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Economic-Environmental Description of the Exploitation Method by Horizontal Slices and Ore pass in Italian Surface Crushed Stone Quarries

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ABSTRACT: The considerable spread of the method of exploitation by descending slices in large crushed stone quarries (limestone for cement and the lime industry in general) in Italy has often involved the adoption, by some companies, of the well-known system of hauling by vertical raise and extracting by horizontal drift. This choice İs influenced by a number of different factors: the possibility of reducing traffic on ramps, of reducing the diffusion of dust in me environment resulting from haulage by dumper, and the possibility of avoiding the dumping of blasted rock in open channels or along quarry benches. The bonng of the raise and the tunnel, which can represent an additional cost in quarry exploitation, has nevertheless been proven to be a good investment for the reduction of operation costs. This is because of increases in crew productivity, reductions in energy and equipment consumption and, above all, improvement in the safety and efficiency of the quarry. The final, but not insignificant, advantage İs that the first results of environmental recovery are immediately visible, with progressive exploitation from top to bottom and simultaneous rehabilitation of exploited benches. In the concluding remarks, on the basis of some meaningful examples, indications of the feasibility "scale" of the method are given for major and long-term planned extraction sites.

1 INTRODUCTION

Italian cement production, m spite of a lack of national energy resources, has for 25 years ranked highly in Europe. During the second half of the seventies, Italy was in fact the most important manufacturer, providing nearly 18% of the total production in western Europe and more man 5% of world production. In 1999, Italian production amounted to 37.300 Mt. The huge per capita consumption (up to 800 kg/y) recorded during the nineties gave rise to strong protests led by "environmentalist parties" against the overuse of cement in the country. As a matter of fact, apart from the large availability of raw materials for cement production, Italy has quite an irregular orography, with a high population density, which often involves constructive models requiring large quantities of concrete. Hence, improvements in both environmental aspects and production cost reduction are urgentiy needed in order to reduce administrative problems in the opening of new quarries and to maintain the current level of production.

The examples given below describe the exploitation method currently used in important Italian quarries and are representative of different situations in the country: Ütey are intended to provide information about the current organization of quarrying and transportation systems used to feed large plants, while having competitive costs.

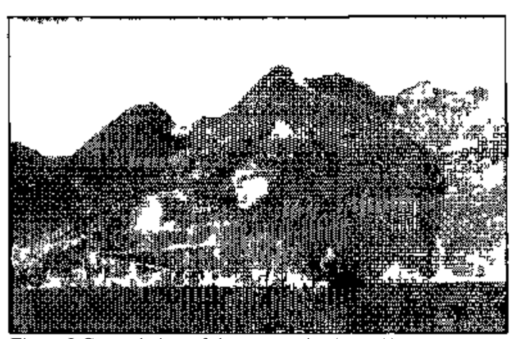

Figure I General view of the quarry site (case A)

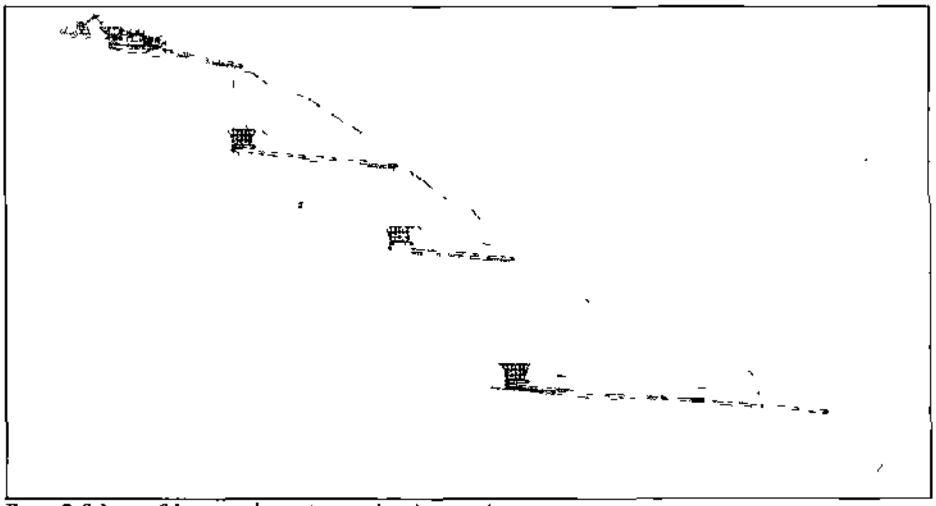

Figure 2 Scheme of the conveying system employed in case A.

2 CASE A

The section of the mine presently worked (see Figure 1) has been in production for one and a half years. The previously exploited section was worked by a different method, consisting of blasting by high benches (15 20 m), dozing to collecting troughs, rehandling by wheel loaders, and hauling to the crushing plant. A subsequent working method, in use until exploitation of the old section was terminated, was by ripping-dozing, with haulage by wheel loader directly to the plant.

The start of the present exploitation by horizontal descending slices (4 6 m thick), haulage by wheel loader to a mobile crushing plant, and subsequent transportation to the factory by an ore pass belt conveyor.system, entailed important development works:

- driving the ore passes (raises) and tunnels, representing the haulage way to the secondary crushing installation. Ore passes were excavated by raise borer;
- building access roads;
- installing an 18 kV power line;
- installing marl transportation facilities;
- installing the mine-factory transportation system.

A scheme-of the conveying system from the exploitation workings to the mine stockage site is shown in Figure 2.

Presently, the mine covers an area of 65,000 m^2, between the levels 930 m and 850 m a.s.l.. The exploitable volume is 1,100,000 m3. Future extensions are foreseen down to 640 m a.s.l., for an exploitable volume of 19,000,000 m^3.

During the exploitation of the slices, a rock curtain is left in place, as shown in Figure 3.

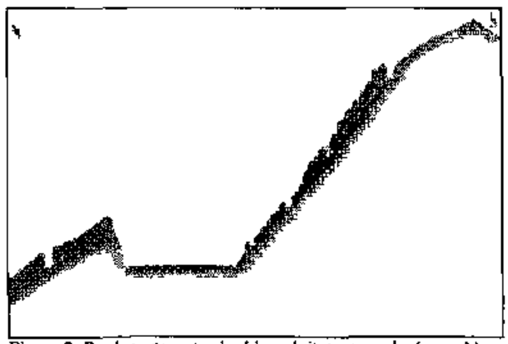

Figure 3. Rock curtain, to shield exploitation works (case A).

The average slope of the abandonment profile will be 36°, and the profile will be modelled by benches 4 m high and 4 m wide. The operational steps of the exploitation are:

1. Stripping the overburden, making the area to be exploited clear.
2. Drilling a square mesh, 3.5 x 3.5 m, of vertical holes 4 m deep, with a diameter of 70 to 80 mm, moderately charging the holes (less than 200 g/m^3 of explosive) and blasting, just to loosen the rock.
3. Removing the loosened rock by ripper and backhoe excavator.
4. Hauling the rock to the primary crushing mobile plant.

Rehabilitation of the abandoned wall takes place as soon as the 4-m thick slice is removed, as shown in Figure 4; hence, excavation and rehabilitation are in progress simultaneously during the exploitation.

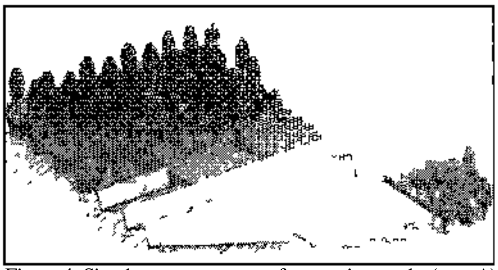

Figure 4. Simultaneous progress of excavation works (case A)

The workplace contains 9 people, of which 6 are engaged İn exploitation and primary crushing, and 3 are employed in crushed rock transportation, secondary crushing and stockage.

As for the fleet, the main items are:

- 1 Tamrock CHA 660 drilling machine;
- 1 CAT 345 BL excavator and 2 Perlini DP 255 dumpers for production work;
- 1 CAT 330 BL excavator and 1 CAT 966 G wheel loader for environmental rehabilitation work.

The overall production is 3,550,000 t/y, constituting 70% of the factory's demand. As for the exploitation costs, İn total they approximate 2 US$/t (50% drilling and blasting, 45% mucking and hauling, 5% crushing and conveying to the stockpile).

3 CASEB

The cement factory has a nominal output of approximately 1,000,000 t of clinker per year (from 1,700,000 t of raw mix). The supply of raw material is provided by 3 quarries: two of these produce limestone and are located at 21 km and 0.5 km from the factory (the latter has been undergoing environmental rehabilitation since 1999, hence producing a very small output); the other produces clay, and is located 11 km from the factory.

Limestone represents 78% of the raw mix, and clay 22%. Hence, the main suppler of the factory is the first limestone quarry, producing around 800,000 t/y.

The original layout of this quarry comprised a mobile crusher, fed with run-of-mine rock taken from the muckpile with a hydraulic shovel and transferred to the crusher by a mobile belt system. The crushed material was then hauled by means of a conveyor belt installed at the surface to an ore pass, then by a conveyor installed in a tunnel to the facilities of the second quarry, and finally on to the quarry itself.

Later, on the basis of detailed studies and experience gained with similar plants, the design was revised so as to emphasize the importance of the environmental problem and make use of up-to-date technologies. The mobile crusher was replaced by a fixed model, and the quarry-factory link was established with a system of interconnected conveyors installed m tunnels and ore passes. Due to the location of the quarry with respect to the factory, haulage of the crushed material by truck is not possible, owing to the excessive distance and the unfavourable layout of the road.

The quarry floor is located at a height of approximately 650'm above the level of the old quarry, where the secondary crushing system is installed, and at a horizontal distance of 2000 m. The maximum size of the material obtained from primary crushing is 300 mm. The conveyor system linking primary crushing to secondary crushing consists of 3 ore passes and 3 tunnels hosting the conveyors, with a maximum slope of 17%. Tunnel-driving work started m 1993, and was completed in January 1998. The plant went into operation in June 1996. In Figure 5, a scheme of the system is shown.

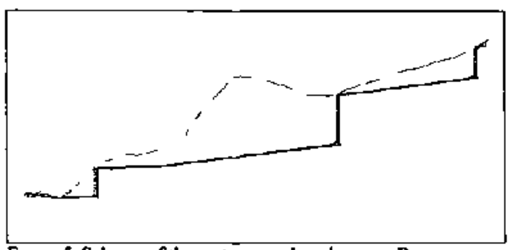

Figure 5. Scheme of the system employed in case B

Some details of the system and performance data are provided below.

The primary crusher directly feeds the first (upper) ore pass; a dust-collecting system İs installed at the feeding point. From the bottom of the first ore pass (vertical), the crushed material is transferred to the conveyor belt by an apron feeder. The conveyor runs in a tunnel and feeds the second ore pass (vertical), from which the material is transferred to the second belt, running partly underground, partly at the surface. The second belt feeds the third ore pass. A second dust collecting plant is installed at this feeding point.

The third ore pass is considerably larger than the first and second, serving as a surge bin as well as ore transportation facility, and has a capacity of 7,800 m^3 (11,800 t) of crushed limestone, which is a 2-day supply for the plant, working at full rate.

At the bottom of the third ore pass, in the third tunnel, an apron feeder feeds the third belt at the rate of 400 t/h, which represents the capacity of the secondary crusher, which is fed directly by the third belt

The secondary crusher is installed in the old quarry, and is an impact crusher with a maximum capacity of 500 t/h. It is driven by a 600-kW motor, with an inlet opening size of 2000 mm x 650 mm. The crushed product is conveyed to the factory.

The three ore passes connecting the conveying tunnels were driven by raise borer in order to obtain smooth and regular wall surfaces and to reduce construction time. The relevant geometrical data are given in Table 1.

Table 1. Geometrical data for ore passes pertaining to case B.

	Diameter (m) •	Height (m)	Volume (m^3)
Ore pass A	3.70	124 00	1,330
Ore pass B	3.70	202 05	2,170
Ore pass C	10.00	112 02	7,850

The tunnels have a cross section of 20 m , which provides ample room for inspection and maintenance. They were driven by drilling and blasting. The relevant geometrical data are given in Table 2.

Table 2. Geometrical data for tunnels pertaining to case B.

	Length <m)	Gradient (m)	Slope (%)
Tunnel A	718	75.60	12
Tunnel B	930	97.81	12
	304	8.64	3
Tunnel C	169	4.50	3

The exploitation method presently adopted by the quarry involves horizontal descending slices, leaving a rock curtain to hide the quarry work from the surrounding sites, thus minimising the visual impact, which is important in an area valued for its natural beauty.

Excavation is by drilling and blasting; the bench height varies from 10 m to 20 m (max). The explosives employed are ANFO (main charge) and Slurry (toe), with a powder factor of 260g/m^3. Oversize blocks are crushed by a hydraulic breaker. Mucking and transportation to the primary crusher are carried out by means of a wheel loader and 24-m^3 dumpers.

The primary crusher is a double rotor impact crusher, with a capacity of 800 t/h.

The quarry machinery fleet consists of:

- 3 heavy drilling machines, with diameters of 115, 105 and 89 mm;
- 1 hydraulic breaker installed on a backhoe excavator;
- 1 wheel loader with 5.4-m^3 bucket;
- 5 dumpers with 2.4 m^3 capacity;
- 1 crawler tractor for small works and site rehabilitation;
- 2 4wd vehicles and one minibus for the personnel.

The quarry is worked 1 shift per day (from 7.00 to 15.00), 5 days per week, by a crew of 9 workers.

A conventional transportation system would require a 30-km journey and 17 trucks, and could not compete with the system adopted.

4 CASEC

The cement factory rated capacity is around 1,600,000 t/y of clinker (2,560,000 t/y of raw mix), and the supply comes from 3 quarries. Two of these produce limestone and are located 12 km from the factory, while the other produces schist and is located 0.5 km from the factory.

Limestone represents 77% of the raw material needed, and schist (clay) 23%.

The total production of the two limestone quarries is 2,000,000 t/y. They went into operation at different times: the first in the sixties, and the second in the nineties.

Figure 6. General view of the quarry site (case C).

The original method of exploitation was quite conventional, by high benches (15 m) starting from the toe of the mountainside. The exploited rock İs a grey Jurassic limestone, fine grained, in beds dipping against the slope. The stratigraphie succession is locally upturned, and the Triassic dolomia (not exploitable) rests above the Jurassic beds, representing the upper boundary of the pay rock.

At first, the transportation of the limestone to the factory was carried out by truck, which caused serious traffic problems. Later, in the seventies, a tunnel 6 km long and still in use, connecting the quarry to the factory, was driven, equipped with a conveyor belt, and a mobile (non-self-propelled) crushing plant was installed at the quarry. Meanwhile, the production of the factory increased (from 300,000 to 800,000 t/y of clinker),


Figure 7. Conveyor belt in the tunnel connecting the quarry to the factory (case C).

Exploitation by descending slices started ahead of the completion of the exploitation of the old quarry in order to exploit the large reserves (>10 Mm) located on the same side of the valley, just above the village there.

The thickness of the pay was more or less the same as that in the old quarry (approximately 200 m), but the old method, consisting of successive exploitation of long benches, and dozing down the blasted rock from the upper benches to the quarry yard, was no longer practical, due to, among other things, the proximity of the inhabited area.

The exploitation by horizontal slices, starting from the top, minimised the circulation of machinery {access roads are needed, in principle, only for machine repair) and preparation work (one slice, covering a surface of approximately 6 hectares and being 15 m thick, gives 1 year of supply), provided that the transportation system was prepared in advance.

Transportation by ore pass provided a suitable solution (transportation by simply dumping the blasted rock in an inclined channel, employed for a small part of the upper levels of the quarry, proved to be unsuitable because of dust diffusion rain, snow collection and other problems).

An inclined (65°) raise, 145 m long (with a diameter of 4.5 m) was driven by drilling and blasting, employing several adits from the mountainside as intermediate attack points, in order to connect the top level to an underground crushing plant (see Figure 8).

The crushing plant is installed in a camera having a cross section of 110 m^2, and performs the primary and secondary, stages of crushing at a rate of 800 t/h; the crushed rock Is then hauled by the belt system to the factory. The excavation is by drilling and blasting with large diameter holes (115 mm), wide blasting mesh (4m x 4m) and low powder factor (80 g/t of ANFO explosive). Holes are detonated by cord, with interposed detonating relays to reduce vibrations. The preparation of a slice for the production stage consists simply in opening a trench reaching the ore pass collar. Mucking and transportation of the blasted rock to the ore pass is effected by wheel loaders.

The fleet consists of:

- 2 rotary drills;
- 1 hydraulic breaker for oversize block reduction;
- 3-wheel loader, with bucket capacity of 6, 8 and 10 m3;
- 1 excavator and 1 small wheel loader for preparation works and road maintenance.

A simple access road (1 km) is required, while the previously employed long benches method needed more access roads, which had to be maintained and adapted.

The ore pass has not become clogged to date. In any case, a stockpile of 10 production shifts is maintained at the factory (100,0001).

The work force was previously 18 people, which has been ceduced to 15 (the number of operators of wheel loaders and drills has increased, while the personnel required for road-building and maintenance has been reduced) and productivity has increased from 45 t/m.s. to 70 t/m.s.

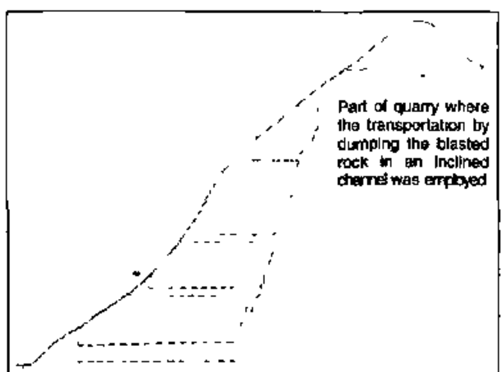

Figure 8. Scheme of the system employed in case C


Figure 9. Preparation of a slice for production stage (case C).

Cost reduction with respect to the previous method is estimated to be 25%. the previous long benches method utilized belt haulage; in the seventies, when transport to the factory was done by truck, the cost was much higher.

5 CONCLUSIONS

The exploitation method of horizontal descending slices with ore passes, crushing plants and tunnels representing the haulage way to the secondary crushing installation has several advantages:

Safety: quarry work is safer

- nobody has to work under the quarry front;
- there are bigger spaces for manoeuvring machinery;
- there are no falls of blasted rock in open channels or along the quarry benches;
- loading is simpler and faster.

Environment: environmental rehabilitation is very quick

- the progressive exploitation from top to bottom allows the simultaneous rehabilitation of exploited benches;
- the results are immediately visible;
- only a small part of the front is quarried.

Economy: exploitation costs are smaller

- rehabilitation of roads is not required;
- dozers are not needed and wheel loader work is more efficient and more flexible;
- the blasted rock is hauled in a simpler way;
- it is possible to improve the crusher efficiency by pre-screening the material;
- less manpower is needed.

In order to illustrate the technological progress and improvement of the methods of exploitation in Italian limestone quarries, some performance data are provided in Table 3.

The last datum refers to one situation and does not represent the national average. However, the result obtained is a great success for the cement industry in terms of technical-economic aspects and safety. It is also interesting to observe that this was achieved by an open pit exploitation method using large machines and underground development for efficient haulage. Such a method requires considerable investment, but it provides great results İn terms of safety,"productivity and environmental aspects.

Table 3. Crew productivity in Italian quarries of limestone for cemenl in different periods,

	crew productivity	
1960	< 10	Underground exploitation by sub levé I caving
1970	<= 150	Open pit exploitation by vertical slices from bottom to top
1990	> 500	Open pit exploitation by descending slices, hauling by vertical raise and extracting by horizontal drift

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