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Excavation of the foundation of piers S1L and S1R of the Vranduk I bridge by controlled blasting on the motorway route: Zenica Municipality Northern Administrative Boundary - Zenica North

Ekrem Bektašević
PPG d.o.o. Sarajevo, Ph.D, bektasevic.ekrem@gmail.com
Reuf Kadrić
JP Autoceste FBiH Mostar, B. Sc.(Mining), k.reuf@jpautoceste.ba
Marin Nikolić
Trasa d.o.o. Sarajevo, Ph.D, marinnik9@gmail.com
Kemal Gutić
University of Tuzla, Faculty of Mining, Geology and Civil Engineering, Ph.D, kemal.gutic@untz.ba
Sead Kadrić
FM INŽENJERING d.o.o. Sarajevo, B. Sc.(Mining), sead.kadric@gmail.com

Abstract: The Vranduk I bridge is located on the motorway route, on the part of the subsection: Zenica Municipality Northern Administrative Boundary - Zenica North. The bridge consists of two parallel structures, one for the left side, and the other for the right side of the motorway. The Vranduk I bridge rests on three piers. The paper deals with the excavation of the pier site S1R and S1L by controlled blasting. By correctly choosing the equipment for drilling blast holes, defining the drilling and blasting parameters and excavation steps, a minimal zone of damage to the surrounding rock outside the line of excavation of pier sites S1R and S1L, which is inevitable during blasting excavation, has been achieved, which has the effect of preserving the bearing capacity of the rock mass as the most important supporting element.

Key words: excavation, piers, drilling pattern, blasting, explosives

Iskop temelja stupnog mjesta S1L i S1D mosta Vranduk-I kontroliranim miniranjem na trasi autoputa: sjeverna administrativna granica općine Zenica - Zenica Sjever

Sažetak: Most Vranduk-I nalazi se na trasi autoputa na dijelu poddionice: sjeverna administrativna granica općine Zenica - Zenica Sjever. Most se sastoji od dva usporedna objekta za lijevu i desnu stranu autoputa. Most Vranduk-I se oslanja na tri stupa. U radu je obrađen iskop stupnog mjesta S1D i S1L mosta Vranduk-I kontroliranim miniranjem. Pravilnim odabirom opreme za bušenje minskih bušotina, definiranjem bušačko-minerskih parametara i koraka iskopa postignuta je minimalna zona oštećenja okolne stijene van linije iskopa stupnih mjesta S1D i S1L, koja je neminovna pri iskopu miniranjem, što ima za posljedicu očuvanje nosivosti stijenske mase kao najvažnijeg „podgradnog“ elementa.

Ključne riječi: iskop, stupno mjesto, geometrija bušenja, miniranje, eksploziv

1. INTRODUCTION

Corridor Vc, as one of the branches of Corridor V, starts in Hungary (Budapest), continues through Croatia (Osijek) and Bosnia and Herzegovina (Zenica, Sarajevo, Mostar) and ends in Croatia on the coast of the Adriatic Sea in the port of Ploče.

For Bosnia and Herzegovina, realization of construction of the Corridor Vc has multiple meanings. First, because it would be the first international route that would run through its territory and in this way include it in the international modern transport network. Also, this route provides Bosnia and Herzegovina with a high-quality access to the Adriatic Sea through the port of Ploče in Croatia and opens an access to the area of Central and North-Eastern Europe on the north side. For Bosnia and Herzegovina, which suffered war atrocities, massive destruction and social and political division at the end of the last century, this corridor will be one of the drivers of economic development, but also one of the factors of integration processes of its political space.

Figure 1. Network of European road corridors

The route of the designed motorway section Zenica Municipality Northern Administrative Boundary (Nemila) - Zenica North (Donja Gračanica) stretches along the Bosna River, mainly following its right bank [1].

The route of subsection II starts on the southeastern side of the Stara Stanica (Old Station) settlement on slopes of Stranata Vlasača hillside. Passing by the Stara Stanica settlement, the motorway route extends southwards towards the Vranduk area. Further in the southeast direction between the slopes of Stranata Vlasača and Suvodolska Kosa hillsides, the motorway route passes with two bridges "Vranduk I" and "Vranduk II" and through the

Suvodolska Kosa hillsides by the "Vranduk" tunnel, further to the southeast over the Krša hillsides toward the Koprivna settlement. The motorway route further runs with three smaller viaducts east of the Koprivna settlement over the Osoja hillside. Passing close to the Koprivna settlement, the motorway route further extends southwards towards the Ponirak settlement. The end of subsection II Vranduk-Ponirak is southeast of the Ponirak settlement. Subsection II is designed in a length of l=5309.30 m.

The Vranduk I bridge consists of two parallel structures for the left and right side of the motorway. In this part of the route, the bridge spans a valley and the viaduct height from the lowest ground level is approximately 57.00 m.

The right bridge has a total length of 390 m'. It starts with abutment U1D and ends with abutment U2D. The bridge rests on three piers (S1D, S2D and S3D). The left bridge, with a total length of 380 m, starts with abutment U1L and ends with abutment U2L. The left bridge rests on three piers (S1L, S2L and S3L).

Bridge piers S1L and S1D are founded on a well in circular shape with a diameter of 9.00 m and the depth of the well is 8.00 m. Piers S2L and S2D are founded on 16 piles 1.20 m in diameter and 9 m in length which are connected to the foundation slab with dimensions 13.00 x 13.00 x 3.00 m. Piers S3D and S3L are founded in the same way as S2, only the length of piles is increased to 19 m. The appearance of the Vranduk I bridge is shown in the following figure.

Figure 2. Bridge Vranduk I

Excavation of the foundations for piers S1L and S1D, which are founded on a circular well, presents a special requirement to the contractor, to minimize the damage to the rock mass outside the excavation profile during the excavation. Also, an additional aggravating circumstance when excavating the foundations of piers S1L and S1D is their spatial position with regard to the proximity of the main road M-17. The drilling and blasting works for the execution of controlled blasting during excavation of the foundations for piers S1L and S1D of the Vranduk I bridge are elaborated in detail in the following.

2. GEOTECHNICAL CHARACTERISTICS OF THE MATERIALS IN THE VRANDUK I BRIDGE CONSTRUCTION ZONE

In the bridge route area, the terrain is composed of solid rock masses - compact sandy and silicified claystone and limestone (^{2}J;K), that are stratified with thickness of strata from 0.2 to over 1 m and intercalations of thinly stratified and foliated claystone 10 to 30 cm thick, occurring in intervals from 5 to 10 m. The terrain is covered with deposits of decomposed surface cover - surface weathering zone made of debris, clay and silt as a product of complete decomposition of bedrock 0.3 to 0.5 m in thickness (CW). On slopes with greater gradients this surface weathering zone wedges out.

In hydrogeological terms, the surface weathering zone is permeable with predominant medium developed intergranular porosity, and the rock mass of compact sandy and silicified claystone and limestone has medium to low developed fracture porosity and medium conductivity.

Field and laboratory tests provided data on rock mass: uniaxial strength of samples, RQD, condition of discontinuities in the rock mass, etc. based on which individual zones were rated according to the RMR geomechanical classification [2]. Geological strength index - GSI - was obtained from these points. Table 1 shows the obtained data necessary for the calculation of drilling and blasting parameters.

Table 1. Geological characteristics of the terrain in the bridge construction zone

Rating according to the geotechnical rock mass classification (Bieniawski, 1989) (RMR)	Geological strength index defined by the expression $GSI=RMR_{89}-5$ (GSI)	Uniaxial rock strength determined by laboratory tests of rock samples (σ_c)
49.00	44.00	45.00

3. CALCULATION AND SELECTION OF DRILLING AND BLASTING PARAMETERS FOR THE EXECUTION OF CONTROLLED BLASTING DURING THE EXCAVATION OF THE FOUNDATION OF PIER S1L

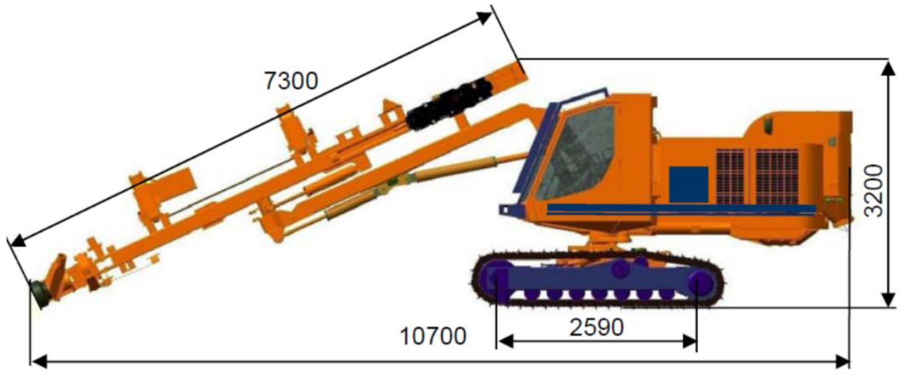
3.1 Equipment for production drilling

The selection of equipment for production drilling of blast holes for the execution of conventional controlled blasting for construction of the foundation of pier site S1L near Zenica was carried out in accordance with the "Supplementary mining project for the execution of conventional and special drilling and blasting works on the route of the Corridor Vc motorway, subsection "Vranduk - Ponirak" near Zenica, with protection measures for buildings in the immediate vicinity of the route".

A drill made by TAMROCK 700RP was used to drill the blast holes. The appearance and technical data of this drill are given in Table 2.

Table 2. Appearance and technical data of the drilling rig

Type	Tamrock 700RP
Mass of the drill (kg)	14800
Fuel consumption (l/h)	17-22
Pressure to blow out the hole (bar)	4-10
Drilling operating pressure (bar)	100-190
Dimensions of the drill (mm)	10700x2590x3200
Recommended drilling diameter (mm)	64-115
Drilling angle tolerance	±10°
Max. torque (Nm)	1355
Engine power (kW)	145



3.2 Calculation and selection of drilling and blasting parameters

The selection of optimal drilling and blasting parameters depends on: the physical and mechanical characteristics of the rock in which the blasting is carried out, the required fragmentation, available drilling equipment, spatial location of the place where the blasting is carried out, allowable level of seismic displacement, the requirements in terms of the minimum possible rock mass damage zone outside the excavation line, etc.

3.2.1 Calculation of the specific consumption of explosives

The specific consumption of explosives is a factor that has a significant effect on the determination of the amount of explosives and the number of blast holes for one blasting. It is determined independently of the surface being blasted and the diameter of the hole.
Calculation of the specific consumption of explosives q(kg/m^3) was made according to the empirical formula of Š.I. Ibrajev which reads [3]:

$$q = \frac{\sqrt{f} - a\sqrt{F_i}}{b} \quad (1)$$

Where:
a - is the coefficient ranging from 0.12 to 0.15 for vertical excavations. We adopt a=0.15.

f - is the rock strength coefficient according to Protodyakonov. Based on the geotechnical characteristics of the materials in the construction zone of the Vranduk I bridge, the rock strength coefficient according to Protodyakonov is 8.
F_i - is the surface area being blasted. In our case it is 63.58 (m^2).
b - operating efficiency coefficient of the explosive used (for plastic explosives, this value ranges from 1.2 to 1.4). b=1.25 is adopted.

Substituting the defined parameters in the empirical formula (1), the specific consumption of explosives is calculated as follows:

$$q = \frac{\sqrt{f} - a\sqrt{F_i}}{b} = \frac{\sqrt{8} - 0.15 \cdot \sqrt{63.58}}{1,25} = 1.3\ \left(\frac{kg}{m^3}\right)$$

3.2.2 Selecting the type of explosives

Considering that the work is performed in medium-hard to soft rock materials, and due to the proximity of the main road M-17 and other facilities, plastic explosives (as initial) will be used in combination with ANFO explosives.

RIODIN will be used as the initial explosive, which is filled in Ø60 and Ø40 mm cartridges, while the ANFO explosive that will be used is ELMEKS (bulk or cartridge) and the RIOSPLIT explosive with a diameter of Ø17 mm will be used for contour blasting. Based on the selected type and diameter of the explosives that will be used for blasting the minefield, the diameter of the blast holes of 76mm is adopted.

3.2.3 Determining the required number of blast holes

When constructing a well by blasting, the required number of blast holes can be roughly determined using the following empirical formula [4].

$$N_o = \frac{q \cdot F_i}{p} \tag{2}$$

Where:
q - is the specific consumption of explosives (kg/m^3).
F_i - is the surface area being blasted (m^2).
p - the quantity of explosives per meter of hole (kg/m'). Plastic explosive combined with ANFO in bulk takes a mass of approx. 4.35 (kg/m').

Substituting the defined parameters in the empirical formula (2), the required number of blast holes is calculated as follows:

$$N_o = \frac{q \cdot F_i}{p} = \frac{1.3 \cdot 63.58}{4.35} = 19\ (holes)$$

3.2.4 Determining the line of least resistance

The line of least resistance is roughly calculated using the formula that is a function of the blast hole diameter [5].

$$W = (20 - 40) \cdot d_b \tag{3}$$

A smaller value is adopted for hard-to-crush rocks and when blasting with one free surface, so in our case we have:

$$W = 20 \cdot d_b = 20 \cdot 76 = 1{,}520\ (mm); W = 1.5\ (m)\ is\ adopted$$

3.2.5 Determining the spacing and pattern of blast holes

The pattern of blast holes is determined by the spacing between the holes in a row (a), between the rows of holes (b) and the line of least resistance (W).

The pattern of blast holes is best characterized by the overlap coefficient, which represents the blast hole density coefficient and is calculated by the formula [5]:

$$m = \frac{a}{W} \tag{4}$$

Where:
a - is the spacing between holes in a row (m).
W - is the line of least resistance (m).
m - is the coefficient of overlap (density) of blast holes in a row.

Depending on the resistance of the rock to blasting, the coefficient of overlap (density) of blast holes is adopted within the limits (0.8-1.6). A lower value is adopted for hard-to-crush rocks. For this case, m = 1.20 is adopted, and substituting the defined parameters in formula (4), the spacing between blast holes is calculated as follows:

$$m = \frac{a}{W} \rightarrow a = m \cdot W = 1.2 \cdot 1.5 = 1.8\ (m)$$

The spacing between the rows can be roughly determined using an empirical formula that is a function of the spacing between holes, which is:

$$b = a \cdot 0.87 = 1.8 \cdot 0.87 = 1.56\ (m);\ b = 1.5\ (m)\ is\ adopted \tag{5}$$

3.2.6 Calculation of the length of stemming of blast holes

Appropriate stemming of blast holes is one of the most important prerequisites for blasting to be well performed. The length of stemming refers primarily to the upper part of the borehole when continuously filling blast holes with explosives. Proper closure of blast holes is exceptionally important in order to:

- prevent the loss of explosion gases from the borehole, because the gases break the rock,
- prevent scattering of blasted rock material,
- better control the air impact.

The length of stemming depends to the greatest extent on the diameter of the blast hole and the resistance at the bottom of the floor or rock block being blasted, and is calculated by the formula [6]:

$$l_{\check{c}} = (20 - 40) d_b \tag{6}$$

Where:
d_b - is the borehole diameter (m)

$l_{\check{c}} = (20 - 40) \cdot 76 = 1{,}520 - 3{,}040\ (mm)$; *Stemming with the length 2.5 (m') is adopted*

The obtained necessary parameters for defining the scheme according to which the drilling of the central minefield will be carried out in the process of excavating the foundation for pier site S1L are presented in Table 3.

Table 3. Central minefield drilling data

Parameter	Meas. unit	Quantity
Drilling diameter of blast holes (Φ)	mm	76
Drilling angle of blast holes (α)	°	90
Line of least resistance (W)	m	1.5
Spacing between blast holes (a)	m	1.8
Spacing between rows of blast holes (b)	m	1.5
Number of blast holes (Nb)	pcs	19
Total depth of blast holes (ΣLb)	m	171
Average depth of blast holes	m	9

The layout of mines on the minefield and their spatial position depend on the shape of the surface being mined, the dip of the strata, the general principles of action of explosives, as well as the purpose of the space where the blasting is carried out (minimum degradation of the surrounding rock).

Based on the defined drilling and blasting parameters for the central minefield, and taking into account the requirement to minimize the damage to the rock outside the excavation contour by blasting when excavating the foundation of pier site S1L, the use of the rock presplitting technique was adopted.

A drill bit with the same diameter as when drilling holes for the central minefield 76 mm will be used for drilling. Based on the diameter of the blast holes, the spacing between contour blast holes is recommended to be (0.6-0.9) m. The spacing between the contour blast holes of 0.6m' is adopted.

Table 4. Contour minefield drilling data

Parameter	Meas. unit	Quantity
Drilling diameter of blast holes (Φ)	mm	76
Inclination – drilling angle of blast holes (α)	°	90
Spacing between blast holes (a)	m	0.6
Number of blast holes (Nb)	pcs	46
Total depth of blast holes (ΣLb)	m	414
Average depth of blast holes	m	9

Figure 3 below shows a section of the central minefield blast holes and contour blast holes.

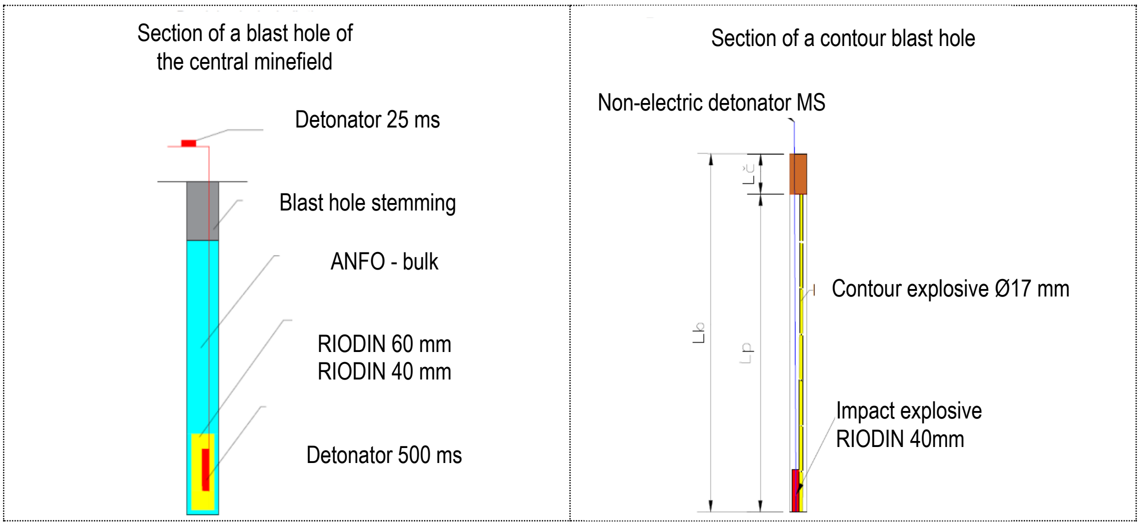


Figure 3. Section of blast holes

3.2.7 Consumption of explosives for blasting

A scheme of the minefield with the layout of all blast holes in the minefield was prepared based on the calculated and adopted parameters of the drilling and blasting works. Taking into account the geometry of the minefield and the depth of the blast holes, a parallel cut with one central borehole (which is not filled with explosives during blasting) with a diameter of 115mm was applied. Figure 4 below shows the pattern of blast holes for the excavation of pier site S1L with indicated all the geometric parameters necessary for drilling and blasting works.

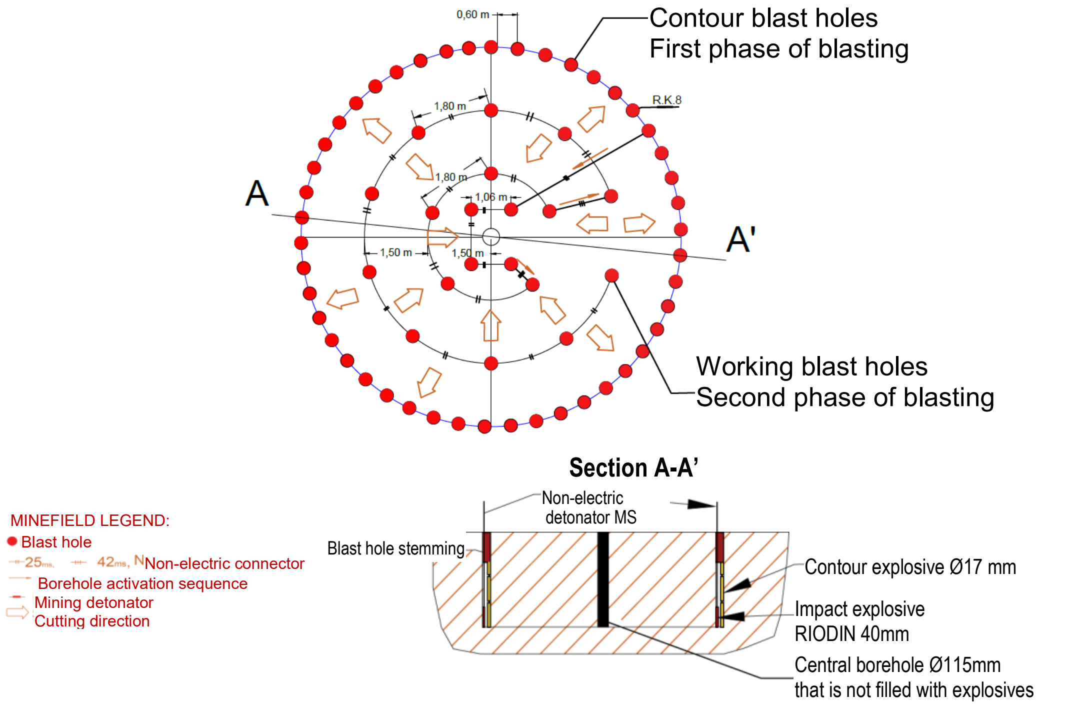


Figure 4. Minefield schemes with the layout of all blast holes in the minefield

Table 5 provides an overview of the necessary total quantities of explosive agents for the excavation of pier site S1L.

Table 5. Necessary quantities of explosive agents for blasting when excavating pier site S1L

Parameter	Meas. unit	Quantity	Total
Commercial explosive RIODIN Φ60 mm	kg	237.50	237.50
ANFO explosive ELMEKS - bulk	kg	380.00	380.00
Commercial explosive RIODIN Φ40 mm	kg	32.844	32.844
Contour explosive Riosplit Φ17 mm	kg	93.38	93.38
DUAL Detonators 25/500 ms (12 m)	pcs	19.0	19.0
Connectors DETINEL 42 ms (4.8 m)	pcs	17.0	17
Blasting cap no. 8	pcs	2.0	2.0
Safety fuse to activate the minefield	m	2.0	2.0
Non-electric detonator Detinel LP	pcs	46.0	46.0

Figure 5 shows the minefield during the process of filling the blast holes when excavating the pier site S1L.

Figure 5. View of the minefield during the filling of the blast holes

Tables 6 and 7 below provide a detailed overview of the consumption of explosive agents for each blast hole after blasting was carried out.

Table 6. Consumed quantities of explosive agents, central minefield

Blast hole number	Drilling diameter (mm)	Depth (m)	B. h. stemming length (m)	Explosive charge			Initiating agents	
				ANFO - bulk (kg)	Riodin Ø60	Total explosives (kg/hole)	DUAL Detonators (25/500) - 12	Connectors 42 ms - 4.8 m
1	82	9	2.5	20	12.5	32.5	1	
2	82	9	2.5	20	12.5	32.5	1	
3	82	9	2.5	20	12.5	32.5	1	
4	82	9	2.5	20	12.5	32.5	1	
5	82	9	2.5	20	12.5	32.5	1	
6	82	9	2.5	20	12.5	32.5	1	
7	82	9	2.5	20	12.5	32.5	1	
8	82	9	2.5	20	12.5	32.5	1	
9	82	9	2.5	20	12.5	32.5	1	
10	82	9	2.5	20	12.5	32.5	1	
11	82	9	2.5	20	12.5	32.5	1	
12	82	9	2.5	20	12.5	32.5	1	
13	82	9	2.5	20	12.5	32.5	1	
14	82	9	2.5	20	12.5	32.5	1	
15	82	9	2.5	20	12.5	32.5	1	
16	82	9	2.5	20	12.5	32.5	1	
17	82	9	2.5	20	12.5	32.5	1	
18	82	9	2.5	20	12.5	32.5	1	
19	82	9	2.5	20	12.5	32.5	1	
Total:		171	47.5	380	237.5	617.5	19	3

Table 7. Consumed quantities of explosive agents, contour blast holes

Blast hole number	Drilling diameter (mm)	Depth (m)	B. h. stemming length (m)	Explosive charge			Initiating agents	
				Riosplit Ø17 mm (kg)	Riodin Ø40 mm (kg)	Total explosives (kg/hole)	Detinel LP 4.8m	Non-electric connector 42 ms L=4.8m
1	82	9.00	2.50	2.03	0.7140	2.75	1	
2	82	9.00	2.50	2.03	0.7140	2.75	1	
3	82	9.00	2.50	2.03	0.7140	2.75	1	
4	82	9.00	2.50	2.03	0.7140	2.75	1	
5	82	9.00	2.50	2.03	0.7140	2.75	1	
6	82	9.00	2.50	2.03	0.7140	2.75	1	
7	82	9.00	2.50	2.03	0.7140	2.75	1	
8	82	9.00	2.50	2.03	0.7140	2.75	1	
9	82	9.00	2.50	2.03	0.7140	2.75	1	
10	82	9.00	2.50	2.03	0.7140	2.75	1	
11	82	9.00	2.50	2.03	0.7140	2.75	1	
12	82	9.00	2.50	2.03	0.7140	2.75	1	
13	82	9.00	2.50	2.03	0.7140	2.75	1	
14	82	9.00	2.50	2.03	0.7140	2.75	1	
15	82	9.00	2.50	2.03	0.7140	2.75	1	
16	82	9.00	2.50	2.03	0.7140	2.75	1	
17	82	9.00	2.50	2.03	0.7140	2.75	1	
18	82	9.00	2.50	2.03	0.7140	2.75	1	
19	82	9.00	2.50	2.03	0.7140	2.75	1	
20	82	9.00	2.50	2.03	0.7140	2.75	1	
21	82	9.00	2.50	2.03	0.7140	2.75	1	
22	82	9.00	2.50	2.03	0.7140	2.75	1	
23	82	9.00	2.50	2.03	0.7140	2.75	1	
24	82	9.00	2.50	2.03	0.7140	2.75	1	
25	82	9.00	2.50	2.03	0.7140	2.75	1	
26	82	9.00	2.50	2.03	0.7140	2.75	1	
27	82	9.00	2.50	2.03	0.7140	2.75	1	
28	82	9.00	2.50	2.03	0.7140	2.75	1	
29	82	9.00	2.50	2.03	0.7140	2.75	1	
30	82	9.00	2.50	2.03	0.7140	2.75	1	
31	82	9.00	2.50	2.03	0.7140	2.75	1	
32	82	9.00	2.50	2.03	0.7140	2.75	1	
33	82	9.00	2.50	2.03	0.7140	2.75	1	
34	82	9.00	2.50	2.03	0.7140	2.75	1	
35	82	9.00	2.50	2.03	0.7140	2.75	1	
36	82	9.00	2.50	2.03	0.7140	2.75	1	
37	82	9.00	2.50	2.03	0.7140	2.75	1	
38	82	9.00	2.50	2.03	0.7140	2.75	1	
39	82	9.00	2.50	2.03	0.7140	2.75	1	
40	82	9.00	2.50	2.03	0.7140	2.75	1	
41	82	9.00	2.50	2.03	0.7140	2.75	1	
42	82	9.00	2.50	2.03	0.7140	2.75	1	
43	82	9.00	2.50	2.03	0.7140	2.75	1	
44	82	9.00	2.50	2.03	0.7140	2.75	1	
45	82	9.00	2.50	2.03	0.7140	2.75	1	
46	82	9.00	2.50	2.03	0.7140	2.75	1	
Total:		414	115	93.38	32.844	126.5	46	14

4. SELECTION OF DRILLING AND BLASTING PARAMETERS FOR THE EXECUTION OF CONTROLLED BLASTING DURING THE EXCAVATION OF THE FOUNDATION OF PIER SITE S1D

Excavation of pier site S1D cannot be carried out with the same equipment and in the same way as excavation of pier site S1L was done. The pier site S1D is located in the immediate slope of the side cut towards the main road M-17. The spatial position of pier site S1D in relation to the main road M-17 is shown in Figure 6.

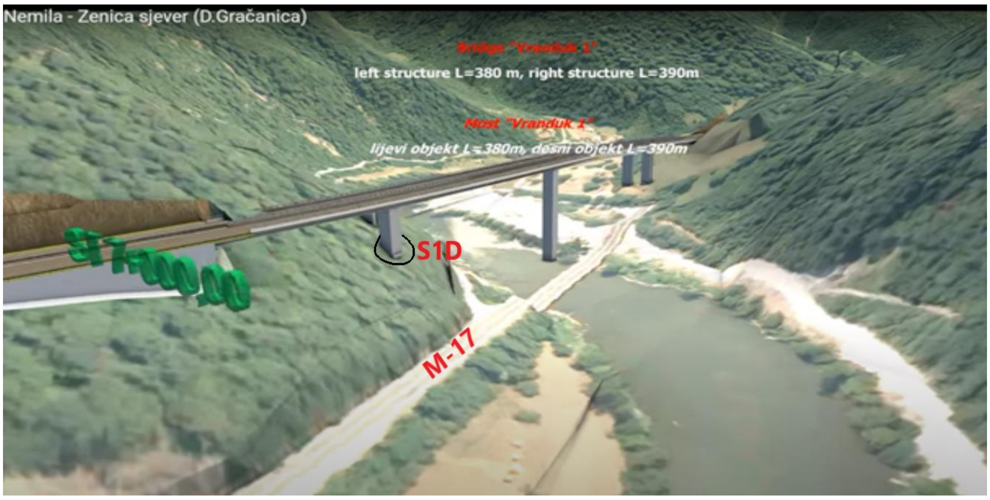


Figure 6. View of the spatial position of pier site S1D in relation to the main road M-17

Due to the very small layer of material in the part of the slope towards the main road M-17, it is not possible to excavate the pier site with a single blasting with approx. 9 m deep blast holes without damaging the surrounding rock outside the excavation line. For this reason, it was decided to carry out the excavation of pier site S1D in phases. In the first phase, using a hydraulic excavator with a hammer, the decomposed (surface) layer of the terrain will be removed from the surface where the excavation of pier site S1D will be carried out. After that, the excavated depth will be protected (reinforced and concreted) with the help of a hydraulic excavator. In the next phase, the excavation will continue with drilling and blasting works to the required depth. Figure 7 below shows the first phase of the works.

Figure 7. View of the first phase of the works during the excavation of pier site S1D

4.1 Selection of equipment for drilling blast holes when excavating pier site S1D

Taking into account the above, the drilling of blast holes will be performed using a pneumatic hammer with pusher leg YT29 or some other rock drill with similar technical characteristics to the specified one. The lengths of the bits will be adapted to the depths of the blast holes. The appearance and technical data of the rock drill are given in Table 8.

Table 8. Appearance and technical data of the rock drill

Manufacturer, type	Atlas Copco, YT29A	
Mass	27 kg	
Dimensions (LxWxH)	659x248x205 mm	
Cylinder diameter	82 mm	
Piston stroke	60 mm	
Operating pressure	(4-6.3) bar	
Impact energy (at 5 bar)	≥70 J	
Air consumption (at 5 bar)	≤ 65 l/s	
Impact frequency (at 5 bar)	≥ 37 Hz	
Water pressure	(Operating pressure – 1) bar	
Inner diameter of air tube	25 mm	
Drilling diameter	(32 - 45) mm	
Max. drilling depth	5 m	
Operating temperature	(-35 to +45) °C	
Bit grip	H22/25 x 108	

4.2 Defining drilling and blasting parameters

The selection of optimal drilling and blasting parameters was made on the basis of the available equipment for drilling blast holes, the spatial location of the place where the blasting is carried out, as well as the requirements regarding the minimum possible damage zone of the rock mass outside the excavation line.

Bearing in mind the selected equipment for drilling blast holes, with which precise parameters of the geometry (inclination and parallelism) of the boreholes cannot be achieved, application of standard cuts in this particular case would not be effective. The adopted drilling depth for blast holes in one step is approx. 1.6 m', and the blast hole drilling diameter is 40 mm.

Based on the stated facts, selection of explosives for blasting, and taking into account the theory of the effect of a mine explosion in an unlimited solid environment, a scheme with the pattern of blast holes in the minefield was made. The layout scheme of blast holes in the minefield is shown in Figure 8 below.

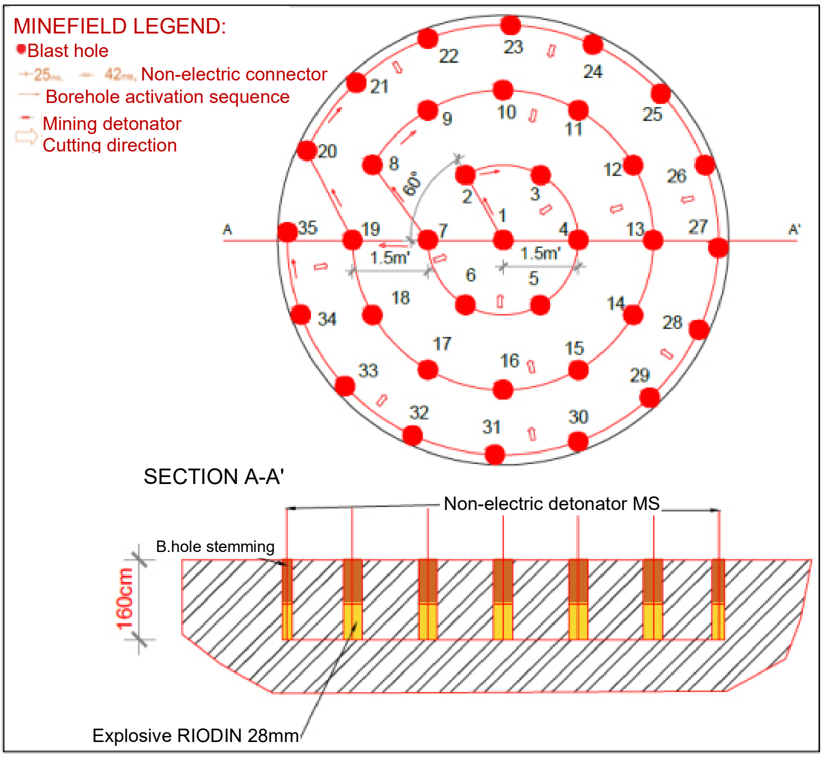


Figure 8. The layout scheme of all blast holes in the minefield

Upon completion of the first phase of the excavation of pier site S1D, protection of the excavated part (reinforcement and concreting) was carried out, so that the excavation was continued with drilling and blasting works. Figure 9 below shows the method of drilling blast holes according to the previously defined scheme (Figure 8).

Figure 9. Drilling of blast holes

4.3 Minefield drilling data

All the minefield data, which are shown in Table 9, were obtained based on the defined scheme (Figure 8), according to which the minefield was drilled for the excavation of the foundation for pier site S1D.

Table 9. Central minefield drilling data

Parameter	Meas. unit	Quantity
Drilling diameter of blast holes (Φ)	mm	40
Inclination – drilling angle of blast holes (α)	°	90
Spacing between blast holes (a)	m	1.5
Spacing between rows of blast holes (b)	m	2-3
Number of blast holes (Nb)	pcs	35
Total depth of blast holes (ΣLb)	m	56
Average depth of blast holes	m	1.6

4.4 Planned consumption of explosives for blasting

Table 10 provides an overview of the selected type of explosives, as well as the planned consumption of explosive agents for blasting per one excavation step. These parameters are defined on the basis of the selected drilling scheme for the minefield (Figure 8), the diameter of the blast holes, as well as the geology of the rock mass.

Table 10. Necessary quantities of explosive agents per step for blasting during the excavation of pier site S1D

Parameter	Meas. unit	Quantity	Total
Commercial explosive RIODIN Φ28 mm	kg	21.0	21.0
DUAL Detonators 25/500 ms (4.8 m)	pcs	35.0	35.00
Blasting cap no. 8	pcs	2.0	2.0
Safety fuse to activate the minefield	m	2.0	2.0

Figures 10 and 11 show the minefield during the excavation of pier site S1D before activating the blast holes filled with defined explosives (Table 10), while Figure 12 shows the minefield after the blasting was carried out.

Figure 10. Minefield before activation

Figure 11. Minefield ready to be act.

Figure 12. View of the minefield after blasting

Table 11 below gives an overview of the consumed explosive agents for all blast holes during the excavation of one step.

Figure 13 below shows the constructed piers S1D and S1L of the Vranduk I bridge on the route of the designed motorway section Zenica Municipality Northern Administrative Boundary (Nemila) - Zenica North (Donja Gračanica).

Figure 13. View of the constructed piers S1D and S1L on the Vranduk I bridge

Table 11. Table of consumption of explosive agents for blast holes during the excavation of one step

Blast hole number	Drilling diameter (mm)	Depth (m)	B. h. stemming length (m)	Explosive charge		Initiating agents
				Riodin Ø28 mm (kg)	Total explosives (kg/hole)	DUAL Detonator (25/500) 4.8m
1	40	1.6	0.88	0.6	0.6	1
2	40	1.6	0.88	0.6	0.6	1
3	40	1.6	0.88	0.6	0.6	1
4	40	1.6	0.88	0.6	0.6	1
5	40	1.6	0.88	0.6	0.6	1
6	40	1.6	0.88	0.6	0.6	1
7	40	1.6	0.88	0.6	0.6	1
8	40	1.6	0.88	0.6	0.6	1
9	40	1.6	0.88	0.6	0.6	1
10	40	1.6	0.88	0.6	0.6	1
11	40	1.6	0.88	0.6	0.6	1
12	40	1.6	0.88	0.6	0.6	1
13	40	1.6	0.88	0.6	0.6	1
14	40	1.6	0.88	0.6	0.6	1
15	40	1.6	0.88	0.6	0.6	1
16	40	1.6	0.88	0.6	0.6	1
17	40	1.6	0.88	0.6	0.6	1
18	40	1.6	0.88	0.6	0.6	1
19	40	1.6	0.88	0.6	0.6	1
20	40	1.6	0.88	0.6	0.6	1
21	40	1.6	0.88	0.6	0.6	1
22	40	1.6	0.88	0.6	0.6	1
23	40	1.6	0.88	0.6	0.6	1
24	40	1.6	0.88	0.6	0.6	1
25	40	1.6	0.88	0.6	0.6	1
26	40	1.6	0.88	0.6	0.6	1
27	40	1.6	0.88	0.6	0.6	1
28	40	1.6	0.88	0.6	0.6	1
29	40	1.6	0.88	0.6	0.6	1
30	40	1.6	0.88	0.6	0.6	1
31	40	1.6	0.88	0.6	0.6	1
32	40	1.6	0.88	0.6	0.6	1
33	40	1.6	0.88	0.6	0.6	1
34	40	1.6	0.88	0.6	0.6	1
35	40	1.6	0.88	0.6	0.6	1
Total:		56	30.8	21	21	35

5. CONCLUSION

Excavations in rocks of different strengths, as well as excavations in demanding locations, involve the use of appropriate blasting techniques. These techniques also reduce the seismic effects of explosions, reduce overbreaks and enable better utilization of blast holes. In order to achieve all of the above, it is necessary to determine the optimal values of drilling and blasting works for each excavation performed by blasting and to make a detailed blasting scheme.

The main task of any excavation is to choose the appropriate blasting method, depending on the geotechnical conditions, while taking into account all technical parameters. The effect of blasting depends to the greatest extent on the layout of blast holes in the minefield. Similarly, the desired blast hole loading sequences can be obtained using the blasting scheme.

By correctly choosing the equipment for drilling blast holes, defining the drilling and blasting parameters and excavation steps, a minimal zone of damage to the surrounding rock outside the line of excavation of pier sites S1R and S1L of the Vranduk I bridge, which is inevitable during blasting excavation, has been achieved, which has the effect of preserving the bearing capacity of the rock mass as the most important supporting element.

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