ANALYSIS OF FUEL CONSUMPTION WITH TWO METHODS OF EXPLOITATION OF LIMESTONE

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Abstract: *Modern exploitation of limestone requires a more detailed analysis of all its working and production processes in order to optimize them. The main task in the organization of exploitation is to ensure safe operation by introducing the latest achievements of science and technology and get a product with a lower production price but also with the lowest possible negative effects on the environment and people. Gravity transport is usually used in combined transport (mainly mineral raw materials) in mountain surface mines. At the quarries, this transport is almost a typical solution. This is especially pronounced with small capacities and short quarry life Previous research has shown that gravity transport, compared to mechanized (truck, rail) provides 2 - 4 times shorter transport length, which reduces investment in communications and transport, and also reduces operating costs and pollution levels. This article analyses the possibility of economically justified application of partial gravity transport within the existing production technology, in terms of reducing the consumption of fossil fuels in the process of exploitation. In order to achieve the goal, about 2000 in situ data were collected and statistical analysis was performed. The results of the analysis showed large savings in fuel consumption with the proposed method of stone exploitation compared to the current one used.*
Keywords: *CO2 emissions, environment, exploitation, fuel consumption, gravity transport, limestone quarry, truck transport*

INTRODUCTION

Study case

Limestone deposit "Duboki Potok - Bijela Rijeka" is located southeast of Srebrenik at a distance of about 6.5 km. The deposit is built of limestone and marl, clay and alluvium of the river Tinja. The limestone deposit has the shape of an elongated lens, deformed under the influence of tectonic and erosion factors, in the east-west direction, over 1000 meters long. Fault faults can be divided into longitudinal and transverse. According to the mechanism of formation, they are divided into shear faults and tension faults. The engineering - geological characteristics of the deposit are the result of structural - tectonic factors, which directly affect the conditions of exploitation, mining, stability of working slopes and the orientation of the progress of exploitation works. The perennial and current orientation of the working benches and the width of the working plateau are favourable in relation to the open part of the deposit, and so far no sliding phenomena have been registered in the stratification planes [6, 10].

METHODS

It is evident a process of continuous warming since the industrial revolution. According to the report issued by the UN Intergovernmental Panel on Climate Change in 2014, the global average surface temperature has risen by approximately 0.85°C. Global warming is mainly caused by greenhouse gas (GHG) emissions. In 2017, the concentrations of the three major GHGs, namely carbon dioxide, methane, and nitrous oxide in the atmosphere were 405.5 ppm, 1859 ppb, and 329.9 ppb, respectively, which were approximately 46%, 157%, and 22% higher, respectively, than the levels before widespread industrialization. To control the ecological deterioration caused by global warming, it is essential to reduce GHG emissions, especially carbon dioxide emissions [1, 2, 5]. This, along with increased documentation of the environmental, social, and economic consequences of associated sea-level rise and extreme weather events, has led the majority of nations to join in a declaration to limit man-made warming through Nationally Determined Contributions to global GHG emission-reduction [1].

Recent increases in fuel prices have a great impact on global economic changes. Excessive use of petroleum not only increases the budget but also emits more pollutants. Hence the reduction of fuel consumption can minimize the pollutant emission and preserve the environment clean and green [7]. One of the construction sectors that produce significant greenhouse gas emissions is road construction. Life cycle assessment on flexible pavement construction activities showed that it generated twice higher carbon emissions than that of rigid pavement construction activities [4].

According to Fontaras et al. (2017) An official investigation funded by the French ministry of transport has shown that most of the reported CO2 values cannot be reproduced under laboratory test conditions and that a reproduction of the certification test results in consistently higher CO2 emissions by 15%, on average, with a standard deviation of 8%.

Trucks, whether used for freight transportation or as utility vehicles, play an important role in a countries economy and improving their fuel efficiency can undoubtable prove highly beneficial [11].

Applied system of limestone exploitation at the surface mine "Duboki Potok-Bijela Rijeka"

The system of limestone exploitation at the surface mine "Duboki Potok-Bijela Rijeka" is built of complex mechanization, which is reflected in the mutual harmonization of structural and technological parameters of mining and construction machines and parameters of the surface exploitation system. The main feature of this mine is the absence of classical discovery. Selective separation and loading into dumpers of quality batches of limestone rock mass from mined mass is done with a loader on the working surfaces of each bench [6, 8, 10].

Proposed system of limestone exploitation at the surface mine "Duboki Potok-Bijela Rijeka" - gravity transport

Before designing gravity transport, it is necessary to examine in detail all the physical characteristics of the ore that will be transported in this way. Gravity transport means opening a surface stone mine with external or internal semi-sections and for gravity transport with open bars. For the analysis of the justification of the application of gravitational exploitation the division of the mine by height into bench is adopted: E +280, 310, 340 and 370 (m), with the width of the berm bench Be=8 (m). The main advantage of the proposed system of exploitation is reflected in the reduction of the required number of machines and lower consumption of diesel fuel at the same production capacity. Based on all influential factors, for the exploitation of limestone, a transport system with felling (gravitational transport) of limestone rock mass (with tailings) from all working benches through the working slope of the surface mine to the main bench 280 is proposed [6, 8].

RESULTS AND DISCUSSION

Fuel consumption analysis

Review of planned fuel consumption of transport machinery - the existing system of exploitation

The annual plan of mining works at the surface mine "Duboki Potok-Bijela Rijeka" for 2008 envisages a plan for the production of limestone by benches and it is shown in Table 1 [6].

Table 1 Limestone stone production plan by benches

Bench	Exploitation mass of limestone
(m)	(t)
E+280	205875
E+300	226462
E+320	236756
E+340	133818
E+360	82350
Total	885261

Based on the results obtained by measuring and the Limestone Production Plan by benches for 2008, it is possible to plan the fuel consumption of transport machinery by benches, which is presented in Table 2 [6].

Table 2 Fuel consumption of transport mechanization by benches

		B +280			B+300			B +320			B +340		
nc	M	Qg	L	Qg1t	Qg	L	Qg1t	Qg	L	Qg1t	Qg	L	Qg1t
30	750	35	190	0,047	60	332	0,08	82	456	0,109	140	611	0,187
30	750	40	230	0,053	67	377	0,089	90	501	0,12	157	671	0,209
30	750	46	280	0,061	79	442	0,105	120	596	0,16	170	726	0,227
Average		40,33	233,33	0,054	68,66	383,67	0,092	97,33	517,67	0,1298	155,67	669,33	0,207

n_c - number of cycle
M - total mass of limestone (t)
L - length of transport route (m)
Qg - total fuel consumption (l)
Qg1t - fuel consumption per 1 t of limestone mass (l/t)

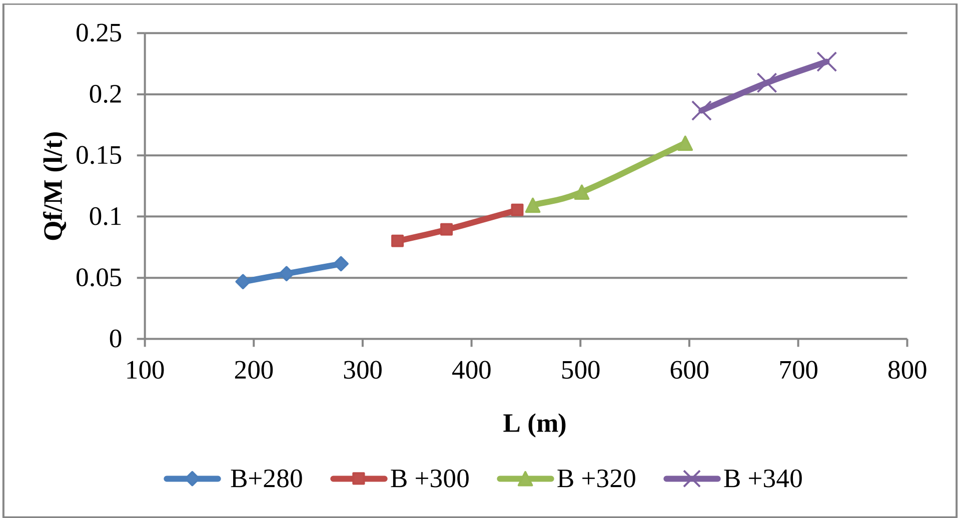

Figure 1 Fuel consumption per ton of limestone as a function of transport length

Table 3 Plan the average fuel consumption of transport machinery by benches

Bench	Exploitative mass of limestone M	Specific fuel consumption Qg/M	Total planned fuel consumption Qg	Fuel price	Value
(m)	(t)	(l/t)	(l)	(BAM/l)	(BAM)
E+280	205875	0,0538	11076	2,05	22705,8
E+300	226462	0,0916	20744	2,05	42525,2
E+320	236756	0,1298	30731	2,05	62998,5
E+340	133818	0,2076	27780	2,05	56949
E+360	82350	0,2933	24153	2,05	49513,6
Total	885261	0,7761	114484	2,05	234692,2

Planned fuel consumption of transport machinery, i.e. EUCLID R32 tipper, with the existing system of exploitation, is 114484 (l), which at the then prices of diesel fuel was: 234692,20 (BAM).

Calculation of fuel consumption of transport machinery for the proposed system of exploitation-gravity transport

By applying the new exploitation system, the entire mass of limestone would be transported from the bench E+280 m. In that case, the fuel consumption of the transport machinery, i.e. tipper EUCLID R32 would be:

Qg = 885261 x 0,0538 = 47627 (l),
which at the then fuel prices is: 97635,35 (BAM)

For comparative analysis of fuel consumption, existing and proposed exploitation system, it is necessary to calculate the fuel consumption of hydraulic shovel Terex TC240NLC and bulldozer Liebherr PR742B for digging and transporting mined limestone rock mass for gravity transport through the working slope of the surface mine to the ground bench +280 m [6].

Fuel consumption calculation for Liebherr PR742B bulldozer and Terex TC240NLC hydraulic shovel for the proposed exploitation system-gravity transport

The collapse width of the demined limestone rock mass on the bench can be calculated approximately by Eq. (1):

$$Bo = k_m \cdot k_\beta \cdot q^{1/2} \cdot H \quad (m) \tag{1}$$

where:
k_m - coefficient of rock fragmentation by blasting (k_m=2 -3 for medium crushing rocks)
k_β - the slope coefficient of the well $k_\beta=1+0,5 \sin 2(\pi/2 - \beta)$ (k_β=1,32)
q - specific consumption of explosives (q=0,30-0,35) (kg/m^3)
W - the least resistance line (m)

For bench high H=30 (m), W=4 (m), q=0,30 (kg/m^3) collapse width is Bo=44 (m),

The length of the upper side of the trapezoid P is calculated by the formula:

$$P = 0,3 \cdot (Bo - W) + 3,5 = 15,5 \ (m) \tag{2}$$

The height of the trapezoid Ho″ is calculated by Eq. (3):

$$Ho'' = \frac{2 \cdot H \cdot W \cdot k_r}{Bo+P} = 7{,}2 \ \ (m) \tag{3}$$

The area of the collapse trapezoid is:

$$Pt = \frac{(Bo+P) \cdot Ho''}{2} = 214{,}2 \ \ \ (m^2) \tag{4}$$

The area of limestone rock mass that is retained on the berms of the bench lower than the bench, on which the extraction is performed, is determined according to Eq. (5):

$$Psm = \frac{B_{min} \cdot Ho''}{2} = 28{,}8 \ \ (m^2) \tag{5}$$

From the total area of demined limestone rock mass Pt=214,2 (m^2), the area retained on the berms of the bench is Psm=28,8 (m^2), which is 13,44% according to the calculation.

For the calculation of the masses that remain on the berms that need to be dug and transported by Liebherr PR742B bulldozer and Terex TC240NLC hydraulic shovel through the working slope of the surface mine to the ground bench E+280 m, 15% of the total demined mass is adopted.

Based on the known capacity of bulldozers and excavators, fuel consumption per hour ql=35 (l/h), qt=20 (l/h) (empirical data), and the fact that the material would be dug and transported by these machines through the working slope of the surface mine to the ground bench E+280 m in 1:1 ratio can be used to calculate fuel consumption [6].

Table 4 Overview of fuel consumption of auxiliary machinery by benches

Bench	Total mass of limestone (t)	Limestone mass for gravity transport Mg(t)	Required number of working hours of the bulldozer (h)	Required number of working hours of the shovel (h)	Bulldozer fuel consumption Qb (l)	Shovel fuel consumption Ql (l)	Total fuel consumption Q (l)
E+280	319 106	0	0	0	0	0	0
E+310	349 987	52 498	175	257	6125	5140	11 265
E+340	174 993	26 249	88	129	3080	2580	5660
E+370	41 175	6 176	21	30	735	600	1335
Total	885 261	84 923	284	416	9940	8320	**18 260**

The planned fuel consumption of auxiliary machinery, with the proposed system of exploitation, is 18260 (l), which at the then fuel prices was: 37433 (BAM). Total fuel consumption: Q=47627 + 18260=65887 (l) i.e. 135068,35 (BAM)

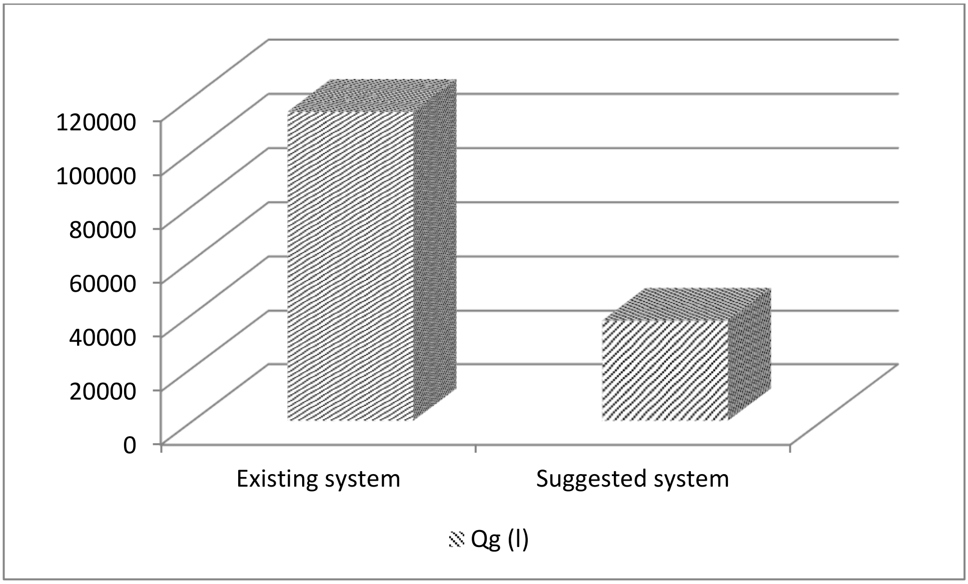

Figure 2 Fuel consumption with the existing and proposed system of exploitation

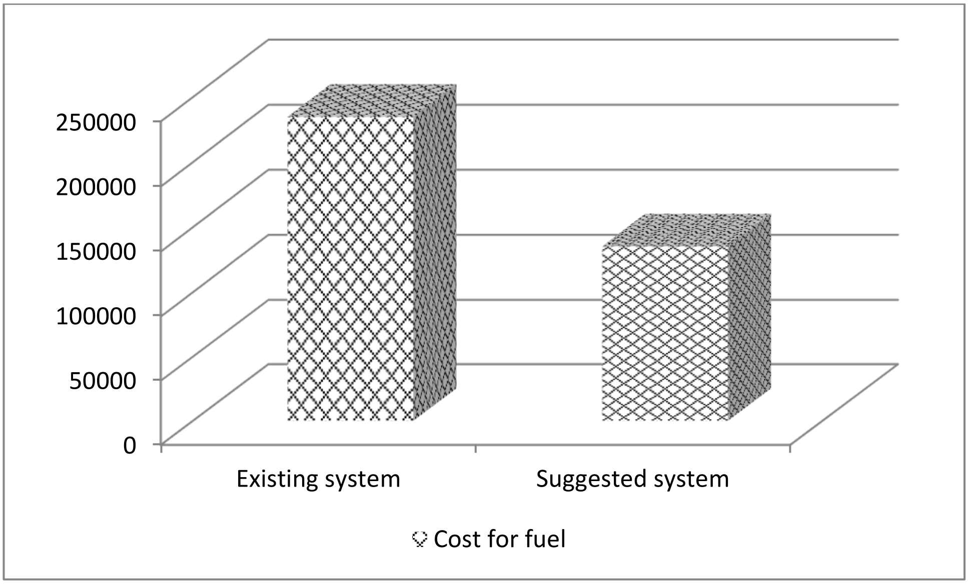

Figure 3 Fuel cost for existing and proposed system of exploitation

CONCLUSION

For the analysis of the justification of the application of gravitational transport, i.e. for the new system of surface exploitation, the division of the mine into benches is adopted: E+280, 310, 340 and 370 (m), with the width of the berm bench Be=8 m and the safety factor of the working slope of the mine Fs=1.45. Partial application of gravity transport, above the level of E+280 (m), would significantly reduce the length of transport routes. The adopted division enables a higher degree of stone utilization in the last ten-meter bench than in the existing system where the last bench is twenty meters high. Planned fuel consumption of transport machinery, i.e. EUCLID R32, with the existing exploitation system for 2008, is 114484 (l), i.e. 234,692.20 (BAM).

By applying the new exploitation system, the total fuel consumption of dump trucks and auxiliary machinery would amount to 65887 (l) or 135068.35 (BAM), which is 99623.85 (BAM) (42%) less than in the existing exploitation system. The amount of CO2 the machines emit is directly related to the amount of fuel it consumes. Fuel efficiency, sometimes referred to as fuel economy, is the relationship between the distance travelled and the fuel consumed. Knowing the quantities and effects of exhaust gases when using diesel fuel in the applied machines, it can be concluded that the same percentage is evident in the reduction of environmental pollution, which has a positive impact on the local community and generally accepted social norms of work and business.

Where large distance of transporting materials contributes significantly to the amount of CO2 emissions, it is very important to manage plant and resource allocation to get optimum results. The carbon emissions have been closely linked to global warming and will leave carbon footprint. Carbon footprint is; a measure of the whole sum of CO2 emissions resulted directly or indirectly from activities of individual, organization, and process, industry sectors over the life cycle of a product (goods and services). The importance of relating the environmental aspects, in terms of energy consumption and carbon emissions, with the decision of pavement design has been promoted as opposed to typically cost consideration [4]. According to the current emissions reduction efficiency, the goals of the Paris Agreement may not be achieved, but current policies to reduce carbon emissions should focus on improving the energy structure and thereby reducing the energy intensity [2].

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