SVEUČILIŠTE U SPLITU
FAKULTET GRAĐEVINARSTVA, ARHITEKTURE I GEODEZIJE

UNIVERSITY OF SPLIT
FACULTY OF CIVIL ENGINEERING, ARCHITECTURE AND GEODESY

Long term stability of an abandoned construction pit in Eocene flysch rock mass: case study of Bračka street construction site (Split, Croatia)

Goran Vlastelica, Ana Duhović, Marija Relota

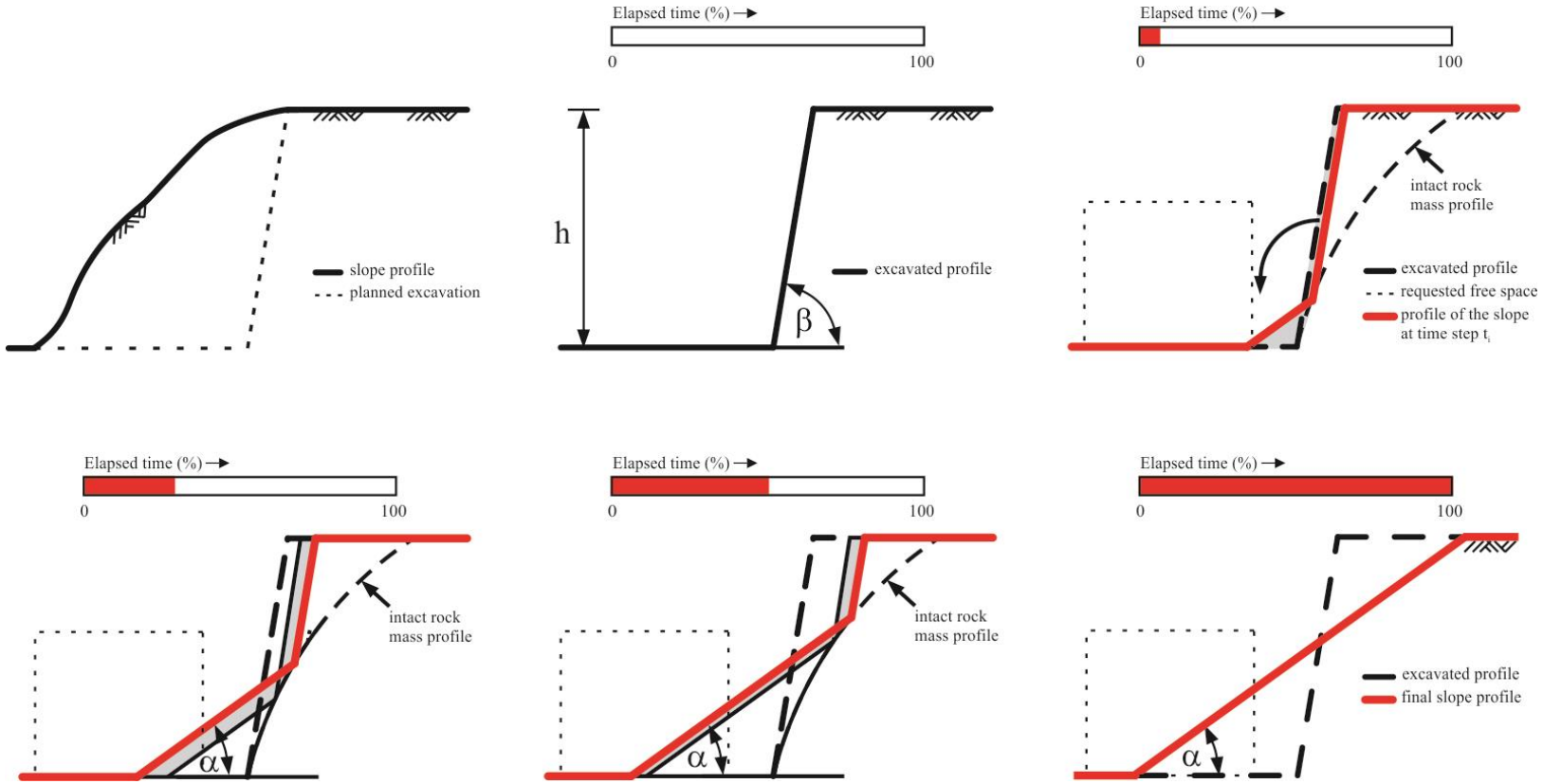
EGU General Assembly 2022

Introduction

- Abandoned construction pit in Eocene flysch rock mass
- Material properties (Flysch rock mass, in this case thick bedded **marl**)
- Lab tests: Intact rock – mechanical properties, Residual properties – changes due to weathering into soil (mostly due wetting-drying)
- Field measurements of slope geometry changes in time
- Slope stability analysis

Introduction

- **Soft rocks** are a complex material which when exposed subject to intense change in engineering properties over time. Sedimentary rocks characteristic of the Adriatic coast - flysch Flysch members (eg marls, calcareous marls, clay marls)
- **Weathering** - change of rock properties as a consequence of the process: drying and wetting, swelling, hydration, cracking, heating and cooling, etc.
- **Erosion** - the process of removing weathered rock



Laboratory testing

- Index properties
- Shear strength at multiple cycles of laboratory drying – wetting
- Shear strength of weathered material sampled from the location

Laboratory testing

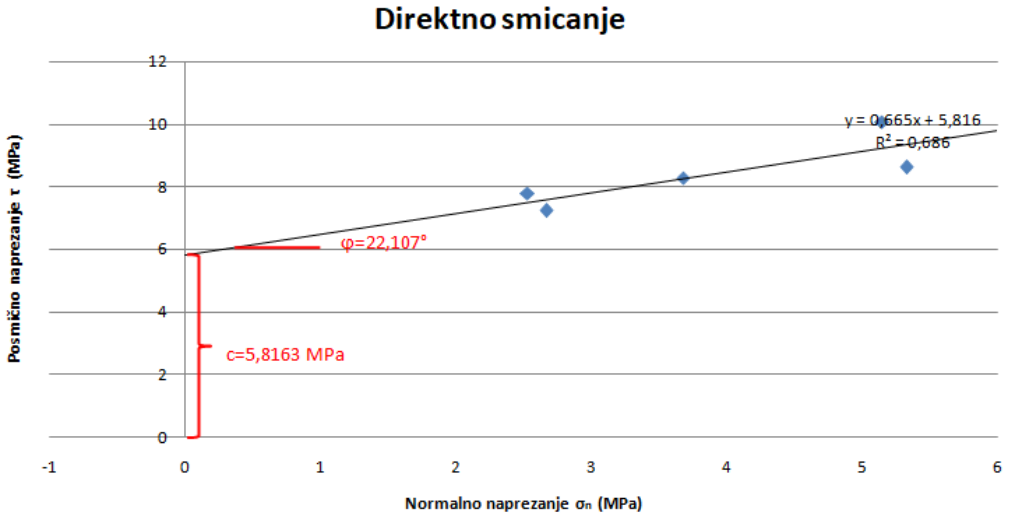
Intact rock – shear strength – portable shear apparatus

Laboratory testing

Residual properties – shear strength – direct shear for soil

Laboratory testing

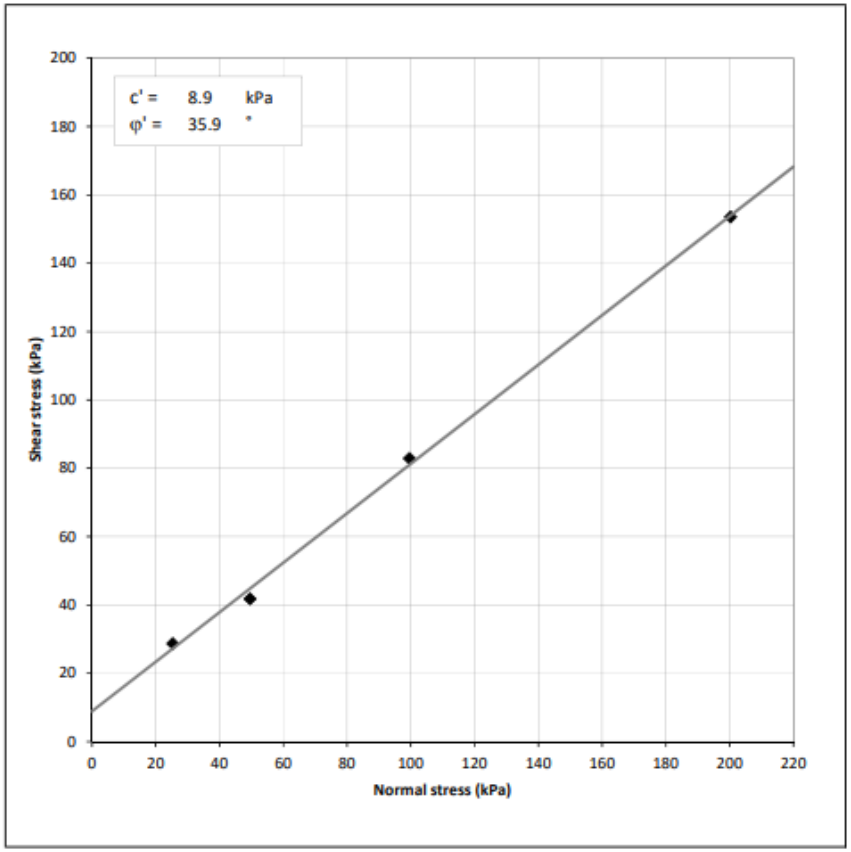
Results for intact material



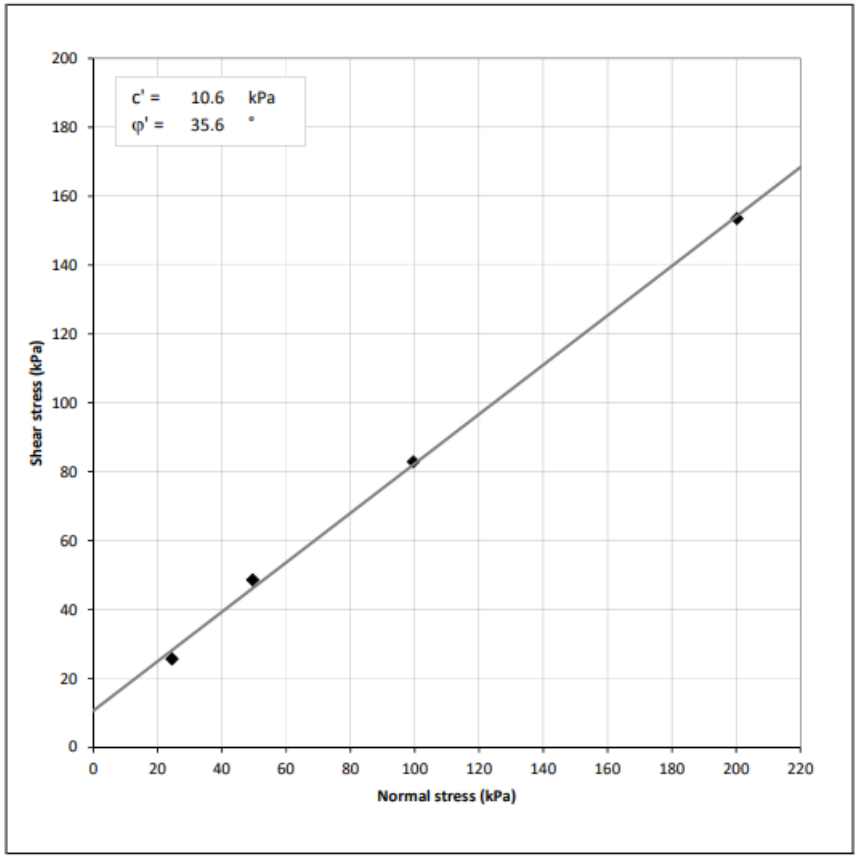
Laboratory testing

Results for weathered material

Laboratory weathering



Sample from the field



Determination of slope geometry

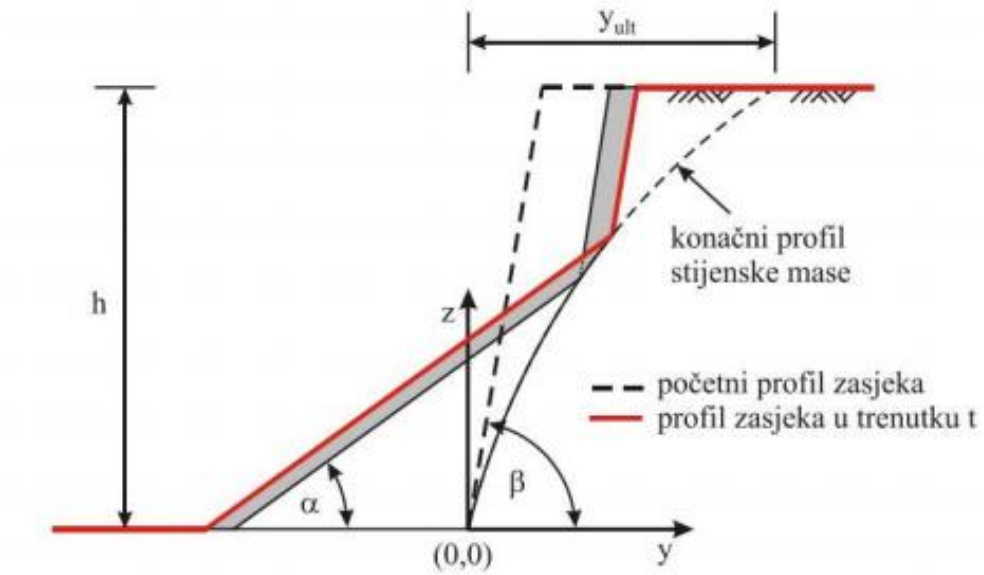
- Simplified geometry calculation based on Fisher-Lehmann model
- Input parameters defined by field monitoring (TLS)

$$\frac{zapremina\ stijene}{zapremina\ sipara} = \frac{1-c}{1}$$

$$\frac{A_2}{A_1} = \frac{1-c}{1}$$

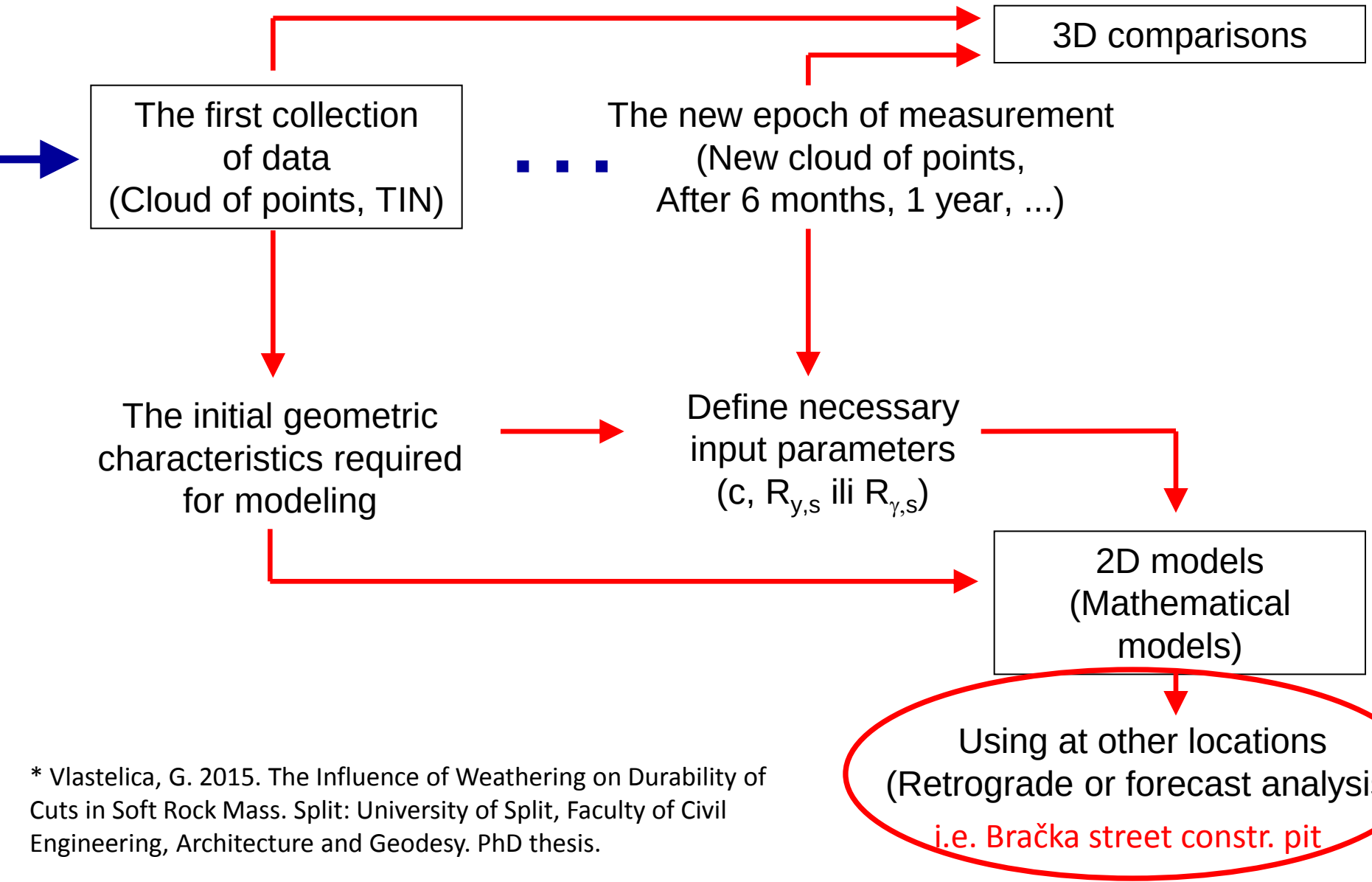
$$A_1 = \frac{A_2}{1-c}$$

$$A_1 = 1{,}67 \cdot A_2$$



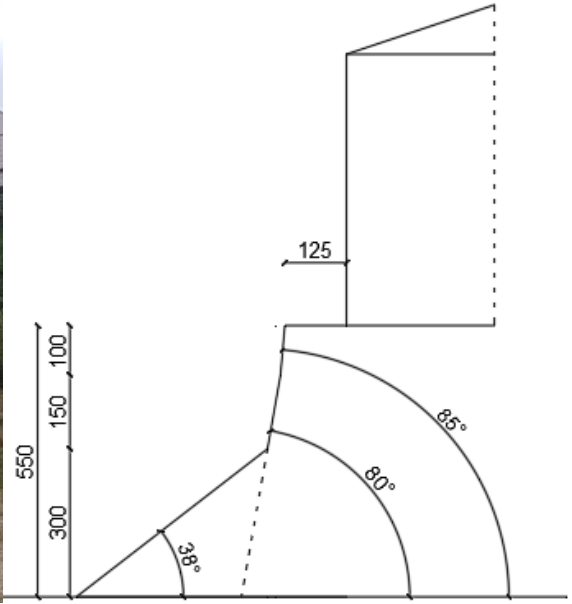
Parametar	Oznaka	Vrijednost	Mjerna jedinica
Nagib sipara	α	38	(º)
Nagib pokosa 1	β	80	(º)
Nagib pokosa 2	β	85	(º)
Visina zasjeka	h	5,5	(m)
Koeficijent rastresitosti	c	0,4	/
Prosječna godišnja erozija	$R_{y,s}$	5	(cm/god)

Input parameters defined by field monitoring (TLS) *

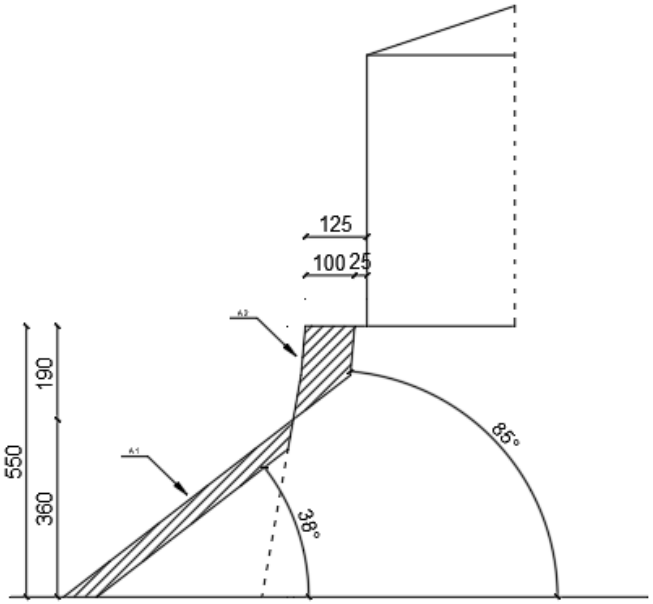


* Vlastelica, G. 2015. The Influence of Weathering on Durability of Cuts in Soft Rock Mass. Split: University of Split, Faculty of Civil Engineering, Architecture and Geodesy. PhD thesis.

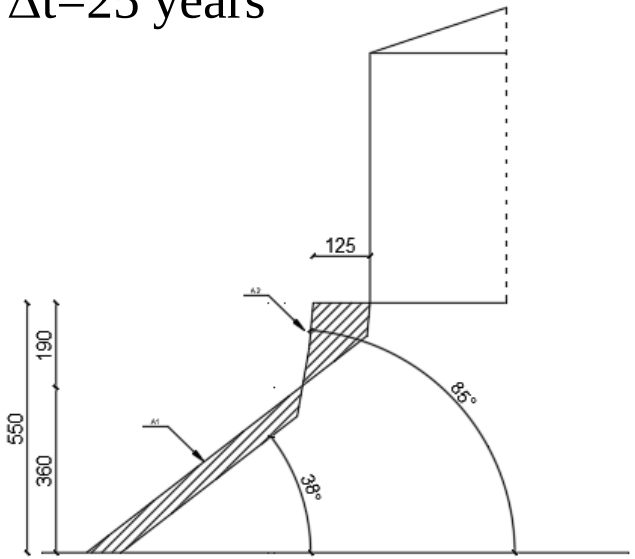
Δt=0 years



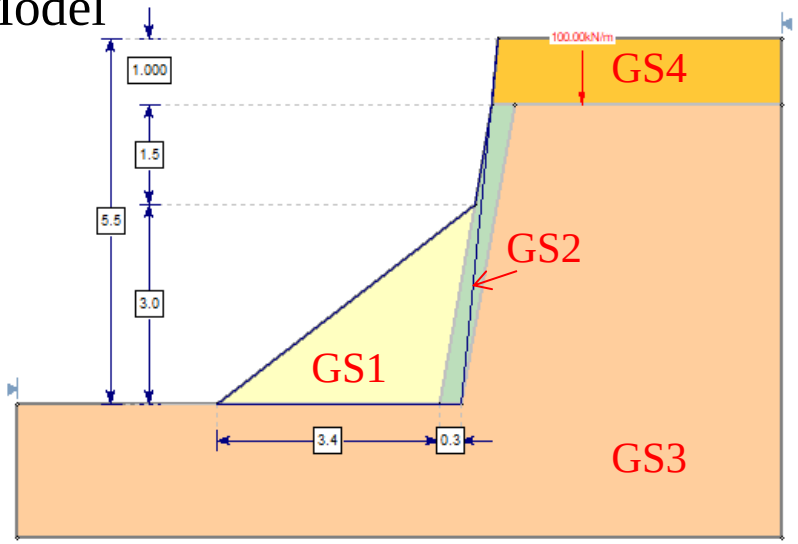
Δt=20 years (forecast)



Δt=25 years



Model



Selection of shear strength parameters

GS1 parameters (talus)

Uzorak	20/20	24/21
c (kPa)	8,9	10,6
φ (°)	35,9	35,6
γ (kN/m^3)	-	17,04

GS2 parameters

- After couple cycles of weathering

Oznaka uzorka	20/20	DS-6 (*)	DS-3 (*)
$CaCO_3$ (%)	45,87	44,44	54,63
Upijanje (%)	9,95	8,59	8,40
γ_d (kN/m^3)	22,95	21,8	23,5
I_{d2} (%)	92,400	89,75	76,04
I_{d4} (%)	84,99	84,11	42,22
$I_{s(50)}$	1,240	1,071	0,666
c (MPa)	1,135	0,1	0,1
φ (°)	26,09	36,4	29,7

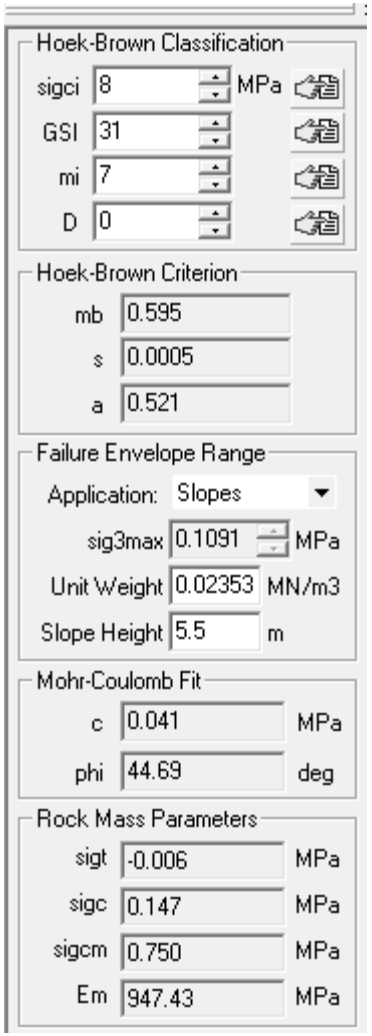
* Vlastelica, G., Miščević, P., Pavić, N. 2016b. Testing the shear strength of soft rock at different stages of laboratory simulated weathering, Građevinar 68 (12), pp 955-966.

Selection of shear strength parameters

GS3 (Rock mass properties)

- GSI ⇨ Hoek-Brown ⇨ RocLab

M-C parametri	Intaktna stijena (direktno smicanje)	Stijenska masa (Hoek-Brown kriterij)	Mjerna jedinica
c	5,816	0,041	MPa
ϕ	22,107	44,69	°



GS4 (Quaternary deposits)

γ_4=17 kN/m^3

c_{k4}=5 kPa

φ_{k4}=28^0

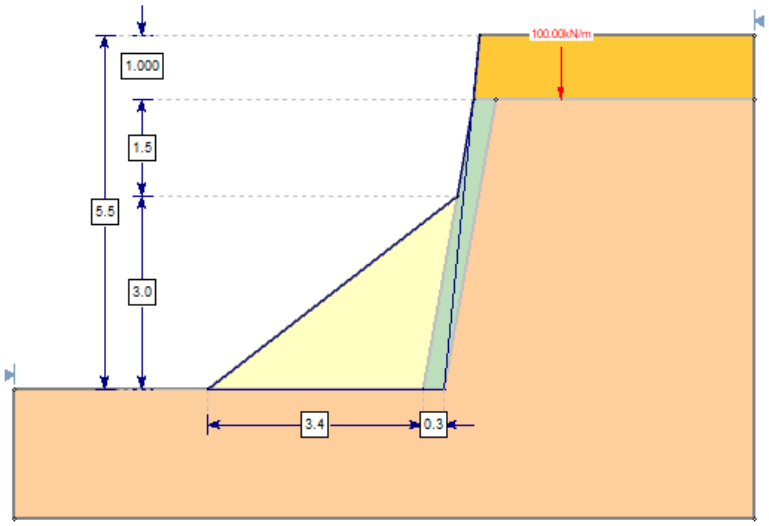
Selection of shear strength parameters

HRN EN 1997-1:2012/NA (Eurocode 7), DA3

Geotehnička sredina	Karakteristične vrijednosti		Projektne vrijednosti	
Geotehnička sredina 1 (talus)	φ_k (°)	35.6	φ_d =arctg (tg φ_k /1.25)	29.8
	C_k (kPa)	10.6	Cd=Ck/1.25	8.48
Geotehnička sredina 2	φ_k (°)	36.4	φ_d =arctg (tg φ_k /1.25)	30.5
	C_k (kPa)	5	Cd=Ck/1.25	4
Geotehnička sredina 3 (stijenska masa)	φ_k (°)	44.7	φ_d =arctg (tg φ_k /1.25)	38.4
	C_k (kPa)	41	Cd=Ck/1.25	32.8
Geotehnička sredina 4 (površinski sloj)	φ_k (°)	28	φ_d =arctg (tg φ_k /1.25)	23.1
	C_k (kPa)	5	Cd=Ck/1.25	4

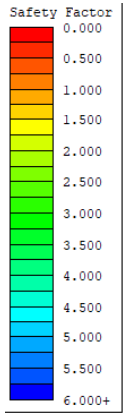
Analysis of global stability using Slide (Rocscience)

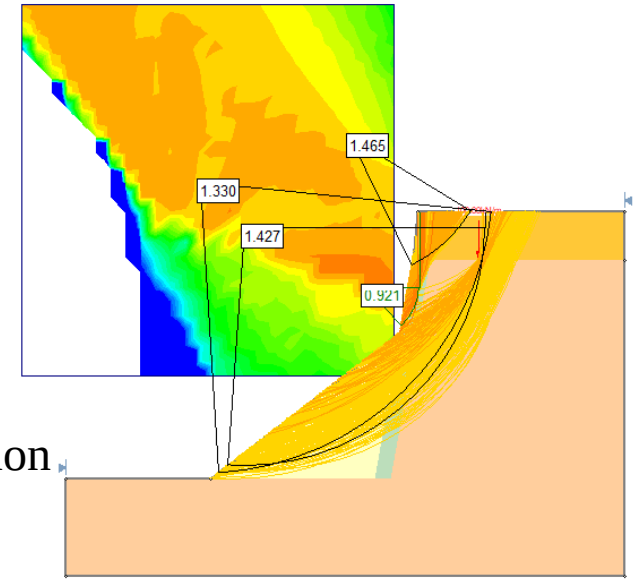
Δt=0



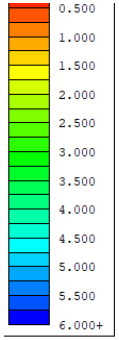
Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kN/m2)	Phi	Water Surface	Ru
Geotehnička sredina 1		17	Mohr Coulomb	10.6	35.6	None	0
Geotehnička sredina 2		21.8	Mohr Coulomb	5	36.4	None	0
Geotehnička sredina 3		23.53	Mohr Coulomb	41	44.7	None	0
Geotehnička sredina 4		17	Mohr Coulomb	5	28	None	0

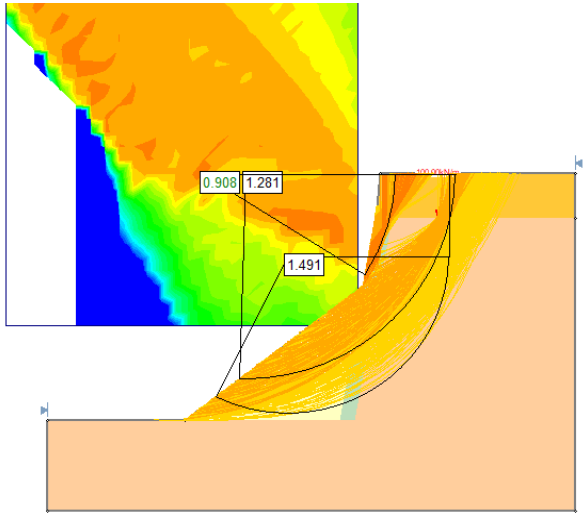
Geometry





Usual load combination

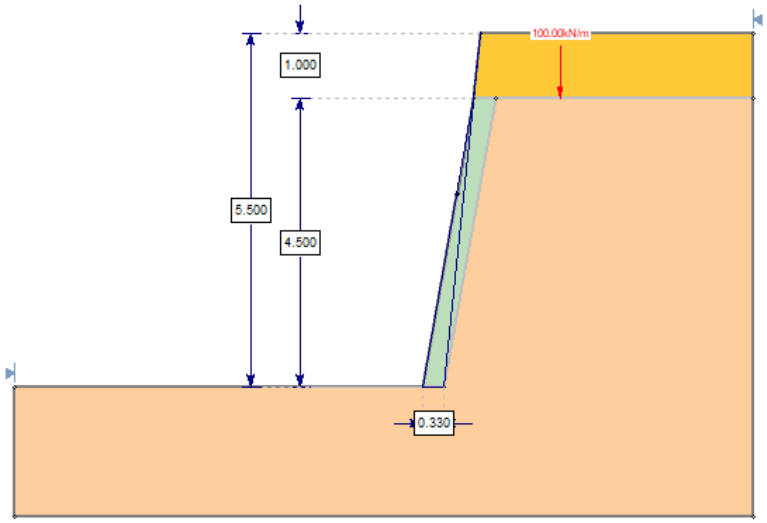




EQ included

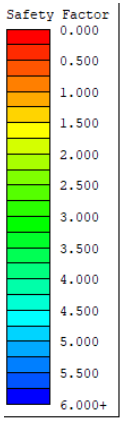
Analysis of global stability using Slide (Rocscience)

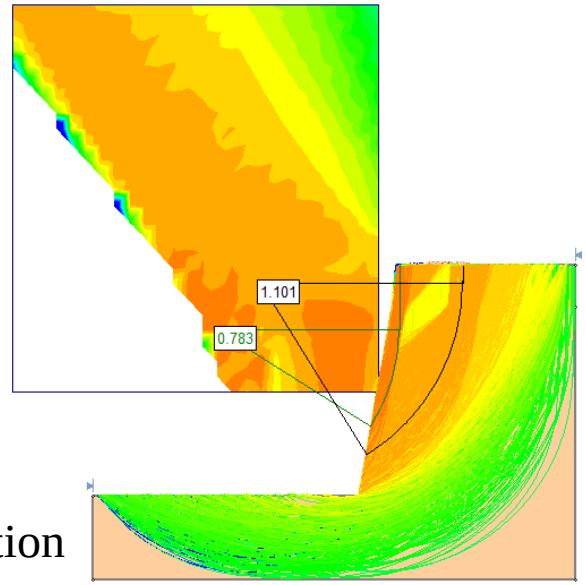
Δt=0 - talus removed



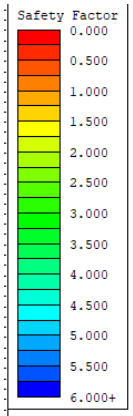
Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kN/m2)	Phi	Water Surface	Ru
Geotehnička sredina 1		17	Mohr-Coulomb	10.6	35.6	None	0
Geotehnička sredina 2		21.8	Mohr-Coulomb	0	36.4	None	0
Geotehnička sredina 3		23.53	Mohr-Coulomb	41	44.7	None	0
Geotehnička sredina 4		17	Mohr-Coulomb	5	28	None	0

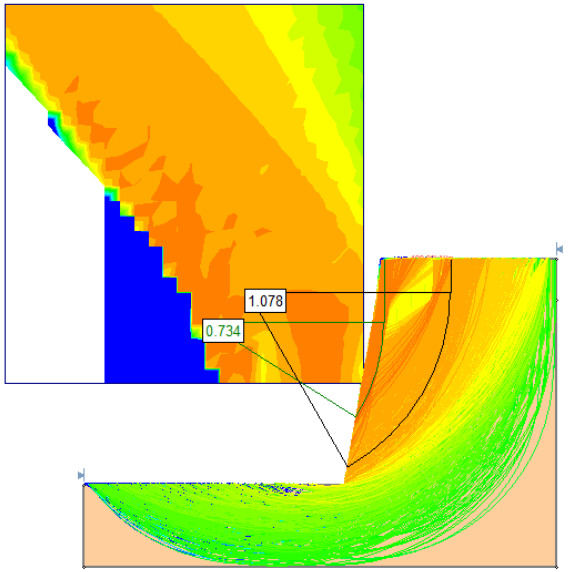
Geometry





Usual load combination

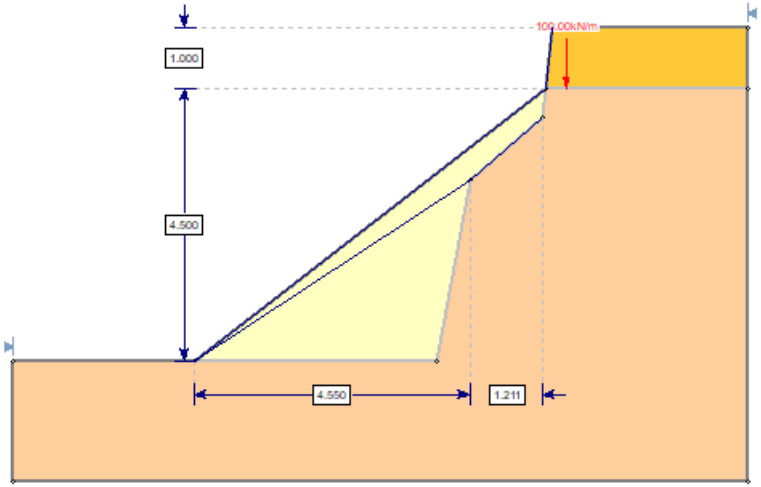




EQ included

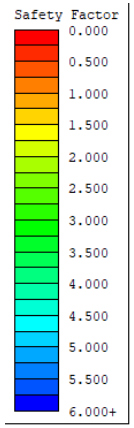
Analysis of global stability using Slide (Rocscience)

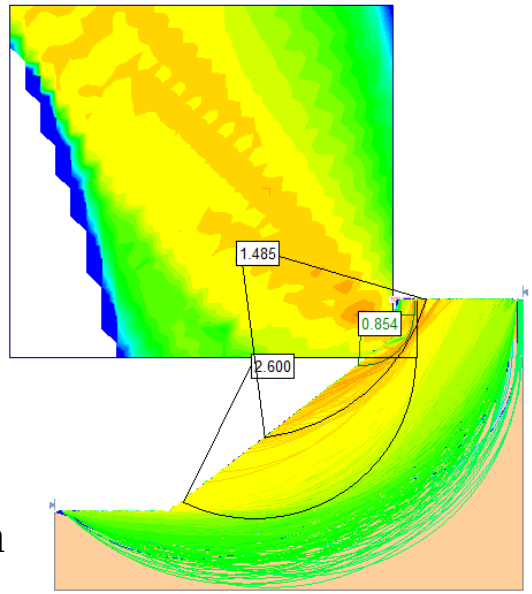
Δt=20 years (forecast)



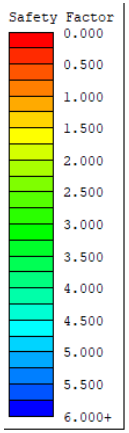
Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kN/m2)	Phi	Water Surface	Ru
Geotehnička sredina 1		17	Mohr-Coulomb	10.6	35.6	None	0
Geotehnička sredina 3		23.53	Mohr-Coulomb	41	44.7	None	0
Geotehnička sredina 4		17	Mohr-Coulomb	5	28	None	0

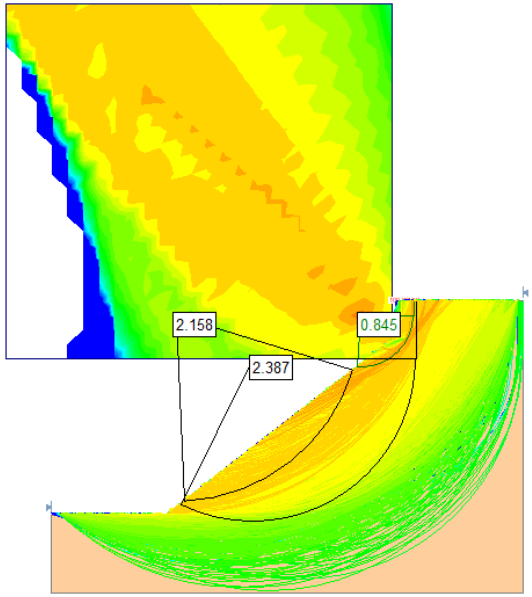
Geometry





Usual load combination

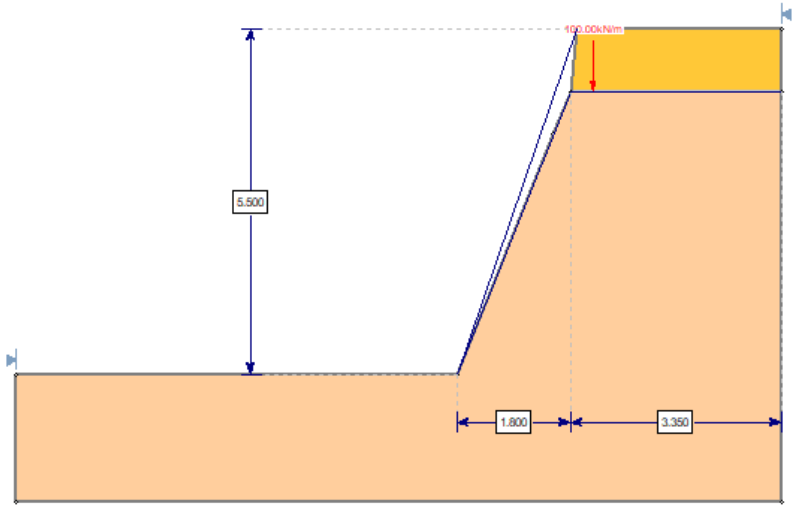




EQ included

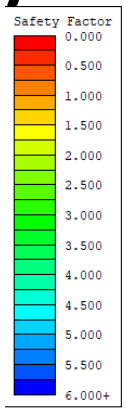
Analysis of global stability using Slide (Rocscience)

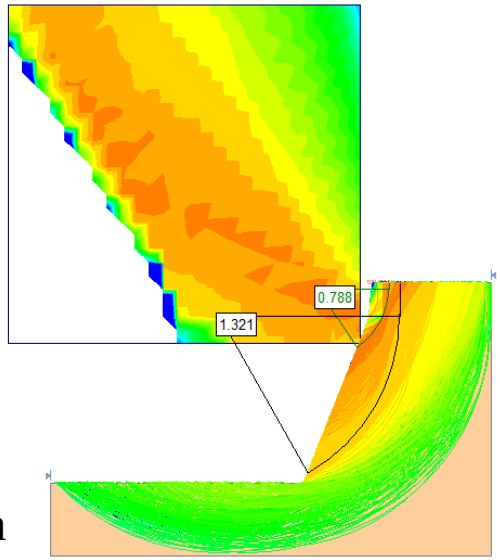
Δt=20 years – talus removed



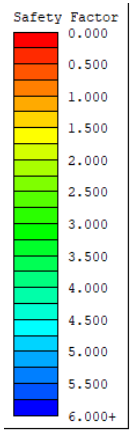
Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kN/m2)	Phi	Water Surface	Ru
Geotehnička sredina 3		23.53	Mohr-Coulomb	41	44.7	None	0
Geotehnička sredina 4		17	Mohr-Coulomb	5	28	None	0

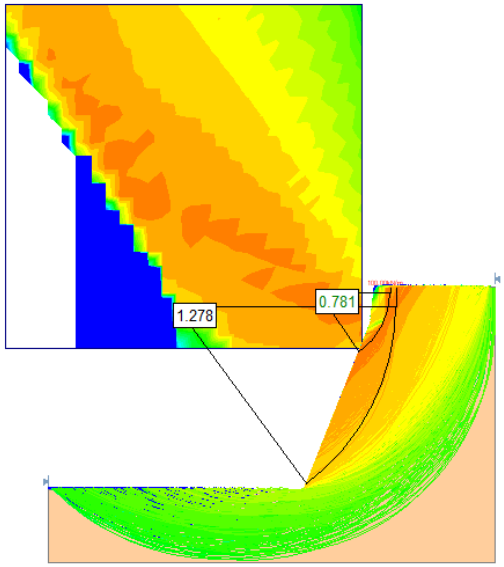
Geometry





Usual load combination





EQ included

Analysis of global stability using Slide (Rocscience)

Safety factors

Vrijeme ΔT	Fs-globalna stabilnost Osnovna komb.	Fs (talus) Osnovna komb.	Fs (kritični dio zasjeka) Osnovna komb.	Fs-globalna stabilnost Potresna komb.	Fs (talus) Potresna komb.	Fs (kritični dio) Potresna komb.
0 god.	1,330	1,427	0,921	1,281	1,491	0,908
0 god.(bez talusa)	1,101	-	0,783	1,078	-	0,734
20 god.	1,485	2,60	0,854	1,385	2,158	0,845
20god.(bez talusa)	1,321	-	0,788	1,278	-	0,781

- Global stability Fs > 1,0
- Local (upper part) Fs < 1,0

Some conclusions

- Analysis of global slope stability - global safety factor larger than 1.0 in all combinations
- Locally top surface layer and free face are critical
- Not recommended to remove talus
- Prognosis: Δt = 25 years for undercutting the house foundation, and questionable safe usage (in next 10-15 years)

Thanks for your attention!