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CONTENT

DOI 10.51558/2303-5161.2023.11.11.1 Scientific Paper

LOCALLY CHARACTERISED REPETITIVE ILLEGAL LANDFILLS CLASSIFICATION

Tihomir Knežiček[1], Dean Osmanović[2], Sabina Sinanović Ćatibušić[3]

SUMMARY

Illegal dumping of waste material is present in almost all local communities in Bosnia and Herzegovina, including in the areas of urban and rural local communities of the City of Tuzla. Uncontrolled waste dumping at the landfields, as the illegal dumping, are created by dumping different types of waste material in areas that are not intended for waste material disposal. These are areas that are usually next to roads with less traffic, or in the immediate vicinity of roads where access is possible for motor vehicles with a lower load capacity. Illegal landfills have a direct negative impact on the living environment from several aspects. Primarily, watercourses and soil are polluted, the ambient space is disturbed, and by attracting animals, there is the possibility of infections that are dangerous for the population. Waste materials in illegal landfills are often deliberately set on fire, which causes additional problems of air pollution with smoke and gases resulting from combustion, as well as the possibility of fire outbreaks, especially in forest areas. In the current practice, illegal waste landfills did not have scientific and professional interest because they are often of a temporary nature and were not considered interesting from the aspect of the scientific approach to defining landfills by different classifications. This paper defines the classification of illegal landfills in the spheres of data processing possibilities of interest for the treatment of illegal waste landfills, and the experimental definition of the classification was confirmed on the example of the recording and analysis of illegal waste landfills in the local community of Kiseljak, City of Tuzla in the phase of implementing the project „Inclusive development of Kiseljak community for improvement of social and economic aspect of citizens, emphasizing Roma population", finance by Foundation of Tuzla community, Tuzla. The basis of the classification is made up of repetitive local waste landfills, while permanent regional waste landfills are not the subject of research and classification since there are already known classifications for permanent waste material landfills.

Consent for the publication of the paper was given by the Tuzla Community Foundation, which financed the referral research within the project "Inclusive development of the Kiseljak community, for the improvement of the social and economic aspects of the citizens' life, especially the Roma", implemented by the Tuzla Community Foundation in partnership and financial support of the Freudenberg Foundation and the German Federal Ministry for External Development (BMZ).

1. INTRODUCTION

The analysis of the ambient and the conditions for the generation of illegal dumping of waste material landfields in the Kiseljak community resulted, on scientific grounds, in the classification of illegal landfills according to several criteria. In the earlier practices of the illegal landfills analyses, the scientific and professional aspects of illegal landfills are not adequately defined, so the research and analysis are of particular importance not only for a practical systemic solution to the reduction or removal of illegal

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landfills, but also for contributing to the scientific overview of the problems related to locally generated illegal landfills. Categorization facilitates the monitoring of the creation, development and removal of illegal landfills using landfill databases and GIS. The composition of locally generated landfills of waste material are mainly based on:

• unsorted household waste (mixed organic and inorganic waste, solid waste),
• construction waste and car tires (building material, glass, car tires),
• biological waste (plant remains, branches, animal remains) and
• waste material remains after recycling selection (material of useless disassembled devices, machines and vehicles and separating material that has no market value).

With regard to the various aspects of the generation and development of illegal or legal landfills at the local (community) level, i.e. the disposal of different types of materials, and the already established methodology and categorization of waste material, the classification does not include the following types of landfills and types of waste material:

• regional or local communal / sanitary landfills;
• industrial waste landfills (sludge, lubricants, slag or tailings landfills, waste generated by production processes);
• hazardous waste landfills (medical, slaughterhouse, pesticides, oils, lubricants);
• landfills containing liquid waste (water and additives in technological processes, chemical reagents, detergents).

It is expected that local illegal landfills do not contain industrial, hazardous waste and waste in a liquid state, and even if it is present, its localization is an isolated case and there is no systemic negative impact on the environment.

2. GROUPING ILLEGAL LANDFILLS

Illegal landfills of municipal waste, household waste and other types of locally generated waste are divided into permanent regional landfills and repetitive local landfills based on their origin and volume.

i. Permanent regional landfills

Permanent regional landfills are used for unselected depositing of all types of waste, including potentially dangerous materials for the environment.

They are divided into flat terrain landfills (depositing waste at the level of material dumping) and slope landfills (dumping material below the ground level i.e. down the slopes, mostly near roads).

Slope landfills generated down the slopes where at the bottom are waterflows or watersheds are a direct source of water and soil pollution. They are characterized by large volumes of waste material (regularly shaped with the volume of more than 100 m^3 of waste material), with a significant impact on waterflows and soil, and with a significant presence of animal species that are potential carriers of diseases (birds, rodents, dogs, foxes, wild pigs and others animals that look for food and find it in illegal landfills). Their elimination requires significant financial sources for the removal and transportation of waste material to another location that must be a legal/sanitary waste dump. The possibility of regenerating permanent regional landfills is great, and to eliminate the process of generating illegal landfills, it is necessary to either apply restrictive measures that would affect the reduction of the amount of waste material in illegal landfills, or provide containers in which waste material that would otherwise be dumped on illegal landfill locality.

Permanent regional landfills are not the subject of locally characterised illegal landfills classification.

ii. Repetitive local illegal landfills

Repetitive local landfills are temporary landfills. These are landfills that are generated at one time, and after a certain time, the landfills are removed by the competent municipal services or citizens through environmental cleaning actions. In a large number of cases, in the same localities, illegal landfills are repeatedly generated and the cycle repeats itself. The possibility of regenerating illegal landfills tends to decrease with the achievement of the prerequisites for systematic waste management.

They are characterized by medium volumes of waste material (10 m^3 to 100 m^3) or small volumes of waste material (0.5 m^3 to 10 m^3), without significant impact on waterflows and soil, unless the landfills are in the immediate vicinity of the water source. Repetitive local landfills do not have a significant presence of animal species that are potential carriers of diseases, which are mainly dogs and rodents. Their disposal does not require significant financial resources for the removal and transportation of waste material to another location, that must be a legal waste dump.

An important characteristic of repetitive local landfills is the negative impact on the visual environment within the local community, especially if the local community bases its strategies on the tourist potentials or recreational facilities and infrastructure, such as the example of the suburban local community of Kiseljak, Tuzla, which has quality prerequisites for community development by offering tourist and recreational facilities.

3. LOCALLY CHARACTERISED REPETITIVE ILLEGAL LANDFILLS CLASSIFICATION

i. Compact illegal landfills occupy one compact area with clearly defined spatial boundaries, in which there is only one landfill with dimensions up to 50 X 50 m. The space of the landfill is of regular or irregular shape. The height of the deposited waste material is in the range of 0.5 m to 1 m, formed in shallow piles. The composition of waste material is extremely diverse and unselected. Waste material is dumped by trucks, tractor's trailers, motor cultivator's trailers or vans. Landfills has adequate access from official roads (paved or unpaved), at least 2 km away from the human settlements.

Figure 1. An example of a compact illegal landfill in Kiseljak community, Tuzla

ii. Linear scattered illegal landfills occupy area mainly along the length of the line, with possible smaller gaps between the dumped waste material, length 2 m to 50 m, depth of dumping usually up to 2 m, contains different waste material, mainly household or construction waste (tiles, bricks, mortar, glass). The height of the dumped material is up to 0.5 m. The material is dumped from cars, tractor trailers or vans. They are located right next to the official road (paved or unpaved), at least 100 m away from the human settlement, although there are cases where it is located in the settlement itself.

Figure 2. An example of a linear illegal landfill in Kiseljak community, Tuzla

iii. Lenticular illegal landfills occupy an irregular formation, often in the shape of lenses, characterized by individual shallow piles of waste material. The height of the deposited material is up to 0.5 m, the volume is up to 0.5 m^3, and they are 5 to 10 m apart from each other, making usually one spatially dispersed landfill. The composition of the waste material is different and partly selective, and it consists household waste, construction waste material or other types of waste. They are mostly located in the forest area, and the material is brought in by handcarts or cars if there is a possibility for cars to approach.

Figure 3. An example of a lenticular illegal landfill in Kiseljak community, Tuzla

iv. Infrastructural illegal landfills take a mostly regular shape that closely matches the dimensions of the infrastructural object that has been demolished, devastated and is not in use. The composition of the waste material is in the category of construction waste (mainly concrete elements, siporex solid blocks, bricks, tiles, salonit panels). The landfill is not generated because it represents the rest of the former infrastructure facility. They are located outside urban areas or near urban areas, often in the settlement itself or in the immediate vicinity.

Figure 4. An example of an infrastructural illegal landfill in Kiseljak community, Tuzla

Often, in addition to the infrastructural landfill, lenticular landfills located next to the demolished building or in the building itself are also generated, and the composition of the waste material is different and partly selective, consisting of household waste, construction material waste, solid plastics, textiles, dead animals or other types of waste. The material is brought in by handcart.

Figure 5. An example of a hillside illegal landfill in Kiseljak community, Tuzla

v. Hillside illegal landfills, occupy a fairly regular shape that is formed by the generation process of the landfill. The shape is a trapezoid where the width of the landfill is greater in the upper part (up to 15 m), the landfill stretches down the slope towards the valley and ends with a width of up to 3 m. The length of the slope is variable and ranges from 3 m to 20 m, and the height of the dumped material is up to 1 m, including bulky waste. It contains various waste materials, mainly bulky waste (solid plastics, household appliances, furniture parts) and construction material waste, very rarely household waste. The material is dumped from a van, from a tractor trailer, a motor cultivator trailer or from a handcart. They are located next to official road communications (paved or unpaved), at least 100 m away from the human settlement. They represent the most- risky type of landfill, given that it is generated in hillside parts that make up watersheds or waterflows, and which are difficult to remove due to the hillside characteristics of the landscape.

vi. Covered illegal landfills are landfills that have been generated, not removed, and covered with soil or other material for the purpose of remediation, or they were created by backfilling, i.e. by covering with soil, sand or gravel that has no use value. They contain mainly unsorted household waste from the household, biological waste or other types of non-bulky waste material.

Figure 6. An example of a cover illegal landfill in Kiseljak community, Tuzla

vii. Private illegal landfills are landfills that are generated and located on the private properties of local residents. Private landfills contain construction waste or waste from the processing of selecting secondary raw materials. Landfills are created by depositing construction material waste as a result of demolition or remodelling private infrastructure, located on private property. Often, after a certain time, the deposited material is removed by the owner of the property. Another type of private illegal landfills is created as a result of the collecting secondary raw materials, so that families engaged in collecting and selling secondary raw materials in their own yard generate small heaps landfills of material that has no use value. The treatment of these landfills depends solely on the owner of the property, and the waste material mainly consists of solid plastic, electronic or construction waste. Private landfills have a negative impact on the visual environment in the community, since they are often located in urban areas of the local community.

Figure 7. An example of a private illegal landfill in Kiseljak community, Tuzla

4. CONCLUSIONS

In the context of the need to preserve the environment, it is necessary to establish the treatment of Illegal landfields that are created by depositing waste material, of different composition, in the wider area of local communities. From a scientific and professional point of view, illegal landfields of a regional character are analysed, which generally contain more than 100 m^3 of different mixed waste material. The need for analyses is based on the significant negative impact on the environment - on soil, water and air, as well as the consequences arising from the impact of illegal waste deposing at landfields. On the other hand, locally formed illegal landfields are not the subject of scientific and professional research, since they are repetitive in nature, they are not considered as threats for the environment and can be removed in a short period of time and without large costs for removing the deposited waste material. Local landfields and waste material content are categorized into seven occurrence groups: compact landfields, linearly scattered landfields, lenticular landfields, infrastructural landfields, hillside landfields, covered landfields, and private landfields. The classification of repetitive illegal waste landfields locally characterised was researched and confirmed on the example of illegal landfields in the area of the local community Kiseljak, Tuzla. The classification of local waste landfields enables systematic monitoring of the generating, development and removal of illegal landfields using information technologies and Internet tools.

Annex 1. The example of database for repetitive illegal landfills in Kiseljak community.

ID	NAZIV	ISTOCNO	SJEVERNO	NADMORSKA_VISINA	IME_VEZA	DATUM	OPIS	OBLIK	površina, m^2	zapremina, m3 (veličina simbola)	sastav deponije	stepen prioriteta	kategorija
1	A_ASFALT1	6543824	4927695	220	44	24.4.2022	Uvučena pored asfalta put vikendice, nedavno očišćena, bivša (po	više gomila	2 X 2 X 0,3	1,2	čvrsta plastika, suva trava, građevinski	Treći, Na općini Lukavac	kompaktna
1	A_ASFALT2	6543865	4927769	227	45	24.4.2022	Pored puta za vikendice 1	trapez padina	15 X 3 padina 8 (72), visina 0,4	28,8	kućni otpad, plastika,boce, čvrsta plastika, gume, deke,	Prvi	padinska
1	A_ASFALT3	6543864	4927752	225	46	24.4.2022	Pored puta za vikendice 2	kvadar dugački	3 X 1 X 0,5	1,5	plastika, građevinski, kućni otpad	Prvi	linijski razuđena
1	A_ASFALT4	6543879	4927840	232	47	24.4.2022	Pored puta za vikendice 3	kvadar	2 X 1 X 0,5	1	plastika, građevinski, kućni otpad	Prvi	linijski razuđena
1	A_ASFALT5	6543891	4927857	234	48	24.4.2022	Pored puta za vikendice 4	okrugla gomila	1 X 1 X 0,2	0,2	smotani kablovi	Prvi	linijski razuđena
1	A_ASFALT6	6543907	4927944	244	49	24.4.2022	Pored puta za vikendice 5	trapez padina	5 X 3 padina 4 (16), visina 0,4	6,4	čvrsta plastika, deke, građevinski	Prvi	padinska
1	A_ASFALT7	6543927	4928001	251	50	24.4.2022	Pored puta za vikendice 6	kvadar dugački	3 X 1 X 0,5	1,5	plastika, građevinski, kućni otpad	Prvi	linijski razuđena
2	B_PARKING1	6544587	4927890	279	51	24.4.2022	Asfalt prema parkingu 1	kvadar dugački	5 X 1 X 0,3	1,5	plastika, građevinski, kućni otpad	Drugi	linijski razuđena
2	B_PARKING2	6544604	4927523	249	52	24.4.2022	Asfalt prema parkingu 2	kvadar dugački	5 X 1 X 0,3	1,5	plastika, građevinski, kućni otpad	Drugi	linijski razuđena
2	B_PARKING3	6544640	4927521	249	53	24.4.2022	Asfalt prema parkingu 3	kvadar dugački	5 X 1 X 0,3	1,5	plastika, građevinski, kućni otpad, drvo	Drugi	linijski razuđena
2	B_PARKING4	6544685	4927588	257	54	24.4.2022	Asfalt prema parkingu 4	kvadar dugački	5 X 1 X 0,3	1,5	plastika, građevinski, kućni otpad, gume	Drugi	linijski razuđena
2	B_PARKING5	6544682	4927650	263	55	24.4.2022	Asfalt prema parkingu 5	kvadar dugački	6 X 1 X 0,5	3	plastika, kućni otpad	Drugi	linijski razuđena
2	B_PARKING6	6544683	4927736	269	56	24.4.2022	Asfalt prema parkingu 6	kvadar dugački	1 X 1 X 0,3	0,3	plastika, građevinski, kućni otpad	Drugi	linijski razuđena
2	B_PARKING7	6544673	4927772	273	57	24.4.2022	Asfalt prema parkingu 7	kvadar dugački	5 X 1 X 0,3	1,5	plastika, kućni otpad	Drugi	linijski razuđena
2	B_PARKING8	6544618	4927857	277	58	24.4.2022	Asfalt prema parkingu 8	kvadar dugački	5 X 4 X 0,3	6	plastika, kućni otpad	Drugi	linijski razuđena
2	B_PARKING9	6544645	4927546	245	NA	24.4.2022	Parking gornji	kvadrat	20X10X0,3	60	goretina, kruti otpad, odjeća, obuća,	Prvi	kompaktna
2	B_PARKING10	6544655	4927522	244	NA	24.4.2022	Parking donji	kvadrat	20X12X0,3	40	kruti otpad,	Prvi	kompaktna
2	B_PARKING11	6544623	4927521	244	NA	24.4.2022	Pojas uz donji parking	kvadar	35X1,5X0,5	46,6	kruta plastika, granje, građevinski	Prvi	infrastrukturna
3	C_KISELJAK1	6545421	4927571	221	38	24.4.2022	Stari TTU hotel ruševina	kvadar	25 X 15 X 1,5	562,5	betonski elementi	Treći	kompaktna
3	C_KISELJAK2	6545425	4927574	221	NA	24.4.2022	Uz stari TTU hotel 1	nepravilan	3 X 1,5 X 0,5	2,25	spužve, plastika, deke, kućni otpad, čvrsta plastika	Prvi	sočasta
3	C_KISELJAK3	6545425	4927571	221	NA	24.4.2022	Uz stari TTU hotel šuma 2	kvadar dugački	7 X 1 X 0,2	1,4	kućni otpad, plastika	Drugi	sočasta
3	C_KISELJAK4	6545420	4927568	221	NA	24.4.2022	Uz stari TTU hotel šuma 3	5 malih gomila	5 X 0,6 X 0,6 X 0,2	0,36	kućni otpad, plastika	Drugi	sočasta
3	C_KISELJAK5	6545350	4927571	235	39	24.4.2022	Put od starog TTU hotela u blizini privatne kuce u sumi	6 gomila	13 X 1 X 0,2	2,6	kućni otpad, plastika, piljevina, boce, čvrsta plastika	Drugi	linijski razuđena
3	C_KISELJAK6	6545360	4927568	233	NA	24.4.2022	Put od starog TTU hotela u šumi	5 gomila malih	5 X 0,5 X 0,5 X 0,2	0,25	kućni otpad, plastika	Drugi	sočasta
3	C_KISELJAK7	6545446	4927498	220	40	24.4.2022	Merhamet do bazena	nema / vrlo mala go	0,4 X 0,4 X 0,2	0,03	kućni otpad	Drugi	kompaktna
3	C_KISELJAK8	6545166	4927384	214	41	24.4.2022	Uz devastirani privatni hotela (pored puta) Jezero	kvadar dugački	30 X 2 X 2	120	kućni otpad, plastika,boce, čvrsta plastika, gume, deke,	Prvi,Na općini Živinice	kompaktna
3	C_KISELJAK9	6545117	4927387	212	42	24.4.2022	U nastavku devastiranog privatnog hotela pored puta	kvadar dugački	35 X 2 X 0,5	17,5	kućni otpad, plastika,boce, čvrsta plastika, gume, deke,	Prvi,Na općini Živinice	kompaktna
3	C_KISELJAK10	6545105	4927419	218	43	24.4.2022	Preko puta devastirani ugostiteljski objekt, u šumi	nepravilan	3 X 2 X 0,2	1,2	kese, piljevina, plastika	Treći	sočasta
3	C_KISELJAK11	6545538	4927598	211	23	24.4.2022	Kod betonske kanalice sa vodom kod izvora Kiseljak	kvadar dugački	9 X 1 X 0,2	1,8	kućni otpad, plastika, kese, boce	Prvi	sočasta
3	C_KISELJAK12	6545546	4927578	230	NA	24.4.2022	U šiblju kod izvora Kiseljak	kvadar	1,5 X 1 X 0,2	0,3	kućni otpad, deke, guma, salonit ploče	Prvi	kompaktna
4	D_NETEKE1	6547303	4926695	208	wpt4	24.4.2022	Neteke kompleks deponija - velika pored pruge	nepravilan	12 X 7 X 0,3	25,2	gume, građevinski, čvrsta plastika, granje	Treći	kompaktna, prekrivena
4	D_NETEKE2	6547296	4926664	207	NA	24.4.2022	Neteke kompleks deponija - šumski put 1	kvadar	8 X 2 X 0,5	8	građevinski, drvo, rastinje, boce, plastika, kućni	Treći	linijski razuđena
4	D_NETEKE3	6547295	4926645	207	NA	24.4.2022	Neteke kompleks deponija - šumski put 2	kvadar	3 X 1 X 0,5	1,5	građevinski	Treći	infrastrukturna
4	D_NETEKE4	6547294	4926631	207	wpt1	24.4.2022	Neteke kompleks deponija - šumski put 3	kvadar	5 X 3 X 0,2	3	plastika, boce	Treći	sočasta
4	D_NETEKE5	6547287	4926602	207	wpt2	24.4.2022	Neteke kompleks deponija - šumski put 4	3 gomile	3 X 2 X 2 X 0,3	3,6	kruta plastika, granje, građevinski	Treći	sočasta
4	D_NETEKE6	6547316	4926676	208	NA	24.4.2022	Neteke kompleks deponija - put za prugu 1	2 gomile	2 X 1,5 X 1,5 X 0,3	1,35	građevinski	Treći	infrastrukturna
4	D_NETEKE7	6547317	4926690	208	wpt6	24.4.2022	Neteke kompleks deponija - put za prugu 2	kvadar	3 X 1 X 0,5	1,5	građevinski	Treći	infrastrukturna
4	D_NETEKE9	6547287	4926688	208	NA	24.4.2022	Neteke kompleks deponija - šuma uz veliku deponiju i potok	gomila	3 X 2 X 0,3		gume (uračunata zapremina u Neteke	Prvi	kompaktna
5	F_USKA PRUGA1	6548010	4927792	240	wpt6	24.4.2022	Uskotračna pruga - crijep 1	kvadar	4 X 1 X 0,3	1,2	crijep	Treći	infrastrukturna
5	F_USKA PRUGA2	6548012	4927806	240	NA	24.4.2022	Uskotračna pruga - crijep 2	kvadar	6 X 1,5 X 1	9	crijep	Treći	infrastrukturna
5	F_USKA PRUGA3	6548013	4927823	240	wpt7	24.4.2022	Uskotračna pruga - šumski put 1	nepravilna	2 X 1 X 0,3	0,6	čvrsta plastika, kućanski aparati, granje	Drugi	sočasta
5	F_USKA PRUGA4	6548021	4927850	240	wpt8	24.4.2022	Uskotračna pruga - šumski put 2 vododjelnica	nepravilna	10 X 8 X 0,3	24	piljevina, granje, boce, plastika, građevinski	Prvi	sočasta
5	F_USKA PRUGA5	6548043	4927879	241	wpt9	24.4.2022	Uskotračna pruga - šumski put 3	kvadar	3 X 1 X 0,5	1,5	crijep	Treći	infrastrukturna
5	F_USKA PRUGA6	6548070	4927899	242	wpt10	24.4.2022	Uskotračna pruga - šumski put 4 potok	kvadar	4 X 3 X 0,5	6	crijep, građevinski, čvrsta plastika	Treći	infrastrukturna
5	F_USKA PRUGA7	6548036	4927866	241	NA	24.4.2022	Uskotračna pruga - crijep 7	kvadar	3 X 1,5 X 0,2	0,9	šiblje	Treći	kompaktna
6	H_KLIUŠA1	6545727	4928780	214	wpt15	24.4.2022	Poljana pruga Šabići	nepravilan, više gon	5 X 3 X 0,3	4,5	građevinski, gajbe, plastika, čvrsta plastika, klasure	Treći	kompaktna
6	H_KLIUŠA2	6545708	4928862	208	wpt16	24.4.2022	Kliuša - put za pčelinjak 1	1 gomila	2.8 X 1 X 0,6	1,7	crijep	Treći	infrastrukturna
6	H_KLIUŠA3	6545693	4928888	207	wpt17	24.4.2022	Kliuša - put za pčelinjak 2	1 gomila	2.8 X 1 X 0,6	1,7	crijep	Treći	infrastrukturna
6	H_KLIUŠA4	6545685	4928916	206	wpt18	24.4.2022	Kliuša - put za pčelinjak 3	1 gomila	2.8 X 1 X 0,6	1,7	crijep	Treći	infrastrukturna
7	I_RAKOVAC	6544968	4928894	198	35	24.4.2022	Deponija na potoku Rakovac	trapez	24 X 20 X 1,5	720	građevinski otpad, gume	Prvi	linijski razuđena
8	J_ZASJEKE1	6544181	4928649	208	wpt19	24.4.2022	Put Poljana - Bokavići Zasjeke 1	nepravilna	6 X 1 X 0,2	1,2	drvo, vuna, keramika	Prvi, Na općini Lukavac	linijski razuđena
8	J_ZASJEKE2	6544212	4928659	207	wpt20	24.4.2022	Put Poljana - Bokavići Zasjeke 2 put šuma	kvadar, više gomila	3 X 1 X 0,3	0,9	keramika, građevinski, staklo	Prvi, Na općini Lukavac	linijski razuđena
8	J_ZASJEKE3	6544213	4928672	206	wpt21	24.4.2022	Put Poljana - Bokavići Zasjeke 3 put šuma	kvadar	15 X 1 X 0,3	4,5	građevinski, gume, drvo, staklo	Prvi, Na općini Lukavac	linijski razuđena
9	K_OSTALE1	6546002	4928056	252	wpt23	24.4.2022	Izlaz iz MZ pored puta i pruge	kvadar	7 X 3 X 1	21	građevinski	Treći	inrastrukturna
9	K_OSTALE2	6545666	4927321	227	22	24.4.2022	Porušena građevina hotel - od poste jugoistocno 100 m	kvadar (50% prosto	30 X 30 X 0,5 (50%) = 450 m2	225	betonski elementi	Treći	inrastrukturna
9	K_OSTALE3	6546241	4927484	219	24	24.4.2022	propust kanala (otvorena kanalizacija sa smecem)	linijski	7 X 0,2 X 0,1	0,14	fekalije i kućni otpad na obali potoka	Prvi	kompaktna
10	L_PRIVATNE1	6545751	4927637	218	wpt22	24.4.2022	U dvorištu srušena kuća - nasipanje parcele	gomila	2 X 2 X1	4	građevinski - možda služi kao nasipni materijal za objekat	Treći	privatna
10	L_PRIVATNE2	6545697	4927758	222	37	24.4.2022	Privatna parcela (deponovano smeće - sakupljač sekundarnih siro	drovište	neodređeno	1,5	čvrsta plastika, najlon	Prvi	privatna
11	M_VRUCAK1	6547330	4927649	242	wpt11	24.4.2022	Vrućak - šuma 1	kvadar	6 X 4 X 0,2	4,8	kućni otpad, kese	Treći	sočasta
11	M_VRUCAK2	6547309	4927657	246	wpt12	24.4.2022	Vrućak - šuma 2	gomila	3 X 3 X 0,2	1,8	kućni otpad, kese, kruti otpad	Treći	sočasta
11	M_VRUCAK3	6547321	4927655	244	NA	24.4.2022	Vrućak - šuma 3	mala gomila	1 X 1 X 0,2	0,2	kućni otpad, kese	Treći	sočasta
12	N_BREZE1	6546593	4927000	211	25	24.4.2022	Breze stara deponija, očišćeno, opet nastaje deponija	gomila	1,5 X 1 X 0,2	0,3	goretina, kućni otpad	Treći	kompaktna
12	N_BREZE2	6546618	4926975	211	NA	24.4.2022	Breze šuma pored puta, očišćena, ponovo nastaje	kvadar	5 X 2 X 0,2	2	kućni otpad	Treći	kompaktna
									ukupno zapremina	1998,48			

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DETERMINING THE OPTIMAL METHOD OF EXCAVATION OF THE ZENICA TUNNEL AS A FUNCTION OF MINIMAL DAMAGE TO ROCK MASS OF POORER QUALITY OUTSIDE THE EXCAVATION PROFILE

Ekrem Bektašević[1], Reuf Kadrić[2], Kemal Gutić[3], Sead Kadrić[4]

ABSTRACT

Corridor Vc enhances the connection of Bosnia and Herzegovina with neighboring countries and improves the potential for economic development. The Corridor Vc motorway in Bosnia and Herzegovina stretches from the northern border with the Republic of Croatia from Svilaj to Čapljina on the southern border with the Republic of Croatia, in Bijača. The Zenica tunnel is part of the Corridor Vc motorway in the municipality of Zenica and is currently the longest excavated tunnel with a total length of 3,330 meters. Excavation works were performed by a combination of blasting and machine excavation. The excavation of the tunnel was performed in sedimentary formations (flysch-like Upper Vranduk series ^{2}JK). Excavation of tunnels by blasting with adjusted drilling and blasting parameters in rock mass of poorer quality achieves better results in relation to machine excavation.

Key words: tunnel, rock mass, machine excavation, drilling, blasting, overbreak

1. INTRODUCTION

The Zenica tunnel is part of the motorway on Corridor Vc, section Zenica Municipality Northern Administrative Boundary (Nemila) - Zenica North, subsection Ponirak - southern exit from the Zenica tunnel. The tunnel is designed with two tunnel tubes, each having two traffic lanes with a width of 3.50 m and a marginal strip with a width of 0.35 m.

The beginning of excavation of the left tunnel tube is from chainage km 0+153.62, and the end of the tunnel, or of the excavation, is at chainage km 3+435.614, and the length of the left tunnel tube is L=3,281.994 m'. The beginning of excavation of the right tunnel tube is from chainage km 0+155.76, and the end of the tunnel, or of the excavation, is at chainage km 3+485.61, and the length of the right tunnel tube is L=3,329.850 m'.

The excavation of the left tunnel tube in the length of 2,395.36 m' and the right tunnel tube in the length of 2,440.14 m' was carried out by the contractor Euro-asfalt, while the rest of the tunnel excavation was carried out by the Turkish company Cengiz. The maximum overburden of the Zenica tunnel is approximately 470 m'.

The left and right tunnel tubes are connected with ten cross passages for pedestrians and three passages for vehicles.

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Figure 1. Geographical position of the Zenica tunnel on the Corridor Vc route

2. ENGINEERING GEOLOGICAL CHARACTERISTICS OF THE ROCK MASS IN THE ZENICA TUNNEL EXCAVATION ZONE

The lithological composition of the terrain is represented by Mesozoic formations (flysch-like Upper Vranduk series 2JK). Based on the mineral-petrographic analysis of rocks from the excavation, it was established that the following lithological members are present in the lithological composition: marls, clayey marls, tectonized hematite claystones and subordinately sandstones.

Based on the geomechanical RMR classification for the rock mass, geological mapping defined the following parameters from chainage 1+499.10 to 1+536.00 in the left tunnel tube:

- The lithological composition of the rock mass consists of claystones and marls. The percentage of claystone is about 60%, and marl about 40%. Claystone is characterized by a thinly stratified texture and poor physical and mechanical properties, while marl is characterized by a stratified texture and pelitic-clastic structure.

- Based on previous laboratory tests and field tests using a geological hammer, the uniaxial compressive strength of claystone is in the range from 25 to 50 MPa, and that of marl is in the range from 50 to 100 MPa. The mean value of compressive strength was determined based on the percentages of claystone and marl.

- The quality of the rock mass (RQD) measured at the face of the excavation is in the range from 25 to 50%, which corresponds to fractured rocks of poor quality.

- The discontinuity spacing is smaller, ranging from 6 to 20 cm, while the length of discontinuities is within the limits from 10 to 20 m.

- The discontinuity aperture is closed, and ranges from 1 to 5 mm, while larger ones of 5 mm are recorded. The discontinuities are smooth and slightly rough, filled with hard calcite and soft clayey infilling. Bedding discontinuity is dominant. The strata strike perpendicularly to the tunnel axis with a dip of 15° opposite to the direction of progress of tunnel excavation, which is a good bedding orientation in relation to the tunnel axis.

- Groundwater percolation is registered at the contact of claystone and marl in the form of wetting (less than 10 l/min).

Figure 2. View of the work face, chainage 1+499.10 - left tunnel

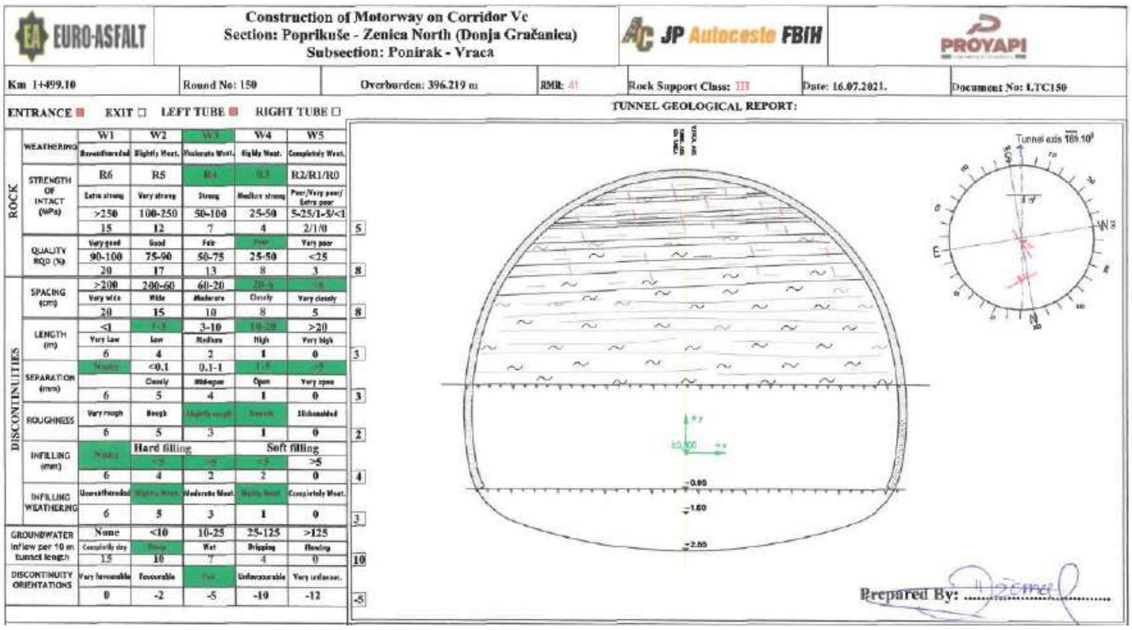
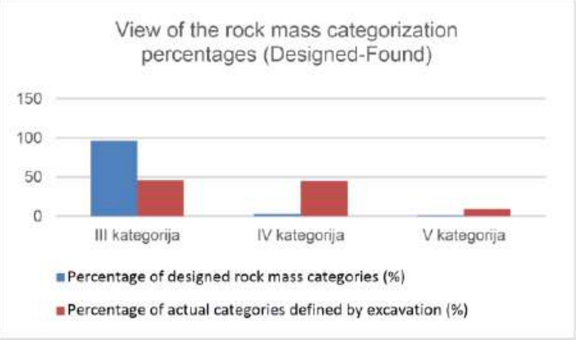


Figure 3. Geological report, chainage 1+499.10 - left tunnel tube

The following table shows the percentage shares of the designed rock mass categories and those defined during excavation for both tunnel tubes.

Table 1. View of the rock mass categorization percentages (Designed-Found)

Rock mass categorization	Percentage of designed categories (%)	Percentage of actual categories defined by excavation (%)
Category III	96.43	45.72
Category IV	2.74	44.93
Category V	0.83	9.35
Total:	100.00	100.00



It is evident from the previous table that there are significant differences in the rock mass categorization percentages between the designed categories and the actual categories defined by excavation. Geological investigations were performed as a basis for development of the Main Design, but they were not sufficient for a more precise assessment of the geological structure in the Zenica tunnel excavation zone, which is why there were significant differences between the shares of the designed categories and the actual categories defined by excavation.

3. DETERMINING THE OPTIMAL METHOD FOR EXCAVATION OF THE ZENICA TUNNEL IN THE ROCK MASS WITH LOWER RMR VALUE

Excavation of the Zenica tunnel was carried out using the New Austrian Tunneling Method (NATM). Bearing in mind the frequent changes in engineering-geological properties of the rock mass in a part of the tunnel excavation, NATM made it possible to apply the multi-phase excavation, while simultaneously securing the excavation with primary support. The tunnel excavation was carried out by machines, by blasting or by combining blasting with machine excavation, all depending on the geological characteristics of the rock mass in the tunnel excavation zone.

Based on the conducted investigation works and available geotechnical data, it was estimated by the main geotechnical design that the excavation of the Zenica tunnel would be carried out in 96.43% of rock mass category III, and that only 3.57% would be category IV and V. Based on the assessment of rock mass categories by the supplementary mining project (SMP), all the technical and technological parameters of drilling and blasting for the rock mass with uniaxial compressive strength of 100 MPa were processed, and on the basis of the adopted strength, all the technical parameters for drilling and blasting were calculated, which are listed below:

q - specific consumption of explosives 1.60(kg/m^3);
Naux - number of auxiliary blast holes 69 (holes);
Nfloor - number of floor blast holes 12 (holes);
Ncon - number of contour blast holes 44 (holes);
N - number of all blast holes 125 (holes).

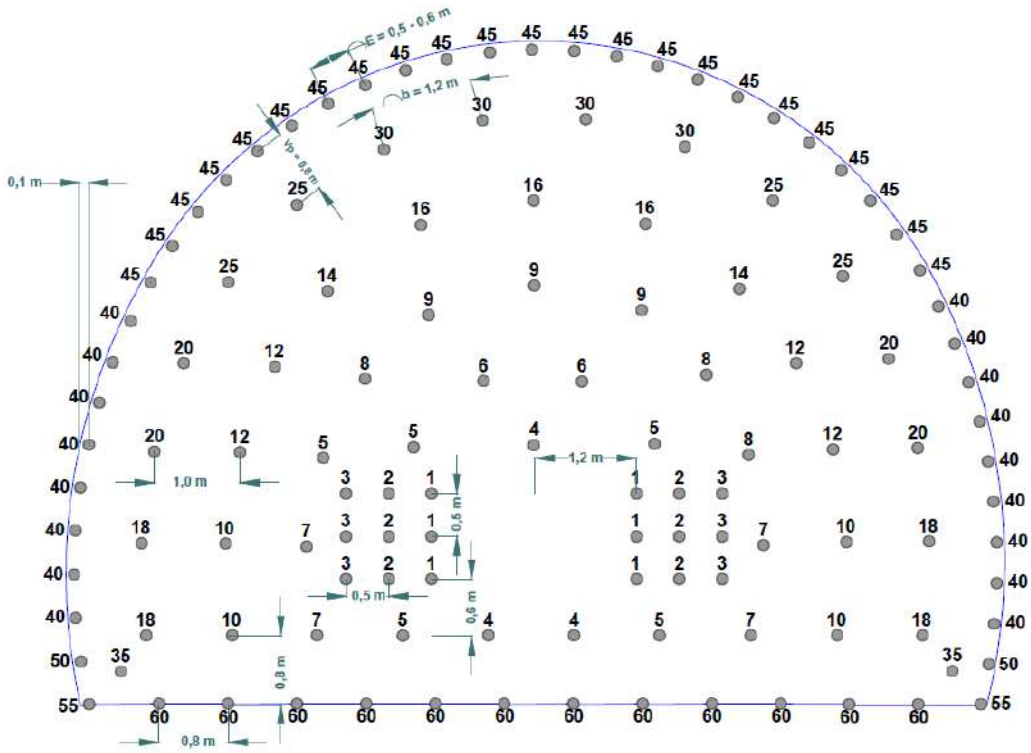


Figure 4. Layout scheme of blast holes on the cross section, as well as the layout of detonators by boreholes, for an advancement step of 3.0 m'

To excavate the tunnel, the contractor used the blasting method in both tunnel tubes with some corrections of technical parameters that they determined approximately without detailed analysis of engineering geological properties of the rock mass, and of the drilling and blasting parameters in the weaker rock mass of RMR (32-43) and as the result had irregular excavation profile shapes and significant overbreaks that exceeded more than 13 m^2 over the entire tunnel profile. One such typical profile of tunnel excavation by blasting is shown on the geodetic survey (Figure 5) of the tunnel face in LTT below, chainage 1+435.998.

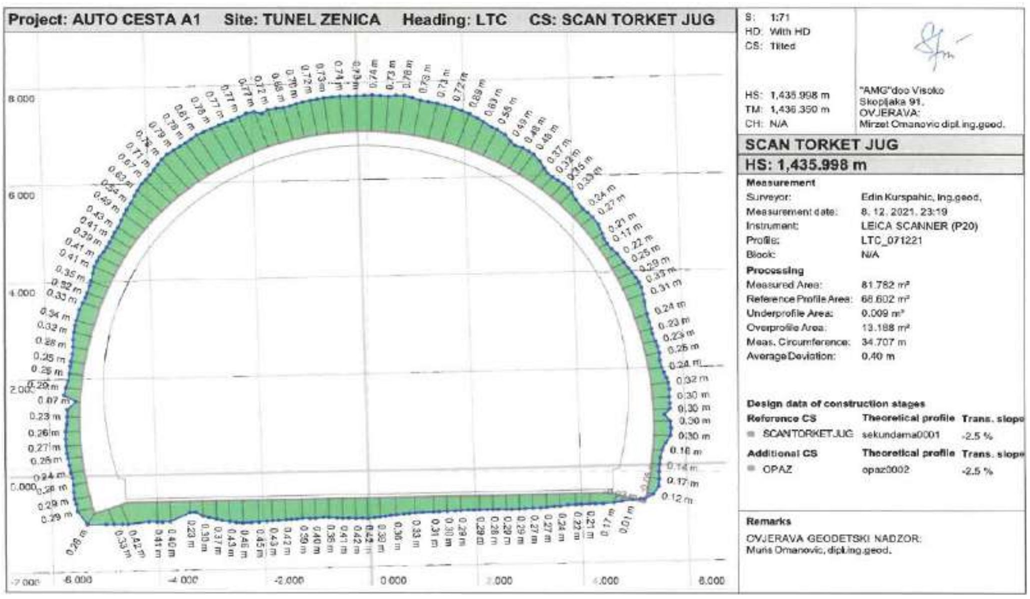


Figure 5. Geodetic survey after excavation by blasting in a weaker rock mass

After obtaining very poor results of the tunnel excavation by blasting, the contractor decided to perform the tunnel excavation in weaker rock masses (defined by RMR from 32 to 43) by machines. The following figure (Figure 6) shows the full cross section excavation by machine in LTT from chainage 1+518.00 to 1+520.00, while the figure (Figure 7) provides a geodetic survey of the face in LTT after the excavation by machine from chainage 1+518.00 in a length of 2.0 meters.

Figure 6. Machine excavation of full cross section in LTT at chainage 1+518.00 to 1+520

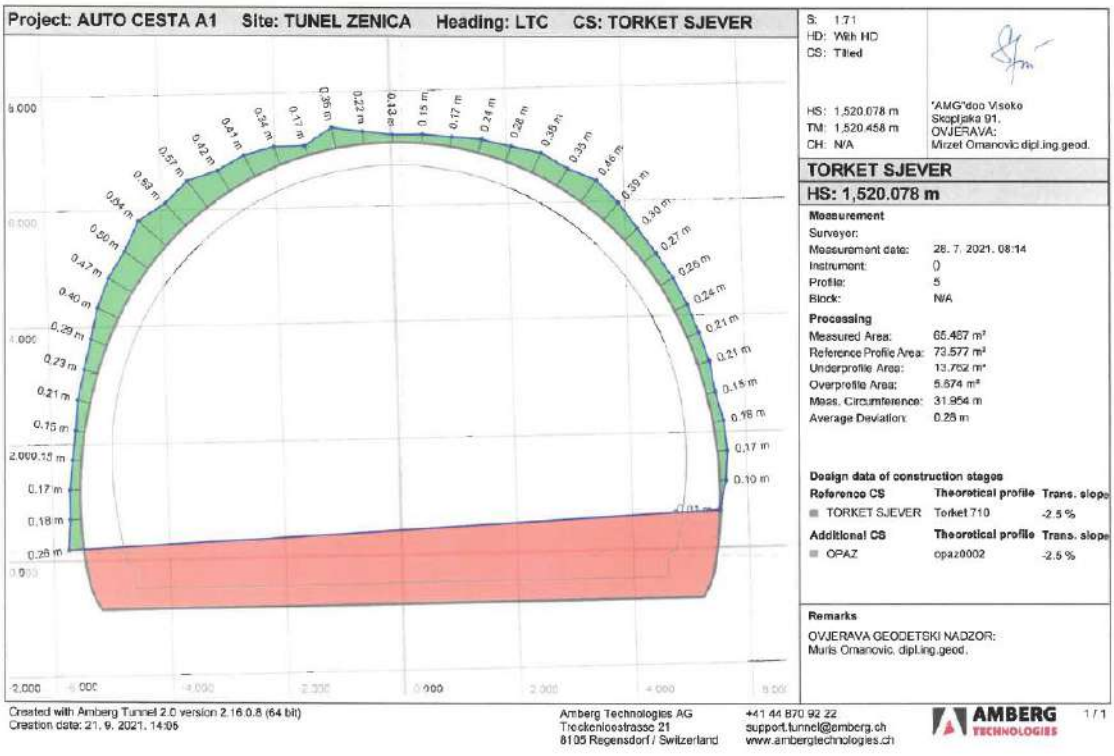


Figure 7. Geodetic survey of the face in LTT after machine excavation

As a result of this method of excavation, the contractor reduced the overbreak from 8-13 m^2 to the overbreak of 5-6 m^2, however, due to the structural geological properties of the rock mass, the hammer tunnel excavation still caused a large overbreak.
Any tunnel excavation that does not have an approximately regular shape, as well as an overbreak larger than 3 m^2, is not acceptable from an economic point of view, which is why the authors of this paper undertook a thorough analysis for determining all the necessary drilling and blasting parameters in a weaker rock mass.

Determining the coefficient of rock mass strength (f)
In order to calculate the approximate drilling and blasting parameters, it is necessary to determine the coefficient of rock mass strength (f), which is the basis for calculating the number of blast holes on the tunnel cross section (pcs), as well as the specific consumption of explosives (kg/m^3). The coefficient of rock mass strength is determined by Baron's equation:

$$f = \frac{\sigma_p}{300} + \sqrt{\frac{\sigma_p}{30}}$$

The determined RMR by the Contractor's geologists and Supervision [8] from chainage 1+499.10 to chainage 1+536.00 is 41, and based on this, the uniaxial compressive strength is adopted, taking into account all other geomechanical parameters for the calculation of 40 MPa so that we can calculate the coefficient of rock mass strength for the specified part of the tunnel.

$$f = \frac{\sigma_p}{300} + \sqrt{\frac{\sigma_p}{30}} = \frac{400}{300} + \sqrt{\frac{400}{30}} = 4{,}98 \approx 5$$

Determining the specific consumption of explosives in excavations with one free surface (q)
In the construction of road, railway and hydraulic tunnels (with larger cross-sections > 25.0 m^2), the specific consumption of explosives is determined based on the cross-sectional area of the room, the number of free excavation surfaces, the drilling diameter of blast holes, the characteristics of the explosives and the characteristics of the rock mass. To calculate the specific consumption of explosives, one can use one of the most common formulas for determining this blasting parameter, the F. Lares formula, which takes into account the type of rock mass (its physical and mechanical characteristics), but also the type of explosive used, which is:

$$q = q_1 \cdot v \cdot s \cdot \frac{e}{g} \cdot d \cdot k \left(\frac{kg}{m^3} \right)$$

Where is:

$$q_1 = \frac{\sigma_p}{2000}$$

σp- is the compressive strength of the rock mass in which blasting is carried out, 40MPa=400bar;
v - blast confinement coefficient (for one free surface - tunnel face) 2.5;
s - coefficient of rock mass structure complex for conditions of massive homogeneous structure 1.0;
g - explosive charge compactness coefficient (for plastic explosives) 1.0;
d - blast stemming coefficient (for holes that are not well plugged) 0.8;
k - correction coefficient (for the corresponding hole diameter to explosive diameter ratio) 1.0;

e - coefficient of relative strength of explosive and is calculated using the following formula:

$$e = \frac{A}{A_x}$$

The coefficient of rock strength for the given conditions is:

$$q_1 = \frac{\sigma_p}{2000} = \frac{400}{2000} = 0,20$$

The coefficient of relative strength of explosive is:

$$e = \frac{A}{A_x} = \frac{480}{390} = 1,23 \approx 1,25$$

Using the Lares formula and substituting the calculated coefficient values in it, we obtain the specific consumption of explosives:

$$q = q_1 \cdot v \cdot s \cdot \frac{e}{g} \cdot d \cdot k = 0,20 \cdot 2,5 \cdot 1,0 \cdot \frac{1,25}{1,0} \cdot 0,8 \cdot 1,0 = 0,50 \left(\frac{kg}{m^3} \right)$$

To ensure the positive effect of blasting, the specific consumption of explosives obtained by calculation should be increased by approximately 10%, so that the specific consumption of explosives of 0.55 (kg/m^3) is adopted for further calculation.

Determining the number of blast holes for excavation of full cross section (Nb)
There are a number of empirical formulas and expressions of individual authors (Protođakonov, Sieberg, Š. I. Ibrajev) for the approximate determination of the number of blast holes. The total required number of blast holes, in the presence of one free surface, depends on the type of explosive used, the size of the tunnel cross section and the coefficient of rock strength, and is divided into two different calculations:

$$N_b = N_p + N_k (buš.)$$

Where:
- Np – is the number of auxiliary blast holes (holes);
- Nk – number of contour blast holes (holes). (Note: buš. = borehole)

Determining the number of auxiliary blast holes (Np)
The number of auxiliary blast holes can be determined on the basis of several relations, where it is best to take one that is a function of the strength of the rock being blasted and the area of the cross section being excavated; one of such relations is as follows:

$$N_p = 0,27 \cdot F_i \cdot \sqrt{\frac{10 \cdot \sigma}{F_i}}$$

Where:
- Fi - is the area of the cross-section being excavated (77 m^2 without shallow foundations);
- σ - compressive strength of the rock massive in which blasting is carried out (40 MPa).

$$N_p = 0{,}27 \cdot F_i \cdot \sqrt{\frac{10 \cdot \sigma}{F_i}} = 0{,}27 \cdot 77 \cdot \sqrt{\frac{10 \cdot 40}{77}} = 47{,}39 \approx 48\,(bu\check{s}.)$$

Determining the number of contour blast holes (Nk)

In order to determine the number of contour blast holes, first of all we must determine the distance between the contour blast holes.

The distance between contour charges (in the tunnel crown and walls) can be expressed based on the following relation:

$$E = (12 \div 15) \cdot d\,(m')$$

Where:

d – is the blast hole diameter 0.045 m'.

$$E = (12 \div 15) \cdot d = (12 \div 15) \cdot 0{,}045 = 0{,}55 \div 0{,}65 (m')$$

Considering that this is a case of weaker rock strength, the mean value is adopted: E=0.60 m′

The number of contour holes depends on the circumference of the room without the floor (Po) and the distance between the contour blast holes and is calculated according to the formula:

$$N_k = \frac{P_o}{E}\,(bu\check{s}.)$$

Both data are known, so that:

$$N_k = \frac{P_o}{E} = \frac{21}{0{,}6} = 35 (bu\check{s}.)$$

So, when blasting in full cross section, the total number of blast holes is:

$$N_b = N_p + N_k = 48 + 35 = 83 (bu\check{s}.)$$

Based on the calculated distance between contour blast holes, we determine the line of least resistance for contour blast holes (W), according to the following relation:

$$W = \frac{E}{m}\,(m')$$

Where:

E – is the distance between contour holes 0.60 m';

m – convergence coefficient of blast holes, which for weaker rocks is on average 0.8.

$$W = \frac{E}{m} = \frac{0{,}6}{0{,}8} = 0{,}75 \approx 0{,}80 (m')$$

Determining the geometry of the blast field (a, b)

The distance of the contour blast holes is known, and so is the distance of the floor blast holes, while the spacing between the contour blast holes and the first row of separation -auxiliary blast holes is determined for harder rocks based on the following relation:

$$V_p = W + (0,2 \div 0,3)(m')$$

W - is the line of least resistance in our case is 0.8 m', so we obtain:

$$V_p = W + (0,2 \div 0,3) = 0,8 + (0,2 \div 0,3) = 1,0 \div 1,1(m')$$

The distance between auxiliary blast holes is equal to the line of least resistance of auxiliary mine holes and is calculated according to the formula:

$$b = k_z \cdot W$$

Where:

kz - is the blast hole convergence coefficient, for our case we adopt 0.95;

W - line of least resistance of auxiliary blast holes (m').

The line of least resistance for auxiliary blast holes can be determined based on the following formula:

$$W = d \cdot \sqrt{\frac{7,85 \cdot \rho \cdot k_p}{q \cdot k_z}}(m')$$

Where:

d - is the drilling diameter, in our case it is 45 mm, i.e. 0.45 dm;

ρ - bulk density of the explosive 1.45 kg/dm^3;

q - specific consumption of explosives 0.55 kg/m^3;

kz - hole convergence coefficient is 1.0;

kp - coefficient of filling of the blast hole cross section and is calculated using the following formula:

$$k_p = \frac{d_1^2}{d^2}$$

Where:

d1 - is the diameter of explosive cartridge 38 mm;

d - is the blast hole diameter 45 mm.

$$k_p = \frac{d_1^2}{d^2} = \frac{38^2}{45^2} = 0,72$$

So we can calculate the line of least resistance for auxiliary blast holes:

$$W = d \cdot \sqrt{\frac{7,85 \cdot \rho \cdot k_p}{q \cdot k_z}} = 0,45 \cdot \sqrt{\frac{7,85 \cdot 1,45 \cdot 0,72}{0,55 \cdot 1,0}} = 0,45 \cdot \sqrt{14,9} \approx 1,74(m')$$

This means that the distance between auxiliary blast holes is equal to:

$$b = k_z \cdot W = 0,95 \cdot 1,74 = 1,65(m')$$

We adopt a distance between auxiliary blast holes of 1.60 to 1.70 (m'). The quantity of explosive for one blasting is calculated according to the formula:

$$Q = q \cdot S \cdot l (kg)$$

Where:

q - is the specific consumption of explosives 0.55 kg/m^3;
S - area of the excavated cross section, in our case it is approximately 77 m^2;
I - length of the blast hole approximately 2.0 m'.

So we obtain the consumption of explosives per blasting for an advancement step of 2.0 m' in the amount of:

$$Q = q \cdot S \cdot l = 0{,}55 \cdot 77 \cdot 2{,}0 = 84{,}70 (kg)$$

On the basis of all the defined and calculated parameters, the layout scheme of blast holes on the tunnel face is made, as well as the layout of series of non-electric detonators by holes, which is shown below.

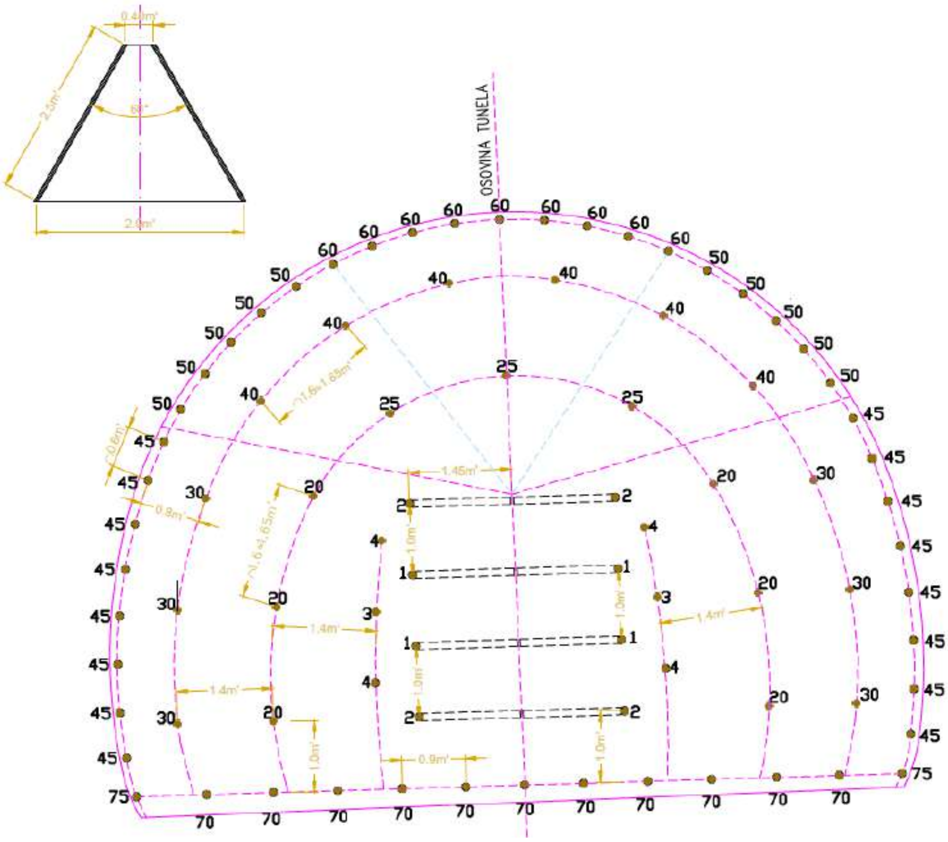


Figure 8. New layout scheme of blast holes and detonators on the tunnel face

The layout of the series of non-electric detonators is given on the sketch with numbers 1-75. The connection of non-electric detonators into a grid is carried out using a C-10 or C-12 detonating fuse for each detonator separately. The connection is performed by connecting the C-10 (C-12) detonating fuse to each conductor line of the non-electric detonator individually and attaching it to the detonator line with a special plastic clip that is manufactured at the factory and delivered on each of the detonator conductors.

The detonating fuse is taken out of the blast field to a shorter distance of 2 to 3 m' from the work face, where it is attached with insulating tape to the electric detonator, which is further connected to the main line of the blast field grid, which leads to the blasting machine.

Table 2. Overview of quantities, types of explosives and non-electric detonators by individual boreholes for one step of advancement, with the depth of blast holes of 2.0 m'

OVERVIEW OF THE QUANTITIES OF EXPLOSIVES BY BLAST HOLES													
Series of non-electric detonators used	1	2	3	4	20	25	30	40	45	50	60	70	75
Number of holes of the series	4	4	2	4	6	3	6	6	16	10	9	11	2
Total number of holes	83.00												
Σ expl. per hole (kg/hole)	1.61	1.60	1.60	1.60	1.60	1.44	1.60	1.43	0.256	0.256	0.256	1.60	1.80
Σ expl. for one blasting (kg)	84.70												

The basic technical characteristics of the initiation means and explosives used during the excavation of the left tunnel tube of the Zenica tunnel in the part considered in this paper are given below.

Table 3. Overview of non-electric detonators used

The serial non-electric detonators used marked on the layout scheme of blast holes	1	2	3	4	20	25	30	40	45	50	60	70	75
Delay (ms)	100	200	300	400	2000	2500	3000	4000	4500	5000	6000	7000	7500

Table 4. Overview of basic characteristics of explosives used

Characteristics of explosives used	Plastic explosive	Contour explosive
Density (kg/dm³)	1.20	1.10
Explosion energy (KJ/kg)	4850.00	4850.00
Gas volume (l/kg)	921.00	921.00
Cartridge diameter (mm)	38.00	27.00
Cartridge length (mm)	400.00	230.00
Cartridge weight (kg)	0.475	0.128

By defining the scheme of blast holes (Figure 8) with the layout of detonators by holes on the cross section for excavation of the Zenica tunnel in the weaker rock mass RMR (33÷43), all the obtained drilling and blasting parameters at chainage 1+522.08 were applied, which is shown in figures below. The photo (Figure 9) shows the face of the LTT at chainage 1+522.08 after drilling all blast holes according to the defined scheme (Figure 8). After all blast holes at the specified chainage were drilled, filling and blasting were carried out while adhering to all defined technical parameters (Figure 8 and Tables 2 and 3). Upon completion of blasting and ventilation of the site, loading and removal of blasted material was carried out, as well as processing of the excavation profile (Figure 10) and geodetic verification of the excavation line in LTT at chainage 1+524.088 (Figure 11).

Figure 9. LTT face cross section at chainage 1+522.08 after completion of drilling of all blast holes according to the defined scheme

Figure 10. LTT face cross section at chainage 1+524.088 after blasting and treatment of the cross section

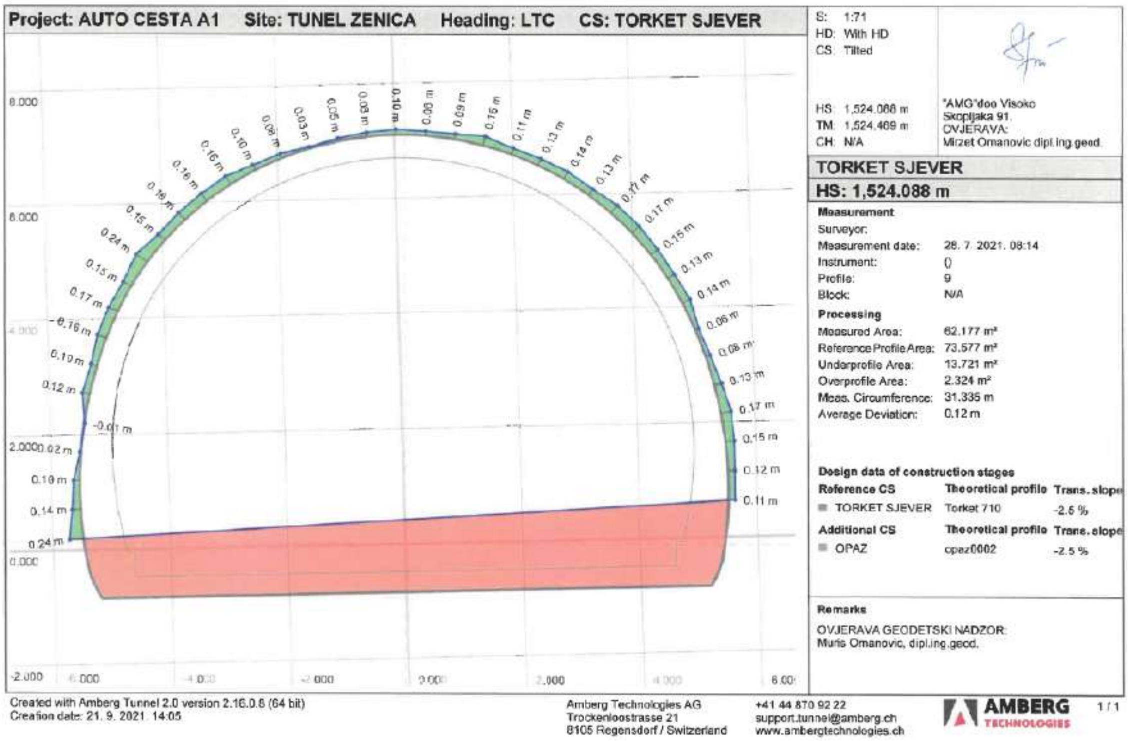


Figure 11. Geodetic survey of the face in LTT at chainage 1+524.088 after the completion of the excavation by blasting according to the defined scheme

CONCLUSION

The behavior of the underground excavation contour is primarily controlled by the structural geological characteristics of the rock mass. In carbonate rocks, the general stability of the excavation contour is reduced to the occurrence of local instabilities in the form of falling out of blocks due to the loss of shear strength of discontinuities. The depth of the zone damaged by blasting has the greatest influence on the initiation of local instability. If excessive, it can lead to progressive local failure, i.e. endangering the stability of the entire underground opening. In order to confirm or correct the drilling and blasting parameters defined by the supplementary mining project, it is customary to perform a test blasting in each category of rock mass that is planned for blasting in the project.

The optimal method of tunnel excavation, which ensured an approximately correct shape of the excavation, and a smaller tunnel overbreak, was selected by meticulously analyzing all available technical and technological parameters in the Zenica tunnel.

When excavating certain sections of the Zenica tunnel by machine, the shape of the excavation profile as well as the overbreak area largely depended on the structural geological characteristics of the rock mass and the skills of the worker operating the excavation machine, which directly reflected on the economic viability of the tunnel excavation.

Also, the excavation of certain sections of the tunnel by the method of drilling and blasting in a weaker rock mass due to the non-adjustment of all drilling and blasting parameters to the geological conditions in which the tunnel was excavated resulted in a negative economic viability in relation to the tunnel excavation in the same conditions using the method of mechanical excavation.

By choosing the optimal excavation method, the damage zone, which is inevitable during blasting excavation, was minimized in the sense that the strength and stiffness of the rock mass around the excavation contour were minimally reduced, which resulted in the preservation of the bearing capacity of the rock mass as the most important support element. Such an approach reduced the quantities of support set elements and the construction costs of the Zenica tunnel.

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A TIME PICTURE OF WORK AND TRANSPORTATIONAL COMPLEX DOWNTIME/FAILURE ON SEPARATION OF SC COAL MINE „GRAČANICA“ LLC GORNJI VAKUF – USKOPLJE

Rusmir Razić[1], Sunčica Mašić[2], Nedžad Alić[3]

ABSTRACT

The review and analysis of a timeline work and stoppage/failure of transportational complex on separation in SC coal mine „Gračanica“ LLC Gornji Vakuf – Uskoplje has been given in this work.
The work is based on collecting and analysing data. Collecting data lasted for one year and it is analysed and shown in this work. Rightfully determined the state of work and stoppage/failure, allows precautions and choice of strategy for the next period. Conclusions about which stoppage/failure affected the stoppage of transportational system and separation in full are derived from the research, and based on those conclusions, suggestions about activities which would minimize these stoppages on acceptable value are given.

Key words: mine, coal, effective work, stoppage, failure, transportational complex, separation, belt conveyor, scraper.

1. INTRODUCTION

Subsidiary company Coal mine „Gračanica“ LLC Gornji Vakuf – Uskoplje is placed on the right shore of river Vrbas, 7 kilometers northwest of Gornji Vakuf – Uskoplje and 8 kilometers southeast of Bugojno. Coal mine is working on production and preparation of coal lignite. Currently, the mine is working on exploatation of coal on SM „Dimnjače“. Surface mining „Dimnjače“, objects of coal separation, as well as accompanying objects of mechanical workshops and administration building are placed on the teritory of municipality of Gornji Vakuf – Uskoplje.

Exploatation on surface mine „Dimnjače“ began in 1986, and coal separation was done by separation whose capacity was approximately 50 t/h and it mostly gave fractional coal (0 – 60 mm). Because of increased production of coal, and the surface mining „Gračanica“ was in final stage of exploatation, the building of new separation on surface mining „Dimnjače“ was approached. The building of separational objects was shortly finished by 1987. Technological scheme of separation SC Coal mine „Gračanica“ LLC Gornji Vakuf – Uskoplje is shown on picture 1.

Through this work, all individual working units (system elements: scraper transporter and belt conveyors) are observed, as well as system as a whole. To get full information about behaving of continuous transportational system, as well as elements of system, is it neccessary to dispose to a big number of data about time of work and stoppage/failure of transporters (elements of system) at separation of coal at surface mining „Dimnjače“.

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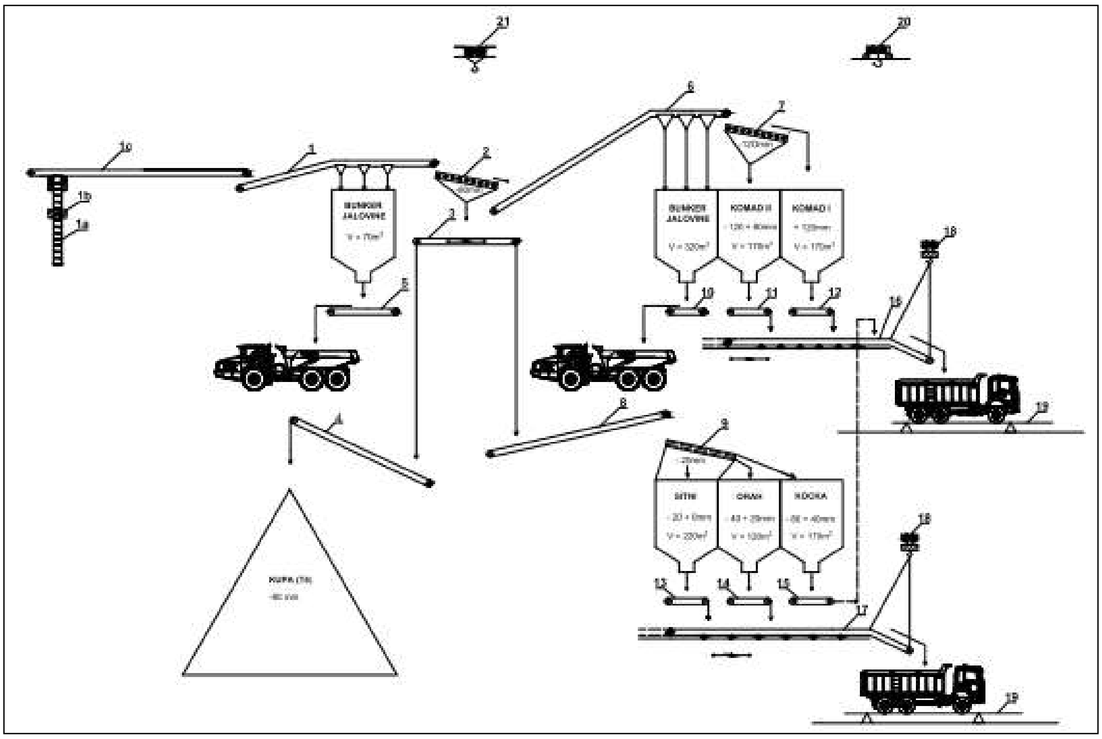
Transportational system at separation has 13 belt conveyors (T1A, T1, T3, T4, T6, T8, T11, T12, T13, T14, T15, T16, and T17), three scrapers, caliber sieve 80x80 mm, caliber sieve 120x120 mm, single-stage sieve and command desk.



Picture 1. Transportational system of separation (technological scheme)

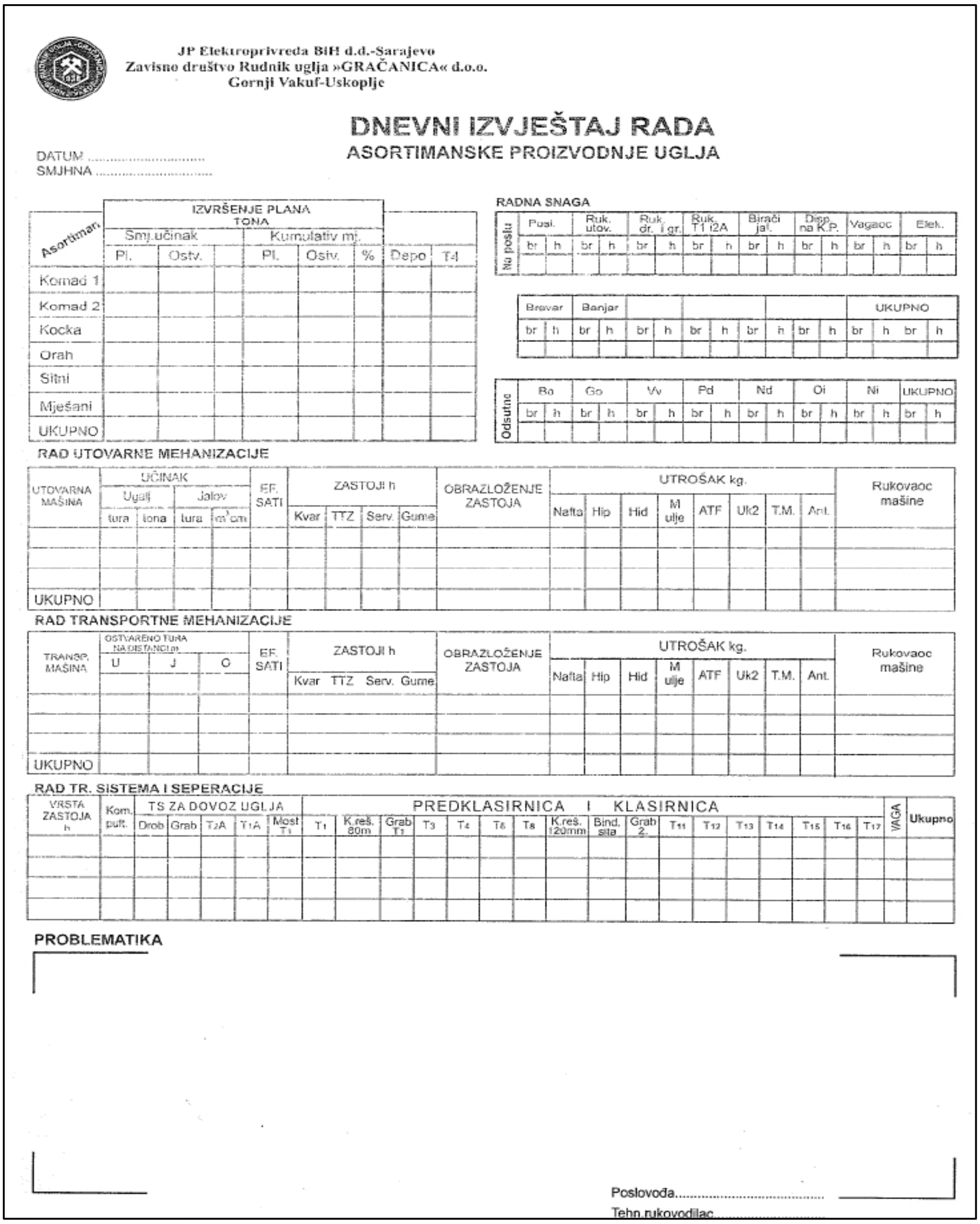
2. COLLECTING DATA ABOUT WORK AND STOPPAGE (DOWNTIME) OF ELEMENTS OF TRANSPORT AT SEPARATION

The exchange of information between supervisory – technical staff and operator of machines, auxilliary equipment, as well as communication between machines operators themselves, has been done by telephone connection. Telephones are installed as stable in separation, administration and repeairing workshops.

Manager and supervisor of coal separation communicate and exchange information with the dispatcher of command desk, scraper operator and operators of loading machines via radio and telephone connections. Shift managers or separation supervisors direct trucks, auxilliary equipment and other mechanizations via radio or oral connection according to the situation in production process and determine priorities by directing to serving certain segments of separation.

At the end of the shift, shift mechanic or locksmith and electrician write in the observatory book all fixtures that occred at separation during the shift describing malfunction, as well as time required for the fixture.

Shift manager controls and writes all collected information into the shift report book, and hands it over to technical operator of the mining and separation (picture 2.).



JP Elektroprivreda BiH d.d.-Sarajevo
Zavisno društvo Rudnik uglja »GRAČANICA« d.o.o.
Gornji Vakuf-Uskoplje

DNEVNI IZVJEŠTAJ RADA
ASORTIMANSKE PROIZVODNJE UGLJA

DATUM ....
SMJHNA ....

Asortiman	IZVRŠENJE PLANA TONA							
	Smj.učinak		Kumulativ mj.					
	Pl.	Ostv.	Pl.	Ostv.	%	Depo	T4	
Komad 1								
Komad 2								
Kocka								
Orah								
Sitni								
Miješani								
UKUPNO								

RADNA SNAGA

	Posl.	Ruk. utov.	Ruk. dr. i gr.	Ruk. T1 i2A	Birači jal.	Disp. na K.P.	Vagaoc	Elek.
Na poslu	br h	br h	br h	br h	br h	br h	br h	br h

Bravar	Banjar					UKUPNO
br h	br h	br h	br h	br h	br h	br h

	Bo	Go	Vv	Pd	Nd	Oi	Ni	UKUPNO
Odsutni	br h	br h	br h	br h	br h	br h	br h	br h

RAD UTOVARNE MEHANIZACIJE

UTOVARNA MAŠINA	UČINAK Ugalj tura	tona	Jalov tura	m³ čm	EF. SATI	ZASTOJI h Kvar	TTZ	Serv.	Gume	OBRAZLOŽENJE ZASTOJA	UTROŠAK kg. Nafta	Hip	Hid	M ulje	ATF	Uk2	T.M.	Ant.	Rukovaoc mašine
UKUPNO																			

RAD TRANSPORTNE MEHANIZACIJE

TRANSP. MAŠINA	OSTVARENO TURA NA DISTANCI U	J	O	EF. SATI	ZASTOJI h Kvar	TTZ	Serv.	Gume	OBRAZLOŽENJE ZASTOJA	UTROŠAK kg. Nafta	Hip	Hid	M ulje	ATF	Uk2	T.M.	Ant.	Rukovaoc mašine
UKUPNO																		

RAD TR. SISTEMA I SEPERACIJE

VRSTA ZASTOJA h	Kom. pult.	TS ZA DOVOZ UGLJA Drob	Grab	T2A	T1A	Most T1	PREDKLASIRNICA I KLASIRNICA T1	K.reš. 80m	Grab T1	T3	T4	T6	T8	K.reš. 120mm	Bind. sita	Grab 2.	T11	T12	T13	T14	T15	T16	T17	VAGA	Ukupno

PROBLEMATIKA

Poslovođa.......................................
Tehn.rukovodilac..............................

Picture 2. Daily report of distributional coal production

The systematization of data about working times and **downtime** /failure of all members of transportational system has been conducted for a period of 12 months.

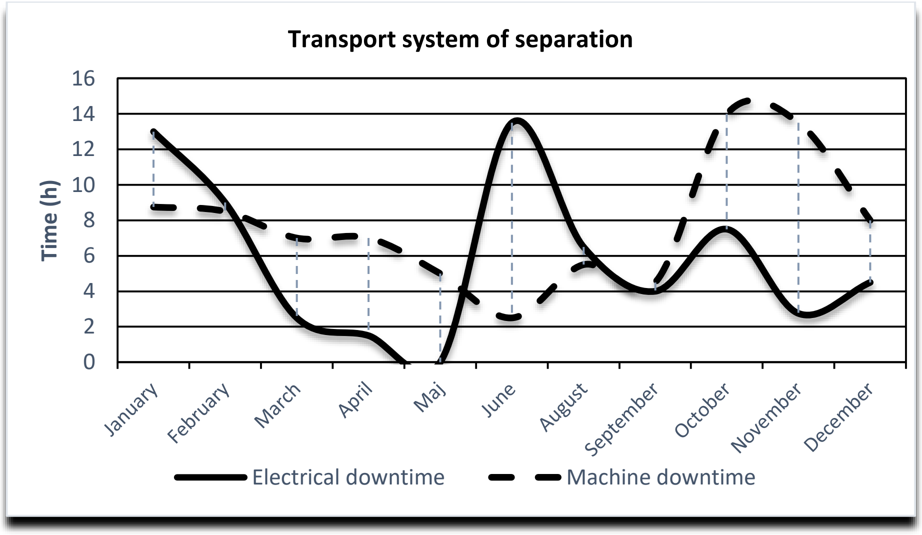
3. TIME PICTURE OF WORK AND DOWNTIME/FAILURE OF TRANSPORTATIONAL COMPLEX AT SEPARATION

To get basic parameters, observing and gathering of time information about work and **downtime** /failure of transportational units had to be done. Based on gathered information about basic transportational equipment on separation, the time picture of work and stoppage/failure has been researched.

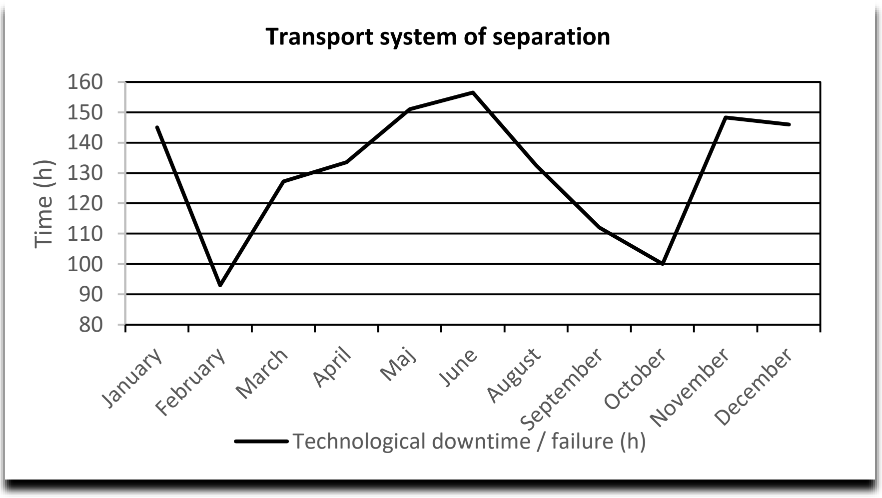
The review of registered data of **transport system of separation** has been shown in **Table 1.**

Table 1. Registered time data about work and downtime/failure for transportational system

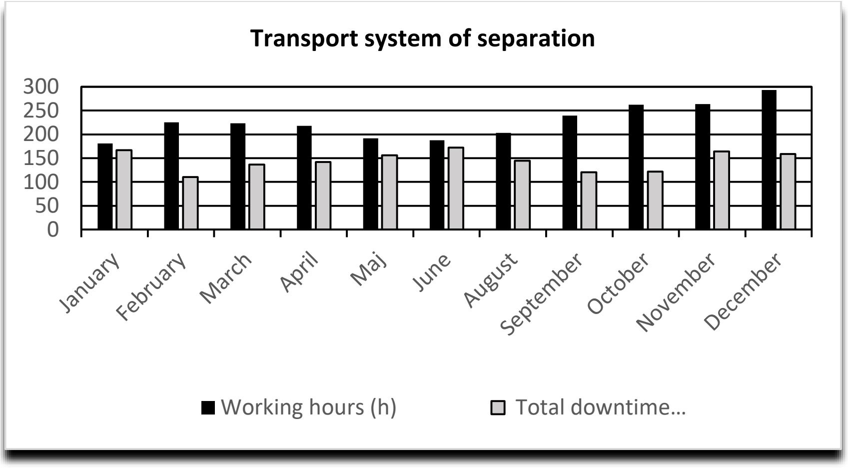
Transport system of separation						
Month/2013	**Working hours (h)**	**Technological downtime / failure (h) (h)**	**Electrical downtime / failure (h)**	**Machine downtime / failure (h)**	**Total downtime / failure (h)**	**Total time during the month (h)**
January	181,25	145	13	8,75	166,75	348
February	225,5	93	9	8,5	110,5	336
March	223,25	127,25	2,5	7	136,75	360
April	218	133,5	1,5	7	142	360
Maj	192	151	0	5	156	348
June	187,5	156,5	13,5	2,5	172,5	360
August	203,5	132,5	6,5	5,5	144,5	348
September	239,5	112	4	4,5	120,5	360
October	262,5	100	7,5	14	121,5	384
November	263,5	148,25	2,75	13,5	164,5	428
December	293,5	146	4,5	8	158,5	452
UKUPNO	**2662,25**	**1641**	**67**	**85,75**	**1793,75**	**4456**



Picture 3. Review of mechanical and electrical downtime /failure by observed months



Picture 4. Review of technological downtime /failure by observed months



Picture 5. Review of effective work time and total downtime /failure by observed months

Based on the data about time condition of work and **downtime /failure**, transportational system of separation by position 7 and position 9 in researched time (12 months), can be concluded that:

-Total duration time of effective work for observed period is 2662,25 h. Average work time for one month of observation is 221,85 h

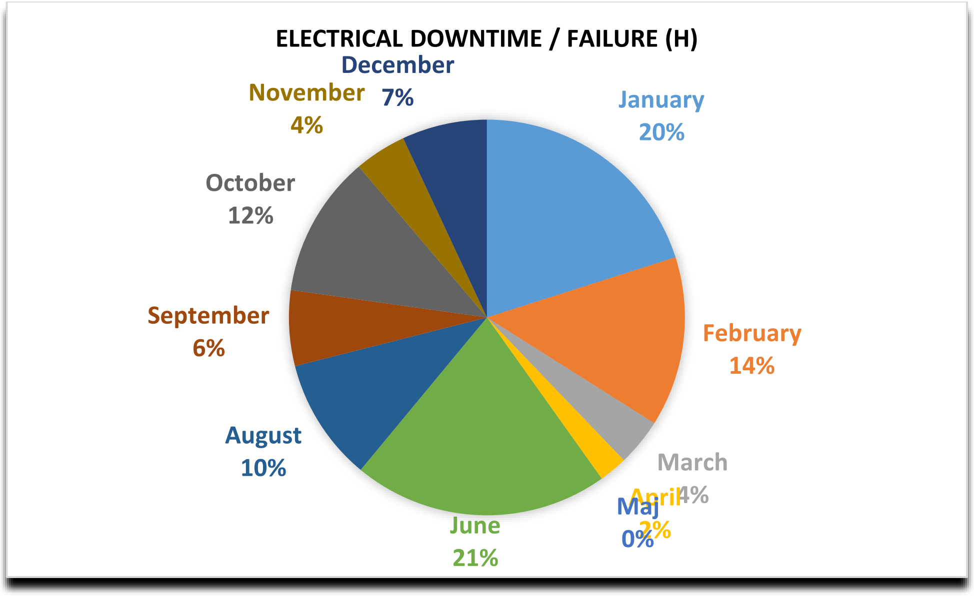
-Total duration time of electrical downtime/failure for observed period is 67 h. Average duration time of electrical downtime/failure or one month is 5,58 h

-Total duration time of mechanical downtime/failure for observed period is 85,75 h. Average duration time of machanical downtime/failure for one month is 7,15 h

-Total duration time of technological and organizational downtime/failure for observed period is 1641,00 h. Average duration time of technological and organizational downtime/failure for one month is 136,75 h

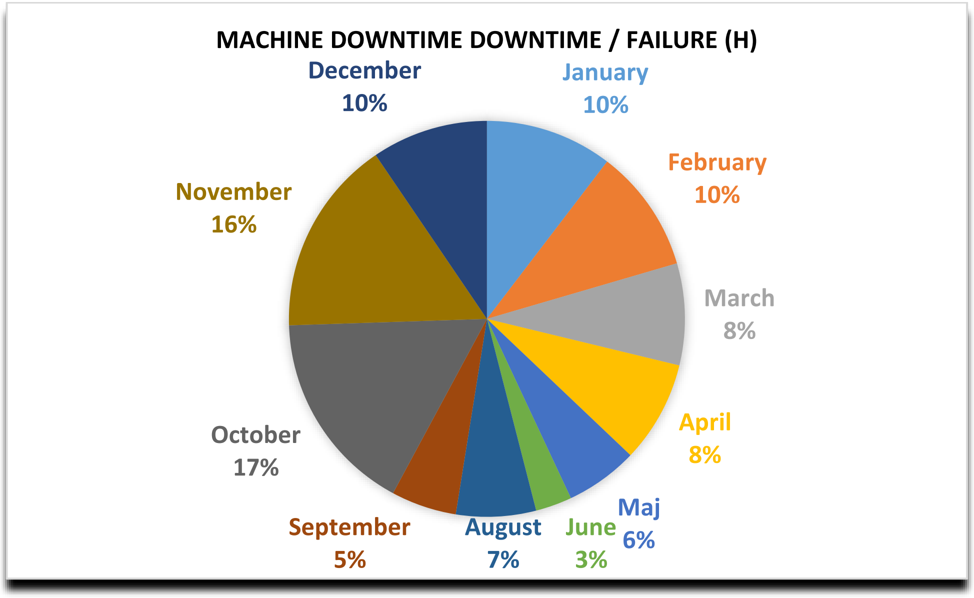
-Total duration time of all downtime/failure for observed period is 1793,75 h. Average time of all downtime/failure for one month is 149,48 h

Based on latter data, it can be concluded that transportational system of separation by position 7 and position 9, 59,75% of available time has spent working, 1,5% of time has spent in electrical stoppage/failure, 1,9% in mechanical stoppage/failure, and 36,83% of available time has spent in technological and prganizational stoppage/failure.



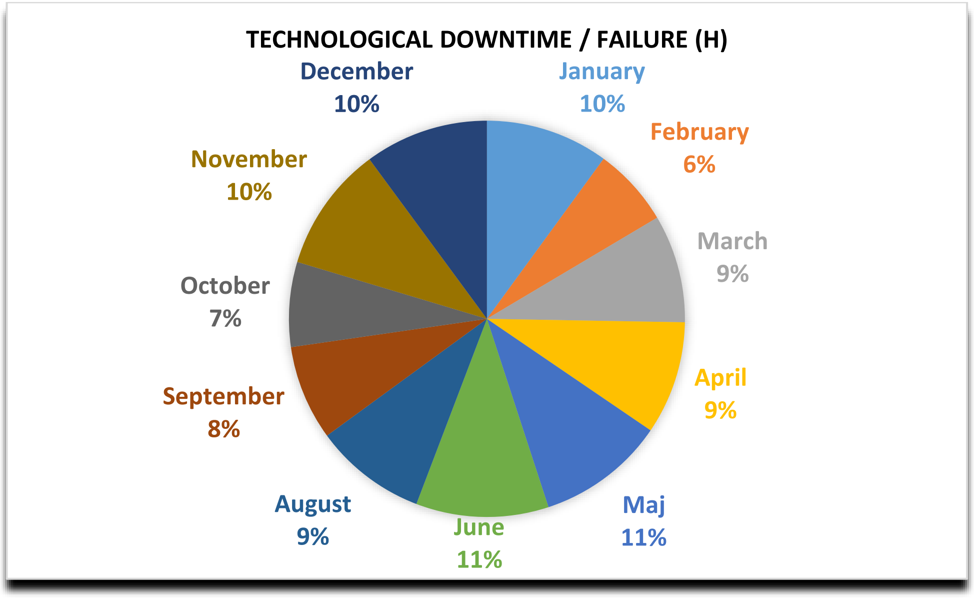
Picture 6. The percentage of electrical downtime/failure by observed months

Electrical downtime/failure have been recorded during 11 months, but in May hasn0t been any downtime/failure, the rest of the months had 2 – 20% of stoppage, and the most common malfunctions were repair of outlet, repair of switch, fixture of junction box, replacement of side switch, insertion of side switch assembly, replacement of sound signal, power outage, unblocking of pull-out switch, repair of distribution cabinet, repair of sound signalization, turning on the pull rope, seized valve stem, repair of buttons, replacement of electrical engine, replacement of direction of movement, engine bearing replacement, repair and posture of sound signal.



Picture 7. The percentage of mechanical stoppage/failure by observed months

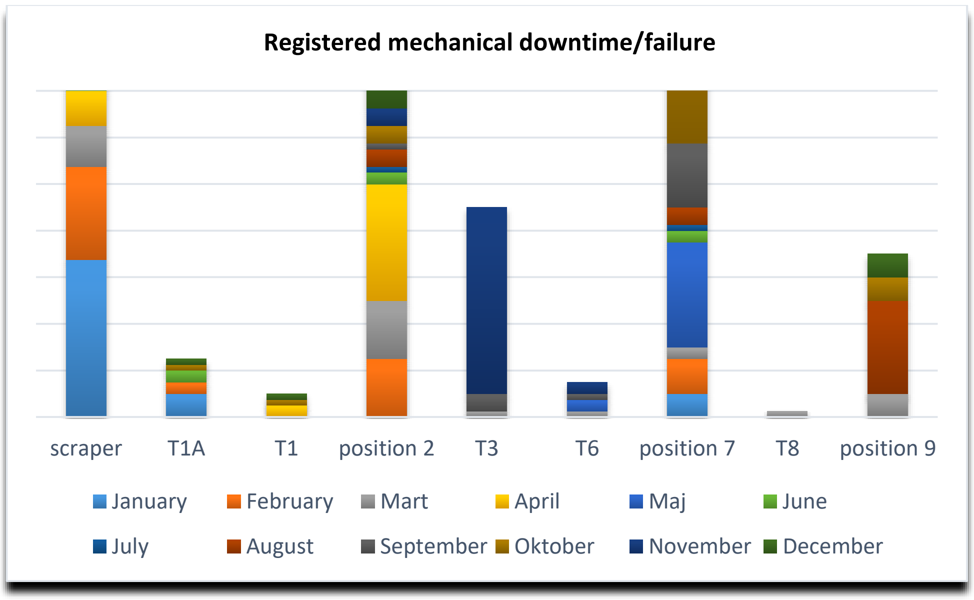
Registered mechanical downtime/failure have been moving from 2 to 16% (1,5 h to 14 h). downtime/failure that follow these transporters of mechanical type are tape centering, rollers changing, scraper changing, replacement of chain clips, doping oil into reducers, oiling, cutters' defrosting in winter period, mixed cutters, oiling, cutters' malfunction (beds), oiling, tape splicing (stitching), oiling of rollers, replacemtn of side rollers, tape popup, replacement of beds, oiling the chain, slipped hydro coupling, chain binding and cutters repair, case welding, shield welding etc.



Picture 8. The percentage of technological stoppage/failure by observed months

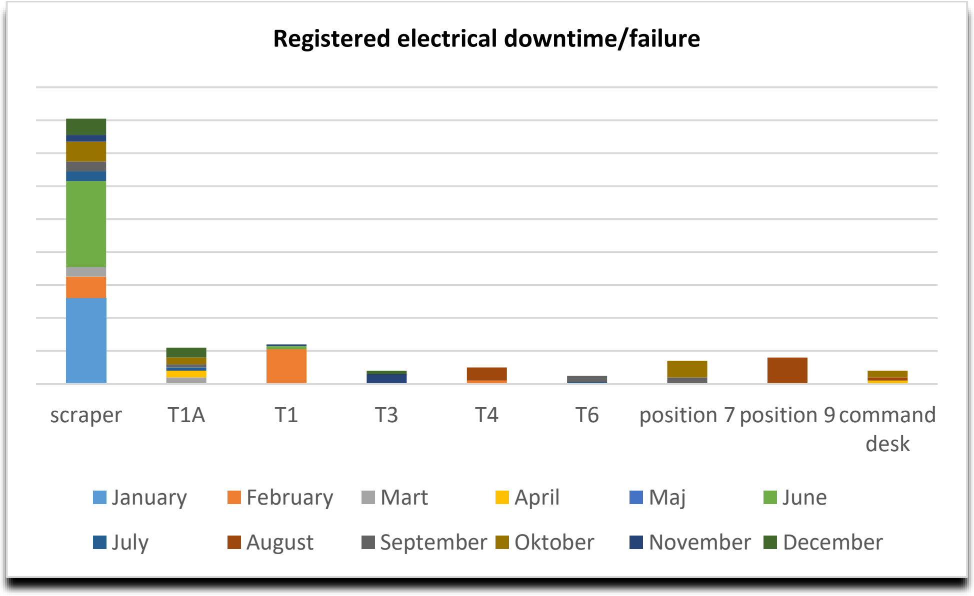
During 12 months of observation, transporters had the most technological downtime/failure in July, 12%, while in other months downtime/failure were between 6, 7, 8 and 9%. Technological failures that follow these transporters are mostly caused by human factor, waiting for loader or separation not included into work, as well as some of the transporters.

All elements in transportational complex system had registered technological downtime/failure in period of 12 months. Some elements in part of the transportational systemon separation during the observation had registered mechanical and electrical downtime/failure, while some of them did not.



Picture 9. Registered mechanical downtime/failure by individual months

The element of position 7 had registered downtime/failure during 11 months, while the scraper had registered downtime/failure during 10 months. The element of position 2 had registered downtime/failure during 10 months, and position 9 had failures during 4 months, while the transporter T1A had failures during 6 months, T1 during 3 months, transporter T8 during one month and T6 during 4 months. The remaining transporters and positions didn't have registered failures.



Picture 10. Registered electrical downtime/failure by individual months

The element of position 7 had registered downtime/failure during 2 months, scraper had failures during 9 months, transporter T1A during 6 months, T1 during 3 months, T3 during 2 months, command desk during 3 months, T6 and position 7 during 2 months, transporter T4 during 2 months and position 9 during one month.. The remaining transporters/elements didn't have registered mechanical failures.

4. CONCLUSION

Based on the conducted research, it can be concluded that the transportational system didn't work because of the following technological failures:

- Human factor,
- Waiting for loader,
- Usual failures on T6 conveyor because of separating the tailings,
- Empty baskets,
- Cleaning and washing the doser,
- Separation was not included into work.

Suggestion of activities to reduce failures to acceptable rate:

- Stoppages related to human factor were 246 hours due to lateness of workers to workplace. With strict supervisor of technical and supervisory staff, these stoppages could be reduced to acceptable rate.
- It's neccessary to have 2 loaders in production, but to reduce stoppage of waiting separation due to loaders, there is need for a third one.
- T6 transporter is the transporter that is used for segregating tailings. The content of tailings that is not segregated from it is crucial for the quality of coal in baskets.Due to that problem, in the period when there is a big amount of tailings in material on belt transporter T6 , that transporter is mostly

stopped, which leads to stoppage of remaining transporters. To have less stoppages of transporter, it is neccessary to secure better quality of pit coal and increase number of workers who are working on segregating the tailings of T6 transporter.

- Empty baskets are related to dosing transporters and they are in waiting mode. To improve production system and material floww on belts, it is neccessary to spread material evenly on the belts and that is possible with just 2 loaders that shift material from terminal to scraper which transports in further to separation. In this way, the baskets would be loaded faster and more evenly, and dosing transporters would have less technological stoppages.
- The work on separation has to be stopped due to the need of cleaning and washing the separation. The separation doesn't work while power outage, but during that time, the old separation that crumbles material which is transported to terminal is working, so the production is not endangered.

The presented methods of treatment, analysis and seclusion of relevant information about work parameters and transportational system downtime/failure in separation has been done for the first time in this way and in these areas and can be repeated for continuous transportational systems on other separations.

Contribution of this work to professional literature is that, for the first time, certain time picture of work and downtime/failure of transportational system on separation has been determined and based on the data can give suggestions for activities that lead to increasing effective work time.

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IMPROVEMENT OF TECHNICAL MEASURES FOR PROCEDURES IN ACCIDENTS ON GAS SYSTEM

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SUMMARY

Due to properties as flammability, explosiveness, suffocation (decreased oxygen content), toxicity (incomplete combustion), large lengths of gas pipelines, risk of leakage, etc., natural gas is media that requires special care during transport and use. There are many examples in the world where unprofessional and negligent use of gas led to unimaginable and tragic consequences with human casualties and huge material damages. This paper analyzes management of accidental situations at the Sarajevo Canton gas system. Problematic aspects of management will be presented through two case studies instead of presenting idealized models that integrate all structures responsible for dealing with such accidental situations. The methodological approach in this paper is presented through selection of accidents on gas network that had a significant impact and required a coordinated response from the competent services. The goal is to consider possibilities of improving technical measures by installing valves with remote control, which would raise safety to a higher level. With this step forward in technical terms, it would be possible to close the valve on gas system in the shortest period of time by controlling it from the dispatch center, which would stop the uncontrolled gas release.

The paper will suggest locations where it would be optimal to install valves with remote control, in order to close the necessary section, and at the same time, the least number of consumers would have a gas supply interruption.

Key words: gas system, accident, technical measures

INTRODUCTION - SARAJEVO CANTON GAS SYSTEM

The gas network in the Sarajevo Canton (SC) is conceived as a multi-stage distribution system. The basic city gas network is designed as a steel gas pipeline of pressures 8 (14.5) [bar] and 3 (4) [bar], which is in form of a ring due to the uniformity of gas supply to customers, so that the basis for gas distribution is steel gas network pressure 8 (14.5) [bar] with three main metering and regulating stations (GMRS): Butile, Hum and Ilijas. At the entrance to the most populated parts of the city this pressure is reduced for safety reasons in pressure reduction stations from 8 (14.5) [bar] to 3 (4) [bar]. The regional reduction stations (RRS) for the supply of a certain city area and the receiving-reduction stations (PRS) for the supply of larger industrial and other consumers are connected to this gas network. The outlet pressures from these stations are 0.1 (0.2) [bar], 0.5 [bar] or 3 [bar] depending on the further way of gas distribution and use.

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The gas network with pressure 8 (14.5) [bar] is divided into 24 sections and contains 33 valve batteries, emergency valves for RRS and PRS, branch valves and sectional valves for 53 RRS, 93 PRS-industrial consumers and 27 PRS for Heating plant boiler rooms. There are a total of 519 valves of various diameters on this network. The batteries have a function of shutting off the gas supply to certain sections of the gas network and possibly releasing the gas using the vent valves that are an integral part of the batteries. Gas pressure network 8 (14.5) [bar] is built with steel pipes and extends from GMRS I in Butile and with two branches (north and south) closes in a ring, and ends with RRSs 8/3 [bar] which supply gas to the narrower part of the city and from GMRS II on Hum. An independent unit of this gas network is part of network 8 (14.5) [bar] in the Municipality of Ilijaš, which is supplied via GMRS III. The total length of this network is 101,839 [m].

The general characteristic of the gas network 3 (4) [bar] is that it is made as an underground pipeline of steel and polyethylene pipes of different cross-sections. This network covers most city municipalities. The gas pressure network 3 (4) is 70,957.50 [m] long (Figure 1).

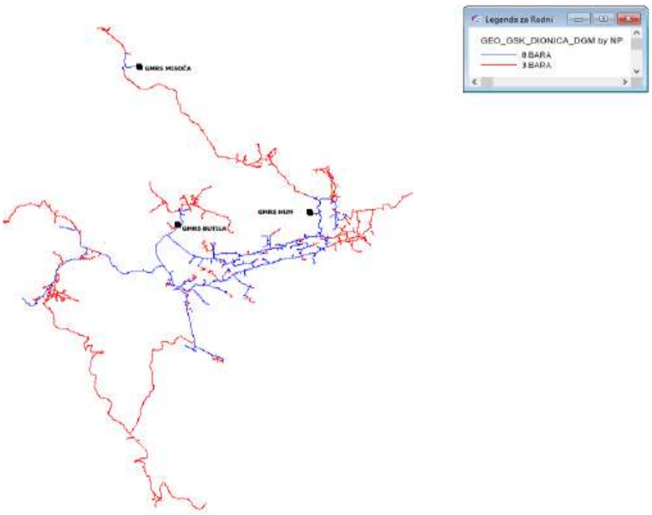


Figure 1. Gas network SC 8 [bar] and 3 [bar] [4] [8]

The gas network with a pressure of 0.1 (0.2) [bar] and 0.5 [bar], is built with polyethylene pipes and covers the entire territory of Sarajevo Canton. According to numerical indicators of the laid pipelines' length, this is the largest network with a total length of 1,074,453.50 [m].

In the recent past, Sarajevogas[5] had a number of serious damages to gas pipelines with a nominal pressure of 3 [bar] and 8 [bar], which did not result in material consequences or human casualties. However, such situations indicated that there are elements which are not within the domain of the company's responsibility and they could have impacted the further course of the accident itself. Bearing in mind that an adequate and appropriate reaction is not always possible by acting on the ground, it is necessary to enable faster and more effective handling of accidents by improving technical measures on the gas system, which results in higher safety level in the aforementioned situations. These measures would not be related to the human factor action in the field, but to the coordination and activities of the dispatch center.

This paper analyzes possibilities for technical measures improvement by installation of valves with remote control from the dispatch center.

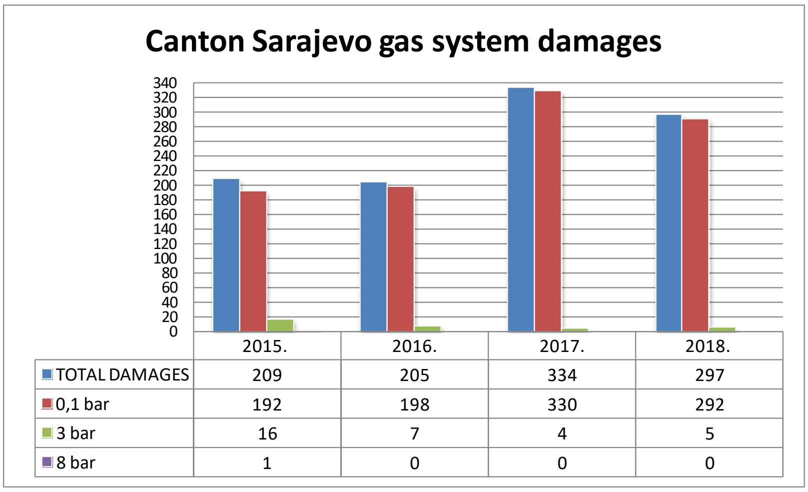
[4] 100 [mbar] network is not shown due to its size, i.e. density, as well as gas plants, i.e. stations

[5] "Sarajevogas" d.o.o. Sarajevo is a company for the supply of natural gas to the Canton of Sarajevo

1. CASE STUDIES

The risk of city gas pipelines leak is high and occurs for multiple reasons. The main reasons are pipe damage, corrosion, problems in the construction of the pipeline itself, damage from a third party, damage caused by natural (environmental) factors such as landslides.

In the observation period 2015-2018, damages to the CS gas system were recorded, with the 0.1 [bar] system damages dominating (Diagram 1).

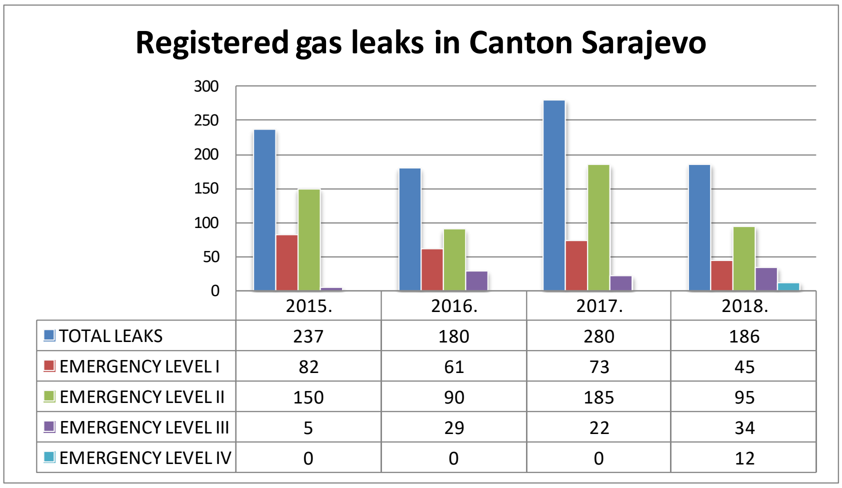


	2015.	2016.	2017.	2018.
TOTAL DAMAGES	209	205	334	297
0,1 bar	192	198	330	292
3 bar	16	7	4	5
8 bar	1	0	0	0

Diagram 1 - Statistics of damage by network (pressure) during period 2015-2018 (source: Sarajevogas)

In order to help in deciding on urgent measures, as well as to help decide on the type and order in underground gas pipelines repairs, 4 levels of urgency are defined, where the degree of urgency 1 is the highest level of threat (explosions, fires, large-scale gas leaks, damage to the distribution gas network, etc.) and 4 is the lowest (regular maintenance of the gas system).

Diagram 2 shows an overview of detected gas leaks on the CS gas system during period 2015-2018, with regard to the urgency degree. The largest share of the total registered leaks in each year belongs to the urgency level II: the location of it or the boundary line is located at a distance of less than 1 meter from the building, where the presence of gas is not registered in the building and buildings or hollow spaces near the leak location. Safety measures for the level of urgency II, which are being implemented without delay, include, for example, the excavation (release) of piping with the aim to enable the unhindered gas discharge into the atmosphere, control of neighboring buildings and cavities, after which repairs are being carried out.



	2015.	2016.	2017.	2018.
TOTAL LEAKS	237	180	280	186
EMERGENCY LEVEL I	82	61	73	45
EMERGENCY LEVEL II	150	90	185	95
EMERGENCY LEVEL III	5	29	22	34
EMERGENCY LEVEL IV	0	0	0	12

Diagram 2 - Statistics of detected gas leaks during the period 2015-2018 (source: Sarajevogas)

Detection is one of the most important segments of gas system maintenance, with task to carry out planned measures to check the distribution gas system for permeability, as well as visual control of the correctness of the distribution gas system parts. After gas leakage is detected, appropriate measures are taken. It is necessary, if there are buildings nearby, to carry out detection in them as well.

There are several possible approaches and methods of dealing with natural gas accidents. It is necessary to have procedures or written documents that will define roles and tasks of persons conducting repairs as well as those who manage, whether management is on the spot or indirectly from a remote center through the communication system.

Through case studies, this paper investigates the management of crisis situations during uncontrolled gas leak in Sarajevo Canton. The first case study refers to the uncontrolled gas release under the surface that occurred in 2010 in the central part of the city in the area of a very busy street, in the immediate vicinity of business premises and residential buildings.

The second case study presents a gas leak from 2018 in the settlement of Bjelave, when gas concentrations were also registered in a large number of residential buildings.

1.1 UNCONTROLLED SUBSURFACE GAS LEAK IN THE CITY CENTER

In 2010, the gas leak was registered in the evening based on a notification from citizens that presence of gas was felt in M.M. Baseskije street. Measurement and detection found the presence of gas with different concentration values depending on the location where the measurement was performed. The highest concentration of gas was found in two shafts used by the telecom operator for its installations in the immediate vicinity of the intersection of M.M. Baseskije and Jeliceva street, and in M. M. Baseskije street near number 22 in the sidewalk area, and in two sewer shafts in the M. M. Baseskije road itself near the aforementioned intersection of M. M. Baseskije and Jeliceva and near the intersection of M. M. Baseskije and E. Mulabdica streets (Figure 2). The measured concentration in these shafts reached a value of up to 95% of the gas volume, and all employees from the "Standby Organization" as well as additional employees who perform work tasks in detection jobs were called and directed to the location.

Given that this street is the central one through which traffic for vehicles and trams takes place, the police closed this street to traffic, as well as to pedestrians, for preventive - safety reasons; Members of the Sarajevo Professional Fire Brigade were also present, as were the workers of power supply company, who turned off the electricity for a wider area around the accident site.

The presence of gas was not registered in the building itself. Excavation was carried out at several locations, but the cause of the uncontrolled presence of large concentrations of gas was not discovered. In telecom operators shafts, the concentration varied, it would increase over time and then decrease, and it had to be constantly ventilated.

Figure 2. Uncontrolled gas leak location

Taken into account that the location of the uncontrolled gas leak was not found during the night, construction of sections started next day by installing section valves. Electricity was still out for the wider accident site. By installing sectional valves using the method of eliminating part of the gas network, the area of uncontrolled leak was narrowed. First, two valves were installed at the ends of the gas network pipes where the devices did not registered gas. By closing these valves, it was determined by measurement that there was a decrease in gas concentration in the section between these two sectional valves, and then installation of a two more valves began. When the sectional valve was installed, it would be closed for a certain period and during that period the gas concentration would decrease, and then by opening it, the concentration would be measured and checked again in order to determine more closely the location of the gas release. Four measuring points were placed on the section that could be, with certainty, determined to being damaged. These measuring points served to eliminate sections by measuring the pressure drop and narrowing the area where excavations should be carried out for the final finding of the damage (Figure 3).

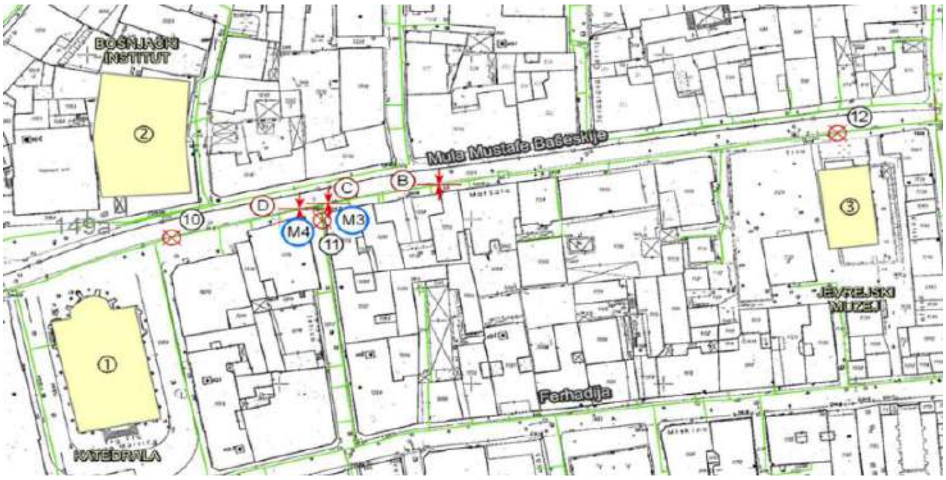


Figure 3. Locations of valves and pressure gauges placement to narrow section during the damage site locating

When it was identified a section of about six meters long gas network where there was a constant concentration of gas, excavation of this section started. After these actions, damage was found on the gas network pipe where the gas was leaking. The cause of the damage was a 0.4 [kV] electric power cable that was completely resting on the gas system pipe, and the heating of the cable caused plastic pipe melting (Figure 4) and an opening was created where the gas flowed out in large quantities.

Figure 4. Damaged gas network pipe

It can be concluded that in the accident in M. M. Baseskije Street, during which a large concentration of natural gas was released, the action was systematic and organized; and the cause of this accident is exclusively human factor.

1.2 GAS DISTRIBUTION NETWORK PIPES ACCIDENTAL DAMAGE

In the afternoon of 2018 (Friday) at Bjelave address no. 43 due to works on the water supply network reconstruction, the DGM pipe (gas distribution network) PE Ø 160mm pressure 3 [bar] was damaged and team from the "Standby Organization" went to the scene.

Officials of the Ministry of Internal Affairs of Sarajevo Canton who secured the scene, members of the Professional Firefighting Unit of the Sarajevo Canton Civil Protection Administration, as well as members of the Voluntary Firefighting Society of Bjelave were present at the location. The damage occurred when the local utility company excavator damaged the DGM pipe while excavating water pipe for the purpose of repairing it (Figure 5).

Figure 5. Damaged gas pipe (Source: https://www.faktor.ba)

Taken into account that the damage occurred during the peak traffic hour in the city, the arrival of the teams at the scene took longer. The mitigating circumstance was that the damaged pipe was supplied on one side, so it was enough to locate the nearest valve and shut off the gas. Upon arriving at the scene, the B3-07 valve battery was located, about a hundred meters from the gas leak, and the gas was shut off on the damaged DGM pipe. Taking into account that the intervention teams needed a longer time to arrive at the scene due to rush traffic hour, and the time necessary to locate and close the valve battery, about forty minutes passed from the moment of damage to the moment of shutting off the gas supply. Due to the gas pressure of 3 [bar], it was not possible to perform a temporary repair, but the gas supply had to be closed at the valves.

The long period of gas leakage had a psychological effect on citizens due to the fact that the pressure in the damaged pipe was 3 [bar] (which, due to the sound it created, also had a psychological effect on the citizens), and leakage happened in an old town settlement where the roads are narrow and the buildings are close to each other (Figure 6), and also due to this certain amount of gas entered the nearest residential buildings caused fear and panic among the citizens.

A large number of calls to the dispatcher on duty were made due to citizens' fear of the possibility of a gas explosion. Response to this accident was characterized by good coordination between the duty dispatchers of Sarajevogas and the duty dispatchers of external entities such as power supply company and the Professional Fire Brigade. The power company team immediately arrived at the scene, whose employees turned off the power supply to the affected location. Also, the duty dispatcher of the Professional Fire Brigade sent one fire engine of the Professional Fire Brigade and one vehicle of the Bjelave Volunteer Fire Brigade to the scene.

Picture 6. Damaged gas network pipe in the settlement of Bjelave

After the gas was turned off, the gas detection in buildings which were located in the immediate vicinity of the damage site started. After first control, the presence of gas in concentrations of 600 [ppm], 800 [ppm], 200 [ppm] and 120 [ppm] was registered in individual residential buildings, while the presence of gas up to 50 [ppm] was registered in the buildings of Home for children without parental care (which are in the immediate vicinity). In all buildings where detection was carried out, the windows were opened and ventilation of these buildings were carried out. After half an hour, the detection of these buildings was performed again, when the gas presence was not determined in the buildings where it was registered during the first measurement.

After the investigation by the authorized officers of the Ministry of Internal Affairs was completed, the repair of the damaged pipe began. After repairs were completed, gas was released into the DGM.

2. BLOCK VALVE STATIONS INSTALLATION PRIORITIES ANALYSIS

When responding to accidents without fire or explosion, it is necessary to stop uncontrolled gas release as soon as possible, in order to prevent the aforementioned phenomena. Stopping uncontrolled gas release at the dispatcher's order is mainly done by emergency teams on duty, or other teams if they happen to be nearby.

A big problem is the accessibility of the valves and possibility to act, i.e. their timely closing. It often happens that valves cannot be accessed due to parked vehicles or other obstacles. There are a series of events that happened in practice, which showed that closing the valve and stopping the gas flow could have been done in a shorter time.

Possible solutions that would enable faster action in extreme situations would be the installation of devices on some valves (valves batteries) that would enable remote control from the dispatch center. This way, in case of accidental situations, the valves would be closed in a short period of time, and the only amount of gas that would be released is the amount that remained trapped in the distribution gas network. Sometimes, in practice, this could require closing several valves, but most often two valves or two valve batteries (given that the network is made in a ring, closing one valve would not be effective).

Remotely controlled valves systems are also called blocking devices (block valve stations). There are three ways to activate the system and control blocking devices: manual, automatic and remote control. The older generation of these devices was pneumatically driven, while the new generation is electronically controlled. With devices managed in this way, greater reliability, insensitivity to weather conditions, etc.

would be obtained. The role of gas block valve stations is to perform sectioning of the transport gas pipeline or distribution gas network in the event of accident or damage. In more densely populated places, they should be installed at smaller intervals, if possible.

Damage to a pressure pipe of 0.1 [bar] does not represent a significant accident, and its temporary repair can be done in several simple ways and operations. However, damage to the pipe with the pressure of 3 [bar] or 8 [bar], will cause a general danger that may ultimately result in human casualties. It is not possible to stop gas leakage in case of damage to the pipes where the mentioned pressures prevail in the same way as in the case of damage to the pipe with the pressure of 0.1 [bar]. In case of damage to a pipe with a smaller diameter and a pressure of 0.1 [bar], it can be stopped by bending the pipe or possibly inserting a wedge, which prevents further gas release, thus eliminating the risk of fire or explosion.

When there is damage to pipes with the pressure 3 [bar] or 8 [bar], the only way to stop the gas leak is to close the valve and cut off the gas flow. Logical solution is to close the gas at the nearest valves in relation to the place of damage. However, the problem is that it is sometimes not possible to do this in practice since valves are often not accessible due to parked vehicles, unmarked valves or some other reasons. In such situations, the solution would be the installation of block valve stations with devices for automatic or remote control.

Respecting safety reasons, when designing the CS gas system, care was taken of its dimensioning, and a gas system with a pressure of 3 [bar] was designed in the very center of the city. This system starts with gas stations at the end of the system 8 [bar], which lower the pressure to 3 [bar].

2.1 INSTALLATION OF BLOCK VALVE STATIONS ON THE 3 [BAR] NETWORK

The gas system 3 [bar] is made in "ring" formation that is with both sides supply. There are 11 valve batteries on this part of the system, and the system is divided into 16 sections. Considering that almost the entire 3 [bar] system is in the center of Sarajevo, it would be a priority to install a blocking station on each of the valve batteries, because damage to pipe 3 [bar] in dense and frequent settlements always represents a great danger and the possibility of unwanted consequences.

In addition to the valves on the batteries, Fig. 7 also shows installed sectional intervention valves as well as a proposal for the installation of additional sectional valves which would require the installation of actuators in order to achieve remote closing.

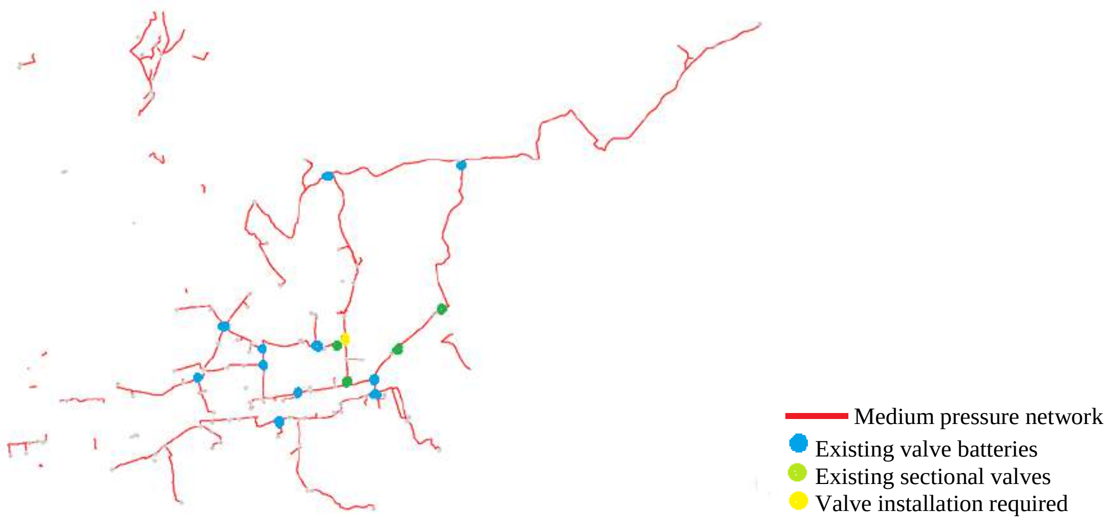


Figure 7. Detail of DGM - valve battery on medium pressure ring - PSP [8]

Such reconstruction would require a longer period of time due to construction and mechanical preparatory activities. The reason is that for the blocking stations installation, it would be necessary to carry out a larger excavation around valve battery to accommodate equipment and blocking devices, as well as accompanying installations, then mechanical and electrical work to connect all elements into one unit, and finally, testing the system before backfilling. Bearing in mind the increase of safety level, the installation of blocking stations on all valve batteries and on sectional intervention valves on the network of pressure 3 [bar] is fully justified.

From this part of the gas network, gas is further supplied to regional - regulation and receiving regulation stations, which reduce the pressure from 3 [bar] to 0.1 [bar]. Regional-reduction stations supply gas to the general public, i.e. citizens, while receiving-reduction stations supply gas to large consumers such as boiler houses and some businesses.

2.2 INSTALLATION OF BLOCK VALVE STATIONS ON THE 8 [BAR] NETWORK

Given that there are 33 valve batteries on the 8 [bar] pressure gas pipeline, which is much longer than the 3 [bar] pressure pipeline, the installation of blocking stations on all valve batteries would be a large and expensive investment. Also, for some sections with valve batteries there is no justified need to install a blocking station. A certain number of valve batteries and part of the gas system are located in the area of agricultural property and other "green areas" that are outside urban areas. The possibility of damage due to construction activities is low, and it can be concluded that the installation of a blocking station is not a priority in this part of the gas system. It should be noted that the valve batteries on the 8 [bar] gas system are designed so that on most of the sections, besides the branch valve, there are breathers and breather valves. The position and location of valve batteries, their importance in supplying consumers, but above all the importance of individual branching, as well as the reduction of section lengths, were taken into account as criteria for the installation of blocking stations in this paper.

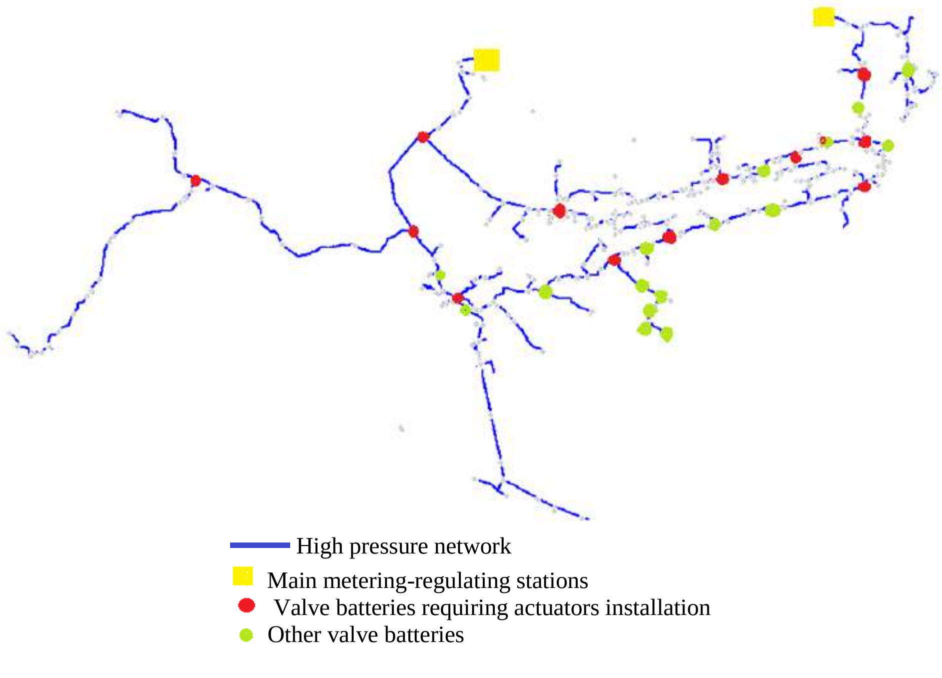


Figure 8. Detail of the DGM - valve batteries on the high-pressure ring [8]

At the end of the analysis, it is concluded (Figure 8) that it is necessary to install remote control systems on 13 batteries, and on the B8-02 battery an actuator would be installed on only one valve, on the branch of the battery that leads the gas to the B8-33 battery. Also, on battery B8 - 33, actuators would be installed on branches for Municipality of Hadzici and settlement of Rakovica, and since it is not supplied on both sides, no actuator would be installed on the valve for the branch towards battery B8 - 02. Actuators would be installed on all other valve batteries, which have three branches each and valves on each branch, i.e. on all valves located on the battery.

3. CONCLUSION

Procedures for accidental situations on the gas system of Canton Sarajevo, in terms of the organization itself, are carried out on the basis of internal documents. Technical measures and practical handling in the event of accidents depend on several factors, the most important of which is the pressure in the damaged pipe. At pressures of 3 [bar] and 8 [bar], it is necessary to cut off the gas flow to the place of damage. If the pipe is possibly made of polyethylene, and if it is accessible enough, it is possible to stop the gas flow by placing a clamp, crushing the pipe, although these situations are very rare. If the pipe is made of steel, the only way to stop the gas flow is by closing the valve. This is possible on valve batteries or on sectional valves if they exist on that part of the pipeline.

When the gas system is damaged, it takes a certain amount of time for the emergency teams to arrive, which directly depends on the traffic conditions. Sometimes an emergency intervention team cannot adequately and quickly respond to the gas accident. All this leaves the possibility that the gas will leak out uncontrollably for a certain period of time and thus represent the possibility of a fire or possibly entering nearby buildings, which would be very dangerous, because an explosive mixture could be created in a short time due to the pressure in the pipe. In addition to the above, the noise that appears due to gas release under high pressure causes panic in people. In order to improve the action in the event of damage and accidents on gas network, the proposal is to install block valve stations on networks 3 [bar] and 8 [bar]. This way, a step forward in terms of safety would be made, as it would be possible to close the valve in the shortest possible time. Block valve stations with blocking devices are preventive measures, but they are repressive in nature. They provide the possibility to automatically or remotely control the gas from the dispatch center on the closest valve batteries to the accident site, thus preventing further gas leakage that would endanger human life and property. The valve closing this way takes place within a few minutes from the moment of damage. In this regard, it is necessary to make a step forward and start installing block valve stations with one long-term project. This way, until the arrival of the first emergency teams, the gas supply would be closed, and the employees of the emergency intervention team would have time to secure the area around the accident site, without wasting time on finding the valve and closing it. Analyzed gas accidents from the past testify that only with a serious approach, good organization and professional action accidental situations on gas system can be maximally controlled and ended without human and material losses. It is also necessary to carry out a thorough analysis of the protection and rescue services functioning, as well as to ensure professional management of the competent institutions of this system. It is also necessary to form specialized response teams from various dangers, establishment of continuous training for professionals who would manage operations in gas accidents, as well as members of specialist teams who would represent the operative base for protection and rescue in the field.

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NEW KNOWLEDGE ABOUT THE GEOTHERMAL POTENTIAL OF Sl-1 WELL IN SLAVINOVICI

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SUMMARY

Today's use of geothermal energy is mostly complex and includes several basic branches of utilization, such as: balneology, household use, extraction of various minerals, electricity production, heating of settlements, heating of agricultural farms, as well as industry use.

This paper includes the latest research of thermo-mineral water quality from the Sl-1 well in Slavinovići and according to these results, a new classification and categorization of thermo-mineral water, which on the principle of "air-lift" erupts on the surface of the well.

The results of new chemical analyzes of thermal water from the Sl-1 well in Slavinovići were compared with the data obtained during the construction of the well, which date back to the late 1930s.

Finally, measures for the remediation of the condition of the Sl-1 well are given and also are proposed some further activities that would result withits complex use for balneological, but for any other suitable purpose.

Key words: geothermal energy, thermo-mineral water quality, categorization

INTRODUCTION

In the period between 1929 and 1941, large-scale exploratory drilling for oil was carried out (27 wells were drilled) in the wider area of the city of Tuzla. Most of the wells (24), with depth between 315.0-2025.0 m, were drilled on the Jala-Pozarnica anticline. However, despite many surface appereances of oil, a profitable oil deposit has not been found.

For consolation, a "layer" of warm thermo-mineral water, with temperature of 36 ^{o}C, in the amount of about 500 l/min was drilled in the exploratory well Sl-1, among others (Z. Hadzihrustic, Z.; Ibrisimovic, Z.; Nuhanovic, S.: "Possibility of complex use of thermo-mineral water from borehole Sl-1 in Slavinovici near Tuzla", Monograph of the International Conference on Trends in Modern Mining "TIMC05/06", Proceedings of the RGGF of the University of Tuzla (ISSN 1512- 7044), No. 32, pp. 23-27, Tuzla, 2006).

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The specificity of this well is the occasional eruptive ejection of hot water with an abundance of gases, without which it could never come to the surface. Its static level is located at 37.0 m (undetermined assumption) below the ground surface.

However, in addition to the mild and pleasant temperature of the bathing water, there are also indications of its medicinal, pharmacological, and even cosmetic value. Also, the need to reduce the share of non-renewable energy sources in the total energy balance of a country leads to an increasing use of geothermal energy. Nine kilometers to the east, on the same anticlinal structure, in the well Pozarnica -1 (1515 m), warm water with a temperature of 50 ^oC was also pumped up, which is a sufficient reason for some new research and discoveries of thermal waters in larger quantities.

The pleasant temperature of the thermal water from the well Sl-1 in Slavinovići has been used for many years for the spa activities of the locals, as well as for oral use. The last tests on the well itself were done at the time of its construction, which has already been over 85 years.

All previous research on the well Sl-1 in Slavinovici pointed to the need for more detailed tests of the content and quality of the thermal water, because over time, its chemical composition changed, as well as the yield of the well itself.

The new data, obtained from the conducted research, indicate some irregularities in the old data and also testify to the reflection of the past time, because each eruption period, of any well, is limited by time, but also by the change in the chemical composition of the fluid that is being exploited.

1. THERMAL CHARACTERISTICS OF THE SLAVINOVICI AREA

The most important geothermal parameters, thermal conductivity of rocks, geothermal gradient and heat flow for this area, were mostly obtained based on the results of temperature measurements made during the construction of wells, or by correlation of data obtained from measurements made in wells made in neighboring countries, together with literature data.

The Tuzla Basin belongs to the zone of "medium warm" depressions within the Pannonian depression, which is significantly warmer in its central part. The power of the heat flow in the center of the Hungarian depression is up to 138 mW/m^2, while in the Tuzla basin it is around 60-90 mW/m^2.

It should also emphasized that the determined thickness of the Earth's crust in the territory of Hungary is about 25 km, while the same is much thicker in Bosnia and Herzegovina (the average thickness of the Earth's crust in the territory of Bosnia and Herzegovina is about 45 km).

For the well Sl-1 in Slavinovici, it was determined a strong convective mode of heat transfer, by the circulation of warm waters from greater depths (Miosic, N.: "Geothermal parameters and features of hydrogeothermal regions of Bosnia and Herzegovina", Geoloski glasnik, no. 35, p. 279-307, Sarajevo, 2003).

Data aboutthe well Sl-1 in Slavinovici, which can be obtained by processing literature, mention a geothermal gradient value of 56.3 K/km, which gives a heat flow value of over 120 mW/m^2 (convective parameters), and EU standards each narrow geothermal area with a heat flow value above 100 mW/m^2 is called a thermal field. Some EU countries have lowered this value of the determined heat flow even to a lower level by their laws.

For example, in Hungary, according to their laws, as a positive geothermal anomalie is considered any region, that has a heat flow value above 50 mW/m^2 (Jan-Diederik van Wees, Thijs Boxem, Luca Angelino, Philippe Dumas: "GEOELEC – A perspective study on the geothermal potential in the EU", November, 2013).

So, in the area of Slavinovici, but also in the Tuzla basin in general, geothermal parameters, conditioned by the convective movement of heated fluids from lower chronostratigraphic levels, due to great erosion are quite expressed.

The aforementioned data would have to be practically confirmed by carrying out detailed geological and geophysical tests, especially by carrying out logging measurements in the borehole channel Sl-1 in Slavinovici, which would result in exact data on the values of the heat flow and other thermal parameters in the borehole, but also in the wider area of Jala-Pozarnica anticlines.

During the construction period of the borehole and especially after that, the mentioned tests were not performed, because the borehole was not designed as geothermal, whatever their performance is these days emphasized as an imperative for all future works with purpose of using geothermal energy from this borehole.

In Figure 1, the spatial position of the well Sl-1 in Slavinovici is presented, and in Figure 2 its construction.

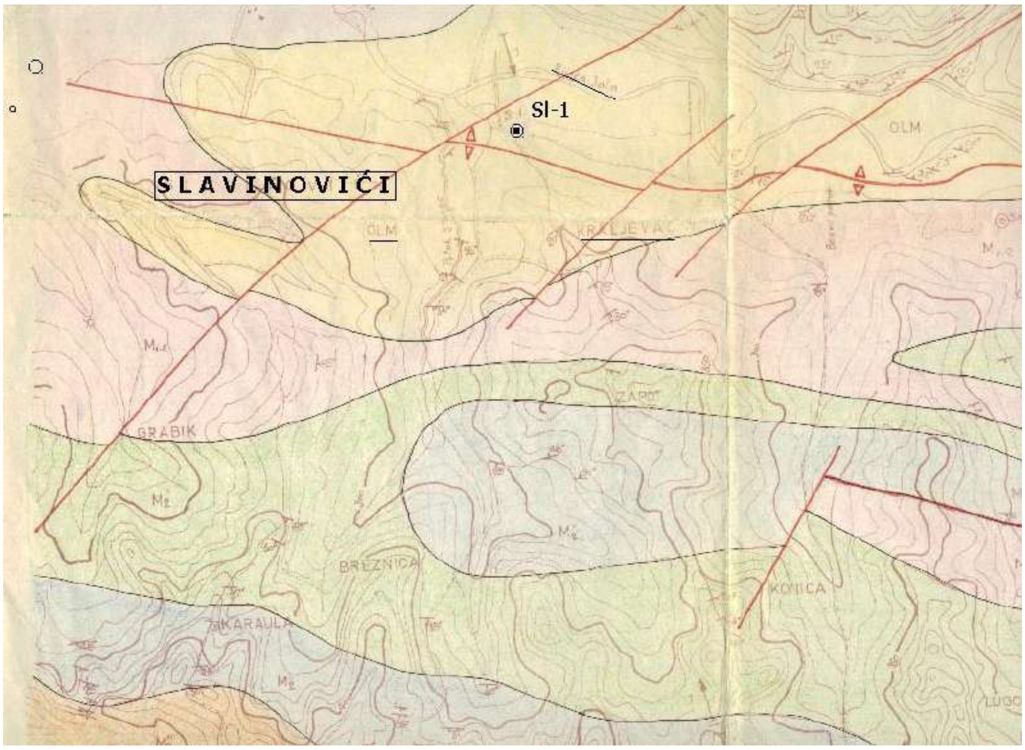

Figure 1. Slavinovici part of Jala-Pozarnica anticline, with the position of the well Sl-1 (Scale - 1: 10 000)

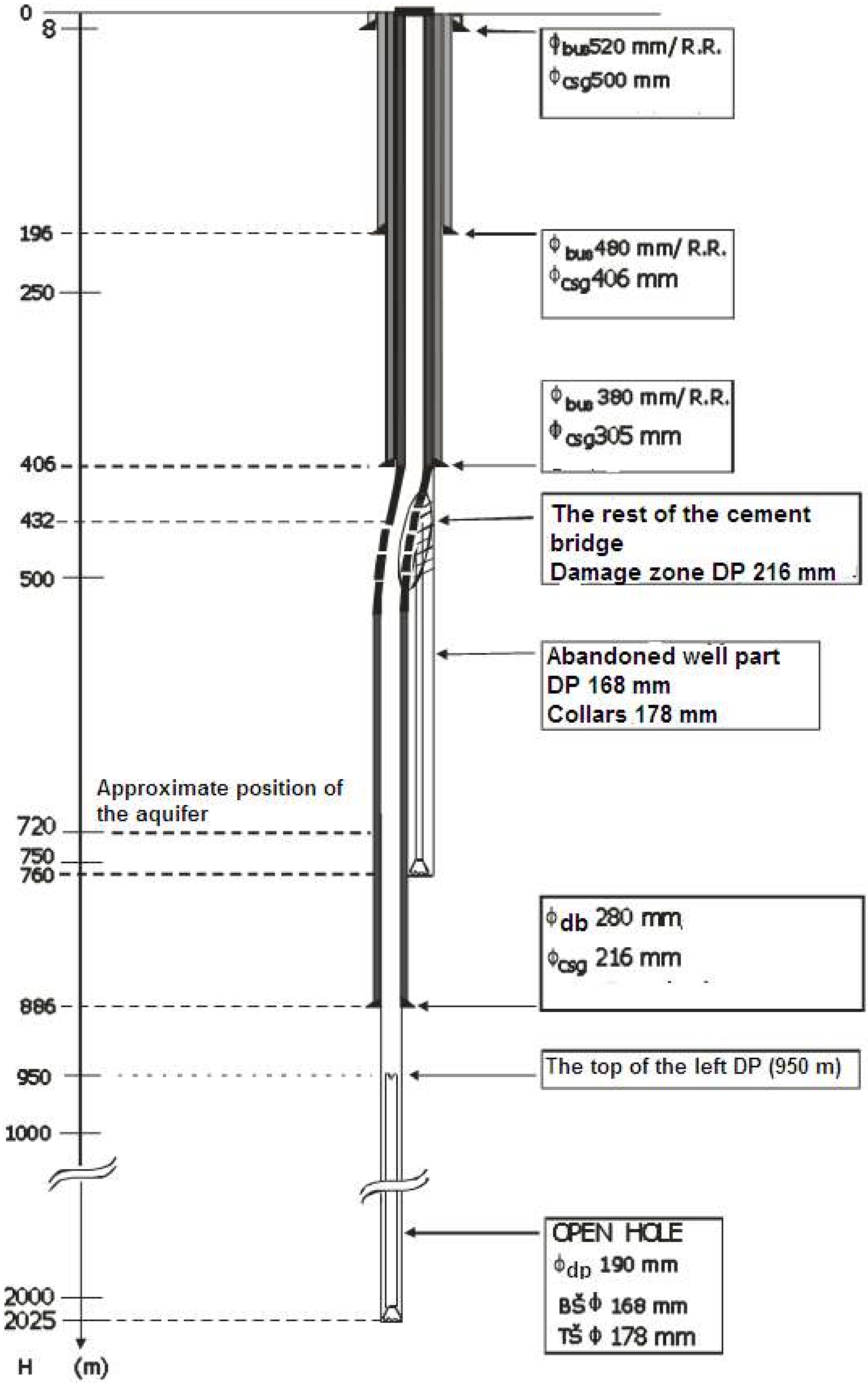

Figure 2. Construction of the exploratory well Sl-1 Slavinovici(Hadzihrustic, Z., 2006.)

2. PHYSICAL AND CHEMICAL ANALYSIS OF THERMO-MENERAL WATER FROM THE WELL SL-1 IN SLAVINOVICI

In March 2021, a new sampling and analysis of water from the well Sl-1 were carried out. The sample was taken from the surface of the terrain, i.e. at the point of thermo-mineral water outflow. Water samples were analyzed in two laboratories at the sametime; one sample was tested in the laboratory of ZZJZ TK (Institute of Public Healt of Tuzla Canton), and the other one in the laboratory for chemical analysis of water at RGGF Tuzla (Faculty of Mining, Geology and Civil Engineering Tuzla).

The results of physical and chemical tests are given in tables 1 and 2.

Table 1. Results of the physical-chemical analysis of thermo-mineral water from well Sl-1 in Slavinovići, obtained by the analysis carried out in the laboratory of ZZJZ TK (Institute of Public Health TK)

PARAMETER	*UNIT*	*VALUE*	*TEST METHOD*
Color	-	Yellowish	Sensor
Smell	-	likeH_2S	Sensor
Taste	-	-	Sensor
Turbidity	NTU	4,9	BAS EN ISO 7027-1:2017*
pH (25℃)	pH	8,27	BAS EN ISO 10523:2013*
Consumption KM_nO_4 (oxidizability)	mg/ l O_2	5,12	Volumetry
Dry residue	mg/l	10434	Gravimetry
Electrical conductivity (25℃)	$\mu S/cm$	11200	BAS EN ISO 27888:2002*
Electrical conductivity (20℃)	$\mu S/cm$	10036	BAS EN ISO 27888:2002*
Ammonium (NH_4^+)	mg/ l	2,75	Spectrophotometry
Residual chlorine	mg/ l	0,00	Colorimetry
Chlorides	mg/ l	2100,00	Volumetry
Nitrites (NO_2^-)	mg/ l	0,01	BAS EN 26777 :2000
Nitrates (NO_3^-)	mg/ l	5,47	Standard Methods for the Examination of Water and Wastewater, 4500 NO3-B 2017*
Ferrum (Fe)	mg/ l	0,21	Spectrophotometry
Manganese (Mn)	mg/ l	0,037	Spectrophotometry
Total hardness	$°nj$	1,23	Volumetry
Alkalinity	$°nj$	151,20	Volumetry
Sulfates	mg/ l	1,78	Spectrophotometry
Calcium (Ca)	mg/ l	3,20	Volumetry
Magnesium (Mg)	mg/ l	3,40	Volumetry
Bicarbonates	mg/ l	3294,00	Volumetry

Table 2. Results of the physical-chemical analysis of thermo-mineral water from well Sl-1 in Slavinovići, obtained by the analysis carried out in the laboratory of Faculty of Mining, Geology and Civil Engineering Tuzla

PARAMETER	***DETERMINED CONCENTRATION (mg/l)***
Sodium (Na^+)	2553,00
Calcium (Ca^{++})	2,213
Magnesium (Mg^{++})	1,300
Potassium (K^+)	16,630

Analyzing the data obtained from the latest research (year 2021.) and comparing it with the data dating from the construction of the well Sl-1 in Slavinovici (year 1936), qualitative conclusions can be drawn about the type and quality of thermomineral water, after 85 years of work, i.e. periodic eruption of well Sl-1 in Slavinovici.

A comparative analysis of the chemical composition of thermomineral water is presented in table 3 (the results shown in the table, which date from the period of construction of the well, were taken from a depth of 540 m).

Table 3. Comparative analysis of the basic parameters of the chemical composition of thermo-mineral water from well Sl-1 in Slavinovici, according to the results, by years of water testing

Parameter	***The results of the analysis in 1936. (mg/l)***	***The results of the analysis in 2021. laboratory ZZJZ TK (mg/l)***	***The results of the analysis in 2021. laboratoryRGGF Tuzla (mg/l)***
Na^+	2026,30	-	2553,00
K^+	5,00	-	16,63
Ca^{++}	13,00	3,20	2,21
Mg^{++}	3,70	3,40	1,30
Cl^-	1434,00	2100,00	-
SO_4^{--}	13,40	1,78	-
HCO_3^-	2942,60	3294,00	-

Cation-anion ratios from the Suharev classification, in order to determine the categorization of water from the well Sl-1, this time gave the following coefficients:

$$\frac{Na^+ + K^+}{Cl^-} = \frac{2553+16{,}63}{2100} = 1{,}22 > 1$$ =>*bicarbonate-sodium or sulfate-sodium type of water*

$$\frac{\gamma Na^+ - \gamma Cl^-}{\gamma SO_4^{--}} = \frac{2553-2100}{1{,}78} = 142{,}9 > 1$$ =>*bicarbonate-sodium type of water*

$$\frac{SO_4^{--}}{Cl^-} = \frac{1{,}78}{2100} = 0{,}00085 < 1$$ =>*chloride group of water*

So, it can be seen from the presented that, although the coefficients have changed to a greater or lesser extent, it does not affect the final result, i.e. the water still belongs to the same type, group and subgroup of thermomineral waters.

Based on the latest data, it can be concluded that the thermal mineral water from well Sl-1 still belongs to the **genetic type of hydrocarbonate-sodium waters** and that within this type of water it can be classified in group C, i.e. in **chloride waters** with the corresponding **subgroup of sodium waters**.

3. CAPACITY OF THE SL-1 SLAVINOVICI WELL

According to the analyzed literature data, which were available to us, the determined capacity of thermomineral water, measured at the time of the construction of the well Sl-1 in Slavinovici (year 1936), was about 500 l/min (Z. Hadzihrustic, Z.; Ibrisimović, Z .; Nuhanovic, S.: "Possibility of complex use of thermo-mineral water from borehole Sl-1 in Slavinovici near Tuzla", Monograph of the International Conference on Trends in Contemporary Mining "TIMC05/06", Proceedings of the RGGF of the University of Tuzla (ISSN 1512-7044), No. 32, pp. 23-27, Tuzla, 2006). This information has not been checked for years.

The measurements, carried out in September 2020, determined the total capacity of well Sl-1 to be about 300 l/min (about 5 l/s).

Capacity measurements were carried out using the "primitive" method, that is, using a container with a volume of 5.0 liters and a stopwatch, whereby the time required to fill the full volume of the container was measured on each of the showers, that is, the distribution lines (figure 3). The total capacity was obtained as the sum of the individual capacities of the outlet lines (showers) at the wellhead.

Figure 3. View of the mouth of the borehole Sl-1 in Slavinovici, with the construction of the choke manifold (showers) (Photo: Nuhanovic, S; Barusic, B., 2020.)

It should be noted that the capacity measurement was carried out during the dry period, and that the measurement was carried out in a period that corresponds to the half of the beginning of the eruptive period of the well.

If we compare the stated capacity values of 500 l/min (measured 85 years ago) and 300 l/min (measured in September 2020), we can conclude that the drop in pressure, i.e. the capacity of the well, is realistic and quite expected, since the thermo-mineral water, in such a long period of time, was not "returned", i.e. injected back into the reservoir, but was wasted, i.e. spilled into the surrounding watercourses, which not only wasted energy, but also polluted the environment.

4. TEMPERATURE OF THERMO-MINERAL WATERAT THE WELL MOUTH SL-1 IN SLAVINOVICI

The data about the temperature of the thermo-mineral water at the mouth of the borehole Sl-1 in Slavinovici do not match the literature. Namely, in the paper "Geothermal parameters and features of hydrogeothermal regions of Bosnia and Herzegovina" (Miosic, N., Geološki glasnik 35, UDK 551.1/4 (058) "55", page 279-307, Sarajevo, 2003) the temperature at the mouth of the borehole Sl-1 in Slavinovici was stated to be 34.5 ^oC.

In the paper "Possibility of complex use of thermo-mineral water from well Sl-1 in Slavinovici near Tuzla" (Z. Hadzihrustic, Z.; Ibrisimovic, Z.; Nuhanovic, S., Monograph of the International Conference on Trends in Contemporary Mining "TIMC05/06", Proceedings of the RGGF of the University of Tuzla (ISSN 1512-7044), No. 32, pp. 23-27, Tuzla, 2006) states that the temperature at the mouth of well Sl-1 in Slavinovici is 36^oC.

Temperature measurements of thermomineral water at the mouth of the borehole Sl-1 in Slavinovici were carried out in June 2021 and was determined to be 34 ^oC.

5. THE MODE OF OPERATION OF THE WELL SL-1 IN SLAVINOVICI

The mode of operation of the Sl-1 geothermal well in Slavinovici was established in the period August-September 2020, taking into account the periodic, eruptive operation of the well, based on the gas-lift principle.

Earlier data indicated that the geothermal well in Slavinovici has a period of "active work" of 12 hours, and a some kind of a "rest"period that lasts 36 hours (Z. Hadzihrustic, Z.; Ibrisimović, Z.; Nuhanovic, S.: "Possibility of complex use of thermomineral water from borehole Sl-1 in Slavinovici near Tuzla", Monograph of the International Conference on Trends in Modern Mining "TIMC05/06", Proceedings of the RGGF of the University of Tuzla (ISSN 1512-7044), no. 32, pp. 23-27, Tuzla, 2006).

Observations made in the unknown period established the following:

- 25.08.2020. – the well stopped working at 17:00 h
- 27.08.2020. - the well started working at 04:00 h
- 27.08.2020. – the well stopped working in 20:00 h

The period of "rest" of the well was determined to be 35 hours, while the period of "work" of the well was 16 hours. To some extent, this coincides with the defined operating regime of the Sl-1 well in Slavinovici, which implies 12 hours of "work" and 36 hours of "rest" of the well.

Due to the short time of monitoring the regime of the borehole, it can be concluded that the borehole Sl-1 in Slavinovici still operates according to the same regime, even after 85 years of eruption, depending on the amount of precipitation in a certain period of time. Also, the obvious conclusion is that the thermomineral outcrop is fed from the surface of the terrain, by weathering and surface watercourses, which is logical, taking into account the mentioned fissures and erosion of the geological formations that make up this terrain.

Also, it should be noted, since it is quite important observation, that the gas which brings the water to the surface is flammable (burns on the pipe) in atmospheric conditions.

DISCUSSION AND CONCLUSIONS

Back in 1937, the drilling of the exploration well Sl-1 in Slavinovići, near the city of Tuzla, was completed. This deep exploration well, with depth of 2025 m, is located approximately at the top western part of the 9 km long Jala-Pozarnica anticline.

The well did not produce the expected oil and gas results, but during drilling, around the depth of 720 m, it suddenly appeared hot mineral water, with temperature of 36 ºC, in the amount of 500 l/min. The water erupted in the form of a 25 m high water column, with an abundance of oil gases, which constitute the driving energy of the eruption.

The duration of one eruption cycle is approximately two days (48 hours), i.e. 12 hours of eruption and about 36 hours of rest, which was also confirmed by these studies. Thermomineral water from well Sl-1 in Slavinovici, according to the assumptions, breaks through the damaged part of a casing ϕ 216.00 mm, in the part of the well with a strong "dog leg", which is why the original construction of the well was abandoned. .

The mentioned claim must be proven by more detailed geological, and especially geophysical research, in order to define the mentioned phenomenon in its entirety.

According to the research results, thermo-mineral water from the well Sl-1 belongs to the group of low enthalpy waters, and can be used for many purposes, and even, with possible additional heating, for heating and cooling the space.

The research carried out in this paper shows the following:

- If we adopt the determined capacity of the well of 300 l/min, its energy potential, according to our calculations, corresponds to the equivalent of 2200 kg/day of lignite from the "Kreka" coal mine. Expressed in money, it is about 200 BAM/day.
- The separation and "capturing" of oil gases at the wellhead, and their adequate use, could significantly increase its energy potential.

However, although the water from the well Sl-1 does not have enough energy potential for its energy utilization, there are all indications that it has a much greater value if it is used for recreational purposes, and in medicine and pharmacy. In several developed countries, geothermal energy has been used for these purposes for many years.

Cation and anion analyzes of microelements promote this water as bicarbonate-sodium water, which we proved by calculating the corresponding coefficients.

Thermomineral water from well Sl-1 in Slavinovici should have a high balneological value and be used as drinking (bottled) water.

For other purposes, it would have to be used not far from the mouth of the well, because it cannot withstand longer transport, due to the relatively low temperature (34 ºC). However, as bottled water, this water can also be used over much longer distances.

Based on all the above considerations, it is suggested that, in order to further use this water, conduct general and targeted research in the direction of its potential multiple uses.

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SIGNIFICANCE OF HYDRODYNAMIC MEASUREMENTS IN OIL FIELD DEVELOPMENT

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SUMMARY

The "Sopron - X" oil field is part of the "Z-1" oil field, located on the territory of Hungary. Several wildcat wells have been drilled within it so far, and their construction was preceded by numerous geological, geophysical, geochemical and hydrodynamic tests. They are used to define the stratigraphic characteristics of the deposit, tectonic relations, petrophysical characteristics of the rocks, and physical-chemical and PVT characteristics of the deposit fluids. Hydrocarbon reserves in the reservoir are also defined.

The paper presents the production characteristics of the deposit and the characteristics of the fluid inflow into the considered wells were processed. To predict the possible production of wells, an analysis system was made in the software package "PIPESIM". Data obtained by hydrodynamic measurements, as well as data on fluid characteristics, were used for the analysis.

At the "Z-1" deposit, after the hydrodynamic measurements were carried out, the production characteristics were determined, which are of great importance when making decisions about the way and methods of deposit exploitation, production intensity, economic profitability, as well as the length of commercial profitability of the "Sopron-X" oil field and Z-1 oil deposit in general.

Key words: oil, gas, oil field, hydrodynamic measurements, stocks, oil recovery factor

INTRODUCTION

In order to test the presence of hydrocarbons on the "Sopron-X" structure, the first exploratory well was located and drilled in 1980. The task of the well was to drill Tertiary sediments, drill the paleo-relief, examine the composition and development of the drilled formations and check the presence of hydrocarbons in the rock masses.

Exploratory wells revealed commercial quantities of hydrocarbons, and the drilling was repeated with the creation of well X-001. Drilling confirmed the assumed structural form and discovered the "Sopron-X" oil field.

Intensive exploratory drilling has continued, and so far, several exploratory and contour-exploratory wells have been drilled in the field. The goal of everything is to increase the utilization of established hydrocarbon reserves.

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At well X-001, during the hydrodynamic measurement, corresponding data on pressure and production were obtained, which were also interpreted. Based on them, the dependence of the fluid flow through the pore space on the dynamic pressure at the bottom was obtained, whereby the productivity index method (Well PI) was applied and the indicator curves (IPR) were determined.

1. RESULTS OF LABORATORY PVT ANALYSIS

Laboratory PVT analyzes were performed on a representative oil sample from well X-001.

On the oil sample from the interval 2279.0 - 2567.0 m, which was tested at reservoir temperature, the extraction pressure is 131.6 bar, which gives a volume factor for oil of 0.7278339 (B_{oi}). The amount of dissolved gas in oil obtained by differential degasification is 60.6 m^3.

The characteristics of oil based on PVT tests are given in table 1 and in figures 1 and 2.

It was concluded that the deposit "Z-1" belongs to the group of unsaturated deposits, with a saturation pressure of approximately 131.6 bar, which coincides with the differential degasification values.

Table 1. PVT characteristics of oil field "Z -1"

Pressure (bar)	**Rs (m^3/m^3)**	**Bo (m^3/m^3)**	**Oil viscosity (mPa*s)**	**Oil density (kg/m^3)**
344,8	60,6	1,261	-	-
310,3	60,6	1,2696	0,82061	747,29
260,6	60,6	1,2784	0,76793	740,52
206,9	60,6	1,2889	0,72175	733,41
172,4	60,6	1,2964	0,69599	729,59
137,9	60,6	1,3046	0,67076	725,79
131,6	60,6	1,3065	0,66544	725,23
103,4	49,9	1,2794	0,73558	732,74
82,8	42,01	1,2638	0,78558	738,38
62,1	33,81	1,2457	0,83324	744,55
41,4	25,17	1,2251	0,89099	751,24
20,7	15,36	1,1955	-	-
3,4	3,88	1,1607	-	-
1	0,02	1,1175	-	-

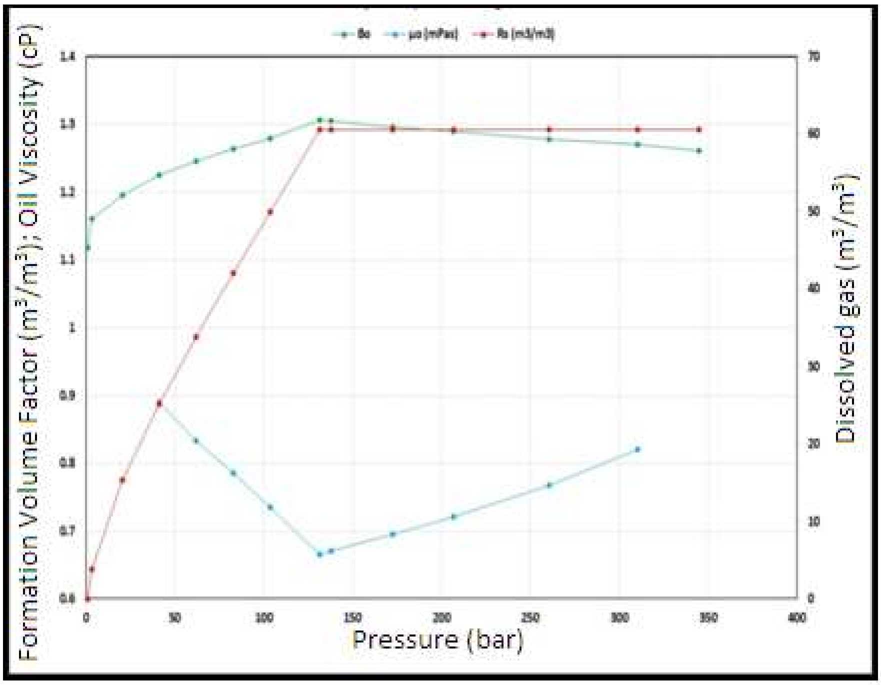

Figure 1. PVT characteristics of oil field "Z -1"

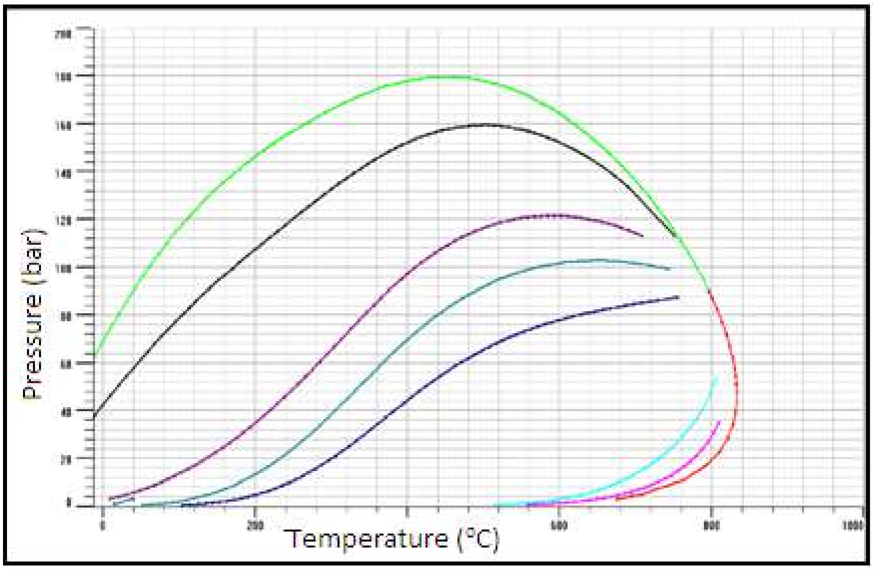

Figure 2. Phase diagram of the "Z-1" oil field

Based on the oil saturation pressure (131.6 bar), the initial reservoir temperature (133.96 °C) and the relative density of gas in relation to air (0.82), using the specialized program "Kappa PVT", the volume factor was calculated free gas formations – Bg (0.0100458), gas compressibility – Z (0.92544) and gas viscosity (0.017427 mPa s).

The values of PVT gas characteristics are shown in table 2 and in figure 3.

Table 2. PVT characteristics of dissolved gas of oil field "Z-1"

P (bar)	Bg (m^3/m^3)	Z	µg (mPas)
Pb=131,6	0,0100458	0,925446	0,017427
130	0,0101737	0,925838	0,017364
120	0,0110556	0,928702	0,016979
110	0,0121069	0,93226	0,016614
100	0,0133778	0,936474	0,016269
90	0,0149408	0,941297	0,015947
80	0,0169044	0,946673	0,015646
70	0,0194389	0,952536	0,015367
60	0,0228282	0,958813	0,015111
50	0,0275827	0,965422	0,014878
40	0,0347229	0,97227	0,014668
30	0,0466301	0,979261	0,014484
20	0,0704471	0,986288	0,014326
10	0,141887	0,99324	0,014201

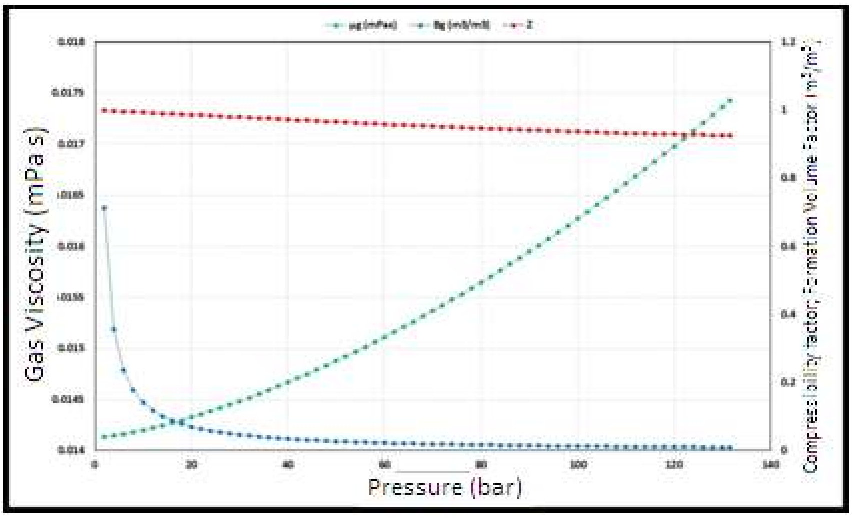

Figure 3. PVT characteristics of dissolved gas of oil field "Z-1"

2. RESULTS OF HD MEASUREMENTS CARRIED OUT ON THE WELL X -001

Well testing methods occupy a special place in oil and gas exploitation. The aim of these tests is, first of all, practical knowledge of the state of the deposit and determination of its productive possibilities.

In the period before the start of exploitation, these tests represent a necessary phase of studying the deposit, while during the exploitation of the well, hydrodynamic tests are used to control the operation of the well itself.

By processing the results of hydrodynamic tests, important physical parameters are obtained, which also serve as a parallel method to similar tests on core samples (permeability).

These tests allow us to obtain significant data about the well, but also about the deposit itself. These are data on the pressure, temperature and flow (production) of oil, gas and water, as well as the percentage of oil saturation with water (water content), and the size of the gas factor (GOR).

Knowledge and analysis of reservoir pressure, combined with oil production data and laboratory data on fluid and rock properties, provide us with the basis for determining reservoir characteristics and determining reservoir fluid reserves.

There are different HD measurement methods, such as:
- fluid level measurement,
- measurement of fluid gradient in the well,
- pressure drop measurement,
- measurement using the pressure rise method,
- testing of injection wells using the pressure drop method,
- limit test,
- interference test,
- pulse test.

During these measurements, it is necessary to collect the following surface data:
• pressure on the tubing,
• pressure on the casing,
• fluid flow at surface conditions (Qfl, Qn, Qg, Qv),
• fluid level in the well.

Measurement data, which are obtained at the bottom of the well, are:
• pressure at the measurement depth (depth of manometer installation, ESP pump depth),
• temperature at the measurement depth (manometer installation depth);
• static and dynamic fluid levels.

The production characteristics of the "Z-1" oil field were determined by hydrodynamic measurements on wells. Hydrodynamic measurements on these wells were made at several nozzle openings and the wells were closed, due to pressure increase measurements. One of those wells was well X-001.

Table 3. Productivity measurement results at the "Z-1" field

Nozzle diameter	**Ps**	**Pd**	**Depression**	**Qo**	**Qg**	**Qfl**
(mm)	**(bar)**	**(bar)**	**(bar)**	**(m^3/dan)**	**(m^3/dan)**	**(m^3/dan)**
2,3	260,89	249,6	11,3	25,4	1155,8	25,6
2,6		249,1	11,8	30	1388	30,5
3		247,8	13,1	43	2011	43,6

Ps - static pressure; P_d - dynamic pressure; Qo - oil production; Q_g - gas production;
Q_{fl} - production of fluids; GOR - gas factor; IP – I ndex of Productivity

The the pressure rise measurement, made on the well X-001, based on the interpretation of the pressure rise curves, gave values for permeability (k), layer capacity (kh) and skin factor.

The presented results of the measurement of the pressure increase in the well X-001, but also in several other wells, show that the collectors of the deposit "Z-1" belong to medium to well permeable collectors, and in the well X-001, based on the skin values obtained, it was established pollution of the near-well zone (and not only in it).

Based on the interpretation of the derivation curve, it can be clearly seen that the well is located in a reservoir with a strong active water pressure regime, which causes the derivation curve to drop sharply downwards (Figures 4, 5 and 6).

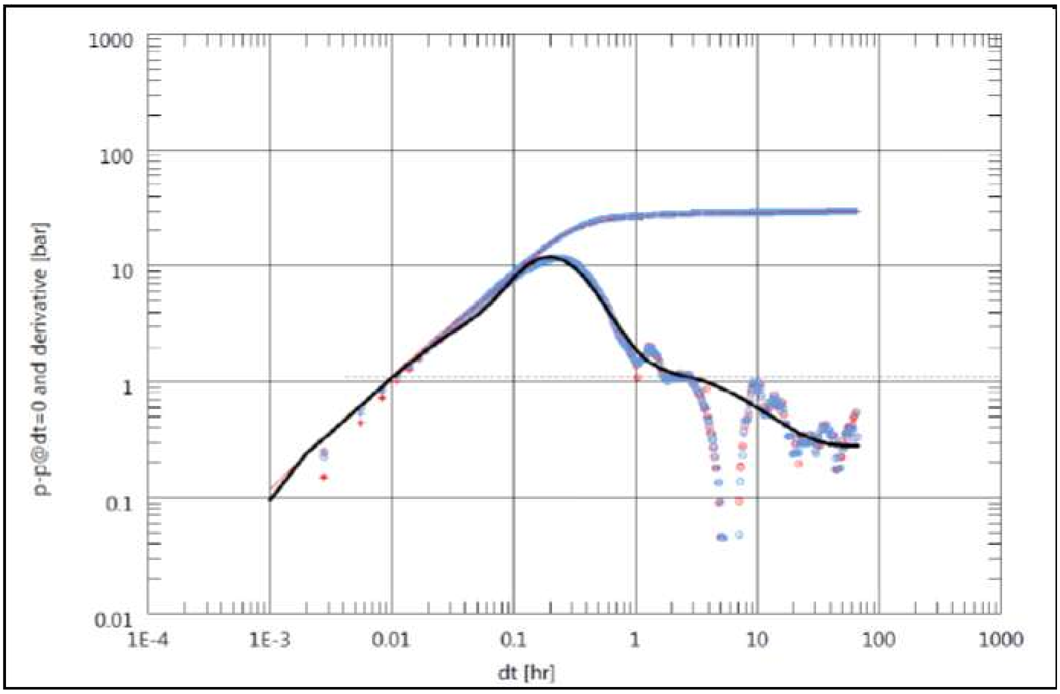

Figure 4. Derivative curve of well X-001

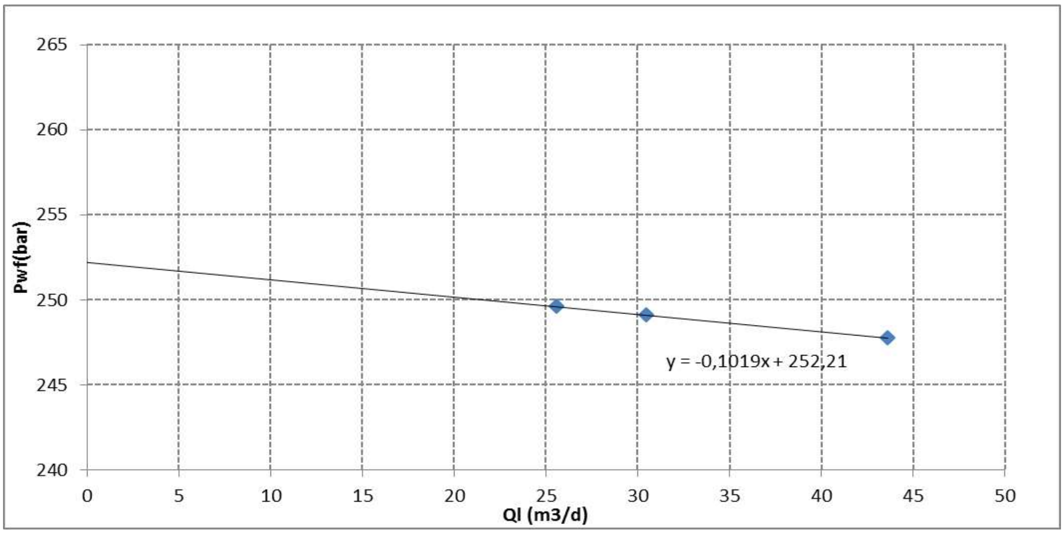

Figure 5. Results of IPR analysis for individual nozzle diamaters

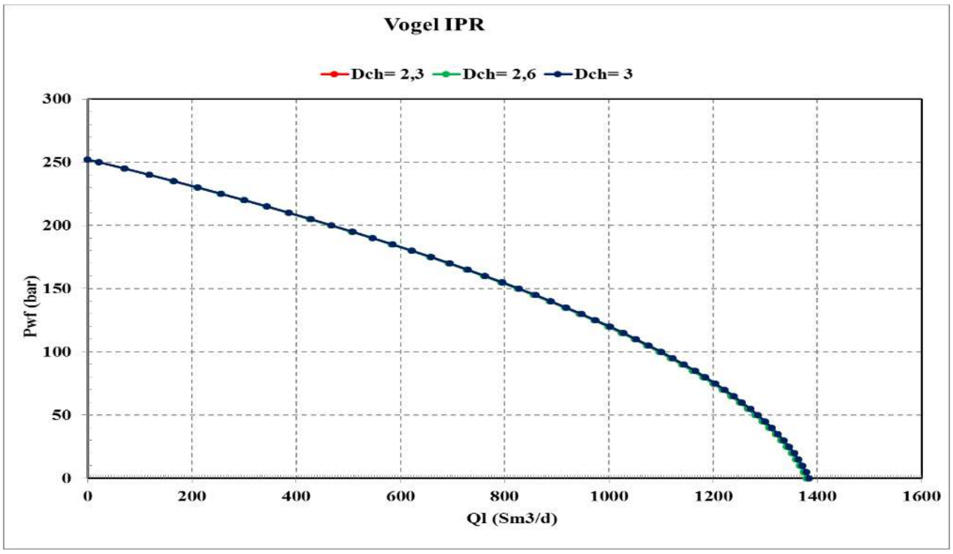

Figure 6. Results of the reservoir pressure analysis performed using the interpolation method

Taking into account the PI and the behavior of the pressure on the tubing, the optimal mode was the one achieved with a nozzle diameter 2.3 mm. Unlike the 3 mm mode, the 2.3 mm opening shows more stable operation and more stable tubing pressure.

3. TECHNOLOGY OF OIL AND GAS PRODUCTION

The production characteristics of the deposit and the characteristics of the fluid inflow into the wells can be discussed on the basis of the hydrodynamic measurements performed on the wells.

As an example, among others, well X-001 was taken.

At well X-001, during the conducted hydrodynamic measurement, corresponding data on pressure and production were obtained, which were also interpreted.

Based on them, the dependence of the fluid flow through the pore space on the dynamic pressure at the bottom was obtained, whereby the productivity index method (Well PI) was applied and the indicator curves (IPR) were determined, which is presented in Figure 7.

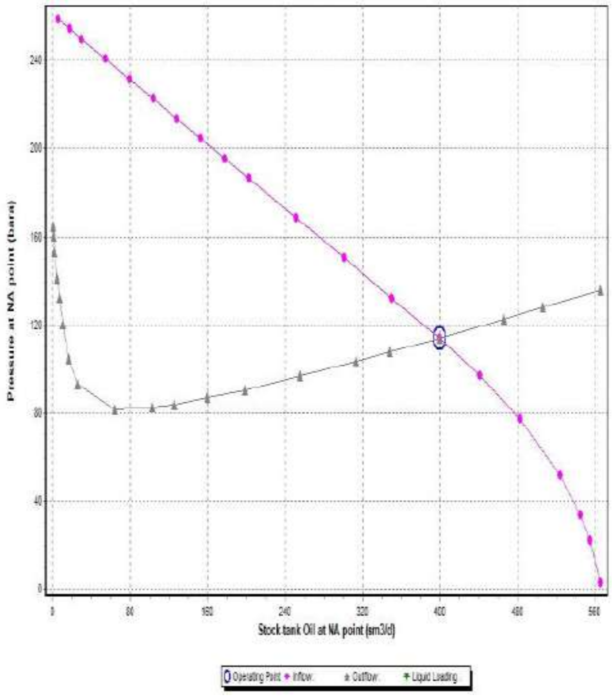

Figure 7. Indicator curve of well X-001

4. SYSTEM ANALYSIS OF WELLS PRODUCTION

To predict the possible production of wells, a system analysis was made in the "PIPESIM" software package. Data obtained by hydrodynamic measurements, as well as other, previously obtained data, were used for the analysis.

4.1. ANALYSIS OF THE INFLUENCE OF NOZZLE DIAMETER

Most eruptive oil wells, as well as a certain number of wells with a mechanical method of production, are equipped with nozzles on the surface, in order to control pressure and regulate production. The nozzles are installed at the mouth of the well or on the collection collector. When analyzing the influence of nozzle diameter, the nodal point is taken on the surface, i.e. at the mouth of the well.

At well X-001, in order to solve possible problems of lagging and collection of the liquid phase at the bottom of the well, a prediction of the behavior of the well with a drop in reservoir pressure with different nozzle openings was made, which is shown in Figure 8.

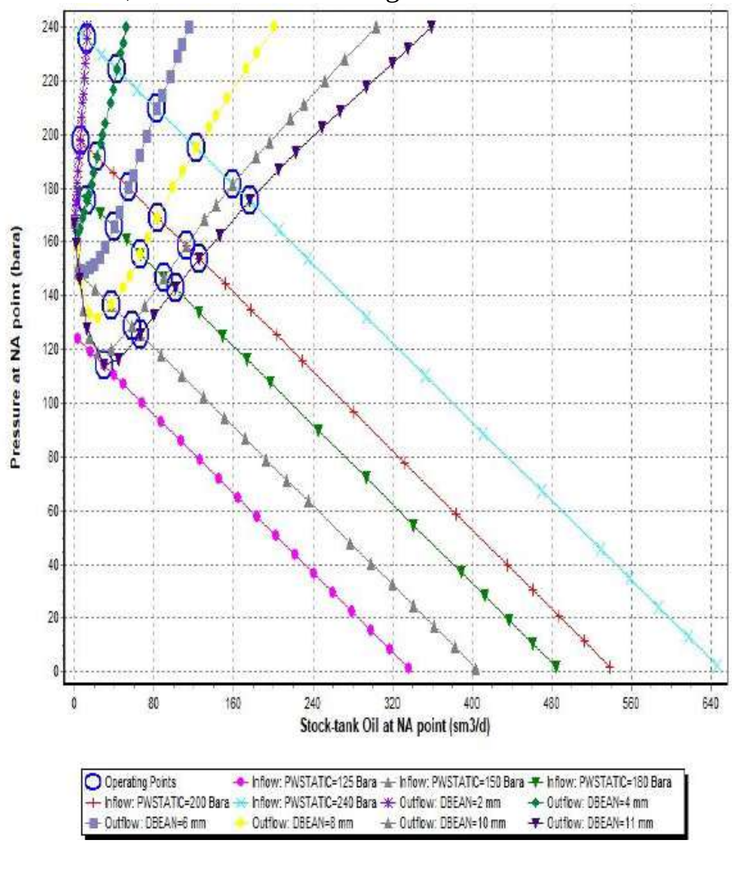

Figure 8. Graphic presentation of the analysis of the influence of reservoir pressure drop and nozzle diamaters on flows - well X-001

It can be seen on the diagram that, when the reservoir pressure drops below 180 bar, on smaller nozzle diameters, there is a problem with the release of fluid by eruptive work, and it is necessary to include some of the mechanical exploitation methods.

DISCUSSION

Hydrodynamic measurements represent the basic type of measurement that is carried out during the exploitation phase of each individual well, that is, the development of the oil reservoir as a whole. These measurements determine the production characteristics of the reservoir, obtain data on the flow and phase state of the fluid in the reservoir, pressures in individual parts of the system, and define the optimal production regime of each individual well within the reservoir.

Based on these input data and with the help of the analysis system (PIPESIM software package), we are able to effectively forecast the production of the entire field.

Based on this approach, the diameter of the nozzle opening was defined for the optimal production regime, which should lead to an increase in the degree of utilization of the deposit.

CONCLUSION

The application of hydrodynamic (HD) measurements collects the necessary data on the production characteristics of the reservoir and data on the change in pressure in the reservoir. At the "Z-1" oil deposit, after the hydrodynamic measurements were made, production characteristics were determined that are of great importance when making decisions about the way and methods of deposit exploitation, production intensity, economic profitability, as well as the length of commercial profitability, as the deposit " Z-1", as well as the entire field "Sopron-X".

On the well X-001, the pressure rise was measured and, based on the interpretation of the pressure rise curves, data were obtained on permeability (k), layer capacity (kh) and skin factor, the values of which enable more successful calculations, the results of which provide us with values that are precisely they indicate the total amount of reserves that can be exploited, the optimal mode of operation of the well and the reservoir, the optimal opening of the nozzle that we will use, as well as a better determination of the value of the reservoir pressure.

The obtained data indicate that the well X-001 is located in a part of the reservoir with a pronounced water pressure regime, which directly affects more successful exploitation and greater utilization of the reservoir.

At well X-001, production measurements were made at 3 nozzle diameters, in order to define the optimal mode of operation of the well. Based on the measurement of the productivity of the well, an analysis of the IPR curve and determination of the reservoir pressure using the interpolation method was performed. The reservoir pressure at a depth of 2200 m is 252 bar, reduced to the middle of the perforation 2277 m, with a gradient of 0.74 bar/m, it is 258.91 bar.

By reading Vogel's IPR curve and checking the IP, it is concluded that the optimal production mode will be on a nozzle diamater of 2.3 mm.

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HYDROTERMAL PRODUCTS OF THE SPRECA FAULT ZONE

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SUMMARY

Complex endogenous geotectonic processes predisposed the Spreca fault zone with different geotectonic structures, within which an aquifer of thermomineral waters with CO_2 escalation was formed, in the Gracanica area, located in the lower Spreca depression, which makes contact with two different rock complexes: volcanogenic-sedimentary and ultramafic of the "central ophiolitic mélange" complex south of the Spreca fault zone and the Cretaceous-Tertiary complex of sediments "internal ophiolitic tectonized mélange" north of the fault zone.

Key words: Spreca fault, thermo-mineral water, borehole, temperature

INTRODUCTION

The origin of the thermomineral waters of this locality, the geotectonic and hydrogeological conditions that take place here, have attracted the attention of many researchers. Analyzing the results of previous research, it can be determined that the overgrown Triassic limestones are transit aquifers (released) of thermomineral waters, in which the water is under artesian pressure.

According to their hydrogeological functions, rock masses on this terrain can be divided into hydrogeological collectors and hydrogeological insulators.

Hydrogeological collectors can be divided into ordinary, thermomineral and mixed water collectors.

Collectors of ordinary water are formed in alluvial sediments, river terraces and siparis. These are collectors of intergranular porosity and are heavily influenced by the Spreča River.

In the Cretaceous (K) and Tertiary (Tc) carbonate rock masses, streams of ordinary water with a complex hydraulic mechanism were developed. These are low to medium permeable terrains. Within the alluvial sediments, mixed water releases were registered in different locations. Their occurrences have been registered at springs, dug wells and village "Norton" pumps.

Diabase-rose formation of Jurassic age is represented by metamorphosed sandstones, marls and other lithological members with insignificant porosity. It was raised by Neogene geotectonic activities, which is shown on the geotectonic-hydrogeological model and represents a roof barrier to the upward movement of thermal-mineral waters as well as a podina barrier to the descending movement of surface cold waters in a wider area than the Sprečan fault zone.

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Thanks to the existence of faults in the mentioned fault zone, there is a convective upward flow of thermomineral waters and CO_2 from already established aquifers (issued).

Analyzing the presented model with the fault structure and water movement mechanism based on previous research, the dilemma remains whether there are accumulations of the same in the limestone floor, as an aquifer of thermo-mineral waters, which slowly rise to the surface of the terrain.

1. GEOLOGICAL CHARACTERISTICS

Collectors of thermo-mineral waters and CO_2 in this area are carbonate rocks, probably of Triassic age. The Triassic age of these rocks has not been established paleontologically. The depth to the primary collector is different from locality to locality and is conditioned by tectonics.

The geotectonic-hydrogeological transverse profile of the thermal-mineral water locality in the Sočkovac-Gračanica locality is presented in Figure 1.

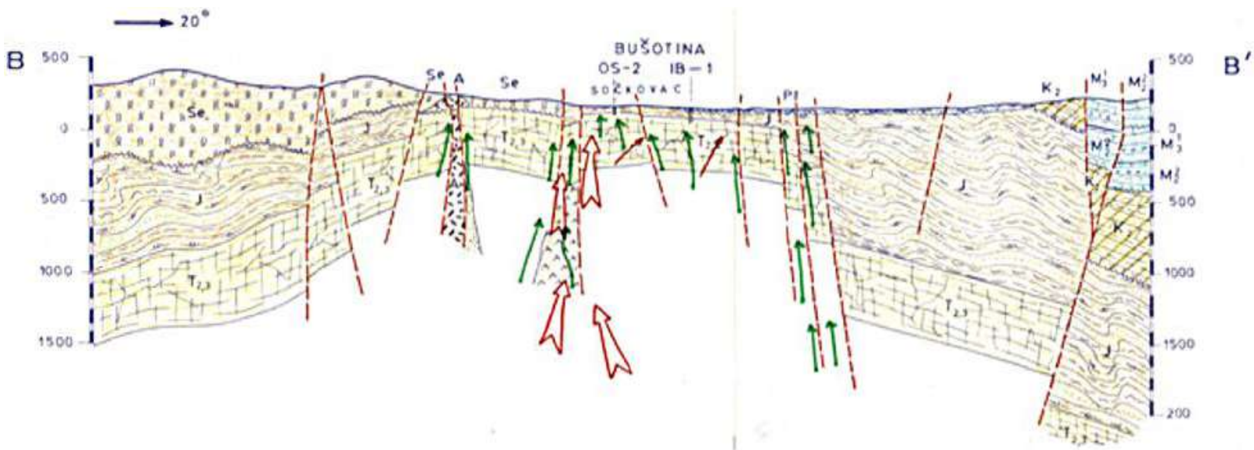

Figure 1. Geotectonic and hydrogeological transverse profile of the Gracanica locality

Analyzing the transverse profile (B-B), one can observe a large tectonic disturbance and outcropping of the lithological formations of both structural-facies units, including the formations of the Spreca depression, with the exception of the Quaternary (Q), which indicates an intense and complex Tertiary geotectonic activity, especially pronounced at the end of the Paleogene and the beginning of the Neogene, which puts it in the Oligomiocene.

The Spreca fault zone has been multiphase regenerated, and is currently active, which can be confirmed by frequent seismic earthquakes, as well as by the occurrence and analysis of the isotopic composition of CO_2 and the content of radon in thermo-mineral waters, which is shown in the analysis of topometric elements in the composition of thermo-mineral waters (table 1).

Analyzing the physical and chemical composition of thermal-mineral water from the locality, it can be concluded that it is hyperthermal, mineral, sodium-calcium hydrocarbonate, while CO_2 in this part of the Spreca fault zone is of dual origin.

From shallower zones, where it is formed by active chemical processes in Triassic limestones, and from deeper zones, where it is formed by thermometamorphic processes in outcropped serpentine-peridotite rocks, which form the Triassic limestone floor where temperatures are extremely high.

Table 1. Physical and chemical composition of thermal mineral waters of Gracanica

Cations (mg/l)	Anions (mg/l)	Gases (mg/l)	Microelements (mg/l)		Radioactivity	Physical characteristics
NH4 **0,1-3,**27	HCO3 **2322-2391**	CO2 **198-642**	Li **270-2100**	Pb **1**	Ru **0,49-1,68**	**Mineraliz. 3538-4119 mg/l**
Fe2+ **4,2**	SO42 **- 3,5-5,0**	O2 **11,86**	Rb **470**	As **4**	Ra **0,19-0,39**	**Dry residue 2240-2343**
Na+ **277,2-606**	Cl - **187-198**	N2 **13,26**	Sr **2050**	Ag **0,2**	U **0,1**	**Hardness 15,43-32 mg/l**
K + **35,5-40**	F - **0,76-1,11**	H2S **0,07**	Ba **1500**	Cd **0,2**	**SiO2 38-40,1**	**pH 6,9-7,2**
Mg+ **63,6-134,2**	Br - **0,16-0,20**		Cr **3**	Ti **2**	**HBO2 19-25**	**Eh +60 mV – 2,81 mS/em**
Ca+ **204,4-420**	J - **0,04-0,06**		Zn **2**	Mo **0,5**		**Temperature 39°C**
	NO3 - **6,88**		Ni **1**	Hg **0,2**		
	HPO42**- 0,09-0,32**		Co **1**	Se **1**		
	HS - **0,05**		Cu **1**	Al **24-430**		

2. NATURAL MINERAL WATERS IN THE SPRECA DEPRESSION

The natural mineral waters of the Spreca depression have very complex geological and hydrogeological conditions in which they were formed and exist. It was found that the natural mineral waters on the edges of this depression have an increased content of Mg, Fe ions, and an increased content of CO_2.

The natural mineral water "Tuzlanski kiseljak Mg^{++}" contains a Mg concentration of 650 mg/l, which indicates specific hydrogeological conditions, and the increased mineralization of Mg originates from decomposed ultrabasic rocks with forsterite (Mg_2SiO_4) and enstatite ($MgSiO_3$).

The presence of CO_2 in the mineral waters of this depression can be linked to deep structural faults, as branches or parts of the Spreca fault zone, along which CO_2 reaches from greater depths, and is formed by the reaction $CaCO_3 + SiO_2 = CaSiO_3 + CO_2$.

Thus, CO_2 is linked to metamorphic processes, caused by magmatic eruptions during the Cretaceous period.

At the "Ljubace" site (IEB-1), CO_2 can be bound to deeper magmatic processes, and its release to the surface in the form of acidic water is a consequence of tectonic disturbances.

This is also confirmed by the appearance of thermal and mineral waters, as well as acidic waters along the entire Spreca depression, from Toplice (24° C), through Ljubace, Stari kiseljak and thermal water (22 °C) in the village of Kiseljak (Shevar), all the way to acidic waters in Miricina and thermal waters of Sockovac (39 °C) near Gracanica.

3. RESULTS OF HYDROGEOLOGICAL RESEARCH

The thermal mineral waters of Gracanica, Sockovac and Kakmuz belong to the Spreca hydrothermal anomaly. Based on previous research and tests, it can be concluded that Triassic limestones are the basic aquifer of thermomineral waters and gas (CO_2).

Based on the results of drilling so far and the results of chemical analyzes of water and gases, as well as registered occurrences of gas escalations on the surface of the terrain, we can conclude that, in the investigation area, Triassic limestones are located at different depths from the surface of the terrain.

Wildcat wells GB-1 and GB-2 pierced Triassic limestones at depths of 45 m and 60 m, and wildcat wells GB-3 and GB-6 at depths of about 100 m.

Wilcat well GB -5, on the right bank of the Spreca river, was drilled to a depth of 621 m and did not pierce the Triassic limestones, that is, it remained in the sediments that make up the roof of the Triassic limestones on the left bank of the Spreča River. The consequence of this is that the northern wing of the fault zone is lowered compared to the southern one.

It is important to point out that in the area of Sockovac - Kakmuz, and the area of depression on the right side of the river Spreca, Gracanica area, where we have CO_2 gas escalation, there is an intense incrustation in the wells, which occurs due to pressure changes.

In this zone, thermo-mineral waters have a significantly higher temperature and a different chemistry compared to the waters in the Boljanic area, where the waters have a lower CO_2 content, are hyperalkaline (pH ≈ 11), lower temperatures, without incrustations, but with methane escalations.

3.1 SPATIAL LOCATION OF THERMO-MINERAL WATER AND GAS AQUIFERS

Figure 2 shows the spatial position of environments with different hemism of water, while the satellite image (Figure 3) shows the position of thermo-mineral waters in the localities of Sockovac – Kakmuz and Gracanica locality.

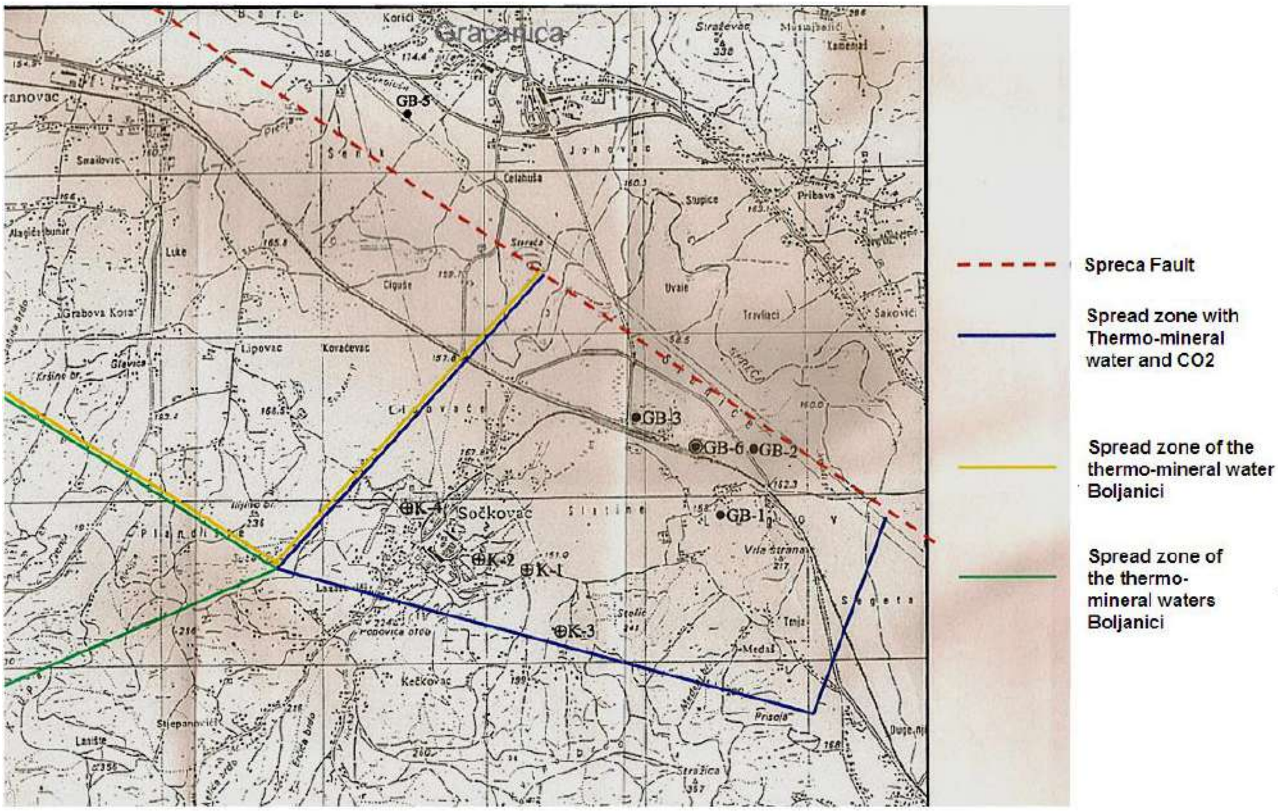

Figure 2. Spatial position of environments with different hemism of water (Scale 1 : 25000)

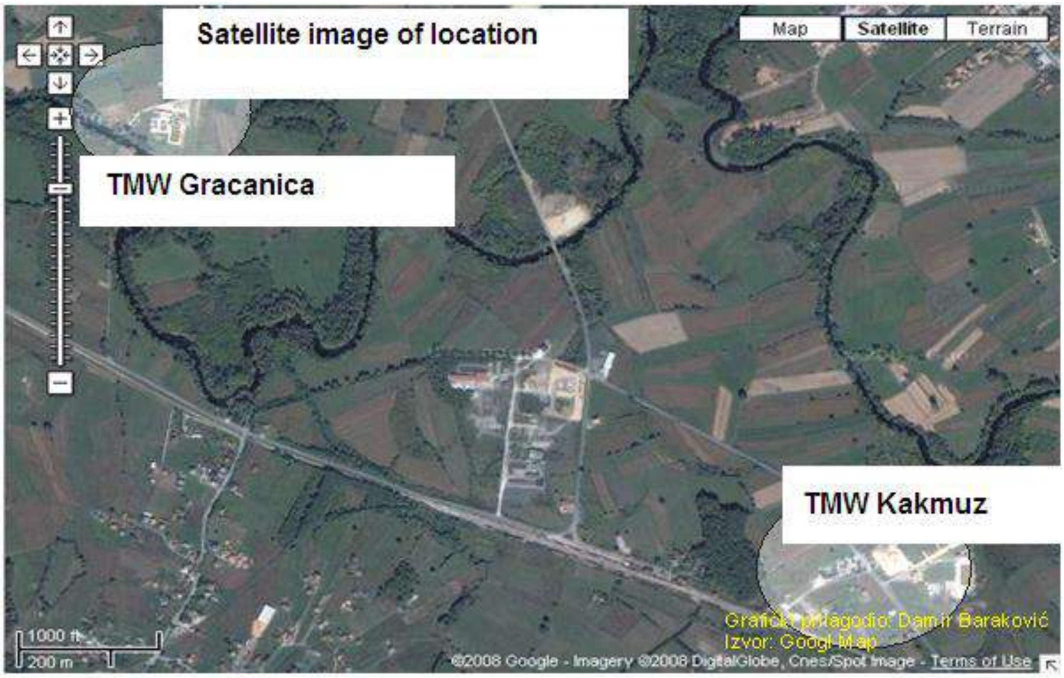

Figure 3. Satellite image of the central part of the Spreca depression with the positions of the occurrence of thermo-mineral waters

Water inflows in wells made in limestone are at various depths and in most cases hydraulically independent in the natural regime before drilling. This is proven by the different temperatures, pressures and physical-chemical characteristics of the water, determined during drilling.

It can be seen from this that there is also an interstratification horizontal to subhorizontal cavernous and cracked limestone at various depths, which is more pronounced than faulting and which provides ascending convection to vertical communication drains. This justifies conducting deeper drilling into the limestone collector, as this will yield larger amounts of water.

Exploratory drilling, carried out in 2003, obtained CO_2 escalations from the aquifer without the occurrence of thermo-mineral waters. This fact indicates that the formation of CO_2 takes place without the presence of water and at greater depths than the thermal-mineral water aquifer.

The thermo-mineral waters of the research area are old waters, pre-nuclear in terms of tritium, and according to some data they are 20.000-40.000 years old. Water exchange and circulation is slow, and they are fed from the hypsometrically higher parts of Ozren and the surrounding mountains.

The mineralization of these waters, as well as the enrichment with CO_2, takes place at greater depths and significantly higher temperatures. The origin of CO_2 and the place of its inflow is at greater depths than the depth of the appearance of thermo-mineral waters.

This is indicated by the fact that there are larger amounts of radon in gas than in thermal mineral waters.

At the depth of the formation of CO_2, high hydrostatic pressures and temperatures prevail, higher than in the aquifer of thermo-mineral waters, and thanks to this, there is an escalation or an eruption of thermo-mineral waters.

4. WILDCAT TGP-2

Based on the stated needs for new amounts of CO_2, i.e. the needs of companies engaged in the exploitation and processing of this mineral raw material in the researched area, a new well (TGP-2), 472 m deep, was drilled in 2007, at the position shown in Figure 4.

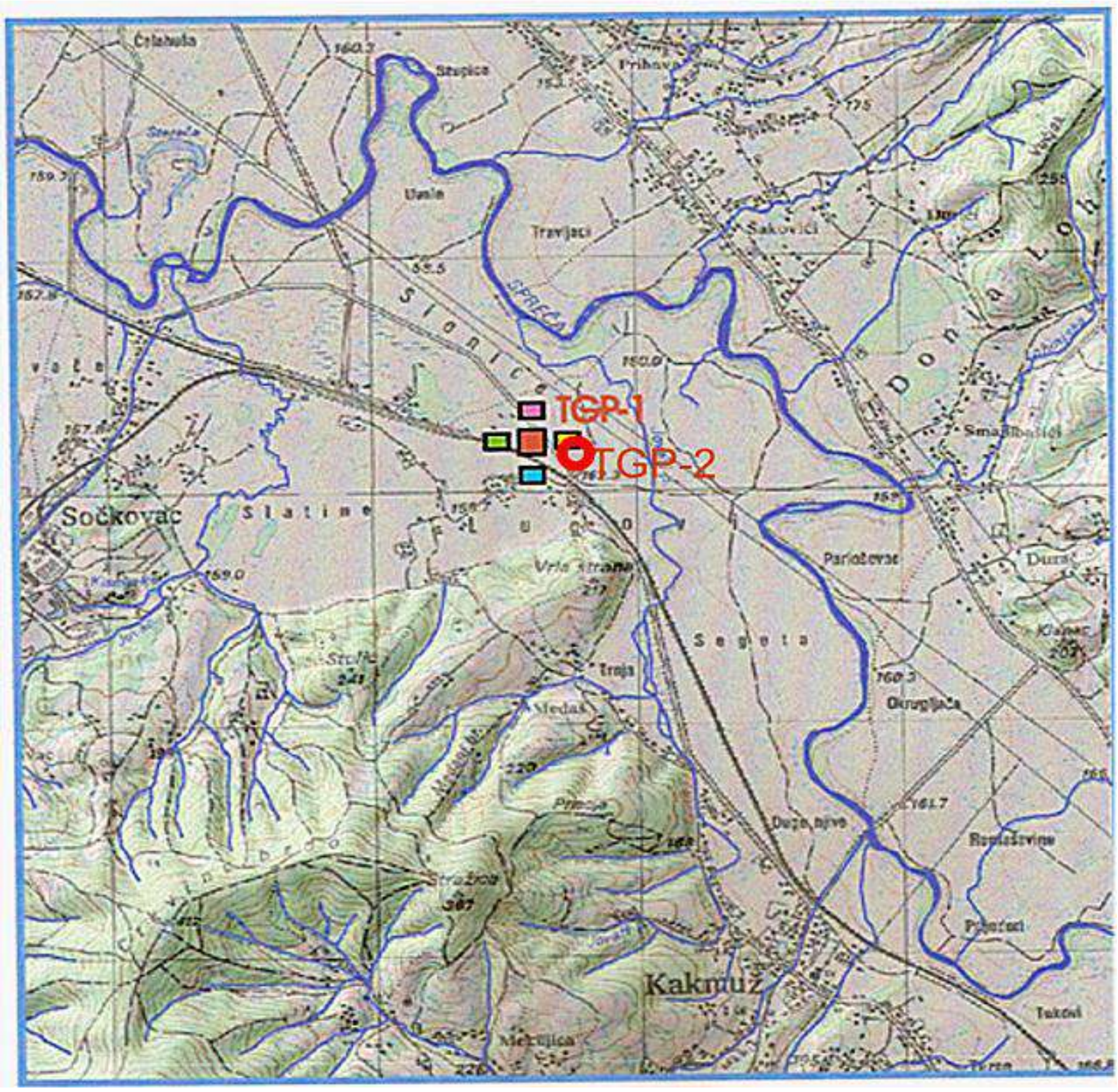

Figure 4. Spatial location of the well TGP-2

4.1. LITHOLOGICAL AND TECHNICAL PROFILE OF THE WELL TGP -2

The TGP-2 well was drilled on the basis of geophysical investigations and the results obtained on the basis of those tests. Figure 5 shows the lithological - technical profile of the well TGP-2.

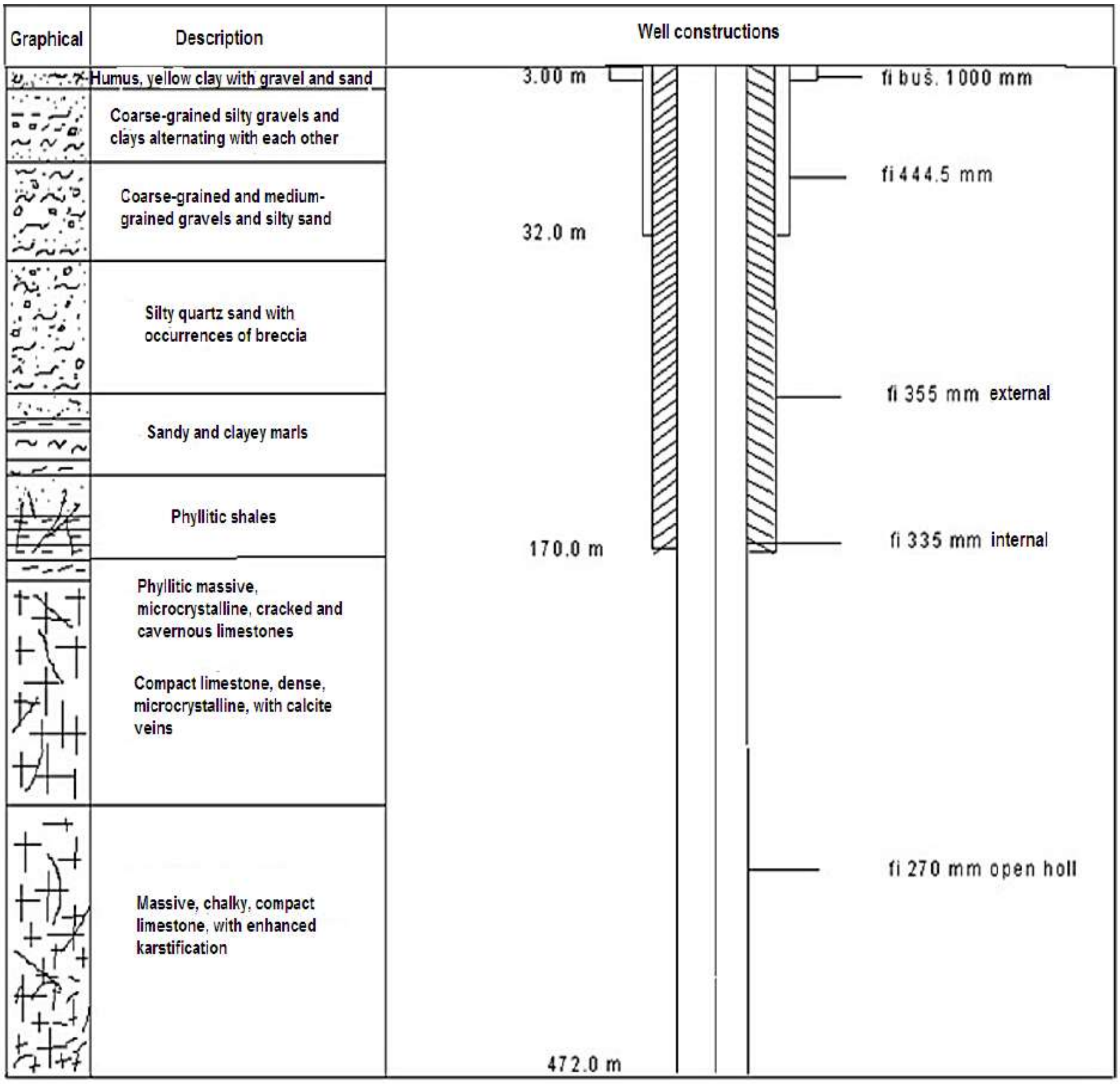

Figure 5. Lithological profile with the construction of well TGP-2

5. RESULTS OF EXPLORATION DRILLING

During drilling, in the limestone zone, three series of blocks, or aquifers, separated by fault planes, which are the main carriers of mineralized water, were identified. On that occasion, at a depth between 200 m and 250 m, the drilling tool failed and the mud was lost. It can be assumed that it is a larger "cavern", from which larger amounts of gas and water are escalating. The second aquifer is in the interval from 280 m to 340 m, and the third from 380 m to 450 m.

Within all the mentioned intervals, there is a drop in the value of the specific electrical resistance, which indicates the karstification of the limestone.

The measurement of the yield of the well was carried out for the first time on 18.12.2007. year, whereby the following results were obtained:

First measurement: 18.12.2007.

The measurement of the water outflow from the TGP-2 borehole was performed (airlift performed by releasing processed CO_2)

Observed characteristics:

- Water capacity:
  In 6.5 sec. the container is filled (V=700 l)
  Q_v = 385 m³/h respectively 107 l/s

- Gas capacity (ϕ150 mm),
  Container (8 m³) filled for 53 sec.
  Q_g = 550 m³/h, respectively 770 kg/h
  Q_{fakt} = 1:1,4 – H_2O : CO_2

Second measurement: 14.02.2008.

Measurement performed with a compressor (p = 2.5-3 kW) max power. At a depth of 250 m, pumped air under a pressure of 23 bar.

Observed characteristics:

- Gas capacity (ϕ 250 mm)
  Container (8m³) filled for 40 sec.
  Q_g = 720 m³/h, respectively 1008 kg/h

For the calculation, we take a coefficient of 1.4 from the production of 1m³ of gas, i.e. 1.4 kg, which gives the result:

Qv = 385-396 m³/h, respectively 107-110 l/s

The pressure value of the compressor in free operation without load was also measured.

The 8 m³ balloon (container) fills in 6.5 minutes.

Pcomp. ≈ 1.5 m³/min.

Based on the well testing, the hydrogeological parameters of the aquifer environment were calculated. It is located near the borehole of TGP-1 (approx. 70 m), and these parameters can also be used for the aquifer drilled with the TGP-2 borehole.

Transmissibility coefficient:

$$T = 1.05 \times 10^{-2} \text{ m}^2/\text{s}$$

Filtration coefficient:

$$k = 1.05 \times 10^{-9} \text{ m/s}$$

From the given values of the parameters of the water environment, it can be seen that the Triassic aquifer belongs to water-abundant environments, which has been confirmed by previous research.

6. PHYSICAL - CHEMICAL CHARACTERISTICS OF WATER AND GAS

Thermo-mineral, carbonic acid waters of the investigated area are hyperthermal, mineral HCO_3-Ca-Na-Mg type, acidic, with a content of dissolved CO_2 in the amount of 200-620 mg/l, with free CO_2 of 2 dm/l of water, with increased content of SiO_2 and HBO_2, and are made of iron with a rich content of effective microelements with a mineralization of 3.5 g/l, slightly radioactive. Water temperatures are 37-39 ºC. The content of dissolved and free CO_2 is 98 – 99 %.

During the research, complete chemical water analyzes and radioactivity analyzes were performed for the research area on the left side of the Spreca river bank.

Comparison of chemical analyzes of water that were carried out in previous research (1989) by the Geoinstitut (Belgrade) and the Institute Jozef Stefan (Ljubljana), and the results carried out in 2003 at the Institute of Health in Banja Luka, indicates that the thermo - mineral waters of this area are hydrocarbonate-chloride-sodium-calcium waters. The mineralization of these waters ranges from 3,700 - 4,500 mg/l, with a dry residue of 1,400 - 2,500 mg/l. The water temperature is 312 K (39 °C).

In this time interval, it can be observed that there was no change in the hemism of the water, that is, that the differences are within the permissible limits.

These waters contain an increased concentration of iron, ranging from 2.78 to 3.12 mg/l.

Of the other metals, aluminum (0.25), copper (0.18), zinc (0.97) are present, while arsenic, lead, mercury, selenium and chromium occur in concentrations below 0.05 mg/l. Also, these waters are low radioactive with a radon content of 0.57 Bq/l.

The content of dissolved gases in water is:

CO_2 – 488.56 mg/l, O_2 – 7.11, N_2 – 9.88 and H_2S – 0.09 mg/l

CONCLUSION

The geological picture of the terrain of the Spreca fault is very complex. The appearance of thermal-mineral waters is a real result of complex geotectonic activities in this area. The results of the conducted research indicate that the waters of the Spreca fault are of thermo-mineral character, originating from Triassic fractured sediments.

Triassic aquifer belongs to water-abundant environments, which has been confirmed by previous research, but its thermal characteristics need to be determined by additional tests.

The thermal mineral waters of this area are hydrocarbonate-chloride-sodium-calcium waters. The mineralization of these waters ranges from 3,700 - 4,500 mg/l, with a dry residue of 1,400 - 2,500 mg/l. The water temperature is around 39 °C.

The increased CO_2 content is probably a product of the influence of high hydrostatic pressures and temperatures, which are much higher than in the thermo-mineral water aquifer.

Because of this, there is an eruption of thermo-mineral waters.

The capacities of water and gas were determined, measured at the TGP-2 well, which, in addition to confirming the formation of thermo-mineral water, also indicate the existence of other elements, some of which are radioactive, which must be a sufficient indicator of the future possibility of using this thermo-mineral water.

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APPLICATION OF ADDITIVES IN COMPLEX DRILLING CONDITIONS

Dinka Pašić-Škripić[1], Edin Šehić[2], Amir Jahić[3]

ABSTRACT

Exploration drilling represents one of the fastest and most efficient methods for recovering data regarding the geological structure of the terrain. One of the important factors in exploration drilling is the use of additives during drilling otherwise known as drilling mud. The additive is used to improve and enable continuous removal of drilled material from the bottom of the well as it can stop the circulation of the water and in turn, bring the stability of the well into question. It can also increase the pressure of the rotation, make it harder to extract the pipes as well as slow down progress. Drilling additives must be carefully chosen and dosed while doing permanent control and adjusting characteristics during drilling.

At the Vareš exploration area (Rupica), several drilling mud materials were used in very complex drilling conditions. The additives were based on water, oil, and synthetics and their use, function, and choice will be elaborated on in this paper.

Keywords: additives, types of additives and application, exploration drilling, hydrogeological conditions of the environment, ecological aspects of protection.

INTRODUCTION

The drilling plan for the Rupica location included a 160-meter well with a 90-degree drilling angle and an adequate azimuth for a vertical well. To drill the well, preparation work such as determining the position of the well, the coordinates, and the elements of the well needed to be done. Drill site preparation was the next step. A key factor for a successful drilling operation is carefully preparing the drilling mud or additive. To create adequate drilling mud a calculation of the pipe volume must be conducted to get the proper amount of water or drilling mud required for the pipe to be full. During that process, additives are chosen and properly dosed while being constantly controlled during drilling and their characteristics being changed if needed. When additives are applied during drilling, their viscosity must be checked two to three times a day using the Marsh funnel. During the Rupica exploration drilling, several types of additives have been used and their characteristics, advantages, flaws, and functionalities have been noted. Another thing that was noted was their negative impact on the soil and water as well as their general impact on the environment which was reduced to a minimum while providing the necessary tasks during drilling.

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1. GEOLOGICAL CHARACTERISTICS

The Vareš area – Rupica and Juraševac-Brestić – is in the southwest part of the Borovica-Vareš-Čevljanovići (Image 1) mining area. Around a dozen discoveries of complex lead ore as well as zinc and barite were made in this 20-kilometer mining zone. Those discoveries had differing contents of silver, gold, copper, and antimony as well. The terrain around Rupica and Juraševac-Brestić consists of Lower Triassic, Middle Triassic, and Jurassic-Cretaceous sediments.

According to data from previous exploration, Sediments of the Lower Triassic in the Borovica-Vareš-Čevljanovići mining zone are split into two: sandy limestones, marls, clays with interlayers of sandstones, and quartz sandstones while the other is sandy clays.

Middle Triassic sediments hold the bulk of the ores, so their analysis was done in detail. Several levels of the Middle Triassic are rich in fauna – mostly mollusks – so the age of those sediments is reliable. At a wider area, those sediments consist of Anisian calcareous limestones, dolomites, dolomitic limestones, and limestones; Anisian-Ladinian Fe-Mn alumina, and cherts; spilites, Ladinian red cherts, and tuffites; Ladinian red limestones, cherts, and Jurassic-Cretaceous turbidite sediments.

Jurassic-Cretaceous turbidite sediments form the northeastern rim of the Rupica exploration area. They consist of marl, limestones, clays, and breccias which are in tectonic contact with Middle Triassic formations. At Rupica, Calpionella alpina Loremz and Tintinopsella point to an Upper Jurassic to Lower Cretaceous age.

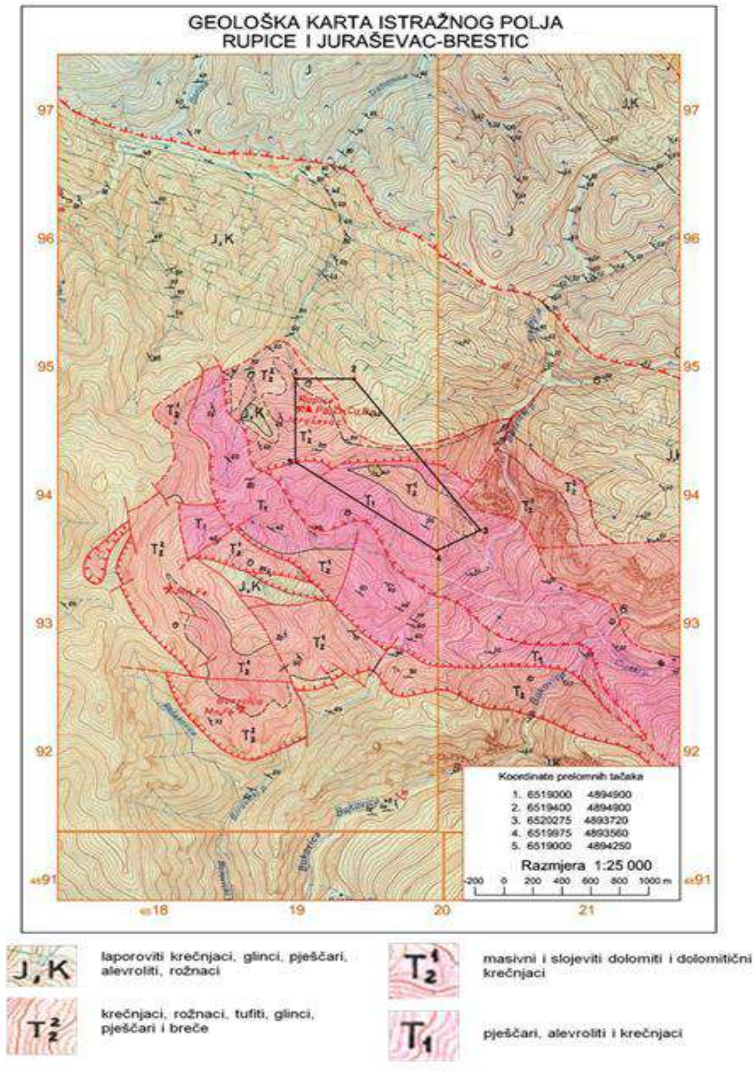

Image 1. Geological map of the wider Rupice-Juraševac Brestić area

2. HYDROGEOLOGICAL RELATIONS IN THE EXPLORATION AREA

The aquifer within the Middle Triassic dolomites and dolomitic limestones (T21) at Rupica has a very complex structure with multiple erosions and depositions so separate blocks can be seen which are in direct or indirect contact. In the southeast part of the Brestić-Juraševac area, this aquifer takes up a larger space than in the Rupica area and is separated by a thick layer of Lower Triassic clastites (T1) and Middle Triassic layered cherts (1T2), with manganese schists, tuffites, and tuffitic sandstones. This layer of waterproof rocks makes a hydrogeological barrier between the Rupica and Brestić-Juraševac areas so a conditional conclusion can be made that there are two separate accumulations of underground waters in the same aquifer layer and formed independent fields of groundwater filtration within them. Geological mapping has clearly shown a more complex structure in the Rupica area. This is conditioned by erosion and deposition and confirmed with explorational drilling in the vertical profile. But, hydrogeologically speaking, this complex structure does not cause fragmentation of the groundwater filtration field since there are several direct and indirect links between the blocks of the aquifer. Also, erosion and deposition zones have an important role in groundwater communication. Another conclusion is that erosion and deposition zones as a limitation of certain aquifer blocks do not necessarily mean that the function of the aquifer or the field of groundwater filtration will stop. The way some blocks make contact is especially important for creating a field of groundwater filtration and attention must be directed toward that in future hydrogeological exploration.
A dolomite-limestone aquifer is in a complex relationship with accompanying lithostratigraphic members that are waterproof hydrogeological insulators (aquitards). Generally, aquifer floors (1T22) are made of marl, clay, and quartz sandstone sediments (T1) when in a normal stratigraphic sequence. They can also create an aquifer cover as a result of deposition. It is not rare that these sediments (T1) simultaneously create the floor and the cover of the aquifer.
In a normal stratigraphic sequence, alumina and cherts (1T22) also represent the cover of the aquifer and with tectonic movements have been brought to the floor. Although erosion and deposition have made the situation more complex, this kind of status of the aquifer with the waterproof cover and floor has stayed the same in the entire Rupica area.
Replenishment of this aquifer is done via precipitation at the surface level while drainage occurs on the peripheral areas of the massif in streams in the form of diffuse discharge because no significant spring or concentrated discharge phenomena were observed. The infiltration of rainwater is immediate, so there is an oscillation of the underground water level depending on the hydrological conditions.
It can be considered that it is the filtration of underground water under sub-artesian pressure and artesian pressure is also possible locally. The distribution of pressures at groundwater levels in the area of the deposit has been determined in a small number of locations and in a limited area and shows the expected directionality of the underground flow from the center to the periphery of the massif.

3. EXPLORATION DRILLING

Exploration drilling is the most accurate method for geological and hydrogeological data gathering. It also enables gathering data on lithostratigraphic relationships, and tectonic disturbances while proper core mapping enables the creation of vertical and horizontal profiles.
There are several methods of drilling:

- Rotational exploratory drilling
- Percussive exploratory drilling
- Combined exploratory drilling

Drilling wells is most frequently conducted via rotational drilling done by drilling rigs. Exploration well depths can go from just a few meters up to several kilometers depending on the drilling rig type and the drilling target.

Image 2. Mustang 13 Atlas Copco Drilling Rig (Rig Teh East Sarajevo)

4. ADDITIVES FOR EXPLORATION DRILLING

The success of exploration drilling is dependent on properly choosing drilling additives. Without drilling mud drilling would be much more difficult and planned results could not be reached. The purpose of the additives is to improve and enable the continuous removal of drilled material from the bottom of the well. If the drilled material from the bottom of the well is not removed, it can stop the circulation of the water and in turn, bring the stability of the well into question. It can also increase the pressure of the rotation, make it harder to extract the pipes as well as slow down progress. The most important aspect of the additives is the cooling of the diamond crown drill bit and the lubrication of the drill pipe which enable better progress during drilling. Drilling additives have gone a long way from the simple mix of clay and water – today's additives consist of organic and nonorganic compounds. When additives are applied, the type and dose of additives must be considered. They are also continuously controlled while their characteristics are adjusted during drilling. The most important additive characteristics are density and viscosity. Liquids or additives for drilling are created for a large array of functions.

At the Rupica exploration site, several additives have been used in very complex drilling conditions. Their characteristics, dosage, reason for use, and how they assisted during drilling can be seen below.

PLUG

It is a granulated polymer that absorbs up to 500 times its volume in water. Plug is ideal for sealing zones where circulation has been lost and can also be used for reducing pipe vibrations in wells.

Plug needs to be partially hydrated in sweet water before pumping it into the well. It will quickly swell up to assist with sealing cracks and porous formations. Drilling can be continued after 30 minutes. If salinity and hardness are present, drilling should be resumed after 1 hour. This procedure can be repeated until

circulation resumes. Where the water level is low or there is a complete loss of water Plug can be poured into the well ring to reduce vibrations.
Plug is in the form of white liquid crystals and its typical physical characteristics are a volume density of 510 ± 50, a particle size of 2 to 4 millimeters, quick swell-up upon contact, and a pH of 7.0 – 8.0. Plug can be used individually or in combination with other additives for circulation control.

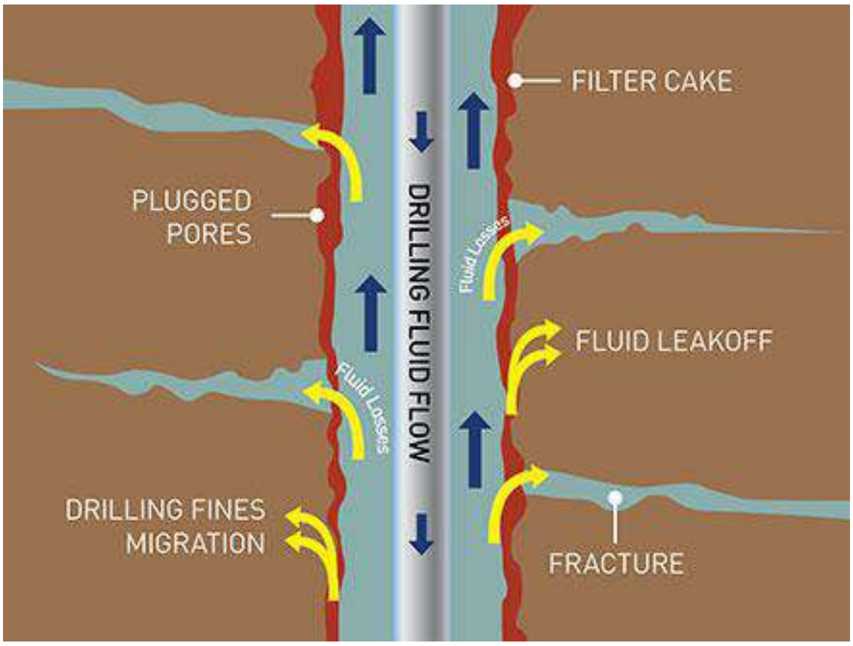

Image 3. Schematic of Plug application

BORE SEAL

This is an additive used to improve the stability of the well as well as for a better core recovery which improves and returns proper circulation of drilling mud. Bore Seal is ideal for the stabilization of formations like micro-fractured shale, coal, unconsolidated sand, and limestone. It is most efficient to seal medium to fine fractures and porous zones. It can be used with most drill bits.
Bore Seal is a light-brown or brown powder that can't be dissolved in water. It is used between 3 and 15 kilograms per cubic meter (1 – 5 lbs/bbl) depending on the drilling mud and the formation being drilled. Medium and coarse types are applied as concentrated pills which are most frequently used between 40 and 115 kilograms per cubic meter (14 – 40 lbs/bbl) depending on the severity of the losses.

CR 650

CR 650 is a high molecular weight polymer powder developed to improve the removal of drilled material as well as help stabilize the formation. It forms a protective polymer layer on the drill pipe and the drill bit as well as on the wall of the well and helps with lubrication during drilling in problematic formations. CR 650 is ideal for use in horizontal drilling, ordinary wells, mining, and tunnel drilling.
It can be used as an individual product or in combination with gels or other clay and shale stabilizers like potassium chloride.
CR 650 is white-colored and can be dissolved in water. The pH of a 0,5% solution is 7 – 8. It is ecologically acceptable and is not toxic.

Table 1. How to use CR 650

Application	kg/m^3	Lbs/bbl
Add to fresh water during drilling	0.5 – 0.75	0.15 – 0.3
For stabilizing swelling clays and shale	0.5 – 1.0	0.15 – 0.4
To improve core recovery in problematic formations and increasing well stability	1.0 – 3.0	0.4 – 1.0

Image 4. CR 650

COREWELL

Corewell is a multifunctional additive created for coring drilling activities as it provides good core protection and stability to the side walls. Corewell assists with preserving the original state of the core sample which enables better data acquisition from the core. It is used to stabilize unconsolidated soils and broken parts, to prevent additional crushing.
Water is recommended for this additive to work to its best, with a pH between 8.5 and 9.5. Between 1.5 and 3 kilograms per cubic meter (0,5 – 1,05 lbs/bbl) is mixed with water and mixed for 20 to 30 minutes. The viscosity of the product will vary depending on the dosage, so a test is recommended before use. Corewell is an off-white crystalline grainy product without a smell that can be dissolved.

LIQUI POL (POLYMER)

This is a polymer that is most frequently used during deep exploration drilling in Bosnia and Herzegovina due to its several positive characteristics. It is a high molecular-weight polymer that is added quickly because of its liquid form which ensures viscosity. It can also be combined with other polymers and additives, so it is used often by all drilling companies in Bosnia and Herzegovina since it enables material savings.
The polymer is easily mixed, controls sticky clay and prevents swelling up, and decreases vibration and drill pipe resistance while at the same time being an economical choice. Liqui pol is a white viscous solvable liquid with a specific weight of 1.00 – 1.10.

BENTONITE

Sodium bentonite is most frequently used during exploration drilling. It creates drilling mud of high viscosity. It is suitable for the preparation of water-based drilling mud for all types of drilling operations. It combines well with polymers and other additives. Bentonite's advantages include the cooling and lubricating of the drill bit, reducing the loss of mud through well walls, bringing drilled material to the surface, keeping drilled material in suspension during drill pipe stoppage, stabilizing the well, creating an impermeable layer on the well walls, enabling the application of other materials in the mud.
Bentonite is prepared by slowly adding it to water and mixing the solution intensely. It is prepared with clean water, quickly and efficiently. For the best results, sodium is added to the water (before the bentonite is put in the mix). The pH of the water is adjusted to an 8.5 to 9.5 interval when preparing the drilling fluid. Water purity affects the results of bentonite application.

Image 5. Mixing bentonite in a 1000-liter container

Table 2. How to add bentonite depending on the soil is shown in

Soil characteristics	Bentonite dosage
High permeability soil: gravel, sharp sand	60-70 kg/m³
Non-cohesive soil of medium permeability: sand formation	50-60 kg/m³
Cohesive soil of medium permeability: silty sand	40-50 kg/m³
Cohesive soil with low permeability: limestone, clay	35-40 kg/m³

CONCLUSION

The main goal of exploration drilling via a complex 160-meter well in central Bosnia on the territory of the Vareš municipality near Rupica is to analyze in detail the geological and hydrogeological characteristics of the area with a special focus on the use of adequate additives during drilling and their ecological impact.
Drilling success greatly depends on the correct choice and proper dosage of additives during drilling operations. Without drilling mud, drilling would be difficult and planned results could not be achieved. Also, important geological data couldn't be acquired. The purpose of the additives is to improve and enable continuous removal of drilling material from the bottom of the well. Continuous removal of the drilling material is essential as it can block the circulation of water, bring the stability of the well into question, create complications for drill pipe extraction, decrease the rate of progress, and increase pressure on the rotation. The most important thing the additives do is serve as a coolant for the diamond drill bit and as a lubricant for the drill pipe which in turn reduces wear and tear and enhances progress during drilling.
There is another goal in all drilling operations. Namely, it relates to the safety and ecological aspects of drilling while maintaining a high level of performance. Drilling and service companies use adequate measures to decrease the potential danger of accidents and enable safe working conditions while simultaneously protecting the geological and work environment. Ecological policy (HSE) of many companies is stricter than those requested by national governments and agencies which supervise drilling operations. Packing, transport, and storage of additives for drilling fluids are carefully tested regarding protecting the environment.

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VULNERABILITY AND PROTECTION OF THE WATER BODY "MODRAC"

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INTRODUCTION

Hydroaccumulation Modrac was built in 1964 to provide technological water for the needs of industry, and today it also has a water supply role for the drinking water of Tuzla and Lukavac. Given that wastewater is discharged into waterways mostly without any remedial treatment, the water body "Modrac" is therefore continuously exposed to contamination by various harmful and dangerous pollutants.
Due to the complex geological and hydrogeological conditions in which the waters of the Modrac reservoir exist, as well as the great influence of anthropogenic pollution factors, the degree of vulnerability of these waters is significantly high. By defining the pollution cadastre, analyzing the degree of vulnerability, and assessing risk based on hazard and vulnerability, adequate prerequisites are created for the application of methods to protect the quality of these waters. This would ensure the preconditions for adequate protection of water quality, and improve the conditions for the use of these waters, especially in the sphere of water supply, given that these waters, along with previous treatment at the water factory in Cerik, are remedied and brought to the condition of drinking water, which must meet the regulations on the use of drinking water.

Key words: vulnerability of water, water body, pollutants, polluting substances

1. GENERAL CHARACTERISTICS OF THE "MODRAC" WATER BODY

The catchment area of the Modrac reservoir is located in the central part of the Tuzla Canton, in the northeast of Bosnia and Herzegovina, covering an area of more than 1189 km2, which is administratively divided between the municipalities of Banovići, Živinice, Tuzla, Kalesija, Kladanj, Lukavac and Osmaci.

The water body has an area of 1673.98 ha, of which 30.00 ha or 1.8% of the total area belongs to the municipality of Tuzla, 35.8% to the area of municipality of Živinice, and 62.4% to the area of the municipality of Lukavac. Of the total area of the basin, which is 1189 km2, 832 km2 belong to the Spreča river basin, 240 km2 to the Turija basin, and about 117 km2 to the immediate accumulation basin.

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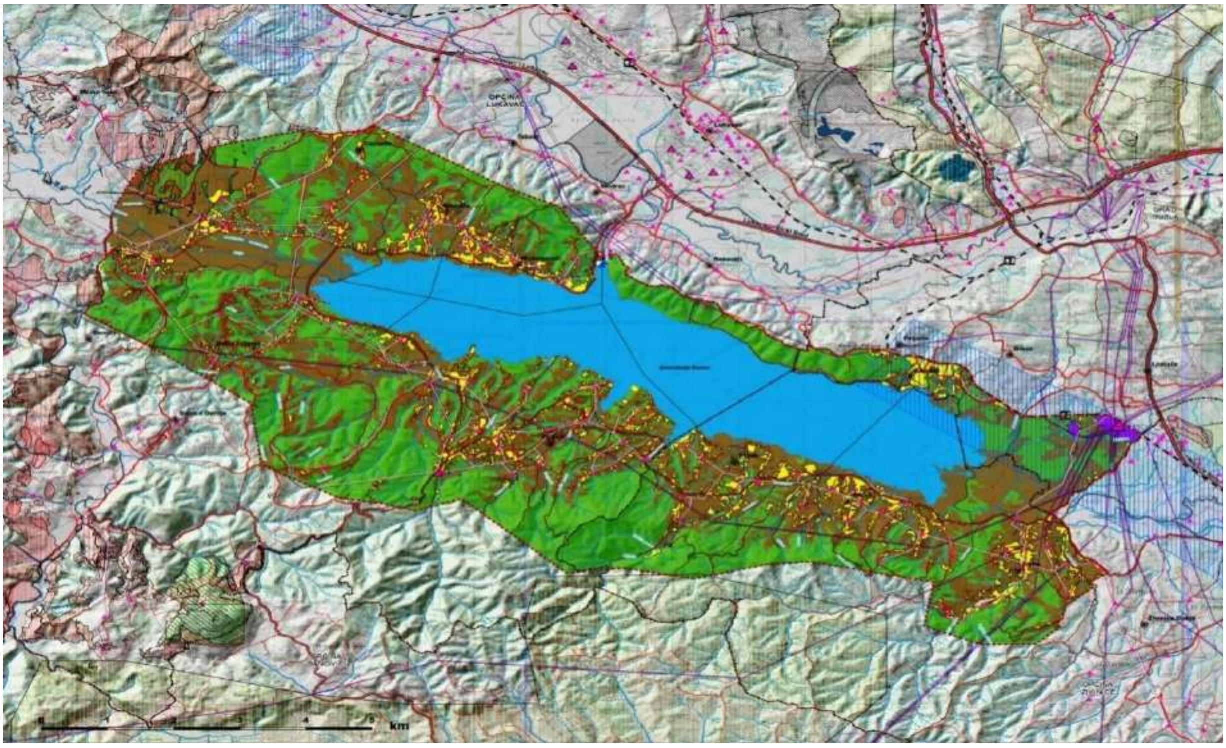

Figure 1. Map of the catchment area of the water body Modrac

2. CHARACTERISTICS OF THE CATCHMENT AREA

One of the very important factors in regulating the quantity and quality of water in the catchment area of the "Modrac" water body is the forest cover since it significantly affects the regime of both surface and underground waters. In the last ten years, the consequences of uncontrolled forest cutting could be noticed on the water body itself, in the form of frequent inflows of large waters and the deterioration of water quality.
The basin of the artificial lake Modrac is particularly interesting due to the protection of the lake from uncontrolled sediment and silt influx. Even before the construction of the Reservoir, significant erosion in the basin, production with transport of sediments into the artificial lake was predicted. Seen as a whole, the catchment area of the artificial lake Modrac has all the previous conditions for relatively sudden torrential inflows.
The average slope for the entire area is about 23%, with an average height difference of D = 211 m, which indicates that the configuration of the terrain is moderately pronounced. Deep and surface erosion processes occur throughout the catchment area.
It is necessary to emphasize the following for the hydrological characteristics of the basin of the water body, which have a significant impact on the morphometric characteristics and water quality:

- The state of the water regime in the area of the Reservoir basin can be characterized by two elements: precipitation and water runoff. In the area of the basin, the average annual precipitation is about 1000 mm (l/m2), which is far less than the average for Bosnia and Herzegovina, which is 1250 mm;
- The specific runoff of water from the area of Tuzla Canton (of 12,50 l/s), indicates that this area is one of the poorest with water in Bosnia and Herzegovina;
- Although the basin of the Accumulation, on average, has relatively high precipitation, their variations in individual years, as well as within one hydrological year, are significant. The unevenness of water regimes of watercourses is characterized by the sudden arrival and short duration of large waters and the long duration of small and very small waters. That is why most

watercourses in the basin area have a torrential character, where the ratio of large and small waters is on average 1:1000;

Based on the above data, it can be concluded that in the catchment area of the "Modrac" water body, there are mostly watercourses with small water flows.

3. QUALITY OF WATER STREAMS

Inadequate attitude towards the problem of wastewater and preservation of water quality, above all surface water, has caused in the last 50 years a very complex situation in terms of pollution of surface (ground) water in the area of the entire basin of the "Modrac" water body. A sudden increase in wastewater, without adequate measures for its remediation, led to the direct discharge into surface waters, which changed the water quality of almost all watercourses in the Modrac reservoir basin.

According to the current legal regulations of Bosnia and Herzegovina, the Decree on the Categorization of Watercourses and the Decree on the Classification of Waters, all watercourses in the area of the Modrac reservoir basin are classified in the II category of watercourses, i.e. the II class of water quality.

When it comes to the state of surface water quality in the basin of the Modrac water body, by analyzing the results of the research, it can be concluded that the results of the latest research indicate that the water in the watercourses (Litva, Oskova, Gostelja, Spreča) is still of poor quality, in other words, worse than quality that is prescribed by law. Before a more detailed analysis of the water quality of the Modrac reservoir, it is necessary to bear in mind that the water body belongs to the river type of lake, which is unfavorable from the aspect of water quality maintenance, and that the reservoir has unfavorable morphometric characteristics, especially when it comes to the relationship between the surface and the depth of the reservoir. In addition to the above, the reservoir is supplied with water from the basin of a large area in which important commercial facilities are located, especially when it comes to coal exploitation (surface mines, pits, separations); the basin of the reservoir is poor in water, all watercourses in the basin have low water flows.

From the very formation of the reservoir until today, significant amounts of waste water, which are loaded with large amounts of various pollutants, especially suspended substances, are discharged into the waters of the watercourse in the basin of the reservoir continuously and without prior purification. Society as a whole, in the past 50 years, did not take appropriate measures to protect the "Modrac" water body, which in part affected the excessive endangerment of the reservoir, namely on two basic aspects: preserving the volume and preserving the water quality of the water body.

According to previous investigations of the state of water quality in the basin area of the Modrac water body, it is clear that the surface waters are excessively polluted and that the quality of the water, in the earlier period as well as today, is far worse than the quality defined by the Regulations on water classification and categorization of watercourses of BiH.

This situation is a consequence of the daily discharge of untreated municipal and industrial wastewater into the watercourses of the reservoir basin. Also, based on previous investigations of the state of the water quality of the Modrac reservoir, it can be concluded that there is a constant trend of deterioration, which is a consequence of the constant input of a significant load of pollution that occurs in the reservoir basin and is discharged into surface waters, mostly without purification, and tributaries (Spreča and Turija) enters the Modrac reservoir.

First of all, it should be emphasized that the introduction of suspended matter (as a consequence of mining activities in the basin) and nutrient substances (as a consequence of the discharge of sewage wastewater into the basin) is detrimental to the quality of the water of the reservoir. When it comes to surface water pollution in the reservoir basin, there is a significant number of scattered (diffuse) uncontrolled pollutants (rural settlements that do not have sewage systems, urban areas, roads, agricultural lands, etc.).

To gain insight into the problem of surface water pollution in the basin, as well as water pollution of the reservoir itself, pollutants are divided into municipal, industrial, and other. About 130,000 inhabitants live in the reservoir's catchment, whose wastewater without prior treatment ends up in the Modrac reservoir's catchment, and this specifically refers to the sewerage of municipal water in the settlements of Lukavac, Banovići, Tuzla, Živinice and Kalesija. According to the available data, 12 major industrial polluters and around 60 minor polluters are located in the catchment area of the reservoir.

The most significant are coal mines (surface mines and pits), Dubrave, Banovići, and Đurđevik; Coal mines (separation), Banovići and Đurđevik. The most significant other polluters include garbage and waste dumps located in the basin of the reservoir, as they pose a serious threat to its pollution.

4. ASSESSMENT OF WATER VULNERABILITY

The Modrac reservoir was formed in 1964, with the primary purpose of providing industrial water for the economic capacities of Tuzla and Lukavac, as well as providing the water management (hydrobiological) minimum for diluting wastewater that is discharged into the river Spreča, downstream. Since the end of 2006, it has also been used to supply water to the population of Tuzla and Lukavac.
Vulnerability maps of underground and surface water represent the basis for the quality protection of these resources. They are an important factor in spatial planning so that construction does not cause negative impacts on groundwater quality. Therefore, they, along with other maps such as maps of potentially polluting substances of surface and underground water, help to identify possible risks.
Risk determination plays a significant role in the protection of underground and surface waters. Assessment of groundwater and surface water vulnerability to pollution varies in complexity, from simple and relatively inexpensive approaches, to rigorous quantitative and expensive assessments. By analyzing the negative impacts on the quality of surface and underground water, certain conclusions can be reached through the creation of a map of the vulnerability of the Tuzla Canton (Figure 2), which is of great importance for establishing the basis of quality protection of underground (surface) water.

The sensitivity of an aquifer is a measure that shows the ease with which water enters the aquifer and moves through it, which is a characteristic of the aquifer itself covering sediments, i.e. overall hydrogeological conditions and is independent of the chemical characteristics of possible pollutants and sources of pollution. Aquifer characteristics include: filtration coefficient, porosity and hydraulic gradient, where it is important to know recharge conditions, relationships with surface water and movement through the overburden zone. The vulnerability of groundwater to pollution depends on the naturally existing sensitivity, as well as on the location of the type of source, natural or anthropogenic pollution, mass transport, and mass exchange of pollutants. In recent years, several methods have been developed that treat groundwater vulnerability, with different authors providing their definitions and understanding of the term "groundwater vulnerability".

The GOD method, which was used to create the vulnerability map of the Tuzla Canton (Figure 2), is a simpler version of the DRASTIC method, and as an index method, it includes the knowledge of three input values, namely: the circumstances in which groundwater exists, the overall lithology and the depth to the level of underground water.
The method was named after S. Foster and R. Hirata (1988), who patented it, and it stands for Groundwater occurrence – Overall lithology – Dept to groundwater. This method is suitable to be applied on maps at a scale of 1:100,000, which cover a fairly large area and include several influencing factors on water pollution.

In the GOD method, in the scheme of the indexing system for groundwater vulnerability, the starting point is the type and depth of groundwater, as well as the overall lithology of the permeable or semi-permeable formation, whereby vulnerability ratings are given in the step value gradation, from no to extreme vulnerability. The vulnerability of the "Modrac" water body, defined according to the GOD vulnerability method, indicates that the "Modrac" water body is classified as very vulnerable.

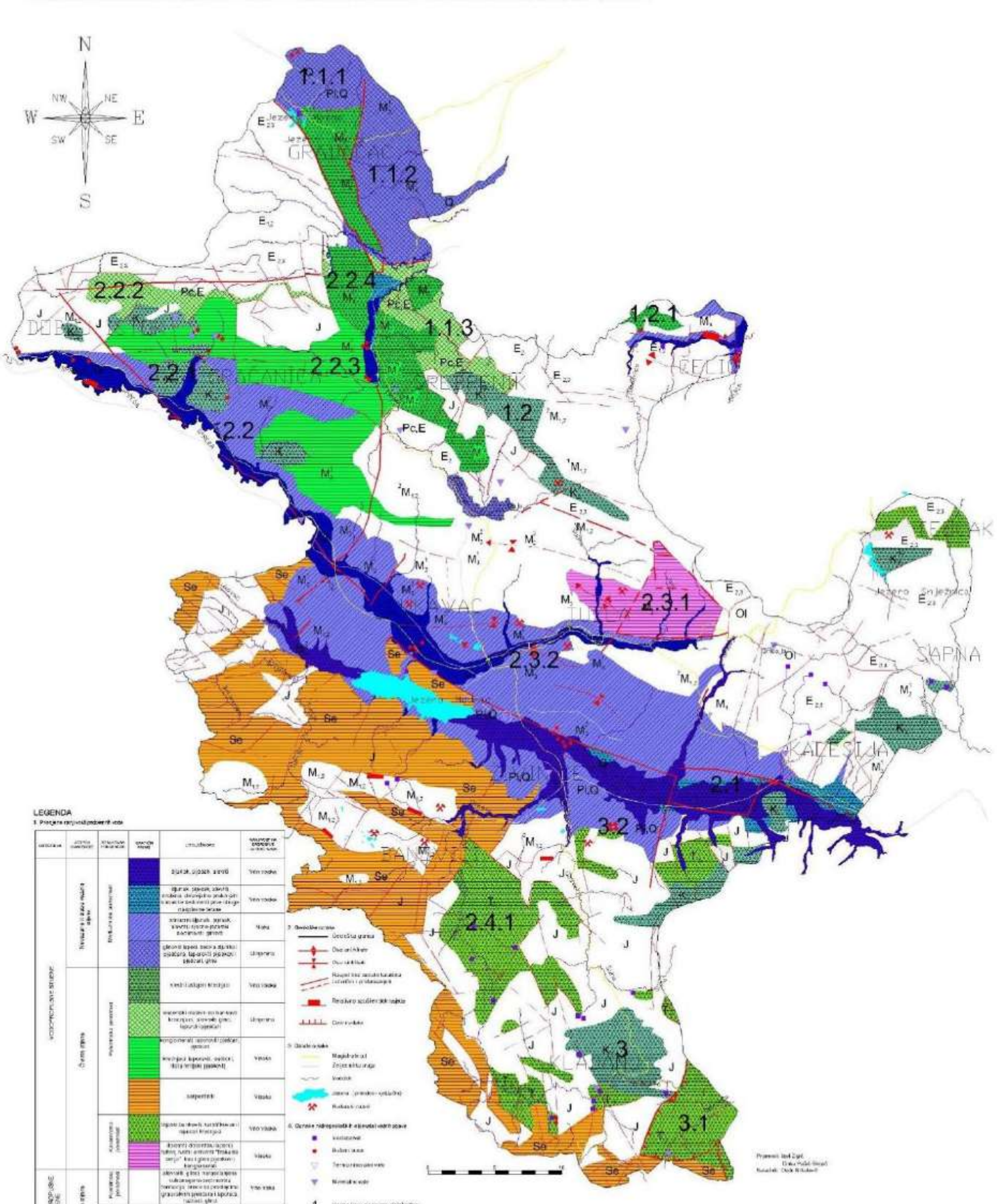

Figure 2. Vulnerability map of groundwater bodies of Tuzla Canton 1:100,000

5. PROTECTION OF WATER BODY MODRAC

The quality of water in the Modrac reservoir has been steadily deteriorating over the last four decades, as evidenced by continuous discharges of untreated wastewater from various sources of pollution, the largest of which are mine wastewater from separations, municipal water, and water from industrial plants. Little progress is evident in the goal of water protection of this watercourse, which is defined through the drafting of several laws on water protection and monitoring, but the laws are insufficiently applied, and monitoring is not aligned with needs and is not carried out continuously.

Regardless of the accumulated problems, in the water body and the area of the basin, biodiversity has been established that deserves European and world attention, especially since the construction of wastewater treatment plants in a wider area has recently started.

To stop the trend of water quality deterioration and improve the water quality of the water body "Modrac" and the environment, a more active coordinated joint action of the competent ministries, municipalities, as well as experts who will be able to recognize, first of all, the importance of this water body, not only from the aspect of industrial and drinking water needs but also as sport-recreational and sustainable biodiversity of wider significance, than the narrow perception of the reservoir as an exclusively hydro-technical object. It is necessary to urgently take appropriate measures at the sources of pollution to reduce (remediation) the introduction of polluting substances into surface waters, to start applying legal regulations, and to raise the awareness of all users of the water body about the necessity of its protection.

CONCLUSION

The problem of pollution of underground and surface water and the geological environment, as well as their remediation, appears as an integral part of the overall problem of protection and preservation of the human environment. Their protection from pollution, as well as the protection of the environment in which they exist, is very complex, especially their remediation. The complexity of remediation can be seen in the fact that it is a multidisciplinary issue. Considering the complex geological and hydrogeological conditions in which the waters of the "Modrac" water body exist, as well as the great influence of natural and anthropogenic pollution factors, the degree of vulnerability of these waters is significantly high. By defining the pollution cadastre, analyzing the degree of vulnerability, and assessing risk based on hazard and vulnerability, adequate prerequisites are created for the application of methods to protect the quality of these waters. This would ensure the preconditions for adequate protection of water quality, and improve the conditions for the use of these waters, especially in the sphere of water supply, given that these waters, along with previous treatment at the water factory in Cerik, are remedied and brought to the condition of drinking water, which must meet the regulations on the use of drinking water.

The provision of all the aforementioned prerequisites results from adequate water remediation methodologies aligned with complex geological, hydrogeological, hydrological, and hydro-technical research, following adequate vulnerability maps, as well as the definition and establishment of high ecological standards in the researched area.

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RELIABILITY OF RMR CLASSIFICATION DURING THE CONSTRUCTION OF ZENICA TUNNEL

Ahmed Mušija[1]

SUMMARY

Construction of underground tunnels in the rock mass is a very complex task from the aspect of stability of the rock mass in the secondary state of stress and defining the method of support. The method of excavation and the construction of the primary support are adapted to the state of the rock mass, which is why an adequate analysis of the rock mass as a work environment is of great importance. In order to define as precisely as possible, the quality of the rock mass as a work environment, classifications of the rock mass have been developed in recent times. The classifications are based on which the condition is assessed and its characteristics important for design are defined. In tunnel construction in Bosnia and Herzegovina, the RMR classification is most often used, the reliability of which varies depending on the characteristics of the rock mass in which the room is made. The paper analyzed the reliability of the RMR classification for the construction of the "Zenica" road tunnel, which was built in complex geotechnical conditions.

Key words: rock mass, uniaxial compressive strength, reliability, RMR classification

1. GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS OF THE ZENICA TUNNEL CONSTRUCTION

The Zenica road tunnel is located on the route of corridor Vc, it passes under the Vepar mountain, it is 3360 m long, while the maximum upper layer of the tunnel is approx. 478 m. The tunnel has 13 cross connections, 11 for pedestrians and 2 for motor vehicles. The distance between the shafts of the tunnel tubes is 25 m, and the tunnel has 3 parking spaces in each tunnel tube.

The geological characteristics of the massif in which the Zenica tunnel was excavated are determined by the Jurassic-Cretaceous fiche (2J,K) of the "Vrandučke serije", which consists of sedimentary rocks with a dominant presence of sandstone. In addition to sandstone, there are compact sandy and silicified clays, limestones and marls (2J;K). The rock massif is significantly layered, with layers from 5 to 100 cm thick and thin clay layers from 1 to 30 cm thick. The repetition of the sequence of layers occurs at intervals of 5-10 m. The flysch of the „Vrandučke serije“ is an extremely heterogeneous rock mass and is heavily folded, so it was a big challenge to define the engineering geological and geomechanical conditions for such rock mass. There is no clearly expressed rules of layers and folding mechanism change, which makes it difficult to determine the engineering geological conditions. Altogether, in combination with faults and folds, results in the degradation of the geomechanical properties of the rock mass, which makes their adequate definition significantly more difficult.

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Figure 1. The head of the Zenica tunnel excavation

During the excavation of the tunnel, large amounts of underground water were recorded, and they were constantly measured. During the measurement of groundwater inflow, it was sometimes difficult to capture all the water in one point.

Table 1. Part of the inspection of water inflow measurement in the Zenica tunnel

08.06.2020.	0+555.62	47.00 l/s
15.06.2020.	0+562.60	62.50 l/s
23.06.2020.	0+578.00	51.00 l/s
24.06.2020.	0+583.24	30.00 l/s
26.06.2020.	0+585.65	60.00 l/s
30.06.2020.	0+594.426	29.00 l/s
10.07.2020.	0+603.710	30.00 l/s
15.07.2020.	0+611.880	20.00 l/s
17.07.2020.	0+611.880	15.00 l/s
21.07.2020.	0+612.041	13.00 l/s
23.07.2020.	0+612.041	15.50 l/s
04.08.2020.	0+626.270	10.00 l/s
07.08.2020.	0+629.640	7.50 l/s
17.02.2021.	1+083.000	1,80 l/s
01.10.2021.	2+117.230	5,50 l/s

Figure 2. The emergence of underground water in the Zenica tunnel

In certain sections of the Zenica tunnel, the presence of large amounts of water significantly affected the classification of rock mass according to the RMR classification, and due to the significant influence of groundwater in some situations, the classification of rock mass according to the RMR classification was unreliable.

2. GEOTECHNICAL CONDITIONS IN THE ZENICA TUNNEL

The rock mass in certain sections was weakened and tectonized, which significantly affected the stability of the newly constructed part of the tunnel. Tectonic activity in the soft lithological members of the mentioned complex was most often reflected through the disintegration of the softer lithological members, while a large number of discontinuities were present in the hard lithological members. In tectonically disturbed zones, the rock mass is mostly defined as highly eroded and disintegrated, and the primary conditions are only partially preserved. The structure of the rock mass in the tectonically disturbed zone showed that the layering relationship and discontinuities systems have a wide range of spatial orientation element values, which posed a problem when classifying the rock mass according to the RMR classification.

The discontinuities are mostly filled with soft clay and hard calcite filling, and some discontinuities are open and without filling. The walls of fissures filled with calcite are slightly rough, while the walls of fissures filled with clay are smooth to slippery.

Figure 3. Structural properties (folding) of J/K flysch of the “Vrandučke serije” in the Zenica tunnel

3. OVERVIEW OF THE CATEGORIZATION OF THE ROCK MASS ACCORDING TO THE RMR CLASSIFICATION IN THE ZENICA TUNNEL

During the construction of the Zenica tunnel, lower RMR values were determined compared to those projected in the Main Project of the Zenica tunnel. Continued research during the construction of the tunnel showed that the rock mass is of lower quality, and a significantly higher content of category IV and category V according to RMR was determined. Therefore, the share of category III rock mass on the tunnel route was significantly reduced (almost by half), which is why it was necessary to approach with different type of the construction in the tunnel.

The cause of this change is the real geotechnical characteristics of the terrain where the excavation is being carried out, primarily the heterogeneity of the structure, i.e. the changing values of the physical-mechanical characteristics of the rock mass and the unfavorable hydrogeological conditions in which the tunnel was built. Low values of the basic parameters of uniaxial strength, the presence of clayey materials, constant vertical and horizontal changes of soft and hard rocks, and the unfavorable orientation of the discontinuity, had a significant impact on the reduction of the rating points of the rock mass along the route.

Table 2. Prognostic percentage of rock mass categories according to RMR classification in the Zenica tunnel

Left and right tunnel tube Zenica- projected		
Categorization of rock mass	**Length (m)**	**Percentage (%)**
II category	-	-
III category	6376,18	96,43
IV category	181,00	2,74
V category	54,66	0,83
Total length	6611,84	100,00

By monitoring the excavation of both tunnel tubes of the "Zenica" tunnel, it was determined that out of the total observed 4835.50m of tunnel excavation length, the tunnel excavation through the rock of the III RMR category was 2211.07m or 45.72%, the excavation through the rock of the IV RMR category in length of 2172.42m or 44.93%, and excavation through V RMR category 452.01m or 9.35%, which is shown in table no. 4.

Table 4. Overview of the representation of RMR categories according to the actual condition of the Zenica tunnel

Left and right tunnel tube Zenica- constructed		
Categorization of rock mass	**Length (m)**	**Percentage (%)**
II category	-	-
III category	2211,07	45,72
IV category	2172,42	44,93
V category	452,01	9,35
Total length	4835	100,00

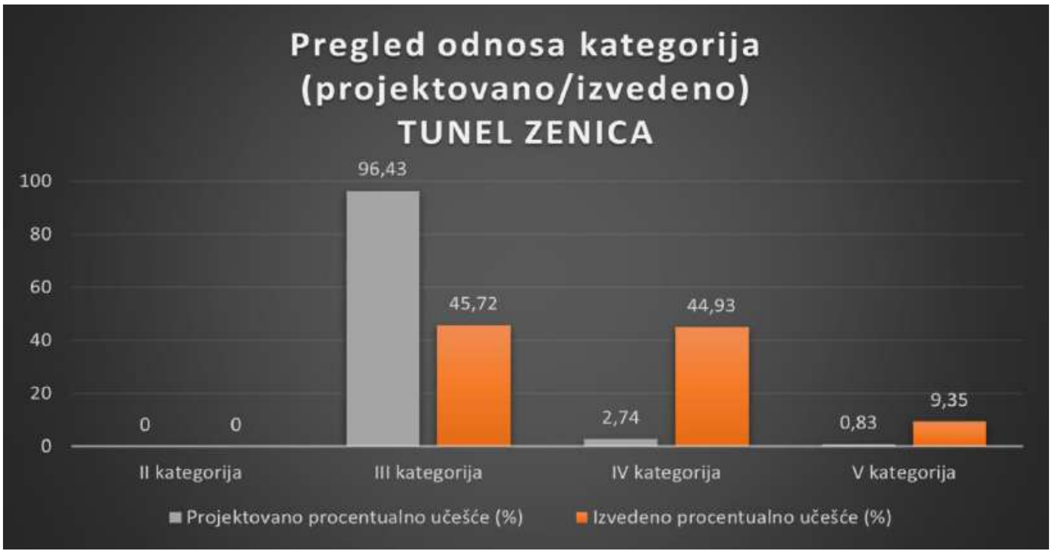

Figure 4. Overview of designed (gray) categories of rock mass and categories determined during construction (orange)

4. RELIABILITY OF THE RMR CLASSIFICATION DURING THE CONSTRUCTION OF THE ZENICA TUNNEL

Considering the geological, engineering geology, geotechnical, hydrogeological and other data collected during the design and construction of the Zenica tunnel, it can be stated that the Zenica tunnel was built in extremely complex geological, engineering geological and geotechnical conditions. The geotechnical conditions in which the Zenica tunnel was built are significantly less favorable than those assumed in the Main Geotechnical Project, as shown by the results presented in Tables 3 and 4.

The reliability of the RMR classification of the rock mass during the preparation of the Main Project was very low, which was shown during the 3,558 scoring of the rock material of the excavation face of the Zenica tunnel, including both tunnel tubes. The differences in what was defined in the project and during the construction of the tunnel can be seen in Figure 4, where the correlation between the predicted categorization and the categorization determined during construction, according to RMR, is shown. Such differences may also be a consequence of the insufficient scope of investigative work during design.

Figure 5. Fallout of rock blocks in the Zenica tunnel

However, the application of the RMR classification during tunnel construction was limited and often impossible. Defining input parameters for rock mass classification was very complicated, considering the wide range of values of individual input parameters. Sudden unexpected occurrences of groundwater, large differences in discontinuity characteristics and significant differences in the uniaxial strength of individual lithological members often forced contractors to classify the rock mass in a lower category, which in some cases was justified. In certain zones, due to a wrong assessment of some of the input parameters, it was necessary to carry out additional work to ensure the stability of the excavation, because some parameters did not correspond to the actual situation. The most common question is how and to what extent the parameters of one lithological member affect the complete stability of the excavation. As an example, one can cite the uniaxial compressive strength of individual lithological members, which can affect the deformation characteristics of the rock mass during excavation. The position, orientation and representation of individual lithological members in the excavation zone affected in different ways the very stability of the rock mass. Also, differences in uniaxial strength in the same lithological member, presented a problem for engineers. The position of a certain lithological member in the flanks or head of the excavation had an impact on the deformation characteristics of the excavation itself. Because of all this, the engineers who did the classification of the rock mass, very often based on their own assessment made the choice of input parameters for the classification, so often e.g. the choice of uniaxial compressive strength was an uncritically chosen mean value obtained in the laboratory. The reliability of the taken strength parameter often depended solely on the judgment of the engineer. In addition, the presence of lithological members with very low uniaxial compressive strength led to difficulties in the selection of this input parameter. The question arose as to what percentage of the presence of a lithological member with low uniaxial compressive strength in the excavation has an impact on the stability of the excavation and when to take that strength as relevant. Defining other input parameters was, in such complex geotechnical conditions, significantly more difficult, which forced engineers to often include the rock mass in a lower category. In spite of the fact that the engineers often classified the rock mass in a lower category, in order to ensure the unquestionable stability of the excavation, blocks fall out and part of the excavation collapsed. It was difficult to adjust the excavation step and the substructure of the Zenica tunnel, so that the excavation of the tunnel would be safe, without unforeseen blocks falling out and convergences, without over-dimensioning the substructure of the tunnel. All this shows that the reliability of RMR classification in complex geotechnical conditions is significantly reduced and depends solely on the experience of the engineer in the field. Introduction of reduction factors for certain input parameters, e.g. uniaxial compressive strength and the development of additional guidelines for the selection of individual parameters in complex geotechnical conditions would increase the reliability of the RMR classification.

CONCLUSION

The RMR classification is the most commonly used classification in Bosnia and Herzegovina when constructing road tunnels. Its reliability directly depends on geological, engineering geological and geomechanical conditions, that is, geotechnical conditions in the rock mass. Research works for the development of the main project should be carried out in an optimal scale, in order to reduce the differences between what is designed and what can be realistically expected in the rock mass. Only the experience of engineers in the field and adequate assessment of each of the input parameters enables optimal construction in the rock mass.

The scoring of rock material according to the RMR classification, in the complex geotechnical conditions of the Zenica tunnel, clearly showed that: "The RMR classification should be used in the cases for which it was developed, and not as an answer to all design problems" (Bieniawski 1989). The problem of the reliability of the categorization of rock material according to RMR calcification during the construction of the Zenica tunnel is a consequence of the complex geotechnical conditions in J/K “Vrandučki fliš”. A special problem is the relation to the test results and uniaxial strength values of the rock material, which resulted in often unrealistic scoring of the rock material according to the RMR classification. Considering the heterogeneity of the rock material, at the head of the excavation and the content of thin layers of clays, the question arises from which lithological member to take the value of uniaxial compression strength.

Due to the fact that the RMR classification is the most used classification, it is necessary to refine the classification in more detail, which would make the selection of input parameters easier. Correction factors for uniaxial compressive strength represent one of the steps to increase the reliability of RMR classification in complex geotechnical conditions.

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