Sløvågen Gulen Substation – Rock Fall Risk Assessment

Prosjekt:	Sløvågen_Gulen Substation Bergsikring	Prosjektnr.:	10241238
Kunde:	Wergeland Base AS	Prosjektleder:	Felix Kluge
Utarbeidet av:	NOFELI	Dato:	22.02.2024
Kontrollert av:	NOROAN		
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Revisjonshistorikk

Rev	Dato	Beskrivelse av endringen	Utarbeidet av	Kontrollert av	Godkjent av

Summary

GE Offshore Wind and Wergeland Base AS have commissioned Sweco Norge AS to assess the rock fall risk from an existing rock cut near Sløvågen, located in Gulen commune in Western Norway. The assessment is conducted to ensure an adequate level of safety for the construction of a new substation planned to be located near the cliff.

Geologists from Sweco inspected the construction site, collecting geological data for stability analyses as well survey data to construct a digital outcrop model. The digital outcrop model was used to identify potentially unstable large-scale rock volumes and to extract long sections to use in rock fall analyses.

GE- Offshore Wind have conveyed that the planned facility is to be unmanned except during maintenance 1 – 3 days a year and during the temporary construction phase of ca. one year and requested the assessment to be made in terms of acceptable risk for this sort of facility. Based on the Norwegian Planning and Building Act, Sweco has determined it suitable to assign landslide safety class S2 for the structures and S1 for the planned road and temporary construction phase. This necessitates a nominal annual probability of rockfall to be less than 1/1000 for the structures and less than 1/100 for the road and temporary construction phase. The assessment is placed in project class 2 and project control class 2, requiring a limited control by an independent company PKK2/UKK2.

After analyzing the reach probability using Rocfall software by RocScience and considering the likely maximum reach of large-scale rock failures, the boundaries for the S2 and S1 zones were established. It has been determined that both the facility and road meet the specified criteria for acceptable risk. The analysis presupposes that the ground level is covered by rock debris/gravel. Given that exposed hard rock protrusions at the base can significantly amplify the deflection of rock fragments upon impact, any exposed rock surfaces beneath the cliff face need to be covered with a minimum of 0.5 meters of loose gravel (e.g. 32 - 62 mm fraction). Apart from this, no additional mitigating construction measures, such as bolting, need to be implemented for the facility, if the area within the S1 zone is not intended for use (e.g., for equipment storage).

It is advisable to erect a construction fence along the S1 boundary during the construction phase and install a permanent fence to prevent trespassing during the permanent phase.

1 Content

1. Introduction

Sweco Norge AS was commissioned by GE Offshore Wind and Wergeland Base AS to conduct an assessment of rockfall hazards and propose potential mitigation measures for a forthcoming substation project adjacent to Wergeland Base in Sløvågen, Western Norway (Figure 1).

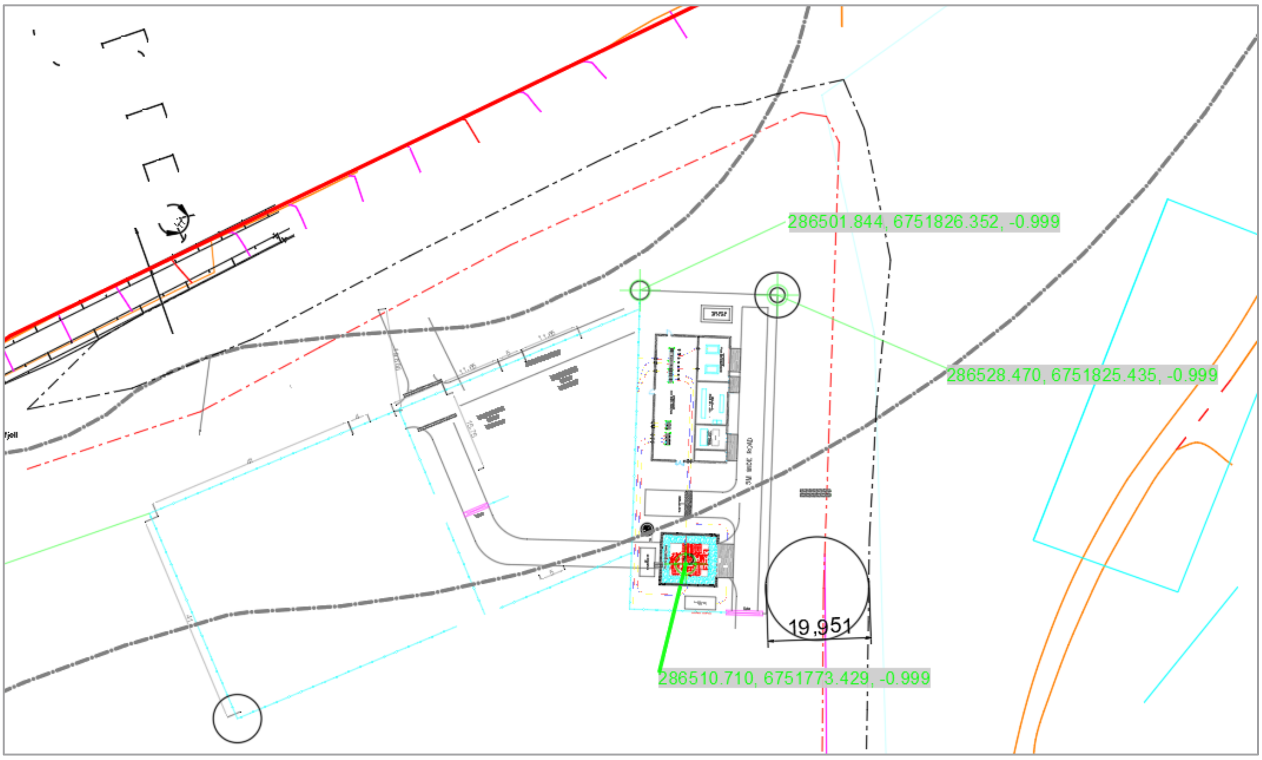


Figure 1 Drawing of the planned substation. The approximate placement of the rock cut is symbolized by a dotted black line.

The construction site for the proposed substation was excavated in the early 2000s (as per Norge I bilder circa 2008) and graded to approximately +3 to +4 meters above sea level (ASL). To the northwest and east, the site is delimited by rock cuts/slopes ranging in height from 5 to 26 m. The eastbound cut spans approximately 230 meters in length, while the northwest bound cut extends approximately 210 meters. The rock slopes remain untrimmed, unscaled, and unsupported by bolts. Loose rock fragments and potentially unstable rock structures are prevalent throughout the entire rock cut. Throughout most areas of the site, a trench measuring approximately 1 meter in depth and spanning around 6 meters in width is excavated at the base of the rock face.

The initial scope of this investigation aimed to assess and estimate the most effective and cost-efficient standard mitigation method for rockfall hazard, including options such as scaling, bolting, or constructing a berm. However, further investigation revealed that while bolting and scaling the rock face would be costly, constructing an effective berm would demand a considerable amount of space. Moreover, the safety zone gained from the berm would not significantly exceed the likely maximum reach of rockfall from the rock face i.e. there would locally only be a few meters difference.

Upon request by GE-offshore wind, specifying that the structure would be generally unmanned, the investigation was conducted to assess the probability of reach relative to designated acceptable risk levels for different parts of the structure and the construction phase (1 year). Levels of acceptable risks are chosen in concurrence with TEK 17 safety classes described of the Norwegian Planning and Building Act (PBL).

That is:

- The substation and structures on site are required to satisfy S2, with the greatest nominal annual probability < 1/1000
- Roads are required to satisfy S1, with the greatest nominal annual probability < 1/100
- Temporary safety during construction (1 year) is required to satisfy S1, with the greatest nominal annual probability < 1/100

Although the initial inspection focused on the site as a whole the later analysis was limited to the precise location of the facility, as depicted in Figure 1. Consequently, other areas of the site were not thoroughly assessed for rockfall hazard, thus precluding definitive claims regarding their safety.

2. Site visit

A site visit was conducted on the 25.01.24 by the engineering geologists Felix Kluge and Stig Vevatne, together with Jonathan Mechineau form GE offshore wind (Figure 2, drone overview of the site).

During the site inspection, comprehensive data on rock quality, including discontinuity orientations, persistence, roughness, and spacing, was collected. Additionally, the outcrop was methodically photographed using a drone (Mavic Mini 3) to generate a digital outcrop model. Ground control points were marked on both the ground and the outcrop surface with spray, then surveyed using a GPS-antenna.

Figure 2 Drone photograph giving an overview of the site

2. Digital outcrop model

A digital outcrop model was constructed (Figure 3) using the software Shape metrix with 1200 drone photographs covering the rock cuts in the east and northwest. The model has an average point spacing of 7 cm and an estimated precision of 13 cm. Discontinuities are mapped manually using the shape metrix analyst tool.

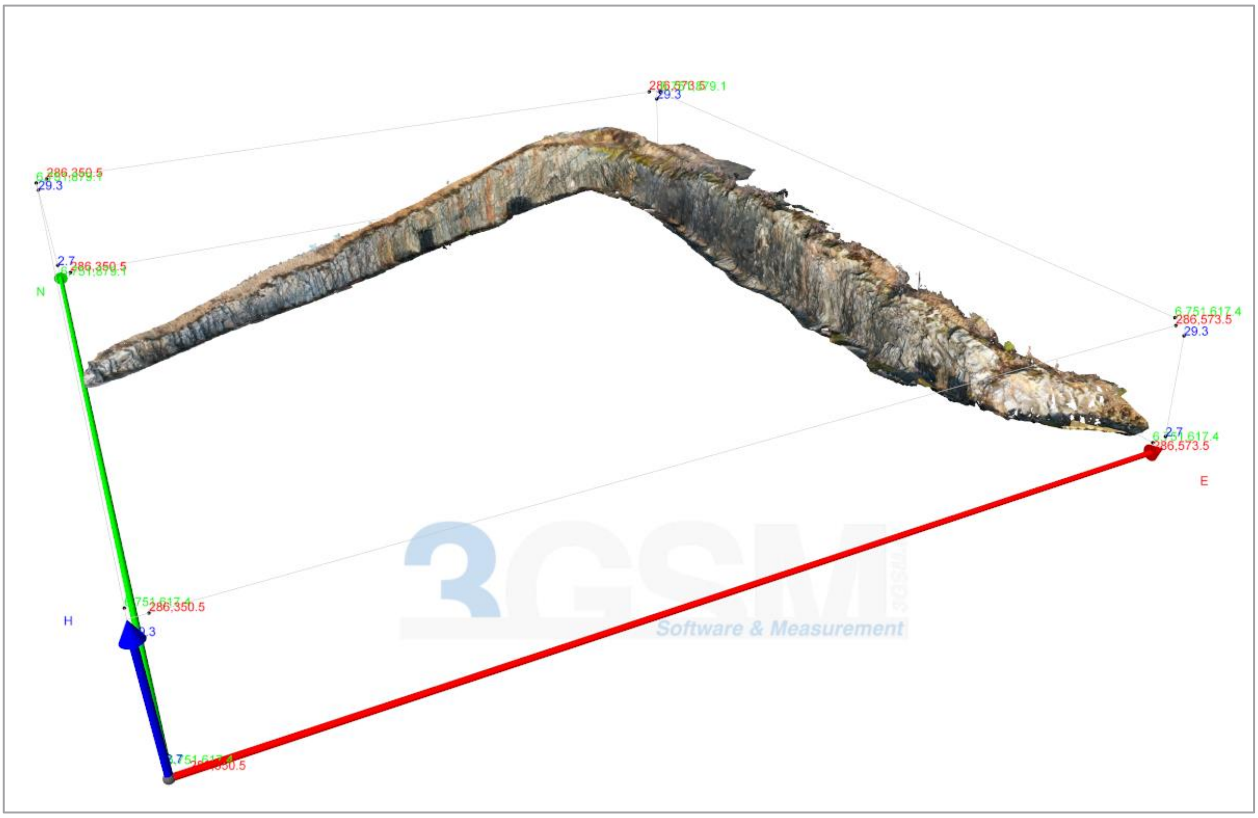


Figure 3 Digital outcrop model produced using photogrammetry

3. Rules and regulations

3.1 List of regulations, standards, and norms

The following section summarizes relevant rules and regulations that apply to geotechnical/rock mechanical design according to Norwegian and European law. Relevant standards and manuals used for the design (Norwegian general practice), are also listed.

Laws and regulations:

- The Planning and Building Act, Regulations on technical requirements for construction works (Plan- og bygningsloven, "Byggteknisk forskrift - TEK17") The Planning and Building Act, Regulations on technical requirements for construction works (Plan- og bygningsloven, "Byggteknisk forskrift - TEK17") The Planning and Building Act, Regulations on technical requirements for construction works (Plan- og bygningsloven, "Byggteknisk forskrift - TEK17")

Standards:

- Eurocode 0 - Basis of structural design - NS-EN 1990:2002+A1:2005+AC:2010/NA:2016
- Eurocode 7 - Geotechnical design - Part 1: General rules - NS-EN 1997-1:2004+A1:2013+NA:2020

Manuals:

- Norwegian Rock Mechanics Group, Manual for using Eurocode 7 for rock mechanical design, 2011 [1]

3.2 Norwegian Building Acts and Regulations

Construction projects on Norwegian soil are required to align with Norwegian Building acts and regulations, "Plan- og bygningsloven, byggteknisk forskrift – TEK 17". According to the Norwegian Building Authority "These regulations are intended to ensure that projects are planned, designed and executed on the basis of good visual aesthetics, design for universal accessibility, and in a manner that ensures the project complies with the technical standards for health, safety, the environment and energy." [2]. TEK 17 defines e.g., safety requirements for construction projects regarding natural hazards such as landslide risk (e.g. rockfall), slope stability and design control.

Regarding the rockfall hazard from blasted rock slopes, TEK 17 § 7-3 defines safety requirements in terms of greatest nominal annual probability for rockfall according to three different safety classes (Table 1). Safety classes are chosen according to the presumed consequence resulting from a rock fall event with regards to different construction types, economical risk, and other social considerations.

The present construction project plans an unmanned facility and substation, road that is rarely used and a one-year construction phase. With regards to the relatively low risk of personal injury, resulting from short stay durations and the limited economical consequence with regards to the planned structures it is found to be adequate to place the planned structures in S2 and the road and construction period in S1, requiring the greatest nominal annual probability for rockfall to be lower than 1/1000 and 1/100 respectively.

Table 1 Landslide/avalanche safety classes and requirements for the greatest nominal annual probability of land slide/avalanche according to TEK 17 § 7-3.

Landslide/avalanche safety class	Impact	Greatest nominal annual probability
S1	slight	1/100
S2	moderate	1/1000
S3	severe	1/5000

Norwegian Building Application Regulations, "Byggesaksforskriften" (SAK10) § 9 prescribe that "Tasks associated with a project shall be divided into project classes 1, 2 or 3 within one or more fields based on their complexity, degree of difficulty and possible consequences, deficiencies and errors may have for health, safety and the environment".

Tasks associated with rock fall assessment in this project are placed in **project class 2** described as follows:

"b) moderately complicated or have a moderate degree of difficulty, but in which deficiencies or errors will have minor to moderate consequences for health, safety and the environment"

This project class is chosen since the estimation of rock fall reach probability is moderately difficult whilst the consequences of errors in the analysis are assumed to be relatively minor.

SAK10 § 14 prescribes compulsory requirements relating to **independent verification/project control by an independent company**. Both design and execution shall be verified.

With regard to the current project, that is placed in project class 2, the responsible controllers shall verify:

“a) that the responsible designers' management systems contain routines for quality assuring the work that is going to be executed within the verification area in accordance with relevant requirements in or pursuant to the Planning and Building Act, and that these are complied with and documented.

b) that the quality assurance has been carried out and documented pursuant to the management system and relevant requirements stipulated in or pursuant to the Planning and Building Act

c) that the concept drawn up provides an adequate basis for detailed design

d) that the detailed design is sufficient as the production documentation for execution “

Responsible controllers for execution of the current project shall verify:

“a) that the responsible contractors' management systems contain routines for quality assuring the work that is going to be executed within the verification area in accordance with relevant requirements in or pursuant to the Planning and Building Act, and that these are complied with and documented

b) that the quality assurance has been carried out and documented pursuant to the management system and relevant requirements stipulated in or pursuant to the Planning and Building Act.”

3.3 Eurocode and Norwegian standardized design

The design and quality control methods for the current project are done in accordance with the Eurocode and Norwegian standards.

For rock mechanical design, the Norwegian Rock Mechanics Group describes how the geotechnical category is to be chosen in accordance with Eurocode 7 [3]. Geotechnical category is to be defined in terms of reliability class based on Eurocode 0 [4] (Table 2) and a presumed degree of difficulty “low”, “medium”, or “high” (Table 3).

For the current project is placed in **reliability class 2** (Table 2) and is associated with a **“medium” degree of difficulty.**

The current project is thus placed in **geotechnical category 2** according to Table 3.

Table 2 Choice of reliability class. The chosen class is marked with violet, i.e. CC/RC 3.

Examples of projects	Reliability class (CC/RC)			
	1	2	3	4
Nuclear reactors, storage facilities for radioactive waste.				X
Groundworks for foundations and tunnels in complex conditions		(x)	x	(x)
Groundworks for foundations and tunnels in simple conditions	x	(x)		

Table 3 Choice of geotechnical category. The chosen category is marked with violet, i.e. 3.

Reliability class	Degree of difficulty		
	Low	Medium	High
CC/RC 1	1	1	2
CC/RC 2	1	2	2/3
CC/RC 3	2	2/3	3
CC/RC 4	*	*	*

According to Eurocode 0, reliability class 2 leads to design control class, “Prosjekteringskontrollklasse”, **PKK2** (Table 4) and execution control class, “Utførelsesklasse”, **UKK2**. Design- and execution control classes 2 require that designs and the execution are subjected to a **control by an independent company** in addition to regular internal systematic control routines. In PKK 2, the control can be limited to controlling that the self-check and internal systematic control are conducted according to the designing enterprises quality procedures. Extended controls in accordance with Eurocode 0 are commonly performed in conjunction with controls required by the Norwegian Building Application Regulations (SAK10) § 14, i.e. by the same controller.

Table 4 Choice of design control class requirements to type of control, i.e., PKK3.

Choice of design control class		**Requirements to type of control**		
Reliability class	Minimum design control class	Self-check	Internal systematic control	Extended control
1	PKK 1	required	not required	not required
2	PKK 2	required	required	required*
3	PKK 3	required	required	required
4	PKK 4	required	required	required
** Extended control in control class PKK2 may be limited to controlling that the self-check and internal systematic control are conducted according to the designing enterprises quality procedures.*				

Table 5 Choice of execution control class requirements to type of control, i.e., UKK3.

Choice of execution control class		**Requirements to type of control**		
Reliability class (CC/RC)	Minimum executiuon control class	Self-check	Internal systematic control	Extended control
1	UKK 1	required	not required	not required
2	UKK 2	required	required	required*
3	UKK 3	required	required	required
4	UKK 4	required	required	required
* *Extended control in control class UKK2 may be limited to controlling that the self-check and internal systematic control are conducted according to the executing enterprises quality procedures.*				

4. Rock mass conditions

The rock type observed at the site is a high-grade metamorphic migmatite gneiss, predominantly dark gray with characteristic tightly folded bands rich in pinkish feldspar. This agrees with the bedrock map published by NGU, which displays a northwest-southeast striking formation of migmatite gneiss protruding through the area [5]. Pictures of the rockmass are showed in Figure 4 and a bedrock map in Figure 5.

Figure 4 Showing typical appearance of the rock mass

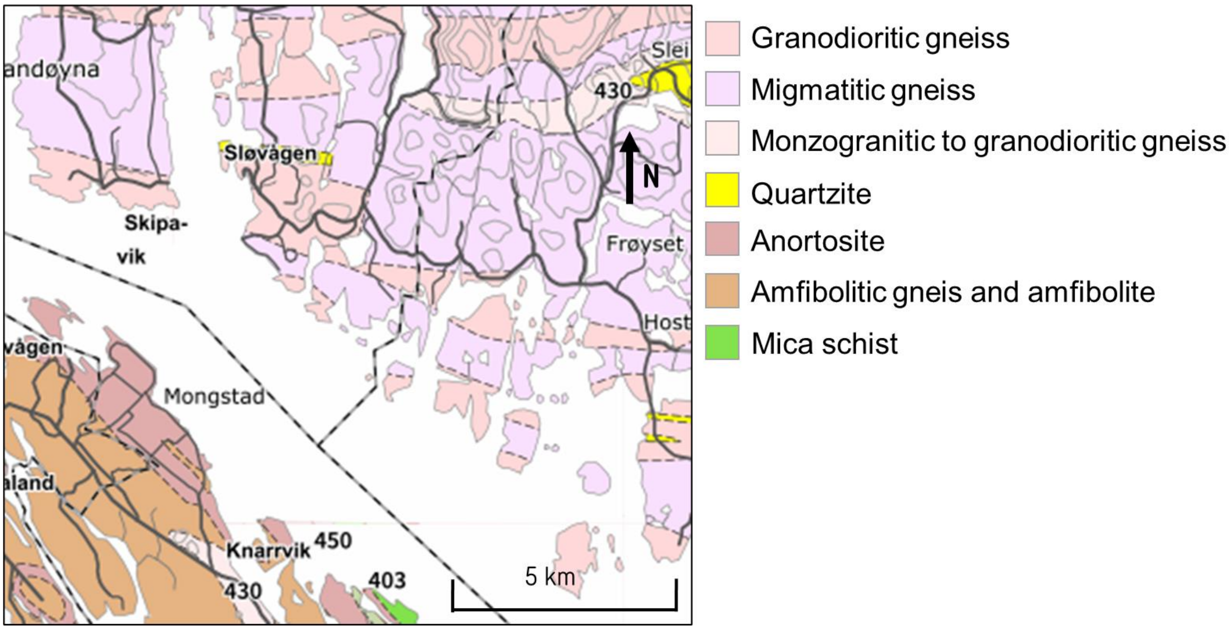


Figure 5 Showing NGUs regional bedrock map including the area of investigation [5].

The rock mass is characterized by av varying degree of jointing. Three main joint sets are distinguished as well as abundant joints with seemingly sporadic orientations. Joint sets are described in Table 6 and shown as a stereographic projection and rose diagram in Figure 6.

Table 6 Summarizing key characteristics of three main observed joint sets

Joint Set	Mean orientation (Azimuth/dip)	Persistence	Joint spacing	Roughness	Comment
Set 1	094/84	High	Moderate - Wide	Wavy rough to planar rough	Parallel with easter cut
Set 2	194/84	High	Very- extremely wide	Wavy rough to planar rough	Sub parallel to northern western cut
Set 3	212/17	Low to medium	Moderate	Wavy rough to stepped/discontinuous	Low angle fissures

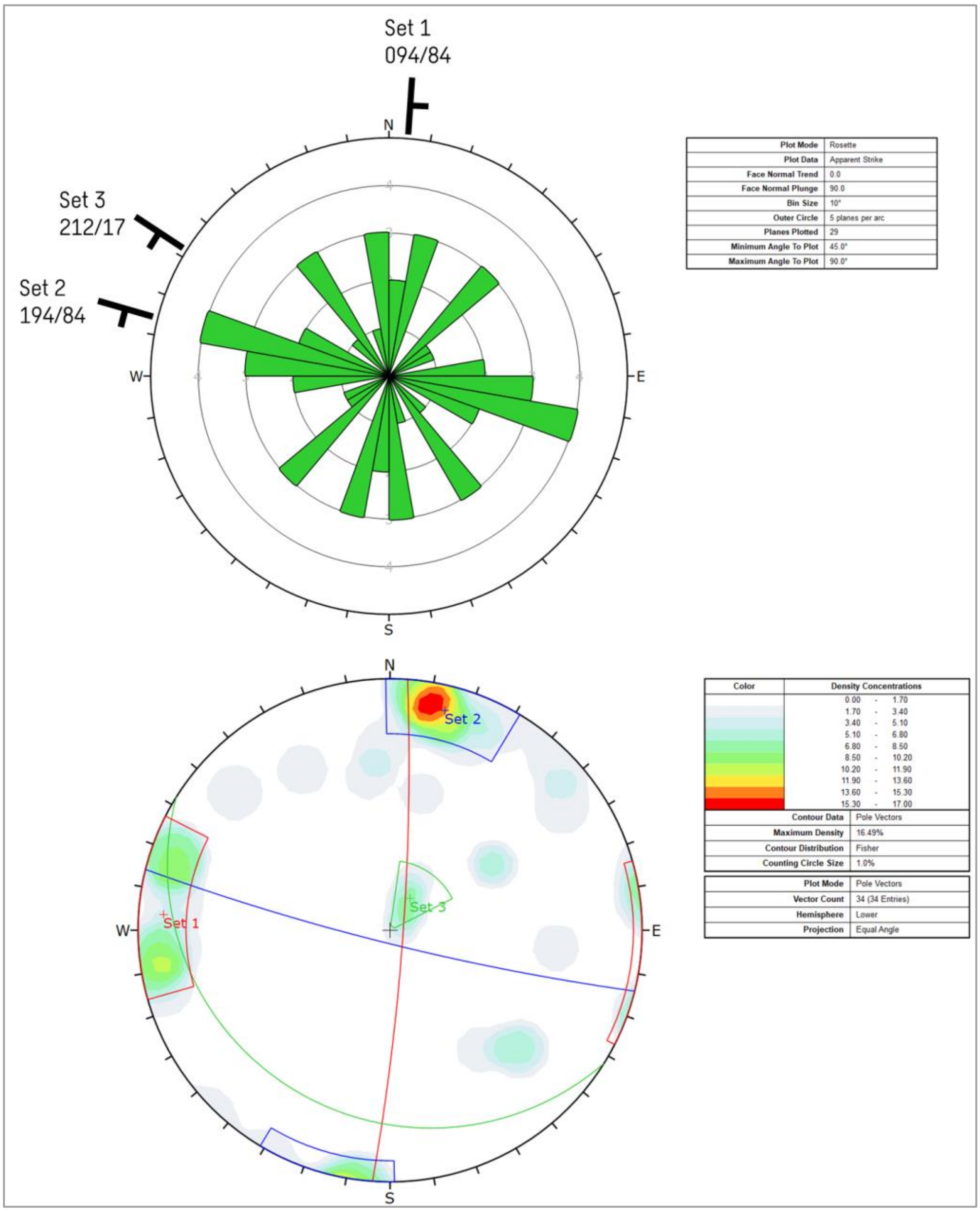


Figure 6 Stereographic projection and rose diagram showing discontinuity measurements collected with compass and clinometer

5. Stability assessment

The rock cut generally appears very rugged, characterized by an abundance of loose rock fragments and structures delineated by discontinuities. This indicates a clear rock fall potential although Sweco is not aware of any reported incidents from the site. It is likely that some rock fragments observed on the ground originated from rockfall events, but they cannot be confidently attributed as such.

The method for rockfall risk assessment for the site comprises the following main considerations:

- Analyzing the general fracture network by means of kinematic analysis in order to identify the most likely failure mechanisms and block shapes.
- Mapping of large (larger than ~ 30 m^3), potentially unstable rock structures using digital outcrop model, and estimating a probable maximum reach.

- Estimating the reach probability/run out distance for single rock fall events (blocks and rock fragments) of small to medium size.

5.1 Kinematic analysis

A kinematic analysis for the rock face closest to the planned facility is performed using joint orientation measurements from the site (Figure 7).

The analysis indicates that the systematic joint network can facilitate toppling as a probable failure mechanism. Planar sliding and wedge sliding are deemed unlikely to occur solely due to the systematic joint network, although they could potentially manifest in combination with sporadic discontinuities.

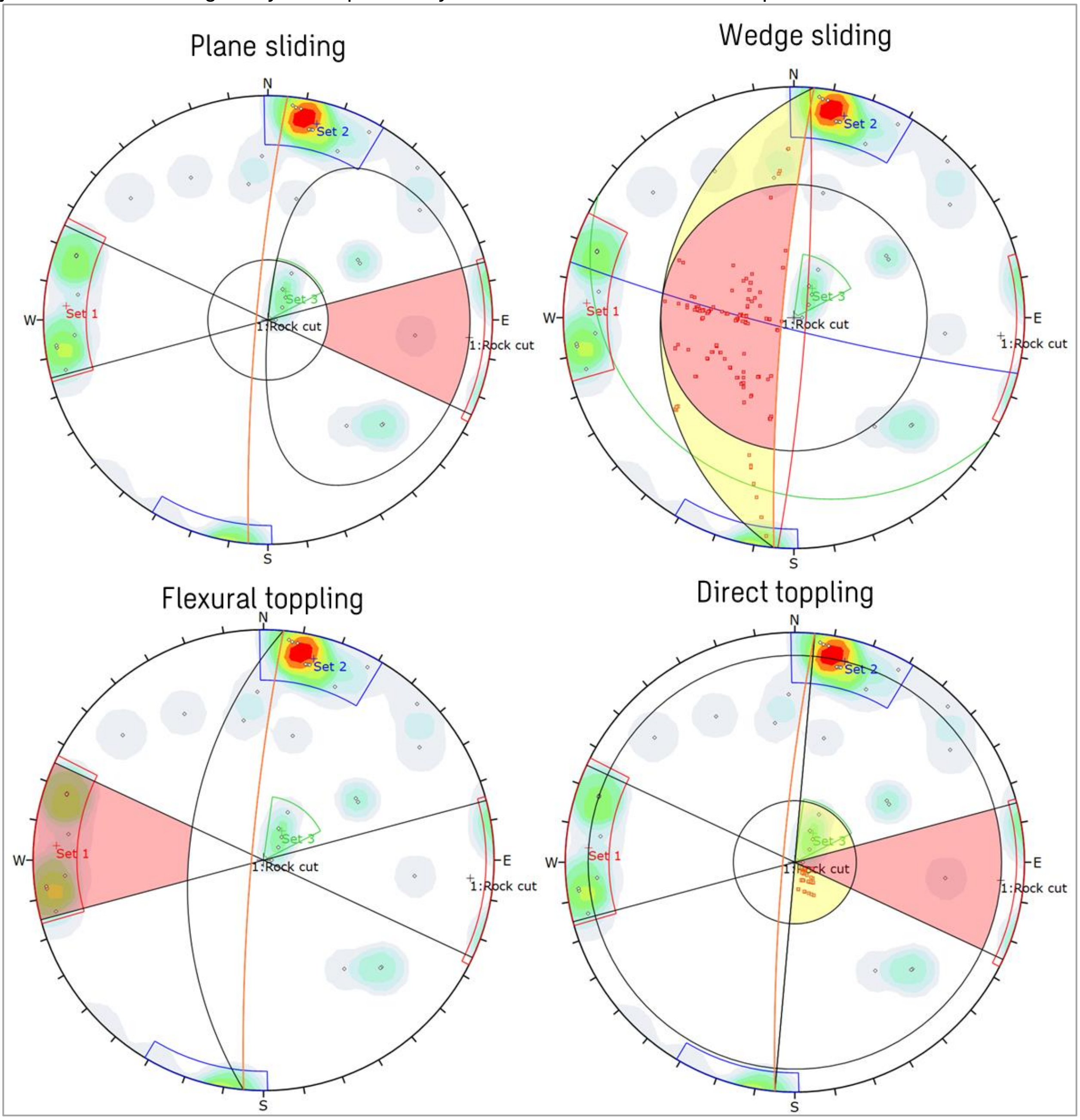


Figure 7 Kinematic analysis for the rock face closest to the planned facility

5.2 Largescale structures

The digital outcrop model was employed to identify potential large-scale unstable structures within the rock cut. Several large-scale structures were identified throughout the site. Some of the large-scale structures on the northwestern rock face are considered too distant (>30 m) from the facility to warrant additional investigation. However, two structures along the eastern rock face, being closer to the planned facility, are described below.

Along the southernmost section of the facility, a significant wedge-shaped structure is evident (Figure 8 and Figure 9). Below, it is bounded by a distinct joint, oriented at 280/79 (Joint 1). While the joints delineating the structure to the north are less defined, several intermittent fissures related to joint set 2 may intersect with joint 1. A potential joint, indicated by a faint trace, is estimated to have an orientation of 208/84 (Joint 2). At its peak the structure is ca. 15 m high and comprises a volume of ca. 300 m^3. Based on stability analyses with the software Swedge, it is found to be very unlikely that the structure would be stable based only on joint roughness (friction), suggesting stability is governed by rock bridges and/or cohesion. Based on the model, it appears that joint 1 terminates just before reaching the intersection, leaving some uncertainty regarding the complete delimitation of the rock volume. Rock bridges near the intersection between joint 1 and joint 2 may currently be preventing the structure from failing, but it's possible they could deteriorate over time due to weathering, potentially leading to future instability.

Another potentially unstable rock mass is identified to the south of the planned facility. This mass, resembling a vertical column of ca 16 m height (ca 80 m^3), delimited by vertical joints oriented approximately 088/88 (Figure 11). Steep joints dipping slightly into the rock face, coupled with gently inclined to sub-horizontal fissures intersecting the structure, suggest that the structure might be prone to toppling.

Figure 8 View of the large-scale rock wedge

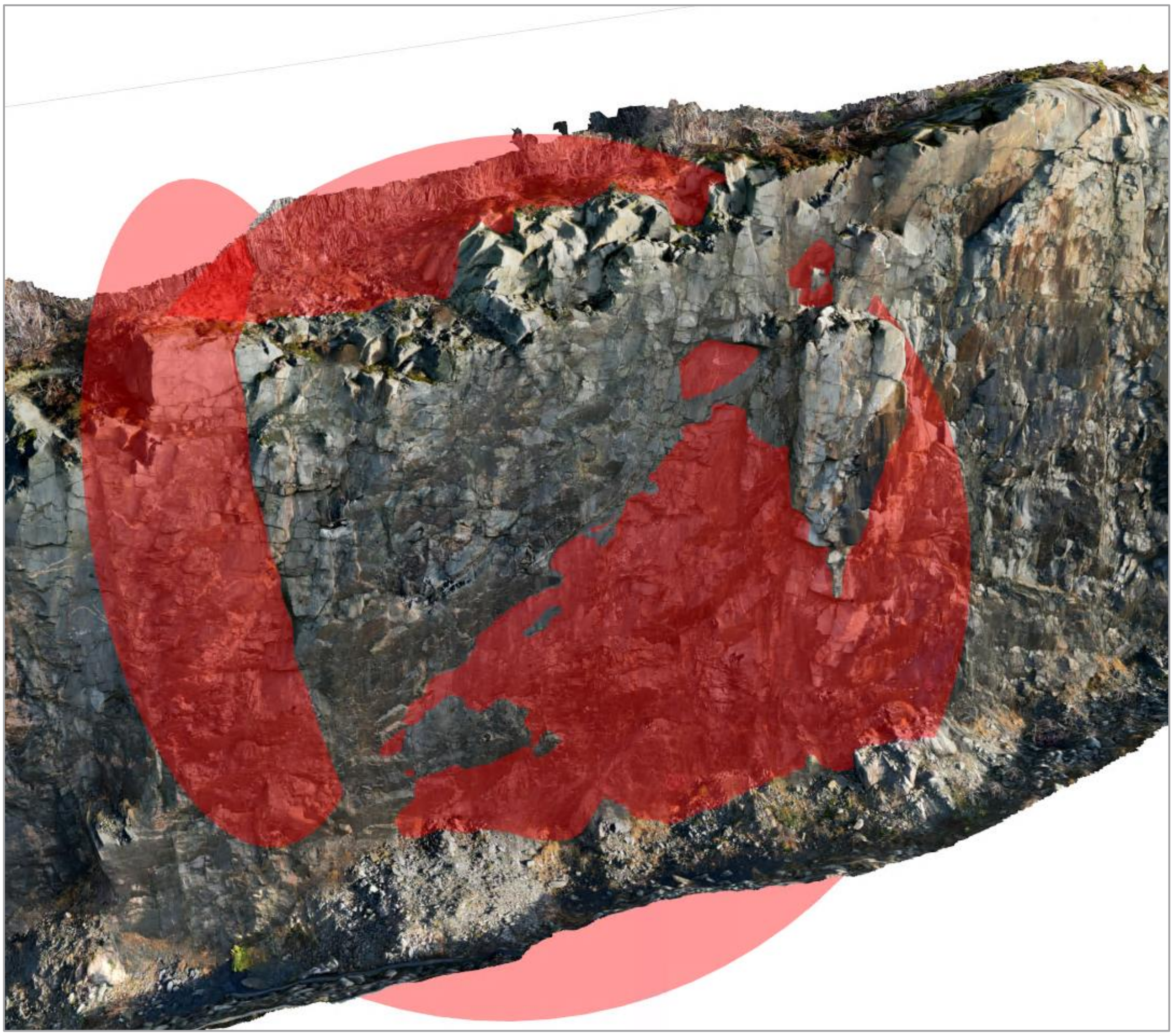


Figure 9 Mapped wedge-shaped rock volume near the planned facility. The estimated volume is ca 300 m^3

Figure 10 View of a potentially unstable rock column

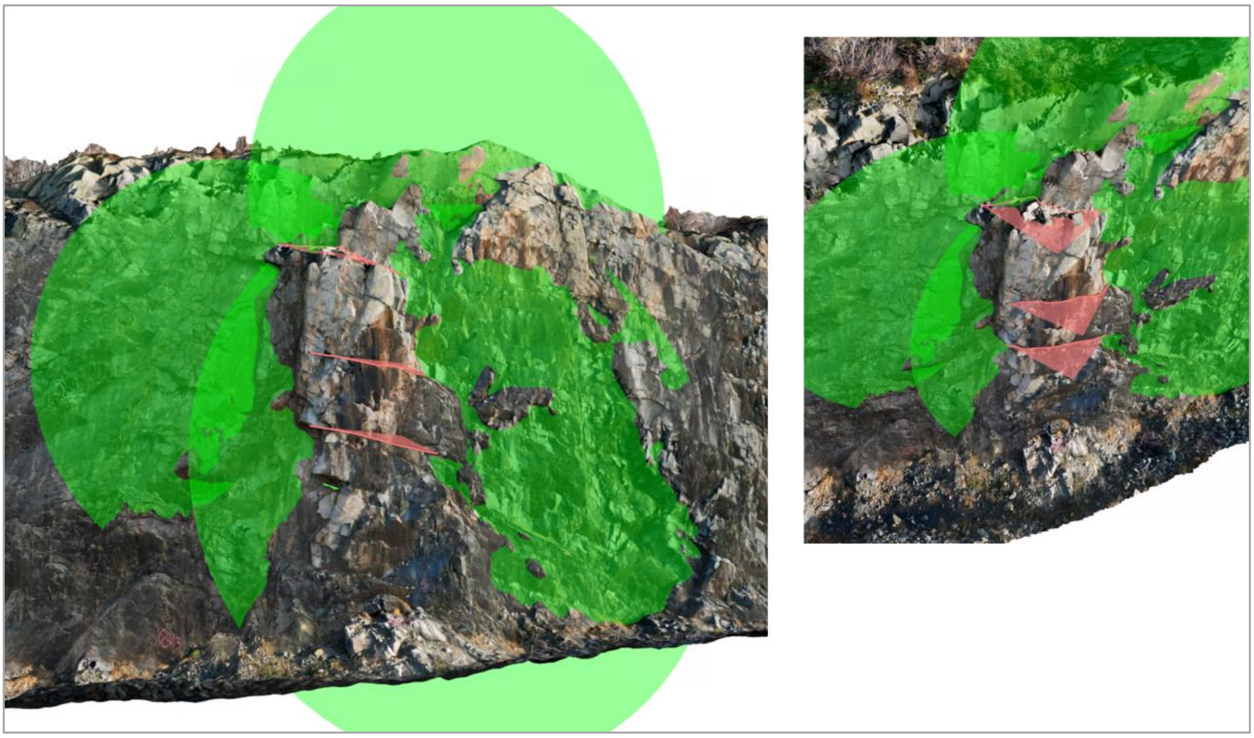


Figure 11 Mapped vertical rock column delimited by vertical joints. The estimated volume is ca. 80 m^3. The column might topple with prolonged weathering.

5.3 Reach probability assessment and risk boundaries

The Rocfall software by Rocscience was used to evaluate the reach extent of fragments falling from the rock face, bouncing off it, and rolling along the gravel surface (Figure 12).

The analysis uses input parameters from the software's library for bedrock and rock debris respectively to mimic dampening properties of the rock face and the gravel cover beneath the slope. Four rock shapes (circle, elipse 5:6, elipse 2:3 and super elipse^6 1:2) are modelled with a constant mass 15000 kg for each rock type. For the "super ellipse^6" this mass is equivalent to a rock of 3.5 m in height. It was found that the reach of different rock shapes in most cases does not differ significantly. In some instances, the "super elipse^6" (Elipse1) has a somewhat shorter reach, but higher bounce height than other shapes. It is however also considered to be the most realistic of the modelled rock shapes based on observations and probable toppling failure mechanisms.

The analysis was systematically repeated for 10 different profiles intersecting the eastern rock face. The cumulative endpoint distances, measured from a defined line along the base of the rock cut, were plotted to ascertain the 1% and 0.1% probabilities of reach. For more details about the analysis see appendix 1.

In general, it was observed that the uppermost blocks are prone to bouncing off the rock face and potentially impacting several meters away from the base. Whilst oftentimes fragments falling more vertically, sometimes are deflected from protrusions at the base which provides a higher potential for rolling before stopping. This highlights the importance of covering hard rock protrusions at the base with energy absorbing material (e.g. loose gravel).

The endpoint distance from each profile was used to guide the definition of two lines, defining the boundaries for the S1 and S2 risk zones (Figure 12 and Figure 13). The equivalent sight angle for the S1 varies between 40 – 55º (average 45º) whilst the angle varies between 35 – 50º for S2 (average 40º) (Table 7).

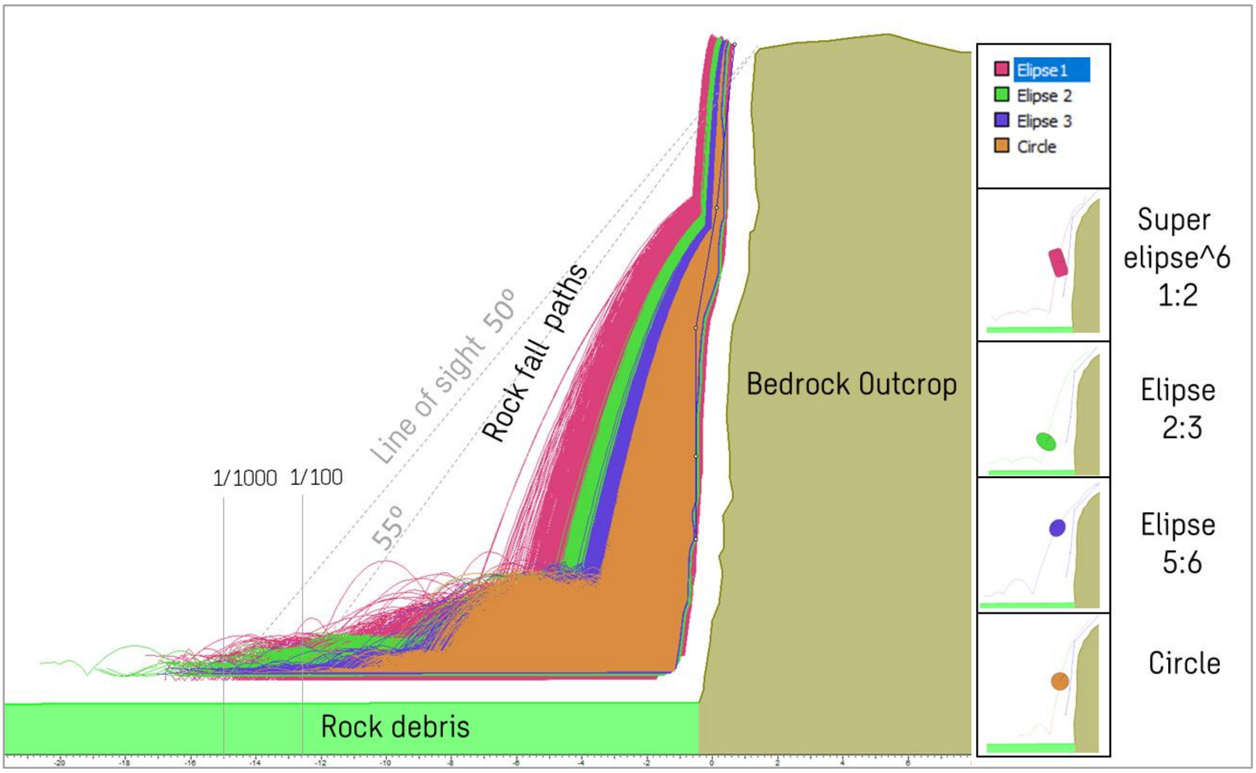


Figure 12 Example of profile analyzed with Rocfall (profile P3). Approximate S1 and S2 boundaries are shown annotated 1/100 and 1/1000 respectively. Rockfall paths are color coded according to four different rock shapes considered. All rock shapes are dimensioned as such that they measure 15000kg (2D shape). For Elipse 1 this corresponds to an approximate size of 3 .5 *1.5*1 m.

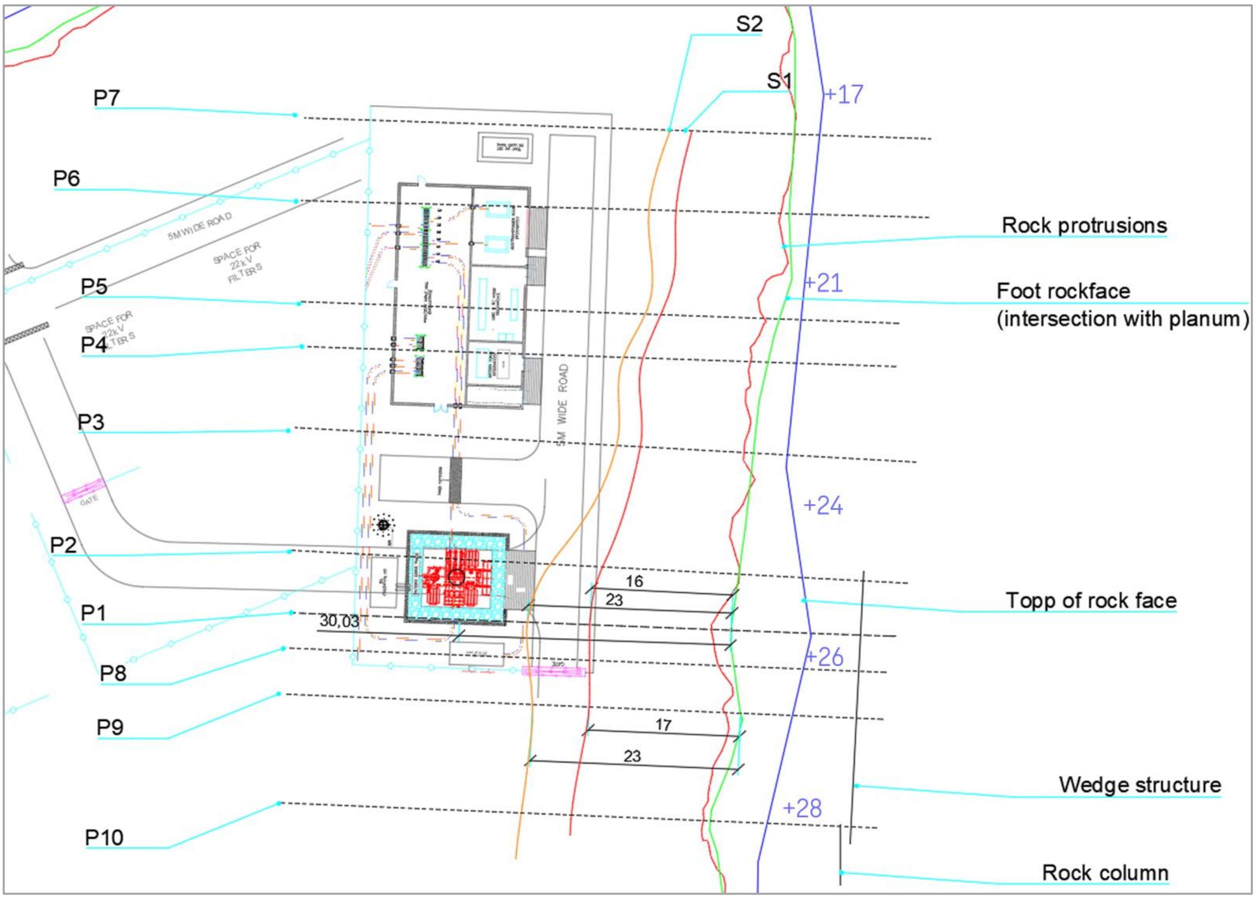


Figure 13 S1 and S2 boundaries in relation to the planned substation facility. The horizontal distance is measured from the base of the rock face (green line) which is chosen as the extrapolated intersection of the planar ground surface and the rock face. The top of the clip is shown as a blue line with spot elevations annotated. There is a trench at the base of the rock cut featuring several exposed rock protrusions (red line). The placement of the described wedge-structure and rock column are marked (black line). The location of long sections /profiles used for rocfall analyses are shown P1 – P10.

Table 7 Angle of line of sight measured between the S1 and S2 boundaries to the top of the rock face along each analyzed profile.

Profile	Angle of line of sight (º)	
	S1	**S2**
1	40	36
2	43	38
3	55	50
4	47	42
5	55	50
6	46	40
7	41	37
8	40	35
9	46	40
10	46	40

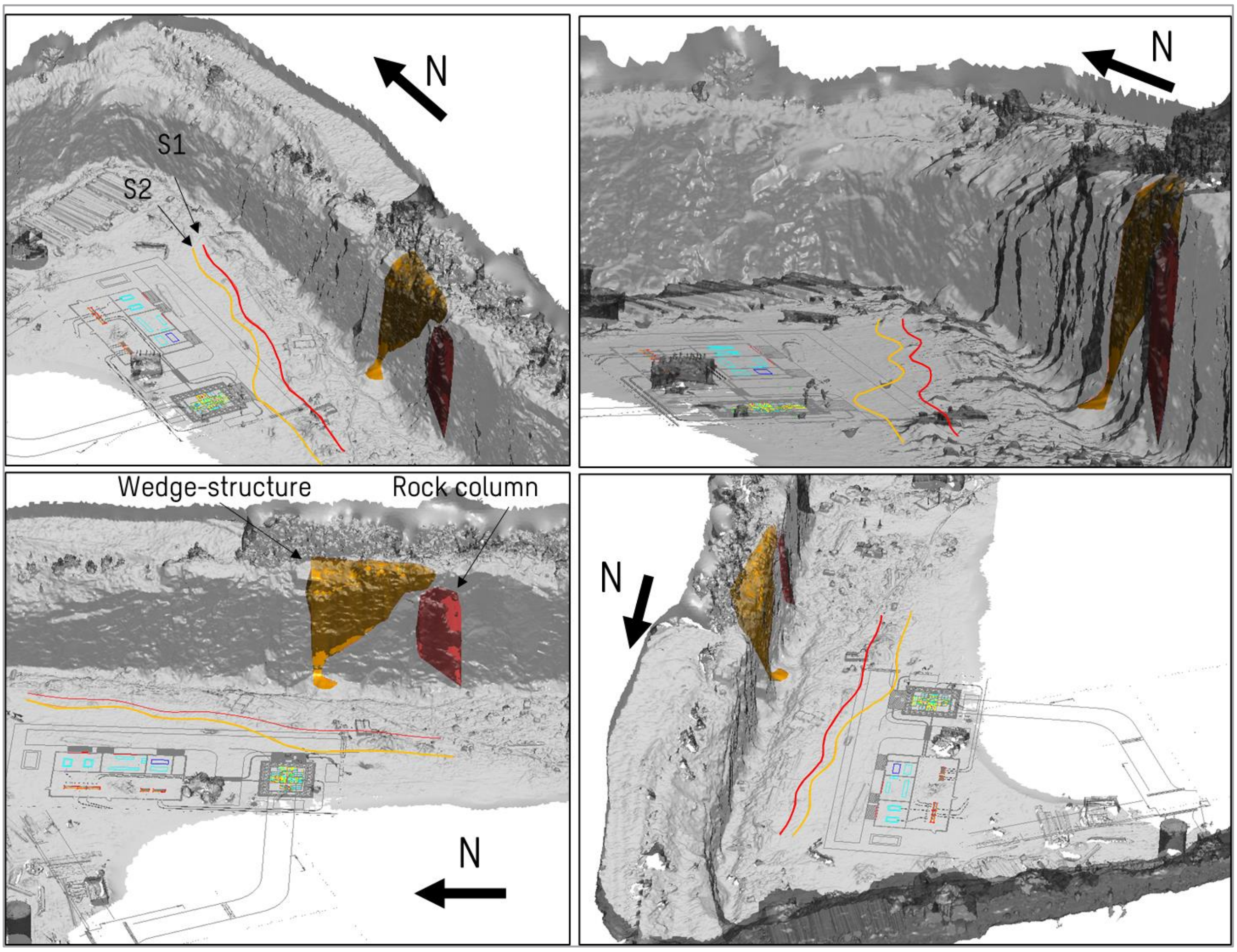


Figure 14 3D Perspectives showing the planned facility in relation to the S1 and S2 line as well as the potentially unstable large-scale rock wedge (orange) and rock column (red).

6. Discussion

The nominal annual probability for rockfall (P_N) applies to individual 30-meter intervals of the facility (according to PBL) and is composed of:

P_F = The probability of block failure pr year

P_R = The reach probability

Where $P_N = P_R * P_F$

Discontinuity mapping of the rock cut indicates a present potential for both large-scale and small-scale block failures. However, the annual probability of a block failure occurring within a specific section of the face cannot be predicted with certainty.

Seeing that major events have not been reported and no clear indications for previous rockfalls are identifiable (no large blocks scattered below the face) it is reasonable to assume that the probability $P_F < 1$ for a given section of 30 m. This means that using the reach probability to indicate the nominal annual probability P_N should yield conservative results.

When considering large-scale structures, assessing the probability of reach through analysis becomes notably more challenging. Drawing from experience with comparable events, it is deemed highly improbable for rock fragments from a large-scale slope failure to reach the S2 line with significant force. Additionally, the angle of the line of sight between the S2 line and the wedge structure (35 – 40º) is similar to that of the maximum reach of rock avalanches, which by definition comprise much larger events, suggesting a conservative estimation for the S2 line. Moreover, the likelihood of failure for large-scale structures is anticipated to be considerably lower than for standard rockfall events, thereby significantly reducing the weight of the reach probability. It is to be pointed out that there is a greater uncertainty in the assessment of the nominal annual probability with regards to large scale slope failures e.g. with regards to possible fly debris. However, the residual risk is judged to be acceptable for the planned facility.

7. Conclusion

The planned substation is required to satisfy safety levels in accordance with S2 for the structures and S1 for the roads.

Based on geological investigations and a range of analyses the boundaries for the S1 and S2 risk zones have been drawn out.

Substation structures are drawn to lay outside of the S2 zone and satisfy thereby the requirements of S2 with a nominal annual risk < 1/1000, whilst the road satisfies the requirements of S1 with a nominal annual probability <1/100. The demarcation of the lines presupposes that rock protrusions at the base of the rock face are covered with loose gravel e.g. 32- 64 mm fraction with min. 0.5 m thickness (Figure 15). The thicker the gravel cover the greater the expected energy absorption. When this is fulfilled, there is no immediate necessity for the installation of mitigating construction measures such as rock bolts.

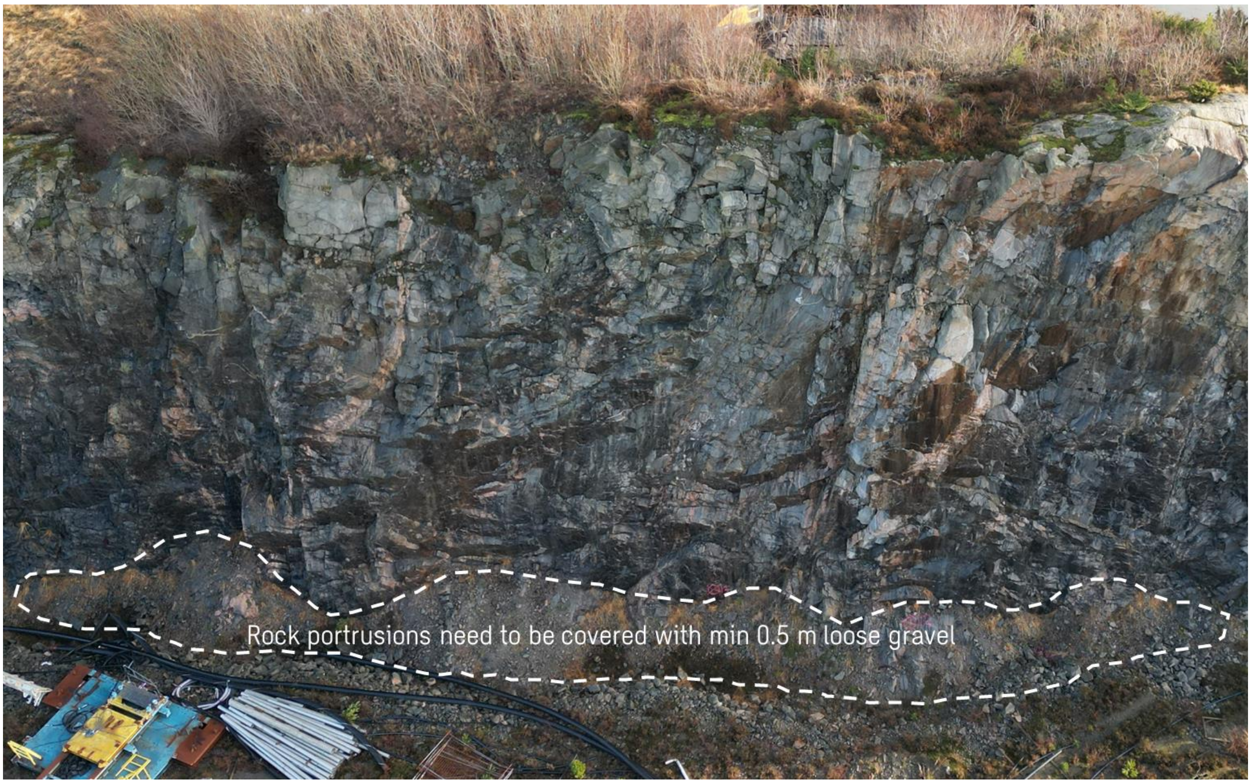


Figure 15 Exposed rock protrusions along the base of the rock cut need to be covered with energy absorbing material e.g. min. 0.5 m of loose gravel.

8. Further recommendations

It is the responsibility of the site owner and contractor that the limitations set by the rock fall risk zones are adhered to i.e. that the area within between the S1 line and the cliff is not used for storage or work-operations. It is recommended to put up a work fence along the S1 line during the construction phase.

It is also pointed out that barracks/ worker residences have to adhere to higher safety classes than S1 i.e. S2 or S3 depending on the number of residence.

9. References

[1] Norsk Bergmekanikk Gruppe, «Veileder for bruk av Eurokode 7 til bergteknisk prosjektering,» NBG, Trondheim, 2011.

[2] Norwegian Building Authority, «Regulations on technical requirements,An unofficial English translation of the regulation,» Norwegian Building Authority, OSLO, 2017.

[3] Eurocode 7 NS-EN 1997-1:2004+A1:2013+NA:2020 Geotechnical design - Part 1: General rules, 1997.

[4] Eurokode, Eurokode 0 NS-EN 1990:2002+A1:2005+AC:2010+NA:2016 Grunnlag for prosjektering av konstruksjoner, Oslo, 2002.

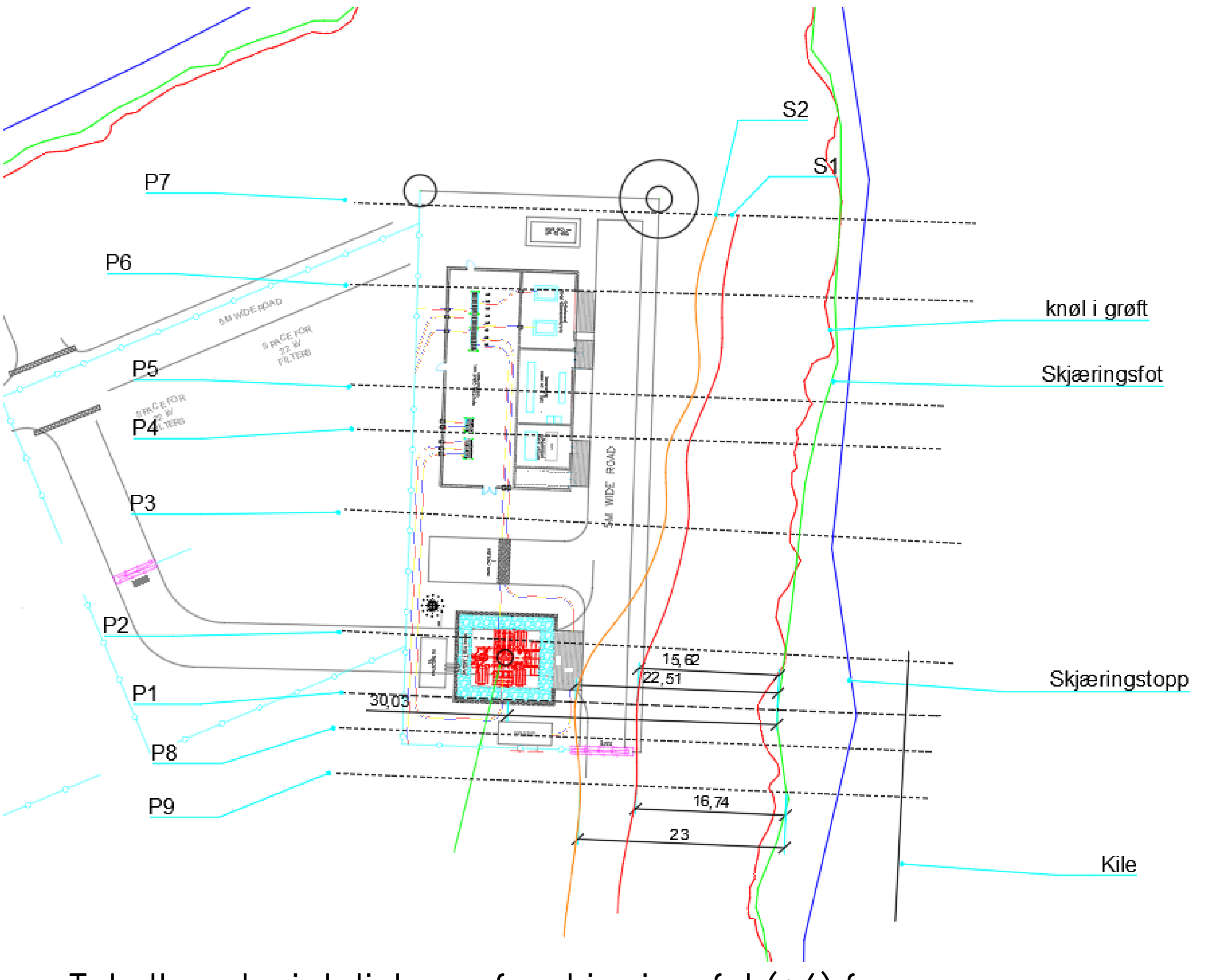
[5] NGU, «Kart over berggrunn,» https://geo.ngu.no/kart/berggrunn_mobil/.

10. Appendixes

Appendix 1 – Rocfall analysis

Appendix 1
Rocfall analysis

Oppsummering



Tabell: endpoint distanse fra skjæringsfot (+4) for hver profil ved forskjellig sannsynlighet

	Rund blokk og 3 elipser			Kunn elipse 1			
	1/100	1/1000	1/5000	1/100	1/1000	1/5000	
Profil 7	12	15	16	10.5	12.5	15	m
Profil 6	12.5	15.5	17	12.5	15.5	18	m
Profil 5	14.5	18	21	10.5	13.5	17	m
Profil 4	11	13.5	16	13.5	17	21	m
Profil 3	12.5	15	16	12.5	15	17	m
Profil 2	17.5	22	26	14.5	19.5	22.5	m
Profil 1	20.5	25	30	17.5	21	24.5	m
Profil 8	21	26	29	17	22	24	m
Profil 9	18	22.5	25	15	19	24	m
Profil 10	16	19.5	24	14	17	21	m

Project Settings

General Settings

Engine	Rigid Body
Units	Metric (m, kg, kJ)
Rock throw mode	Number of rocks controlled by seeder
Use tangential CRSP damping	Yes

Engine Conditions

Maximum steps per rock	20000
Normal velocity cutoff (m/s)	0.1
Stopped velocity cutoff (m/s)	0.1
Maximum timestep (s)	0.01
Switch velocity (m/s)	-1e-09

Random Number Generation

Sampling method	Latin-Hypercube
Material Properties Sampling	Per simulation
Random seed	Pseudo-random seed: 12345234

Material Properties

Bedrock Outcrops

"Bedrock Outcrops" Properties					
Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.35	Normal	0.04	0.12	0.12
Tangential Restitution	0.85	Normal	0.04	0.12	0.12
Dynamic Friction	0.56	Normal	0.04	0.12	0.12
Rolling Friction	0.65	Normal	0.02	0.06	0.06
"Bedrock Outcrops" Advanced Properties					
Forest and Vegetation Damping		Disabled			
Scarring		Disabled			
Viscoplastic Damping		Disabled			

Rock debris

"Rock debris" Properties					
Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.35	Normal	0.04	0.12	0.12
Tangential Restitution	0.85	Normal	0.04	0.12	0.12
Dynamic Friction	0.56	Normal	0.04	0.12	0.12
Rolling Friction	0.65	Normal	0.04	0.12	0.12
"Rock debris" Advanced Properties					
Forest and Vegetation Damping		Disabled			
Scarring		Disabled			
Viscoplastic Damping		Disabled			

Seeders

Seeder 1

Seeder Properties					
Name	Seeder 1				
Location	(5.513, 24.409), (5.202, 23.187), (5.202, 22.133), (5.202, 21.357), (4.869, 20.284), (4.37, 19.323), (3.686, 18.491), (3.686, 17.585), (3.39, 16.402), (3.019, 15.17), (3.019, 14.398), (3.019, 13.279), (3.019, 11.069)				
Rocks to Throw					
Number of Rocks	10000 Overall				
Rock Types	Elipse1,	Elipse 2,	Elipse 3,	Circle	
Initial Conditions					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (m/s)	0	None			
Vertical Velocity (m/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Rock Types

Elipse1

Properties					
Name	Elipse1				
Color					
Smooth Shapes	Super Ellipse^6 (1:2)				
Polygons	None				
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Mass (kg)	15000	None			
Density (kg/m3)	2700	None			

Elipse 2

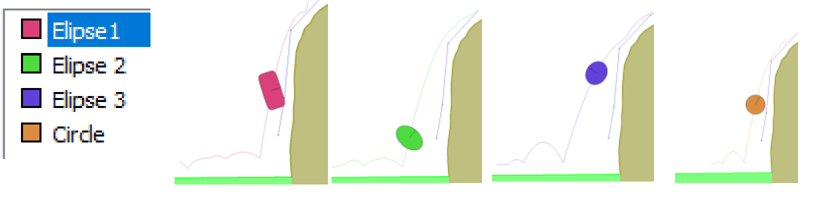
Properties					
Name	Elipse 2				
Color					
Smooth Shapes	Ellipse (2:3)				
Polygons	None				
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Mass (kg)	15000	None			
Density (kg/m3)	2700	None			

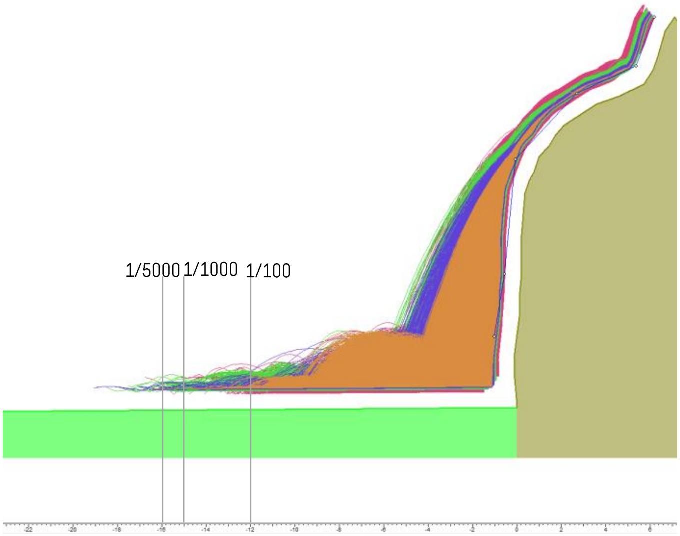
Elipse 3

Properties					
Name	Elipse 3				
Color					
Smooth Shapes	Ellipse (5:6)				
Polygons	None				
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Mass (kg)	15000	None			
Density (kg/m3)	2700	None			

Circle

Properties					
Name	Circle				
Color					
Smooth Shapes	Circle				
Polygons	None				
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Mass (kg)	15000	None			
Density (kg/m3)	2700	None			

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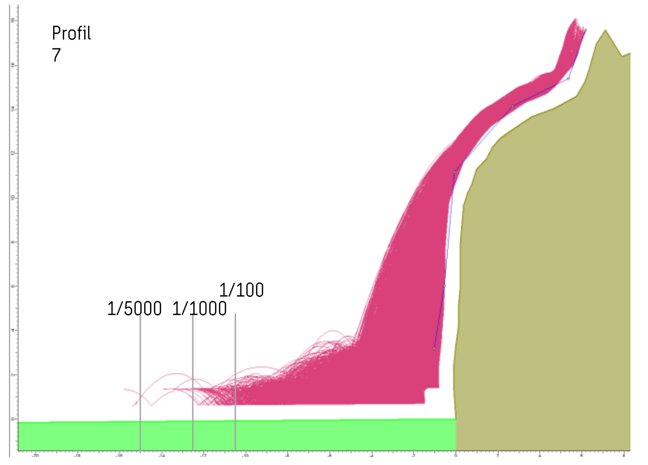
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7
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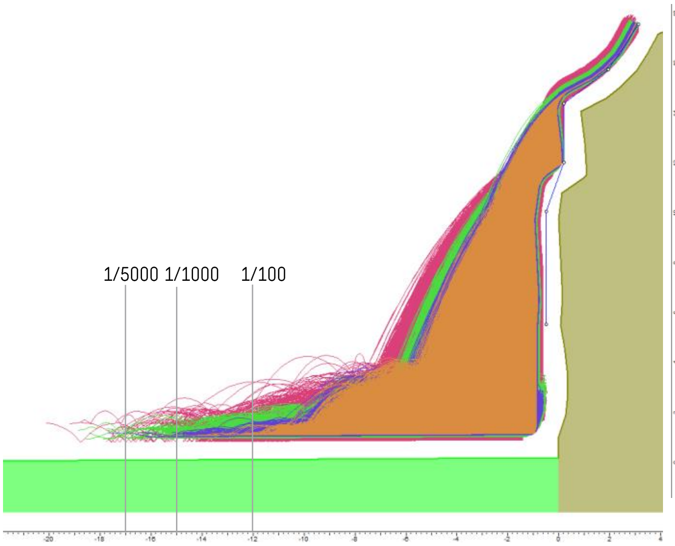
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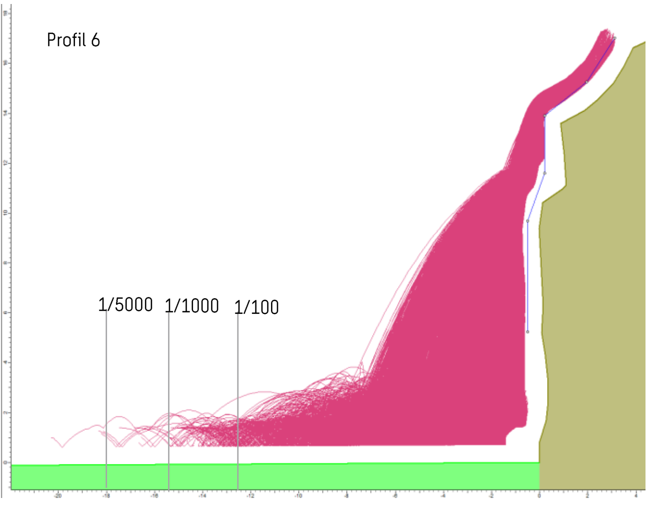
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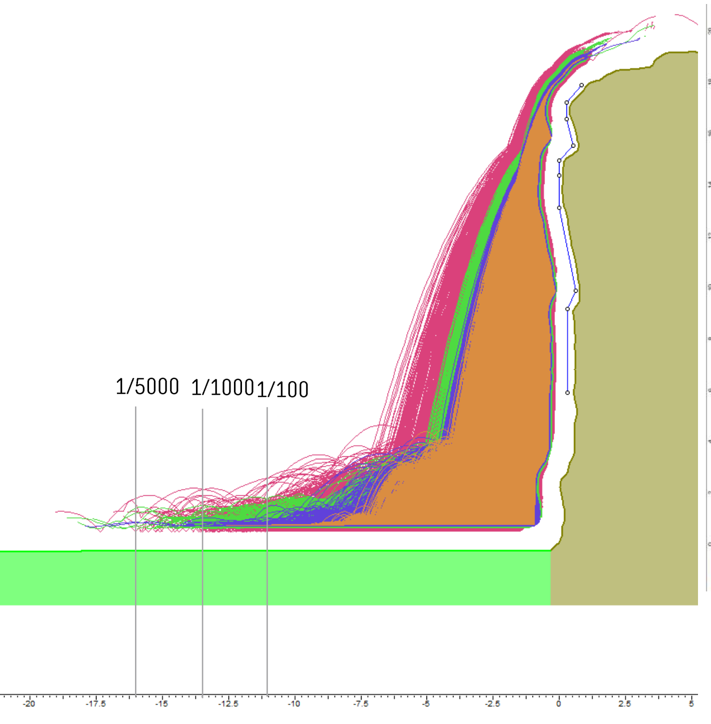
1/100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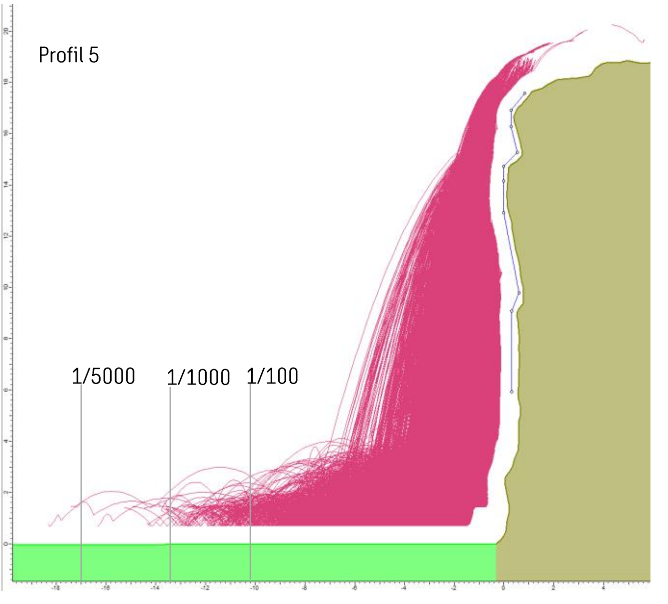
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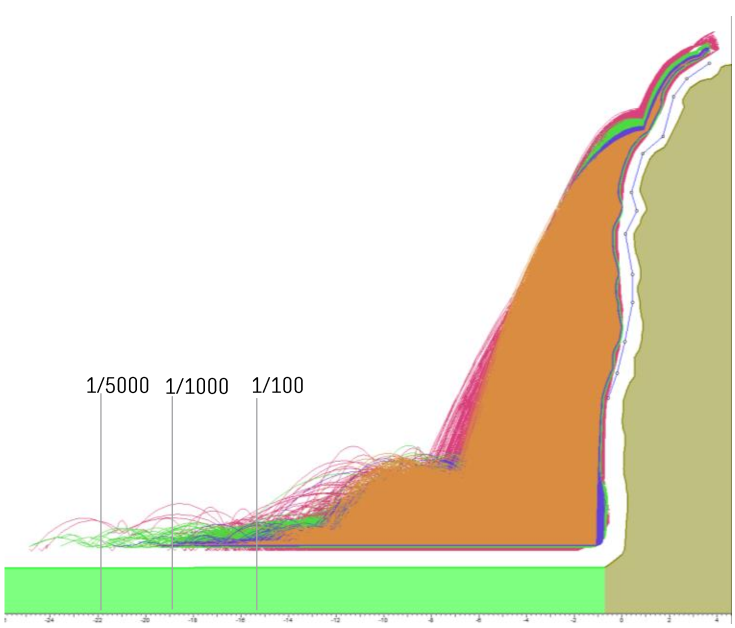
1/100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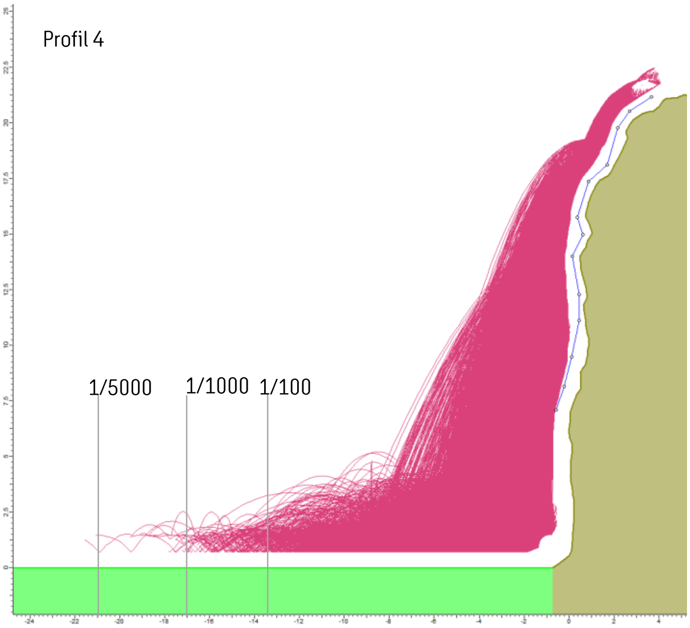
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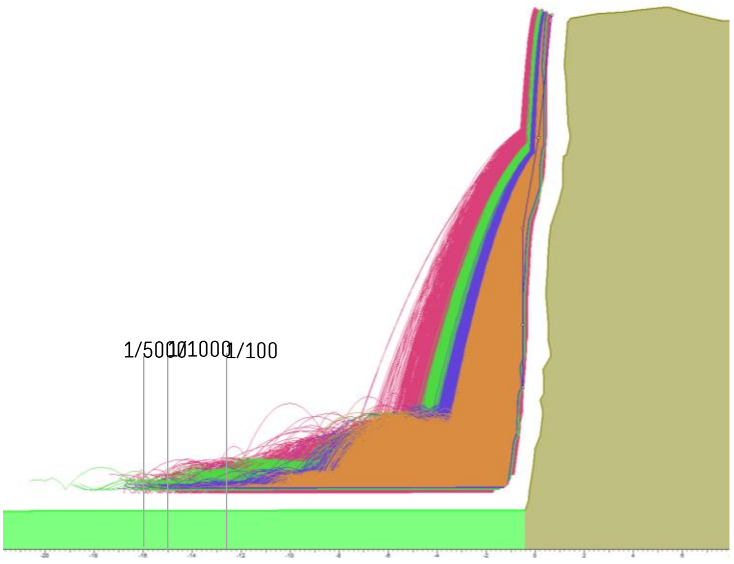
1/100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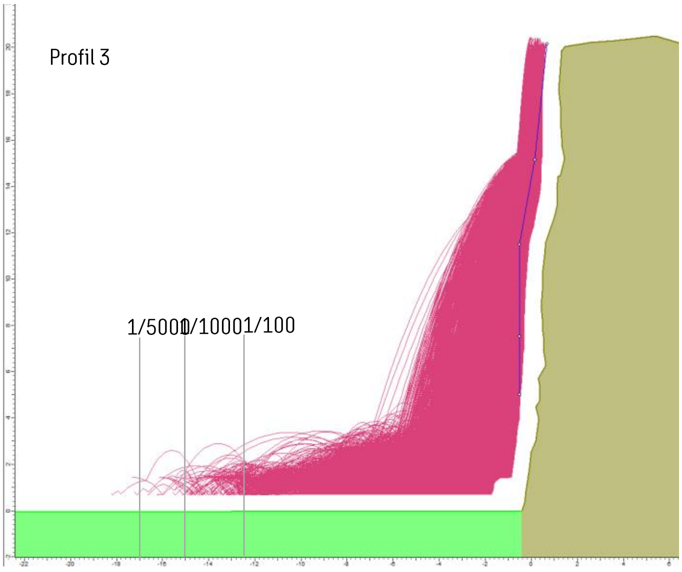
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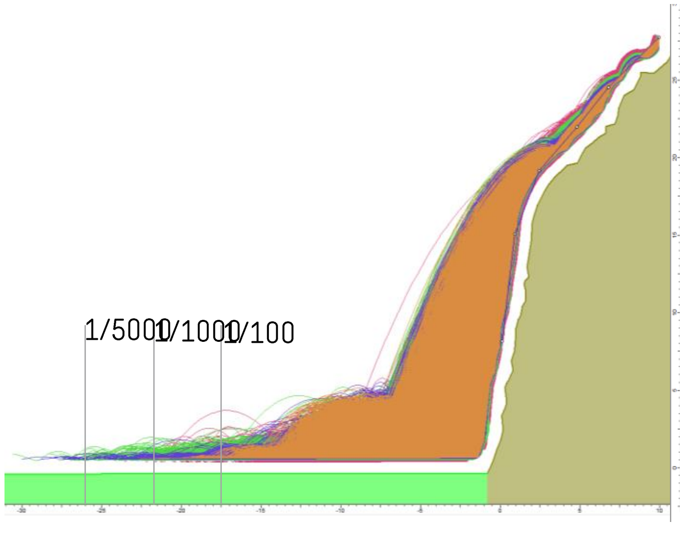
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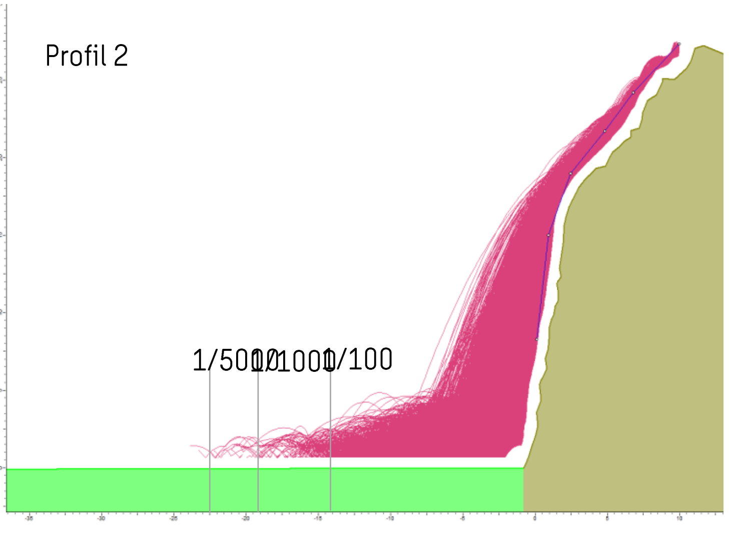
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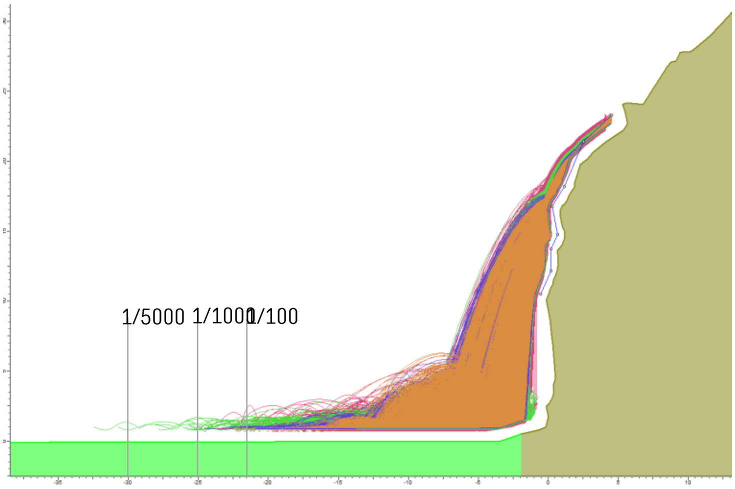
1/100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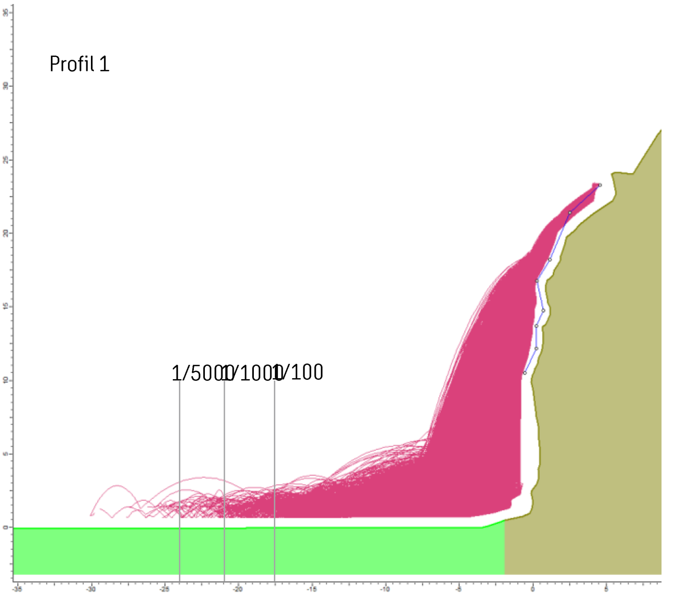
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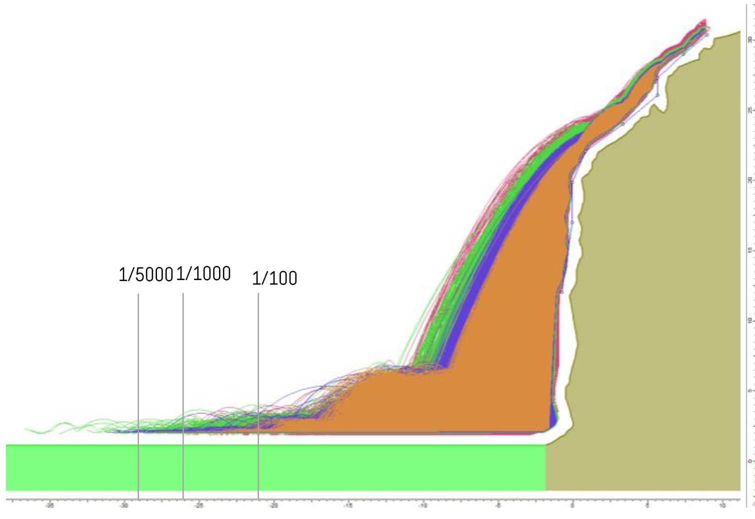
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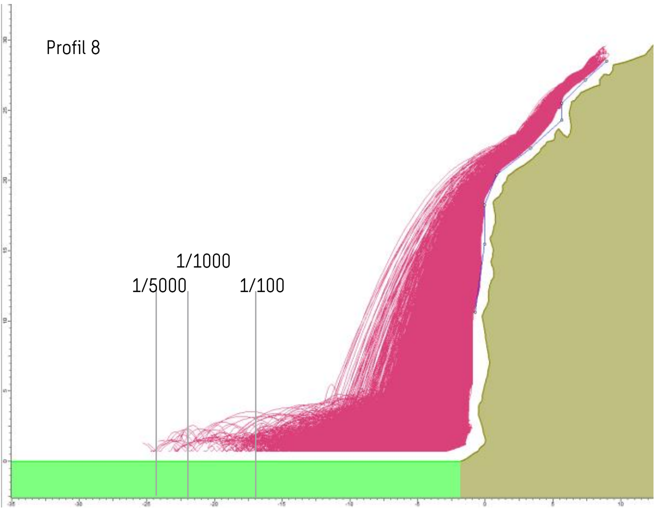
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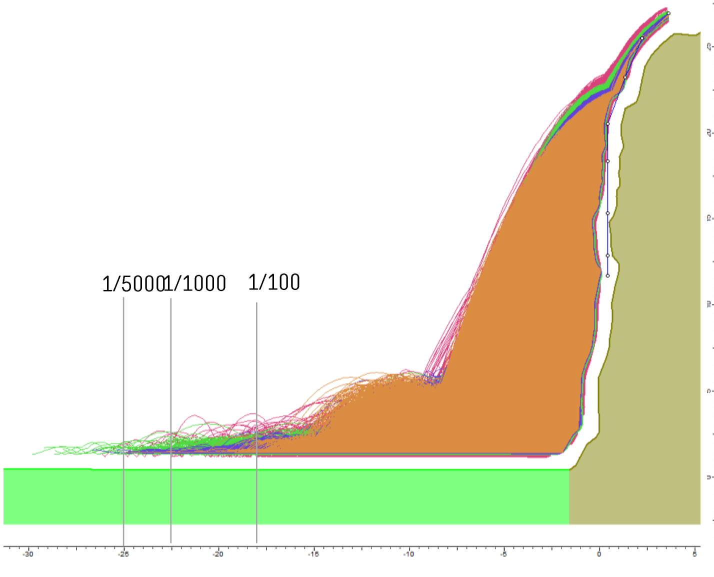
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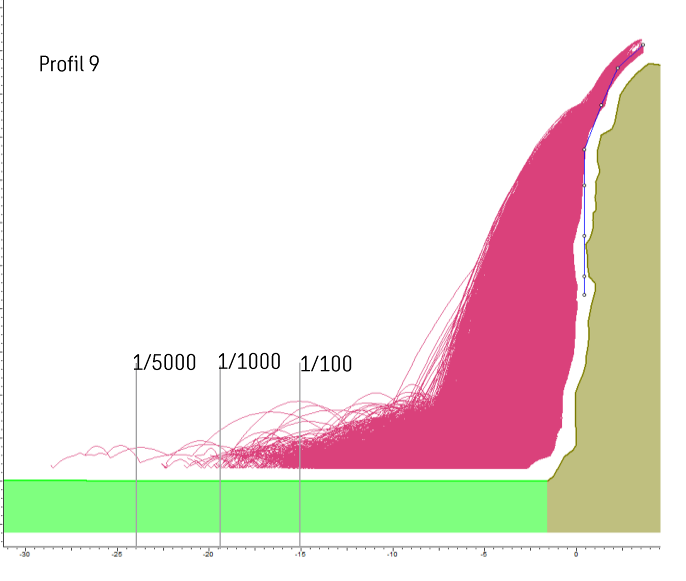
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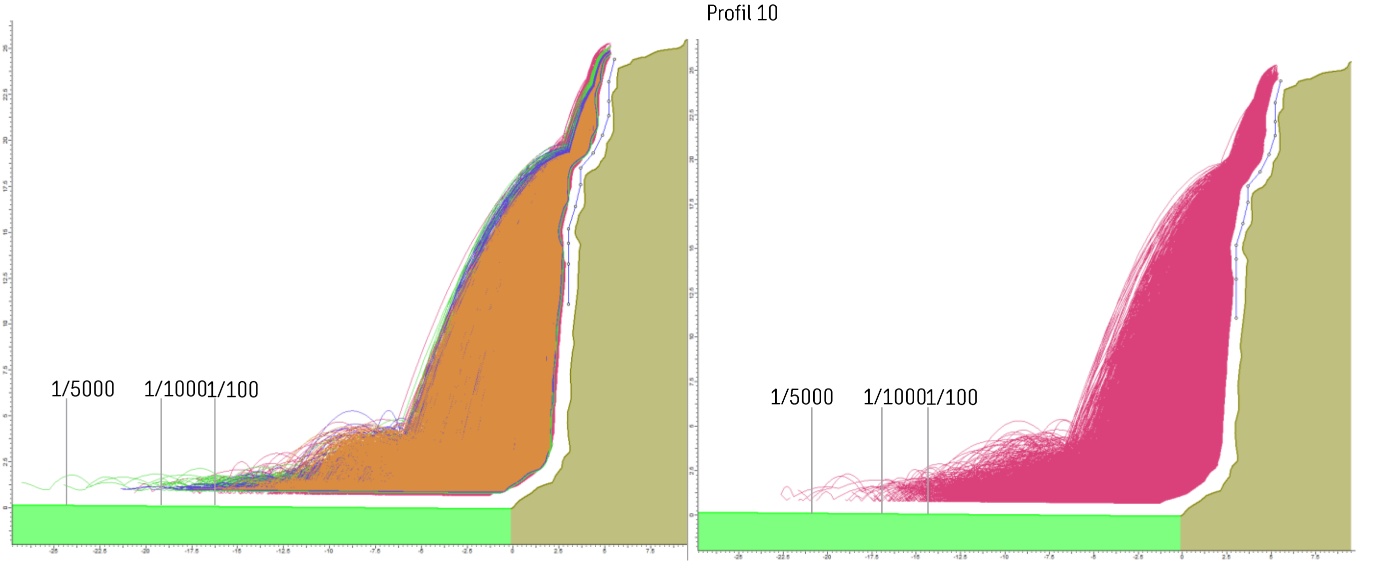
1/5000
1/1000
1/100

Profil 10



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