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Review paper

UNDERGROUND EXPLOTATION BLOCKS OF NATURAL STONE IN THE COMPANY OF MARMOR, SEŽANA D.D.

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Abstract: The company Marmor, Sežana d.d. was formed in year 1947 under the name of Industrija kraškega marmorja Sežana. The company changed a lot during its history merged with other companies and changed his name few times. In 1996 the company changed its name in former Marmor, Sežana d.d. The company has three active quarries (Lipica 1, Lipica 2 and Doline) where it extracts natural stone – limestone. The stone is used in company's production unit. The natural stone (Lipica enotni, Lipica rožasti and Repen) is used for buildings in Slovenia and other parts of the world. In addition to the production and processing company has also high quality manual processing.

Key words: underground excavation of natural stone, geological studies, mineral raw materials, Fantini chain saw machines

1. INTRODUCTION

A special and distinctive feature of natural stone is its hardness, stability and its possibility of shaping. Natural stone is unique and exceptional in itself, as its colours and structure are very different and dependent of the nature.

Beside physical and mechanical properties of stone, the excavation method is also influenced by mining and geological conditions as well as technical conditions of excavation. Judging from experience, the most problems in natural stone excavation are caused by tectonic influences, mainly cracking and fragmentation which, together with stratification and karstification, usually significantly reduce the yield or even prevent further excavation of blocks of natural stone.

2. GEOLOGICAL RESEARCH WORK

Geological researches play an important role in extraction of natural stone. With them we can determine the size, quality and economy of a deposit. They should be done before even starting a quarry and should also be done during the actual extraction to verify all previous collected information and if neccessary to change methods and/or place of excavation. With geological researches we can determine dangerous parts in the quarries and with right measurment taken we can improve the

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safty of work. With knowing the exact geological properties of a deposit we can also lower the expensses of excavation.

Figure 1 - Marmor, Sežana d.d. quarry

Geological methods in the quarries:

- tracking methods (geological mapping, sampling and examination of samples, geophysics, etc.);
- detailed geological mapping of stratigraphy, tectonic structures especially mapping of discontinuities in quarries' wall;
- oriented core drilling and mapping of the core;
- experimental cutting;
- sampling the querries' walls and cores;
- laboratory sample testing for usability;
- evaluation of field and laboratory data with the appropriate interpretation, reports writing.

Oriented core drilling has a special value in geological researches in the quarries. With it we can determine geological structure of the deposit, appearance, quality, resources and compactness of natural stone. With oriented core drilling we can determine spacial orientation of all discontinuities in the core. This is an important information as are geological structure, quality and resources and is used to plan excavation works and primary underground galleries (Kortnik, 2009b).

During the underground excavating of natural stone is very important to monitor all the discontinuities and map the walls, ceiling and floor. With collected data we can make a discontinuity map of the deposit as shown in figure 2. The data is used to further plan the underground spaces, provide security (anchoring) and calculation of the yield.

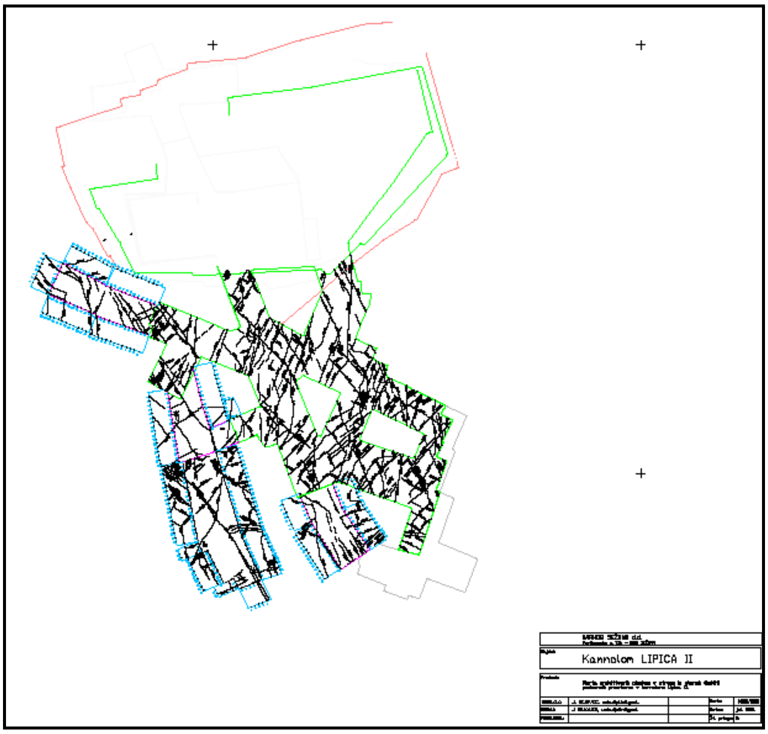

Figure 2 - Map of discontinuities in the quarry Lipica 2

3. THE EXCTRACTION OF NATURAL STONE

The demand for natural stone has rapidly grown in last few decades. That is why the exctraction of natural stone has moved also underground (Carrara - Italy, Kanfanar - Croatia and Marmor, Hotavlje - Slovenia). In our company we went to underground excavation in 2002 in Lipica 2 quarry. In 2006 we verified our own method chamber pillar excavation method which was made in colaboration with University of Ljubljana - Assis. Prof. Kortnik and Geological Survey of Slovenia – Vesel and Senegačnik. In 2009 we expand the underground excavation to the the quarries of Lipica 1 and Doline.

In 2006 we verificated our modificated room and pillar method.

Advantages of underground explotation:

- selective production of stone;
- working in all weather conditions;
- undamaged surface;
- less noisy and less dusty for surroundings.

Disadvantages of underground explotation:

- special machinery and cutting;
- material stays in the pillars;
- need of lighting, ventilation, anchoring, measuring instruments, etc.

4. DEVELOPMENT OF QUARRY EQUIPMENT

Until a few decades ago, the exploitation of stone was based on making use of its natural properties, mainly the cracks which were used for breaking the stone into smaller pieces. All works were done on the surface, manually, with primitive tools such as mallets, chisels, picks and various simple levers. The pieces of stone appearing on the surface were carved by picks and mallets until they broke. The work was long-lasting and strenuous.

A true revolution in the quarry work was brought about by boring drills. The work was still manual. Natural features of sites were exploited. In winter, people poured water in cracks. Freezing water expanded the cracks and made breaking of stone easier. Hazelnut rods and oak wedges were also used; they were hammered into cracks and moistened with water (Čuk, 2004).

The development of pneumatic drilling tools additionally changed and increased the production. Using pneumatic drilling equipment, people drilled under and around the rock mass which was then split into smaller blocks by means of wedges and heavy mallets. In most cases, they made use of natural features of the sites (discontinuities, stratification, etc.), but they also used various emulsions, gunpowder and detonating cord to split the rock mass apart (Jesenko et al. 2009).

The development of quarry equipment continued with helicoid wire and quartz sand. This method was first used in the year 1854. In our country, it continued to be used by mid-1980s. At cutting sites, vertical bores with a diameter of 240 - 360 mm and horizontal bores with a diameter of 90 mm were first drilled. A 5.8 mm helicoid wire was threaded through the bores and used, together with quartz sand, for cutting of stone. An engine room with a diesel aggregate was required for the start-up. Water was used as an additive and a coolant. The cutting efficiency was low, amounting to 1.5 to 2.0 m^2/h, depending on the hardness of the stone. The length of the wire system line was sometimes up to 2.5 km (Čuk, 2004). In the present time, helicoid wire has been replaced by diamond wire.

A new revolution in quarry mining was introduction of diamond wire saw. The first diamond wire saws came into operation in the 1970s. The cutting process is similar to the preceding technology; i.e. a combined method with previously drilled bores (34 - 90 mm in diameter) and diamond wire saw. The speed of cutting ranged from 8 to 12 m^2/h, which meant new possibilities in exploitation and processing of natural stone. In the beginning, diamond wire saws with 40 hp motors were used, which allowed cutting of surfaces of up to 150 m^2 (Čuk, 2004). Today, diamond wire saws with 25 - 75 hp motors are used, allowing cuts of up to 300 m^2. The use of water and wet cutting is compulsory, as it extends the service life of the diamond wire. The use of diamonds depends on the structure, compactness and type of the stone.

Additional development of quarry equipment was brought about by the introduction of chain saw cutting machines. The machine's principle is similar to that of a power wood saw; however, the machine has larger dimensions and an additional hydraulic and electrical system. The most important component of the machine is a blade with a chain. The blades are of various lengths, ranging from 1.5 m to 7 m, depending on the use of the machine. Cutting of stone is performed by using a chain blade with "widia" or diamond plates mounted on it. Diamond plates are made of small grains of polycrystalline diamond introduced in the tungsten carbide base. The plates are mounted, in different directions, in brackets on the chain. We have an option of wet or dry cutting.

Figure 3 - Chain saw on the rail and widia cutting elements (http://www.fantinispa.it)

The construction of the chain saw cutting machine allowed both horizontal and vertical cuts. In the beginning, machines for underground excavations were designed to have the cutting machine mounted on fixing pillars which allowed raising and lowering of the cutting section (Figure 3).

Deficiencies of older models encouraged the development of cutting machines towards greater mobility. So, presently, chain saw cutting machines are being used that consist of a single segment and have their own mobile unit. Due to their mobility, they can be used for both open-surface and underground exploitation.

Figure 4 - An old and a new model of the chain saw machine for underground mining. Left: the Fantini G.70 model on fixing pillars (Primavori, 2005). Right: the new Fantini GU70/R model (Kortnik, 2009a)

The Fantini G.70 chain saw cutting machine has been used by the company Marmor, Sežana d.d. since the year 2002. As evident from the photo, transportation of the machine requires a high-performance loader. Additionally, the connection to the control unit is done via hydraulic hoses which must be disconnected and reconnected for every movement of the machine. Machine setting procedures require a lot of time; approximately 2 hours are needed for each cut. An advance section consists of four horizontal and three vertical cuts.

An upgrade to the old Fantini G.70 cutting machine is represented by numerous new mobile models. At the company Marmor, Sežana d.d., we have selected the Fantini GU70/R model. The Fantini GU70/R model has been upgraded with a mobile unit, problems with hydraulic hoses have been eliminated, its dimensions and mobility allow cutting of larger widths and lengths, rotation of the blade in several directions allows cutting of the rear wall. After finished cutting, the machine automatically corrects the cut in order to avoid the risk of cutting into the safety pillars. Diamond cutting elements are used for cutting. An advance section cut with the new machine consists of five horizontal and three vertical cuts.

Table 1 - Presentation of properties of both Fantini chain saw cutting machines (Kortnik, 2009a)

	Chain saw cutting machine Fantini G.70	Mobile chain saw cutting machine Fantini GU70/R
Weight	6,000 kg	26,000 kg
Weight of the hydraulic unit	2,000 kg	-
Total instelled power	52.2 kW	60 kW
Blade run speed	0–0.07 m/min	0–0.08 m/min
Hydraulic oil tank capacity	300 l	450 l
Cut width	38 mm	38 mm
Blade length	2,900 mm	3,200 mm
Minimum gallery advance	71 m^3	85 m^3
Minimum advance section cutting cycle	41 h	47 h
Maximum height of cutting	4.5 m	5,4 m

Advance effects resulting from the introduction of the new machine compared to the previous model:

- approximately 20% more material excavated from a minimum advance section;
- the time required for setting the machine before operation has been cut in half;
- easier movement and faster retreat from the cutting location in case of danger;
- a new blade and electronics prevent the risk of cutting into the safety pillars;
- modified geometry of cutting the advance section (increased distances between cuts).

Beside the cutting equipment, natural stone excavation also requires high-performance loaders, powerful compressors, lifts, hydraulic rollers and water cushions with a water pump.

The effective cutting depth of the new Fantini GU70/R machine is 3.2 m. The geometry of cuts consists of five horizontal and three vertical cuts. If compared to the previous Fantini G.70 machine, the distribution of horizontal cuts is changed by adding another horizontal cut which increases the height of the underground terrain from 4.5 m to 5.2 m or more. The distribution is adapted to the best possible yield of material from an advance section. Lower distances between horizontal cuts have been increased in order to obtain blocks of maximum height dimensions for further processing. Certain horizontal cuts can be omitted, but due to the structure and cracking of the site, this might aggravate the work and increase the exploitation costs. As excavation at higher levels is more difficult, the distances between horizontal cuts are increasingly smaller with height. Sometimes, a horizontal cut can be omitted, contributing to a better yield from an advance section.

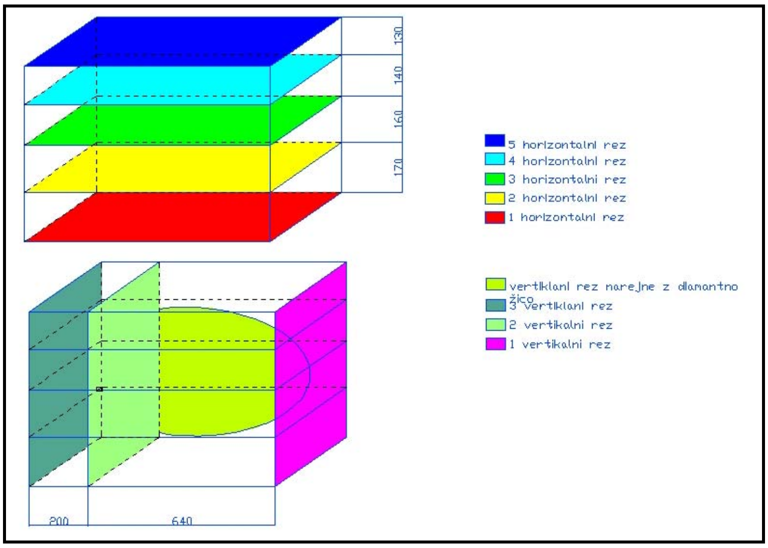

Figure 5 - System of cutting with new chain saw Fantini GU70/R

5. GEOTECHNICAL MEASUREMENTS

Geotechnical measurements are used for the observation of the deformation field around an excavation. Monitoring of stress and deformation are very important to insure underground stability and safety. the following geotechnical equipment was installed into safety pillars:

- crack – meters for measuring distances between the sides of joints (El – beam sensor);
- Vibrating wire biaxial stressmeters for monitoring stresses, temperature and deformation in pillars. The stressmeter is installed in the borehole and grouted (Fifer-Bizjak, 2003);
- Measuring distances between three screws on the main joint in the form of triangle.

To control measurements of the changes in stress state oh high safety pillars, a 2D stressmeter (vibrating wire biaxial stressmeter model 4350-1 made by Geokon was used to monitor the main stresses in a single vertical plane perpendicular to the axis of the drill hole. Measurements of the main stresses are enabled by three vibrating wire sensors, which are oriented at 60^o angles within the probe. The instruments can also measure a temperature. The stressmeter body is made of a steel cylinder with a maximum external diameter of 57.1 mm (Kortnik, 2009b).

Figure 6 - Vibrating wire -VW (biaxial stressmeter 4350BX)

Technical characteristics of stressmeter (model 4350BX):

- standard stressmeter range: 70 MPa
- resolution: 14 to 70 kPa
- accuracy: ± 0.1% F.S.
- temperature range: -20 to +80^{o}C (253 to 353^{o}K)
- borehole diameter: BX (60 mm)

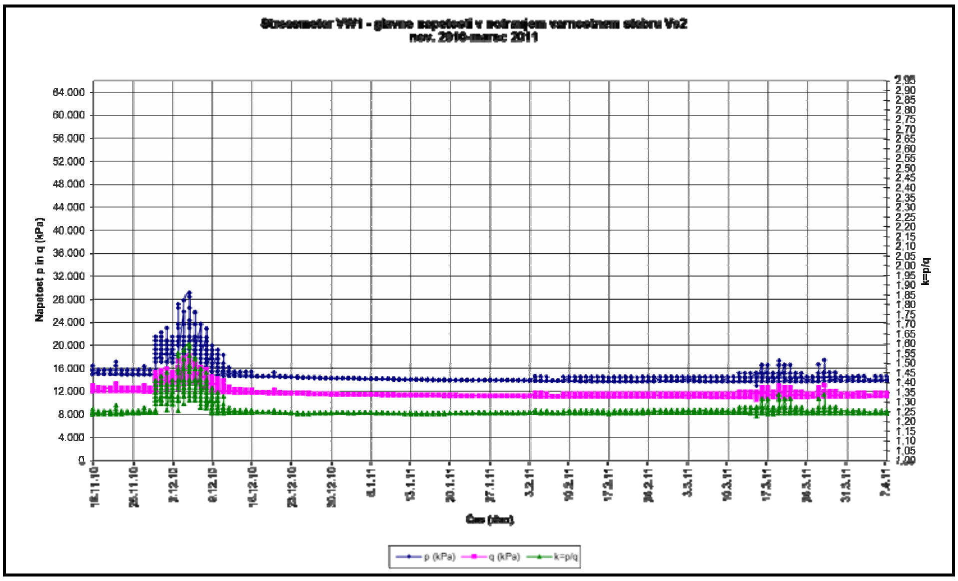

Figure 7 - Analize data from stressmeter in the quarry Lipica 2

For transferring data from the stressmeter, a memory unit (datalogger CR10 modul, AVW1, SC32B) is used for the data capture, along with the appropriate software (the PC200W software package). The data capture is done automatically, using the time interval set in the program (1 min, 1 hour, or 4 hours).

6. CONCLUSIONS

Based on the research results we can choose the optimal technology and technological processes of production which will give us a satisfactory economic - technological results.

Although the technology is further developing it is still necessary to consider natural features and characteristics of deposits when extracting natural stone.

The new approach of excavation requires tecnologically, organizationally and in terms of safety professional approach. Furthermore we have to give great importance to the safety at work such as monitoring the stress parameters in the security pillars, daily observation of security seals on cracks and anchoring hazardous areas.

With professional approach and continuous learning and training we can make underground excavation of natural stone successfull and safe. Training includes attending and organizing rescue trainings with which we can verify our competence and response to major emergencies. With the analysis and actions that follow we can strongly improve response times, correctness of actions during the intervention and correct actions which in a real accident could prove fatal. In addition it is also an opportunity to verify and coordinate the activities of individual rescue departments which are specialized for certain natural or other disasters and to teach them how to work together. Coordinated actions of these services are often crucial. Only a coordinated team of rescuers can save lives, prevent ecological disasters and ultimately protect infrastructure. And this was the purpose of rescue training that was organised in the Lipica 2 quarry.

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