COMBINED METHODS FOR EXTRACTION OF LARGE DIMENSION STONE BLOCKS FOR DECORATIVE PURPOSES

Nadezhda K. Stoycheva

University of Mining and Geology "St. Ivan Rilski", 1700 Sofia; nandy_f@abv.bg

ABSTRACT. The report discusses combined methods for extraction of large rock blocks. For primary separation of the lamellae from the main rock body and its splitting into smaller blocks, suitable for transportation and subsequent processing to finished products, different types of stone cutting machines and precise drilling and blasting activities are used. The main problem when working with high-speed or industrial explosives for extracting large blocks of expensive stone is the aggressive impact of the shock wave on the solid medium. The overpressure of the shock wave front during detonation shatters the rock around the blast hole and can cause cracks in unwanted directions. Under complicated conditions, it is necessary to interrupt the rock environment in advance to shield the propagation of pressure waves caused by the detonation of larger explosive charges. Techniques that combine the simultaneous use of explosive and mechanical methods to separate rock blocks from the massif are discussed. Emphasis is placed on various methods for protecting the surfaces of the rock block and the main massif from unwanted cracking during blasting activities.

Keywords: extraction of rock cladding materials; splitting of dimension stone blocks; precise blasting; low explosives; stone cutting machines

КОМБИНИРАНИ МЕТОДИ ЗА ДОБИВ НА ЕДРОГАБАРИТНИ ОРАЗМЕРЕНИ КАМЕННИ БЛОКОВЕ ЗА ДЕКОРАТИВНИ ЦЕЛИ

Надежда К. Стойчева

Минно-геоложки университет „Св. Иван Рилски", 1700 София

РЕЗЮМЕ. В доклада са разгледани комбинирани методи за добив на едрогабаритни скални блокове. За първично отделяне на ламелите от основното скално тяло и разцепването му на по-малки блокове, подходящи за транспортиране и последваща обработка до готови продукти се, използват различни видове каменорезни машини и прецизни пробивно-взривни работи. Основен проблем при работа с високоскоростни експлозиви за извличане на големи блокове от качествен материал е агресивното въздействие на ударната вълна върху твърдата среда. Свръхналягането на фронта на ударната вълна при детонацията раздробява скалата около взривната дупка и може да причини пукнатини и в нежелани посоки. При усложнени условия е необходимо предварително прекъсване на скалната среда за екраниране на разпространението на вълни на натиск, причинени от детонацията на по-големи заряди. Обсъдени са техники, които комбинират едновременното използване на експлозивни и механични методи за отделяне на скални блокове от масива. Акцентира се върху различни методи за защита на повърхностите на скалния блок и на основния масив от нежелано напукване при взривно въздействие.

Ключови думи: добив на скално-облицовъчни материали; отцепване на оразмерени блокове; прецизно взривяване; ниско-скоростни експлозиви; каменорезни машини

Introduction

The modern techniques and technological schemes in the extraction of ornamental stone aim at high-performance and efficient extraction with minimal losses of valuable raw material. Therefore, it is crucial to select the most rational way to discover the deposits, as well as to apply the appropriate technology for the specific conditions with relevant mechanization. The use of modern technologies and their rapid development, which has been observed over the last 50 years, is a clear sign of the need for this type of minerals. The technologies and methods considered in the present study are focused on separating the rock blocks by cutting from the massif.

Technologies for quarry extraction of dimension stone

The quarry stage of production has the following phases: preparation of the bench, separation of the primary lamella (whose size varies from ten to one hundred cubic meters) and finally dismantling of the rock lamella on the pit floor to be cut into smaller blocks with commercial sizes. The technologies for extraction of natural stones are:

Technology with drilling mechanization and wedge separation of the blocks from the massif. In this method, the separation of the blocks from the massif is done by drilling and wedge works, which overcome the cohesion forces of the rock particles and disrupt their integrity. The main operations in this technology are two - drilling holes at a certain distance (vertical, horizontal or inclined) and splitting with different types of wedges. Nowadays, hydraulic wedges are used - both manual and automated. The holes are drilled along the contours of the block. The depth, diameter and distance between them depend exclusively on the physical and mechanical properties of the rocks. The desired splitting occurs in the area between the perforations - the distance of least resistance on the rock.

Technology with chain saw cutting machines. Chainsaws are driven by electric engine. The essence of this technology is to make vertical and horizontal cuts with a cutting chain, which is equipped with teeth made of hard steel or diamond. In a technological plan with chain saw stone-cutting machines, high productivity and large block sizes are achieved, if the mining and geological conditions allow it.

Diamond wire cutting technology. In general, this method is cutting the rocks by movement and applying the principle of abrasive wear on the rocks. The cutting element of the machine is the so-called "Diamond" wire. It is formed in a closed loop around the section which has to be cut. The cooling of the wire and the cleaning of the cut are guaranteed by a constant water supply. To ensure a closed loop, it is necessary to drill two intersecting holes in the massif. The wire passes through them so as to obtain a closed circle. During the cutting itself, the machine, which most often travels on a rail track, moves away from the massif. In this way the wire is stretched and cuts optimally. Diamond wire stone cutting machines can operate in a wide range of angles to the face. They can change the directions of the "diamond" wire in terms of the type of cut and the specific situation.

Technology with drilling mechanization and chemical agents. This technology is based on the property of certain chemical compounds when wet to "absorb" water by binding it to their own molecules in the so-called “chelate coordination complexes”. Upon apparent drying of the material, the water molecules appear to be part of the crystal lattice of the compound. This leads to a drastic increase in the coefficient of volumetric expansion. Thus, these substances, when placed in the drilled holes and in contact with water, are able to harden and expand after a period of time. In this way, they create stresses in the rocks up to 40-45 MPa. The essence of the technology is the same as in the drilling-wedge and drilling-blasting method. With the drilling mechanization (perforators, drilling rig boomers, jumbo drillers or borers) vertical and horizontal holes with a diameter of 30-50 mm are perforated along the contours of the block. The distance between the holes depends on the specific conditions, the type of rocks extracted and the expansion capacity of the chemical compound.

Technology with flame-jet cutting. Thermal "cutting" of rocks is an effective non-contact method. The so-called thermo-cutters (thermal burners, flame-jets, air-jet burners, etc.). They are used for the destruction of hard rocks, such as granite, granodiorite, sandstones and others with quartz content. Flame-jets are mainly used for making incisions in the rock massif, but can also be used for drilling in the massif and secondary fragmentation of rocks.

Technology with water jet cutting. In general, this technology is the destruction of rocks by means of a high-pressure water jet (about 350 MPa). The cutting of the rocks itself is not done by friction, impact or chemical reaction, but by breaking and separating the constituent compounds of the material. The bonds between the minerals in the rock medium are literally falling apart due to the thrust of the high water pressure. The system of the water jet cutting machine consists of two main components - a pressure generator and a nozzle.

Technology with drilling equipment and energy of the explosion. This method of extraction comes into use when the application of stone cutting machines from a practical, economic and environmental point of view are irrelevant. It is workable for extraction of ornamental stones with compressive strength greater than 100 MPa, strongly cracked rocks, with the content of hard and highly abrasive inclusions in the rock mass, as well as in the presence of horizontal cracks in rocks such as granite, gabbro, limestone and others. In the presence of layers over 1.5 m thickness, when mechanical splitting methods are not effective, as well as in the development of inclined layers up to 40°, this technology is applicable also.

The sequence of the technology is as follows: blastholes (horizontal and/or vertical) are drilled in the chosen direction for splitting the rocks. Drilling mechanization is the same as in the drilling-wedge method. The diameter of the blast-holes is between 20 and 50 mm. In some cases drillings with larger sizes are applied. Then, a multi-deck charges of high-explosive or a certain number of detonating cord threads, could be loaded in the drilled holes.

Combined technologies for extraction of rock cladding materials. They are a blend of some of the methods already mentioned. The parameters and the construction of the quarry with applied combined technology depend on the specific mining and geological conditions of the deposit and the technical characteristics of the used mechanization. The complex technology is flexible and allows to use the advantages of the separate technologies, which when properly matched with appropriate equipment can afford very good results for obtaining higher quality blocks and higher yield. One of the most popular/common combined methods Is those between mechanical pre-cutting and controlled blasting with various explosive.

Advantages and drawbacks when using high explosives or non-detonating charges

Knowing the assets and shortcomings of using various explosives is crucial for managing blasting energy and preventing the harmful effects of the detonations.

The main advantage of high explosives is the low price. They easily cause the formation of a crack in the rock thanks to the energy of the pressure shock wave. This is achieved by drilling a series of blast holes in a given plane, which are charged and detonated simultaneously. The resulting shock waves are superimposed along the line between the boreholes, increasing the compressive forces generated in this plane. The compressive forces cause tensile forces in the rock perpendicular to the direction of action. In this way, splitting takes place along the line between the holes as a result of exceeding the tensile strength of the rock. With a small amount of industrial explosive, the necessary clefts for separation of the dimension stone could be achieved. Their disadvantage is the difficult control of the explosive energy, released by the detonation. In many cases, this energy causes the formation of parasitic cracks, which degrade the performance of the material and lead to a decrease in yield.

Modern non-detonating explosives combine the throwing properties of the blasting gunpowder with preferences such as: water resistance, improved energy, reduced emissions of harmful gases and solid particles. An important advantage of deflagrating charges is their non-aggressive impact on rock splitting. It is obtained due to the slower chemical reaction. The expansion of the hot gaseous products creates compressive forces on the walls of the blast holes that overcome the tensile strength of the rock. The result is a smooth slit in the specified direction, without unnecessary cracking of the material.

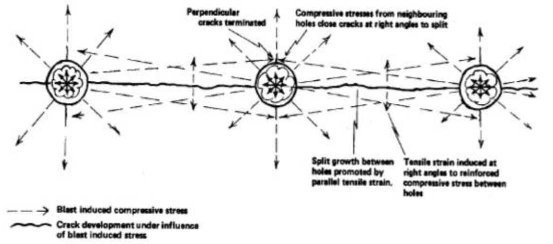

Fig.1. Crack-formation process

Another asset of ready-made non-detonating explosive cartridges is their low hazard class in accordance with international agreements and the national laws of most countries. A lighter conditions for acquisition, transportation, storage and use contributes to cost reduction. Their application is accompanied by the absence of air blast, insignificant fly-rocks and lack of seismic vibrations. For these reasons, quarries for decorative rock materials in developed countries are gradually putting into operation the new generation of propellant based blasting devices. These charges are a successful solution against damages, caused by conventional explosives during the extraction. At the same time, they are the better substitute for blasting gunpowder.

A drawback when working with non-detonating charges is the relatively higher cost of the products, compared to traditional explosives. Another negative is the relatively higher consumption of explosives to form one square meter of sloping surface. As a disadvantage, it can also be noted the need for a reliable plug, which ensures the retention of exhaust gases to achieve optimal blasting effect.

Methods for limiting the harmful effects of the propagation of the pressure wave in the rock medium

In the extraction of dimension stones, drilling and blasting activities are applied for removal of soil layers and rocks of poor quality (overburden), as well as for primary separation of the lamella from the massif and its splitting into smaller blocks, suitable for transportation and post-processing to finished products. In these operations, a risk of creating compressive stresses and irreversible deformations in the valuable raw material is existing. This requires additional measures to protect the windrow surfaces and the rock body in depth.

Fig.2. Bench blasting for removal of waste rock in dimension stone quarry

The most effective method for limiting the propagation of a pressure wave in the massif is to break the rock medium by creating a shielding surface for wave reflection. The ways for intersection of the rock are: mechanical cutting with diamond-wire cutters, cutting with chain-saw cutters, cutting with a series of overlapping perforations and by presplit blasting.

Fig.3. Decoupled multi-deck chained charge loading

Presplit blasting with industrial explosives in the separation of rock blocks has been used less and less in recent years. The blasting action caused by the detonation and the high energy of the shock wave are prerequisites for the formation of unwanted cracks in the extracted lamella and the residual massif. The danger of damaging high-quality material forces quarry owners to look for alternative approaches with reduced risk. Presplit blasting finds greater application in removing the overburden.

Fig.4. Pre-split blasting preparation

The methodology is based on the creation of a shielding surface to separate low-quality material from the deposit, which is intended for extraction. It is performed before the main blasting to break up the overburden. This surface is usually performed in the vertical direction.

Fig.5. Split-blasting for removal of waste rock close to high quality material

Fig.6. Pre-splitting crack and displacement of the low quality limestone after split-blasting

Fig.7. Effect of smooth blasting on the limestone wall after excavation

Under suitable conditions for access of drilling equipment in the face, a presplit row can also be perforated in the horizontal direction. The horizontal shielding surface is performed over an existing vein or over the visual boundary between the overburden layer and the high quality material layer, parallel to the occurrence direction.

Fig.8. Horizontal drill holes for pre- split blasting

Depending on the diameter of the drilling chisel and the calculated specific explosive consumption, it is desirable to drill the horizontal holes at a distance of 1.0 - 1.5 m above the extraction layer. Presplit blasting is carried out with garland charges of high explosives.

Fig.9. Horizontal split crack in limestone

The section with a curve contoured by shielding surfaces is considered as prepared for fragmentation with blasting drill-holes. The charges in production blast-holes on the periphery of the blast field should be with 40-60% less mass than the others. It is recommended that the horizontal shielding row to be perforated 1.5 - 2 m below the level of the bottoms of the production drill-holes. All this is done to ensure that when the overburden is fragmented by detonation, the cracking will not reach the high quality stone. In cases where no clear boundary is observed and there is no natural crack that separates the quality material from the unnecessary material in the massif, it is recommended that it should be cut mechanically. This interruption of the rock environment is a reinsurance against the transmission of compressive stresses from the presplit blasting to the deposit, intended for subsequent extraction.

Combined methods for removing the overburden during extraction of dimension stones

In some deposits of dimension stones, the ledges with high quality raw material are not compact, but are surrounded by rocks with poor exploitation characteristics. The quarry is developed in areas around the relevant ledges, and the unnecessary rock mass is excavated and removed. Each section is developed with faces and trenches on extraction benches to provide open surfaces and easy access. Proximity to the valuable raw material requires more attention and precision in removing the useless rock. The last remaining volumes of the overburden are approached literally as a quality material - taken out in large blocks. Subsequently, they are crushed on the pit floor and transported. In such situations it is necessary to use a combination of mechanical and explosive methods for separation and fragmentation of the blocks with waste rock.

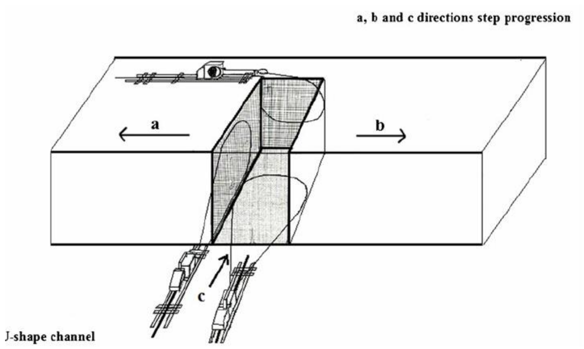

Fig.10. Diamond saw cutting for separation of the stone-volume to be crushed

The maximum volume of the block is determined according to the parameters of the bench and the capabilities of the available mechanization. Depending on the access, the contours are cut with chain-saw cutters and diamond-wire cutters. If any of the pre-cuts cannot be made, it should be replaced with pre-splitting blast holes in a row. If a wider protective crack is required, pre-split blast holes could be perforated parallel to the finished cuts along the inner contour of the block. The distance from the pre-splitting row to the pre-cut should not be less than 0.50 m. The blast field has to be perforated with vertical boreholes, and the parameters of the blasting pattern should be calculated for a "charge of low swelling", depending on the diameter of the chisel of the drill. This reduced explosive effect is achieved by decreasing the relative consumption of the explosive.

Fig.11. Pre-cutted along the perimeter block of overburden, repared for loading with explosives.

The distance from the peripheral production blastholes to the mechanical pre-incision should not be less than the distance between two production blastholes. It is preferable to form oversized boulders, rather than transmitting a shock wave when shrinking the narrow pre-cut.

Fig.12. Effect of mechanical pre-cutting

For a more even distribution of the explosive energy along the perforation, a multi-deck design of the charges in the blastholes is recommended. To better control the propagation of the blast-induced seismic vibrations in the massif, the individual charges should be initiated with a millisecond delay. When using an inert intermediate stemming, the bottom charge in each of the blastholes explodes 25 ms before the upper charge. Depending on the shape of the undermining cut, the smallest possible number of blastholes has to be initiated simultaneously in a series. To achieve really low levels of vibration, it is allowed the blastholes to be sequentally initiated one after another. When the charges work individually, the fragmentation of the muckpile also decreases. There are practically no strict requirements for the granulometry of the overburden. The size of the boulders is determined by the cargo space and the technical parameters of the available transport equipment.

Fig.13. Muckpile of waste rock after blasting of the pre-cutted block

Due to the weak blasting effect, the crushed rock remains as a compact pile within the bench. During the excavation, a perfect separation along the perimeter of the preliminary cuts was observed. There are no visible traces of damage and deformation on the smooth vertical walls of the residual massif.

Conclussions

In developed countries, ornamental stone quarries are using high explosives only to remove overburden. For the fine work of displacement the primary lamella and the splitting operations for its cutting into commercial-sized blocks, they rely mainly on combined methods and partly on low-speed explosive charges. Thus, the losses from the cracked outer layer of the rock materials with first-class decorative characteristics are drastically reduced.

The desired splitting with high-speed explosives is achieved through the optimal balance of the distance between the holes and the power of the explosive. The tensile strength of the rock is exceeded only where there is an accumulation of shock waves, ie. along the line between the holes.

The application of combined methods, which include pre-contouring with mechanical cuts of the volume of waste rock intended for explosive crushing and removal, is a successful way to protect the deposit from cracking during blasting.

Refferences

Belin V., Mitkov V., 2015. Vliyanie kachestva vzrivchatih materialov promishlenogo naznacheniya na efektivnosti drobleniya gornoy masi vzrivom, Informatsionno-analiticheskiy biyuletin ANO “Natsionalnaya organizatsiya inzhenerov-vzrivnikov v podderzhku profesionalnogo razvitiya", № 2, pp. 37-39, ISSN 2411-491X. (in Russian)

Boychev Y., Asenov S., 2018, "Pirotehnicheski sastavi za neletalni svetlinnozvukovi sredstva", ISBN:978-619-7246-20-9, ISSN:2367-7481, 614-620, National Academic Publishing House. (in Bulgarian)

Boychev Y., 2018, "Pirotehnicheski neletalni sredstva za zashtita", National conference with international attendance "Defence Industry – Leader of the Innovations in Bulgaria", 20.09.2018, Sofia, Bulgaria. (in Bulgarian)

Mitkov V., 2007. *Proizvodstvo na eksplozivi za grazhdanski tseli*, ISBN 978-954-353-049-6. (in Bulgarian)

Mitkov V., 2010. *Bezopasnost pri proizvodstvoto i upotrebata na eksplozivi*, ISBN 978-954-353-131-8. (in Bulgarian)

Shishkov P., Stoycheva N., 2018. "Savremenni vzrivni tehniki za dobiv na skalno-oblicovachni materiali" - *Mining and geology magazine*, 10-11, p.42-49, ISSN 0861-5713. (in Bulgarian with English abstract)

Shiskov, P. 2019. *Spravochnik na vzrivnika*. Izdatelska kashta Sv. Ivan Rilski, Sofia - 244 p. ISBN 978-954-353-378-9. (in Bulgarian)

Stoilova S., Mitkov V., Belin V., 2014. Analiz na vuzdeistvieto na vazdushnata udarna valna za usloviyata na kariera "Tselovizhda" , *Annual of the University of Mining and Geology "St. Ivan Rilski"* – Sofia, v. 57, Part II: Dobiv prerabotka na polezni surovini, pp.108-110, ISSN 1312-1820, (in Bulgarian with English abstract).

Stoyanov D.,1994. *Rakovodstvo za uprazhneniya po probivno-vzrivni raboti v otkriti rudnici, karieri i stroitelstvoto*", MGU, Sofia. (in Bulgarian)

Stoycheva N., Shishkov P., 2019. „Innovative formulations for a new generation of low-speed explosive compositions, designed for blasting in tender conditions and for extraction of rock-cladding materials" – *Journal of Mining and Geological Sciences*, p.94 – 99, vol.62, Nr.2 (in English).