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LOGISTIC APPROACH TO INVESTIGATION OF SLICE THICKNESS-HEIGHT RATIO EFFECTS ON EXCAVATION RESISTANCE OF BUCKET WHEEL EXCAVATOR

LOGISTIČKI PRISTUP ISTRAŽIVANJU UTICAJA ODNOSA DEBLJINE I ŠIRINE ODRESKA NA OTPORE NA KOPANJE KOD ROTORNIH BAGERA

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Abstract: *The coordination of technological parameters with working environment conditions is of great importance for the realization of the desgned production in open pits coal mine. The slice thickneks-height ratio has a substantial effect on the digging resistance of an bucket wheel excavator. The investigations of this effect in the operational conditions at overburden excavation in the open mine pits in Republic of Serbia are the subject of this paper. The investigations were conducted on the SRS 2000 bucket wheel excavators in the conditions of the working environment of Tamnava–West field at Drmno open pits coal mine. The investigation methodology of the power applied to the excavator bucket wheel is used for the calculation of the specific digging resistances, applying contemporary measuring instruments and GPS technology. The developed investigation methodology can be applied for all working environments and excavator types and eventual use of the investigation results can have a contribution to the improvement of the excavator efficiency.*

Key words: *bucket wheel excavator, digging resistances, investigation*

Apstrakt: *Za ostvarivanje projektovane proizvodnje na površinskim kopovima od velikog značaja je usklađenost tehnoloških parametara sa uslovima radne sredine. Odnos debljine i širine odreska kod rotornih bagera bitno utiče na vrednosti otpora na kopanje. Istraživanje tog uticaja u uslovima rada na otkrivci na površinskim kopovima u Republici Srbiji predmet je ovog rada. Istraživanja su sprovedena na rotornim bagerima tipa SRs 2000 u uslovima radne sredine na površinskim kopovima Tamnava-Zapadno polje i Drmno. Za proračun specifičnih otpora na kopanje primenjena je metodologija istraživanja merenjem snage na motoru za pogon rotora na rotornim bagerima, uz korišćenje savremenih mernih instrumenata i GPS tehnologije. Razvijena metodologija istraživanja je primenjiva za sve radne sredine i tipove rotornih bagera a eventualna primena rezultata istraživanja može da doprinese povećanju efektivnosti rada bagera.*

Ključne reči: *rotorni bager, otpor na kopanje, istraživanje*

1 INTRODUCTION

About 65% of annual production of electricity energy in the Electrical Power Industry of Serbia is based on coal production. Over 50 bucket wheel excavators at eight active open pits coal mine in Serbia operate in exploitation of coal and overburden excavation. For the quality planning of required quantities of overburden and coal, it is necessary to provide operation efficiency of the bucket wheel excavators, and thus of complete continuous systems. Future increase in coal production and consumption depend to a large extent on the development of new technologies that allow coal to be mined in a manner that ensures maximum utilization of available reserves and the use of economically and environmentally sound manner.

The most significant technological systems of coal exploitation at open pit mines in Serbia are the continuous surface mining systems with a large manufacturing capacity. For them, it is necessary to use the possibility of changing the technology solutions, increase the effective operating time, increase the reliability and stability of production and the development of specific technologies of selective mining of the open pit mines.

Material excavating with bucket wheel excavators is very complex physical and mechanical process. The efficiency indexes of the process depend on many various factors. The physical and mechanical characteristics of the excavated material, operation regime of an excavator, selection of the technological parameters of an excavated block, sublevel and slice, geometry and condition of cutting elements, should be specially noted.

Maximum efficiency of an operating bucket wheel excavator can be achieved only if the construction parameters of a bucket wheel excavator and cutting elements, excavation technology and slice parameters are in agreement with the characteristics of the operation environment. One of the basic preconditions for the efficient operation and realization of satisfactory bucket wheel excavator efficiency, along with the efficiency of the whole technological system in open pits, lies in the right selection of power for the rotor drive, meaning the coordination of excavation force with the expected excavation resistance. In other hand, it lies also in the right selection of the excavation block, sublevel and slice optimal parameters for the particular environmental conditions.

1 UVOD

U proizvodnji energije u Elektroprivredi Srbije oko 65 % godišnje proizvodnje električne energije zasniva se na proizvodnji uglja. Na osam aktivna površinska kopa uglja u Srbiji, na eksploataciji uglja i otkrivke radi preko 50 rotornih bagera. Za kvalitetno planiranje potrebnih količina otkrivke i uglja, veoma je bitno obezbediti efikasnost rada rotornih bagera, pa time i kompletnih kontinualnih sistema. Buduća povećanja proizvodnje i potrošnje uglja u velikoj meri zavise od razvoja novih tehnologija koje omogućavaju da se ugalj eksploatiše na način koji obezbeđuje maksimalno iskorišćenje raspoloživih rezervi i upotrebljava na ekonomski i ekološki prihvatljiv način.

Najznačajniji tehnološki sistemi eksploatacije uglja na površinskim kopovima u Srbiji su kontinualni sistemi površinske eksploatacije sa velikim proizvodnim kapacitetima. Na njima je neophodno koristiti mogućnost promene tehnoloških rešenja, povećanja efektivnog vremena rada, podizanja pouzdanosti i stabilnosti proizvodnje, kao i razvoj specifičnih tehnologija selektivne eksploatacije na površinskim kopovima.

Otkopavanje materijala rotornim bagerom je veoma složen fizičko-mehanički proces a pokazatelji efikasnosti tog procesa zavise od brojnih i raznovrsnih činilaca. Od njih treba posebno istaći fizičko-mehaničke osobine materijala koji se otkopava, režim rada bagera, izbor tehnoloških parametara bloka, podetaže i odreska, geometriju i stanje reznih elemenata i dr.

Maksimum efikasnosti rotornog bagera u radu može se postići samo ako su konstruktivni parametri rotornog bagera i reznih elemenata, tehnologija otkopavanja i parametri odreska u saglasnosti sa karakteristikama radne sredine. Jedan od osnovnih preduslova za efikasnost rada i ostvarivanje zadovoljavajućeg kapacitetnog iskorišćenja rotornih bagera, a time i tehnoloških sistema na površinskim kopovima, leži sa jedne strane u pravilnom izboru snage za pogon rotora, dakle u stepenu usaglašenosti sile kopanja sa očekivanim otporima na kopanje, i sa druge strane u pravilnom izboru optimalnih parametara bloka, podetaže i odreska za konkretne uslove radne sredine.

This work presents a methodology for the exploration of excavation resistance of the bucket wheel excavator of SRs 2000 type as a function of the slice parameters variation in the open pits mine Tamnava – West field and Drmno. Field explorations have been conducted in September and Oktober 2006., when the measurements of the engaged power on rotor wheel drive motor and calculations of the specific excavation resistance, specific power consumption and resulting bucket wheel excavator output in the specific operational conditions were performed. Special attention is given to the slice parameters variation in order to determine their optimal values and increase the operation efficiency of excavator.

U ovom radu se daje prikaz metodologije istraživanja otpora na kopanje rotornog bagera tipa SRs 2000 u funkciji promene parametara odreska na površinskim kopovima Tamnava-Zapadno polje i Drmno. Terenska istraživanja izvršena su u Septembru i Oktobru 2006. godine, merenjem angažovane snage na motoru za pogon rotora i proračunom specifičnih otpora na kopanje, specifične potrošnje energije i ostvarenog kapaciteta rotornog bagera u konkretnoj radnoj sredini. Posebna pažnja posvećena je promeni parametara odreska u cilju određivanja njihovih optimalnih vrednosti i povećanja efektivnosti rada rotornog bagera.

2 APPLIED METHODOLOGY FOR CALCULATION OF SPECIFIC CUTTING RESISTANCE

During the material excavation, the rim force of the rotor subdues the following resistances:

- P_{res} - cutting resistance of the material cut from the massive block, including friction resistance of the cutting elements on working block front,
- P_{pod} - resistance on the material elevation in buckets to the unloading height in the rotor unloading sector,
- P_{punj} - resistance on the material loading into buckets,
- P_{tr} - friction resistance between material in buckets and circular slides of rotor in the process of material elevation to the buckets unloading height,
- P_{kin} - resistance on kinetic energy transfer to the material in a bucket, i.e. acceleration of the material to the bucket velocity.

Therefore, the rim force on the rotor can be defined with:

$$P_t = P_{res} + P_{pod} + P_{punj} + P_{tr} + P_{kin}$$

All the world`s major producers of bucket wheel excavators use the following way to determine the rim force on a rotor:

$$P_t = P_k + P_{pod}, \quad \text{in which}$$

$$P_k = P_{res} + P_{punj} + P_{tr} + P_{kin}$$

where: P_k – is excavation force.

2 PRIMENJENA METODOLOGIJA ZA IZRAČUNAVANJE SPECIFIČNIH OTPORA NA KOPANJE

Pri otkopavanju materijala obodna sila na rotoru savlađuje sledeće otpore:

- Prez - otpor na rezanje (odvaljivanje) materijala iz masiva, uključujući otpor trenja reznih elemenata o čelu radnog bloka,
- Ppod - otpor na podizanje materijala u vedricama do visine pražnjenja istih u okviru istovarnog sektora na rotoru,
- Ppunj - otpor na punjenje vedrica materijalom,
- Ptr - otpor trenja između materijala u vedrici i kružne skliznice rotora u procesu podizanja materijala do visine pražnjenja vedrica,
- Pkin - otpor na saopštenje kinetičke energije materijalu u vedrici tj. ubrzanje materijala do brzine vedrice.

Obodna sila na rotoru se prema tome može definisati izrazom:

$$P_t = P_{res} + P_{pod} + P_{punj} + P_{tr} + P_{kin}$$

Svi veliki proizvođači rotornih bagera u svetu kao što su Rusija, Nemačka, Češka , itd., danas koriste sledeći način za određivanja obodne sile na rotornom točku:

$$P_t = P_k + P_{pod}, \quad \text{pri čemu je:}$$

$$P_k = P_{res} + P_{punj} + P_{tr} + P_{kin}$$

gde je P_k – sila kopanja.

The most applied method for testing the cutting resistance for field measurements is the Wattmeter method, which I used for the measurement of bucket wheell excavator in the Kolubara and Kostolac coal basins.

Od većeg broja poznatih metoda za ispitivanje otpora na kopanje najširu primenu za terenska merenja ima Vatmetarska metoda, koju sam koristio za merenja na rotornim bagerima u kolubarskom i kostolačkom basenu uglja.

In the Wattmeter method, the measurement of motor power engaged for the rotor drive is used to determine excavation specific resistance.

Vatmetarska metoda je metoda kod koje se specifični otpor na kopanje određuje preko merenja angažovane snage na motoru za pogon rotora.

Electro motors for the rotor drive are exposed to variable loads, varying from neutral to maximal, peak loads. these variable loads occurs due to anisotropy of the excavated material and discontinuous arrangement of buckets along the rotor rim. This can be regarded as the most frequent occurrence. This variability requires a special regime for the measurement of power used in the excavation process. It is a continuous measurement regime using an electric current recorder. This recorder registers torque current used to calculate the total power consumed in the excavating process, i.e. the effective power. With this effective power, we determine the engaged power. The recorder can be double-channel or multi-channel recorder, so that it can be used not only to measure the current of the motor for the rotor drive and dc motor for turning the upper frame, but also to measure other values.

Elektromotori za pogon rotora izloženi su u radu promenljivom opterećenju, koje varira od opterećenja praznog hoda do maksimalnih, takozvanih vršnih, opterećenja. Do ovoga dolazi zbog anizotropije materijala koji se otkopava i diskontinualnog rasporeda vedrica po obimu rotora što se može smatrati najčešćim uzrocima. Ova promenljivost iziskuje poseban režim merenja snage koja se troši u procesu kopanja, odnosno režim kontinualnog merenja pomoću pisača struje određene brzine. Pisač registruje momentnu struju, pomoću koje izračunavamo ukupnu snagu koja se troši u procesu kopanja, odnosno efektivnu snagu. Preko efektivne snage dobijamo angažovanu snagu. Pisač je dvokanalni ili višekanalni, tako da se uz merenje struje motora za pogon rotora i struje motora za pogon okreta gornje gradnje, koja je jednosmerna, mogu meriti i druge vrednosti.

The average torque current is estimated by planimetry, while maximum and minimum values are read from the recorder paper. Effective current can be calculated by:

$$Ief = \frac{I\ mom}{\sqrt{2}}$$

Srednja momentna struja se dobija planimetrisanjem, dok se maksimalne i minimalne vrednosti očitavaju sa zapisa na traci. Efektivna struja se proračunava iz odnosa:

$$Ief = \frac{I\ mom}{\sqrt{2}}$$

The power consumed in the excavating process is estimated by the following relation:

$$Ns = \sqrt{3}U\ Ief\ \cos\varphi 10^{-3}$$

Snaga koja se troši u procesu kopanja računa se po obrazcu:

$$Ns = \sqrt{3}U\ Ief\ \cos\varphi 10^{-3}$$

where: I_{ef} - effective current (A);
I_{mom} - torque current (A),
N_s - engaged power (kW);
U - rated voltage (V);
cosφ - power factor.

gde je: I_{ef} - efektivna struja, (A);
I_{mom} - momentna struja, (A);
N_s – angažovana snaga, (kW);
U – nominalni napon, (V);
cosφ – faktor snage.

Power consumed by the motor is calculated as:

$$N_P = N_s\ \eta$$

where: η - is efficiency of the motor.

Predata snaga na motoru se dobija po obrazcu:

$$N_P = N_s\ \eta$$

gde je: η – koeficijent korisnog dejstva motora.

Power used for excavation is estimated when a power needed for lifting the excavated material to the unload height is subtracted from the total transferred power:

$$N_k = N_p - N_{pod}$$

Power required for elevating the material to the unload height is calculated as:

$$Npod = \frac{Q\,\gamma\, g\, hd}{3600}$$

where: Q – is capacity of excavator (m3/h);
γ - is mass of the material (t/m^3);
g – gravity acceleration (m/s^2);
hd – material unload height (m).

Force required for the material excavation is calculated through power needed for the excavation:

$$Pk = \frac{Nk}{V}$$

where: V – is rotor rim velocity (m/s).

On the basis of the known excavating force and calculated length of all cutting edges, i.e. total cross sections of the slices of all buckets which are in contact with the material simultaneously, the specific cutting resistance is calculated as:

$$Kl = \frac{Pk}{\sum_{i=1}^{i=m} Li} \quad \text{or} \quad Kf = \frac{Pk}{\sum_{i=1}^{i=m} Fi}$$

where: K_l – specific cutting resistance of material along the bucket cutting edges (N/cm)
K_f – specific cutting resistance of material on the cross section (N/cm^2)
P_k – excavating force (N)
$\sum_{i=1}^{i=m} Li$ - total length of all bucket cutting edges that are in the contact with material simultaneously (cm)
$\sum_{i=1}^{i=m} Fi$ - total area of slice cross-section of all buckets which are in contact with the material simultaneously (cm^2)
i,m – number of buckets which are in contact with the material simultaneously.

Snaga koja se troši na kopanje dobija se kada se od ukupno predate snage oduzme snaga potrebna za dizanje otkopanog materijala do visine pražnjenja, odnosno:

$$N_k = N_p - N_{pod}$$

Snaga potrebna za podizanje materijala do visine pražnjenja računa se po obrazcu:

$$Npod = \frac{Q\,\gamma\, g\, hd}{3600}$$

gde je: Q – kapacitet bagera, (m^3/h);
γ – masa materijala, (t/m^3);
g – ubrzanje zemljine teže, (m/s^2);
h_d – visina dizanja materijala do visine pražnjenja, (m).

Sila potrebna za kopanje materijala proračunava se iz snage potrebne za kopanje po obrazcu:

$$Pk = \frac{Nk}{V}$$

gde je: V – obodna brzina rotora, (m/s).

Na osnovu poznate sile kopanja i proračunatih ukupnih dužina reznih ivica, odnosno ukupnih površina poprečnih preseka odrezaka, svih vedrica koje su istovremeno u kontaktu sa materijalom, specifični otpor na kopanje se računa po obrazcu:

$$Kl = \frac{Pk}{\sum_{i=1}^{i=m} Li} \quad \text{odnosno} \quad Kf = \frac{Pk}{\sum_{i=1}^{i=m} Fi}$$

gde je: K_l – specifični otpor materijala na kopanje po reznoj dužini vedrica, (N/cm)
K_f – specifični otpor materijala na kopanje po površini poprečnog preseka, (N/cm^2)
P_k – sila kopanja, (N)
$\sum_{i=1}^{i=m} Li$ - ukupna dužina reznih ivica svih vedrica koje se istovremeno nalaze u kontaktu sa materijalom, (cm)
$\sum_{i=1}^{i=m} Fi$ - ukupna površina poprečnih preseka odrezaka svih vedrica koje se istovremeno nalaze u kontaktu sa naterijalom, (cm^2)
i, m – broj vedrica koje se istovremeno nalaze u kontaktu sa materijalom.

Specific energy consumption, required for the excavation of 1 m^3 of material, can be estimated when a difference between the consumed and neutral power is divided by the realized capacity:

$$E = \frac{Np - Npr}{Qt}$$

where: E – specific energy consumption (kW/m^3)
N_p - consumed power (kW)
N_{pr} – neutral power (kW)
Q_t – capacity of bucket wheel excavator (m^3/h).

Specifična potrošnja energije, potrebna za otkopavanje 1 m^3 materijala, dobija se kada se razlika predate snage i snage praznog hoda podeli sa ostvarenim kapacitetom:

$$E = \frac{Np - Npr}{Qt}$$

gde je: E – specifična potrošnja energije, (kWh/m^3)
N_p – predata snaga, (kW)
N_{pr} – snaga praznog hoda, (kW)
Q_t – kapacitet rotornog bagera, (m^3/h).

3 PERFORMED FIELD INVESTIGATIONS

Field investigations or measurements of excavation resistance were performed in open pits mine in Electric Power Industry of Serbia:

a) in Kolubara coal basin in Tamnava – West field open pit mine, on overburden excavation System I, on SRs-2000*32/5 + VR bucket wheel excavator,
b) in Kostolac coal basin in Drmno open pit mine, on overburden excavation System I, on SRs 2000*28/3 + VR bucket wheel excavator.

Excavation resistance, in both cases was carried out using Wattmeter method, i.e. measuring the engaged power for the rotor drive. There were no special preparations on the system and bucket wheel excavator during the measurements on both open pit mines, since we had management agreement and very professional relations with the supervisory and technical staff on overburden excavation systems. After the installation of equipment and measuring instruments, the measurements were carried out in real operating conditions of the bucket wheel excavator. The excavation was in vertical cuts with the given parameters of a slice. The measurements were performed with partially worn out angle teeth. Along with the clasic way of measurement with the tape measure, geodetic measurements, flowmeter and instrument readings on the bucket wheel excavators, a very sophisticated GPS system was used in open pit mine in Drmno to check the accuracy of the slice prameters measurements and realized excavator capacity, as weel as to improve the measurement process creating the possibility for the on-line monitoring of realized capacity.

3 OBAVLJENA TERENSKA ISTRAŽIVANJA

Terenska istraživanja odnosno merenja otpora na kopanje obavljena su na površinskim kopovima u sastavu Elektroprivrede Srbije:

a) u kolubarskom basenu uglja na površinskom kopu Tamnava – Zapadno polje, na I BTO sistemu, na rotornom bageru tipa SRs 2000 32/5 + VR,
b) u Kostolačkom basenu uglja na površinskom kopu Drmno, na I BTO sistemu, na rotornom bageru tipa SRs 2000 28/3 + VR.

Određivanje otpora na kopanje u oba slučaja izvršeno je merenjima angažovane snage za pogon rotora, odnosno Vatmetarskom metodom. Prilikom merenja na oba površinska kopa, uz saglasnost menadžmenta i veoma profesionalan odnos nadzorno tehničkog osoblja na BTO sistemima, posebnih priprema na sistemu i bageru nije bilo. Nakon instalacije opreme i instrumenata za merenje, merenja su vršena u realnim uslovima rada bagera, otkopavanjem vertikalnim rezovima sa zadatim parametrima odreska. Merenja su vršena sa delimično istrošenim ugaonim zubima. Radi provere tačnosti merenja veličina parametara odreska i ostvarenog kapaciteta bagera, kao i unapređenja praćenja procesa merenja stvaranjem mogućnosti on-line praćenja ostvarenog kapaciteta, za merenja na površinskom kopu Drmno pored klasičnog načina merenja veličina metrom, geodetskim merenjima, protokomerom, i očitavanjem sa instrumenata na bageru, korišćen je veoma savremen GPS sistem.

During the measurements in Tamnava – West field open pit mine, the weather was fair, with sunny periods, without wind, and the air temperature was 23 to 25˚C. In Drmno open pit mine, the weather was without wind, with sunny periods, and the air temperature was 17 to 20˚C.

U toku merenja vreme na površinskom kopu Tamnava – Zapadno polje je bilo lepo i sunčano, bez vetra, sa temperaturom vazduha od 23 do 25 ºC, a na površinskom kopu Drmno vreme je bilo bez vetra, sa sunčanim periodima i sa temperaturom vazduha od 17 do 20 ºC.

Technical parameters of bucket wheel excavators on which measurments were performed are presented in Table 1, and the basic values of physical and mechanical characteristics of working enviroment are presented in Tables 2 and 3.

Tehničke karakteristike rotornih bagera na kojima su vršena merenja prikazane su u Tabeli 1., a osnovne vrednosti fizičko - mehaničkih karakteristika radnih sredina date su u Tabeli 2 i 3.

Individual measurements at the Tamnava – West field open pit mine are related to the limited length of a turning process of the excavator for at least 15˚ and maximum of 30˚ from the excavator longitudinal axe towards the left or right side, or for a minimum of 28º and a maximum of 45 º from the excavator longitudinal axe towards the left or right side, at the Drmno open pit mine. Four sets of measurements were performed on both open pit mines. Values of specific cutting resistance k_L and k_F, excavator capacity and specific energy consumption are obtained.

Pojedinačna merenja na površinskom kopu Tamnava – Zapadno polje odnose se na ograničenu dužinu procesa zaokretanja bagera za minimalno 15º i maksimalno 30º od podužne ose bagera u levu odnosno desnu stranu, odnosno za minimalno 28º i maksimalno 45º od podužne ose bagera u levu odnosno desnu stranu, na površinskom kopu Drmno . Izvršeno je po četiri serije merenja na oba površinska kopa. Dobijene su vrednosti specifičnog otpora na kopanje k_L i k_F, kapaciteteta bagera i specifične potrošnje energije.

A total of 96 measurements were performed at Tamnava-West field open pit mine, with variations of two slice heights (h_1=6,3 m and h_2=2,8 m); two speed of circular movement of upper construction of excavator (V_1=20 m/min and V_2=40 m/min), that yields constant slice width (b_1=0,23 m and b_2=0,46 m), due to constant number of excavator unloads in a given time unit, and triple slice thickness change (s_1=0,3 m; s_2=0,50 m i s_3=0,75 m).

Na površinskom kopu Tamnava – Zapadno polje varijacijom dve visine odreska (h_1=6,3 m i h_2=2,8 m), dve brzine okretanja gornje gradnje bagera (V_1=20 m/min i V_2=40 m/min), koje zbog stalnog broja istresanja bagera u jedinici vremena daju konstantne širine odreska (b_1=0,23 m i b_2=0,46 m), i trostrukom promenom debljine odreska (s_1=0,3 m; s_2=0,50 m i s_3=0,75 m) izvršeno je ukupno 96 merenja.

Table 1 Technical characteristics of bucket wheel excavators
Tabela 1 Tehničke karakteristike rotornih bagera na kojima su vršena merenja

Excavator type	Unit	SRs-2000*32/5	SRs-2000*28/3
Manufacturer	/	TAKRAF	TAKRAF
Power of bucket wheel drive motor	KW	2x670	2x500
Volume of bucket with ring-shaped space	lit	1000	1300
Number of buckets	kom	20	18
Number of bucket unloads	min^{-1}	86	70-90 (90)
Diameter of bucket wheel	m	12	11
Length of bucket wheel mast	m	44	41
Cutting speed	m/s	2,59	2,92
Specific cutting force	N/cm	1000	900
Theoretical capacity	m^3/h	6600	6000
Mass of excavator framework	t	2304	2658
Total installed power	KW	4590	3000
Excavation height	m	32	28
Excavation depth	m	5	3
Speed of lifting and lowering the rotor mast	m/min	5	5
Speed of circular movement – turning: from-to	m/min	8-40	8-40

Table 2 Review of average values of physical and mechanical characteristics of working enviroment at Tamnava – West field open pit mine

Tabela 2 Pregled prosečnih vrednosti fizičko-mehaničkih parametara radne sredine na površinskom kopu Tamnava-Zapadno polje

Lithological members, Complex	Humidity W (%)	Volumetric weight γ (kN/m^3)	Angle of inner friction; φ (°)	Cohesion C (kN/m^2)
Quaternary clays	25,00	19,90	25	16,00
Alluvial sands	22,00	18,10	26	1,00
Alluvial gravels	30,00	19,00	28	0,00
Alluvial gravels-sends	29,00	18,60	30	2,00
Pontian clays	31,00	18,60	25	20,00
Coal		11,50	39	30,00
Coaly clay	58,00	16,40	16	15,00
Pontian sands	20,00	17,10	28	4,00

Table 3 Review of average values of physical and mechanical characteristics of working enviroment at Drmno open pit mine

Tabela 3. Pregled prosečnih vrednosti fizičko-mehaničkih parametara radne sredine na površinskom kopu Drmno

Lithological members, Complex	Humidity W (%)	Volumetric weight γ (kN/m^3)	Angle of inner friction; φ (°)	Cohesion C (kN/m^2)
Peat	29,00	20,00	26 ± 2	15 ± 5
Sand - gravel	14,50	20,50	33 ± 2	3 ± 1
Fine sand	24,00	20,00	29 ± 1	5 ± 1
Clay	36,00	19,50	21 ± 3	28 ± 4
Coal	/	11,80	38 ± 4	39 ± 10
Foothill clays	39,00	18,00	22 ± 3	28 ± 3
Foothill sands	16,50	20,00	30 ± 3	5 ± 3

A total of 128 measurements were performed at Drmno open pit mine, with variations of two slice heights (h_1=4,65 m and h_2=2,9 m); two speed of circular movement of upper construction of excavator (V_1=18 m/min i V_2=26 m/min), that yields constant slice width (b_1=0,20 m i b_2=0,29 m), due to constant number of excavator unloads in a given time unit, and four slice thickness (s_1=0,3 m; s_2=0,50 m i s_3=0,75 m).

Na površinskom kopu Drmno varijacijom dve visine odreska (h_1=4,65 m i h_2=2,9 m), dve brzine okretanja gornje gradnje bagera (V_1=18 m/min i V_2=26 m/min), koje zbog stalnog broja istresanja bagera u jedinici vremena daju konstantne širine odreska (b_1=0,20 m i b_2=0,29 m), i četvorostrukom promenom debljine odreska (s_1=0,24 m; s_2=0,30 m, s_3=0,50 m i s_4=0,75 m) izvršeno je ukupno 128 merenja.

a)

b)

Figure 1 Appearance of working environment in which the excavation resistance was measured: a) Tamnava – West field open pit mine; b) Drmno open pit mine

slika 1 Izgled radne sredine u kojoj su vršena terenska merenja: a) površinski kop Tamnava-Zapadno polje; b) površinski kop Drmno

4 INVESTIGATION RESULTS

The obtained results of four measurement series in the working environment of the Tamnava – West field and Drmno open pit mines, for the values of specific cutting resistance along the total cutting length (k_L), and along total slice cross-section (k_F), as a function of the slice thikness and slice width, were presented graphically in Figure 2.

Qualitative diagram course of the specific excavation resistance along the total length of bucket cutting edges (k_L), as the function of slice thickness and width ratio (s/b), at constant slice height, shows that the increase of s/b values reduces the k_L value. The k_L curve decreases, converging to the approximate constant course with the increase of s/b values.

At the Tamnava – West field open pit mine, maximal value of k_L, for the slice height h=6,3 m, occurs when ratio s/b=1,1; while for the slice height of h=2,8 m, maximal value of k_L occures at the ratio value s/b = 1,3. At the Drmno open pit mine, maximal value of k_L, for both values of slice height, occurs at s/b = 1,2.

Qualitative diagram course of specific excavation resistance, along the total slice cross-section area (k_F), as the function of slice thickness and width ratio (s/b), at constant slice height, also shows that the k_F value decreases when value of s/b ratio increases. The k_F graph decreases and converges to the approximate constant course with the increase of s/b value.

At the Tamnava – West field open pit mine, maximal value of k_L, for both values of slice height, occurs at the ratio s/b = 1,3. At the Drmno open pit mine, maximal value of k_F, for both values of slice height, occurs at the ratio s/b = 1,2.

The values of k_L and k_F, in all analyzed cases, are significantly greater for smaller slice heights than for the optimal slice heights.

4 REZULTATI ISTRAŽIVANJA

Dobijeni rezultati, četiri serije merenja u radnoj sredini površinskih kopova Tamnava-Zapadno polje i Drmno, za vrednosti specifičnog otpora na kopanje po ukupnoj dužini rezanja (k_L) i po ukupnoj površini poprečnog preseka odreska (k_F), u zavisnosti od odnosa debljine i širine odreska, prikazani su grafički na slici 2.

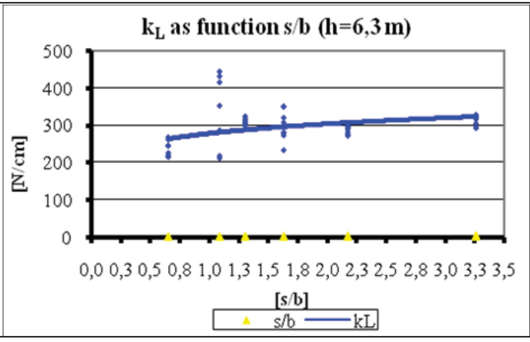
Kvalitativni tok krive zavisnosti specifičnog otpora na kopanje po ukupnoj dužini reznih ivica vedrica (k_L) od odnosa debljine i širine odreska (s/b), pri konstantnoj visini odreska, pokazuje da se sa povećanjem vrednosti odnosa s/b vrednost k_L smanjuje. Kriva vrednosti k_L opada da bi sa povećanjem vrednosti s/b težila približno konstantnom toku.

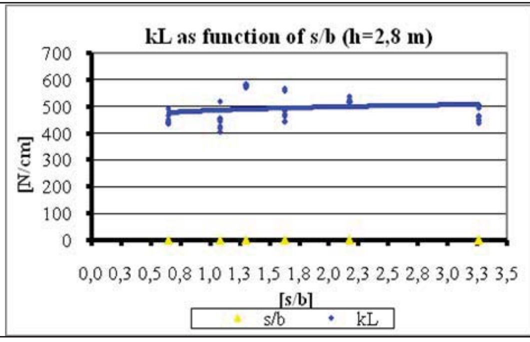
Maksimalna vrednost k_L, za visinu odreska od h=6,3 m na površinskom kopu Tamnava-Zapadno polje je kod odnosa s/b=1,1, dok je za visinu odreska od h=2,8 m, maksimalna vrednost k_L kod odnosa s/b=1,3. Maksimalna vrednost k_L, za obe visine odreska na površinskom kopu Drmno je kod odnosa s/b=1,2.

Kvalitativni tok krive zavisnosti specifičnog otpora na kopanje po ukupnoj površini poprečnog preseka odreska (k_F) od odnosa debljine i širine odreska (s/b), pri konstantnoj visini odreska, takođe pokazuje da se sa povećanjem vrednosti odnosa s/b vrednost k_F smanjuje. Kriva vrednosti k_F opada da bi sa povećanjem vrednosti s/b težila približno konstantnom toku.

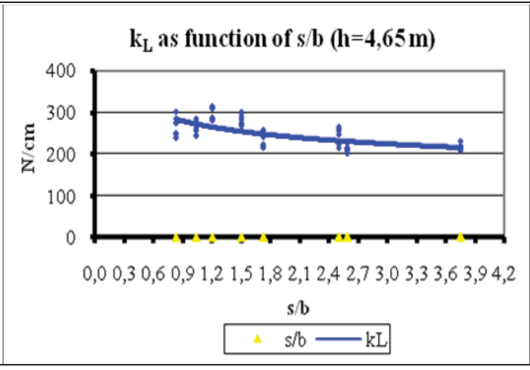
Maksimalna vrednost k_F, za obe visine odreska na površinskom kopu Tamnava-Zapadno polje je kod odnosa s/b=1,3. Maksimalna vrednost k_F, za obe visine odreska na površinskom kopu Drmno je kod odnosa s/b=1,2.

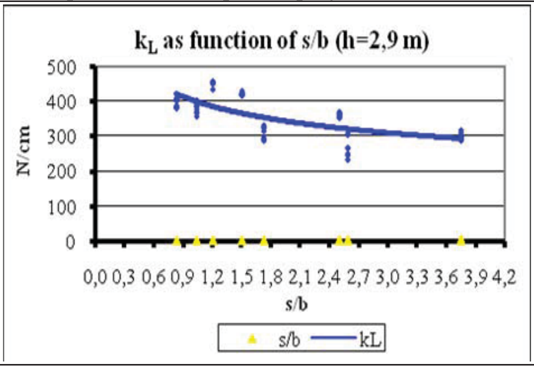
Vrednosti k_L i k_F su, u svim anliziranim slučajevima, znatno veće kod manjih nego kod optimalnih visina odreska.



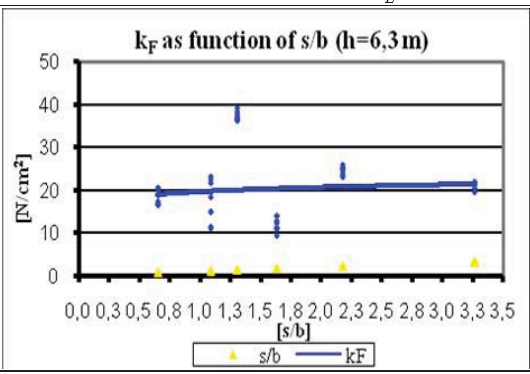


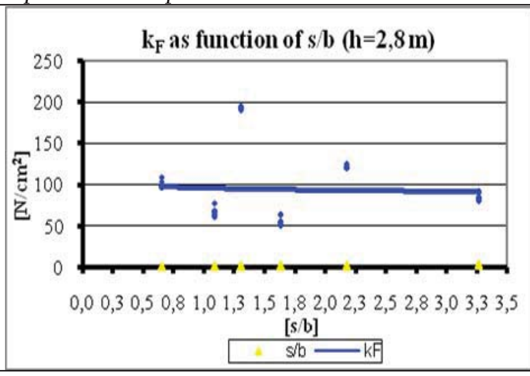
Values of k_L as the function of (s/b) for Tamnava – West field open pit mine
Vrednost k_L u zavisnosti od s/b za površinski kop Tamnava-Zapadno polje



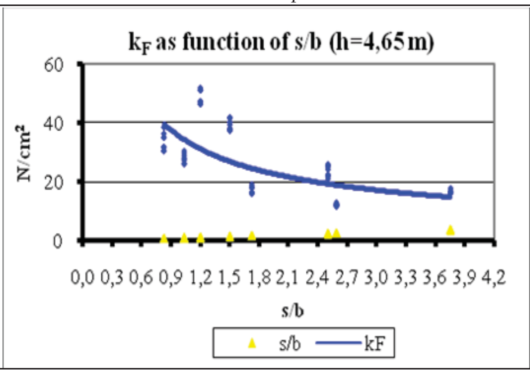


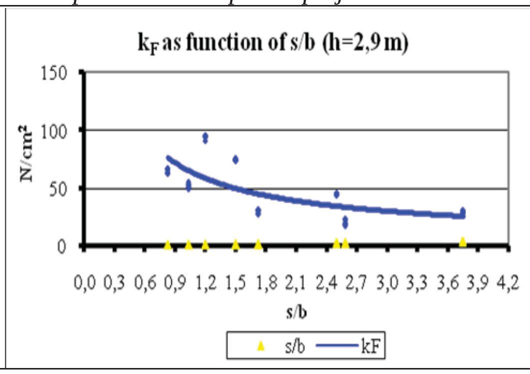
Values of k_L as the function of (s/b) for Drmno open pit mine
Vrednost k_L u zavisnosti od s/b za površinski kop Drmno





Values of k_F as the function of (s/b) for Tamnava – West field open pit mine
Vrednost k_F u zavisnosti od s/b za površinski kop Tamnava-Zapadno polje





Values of k_F as the function of s/b for Drmno open pit mine
Vrednost k_F u zavisnosti od s/b za površinski kop Drmno

Figure 2 Graphical presentation of specific cutting resistances k_L i k_F as function of ratio s/b at the Tamnava – West field and Drmno open pit mines
slika 2 Grafički prikaz zavisnosti specifičnog otpora na kopanje k_L i k_F od odnosa s/b na površinskim kopovima Tamnava-Zapadno polje i Drmno

5 CONCLUSIONS

The conclusions for the effect of slice thickness and width on the specific excavation resistance, along the total slice cross-section area (k_F), and along the total length of bucket cutting edges (k_L) based on the results of measurements carried out on the open pit Tamnava West field and Drmno can be grouped as following:

- According to the measurement results at Tamnava – West field open pit mine, the specific excavation resistance increases at the beginning and then slightly decreases with the increase of slice thickness and width ratio (s/b). The highest value for the specific cutting resistance k_L is at the ratio value of s/b = 1,1; and the highest specific cutting resistance k_F at the ratio value s/b=1,3.
- According to the measurement results at Drmno open pit mine, the specific excavation resistance increases at the beginning and then slightly decreases with the increase of slice thickness and width ratio (s/b). The highest value for the specific cutting resistance k_L and k_F is at the ratio s/b = 1,2.
- The values of k_L and $k_{F,}$ in all analyzed cases, are significantly greater for smaller values of slice height than for the optimal slice height.

5 ZAKLJUČCI

Za uticaj odnosa debljine i širine odreska na specifične otpore na kopanje specifičnog otpora na kopanje po ukupnoj dužini rezanja (k_L) i po ukupnoj površini poprečnog preseka odreska (k_F) na osnovu rezultata merenja izvedenih na površinskim kopovima Tamnava-Zapadno polje i Drmno može se zaključiti:

- Po rezultatima merenja na površinskom kopu Tamnava-Zapadno polje, specifični otpor na kopanje prvo raste a zatim blago opada sa porastom vrednosti odnosa debljine i širine odreska (s/b). Pri tome je najveća vrednost za specifični otpor na kopanje k_L kod odnosa s/b=1,1., a za specifični otpor na kopanje k_F kod odnosa s/b=1,3.
- Po rezultatima merenja na površinskom kopu Drmno, specifični otpor na kopanje prvo raste a zatim blago opada sa porastom vrednosti odnosa debljine i širine odreska (s/b). Pri tome je najveća vrednost za specifične otpore na kopanje k_L i k_F kod odnosa s/b=1,2.
- Vrednosti k_L i k_F su, u svim anliziranim slučajevima, znatno veće kod manjih nego kod optimalnih visina odreska.

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