ASSESSMENT OF EXCAVATOR ENERGY CONSUMPTION AND CUTTING RESISTANCE BASED ON CUT AND SLICE GEOMETRY AND EXCAVATION VELOCITY

DOI: 10.25075/BMC.2022.54

Trivan J. [1], Kostić S. [2]

[1]UNIVERSITY OF BANJA LUKA FACULTY OF MINING, PRIJEDOR, REPUBLIC OF SRPSKA, B&H
srdjan.kostic@jcerni.rs

[2]WATER MANAGEMENT INSTITUTE JAROSLAV ČERNI, BELGRADE, SERBIA

Abstract: *In present paper we examine the dependence of the energy consumption of the excavator and overburden cutting resistance on the cut and slice geometry and excavator arrow velocity. Data analyzed were collected from the bucket wheel excavator at ''Tamnava Eastern Field'' that was operating until 2008. Using the multiple linear regression, we provided three separate explicit models for estimation of the energy consumption, linear and areal cutting resistance. Results obtained indicate statistically insignificant effect of starting and final cutting angle, while slice height and width and excavator velocity have negative effect of the energy consumption and cutting resistance. This could be explained by the lower resistance to excavation force along the cutting surface, which is reduced to the residual friction angle ones this force overcomes the shear strength. Results obtained confirm that higher excavation efficiency is obtained for larger slice elements.*

Key words: CUTTING RESISTANCE, ENERGY CONSUMPTION, SLICE GEOMETRY, CUT GEOMETRY, EXCAVATION VELOCITY

INTRODUCTION

Influence of the cutting geometry on the excavation resistance has been in the focus of previous research. According to Trivan [2021], Zelenski was among the first who suggested that both linear and areal cutting resistance are variying with the change in shape and size of the cut element. According to Bošković [2016], Wojtkiewitch analyzed cutting resistance as a function of surface and shape of the cut element, on the basis of which a new methodology for determining the specific cutting resistance and length of the cutting edges was developed. Jakovljević [2007] examined the impact of the parameters of the cut element on the linear and areal cutting resistance, for bucket wheel excavators. Jakovljević et al. [2010] investigated the effect of slice thickness and width on the specific excavation resistance, along the total slice cross-section area and along the total length of bucket cutting edges, for open pits Tamnava West field and Drmno. Results obtained indicate that specific excavation resistance firstly increases and then it decreases with the increase of slice thickness and width ratio, while excavation resistance in all analyzed cases was significantly greater for smaller slice compared to the optimal slice height. Bošković [2016] analyzed the effect of rock material with the increased strength on the cutting resistance in case of bucket wheel excavator at Gacko surface coal mine. Results obtained indicated that cutting forces is much higher for vertical cut compared with horizontal cut, and that the optimal parameters of the vertical cut for rock material with increased strength are 0.20m for cut thickness and 24 m/min for the rotary velocity of excavator arrow. Miletić et al. [2020] implemented adaptive neuro fuzzy inference system to analyze the bucket wheel drive as a function of the wear of the cutting elements, and conducted analyzes resulted in a reliable predictive model for horizontal frequency. Brinas et al. [2021] established a correlation between the height of the excavated slice and the slewing speed of the boom in order to optimize the drive power of the bucket wheel, in which way the energy efficiency, performance of excavators were improved, reducing, in the same time, operating costs.

Unlike previous research, in present paper we examine the dependence of the maximum energy consumption and cutting resistance (both linear and areal) on the slice geometry (width and height), cut geometry (staring and final cutting angle) and on the rotary velocity of excavation arrow. The aim is to determine the impact of these input parameters on the excavation process, in order to optimize the use of bucket wheel excavators regarding the slice and cut geometry and the velocity of excavation arrow. For this purpose, we implement the method of multiple linear regression, which provided reliable results in our previous research also conducted for bucket wheel excavator [Kostić and Trivan, 2022].

Paper is structured as follows. In Section 2 we describe applied methods and data analyzed. In Section 3 we provide results of our analyzes and corresponding discussion, while final conclusions and given in Section 4.

APPLIED METHODS

In present paper we analyze data from ”Tamnava Eastern Field”, where bucket wheel excavator SchRs 900 25/6 was in operation until 2008. [Ignjatović, 2003]. In particular, we examined the dependence of maximum energy consumption, linear and areal cutting resistance on the following parameters: starting and final cutting angle, cutting height and depth and perimeter wheel velocity. For this purpose, we use the multiple linear regression analysis, which results in derivation of explicit nonlinear models, whose statistical significance is assessed by ANOVA testing. Data analyzed are presented in Table 1.

Table 1. Overview of the examined parameters and their range of values.

Analyzed factors	Range of values
E_{max} maximum energy consumption (KWh/m^3)	0.16-0.27
K_{Lmax} maximum linear cutting resistance (N/cm)	473-833
K_{Fmax} maximum areal cutting resistance (N/cm^2)	56-104
Ang_s starting cutting angle (^{0})	-15 - 15
Ang_F final cutting angle (^{0})	-15 – 15
H cutting height (m)	3-4
D cutting depth (m)	0-1
V perimeter wheel velocity (m/min)	13-24

RESULTS

Results of the performed analysis are shown in the following expressions:

$$E_{max} = 1.44 - 0.00015 \cdot Ang_s + 0.0004 \cdot Ang_F - 0.12 \cdot H - 1.21 \cdot D - 0.013 \cdot V \quad (1)$$

$$K_{Lmax} = 4034.67 - 0.68 \cdot Ang_s + 1.49 \cdot Ang_F - 394.1 \cdot H - 3413.55 \cdot D - 22.05 \cdot V \quad (2)$$

$$\ln(K_{Fmax}) = 128.51 - 0.0011 \cdot Ang_s + 0.0021 \cdot Ang_F - 14.48 \cdot H - 144.77 \cdot D - 0.069 \cdot V \quad (3)$$

where E_{max} stands for maximum energy consumption (KWh/m^3), K_{Lmax} is the maximum linear cutting resistance (N/cm), K_{Fmax} is the maximum areal cutting resistance (N/cm^2), Ang_s and Ang_F are the starting and final cutting angle, H and D are the height of the cut piece and cutting depth (m), while V represents the perimeter wheel velocity (m/min). Physically possible results are obtained for D<0.65m. Table 2 represents the results of ANOVA tests for Eqs. (1)-(3).

Table 2. Results of ANOVA tests for models (1)-(3)

Model (1)			
factors	**Sum of squares**	**F value**	**P value**
Ang_s	9.994E-005	0.29	0.5957
Ang_F	7.103E-004	2.04	0.1625
H	0.018	50.90	< 0.0001
D	0.016	46.32	< 0.0001
V	0.027	77.77	< 0.0001
residual	3.484E-004		
Lack of fit	3.338E-004	0.86	0.6418
Pure error	3.889E-004		
Model (2)			
factors	**Sum of squares**	**F value**	**P value**
Ang_s	2095.82	0.67	0.4188
Ang_F	9967.26	3.19	0.0832
H	1.852E+005	59.19	< 0.0001
D	1.285E+005	41.07	< 0.0001
V	82535.93	26.38	< 0.0001
residual	1.064E+005		
Lack of fit	72202.32	0.76	0.7215
Pure error	34186.93		
Model (3)			
factors	**Sum of squares**	**F value**	**P value**
Ang_s	5.183E-003	0.53	0.4721
Ang_F	0.020	2.06	0.1600
H	250.14	25517.64	< 0.0001
D	231.14	23579.37	< 0.0001
V	0.80	82.11	< 0.0001
residual	0.33		
Lack of fit	0.23	0.83	0.6685
Pure error	0.10		

Statistical analyzes indicated high value of determination coefficient and small values of MSE: R=0.86, MSE=0.017 (for Eq.1), R=0.81, MSE=51.57 (for Eq.2) and R=1.0, MSE=0.091 (for Eq.3). It is clear from normal plots of residuals in Figure 1 that error terms are normally distributed.

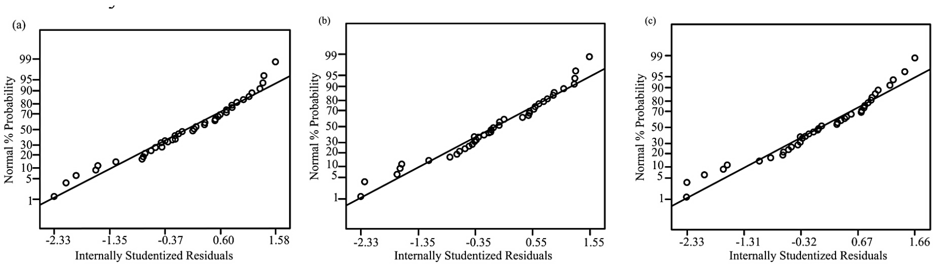

Figure 1. Normal probability plots of residuals for Eq.1 (a), Eq.2(b) and Eq.3 (c).

In all examined cases, analysis showed that only three input factors are significant: height of the cut piece H (m), cutting depth D (m) and the perimeter wheel velocity V (m/min). No significantg two-factor interactions were found. Starting and final cutting angle does not have staististically significant effect on the energy consumption nor cutting resistance. As it is seen in Figures 2-4, increase of the cut slice and arrow velocity leads to the decrease of energy consumption and cutting resistance. Such dependence is rather unexpected, since one could assume the increase of cutting resistance and energy consumption with the increase of slice geometry and arrow velocity. However, in this case, decrease of energy consumption and cutting resistance could be explained by the lower cutting resistance for the greater slice once the excavation force overcomes the shear strength along the cutting surface. This is when only the residual friction angle opposes the excavation process. In present case, this residual friction angle is well below 20^0, considering the fact that overburden material is mainly composed of small-grained fraction (silt, clay and small-grained sand). These results comply well with the results of Jakovljević et al. [2010].

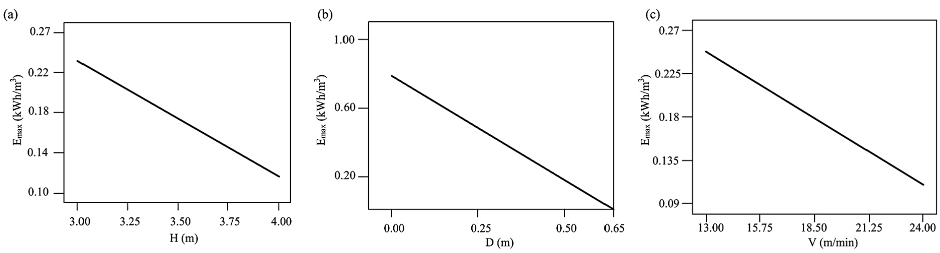

Figure 2. Statistically significant impact of indivudal controlling factors for maximum energy consumption E_{max} (Eq.1). While a single parameter is varied, other parameters are being held constant at the following values: H=3.5m; D=0.5m; V=18.50m/min.

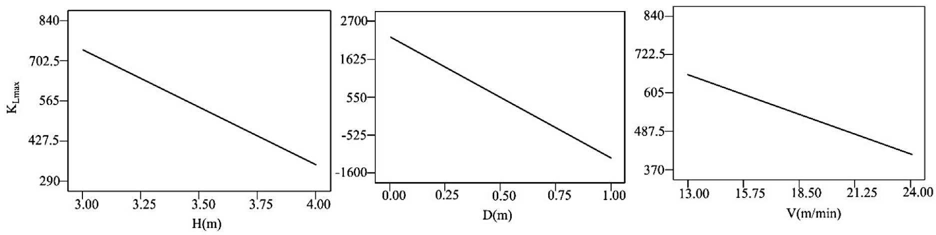

Figure 3. Statistically significant impact of indivudal controlling factors for linear cutting resistance K_{Lmax} (Eq.2). While a single parameter is varied, other parameters are being held constant at the following values: H=3.5m; D=0.5m; V=18.50m/min.

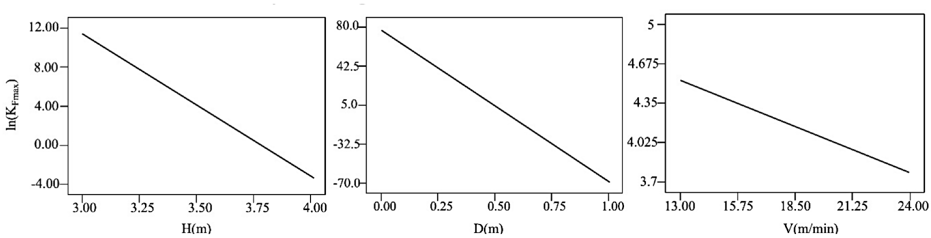

Figure 4. Statistically significant impact of indivudal controlling factors for areal cutting resistance K_{Fmax} (Eq.3). While a single parameter is varied, other parameters are being held constant at the following values: H=3.5m; D=0.5m; V=18.50m/min.

CONCLUSIONS

In present paper, we present results of the analysis of the effect of cut and slice geometry and excavator arrow velocity on the cutting resistance and energy consumption. Data analyzed were collected for the bucket wheel excavator SchRs 900 25/6 that was in operation at ''Tamnava Eastern Field'' until 2008. Starting and final cutting angle, slice height and thickness and excavator arrow rotary velocity were examined using multiple linear regression. Results of performed analyzes indicate the following:

- starting and final cutting angle does not have any influence on energy consumption and cutting resistance;
- remaining parameters: slice height and thickness and excavator arrow rotary velocity have a reverse effect on the energy consumption and cutting resistance. In particular, the increase of slice height and thickness and arrow velocity leads to decrease of linear and areal cutting resistance and energy consumption. This could be explained by the lower resistance of the overburden to excavation force, once the shear strength along the potential cutting surface has been overcome.

The results obtained confirm that higher efficiency of the excavation process is obtained with larger cut elements and, consequently, lower arrow velocity, while starting and final cutting angle have no effect on excavation process and can be determined accorindg to the manufacturer's instructions, on the voluntary basis, or can be changed during the excavation process depending on the current needs.

REFERENCES

1. Trivan, J.:Complex study of excavation resistance for application of cross-pit spreader system in conditions of hard rock masses at surface mines. PhD thesis, University of Banja Luka Faculty of Mining Prijedor, 2021, p. 121 (in Serbian).
2. Bošković, S.: Optimization of bucket wheel excavator cutting parameters at mining of materials with increased strength. PhD thesis, University of Belgrade Faculty of Mining and Geology, 2016, p. 173 (in Serbian).
3. Jakovljević I.: Determining the optimum slice parameters for bucket wheel excavators as function of excavation resistance. PhD thesis, University of Belgrade Faculty of Mining and Geology, 2007, p. 173 (in Serbian).
4. Jakovljević, I., Stepanović, S., Šubaranović, T.: Logistic approach to investigation of slice thickness-height ratio effects on excavation resistance of bucket wheel excavator. International Journal of Transport & Logistics 19/10, 2010, pp. 69-79.
5. Miletić, F., Jovančić, P.D., Milovančević, M., Ignjatović, D.: Adaptive neuro-fuzzy prediction of operation of the bucket wheel drive based on wear of cutting elements Advances in Engineering Software 146,102824, 2020.
6. Brinaș, I., Andraș, A., Radu, S.M., et al.: Determination of the bucket wheel drive power by computer modeling based on specific energy consumption and cutting geometry. Energies 14(13), 2021, 3892.
7. Kostić, S., Trivan, J.: Optimization of coal overburden excavation considering variable geomechanical properties and states of excavator teeth, Archives of Mining Sciences 67, 2022, pp.123-142.
8. Ignjatović, D.: Study on optimization of excavator bucket construction for increasing of capacity. University of Belgrade Faculty of Mining and Geology, 2003, p. 218 (in Serbian).

8th BALKAN MINING CONGRESS

PROCEEDINGS

September 28 – 30, 2022
Belgrade

MINING INSTITUTE BELGRADE

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

622(082)
553(497)(082)

BALKAN Mining Congress (8 ; 2022 ; Beograd) Proceedings /
8th Balkan Mining Congress, September 28-30, 2022, Belgrade ;
[editors Slobodan Vujić, Milinko Radosavljević, Svetlana Polavder] ;
[organizer Mining Institute Belgrade] ; [co-organizers Balkan

Academy of Mining Sciences [and] Department of Mining, Geological
and Systems Sciences of the Academy of Engineering Sciences of
Serbia]. - Belgrade : Mining Institute, 2022 (Belgrade : Colorgrafx).
- 803 str.: ilustr. ; 25 cm

Tiraž 300. - Bibliografija uz svaki rad. - Abstracts.

ISBN 978-86-82673-21-7

а) Рударство - Зборници б) Лежишта минералних сировина
- Балканске државе - Зборници

COBISS.SR-ID 72313353

8^{th} BALKAN MINING CONGRESS

PROCEEDINGS
Belgrade, September 28 – 30, 2022

Editors:

Academician prof. Dr. Slobodan Vujić
Dr. Milinko Radosavljević
Dr. Svetlana Polavder

Organizer of the Congress and Publisher:

MINING INSTITUTE Ltd. BELGRADE
Serbia, 11080 Belgrade, Batajnički put 2
Phone: +381 11 21 95 112; +381 11 21 98 112
Fax: +381 11 26 14 632
http://ribeograd.ac.rs; office@ribeograd.ac.rs;

Co-organizers:

Balkan Academy of Mining Sciences

Department of Mining, Geological and Systems Sciences
of the Academy of Engineering Sciences of Serbia

For the publisher:

Dr. Milinko Radosavljević.
director of the Mining Institute Belgrade

Technical editors:

MSc Jasmina Nešković
Rade Šarac, mining engineer
Pavle Stjepanović, mining engineer

Prepress:

Leposava Knežević

The press:

Colorgrafx, Belgrade

Circulation: 300

Publication year: 2022

ISBN 978-86-82673-21-7
DOI: 10.25075/BMC.2022.00

The papers are printed in their original form. The authors are responsible for the data presented.

INTERNATIONAL COORDINATION COMMITTEE

Academican prof. Dr. Slobodan Vujić, Serbia, president
Prof. Dr. Tzolo Voutov, Bulgaria
Prof. Dr. Vladimir Malbašić, Republic of Srpska B&H
Dr. Marjan Hudej, Slovenia
MSc. Sasho Jovchevski, Northern Macedonia
Prof. Dr. Bahtiyar Unver, Turkey
Prof. Dr. Nicolae Iliaş, Romania
Dr. Miodrag Gomilanović, Montenegro
Prof. Dr. Jani Bakallbashi, Albania
Emeritus prof. Konstantinos Panagopoulos, Greec

NATIONAL SCIENTIFIC COUNCIL

Academican prof. Dr. Slobodan Vujić, president
Academican prof. Dr. Aleksandar Grubić
Dr. Milinko Radosavljević
Emeritus prof. Nadežda Ćalić
Prof. Dr. Rade Jelenković
Prof. Dr. Milan Trumić
Prof. Dr. Slobodan Trajković
Prof. Dr. Jasminka Cvejić
Prof. Dr. Milenko Pušić
Prof. Dr. Aleksandar Milutinović
Prof. Dr. Predrag Lazić
Prof. Dr. Lazar Kričak
Prof. Dr. Vladimir Čebašek
Prof. Dr. Tomislav Šubaranović
Prof. Dr. Miloš Tanasijević
Prof. Dr. Bojan Dimitrijevic

NATIONAL ORGANIZING COMMITTEE

Dr. Milinko Radosavljević, president
Dr. Svetlana Polavder, vice president
MSc. Jasmina Nešković, vice president
Pavle Stjepanović, secretary
Rade Šarac, secretary
Prof. Dr. Srđan Kostić
Dr. Sandra Petković
Dr. Dragica Jagodić Krunić
Dr. Dragana Savić
Dejan Milijanović, mining engineer
Željko Praštalo, mining engineer
Dragan Milošević, mining engineer
Marko Pavlović, mechanical engineer
Vladan Čanović, engineer of geology
Stevan Ćorluka, engineer of geology

GEOMECHANICS AND ROCK MECHANICS