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## **Comparing alternative cutting technologies in marble quarries**

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## The history...

Marble is probably the most popular ornamental stone in the world.

The procedures used in ancient times for marble extraction did not differ much from those applied a few years ago.

The main aim was always the extraction of a block from the solid rock with as little damage as possible.



# The history...

## Hewing of the stone



## The present...

**Technological evolution** in the extraction techniques resulted in significant improvements with regard to **productivity and quality** of the commercial blocks.

The most significant technological development was put into practice when **diamond wire cutting** started being used in the '70s.

There is a continuous attempt for further evolution based either on **current technologies equipped with modern tools and parts** or on **completely new technologies**.

The success of each technique differs in each quarry case, depending on the properties of the rock and the formation.

# The "Dionyssos" marble quarry

The quarry is located at the Penteli Mountain, Attica, Greece, just about 30 km northeast of Athens.



# The "Dionyssos" marble quarry

The company exploits a white to semi-white marble stratigraphically overlying the famous "Pentelikon marble" also known as "Bianco di Pendeli" or "Marmo Greco Fino".



The "Pentelikon marble" has been used in the construction of the Parthenon, the Propylaea on the Acropolis and other ancient Greek cities.



# The “Dionyssos” marble quarry

The exploitation in the quarry is carried out by **open pit** and **underground** methods.



The open pit quarrying method applied is by vertical benches of 6 m height.



Underground quarrying of marble is performed by the room and pillar method.

# The “Dionyssos” marble quarry: underground

During the development phase in underground quarrying **chain saw** is used, while for the excavation of marble blocks as the quarry develops to the lower horizons, **chain sawing is combined with diamond-wire cutting**.

The chain saw used was replaced by a newer one, with a **more effective cutting length**, a **widening shape of the arm**, allowing easy cutting at the final cutting stage, without the need of swivelling the arm, and a **higher cutting speed** (8 m<sup>2</sup>/h instead of 5 m<sup>2</sup>/h achieved by the old machine).





# The "Dionyssos" marble quarry: open pit

The detachment of primary rock is performed by **drilling and diamond-wire techniques**, as well as by **soft blasting of horizontal cuts**.

For the soft blasting, parallel horizontal holes are drilled (at a distance of 25 cm from each other) which are then charged also with detonating penta-erythrite (12 gr PNT/m) and fired using a common cap and safety fuse.



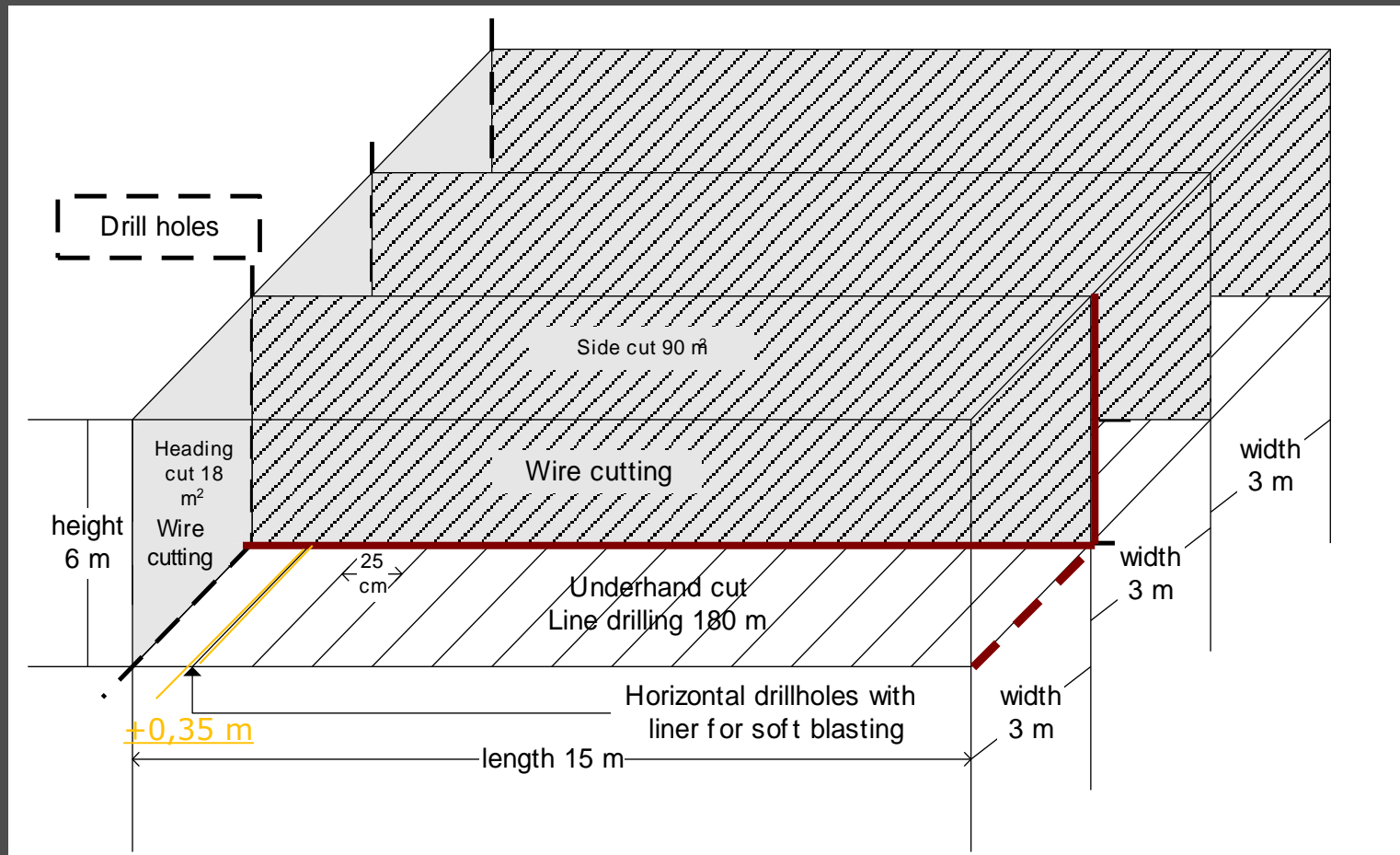
# The main idea

The question:

**Could chain sawing replace soft blasting for horizontal cuttings in the open pit quarry?**

# The alternatives examined

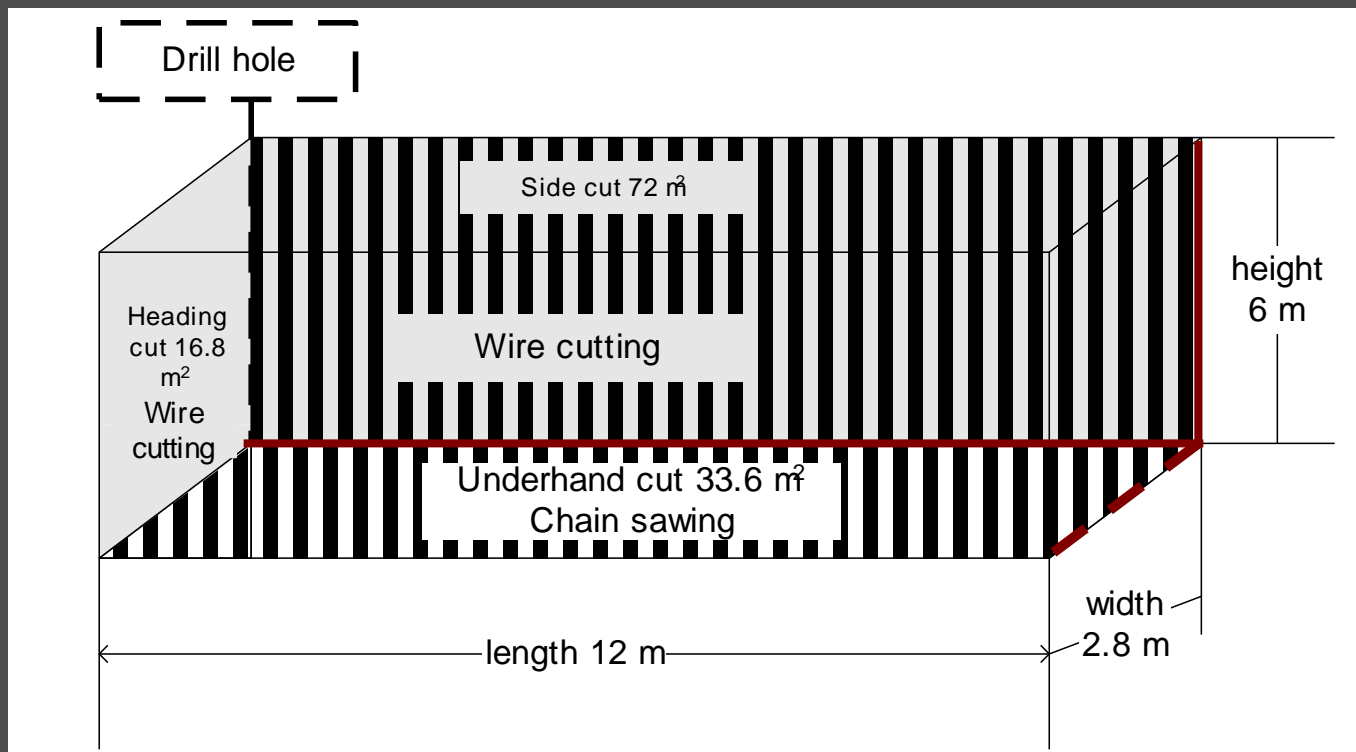
## Diamond-wire cutting with soft blasting



Total volume of initial block: 810 m<sup>3</sup>

# The alternatives examined

Diamond wire cutting combined with chain sawing



Total volume of initial block: 201.6 m<sup>3</sup>

# Assumptions

Cost parameters:

- Depreciation cost for an estimated life of 5 years for each machine
- Operating costs including the cost of energy, water, wear parts and maintenance
- Operating labor cost

For the extraction of the marble block two operators are needed in total.

The scheduled working days are 220 annually.

Daily labor cost: 100 €

Energy unit cost: 0.075€/Kwh

Water cost (purchase and transportation: 4€/m<sup>3</sup>).

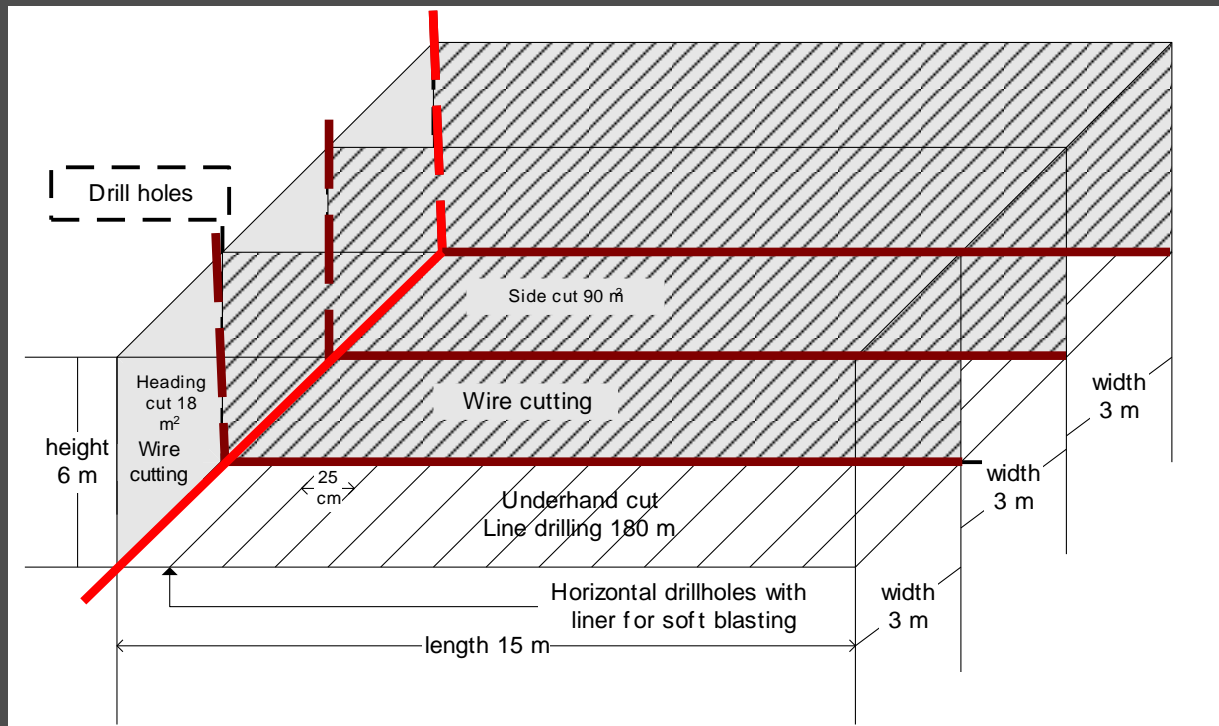
# Assumptions

Wear parts:

- ❑ The lifetime of a 60 m diamond wire is 3,600 m<sup>2</sup> of cutting and the replacement of the cutting elements is carried out after 900 m<sup>2</sup> of cutting.
- ❑ The lifetime of drill pipes is 1,200 m of drilling.
- ❑ The water consumption for wire cutting is from 15 to 25 lt/min.

The vertical drilling in the case of diamond wire cutting combined with soft blasting requires 3 drills of 6 m each for the side cuts and one drill of 6 m for the heading cut. The success percentage of vertical drilling is 50% meaning that for each vertical drilling 2 holes are usually drilled in order to meet horizontal drill holes.

# Assumptions



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## Cost parameters of the equipment

	<b>Purchase price</b>	<b>Daily usage</b>	<b>Production rate</b>		
<b>Chain saw (Fantini GU-70/R)</b>	340,000 €	5 h	8 m <sup>2</sup> /h		
<b>Diamond-wire cut (Benetti VIP 910)</b>	27,000 €	5 h	10 m <sup>2</sup> /h		
<b>Crawler drill</b>	150,000 €		50 m/day		
<b>Liner (Tamrock)</b>	150,000 €		150 m/day		
<b>Crane</b>	60,000 €	5 h			



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<b>Chain saw (Fantini GU-70/R)</b>	340,000 €	5 h	8 m <sup>2</sup> /h		
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<b>Diamond-wire cut (Benetti VIP 910)</b>	270,00 €	5 h	10 m <sup>2</sup> /h		5,4000 €
<b>Crawler drill</b>	150,000 €		50 m/day		30,000 €
<b>Liner (Tamrock)</b>	150,000 €		150 m/day		30,000 €
<b>Crane</b>	60,000 €	5 h			12,000 €

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<b>Crawler drill</b>	150,000 €		50 m/day	11,000 m	30,000 €
<b>Liner (Tamrock)</b>	150,000 €		150 m/day	33,000 m	30,000 €
<b>Crane</b>	60,000 €	5 h		1,100 h	12,000 €

# Calculations

Estimation of the cost of each machine per unit of cut block

	<b>Depreciation cost</b>	<b>Energy cost</b>	<b>Labor cost</b>	<b>Wear parts and maintenance cost</b>	<b>Total cost per unit of cut block</b>
<b>Chain saw (Fantini GU-70/R)</b>		0.53 €/m <sup>2</sup>	2.5 €/m <sup>2</sup>		
<b>Diamond-wire cut (Benetti VIP 910)</b>		0.25 €/m <sup>2</sup>	2.0 €/m <sup>2</sup>		
<b>Crawler drill</b>					
<b>Liner (Tamrock)</b>					
<b>Crane</b>					

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<b>Diamond-wire cut (Benetti VIP 910)</b>		0.25 €/m <sup>2</sup>	1.28 €/m <sup>2</sup>	0.38 €/m <sup>2</sup>	
<b>Crawler drill</b>			7.20 €/m		
<b>Liner (Tamrock)</b>			1.74 €/m		
<b>Crane</b>			20 €/h		

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<b>Chain saw (Fantini GU-70/R)</b>	7.73 €/m <sup>2</sup>	0.53 €/m <sup>2</sup>	2.5 €/m <sup>2</sup>	6.60 €/m <sup>2</sup>	
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<b>Crawler drill</b>	2.73 €/m		7.20 €/m		
<b>Liner (Tamrock)</b>	0.91 €/m		1.74 €/m		
<b>Crane</b>	10.91 €/h		20 €/h		

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<b>Diamond-wire cut (Benetti VIP 910)</b>	0.49 €/m <sup>2</sup>	0.25 €/m <sup>2</sup>	1.28 €/m <sup>2</sup>	0.38 €/m <sup>2</sup>	2.4 €/m <sup>2</sup>
<b>Crawler drill</b>	2.73 €/m	7.20 €/m			9.93 €/m
<b>Liner (Tamrock)</b>	0.91 €/m	1.74 €/m			2.65 €/m
<b>Crane</b>	10.91 €/h	20 €/h			30.91 €/h



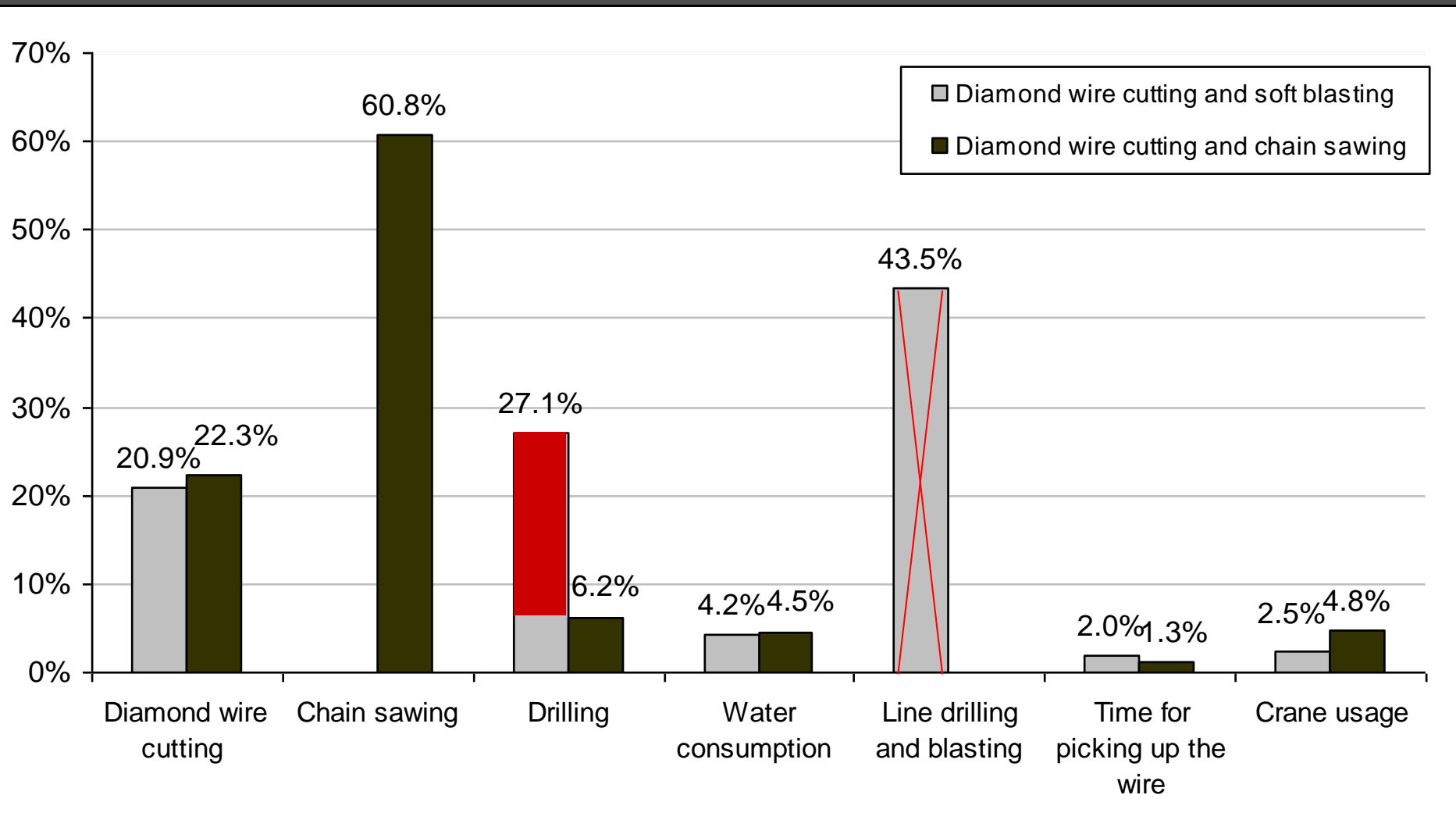
Works to be done	Wire cutting combined with soft blasting			Wire cutting combined with chain sawing		
	Length, surface, volume or hours	Cost per unit	Total cost for blocks	Length, surface, volume or hours	Cost per unit	Total cost for blocks
<b>Diamond wire cutting (side cut)</b>		2.4 €/m <sup>2</sup>			2.4 €/m <sup>2</sup>	
<b>Diamond wire cutting (heading cut)</b>		2.4 €/m <sup>2</sup>			2.4 €/m <sup>2</sup>	
<b>Chain sawing</b>					17.36 €/m <sup>2</sup>	
<b>Horizontal drilling (heading cut)</b>		9.93 €/m				
<b>Horizontal drilling (side cut)</b>		9.93 €/m				
<b>Vertical drilling (side cut)</b>		9.93 €/m				
<b>Vertical drilling (heading cut)</b>		9.93 €/m			9.93 €/m	
<b>Water consumption</b>		4 €/m <sup>3</sup>			4 €/m <sup>3</sup>	
<b>Line drilling</b>		2.65 €/m				
<b>Fuse needed</b>		0.17 €/m				
<b>Charge time needed</b>	0.75 h	12.5 €/h				
<b>Time for picking up the wire</b>	6 h			1 h	12.5 €/h	
<b>Crane usage</b>	3 h	30.91 €/h		1.5 h	30.91 €/h	
<b>Total cost</b>						
<b>Total cost /m<sup>2</sup></b>						

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Works to be done	Wire cutting combined with soft blasting			Wire cutting combined with chain sawing		
	Length, surface, volume or hours	Cost per unit	Total cost for blocks	Length, surface, volume or hours	Cost per unit	Total cost for blocks
<b>Diamond wire cutting (side cut)</b>	270 m <sup>2</sup>	2.4 €/m <sup>2</sup>		72 m <sup>2</sup>	2.4 €/m <sup>2</sup>	
<b>Diamond wire cutting (heading cut)</b>	54 m <sup>2</sup>	2.4 €/m <sup>2</sup>		16.8 m <sup>2</sup>	2.4 €/m <sup>2</sup>	
<b>Chain sawing</b>				33.6 m <sup>2</sup>	17.36 €/m <sup>2</sup>	
<b>Horizontal drilling (heading cut)</b>	9 m	9.93 €/m				
<b>Horizontal drilling (side cut)</b>	45 m	9.93 €/m				
<b>Vertical drilling (side cut)</b>	36 m	9.93 €/m				
<b>Vertical drilling (heading cut)</b>	12 m	9.93 €/m		6 m	9.93 €/m	
<b>Water consumption</b>	38.88 m <sup>3</sup>	4 €/m <sup>3</sup>		10.66 m <sup>3</sup>	4 €/m <sup>3</sup>	
<b>Line drilling</b>	531 m	2.65 €/m				
<b>Fuse needed</b>	1098,65 m	0.17 €/m				
<b>Charge time needed</b>	0.75 h	12.5 €/h				
<b>Time for picking up the wire</b>	6 h			1 h	12.5 €/h	
<b>Crane usage</b>	3 h	30.91 €/h		1.5 h	30.91 €/h	
<b>Total cost</b>						
<b>Total cost /m<sup>2</sup></b>						

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<b>Diamond wire cutting (side cut)</b>	270 m <sup>2</sup>	2.4 €/m <sup>2</sup>	648.25 €	72 m <sup>2</sup>	2.4€/m <sup>2</sup>	172.8 €
<b>Diamond wire cutting (heading cut)</b>	54 m <sup>2</sup>	2.4 €/m <sup>2</sup>	129.65 €	16.8 m <sup>2</sup>	2.4 €/m <sup>2</sup>	40.32 €
<b>Chain sawing</b>				33.6 m <sup>2</sup>	17.36 €/m <sup>2</sup>	583.29 €
<b>Horizontal drilling (side cut)</b>	45 m	9.93 €/m	446.85 €			
<b>Horizontal drilling (heading cut)</b>	9 m	9.93 €/m	89.37 €			
<b>Vertical drilling (side cut)</b>	36 m	9.93 €/m	357.48 €			
<b>Vertical drilling (heading cut)</b>	12 m	9.93 €/m	119.16 €	6 m	9.93 €/m	59.58 €
<b>Water consumption</b>	38.88 m <sup>3</sup>	4 €/m <sup>3</sup>	155.52 €	10.66 m <sup>3</sup>	4 €/m <sup>3</sup>	42.64 €
<b>Line drilling</b>	531 m	2.65 €/m	1407.15 €			
<b>Fuse needed</b>	1098,65 m	0.17 €/m	186.77€			
<b>Charge time needed</b>	0.75 h	12.5 €/h	9.38 €			
<b>Time for picking up the wire</b>	6 h		75.00 €	1 h	12.5 €/h	12.5 €
<b>Crane usage</b>	3 h	30.91 €/h	92.73 €	1.5 h	30.91 €/h	46.37 €
<b>Total cost</b>	<b>3,717.30 €</b>			<b>957.5 €</b>		
<b>Total cost /m<sup>3</sup></b>	<b>4.59 €</b>			<b>4.75 €</b>		

# Cost allocation



## Technical issues

The additional cost per square meter of extracted block by the use of the chain saw not only is affordable but also comparable to the cost produced by the method used until now, taking into consideration the advantages obtained over the current method applied.

- ❑ Chain sawing allows for **more precise cuts** producing rectangular blocks with reduced losses, since there are not drilling deviations as in the case of wire cutting combined with soft blasting.
- ❑ The planes produced by wire cutting combined with chain sawing are usually adjoining and thus **there is no chance that a section of uncut marble will be left** resulting in the wider breakage of the robust marble block.
- ❑ The **perfect planar and wide cut** achieved by the chain saw machine, **facilitates** among other, **the truck movement** diminishing the work load.

## Diamond wire cutters vs chain saw

Diamond wire cutters marked a new era in the way of working in marble quarries and the cutting with diamond wire is a common technology in most of marble quarries. Despite its versatility in use and its contribution to the reduction of marble wastes, diamond wire cutting necessitates precise drilling, skilled manpower and continuous supply of water.

On the other hand the main advantages of the chain saw technology are the simplicity of operation, meaning that there is no need for skilled personnel, and the regularity and planarity of the cut produced. The reduced depth of cutting though, limited to the length of the arm, as well as the relatively low cutting speed, consist the main restrictions for its use in open pit quarrying.

## Concluding

The investigation of the introduction of the new chain saw machine in the production procedure of the “Dionyssos” marble open pit quarrying **revealed the possibility of its use at the quarry site on a standard basis**, since its cutting length proved to be adequate. This is mainly due to the **highly fractured rock mass that does not allow for deep cuts anyway**.

Continuous technological evolution in dimension stone quarrying gives rise to the application of a lot of different techniques for performing different operational phases in a safe and productive way **based in each case on the specific characteristics of the quarry site under examination**.