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Nikola Stanić[*], Saša Stepanović[*], Dejan Govedarica[**], Aleksandar Doderović[*]

APPLICATION THE SOFTWARE SOLUTION FOR CALCULATION THE CAPACITY OF BUCKET WHEEL EXCAVATORS IN THE COMPLEX CONDITIONS FROM THE ASPECT OF RESISTANCE TO EXCAVATION

Abstract

This paper describes a software solution for calculation and analyzed the impact resistance to excavation on technical capacity of a bucket wheel excavator was analyzed at the open pit Gacko. The analysis was carried out for many characteristic cases with the values of resistance to excavation of 750, 1000, 1250 and 1500 N/cm' and in accordance with the set values in the working environment of the open pit Gacko - Central Field.

Keywords: *capacity, bucket wheel excavator, resistance to excavation, open pit mining*

INTRODUCTION

Excavation of overburden and inter-seam waste at the open pit Gacko - Central Field was predicted using a continuous and discontinuous equipment. Excavation and loading of overburden by a continuous equipment is carried out by bucket wheel excavators type ER 1250*17/1.5 and ER 1250*16/1.5.

In addition to these two bucket wheel excavators, which are currently involved in the exploitation process, there is another type of a bucket wheel excavator ER 1250*16/1.5 to be included in the production as an aggregate reserve within the I BTO system.

Technological parameters of the bucket wheel excavator ER 1250*16/1.5 are presented in Table 1.

Table 1 *Technological parameters of the excavator ER 1250 * 16/1.5*

Parameter	**Value**
Excavation height (m)	15
Angle of excavator rotation according to massif (^{o})	90
Angle of excavator rotation according to the excavated area (^{o})	22
Angle of inclination of lateral floor slope (^{o})	70
Angle of inclination of frontal block slope (^{o})	70

[*] *Mining and Metallurgy Institute Bor - Department Coal Engineering Belgrade, e-mail: nikola.stanic@irmbor.co.rs, sasa.stepanovic@irmbor.co.rs, aleksandar.doderovic@irmbor.co.rs*
[**] *Mine and Power plant Gacko, dejan.govedarica@ritegacko-rs.ba.*

CONTINUOUS SYSTEMS - CAPACITY THE BUCKET WHEEL EXCAVATORS

Procedure of calculation the capacity of bucket wheel excavator on overburden was carried out according to the methodology presented in the following text.

Border angle of regulation:

$$\cos \xi_{rI} = \frac{q \cdot n}{h_I \cdot s \cdot k_r \cdot V_{b\max}}$$

where:

q - volume of bucket, (0.375 m^3)

n - number of bucket discharging (76.5 min^{-1})

h_i - sublevel height (3.75 m)

s - maximum thickness of slice, (0.6 m)

V_{bmax} - maximum speed of boom rotation, (30 m/min)

The basic rotation speed of bucket wheel carrier:

$$v_{boI=} = \frac{q \cdot n}{h_i \cdot s \cdot k_r}$$

The medium rotation speed of bucket wheel carrier:

$$V_{bsI} = \frac{\xi_{uI} + \xi_{sI}}{\frac{57.3 \cdot (\sin \xi_{rI} + \sin \xi_{sI})}{V_{boI}} + \frac{\xi_{uI} - \xi_{rI}}{V_{b\max}}}$$

where:

ξui - turning angle of rotor boom in a sublevel towards the inside lateral slope (900 for the I sublevel)

ξsi - turning angle of rotor boom in a sublevel towards the outer lateral slope

ξri - angle regulation in a sublevel

The medium time of rotation of wheel carrier:

$$t_{sI} = \frac{\pi \cdot (L + e + r) \cdot (\xi_{uI} + \xi_{sI})}{180^o \cdot V_{bsI}}$$

where:

L – boom length, m

e - horizontal distance the pivot point of rotary boom from vertical axis of excavator rotation, m

r - radius of operating wheel, m

Time of cut change in a block:

$$t_r = \frac{s_{\max}}{V_t}$$

S_{max} - maximum thickness of cut, m

V_t - transport speed of excavator, m/min

Number of cuts in a sublevel is determined according to the relationship:

$$n_r = \frac{Z_{\min}}{s}$$

where:

Z_{min} is the length of block excavation for one technological cycle, which is obtained on the basis of limitations until the boom strikes on the other, the bottom sublevel:

$$Z_{\min} = r + \left(r - \frac{d + t}{\cos \alpha_g} \right) \cdot ctg\alpha_g - h_I \cdot ctg\beta_{\check{c}}$$

Changing time of zone:

$$t_e = \frac{Z - s_{\max} + \frac{h_i}{tg\beta_{\check{c}}}}{V_t}$$

Z - length of block excavation for one technological cycle, m

Time of a block changing defined by the formula:

$$t_{pb} = \frac{(H - h_i) \cdot tg\beta_{\check{c}}}{V_t},$$

Time of a block dredging:

$$T_b = \left\{ \sum \left[(t_{si} + t_u + t_r) \cdot n_r + t_{ei} \right] \right\} + t_{pb}$$

Volume of a block:

$$V = H \cdot B \cdot Z$$

Technical capacity of a bucket wheel excavator for defined technological parameters is:

$$Q_{th} = \frac{V}{T_b} \cdot k_o$$

K_o - correction coefficient that takes into account the conditions of material excavation material; $k_o = 0.97$.

The average technical capacity - Q_{thpr} is less than the technical capacity obtained on the basis of technological scheme of block mining for pure technological inability to continuously work in a regular block, i.e. due to the loss of capacity in cutting of excavator at the end of floor in a new block. Consequently the average technical capacity of the excavator is:

$$Q_{thpr} = Q_{th} \cdot k_g \; .$$

where:

k_g - mass loss in capacity due to the amount of interference excavator in the new block reduced the capacity of the excavator in the regular block.

$$k_g = \frac{(L - l) \cdot k_{kl}}{L}$$

L - floor length, m

l - length of the zone in which the interference is done in the new block, m

k_{kl} - correction coefficient of technical capacity

CALCULATION THE CAPACITY OF BUCKET WHEEL EXCAVATOR

On the basis of this methodology, a software solution was formed to calculate the capacities of the bucket wheel excavator on excavation the overburden for typical cases.

As the most important influencing factor on the capacity of bucket wheel excavator in the overburden excavation in the current period is a problem of excavation a part of overburden with increased parameters of strength, or an increased resistance to excavation. In the Gacko coal basin in the Central field, the terrain complexity is evidently demonstrated in the engineering-geological terms. The engineering-geological explorations in 2011 and 2012 should have to establish the value of engineering-geological parameters of isolated homogeneous or quasi - homogeneous zones for the investigated areas.

Zoning of a terrain and rock mass classification of the exploration area was carried out using two categories.

The first classification was made in accordance with Ćirić S. (1986). According to this categorization, the entire complex of neogene is classified into five categories (K1 to K5), each of which is an engineering geological unit with the specific physical and mechanical properties, deformation and structural properties expressed to the certain limits.

Category K1 includes the surface cover rocks as well as the lowest package of series with the values of uniaxial compressive strength less than 1,000 kPa.

Category K2 includes the rocks of the super positioning packages with the uniaxial compressive strength ranging from 1,000 to 2,500 kPa. This category within the exploration area includes clayey marls and coaly and tuffitic marls.

Category K3 is composed of two variety of rocks. The first variety is represented by gray marls of fine pelitic structure, while the other variety consists of yellow to yellow-gray marls. Varieties are altered in layers of 1.5-3.0 m thickness. Compressive strength ranges from 2,500 to 4,500 kPa.

Category K4 includes marly limestones, limestone marls, clayey and coaly marls and multicolored marls. Thickness of the unit ranges from 20 m to 25 m. Thickness of the package is quite variable, especially in the parts of basin, where the first main and floor coal seams have the super positioning ap proaching. Testing the uniaxial compressive strength of these sediments show the value of compressive strength between 4,500 and 6,000 kPa.

Category K5 includes the rocks with the uniaxial compressive strength greater than 6,000 psi.

Based on the test results of the cutting force, the propagation speed of longitudinal waves (v_p) and testing parameters of compressive strength, ***the second categorization*** of the rocks masses was done per cutting and possibilities of application the rotor excavation technology within the lithostratigraphic member 8NG member, as follows:

For the rock masses with the cutting resistance up to 500 N/cm, at speed of propagation of longitudinal elastic waves Vp = 500 - 1,000 m/s, that is, compressive strength up to 25 daN/cm^2, it is possible to use a large bucket wheel excavator, **the category K1**;

For the rock masses with the cutting resistance up to 500-1000 N/cm, at speed of propagation of longitudinal elastic waves Vp = 1000 - 2000 m/s or compressive strength of 25-50 daN/cm^2, it is possible to use a large bucket wheel excavator, **the category K2**;

Of the rock mass from the cutting resistance is 1000-1500 N/cm, at a speed of propagation of longitudinal elastic waves Vp = 2000 - 3000 m/s or compressive strength of over 50 to N/cm^2, on the border of the possible use of a large bucket wheel excavator, **the categor is K3**;

For the rock masses with the cutting resistance of over 1500 N/cm and propagation speed of longitudinal elastic waves Vp≈3000 m/s, **the categories K4** that is difficult to ripping;

Previous investigations and monitoring the resistance to cutting K_L in a function of moisturechange w indicated a possible variation of resistance when cutting " in situ " in a function of the seasons, lowering of the groundwater level and others. Increasing the resistance to cutting due to the reduced moisture content w can lead to application the bucket wheel excavator in excavation and can be the cause of accidents and reducing effect.

Categorization of rock masses within lithogenetic unit $8N_G$ was carried out according to the parameters obtained by laboratory tests on the basis of that categorization. Seams with an increased resistance to cutting are shown in the engineering geological profiles

Two media occurs in generalization by interpretation a high roofing terrain of the main coal seam.

MEDIUM I (Categories of rocks K1 and K2), which is not a problem for operation the bucket wheel excavator for overburden excavation.

The following physico-mechanical parameters of the medium I were obtained by laboratory tests:

- natural moisture immediately after opening the sample ω = 8.61 – 32.61 (%);
- bulk density γ = 16.97-22.96 (KN/m^3);
- speed of longitudinal el. waves Vp = 1193 -2017 (m/s).

MEDIUM II (Category K3)

In lithological terms, the rock masses pf Medium II correspond to marly limestone with the percentage of CaCO3> 85%. These rock masses are followed by stratification and build a larger part of the fieldcovered by explorations. It is represented by a plurality spaced seams with resistances to cutting >1000 N/cm in the conditions of the working environment.

These seams occur in the shallow parts of the field with the small thicknesses of 0.30 – 1.45 m. Their inclination towards the bottom of syncline results into increase of this system thickness, and even in the drillhole B-811gm it is 5.95 m, or in the borehole B-772 7.50 m.

Based on the existing data, calculation the amount of material categories K3 was done. Figure 1 shows the propagation of marls with increased resistance characteristics to the characteristic geological cross-sections.

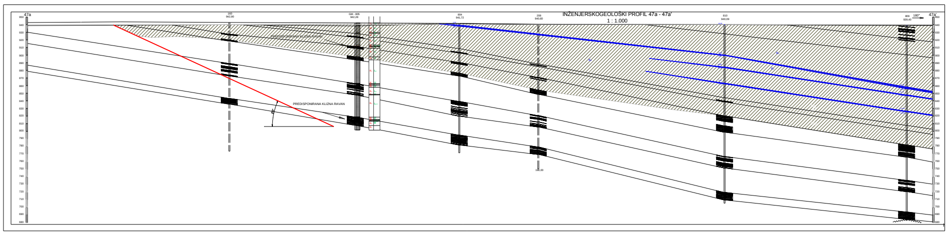

Figure 1 *Propagation of marl with increased resistance to excavation at cross sections 42-42'*

Marl (Pu), *Marl of categories K3 and K4 (Pk3)*

Conducted studies have included the western part of the Central field (Figure 2). Marl amounts with increased characteristics for resistance to exploration were tested by the method of cross sections, given in Table 2.

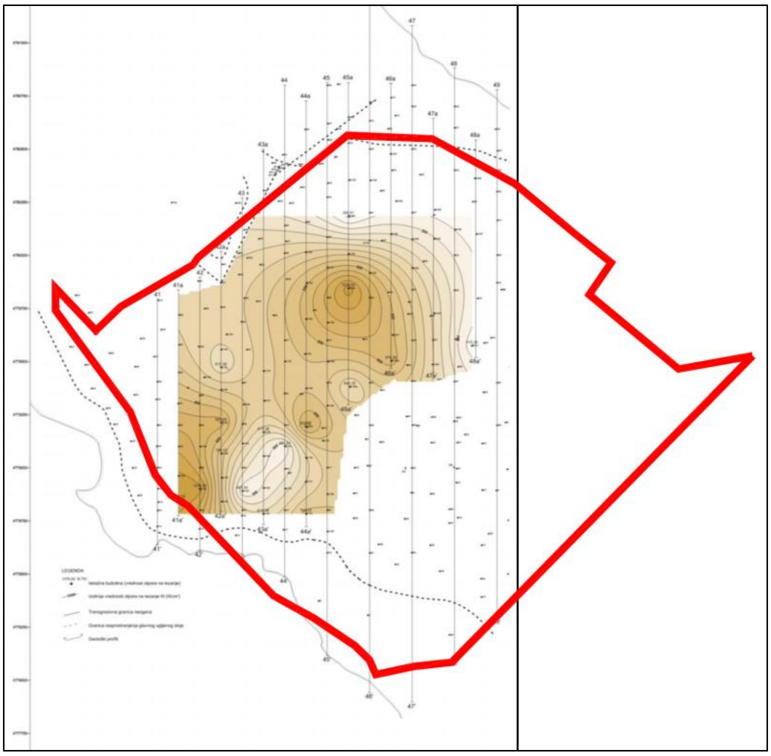

Figure 2 *The position of exploratory wells to the tested parameters and contours digging resistance in the area of box C (the borders of the Central Fields)*

Table 2 *Calculation the amount of marl with increased resistance to excavation*

Profile	Surface area (m^2)		Central area (m^2)		Distance (m)	Volume (m^3)	
	Pu	Pk3	Pu	Pk3		Total marl	Marl with increased resistance to excavation
41a-41a'	40,208	5,529	43,709	5,810	100	4,370,900	581,000
42-42'	47,210	6,091	57,143	6,299	100	5,714,250	629,850
42a-42a'	67,075	6,506	70,072	6,687	100	7,007,150	668,700
43-43'	73,068	6,868	77,237	7,980	100	7,723,700	798,000
43a-43a'	81,406	9,092	92,313	7,752	100	9,231,250	775,200
44-44'	103,219	6,412	107,508	7,536	100	10,750,750	753,600
44a-44a'	111,796	8,660	93,277	7,858	100	9,327,700	785,750
45a-45a'	74,758	7,055	117,627	4,153	100	11,762,700	415,250
46-46'	160,496	1,250	117,890	3,577	100	11,788,950	357,700
46a-46a'	75,283	5,904	79,963	3,618	100	7,996,250	361,800
47a-47a'	84,642	1,332	90,763	2,897	100	9,076,250	289,700
48a-48a'	96,883	4,462			**Sum**	94,749,850	6,416,550

Pu - total surface area of marl, Pk3 - surface area of K3 and K4 category

Percentage share of marl with increased resistance to excavation is about 7% of the total masses. In case of consideration the amount of marl in the whole zone in which there are marls with increased resistance to excavation, on the basis of calculation given in Table 3, the share of the entire zone in total amount of marl in the overburden is about 30%.

Table 3 *Calculation the amount of marl in the zone in which marls are present with increased resistance to excavation*

Profile	Surface area	Central area (m^2)	Distance (m)	Volume (m^3)
41a-41a'	22,286	22,708	100	2,270,800
42-42'	23,130	22,748	100	2,274,800
42a-42a'	22,366	27,270	100	2,726,950
43-43'	32,173	37,479	100	3,747,900
43a-43a'	42,785	39,304	100	3,930,400
44-44'	35,823	32,064	100	3,206,400
44a-44a'	28,305	28,060	100	2,805,950
45a-45a'	27,814	16,819	100	1,681,900
46-46'	5,824	16,694	100	1,669,400
46a-46a'	27,564	21,116	100	2,111,600
47a-47a'	14,668	15,161	100	1,516,100
48a-48a'	15,654		The forest	27,942,200

Bearing in mind the above presented values of resistance the overburden excavation and the presence of materials with increased resistance characteristics, calculation the capacity of bucket wheel excavator was done in overburden excavation. The calculation was made for more characteristic cases, and the results of calculations are given in the form of software solutions and tabulated. The first four typical cases are analyzed for the value of resistance to excavation of 750, 1000, 1250 and 1500 N/cm', respectively, and two characteristic cases with operation in the bewlts of material with resistance to excavation of 1000, 1250 and 1500 N/cm' (Figure 3).

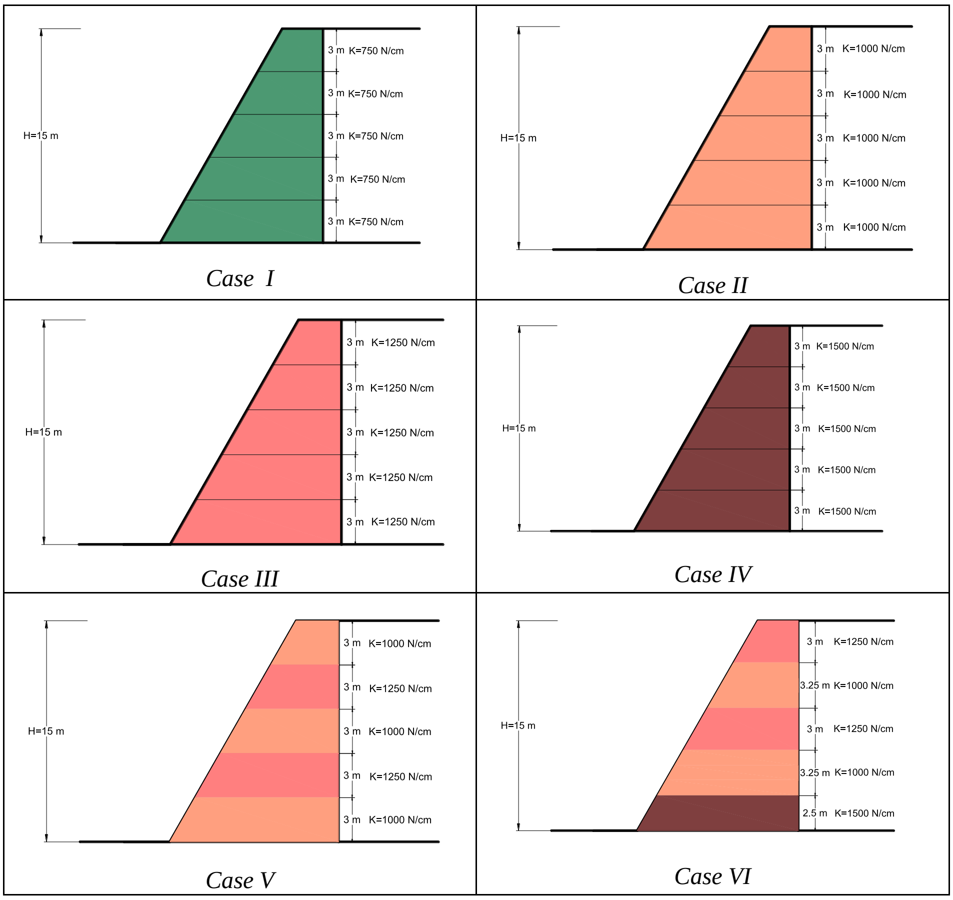

Figure 3 *Review the characteristic cases for analysis with different values of resistance to excavation*

CASE I

Calculation the capacity for resistance to excavation K_L = 750 N/cm and height of cut h = 3 m is given in this case. Figure 4 shows the technological parameters of the bucket wheel excavator for the level of 15 m. Figure 5 shows the calculation results of capacity the bucket wheel excavator for the case I; the same is also given in tabular a (Table 4).

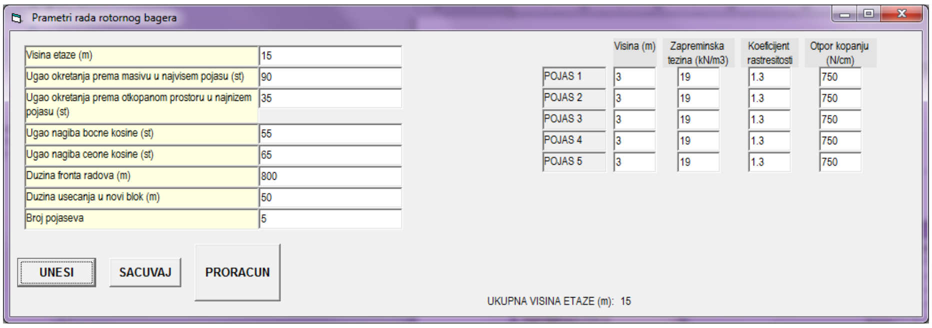

Figure 4 *Technological parameters*

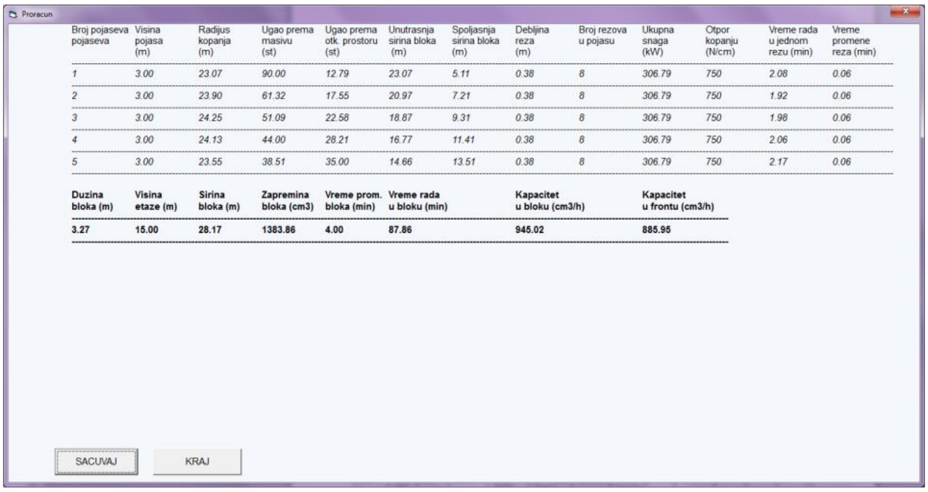

Figure 5 *Calculation results*

Table 4 *Review the results of capacity calculation for the bucket wheel excavator*

No.of belts (m)	Belt height (m)	Excav. radius (m)	Rotation angle towards massif (st)	Rotation angle to the excavated area (st)	Internal block width (m)	Outside block width (m)	Thickness of cut (m)	No. of cuts in belt	Total required power (kW)	Resistance to excavation (N/cm)	Operating time in one cut (min)	Time of cut changes (min)
1	3.00	23.07	90.00	12.79	23.07	5.11	0.38	8	306.79	750	2.08	0.06
2	3.00	23.90	61.32	17.55	20.97	7.21	0.38	8	306.79	750	1.92	0.06
3	3.00	24.25	51.09	22.58	18.87	9.31	0.38	8	306.79	750	1.98	0.06
4	3.00	24.13	44.00	28.21	16.77	11.41	0.38	8	306.79	750	2.06	0.06
5	3.00	23.55	38.51	35.00	14.66	13.51	0.38	8	306.79	750	2.17	0.06
Length of block (m)	Height of level (m)	Width of block (m)	Volume of block (cm^3)	Time of block change (min)	Excav. time in block (min)	Capacity in block (cm^3/h)	Capacity in front (cm^3/h)					
3.27	15.00	28.17	1383.86	4.00	87.86	945.02	885.95					

The same methodology was also performed for other cases, the results of calculation the capacities are given in the Summary Table (Table 5), as well as in the chart (Figure 6).

Table 5 *Calculated values the capacity of bucket wheel excavator for individual cases*

Case	Technical capacity (čm^3/h)	Resistance to excavation (N/cm')	Evaluation of participation in the total mass (%)
1	885	750	10
2	560	1000	40
3	370	1250	40
4	234	1500	10
The weighted average value for the first four cases	484	1125	100
5	427	1000-1250	
6	406	1000-1500	
The average value for the analyzed characteristic cases	439		

The annual capacity of continuous systems with 3,500 effective working hours and utilization the hour of time of 70% in the complex operating conditions with variable resistance to excavation, is per system:

$$Qex = 439 \cdot 3500 \approx 1{,}500{,}000 \text{ čm}^3\text{/year}$$

With procurement of another one continuous system with bucket wheel excavator as the basic excavation equipment, the total amount of overburden that will be excavated by continuous technology is:

$$Qexyear = 3 \cdot 1{,}500{,}000 = 4{,}500{,}000 \text{ čm}^3\text{/year}$$

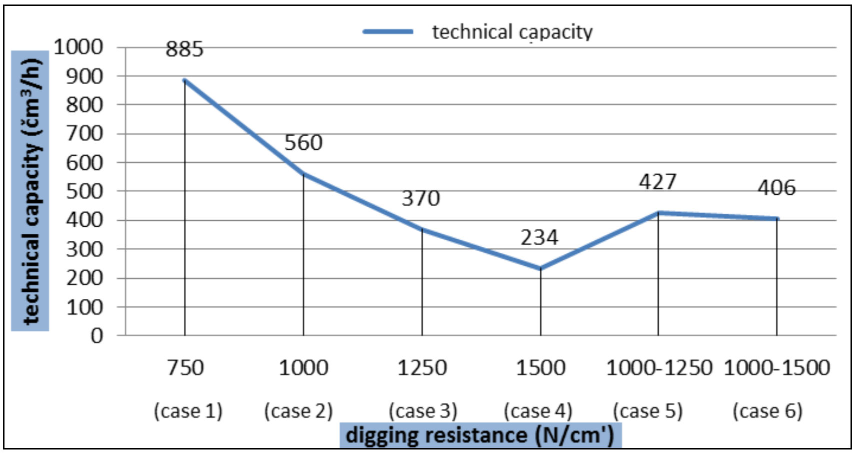

Figure 6 *Overview the calculated value of the bucket wheel excavator capacity for individual cases*

CONCLUSION

Capacity of excavation equipment at the open pits is in a function of many factors, and the problem of determining the excavated capacity has been always reduced to less than or greater generalization and negligences, sometimes very important technological parameters of the working environment. Knowing the real capacity of excavation equipment, implemented in the complex heterogeneous conditions of working environment, and the possibility of modeling and testing in terms of the variables, is the basis in the selection procedure and dimensioning the basic excavation equipment, design, planning and monitoring the mining dynamics.

Overburden at the open pit Gacko - Central Field, which is designed to excavate using the existing bucket wheel excavators is characterized by the complexity of material, and a crucial parameter that limits the capacity of the bucket wheel excavators is resistance to excavation.

Displayed procedure to analyze the spatial distribution of overburden with increased resistance characteristics, together with the software solution to calculate the capacity of bucket wheel excavator, which takes into account the relevant technical and technological parameters of the working environment in calculation the technical capacity of the bucket wheel, has enabled calculation the real capacities of overburden excavation. Also, it is possible for the given conditions of the working environment to carry out a series of analyses the capacities with variable technological parameters, and thus to realize the maximum capacities of the concrete conditions of the working environment.

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