A COMPARISON STUDY BETWEEN BUCKET CRUSHER AND MOBILE CRUSHER PERFORMANCE FOR LIMESTONE QUARRIES

Danail Terziyski, Ljupcho Dimitrov, Dimitar Kaykov

University of Mining and Geology “St. Ivan Rilski”, 1700 Sofia; E-mail: d.terziyski@mgu.bg

ABSTRACT. This article treats the problem of rock crushing utilising the bucket crusher technology. The main factors for using this type of technology are identified in this study. A comparison analysis is conducted in order to differentiate the excavation cycle duration between the bucket crusher and a conventional hydraulic excavator’s bucket. Furthermore, the differences between the volumes in the shift’s productivity are also pointed out. A comparison analysis is used as an argument for pointing out the narrow range of cases where this technology is applicable. Nevertheless, the main advantages of the bucket crusher technology are considered to be the lower volume of capital investment costs as well as the narrower width required for the pit ramps compared to using mobile crushers in the pit.

Key words: crushing, bucket crusher, productivity, limestone quarries

СРАВНИТЕЛЕН АНАЛИЗ МЕЖДУ РАБОТАТА НА КОФОВА ТРОШАЧКА И МОБИЛНА ТРОШАЧКА В КАРИЕРИ ЗА ВАРОВИК

Данаил Терзийски, Люпчо Димитров, Димитър Кайков
Минно-геоложки университет „Св. Иван Рилски“, 1700 София

РЕЗЮМЕ. Настоящият доклад третира проблема за натрошаване на скалата посредством кофови трошачки. Основните фактори за приложение на тази технология са посочени в настоящото изследване. Сравнителен анализ е извършен с цел да се установят разликите в технологичните цикли при използването на кофова трошачка и при използването на конвенционална кофа за хидравличен багер. Освен това са сравнени и сменните производителности в двата случая. Направен е и сравнителен анализ на условията, в които могат да бъдат прилагани двата типа технология. Независимо от наличните недостатъци, основното предимство на използването на технологията с кофова трошачка се оказват по-ниските капитални разходи и по-малката широчина на работните площадки в сравнение с площадките при изозлването на мобилна трошачка в забоя на кариерата.

Ключови думи: трошене, кофова трошачка, производителност, кариери за варовик

Introduction

The processes of excavating, transporting, crushing, and stockpiling have a major impact on a quarry’s life, in terms of material output and costs. Therefore, establishing an optimum sequence quarrying operation requires careful planning, due to the small scale of the operation, where incremental costs can significantly decrease the profit. However, the search of a better and newer technology often tends to bring unexpected solutions which have been overlooked.

An unconventional crushing technology which is so far only used as an auxiliary equipment is the so called “bucket crusher”. The technology is composed of an excavator and a small mobile crusher, replacing its bucket. The small mobile bucket crusher is fed directly by the excavator for primary or secondary crushing. The conventional crushing technology via a mobile crushes has the following sequence of operations: the material is transported and dumped near the crusher and then fed into the mobile crusher by a front end loader. The presence of this abundance of machines makes it more complicated as they become co-dependent on one another. The capital costs are higher in the beginning, and the need of staff is increased.

By deciding to implement the bucket crusher, there can be several advantages, like decreasing the initial capital investment costs, eliminating the need of a mobile crusher, eliminating the need of mobile crusher operator staff. With the implementation of the crushing bucket, the crushing machine will be wherever the excavator is, which means it can excavate and load in unpleasant places for the mobile crusher, i.e. in confined spaces.

Construction and work principles

There are different types of bucket crushers that are constructed for different types and strength of the materials. Currently, there are three types of bucket crushers (Eftimie D., 2014), such as:

- Jaw bucket crusher, or JBC (see Fig.1),
- Hammer bucket crusher (Fig.2),
- Crushing mill bucket type (Fig.3).

Fig. 1 Jaw bucket crusher (JBC)

Fig. 2 Hammer bucket crusher

Fig. 3 Crushing mill bucket

For this research, the jaw bucket crusher will be used as an example. The jaw bucket crusher will be used because it offers more widely crushing capabilities in terms of rock strength and size.

The procedure of loading a jaw bucket crusher is the same as with the ordinary excavator bucket. The difference is that it is heavier and larger compared to a bucket with the same volume capacity.

When loaded, the JBC needs to be manoeuvred in an upright position so the gravity can carry the material downwards. After fixing the position of the bucket, the operator needs to take it above the unloading (crushing) place and start crushing the material. When the bucket is emptied, the process is restarted.

Determining the crusher productivity

Theoretically, the jaw-action crusher evacuates “n” prisms of material per minute; so, for an hour, we can write (Eftimie D., 2012):

$$Qv = 60\ V\ n \quad (1)$$

where:

V is the volume of the material prism.

Although the proposed method is theoretically correct, it can be difficult to apply it in a straightforward manner in the conditions of a mining site. The productivity for the bucket crusher can also be established by measuring the duration of each operation from the loading cycle of an excavator. The duration of the shovelling cycle of the bucket crusher excavator can be determined by the following equation:

$$T^{bc}{}_{sc} = t_d + t_{frm} + t_c + t_{erm}, \text{ min} \quad (2)$$

where:
$T^{bc}{}_{sc}$ is the shovelling cycle time for a bucket crusher excavator, min;
t_d – digging time, min;
t_{frm} – the filled bucket rotational movement, min;
t_c – crushing time, min;
t_{erm} – the empty bucket rotational movement, min.

The number of shovelling and crushing cycles within a period of 1h can be determined by the equation:

$$N^{bc}{}_c = \frac{60}{T^{bc}{}_{sc}}, \quad (3)$$

where:
$N^{bc}{}_c$ is the number of shovelling and crushing cycles per 1h;

$$Q^{bc}{}_h = \frac{E.N^{bc}{}_c.F_f}{F_s}, \text{ m}^3\text{/h} \quad (4)$$

where:
$Q^{bc}{}_h$ is the bucket crusher excavator productivity per hour, m³/h.

The bucket crusher’s hourly output of material can be calculated by the following formula:

$$Q^{bc}{}_s = Q^{bc}{}_h.T_s.K_{te}.K_{tr}.K_{dt} \quad (5)$$

where:
$Q^{bc}{}_s$ is the bucket crusher excavator productivity per work shift, m³/s;
K_{te} – coefficient accounting for the excavator’s technical efficiency;
K_{tr} – coefficient accounting for the truck waiting time per shift;
K_{dt} – coefficient accounting for the excavator downtime per shift.

The annual material output for the bucket crusher excavator can be determined by the formula:

$$Q^{bc}{}_{a} = Q^{bc}{}_{s}.N_s \qquad (6)$$

where:
N_s is the number of work shifts per year.

Material output comparison for a bucket crusher operation

In most cases, a conventional quarry operation utilises an excavator, a front end loader, a haulage truck, and a mobile crusher. For quarrying sites, the output of the mobiles crusher can vary from 200 t/h to 400 t/h and the suitable rock size for feeding the crusher is usually up to 600 mm. The main objective of this case study is to verify the pros and cons of utilising a bucket crusher in a quarrying operation.

The BF 150.10 bucket crusher model is suitable for excavators with an operating weight of between 70 and 100 tons and provides a bucket opening of 1450 x 700 mm and an output adjustment from 100 to 200 mm. This machinery is considered to be essential for primary crushing in quarries and large scale operations. The BF 120.4 S4 bucket crusher model is suitable for excavators with an operating weight between 30 and 45 tons and provides a bucket opening of 1205 x 540 mm. The output material size of the BF 120.4 S4 bucket crusher is from 15 to 145 mm and therefore it can be used for secondary crushing in quarrying. Both bucket models are suitable for inert material, including the hardest rock types. (https://www.mbcrusher.com/). Studies show that an average shovelling cycle is approximately 2 min; therefore, the shovelling cycles for the 2 models are thus assumed in this case study.

Calculations for an excavator with the BF 150.10 bucket model

$$N^{bc}{}_{c} = \frac{60}{T^{bc}{}_{sc}} = \frac{60}{2} = 30\ cycles$$

$$Q^{bc}{}_{h} = \frac{E.N^{bc}{}_{c}.F_f}{F_s} = \frac{2,3.30.0,65}{1,4} = 32\ m^3/h$$

$$Q^{bc}{}_{s} = Q^{bc}{}_{h}.T_s.K_{te}.K_{tr}.K_{dt} = 32.8\ .0,9.0,95.0,95 = $$
$$= 207,9\ m^3/shift$$

$$Q^{bc}{}_{a} = Q^{bc}{}_{s}.N_s = 207,9\ .240 = 49\ 896\ m^3/year$$

Therefore, the required number of excavators equipped with the 150.10 bucket crusher is 1.

Calculations for an excavator with the BF 120.4 S4 bucket model

$$N^{bc}{}_{c} = \frac{60}{T^{bc}{}_{sc}} = \frac{60}{2,2} = 27\ cycles$$

$$Q^{bc}{}_{h} = \frac{E.N^{bc}{}_{c}.F_f}{F_s} = \frac{1,3.27.0,8}{1,3} = 21,6\ m^3/h$$

$$Q^{bc}{}_{s} = Q^{bc}{}_{h}.T_s.K_{te}.K_{tr}.K_{dt} = 21,6.8\ .0,9.0,95.0,95 =$$
$$= 140,35\ m^3/shift$$

$$Q^{bc}{}_{a} = Q^{bc}{}_{s}.N_s = 140,35\ .240 = 33\ 684\ m^3/year$$

Therefore, the required number of excavators equipped with the 120.4 S4 bucket crusher is 1.

$$N^{bc}{}_{c} = \frac{60}{T^{bc}{}_{sc}} = \frac{60}{0,3} = 200\ cycles$$

$$Q^{bc}{}_{h} = \frac{E.N^{bc}{}_{c}.F_f}{F_s} = \frac{1,76.200.0,8}{1,3} = 216,6\ m^3/h$$

$$Q^{bc}{}_{s} = Q^{bc}{}_{h}.T_s.K_{te}.K_{tr}.K_{dt} = 216,6.8\ .0,8.0,95.0,95 =$$
$$= 1251\ m^3/shift$$

Since the average output of material per shift is 125 m³, the excavator can satisfy this requirement in the time limit of one work shift.
Therefore, 2 work shifts are needed for the quarry as shown in Fig. 4:

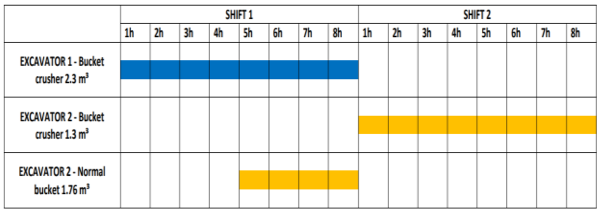

Fig. 4 Work shift plan for both bucket crusher excavators

Workspace comparison

Calculation of the work bench width in the case of utilising a bucket crusher

Following I. Koprev’s (2017) formulae, we propose the following formula for the calculation of the work bench width in the case of utilising a bucket crusher:

$$B^{bc}{}_{wb} = B_{bb} + B_a + B_r + B_{mp} = 3 + 3 + 5 + 22 = 33\ m \qquad (7)$$

$$B^{bc}{}_{wb} = B_{bb} + B_a + B_{mp} = 3 + 3 + 22 = 28\ m \qquad (8)$$

where:
$B^{bc}{}_{wb}$ is the work bench width (when utilising a bucket crusher), m;
B_{bb} – back break width, m (B_{bb} = 3 m);
B_a – ramp width for auxiliary equipment (B_a = 3 m), m;
B_r – road width, m, (B_r = 5 m);
B_{mp} – muck pile width, m (B_{mp}= 22 m).

Equation 7 can be applied in the general case of utilising a bucket crusher with a haul road, situated outside the ramp width intended for holding the muck pile (see Fig. 5).

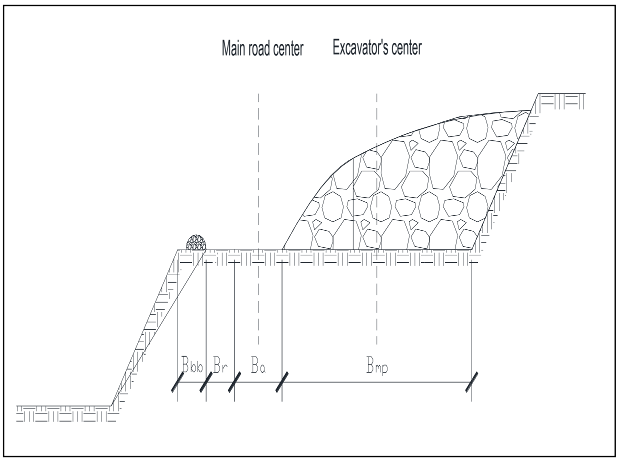

Fig. 5 Bench width with a road access

Equation 8 is applied when there is a possibility to situate the haul road behind the muck pile, which is usually wider than the minimum width needed for one-lane haul truck road in quarrying (Fig.6).

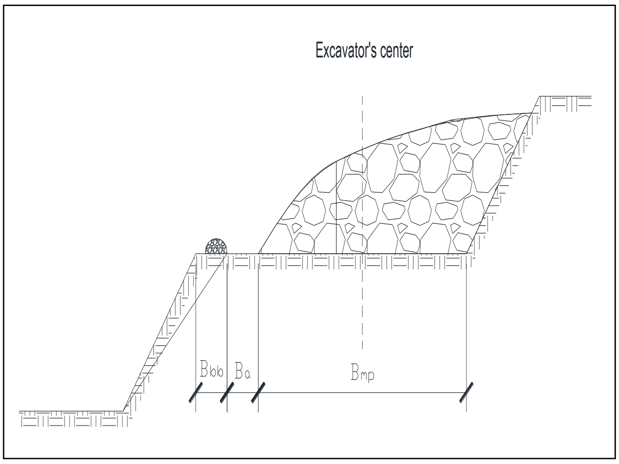

Fig. 6 Bench width with only muck pile width access

Therefore, equation 7 represents the maximum needed width required for utilising a bucket crusher, while equation 8 represents the minimum needed width required for a bucket crusher. However, one should notice that in the case of Fig. 6, the productivity of the excavator would be less, due to the longer excavation cycle required for shovelling the material from the muck pile.

Calculation of the work bench width in the case of utilizing a mobile crusher

Following I. Koprev’s (2017) and A. Atanasov’s (2003) formulae, we propose the following formula for the calculation of the work bench width in the case of utilising a mobile crusher:

$B^{mc}{}_{wb} = B_{bb} + B_a + B_{cm} + B_{mp}$ =
= 3 + 3 + 3.5 + 22 = 31.5 m (9)

$B^{mc}{}_{wb} = B_{bb} + B_a + L_{mc} + B_{cm} + B_{mp}$ =
= 3 + 3 +1.6 + 14.8 + 22 = 46.4 m (10)

where:

$B^{mc}{}_{wb}$ is the work bench width (when utilising a mobile crusher), m;
B_{bb} – back break width, m (B_{bb}= 3 m);
B_a – ramp width for auxiliary equipment, m (B_a = 3 m);
B_{cm} – crushed material width, m (B_{cm} = 3.6 m);
B_{mp} – muck pile width, m (B_{mp} = 22 m);
L_{mc} – mobile crusher length, m (L_{mc} = 14.8 m).

Equation 9 is applied in the case when there is an excavator shovelling the material from the muck pile directly into the mobile crusher, which is positioned parallel to the bench crest (see Fig.7).

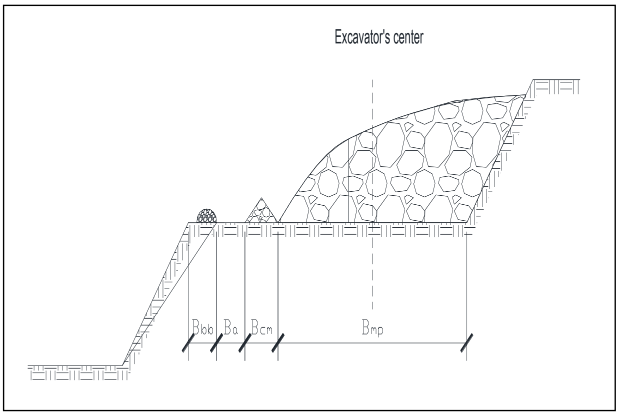

Fig. 7 Bench width when the mobile crusher is placed parallel with the bench

Equation 10 also applies when an excavator shovels the material into the mobile crusher, which is positioned perpendicular to the bench crest (Fig.8).

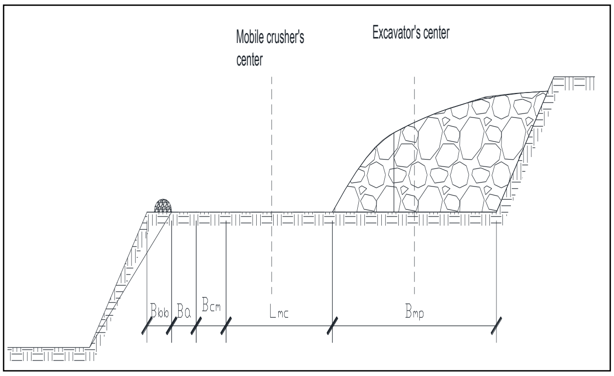

Fig. 8 Bench width when mobile crusher is placed perpendicular to the bench

Therefore, equation 10 represents the maximum needed width required for utilising a mobile crusher, while equation 9 represents the minimum needed width required for a mobile crusher. Therefore, the bucket crusher can be utilised in confined spaces and, therefore, a smaller work bench width is required for shovelling and crushing the material in the bench limits, as was shown in Fig. 9.

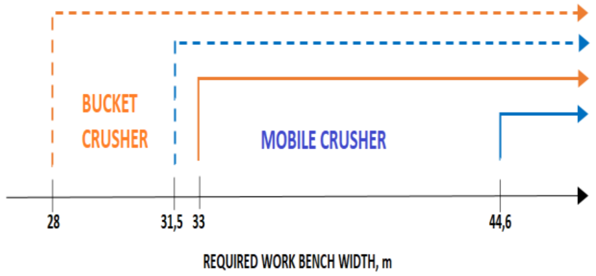

Fig. 9 Minimum required work bench width

Costs and profit comparison

Table 1 represents the costs required for starting a quarry operation with a bucket crusher or with a mobile crusher.

Table 1. *Investment and operation costs for the two quarrying operations*

MINING OPERATION WITH A BUCKET CRUSHER EXCAVATOR		
Equipment name	**Investment costs, EUR**	**Operational costs, EUR/h**
Bucket crusher 2.3 m³	197 300	35
Excavator (94 t)	400 000	
Bucket crusher 1.3 m³	73 800	26
Excavator (31 t)	180 000	
Haulage truck	48 000	17
TOTAL	**899 100**	**78**
MINING OPERATION WITH A MOBILE CRUSHER AND A CONVENTIONAL EXCAVATOR		
Equipment name	**Investment costs, EUR**	**Operational costs, EUR/h**
Mobile crusher	560 000	44
Excavator (26 t)	150 400	23
Haulage truck	48 000	17
Front end loader	170 000	18
TOTAL	**976 000**	**102**

Furthermore, salaries and wages are also included for the calculation of the total annual costs for the two cases. Both cases require personnel of 4 workers in total (Table 2):

Table 2. *Costs required for personnel in both cases*

	Bucket crusher operation		**Mobile crusher operation**	
	Number of operators	Salary, EUR/month	Number of operators	Salary, EUR/month
Mobile crusher	-	-	1	1200
Excavator 1	1	1200	1	1200
Excavator 2	1	1800	-	-
Haulage truck	1	1200	1	1200
Front end loader	1	1200	1	1200
TOTAL	**4**	**5400**	**4**	**3600**

Figures 10 and 11 represent the results from the feasibility study, which show that utilising a bucket crusher quarry operation may prove to be more profitable in the long term.

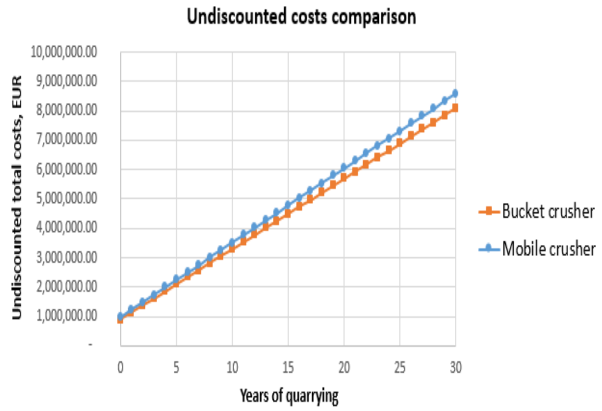

Fig. 10 Undiscounted costs comparison for a bucket crusher and mobile crusher quarry operation

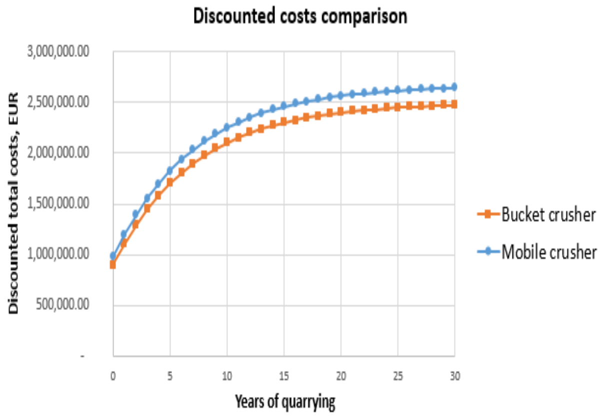

Fig. 11 Discounted costs comparison for a bucket crusher and mobile crusher quarry operation

Assuming an average selling price of crushed limestone of 10 EUR/t and an annual output of material for the quarry of 30 000 m³ (78 000 t), the undiscounted and discounted profits are calculated for the quarry operation (Fig. 12 and Fig. 13).

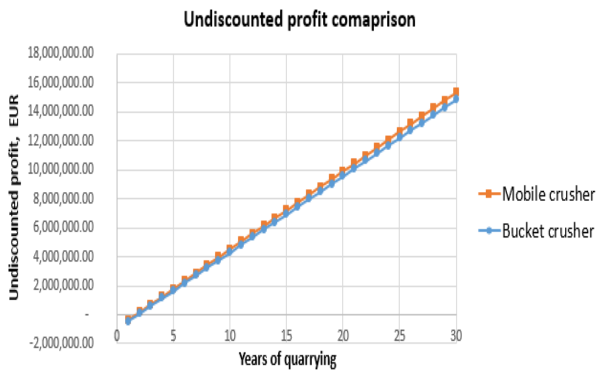

Fig. 12 Undiscounted profit comparison for a bucket crusher and mobile crusher quarry operation

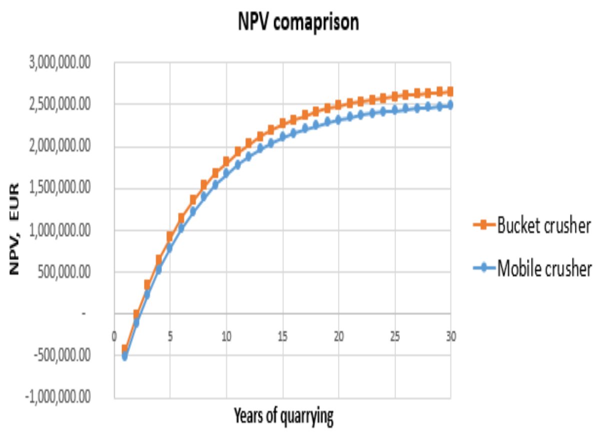

Fig. 13 NPV comparison for a bucket crusher and mobile crusher quarry operation

Table 3 represents the results from the feasibility study for the 15th and the 30th year of quarrying.

Table 3. *Results from the feasibility study*

	Years of quarrying	**Bucket crusher operation**	**Mobile crusher operation**
Investment costs, EUR	-	889 100	976 000
Undiscounted costs, EUR	15	4 491 900	4 777 600
Discounted costs, EUR (r = 0,15)	15	2 299 662	2 457 957
Undiscounted profit, EUR	15	7 208 100	6 922 400
NPV, EUR (r = 0,15)	15	2 261 287	2 102 991
Undiscounted costs, EUR	30	8 084 700	8 579 200
Discounted costs, EUR (r = 0,15)	30	2 471 783	2 640 082
Undiscounted profit, EUR	30	15 315 300	14 820 800
NPV, EUR (r = 0,15)	30	2 649 681	2 481 382

In the cases of 15 and 30 years of quarrying, the feasibility study shows that although the investment costs for the bucket crusher operation are slightly lower, the incremental profit gained from it is worthwhile.

Conclusions and possibility for further studies

The main conclusions of this case study are as follows:

- The material output analysis from this case study has shown that, so far, the utilisation of the bucket crusher technology is suitable for small mining sites and quarries (material output up to 30 000 m^3/year).
- The required work bench width for utilising a bucket crusher is smaller than the one required for utilising a mobile crusher. Therefore, the bucket crusher excavator can be flexibly used in quarries or small mining sites where the workspace is limited.
- The results from the feasibility study show that although the investment costs are slightly lower for the bucket crusher operation, the operational costs are less than the quarry operation, utilising a mobile crusher.
- However, in the case of using a bucket crusher, the quarry has to operate in 2 work shifts per day in order to maintain its planned material output throughout the years. At the same time, a mobile crusher operation, although more expensive, has to operate with 1 work shift per day.

One should notice that this feasibility study is site specific and any further investigations into this topic should be compliant with the specific equipment prices for the particular country and the market value of the crushed stone. In addition, this study lies on the assumption that drilling and blasting costs are equal for both cases and that the rock fragmentation size is similar for both cases (600 mm maximum rock fragment size).

However, further studies on the rock fragmentation size can be conducted in order to revise the comparison between the two proposed technologies. Also assuming that different rock size fragmentation for both cases and, therefore, different drilling and blasting costs can lead to a different outcome, which has to be further investigated.

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