STONE QUARRYING: THE ITALIAN EXPERIENCE

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ÖZET

Bu bildiride taşocağı işletmeciliğinin bugünkü durumu, üretim yöntemleri, geleneksel ve yeni taş teknolojileri, üretim maliyetleri ve iş idaresi açısından incelenmektedir.

Yeni teknolojilerin getirdiği avantajlar belirtilerek, çevresel sorunlar da tartışılmıştır.

ABSTRACT

The paper gives an overview of the present state of stone industry, pointing out the main aspects regarding quarrying methods, traditional and advanced cutting technologies, production cost and operations management.

The problems related to the environmental impact are also discussed, with particular stress on the advantages offered by the introduction of novel technologies.

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1 - INTRODUCTION

Despite the present stagnation, stone industry is expected to continue its growth trend worldwide, under the increasing pressure of a widespread demand for natural materials to be employed in various branches of construction engineering, such as industrialized building, urban fitting, road paving and interior decoration, to mention but the most important.

In this context, Italy is by far the leader Country, accounting for about one third of the overall production (between marble and granite) and for more than half of stone processing output. Moreover machinery and equipment made in Italy are exported all over the world.

Stone quarrying and processing activities have recently been involved in an impressive technological progress characterized by the introduction of advanced cutting methods, the use of powerful material handling equipment, the improvement of stone working machinery and the application of sophisticated management tools, resulting in a spectacular increase of productive parameters accompanied by a substantial improvement of the material quality (C. COSTA, 1986).

At the same time, pit geometry (size of the faces, extension of the working areas), quarry design, plant lay-out and operations management (optimization of the working cycle), were adapted accordingly, availing of a better technical knowledge and of higher manpower skill.

2 - INDUSTRIAL OVERVIEW

World production of ornamental stone, in terms of quarried blocks, is believed to be well in excess of 25 million tonnes, between "marble" (16 million) and "granite" (nine million), with a compound rate of growth approaching 6.5% over the last ten years.

The corresponding figure in terms of conventional slabs (2 cm thick) is 275 million m2, taking into account that about 50 % of the volume is lost as processing scrap (block leftover, sawing dust, trimming waste).

The Italian contribution to that output can be estimated to be at least 7.5 million tonnes, consisting prevailingly of carbonate materials (marble, travertine, polishable limestones) accounting for 70 % of the total, while materials of magmatic origin (granite and alike intrusive rocks) represent a minor share (about 15 %) , the balance being covered by other materials (sandstone, porphyry, basalt, trachyte, gneiss, slate and tuff).

Long term prospects appear brighter for granite, the overall demand of is tendentially growing faster than in the case of marble, due to its intensive use for exterior facing and paving.

Italy is very active in the world trade. The Country exports more than 2.2 million tonnes of stone materials and imports about 1.7 million tonnes, corresponding to about 25 % and 20 % of total world interchange, respectively. Import consists for the largest part (86 %) of granite blocks, whereas export is chiefly represented by finished products (80 %) .

The outline of the Italian stone industry can be assumed as representative of the European situation, whereas in developing Countries the progress is still lagging behind, though gaining pace from the dissemination of the technological know-how.

In a comprehensive overview, direct manpower in Italian stone quarries amount to about 35,000 workers, including most enterpreneurs themselves, divided among 2,500 firms, to which an indirect occupation of at least 5,000 people involved in transport, maintenance and services should be added, giving a total exceeding 40.000.

Stone processing activity is carried out by about 12,000 firms of different size. More than 25,000 employees pertain to a group of major concerns (representing about 15 % of the total, by number) dealing with the production of both finished and semi-finished products. A large number of smaller companies and craftsmen accounting for a further employment of about 30,000 workers, deal chiefly with the production of commissioned manufacts, starting from the semi-finished slabs supplied by the former.

Therefore, the total number of enterprises operating in the stone industry amounts to about 15,000 subjects, each with an average workforce of six persons (more than 15 for the group of major concerns and about three for the smaller firms), totalling at least 90,000 employees.

The world turnover of finished products of stone is around 13 billion !j>$, with an average selling price of 42 US$/m2.

Overall fixed assets of stone industry (capital investments subjected to depreciation) are about 12 billion US$ with a replacement period of 10 years.

Stone industry is rather labour-intensive: production cost splitting gives a manpower incidence of 51 %, while energy accounts for 27 %.

3 - QUARRYING METHODS

A number of options are available for mining out a stone deposit. The choice among them depends on the kind of material, the shape and size of the geologic formation, the topography of the àite, the overburden thickness, the location of the quarry, the production level and the imposed restrictions (R. CICCU, 1989).

Caving methods based on huge blasts of rock were quite popular in the past, before the advent of cutting technologies. They still survive in few instances where no alternate is available, but their procrastination will no longer be tolerated, in compliance with environment protection rules.

If the use of continuous cutting technologies is hindered by unfavourable structural features, such as the presence of families of fractures across the massif, selective quarrying methods can be adopted. Unshaped blocks, whose liberation is completed by means of suitably directed explosive splitting cuts, are individually drawn from the quarry faces and trailed to the working site for final shaping into marketable blocks. In this way stone recovery can be maximized and hence the amount of waste is reduced. Target output is achieved by resorting to a high level of mechanization regarding both drilling and material moving operations, enabling a faster progress of the quarrying activity.

The large majority of stone quarries are now conducted according to a regular bench design, using a proper combination of cutting technologies, suggested by the peculiarities of each situation.

The shallow bench variant, whereby blocks of commercial size are directly extracted from the massif, is conveniently applicable in the case of homogeneous rocks having constant features and structural discontinuities sufficiently spaced apart. The advantages deal with safety, mechanization and environmental care.

For marble, an attractive technical solution matching the shallow bench design is the following (Figure 1):

- orthogonal vertical cuts made with the rock cutter machine
- undercut with diamond wire for groups of blocks

In the case of defective heterogeneous rock, material selection is needed for producing blocks exempt from flaws. The goal can be attained by resorting a high bench design, following a sequence of cascade

Figure 1 - Shallow bench method in a marble quarry (Italy)

Figure 2 - High bench method in a granite quarry (Sardinia, Italy)

subdivisions: huge primary blocks (usually some thousand m3 in size) are first isolated and subsequently split into individual slices (typically of the order of some hundred m3 in size), toppled to the floor and worked out on the site. Blocks are obtained by means of suitably directed cuts, whereas the discarded parts are sent to dump. The production is usually divided into classes of quality on the basis of acceptability criteria (shape, size and aesthetic features). Irregular blocks of marble are still amenable to processing for the production of tiles, whereas for granite this would be economically unfeasible.

The high bench method is widely applied both in marble and granite quarries, though with some differences regarding the technologies employed (Figure 2).

For marble the following operations are customarily carried out:

- Undercut by means of the rockcutter machine or diamond wire
- Vertical cuts with diamond wire
- Block shaping cuts with diamond wire or drill-and-shear techniques

For granite:

- Bench opening cut using flame, diamond wire or continuous drilling
- Primary cuts through explosive splitting
- Bench undercut again with explosive splitting, simultaneously to the former
- Secondary bench slicing cuts with explosive splitting or diamond wire
- Block shaping and squaring by wedge shearing

For bench undercut as well as for block working cuts, interesting prospects of industrial application can be assigned to waterjet.

Underground room and pillar methods are increasingly being adopted using diamond-based tecnologies in many marble quarries, located in steep mountainous regions where the stone formation is surmounted by thick

Figure 3 - Underground room and pillar method in a marble quarry (Carrara, Italy)

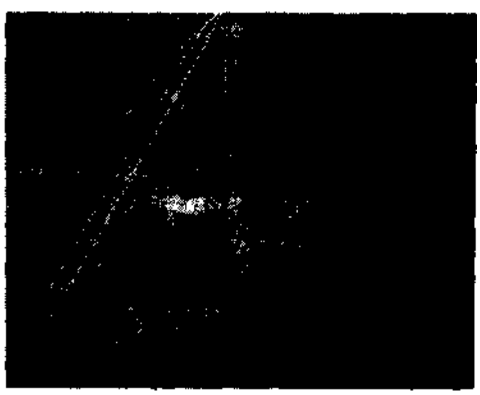

Figure 4 - A travertine quarry (Latium, Italy) using diamond wire equipment

overburden (Figure 3).
Among the advantages offered by the method, worth mentioning is the possibility of extending the active working time the whole year round owing to the favourable microclimate conditions, together with a better control of wall stability, reduced amount of dump waste and less impact on the environment. In addition,'the possibility of using the left stopes for other economic activities should not be overlooked.

4 - TECHNOLOGICAL STATE-OF-ART

The technological progress in stone industry took place with different traits according to cases. In some instances it simply consisted of a transfer of methods and techniques already developed in akin sectors, but more often it was the result of new efforts intended to set forth novel case-specific solutions that were later exported to other industrial sectors.
For the sake of a clear representation of the subject, though in a synthetic form, the two sectors of "marbles" and "granites" are dealt with separately since they show distinct features, mainly as far as cutting technologies are concerned.

4.1 - Marble quarrying

Under this tecnical term, having a broader meaning than the mere lithological definition, the whole class of carbonate rocks of variable hardness amenable to sawing and polishing are included.
Today, marble stone is generally quarried using diamond-based technologies (M. PINZARI, 1989).
The advent of these advanced methods of cutting, dating about ten years ago, represented the second technological breakthrough after a period dominated by the helichoid wire that in turn allowed the disadvantages and drawbacks of explosive blasting to be overcome.
The intense effort devoted to the improvement of the active tool and of the driving equipment, backed by a better scientific knowledge of the cutting mechanism, eventually led to the achievement of considerble performance levels of diamond wire in marble quarries, thus promoting its dissemination within very short time: exposure rates as high as 15 m2/h with tool productivity of the order of 30 m2/m are now customary in the most favourable cases (Figure 4).
In particular, the technological progress involved the driving unit, developed from the original whole-hydraulic solution to the integrated system of the last generation, powered by direct-coupled electric or Diesel engine; the authomatic control of the pull-back force allows the

real-time adjustement of setting to tha variable conditions encountered during tne actual operation*

Meanwhile, the tool itself has gradually been improved: the moat widely used solution consists of a steel rope on which the beads (obtained by electrodeposition or synthering according to the hardness of the rock) are strung, separated by metal springs.

In marble quarries the technological frame is completed by the rock cutter, derived from the machine used in coal and salt mines for face undercutting. The availability of this kind of equipment allowed to set up an efficient combination with diamond wire, amenable to a variety of excavation methods, face geometry and quarry configuration, including underground operations (H. FORNARO et AL., 1992).

Also the rock cutter underwent major developments regarding the structure of the system and the nature of the active elements.

Substantially, three distinct versions are now commercially available: the machine specialized for horizontal or vertical cuts, moving on rails (Figure 5), the universal-type rock cutter, having a slotting capability along both directions, structurally more complex and again moving on rails, and the machine especially designed for underground operations, mounted on supporting colums and moving along twin horizontal bars, suitably positioned according to the intended cut plane (Figure 6).

Concerning the active elements, two options are available: carbide bits, cheaper but subjected to relatively rapid wear, and diamond tips, both applicable to the chain moving along the arm periphery.

The choice between the two depends on the technical restrictions (overall cut area, working time) as well as on the relevant rock-related properties (mechanical resistance, abrasivity). Economic considerations suggest that diamond tips should be preferred when the machine is

Figure 5 - Rock cutter for vertical cuts at work in a marble quarry (Carrara, Italy)

Figure 6 - Underground rock cutter in a marble quarry (Carrara, Italy)

intensely employed, especially in the case of relatively hard rocks, in order to reduce the idle replacement time, thus improving the technical efficiency, of the equipment; on the other hand, carbide bits may be convenient for performing small-area cuts into softer rocks.
Recently, a novel solution has been proposed wherein the bit-supporting chain is replaced by a diamond-tipped belt, sliding on plastic skids; cooling and lubrication at the contact points are suitably assured by water injection through a number of nozzles along the arm periphery. This whole electric machine is simpler and less expensive due to the absence of hydraulic components but seems less flexible than the conventional counterpart.

The first results of industrial application appear very promising.
Overcome by the advanced technologies, traditional methods are now deprived of interest in modern marble quarries of developed Countries. However there are cases where they can be advantageously applied for some marginal operations or for working out those parts of the deposit where the rock is broken or deteriorated.

Occasional resort is made to helichoid wire for the opening cuts of large area in some quarries of older style. Wedge splitting (mechanical or hydraulic) is often used for the rough shaping of blocks, which can subsequently be finished by means of the diamond-blade framesaw.

4.2 - Granite quarrying

With this term, the whole set of eruptive rocks having granular structure and polymineral composition are conventionally designated. Since hardness is generally high, granites are rather difficult-to-saw; in return, they are characterized by considerable durability and resistance to wear, rendering them particularly suitable for exterior facing and paving.
Contrary to marble, the granite sector has not yet been involved in a process of radical technological substitution. Actually cutting operations are generally accomplished using traditional methods and techniques, though refined by the experience gained, improved by a deeper scientific knowledge, rendered more efficient by the progress in the development of machinery and availing of better engineering.
Different reasons account for this delay (R. CICCU, 1989).
First of all, granite lends itself better than marble to the application of some specific techniques such as flame torching, explosive splitting and wedge shearing, thanks to its minéralogie composition (content of quartz) or structural characteristics (presence of easier splittability planes). These techniques, mastered by a lasting and diffuse experience, are still preferred by the quarriers for the relatively low cost of cutting, their inherent simplicity and flexibility, as well as for the small capital and maintenance expenses.

On the other hand, even when they are properly applied, a certain damage may be induced to the rock mass, with the consequence that the pay-volume of the production and the overall quarry yield are somewhat penalized, the economic loss becoming increasingly important as the stone worth is higher and the individual blocks are smaller.
Therefore, it is to be expected that, parallel to the enhancement of traditional methods, the adoption of substitute advanced technologies, capable of overcoming the above limitations, will take place in the near future.
Concerning the drilling-based methods, considerable progress has been made in the development of the drill machines themselves (pneumatic or hydraulic with dry or wet flushing) and of the supporting and guiding structure (quarry bar, ligth to heavy blockcutters, complex hydraulic rigs).
The choice between them depends essentially on the drillhole requirement. In most Italian quarries, where the incidence of drilling on the unit product is moderate (less than 20 m of hole per m3 of commercial block, final shaping included), simple equipment, easy-to-operate, is still generally preferred (Figure 7); on the other hand, complex mobile rigs (Figure 8), rapidly available for work and capable of drilling in whatever direction, would be profitable in low-yield quarries, where the overall drilling incidence may attain 80-90 m/m3.
As regards the kind of explosive, the advantages of using the detonating fuse are confirmed by the experience of Mediterranean Countries, whereas decoupled charges of low-explosive supplied as self-centering cartriges are preferred elsewhere. Despite the differences in the blast action, final results are however comparable.
As for block shaping and squaring, traditional plug and feather shearing

Figure 7 - Bench drilling in a granite quarry (Sardinia, Italy)

Figure 8 - Hydraulic drilling rig in a block shaping operation (Norway)

is generally applied/ hydraulic wedging is seldom used while bulging seem to have little interest because of their slow action and high purchase cost.
Considerable changes have been introduced as regards ma ial moving. Both bloftk handling and waste mucking at the workplace are how often carried out by means of powerful wheel loaders, versatile and Capable of accomplishing different functions (loading, lifting, pushing*, towing, hauling) by rapid change of the working tool (bucket, fork lift, pull boom).
Conversely, fixed hoisting and towing structured (derrick» and drum winches') are gradually disappearing in shallow quarries With cbnsiderable horizontal extent, enduring however in deep pit quarried.
Concerning the advanced continuous cutting technologies» developed by the modern progress, very interesting prospects can be assigned to both diamond wire and high velocity waterjet (A. BORTOLUSSÎ et AL., 1992).
Diamond Wire has been introduced few years ago in aome granite quarries for driving the bench opening cuts, gradually replacihg the flame which if burdened by a series of drawbacks of different nature (high cost, material damage, noise, environmental impact, slow exposure rate, incompatibility with other operations in the site).
In the case of valuable materials, diamond wire is already being employed for bench slicing, with the advantage of obtaining blocks with at least two smooth faces, resulting in a substantial increase in their pay-volume due to a better final shape (Figure 9). In addition, the commercial allowance accounting for material damage credited to rough cutting technologies would not here be pertinent (A. BORTOLUSSI et AL., 1989).
The suitability of diamond wire for bench undercutting has not yet been thoroughly proved, despite some attempts; actually, excessive wear can be

Figure 9 - Diamond wire cutting in a granite quarry (Piedmont, Italy)

Figure 10 - Waterjet undercutting in a granite quarry (Colorado, USA)

incurred due to insufficient cooling of the tool, in addition to the risk of wire trapping caused by unexpected failure of the overlying rock.

Being granite rather hard and abrasive, technical results are considerably inferior to those obtained with marble: In fact, the exposure rate must be limited in order to save the tool, since wear represents a major item in the cutting cost split.

At the state of the art, wire productivities around 4-6 m2/m can be attained in true granites, provided that exposure rate does not exceed 3-2 m2/h. Results are generally better as the quartz content decreases.

The driving unit of the last generation is characterized by high power, up to 60-80 kW, and is provided with real-time pull-back adjustement facilities, using the active current or the flywheel speed as the control variables, according to the kind of prime mover (electric or Diesel).

The tool used for granite consists of synthering beads strung on a steel rope protected by a Continuous plastic or rubber sheath. With this kind of assembly, rope wear is slowed down and the risk of sudden rupture consistently reduced, rendering this solution recommendable also for marble, for safety reasons.

Waterjet cutting technology is based on the erosive action of high velocity water jets, generated by means of high pressure pumps.

For deep kerfing of rocks in the quarry, stationary plain jets represent the best solution, while waiting for further development of abrasive jets (A. BORTOLUSSI et AL., 1989).

Different systems have been proposed by a number of American and European manufacturers: traversing lances of special design provided with one or more nozzles, either fixed, rotated or oscillated are used in order to get a slot wide enough for further penetration of the cutting head down to the intended kerf bottom (Figure 10).

Their efficiency has been tested in the field with very encouraging results to the extent that equipment is now commercially available.

Technical results achievable on optimum setting of operational variables (traverse velocity, rotation speed or oscillation frequency, stand-off distance) are directly related to the hydraulic power (pressure and flowrate) and depend on nozzle configuration.

Recent systematic studies using twin oscillating jets showed that a specific energy in the range of 20-40 kJ/cm2 is required for granite kerfing; therefore a input power of at least 120-240 kW would be necessary for achieving an exposure rate of 2 m2/h, adequate for the industrial acceptability of the technology.

Most Italian granites are amenable to waterjet cutting, since their specific energy falls close to the lower limit of this range. Accordingly, the prospects of industrial application appear very interesting.

5 - CONCLUSIONS

Development and dissemination of advanced cutting technologies are promoted by different factors, whose importance is likely to grow in the near future: product quality, energy efficiency, safety and health at the workplace and impact on the environment. Of course, economic factors will exert a decisive pressure ön the technical choice.

The problem of quality is today of a major concern in relation to the more elaborate and delicate use of the material, requiring well established technological properties; in addition, a process of more severe selection among available materials is induced by the international competition.

In such a context quality must meet very strict specifications, within the frame of internationally recognized rules.

It ensues that continuous research for the development of suitable technologies will be carried on in the future, aiming at improving product quality (P. BERRY, 1989).

Energy represents, directly or indirectly, an outstanding factor in stone quarrying and processing, having a considerable incidence on production cost. Consequently, consistent economic advantages can be achieved by its rational use.

Traditional technologies, especially those using compressed air or flame, are generally affected by low energy efficiency. Their replacement with more proficient novel technologies appears justified also from this point of view.

The need for assuring acceptable conditions at the workplace, safeguarding the health and safety of personnel, has today assumed great relevance, in the light of the recommendations issued by the European Community. Accordingly, the exposure to risk of personal damage (accidents or professional illness) originating from physical pollution of different nature (dust, noise, vibration) must be minimized.

Consequently, the ban of harmful technologies (flame, for instance) appears ineluctable, opening the way to the advent of substitute methods, such as diamond wire and waterjet. In particular wet hydraulic drilling is expected to replace the dry pneumatic counterpart.

The most important impact of quarrying activity on the surrounding land is produced by the huge volume of waste, which often exceeds that of the original rock in place.

Though quantitative figures are difficult-to-evaluate, it is however evident that consistent improvement in quarry recovery can be achieved with the use of cautious technologies, thus diminishing the amount of material to be cast to dump.

Simple comparison on the basis of cost figures referred to the unit cut area is not sufficient for a correct appraisal of the economic results

achievable with novel technologies. The evaluation should also be **extended to the advantages** deriving from the block face quality, consisting in **a** higher pay-volume and in a better selling price.
Consequently the final balance, in terms of overall profit at equal **production level, can be** more favourable than in the case of intensive **use of cheaper** traditional methods, especially for valuable stone.
Important modification in the structural pattern and in the competitive **behaviour of stone enterprises** is taking place under the pressure of **international demand. Reliability** and promptness in the supply of stone **materials,** in addition to the availability for support services and **assistance to the** final user, are becoming the necessary conditions for **gaining and maintaining a** pre-eminent position in the market.
Few leader enterprises are emerging, playing the role of fulfilling the **various tasks of supply** committments, from the purchase of the raw **materials to the delivery** of the manufacts ready for use on the site, **including the design and** the application of fastening devices. Minor **firms are generally involved** in the sawing and finishing phases as **sub-contractors.**

These major concerns are capable of coping with the different management **functions (R&D, production, purchase** and **sale,** administration, promotion, **design), acting through a** integrated management structure.
In this context, the general progress of the stone industry will receive **a significant support.**

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