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ENGINEERING METHOD VERSUS ERASO METHOD OF STRUCTURAL ANALYSIS IN HYDRAULICAL STUDY OF FRACTURED ROCK - CASE STUDY AT UNŠKA KOLIŠEVKA

PRIMERJAVA UPORABE INŽENIRSKE METODE IN METODE ERASO STRUKTURNE ANALIZE PRI HIDRAVLIČNEM PROUČEVANJU KAMNINE - PRIMER UNŠKE KOLIŠEVKE

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Miran Veselič & Barbara Čenčur Curk & Stanka Šebela: Primerjava uporabe inženirske metode in metode Eraso strukturne analize pri hidravličnem proučevanju kamnine - primer Unške Koliševke

Namen raziskave je bil narediti primerjavo med dvema metodama strukturne analize: metodo Eraso ter inženirsko metodo in ugotoviti primernost obeh za ugotavljanje toka podzemne vode. Ti dve metodi temeljita na različnih principih: prva temelji na mikrotektonski analizi in se večinoma uporablja na površinskih golicah, medtem je bila druga razvita v namene pručevanja geotehničnih in hidravličnih lastnosti kamnine. Meritve so bile izvedene na površinskih golicah in v raziskovalnem rovu pod njimi, in sicer v dveh različnih sezonah (jesen 95 in poletje 96). Metoda Eraso se pogosto uporablja v regionalnem (mega) merilu za določanje najpogostejših smeri drenaže na krasu. Inženirska metoda pa se uporablja navadno v makro merilu, vendar so rezultati pokazali, da lahko sklepamo tudi na regionalne smeri drenaže.

Ključne besede: razpoklinske kamnine, karbonatne kamnine, kras, strukturna analiza, tok podzemne vode.

Abstract UDC 556.3: 552.54 (497.4)

Miran Veselič & Barbara Čenčur Curk & Stanka Šebela: Engineering method versus Eraso method of structural analysis in hydraulical study of fractured rock - case stady at Unška Koliševka

The main goal of the study was to compare the Eraso method and engineering method for determining water drainage. These two methods are based on different principles: the first one is based on microtectonic analysis and is mainly applied on surface outcrops, while the second one was developped with purpose of studying geotechnical and hydraulical properties of the rock. Measurements were carried out on surface outcrops and within underground artificial tunnel in two different seasons (autumn 95 and spring 96). The Eraso method is frequently used in karst area to determine direction of regional drainage (mega scale). The engineering method was developed for studies in macro scale, but from the results is evident, that direction of regional waterflow can be obtained.

Key words: Fractured rock, Carbonate Rock, Karst, Structural analysis, Underground water drainage.

INTRODUCTION

Fractured and karstified rocks owing to their geometry and topology of voids, are heterogeneous and complex, which results in complicated hydraulical, mechanical, thermical and chemical processes and varying of their parameters (Veselič 1995a). Therefore the detailed study of these processes has to be performed on a detailed scale, on experimental field sites for example.

Experimental field sites are a very important tool for detailed studies of flow and solute transport in karstified rocks. Possible locations for such sites include mine tunnels, artificial tunnels, karstic caves and quarries. For natural caves, their specific features need to be taken into account, since they were created along the most permeable conduits and are therefore predetermined, while in artificial tunnels the stress-strain state of rock in the vicinity of the tunnel changes as a result of digging.

When an experimental field site is selected, an accurate survey of the surface and underground structures is first performed. The basic characteristics of rock at the site must be determined first. This is followed by petrographic and structural analyses of the rock in order to determine fracture parameters. Only then a group of experiments (agrohydrological, tracer test, geophysical and geochemical methods) can be performed on such experimental field site (Čenčur Curk1997b).

For these purposes several experimental field sites in Slovenia were selected, where structural analysis was performed. Two experimental field sites were located at Unška Koliševka and at Sinji Vrh, where structural analysis of the surface outcrops and within the artificial tunnels was performed. In case of mine tunnels structural analysis was performed in two layers at the Pb-Zn Mine Mežica while Idrija Mercury Mine was not selected (Obal, Rozman & Miklavčič, 1996). This work was performed as a part of a research project with the objective of studying solute (pollutant) transport in fractured and karstified rock (Čenčur Curk, Veselič & Vižintin 1997a), i.e. more accurately in the unsaturated zone of aquifers in these types of rock (Veselič 1995b). The first phase of this project comprised a detailed structural analysis of the carbonate rock. In this paper results of structural analysis at the experimental field site at Unška Koliševka are presented.

The aim of this study was to compare two methods of structural analysis, which are based on different principles. The *Eraso method* is based on microtectonic analysis and is mainly applied on surface outcrops which are more or less weathered and is applied more in mega (regional) scale (Eraso 1985/86). Although an application of this method to quarries is envisaged (Eraso and others 1995), it is not found in the accessible published literature. An *engineering method*, where a quantitative description of discontinuities is performed, was developed with purpose to study geotechnical and hydraulical properties of fractured rock in a macro scale (Brown 1981; Louis 1972). This method is therefore applied on freshly excavated rock in quarries, tunnels and engineering construction sites.

The main goal of our research was to study hydraulical properties of fractured and karstified rock and to compare the results and applicability of both methods in this kind of rock. Owing to the fact that measurements were performed twice within a certain time distance, a repeatability of each method could be studied. Furthermore an accordance of surface data and tunnel data results of each method was examined, namely with the intention of verifying the applicability of engineering method to the natural surface outcrops and the Eraso method to the artifical structures (excavations). Moreover an analysis of applicability of both methods to real structures in macro scale was committed.

METHODS OF DISCONTINUITY ANALYSIS

Fractured and karstified rocks are very heterogeneous and anisotropic, hence a continuum approach can not be used. Due to this fact a discontinuum approach has to be applied, furthermore a good knowledge of rock structure, i.e. distribution of discontinuities in space on a detailed scale is very important.

Engineering method (quantitative description of discontinuities)

For purpose of mathematical modelling of flow and transport in fractured and karstified rock enough data on parameters is required. A detailed statistical analysis of fractured rock is needed for determining the geometrical characteristics of the rock. This is the first step of studying hydraulic characteristics of rock and the data are after that used for in situ measurements of permeability in boreholes (Louis 1972). This method was used on the experimental field sites in Slovenia (Veselič and Čenčur Curk 1996, 1997).

In the first phase all discontinuities have to be precisely described. Thus orientation, density (spacing), persistence (length) of discontinuities, roughness, wall strength, aperture and filling of discontinuities, seepage, number of sets and block size have to be determined. These parameters define a geometry of fractured system. For the sake of easier data gathering the discontinuities have to be written in a special form, which was modified from Louis (1972) and Brown (1981). The parameters, such as type of structural element (bedding plane, fracture, fault, stylolite, bedding shifts), orientation, fracture system, spacing and length have to be filled in the form. Aperture and roughness in case of open discontinuity and width, filling in case of filled discontinuity and weathering grades, water content for both have to be determined. The description of roughness ranks and seepage ratings was resumed after Brown (1981). Statistical analysis is more reliable the more data is gathered.

In the second phase the statistical analysis is carried out. However the classical statistical analysis is not sufficient, seeing that not all discontinuities act similarly from hydraulical point of view. Therefore a weighting factor, respectively a significance criteria, consisting of length, continuity and fracture aperture is assigned to each discontinuity. Louis (1972 and 1974) proposes two types of weighting for selecting the hydraulically efficient fractures. The first gives a significance to fracture aperture and length. Extending of a plane in space is very difficult to determine, therefore the continuity values are only approximate. Due to this fact we decided for the second type of weighting, which takes into consideration fracture aperture and water content. The weight is consisted of water presence factor (α) and aperture (β):

$$P(N) = (0{,}1 + \alpha + \beta)/2{,}1; \quad [\alpha , \beta] \in [0{,}1], \; P(N) \in [0{,}1],$$

where N is a number of measurements. The applied weighting factors are presented in the table 1.

The majority of fractures has a very small aperture, which can not be seen with unaided eye and are assumed as closed fractures (factor of subjectivity). In detailed researches the aperture is therefore obtained with the means of electronic microscope and can be measured in mm.

The combination of described method and classical detailed mapping (of fractures) is even more efficient method of studying of structural elements. Even better is the combination with ste-

α (water presence / prisotnost vode)	description / opis
0	no water / ni vode
0,2	wet / vlažno
0,4	water present / voda prisotna
0,6	tears / solzenje
0,8	dripping / kapljanje
1	flowing / teče

β (aperture / odprtost)	mm
0	0
0,1	1 - 2
0,2	2 - 3
0,3	3 - 4
0,4	4 - 5
0,5	5 - 6
0,6	6 - 7
0,7	7 - 8
0,8	8 - 9
0,9	9 - 10
1	> 10

Table 1: Weighting factors α and β (Veselič & Čenčur Curk 1996; Čenčur Curk, 1997).
Tabela 1: Utežnostni faktorji α in β.

reophotographs due to greater accuracy. Thus the data on discontinuity location and properties can be obtained and the conceptual model based on physical processes and thereafter a relevant mathematical model, such as single fracture model, parallel fractures model, fracture network model, hybrid model or multicontinuum model (Čenčur Curk 1997b) can be designed.

The Eraso method

The Eraso method has been frequenthy described in papers (Knez and Šebela, 1994; Eraso et al., 1995), therefore only a short description of the method is presented.

The Eraso method is based on two hypotheses. The first one is qualitative and states that karst is predetermined by tectonic conditions suffered by the rock massif, so, it determines the disposition of the tridimensional net of drainage conduits, according to its geological history (Eraso 1985/86). The second hypotheses affirms, that the most probable drainage directions are organized inside planes which have the maximum components$_1$ and the intermedi-

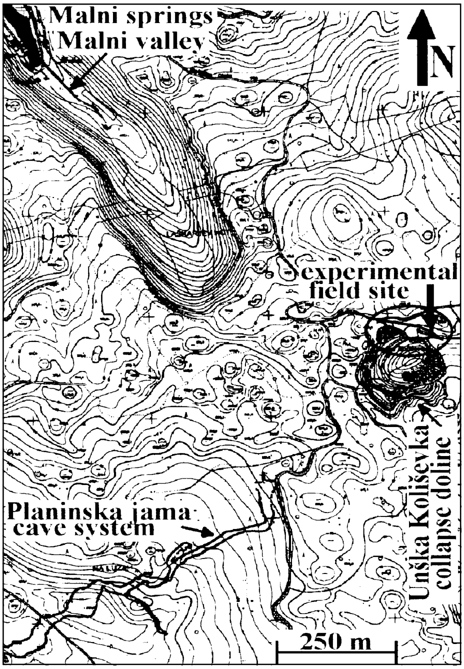

Fig. 1: Position of Unška Koliševka, Malni springs and Planinska jama cave system.
Sl. 1: Lokacija Unške Koliševke, izvira Malni in jamskega sistema Planinske jame.

ate component s_2 of each stress ellipsoid; in consequence, they are perpendicular to the minor component s_3 of each respective ellipsoid (Eraso 1985/86). These components can be defined on a detailed scale by analysing the micro-structures (microtectonic analysis) and specially the tectoglyphs, such as stylolites joints, veins or mineral dykes and friction striation. The tectoglyphs are traces of the permanent deformation caused by tectonic stresses and have a genetic significance which makes them useful to define the ellipsoid (Eraso and others 1995). We'll have the more favourable situation to define the deformation ellipsoid when two or more different tectoglyphs are combined as we define with them the main effort components. The more suitable combinations are: combined faults, fault-vein, stylolite-vein and fault-stylolite (Eraso and others 1995).

CASE STUDY

Description of the experimental field site Unška Koliševka

Experimental field site is situated in the southwestern part of Slovenia at the karstic area. This area is composed of karstic Cretaceous (K_1) limestone (Čar 1984). The research area is at the north edge of the collapse sinkhole. Fractured limestone has the dip direction of SW and the dip from 20° - 40°. The limestone in the research area is 99 % composed of calcite.

The experimental field site at Unška Koliševka is composed of surface outcrops and artificial research tunnels, about 15 meters below. The tunnel directions are relatively parallel to the edge of karst feature, a collapse sinkhole.

Malni springs are 900 m distant from Unška Koliševka collapse doline towards NW (Fig. 1). Morphological valley of Malni is oriented towards NW (325°). The Planinska jama cave system is very close by the collapse doline; this part of the system has direction NE-SW.

RESULTS

At the experimental field site Unška Koliševka the measurements were performed on surface outcrops and within the research tunnel. The measurements were performed in a wet season (autumn 1995) and repeated in a dry season (summer 1996). The walls in the tunnels were painted, therefore the measurements within the tunnel were made difficult. In a small hall (Fig. 2) such difficulties did not appear. In this case more principal strike directions can be seen and the data are more dissipating. The surface outcrops are divided by a fault which caused different dip directions at each side.

Engineering method

The results of the engineering method are presented in figures 2-5 and 10-11 as contours of numbers of poles (expressed as a percentage) per unit of the lower hemisphere of the equal-area (Schmidt) projection. Statistical weigthed average values are shown in the table 2.

The major density (>10 %) of discontinuities data on the surface outcrops in 1995 (Fig. 2) is presented by dip direction and dip of 70/65. The following less presented directions (8-10%) are 345/85 and 260/80. Within the tunnel (Fig. 3) the major density (8-10 %) direction is 255/55, which is more gentle sloping than in the surface data. The major direction from surface data repeats in the

	1995				1996			
	n	>10%	8-10%	6-8%	n	>10%	8-10%	6-8%
surface outcrops	56	70/65	345/85	162/85	92	70/80		200/70
			260/80	258/68				
underground tunnel	51		255/55	200/85	140		313/5	
				200/50				
				273/8				
				313/12				
				74/55				
				122/85				
outcrops and tunnel data	107		70/70	258/55	232			305/5
								70/80

Table 2: Weighted dip directions and dips for discontinuities at Unška Koliševka.
Tabela 2: Ponderirani vpadi diskontinuitet pri Unški Koliševki.

tunnel as less represented (6-8 %) direction with more gentle dip (74/55). The united data (Fig. 10) are thus presented as 70/70 (8-10 %) and 258/55 (6-8 %).

The major discontinuities direction (>10 %) from the measurements in 1996 at surface outcrops (Fig. 4) is 70/80, which is very similar to the 1995 measurements, where the dip was more gentle. The less presented direction (6-8 %) is 200/70. The data from the tunnel (Fig. 5) are more dispersed; the major (8-10 %) direction is 313/5, which is presented also in the 1995 data but with smaller density (6-8 %).

The Eraso method

The results of Eraso method are depicted in figures 6-9 and 12-13. Results of principal drainage planes (the areas of equal concentrations) are shown as poles on stereographic net. Graphics were done with computing programme GEOPOL, which calculates and draws, for a determined population of planes and/or areas with the same poles concentration, according to the established percentage chart.

Most common drainage directions concerning data from year 1995 and 1996 are shown in table 3, which is done on base of hystogrames made by computing programme KOLMO, which calculates and draws hystograms of principal drainage planes (Eraso and others 1995).

Differences in maximum percentage between data from hystograms (Table 3) and data on stereographic nets (Fig. 6 - 9 and 12 - 13) is due to the fact that on steregraphic nets also dip angles are included while hystograms are made just on the basis of strike directions.

In 1995 (Fig. 6) the synthesis of data measured on surface showed maximal concentration of poles on stereographic net 22,73 % representing drainage plane 0-15^0 from N to W. Measurements from surface outcrops in 1996 (Fig. 8) are showing maximal concentration of poles 16,36 % with drainage plane for 0-15^0 from N to W.

Data from artificial tunnel measured in 1995 are on Fig. 7 (max. concentration of poles 14,81 %) and represent most common drainage plane direction oriented 15-30^0 from N to W. After

	surface data golice na površini		tunnel data rov		united data združeni podatki	
drainage direction smer drenaže	1995 N=22	1996 N=55	1995 N=27	1996 N=49	1995 N=49	1996 N=104
0°-15°				18,3%		12,5%
15°-30°						
30°-45°				10,2%		
45°-60°	13,6%					
60°-75°	13,6%	18,1%				11,5%
75°-90°						
90°-105°						
105°-120°						
120°-135°			18,5%		12,2%	
135°-150°						
150°-165°		12,7%	25,9%		14,2%	
165°-180°	27,2%	20%	18,5%	12,2%	22,4%	16,3%

Table 3: Comparison of most common directions of drainage at experimental field site Unška Koliševka.

Tabela 3: Primerjava najpogostejših smeri drenaže na terenskem eksperimentalnem poligonu pri Unški Koliševki.

measurements in 1996 (Fig. 9) maximal concentration of poles is 10,20 % with direction of drainage plane 0-15^0 from N to E. In that example data are not well comparable regarding measurements in 1995 with 1996.

United data (surface and tunnel) measured in 1995 (Fig. 12) are showing principal concentration of poles 12,24 % and principal drainage planes 0-15^0 from N to W. United measurements from 1996 (Fig. 13) represent maximal concentration of poles 8,65 % with drainage plane 0-15^0 from N to W.

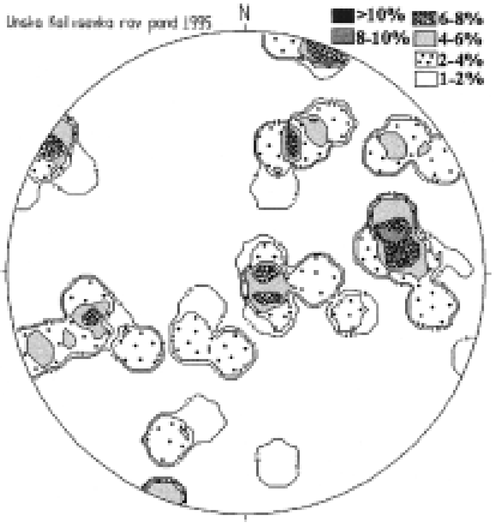

Fig. 2: Results of engineering method: poles of discontinuities for surface outcrops, Unška Koliševka, 1995.
Sl. 2: Rezultati inženirske metode: poli ravnin diskontinuitet - površinske golice, 1995.

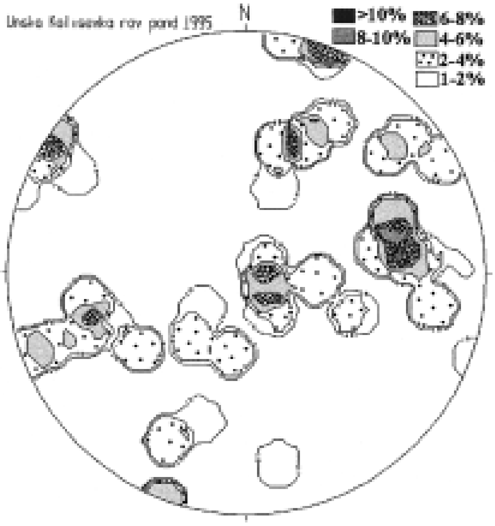

Fig. 3: Results of engineering method: poles of discontinuities for underground tunnel, Unška Koliševka, 1995.
Sl. 3: Rezultati inženirske metode: poli ravnin diskontinuitet - rovi, 1995.

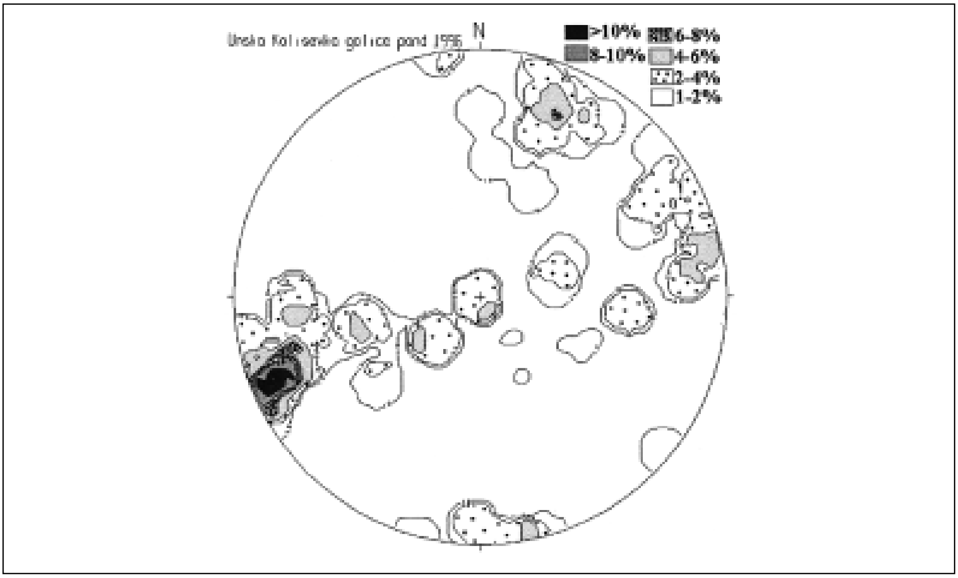

Fig. 4: Results of engineering method: poles of discontinuities for surface outcrops, Unška Koliševka, 1996.
Sl. 4: Rezultati inženirske metode: poli ravnin diskontinuitet - golice, 1996.

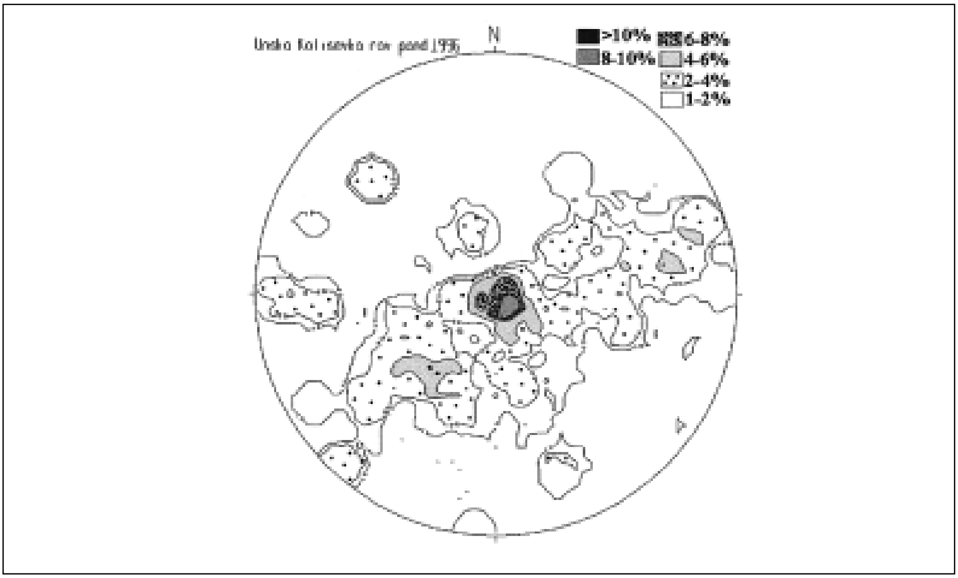

Fig. 5: Results of engineering method: poles of discontinuities for underground tunnel, Unška Koliševka, 1996.
Sl. 5: Rezultati inženirske metode: poli ravnin diskontinuitet - rovi, 1996.

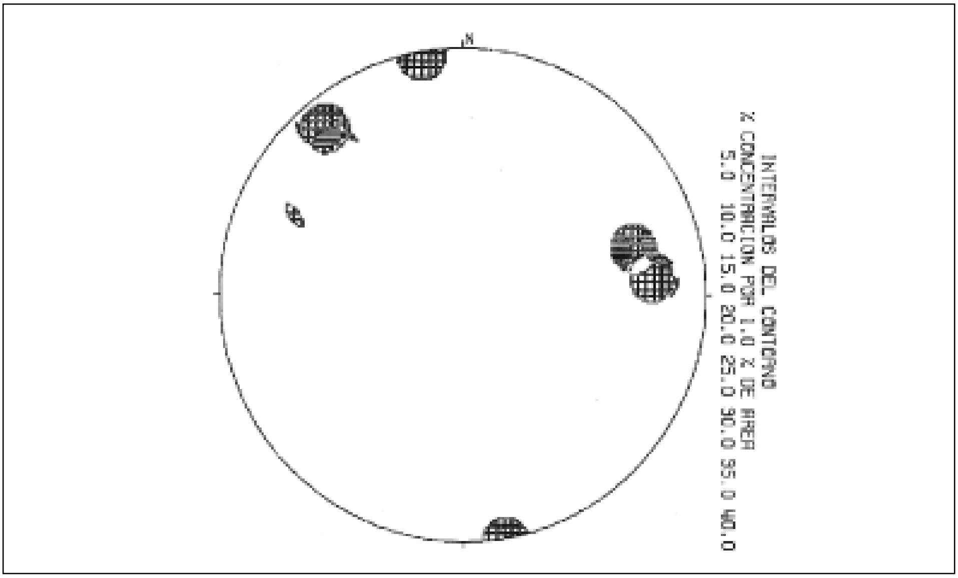

Fig. 6: Results of Eraso method: poles of principal drainage planes for surface outcrops, Unška Koliševka, field measurements in 1995.
Sl. 6: Rezultati metode Eraso: poli ravnin glavnih smeri drenaže - golice, 1995.

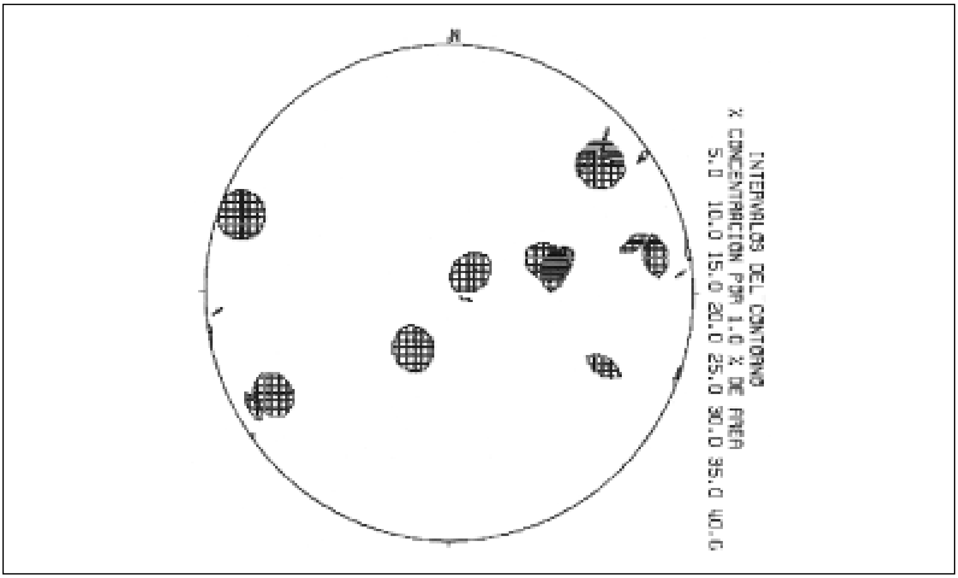

Fig. 7: Results of Eraso method: poles of principal drainage planes for underground tunnel, Unška Koliševka, field measurements in 1995.
Sl. 7: Rezultati metode Eraso: poli ravnin glavnih smeri drenaže - rov, 1995.

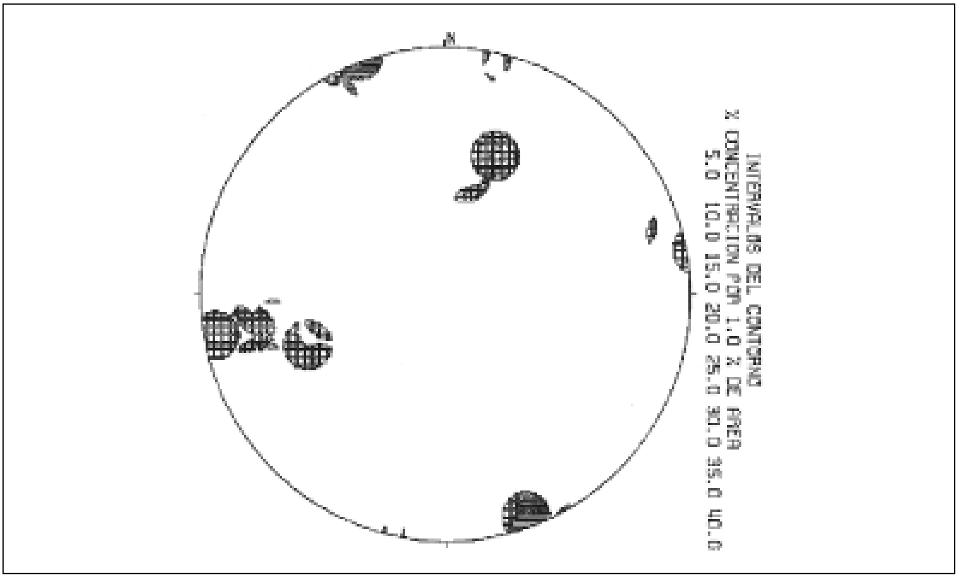

Fig. 8: Results of Eraso method: poles of principal drainage planes for surface outcrops, Unška Koliševka, field measurements in 1996.
Sl. 8: Rezultati metode Eraso: poli ravnin glavnih smeri drenaže - golice, 1996.

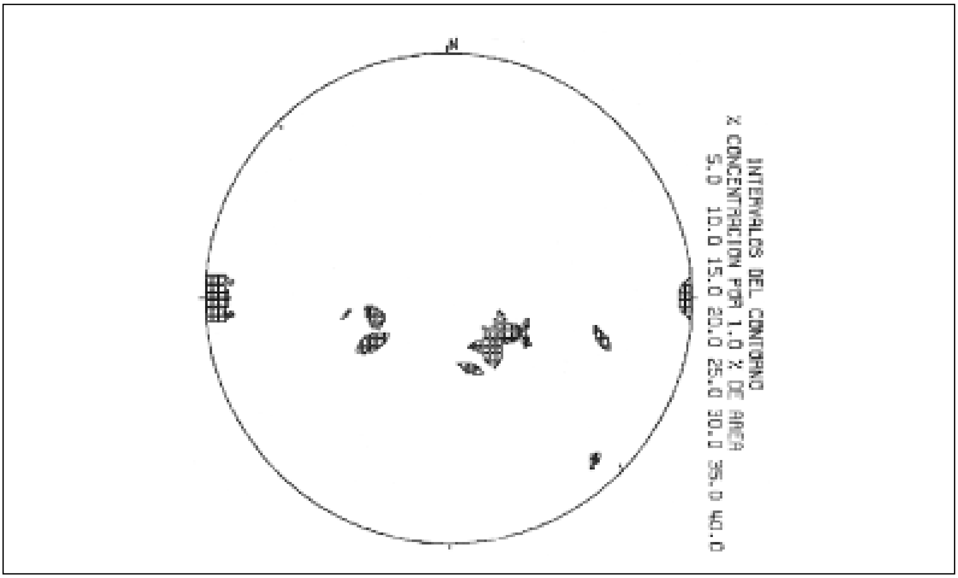

Fig. 9: Results of Eraso method: poles of principal drainage planes for underground tunnel, Unška Koliševka, field measurements in 1996.
Sl. 9: Rezultati metode Eraso: poli ravnin glavnih smeri drenaže - rov, 1996.

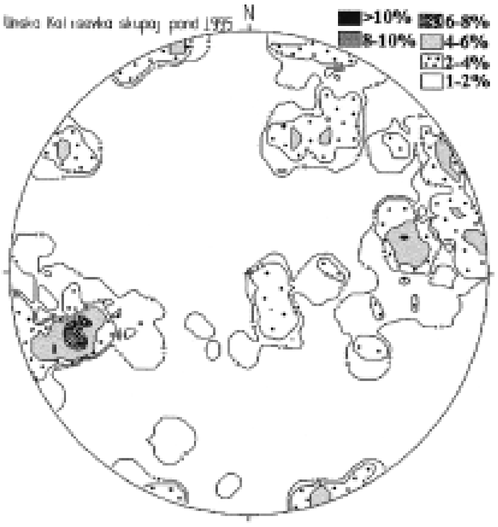

Fig. 10: Results of engineering method: poles of discontinuities for surface outcrops and underground tunnel, Unška Koliševka, 1995.
Sl. 10: Rezultati inženirske metode: poli ravnin diskontinuitet - golice in rov, 1995.

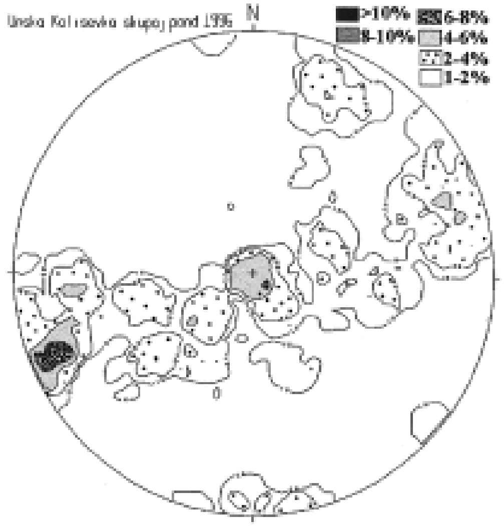

Fig. 11: Results of engineering method: poles of discontinuities for surface outcrops and underground tunnel, Unška Koliševka, 1996.
Sl. 11: Rezultati inženirske metode: poli ravnin diskontinuitet - golice in rov, 1996.

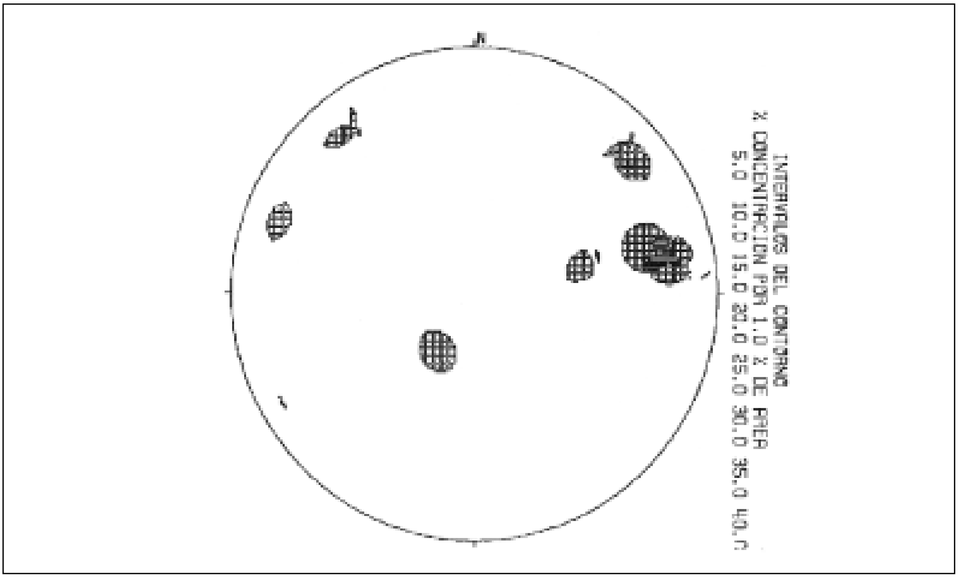

Fig. 12: Results of Eraso method: poles of principal drainage planes for surface outcrops and undreground tunnel, Unška Koliševka, 1995.
Sl. 12: Rezultati metode Eraso: poli ravnin glavnih smeri drenaže - golice in rov, 1995.

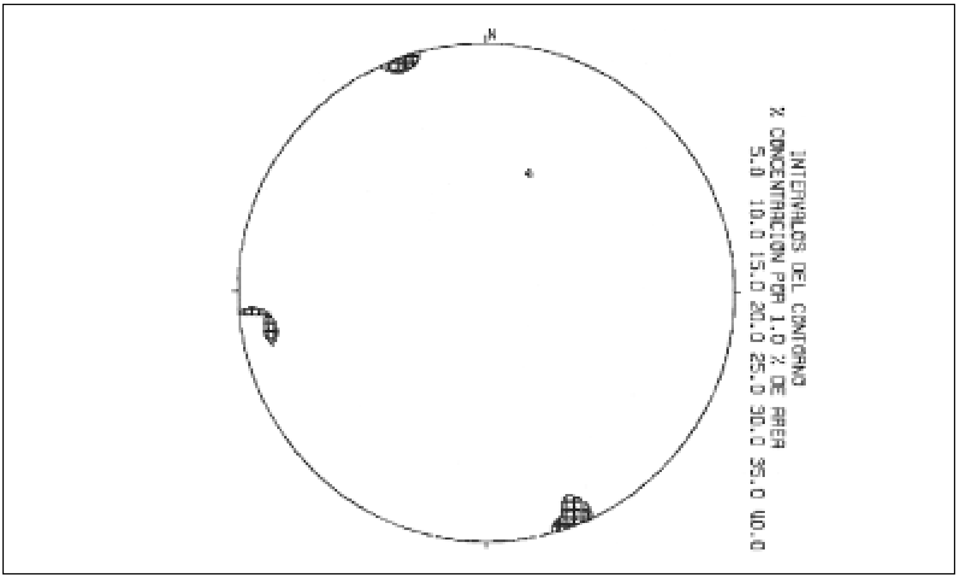

Fig. 13: Results of Eraso method: poles of principal drainage planes for surface outcrops and underground tunnel, Unška Koliševka, 1996.
Sl. 13: Rezultati metode Eraso: poli ravnin glavnih smeri drenaže - golice in rov, 1996.

CONCLUSIONS

From the results of measurements in 1995 and 1996 we can conclude that engineering method is repeatable in this case study. Slight discrepancies are due to different rock saturation states, because measurements were performed in two different seasons (wet season - autumn and dry season - summer), which have an effect on weighting factor a (water presence factor). An accordance of surface and tunnel data in 1995 is observed, which proves applicability of the engineering method not only in freshly excavated rock (underground tunnel in this case) but also on weathered surface outcrops. The accordance is smaller owing to a fault crossing the research area at surface outcrops, meanwhile the tunnel data are only in one side of this fault. The regional drainage direction at Unška Koliševka from NW to SE is evidently presented in all data except the tunnel data in 1996, where this drainage direction is not so obvious. The second drainage direction NE-SW can not be seen at the first moment, but is present in all data.

As far as Eraso method is concerned, number of measurements from area near Unška Koliševka (Table 3) were in 1996 much more enlarged than in 1995, namely from 49 to 104. The most common direction of drainage plane from united data from surface and artificial tunnel is in year 1995 as also in 1996 in general direction 165-180^0, so the direction NNW-SSE. In measurements from surface data also the direction NE-SW is well expressed.

At the end we can draw some basic conclusions from the results of measurements. The repeatability of both methods is good. Both methods are applicable both on the surface outcrops (weathered rock) as on freshly excavated rock (artificial tunnels and quarries) and are applicable on a macro scale. The results have shown, that we can infer from the macro scale data set to the mega (regional) scale. Consequently both methods are useful for the extrapolation of results to the regional scale.

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REFERENCES

Brown, E.T. 1981: Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses, v *Rock Characterization, Testing & Monitoring*.- ISRM, p.3-72, Pergamon Press.

Čar, J. 1984: O geologiji krasa med Postojni in Cerknico.- *Acta carsologica*, **XII**: 91-106.

Čenčur Curk, B., Veselič, M., Vižintin, G. 1997a: Experimental study of solute transport in a carbonate porous media, in *Water Pollution 97, Modelling, Measuring and Prediction*, eds. R. Rajar & C.A. Brebbia, p.409-420, Computational Mechanics Publications, Southampton, UK.

Čenčur Curk, B. 1997b: Experimental field sites as a basis for the study of solute transport in the vadose zone of karstified rock.- *Acta hydrotechnica*, **15/20**, 111p., Ljubljana.

Eraso, A. 1985/86: Método de predicción de las direcciones principales de drenaje en el karst.- *KOBIE* (Serie Ciencias Naturales), **XV**: 15-165, Bilbao.

Eraso, A., Cucchi, F., Fernandez, J., Orden, J.A., Torelli, L. 1995: Application of the directional prediction method to the drainage of the Reka-Timavo underground river.- *Acta carsologica*, **24**: 187-202 (Symposium Man on Karst, Postojna, 1993).

Knez, M., Šebela, S. 1994: Poskus uporabe Erasove metode pri študiju regionalne preskrbe Bele Krajine s pitno vodo.- *Naše jame*, **36:** 67-76.

Louis, C. 1972: Rock Hydraulics, in *Rock Mechanics*, ed. L. Müller, p.300-387, Springer-Verlag, Wien-New York.

Louis, C. 1974: Introduction á l'hydraulique des roches.- *Bulletin du Bureau de recherches geologiques et minieres (B.R.G.M)*, **III/4**: 283-356.

Obal, M., Rozman, S., Miklavčič, V. 1996: The problem of (Pit, Waste Depot) waters During the Shutdown Phase of the Idrija Mine.- in: Idrija as a natural and anthropogenic laboratory: Mercury as a major pollutant, p. 42-47, Idrija.

Veselič, M. 1995a: Groundwater Pollution Control in Fractured and Karstified Rocks, in *Advanced Methods for Groundwater Pollution Control*, eds. G. Gambolati & G. Veri, p.235-244, CISM & SpringerVerlag.

Veselič, M. 1995b: Study of Mass Transport in Fractured and Karstified Rocks.- *Project Proposal for 1995-1997* Research Grant of the Ministry of Science and Technology of the Republic of Slovenia, 12 p, Ljubljana.

Veselič, M., Čenčur Curk, B. and coll. 1996: Study of Mass Transport in Fractured and Karstified Rocks, Report of the first phase.- *Rep. J1-7172-0210-95*, Ministry of Science and Technology, Ljubljana.

Veselič, M., Čenčur Curk, B. and coll. 1997: Study of Mass Transport in Fractured and Karstified Rocks, Report of the second phase.- *Rep. J1-7172-0210-96*, Ministry of Science and Technology, Ljubljana.

PRIMERJAVA UPORABE INŽENIRSKE METODE IN METODE ERASO STRUKTURNE ANALIZE PRI HIDRAVLIČNEM PROUČEVANJU KAMNINE - PRIMER UNŠKE KOLIŠEVKE

Povzetek

Uvod

Kamnine s kraško-razpoklinsko poroznostjo predstavljajo zaradi zapletene geometrije in topologije praznin komplicirano geometrično strukturo s kompleksnimi hidravličnimi, mehanskimi, termičnimi in kemični procesi, ki so med seboj ozko povezani in odvisni. Zaradi tega je potrebna detajlna študija procesov toka in prenosa snovi v velikem merilu (makro skala), ki jo lahko izvršimo na terenskem eksperimentalnem poligonu. Slednji so zelo pomembno orodje pri preučevanju toka in prenosa snovi v kamninah s kraško-razpoklinsko poroznostjo; možne lokacije so lahko rovi v rudnikih in drugi umetni rovi pod površino, kraške jame ali pa deli kamnolomov. V primeru naravne kraške jame moramo upoštevati strukturno specifičnost jam, saj so nastale ob najbolj prepustnih kanalih in križiščih razpok; pri umetnih izkopih pa moramo upoštevati spremembe napetosti v kamnini okoli izkopa. Na izbranem terenskem eksperimentalnem poligonu izvedemo natančno geodetsko izmero, določimo litološko - strukturne značilnosti kamnine in parametre razpok s strukturno analizo; ko je vse to dovolj proučeno, se izvede različne poskuse (agrohidrološki, sledilni poskusi, uporaba geofizikalnih in geokemičnih metod).

V okviru raziskovalnega projekta z naslovom "Študija prenosa snovi v razpoklinskih in kraško-razpoklinskih kamninah" smo izbrali več terenskih eksperimentalnih poligonov. Na dveh smo izvedli strukturno analizo na površinskih golicah in v raziskovalnih rovih (Unška Koliševka, Sinji Vrh). V primeru rudnikov smo izvedli strukturno analizo na dveh obzorjih v rudniku svinca in cinka Mežica, medtem ko rudnik Idrija ni bila izbran kot eksperimentalni poligon (Obal et.all. 1996).V prvi fazi tega projekta smo izvedli strukturno analizo v karbonatnih kamninah; v tem članku predstavljamo rezultate iz terenskega eksperimentalnega poligona pri Unški Koliševki.

Cilj študije je bil ugotoviti hidravlične značilnosti razpokane in zakrasele kamnine in primerjava dveh metod strukturne analize, ki temeljita na različnih principih. *Metoda Eraso* temelji na mikrotektonski analizi (Eraso 1985/86) in se jo večinoma uporablja v regionalnem (mega) merilu na golicah, ki so bolj ali manj preperele. Uporaba te metode v sveži kamnini (kamnolomi) je sicer predvidena (Eraso et. all, 1995), a doslej je še nismo zasledili v dosegljivi literaturi. *Inženirska metoda* je bila razvita za proučevanje geotehničnih in hidravličnih značilnosti razpokanih kamnin (Brown 1981; Louis 1972) v velikem (makro) merilu. Pri tej metodi izvedemo kvantitativni opis diskontinuitet na sveži površini kamnine (kamnolomi, rovi, ipd.).

Meritve diskontinuitet smo izvedli dvakrat v večjem časovnem razmaku, zato smo lahko ugotavljali tudi ponovljivost posamezne metode. Nadalje nas je pri posamezni metodi zanimalo ujemanje podatkov iz površine s podatki iz rovov, da bi lahko ugotovili uporabnost inženirske metode na površinskih golicah in metode Eraso na umetnih rovih. Na koncu smo želeli primerjati rezultate obeh metod z ugotovljenimi regionalnimi strukturami.

Metode analize strukturnih elementov

Razpokane in zakrasele kamnine so zelo heterogene in anizotropne, zato jih ne moremo obravnavati kot kontinuum, temveč kot diskontinuum in je za preučevanje procesov v teh kamninah potrebno dobro poznavanje strukture kamnine, to je razporeditev diskontinuitet v prostoru v natančnem merilu.

Inženirska metoda (kvantitativni opis diskontinuitet: Za določitev geometričnih značilnosti kraško-razpoklinske kamnine je potrebna natančna statistična analiza razpoklinskega sistema. To je po Louisu (1972) prva stopnja pri proučevanju hidravličnih karakteristik takšne kamnine. Metodo po Louisu smo modificirali in uporabili tudi na naših terenskih eksperimentalnih poligonih (Veselič & Čenčur Curk, 1996).

V prvi fazi na terenu natančno opišemo vse diskontinuitete. Tako ugotavljamo orientacijo, pogostnost in obliko diskontinuitet. Ti parametri določajo geometrijo razpoklinskega medija. Za lažje zbiranje podatkov o diskontinuitetah smo pripravili poseben formular, ki smo ga priredili po Louisu. Pri opisu diskontinuitete moramo določiti vrsto strukturnega elementa (razpoka, prelom, plast), vpad, pripadnost sistemu razpok, gostoto, obseg. Pri odprtih diskontinuitetah moramo določiti odprtost, hrapavost, pri zapolnjenih razpokah pa širino, polnitev ter za obe preperelost in vodoprepustnost.

V drugi fazi izvedemo statistično analizo. Za zanesljivo statistično analizo je potrebno zbrati čim več podatkov o diskontinuitetah. Vendar navadna statistična analiza ne zadošča, saj s stališča hidravličnih značilnosti niso vse diskontinuitete enakovredne. Zato vsaki diskontinuiteti dodelimo utež (težnostni faktor ali ponder) oziroma kriterij pomembnosti, ki sestoji iz dolžine, kontinuitete in odprtosti razpok. Pri tem Louis (1972) predlaga dva tipa ponderiranja: prvi daje pomembnost širini in kontinuiteti razpok. Kontinuiteta je razmerje med dolžino razpoke, ki seka steno rova in absolutno dolžino razpoke, če bi bila le ta po celi dolžini zvezna. Na površini je to razmerje dolžine razpoke in referenčne dolžine, ki jo določimo sami. Razprostiranje neke ploskve v prostoru je zelo težko določiti, zato so vrednosti za kontinuiteto le približne. Zaradi tega smo se odločili za drugi tip ponderiranja, ki izbere hidravlično efektivne razpoke: utež (*P*) sestoji iz faktorjev prisotnosti vode v razpoki (α) in odprtosti (β):

$P(N) = (0{,}1 + \alpha + \beta)/2{,}1; \quad [\alpha, \beta] \in [0{,}1], \; P(N) \in [0{,}1],$ kjer je *N* število meritev.

Izbrane uteži so prikazane v tabeli 1.

Večina razpok ima zelo majhno odprtost, zato jo s prostim očesom ne vidimo in določimo take razpoke kot zaprte (odprtost=0; subjektivnost). Pri zelo detajlnih preiskavah odprtost dobimo iz posnetkov elektronskega mikroskopa in jo lahko merimo v mm.

Kombinacija metode po Louisu in površinskega kartiranja je bolj učinkovita metoda proučevanja strukturnih elementov. Še boljša pa je kombinacija s stereoposnetki, saj so te meritve bolj natančne. Tako dobimo podatke o lokaciji in lastnostih diskontinuitet in lahko postavimo konceptualni model na osnovi fizikalnih procesov in zatem še ustrezni numerični model (model posamezne razpoke, model vzporednih razpok, model mreže razpok ali pa hibridni in multikontinuum model).

Metoda Eraso (metoda določanja najpogostejših smeri drenaže): Metoda Eraso je bila že večkrat opisana v prispevkih (Knez & Šebela, 1994; Eraso et al., 1995), zato v nadaljevanju podajamo le kratek opis.

Metoda Erasa omogoča prognozo najpogostejših smeri pretakanja vode, ki so v kraških vodonosnikih zelo različne. Metoda temelji na mikrotektonski analizi in sicer na dveh hipotezah: prva hipoteza je kvalitativna ter trdi, da je kras predeterminiran s tektonskimi dogodki, ki so prizadeli kamninski masiv. Tektonske napetosti so oblikovale mrežo drenažnih kanalov in anizotropnost drenažnih smeri. Tridimenzionalna mreža drenažnih kanalov je torej posledica njegove geološke (tektonske) zgodovine. Druga hipoteza pa je kvantitativna in pravi, da so najverjetnejše smeri pretakanja vode locirane znotraj ravnin, ki so definirane s smermi maksimalne (σ_1) in srednje (σ_2) komponente napetostnega elipsoida. To pomeni, da so pravokotne na najmanjšo komponento (σ_3) vsakega elipsoida. Te komponente lahko določimo z analizo mikrostruktur v detajlnem merilu. Na terenu zbiramo podatke (orientacija in vpad) o stilolitih, žilah in trenjskih strijah na prelomni ploskvi. Ravnina stilolitskega šiva je ponavadi pravokotna na glavno os (σ_1), medtem ko so žile ponavadi pravokotne na najmanjšo os (s_3). Tako so žile in stiloliti iste tektonske faze med seboj pravokotni. *Trenjske strije* na prelomnih ploskvah kažejo na premike obeh ploskev diskontinuitete zaradi strižnih napetosti. Ravnina preloma in glavna komponenta napetostnega elipsoida (σ_1) tvorita nek določen kot q, ki je odvisen od kota notranjega trenja v kamnini. Ravnine prelomov predstavljajo veliko diskontinuiteto, ki zaradi heterogenosti in anizotropnosti kamnine niso prave geometrijske ravnine, saj povprečna orientiranost niha. Za take ploskve potrebujemo več opazovanj, da dobimo prave statistične vrednosti.

Terenski eksperimentalni poligon pri Unški Koliševki

Eksperimentalni poligon je v severovzhodnem delu Unške Koliševke, ki je v spodnje krednih skladovitih apnencih (Čar 1984) z vpadom 20°-40° proti jugozahodu. Terenski eksperimentalni poligon sestoji iz površinskih golic in umetnih rovov, ki so približno 15 m pod njimi. Glavni rovi so bolj ali manj vzporedni z robom koliševke.

Izvir Malni je v smeri proti severozahodu oddaljen približno 900 m, dolina Malni pa je orientirana v smeri proti NW (325°). V neposredni bližini je tudi del jamskega sistema Planinske jame, ki je v smeri NE-SW (Sl. 1).

Rezultati

Na terenskem eksperimentalnem poligonu pri Unški Koliševki smo izvedli meritve diskontinuitet na površinskih golicah in v umetnih rovih pod njimi. Meritve smo izvedli v mokri sezoni (jesen 1995) in jih ponovili v suhi sezoni (poletje 1996). Meritve v rovih so bile otežkočene zaradi prepleskanih sten v rovih; v majhni dvoranci (Sl. 1) pa teh težav nismo imeli. Površinske golice so razdeljene s prelomom in so na obeh straneh različni vpadi diskontinuitet.

Inženirska metoda

Rezultati inženirske metode so prikazani na slikah 2-5 in 10-11 kot izolinije števila polov (izražene v odstotkih) ravnin diskontinuitet na enoto spodnje hemisfere Schmidtove projekcije. Statistična povprečja vpadov so podana v tabeli 2.

Največjo gostoto diskontinuitet (>10%) pri podatkih, pridobljenih na površinskih golicah v letu 1995 (Sl. 2), predstavlja vpad 70/65. Sledeče manj zastopane (8-10%) smeri so 345/85 in 260/80. Znotraj rovov (Sl. 3) predstavlja največjo gostoto diskontinuitet (>10%) smer 255/55, ki bolj blago vpada kot pri golicah. Najpogostejša smer pri golicah se ponovi v rovih kot manj pogosta (6-8%) smer z bolj blagim vpadom (75/55). Združeni podatki (golice in rovi; Sl. 10) so najpogosteje zastopani z vpadom 70/70 (>10%) in 255/55 (6-8%).

Glavni vpad diskontinuitet (>10%) pri meritvah v letu 1996 na površinskih golicah (Sl. 4) je 70/80, ki je zelo podobna rezultatom meritev v letu 1995, kjer je bil vpad bolj položen. Druga zastopana smer (6-8%) je 200/70, ki je prav tako z isto zastopanostjo prisotna pri meritvah v letu 1995. Rezultati meritev v rovih (Sl. 5) so bolj razpršeni; glavni (8-10%) vpad je 310/5, ki ga zasledimo tudi v rezultatih meritev v letu 1995, vendar z manjšo zastopanostjo (6-8%).

Metoda Eraso

Rezultati metode Eraso so prikazani na slikah 6-9 in 12-13 kot poli glavnih ploskev drenaže (območje enake koncentracije) na sterografski mreži. Grafika je bila narejena s programom GEOPOL. Najpogostejše smeri drenaže podatkov iz leta 1995 in 1996 so prikazane v tabeli 3, kjer so prikazani rezultati histogramov, narejenih s programom KOLMO. Razlika v maksimalnih odstotkih rezultatov, prikazanih na histogramih in na stereografskih mrežah je zaradi različnega prikaza ploskev - na stereografski mreži so prikazane smeri vpada in vpadi, medtem ko so na histogramih prikazane le slemenitve.

Rezultati meritev na golicah v letu 1995 (Sl. 6) so pokazali največjo koncentracijo polov (22,73%) v smeri 0°-15° (od severa proti zahodu), ki je enaka glavni smeri drenaže meritev iz leta 1996 (Sl. 8), le da je v slednjem primeru zastopanost te smeri za spoznanje manjša (16,36%). Najpogostejša smer drenaže v rovu (meritve v letu 1995; Sl. 7) je 15°-30° (od severa proti zahodu), njena zastopanost pa 14,81%, medtem ko je v letu 1996 (Sl. 9) glavna smer drenaže 0°-15° (od severa proti jugu), njena zastopanost pa 10,20%. V primeru rezultatov meritev v rovih meritve iz leta 1995 in 1996 ne sovpadajo tako dobro kot v primeru rezultatov meritev na golicah. Rezultati združenih meritev (golice in rovi) v letu 1995 (Sl. 12) so pokazali največjo koncentracijo (12,24%) polov glavne smeri drenaže 0°-15° (od severa proti zahodu), ki se ponovi pri meritvah v letu 1996 (Sl. 13), le da je zastopanost manjša (8,65%).

Sklepi

Primerjava rezultatov meritev diskontinuitet v letu 1995 in 1996 kaže na ponovljivost *inženirske metode*; manjša neujemanja lahko pripišemo različnim sezonam meritev (mokro obdobje jeseni in suho obdobje poleti), ki imajo velik vpliv na utežnostni faktor a (prisotnost vode). Rezultati iz leta 1995 kažejo ujemanje podatkov površine in rova, kar kaže na uporabnost inženirske metode ne samo v sveži kamnini (v tem primeru podzemni rov), temveč tudi na preperelih površinskih golicah. Slabše ujemanje je zaradi vpliva preloma, ki seka področje raziskav na področju golic, medtem ko so rovi le na eni strani tega preloma. Regionalna smer drenaže na območju Unške Koliševke v smeri NW-SE je prisotna tudi v vseh rezultatih meritev z izjemo meritev v rovu v letu 1996, kjer ta smer drenaže ni tako očitna. Druga regionalna smer drenaže NE-SW ni vidna na prvi pogled, vendar je prisotna v vseh rezultatih meritev.

Kar se tiče *metode Eraso* je bilo število meritev v letu 1996 veliko večje kot v letu 1995 (tabela 3), in sicer iz 49 na 104. Najpogostejša smer drenaže združenih podatkov (golice in rov) je v obeh letih v smeri 165°-180°, kar je smer NNW-SSE, ki relativno dobro sovpada z glavno regionalno smerjo drenaže. V rezultatih meritev na golicah je izražena tudi druga regionalna smer drenaže NE-SW.

Na koncu lahko iz rezultatov meritev ugotovimo, da je ponovljivost obeh metod zadovoljiva. Obe metodi sta uporabni tako na površinskih golicah (preperela kamnina) kot tudi na sveži kamnini (umetni rovi in kamnolomi) v makro merilu. Rezultati so tudi pokazali, da lahko iz podatkov v makro (terenski eksperimentalni poligon) merilu sklepamo na regionalno (mega) merilo in sta obe metodi uporabni za ekstrapolacijo podatkov v regionalno merilo.