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CALIBRATION OF EXCAVATOR CUTTING FORCE AND ENERGY CONSUMPTION CONSIDERING THE IMPACT OF THE OVERBURDEN MECHANICAL PROPERTIES

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Abstract: *In present paper authors examine the impact of overburden mechanical properties on the cutting force and energy consumption of the bucket-wheel excavator at the opet pit mines. The conducted research consisted of two parts: experimental and analytical. Experimental phase included terrain and laboratory methods in order to determine the main properties of the overburden, as well as the performance of the excavator, at ''Turija-Banovići'' case study. Analytical phase included the extensive statistical study of the obtained results, in order to detmine the impact of the examined overburden properties on the excavator performance. For this purpose, authors developed explicit mathematical models, where cutting force and energy consumption are represented as the linear function of statistically significant influential factors: unit weight, compressive strength and the cohesion of the overburden. Results obtained indicated that cutting force and energy consumption increases with the increase of unit weight, cohesion and compressive strength, while tensile strength and friction angle have statistically insignificant effect.*

Key words: CUTTING FORCE, ENERGY CONSUMPTION, OVERBURDEN, MECHANICAL PROPERTIES, STATISTICAL ANALYSIS

INTRODUCTION

Determination of the appropriate value of rock cutting resistance for the bucket-wheel excavator represents an important task in geomechanical investigations. One way of achieveing this is by trial-and-error process, i.e. by adjusting the forces based on the current in situ conditions. This way, although efficient, could

be time-consuming , and also has significant effect on the work schedule and the agreed dynamical plan. Another way of determination an appropriate cutting force is by analyzing the previous terrain results combined with the results of laboratory investigation. This procedure assumes the assessment of the statistically significant and insignificant factors, and also the nature of the impact of significant rock properties. In this way, cutting force on the bucket-wheel excavator could be adjusted more accurately, while, in the same time, one could derive more precise work schedule.In present paper, authors analyze the correlation between the maximum cutting force, maximum resistance to cutting and maximum energy consumption, on one side, and some mechanical properties of rock masses,on the other side, including: compressive and tensile strength, unit wieght, cohesion and friction angle. This is done for three different cutting depth using the complex statistical approach.

As authors are aware, there are no previous attempts in establishing the correlation between the geomechanical properties of the overburden and the excavator performance. Mining Institute from Tuzla conducted a study where they suggested series of correlations between the overburden cutting resistance, excavator energy consumption, compressive strength for different cutting depths. Using similar methods, [Kositć et al. 2018] analyzed the effect of the main geomechanical peroperties of the Kovin coal on the linear and areal cutting resistance of the coal. Also, using the similar methodology, previous studies established correlations between physical and mechanical soil and rock properties [Kostić et al., 2016; Kostić, 2017].

METHODOLOGY

Performed research consisted of two parts: experimental part included extensive terrain and laboratory geomechanical analyzes, while numerical part involved thorough statistical analysis of the obtained laboratory results, including the basic statistical approach, ANOVA test and multiple linear regression, Terrain measurements included determination of cutting force and energy consumption on the excavator. In the labottory, the overburden unit weight was determined using the cylinder method, compressive strength test using the hydraulic press, tensile strength using indirect Brazilian method, while direct shear test was used for determination of cohesion and angle of internal friction. All the terrain and laboratory measurements were performed at the Institute of Mining from Tuzla – case study ‘’Turija – Banovići” (overburden – hard rock mass – Miocene grey marlstone). Sampling of overburden was performed from seven different working levels (240,252,264,276, 288, 300, 312).

RESULTS

Dependence of excavator cutting force and energy consumption on the overburden mechanical properties examined for three different cutting depths (0.5m,

0.75m and 1.0m). Laboratory determined values ofoverburden mechanical properties for different cutting depths and from different excavation levels are given in Table 1. Range of output values is given in Table 2.

Table 1. Range of the obtained laboratory values for the examined influential factors

Influential factors	Range of laboratory determined values
Unit weight, γ [kN/m^3]	19.9-22.35
Compressive strength, σ_p [MPa]	8-22.6
Tensile strength σ_z [MPa]	1.4-4.8
Cohesion, c [MPa]	0.2-0.52
Angle of internal friction, φ [^{0}]	19-27

Table 2. Range of the the terrain measured values

Output factors	Range of laboratory determined values
Maximum cutting force, F [N]	720-2240
Maximum energy consumption, E [kWh/m^3]	1.29-3.90

First stage of the analysis indicated two crucial points. There were no significant changes in the values of mechanical peroperties of the overburden from different excavation depths (Figure 1). Another importnat point is that cutting depth has no significant statistical influence on the results of the analysis, i.e. no statistically significant correlations could be established for different cutting depths. This result, together with the preiovus one, allowed the authors to examine as a whole the results of the laboratory and terrain tests from different excavation and cutting depths.

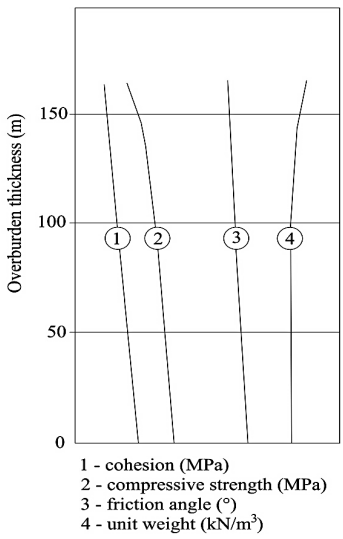

Figure 1. Approximately the same mechanical propertis of the overburden with increasing depth

Obtained results of ANOVA and multiple regression test are given in Figure 2 and 3. As one could see, unit weight and compressive strength have positive impact on cutting force. In particular, results obtained indicate that increase of these two aforementioned parmeters induce the increase of the excavator cutting force. The same effect also comes from the cohesion, while the effect of the friction angle could be neglected (change of friction angle induces 10% change of the cutting force, which order of unit of sampling and laboratory testing error). This could be explained by the following fact: once the rock failure occurs, friction angle of the rock itself does not play significant role in the change of cutting force. Also, results obtained indicated statistically insignificant effect of overburden tensile strength.

Statistically significant dependence of the cutting force on overburden mechanical properties could be described in the following way:

$$F=12.7\cdot\gamma+14.6\cdot\sigma\_p+7458.9\cdot c-1479.5\cdot b \quad (1)$$

where: F - Is the cutting force;

σ_p - Is the compressive strength;

c - Is the cohesion, while

b - is the empirical parameter in the range 0.6-1.9.

Results showed that model (1) is statistically significant, with $R^2=0.88$ (Table 3).

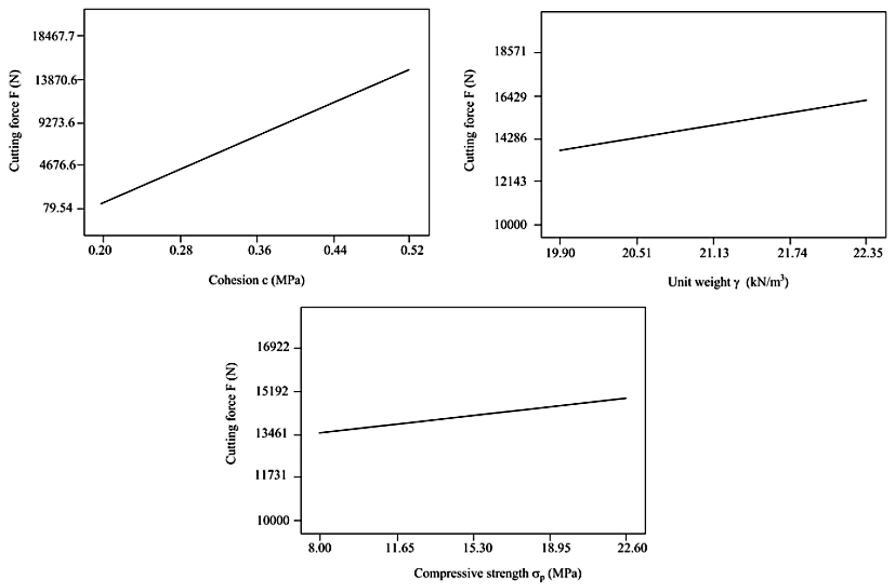

Figure 2. Influence of overburden mechanical properties on the excavator cutting force

**While a single parameter is varied, other parameters are being held constant at the following values: γ=21kN/m³, σp=22.6 MPa, c=0.5 MPa.*

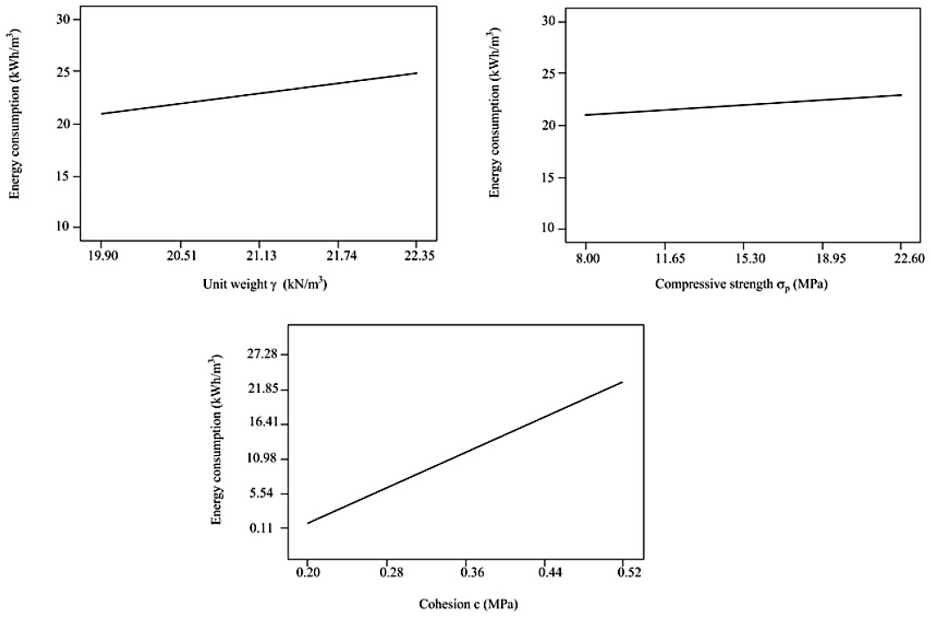

Figure 3. Influence of overburden mechanical properties on the excavator energy consumption

**While a single parameter is varied, other parameters are being held constant at the following values: γ=21kN/m3, σp=22.6 MPa, c=0.5 MPa.*

Table 3. Results of ANOVA test for model (1)

Source	Sum of Squares	Df	Mean Square	F value	P value
Model	4,34E+10	4	1,09E+10	30.37	< 0.0001
Unit weight	1,61E+10	1	1,61E+10	44.95	< 0.0001
Compressive strength	1,61E+09	1	1,61E+09	4.49	0.0490
Cohesion	1,40E+10	1	1,40E+10	39.15	< 0.0001

On the other hand, influence of the overburedn mechanical properties on the excavator energy consumption could be represented as:

$$E=0.03\cdot\gamma+0.012\cdot\sigma\_p+10.9\cdot c-0.84\cdot b \quad (2)$$

where: E - Is the cutting force;

σ_p - Is the compressive strength;

c - Is the cohesion, while

b - is the empirical parameter in the range 1.4-4.8.

Results showed that model (2) is statistically significant, with R^2=0.85 (Table 4).

Table 4. Results of ANOVA test for model (1)

Sum of Source	Sum of Squares	Df	Mean Square	F value	P value
Model	101.28	4	25.32	24.82	< 0.0001
Unit wieght	39.18	1	39.18	38.39	< 0.0001
Compressive strength	3.31	1	3.31	3.25	0.0893
Cohesion	33.16	1	33.16	32.50	< 0.0001

CONCLUSIONS AND RECOMMENDATION FOR FURTHER RESEARCH

In present paper authors perform the calibration of the excavator cutting force and energy consumption based on the impact of overburden mechanical properties. For this purpose, terrain and laboratory measurements were conducted. Firstly, field measurements of energy consumption and cutting force were performed, after which 21 samples of overburden (grey marlstone) were analyzed in laboratory. Laboratory analyzes were performed using the cylinder test, compressive test, direct shear test and Brazilian test. The performed research indicated that both cutting force and energy consumptipon are dependent on unit weight, compressive strength and cohesion, while friction angle and tensile strength show statistically insignificant impact. Statistically significant correlation for both energy consumption and cutting force and overburden mechanical are provided. As authors are aware, this is the first time that such correlation is established in reliable analytical form. One should note that although presented research indicated statistically significant effect of the friction angle, its impact on the cutting resistance and excavator work should be further examined for overburden with different joint properties.

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