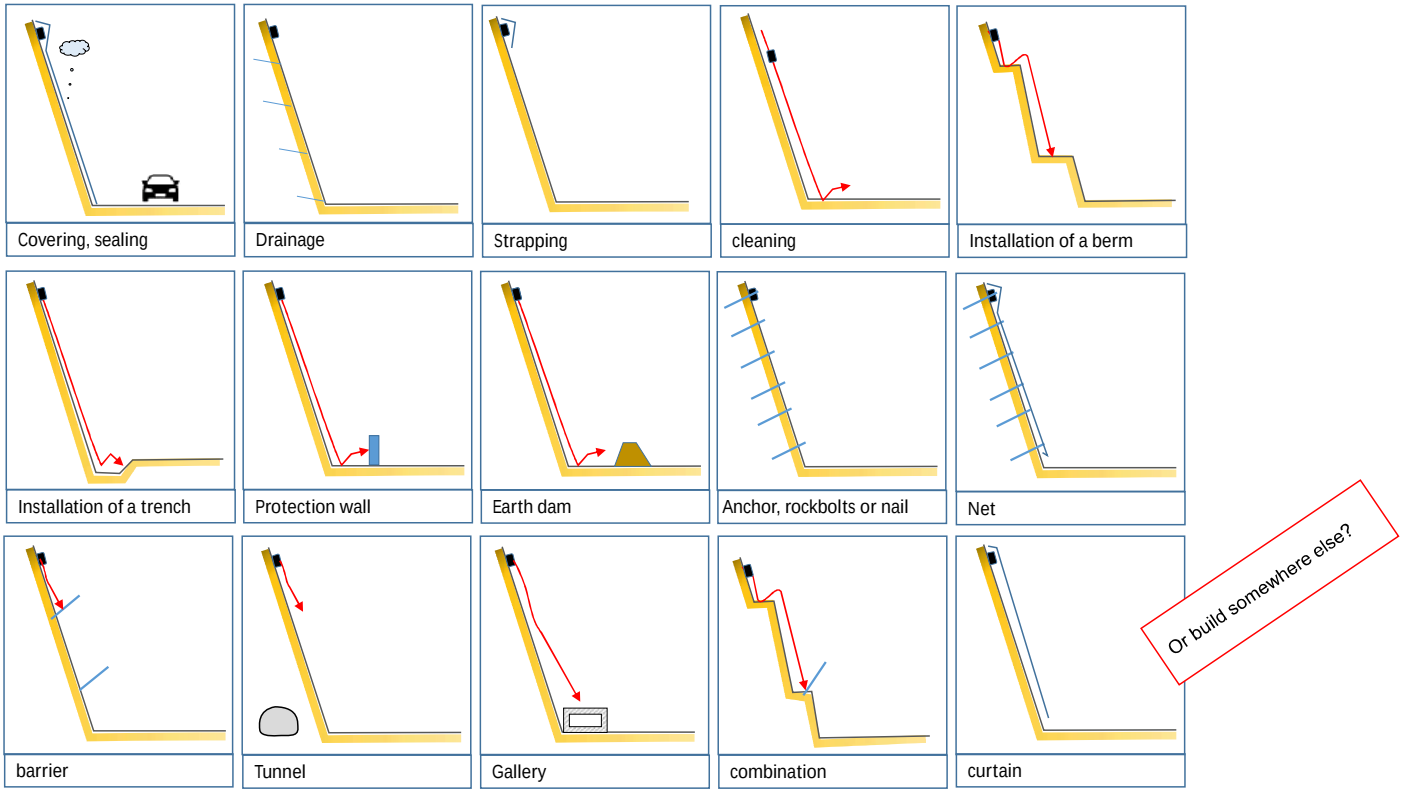






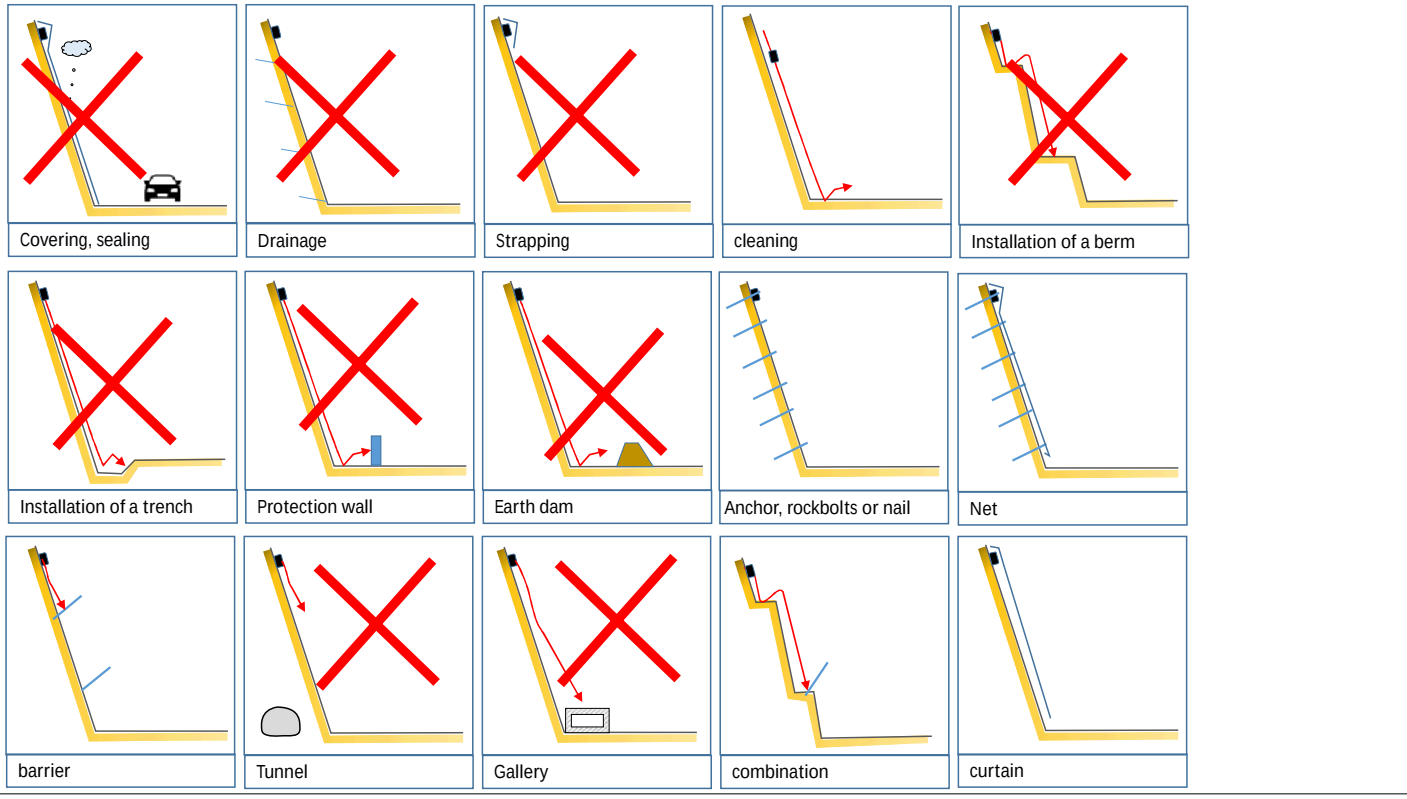
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Solutions



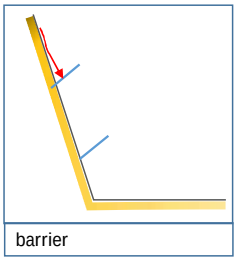
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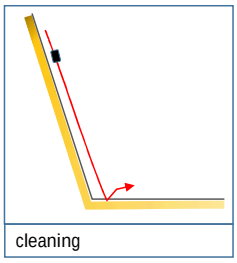
Plausibility check

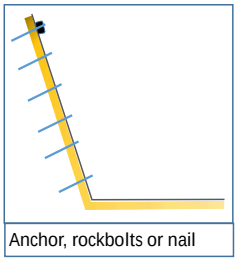


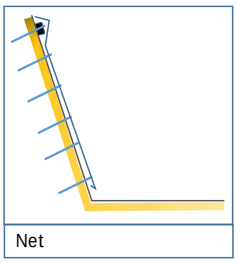
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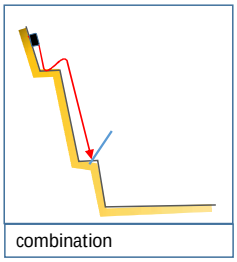
The left over

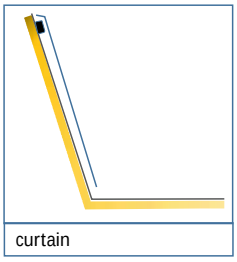












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04 mass movement in soil

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Landslide

Muratli, Osttürkei 2000





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Slope failure, tipping failure



During a landslide on July 18, 2009, part of the settlement collapsed into a lake. Three people died and 41 residents lost their homes.

The landslide occurred at night in the former brown coal open-cast mine and led to the closure of the lake area and long-term consequences for the residents.

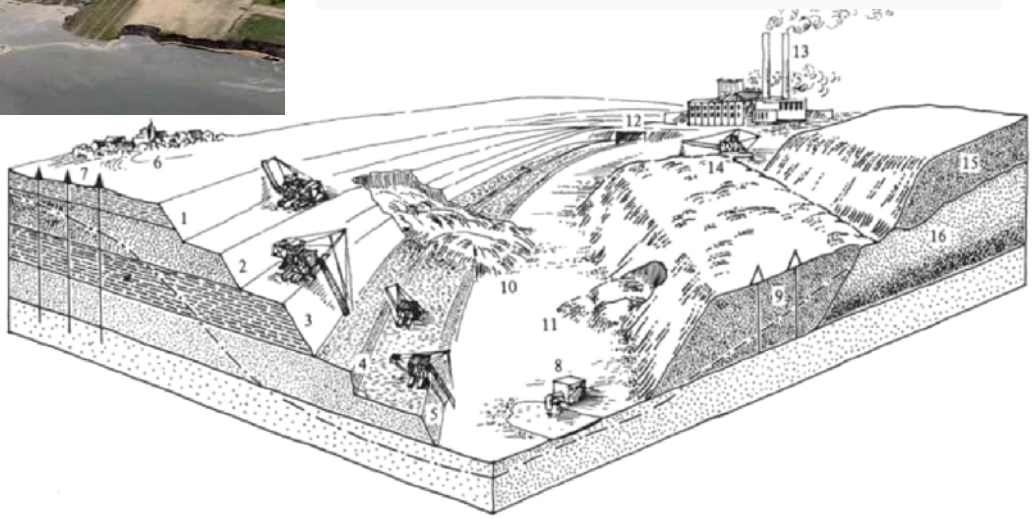
A huge mass of earth, around 4.5 million cubic meters, slid into Lake Concordia, a flooded former open-cast mine.

The lake was to be turned into a local recreation area. To this day, the consequences have not been remedied.

lignite open-cast mining

until today:
- 1,800 km² open-cast
- 6,000 km² groundwater level lowered
- 411 m deep, 300 m below sea level

- 300 villages were given up
- 100,000 people removed



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a) Slopes without safety devices

Slope angle less than 30° or 1 : 1.7 are fine



Neuhof-Ellers, 2023

DIN 4124
Without structural calculation, the following slope inclinations may not be exceeded:
45° non-cohesive or soft soil
60° cohesive soil
80° rock

Some terms

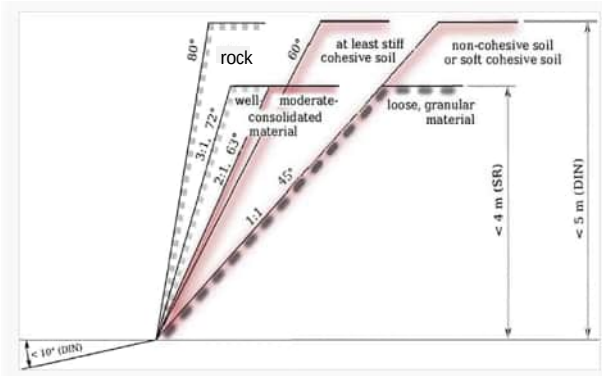
Slope angle is the angle between a slanted surface and a horizontal line, measured in degreesresulting from cohesion and friction angle

≠

Friction angle
The friction angle is a measure of how much a material can resist shear stress

≠

Angle of repose
the steepest angle of a granular material's slope relative to the horizontal before it begins to slide or slump.



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b) Simple slope stabilization methods



+ Corner elements
+ Planting stones
+ Reinforced soil
+ Gabions
+ Dry stone wall
+ Retaining wall

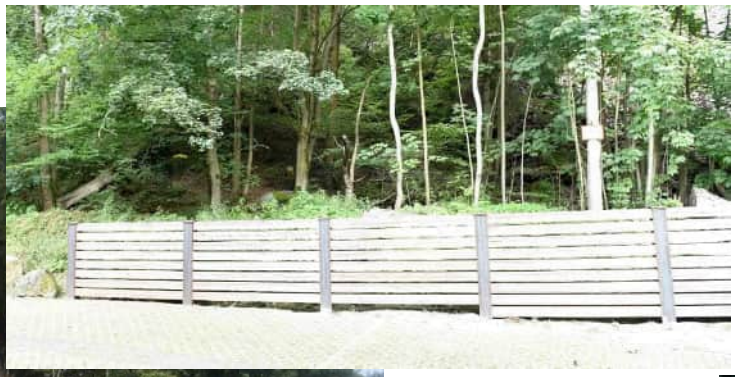






c) Baffle wall, protective wall









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d) retaining wall



Höhnstedt L156

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e) Rigid shoring - shotcrete anchored back

Do not forget to install a drainage system





Kriebethal

2003 A73 Leuketalbrücke bei Suhl

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Shotcrete is not made for eternity - Siegen 18.02.2023



Siegener Zeitung vom 18.02.2023

Later, Siegen 28.02.2023



[Facebookseite der
Fa. Feldhaus, Schmallenberg]

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05 Mass movements caused by debris flow

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https://twitter.com/i/status/1027552830024953859

Debris avalanche



Artvin, East Turkey 2001

- Mixture of flow and slide processes
- Spontaneous slide processes from water-saturated soil layers
- Mixture of stones, wood, soil and vegetation cover
- Mostly steep slopes >30°
- Mostly shallow 1.5 to 2.5 [m]
- Not channelled
- Threaten buildings and infrastructure
- Speeds up to 10.0 [m/s]
- Limited forecasting possibilities

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Landslide or debris flow





A debris flow is a mixture of water and solids of 30 - 60 % (debris, rock material) that usually moves downhill in torrents at high flow velocity.

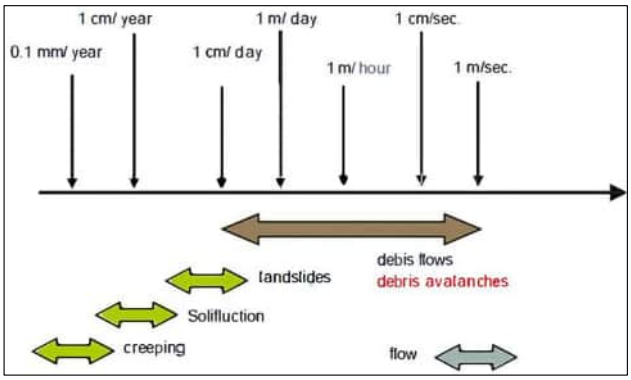
In colloquial language, this is often referred to as a mud or debris avalanche.

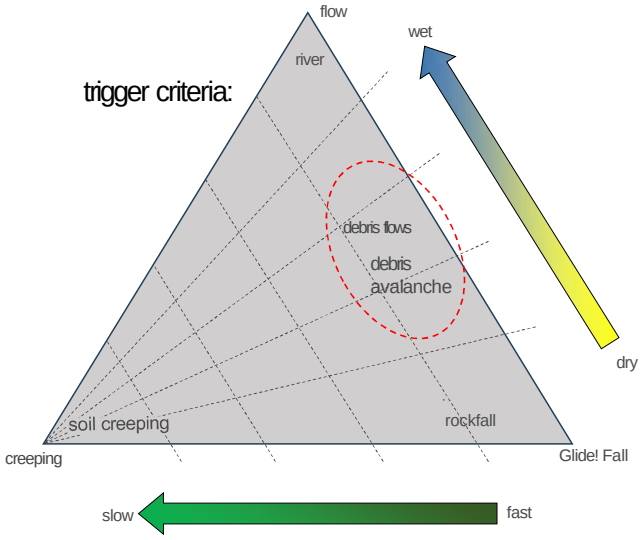
Slope debris flows, also known colloquially as landslides or mudslides, often occur on steep and water-saturated slopes.

It is a superficial sliding of slopes as a spontaneous landslide.

Rockfall and Landslides, UNAM Ongwediva - 03.12.2025 – www.aberle.biz

debris avalanches - Hangmure





Rockfall and Landslides, UNAM Ongwediva - 03.12.2025 – www.aberle.biz

Influencing factors

Influencing factors = rainfall + debris flow structure



loose rock + water from precipitation and/or snowmelt = Debris flow

Buildings

«Innere Sitebach» Kanton Bern (CH), Höhe 5 – 12 m, Breite 40 m



Naturgefahren Projekte weltweit | 39 | 10.02.2023

Rockfall and Landslides, UNAM Ongwediva - 03.12.2025 – www.aberle.biz

before

CHOSICA, PERU

GEOBRUGG BRUGG Safety is our nature





after





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Myrdal, Norwegen 2005







06 tasks of an engineer

01 Introduction

02 technical terms

03 mass movement in rock

04 mass movement in soil

05 debris flows

06 tasks of an engineer

06a structural analysis

06b design and planning

06c finding technical solutions

06d monitoring and control

07 what comes next

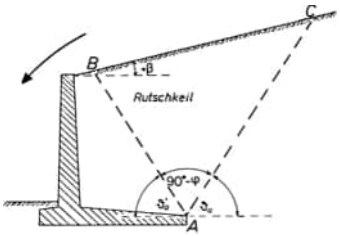
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From structural model to calculation



rock model

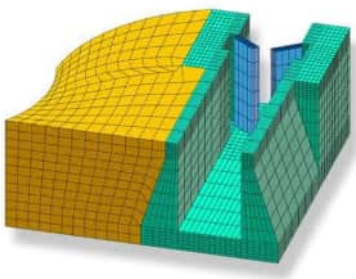
goes to



calculation model

structural models are the basis for construction tasks in rock

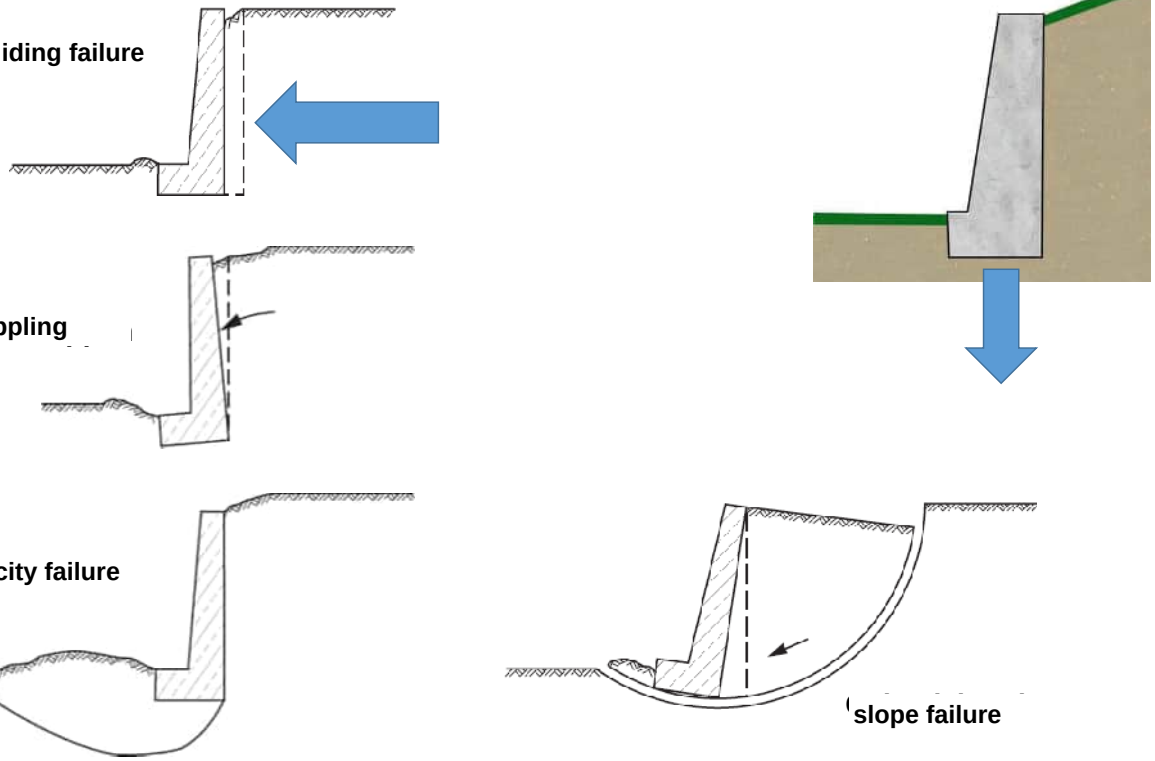




Bezeichnung	Bild	Beschreibung
a) Vielflächiger Gesteinskörper		ungleichförmige Trennflächen ohne Einteilung in eindeutige Scharen, geringer Durchtrennungsgrad
b) Tafelförmiger Gesteinskörper		eine vorherrschende, parallel verlaufende Trennflächenschar (1), zum Beispiel Schichtebenen, mit nicht durchgehenden Klüften; Dicke der Gesteinskörper viel geringer als Länge oder Breite
c) Prismatischer Gesteinskörper		zwei vorherrschende Trennflächenscharen (1 und 2), die ungefähr senkrecht und parallel zueinander verlaufen, mit einer dritten unregelmäßigen Trennflächenschar; Dicke der Gesteinskörper viel geringer als Länge oder Breite
d) Gleichmäßiger Gesteinskörper		drei vorherrschende Trennflächenscharen, die ungefähr senkrecht zueinander verlaufen (1, 2 und 3) und gleichmäßige Gesteinskörper bilden, mit teilweise unregelmäßigen Klüften
e) Rhombischer Gesteinskörper		drei (oder mehr) vorherrschende gegen einander geneigte Kluftscharen (1, 2 und 3), die schrägförmige, gleichförmige Gesteinskörper bilden
f) Säulenförmiger Gesteinskörper		mehrere, gewöhnlich mehr als drei, durchsetzende parallele Kluftscharen (1, 2, 3, 4, 5), die oft von unregelmäßigen Klüften geschnitten werden; Länge viel größer als Breite und Dicke

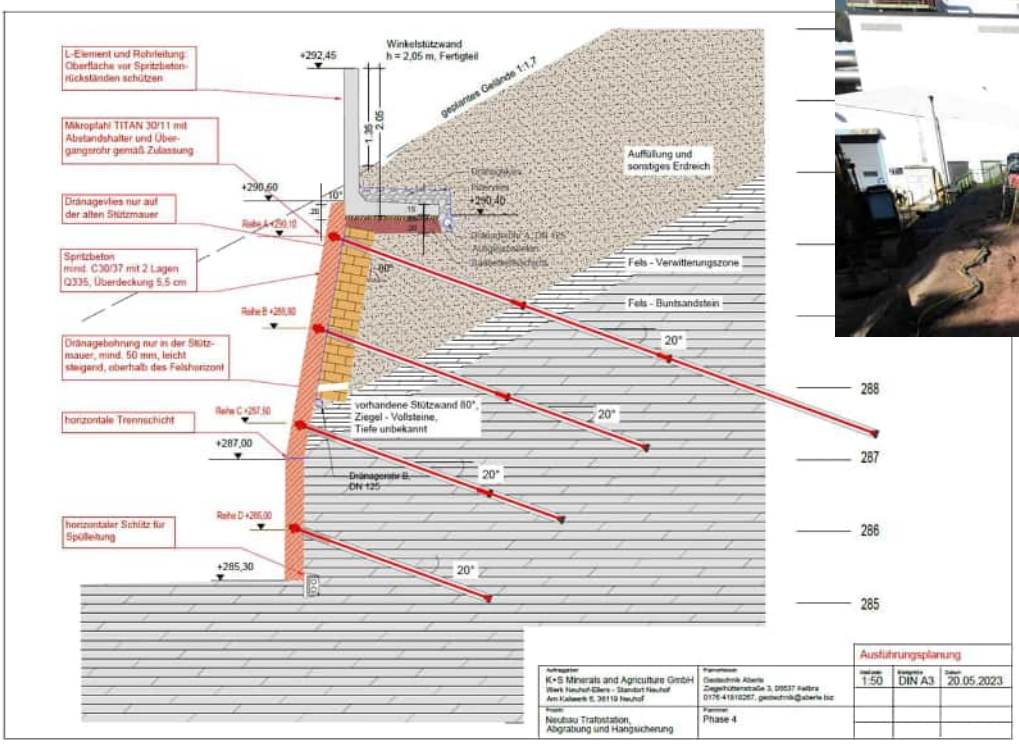
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stability analysis of the slope external influences



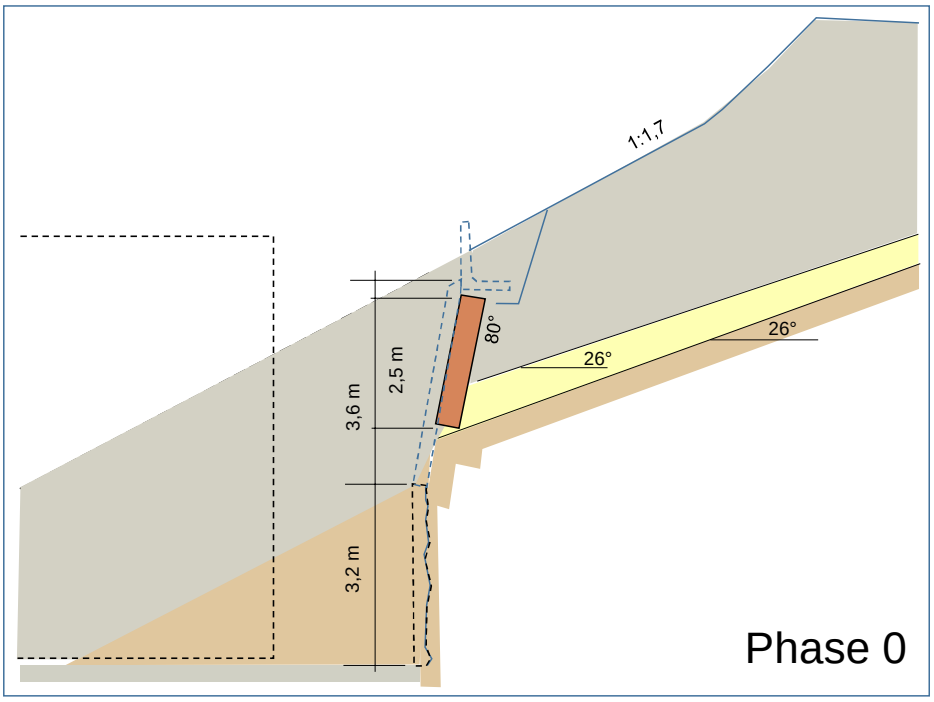
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Structural analysis, execution planning

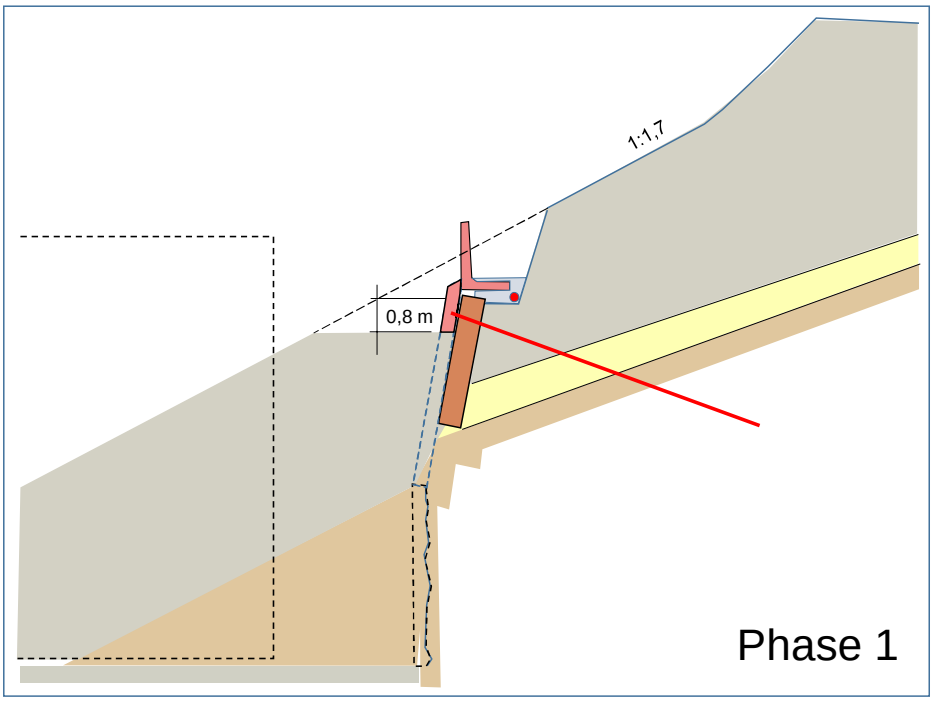




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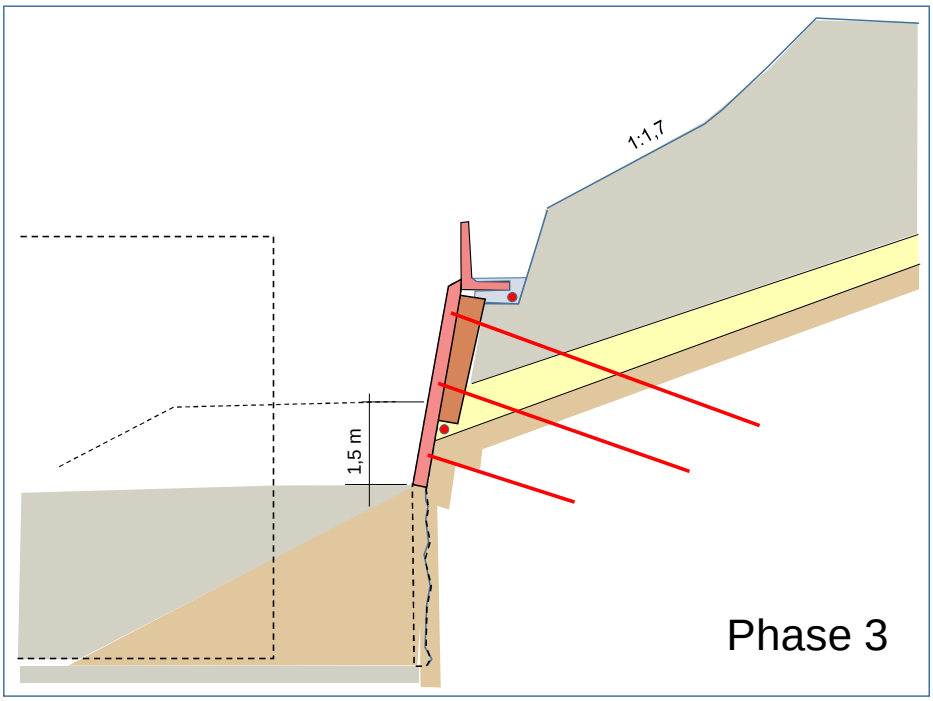
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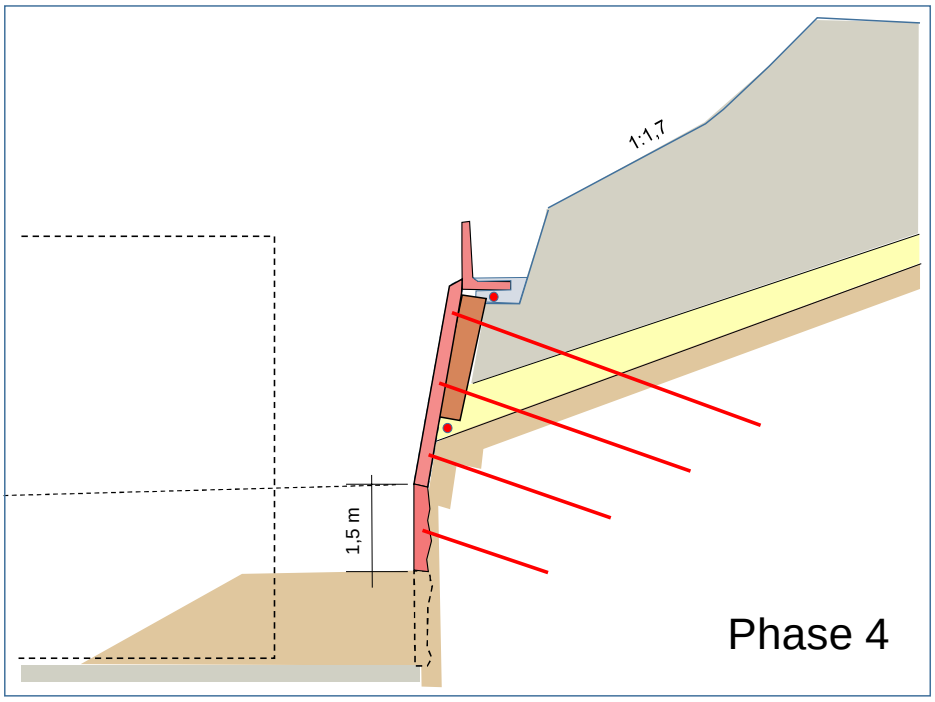
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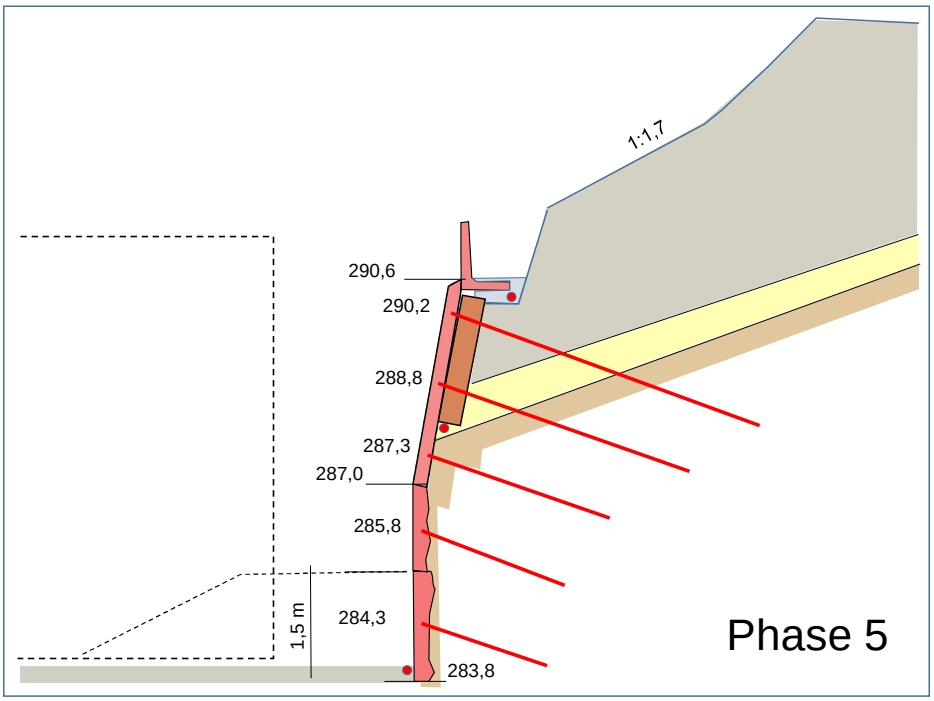
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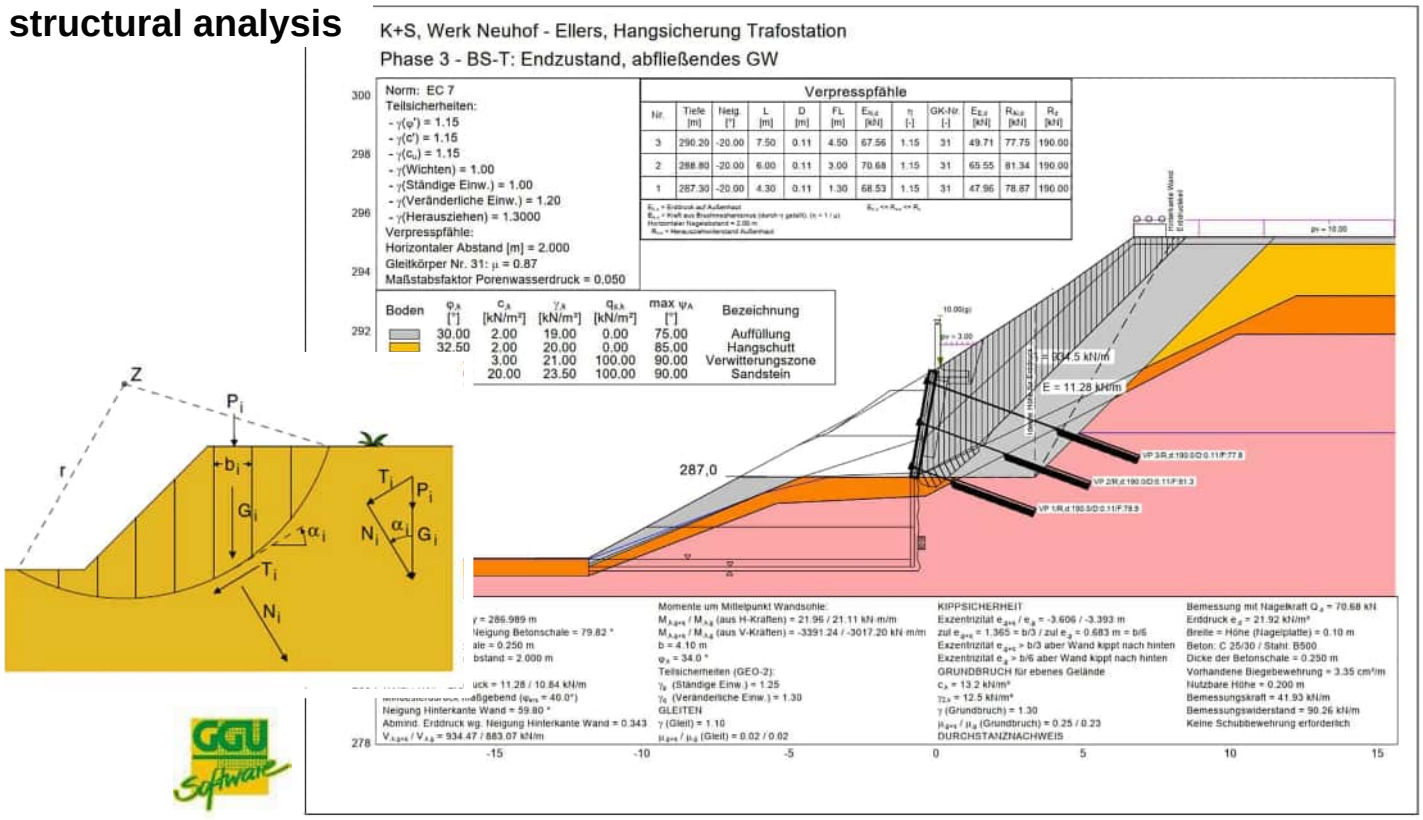


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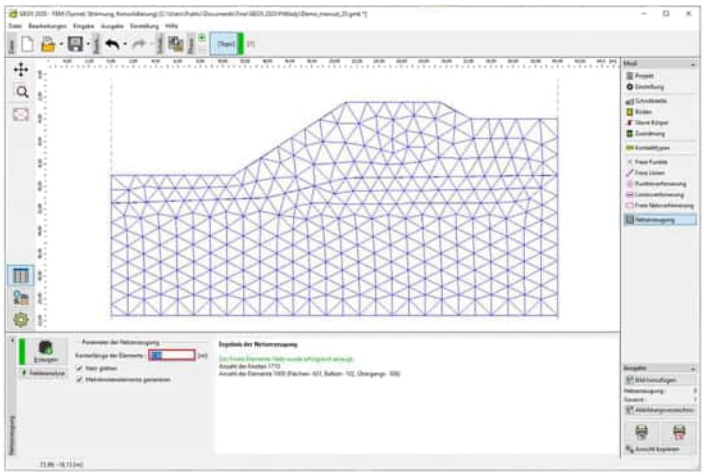
structural analysis



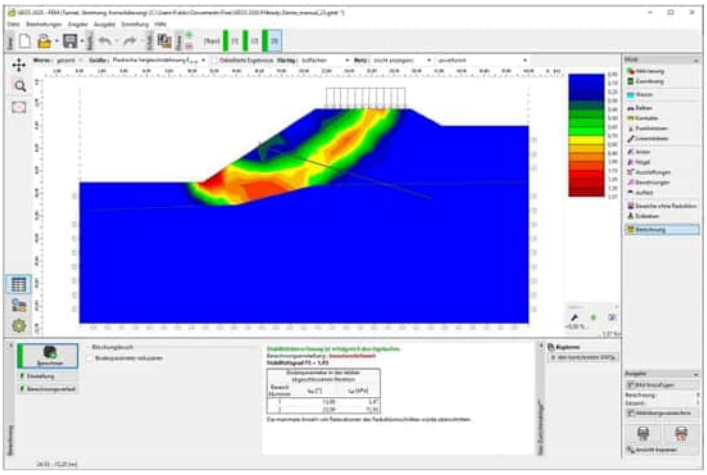
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Slope with finite elements

GEO5



Fenster „Netzerzeugung" – Elementkantenlänge 1,5 m

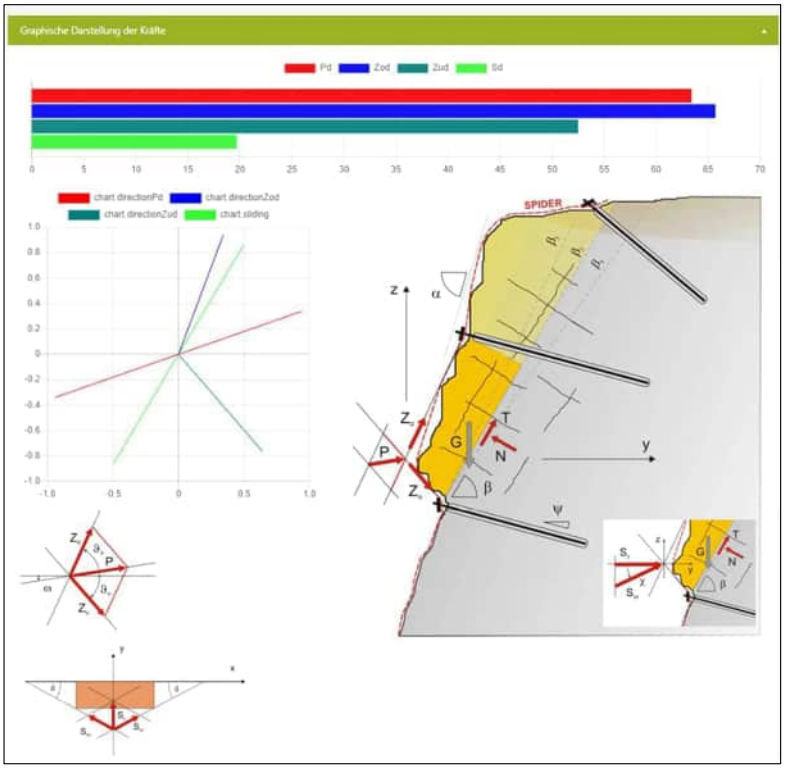


Fenster „Berechnung" – Bauphase 3 (äquivalente plastischen Verformungen $\varepsilon_{eq,pl}$)

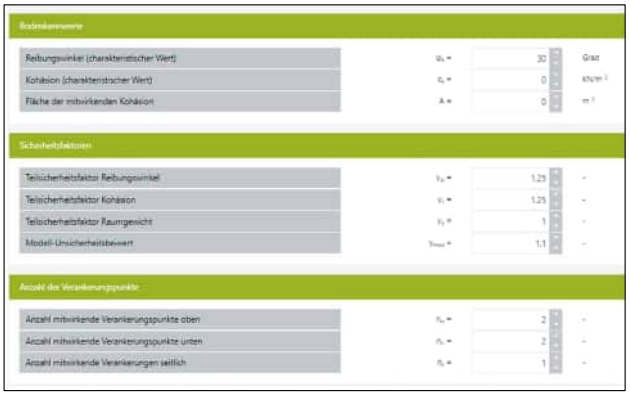
Geotechnische Software GEO5: Ingenieurhandbuch Nr. 25 Aktualisierung: 09/2020 1 Stabilitätsnachweis eines Böschungsbruchs

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Result







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This is not an initial security

Island of Crete, Greece 2025



initial securing



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Example: Wiperti cementary in Quedlinburg



Wibertistraße





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boundary conditions

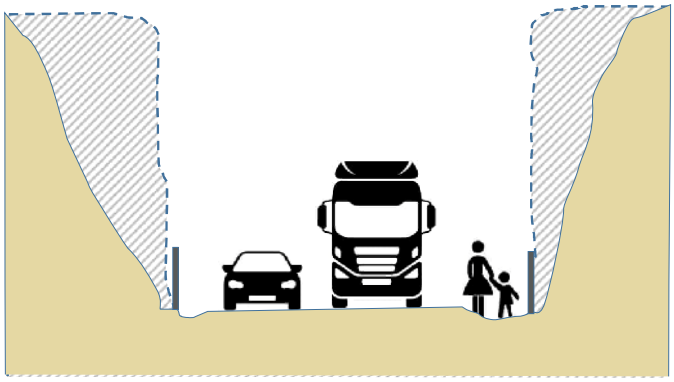
- little money (church)
- monument protection (cultural heritage)
- nature conservation
- busy road
- permanent solution
- lack of skilled personnel





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Option 1 – Removal of the steep embankment

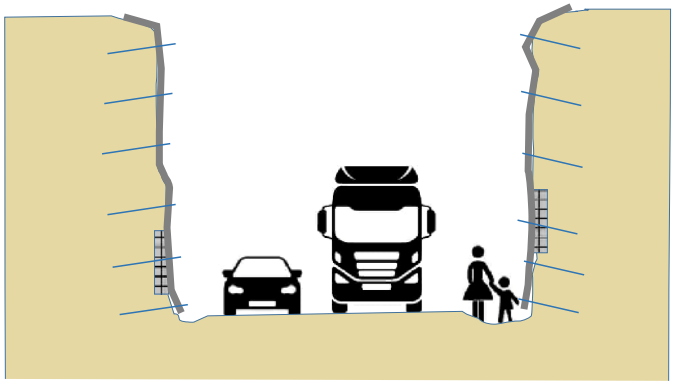




Borcka, Osttürkei 2001

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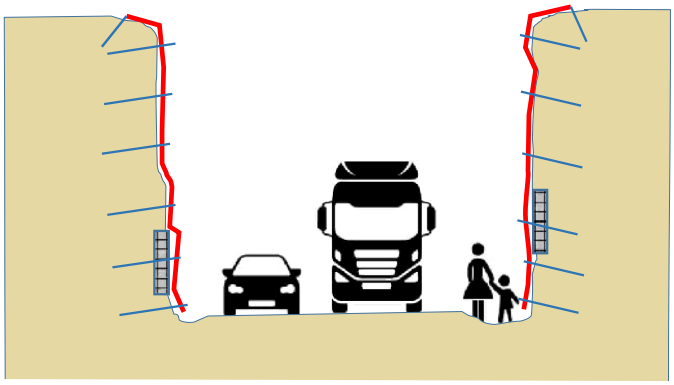
Option 2 - shotcrete





Kriebethal 2003

Option 3 – wire mesh

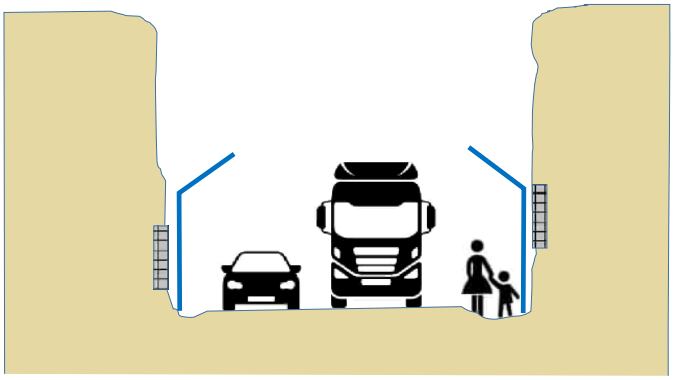




Stadtroda 2003

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Option 4 - Gallery

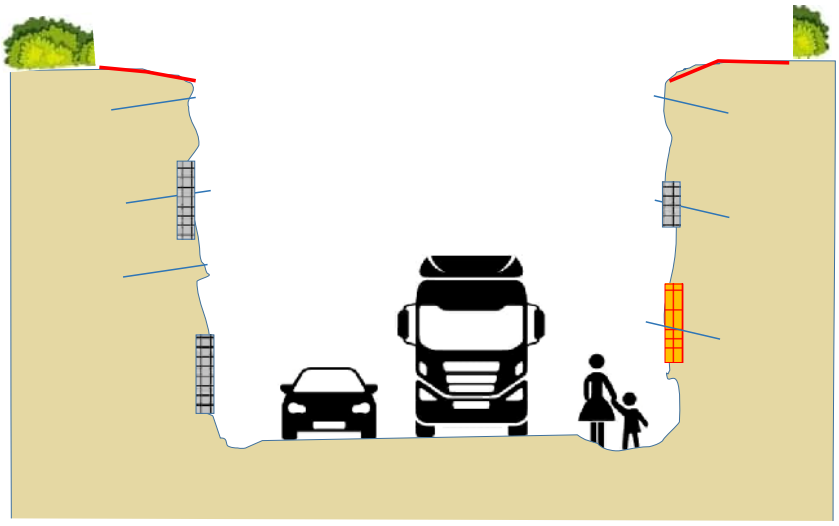




Internetseite Geobrugg 2024

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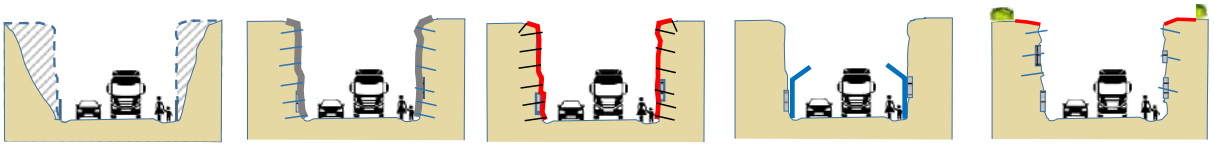
Option 5 – rock cleaning and renovate



- Cutting back vegetation
- Adjusting the top areas of the embankment to prevent surface water from penetrating.
- Clear embankments, remove loose material
  Secure larger crevices with rock needles
- Renovate masonry, replace stones and joints if necessary
- Secure overhanging rock sections with additional masonry
- Due to flora and fauna: work in autumn. Close half of the road at a time
- Match masonry and stones in color and shape

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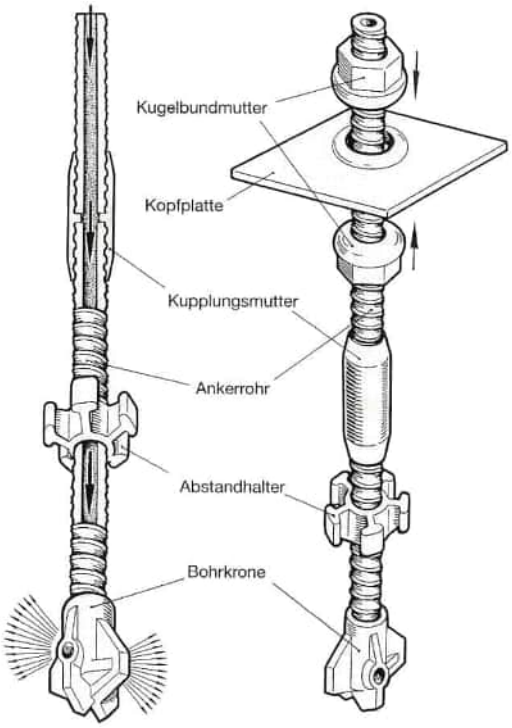
Variant study

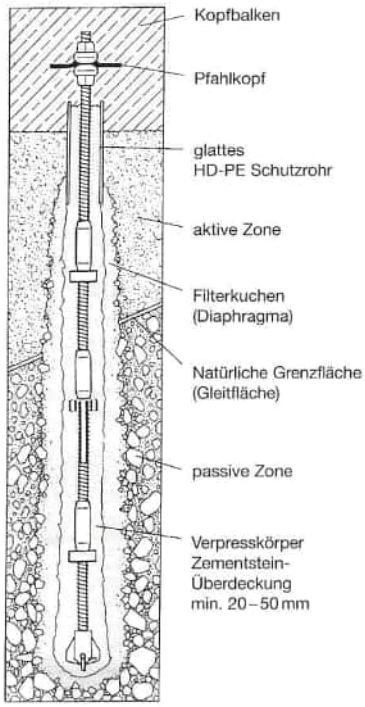


	Removal of the embankment	shotcrete	Wire mesh	Gallery	Rock cleaning and renovate
Security gain	++	++	+	+	+
Costs of the measure	--	-	o	++	+
Follow-up cost, Maintenance	++	+	o	++	o
flora and fauna	--	--	+	++	+
Preservation of historical monument	--	--	-	-	+

Additional criteria: CO_2, durability, planning effort, etc.

Self-drilling anchor





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Use of light drill units



The components can be brought to the site by hand, lorry or cable car



drill unit with mini excavator



Construction crane or carrier for a drill unit





Walking excavator



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Walking excavator



Access by helicopter







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Examination by inauguration

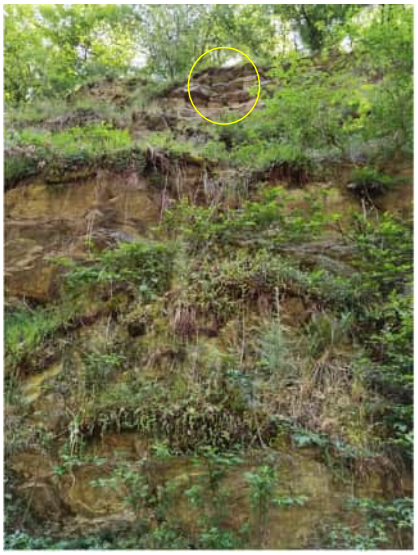


From the street
In summer





Argument for the use of drones





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Drohne 2024

Technische Hochschule Georg Agricola

Technische Hochschule Georg Agricola

Studiengang: Geoingenieurwesen und Nachbergbau

Masterarbeit

Standsicherheitsuntersuchungen an einem Bahneinschnitt im Fels und Variantenvergleich von möglichen Sicherungs- bzw. Sanierungsmaßnahmen

Autor: Irina Engel

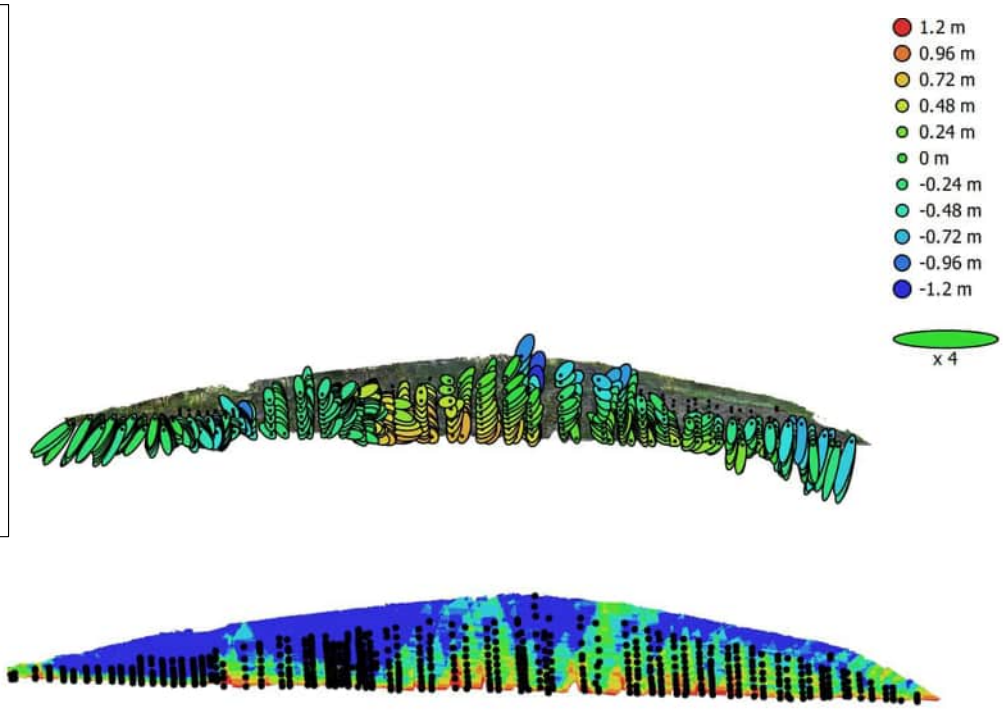
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Adresse: Am Wasserlauf 50
42109 Wuppertal

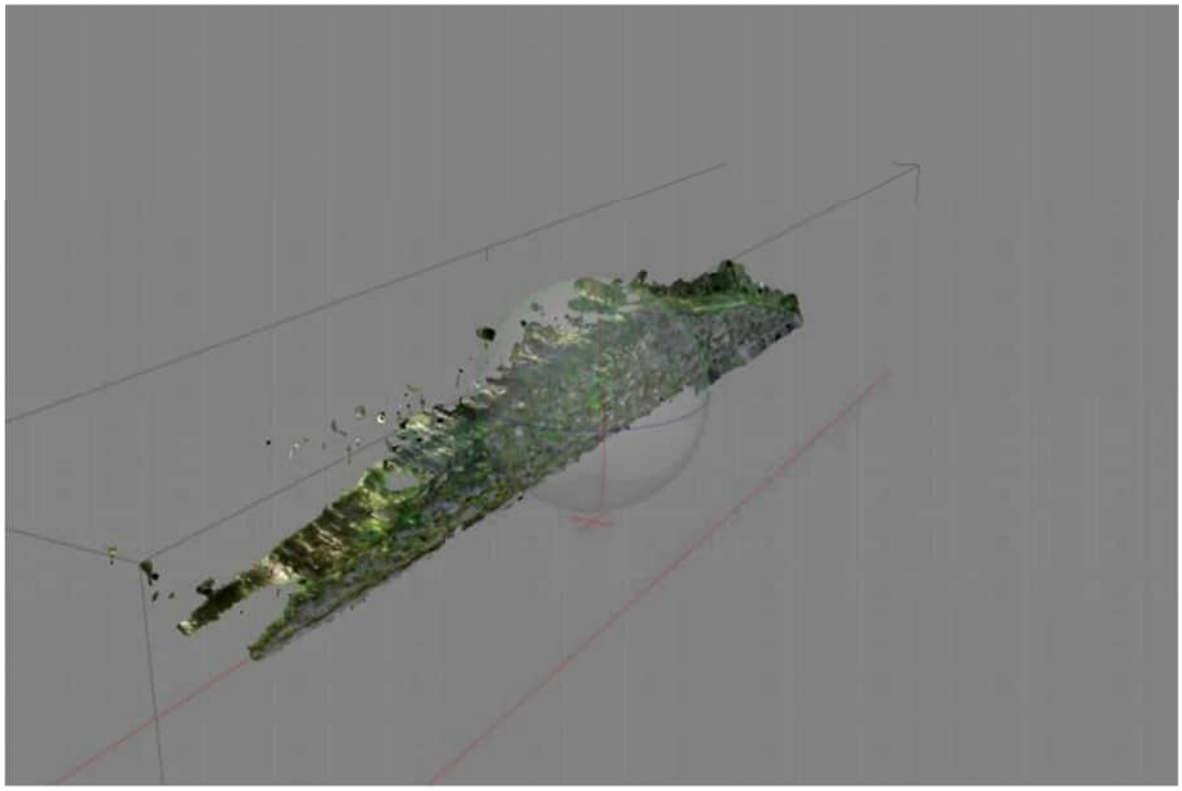
Tel.: 0157/30160684
E-Mail: ira.engel@web.de

Datum: 24.08.2024

1. Referent: Professor Dr. Frank Otto
2. Korreferent: Dipl. -Ing. Bernd Aberle



2024 Video



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07 what comes next

01 Introduction

02 technical terms

03 mass movement in rock

04 mass movement in soil

05 debris flows

06 tasks of an engineer
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06d monitoring and control

07 what comes next

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Dry seeding





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Test area = 120 m², with wet spraying and dry seeding



After some month…



I The seeds are ‘burnt’ due to the mat being too dark
II The best results in the middle area with an open, 3D mat
III Erosion problems, mat was too flat

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Sustainability

Sustainability in construction

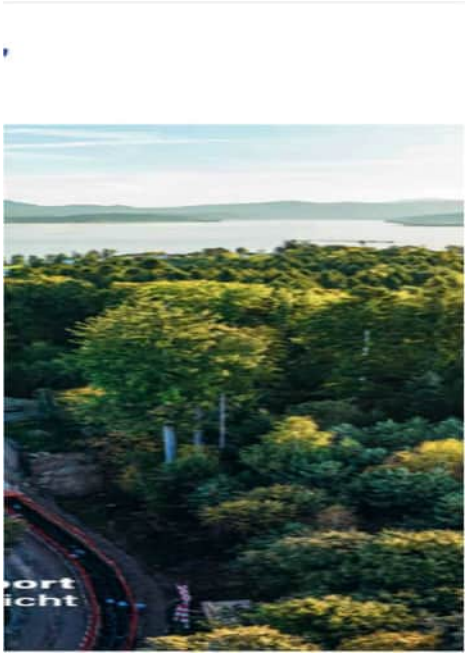
A planning and construction process and a method of use that are geared towards sustainability; i.e. towards preserving the ecosystem and the environment, benefiting people and society, and optimising and increasing the economic potential of a building.
Due to the great importance of ecological, economic and socio-cultural factors in the construction sector, sustainable construction integrates these factors into an overall concept for the building. The factors are considered to be of equal importance and to interact with each other.

Sustainability in geotechnical engineering?

In future: CSRD= Corporate Sustainability Reporting Directive, an EU regulation on the publication of a sustainability report.

In Germany, approximately 15,000 companies are affected.





Getting old…



Norwegen bei Myrdal



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Debris flow Rossstein





Geobrugg GUARD - Technical data

communication:	GS / UMTS / LTE (2G / 3G oder 4G LTE Cat M1)
battery:	7-10 years
data transfer:	once per week
In case of particular stress:	within a few minutes
Data security:	multiple encryption / Own independent operating system
weight:	2.6 kg
durability:	Approved for outdoor use (waterproof, UV-resistant, cold- and heat-resistant), designed for acceleration up to 200 g
installation:	on wire, Ø12 mm – Ø 24 mm
rope load:	0 N – 300 kN (30.000 kg)





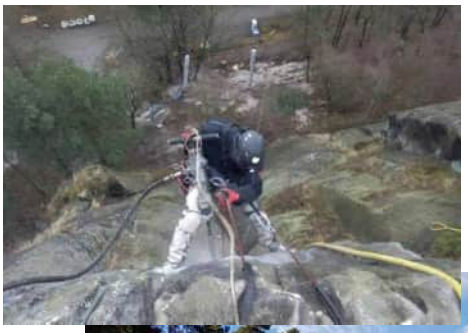


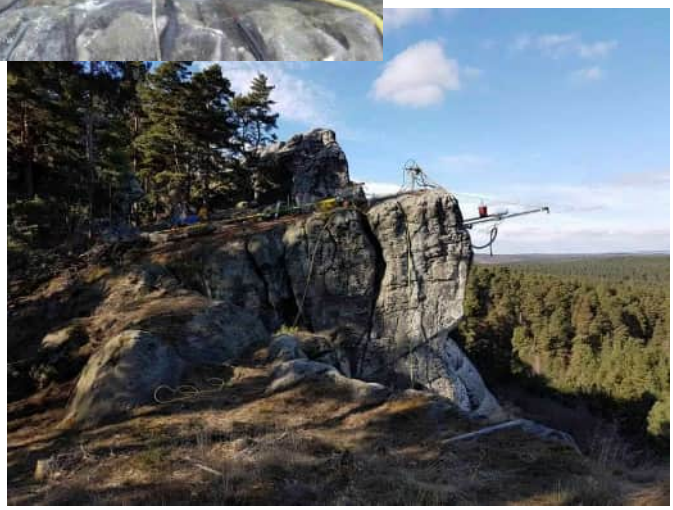
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keeping on rolling -



Single block securing and tension-rope bracing







Rockfall and Landslides, UNAM Ongwediva - 03.12.2025 – www.aberle.biz

Literature

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by Leopold Müller, Springer Vienna, May 2014
978-3-21-181301-0, 978-3-70-914109-0

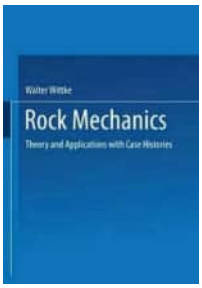
Rock Mechanics: Theory and Applications with Case Histories
Springer; 1990. Edition (3. Dezember 2014)
978-3642881114

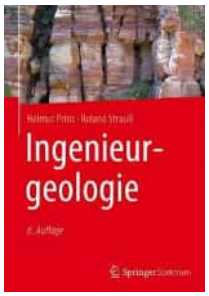
Engineering Rock Mechanics - An Introduction to the Principles
von John P. Harrison; 12. Juni 2000

Only in German language
Ingenieurgeologie;
Helmut Prinz, Roland Strauß, 2018

Arbeitskreis 2.10 „Geomesstechnik" der DGGT und des DVW
Empfehlungen des Arbeitskreises Geomesstechnik





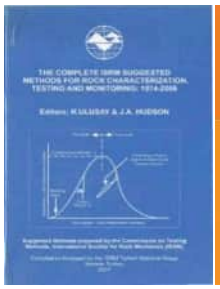




"The ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 2007-2014"
Editor: Reşat Ulusay (President of the ISRM Commission on Testing Methods)
Publisher: Springer, www.springer.com/978-3-319-07712-3
Date of Publication: August 2104
293 pages, 218 illustrations, 53 illustrations in color

"The Complete ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 1974-2006"
Editors: Reşat Ulusay and John Hudson
Publishers: ISRM Turkish National Group and the ISRM
Date of publication: 2007

Only in German:
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Empfehlungen des Arbeitskreises Geomesstechnik





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