Carinthia University of Applied Sciences

Work Package 3: Environmental Impact

Cleanstone Project

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Work Package 3: Protocols to reduce the environmental impact of stone processing - Environmental impact and best practices

Environmental impact: Marble quarry

In the following tables (Tables 1-3) the environmental impacts of the marble quarries will be shortly summarized from the literature *"Toward a holistic environmental impact assessment of marble quarrying and processing: proposal of a novel easy-to-use IPAT-based method"* [1].

Tab. 1: Environmental impact: stages [1]

Marble Processes described by Hanieh				
Site	Phases of marble		Environmental Impacts	
Quarry (Raw material)	Pre production	Mining	Excavation: produces dust when stones fall down, when loading and shipping the blocks or crushed stone.	Detonating cord or explosives also generates sound,vibration and dust
		Transportation from mine to industrial plant	Quarry diesel vehicules produce dust, waste (solid and liquid), noise, vibrations	
		Storage at industrial plant		
Industrial plant (marble sawing/block cutting and slab/tile surface processing	Production	Processing	Sawing activities produce less dust since water is used to cool down blades and tools. Dust ist not blowing again but captured by water	
		Polishing, resin application	Dust is generated	Slurry is generated from polishing, cutting and finishing operations in the cut and clean operations of machinery
		Transportation to the building site		
Building site	Use	Use		
Nature/new product	End of life	landfilling		
		reuse/recylcle		
Summary	Extraction of massive blocks cut of them in smaller blocks to transport it to industrial plants. At the plants the blocks are cut into shaped sizes and forms(slabs or tiles)			
Energy aspects	This quarrying process needs a high consumption of energy. The highest consume of energy occurs during the sawing process.			
Innotative Machinery	Innovative machines diffusion present some obstacules due to often are managed by family run company, very common in Italy, so changes in technology sometimes are difficult			

Tab. 2: Environmental impact: quarry site [1]

Quarry Site		
Storage	Electricity consumption, noise, spillages of oil on soil	Depletion of natural resources, noise pollution, contamination of soil
Operations	Water and electricity consumption, production of waste (Scraps), noise, dust, water discharge, spillage of oil on soil	Depletion of natural resources, abandonment of waste, noise and atmosphere pollution, contamination of soil
Resin reinforcement for failures in marble slabs (refill with resin)	Usage of dangerous substances, Odor, production of special waste	Contamination of soil, atmosphere pollution, waste in the environment not correclty managed
Transport to processing plant	Fuel consumption, dust, spillage of oil on soil	Atmosphere pollution, contamination of soil
Office activities	Water and electricity consumption, production of urban waste ,water discharge (pit imhoff)	Depletion of natural resources, abandonment of urban waste, contamination of soil/groundwater pollution
Waste water treatment	Waste, spillage of contaminated water	Abandonment of waste in the environment, groundwater pollution

Tab. 3: Environmental impact: processing plant [1]

Surface processing plant		
Resin reinforcement	Usage of dangerous substances, Odor, production of special waste	Contamination of soil, atmosphere pollution, waste in the environment not correclty managed
Polishing	Water and electricity consumption, production of waste (grinding wheels, sludge), noise, water dicharge, spillage of oil on soil	Depletion of natural resources, abandonment of waste in the environment, noise pollution, contamination of soil
Distribution of finished product	Fuel consumption	Atmosphere pollution, depletion of natural resources
Waste treatment	Waste, spillage of contaminated water	Abandonment of waste in the environment, contamination of groundwater

Best practices: Dimensional stone clean production

In the following table, the environmental Impacts of the processing and the best practices for dimensional stone are listed. The following chart was summarised from literature *"A methodology for evaluating cleaner production in the stone processing industry: case study of a Shandong stone processing firm"* [2].

Tab. 4: Best practices: Clean production [2]

Clean Production (CP)	
References: Methodology for evaluating cleaner production in the stone processing industry: case study of a Shandong stone processing firm. Authors: Shuo-wei Bai, Jin-sheng Zhang, Zhi Wang, China	
Environment pollution	Waste, noise,sawdust, crushed slabs and scraps during processing stage
Clean Production	Demands all phases of life cycle of a product and the objective is to minimize risks to environment
Clean Production phases	Machining system: optimum sawing parameters: low wear, low energy consumption,high cutting efficiency. The main study is on the interaction between tool surface and stone: reduce friction interactions. Coating diamond tool with Titanium Chromium Alloy. Sandwich-core sawblade to cut natural stone consumes less energy and less noise emission and has less environmental impact than the multi blade gangsaw (MBGS). After making a Life cycle assessment (LCA) between the usage of MBGS and the diamond multi wire saw (DMWS) technologies, the LCA shows that DMWS reduce stone products environmental footprint by 35%.
	Reusing the solid waste: reusing of mud and solid residues that are currently landfilled and causing environmental impact in soil, air and water. Possible resues: Usage of granite and powders in concrete as a replacement of natural aggregates is being studied: the properties studied of this concrete are compr. Strenght, split tensile strength, flexural strength, ultrasonic pulse velocity and elastic modulus. Other usages: Usage of marble waste as acidic neutralizing agent in acid soils. Usage of limestone sawdust as a filler in paper, rubber and paints.
	Wastewater treatment and recycling system: water with particles of powder can be microfiltrated and be reused. Also can be clarified using flocculants and separated from the solids with a filter press. After this treatments the water might be reused.
	Management and planning: Use the principle of 3R (Reduce, Reuse and Recycle). Reduce the energy consumption, use three dimension topographic models to establish land management planning guidelines, treatment of wastes to make secondary raw materials with them.
Problems of Clean Production	Lack of founds or lack of environmental consciousness, or companies adopt clean production techniques blindly without a plan, which cause no significan improvement
	Financial criteria of the decision making of the manager's personal
Tools to quantify potential environmental impact	Life Cycle Assessment (Best practices ISO 14040 Series): normally large amounts of data are needed to perform the LCA. However, most of the times this data is not available or companies don't want to provide. These are some of the difficulties to evaluate the industrial impacts.
Criteria to assess environmental performance	Use national standards for pollutants as the basic requirements, national environmental laws, rules and regulations related to stone industry as legal references
Data collection over years	Field measurements and monitoring in the stone machining process with special instruments: noise-measuring instrument, dust sampler to measure fine particles in suspension in the air, solid waste generated, water that needs to be treated, etc. All this data should be compare them with a place near which is not being mined.

Transport: Environmental impact and best practices

The University of Tennessee published some recommendations in their manual *"Best practices of the natural stone industry. Transportation."* [3]. The main ideas of this document were summarised in order to provide relevant information for the project.

Best practices: the need of strategic transportation

Quarries are located in the geologic deposit. However, not always the processing plants are located in the same place. That's why shipment is unavoidable. The stone heavy transportation can be expensive economically and environmentally. Implementing transportation management promotes shipment efficiency minimising negative impacts of the environment and reducing cost. The main benefits of strategic transport are: reduction of environmental footprint, cost saving, shortened lead-time and efficient shipment.

Movement of stone

Some quarries and fabrication facilities are located in the same site while others can be miles apart. Choosing the simplest route and driving directly from the quarry to the processing plant of the customer is one of the most important best practices in these cases. A quarry can sell blocks to a separated company for processing and sale as finished product, in fact some stone travels between continents. Some countries like the US send the stone to coutries with low labor costs like China for processing. The product is then sold back to the US or Canada and being marketed as imported stone although the original quarry is in the US.

Environmental Impact of Transportation

- Truck: produces noise and air pollutants. Considered the less environmentally preferable.
- Ship: environmental impacts are associated with water vessel operation: nonrenewable energy consumption, displacement of ecosystem elements, discharge of oily bilge and ballast water, disposal of non-biodegradable solid waste in the ocean and air emissions. Discharging ballast water: taking water in one port, stored in a vessel's hull and released at another port, bringing multitude of organisms that can disrupt the new ecosystem (e.g. invasion of the Great lakes by zebra mussels).
- Rail: most favorable regarding CO_2 emissions and cheap profile

Best practices: Transport

- Efficiency: optimisation of fuel efficiency results in cost and emissions savings per cubic foot of stone transported
- Equipment: ask for trucks wide based tires, as opposed to dual tires, on the drive and trailer axles, this reduces tare weight and drag. Proper tire inflation to avoid unnecessary rolling resistance and tire wear. Request trucks with minimal tare weight. Implement maximum speed polices for drivers to reduce fuel consumption and for safety reasons. Stipulate that drivers are trained on fuel reduction techniques, shifting methods, route selection, idling time, number of stops and use of accessories.
- Load wisely: distribute the load stone across the bed area so that the trailer is balanced properly. Stone can be secured correctly with appropriate tie-down techniques, protect

edge and corners of stone to prevent damage that results in lost money, waste generation

- Package with sustainable materials: resusable packaging, reduce the use of throw-away materials. Minimise the usage of plastic wrap which is made of petroleum products and sometimes it is not recycled.
- Discuss the best modes and routes of travels with carriers. The carrier is very knowledgeable about means of transport and many have modeling programs that calculate the most efficient method.
- Employ computer programs: transportation management system (TMS) and electronic data interface/exchange (EDI) make planning and sharing information easier. TMS select the most efficient shipment option based on the inputs of mode, transit time and cost while EDI facilitates the communication with the carrier.
- Employ rail if possible: less environmentally burdensome than trucking.

Best practices: Technology

Diamond Wire technology

In the publication *"Diamond wire sawing in ornamental basalt quarries: technical, economic and environmental considerations"* [4] from the University of Cagliari some benefits about the usage of diamond wire for extraction and processing of decorative stones are explained. In this publication, the benefits of using diamond wire for the cutting process are refered to its usage in the marble and granite industry for ornamental purposes. Besides of the high cost of diamond wire this tool prevents stone damage in decorative stones. Not every stone that is damaged cannot be used in the industry of decorative stones and it is directly discarded and producing waste. The usage of diamond wire reduces the excavation time, costs, the cuts are precise and the production of powder during the cutting process is lower compared with other equipment, so less waste is produced. The diamond wire uses motos and pulley. The diamond wire has central steel woven core with diamond beads and diamond beech. Then a machine rotates the wire through the pulleys and pulls it or pushes it down through the stone with the diamond beads doing all the cutting. This new technology of wires is not only used for the primary cut but also introduce into the slabbing process, this reduce the times of cutting from days to hours to cut blocks compared with the old industry of multi blade marble block sawing machine.

Optimising the cutting performance using diamond wires

In the publication *"Optimization of diamond wire cutting performance in travertine quarrying"* [5] an assessment of the cutting performance was made by analysing the retraction current strength, diamond bead density, distance between cutting machine and working surface, and the number of cutting surfaces required. Based on the results of these studies, it was found that there is a significant relationship between the pullback current strength and the cutting speed for large surfaces, which has to be optimised to improve the cutting process.

In order to minimise the cost of extraction and to reach a clean cutting and good quality processes it is necessary to research into the optimum cutting parameters. This is essential for reducing costs and maximising production.

There are several specific parameters including rock, machine, and operational conditions that can be affected by the wire cutting performance (see Fig. 1). Controllable and non-controllable rock-related parameters represent the two main groups in the subdivision. The "controllable ones" include the equipment available and the machine power, whereas the "uncontrollable ones" cannot be changed by humans, like the properties of the rock.

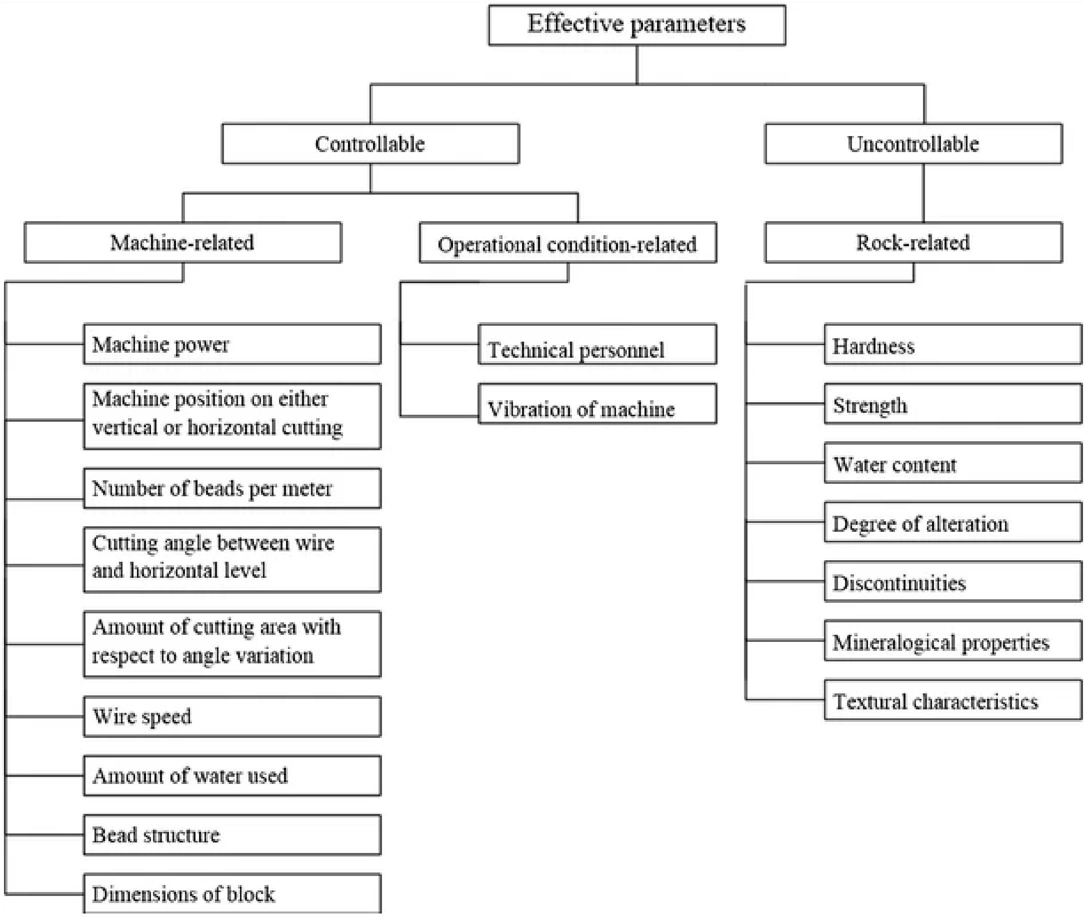


Fig. 1: Effective parameters on cutting efficiency of diamond wire saw method

Nowadays, rock cutting with diamond wire is the most common rock block production in quarry mines. In this cutting method, first, some vertical holes are drilled, and then they are intersected by horizontal holes drilled through the stone. The diamond wire is threaded through these intersected holes then mounted around the machine wheel drive. Fig. 2 shows the wire with diamond beads and diamond cutting procedure (Özçelik and Kulaksız 2000; Ghaysari et al. 2012). In the diamond cutting method, a wheel drive is used to rotate the diamond wire and steel cable, generally with 10 to 12 and 5 mm diameter, respectively. A diamond wire has small diamond beads mounted on specific distances of the wire. Movement of the diamond wire on a rail system in the opposing direction of cutting surface creates a tensional force for rock cutting. During the cutting, water is used as wire coolant and also for removing the small particles of rock.

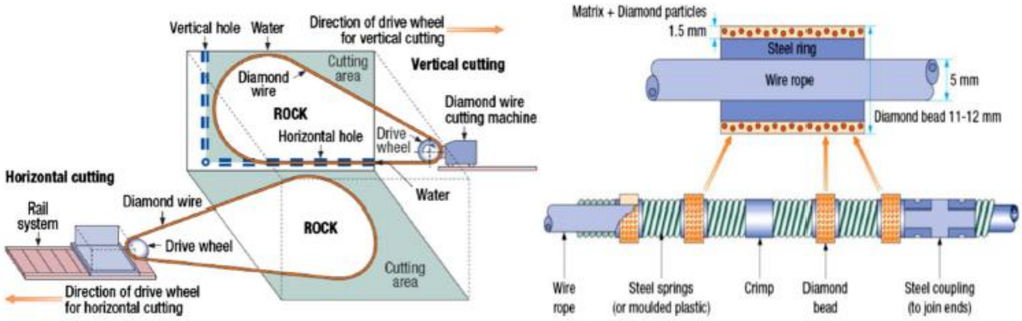


Fig. 2: Wire rope with diamond beads and diamond cutting process

Dewaterting Process

The main reason why it is important the usage of sedimentation pools and filter presses is because the dewatering process of the sludge allows the reuse the water and the dry solids in further recycling applications. The clarification of the water is crucial in order to reuse this water in the same process and recirculate it in a closed system. However, recirculating the water is not always possible since the chemical properties of the water are highly deteriorated resulting in a very alkaline chemical composition which is not optimal for its usage in the cutting process to cool down the blades and neither for the stones themselves.

Digitalisation in mining

The main information about this topic was extracted and summarised from the article *"Digitalisierung im Bergbau – Industrie 4.0"* from the Mining Report website [6]. Digitisation is already well advanced and an integral part of many sectors of industry. Even for the mining sector, although it still needs to catch up, there are already some technologies available in this regard, that mining companies can use to intensify digitalisation. Digitalization optimizes processes in the industry (see Fig. 3). In the past, optimization in the mining industry only served as a method to reduce costs. Now, however, modern technology is opening up new avenues that are leading to significant productivity gains. Continuous investments in automation, power supply and drilling systems are increasing mining volumes while saving on labour and energy costs. Increasing costs, environmental issues, declining global demand and growing safety risks are just some of the challenges facing the mining industry, and these areas will continue to play an increasingly important role in the future. The positive side, however, is that through dedicated implementation of innovations and intelligent data collection and use, these problems can be counteracted. To do this, new technologies must be introduced and information technology must be used more, rather than insisting on optimizing old processes. The mining industry is still at the beginning of the innovation process, although the pioneers from the automotive industry are providing some technologies that the mining industry can adopt. This is, for example, end-to-end process automation and instrumentation, the use of project planning and application software for the entire life cycle phase of the plant and the use of software platforms with which data from different sources can be brought together. This provides a better overview and provides all the information needed to make the best possible decision.

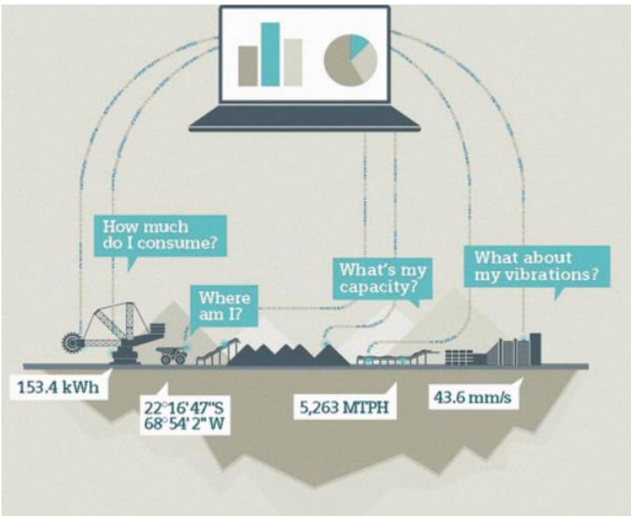


Fig. 3: The potential of digitalization

Industry 4.0 is the term for the fourth industrial revolution. It is based on systems with integrated software and electronics that communicate with the outside world via sensors and actuators. They are based on automation and this should ensure maximum efficiency and availability.

An outstanding example of this is Minerals Automation Standard (MinAS), a process control system from Siemens AG developed for the special requirements of the mining industry. By combining the latest hardware, technologies with functionality matured over 40 years for automation in the mining industry, time and money are saved.

Even before a problem occurs, maintenance functions can be used to quickly diagnose potential faults. Downtimes are thus avoided or shortened. MinAS uses modern process control systems to maximize productivity and reliability.

These products integrate protection, industrial safety and energy management systems, ensuring the protection of employees, equipment and the environment.

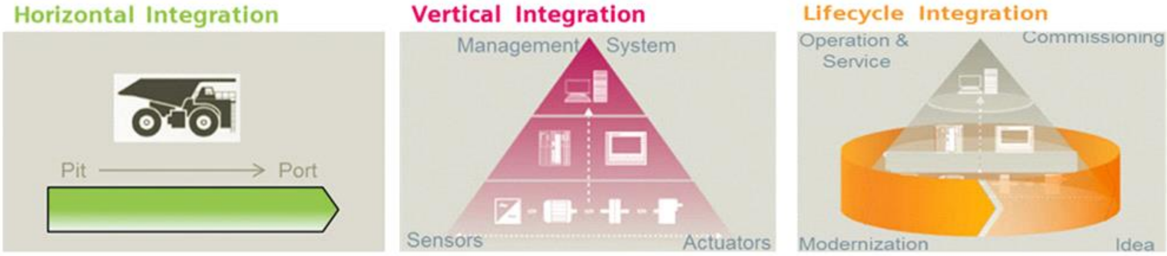


Fig. 4: The three pillars of digitalization

This graphic depicts the three pillars of digitalization (see Fig. 4). This shows that automation alone is not enough. The second illustration shows that for an optimal workflow, all process stages must be interlinked. Characteristically, mining sites are usually located off the beaten track with harsh environmental conditions. The different process sections usually take place at greater distances from each other, for example, mining takes place on the upper levels while the processing plant is located in the valley. In order to ensure smooth work processes, special equipment is required that can withstand the rough influences of a quarry. Standard compliant but robust communication networks and products are required that can withstand strong electromagnetic interference, vibrations and extreme temperatures. The use of radio technology and wirelessly connected components improves the level of mobility. Profinet, for example, enables undisturbed real-time communication over distances of several kilometres, which is often the case in quarries. At the same time, this also serves the safety of the employees. Compliance with international standards such as IEC 61850 and IEEE 1613 is essential for open, reliable and secure transmission.

An important factor for mine operators is always to reduce costs, but in particular, they are now being asked to reduce energy costs. Highly efficient drivelines, in which all components are ideally matched to each other, make this possible. Energy audits provide a transparent picture of all consumers in a mine, making it easy to determine the potential for reducing energy consumption. If continuous automation is in place, carrying out such audits is not a problem.

Cost reductions can be made not only during the operational phase. A software platform called COMOS from Siemens provides plant project planning. Here, applications of all life cycle phases are available - from the engineering and operating phase to modernization and dismantling. A plant operated with COMOS forms a large database in which all information is continuously available and up-to-date.

Since the actual status is always displayed, modernization is made as easy as possible. The current status does not have to be catalogued by laboriously updating old plans. COMOS combines areas that were previously separated from each other in a standardized data structure (process technology, mechanical engineering, electrical and control engineering).

Critical information is usually scattered over a multitude of databases and operational systems, which makes it considerably more difficult for the operating personnel to get a timely picture of the actual situation. Digitization can only draw on its full potential if information is brought together in a meaningful way.

Another Siemens tool is XHQ Enterprise Operations Intelligence. It extracts, collects, compares and presents operational and business data from a variety of information sources. XHQ gives operators in the mining industry access to real-time information that can effectively reduce operational overruns through alarms, warnings and notifications, and effective troubleshooting. With access to equipment monitoring data and the resulting visibility of condition, machine operators, sensor manufacturers and other personnel can perform predictive maintenance of equipment.

The most important questions for successful digitalization are whether the necessary sensors are available for data transmission and where this data is stored, whether on the company's own servers or, for example, in the cloud, which in turn can be public or private. Using the internet, the possibilities are almost limitless, but in return, companies must increasingly deal with security issues. Remote maintenance and remote diagnostics can also lead to increased access violations and data manipulation as well as data loss.

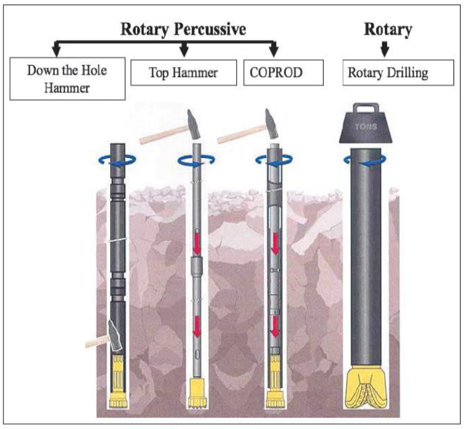
This can cause serious damage to the company in the form of financial losses, environmental damage and even fatal accidents. This requires sufficient financial resources for staff training and equipment, openness to innovation, expert knowledge and awareness of the benefits that can be gained from a technical strategy.

The problems underlying the mining industry can be mitigated by the alternatives offered by digitalization. The systems already in place provide an interface between data collection and the management of this data between the different sites. In order to implement an effective digitalization, a competent partner with the appropriate hardware and software tools is needed to improve competitiveness and increase productivity.

Optimization of blasting methods

In the publication *"Drilling and blasting improvement in aggregate quarry at Thailand – a case study"* [7] the optimization of blasting methods is studied. Data collected from blasting operations in several large quarries in Thailand have been analyzed. In quarries, the height of the blasthole in the blasthole bench is normally determined by the capacities of the drilling machine. The mining engineer can adjust or select plan views to optimize operating costs. To optimize the blast pattern, the desired fragmentation with a minimum powder factor is essential. This counts both for cost reduction in drilling and blasting. These include the rock type and the discontinuities present in it which also influence the optimization of the blasting design.

The use of different drilling methods (see Table 5) and drills depend of the different types of rock (see Fig. 5). The Top Hammer (TH) and Down the Hole (DTH) drilling systems are most suitable for limestone deposits, taking into account the compressive strength of the rock:



Method	Uniaxial Compressive Rock Strength Mpa	Hole Diameter Inch
Top hammer	100 - 500	1 - 9
Down the hole hammer	100 - 500	3.5 - 9
Rotary crushing	100 - 500	5 - > 15
Rotary cutting	0 - 100	1 - 15

Fig. 5: Different types of drills and their applications

Drill Method	Top Hammer	DTH	COPROD
Penetration Rate	0000	000	00000
Straight holes	000	00000	0000
Hole depth	000	00000	0000
Production capacity	0000	000	00000
Low fuel consumption	00000	000	00000
Economic drill string life	000	0000	00000
Low investment for drill string	00000	0000	000
Suitable for difficult conditions	000	0000	00000
Operator friendly	0000	00000	000

00000 Very Good   0000 Good   000 Fair

Fig. 6: Comparison of different drilling methods

Drillers in the COPROD category have the largest investment in drill rods, which are a recurring expense and one that reduces availability. The operation of COPROD drill requires highly skilled personnel.

The DTH drill has the lowest penetration depth, which results in lower production capacity and the highest fuel consumption.

The Top Hammer is characterized by the low fuel consumption and the low investment of the drill pipe. It also has a very good penetration depth and is user-friendly. The hammer drill of this method has proven itself through higher penetration depth, low fuel consumption and low investment for drill rods.

DTH drills are suitable for complex geology or difficult working conditions and greater working heights. With this type of drill, it is necessary for the operator to be trained regularly.

The advanced functions of the drilling machines allows an improvement of the cutting process. In Fig. 6 the basic features of drilling in limestone are shown. Importance is given to each parameter so that blasting planning can be done with utmost precision.

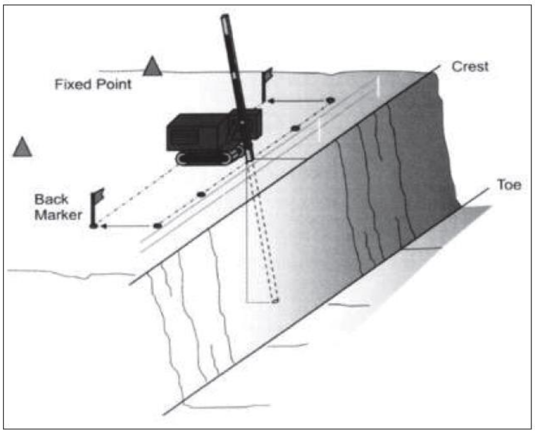


Fig. 7: Basic features of drilling in limestone bench

The Following features are selected for improving drilling accuracy:

- Setting out
- Checking holes for following features
- Straightness
- Angle and direction (azimuth) of inclination
- Depth
- Checking holes
- Collar position

Often the floor of the work area becomes uneven when blasting, which affects the efficiency of loading and transport. Safety is an issue due to poor road conditions.

The main conclusions of the study in order to improve the blast performance were the following:

- Usage of non-electric detonators instead of electric detonators for reducing environmental impact (Air overpressure, flyrock and ground vibration) due to blasting and improving fragmentation. In order to reduce the seismic manifestation of the explosion and improve the quality of blasting operations to reduce accidents and injuries, the use of non-electric detonation elements has come into use, as they can change the delay between explosions over a wide range
- Use of bulk emulsion with expanded pattern due to higher energy and also water resistance for watery holes
- DTH drilling machine has lowest penetration rate resulting in lowest production capacity and highest fuel consumption
- Top hammer has advantages of lowest fuel consumption and low string investment
- Top hammer has very good penetration rate and is operator friendly

Conclusion

The aim of this document was to collect information and analyze the environmental impact of the different phases like mining, transportation, storage and processing of the quarrying process. The life cycle assessment is the tool to quantify the potential environmental impact produced by these activities. The identification of the impacts aims to create a list of best practices that will lead the quarry sector to a cleaner production. The principle of reduce, reuse and recycle will allow the now called 'waste materials' to be considered as 'secondary raw materials'. This change of perspective will lead to include and contemplate the secondary raw materials in national guidelines and standards and reinsert them in the market as a valuable material. The strategic transportation, the optimization of the cutting and blasting process, the digitalization of the quarrying sector are some of the main aspects to improve in order to reduce the environmental impact.

List of figures an tables

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