Excursion to the Romberg Quarry, Gildehaus, Germany

Robert Hack, University Twente/ITC

On 25 August 2018 a day excursion in rock mass classification was organized in Bad Bentheim, Germany, by the Dutch Association of Engineering Geologists (Ingeokring). In the Sandstone Museum of Bad Bentheim a short presentation was given on the Slope Stability Probability Classification (SSPC) (Hack et al., 2003). A rock mass classification and slope stability assessment was done to show the practical application of the SSPC system in the nearby Romberg Quarry in Gildehaus (Fig. 1). The Romberg Quarry is a still active quarry and produces the so-called “Bad Bentheim” sandstone. An early Cretaceous sandstone (Valanginian – 136 Ma) consisting of generally uniformly graded grains of mainly quartz. The grains are bonded by interlocking, growth of grain contacts acting as cementation, and at some locations it is somewhat cemented by more recently formed kaolinite cement (Nyland et al., 2003). In some layers carbonate cement is present (Bock & Schmidt, 2010). The clay content is less than 1 %, but can be considerably higher. Small quantities of iron in different forms cause coloring of the sandstone from crème colored to ocher and more reddish colors. Fig.1 shows the location of the quarry and the location where the SSPC classification is done. Figs 2 and 3 show the classified unit and Fig. 3 shows the different discontinuity sets. Nowadays the quarry is excavated by small excavators and small hydraulic or pneumatic hammers for layers that are not interesting for construction stone. The actual construction stone is excavated in blocks by drilling small-diameter boreholes that are filled with expanding chemicals (Fig. 2). In some locations remnants of small-diameter boreholes are visible made long ago that resemble boreholes for old-fashioned blasting by black powder or something alike (the south-dipping boreholes in Fig. 2). Whether these are indeed boreholes for blasting is speculative and not confirmed.

Bad Bentheim sandstone is the reservoir rock for many oil fields in Northwest Europe and has been used as construction stone for numerous landmark buildings in the Netherlands, such as parts of the mediaeval “Burcht van Leiden”, many churches in Delft, Dom in Utrecht, and “Paleis op the Dam” in Amsterdam. An interesting publication on the Bad Bentheim sandstone as construction stone is by Bock & Schmidt (2010) and more information can be found in Nyland & Dubelaar (2015) and Nyland et al. (2003); both in Dutch.

In the quarry, the Ingeokring group was initiated to the acquisition of the SSPC parameters. The determination of the small-scale roughness of the bedding planes infilled with soft clay caused most difficulties (see below). Regrettably the weather on the day of the excursion was very poor with heavy thunderstorms that limited the stay in the quarry. Therefore, the classification in this article was finalized a couple of days later when the weather was better.

Research

The quarry and the sandstone are often used for research and education purposes by German and Dutch universities and research institutes. A recent research of which the remains are still present in the quarry, is an investigation to the performance of water jet drilling and acoustically monitoring the nozzle position by among others the GFZ German Research Centre for Geosciences, Potsdam and TNO (Reinsch et al., 2018). The boreholes and other installations are visible in Fig. 2 and Fig. 3.

SSPC classification and slope stability

The classification is done on the face which is formed by joint J2 (about perpendicular to the photo direction in Fig. 2 and Fig. 3) and the slope stability analysis for slope 1 is done on the same part of the exposure with the same degree of weathering and same means of excavation (Table 1 through 5). The results of the classification show that slope 1 with orientation 030/65 (Fig. 3) is stable for all failure mechanisms considered in the SSPC system, i.e. for orientation-dependent and -independent stability. This is in agreement with the visual assessment. The clayey softening infill in bedding planes (B1) and joints (J3) is likely different in origin. The clay infill in the bedding planes is in-situ, but the fill in J3 is likely due to influx by percolating groundwater of material from surface weathering above at the top of the quarry. The stability calculation is based on a slightly weathered rock mass as is present in the face where the classification is done and is valid for the rock mass forming slope 1 except the surface layer of slope 1 (see below).

Weathering

Slope 1 (030/65) has been excavated likely a long time before the face on which the classification is done and hence, has been exposed for a longer time to weathering by surface agents. The surface layer and the rock mass directly behind the surface, say for a depth of some 20 to 30 cm are therefore more weathered (Fig. 2). The longer exposure time also allowed for more vegetation to develop that likely allowed weathering even more. Another factor that increased weathering is the dip of the slope (65º) that is such that rain and surface water runs over the slope and can easily penetrate into discontinuities. This in contrary to the face on which the classification is done which is vertical. Moreover at the corner the rock mass is exposed on two sides allowing more and faster temperature changes of the rock mass and subsequent likely more weathering.

The further advanced weathering of the surface layer of slope 1 resulted in a decrease in intact rock strength, a decrease in bedding spacing as more incipient bedding planes became mechanical, and a reduction in shear strength along discontinuities because of more weathered discontinuity walls and infill. This caused that the surface layer of slope 1 in the corner became in part instable for orientation-independent stability (Fig. 2 and Fig. 3). Calculations of orientation-independent stability are shown in Fig. 4 for varying degrees of weathering. The orientation-independent stability for slope 1 reduces to only 20 % if the degree of weathering increases from slightly to highly weathered. A stability of 20 % is effectively instable.

References:

Bock, H., Schmidt, L., 2010. Bridging space and time—Aspects of the Batavia saga as an homage to the outgoing IAEG president and his predecessor. In: Williams, A.L., Pinches, G.M., Chin, C.Y., Mcmorran, T.J., Massey, C.I. (Eds) Geologically Active: Proceedings of the 11th IAEG Congress, Auckland, New Zealand, 5-10 September 2010. CRC Press. ISBN: 9780415600347, pp. CD-rom.

Hack, H.R.G.K., Price, D.G., Rengers, N., 2003. A new approach to rock slope stability - A probability classification (SSPC). Bulletin of Engineering Geology and the Environment. 62 (2). DOI: https://doi.org/10.1007/s10064-002-0155-4. ISSN: 1435-9529; 1435-9537. pp. 167-184. http://dx.doi.org/10.1007/s10064-002-0155-4

Nijland, T.G., Dubelaar, W., 2015. Bentheimer zandsteen. Grondboor & Hamer. 48 (4). pp. 64-73. http://natuurtijdschriften.nl/download?type=document&docid=628973 (in Dutch)

Nijland, T.G., Dubelaar, W., Van Hees, R., Van der Linden, T., 2003. De Bentheimer zandsteen: oliereservoirgesteente en bouwsteen. Grondboor & Hamer. 57 (2). pp. 21-25. http://natuurtijdschriften.nl/record/406068 (in Dutch)

Reinsch, T., Paap, B., Hahn, S., Wittig, V., van den Berg, S., 2018. Insights into the radial water jet drilling technology – Application in a quarry. Journal of Rock Mechanics and Geotechnical Engineering. 10 (2). DOI: https://doi.org/10.1016/j.jrmge.2018.02.001 . ISSN: 1674-7755. pp. 236-248.

Table 1. SSPC exposure characterization.

	exposure characterization Slope Stability Probability Classification (SSPC)		EXPOSURE NO: *1; Unit II*
LOGGED BY: *RH*	DATE: *11/09/2018*	TIME: *15* hrs	LOCATION (map coordinates) *Romberg Quarry, Gildehaus, Germany*

WEATHER CONDITIONS (fill in or tick)	Precipitation: slate/hail/snow	map no: *Google Earth; UTM 32 U*
Estimate temperature: *22* °C	Rain: [✓ dry]/drizzle/slight/heavy	northing: *5,796,342.36 m N*
Sun: cloudy/fair/[✓ bright]	Wind: [✓ calm]/breeze/strong/gale	easting: *370,810.11 m E*

METHOD OF EXCAVATION (**EME**)	
(tick)	
natural/hand-made:	1.00
pneumatic hammer excavation:	0.76
pre-splitting/smooth wall blasting:	✓ 0.99
conventional blasting with result:	
good:	0.77
open discontinuities:	0.75
dislodged blocks:	0.72
fractured intact rock:	0.67
crushed intact rock:	0.62

DIMENSIONS/ACCESSIBILITY			
Size total exposure (m):	length: *300* m	height: *25* m	depth: *15* m
Mapped on this form (m):	length: *10* m	height: *4* m	depth: *15* m
Accessibility: poor/fair/[✓ good]			
Unit II			

FORMATION NAME: *Bentheim Sandstone, Valanginian (Lower Cretaceous), 136 Ma*

DESCRIPTION (BS 5930: 1999):				
color: *yellowish, reddish off-white*	grain size: *medium to fine*	structure & texture: *medium bedded, very widely jointed*	weathering: *slightly*	NAME: *sandstone*

INTACT ROCK STRENGTH (**EIRS**) (tick)		sample number(s):
< 1.25 MPa	Crumbles in hand	*None* *(Intact rock strength about 50 MPa)*
1.25 - 5 MPa	Thin slabs break easily in hand	
5 - 12.5 MPa	Thin slabs broken by heavy hand pressure	
✓ 12.5 - 50 MPa	Lumps broken by light hammer blows	
✓ 50 - 100 MPa	Lumps broken by heavy hammer blows	
100 - 200 MPa	Lumps only chip by heavy hammer blows (Dull ringing sound)	
> 200 MPa	Rocks ring on hammer blows. Sparks fly	

WEATHERING (**EWE**)	
(tick)	
unweathered	1.00
slightly	✓ 0.95
moderately	0.90
highly	0.62
completely	0.35

DISCONTINUITY SET (B=bedding C=Cleavage J=joint, etc.):				*B1*	*J2*	*J3*	…4	…5
Dip direction (**DDD**) (deg):				*170*	*108*	*020*		
Dip (**DD**) (deg):				*20*	*90*	*65*		
Spacing (**EDS**) (m):				*0.25*	*4.00*	*5.50*		
Persistence	along strike (m):			*>*	*>*	*>*		
	along dip (m):			*>*	*>*	*>*		
CONDITION OF DISCONTINUITIES								
Roughness large-scale (**Rl**) (on an area between 0.2 x 0.2 and 1 x 1 m^2) (see reverse side page)	wavy: slightly wavy: curved: slightly curved straight		1.00 0.95 0.85 0.80 0.75	*0.75*	*0.75*	*0.80*		
Roughness small-scale (**Rs**) (on an area of 0.2 x 0.2 m^2) (see reverse side page)	rough stepped smooth stepped polished stepped rough undulating smooth undulating polished undulating rough planar smooth planar polished planar		0.95 0.90 0.85 0.80 0.75 0.70 0.65 0.60 0.55	*0.80*	*0.80*	*0.80*		
Infill material (**Im**)	cemented/cemented infill no infill - surface staining		1.07 1.00	*0.55*	*1.00*	*0.55*		
	non softening & sheared material, e.g. free of clay, talc, etc.	coarse medium fine	0.95 0.90 0.85					
	soft sheared material, e.g. clay, talc, etc.	coarse medium fine	0.75 0.65 0.55					
	gouge < irregularities gouge > irregularities flowing material		0.42 0.17 0.05					
Karst (**Ka**)	none karst		1.00 0.92	*1.00*	*1.00*	*1.00*		

EXISTING SLOPE?

Slope dip-direction/Slope dip (**SDD/SD**) (deg)
030/65

Slope height: *15* m

Stability of existing slope (tick):	
stable ✓	1
small problems	2
large problems	3

Notes:
1) If more than 5 discontinuity sets; use rear of page or second form.
2) If infill material equals ‘gouge > irregularities’ or ‘flowing material’; small-scale roughness should be taken as 0.55.
3) If roughness is anisotropic (e.g. ripple marks, striation, etc.); roughness should be assessed perpendicular and parallel to the roughness and directions noted on this form.
4) Non-fitting of discontinuities should be marked in roughness columns.

SUSCEPTIBILITY TO WEATHERING (**SW**)		
degree of weathering:	date excavation:	remarks:
slightly	*1980?*	*Slightly to moderately > 200 year? (guessed)*

remarks: *The method of excavation is by small excavator or small hydraulic or pneumatic hammer, and probably by some old-fashioned blasting. Little or no damage is inflicted in the rock mass. Therefore, the method of excavation is classified as pre-splitting/smooth wall blasting.*

Table 2. SSPC sample roughness profiles.

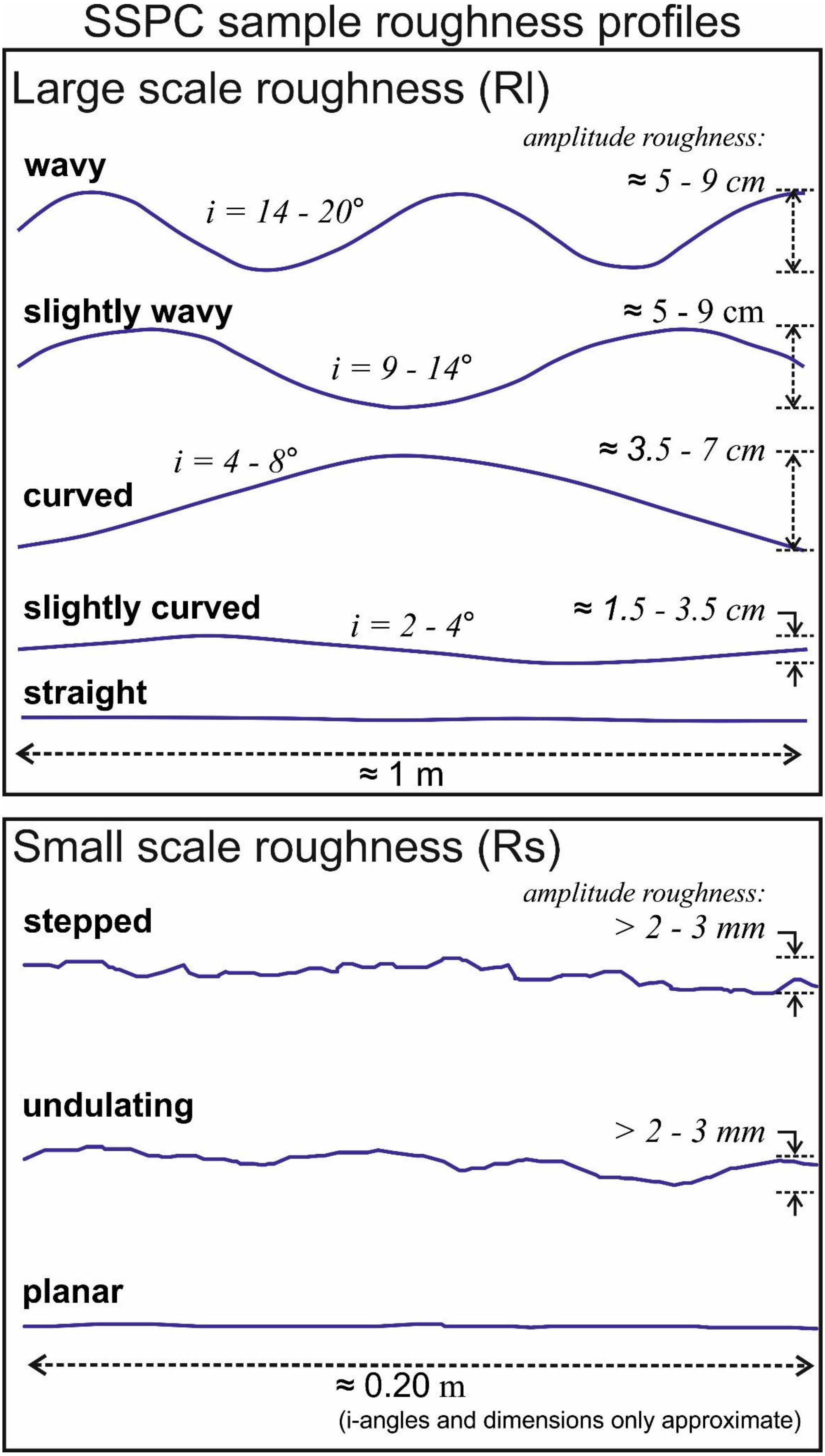


Table 3. SSPC reference rock mass classification.

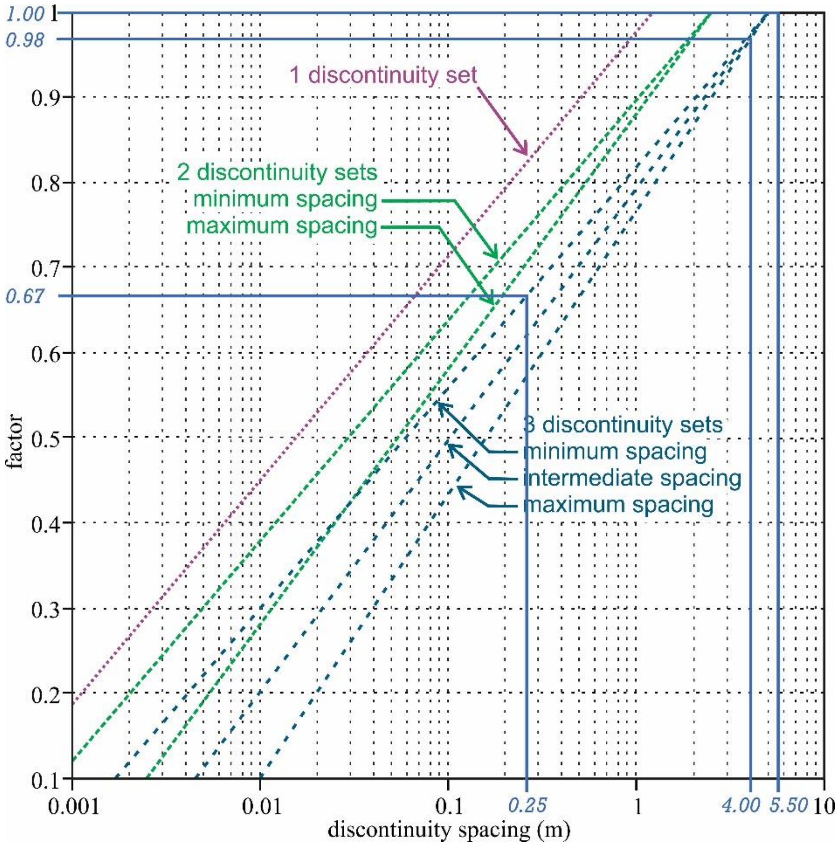
reference rock mass calculation Slope Stability Probability Classification (SSPC)		EXPOSURE NO: *1; Unit II*
CALCULATED BY: *RH*	DATE: *11/09/2018*	REFERENCE UNIT NAME:

INTACT ROCK STRENGTH (**RIRS**)	**RIRS** = **EIRS** (in MPa) / **EWE** (correction for weathering) = *50* / *0.95* =	*52.6* MPa

DISCONTINUITY SPACING (**RSPA**)

DISCONTINUITY SET:	*B*1	*J*2	*J*3	4	5
Dip direction (**DDD**) (deg)	*170*	*108*	*020*		
Dip (**DD**) (deg)	*20*	*90*	*65*		
Spacing (**EDS**) (m)	*0.25*	*4.00*	*5.50*		

The spacing parameter (**ESPA**) is calculated based on the three discontinuity sets with the smallest spacings following figure:



ESPA (see figure left) =
factor1 * factor2 * factor3
ESPA = *0.67* * *0.98* * *1.00* = *0.657*
Corrected for weathering and
method of excavation:
RSPA = **ESPA** / (**EWE** * **EME**)
RSPA = *0.657* / (*0.95* * *0.99*) = *0.699*

CONDITION OF DISCONTINUITIES

DISCONTINUITY SET:	*B*1	*J*2	*J*3	4	5	
Roughness large scale (**Rl**)	*0.75*	*0.75*	*0.80*			
Roughness small scale (**Rs**)	*0.80*	*0.80*	*0.80*			
Infill material (**Im**)	*0.55*	*1.00*	*0.55*			
Karst (**Ka**)	*1.00*	*1.00*	*1.00*			
ETC (= **Rl*****Rs*****Im*****Ka**) =	*0.330*	*0.600*	*0.352*			
ESA (= **ETC**/ 0.0113) (degrees) =	*29*	*53*	*31*			ESA is the exposure sliding angle
$\mathbf{RTC} = \mathbf{ETC} / \sqrt{1.452 - 1.22 \times e^{-\mathbf{EWE}}}$	*0.333*	*0.606*	*0.356*			
RSA (= **RTC**/ 0.0113) (degrees) =	*29*	*54*	*32*			RSA is the reference sliding angle

ECD (Exposure Condition of Discontinuities) (condition weighted by spacing):

$$ECD = \frac{\frac{ETC_1}{EDS_1} + \frac{ETC_2}{EDS_2} + \frac{ETC_3}{EDS_3}}{\frac{1}{EDS_1} + \frac{1}{EDS_2} + \frac{1}{EDS_3}} = \frac{\frac{0.330}{0.25} + \frac{0.600}{4.00} + \frac{0.352}{5.50}}{\frac{1}{0.25} + \frac{1}{4.00} + \frac{1}{5.50}} = 0.346$$

RCD RCD = (condition of discontinuities corrected for weathering) = **ECD** / **EWE** = *0.346* / *0.95* = *0.364*

REFERENCE ROCK MASS FRICTION AND COHESION (**RFRI** & **RCOH**)

φ_{RRM} = **RIRS** * 0.2417 + **RSPA** * 52.12 + **RCD** * 5.779 = *52.6* * 0.2417 + *0.699* * 52.12 + *0.364* * 5.779 = *51°*
(if RIRS > 132 MPa then RIRS = 132; if RSPA > 1 then RSPA =1; if RCD .> 1.0165 then RCD = 1.0165)

coh$_{\mathbf{RRM}}$ = **RIRS** * 94.27 + **RSPA** * 28629 + **RCD** * 3593 = *52.6* * 94.27 + *0.699* * 28629 + *0.364* * 3593 = *26278* Pa
(if RIRS > 132 MPa then RIRS = 132; if RSPA > 1 then RSPA =1; if RCD .> 1.0165 then RCD = 1.0165)

Notes: 1) For IRS (intact rock strength) take average of lower and higher boundary of class. 2) Roughness values should be reduced or shear strength has to be tested if discontinuity roughness is non-fitting. 3) WE = 1.00 for 'soil type' units, e.g. cemented soils, etc. 4) If more than three discontinuity sets are present in the rock mass then the reference rock mass friction and cohesion should be calculated based on the combination of those three discontinuity sets that result in the lowest values for rock mass friction and cohesion.

Table 4. SSPC slope stability calculation – orientation-independent stability

orientation INdependent stability
Slope Stability Probability Classification (SSPC)

SLOPE NO: *1; Unit II; slope 1*

CALCULATED BY: *RH*

DATE: *11/09/2018*

LOCATION (map coordinates):
map no: *Google Earth; UTM 32 U*
northing: *5,796,342.36 m N*
Easting: *370,810.11 m E*

Remarks:

DETAILS OF SLOPE

METHOD OF EXCAVATION (**SME**)

(tick)	
natural/hand-made:	1.00
pneumatic hammer excavation:	0.76
pre-splitting/smooth wall blasting:	✓ 0.99
conventional blasting with result:	
good:	0.77
open discontinuities:	0.75
dislodged blocks:	0.72
fractured intact rock:	0.67
crushed intact rock:	0.62

WEATHERING (**SWE**)

(tick)	
unweathered	1.00
slightly	✓ 0.95
moderately	0.90
highly	0.62
completely	0.35

note: SWE = 1.00 for 'soil type' units, e.g. cemented soil, etc.

GEOMETRY

Slope dip direction (**SDD**) (degrees):	*030*°
Slope dip (**SD**) (degrees):	*65*°
Slope height (**Hslope**) (m)	*15* m
	:

SLOPE UNIT NAME:

ORIENTATION INDEPENDENT STABILITY

SLOPE INTACT ROCK STRENGTH (**SIRS**)

SIRS = **RIRS** (from reference rock mass) * **SWE** (weathering slope) = *52.6* * *0.95* = *50* MPa

SLOPE DISCONTINUITY SPACING (**SSPA**)

SSPA = **RSPA** (from reference rock mass) * **SWE** (weathering slope) * **SME** (method of excavation slope) = *0.699* * *0.95* * 0.99 = *0.657*

SLOPE CONDITION OF DISCONTINUITIES (**SCD**)

SCD = **RCD** (from reference rock mass) * **SWE** (weathering slope) = *0.364* * *0.95* = *0.346*

SLOPE ROCK MASS FRICTION (φ_{SRM})

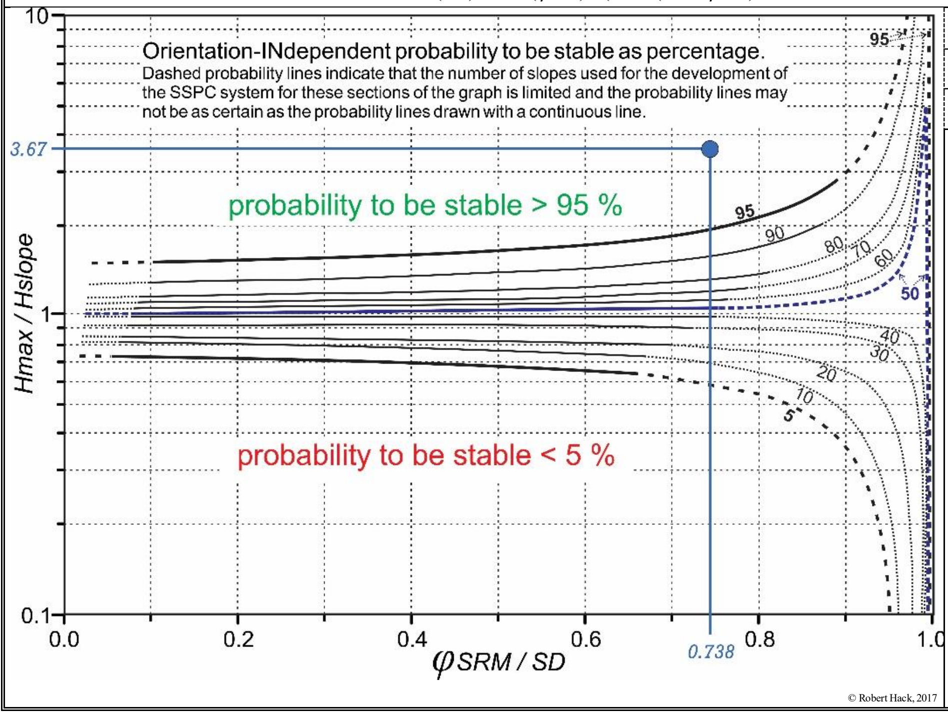
φ_{SRM} = **SIRS** * 0.2417 + **SSPA** * 52.12 + **SCD** * 5.779 = *50* * 0.2417 + *0.657* * 52.12 + *0.346* * 5.779 = *48* °
(if SIRS > 132 MPa then SIRS = 132; if SSPA > 1 then SSPA =1; if SCD .> 1.0165 then SCD = 1.0165)

SLOPE ROCK MASS COHESION (**coh**$_{SRM}$)

coh$_{SRM}$ = **SIRS** * 94.27 + **SSPA** * 28629 + **SCD** * 3593 = *50* * 94.27 + *0.657* * 28629 + *0.346* * 3593 = *24766* Pa
(if SIRS > 132 MPa then SIRS = 132; if SSPA > 1 then SSPA =1; if SCD .> 1.0165 then SCD = 1.0165)

MAXIMUM SLOPE HEIGHT (**Hmax**)

Hmax = 0.00016 * **coh**$_{SRM}$ * sin(**SD**) * cos (φ_{SRM}) / (1-cos(**SD** - φ_{SRM}) = 0.00016 * *24766* * sin(*65*°) * cos(*48*°) / (1-cos(*65*° - *48*°)) = *55.0* m



Ratios for use in graph left:

Hmax / **Hslope** = *55.0* m / *15.0* m = *3.67*

φ_{SRM} / **SD** = *48*° / *65*° = *0.738*

ORIENTATION INDEPENDENT STABILITY

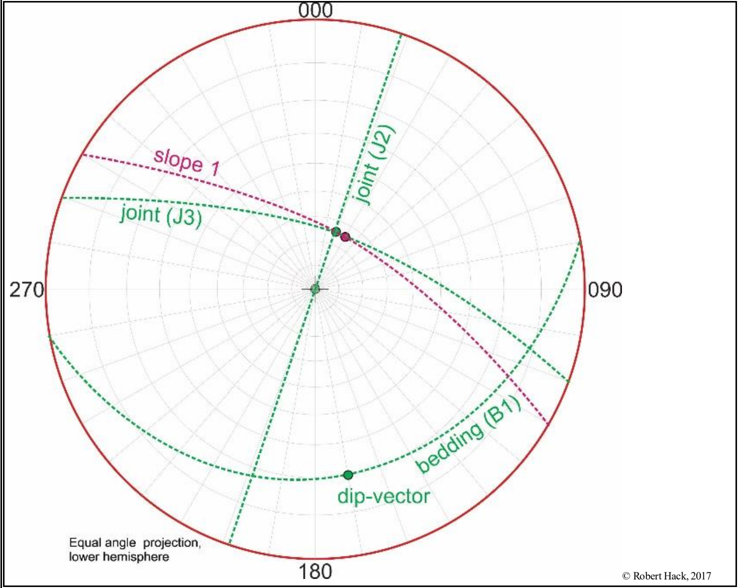
Probability to be stable:
If φ_{SRM} > **SD**, then
probability = 100 %
else
read probability from graph left: *> 95* %

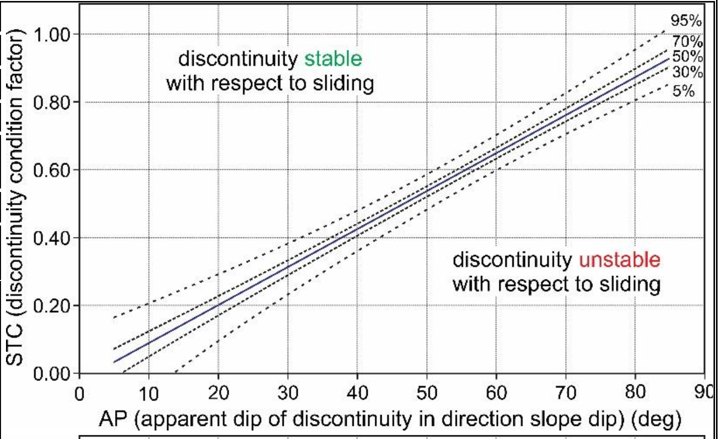
Table 5. SSPC slope stability calculation – orientation-dependent stability

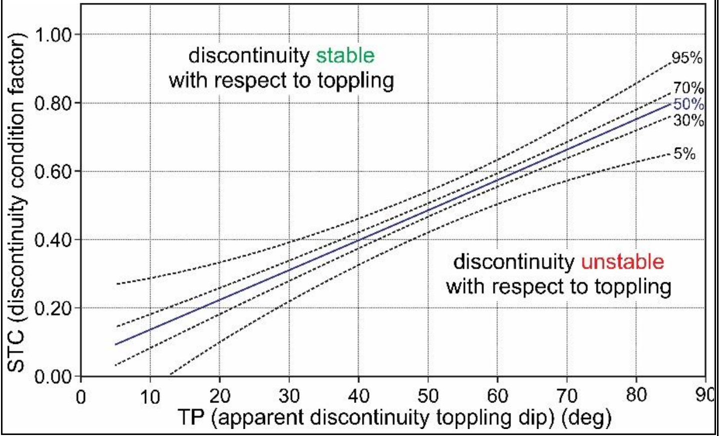
	orientation dependent stability Slope Stability Probability Classification (SSPC)	SLOPE NO: *1; Unit II; slope A*
	CALCULATED BY: *RH* / DATE: *11/09/2018*	LOCATION (map coordinates):
Remarks:		map no: *Google Earth; UTM 32 U* northing: *5,796,342.36 m N* easting: *370,810.11 m E*

ORIENTATION DEPENDENT STABILITY						
DISCONTINUITY SET:	*B*1	*J*2	*J*3	4	5	
Dip direction (**DDD**) (deg):	*170*	*108*	*020*			
Dip (**DD**) (deg):	*20*	*90*	*65*			
AP = arctan(cos(**SDD** – **DDD**) *x* tan **DD**) (deg):	*-15.6*	*-*	*64.7*			AP is apparent discontinuity dip
TP = -90° - **AP** + **SD** (deg):	*-40.6*	*-*	*-89.7*			TP is apparent discontinuity toppling dip
With, Against, Vertical or Equal:	*against*	*vertical*	*equal*			Use options in table left to determine
RTC (from reference form):	*0.333*	*0.606*	*0.356*			
$\mathbf{STC} = \mathbf{RTC}\ \mathbf{x} \sqrt{1.452 - 1.22\ \mathbf{x}\ \mathbf{e}^{-\mathbf{SWE}}} =$	*0.330*	*0.600*	*0.352*			
SSA = **STC** / 0.0113 (deg):	*29*	*53*	*31*			SSA is the slope sliding angle
Probability stable sliding (see table below):	*100* %	*100* %	*100* %	%	%	
Probability stable toppling (see table below):	*100* %	*100* %	*100* %	%	%	

options (use stereo plot below):		sliding	toppling
AP ≥ 85° or AP ≤ -85°	vertical	100 %	100 %
(Slope dip+5°) < AP < 85°	with	100 %	100 %
(Slope dip-5°) ≤ AP ≤ (Slope dip+5°)	equal	100 %	100 %
0° ≤ AP < (Slope dip-5°)	with	use graph sliding	100 %
AP < 0° and TP ≤ 0°	against	100 %	100 %
AP < 0° and TP > 0°	against	100 %	use graph toppling







Remarks:

Slope is fully stable

Orientation independent stability: Rock mass is strong enough for the slope height

Orientation dependent stability: J3 is slope forming; B1 and J2 form no problem as they give no options for sliding nor toppling

For the partially collapsed corner see text.

Fig. 1. Gildehaus, Romberg Quarry with photo location and photo direction.

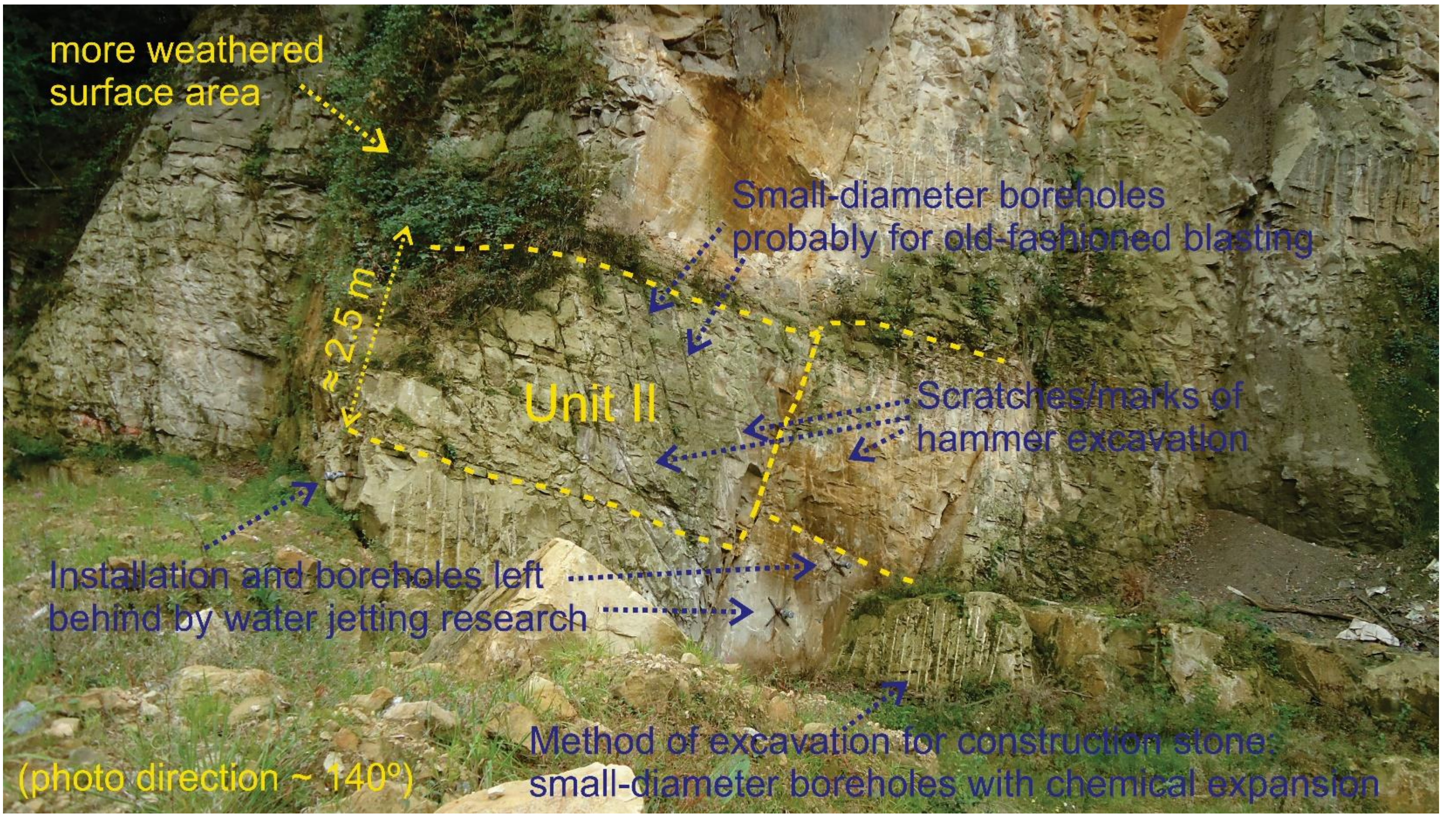


Fig. 2. Location Unit II.

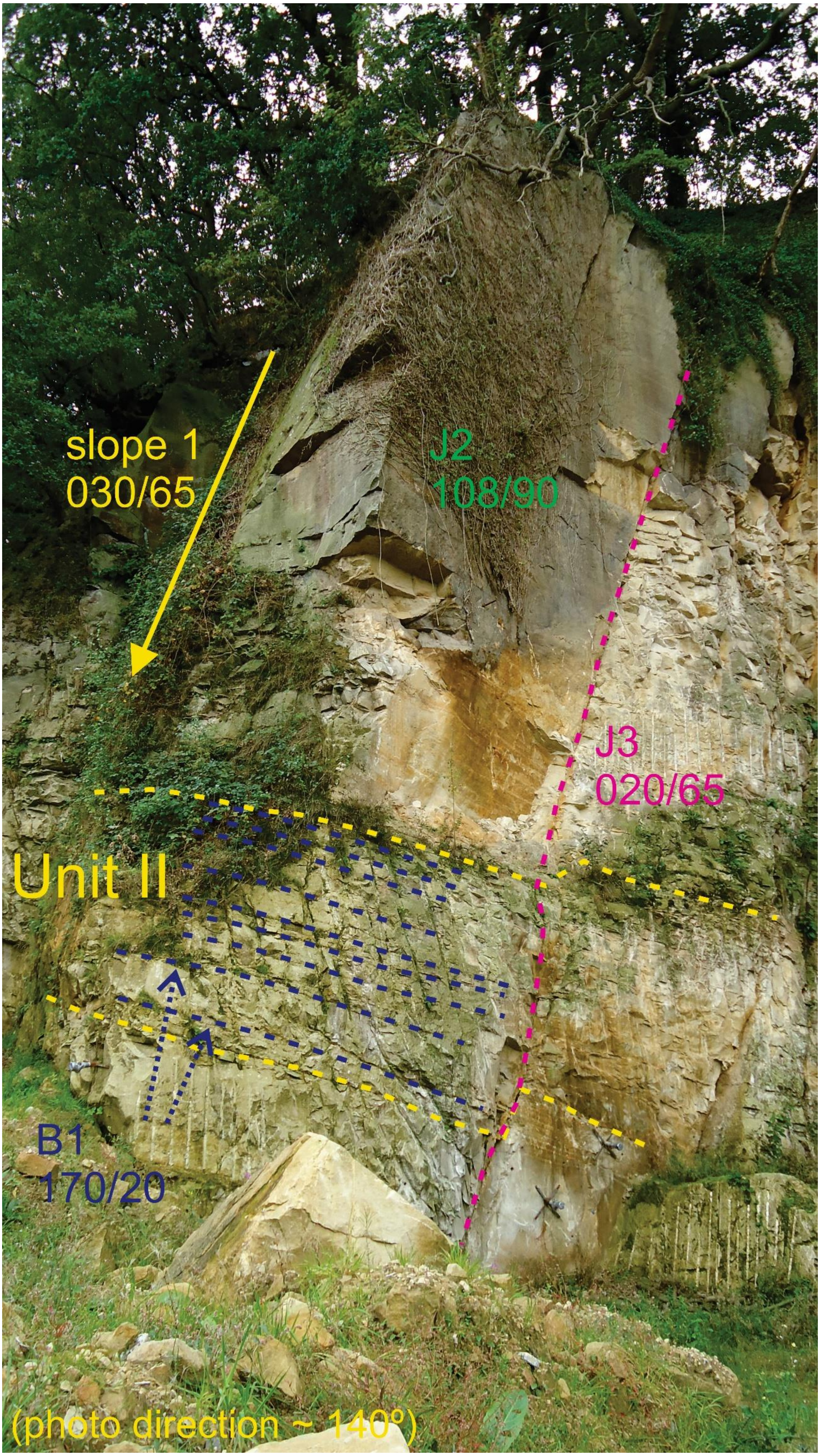
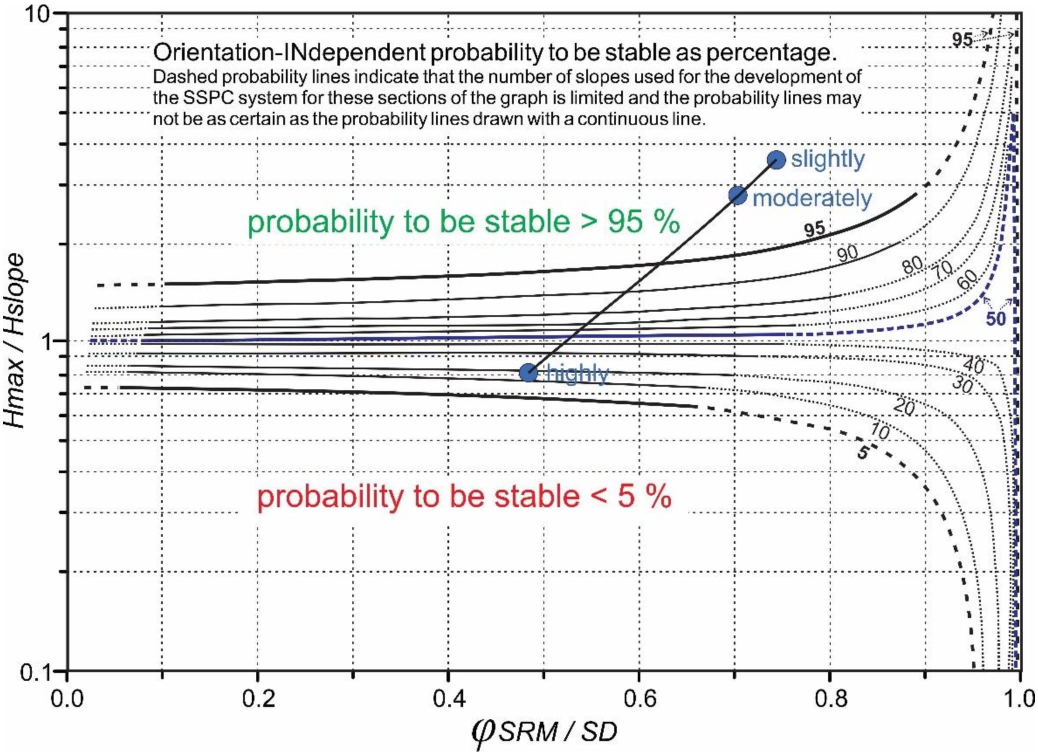


Fig. 3, Slope and interpretation of discontinuities (J2 is the face on which the classification is done).



Orientation-INdependent probability to be stable as percentage.

Dashed probability lines indicate that the number of slopes used for the development of the SSPC system for these sections of the graph is limited and the probability lines may not be as certain as the probability lines drawn with a continuous line.

Fig. 4. SSPC orientation-independent stability with different degrees of weathering.