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BENEFITS OF USING MOBILE CRUSHING AND SCREENING PLANTS IN QUARRYING CRUSHED STONE

1. Introduction

Mobile crushers have been used for long time mostly in limestone quarries. They provided advantage of belt conveyor transport and eliminated road construction and truck haulage, and thus resulted in cost savings [1]. Mobile plants for crushing and screening (in further text mobile plants) are increasingly used on mining fields of crushed stone and also with the preparation of the construction material in construction engineering sites (highways, tunnels) and building construction (construction pits). They are used on mining sites of crushed stone where blasted raw material, old spoil dumps and overburden are processed.

Depending on the type of the material and on the targeted stone product, an appropriate configuration of the mobile processing plants is set. A common trait is the access of the mobile plants to the raw material, which is a primary advantage, especially in terms of reducing the transport costs.

Limiting the expansion of the mine fields, especially in protected parts of nature, along with a long and dubious process of obtaining the concession for mining of mineral raw materials, pointed the interest of the mining concession carriers towards old spoil dumps, in which the rock is predominantly mixed with dirt. The advantages of old spoil dumps mining are that there is no drilling and blasting, overburden removal, neither exploration work. The separation of stone from the spoil dumps is done on site, which is likewise applicable to the low-quality parts of the stone deposit and to the overburden that potentially contains quality stone.

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Key postulates of the mining economy are realized with the application of mobile plants:

- rational use of non-renewable mineral resource,
- rational use and protection of spatial resource,
- reduction of loading-haulage capacities and reduction of the transport costs,
- lesser impact of mining work on environment and nature,
- energy efficiency.

The need to expand the mining field, the volume of the spoil dump and the space needed for its position is reduced by mining of the overburden and low-quality parts of the deposit.

The aim of this paper is the comparison of the efficiency of mining of crushed stone with the use of mobile and stationary plants for processing. The capacity and costs of the loading, transport and processing are considered during that process.

2. The comparison of quarrying with mobile and stationary plants

The comparative analysis was conducted for two models of crushed dolomite mining for concrete aggregates. The technological process of mining was considered after the removal of the overburden, and drilling and blasting mineral raw material. The models imply:

- the model of quarrying with stationary processing
  - loading of the mined rock mass into dumper,
  - transport to the stationary plant outside of the mining field,
  - processing on the stationary plant,
- the model of quarrying with mobile processing
  - loading of mined rock mass into the mobile plants,
  - crushing and screening on mobile plants,
  - loading and transport of the fraction –4 mm to the stationary plant,
  - refining the fraction –4 mm by a wet process.

The mining field is dislocated by 1.8 km in relation to the stationary processing plant.

The typical technological scheme of mining on the mobile installations inside the mining field is shown below. See Figure 1.

The configuration of the plants consists of mobile plant for crushing and mobile plant for screening. A control screen with opening width of 30 mm is integrated in the mobile impact crusher. The screen overflow +30 mm goes back for reducing size in the impact crusher and the screen underflow –30 mm is further screened in the mobile plant for screening.

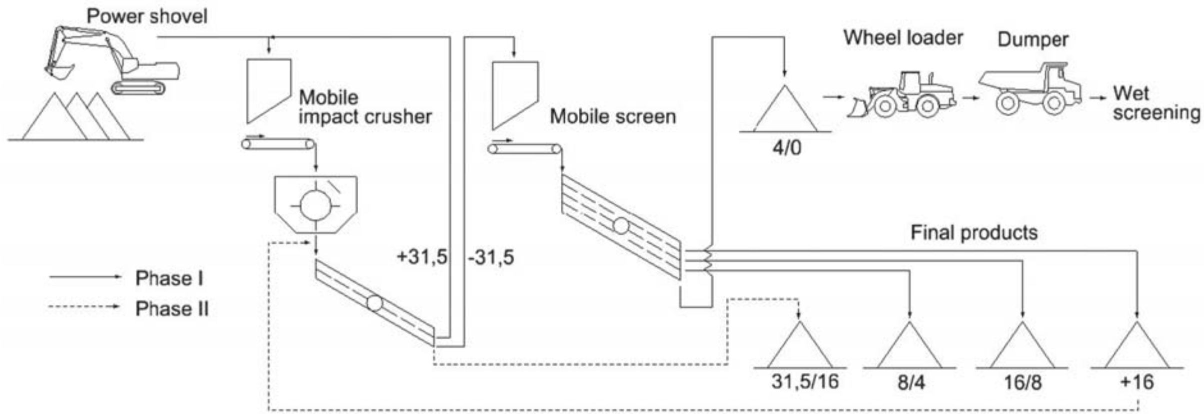

Fig. 1. Technological scheme of mining and processing on mobile plants

Mobile plant for screening is equipped with a inclined three-deck screen with apertures of 4 mm, 8 mm and 16 mm. Completed concrete aggregates are obtained, with fractions of –4 mm, 8/4 mm, 16/8 mm and a fraction of +16 mm. The 16 mm screen overflow goes back to the screen with opening width of 30 mm in order to remove the oversize and the irregular shaped particles. A completed concrete aggregate 16/31.5 mm is obtained in the screen underflow. The sieve oversize is returned to the impact crusher. The fraction of –4 mm does not meet the technical regulations regarding the content of fines and is additionally screened by wet process on the stationary plant [3]. When the rock mass is contaminated with dirt, pre-screening is carried out on the grid with aperture width of 30 or 40 mm.

Mobile plants for crushing and screening are placed along the blasted raw material. Crawler excavator from position of the mined raw material loads the material into to crusher feed hopper, from where a conveyor feeds the impact crusher. Product of the process is aggregate with structure shown in Table 1.

TABLE 1

The structure of the dolomite aggregate produced

Fraction	31.6/16	16/8	8/4	–4	–0.063
Share	20%	20%	25%	30%	5%

3. The costs' analysis

Data on fuel consumption, the costs and the capacities of mining equipment are real, obtained by years-long monitoring of the crushed dolomite mining on surface pits Hercegovac and Oršulica kosa near Orahovica.

The cost of a working hour of each machine (Tables 4 and 5) includes material costs (fuel, lubricant, oils, maintenance materials, spare parts, maintenance services, tires), equipment insurance (1% of the purchasing price), gross paycheck, medical examination costs and safety at work equipment for machine handlers and machine depreciation. Depreciation rate includes 15% of the value because the optimal lifespan of the mining equipment is estimated at 7 to 8 years. The technical and operational features of the loading-haulage equipment and mobile plants are shown in Tables 2 and 3 [2].

The realized working hours of the machines hm are calculated using the formula [4]:

$$h_m = \frac{Q_g \cdot k_r \cdot k_n}{Q_H} \tag{1}$$

where symbols stand for:

Q_g — the bank volume of rock mass, m^3,

$k_r = 1.4$ — swell factor of dolomite,

$k_n = 1.2$ — availability of the machine,

Q_h — hourly productivity of the machine, m^3/h.

The expenses of a certain technological phase T_{th} are calculated using the formula:

$$T_{th} = t_{hs} \cdot h_m \tag{2}$$

where t_{hs} — is an expense per hour of a certain machine obtained by years-long monitoring.

TABLE 2
Technical/operational features of loading/haulage equipment

Feature	Loading into the mobile plants (crawler excavator)	Loading and transport of fraction –4 mm	
		(wheel loader)	(dumper)
Struck capacity of shovel/truck, m^3	1.5	4.0	11.0
Duration of the loading/haulage cycle, s	23	156	942
Hourly productivity, m^3/h	170	200	36.5
Engine power, kW	150	213	–
Fuel consumption, l/h	17.69	14.65	12.45

TABLE 3
Technical/operational features of processing plants

Technical features	Mobile impact crusher	Mobile three-deck screen	Stationary plant
Feed hopper volume, m^3	5	8	–
Power, kW	310	82	–
Nominal production rate, m^3/h	< 110	< 300	–
Hourly productivity, m^3/h	80	150	50
Screen width × length, m	1.1 × 3.0	1.5 × 5.0	–
Fuel consumption, l/h	30.74	14.77	–

The input value in the cost calculation is a designed annual production of 50 000 m^3 as bank volume. Total costs of concrete aggregate production on mobile plants amount to 361.487 € or 7.23 €/m^3 (Table 4). Total costs of concrete aggregate production on stationary plant amount to 400.315 € (with transport distance of 1.8 km) or 8.03 €/m^3 (Table 5). The structure of the production costs for both models is shown by the diagram on Figure 2.

TABLE 4
Costs of the production phases with mobile processing

Production operation	Loading raw material (excavator)	Processing				Loading and transport of fraction –4 mm	
		crushing and screening	screening 16/8/4	screening 31,5/16	wet screening –4 mm	loading (wheel loader)	transport (dumper)
Effective working hours, h	412,0	1.050,0	560,0	140,0	–	126,0	690,0
Fuel consumption, l	7.289,0	32.277,0	8.271,0	1.662,0	–	1.846,00	10.191,00
Hourly costs, /h	63,60	160,40	58,60	52,30	4,04 /m^3	63,60	48,70
Production costs, /h	26.203,00	168.420,00	32.816,00	7.322,00	96.152	8.039,00	33.603,00
∑ 361.487,00							

TABLE 5
Costs of the production phases with stationary processing

Production operation	Loading raw material (wheel loader)	Transport (dumper)	Processing
Effective working hours, h	412,0	2.288,0	1.680,0
Hourly costs, /h	63,60	48,70	156,00
Production costs, /h	26.796,00	111.425,60	262.080,00
∑ 400.315,00			

The costs of mining for both models are calculated for different transport distances between the mining field and stationary processing plant (Fig. 3). Effective productivity of the machines for all production operations are the same, except for transport. The effective productivity of transport is calculated on the fact that the dumper's average speed amounts to 20 km/h and the loading-waiting-dumping time amounts to 4.9 min.

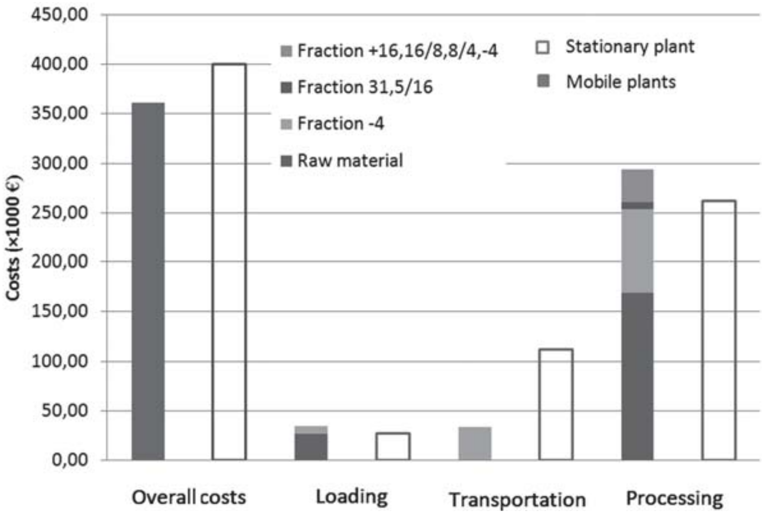

Fig. 2. Comparative costs of production with mobile and stationary plants

4. The results' analysis

A total expense of concrete aggregate production on stationary plant is increased by 11% compared to mobile plants. Primarily, an extra and considerable expense make the transport costs to the stationary processing plant (27.9%).

The costs of processing operation is somewhat greater for mobile then stationary plants model, primarily because of the need of additional wet screening of the fraction –4 mm (23,5%). Otherwise, the costs of mobile processing would be considerably smaller.

The diagram (Fig. 3) shows the proportionality of the production expenses on mobile and stationary plants with the transport distance. In case of mobile plants, the fraction –4 mm is transported to the stationary plant in order to remove the surplus of fines. In relation to processing completely on stationary plant, the quantity of transported material while processing on mobile plants is considerably smaller (only fraction –4 mm), so the gradient of the cost line is considerably milder.

The transport distance of ~0.5 km is situated at the intersection of cost lines where the production costs are equated. On smaller transport distances the production costs on the stationary plant are reducing so the use of mobile plants is not rational. The use of mobile plants is more profitable along with the growth of transport distance.

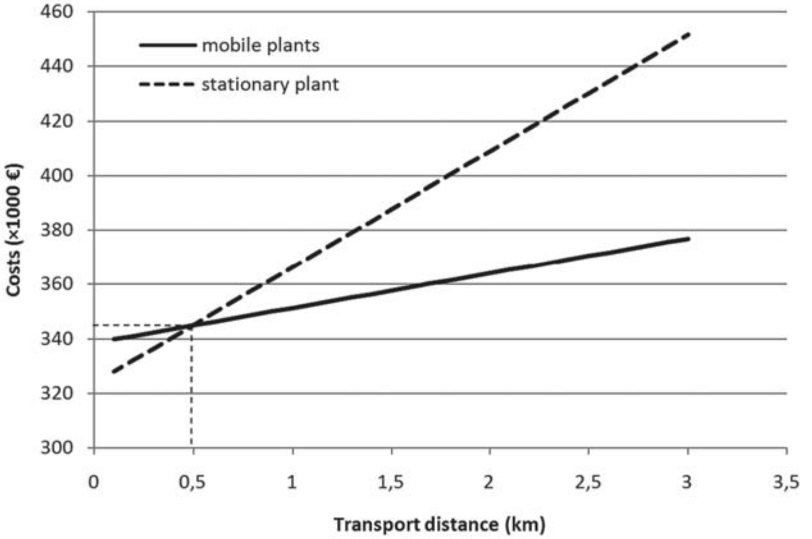

Fig. 3. Mining costs depending on the transport distance

5. Conclusion

The application of mobile plants for crushing and screening the dolomite stone is analyzed in this paper. Two models of mining are compared: one with the application of mobile plants and the other with the application of stationary processing plant. The mine field is dislocated in relation to the stationary processing plant approximately 1.8 km. A parallel cost analysis for the concrete aggregate production from the pure rock mass of dolomite without contamination was conducted. The relation of mining costs to distance between mining site and the stationary processing plant was tested through calculation.

In case of concrete aggregate production from pure rock mass, the justification for the use of mobile plants was proved by reducing the mining costs and by gaining the adequate level of quality of the stone products. The rationality of the use of mobile plants is more noticeable when spoil dumps, contaminated rock mass and overburden are processed. Stationary mobile plants have a longer lifespan and lower depreciation rate. Optimal lifespan of mobile plants is between 5 to 10 years. The application of the adequate configuration of mobile plants depends on variability of the quality of rock mass vertically and laterally. It also depends on market demand, optimization of production costs and the necessity of maintenance of high level quality of stone products by a combination of input raw material of different quality and adequate processing technology.

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