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USAGE OF SHOTCRETE IN NORTH MACEDONIA

Shotcrete is a relatively new technique used in R. N. Macedonia. With the start of the works on the infrastructural projects throughout the territory of North Macedonia, the shotcrete became one of the most important aspect of the projects. Large quantities of sprayed concrete are installed during the construction of tunnels and protection of slopes. Tunnels on the section Demir Kapija-Smokvica and the tunnel on the highway Kicevo-Ohrid are more significant facilities to which this technique was applied. However, we should not forget about the built-in quantities of shotcrete in the landslide protection on the access road to the dam Sveta Petka, as well as when repairing the landslide on the highway Gradsko-Veles. Only in the last building, at the landslide Cucka in front of the entrance of Veles, an area of about 2,000 m² is covered with sprayed concrete.

The technique of sprayed concrete in our country does not stop here. There is a chance to become an even more trendy technique with the announced projects, or projects that are already under construction. One of the many projects that are being carried out is the expressway Prilep - Gradsko that contains the construction of a tunnel and a gallery. Apart from the construction of these elements of the building, sprayed concrete is also used in excavations in rock masses, ie protection of slopes. It is planned to install 500 m³ as the primary support of the tunnel and 20 m³ for slope protection at the gallery. It should be mentioned here that additional quantities have already been applied during the penetration of the route, ≈ 10,000m².

That is a proof that the shotcrete is a trend in our country. The predicted road and railway infrastructure projects pave the way for this technique. However, not only in the infrastructure but also sprayed concrete is expected to be used in other areas, which will further increase the amount of installation. Apart from larger quantities of sprayed concrete, the technique of this process is expected to be improved in the coming years.

Keywords: shotcrete, gallery, tunnel, landslide, infrastructure

1. INTRODUCTION

Sprayed concrete or shotcrete is a technique where the concrete mixture is applied to the surface with the help of high pressure and special equipment. The method of installation can be dry or wet. This technique is flexible and has a fast way of installation, but requires good mechanization and well-trained workers. Can be used alone, but also in combination with anchors, steel mesh and fibers. It is widely used in construction in: tunnel construction; construction of hydro-technical facilities; protection of slopes from landslides; protection of construction pits; mining; reconstruction of buildings; construction of buildings with unusual geometry, etc.

Although sprayed concrete has been used in the world for more than a century in various construction projects, in our country it is a relatively new technique. Mostly, this process is used in tunnel construction and in protection of slopes from landslides. Towards the end of XXcentury, during the construction of the Katlanovo tunnel, the first quantities of sprayed concrete were applied in our country, as the primary support of the tunnel. While larger quantities of shotcrete are installed during the realization of the projects: construction of the dam Sveta Petka; construction of the section Demir Kapija - Smokvica, as well as protection of slopes on the access road to the dam Sv. Petka.

2. TECHNOLOGY OF PRODUCTION AND APPLICATION OF SHOTCRETE

The term technology of sprayed concrete application means including these three basic phases in the process:

- preparation of the mixture for sprayed concrete;

- process of installation of sprayed concrete and

- equipment for installation of sprayed concrete

All three phases are important for performing the shotcrete technique. Preparation of the mixture for sprayed concrete is done according to certain regulations by preparing several combinations of concrete mixture. The difference is in the dosage of certain amounts of each element. Choose the best and most economical, paying attention to the following characteristics: better workability, higher strength, better spraying, minimal rebound and minimal dust. Once the serial preparation of the mixture begins, it should be installed with special equipment.

The basic ingredients for preparing the mixture for sprayed concrete are: aggregate, cement, water and additives. The aggregate used for shotcrete occupies the largest volume in the whole mixture, 75%. When choosing the unit, attention should be paid to the homogeneity of the mixture, workability and mechanical properties.

Portland cement is used to make sprayed concrete without additives, but also other types of cement can be used as an alternative, depending on the conditions. And the third element, ie. water has two roles in this process. The first one, the water together with the cement, starts the hydration, and the second, the wetting of the aggregate. Therefore, the water should be clean, without harmful substances, and should not contain oils, chlorides, sulfates, sugar, salt, etc.

The group of additives used to improve the properties of concrete can include: accelerators, retarders, plasticizers, superplasticizers, aerators, antifreeze and others.

Table 1. Recipe of sprayed concrete installed in several buildings in R. North Macedonia

	Highway D. Kapija-Smokvica	Preseka Tunnel
Cement (kg/m³)	435	524
Aggregate (kg/m³)	1573	1606
Water (kg/m³)	244	220
Accelerators (kg/m³)	No info	3,14 (6%)
Superplasticizers (kg/m³)	6,96	4,19
Total volume weight (kg/m³)	2300	2350

When the sprayed concrete mixture is made, it should be installed, and this is done with special installation equipment using one of the two application procedures. Dry procedure is a method in which the dry mixture of cement and aggregate is installed through a pressure

hose, and water is added to the nozzle, just before installation. While wet procedure is a method where the finished concrete mixture is transported and carried to the application rig. This method is newer than the dry one and is being developed with the evolution of NAMT - The New Austrian Tunnel Construction Method.

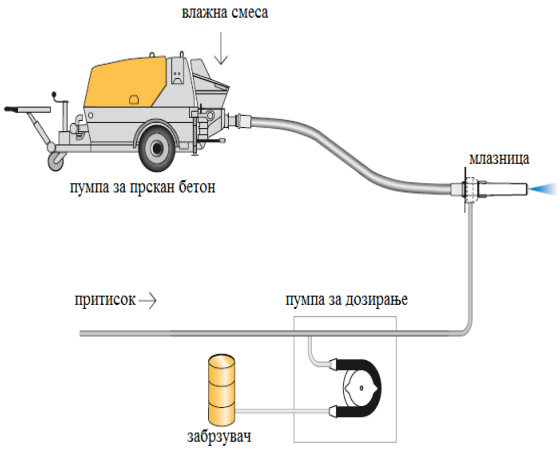

Figure 1. Demonstration of installation of shotcrete - wet procedure

The technical characteristics of the equipment used in the installation of shotcret affect the quality of the sprayed concrete and the success of the whole installation procedure. Therefore, all parts of the equipment to be used should be analyzed in order to make the right choice. The choice of equipment depends on a number of factors, such as: type of installation procedure, project specifications, availability of materials, type of transport of materials, weather conditions, etc.

Sprayed concrete equipment is a technological unit which provides the basic components of the sprayed concrete mixture, their dosage in the required weight ratios, quality mixing of the components, and controlling the mixture in to the outlet nozzle under sufficient pressure.

The basic equipment for making shotcrete are: production pump and nozzle. The pump is used for the production of concrete and through a special hose it is transported to the nozzle. The nozzle, which can be manual or mechanical, is used to apply the concrete mixture. More recently, a robot nozzle has been produced that is very easy to operate and has greater realization.

Figure 2. Robot machine for embedding sprayed concrete

3. CURRENT AND FUTURE USAGE OF SHOTCRETE IN WORLDWIDE

In the world the shotcrete technique began in the United States, with the renovation of the one museum facade. But then it started to be used in the construction of dams, bridges, tunnels, irrigation canals in the field and so on. In one century long time, a lot of money is spent on sprayed concrete, which is a sign that the need for such a technique is increasing every day. The main reason for the growth is the great need for construction of underground facilities, especially in Europe.

The massusage of sprayed concrete around the world can be seen starting from examples in neighboring countries, than in European and around the world. During the construction of the highway G.P. Blace - Pristina, the A1 highway in Serbia, as well as several tunnel solutions through Croatia, Montenegro and Bosnia and Herzegovina. These are proof of the mass useage of this technique. While Turkey has built tunnels with a length of 220 km in just 20 years, and about 300 km are in the design phase. This shows that Turkey will be one of the largest consumers of sprayed concrete.

Table 2. Largest consumers of shotcrete in the world

Europe	North America	Asia and the Pacific
Germany	USA	China
Italy	Canada	Japan
Switzerland	Mexico	Australia

In the world, shotcrete is also used for slopes' protection; protection of construction pits; mining, aviation, industrial floors, etc. However,

it is also used for the construction of objects with unusual geometries, such as swimming pools, buildings with a rounded shape, etc.

As proof that it is widely used stand the numbers. According to some research, in 2019 alone, $ 4.88 billion was spent. The largest consumers are the European countries Germany, Great Britain, Russia, Turkey and others. But the other continents should not be forgotten.

Due to the global pandemic, some projects have been put on hold, but this will not have much effect on the amount of embedded concrete. Thus, in 2023, about $ 11 billion is projected to be spent on this technique

4. CURRENT AND FUTURE USAGE OF SHOTCRETE IN NORTH MACEDONIA

After the successful implementation of the above-mentioned projects, the shotcrete received positive reviews from all our experts, as well as greater application in the following facilities.

At the beginning of 2018, a landslide occurred on the regional road R1102, section Veles-Gradsko, and activities were undertaken to repair it last year in February. Landslide rehabilitation at a place called Cucka, was a combination of several methods for landslide remediation and landslide protection (Figure 1). As part of most methods was the protection of slopes with sprayed concrete in combination with several other protective measures: sprayed concrete with anchors and paving net; sprayed concrete with gabions, etc.

The embedded sprayed concrete is prepared as a dry mixture of cement, aggregate and accelerator additive, and water is added before being applied to the surface. The grains of the aggregate are d = 10-20 mm, and the humidity ranges from 3-6%. The water is clean and without harmful amounts of oils, acids, alkalis, sulfates, aggressive CO_2, organic matter, etc. and the temperature should not be less than 25 ° C. Before applying the shotcrete,the surface on which it is applied is previously cleaned and wellmoistened. The thickness of the torque is 10 cm because it is applied in two layers of 5 cm.

The drainage of the shotcreted surfaces will be done by drilling appropriate holes with Ø50 mm and length 0.5 ÷ 1.0 m. The forecasted distance between the boreholes is 6.0 × 6.0 m. The reinforcement is done by placing wire nets MA 500/560, with a wire diameter of 6 mm and a distance of the hooksfrom 10 × 10 to 15 × 15 cm. Anchors that areSN anchors' type with Ø25 mm and lengths L = 3 m and 6 m are placed in a chess pattern.

Figure 3. Slope protection, p.c. Cucka, on the regional road R1102 Veles-Gradsko

During the construction of the tailings pond no. 4 in "Sasa"mine, the technique of shotcrete is applied during the construction of the bypass tunnel; tubes and pipeline for return industrial water. In the tunnel it is used as a primary underpass, while in the construction phase of the tubes and pipeline it is used as protection of the slopes where these infrastructure facilities' routepasses.

Due to the complexity of the terrain where the route of the tubes and the pipeline passes, a large amount of material has been excavated, and as technical solutions for slope protection and erosion protection, sprayed concrete is used in combination with anchors and safety net. The built-in shotcrete is 15 cm thick and it is applied in two layers. The anchoring is with SN-anchors and IBO with Ø32mm, with lengths L = 3, 6 and 9 m, while the installed safety net is reinforced Q-mesh. The drainage of the

torquered surfaces will be done by drilling appropriate holes with Ø50 mm and length 2.0 m.

When the bypass tunnelwas built, sprayed concrete was used to support it. Portland cement without additives is used to make this mixture. The grains of the aggregate are not larger than d = 16 mm, and the humidity ranges from 3-6%. The water was determined to be clean after a chemical test. The thickness of sprayed concrete ranges from 10-15 cm depending on the type of tunnel profile. It is applied in several layers, and the surface on which it is applied should be clean. The total amount of sprayed concrete installed during the construction of the tunnel is approximately 1,400m³.

SN anchors Ø20mm (RA 400/500) with a length of 2.5 meters are installed, placed in a symmetrical shape, and the Q196 reinforcement mesh is used.

Table 3.

Name of the project	Installed quantities of sprayed concrete (m³)
Landslide repair and landslide protection on R1102 section Veles-Gradsko	191.55
Tunnel T_1 and T_2, the section of the European corridor 10, Demir Kapija - Smokvica	6,368
Construction of tailings pond No. 4, at the Sasa mine	2,143

Although in recent years there are many more buildings where sprayed concrete is installed on the territory of North Macedonia, we mentioned only 3 at random choice. The examples are just a small step for the future of this technique. The next example of shotcrete usage is the Prilep-Gradsko express highway, on which construction activities are ongoing. When drilling the route of this section, it is necessary to perform excavation in solid rock masses, and as a protective measure the protection of slopes with sprayed concrete in combination with anchors and reinforcing mesh is used. During the construction of this phase, a total of about 1,000 m³ of sprayed concrete was installed.

Figure 4. Protection of slopes, on the expressway Prilep - Gradsko

This building contains other elements where the sprayed concrete will be an integral part: a tunnel with two tunnel pipes L_{right}= 159 m and L_{left} = 139.25 m, as well as the gallery near the tunnel.

For the preparation of this mixture, finely ground Portland cement without additives will be used, which will have to reach MB30. The aggregate grains will be with d_{max} = 16 mm, while the water will have to meet the prescribed requirements according to PBBA. Amounts of accelerator additives will range from 4-6% of the total amount of mixture.

With the announced capital investments in road and railway infrastructure, such as the construction of Corridor 8 and the railway to R. Bulgaria, the future of the shotcrete will be bright. It is planned to install large quantities of sprayed concrete and apply this technique. Apart from the realization of these projects, shotcrete will be used in mining, in hydro-technical facilities, as well as in possible remedial measures for protection of slopes from landslides.

The Banica tunnel, which should be part of the newly planned highway Gostivar - Kicevo, will be constructed according to the new methods for construction of tunnels, according to NAMT which is based on the construction of a flexible primary substructure of sprayed concrete..

According to the prepared technical documentation in the Banica tunnel, it is planned to install a total amount of 3,030 m³

shotcrete with different thickness depending on the classes of the tunnel construction:

- class 1: shotcrete d = 5 cm
- class 2: shotcrete d = 10 cm
- class 3: shotcrete d = 15 cm
- class 4: shotcrete d = 20 cm

As in other buildings, so in the Banica tunnel, the sprayed concrete will be used in combination with anchors, reinforcement mesh, etc. During this operation the anchors are SN-anchors Ø25mm and reinforcement mesh Q131 and Q188.

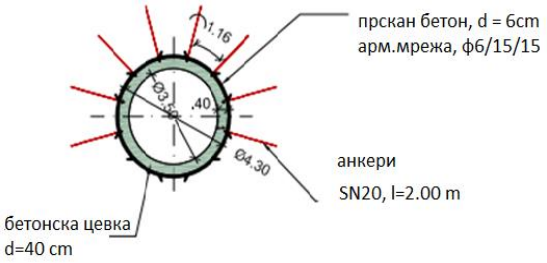

Figure 5. Profile of pipeline, dam HEC Boskov Most

Another facility waiting to be built and play its role is the Boskov Most dam. According to the bill of quantities,in this construction, it's envisaged that shotcrete is used in the construction of the pipeline as a primary substructure with $d_{shotcrete}$ = 5-6 cm (Figure 5) and other interventions, i.e a total of 6,213 m³.

Table 4.

Name of the project	Installed quantities of shotcrete (m³)
Banica Tunnel, highway Gostivar - Kicevo	3,030
Pletvar Tunnel and Gallery, expressway Prilep - Gradsko	1,020
Construction of dam HEC Boskov Most	6,213

But these are just some of the premises in which we expect to encounter shotcreteusage in the future. And of course, the development of shotcrete will not be limited to the construction of tunnels with NAMT technology, but following the rest of the world to be applied in other facilities: protection of construction pits; construction of industrial floors; construction of airfields; construction of swimming pools; reconstruction of buildings, as well as construction of buildings of irregular shape.

With greater application of shotcrete in our country, we are sure that the process of shotcreting will be improved. We will have larger professional teams for construction, more perfect equipment for installation, etc. Thus, in the future we will not need to "import" companies that will work with this technique.

Also, one of the components in shotcrete, often used in the world, but not yet in R. N. Macedonia, arefibers. The fibers, which can be from steel, synthetic, glass or plastic, replace the reinforcing mesh, which simplifies the process, facilitates the work, reduces the realization time.

The great application of sprayed concrete in various buildings will surely be a challenge for all who deal with this technique, improving the positive properties, as follows:

- greater process automation which reduces human error, time savings, increased productivity, reduced cost;
- improving the conditions when using wet procedure;
- improving the characteristics of the equipment (pump, nozzle, dispensers, etc.);
- educating all participants in the process;
- improvement of the physico-mechanical characteristics of the shotcrete, etc.

5. CONCLUSIONS

Sprayed concrete is a technique where the concrete mixture is applied to the surface with the help of high pressure and special equipment using dry or wet method of installation.

Shotcrete construction technology includes three basic components: preparation of the mixture, installation process and equipment for installation of sprayed concrete. All three elements are important for a quality performance of the shotcrete technique.

The technique of world-class interpretation began in the United States, with the renovation of the museum facade. But then continued with the construction of dams, bridges, tunnels, irrigation canals in the field, etc. If in the last few decades shotcrete has also been used to protect slopes; protection of construction pits;

mining, aviation, industrial fields, etc. However, it is also used for the construction of buildings with unusual geometries, such as swimming pools, buildings with a rounded shape, etc.

The numbers speak as a proof. According to some research, in 2019 alone, $ 4.88 billion was spent. The largest consumers are the European countries Germany, Great Britain, Russia, Turkey and others. But the other continents should not be forgotten, and in 2023 it is predicted that about 11 billion dollars will be spent on this technique.

Although in the world, shotcrete is used for more than a century in various construction projects, in our country it is a relatively new technique and mostly this process is used in tunnel construction and protection of slopes from landslides; construction of the dam St. Petka; construction of the section Demir Kapija - Smokvica, as well as protection of slopes on the access road to the dam St. Petka.

After the successful projects, the shotcrete received positive reviews from all experts, as well as massive application in the following facilities: Landslide rehabilitation and landslide protection on R1102 section Veles - Gradsko; Tunnel T_1 and T_2, the section of the European corridor 10, Demir Kapija - Smokvica and Construction of tailings No. 4, at the mine Sasa with a total amount of sprayed concrete of 8,700 m^3.

With the announced capital investments in road and railway infrastructure, such as the construction of Corridor 8 and the railway to R. Bulgaria, the future of the shotcrete will be bright. It is planned to install large quantities of sprayed concrete and application of this technique in several planned facilities has a planned quantity of over 12000 m^3.

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