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Review of a Possibility to use Bulldozers at Vostochno-Bernikovskiy Deposit

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Abstract: The open pit capacity has been increasing over the last year, thus, creating favourable conditions to apply modern mining and hauling equipment and to adopt new advanced mining processes at Vostochno-Bernikovskiy deposit. The open pit operations are equipped with a large fleet of different equipment, however, the basic technical and economic performance indicators (productivity, profitability of mining company and others) are not improving at sufficient rate. The study contains the research data for the dependence of bulldozer performance on the average mucking distance and seismic velocity, adjustment factor for surface slope (downward or upward) as well as an assessment of the rock breaking characteristics by the seismic wave speed using a single-shank or multi-shank adjustable parallelogram ripper and a bulldozer with a capacity of 634 kW and weight 104.5 t. These results allow development of non-explosive mining technologies for construction materials as well as improving technical and economic performance of the open pit.

Keys words: Bulldozer, ripper, rock material, performance, seismic velocity, layer-by-layer excavation

INTRODUCTION

Review of mining conditions and existing production processes used at Vostochno-Bernikovskiy deposit (Russia) showed that application of mobile equipment both for excavation and stripping including rippers, hydraulic hammers and surface miners is the way to improve efficiency of mine operations providing non-explosive mining of the deposit.

Non-explosive processes will be widely applied for mining this deposit with complex structure considering strict requirements for raw materials, however, the field of their application may be determined after the feasibility study of processing routes and operational parameters.

The trend to apply surface miners designed for layer-by-layer mining provides selective extraction of rock material with mineral layers separated from waste ones consequently decreasing production losses and reducing operational load on the milling equipment, increasing the total yield and improving the stability of the pit wall.

According to the work experience gained from the surface miner operation at Dubninskiy construction limestone deposit in Russia, there were significant variations in performance of this equipment due to various physical and mechanical properties of rocks; besides, 60% of its operational time it was either down or moving to the other location (Ligotsky and Mironova, 2018; Burmistrov *et al*., 2017; Argimbaev and Yakubovskiy, 2014; Yakubovskiy *et al*., 2014; Argimbaev and Kholodjakov, 2016). The surface miner was used both for loading haul trucks and unloading to stockpiles (Fig. 1).

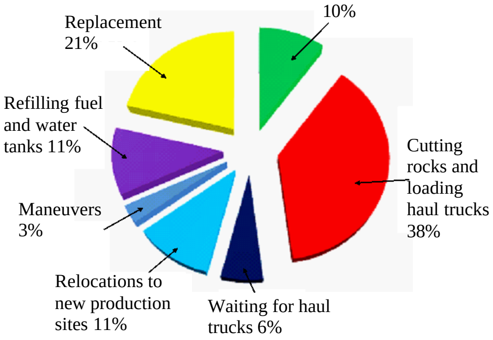

Fig. 1: Time study of limestone mining operations using a surface miner

Operation of the surface miner can be divided into the following stages: cleanup and leveling the production site, cutting rock and loading haul trucks (stockpile), waiting for haul trucks, relocation to other production sites, maneuvers, refilling fuel and water tanks and blade replacement. Time study of operations required for continuous work of the surface miner (Fig. 1) proved a low efficiency of this equipment at limestone deposits.

This type of mining equipment allows relocation of crushing process to the open pit to eliminate oversize rocks, however but as the length of production site gets shorter, the equipment will have to relocate more frequently and more time will be required for leveling the job site to prepare for mining.

Operation of the surface miner is also complicated by various inclusions, clay layers or lenses, excessive moisture on the production site. They complicate the equipment movement (chassis slippage) in fall and Winter and extracted rock material sticks to the conveyor belt. Operation of this equipment was completely ceased at negative ambient temperatures. Hard rock mining results in increased cutter wear consequently increasing the time required for their replacement and affecting the equipment performance.

Actual performance of surface miner at the limestone deposit may decrease by 60% with decreasing equipment utilization ratio up to 0.4 over the time.

Over the past 5 years, powerful and heavy-duty bulldozers were built and ripper designs were improved significantly increasing the scope of mechanical ripping. Now a days, this method is considered as highly efficient process for open pit mining which allows ripping and conveying rock materials (Kaerbek and Maya, 2016; Argimbaev, 2016a, b)

MATERIALS AND METHODS

Bulldozers can move the majority of existing rock material. However, their efficiency may change depending on the following rock parameters (Argimbaev, 2016a, b; Rafkatovich and Mironova, 2018; Gavrishev *et al.*, 2016a, b):

Size and shape of fragments: The bigger individual fragments, the more challenging it is for cutting edge to penetrate them. Sharp-edged particles resist to the natural rolling by the bulldozer blade. Moving such fragments require more power compared to the power required for moving the same amount of material with rounded-shape fragments.

Cavities: Few or absence of cavities means that most part or entire surfaces of rock fragments contact with each other. This creates a bond that must be broken. Uniform particle-size distribution of the rock material with a small number of cavities is usually heavy and it will be challenging to separate it from the rest of rock mass.

Moisture: In most cases, lack of moisture in the rock may result in a stronger bond between fragments making it difficult to separate them from the layer. The high moisture content also complicates bulldozing as the rock material becomes heavy and it takes more efforts to move it. Optimum moisture reduces dusting and provides the best conditions for easy bulldozing and the operator's comfort.

Impact of negative ambient temperature depends on the moisture content. The bond between the fragments frozen together gets stronger as the moisture content increases and ambient temperature drops down. However, if completely dry material gets frozen no changes occur in its properties.

The power in kW per linear meter of the cutting edge features the blade ability to penetrate and create a load on a pile. The greater this value, the greater the penetrating ability of the blade. The ability of blade to push the rock material depends on kW/m^3 of loose rock material. The greater the kW power per m^3 of loose material, the greater the potential ability of the blade to move the rock material at a higher speed.

Performance of the bulldozer moving the rock material can be determined based on the following performance curves and corresponding adjustment factors.

Seismic survey is the quickest and the most commonly used method to assess the rock mass crumbling ability based on the survey of the elastic wave speed depending on physical and mechanical properties and condition of rock mass. This technique allows selecting equipment based on bulldozer capacity and performance depending on the elastic wave speed in the rock mass.

RESULTS AND DISCUSSION

Results of this study are estimated performance for moving and breaking rock material. Bulldozer performance may be calculated by equation:

$$\Pi = \Pi_{max} \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4 \cdot k_5, m^3/h$$

Where:

Π_{max} = The bulldozer maximum performance m^3/h;

$k_1, k_2, \cdots, k_5$ = Adjustment factors (Table 1)

Performance curves of the bulldozer (Fig. 2 and 3) provide maximum unadjusted performance for U-shaped, half U-shaped and straight blades and estimated based on the provisions as follows:

- Operational efficiency is 100% (cycle is 60 min/h)
- Bulldozers with response time of 0.05 min when shifting gear under load
- Bulldozer cuts the rock in the 15 m (50 ft) long area, moves and dumps the rock material to the pile (dump time -0 sec)
- Density of rocks material moved is 1.67 (t/m^3)
- Blades with hydraulic cylinders

Table 1: Adjustment factors based on operational conditions

Variables	Tracked bulldozer
Operator	
Highly skilled	1.00
Semi-skilled	0.75
Underskilled	0.60
Material	
Loose material in blade	1.20
Difficult to cut, frozen	
With the tilt hydraulic cylinder	0.80
Without the tilt hydraulic cylinder	0.70
Difficult to move, packed (dry, fragmented) or very sticky	0.80
Rocky ground, loose or blasted	0.60-0.80
Machines working in pair	1.15-1.25
Visibility	
Dust, rain, snow, fog or darkness	0.80
Labor utilization rate	
50 min/h	0.83
40 min/h	0.67

Table 2: Recommended tips for various conditions

Ripping conditions	Tips
Two bulldozers connected by tow bar	Short
Single-shank and multi-shank	
For extremely hard operating conditions	Short/medium
Moderate hard rock	Long/medium
Abrasive rock	Long

Cutting the first gear forward, moving rock material the 2nd gear forward, return the 2nd gear reverse. This sequence of gearshifts is applicable to a flat or inclined terrain, material with low or medium density and the blade without extenders such as the side plates reducing the rock material loss, rock protection flaps, etc. Conditions that are more complicated may require moving the rock material in the first gear, however, performance will be the same or even exceed "normal conditions" as the more rock material can be moved in the first gear.

Performance in cubic meters of loose rock material is estimated through multiplying adjusted performance calculated above by the respective load factor (f), calculated by equation:

$$f = \frac{100\%}{100\% + P}$$

where, P is degree of the rock material fragmentation%. The following types of shank rippers are used for breaking the rock material: trailed (towed) and hinged (located in the rear part of the bulldozer). Trailed rippers are used for loosening the ground with tree roots, stumping and breaking frozen or packed soil.

Weight of the bulldozer with hinged ripper is summarized with the force created by the hydraulic system providing quick penetration of the ripper into the ground and a permanent ripping depth. Ripper can be simply raised for some other works to be performed, thus, enhancing versatility of the bulldozer.

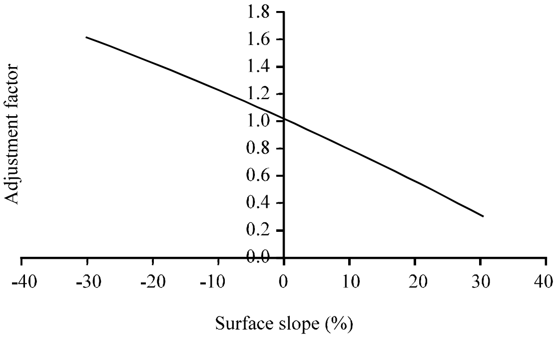

Fig. 2: Dependence of adjustment factor for dozing operations on the surface slope, (-) downward, (+) upward

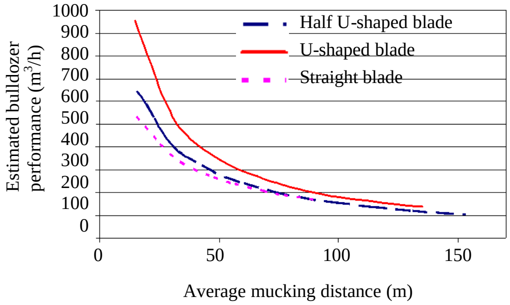

Fig. 3: Estimated dozer performance

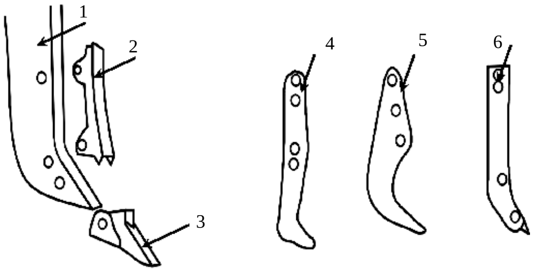

Fig. 4: Ripper attachment body: 1) Rack; 2) Safety plate; 3) Tip, types of racks; 4) Direct; 5) Curvilinear and 6) Smooth-profiled, high-speed

The ripper consists of shank, tip, one or two guard plates intended to protect the lower part of the shank against excessive wear (Fig. 4).

Efficiency of a particular tip depends on the ground to be ripped and the model of bulldozer used for ripping. "Penetrating" tips are to be used for ripping highly dense rock materials. "Axial" tips are used for ripping rock materials applying heavy shock loads. Table 2 for brief recommendations on the tip application.

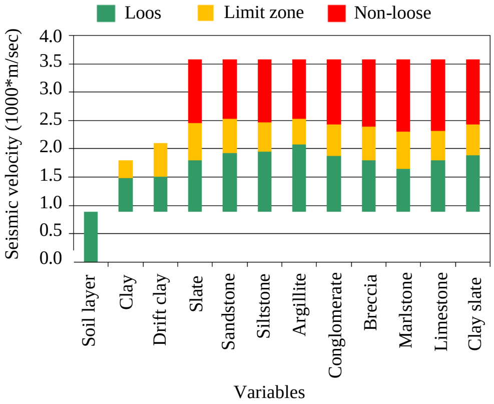

Fig. 5: Evaluation of rock breaking by the seismic wave velocity using single-frame or multi-frame controlled parallelogram ripper and a bulldozer with the capacity of 228 kW and weight of 38.4 tons

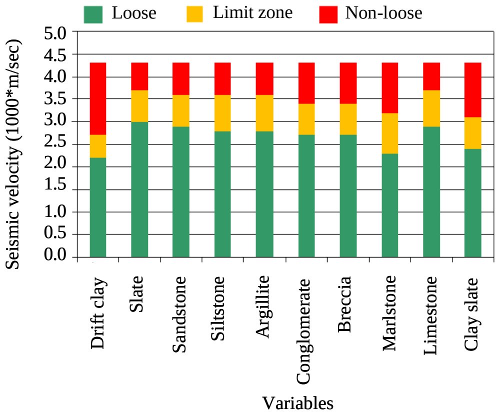

Fig. 6: Evaluation of rock breaking by the seismic wave velocity using single-frame or multi-frame controlled parallelogram ripper and a bulldozer with the capacity of 634 kW and weight of 104.2 tons

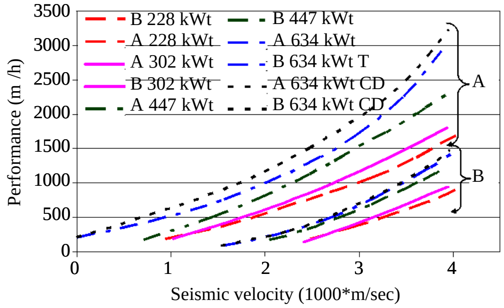

Fig. 7: Performance of bulldozers with various capacities with single-frame ripper of parallelogram type: A) Ideal operational conditions; B) Adverse operational conditions

During this study, the time for one pass was calculated which was 3.66 min. Operator working for 45 min/h on average capable to make 12 passes.

At this rate, the volume of ripped rock material per one pass would be 49 m^3 and total performance would be 604 m^3/h.

Experience proves that the performance under this method is about 10-20% higher than the actual performance may be expected.

Therefore, actual performance would be 483-543 m^3/h. Depreciation and operating costs for a 538 kW bulldozer used for ripping operations only would be 87 USD/h including the operator's salary 30 USD/h. Ripping cost would be within 0.16-0.18 USD/m^3.

Depreciation and operating costs for this would be increased in case of ripping hard rocks. To estimate costs for ripping hard rock, these ripping costs should increased by minimum 30-40%. Results of field trials completed on various types of materials at different deposits were followed by the efficiency diagrams made for rippers based on the seismic wave speed (Fig. 5 and 6).

Considering broad variations in the properties of different materials, even the rocks of same category, these diagrams should be considered as just one of the ripping ability indicators as well as measuring performance based on seismic speed, bulldozer power and ripper type (Fig. 7).

Proper combination of blade and bulldozer is the main driver for maximum performance. First of all, consider the nature of operations the bulldozer will be involved in for the most of its service life. Afterwards, other parameters to be evaluated are rock material to be moved, restrictions associated with bulldozer operational parameters.

In this regard, parameters to be considered when evaluating the technical possibility of rock ripping are bucket teeth penetration. This is specifically applicable for uniform materials such as clay or fine-grained limestone and densely compacted formations (conglomerates, some boulder clays and limestone deposits containing rock fragments).

Low seismic speed in sedimentary rocks may serve as a sign of ripping potential. However, if fractures and joints in layers prevent penetration of teeth, ripping will be not efficient for this material.

Undermining may provide sufficient breakage of the rock material and improve teeth penetration, particularly in limestones, conglomerates and some other rocks; however, economic efficiency should be assessed carefully when it comes to undermining in harder rocks.

Ripping for scraper mucking may require completely different equipment compared to the case where the same material needs to be moved by the bulldozer. Transverse ripping will require another approach as well.

CONCLUSION

Number of shanks, their length and thickness, teeth slope, direction, throttle position everything has to be adjusted to fit operating conditions. Successful ripping may depend on the operator properly combining these parameters based on the existing operating conditions.

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