Session: HS8.2.3 Fractured and karstified aquifers
Convener: Georg Kaufmann
Co-conveners: Steffen Birk, Franci Gabrovsek, Eric Zechner

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Establishment of the Procedure for Blast Mining During Construction of New Highway in the Vicinity of River Treska Spring

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Abstract – 1/4

The waters of Treska river come from a fractured and karstified aquifer. A new highway route running over the aquifer has been designed for this area. Unfortunately, the construction of the new highway demands a series of mining blasts for the purpose of laying out the route. Therefore, it was necessary to investigate whether the blasts could damage the aquifer and affect the water flow or its quality. To that effect, the capacity (flow) and the quality (purity, clarity of water, possible muddiness during and after trial mining) of water were monitored. A procedure had to be established for the purpose of investigating the influence of the blast waves on the rock medium in which the aquifer is embedded.

Abstract – 2/4

The geological structure of the terrain along the route is represented by Triassic dolomite limestone that is cracked on the surface and karstified. Since our country doesn't have any standards that cover the field of blasts and explosions, the Swiss standard (SWISS 640312:2013) was used.The main objective was to evaluate the effects of blasting works on a cut in the zone of the Treska river spring, along the new highway route, namely subsection 2 of Kichevo – Ohrid motorway, in respect to the geological and hydrological characteristics of the terrain of the Treska river spring, define a methodology for performance of trial blasting, evaluate the effect of trial blasting, draw conclusions and provide recommendations of measures and further activities.

Abstract – 3/4

Three trial blasts were performed on three trial fields according to the “far to close” principle and using low destruction blasting technology with continuous monitoring of the velocity of blast waves as well as monitoring of the quantity and quality of the water (possible muddying) flowing from the spring.

The trial blasts were performed in sequences, on blasting fields with a radius of effect of 50 m and using quantities of explosives causing vibrations that are lower than the allowed ground vibration limit. According to the results obtained from the trial blasts, it can be concluded that the trial blasts in the vicinity of Treska river spring performed under good control and high quality monitoring of the blasting process will not have negative effect upon the spring flow regime.

Abstract – 4/4

Also, the results obtained from the conducted geophysical surveys do not point to important changes of the physical-mechanical characteristics of the terrain structure after the trial blasts. In these zones, local disturbances as those during the referent measurements were defined. It is recommended to follow the same procedure for mining the rock medium during the construction works.

1.Hydrogeological characteristics of territories

Triple dolomite limestone ($T_{2,3}$) and icrinoid marble ($MD_{1,2}$) belong to the group of watertight solid rocks with good watertightness. The emission of sources within these lithological members ranges from Qizv = 100-1000 l / s, as well as the existence of multiple sources of lower capacity.

Feeding of karst outflow is done by direct infiltration of atmospheric precipitation. From the performed hydrogeological exploration data were obtained on the percentage of infiltration of 20-30%. The effective porosity is estimated at 3-5%.

1.Hydrogeological characteristics of territories

The sources are of gravity-contact or overflow type, sources at the touch of marble and limestone with surrounding weaker water-permeable rocks (shale and phyloid). The underground leakage coefficient is estimated at 10-15 l /s/km^2.

The Karst spring has a catchment area - a feeding ground mainly from the massif of mountain Bistra, as well as part of the Triassic limestones from the upper part of G. Debarca. According to the RHMZ, the source emission is from 480 - 1396 l/s.

2. Analysis of the source type of the Treska River and the source mechanism

The source of the Treska River is an aquifer of karst type aquifer in limestone.

The source of the Treska River originates from the tectonic contact of the Triassic contact to massive limestone and Devonian phyllitoids that form the source, 30 meters in length, under the local asphalt road to the village of Izvor. It is a constant karst heat that drains the karst embankment formed in limestones (Fig. 1).

2. Analysis of the source type of the Treska River and the source mechanism

Figure 1. Spring of Treska River

3. Basic dimensions and excavation division

The cuts in the terrain have different heights of the finished slope, however, generally rising around 54 m. Together for all cuttings and cutting the width to the bottom, which is about 30 meters.
The final slope of the cut is divided into floors with a height of 6 meters, where a final berm of 4 meters is left on each floor in the final slope. The total number of floors is 9 (nine) and the number of berms is 8 (eight).
The final stage of the cut above the source of the River Treska is shown in Figure 2.

The maximum horizontal distance from the source to the path is L = 66 m and the height from the level of the path to the source is H = 33m

3. Basic dimensions and excavation division

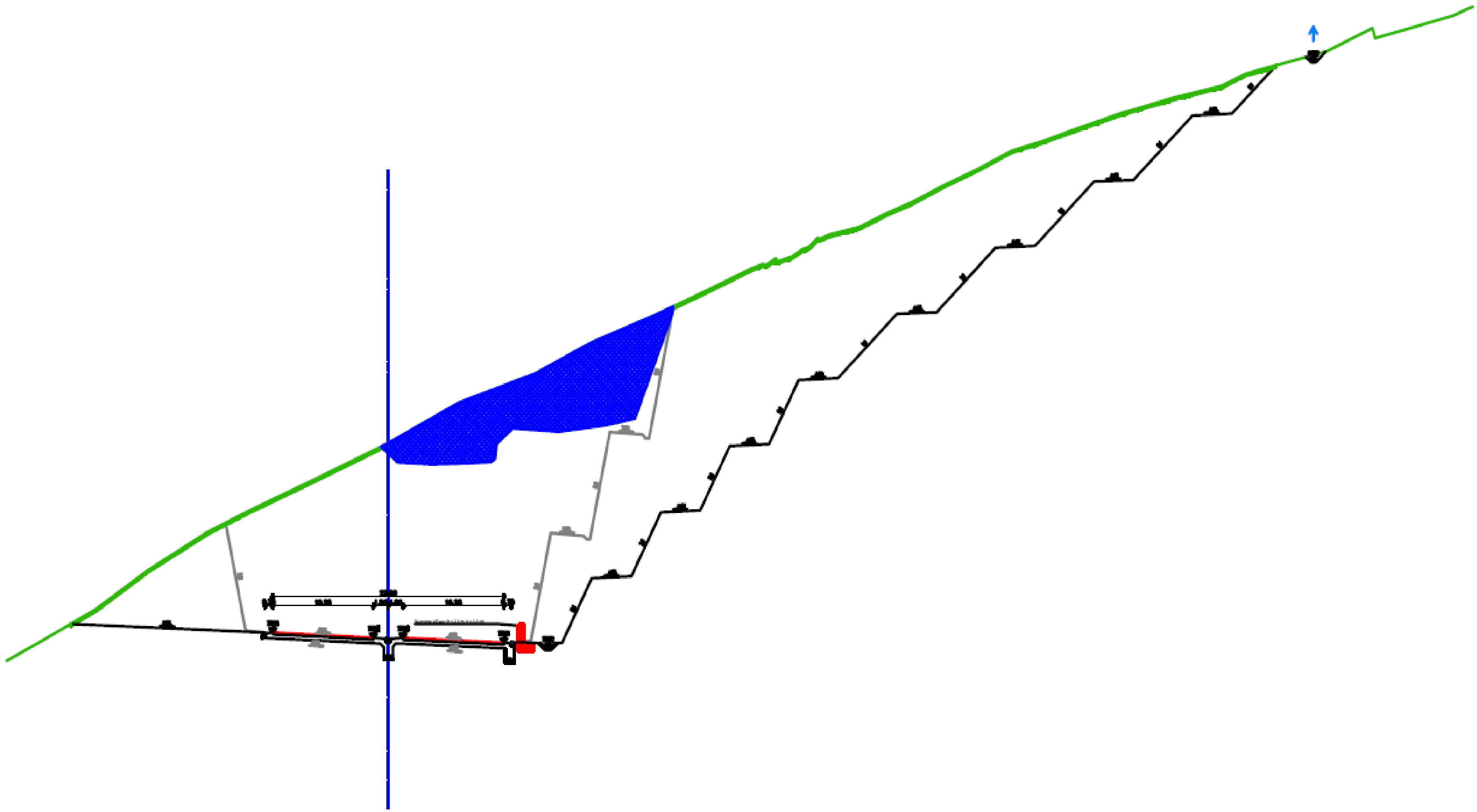

Figure 2. Cross-section of the route per cut

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4. Calculation of Drilling- Mining Parameters

The technological process of drilling and blasting of the mass from the part above the source of the river Treska is directly dependent on the physical-mechanical characteristics of the working environment, as well as on the height division of the masses according to the solutions of the Basic Road Design.

Drilling will be carried out with hydraulic drills with Ø76 mm hole diameter and 3 m hole depth, ie each stage is divided into two sets of 3 m height.

This division of the basic stage into two sets of 3 meters is carried out because of the direct dependence of the vibration rate on the amount of explosives activated by the controlled decelerate of the mines.

4. Calculation of Drilling - Mining Parameters

4.1 Determining the optimal type of explosive

Considering the fact that drilling and blasting operations will be carried out in a relatively humid environment, a DEMULEX type emulsion explosive is chosen. The current technical characteristics of DEMULEX are given in Table 1.

Table 1: Mining technical characteristics of DEMULEX

Mining - technical characteristics		Value
Density of explosives	Kg/Lit	1,15
Detonation speed	m/s	min. 4300
The gas stopped	lit/kg	953
Explosive heat	kJ kg	2830
Explosion temperature	^{o}C	1780

4. Calculation of Drilling - Mining Parameters

4.2 Parameters of a Drilling – Mining

The calculation of drilling and blasting parameters is based on:

-The height of floors .... 3 m.
- Bore diameter .... 76 mm.
- Sloping holes .... 75°
- Patronage Explosive Type DEMULEX .... 65 mm.

The appearance of the explosive charge in the mining hole is shown in Figure 3.

4. Calculation of Drilling - Mining Parameters

4.2 Parameters of a Drilling – Mining

Drilling Ø76 mm
Explosive DEMULEX Ø65mm

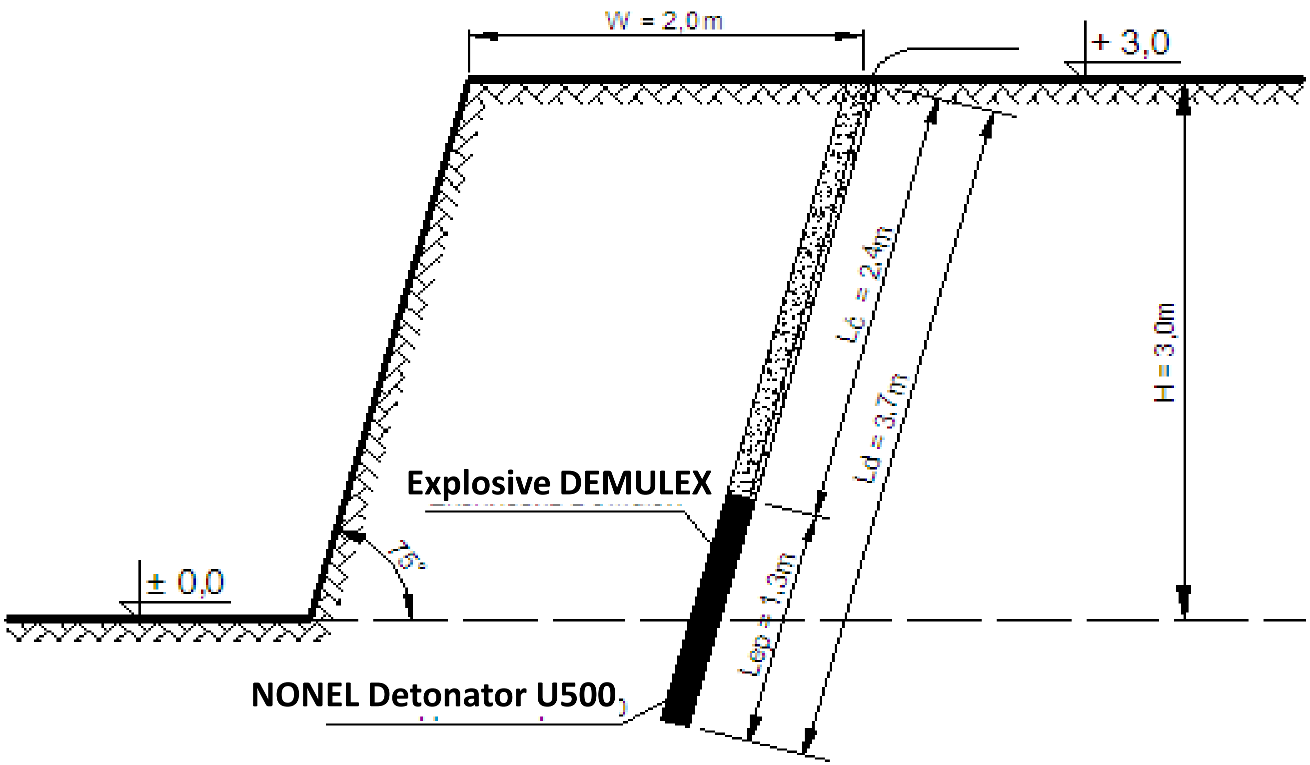

Figure 3. Plan of explosive charge in the well for H = 3 m.

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4. Calculation of Drilling - Mining Parameters

4.2 Parameters of a Drilling – Mining

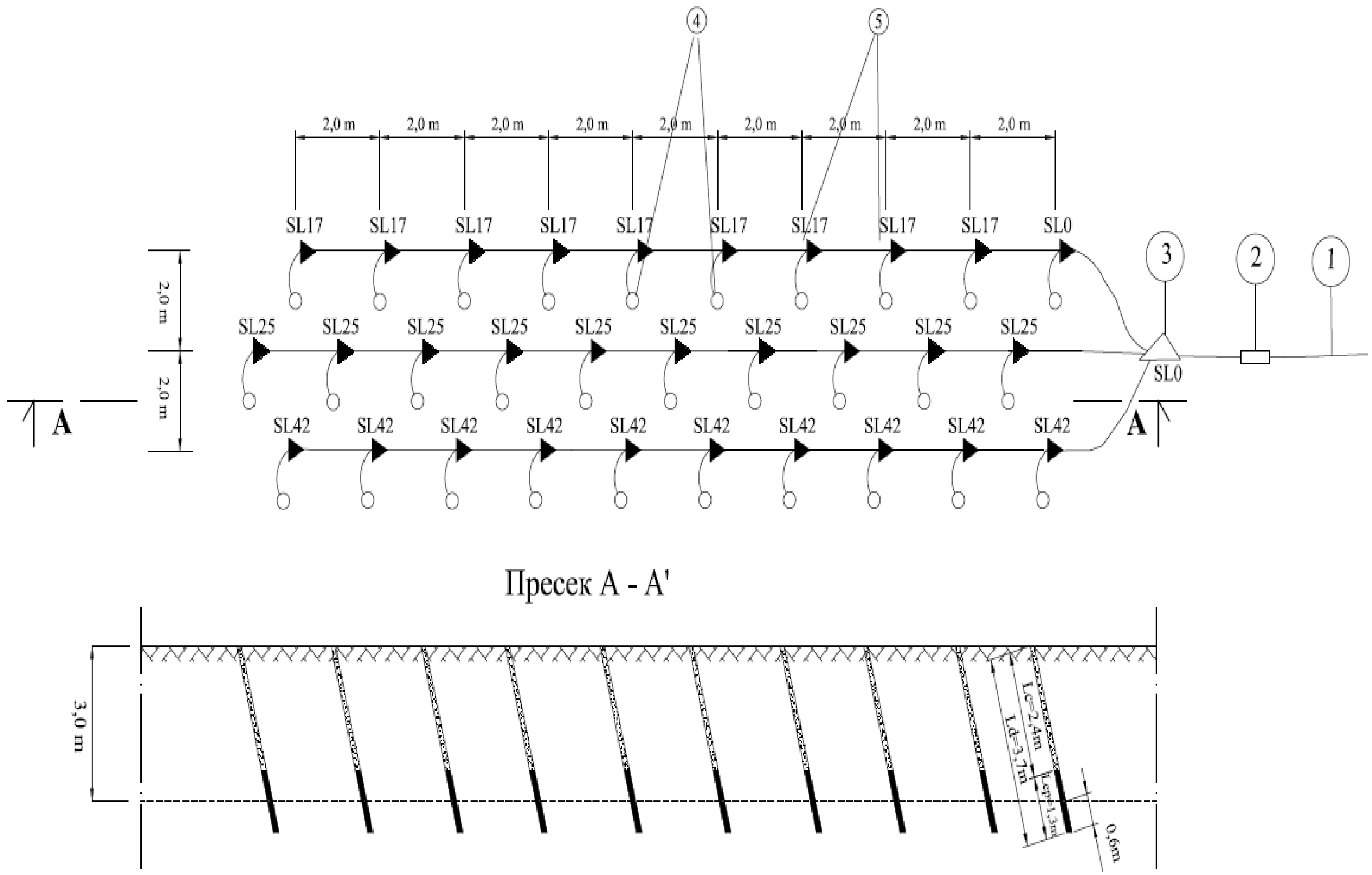


Figure 4. Scheme of blasting

4. Calculationof seismic impact from explosions

4.3 Procedure for controlling explosion (vibration)

The basic concept in vibration control over the source of the River Treske is as follows:

- **based on the condition and geological characteristics of the terrain, the permitted speed of ground oscillations at the location of the facilities will be determined according to European standards, since such a standard does not exist in the Republic of Macedonia;**
- **the ground oscillation rate is calculated depending on the amount of explosives, ie the number of wells that can be launched simultaneously, and the velocity of oscillations at the source does not exceed the permissible speed according to the adopted SWISS standard;**

4. Calculationof seismic impact from explosions

4.3 Procedure for controlling explosion (vibration)

The basic concept in vibration control over the source of the River Treske is as follows:

- **a decelerate interval is determined which will not allow the oscillations to overlap with different decelerate intervals;**
- **measurement of oscillations caused by the explosion of a place from the source and the line of safety distance, which will determine whether the oscillation rate does not exceed the permissible oscillation rate.**

4. Calculationof seismic impact from explosions

4.3 Procedure for controlling explosion (vibration)

The most common situation during an explosion is that very strong environmental vibrations should protect residential buildings, private homes and other buildings, but in this case the main vibration protection is the source of the Treska River.

According to SWISS standard, the permitted ground oscillation speeds are 20 mm/s. This rate of oscillation of the earth can be accepted as the permissible limit for all types of structures and media, i.e. in the case of dolomitic limestone.

For this minimum ground oscillation rate, the amount of concurrent explosives can be calculated using the following formula:

4. Calculationof seismic impact from explosions

4.3 Procedure for controlling explosion (vibration)

$$Qi = \left(\frac{D}{D_R} \right)^2$$

Where are:

Qi (kg) - the amount of explosives that must be fired simultaneously;

D (m) - distance of the object from the place of explosion;

DR (m) - allowed reduced distances.

4. Calculationof seismic impact from explosions

4.3 Procedure for controlling explosion (vibration)

The permitted reduced distance to the US standard for the distance from the explosion site to the source of 0-100 meters is 23 meters. Security zone, ie. the safe distance when the amount of explosive that is triggered is known can be determined by the following formula:

$$D = D_R \sqrt{Q_i}$$

Where are:

D_R (m) - reduced distances;

Qi (kg) - the amount of explosive that is activated in one decelerate stage.;

4. Calculationof seismic impact from explosions

4.3 Procedure for controlling explosion (vibration)

For the protection of soil and structures from excessive vibration, Instruction of the Institute of Earthquake Engineering and Seismology IZIIS at the University of Ss. Cyril and Methodius - Skopje R. Macedonia up to a vibration velocity of Vo <20 mm / s will provide protection for this type of object according to the SVISS standard and which vibration velocity is calculated and verified according to the following formula:

$$V_o\ (\text{mm/s}) = F_s\, k_1\, k_2\, k_3\, 750 \left(\frac{D}{\sqrt{Q_i}} \right)^{-1,67}$$

4. Calculationof seismic impact from explosions
4.3 Procedure for controlling explosion (vibration)

Where are:

Vo (mm/s) - allowed oscillation speed of a specific object

Fs = 2.5 - security factor for the protection of buildings

k1, k2, k3 - correction coefficients:

- **k1 - correction coefficient that depends on the blasting method**
- **k2 - coefficient that takes into account the aperture layout:**
- **k3 - coefficient that takes into account the number of rows:**

4. Calculationof seismic impact from explosions

4.3 Procedure for controlling explosion (vibration)

From the analysis of the projected mining, the following can be concluded:

- The minimum critical distance from the site of the explosion of the section to the source of the river Treske is 66m;
- The maximum amount of explosives to be fired within the same decelerate interval is 5.28 kg of explosives at a height of 3 m by continuous loading;
- At a distance of 50 meters from explosions, the ground oscillation rate with the simultaneous activation of 5.28 kg of explosives is Vo = 14.5 (mm/s) which is less than the permitted standard of 20 (mm/s). which is located 15 to 20 meters in front of the source of the Treska River.

4. Calculationof seismic impact from explosions

4.3 Procedure for controlling explosion (vibration)

For a comparison of these analytical calculations of the vibration velocity of an explosion, Institute of Earthquake Engineering and Engineering Seismology, “Ss. Cyril and Methodius” - Skopje R. Macedonia (UKIM-IZIIS) measured the vibration during the test explosion.

These explosions were approved by the Ministry of Environment - Water Sector.

5. Vibration Measurement Results

For recording of seismic vibrations, instruments produced by "GURALP", models CMG-5TCDE and CMG-5TD, with sampling frequency of 200Hz, were used. The accelerographs were designed for low and high frequency vibrations with a sampling frequency of 100Hz to 1000Hz. The N component was positioned in radial direction, toward the blasting field, the E component was positioned in transverse direction and the Z component was positioned in vertical direction.

The vibrations due to blasting were recorded for the following purposes:

- Analysis of the effect of vibrations due to blasting–recording of vibrations due to trial blasting.
- Control of the effect of vibrations – recording of a reliable set of data on vibrations generated by blasting that could be used during the construction of the motorway in the immediate vicinity of Treska river spring.

5. Vibration Measurement Results

The impact of vibration is recorded by three test explosions and 30 wells from each minefield with millisecond decelerations on each well to control the generated vibration from the blast.

After defining the location of the minefield for the first test blasting (Figures 5 & 6), the locations for positioning the measuring instruments in the appropriate direction were determined.

5. Vibration Measurement Results

Figure 5. Covering of the blasting field with rubber strips due to dispersion of material.

5. Vibration Measurement Results

Figure 6. Results from trial blasting

5. Vibration Measurement Results
First Trial Blasting

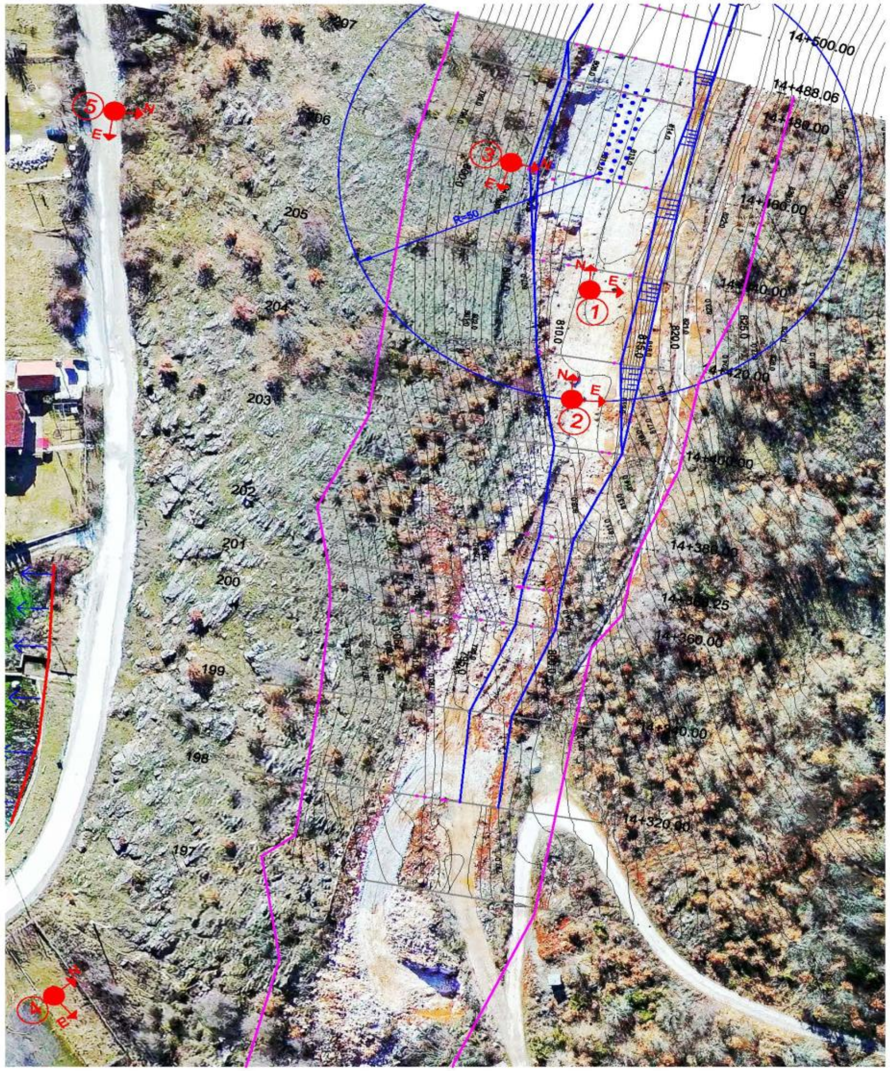
Table 3. Results from the first blasting at Treska river spring

Measuring point	Lh [m]	Lv [m]	L [m]	V [mm/sec]			PPV [mm/sec]
				N	E	Z	R
1	25.0	0.0	25.0	15.0	22.0	12.0	24.00
2	50.0	0.0	50.0	6.0	3.9	3.9	7.46
3	39.7	12.5	41.6	12.0	9.0	5.6	12.58
4	-	-	-	1.4	1.2	1.0	1.90
5	-	-	-	1.2	0.84	2.8	3.00

From the obtained results, it can be concluded that at a horizontal distance of 50 meters, the oscillation rate of the earth was 7.46 mm/s and calculated in the study for the same distance of 50 meters is 14.5 mm/s which is less than the maximum allowed.

5. Vibration Measurement Results

First Trial Blasting -Position of measuring instruments



5. Vibration Measurement Results
Second Trial Blasting

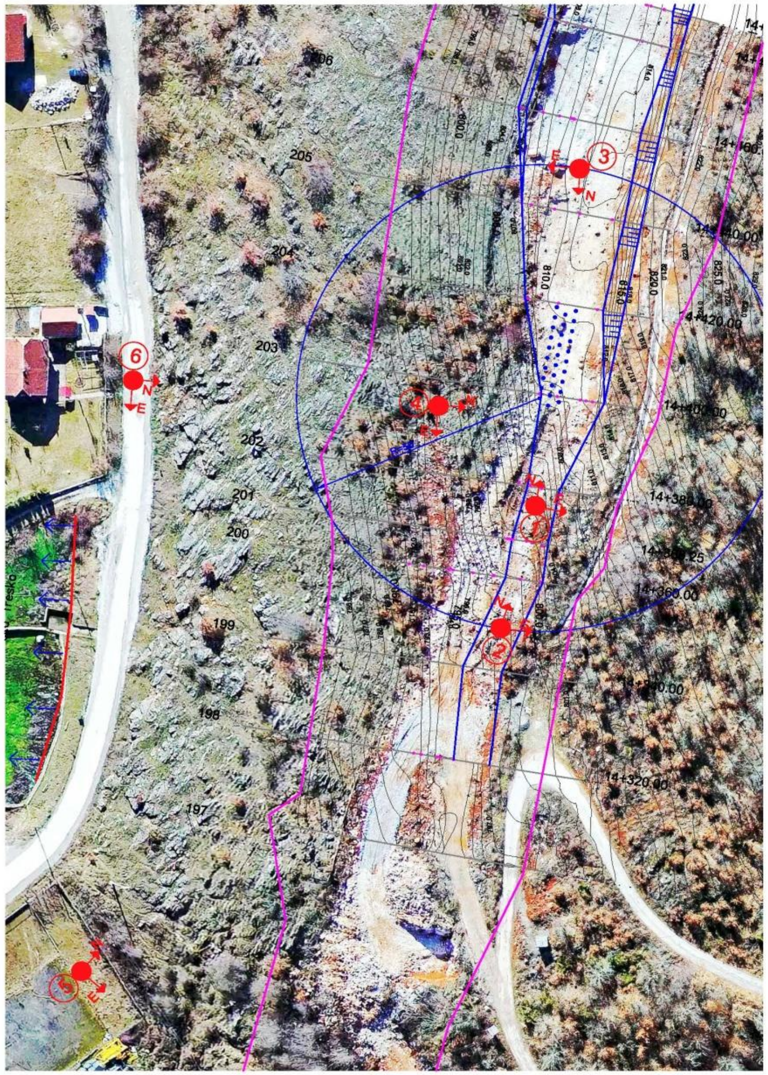
Table 4. Results from the second blasting at Treska river spring

Measuring point	Lh [m]	Lv [m]	L [m]	V [mm/sec]			PPV [mm/sec]
				N	E	Z	R
1	24.0	6.7	24.9	15.0	12.0	7.0	16.30
2	47.0	10.8	48.2	9.0	8.0	4.0	12.26
3	23.5	0.0	23.5	23.0	11.0	5.0	22.80
4	22.7	12.5	25.9	26.0	17.0	11.0	27.14
5	137.5	50	146.3	2.5	1.5	2.4	2.70
6	-	-	-	1.7	1.0	2.87	2.90

Based on the results from monitoring performed on the day of 01.07.2019 for definition of the effect of blasting works done in the zone of Treska spring zone, it was defined that, after the performed trial blasting, there were no changes regarding the capacity and quality of the spring water prior, during and after the performed second blasting.

5. Vibration Measurement Results

Second Trial Blasting -Position of measuring instruments



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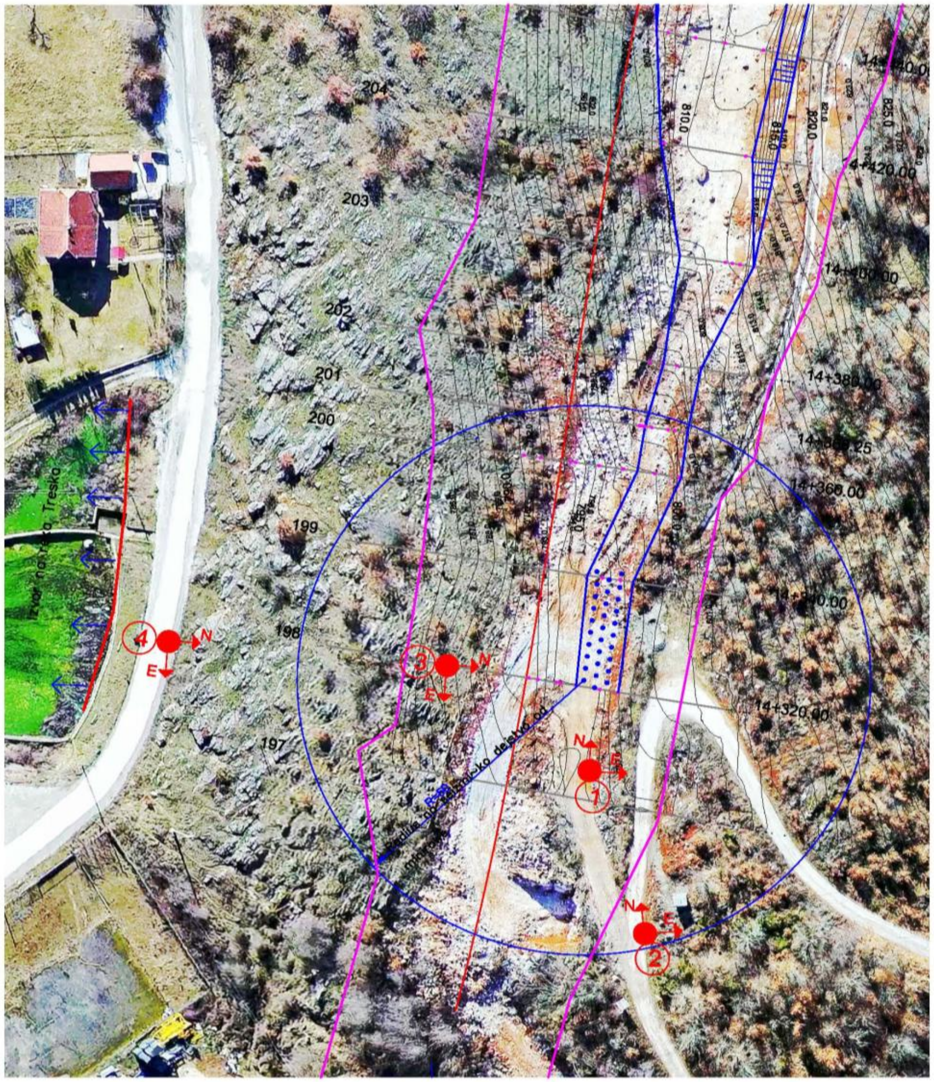
5. Vibration Measurement Results
Third Trial Blasting

Table 4. Results from the third blasting at Treska river spring

Measuring point	Lh [m]	Lv [m]	L [m]	V [mm/sec]			PPV [mm/sec]
				N	E	Z	R
1	28.04	0.22	28.14	20.88	13.88	10.20	21.27
2	52.28	0.33	52.28	7.16	5.18	2.03	7.81
3	22.40	5.70	23.11	15.79	14.99	10.32	16.67
4	69.80	35.50	78.30	2.33	1.37	1.60	2.50

Based on the obtained results, it can be concluded that the distance from the water velocity of 52.3 meters is measured by the measured oscillation speed of 7.81 mm/s, and the calculated elaboration at a distance of 50 meters is 14.5 mm/s.

5. Vibration Measurement Results
Third Trial Blasting -Position of measuring instruments



6. Water monitoring from the Treska river research

As part of the program to identify and evaluate the impact of mining operations on the section in the source zone of Treska River- monitoring the quantity and quality (clearness) of water before, during and after the explosion, was carried out, ie. capacity (flow) and quality (cleanliness, water clarity, possible eclipses) at the source of the Treska River were closely monitored.

Based on the results, a monitoring was carried out to determine if the pilot explosion performed near the springs of the river Treska, would affect the parameters of the spring. It turned out that it did not result in any change in the capacity and quality of the water in the springs.

Conclusion – 1/5

1. The national regulations do not treat completely the considered field, i.e., protection of “excavation contours and surrounding land”, “engineering structures” and “environment” against vibrations caused by blasting. Therefore the evaluation of the effect of the three trial blasts was carried out according to the SWISS 640312:2013 Erschütterungen – Erschütterungse in wirkungen auf Bauwerke standard dated 01.12.2013. According to this standard, the basic parameter for evaluation of blasting effect is the peak velocity of vibration of particles amounting to PPV≤20mm/s for the defined frequency range.

Conclusion – 2/5

2. Optimization of the seismic effect due to blasting is done by limitation of the seismic effect according to analytical computations and experimental measurements. The control of the seismic effect and management of the blasting process from the aspect of vibrations is realized by:
   - Limitation of vibrations according to existing standards;
   - Trial blasting for testing of the obtained vibrations;
   - Optimization of blasting field for the purpose of satisfying the ultimate values defined in the used standards, and
   - Control of seismic effect.

Conclusion – 3/5

3. In accordance with the obtained Main Design, the closest distance from the Treska river spring to the road axis is 72m in horizontal direction and 33.7m in vertical direction. At distance of 50m from the explosions, the ground vibration velocity induced by simultaneous activation of 5.28 kg explosives amounts to PPV = 14.5 (mm/s), which is less than the allowed standard of PPV≤20mm/s, which is at distance of 15 to 20m from the Treska river spring.
4. With the realized control of vibrations from the trial blasts for excavation on the motorway, Kichevo – Ohrid section, at Treska river spring, protection of the Treska river spring against blasts with vibration velocity of PPV≤20mm/s is achieved.

Conclusion – 4/5

5. **Based on the results from the monitoring performed for definition of the capacity (flow) and quality (purity, clarity, possible muddying) of the water from the Treska spring, it was defined that, after the performed trial blasts, there were no changes in respect to the capacity and quality of the spring water prior, during and after the performed trial blasts.**
6. **Based on the results from the performed monitoring, on the day of 12.06.2019, 01.07.2019 and 05.07.2019, it was defined that, there were no changes regarding the capacity and the quality of the Treska river spring water prior, during and after the performed trial blasts. We herewith note that no muddying of the water flowing out of the spring was recorded.**

Conclusion – 5/5

7. The results obtained from the conducted geophysical surveys do not point to important changes of the physical-mechanical characteristics of the terrain structure after the trial blasts. Recorded is a loosened zone in the surface layers, down to maximum depth of 2.5 m in the upper part of the location, at the beginning of seismic profile Rp3, in the vicinity of the third blasting field. In the deeper layers, the values of the seismic velocities are identical to those obtained in the first phase of the investigations. In these zones, local disturbances as those during the referent measurements were defined.

Recomendation

1. Installation of two instruments for permanent recording of vibrations at predefined measuring points in the immediate vicinity of the Treska river spring.
2. Continuous monitoring of the capacity (flow) and quality (purity, clarity and muddying) of the spring water.
3. Based on the results from the trial blasting at the cut in the spring zone of Treska river, for the purpose of elimination of negative effects during the construction of the cut, the professional team gives the recommendations regarding blasting.
4. Excavation of masses from the cut should comply with the Rulebook on Surface Exploitation of Minaral Raw Materials, downwards, for the purpose of safe and low cost excavation and formation of final contours according to the solutions from the Main Design of the road.

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