

Technological process and equipment selection for excavation of natural stone in Lipica quarry

Izbira tehnološkega procesa in opreme za pridobivanje naravnega kamna v kamnolomu Lipica

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Abstract: Stone is an important part of nature. When man realised that stone is useful, they started to think of easiest methods of its exploitation. Through the centuries, there have been numerous research studies and development of expertise necessary for selection of natural stone, methods of its exploitation and most effective procedures for its processing. The development is still continuing today. Improvements in the field of technology have resulted in increased production, safer work procedures and transition from open surface to underground excavation methods. The article presents the development of quarry equipments, proper selection of the technological process and introduction of the new chain saw cutting machine in excavation of natural stone (i.e. limestone) in the quarries of the company Marmor, Sežana, d. d.

Izvleček: Kamen je pomemben del narave. Ko je človek spoznal, da je kamen uporaben, je začel razmišljati o njegovem najlažjem pridobivanju. Skozi stoletja so tekle mnoge raziskave in razvoj potrebnih znanj s ciljem izbire naravnega kamna, načina njegovega pridobivanja in postopkov najbolj učinkovite obdelave. Ta razvoj se nadaljuje tudi danes. Izboljšave na področju tehnologije niso omogočile le povečanja proizvodnje, temveč tudi varnejše delo in prehod s površinskega na podzemni način pridobivanja. V članku je predstavljen razvoj kamnolomske opreme, pravilna izbira tehnološkega procesa in uvedba

novega verižnega zasekovalnega stroja pri pridobivanju naravnega kamna – apnenca v kamnolomih družbe Marmor, Sežana, d. d.

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

Ključne besede: podzemno pridobivanje naravnega kamna, geološke raziskave, mineralne surovine, verižne žage

INTRODUCTION

Natural stone used for construction purposes are the rocks whose colour, compactness or other properties are appealing to a human eye. They were used by old civilisations to glorify their monarchs or even to make them equal to gods. It is precisely the use of stone that made it possible for many great achievements of the past to remain preserved until today.

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.

Additionally, the excavation processes and the final yield in a quarry are mostly influenced by the excavation method, the use of suitable equipment and utilisation of natural features of stone.

DEVELOPMENT OF QUARRY EQUIPMENT

Natural stone is undoubtedly the material that has been used by man throughout the entire history. The prehistoric man exploited the stone by collecting it from the ground or breaking and digging to the depth or size easily lifted and transported. The stone was processed by means of stone and wooden tools. After discovery of metals, metal tools were used for stone processing. The man used stone for tools and weapons in the struggle against nature and for construction purposes. Beautiful stone blocks were used for making monuments, doorposts, portals, etc. The material was transported by oxen, horses, etc. ^[5]

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. ^[2]

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. ^[3]

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 mm and 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 m²/h to 2.0 m²/h, depending on the hardness of the stone. The length of the wire system line was sometimes up to 2.5 km. ^[2] 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 m²/h to 12 m²/h, which meant new possibilities in exploitation and processing of natural stone. In the beginning, diamond wire saws with 30 kW (40 hp) motors were used, which allowed cutting of surfaces of up to 150 m². ^[2] Today,

diamond wire saws with 19–56 kW (25–75 hp) motors are used, allowing cuts of up to 300 m². 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 di-

mensions 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.

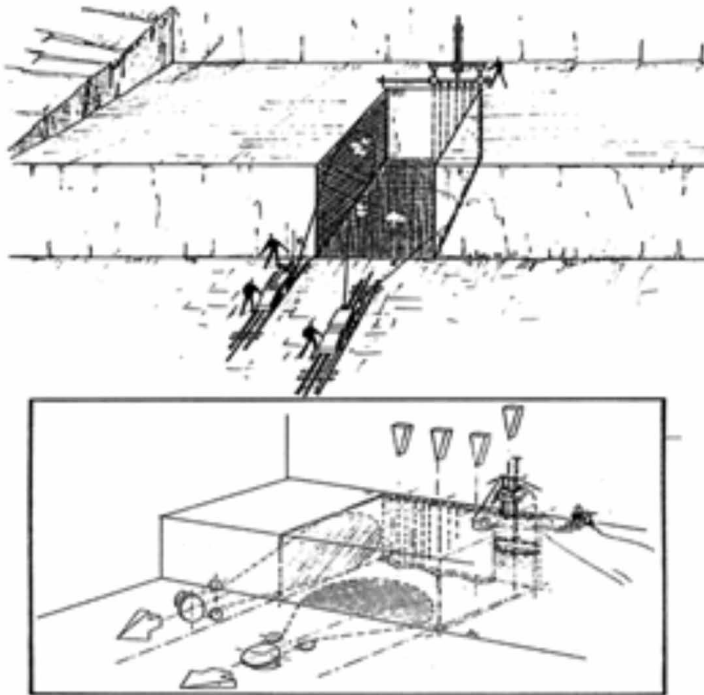


Figure 1. Illustration of exploitation by means of the drilling equipment and diamond wire saw ^[1]



Figure 2. A track chain saw and cutting elements ^[6]



Figure 3. An old and a new model of the chain saw machine for underground mining. Left: the Fantini G. 70 model on fixing pillars. Right: the new Fantini GU 70/R model. ^[6]

Chain saw cutting machines were first produced for open-surface exploitation shown in Figure 2. The construction of the 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 - left).

Deficiencies of older models encouraged the development of cutting ma-

chines 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.

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 h 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 GU 70/R model. The Fantini GU 70/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.

Advance effects resulting from the introduction of the new machine com-

Table 1. Presentation of properties of both Fantini chain saw cutting machines^[6]

	Chain saw cutting machine Fantini G.70	Mobile chain saw cutting machine Fantini GU 70/R
Weight	6 000 kg	26 000 kg
Weight of the hydraulic unit	2 000 kg	-
Total installed 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

pared 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 GU 70/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

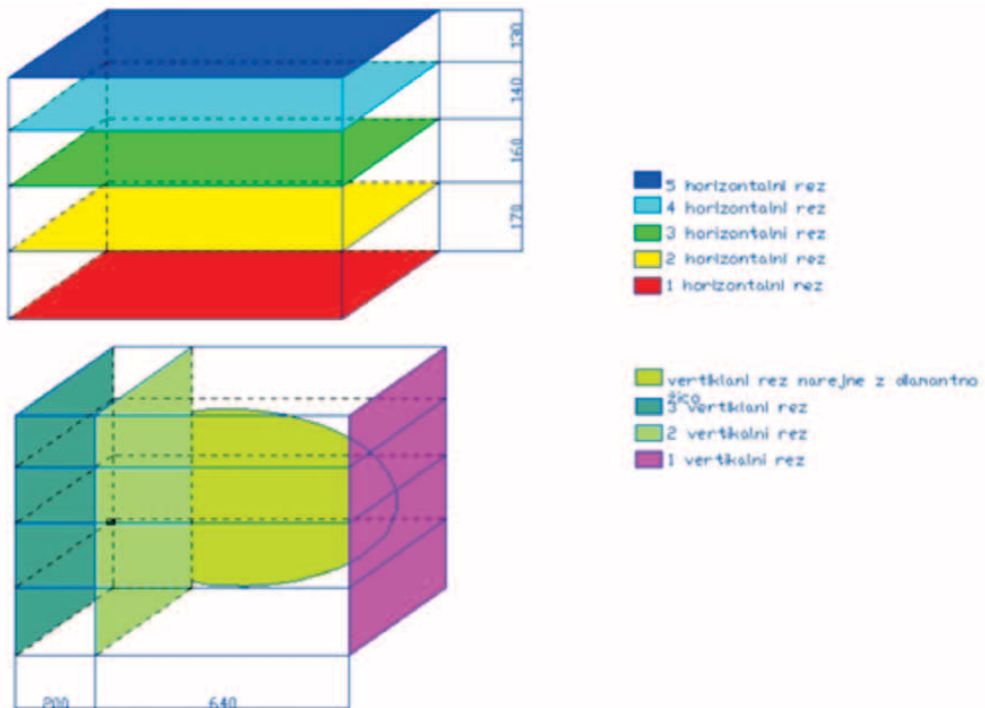


Figure 4. Geometry of distribution of cuts in the use of the new Fantini GU 70/R cutting machine

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. In the excavation of natural stone from quarries of Marmor, Sežana, d. d., the cutting geometry as illustrated in Figure 4 is used. Sometimes, a horizontal cut can be omitted, contributing to a better yield from an advance section.

SELECTION OF EQUIPMENT

Quarry equipment requires careful selection, as the use of unsuitable equip-

ment significantly increases excavation costs.

Before selecting the machines, the following research should be done:

- geological studies must be made to establish the geological structure, reserves and quality of the mineral material,
- geomechanical studies must be made to establish the physical and mechanical parameters of the material, strength, abrasiveness, possibility of swelling, chemical and mineral structure.

Before selecting the equipment, an appropriate excavation method should be selected; i.e. either surface or underground excavation. On the surface, a method of excavation from top to bottom is used; the height of exploitation floors is usually 3 m to 6 m. In underground excavation, the combined



Figure 5. Open surface and underground excavation - Lipica 1 quarry.

chamber-and-pillar method is used. In it of great importance that at the first level the distribution of cuts is precisely determined, as it influences the final yield of material.

Selection of the excavation method or the proper cutting system depends on the type of the material, compactness, quantity and price of the material. In most cases, faster and better work requires combination of various cutting machines to obtain satisfactory excavation results.

Cutting equipment in quarries should be complemented by high performance loaders, as larger and more powerful machines make the excavation process easier and more economic. In excavation operations, the use of various bumper cylinders, water and air cushions is also required.

CUTTING PERFORMANCE COMPARISON

The reasons for underground excavation of natural stone are the following:

- geological properties of the site,
- selective excavation of natural stone,
- less environmental damage and less environmental noise,
- work is possible in any weather conditions,
- possibilities for the use of such underground locations after finished excavation works.

Because of the transfer to underground exploitation, a research is done on the impact of the underground exploitation method that is applied in Lipica II to the surface [8]. The results of the research have shown that the method of underground exploitation applied to Lipica II does not have an impact on the surface. As there is no movement in any direction, there is no deformation and the surface has stayed the same (as if no work is being done below). It has been expected that there will not be any impact to the surface, on the base [9], but because of the specificity of Lipica II, adapted research of [8] research had to be done.

Demand for natural stone blocks, increased production in the quarries, cost reduction in the process of excavation of natural stone and safer work operations are the main requirements regarding the excavation which have contributed to the development of a newer model of chain saw cutting machines.

Relocation of production from the surface to the underground required the development of technology suitable for underground excavation. Initially, chain saw cutting machines with fixating pillars were used (Figure 3 - left). The Fantini G. 70 machine consists of two segments: the cutting segment and the hydraulic control segment. The machine is transported to and from the cutting site by means of a loader.

Before the beginning of each cutting operation, it takes the operators approximately two hours to prepare the machines, set the blade in a horizontal position and to rotate the cutting elements. Before every movement of the machine, it is required to disconnect and arrange the hydraulic hoses. When making the first sections in a gallery, where fixation of pillars in the ceiling is not possible, stabilisation by means of chains is required. Problems may occur in the event of crumbling of the front section, with numerous instances of damage to the pillars.

Models of chain saw cutting machines are very different. Types of machines depend on the customers' requirements. There are several models of chain saw cutting machines. The machines are distinguished from each other by their intended use, cutting characteristics, dimensions and their electrical and hydraulic equipment. The newer machines have certain additional features:

- the machine's mobility,
- increased cutting height,
- the shape of the blade, an automatic blade levelling function has been added,
- faster movement in larger cutting widths,
- possible cutting of the back cut of an advance section,
- elimination of deficiencies of hydraulic cables,
- a computer to monitor the cutting

parameters,

- remote control of the machine.
- the weight of the machines allows easier start in making the first sections in a gallery.

With the new Fantini 70 GU/R machine, the deficiencies have been eliminated and improved. The comparison of the results between the machines G.70 and 70 GU/R is given in the table 1.

By introducing a new Fantini GU 70/R chain saw cutting machine, the company Marmor, Sežana, d. d., has acquired a machine of high quality and high performance. Compared to the old model, G.70, the minimum advance section (5.6 m × 4.5 m × 2.8 m) has been increased in height from 4.5 m to 5.2 m and in depth from 2.8 m to 3.0 m, thus harvesting by 20 % more material from a minimum advance section than by using the old model. Both the old and the new machine can be used to immediately start cutting the maximum width of a gallery. With the new chain saw cutting machine, approximately seven working days are required for an advance section of approximate size of 150 m³; with the older G.70 model, at least nine working days were required. The only problem that occurred was the construction of initial crossroads in a gallery, as the length of the new machine prevented its positioning in the direction of advancement. Therefore, we had to position the machine diago-

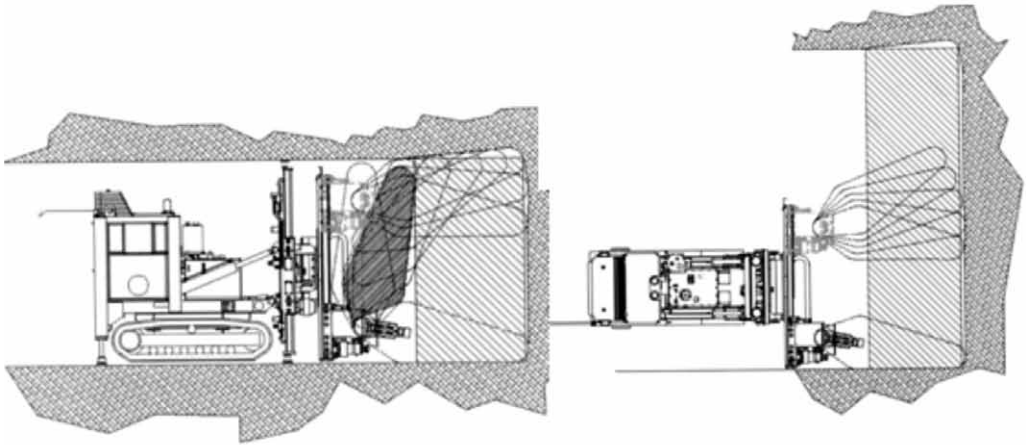


Figure 6. Illustration of making a vertical and horizontal cut by using the Fantini GU 70/R chain saw cutting machine and the XXL blade ^[6]



Figure 7. Comparison of initial cuts for a gallery with both Fantini machines ^[4]

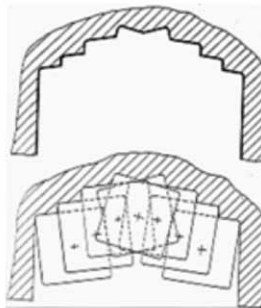


Figure 8. Arrangement of cutting elements in a cut ^[4]

nally to the front and begin cutting in the material.

The arrangement of cutting plates on the chain (shown in Figure 8). The thickness of the cut is still 38 mm, and the system of the blade with cutting plates has remained the same. Different shaped on cutting elements are used: square, trapezoidal, star-shaped and round cross-cut sections of cutting elements. The shapes depend on the properties of the materials being cut as well as on the structure of “widia” plates. In our production, we use square-shaped “widia” plates, which can be rotated eight times, and round-shaped diamond cutting elements. The difference between the both is in price; the diamond plates are 10 times more expensive and more durable.

A proper distribution of horizontal and vertical cuts can also affect the yield of material, but it requires supervisor's constant monitoring and control, as the geological and safety conditions in a stone quarry change from one advance section to another.

CONCLUSION

Technological development in the production of natural stone is still an ongoing process. In the exploitation industry, there is an increasing collaboration among the manufacturers

of working equipment and customers, as they together provide development of new and better equipment. New modifications to machines used in quarry work facilitate excavation and processing of the material. There are numerous manufacturers of chain saw cutting machines worldwide. Customers can choose from models that are most suitable for characteristics of their sites, their excavation preferences and prices. A great emphasis is on the production of suitable tools and cutting elements for different types of natural stone, as each material has its own properties. A new technology which is increasingly gaining in importance is the so-called waterjet technology, i.e. cutting of material by means of a water jet. The said technology is currently used primarily for processing of material in workshops.

Proper selection of technology requires previous elaboration of detailed geological and laboratory studies (mechanical and physical parameters of stone, chemical composition of the material), economic assessment of the site and consideration of nature protection conditions.

Based on results of the studies, we can select the optimal technology and technological processes of excavation to achieve satisfactory economic and technological results.

Despite continuous development of the technology, excavation of natural stone still requires consideration of natural features of sites and properties of stone, as they were observed in the past.

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