Global Journal of Engineering and Technology Advances
eISSN: 2582-5003
Cross Ref DOI: 10.30574/gjeta
Journal homepage: https://gjeta.com/

(Research Article)

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Research on the phenomenon of increasing borehole diameter at the installation of rod anchors in marl using wet technology compared to dry drilling procedure

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Global Journal of Engineering and Technology Advances, 2025, 22(02), 001–014

Publication history: Received on 23 December 2024; revised on 31 January 2025; accepted on 02 February 2025

Article DOI: https://doi.org/10.30574/gjeta.2025.22.2.0019

Abstract

The excavation of the "Kobilja Glava" tunnel takes place in a complex geological environment and in a highly urbanized zone with an extremely large number of residential buildings located above both tunnel pipes, as well as in the very close distance of them. More exactly, at the entrance and exit tunnel portals there is a decaying crust whose thickness varies from 3.50 to 6.0 meters. It is an extremely incoherent material that is exposed to significant degradation processes under the influence of atmospheric conditions, which significantly create difficulties while prediction of the actual characteristics of material. Also, the excavation job is being carried out in a substrate that is made of marl, dark gray colour with a distinctly layered structure. For the purposes of this work, exploratory drillholes were drilled using two different technologies. The first implies that the drillholes are made using a wet procedure (flushing of the material from drillhole is done using water under pressure), with the measurement of the diameter of the drillhole at three reference locations inside the drillhole. For this technology the reference value of the drillhole diameter would be achieved by statistical processing. The second technology implied that the drilling of exploratory drillhole was carried with the same equipment, using a dry method (the mud of the material is carried out using compressed air), and that the diameter of the drillhole was recorded in the same way, under identical conditions. The aim of research was to establish how the applied wet drilling method affect to the degradation of the physical-mechanical characteristics of the marl, which has a several chain effects on the construction of the tunnel itself (increasing convergence due to the decreasing the physical-mechanical characteristics of the rock mass, the need for by applying additional supporting elements, increased consumption of injection mixture that results in an increase of negative impact on the environment, etc.)

Keywords: Exploratory drillhole; Increasing the diameter of drillhole; Degradation of marl under the influence of water; Wet drilling process; Dry drilling process

1. Introduction

The rapid development of urban areas in recent decades contributes to increasing needs for using the underground space[1]. Tunnel construction is a demanding interdisciplinary work [2]. Contemporary design and construction of tunnels requires appropriate techniques and technologies in all phases of the tunnel project [3]. Excavation of the tunnel can be considered as the most important working phases due to the series of consequences it can cause [4]. "Kobilja Glava" tunnel is part of the main project of connecting the trans-European road network at the City road named the First transversal in Sarajevo Canton. It is a two-tube tunnel with separate traffic directions, which is located in a close urban

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area where there is a large number of residential and infrastructure facilities. An additional aggravating circumstance during the construction of this tunnel is the fact that it is located very shallowly below the mentioned buildings, so it is an extremely small layer above the tunnel itself. This fact greatly complicates the construction of the tunnel itself, since by disturbing the "natural state of stress" (in-situ stress) that inevitably occurs during tunnel excavation, there is a redistribution of stress accompanied by displacements, which do not only occur at the level of the tunnel excavation and in the immediate vicinity of it, but depending on the type of soil mass in which excavations are carried out, it is transferred to a wider area around the excavation itself. In a situation where the building are located in the immediate vicinity, it is extremely important that during the excavation of the tunnel, all available measures are applied, which will enable the maximum reduction of the above-mentioned impacts on the surrounding soil, and therefore the reduction of potential damage to residential and infrastructure buildings. For this reason, during the construction of “Kobilja Glava” tunnel, research was started with the main goal of determining how the drilling of drillholes for rod anchors using wet process technology, which involves flushing out the material from the drillhole using pressurized water, affects the weakening of the rock material. Of particular interest was the issue of increasing the diameter of the drillhole, which results in a series of unwanted effects during the construction of the tunnel, both from the point of view of additional weakening of the rock mass, and from the point of view of increased consumption of the injection mixture for filling the mentioned drillhole. The geographic location of “Kobilja Glava” tunnel on the route of the Sarajevo-Vogošća road is shown in Figure 1.

Figure 1 Geographical location of “Kobilja Glava” tunnel on the route of the Sarajevo-Vogošća road [1]

2. Research methodology

2.1. Engineering geological characteristics along the route of "Kobilja Glava" tunnel

During the daily mapping of the open faces during the excavation of “Kobilja Glava” tunnel, the established lithological geological structure of the material along the route of the tunnel consisted of surface cover and substrate. Furthermore, it can be stated that two groups can be observed in the surface cover itself, more excitably that are man-made creations-embankment created by the construction of the surrounding residential and infrastructure facilities, and the eluvial-deluvial cover. Both of these groups represent an extremely unfavourable environment for carrying out construction operations. In the geological substratum, two groups are also observed, more exactly, the decaying crust of the geological substratum and the undisturbed geological substratum. The first of these two groups is built from clayey marl materials, and as such is extremely susceptible to various influences, especially the effect of water and moisture from the environment. The undisturbed geological substrate is made of marl, dark gray colour, with a distinct layered structure. Such substrate has significantly better properties than decay crust, but it is still a material that generally has largely uneven physical and mechanical properties, which also significantly depend on exposure to water. The basic characteristic of marl is that with little exposure to external influences, they change their intact properties extremely quickly, i.e. they degrade [5]. Regarding to this, it would be more correct to treat marl as a soft rock mass. According to the RMR classification (Bieniawski's classification) of rock masses, marls at “Kobilja Glava” tunnel construction site can be classified into V and IV categories.

More exactly, in the portal zones, considering the extremely small layer above the tunnel, and the fact that the slope above the tunnel has a slight increase in height, the V category is predicted. But in the zones where the layer above the tunnel is thicker, a more compact rock mass is expected, which was not exposed to the processes of surface decomposition, and therefore has significantly better characteristics, that zone of the tunnel is characterized as category IV rock mass according to the RMR classification. In accordance with the above mentioned, extensive analyses were carried out on the basis of which the zoning of the tunnel itself was carried out, to which the supporting elements recommended for use during tunnel excavation were adjusted. Based on the analyses carried out, both tunnel pipes were divided into five sectors related to the application of different supporting elements, as shown in Figure 2.

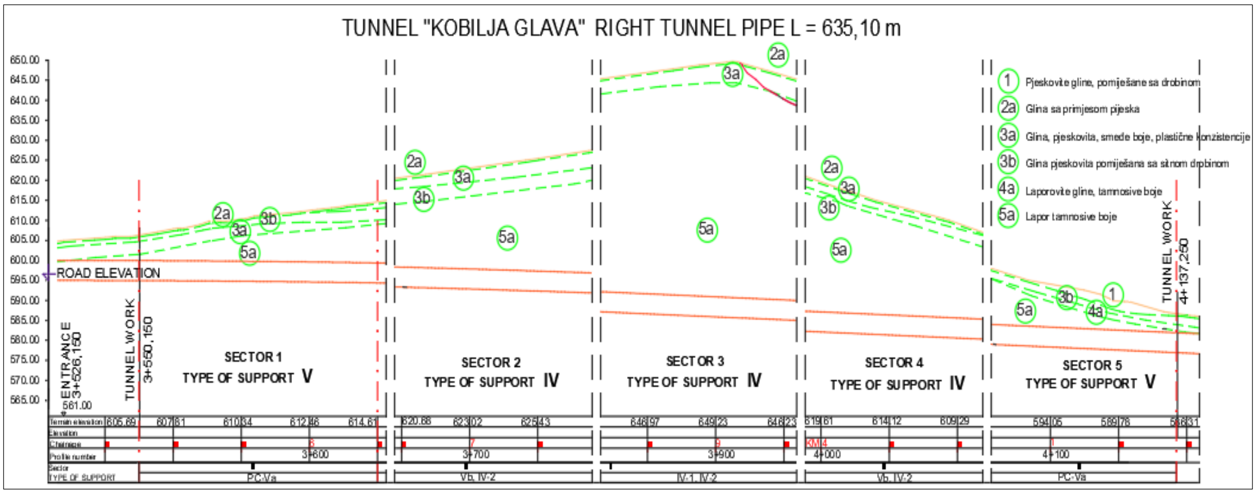

Figure 2 Presentation of the division of the tunnel into sectors by type of supporting elements

In the portal zones of both tunnel pipes, a category V rock mass was found, while in the remaining part of the tunnel, category IV rock mass was found, all based on extensive analyses carried out according to Bienawski [6], Marinos et al. 2007, Marinos and Hoek, 2001[7], NATM recommendations, ONORM 2203 standard, as well as stress and deformation analysis of the rock mass around the underground excavation using the PLAXIS 2D software package (with evaluation of 3D impact during excavation)[8]. According to above mentioned, it has been rationalized and adequate support, consisting of shotcrete, reinforcing mesh, steel belts of appropriate dimensions, and SN and IBO anchors with appropriate diameters.

2.2. Geotechnical characteristics of underground excavation stabilization

"Kobilja Glava" tunnel was excavated using the New Austrian Tunnelling Method (NATM). Bearing in mind the frequent changes in the engineering-geological characteristics of the rock mass in the part of the tunnel excavation, NATM enabled the application of multi-phase excavation, while at the same time securing the excavation with a primary support [9].

NATM (New Austrian Tunnelling Method) represents the general concept or philosophy of tunnel construction. It is a procedure that is based first on the basis of scientifically established ideas and facts that were later confirmed through practice, with the task of achieving optimal safety in the synergy of the capacity of the rock mass with the applied supporting elements, and at the same time the economy of the tunnel construction process itself.

Therefore, NATM represents a successful system of improving the geotechnical characteristics of the rock mass by applying support, which takes advantage of the primary strength of the rock, the rationality of the supporting systems, and the mandatory control of the support by measuring the deformations of the excavated and supported tunnel. In "Kobilja Glava" tunnel, support types for category IV and V were applied with occasional modifications through geotechnical missions.

The decision to apply modified types of support was additionally confirmed and supported by calculations through individual geotechnical missions, which were carried out during the recording of rock mass changes during the tunnel excavation works. The basic supporting elements of category IV are shown below (Figure 3):

- Length of the excavation step 1.0 – 1.2 m depending on the conditions of the environment through which the excavation is carried out;

- IBO anchors ф32 length l=4m in the ceiling part of calote,
- IBO anchors ф32 length l=6m in the sides of calote,
- Lattice girder PS 95/20/30,
- shotcrete C25/30 layer thickness ds=24 cm,
- ribbed reinforcing mesh Q257

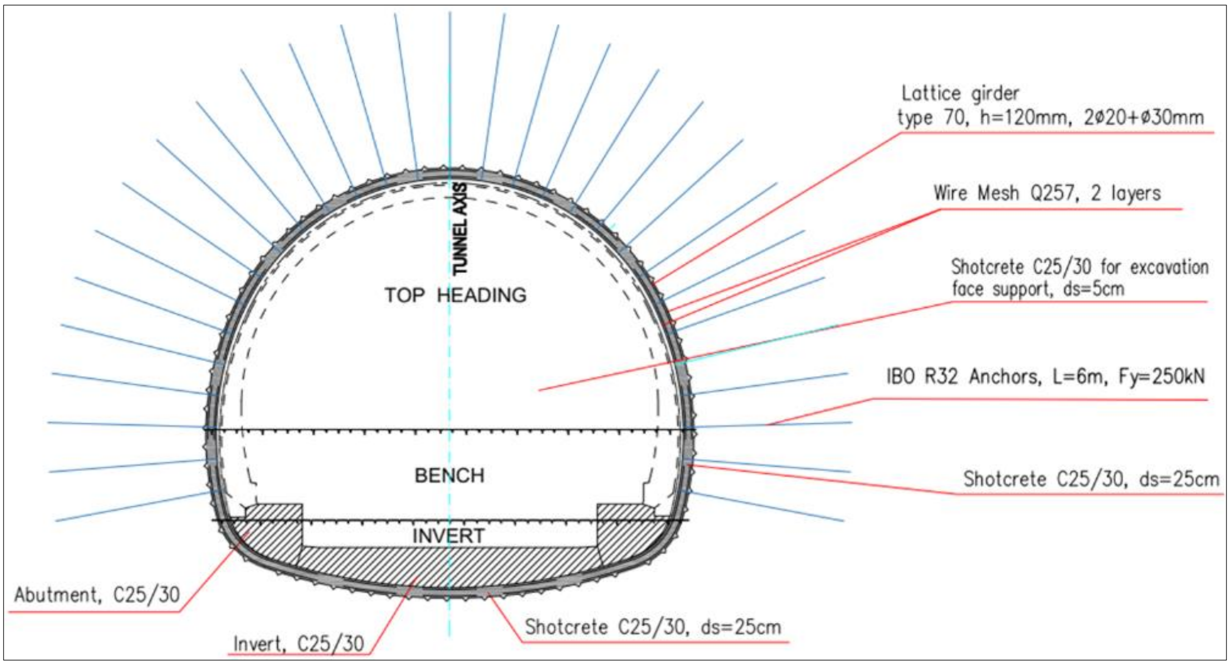

Figure 3 Support type for rock mass category IV

2.3. Basic supporting elements of category V are shown below

- Pipe shield – steel pipes ф114 mm length l=12m to protect the ceiling of the excavation (overlap of 4,0m),
- Length of excavation step 0,5 – 0,8 m depending on the conditions of the environment through which the excavation is carried out,
- Shotcrete C25/30 layer thickness ds=30 cm,
- Ribbed reinforcing mesh Q257,
- Lattice girder PS 95/20/30,
- Ibo anchors ф32 length l=6m,
- Shotcrete thickness ds=25 cm,
- Ribbed reinforcing mesh Q257.

In addition to the basic supporting elements in the IV category of rock mass, during the excavation in certain sections of the tunnel, Ø32mm steel rods were also applied, if necessary, to protect the ceiling of the calote in lengths of l=3 and 4m. As additional support measures in the V category, we can single out the elephant foot in the form of an extension of the support zone in calote area, and SN anchors 51 mm. In regard to SN 51 mm anchors, they were applied after it was determined that there was a shear failure of the installed designed anchors, which resulted in the appearance of uneven settlement along the contour of the tunnel excavation. These anchors did not have a tensile load bearing function, but their primary function was to suspend the straps to reduce uneven convergences, i.e. greater subsidence of one side compared to the other [9]. For the purpose of stabilizing the face of the excavation in the left tunnel pipe on a certain section of the tunnel where longitudinal movements were observed during excavation at the face of the excavation, IBO anchors Ø32 12 meters long were used to strengthen the rock mass in the face as an additional security measure (Figure 4).

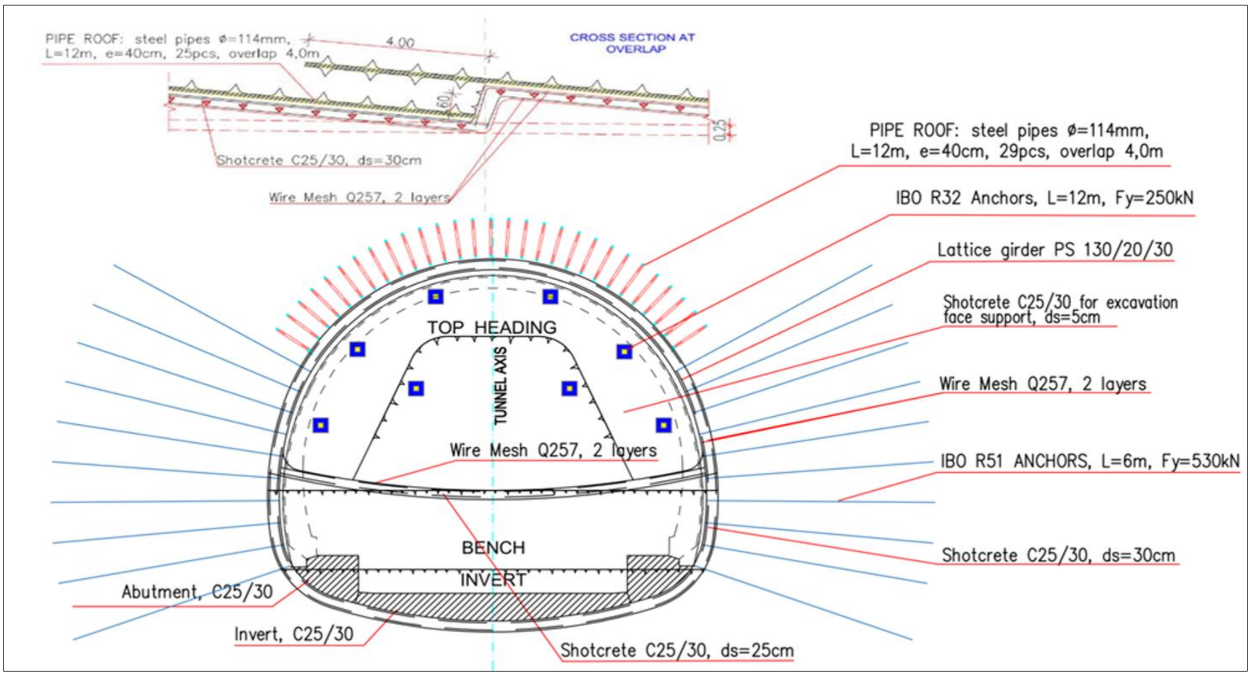

Figure 4 Support type for rock mass category V

2.4. Technology of installing rod self-drilling anchors

Self-drilling IBO-SDA anchors are a special type of rod anchors that represent a combined system of rock anchors and drilling rods. During drilling, the hollow IBO anchor is used as a drill rod. At the end of the anchor, a drilling crown is placed, which can be of different sections [10].

The basic elements of these anchors are: hollow steel pipes of suitable outer and inner diameter (R32, R38, R51), supporting plates of suitable dimensions, nuts which can be dome and hex (R32, R38, R51), connectors used to connect hollow steel rods, whose diameter matches the diameter of the rod itself, the spacer whose primary function is to maintain the central position of the anchor in the well itself, and the associated disposable drill bits (depending on the diameter of the hollow steel rod itself). The following picture shows the installation of self-drilling anchors (Figure 5).

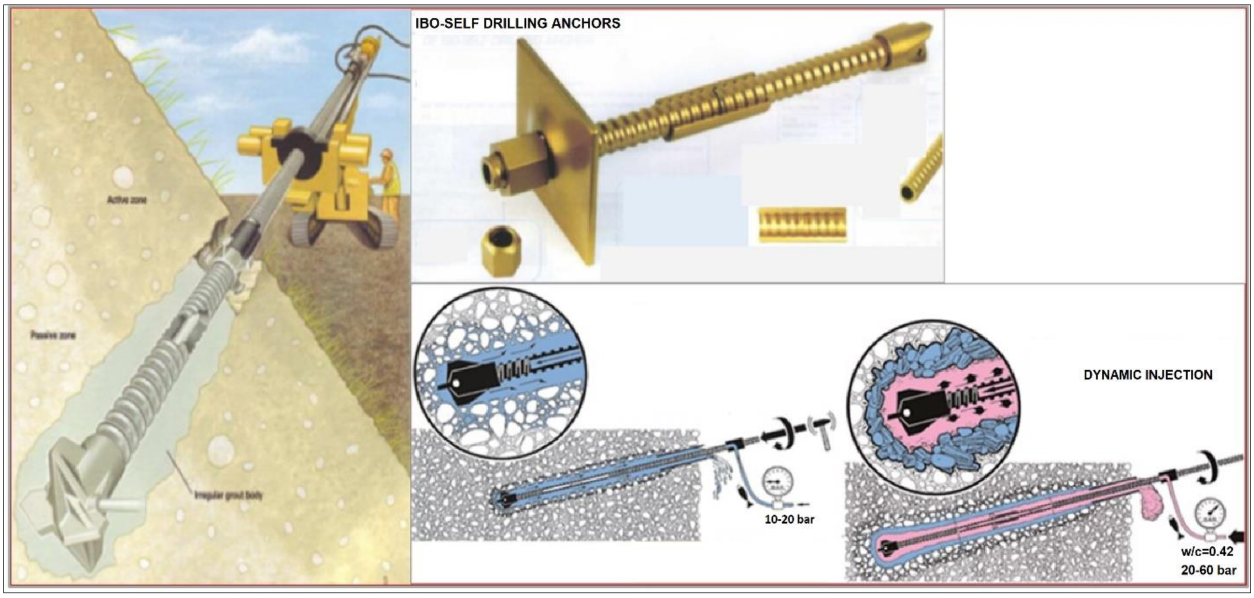

Figure 5 Basic elements of IBO-SDA self-drilling anchors

The use of anchors is inevitable in situations where it is necessary to increase or maintain the stability of rock mass or soil. They have found their wide application in tunnel construction, where they are used as elements of the primary substructure, thereby increasing the shear strength of the surrounding soil. At that stage, the anchors are predominantly loaded in tension. The drilling of the wells for these anchors is performed using a disposable crown and the anchor rod, through which the well is flushed out either by applying water or air. Drilling is carried out using specialized machinery (Figure 6). The machine has two arms that allow drilling at specified locations at the head of the tunnel excavation.

An anchor of the designed diameter with a suitable disposable crown is placed in the arm of the machine, and the drillhole is drilled to the designed depth. During drilling, if it is a wet process, water is injected under pressure, which is used to wash out the excavated material. According to the same principle, drilling is also carried out using a dry process, with the fact that in this case, instead of water, a pipe is connected to the machine through which air is pumped in under pressure. In this way, the cleaning of excavated material from the drillhole is done with compressed air. Each of the procedures has certain disadvantages. When it comes to the wet process, the disadvantage is reflected in the fact that large amounts of water are introduced into the drillhole, so materials that are exposed to the degradation process under the influence of water, leads to the weakening of the rock material. Another disadvantage is a significant accumulation of water in front of the tunnel head, which complicates the work and must be promptly removed from the specified location. The problem with the removing water from this location is even bigger if the direction of progress of the tunnel excavation coincides with the decreasing level of the tunnel. When it comes to the dry process, disadvantage increasing dust, which needs to be urgently removed so that it does not negatively affect the health of workers. Also, in addition to dust removal, it is necessary to adjust the ventilation system in such a way as to ensure the supply of sufficient quantities of air for workers.

Figure 6 Layout of the drilling rig manufactured by Epiroc - Boomer

Injecting the drillholes with the injection mixture through the anchor body as well as the crown can be done either after the completion of drilling (Figure 5) or during the drilling procedure [11].

3. Determining the increase of drillhole diameter in marl using wet drilling technology compared to dry drilling technology

Due to the above mentioned deficiencies, especially when it comes to the wet process, and the construction of "Kobilja Glava" tunnel takes place in marl, a material that is extremely susceptible to degradation under the influence of water, we assumed that flushing the wells with water when drilling would lead to an increase in the diameter. In this connection, we conducted research work paying special attention to this issue. For the purposes of confirming the basic hypothesis expressed in the title of this paper, which is the increase of drillhole diameter when applying wet process compared to the dry process, drilling of exploratory drillhole was carried out at station km 4+049.69 in LTC. Based on its characteristics the rock mass is classified as category IV. In "Kobilja Glava" tunnel, most of the anchors that were installed as a supporting element were anchors with a length of 6 m, the necessary time for the installation of the anchors was standardized. Standardization has been established that the time duration of drilling the drillhole for installation of rod anchors of 6 m is 3.05 minutes. based on the average value of monitoring the installation of three anchors, Table 1.

Table 1 Standardization of installation of 6m long anchors in “Kobilja Glava” tunnel

No.	Type of anchors IBO ϕ32	Unit of measure	Established time of installation
1.	*L=6m*	*min*	*3.20*
2.	*L=6m*	*min*	*2.57*
3.	*L=6m*	*min*	*3.40*
Aver.time	*3.05*		*min*

At the beginning of the tunnel excavation in the left tunnel pipe at station km 4+049.69, 6 drillholes were first marked, which will be used to confirm the hypothesis. After that, drilling was started using specialized machinery.

For the purposes of confirming the basic hypothesis, two series of drillholes were made, marked with the numbers 1 and 2. Number 1 indicates drillholes that were drilled using the dry drilling method, while the number 2 indicates drillholes that were drilled using the wet drilling method (Figure 7).

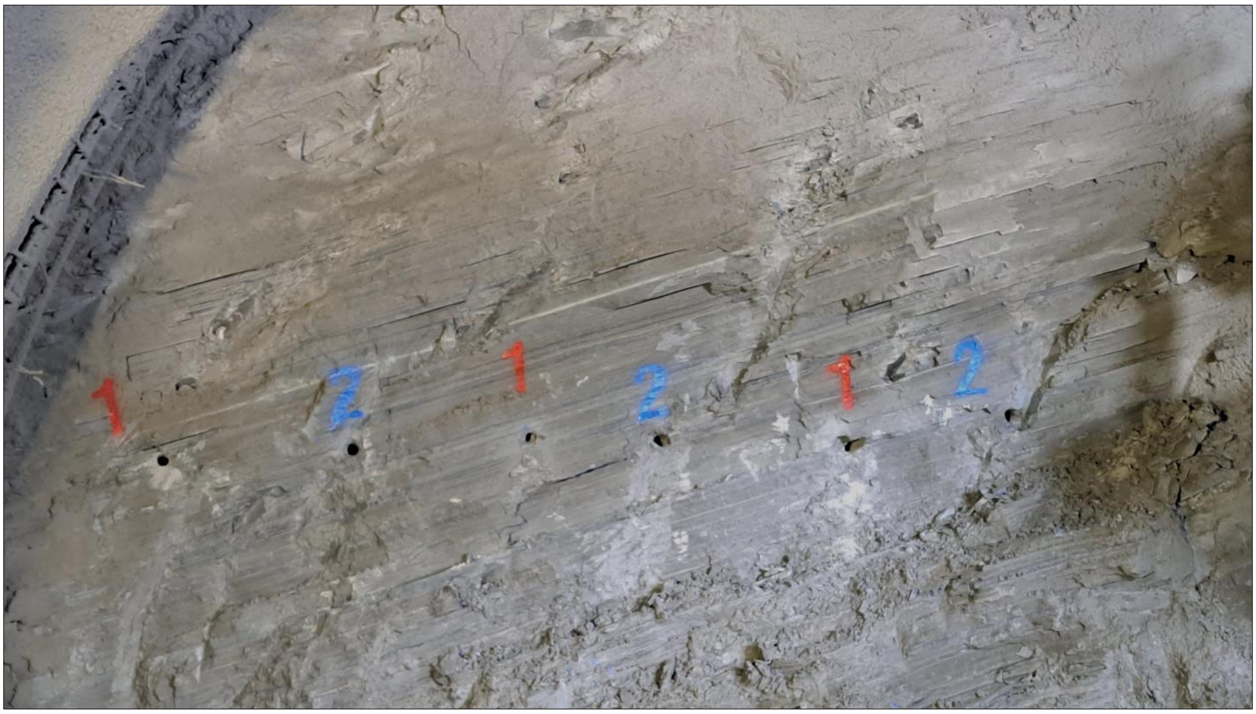

Figure 7 Marked places for drilling at the head of the tunnel excavation

A total of 6 exploratory drillholes were drilled, three using the dry method (using compressed air for drilling mud), and three using a wet procedure (flushing the wells with water). It is important to point out that when drilling wells with water, the drilling period is adapted to the established drilling time of drillholes of 6m, which means that the drilling time of experimental drillholes with a depth of 1.0m was carried out reciprocally to the drilling of drillholes of 6m (approx. 3.0 min.). The view of drilling drillholes is shown in Figure 8.

Figure 8 Presentation of drillholes drilling: a) dry process and b) wet process

Drilling was done in an alternating order, more exactly first a dry one was drilled, then a wet one, and so on. The drilling was carried out according to the previously defined time operations, which precisely defined the length of drilling the drillholes in minutes, with the known consumption of water for flushing the drillholes. For the purposes of this research, and in order to be able to read the diameter of the exploratory drillholes, they were drilled to a depth of approx. 1.0 m.

Furthermore, by using a handy (simple) accessory made of two metal profiles (approx. 1 cm), in such a way that they were connected in the middle by a shaft that allows the movement of these profiles, more precisely opening and closing the angle between the profiles, it was possible at reference depths of 15, 50 and 80 cm inside the drillhole, measure with a digital calliper, actually the diameter of the drillhole at those three positions. The obtained values were averaged for each individual drillhole. A schematic representation of diameter measurements at reference depths inside the drillhole is shown in Figure 9.

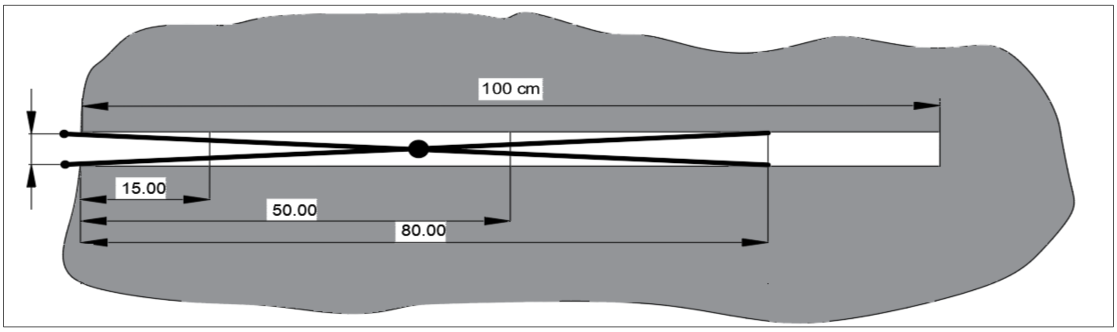

Figure 9 Schematic presentation of diameter measurements at reference positions inside the drillhole

The next step was to determine the final average value on the basis of the average values for each of the series of three drillholes made using the same method, in order to be able to compare the obtained values, which was also to obtain the final difference in the size of the diameters obtained by applying two different drilling methods. It is extremely important to note here that the same rod anchor crown with a diameter of 50.5 mm was used for drilling all the drillholes, which is presented in Figure 10.

Figure 10 Rod anchor crown used for drilling exploratory wells

4. Results

A presentation of all recorded measurement results at reference locations within all six drillholes is given in Table 2 and Figures 11. and 12.

Table 2 Obtained results of measuring the diameter of all six exploratory drillholes

Measurement location in the drillhole (cm)	***TYPE OF DRILLHOLE***					
	dry process	*wet process*	*dry process*	*wet process*	*dry process*	*wet process*
	1	2	1	2	1	2
15	5.07	5.18	5.05	5.20	5.06	5.22
50	5.05	5.23	5.05	5.24	5.02	5.26
80	5.04	5.30	5.04	5.32	5.08	5.34
Averg. time. drillhole	5.05	5.24	5.05	5.25	5.05	5.27
Avrg. drillhole diameter value - dry process (d_s)						5.051
Avrg. drillhole diameter value - wet process (d_m)						5.254
Percentage increase in diameter - dry/wet process						4.03%

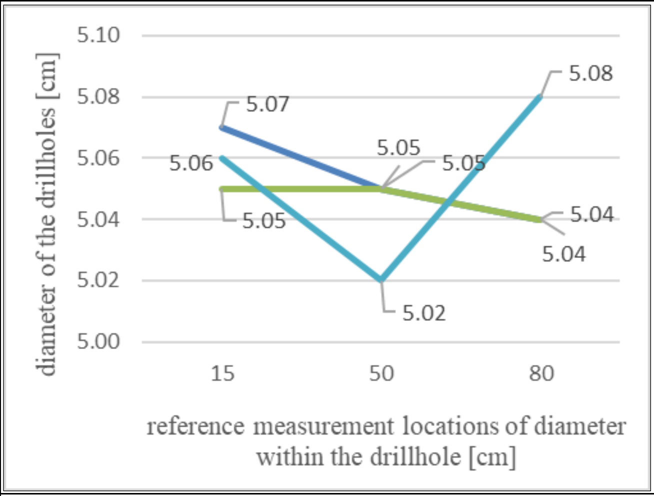

Figure 11 Diameter of three drillholes using dry process

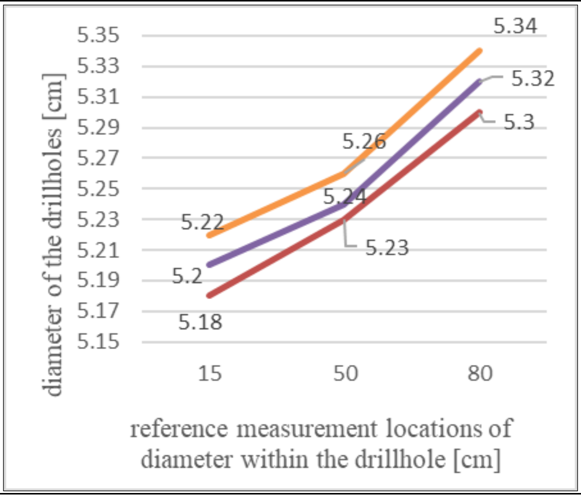

Figure 12 Diameter of three drillholes using wet process

In this way, it was obtained that by applying the dry process, the average value for a series of three drillholes was 50.51 mm, which corresponds to the diameter of the crown itself. When it comes to the drilling of drillhole using the wet procedure, there was a slight dispersion of the results within the series itself, but by averaging those results, it was established that the diameter of the drillhole is 52.54 mm.

From the obtained results, it can be clearly seen that the percentage increase in the diameter of the drillhole drilled with the wet method compared to the borehole made with the dry method is **4.03%.**

5. Discussion

Taking into consideration the values of the diameter of the drillholes for the dry and wet procedure (ds and dm) shown above, we can calculate the cross-sectional areas of the drillhole for both drilling procedures:

$$P = \frac{d^2 \cdot \pi}{4} \text{............}(1)$$

Including the obtained parameters for the diameters in formula no. 1, we obtain the cross-sectional areas of the wells for both drilling procedures

$$P_s = \frac{d_s^2 \cdot \pi}{4} = \frac{5{,}051^2 \cdot 3{,}14}{4} = 20{,}0274(cm^2)$$

$$P_m = \frac{d_m^2 \cdot \pi}{4} = \frac{5{,}254^2 \cdot 3{,}14}{4} = 21{,}6695(cm^2)$$

P_s- cross-sectional area of the borehole for the dry process

P_m - cross-sectional area of the well for the wet process

π - (3,14),

ds –average diameter of the drillhole obtained by the wet drilling process

dm - average diameter of the drillhole obtained by the dry drilling process

The increase in the cross-section of the drillhole by the wet drilling process compared to the drilling of the drillhole by the dry method is obtained as the reciprocal of the cross-sectional area of the drillhole for the wet method in relation to the cross-sectional area of the drillhole for the dry method.

$$\frac{P_m}{P_S} = \frac{21{,}6695}{20{,}274} = 1{,}08199\ (cm^2)…………(2)$$

From formula no. 2, it can be seen that it is a percentage increase in the area of the drillhole obtained by applying the wet drilling procedure compared to the area of the drillhole obtained using the dry procedure in the amount of 8.2%.

It can be stated that this is a not so insignificant increase in the weakening of an already bad rock mass, which may result in the appearance of increased convergences when it comes to the tunnel excavation itself. However, knowing that the convergences that occur within the tunnel excavation itself are directly related to the convergences that occur on the surface of the ground, especially when it comes to the construction of tunnels with a small upper layer , and in the specific case of the construction of “Kobilja Glava”tunnel with the existence of a large number of residential and infrastructure facilities in the zone of tunnel construction, it is very important that these convergences are permanently monitored and kept in the zone of permitted movements.

In addition to the above, the need to rationalize the entire process of tunnel construction should also be taken into consideration. So, if we take into consideration the total number of installed anchors in “Kobilja Glava” tunnel (it is a figure of 15,106 pieces), and if we calculate the change in the total volume of drillhole obtained by the wet drilling process compared to the dry process, respecting the results obtained above and the fact that it is an increase of 8.2%, it can be stated that is an increase of 13.82 m3 in the consumption of the injection mixture. A detailed description of the type and quantity of anchors used during the construction of “Kobilja Glava” tunnel is given in table 3. The table also shows the increase in the volume of drillhole by type of anchors used.

Table 3 Applied anchors on “Kobilja Glava” tunnel with data on the volume consumption of the injection mixture

Type of applied anchors	**Length of drillhole**	**Drillhole surface wet process**	**Drillhole surface dry process**	**Drillhole volume wet process**	**Drillhole volume dry process**	**Total drillhole volume wet process**	**Total drillhole volume dry process**	**Number of anchors**	**Total amount of injection mixture wet process**	**Total amount of injection mixture dry process**
	m’	**cm²**	**cm²**	**m²/m’**	**m²/m’**	**m³**	**m³**	**kom.**	**m³**	**m³**
IBO type rock bolts/IBO anchors, 280 kN, l=4m	4	21,67	20,027	0,002167	0,0020027	0,008668	0,0080108	319	2,77	2,56
IBO type rock bolts/IBO anchors, 280 kN, l=6m	6					0,013002	0,0120162	1820	23,66	21,87
IBO type rock bolts/IBO anchors Ø51 mm, 630 kN, l=4m	4					0,008668	0,0080108	129	1,12	1,03
IBO type rock bolts/IBO anchors Ø51 mm, 630 kN, l=6m	6					0,013002	0,0120162	1910	24,83	22,95
IBO type rock bolts/IBO anchors, 250 kN, l=4m	4					0,008668	0,0080108	3529	30,59	28,27
IBO type rock bolts/IBO anchors, 250 kN, l=6m	6					0,013002	0,0120162	7161	93,11	86,05
IBO type rock bolts/IBO anchors Ø32mm, 250 kN, l=12m	12					0,026004	0,0240324	238	6,19	5,72
TOTAL									**182,27**	**168,45**

Figure 13 (a) shows a comparison of drillhole volumes depending on the applied drilling procedure, while Figure 13 (b) shows the difference in the total amount of injection mixture depending on the applied procedure.

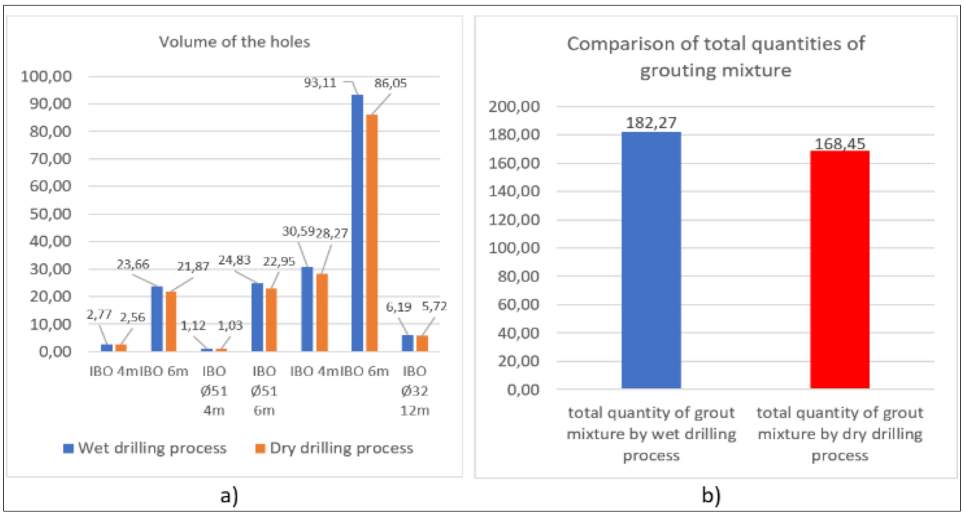

Figure 13 Comparative view: a) volume of wells depending on the applied procedure, b) difference in total amounts of the injection mixture depending on the applied procedure

Furthermore, considering that cement is the primary material used for the preparation of the injection mixture at this location, the total increase in cement consumption for the preparation of increased quantities of the injection mixture caused by the application of the wet procedure when drilling drillhole for rod anchors can be calculated. In order to determine the density of the injection mixture, 3 cubes measuring 5x5x5 cm were sampled and weighed, Figure 14.

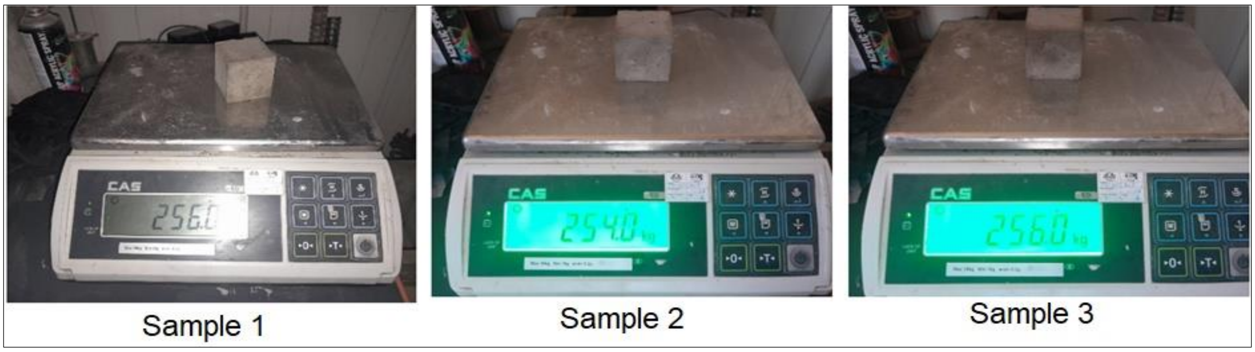

Figure 14 Presentation of the weighing of injection mixture samples

Table 4 shows the results of weighing the injection mass cubes, as well as the determined volume of the cubes that were weighed.

Table 4 Display of measurement data of the mass of samples of injection mixture in the shape of a cube with side dimensions of 5 cm

Serial number	Mass of sample (kg)	Volume of the cube (m^3)
1	0,256	0,000125
2	0,254	0,000125
3	0,256	0,000125
average	0,255	0,000125

Based on the obtained data, it is possible to calculate the density of one cubic meter of injection mixture that was applied during the injection of anchors in “Kobilja Glava” tunnel. Therefore, the specific density of the mixture is calculated according to the following formula:

$$\rho = \frac{m}{V} = \frac{0,255}{0,000125} = 2040,00 \left(\frac{kg}{m^3}\right) \quad \text{…………(3),}$$

For the obtained value with a water-cement factor W/C of 0.42, and if we assume that the amount of cement is marked with C, then the amount of water required for preparation will be 0.42xC. Taking into account the experimentally determined value, then the sum of cement and water should be 2,040 kg. Mathematically presented, the following formula is obtained:

$$C + 0,42 * C = 2040,00 \quad \text{……………(4),}$$

Further

$$1,42 * C = 2040,00 \qquad \text{………… (5),}$$

Where can we get the amount of cement in one m3 of injection mass:

$$C = \frac{2040}{1,42} = 1.436,62\ (kg) \ \text{…………(6)}$$

By solving the above equation, it is obtained that 1,436.62 kg of cement is needed to make 1 m3 of injection mixture, while the following amount is required for water:

$$V = 0,42 * C = 603,38\ (kg)\text{………..(7)}$$

Therefore, the increased consumption of cement caused by the increased consumption of injection mixture when filling the anchor wells from Table 3 made using the wet process compared to those made using the dry process is obtained when 13.82 m3 of additional injection mixture is multiplied by the amount of cement obtained according to formula no. 6. so we get:

$$13,82 * 1436,62 = 19.854,09\ (kg)$$

The contractor for the construction of “Kobilja Glava” tunnel did not keep accurate records of the number of anchors that were drilled using the wet or dry method. The fact is that the contractor repeatedly tried to apply the dry drilling procedure, however, it can be stated that most of the drillholes for rod anchors in “Kobilja Glava” tunnel were still done using the wet procedure, so the amount obtained above actually represents a realistic state of increased cement consumption the applied procedure used in the construction of the mentioned tunnel was taken into consideration.

6. Conclusion

It can be concluded that this research has confirmed the starting hypothesis, which is that under the influence of water there is a significant degradation of marl, and a weakening of its physical and mechanical characteristics. Therefore, it can be concluded that the application of the drilling procedure in which water flushing was used led, as was expected, to a certain degree of degradation of the rock material, based on the known facts about marl as a material.

Taking into consideration that the percentage degradation is not precisely indicated anywhere in the consulted literature, in this research it was stated that for the rock mass in which “Kobilja Glava” tunnel is being drilled, we are talking about a percentage increase in the diameter of the drillhole by the amount of 4.03%.

Therefore, it is very important that when choosing the method of making drillhole for rod anchors, which represent the most numerous support elements within the primary tunnel substructure, the same should be properly selected, in order to minimize the negative effects of the applied method, and to prevent additional weakening of the already bad rock mass.

In addition, the correct selection of the method that will be used for the construction of the mentioned drillholes can significantly affect the dynamics of the works, the reduction of negative impacts from the point of view of environmental protection, as well as the financial aspect of the entire construction of the tunnel.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Bektašević, E., Filipović, S., Gutić, K. i Musa, N. (2024), Defining the optimal distance between technological sequences during tunnel excavation in poor rock mass. e-Zbornik, electronic collection of works of the Faculty of Civil Engineering, Vol. 14 No.28 (2024), p. 47-57. https://hrcak.srce.hr/324584

[2] Bektašević E., Mušija A., Gutić K., Beganović S., Čehajić D., Analysis of the groundwater influence on the categorization of the rock mass and support type of the Zenica tunnel on the route of the Vc corridor, Faculty of Civil Engineering Subotica, Journal of faculty of civil engineering 44, 2023.y., pp. 5-19, https://doi.org/10.14415/JFCE-894

[3] Bektašević, E., Gutić, K., Kadrić, R., Kadrić, S., Sikira, D.: Deformation analysis during tunnel excavation in poor rock mass, 8th International Conference on Road and Rail Infrastructures – CETRA 2024, Cavtat, 2024, pp. 799-805.

[4] Bektašević E., Antičević H., Gutić K., Sikira D., Application of seismic methods for determining the depth of the rock mass damage zone around the excavation profile by blasting, Global Journal of Engineering and Technology Advances, 2024, 18(03), 139–151, Article DOI:10.30574/gjeta.2024.18.3.0051

[5] Miščević P., Roje Bonacci T. (2000.) Requirements for marl use in embankment construction, Građevinar (2001) 1, 9-16

[6] Bieniawski, Z.T. (1989) Engineering Rock Mass Classifications - A Complete Manual for Engineers and Geologists in Mining, Civil, and Petrol

[7] Marinos, P., Hoek, E. Estimating the geotechnical properties of heterogeneous rock masses such as flysch. Bull Eng Geol Environ 60, 85–92 (2001). https://doi.org/10.1007/s100640000090

[8] Geotechnical mission G21: Geotechnical project (2021), developed by FM Engineering Ltd. Sarajevo

[9] Bektašević, E., Antičević H., Kadrić R., Kadrić S., Šehagić N. i Zukan S., 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. e-Zbornik, electronic collection of works of the Faculty of Civil Engineering, Vol. 12 No. 24 (2022), p. 47-62. https://doi.org/10.47960/2232-9080.2022.24.12.47.

[10] Stanković, M. (2020.), Rock improvement – Anchors, Beograd https://diorit.biz/ibo-sda-stapna-sidra/