Rudarsko-geološko-naftni zbornik	Vol. 17	str. 37-45	Zagreb, 2005.

UDC 624.19.622.236:69.08

Preliminary communication
Prethodno priopćenje

Language/Jezik:*English/Engleski*

ORGANIZATIONAL-TECHNOLOGICAL CHARACTERISTICS OF BLASTING WORKS ON THE GRIČ TUNNEL

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Key words: drilling, blasting, blast hole diameter, hole length, explosive quantity, contour blasting, cut, working

Abstract

The paper describes organisational-technological characteristics of blasting works during the excavation of the Grič Tunnel. The significance of blasting works during the excavation of the tunnel is shown through adjustment of blasting parameters taking into consideration the dynamics of the works, cost-effectiveness and in uence of geological circumstances. Successfulness of blasting directly in uences the subsequent tunnel excavation cycle both in terms of duration as well as eventually in terms of in uence on the entire tunnel investment. Comparison of changes of basic blasting parameters during tunnel excavation ensured optimal excavation progress with minimal price per meter of tunnel progress.

Ključne riječi: bušenje, miniranje, promjer minske bušotine, duljina bošotine, količina eksploziva, konturno miniranje, zalom, radni ciklus

Sažetak

U radu su prikazane tehničko-tehnološke i organizacijske značajke minerskih radova tijekom iskopa tunela Grič. Značaj minerskih radova tijekom iskopa tunela prikazan je prilagodbom parametara miniranja u odnosu na dinamiku radova, ekonomičnost poslovanja i geološke prilike. Uspješnost miniranja direktno utječe na daljnji ciklus iskopa tunela vremenski i u pogledu utjecaja na cjelokupnu investiciju tunela. Promjenama osnovnih parametara miniranja tijekom iskopa tunela, utvrđen je optimalni napredak iskopa uz minimalnu cijenu koštanja jednog metra napredovanja tunela.

Introduction

The Grič Tunnel is located in Section III Bosiljevo – Sv. Rok of the Motorway Zagreb-Split, which is the part of European corridor E-71 which links the central part of Europe with the Mediterranean. The tunnel has two tunnel tubes and each of them has two lanes for each direction of traffic. Looking from north to south, the lengths of tunnel tubes are the following: left tunnel tube 1242 m, right tunnel tube 1259 m → total of 2501 m. Out of which 2439 m represent excavation, more specifically 1211 m in the left tunnel tube and 1228 m in the right tunnel tube. The average surface of the cross section in the course of the excavation amounts to 77 m^2. The tunnel tubes are parallel with 25m axis distance. The maximum height of overburden amounts to 60m. The tunnel excavation in carried out by drilling and blasting in accordance with NATM (New Austrian Tunnelling Method). The dynamics of works on the tunnel excavation was very important for the dynamics of the works on the route of that particular section of the motorway, so the establishment of the construction site communication through the Grič Tunnel achieved significant acceleration in the dynamics and completion of the works on the motorway. The starting point for tunnel excavation is a qualitative and speedily carried out excavation progress phase on which future working cycles depend (installation of primary tunnel support system etc), and the stress is placed on the adjustment of the blasting schemes under dynamic circumstances and taking into account cost-effectiveness.

Geology

The terrain for excavations is predominantly of lower cretacaus sediments. Primary rock mass is limestone interchanging with post-sediment limestone breccia. On cretacaus sediments of the rock mass of the Grič Tunnel, there is presence of Jelar sediments, consisting of breccia and breccia-conglomerates. Regarding other sediments, there is presence of clay, most commonly in red and red-brown colour, high-plastical and compressed – "terra rossa" – filling carstification widened discontinuities. The whole area is intensely carstificatad, with spreaded karst sinkholes formations filled with clay material on surface. They are manifested in depth as cavernous zones with tectonically intensely crushed rock material. The tunnel route is divided into four geo-technical units. The first geo-technical unit is dominated by post-sediment limestone breccia of medium strength (90 MPa), the second geo-technical unit is dominated by limestone of high strength (120MPa), the third geo-technical unit is equally dominated by limestone and post-sediment limestone breccia of medium strength (95 MPa), while the fourth geo-technical unit is dominated by post-sediment limestone breccia of medium strength (50 MPa). Categorization of the rock mass is based on RMR classification, and it predicted II, III, IV and V categories of rock mass, with dominant Category III (50% of the total tunnel length).

Basic blasting parameters

The blasting parameters were chosen on the basis of predicted engineering-geological profile, geo-technological foundations and empirical data gathered during tunnel excavations in similar geological conditions. Basic blasting parameters which have decisive in uence on blasting effects are the diameters of blasting borehole and explosive charge, length of drilling, number of holes, the line of least resistence-burden as well as type of explosives and initiation devices. All above-mentioned parameters were determined taking into account physical-mechanical and structural-geological characteristics of the rock mass, technical conditions (the type of drilling machine), surface of the cross section of the tunnel excavation which was determined by the original project design, organisational conditions which ensure minimum works and minimum price per metre of tunnel as well as optimal connection of all operations into one cycle. The diameter of the blasting hole and explosive charge, the type of explosives and initiation devices were chosen on the basis of efficiency in given conditions of excavation, safety criteria and the price and as such they remain unchangeable blasting parameters for the excavation of the Grič Tunnel. The diameter of blasting holes which was chosen is 45 mm, as well as patroned emulsion explosive Austrogel G1, Lambrex 1, Lambrex 2 and electric initiation devices. Table 1 shows the characteristics of unchangeable blasting parameters. Explosive charges of helping holes and cut holes contain explosive Austrogel G1 and Lambrex 1, while explosive charges of contour holes contain explosives Austrogel G1 and Lambrex 2.

Tunnel drilling machine Atlas Copco 353 ES with three drill hands and one hand with platform was used for drilling of blasting holes. Changeable blasting parameters are length of drilling, number of holes, burden. For the purposes of the analysis of the adjustment of the blasting schemes probability of presence of certain categories of rock mass and the duration of excavation working cycle in predominant category III of rock mass were taken into account, while the quality of blasting throughout the whole tunnel excavation was analysed as well.

The number of blasting holes is the same in the mentioned rock mass categories and it amounts to 145, while the length of drilling and progress phase are changeable, because they depend on the rock mass category, which also affects the change of the quantity of explosive charge per hole as well as in total per cycle of blasting. The ratio of mutual distance between contour holes and burden amounts to 0.95.

Table 1 Characteristics of explosives and initiation devices

Tablica 1. Značajke eksploziva i inicijalnih sredstava

Explosive	d [mm]	l [mm]	m [kg]	v (m/s)
Lambrex 1	Ø 37	700	0,833	5600
Lambrex 2 contour	Ø 25	700	0,625	4200
Austrogel G1	Ø 30	350	0,347	6000
Electric detonators: Schaf er				
Moment detonators		TED-BRWP 2x4 m		
Millisecond detonators		80 ms 500MIZP 2x5 m/Cu		

*manufactured data / tvornički podaci

Initial blasting scheme

The initial blasting scheme, shown on Figure 1 is based on empirical data gathered during excavations in other tunnels under the same or similar geological conditions.

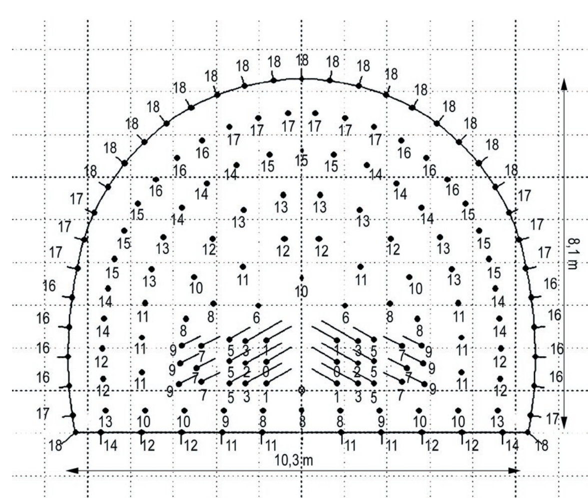

Table 2 Main parameters of blast field-scheme 145

Tablica 2. Glavni parametri minskoga polja-shema 145

Table 2 shows the main parameters of blast field for initial blasting scheme (scheme 145). Figure 2 shows geometrical characteristics of the cut for scheme 145. The number of cut holes is 30 with concentration of explosive charge of 2.846 kg/hole, while the angle of the cut ranges between 60° to 85°. The total length of drilled blasting holes is 478.5 m for category II, 406 m for category III and 333.5 for category IV of the rock mass. The average consumption of explosives amounts to 1.37 kg/m^3 III category, and 1.63 kg/m^3 for category II and IV of the rock mass.

Table 2 Main parameters of blast field-scheme 145

Tablica 2. Glavni parametri minskoga polja-shema 145

Scheme 145	II category	III category	IV category
Number of blast holes	145	145	145
Cut	V	V	V
Holes length [m]	3,3	2,8	2,3
Advance [m]	3,0	2,5	2,0
Tunnel face surface [m^2]	77	77	77
Diameter of blasting hole [mm]	45	45	45
Initiation	electric	electric	electric
Number of ignition level	18	18	18
Retardation between level [ms]	80	80	80
Total blasting time [ms]	1440	1440	1440
Summary explosive mass [kg]	368	317	260

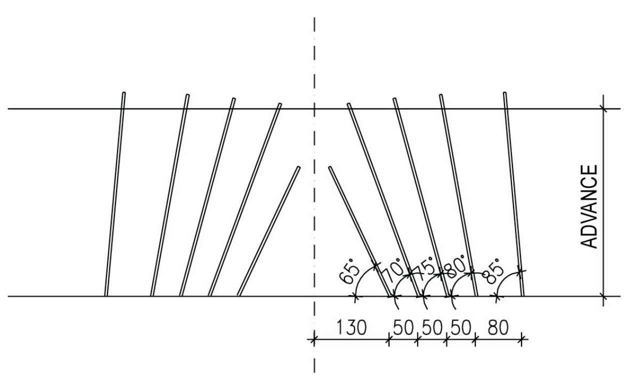

Figure 2 Geometry of cut-scheme 145

Slika 2. Geometrija zaloma-shema 145

Adjusted blasting schemes

The blasting scheme has been adjusted through analysis of the initial blasting scheme in the course of the initial phase of tunnel excavation and through inspection of the realistic state of the rock mass taking into consideration the expected characteristics of the substance in which the tunnel excavation is being performed. The initial blasting scheme had produced good blasting results, but it was concluded that the changes of the drilling length and greater progress rate could result in better dynamics of the work as well as in more qualitative blasting. The adjusted blasting schemes were created through meticulous and detailed monitoring of in situ conditions on the excavation working face. As a result of such monitoring three adjusted blasting schemes were accepted. Those schemes are scheme 131, shown in Figure 3 and Table 3, scheme 113, shown in Figure 5 and Table 4, as well as schemes 92 and 50, shown in Figures 7 and 9 and Tables 5 and 6.

The progress rate in the adjusted blasting schemes remained the same for category II, while it was increased for categories III and IV of the rock mass compared to the initial blasting scheme.

The blasting scheme with 131 blasting holes (Figure 3) was created as the adjustment taking into consideration the characteristics of the rock mass in geo-technical unit 2 of the predicted engineering geo-technical profile that is 200 m long. In accordance with the assumptions for that geo-technical zone presence of limestone of high strength was expected, as well as category II of the rock mass in the greatest part of the zone.

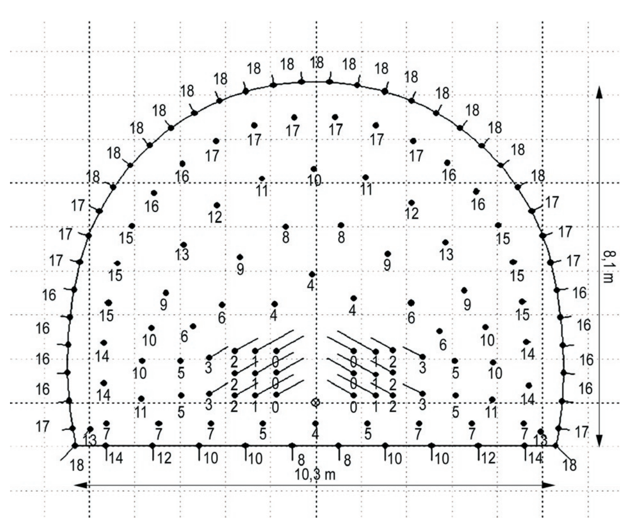

Figure 3 Blasting scheme with 131 blasting holes

Slika 3. Shema miniranja sa 131 minskom bušotinom

The total length of drilled blasting holes is 432.3m for II and III, and 301.3m for IV category of the rock mass. The average consumption of explosives is 1.45 kg/m^3. The number of conical cut holes is 22 with concentration of explosive charge of 2.846 kg/hole, and the angle of the cut ranges from 75° to 80°. The ratio of mutual distance between contour holes and burden is 0.7. Figure 4 shows geometrical characteristics of the cut for scheme 131.

Table 3 Main parameters of blast field-scheme 131

Tablica 3. Glavni parametri minskoga polja-shema 131

Scheme 131	II, III category	IV category
Number of blast holes	131	131
Cut	V	V
Holes length [m]	3,3	2,3
Advance [m]	3,0	2,0
Tunnel face surface [m^2]	77	77
Diameter of blasting hole [mm]	45	45
Initiation	electric	electric
Number of ignition level	18	18
Retardation between level [ms]	80	80
Total blasting time [ms]	1440	1440
Summary explosive mass [kg]	328	232

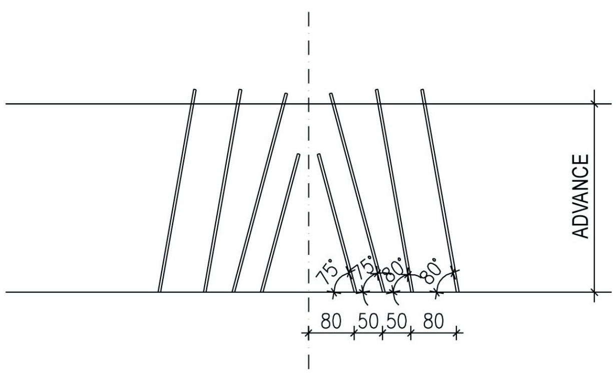

Figure 4 Geometry of cut-scheme 131

Slika 4. Geometrija zaloma-shema 131

Taking into consideration predominant category III of the rock mass, the appropriate blasting scheme with 113 blasting holes (Figure 5) was chosen. The total length of drilled blasting holes is 372.9 m for categories II and III and 259.9 for category IV of the rock mass. Average consumption of explosives is 1.24 kg/m^3. The number of conical cut holes is 25 with concentration of explosive charge of 2.846 kg/hole, and the angle of the cut ranges from 65° to 85°. The ratio of mutual distance between contour holes and burden is 0.8. Figure 6 shows geometrical characteristics of the cut for scheme 113.

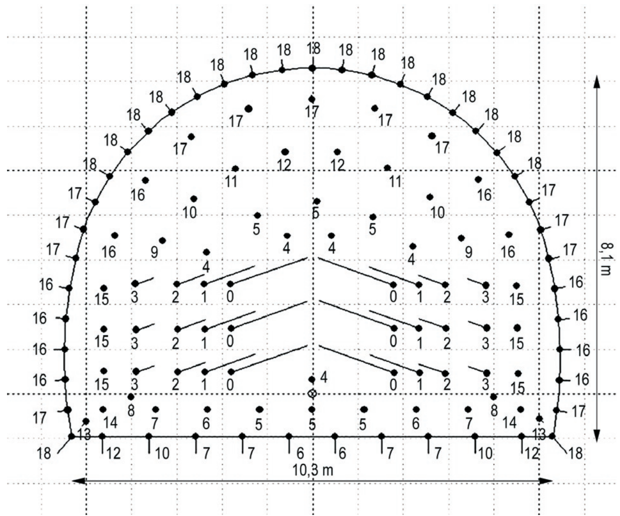

Figure 5 Blasting scheme with 113 blasting holes

Slika 5. Shema miniranja sa 113 minskih bušotina

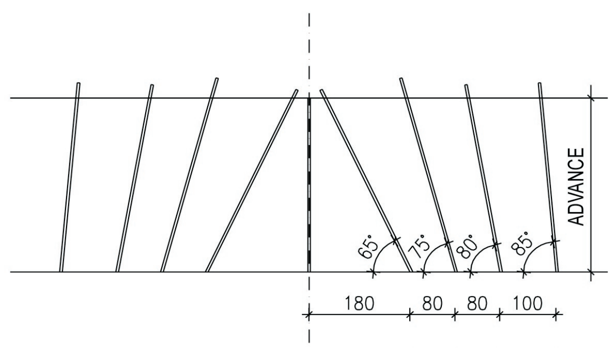

Figure 6 Geometry of cut-scheme 113

Slika 6. Geometrija zaloma-shema 113

Table 4 Main parameters of blast field-scheme 113

Tablica 4. Glavni parametri minskoga polja-shema 113

Scheme 113	II, III category	IV category
Number of blast holes	113	113
Cut	V	V
Holes length [m]	3,3	2,3
Advance [m]	3,0	2,0
Tunnel face surface [m^2]	77	77
Diameter of blasting hole [mm]	45	45
Initiation	electric	electric
Number of ignition level	18	18
Retardation between level [ms]	80	80
Total blasting time [ms]	1440	1440
Summary explosive mass [kg]	280	198

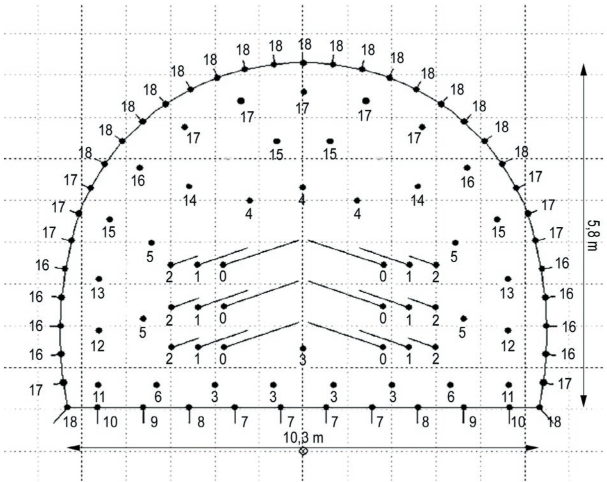

Figure 7 Blasting scheme-first phase of excavation-scheme 92

Slika 7. Shema miniranja-prve faze iskopa-shema 92

Table 5 Main parameters of blast field-first phase of excavation

Tablica 5. Glavni parametri minskoga polja-prva faza iskopa

Scheme 92	II, III category	IV category
Number of blast holes	92	92
Cut	V	V
Holes length [m]	3,3	2,3
Advance [m]	3,0	2,0
Tunnel face surface [m²]	53	53
Diameter of blasting hole [mm]	45	45
Initiation	electric	electric
Number of ignition level	18	18
Retardation between level [ms]	80	80
Total blasting time [ms]	1440	1440
Summary explosive mass [kg]	226	160

Blasting schemes with 92 (Figure 7) and 50 blasting holes (Figure 9) were adjusted to two-phase excavation that also requires different organisation of operations. The blasting scheme with 92 blasting holes was adjusted to the top heading. The total length of drilled blasting holes is 303.6 m for categories II and III of the rock mass, and 211.6 m for category IV of the rock mass. The number of conical cut holes is 19 with concentration of explosive charge of 2.846 kg/hole, and the angle of the cut ranges from 70° to 85°. The ratio of the distance between contour holes and burden is 0.8. Figure 8 shows geometrical characteristics of the cut for scheme 92.

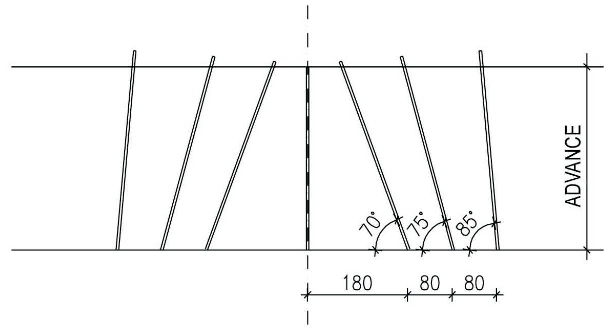

Figure 8 Geometry of cut-scheme 92

Slika 8. Geometrija zaloma -shema 92

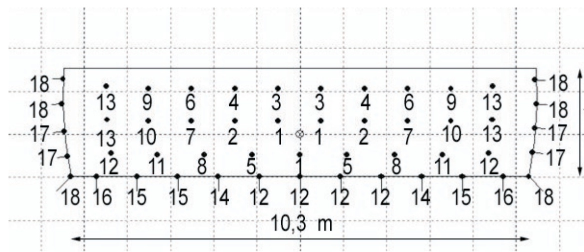

Figure 9 Blasting scheme-second phase of excavation

Slika 9. Shema miniranja druge faze iskopa

Table 6 Main parameters of blast field- second phase of excavation

Tablica 6. Glavni parametri minskog polja druga faza iskopa

Scheme 50	II,III, IV category
Number of blast holes	50
Holes length [m]	4,3
Advance [m]	4,0
Tunnel face surface [m²]	24
Diameter of blasting hole [mm]	45
Initiation	electric
Number of ignition level	18
Retardation between level [ms]	80
Total blasting time [ms]	1440
Summary explosive mass [kg]	172

The blasting scheme with 50 blasting holes was adjusted to the bench. The total length of drilled blasting holes is 215m for categories II, III, IV of the rock mass. The two-phase excavation and corresponding blasting method were created as the adjustment to the small overburden of the tunnel, taking into account the possibility of presence of Jelar sediments which represent potential danger for sudden change of geological conditions in the course of the excavation, but also in order to have a simpler method of installation of more massive primary tunnel support system due to unfavourable geological conditions or possible presence of caverns. This method of excavation was applied throughout most of the length of the left tunnel tube (75% of the total length of excavation of the left tunnel tube).

Measurement of working cycle

From the point of view of dynamics the change of the blasting scheme in uences the duration of excavation working cycle. For every above mentioned blasting scheme of full face excavation the duration of working cycle of the technological phase of drilling and blasting is shown for category III of the rock mass which, according to the predicted engineering-geological profile, was the dominant category of the rock mass and which was proven true during the works. The further phase of the works in the tunnel, such as installation of the primary tunnel support system and similar were not taken into account for the monitoring of the cycle. The blasting of the working face of the Grič Tunnel is carried out by patroned explosives and electric initiation devices. Charging is carried out simultaneously with drilling of blasting holes, however, two rows of empty holes are left between the charged and drilled holes because of safety reasons. Charging is carried out from the bottom of the tunnel and from the platform of the tunnel drill. After the completion of drilling an additional platform is introduced, so that two platforms as well as charging from the bottom are participating in the works. The time of charging and network building reduced to one 3.3 m long blasting hole is less than a minute, that is, 55 s. The time of charging of one kilogram of explosives is 22s. Overlapping, that is, simultaneous performance of operations brings significant time saving. The possibility of such working method depends on organisation of performance of individual technological operations, available equipment and machines as well as competence and experience of employees. During simultaneous performance of individual operations, special attention should be dedicated to safety of staff and equipment in order to avoid accidents due to the speed of progress of the works. During tunnel excavation, work is organized 24 hours a day in two shifts and each shift has a working team consisting of 7 employees. The working cycle is divided into 4 operations. Operation number 1 consists of placing tunnel drill at the working face of the construction site, electrification, stabilization of the machine and positioning of drill hands and its duration is 15 minutes for all blasting schemes. Operation number 2 includes effective time of drilling and adjustments of drill hands in the course of drilling. Operation number 3 includes time of preparation, charging of blasting holes with explosive charges and establishing network structure of the blast field. Operation number 4 includes the duration of detonation of the blast field, ventilation and inspection of the working face of the tunnel site where the detonation had occurred and its duration is 45 minutes for all blasting schemes. The duration of operations number 1 and 2 is included in the total duration of the working cycle according to specific blasting schemes, while for every blasting scheme operations number 3 and 4 are of changeable duration. Table 7 shows duration of the working cycle according to specific blasting schemes for full phase excavation in category III of the rock mass, and Table 8 for two-phase excavation in category III of the rock mass.

Table 7 Working-cycle duration for full face excavation

Tablica 7. Vremensko trajanje radnog ciklusa za puni profil iskopa

Operation No.	Description	Duration		
		Category III		
		Scheme 145	Scheme 131	Scheme 113
2	Drilling blasting holes	2h 40min	2h 25min	2h 5min
3	Charging blasting holes	2h 15min	2h	1h 40min
Totally duration		5h 55min	5h 25min	4h 40min

Table 8 Working-cycle duration for two phases excavation

Tablica 8. Vremensko trajanje radnog ciklusa za dvofazni iskopa

Operation No.	Description	Duration	
		Category III	
		Scheme 92	Scheme 50
2	Drilling blasting holes	1h 25min	1h 15min
3	Charging blasting holes	1h 20min	1h
Totally duration		3h 45min	3h 15min

Results of adjustment of the blasting schemes

Dynamics of the works

The results of the adjustment of the blasting scheme were analysed through dynamics of the works on full-face excavation on 120m long pattern of category III of the rock mass. Two-phase excavation was also compared on 120m long pattern of category III with blasting scheme

113 for full-face excavation. The tunnel excavation was carried out from the northern towards the southern end. According to the initial blasting scheme 43 progress phases are needed for excavation of 120m of category III. With the adjusted blasting scheme with 113 blasting holes 40 progress phases are needed. It is normal that working cycles are shorter in case of blasting schemes with fewer holes and with the same number of progress phases. Figure 10 shows time saving in the working cycle on 120m long pattern of category III. In comparison with the blasting scheme with 113 and 145 blast holes time saving is 45 minutes per progress phase. For 120m top heading excavation of category III 40 progress phases are needed, while 30 progress phases are needed for bench excavation. Comparing two-phase excavation and full-face excavation it can be concluded that in the very working cycling of drilling and blasting two-phase excavation does not have dynamic advantage, but this is greatly compensated by shortening other operations of the tunnel excavation. Especially because during top heading the advance of the excavation working face is 150m and only then the bench starts. Therefore the comparison of full-face and two-phase excavation should be done by comparing top heading and full face, and in that case two-phase excavation is more advantageous. Thanks to continuous monitoring of geological and geo-technical circumstances and through adjustment of blasting parameters in accordance with that monitoring, the dynamics of the works has achieved the planned desired effect and the excavation of the left tunnel tube was completed after 204 days, that is, with average progress of 6m/day, while the excavation of the right tunnel tube was completed after 206 days, that is, with average progress of 6m/day.

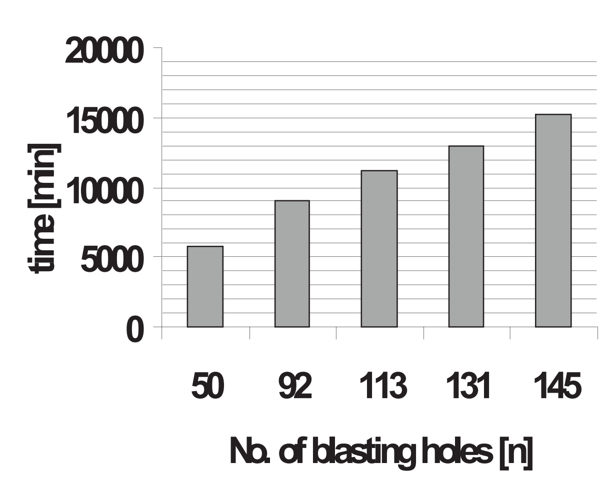

Figure 10 Working cycle-time saving

Slika 10. Radni ciklus-vremenska ušteda

Quality of blasting

Figure 11 shows average consumption of explosives for specific blasting schemes. The figure indicates that the consumption of explosives per progress phase was adjusted to the optimal values for given conditions of the excavation through adjustment of the blasting parameters, with the result of rock mass cracking in the surrounding rock not being so extensive. The concentration of the explosive charge amounted to 75% of the total hole length for cut, helping and bottom holes, while it amounted to 70% of the total hole length for contour holes. It turned out that the ratio of diameter of explosive charge and hole of 0.8 for helping and cut holes and 0.6 for contour holes was appropriate. Through chosen conical cuts it was attempted to use the weakening of the rock mass such as intermediate layer surfaces and fissures, and the chosen angles of cut ranged from 60° to 85° together with adequate number of cut holes. With such chosen parameters of cuts and helping blasting holes complete split of the rock mass is ensured, which is a precondition for the good result of the smooth contour blasting method. Contour blasting holes are initiated as the last series in the blasting cycle. The ratio of mutual distance of contour blasting holes and burden ranging from 0.7 to 0.8 for adjusted blasting schemes turned out to be more qualitative for tunnel excavation contour than the ratio ranging from 0.9 to 1.0 used with initial blasting schemes. Average overbreak excavation achieved satisfactory parameters in comparison to expenses for the performance of tunnel works. The level of fragmentation of the blasted material was favourable for inclusion into the embankment of the motorway, and it did not have to be additionally processed before inclusion in the embankment, which was one of the desired aims. The progress rate for every individual category was adjusted to geo-technical characteristics of the rock mass. At the same time facilitation of future phases of excavation works were taken into account primarily by installing simpler, safer and more qualitative primary tunnel support system and reduced expenses in the construction of the secondary concrete layer. The result of optimum progress has been evidenced the most in the medium overbreak excavation and minimum underbreak excavation, that is, minimum reprofiling and scaling of the tunnel profile. Two-phase excavation reduces the possibility of presence of more extensive overbreak excavations, and the possibility to avoid unforeseen geological circumstances is better, while the installation of the support system is better and more qualitative, progress is faster and blasting is safer. Therefore, the adjusted blasting parameters enabled optimal progress with acceptable price per metre of the tunnel.

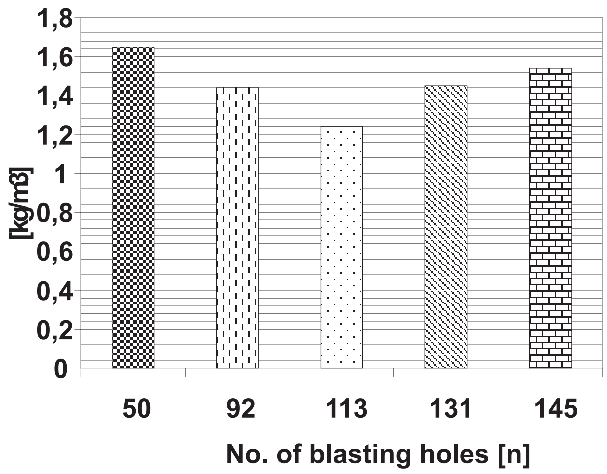

Figure 11 Average consumption of explosives

Slika 11. Prosječna potrošnja eksploziva

Organisational features of blasting works

The fundamental condition for implementation and adjustment of blasting parameters is a solid organisational component which is capable of responding to the requested changes and adjustments during tunnel excavation performance. The quality of tunnel excavation performance, in this case, the quality of blasting works performance, in uences to great extent the price per meter of the tunnel. This is primarily demonstrated in case of tunnel overbreak and underbreak. Overbreak and underbreak result in additional expenses in case of performance of primary and secondary support (installation of greater quantities of shotcrete is needed as well as of tunnel secondary concrete layer support) and cause slowing down of the works dynamics (slowing down of the excavation technological process).

Taking into consideration the fact that performance costs equal performance duration (excavation price per m^3 of the rock mass equals: HRK/m^3= hour/m^3 * HRK/hour), it is in the interest of the contractor to reduce the duration of the performance as much as possible, that is, to achieve the planned dynamics of the works. Preparatory phase is very important in case of tunnel excavation by blasting method in which phase blasting parameters and technical conditions (type of the drilling machine, type of loading-transport units) are defined by taking into consideration physical-mechanical and structural-geological characteristics of the rock mass, while the organisational scheme of the works is adjusted accordingly. The purpose of the organisational component is to harmonize and to adapt as simply as possible for implementation such predefined parameters as the characteristics of the rock mass and project defined excavation profile.

The excavation of the Grič tunnel was carried out from the northern portal towards the southern one. Each tunnel tube was independent from each other in organisational sense, and each tunnel tube had a tunnel drill, loading-transport units, a pump for shotcrete etc.

Adjustment of the blasting scheme and adjustment of the excavation technology- two-phase excavation requires simple organisational solutions that have been envisaged in advance in the preparatory phase. In all adjustments the number of workers per shift remained the same, the number of machines remained the same, but the stress was on operations duration reduction. This was best seen on the example of left tunnel tube excavation in which case the excavation was carried out in two phases almost in its entirety. Comparing two-phase excavation and full phase excavation, it can be concluded that in the very working cycle of drilling and blasting two-phase excavation does not have dynamic advantage (see Figure 10), but this is compensated for considerably by shortening of other operations of the tunnel excavation and also from the general point of view implementation costs are lower. The two-phase excavation reduces the risk of possible unforeseen events to minimum and blasting works performance is of higher quality and safety, which later results in primary support being of higher quality and safety with achievement of planned works dynamics. Optimal organisation of blasting works in case of two-phase excavation achieved optimal effect of entire tunnel excavation working cycle which encompasses not only blasting works but also the subsequent phase of the works such as construction of the primary tunnel support system. Full phase excavation is less complex in organisational sense and in practice it is customary and habitual method of tunnel excavation that has higher risk in terms of quality of the works and in uence on subsequent operations in the cycle.

As was demonstrated in case of the Grič tunnel, the planned dynamics of the works and optimal interconnection of all operations in a cycle can only be ensured by organisational conditions.

Conclusion

Dynamic harmonisation of the blasting parameters does not in uence only the blasting part of excavation, but also the entire working process on the tunnel. The optimal choice of parameters of drilling and blasting achieves appropriate excavation progress rate with optimal dynamics of the works, safety and optimal overbreak excavation. Overbreak excavation is unavoidable in cases of excavation by drilling and blasting, and its extent directly in uences the price per metre of the tunnel. Thorough preparation of the excavation before the beginning of the works is evidenced through selection of explosion devices, technical equipment for carrying out the works in the tunnel and manner in which the works are organized. The selection of devices and equipment for drilling and blasting must be followed by prediction of geological and geo-technical characteristics of the substance in which the excavation is being carried out. In the course of the excavation it is necessary to dynamically harmonize the blasting parameters according to the characteristics of the rock mass and necessary dynamics of the works, while the organisation of the works must ensure that the adjustments in comparison to the initial parameters are as simple as possible and as safe as possible, which will also make them more efficient and which will create conditions for optimal connection of all working phase in one cycle. Firm organisational component with dynamic harmonisation of blasting parameters ensures maximal efficiency of working cycle and minimum price per metre of the tunnel.

Received:15.07.2005.
Accepted:30.09.2005.

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