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SIDE CUTS IN KARSTIFIED ROCKS ON THE EXAMPLE OF TWO PLATEAUS OF WF PODVELEŽJE

Amira Galić, Ph.D.
Faculty of Civil Engineering, University of Mostar, *amira.galic@gf.sum.ba*
Kristina Čulina, M.Sc.

Abstract: Cuts and side cuts, along with embankments, are very common during construction of all types of roads, and consequently also in the realization of access roads and plateaus of wind farms. Side cuts are made when the grade level of a plateau or route is below the ground in a slope. Realization, categorization and stabilization of side cuts in karstified rock masses entail a number of challenges that are mainly related to karstification processes. The specificities of the classification and kinematic stability analysis of karstified rock masses in side cuts are presented on the example of two plateaus of WF Podveležje using geomechanical classification (RMR), geological strength index (GSI) and stereographic projection.

Keywords: side cut, karst, rock, classification.

ZASJECI U OKRŠENIM STIJENAMA NA PRIMJERU DVA PLATOA VE PODVELEŽJE

Sažetak: Usjeci i zasjeci, zajedno s nasipima, su vrlo česti tijekom izgradnje svih vrsta prometnica, pa tako i u realiziranju pristupnih cesta i platoa vjetroelektrana. Zasjeci se rade u slučajevima kada je kota nivelete platoa ili trase ispod terena u padini. Izvedba, kategorizacija i stabilizacija zasjeka u okršenim stijenskim masama nose sa sobom niz izazova koji su, u glavnom, vezani za procese okršavanja. Na primjeru dva platoa VE Podveležje prikazane su specifičnosti klasifikacije i kinematičke analize stabilnosti okršenih stijenskih masa u zasjecima, primjenom geomehaničke klasifikacije (RMR), geološkog indeksa čvrstoće (GSI) i stereografske projekcije.

Ključne riječi: zasjek, krš, stijena, klasifikacija.

1. Introduction

The wider study area is the northwesternmost part of the Podveležje high plains, i.e., the plateau of a Dinaric strike. The west side of the plateau ends in steep slopes towards Mostar, which is at about 5 km away in a straight line. Steep slopes towards Bijelo Polje and Raštani are also in the north. Altitudes range from 680 m a.s.l. (Lipova glava) in highest parts to 877 a.s.l. (Sveta gora). Along the study area, slopes are mildly to moderately inclined, with Dinaric strike (northwest-southeast). The terrain is largely bare or with very sparse vegetation, rare shrubbery and covered with a thin surface covering between distinct limestone outcrops. There are no major settlements except several small villages: Gornje Opine south of the wind farm site, then Šipovac to the east and Dobrč to the north. There are no surface watercourses in the more immediate area, all rainwater quickly drains through a system of connected fractures into deeper parts or runs off on the surface over steep slopes towards the Neretva valley. Due to the high altitude in relation to Mostar (the difference is about 820 m at a 5 km air distance), the area of Podveležje plateau belongs to a typical mountain climate with Mediterranean influence coming from the south by the Neretva valley. The influence of the Prenj, Čvrsnica and Čabulja mountains comes from the north. The main characteristics are: harder winters, longer and dry summers, occurrences of intense precipitation in the spring and earlier winter periods, where two typical winds, bora and sirocco, occur.

2. General geological characteristic

The more immediate area along the access roads and plateaus is made of bedded to thinly bedded Upper Cretaceous limestones of Turonian age, as the bedrock. Quaternary formations are represented by silty-sandy clays, dark brown to brown in color, with many fragments of rock from the base. Cover sediments are thicker and more spacious in natural depressions and sinkholes and on gently dipping slopes

Limestones are always bedded and less frequently massive. There is a difference in thickness of layers, in some parts of the terrain they are well bedded, while in some locations they are thinly bedded to tabular. The strata are usually 10-40 cm thick. The cover is represented by dark brown silty sandy clays with fragments and debris of underlying rocks, with thickness from 0.3 m on gently dipping slopes to 1.0 m in valleys and sinkholes. On a large part of the terrain, cover is reduced to elongated zones between outcrops. These eluvial and eluvial-diluvial formations are most prominent in places of natural accumulation in depressions and in places where slopes have a smaller gradient (Šerifović, 2017).

The investigated area is made of carbonate rocks, which belong to well-permeable rocks with fracture-cavernous porosity, which means that their permeability primarily depends on the degree of karstification of the limestone mass, which is a consequence of tectonic activity, petrographic composition and exposure to exodynamic factors. It is known that fractures are numerous in the surface part of karst, and the direction of movement is generally vertical, which allows rapid seepage of rainwater into deeper parts, where fractures become less frequent and the largest and widest ones take the dominant role in water movement (Bačani, Vlahović, 2012). For this reason and because of the depth of works for the planned facilities, groundwater should not be expected on the locations of wind turbine plateaus and access roads.

Locations of two plateaus are selected for the purposes of this paper. These are:

- Wind turbine 9 plateau with access road OS 5 and
- Wind turbine 14 plateau with access road OS 1.

The engineering geological model of rock mass on these plateaus is adapted to the description developed by Pollak (2007), i.e., to his model with five weathering zones:

I - fresh rock (FR);
II - lower weathering zone (LWZ);
III - upper weathering zone (UWZ);
IV - surface weathering zone (SWZ);
V - cover:
- cohesionless blocks, fragments or debris of rock,
- mixture of clay with fragments of bedrock,
- clay.

On plateaus 9 and 14, the engineering geological model with five weathering zones looks like this:
I - fresh rock: limestone, unweathered.
II - lower weathering zone: limestone, unweathered to slightly weathered, joint aperture 0.1-1.0 without infilling or coating.
III – upper weathering zone: thickness 3.0 – 10.0 m, more pronounced along faults and tectonically disturbed zones. Made of limestone, slightly to moderately weathered, with 1-10 mm aperture joints, coating of calcite and with compressed clay.
IV – surface weathering zone: thickness up to 2.0 m, made of limestones, slightly to moderately weathered, with wide joint aperture (10-50 mm), without infill, clay at the bottom.
V – cover: consists of silty-sandy clay, of firm consistency, red brown and dark brown, with bedrock fragments and debris. Locally spread over larger areas of the terrain on gentle slopes and in marked depressions, on exposed and karstified parts of the terrain it occurs in gaping cracks in rock and between outcrops where it is less thick.

3. Engineering geological and geomechanical characteristics of rock mass on plateau 9

Plateau 9 is constructed partly in side cut, up to 9 m in height, and partly in embankment, up to 5 m in height. The excavation slope strike is 240/90. The excavation profile is divided into zones with similar characteristics, as shown in Figure 1. Four discontinuity systems are present in the rock mass and their description follows.

1st system: bedding joints
Closed, continuous, without infilling, with unaltered, slickensided to slightly rough walls, several tens of meters long, dry and slightly undulating to planar, at a spacing of about 15 cm on the average. Beds dipping to southwest, with bed elements within the range 185-230/40-60, average 200/55.
2nd system: joints perpendicular to bedding
In deeper parts closed, continuous, towards the surface wall spacing increases, up to 5 mm on the average, walls slightly to moderately rough, with thin alteration coating, stretching over the entire height of the cut (over 15 m), dry, slightly undulating, at a spacing of 60 cm on the average. Range of elements 160/80.
3rd system: Joints dipping at a milder angle
Mildly open, wall spacing up to 5 mm, in some places infill of a mixture of terra rossa and clayey minerals, discontinuous, with altered rough walls, which are in places markedly weathered, 1-2 m in length, dry, stepped, at a spacing of 0.4-1 m on the average. Range of elements 40/30.
4th system: fault
Closed, discontinuous paraclase, without infill, negligibly to slightly altered, slickensided walls, several tens of meters long (<50), dry, gently undulating, only one in the entire profile. Spatial orientation: 200/85.

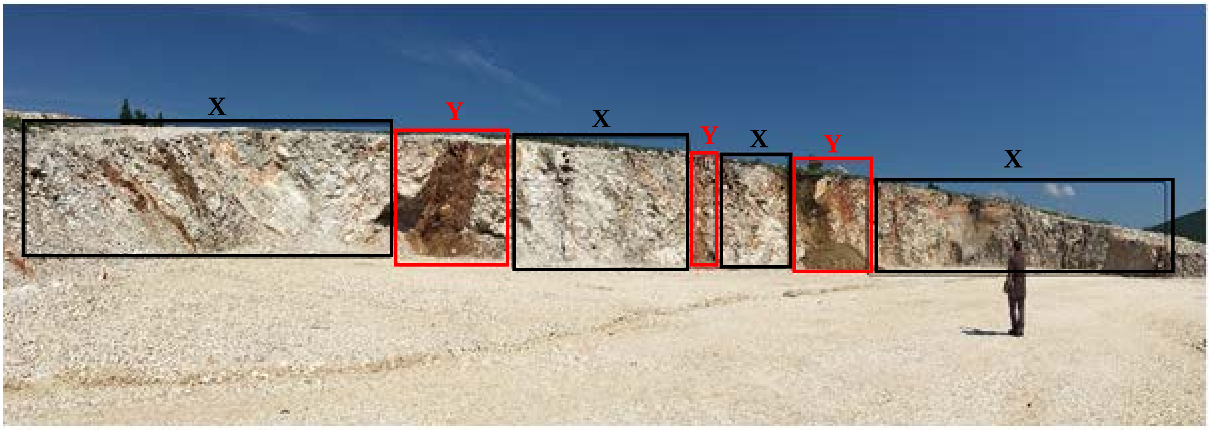

Figure 1. Plateau 9 with identified zones: X-rock mass of bedded to well-bedded limestones, Y-weakened zone, fault zone or highly karstified zone

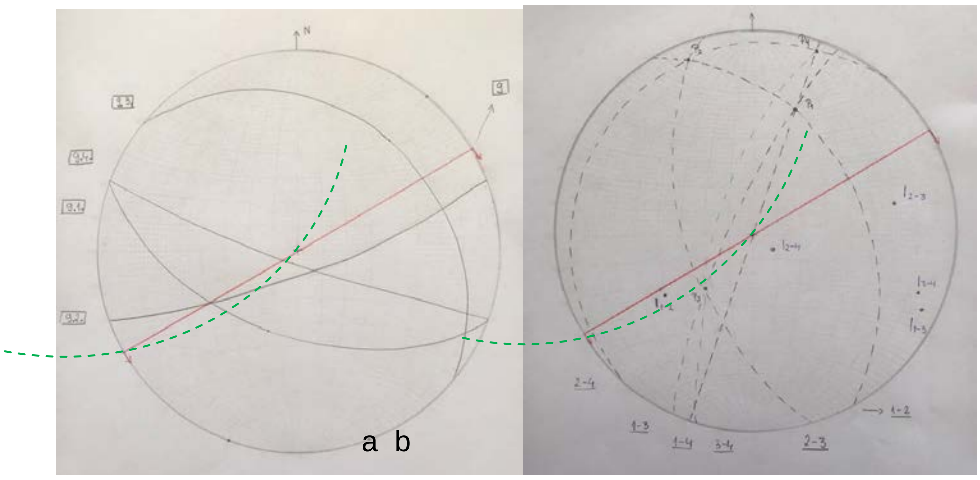

Figure 2. Kinematic discontinuity sliding analysis (a) kinematic wedge analysis (b)
__ vertical side cut; ---side cut at an angle of 60°

The kinematic slope stability analysis using stereographic projection of discontinuities in the plateau 9 area established that discontinuity sets 1 and 2 potentially jeopardize slope stability by their spatial orientation. The adverse effect of these discontinuities could be eliminated by reducing slope gradient by 30 degrees (green dashed line in Figure 2.a). The kinematic wedge sliding analysis shows that projections of all discontinuity plane intersections on the Schmidt diagram are before the excavation plane trace. This indicates that the spatial position of all wedges resulting from intersecting the discontinuities with excavation plane is very unfavorable for slope stability. Reducing the slope face gradient by 30 degrees would eliminate three groups of unfavorably oriented wedges (Figure 2.b). During investigations and classification of rock mass of the Plateau 9 area, trial boreholes were not carried out, so the rock quality designation was done according to the volumetric joint count (Miščević, 2015):

$$RQD = 115\text{-}3.3 \cdot J_v \quad (1)$$

The coefficient J_v is determined according to the number of discontinuities in a cubic meter (Miščević, 2015). For X zones, rock quality designation is:

RQD = 115 – 3.3·Jv= 115-3.3·9= 85.3%

The following rock quality designation is adopted for X zones:

RQD= <25% (weakened zones with very low rock quality designation)

The RMR$_{89}$ classification (Bieniawski, 1989) was made so that each discontinuity system was rated separately by points corresponding to its description. For the four discontinuity systems in zones marked with X, the categories range from V (very poor) to III (fair), which is mostly due to the influence of discontinuity orientation on slope stability. The stability of this slope is most threatened by the first and second group of discontinuities, as shown by the kinematic stability analysis. If the slope face dip would be decreased by 30 degrees, the rock would move from very poor to poor category according to the rating. In zones marked with Y, the rock mass generally falls into category V - very poor. The geological strength index was determined based on visual assessment, according to the table adjusted to karstified carbonate rock masses (Pollak, 2009). The rock mass classification for zones X and Y is shown in Table 1.

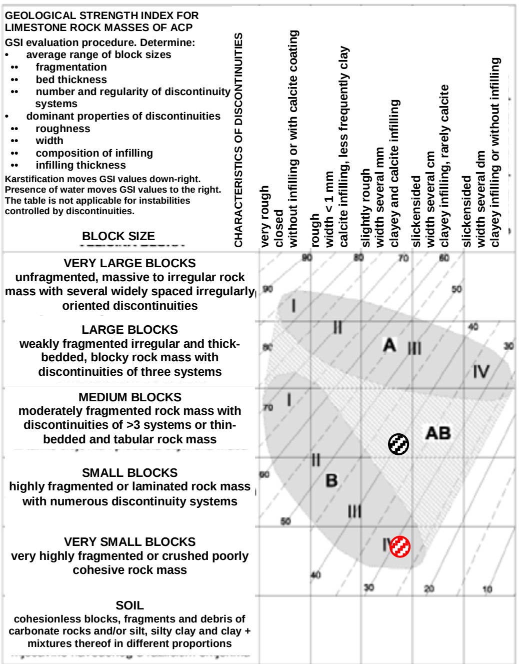

Figure 3. GSI classification of rocks mass in side cut of plateau 9 (-X zones; -Y zones)

Table 1. RMR_{89} classification of rock mass in vertical side cut

RMR CLASSIFICATION	Zones X				Zones Y
Discontinuities:	1st system	2nd system	3rd system	4th system	
1. Uniaxial compressive strength (MPa)	70-90	70-90	70-90	70-90	25-50
Rating	7	7	7	7	4
2.RQD(%)	85.3	85.3	85.3	85.3	<25%
Rating	17	17	17	17	3
3.Discontinuity spacing	≈0.15m	≈0.6m	≈0.4-1.0m	>100m	0.06-0.2m
Rating	8	10	10	20	8
4.Discontinuity condition					
Length	Several tens of m	10-20m	1-2m	>20m	<1m
Rating	0	1	4	0	6
Aperture	closed	1-5mm	1-5mm	closed	>5mm
Rating	6	0.5	1	6	0
Roughness	Slickensided to slightly rough walls	Slightly to moderately rough walls	Altered rough walls	Slickensided walls	Mildly rough
Rating	2	3	3	1	3
Infilling	Without infilling	<5mm	<5mm	Without infilling	Soft, >5mm
Rating	6	0.5	5	6	0
Weathering:	Unweathered	Slightly weathered	In places markedly weathered	Slightly weathered	Highly weathered
Rating	6	4	3	4	1
5. Groundwater					
Inflow per 10m' of tunnel (l/min)	None				
General condition	Completely dry				
Rating	15	15	15	15	15
Total rating without the effect of spatial orientation of discontinuities	67	58	65	76	35
6. Correction for the effect of discontinuity strike and dip (for vertical cut)	unfavorable	unfavorable	good	good	generally good
Rating	-50	-50	-25	-25	-25
Total rating	17	8	40	51	15
RMR CATEGORY	V	V	IV	III	V

Table 2. RMR_{89} classification of rock mass in side cut at an angle of 60°

	Zones X				Zones Y
	1st system	2nd system	3rd system	4th system	
Total rating without the effect of spatial orientation of discontinuities	67	58	65	76	35
6. Correction for the effect of discontinuity strike and dip (for cut at an angle of 60°)	Good	Good	Good	Good	Generally good
Rating	-25	-25	-25	-25	-25
Total rating	42	33	40	51	15
RMR CATEGORY	III	IV	IV	III	V

Table 3. Rock mass category according to the RMR_{89} classification

Rating	100-81	61-80	41-60	21-40	<20
Category	I	II	III	IV	V
Description of rock	Very good	Good	Fair	Poor	Very poor

4. Engineering geological and geomechanical characteristics of rock mass on plateau 14

Plateau 14 is constructed partly in side cut, up to 11 m in height, and partly in embankment, up to 6 m in height. The excavation slope strike is 270/90. The engineering geological model is adjusted to the description developed by Pollak (2009), i.e., to his model with five weathering zones and it is the same as on the previously described plateau 9. Three discontinuity systems are registered.

1st system: bedding joints
Closed, continuous, without infilling, with unaltered, slickensided to slightly rough walls, several tens of meters long, dry and slightly undulating to planar, at a spacing of about 20 cm on the average. Strata generally have a dip toward the southwest with spatial orientation elements averaging 220/63.

2nd system:
The fracture system is mainly with medium persistence, in some places expanded to 5 mm, with weathered and karstified walls, while with depth they are mainly with a small aperture, slightly weathered, undulating rough, with clayey-calcite infilling. They extend over the entire height of the cut (over 15 m), dry, mildly undulating, at a spacing 0.5-1 m on the average. Joints with spatial orientation elements averaging 170/83.

3rd system:
Closed, discontinuous, without infill, negligibly to slightly altered, with slickensided walls, several tens of meters long, dry, mildly undulating, at a spacing of several to ten meters, with spatial orientation elements averagely 200/80.

Figure 4. Plateau 14 with identified zones: X-rock mass of bedded to well-bedded limestones, Y-weakened zone, fault zone or highly karstified zone

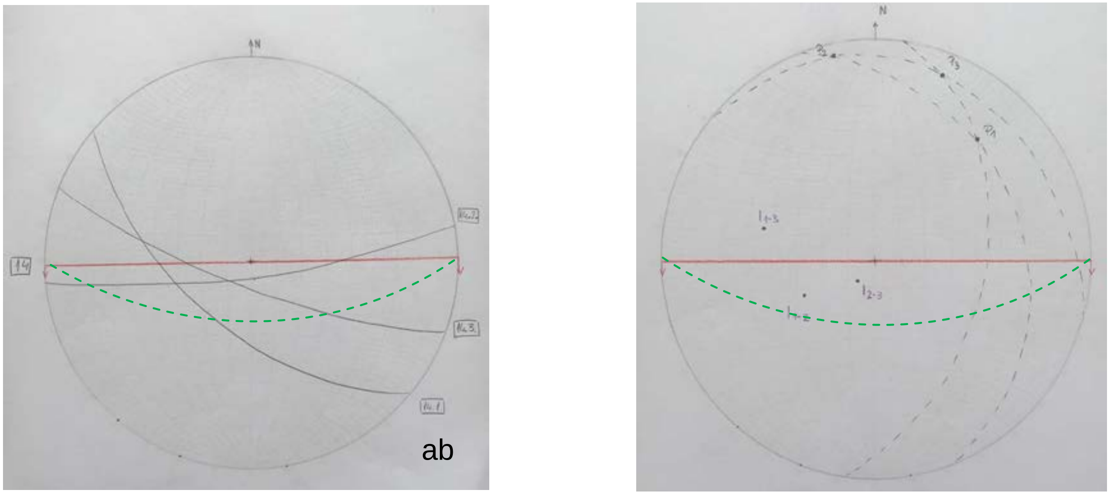

Figure 5. Kinematic analysis of three discontinuity sets (a) and kinematic wedge stability analysis (b) in the area of plateau 14 (__ vertical excavation; ---excavation with dip 75°)

The kinematic slope stability analysis using stereographic projection of discontinuities in the plateau 14 area established that all three discontinuity sets potentially jeopardize slope stability, because their traces are mostly before the slope face. Changing the slope face gradient by 25 degrees would eliminate their adverse effect (Figure 5.a). Kinematic wedge sliding analysis shows two groups of potentially unstable wedges. Reducing the slope face gradient by 25 degrees would eliminate their adverse effect.

During investigations and classification of rock mass of the Plateau 14 area, trial boreholes were not carried out, so the rock quality designation was done according to the volumetric joint count (Miščević, 2015):

$$RQD = 115-3.3 \cdot Jv$$

The coefficient Jv is determined according to the number of discontinuities in a cubic meter (Miščević, 2015). For X zones, rock quality designation is:

$$RQD = 115 – 3.3 \cdot Jv= 115-3.3 \cdot 6= 95.2\%$$

The following rock quality designation is adopted for X zones:

$$RQD= <25\%$$

Each discontinuity system was rated separately by points corresponding to its description, according to RMR_{89} (Table 4). For the three discontinuity systems in zones marked with X, the categories range from V (very poor) to IV (poor), which is mostly due to the influence of discontinuity orientation on slope stability. If the slope face dip would be decreased by 25 degrees, the rock would shift from very poor and poor category to fair category according to the number of points (Table 5). In zones marked with Y, the rock mass generally falls into category V - very poor. The geological strength index was determined based on visual assessment, according to the table adjusted to karstified carbonate rock masses with approximate and average GSI values of the particular model and weathering zone.

Table 4. RMR_{89} classification of rock mass in vertical side cut

RMR CLASSIFICATION	Zones X			Zones Y
Discontinuities	1st system	2nd system	3rd system	
1. Uniaxial compressive strength (MPa)	70-110	70-110	70-110	10-25
Rating	7	7	7	2
2.RQD(%)	95.2	95.2	95.2	<25
Rating	20	20	20	3
3. Discontinuity spacing	0.2m	0.5-1.0m	20-30m	>50m
Rating	10	15	20	20
4.Discontinuity condition				
Length:	10-20m	15m	>20m	1-3m
Rating	1	1	0	4
Aperture:	closed	1-5mm	closed	1-5mm
Rating	6	1	6	1
Roughness	slickensided to slightly rough walls	undulating rough	slickensided walls	slightly rough
Rating	2	4	1	3
Infilling:	without infilling	clayey calcite infilling	without infilling	soft infilling <5mm
Rating	6	3	6	1
Weathering:	unweathered	slightly weathered	negligibly to slightly altered	highly weathered
Rating	6	4	5	1
5. Groundwater				
Inflow per 10m' of tunnel (l/min):	none			
General condition:	dry			
Rating	15	15	15	15
Total rating without the effect of spatial orientation of discontinuities	73	70	80	35
6. Correction for the effect of discontinuity strike and dip (for slopes)	unfavorable	unfavorable	unfavorable	generally good
Rating	-50	-50	-50	-25
Total rating	23	20	30	10
Category	iv	v	iv	v

Table 5. RMR_{89} classification of rock mass in side cut at an angle of 65°

	Zones X			Zones y
Total rating without the effect of spatial orientation of discontinuities	1st system =73	2nd system =70	3rd system =80	35
6. Correction for the effect of discontinuity strike and dip (for slopes)	good	unfavorable	unfavorable	generally good
Rating	-25	-25	-25	-25
Total rating	48	45	55	10
Category	III	III	III	V

Table 6. Rock mass category according to the RMR_{89} classification

Rating	100-81	61-80	41-60	21-40	<20
Category	I	II	III	IV	V
Description of rock	Very good	Good	Fair	Poor	Very poor

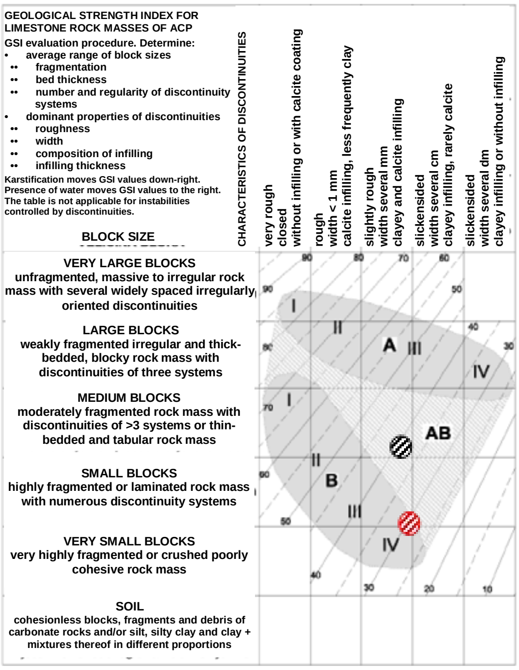

Figure 6. GSI classification of rocks mass in side cut of plateau 14 (⊘ -X zones; ⊘ -Y zones)

5. Conclusion

Four discontinuity systems are registered on plateau 9. Kinematic analysis of their spatial position identified two out of four discontinuity systems that potentially jeopardize stability of the vertical excavation. However, this adverse effect of discontinuity spatial orientation is significantly reduced if the side cut gradient is reduced by 30°. Reducing the side cut gradient also reduces the possibility of forming potentially unstable wedges. In case of a slope at an angle of 60°, the RMR_{89} classification shows that the rock category would change from very poor (V) to poor to fair (IV-III).

Three discontinuity systems are registered on plateau 14. Kinematic stability analysis showed that the unfavorable spatial relation between the discontinuities and the side cut face can be significantly mitigated if the side cut is performed at an angle of 65°. The results of RMR_{89} classification at this angle of side cut showed a change of the category from very poor to poor (V-IV) to fair (III).

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