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GEOMECHNICAL RESEARCH FOR THE NEW BUCKET WHEEL EXCAVATOR TESTING AT OPEN PIT "FILIJALA"

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Vladimir Čebašek, Nebojša Gojković,
Veljko Rupar, Miodrag Pribičević

FACULTY OF MINING AND GEOLOGY, UNIVERSITY OF BELGRADE, SERBIA
vladimir.cebasek@rgf.bg.ac.rs

Abstract: *Since 1976 cement marl excavation at open-pit mine „Filijala" is carried out by continuous exploitation technology using bucket wheel excavator SH 400 manufactured by Orenstein und Koppel (O & K) company. Due to the bucket wheel excavator time-worn and high operating cost it was necessary to replace it with new one. In order to test the new bucket wheel excavator and prove its capacity a testing zone was defined as test block for excavation, in which the bucket wheel excavator testing will be conducted. In the test block area detailed investigations were carried out which included laboratory testing in order to determine the value of material cutting resistance.*

Keywords: *cutting resistance, marl, bucket wheel excavator*

INTRODUCTION

The cement marls deposit „Filijala" is the main source of the basic raw material for the cement factory today. It has been known since 1838, and its exploitation works began in 1869 where the open-pit mine „Filijala" was developed. This deposit consists of three mining areas of unequal size and degree of exploitation called: „Severno polje", „Srednje polje" or „Međupolje" i „Južno polje"(Ganić M. et al., 2012).

The cement marl basic technology of exploatation is continuous with the use of a bucket wheel excavator. Due to the conditions in the deposit, especially due to the quality of marl, it is not possible to apply exclusively continuous technology, so the discountinuous exploitation technology is used as well. Discontinuous technology is used for the exploitation in parts of deposits where the bucket wheel excavator can't operate, as well as for simultaneous excavation from both technologies in order to homogenize the quality of the cement marl. Marl continuous exploitation technology is carried out by a bucket wheel excavator model SH 400, which was produced by the company Orenstein und Koppel (O & K) and has been in operation since 1976. Picture of this excavator in operation at open-pit mine is given in Figure 1.

Lafarge Beočin cement factory management decided to purchase a new bucket wheel excavator, due to the time-worn of the existing rotor excavator. Based on the technical specifications provided by LBFC mining engineers and technicians, a bucket wheel excavator with a working name „new bucket wheel excavator" has been designed, built and delivered. After completing the installation of a new bucket wheel excavator, it is necessary to carry out its testing, which, among other things, includes the proving of the exploitation capacity. For the purpose of testing a new bucket wheel excavator and proving its capacity, a digging test block is defined, in which the testing will be carried out.

At the open-pit mine „Filijala" test block location an detailed research program was carried out which covered both field investigations and geomechanical laboratory tests. Results of this research will serve as a basis for new bucket wheel excavator testing and proving its exploitation capacity.

FIELD INVESTIGATIONS

Field investigation included the exploratory borehole drilling from which core was collected and mapped. A total of sixteen boreholes were drilled at the open-pit mine „Filijala" test block zone. The spatial positions of the exploratory boreholes are shown at the map in Figure 1.

Figure 1, The "old" bucket wheel excavator SH 400.

Figure 2, The "new" bucket wheel excavator.

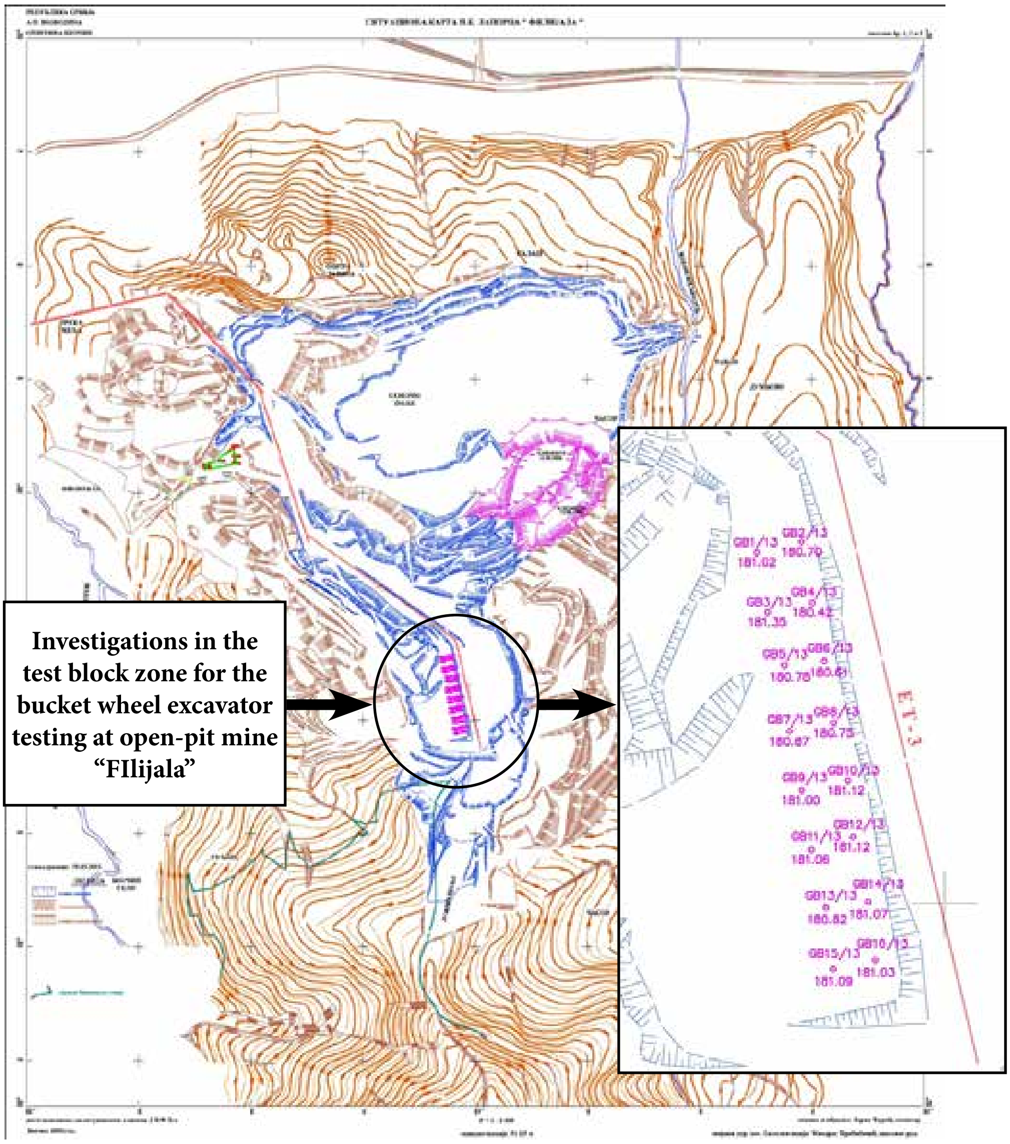


Figure 3, Disposition of investigations in the test block zone at open-pit mine "Filijala".

Exploratory drilling is performed by rotary drilling machine with continuous coring. For these purposes, GAK-300 drilling rig with all associated equipment was used. During the drilling itself, detailed geoengineering and hydrogeological mapping of the collected core was carried out. The results of the core mapping allowed the selection of rock material representative samples, after that the representative samples were labeled and packed for geomechanical laboratory testing. The aim of the conducted field research was to determine the geological structure of the micro-location of the zone and to select and collect the rock material samples for laboratory testing. Boreholes and samples basic data are given in Table 1 (Gojković N. et al., 2013).

LABORATORY TESTING OF PHYSICAL AND TECHNICAL PROPERTIES OF ROCK MATERIAL

Total of 23 rock material samples were collected from open-pit mine „Filijala" test block zone and delivered to Laboratory for rock mechanics at Faculty of Mining and Geology. All samples belong to a group of gray marl. On these samples the laboratory testing was carried out in order to determine the physical and technical properties, such as: the unit weight γ, the water

Table 1, Basic data on exploratory boreholes

Borehole				***Samples***		
Label	***Coordinates***			***No.***	***Depth***	
	Y (m)	***X (m)***	***Z (m)***		***From***	***To***
BGF-01/13	7400928.87	50066333.1	181.02	2	1.30	2.50
					5.35	6.60
BGF-02/13	7400945.80	5006637.10	180.70	2	1.30	2.60
					5.40	6.50
BGF-03/13	7400932.97	5006610.38	181.35	1	3.40	4.60
BGF-04/13	7400949.93	5006614.09	180.42	1	3.40	4.60
BGF-05/13	7400939.38	5006590.47	180.88	2	1.50	2.55
					5.40	6.60
BGF-06/13	7400954.49	5006592.07	180.61	2	1.40	2.60
					5.40	6.60
BGF-07/13	7400941.30	5006565.33	180.87	1	1.80	6.20
BGF-08/13	7400958.09	5006568.56	180.75	1	3.20	4.60
BGF-09/13	7400945.93	5006543.00	181.00	2	1.50	2.60
					5.40	6.60
BGF-10/13	7400963.43	5006546.72	181.12	2	1.40	2.60
					5.45	6.65
BGF-11/13	7400949.60	5006520.46	181.06	1	3.40	4.70
BGF-12/13	7400965.44	5006525.28	181.12	1	3.40	4.60
BGF-13/13	7400955.14	5006498.53	180.82	1	1.90	6.25
BGF-14/13	7400971.16	5006500.67	181.06	2	1.45	2.70
					5.40	6.60
BGF-15/13	7400957.86	5006475.17	181.08	1	3.40	4.60
BGF-16/13	7400973.83	5006478.51	181.02	1	3.40	4.55

content ω, the cutting resistance per unit of cutting edge length engaged K_L and the cutting resistance per unit of slice cross-sectional area K_F.

Physical and technical properties laboratory testing was performed in total of: 111 unit weight tests with paraffin (SRPS U.B1.017), 111 water content tests (SRPS U.B1.012) and 111 tests for determining the cutting resistance per unit of cutting edge length engaged and per unit of slice cross-sectional area. Marl cutting resistance testing of the was performed according to wedge test method proposed by Orenstein und Koppel (Durst W., Vogt W, 1988, Raaz V., 1999). The borehole labels and the number of samples from each borehole for laboratory testing are shown in Table 2.

CUTTING RESISTANCE

Gray marl cutting resistance was determined according the wedge test method proposed by Orenstein und Koppel. For this purpose, a specially constructed wedge was used for the breaking of marl test bodies. This wedge has angle of 34°, the glossy top of b = 5 mm with blade length of l = 65 mm and its schematic representation and appearance is given in Figures 4 and 5 (Radojević J., 1979, Radojević J., 1992).

According to the original test method the wedge is installed into a suitable hydraulic press which is used for vertical force applying. The vertical force increases constantly until the specimen fracture. During the tests, the force value which led to specimen fracture and wedge penetration depth into the specimen were determined.

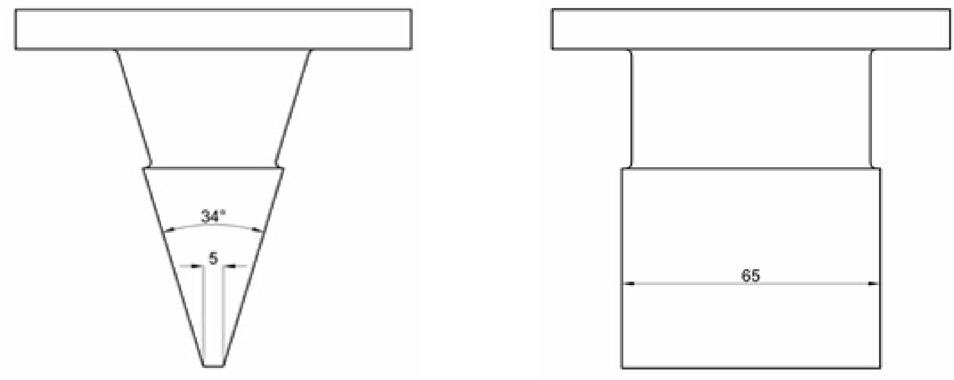


Figure 4, Schematic representation of wedge that was used for cutting resistance testing.

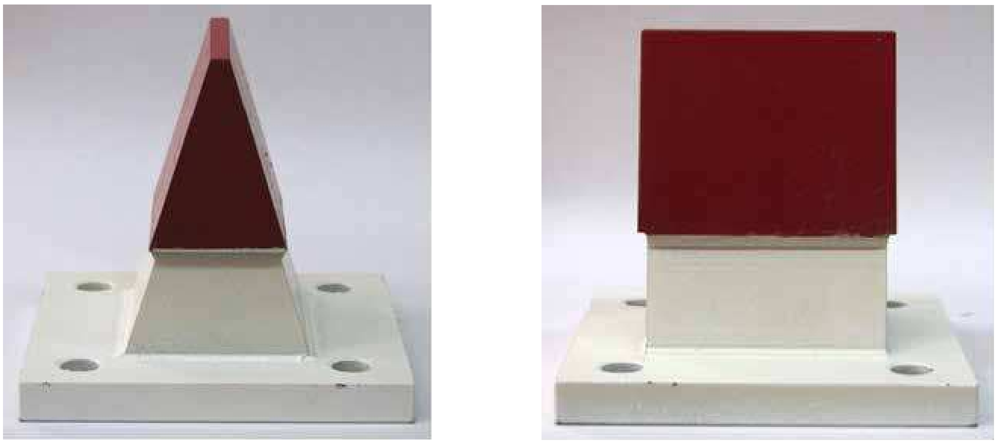
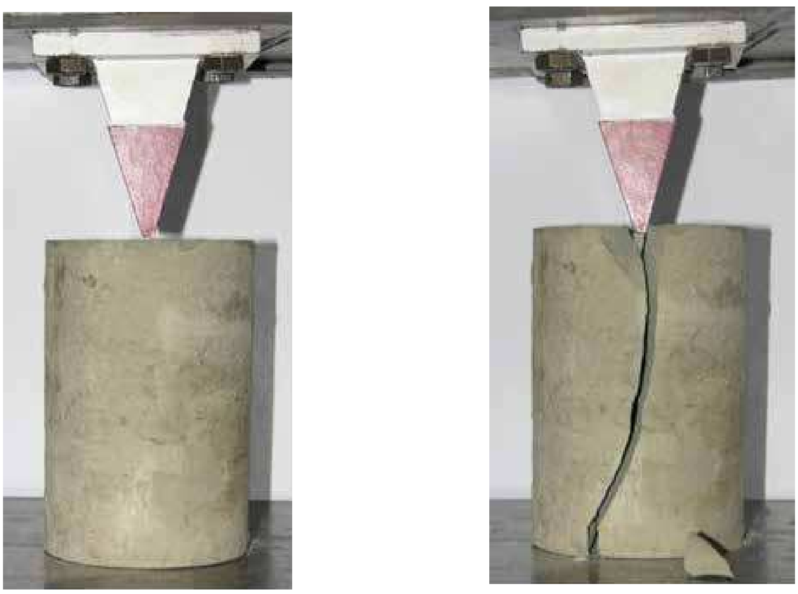


Figure 5, Appearance of wedge that was used for cutting resistance testing.



Before testing *After testing*

Figure 6, Testing body appearance before and after cutting resistance testing.

After testing, the rock material water content for each test specimen was determined. The water content tests were carried out according to the standard testing procedure using an electric dryer (SRPS U.B1.012).

Specific cutting resistance per unit of cutting edge length engaged K_L and the cutting resistance per unit of slice cross-sectional area K_F values are calculated according to the following equations:

$$K_L = \frac{P}{d} \quad (\text{N/cm`}) \quad \& \quad K_F = \frac{P}{F} \quad (\text{N/cm}^2),$$

where: P – breaking force (N),
d – diameter of sample (cm`),
F – specimens cross-section area (cm^2).

ANALYSIS OF THE LABORATORY TESTS RESULTS

A total of 23 gray marl samples were collected from exploratory boreholes for laboratory testing of cutting resistance. Overview of tested rock material (gray marl) samples physical and technical properties mean values is given in Table 2.

The text that follows provides an detailed statistical analyses of rock material (marl) physical and technical properties testing result. The results of statistical analyses are given in the form of overview, tables and corresponding graphic representations.

Table 2, Overview of the rock material samples physical and technical properties mean values

Sample label	***No. of testing bobies***	***Unit weigth γ (kN/m³)***	***Water content w (%)***	***Mean value of digging force K_L (N/cm`)***	***Mean value of digging force K_F (N/cm²)***
BGF - 1/13(1.30 – 2.50)	5	19.32	27.15	649.49	28.70
BGF - 1/13(5.35 – 6.60)	5	19.23	26.49	639.29	28.37
BGF - 2/13(1.30 – 2.60)	5	18.55	23.88	667.84	29.62
BGF - 2/13(5.40 – 6.50)	5	17.65	26.36	650.50	28.35
BGF - 3/13(3.40 – 4.60)	5	18.32	26.19	651.52	28.30
BGF - 4/13(3.40 – 4.60)	5	18.06	26.17	650.50	28.45
BGF - 5/13(1.50 – 2.55)	5	19.48	26.01	652.54	29.78
BGF - 5/13(5.40 – 6.60)	5	18.94	26.07	653.56	28.24
BGF - 6/13(1.40 – 2.60)	5	18.97	25.76	655.60	29.72
BGF - 6/13(5.40 – 6.60)	5	18.96	25.83	654.58	28.13
BGF – 7/13 (1.80 – 6.20)	3	18.58	25.18	655.94	27.27
BGF - 8/13(3.20 – 4.60)	5	19.35	25.56	652.54	28.54
BGF - 9/13(1.50 – 2.60)	5	18.00	25.52	656.62	28.12
BGF - 9/13(5.40 – 6.60)	5	17.80	25.65	655.60	28.05
BGF - 10/13(1.40 – 2.60)	5	18.93	25.24	658.66	29.80
BGF - 10/13(5.45 – 6.65)	5	18.48	25.49	654.58	28.41
BGF - 11/13(3.40 – 4.70)	5	18.08	25.04	657.64	29.29
BGF - 12/13(3.40 – 4.60)	5	18.65	24.96	656.62	29.35
BGF – 13/13 (1.90 – 6.25)	3	18.08	24.70	659.34	27.73
BGF - 14/13(1.45 – 2.70)	5	17.84	24.64	661.72	29.59
BGF - 14/13(5.40 – 6.70)	5	18.32	24.70	662.74	28.37
BGF - 15/13(3.40 – 4.60)	5	18.02	24.61	660.70	29.11
BGF - 16/13(3.40 – 4.55)	5	17.89	24.53	663.76	29.82

UNIT WEIGTH

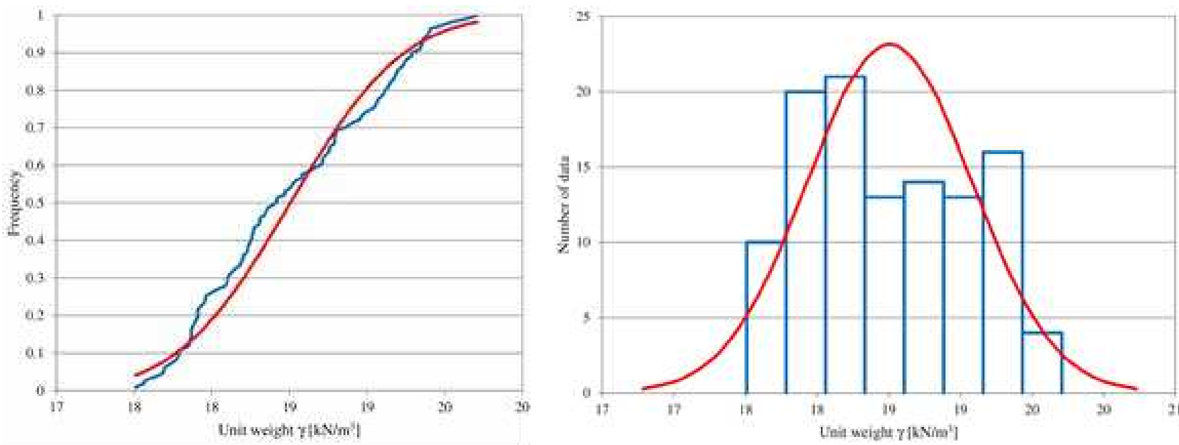
The unit weigth γ was determined on five test body from each cutting resistance laboratory testing specimen. The results of unit weigth testing were statistically analyzed. Total of 111 data were analyzed and statistical parameters are shown in Table 3 and Figures 7a and 7b.

WATER CONTENT

The water content w was determined on five test bodies from each cutting resistance laboratory testing specimen. The results of water content testing were statistically analyzed. Total of 111 data were analyzed and statistical parameters are shown in Table 4 and Figures 8a and 8b.

Table 3, Overview of statistical parameters of the rock material unit weigth testing results

Statistical parameters	***Value***
Number of data	111
Minimum value	17.51
Maximum value	19.71
Value interval	2.200
Sum of all values	2054.16
Average	18.506
Variance	0.329
Mean square deviation	0.574
Standard error	0.054

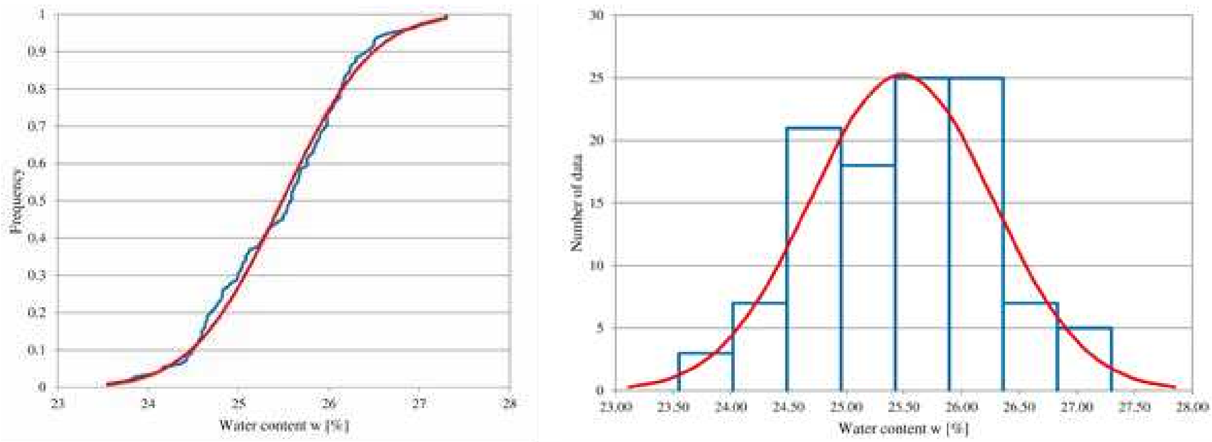


a) *b)*

Figure 7, Cumulative curve (a) histogram and normal distribution, (b) of the unit weigth γ testing results.

Table 4, Overview of statistical parameters of the rock material water content w testing results

Statistical parameters	***Value***
Number of data	111
Minimum value	23.55
Maximum value	27.30
Value interval	3.750
Sum of all values	2828.610
Average	25.483
Variance	0.621
Mean square deviation	0.788
Standard error	0.075



a) *b)*

Figure 8, Cumulative curve (a) histogram and normal distribution, (b) of the water content ω testing results.

CUTTING RESISTANCE

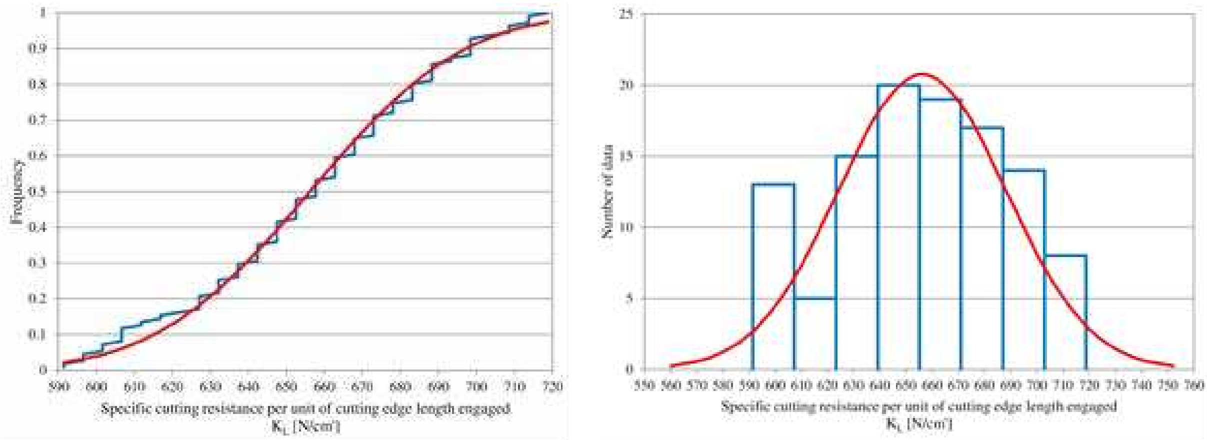
The laboratory testing of cutting resistance was carried out on five test bodies from each testing specimen. The results of samples cutting resistance testing (cutting edge K_L i cross-sectional K_f) were statistically analyzed. Total of 111 data were analyzed and all important statistical parameters are shown in Table 5.

The cutting resistance per unit of cutting edge length engaged values ranged from K_L = 591.37 to 718.82 N/cm, while the average values of this parameter ranged from K_L = 639.29 to 667.84 N/cm and are shown in Table 2 - overview of the samples physical and technical properties. The results of testing the cutting resistance per unit of cutting edge length engaged K_L (111 data) were statistically analyzed and statistical parameters are shown in Table 5. The graphic interpretation of the results of this analysis is shown in Figures 9a and 9b.

The values of the cutting resistance per unit of slice cross-sectional area ranged from K_F = 24.86 to 32.89 N/cm^2, while the average values of this parameter ranged from K_F = 28.05 to 29.82 N/cm^2 for tested samples and are shown in a in Table 2 - overview of the samples physical and technical properties. The results of testing the cutting resistance per unit of slice cross-sectional area K_F (111 data) were statistically analyzed and statistical parameters are shown in Table 5. The graphic interpretation of the results of this analysis is shown in Figures 10a and 10b.

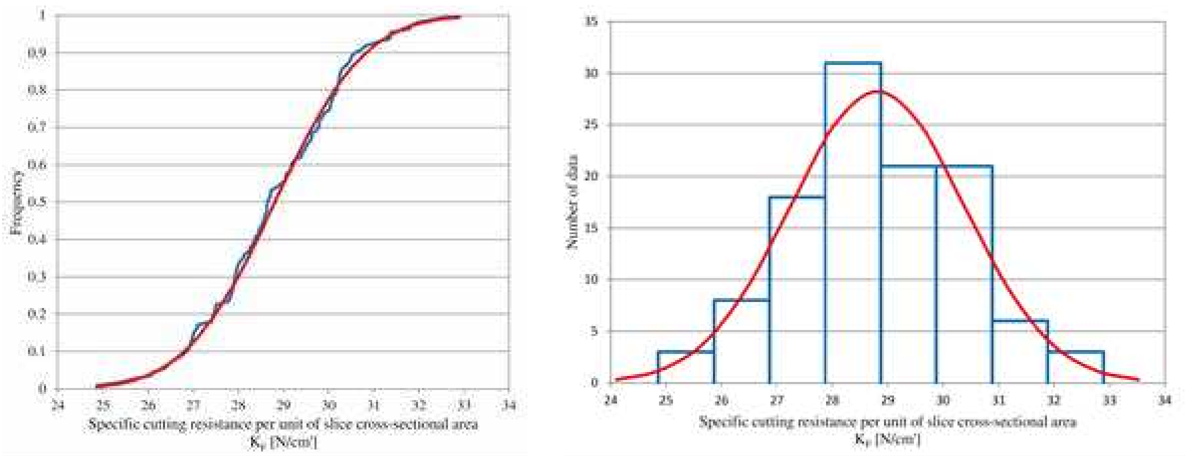
Table 5, Overview of statistical parameters of the rock material cutting resistance testing results

Statistical parameters	***Specific cutting resistance per unit of cutting edge length engaged K_L***	***Specific cutting resistance per unit of slice cross-sectional area K_F***
Number of data	111	111
Minimum value	591.37	24.86
Maximum value	718.82	32.89
Value interval	127.450	8.030
Sum of all values	72835.130	3198.180
Average	656.172	28.812
Variance	1023.248	2.467
Mean square deviation	31.988	1.571
Standard error	3.036	0.149



a) *b)*

Figure 9, Cumulative curve (a) histogram and normal distribution,
(b) of the cutting resistance per unit of cutting edge length engaged K_L testing results.



a) *b)*

Figure 10, Cumulative curve (a) histogram and normal distribution,
(b) of the cutting resistance per unit of slice cross-sectional area K_F testing results.

CONCLUSION

Purpose of the research presented in this paper is to carry out cutting resistance laboratory testing on rock material (gray marl) samples. Samples were collected from boreholes at open-pit »Filijala« site. Laboratory testing results should serve to evaluate bucket wheel excavator cutting resistance at the moment of testing and proving its explotation capacity.

In order to prove the excavator exploitation capacity, a test block zone is determined where the new bucket wheel excavator tesing will be carried out. Detailed research of the test block micro-location at open-pit mine „Filjala" was carried out with the aim to determine the geological structure at test block zone and select rock material representative samples for cutting resistance laboratory testing. In this area at open-pit mine „Filijala", a total of 16 exploratory boreholes were dilled, out of which 23 gray marl samples were collected. On the above-mentioned rock material (marl) samples, physical and technical properties were tested such as: unit weight γ, water content w, specific cutting resistance per unit of cutting edge length engaged K_L and specific cutting resistance per unit of slice cross-sectional area K_F. Laboratory tests covered a total of: 111 unit weight tests with paraffin (SRPS U.B1.017), 111 water content tests (SRPS U.B1.012) and 111 tests for determining specific cutting edge i cross-sectional cutting resistance (Orenstein und Koppel method).

The values of the rock material (gray marl) specific cutting resistance per unit of cutting edge length engaged K_L ranged from K_L = 591.37 to 718.82 N/cm, while the values of specific cutting resistance per unit of slice cross-sectional area K_F ranged from K_F = 24.86 to 32.89 N/cm^2. The technical documentation for the purchase of a bucket wheel excavator required the specific line-cut digging force K_L of 715.00 N/cm. By analyzing the laboratory tests results it can be noticed that only one specific cutting resistance (K_L = 718.82 N/cm) test has a higher value than the defined value of 715 N/cm. According to the previous one, it can be concluded that the defined test block zone fully meets the conditions for testing the bucket wheel excavator in order to prove its capacity.

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