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1. Theoretical basis

1.1 Assessment of the Hazard Indices.

To process a distribution map of the hazard indices, the topographic base has to be divided on the base of a regular grid with *n* rows and *m* columns. Inside each area, individuated by the (i,j), (i+1,j), (i+1,j+1), (i,j+1) nodes, the maximum dip and the dip direction have to be assessed. Then, to every area, the geomechanical parameters of the closest measurement station are to be assigned. Hazard indices are calculated with respect to three kinds of rock landslide: toppling failure, planar sliding and block sliding. The higher index is assigned to the examined area.

Toppling failure

It is to be considered potentially unstable due to toppling failure, a rock volume, isolated by a rock joint, where the following expressions are valid:

$$\beta_g > 75° \text{ e } \beta_v > 75°$$
$$\alpha_v - 10° < \alpha_g < \alpha_v + 10°$$

where:
α_v = dip direction of the slope;
β_v = dip of the slope;
α_g = dip direction of the rock joint;
β_g = dip of the rock joint;

Hazard index is calcualted by the following formula:

$$I_{ribaltamento}(\%) = 100 \frac{N_{rib}}{N_{totale}}$$

where:
N_{rib} = number of joints isolating a rock block unstable by toppling;
N_{totale} = total number of joints.

Planar sliding

A planar sliding of a rock block occurs when a dip-slope rock joint, less sloped than the topographic surface, isolates, at the bottom, the rock block. Another condition is that the angle of the shear resistance mobilized along the joint be lesser than the apparent slope of the topographic surface along its dip direction. By a practical point of view, the following relationships are to be satisfied:

$$\alpha_v - 90° < \alpha_g < \alpha_v + 90°$$
$$\beta_g < \beta_{v\ apparent}$$
$$\beta_g > \varphi$$

Hazard index is calcualted by the following formula:

$$I_{scivolamento}(\%) = 100\frac{N_{sciv}}{N_{totale}}$$

where:
N_{sciv} = number of joints isolating a rock block unstable by sliding;
N_{totale} = total number of joints.

Block sliding

A block sliding of a rock block occurs when the intersection between two rock joints is dip-slope disposed and less sloped than the topographic surface, isolates, at the bottom, the rock block. Another condition is that the angle of the shear resistance mobilized along the intersection be lesser than the apparent slope of the topographic surface along its dip direction. By a practical point of view, the following relationships are to be satisfied:

$$\alpha_v - 90° < \alpha_i < \alpha_v + 90°$$
$$\beta_i < \beta_{v\ apparent}$$
$$\beta_i > \varphi$$

where α_i and β_i are, respectively, the dip direction and the dip of the intersection of the two rock joints.
Hazard index is calcualted by the following formula:

$$I_{blocchi}(\%) = 100 \frac{N_{blocchi}}{N_{totale}}$$

dove:

N_{sciv} = number of joints isolating a rock block unstable by sliding;

N_{totale} = total number of joints.

1.2 Rock mass classification by Romana (S.M.R. - Slope Mass Rating)

The classification represents the application of the 1979 Bieniawski's classification to the case of rock slope stability. The SMR index (Slope Mass Rating) is given by the following relation:

SMR=A1 + A2 +A3 +A4 + A5 + (F1 x F2 x F3) + F4

The A1-A5 indexes are relative to the Bieniawski's classification.

	PARAMETERS		RANGE OF VALUES						
1	Strength of intact rock material	Point-load strength index (MPa)	>10	4 - 10	2 - 4	1 - 2	For this low range, uniaxial compressive test is preferred		
		Uniaxial compressive strength(MPa)	>250	100 - 250	50 - 100	25 - 50	5 - 25	1 - 5	< 1
	Rating		15	12	7	4	2	1	0
2	Rock Quality Designation R.Q.D. (%)		90 - 100	75 - 90	50 - 75	25 - 50	<25		
	Rating		20	17	13	8	3		
3	Joint spacing (m)		>2.0	0.6-2.0	0.20 -0.60	0.06 - 0.20	< 0.06		
	Rating		20	15	10	8	5		
4	Joint condition		Very rough surfaces. Not continuous. No separation. Hard joint wall rock	Sligthlty rough surfaces. Separation <1mm. Hard joint wall rock.	Slightly rough surfaces. Separation <1mm. Soft joint wall rock.	Slickensided surfaces or Gouge <5mm thick or Joint open 1-5 mm. Continuous joints	Soft gouge >5mm thick or Joint open >5mm. Continuous joint.		
	Rating		30	25	20	10	0		
5	Ground water	General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

The sum of the five partial indexes gives the Basic RMR (BRMR). The SMR index has to be calculated by the following formula:

$$SMR = BRMR + (F1xF2xF3) + F4$$

The variables F1, F2 and F3 depend on the orientation of the most unfavorable joint in the rock mass as a function of the slope orientation.
F1 is given by the following expression:

$$F1 = [1 - \text{sen}(| \alpha_j - \alpha_f |)]^2$$

where α_j and α_f are, respectively, the dip direction of the most unfavorable joint and the dip direction of the slope.

F2 is obtained by the formula:

$$F2 = tg^2 \beta_j$$

where β_j is the angle of dip of the most unfavorable joint. When F2>1, it must impose F2=1.

F3 is a correction to apply to the BRMR value as a function of the difference between the dip angle of the most unfavorable joint and the dip angle of the slope (β_j - β_f). It practically corresponds to the Bieniawski's correction:

F 3	Joint dip direction - Slope dip direction	Very favourable(>10°)	Favourable [10°-0°]	Fair [0°]	Unfavourable[0°-(-10°)]	Very unfavourable[<-10°
	Rating	0	-5	-25	-50	-60

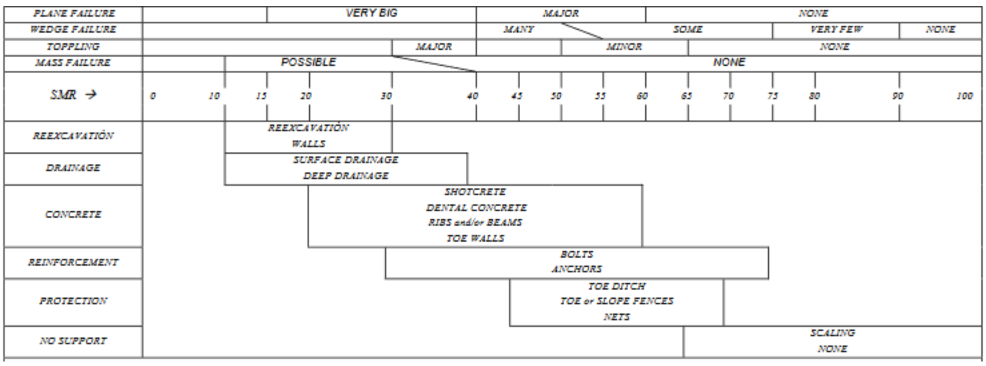
F4 is a correction to apply as a function of the excavation method:

F 4	Excavation method	Natural slope	Presplitting	Smooth blasting	Blasting or mechanical	Deficient blasting
	Rating	15	10	8	0	-8

The SMR index is correlated to the quality of the rock mass and to the stability condition of the rock slope:

SMR	0-20	21-40	41-60	61-80	81-100
CLASS	V	IV	III	II	I

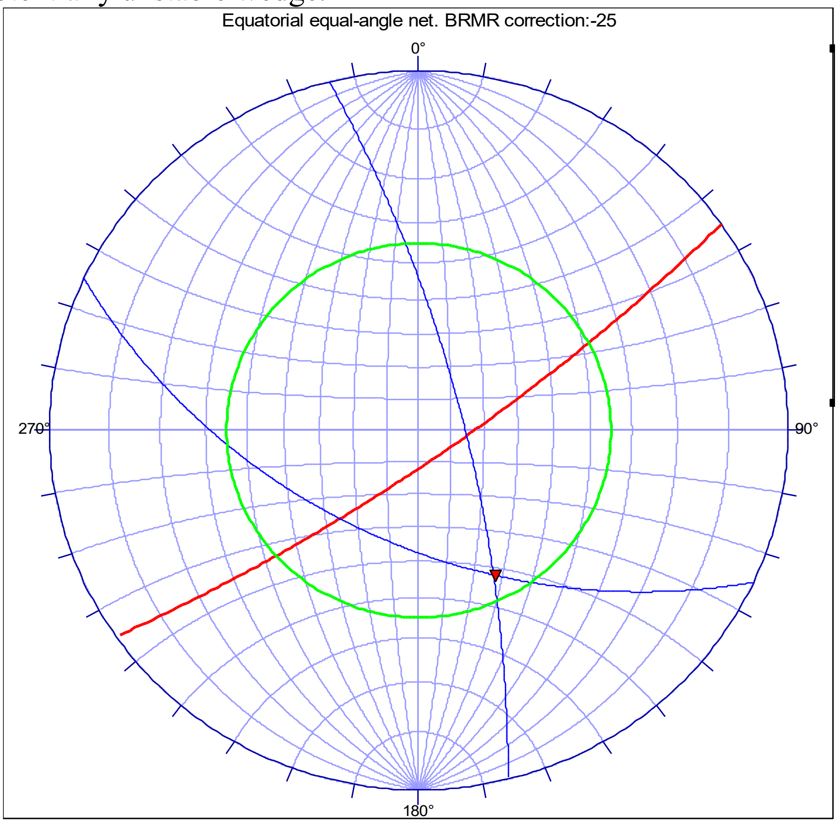
Recommendation about the slope support is also given:



1.3 Markland test

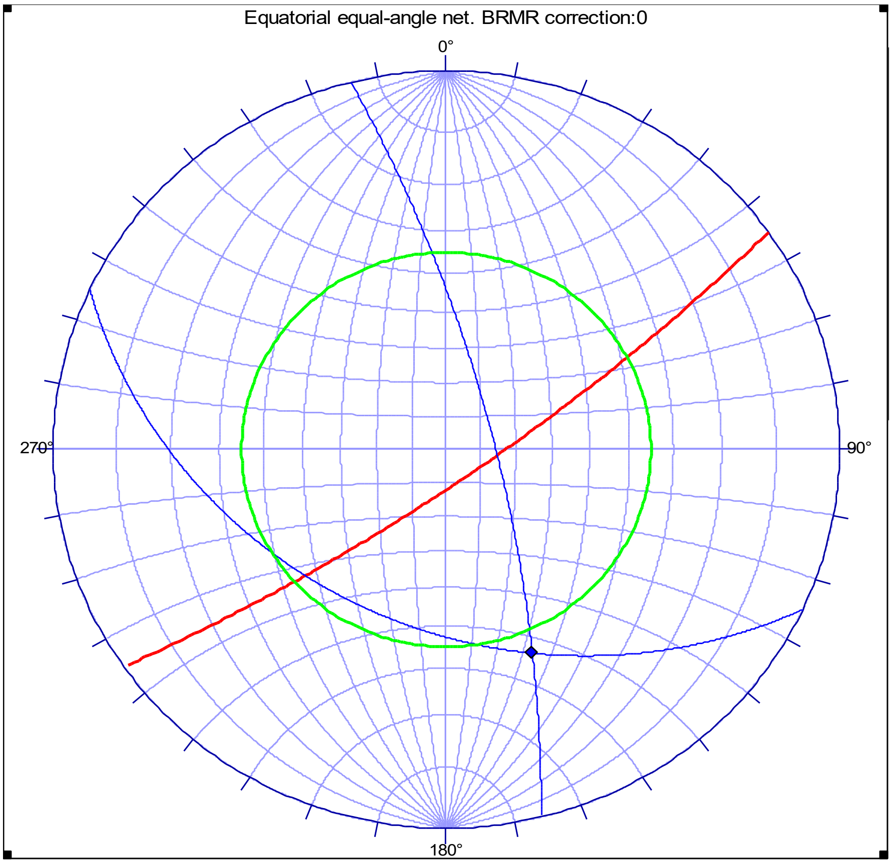
This test allows to get an indication of the stability of the wedges inside of the rock mass as a function of their spatial orientation and of the average shear strength along their discontinuities. The discontinuity shear strength is quantified through an average angle of shear strength.
The method considers five possible conditions.

1. Potentially unstable wedge.



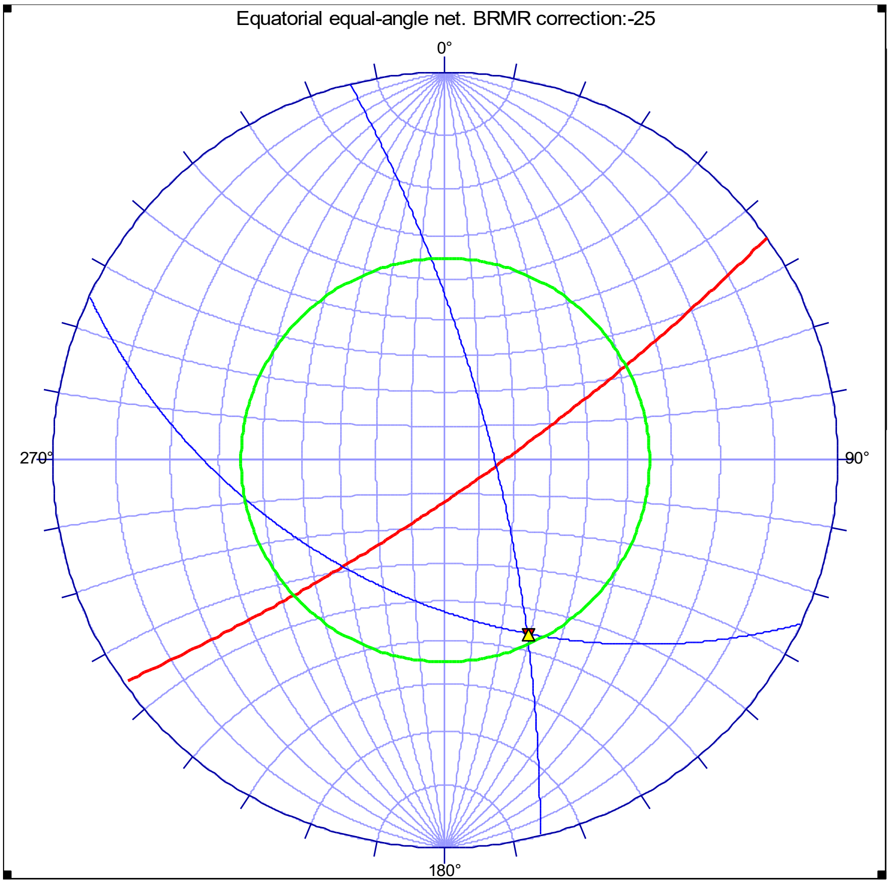
This condition happens when the wedge is oriented in the slope direction and the angle of shear strength is lesser than the angle of dip of the sliding line.

2. Stable wedge.



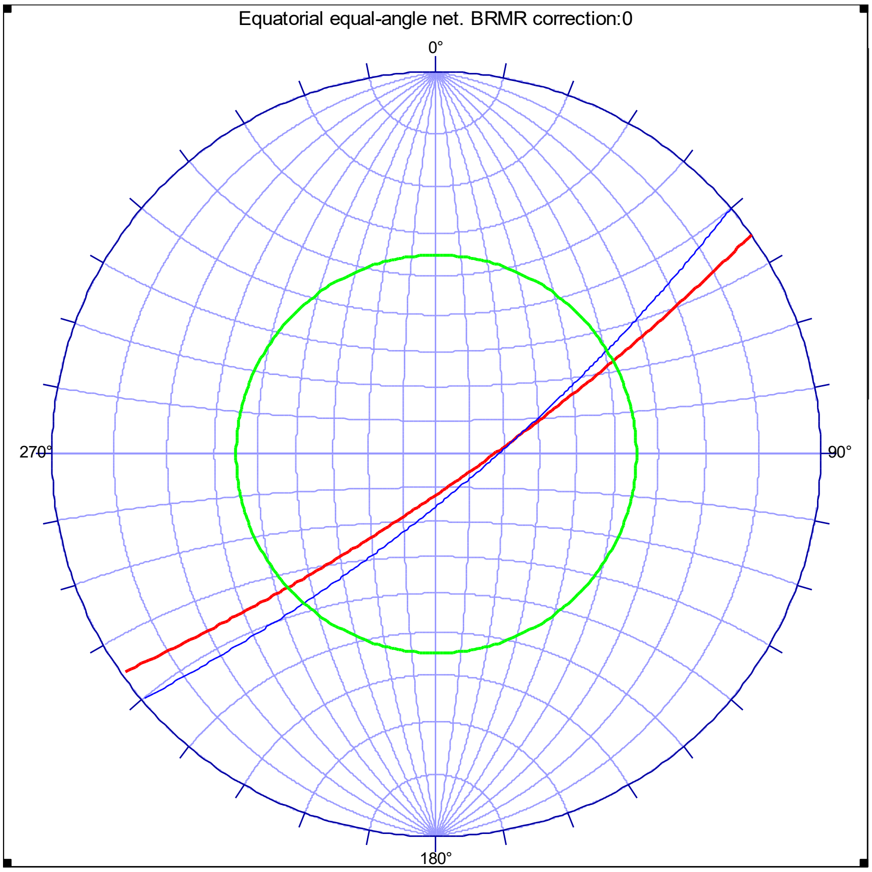
This condition happens when the wedge is oriented in the slope direction and the angle of shear strength is greater than the angle of dip of the sliding line or when the wedge is anti-dip slope oriented.

3. Uncertain instability.



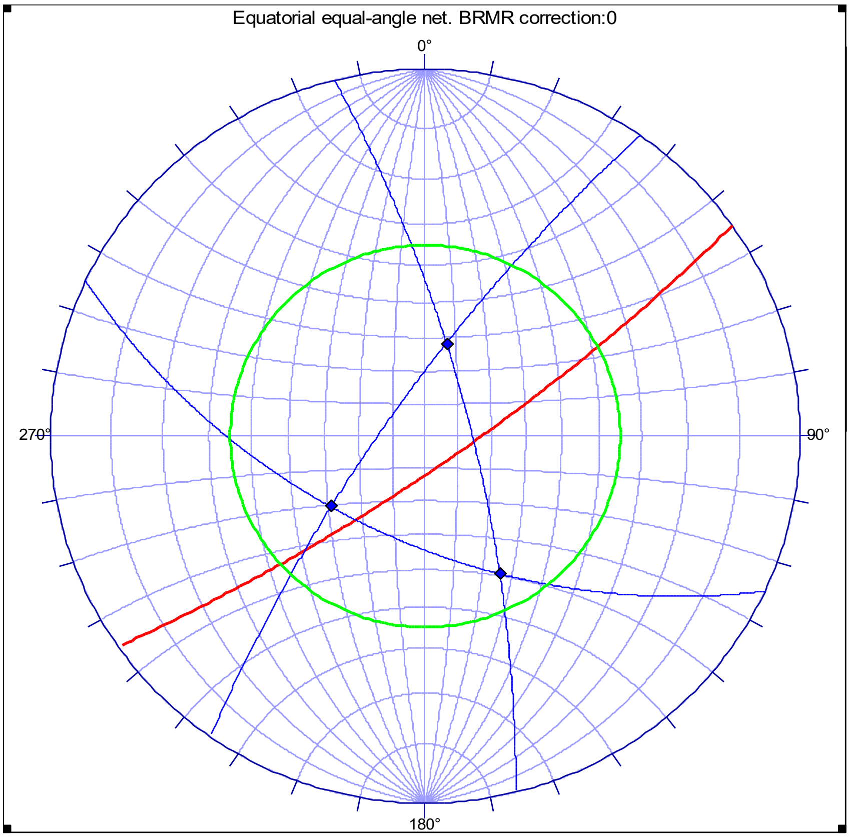
This condition happens when the wedge is oriented in the slope direction and the angle of shear strength is approximately equal to the angle of dip of the sliding line (±2°).

4. Block toppling.



This condition happens when the slope and one of the discontinuity are approximately vertical and have a similar dip direction.

5. Roof stability.



The presence of unstable blocks in the roof of a tunnel is put in evidence by the intersection of three or more discontinuities which form a closed shape.