

The method of assessing the quality of the excavation workmanship in the underground coal mine

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Abstract. A new method of assessing the quality of the heading workmanship was proposed in this article. The method includes 13 parameters characterizing the quality of excavation performance, namely: the heading breach width, the heading useful height, the heading useful width, the angle of inclination of arch, the horizontal offset of arch (direction), the vertical offset of arch (cancellation), distance between mine roadway support, the arch set overlap length, the tightening torque of clamps screws, development of struts, dadding and the contact of support with rock strata. For each element of the excavation the number of quality points is determined based on by the amount of multiples of the quality statistics QN from the qualifying constant. After adding up the points, the final grade is obtained in the form of the quality category. The conclusion is an example of the evaluation of the quality of heading workmanship according to the developed method.

Keywords: mining engineering, underground structure, build quality

1 Introduction

The basic purpose of designing, making and maintaining an excavation is to ensure its stability, which is possible under three basic conditions:

- good design – recognized geological and mining conditions, well-defined properties of the massif, good design methods, flawless calculations,
- exact execution – accurate breakthrough, accurate support (material quality, support quality, assembly accuracy),
- proper maintenance – conducting excavation and support diagnostics and performing necessary maintenance works.

Performance errors are usually the sum of the variability of the conditions under which excavations are made and the inaccuracies of the support elements are made. The variability

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of the drilling conditions of the excavation causes that the dimensions of the excavation breakdown along its run are varied, which affects the quality of workmanship and the conditions of cooperation between the support and the rock mass [1,2].

The reliability of the support and the safety of the mine workings in the mine to a large extent, the quality of its implementation. The design of the excavation assumes accurate, design dimensions and standard parameters regarding the bearing capacity of the support, and possible executive and material inaccuracies are taken into account by assuming appropriate safety factors [1,2]. In this situation, there is a need to develop a uniform method for assessing the quality of excavation performance, allowing for control of the compliance of the project with consideration of tolerances.

2 Assessment of the quality of the heading workmanship

The assessment of the quality of the heading was based on the quality requirements according to the "PN-ISO 3951: 1997" standard. Random sampling of non-compliant units based on a numerical evaluation of properties; procedures and nomograms [3] and the point method [4].

The proposed model for the quality evaluation of a heading does not treat units of poor support performance as a whole, as was the case in the standard [5], but focuses on the assessment of its individual features separately. The final rating gives us not only information on the number of non-compatible openings in the excavation, but most importantly, which features of the excavation are not in accordance with the standard and indicates the amount of deviation of the quality of workmanship from the intended one. This gives us clear and transparent information about mistakes made while mining, their importance and the possibility of repairing them.

The number of supports required to assess the quality of excavation performance and the value of the acceptable limit of AQL quality were determined according to the "PN-ISO 3951: 1997" standard.

As the value of the acceptable limit of AQL quality in accordance with the above a standard is understood as a level of quality that corresponds to the worst tolerable average level of process quality.

In the method of assessing the quality of workings examined in the work, the value AQL = 10% was assumed, which means that 10% of units not complying with the requirements of the norm in a given element of the excavation are allowed. Each element that meets these requirements obtains 10 quality points.

The value of the AQL qualifying constant depends on:

- the purpose of the excavation in the mine's production process,
- the planned lifetime of the excavation.

The recommended form of testing the quality of the excavation of the excavation is such that the controls are carried out on a regular basis during drilling. For this purpose, it is necessary to know the expected length of the designed excavation in order to determine the total number of frames to be tested and to determine the distance between the arches to be tested. With this data one should check the quality of the first made risers in the excavation, and then examine the next arch at distances equal to one another according to the pattern given in Table 1. To obtain the desired distance between the tested arches, divide the total number of risers in the excavation by the number of archs required for testing. For example, for an excavation with a length of 1000 m, check the quality of the 35 risers at a distance of 28 arches.

Table 1. One-stage test plan used during normal control according to "PN-ISO 3951: 1997 [3]

The total number of supports in the excavation	Number of the arch required for testing	The value of the qualifying constant for AQL = 6.5%	The value of the qualifying constant for AQL = 10%
9 to 15	3	0,765	0,566
16 to 25	4	0,814	0,617
26 to 50	5	0,874	0,675
51 to 90	7	0,955	0,755
91 to 150	10	1,03	0,828
151 to 280	15	1,09	0,886
281 to 400	20	1,12	0,917
401 to 500	25	1,14	0,936
501 to 1200	35	1,18	0,969
1201 to 3200	50	1,21	1,00
3201 to 10000	75	1,24	1,03

Each case should be examined in all cases, ie:

1. the heading breach height,
2. the heading breach width,
3. the heading useful height,
4. the heading breach width,
5. the angle of inclination of arch,
6. the horizontal offset of arch (direction),
7. the vertical offset of arch (cancellation),
8. distance between mine roadway support,
9. the arch set overlap length,
10. the tightening torque of clamps screws,
11. development of struts,
12. dadding,
13. the contact of support with rock strata.

The frequency of inspection depends on the progress of the excavation drilling.

Research conducted during the excavation of the excavation allows for ongoing control and possible correction of excavation performance. The data collected and developed at the end of the excavation of the excavation allow for the final evaluation of the entire excavation performed separately in respect of each feature.

For quality assessment according to standard [6], the following values are defined for each mining characteristic:

- average value,

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} \tag{1}$$

where:

n – the number of support elements tested,

x_i – further values of the feature of the tested support element,

- standard deviation:

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} \tag{2}$$

where:

- n - the number of support elements tested,
- x_i - further values of the feature of the tested support element,
- upper tolerance limit T_U – value, which determines the upper acceptable limit of compliance for a single feature of the support,
- lower tolerance limit T_L – a value that determines the lower acceptable limit of compliance for a single support feature,
- upper quality statistics – function of the upper limit of tolerance, average value of the tested support feature and standard deviation:

$$Q_U = \frac{T_U - \bar{x}}{s} \quad (3)$$

- lower quality statistics – function of the lower tolerance limit, average value of the tested support feature and standard deviation:

$$Q_L = \frac{\bar{x} - T_U}{s} \quad (4)$$

Incompatibility is the failure to meet the requirements set by the support. Non-compliances are classified according to the degree of their validity, i.e. class A as having the most significant meaning, class B for non-compliances of lower significance, etc. In the aforementioned studies for class A, an *AQL* value of 6.5% was adopted, whereas for class B the *AQL* value was 10%.

The acceptable level of *AQL* quality is the level that in the random control is the limit value of a satisfactory average percentage of non-compliant units in the process.

The qualifying constant is a constant that depends on a certain value of an acceptable level of *AQL* quality and the number of tested supports.

For the researched workings, the incompatibility class B was assumed, for which the value of the acceptable limit of *AQL* quality is 10%, and the value of the qualifying constant $k = 0.917$ (table 1).

Interpretation of the results of control tests is aimed at reading the scale of executive errors made and finding the reasons for their occurrence.

The next stage of the research is the use of the point method, where the number of quality points is calculated for each element of the excavation. After adding the points, the final assessment of the quality of the excavation and the conditions for its putting into use are obtained. If approval of the excavation is not accepted, a decision should be made about any corrective actions.

The number of quality points is dependent on the multiplicity of Q_N quality statistics exceeding the condition $Q_U > k$ and $Q_L > k$ from the qualifying constant k according to the formula:

$$x = \frac{k - Q_N}{k} \quad (5)$$

where:

- x – the number of times the quality statistics Q exceeds the qualifying constant k ,
- Q_N – quality statistics not meeting the condition $Q_U > k$ and $Q_L > k$,
- k – the qualifying constant.

Depending on the size of this multiplicity, which proves the amount of deviation of the quality of a given feature from the requirements set out at the beginning of the study, a given number of points is awarded (Table 2).

Table 2. Criteria for assessing the quality of excavation performance according to the point method

The multiplicity of exceeding the Q_N quality statistics from the qualifying constant k	Number of points
to 0,5 - times	9
from 0,5 to 1,0 - times	7
from 1,0 to 1,5 - times	5
from 1,5 to 2,0 - times	3
from 2,0 to 2,5 – times	2
from 2,5 to 3,0 - times	1
more than 3,0 - times	0

The total number of points of all features gives a comprehensive assessment of the quality of the excavation performance along with the conditions for the approval of the excavation for use. Table 3 presents the criteria for assessing the quality of excavation performance, where 13 elements are tested, and the maximum number of possible points is 130.

Table 3. Criteria for assessing the quality of excavation performance according to the point method

The total number of points for the test		Quality category	Specification
13 features	12 features		
130	120	I	an excavation with reference quality that meets all quality requirements;
120 – 129	110 – 119	II	an excavation of very good quality, having slight deviations from the reference quality, not requiring any corrections before putting it into service;
100 – 119	90 – 109	III	an excavation of good quality, which may be approved for use, with the acceptance of the execution of elements of the excavation deviating from the required, after its intended use and planned duration or before being accepted for use, requiring some corrections of the elements of the lowest quality, which are very important in given conditions;
80 – 99	70 – 89	IV	an excavation of acceptable quality, requiring certain adjustments to be made prior to being allowed to use of the lowest quality, and of great importance in given conditions; requiring increased control of its behavior during use.
70 – 79	60 – 69	V	an excavation of poor quality, requiring repair to qualify for at least category III with possible admissible shortcomings for given conditions;
Less than 70	Less than 60	VI	an excavation of very poor quality, unfit for use, requiring thorough repair to qualify for at least category III with possible admissible shortcomings for given conditions;

Assessment criteria for workings where fewer elements have been examined are analogous, ie for workings with 12 elements tested maximum number of points is 120, and the rating categories are automatically lower by 10 points. The research presented in this

article presents a control of 12 elements in coal excavations and 13 in stone excavations, in which the leveling of the excavation was additionally examined.

The test results according to the new model of the quality assessment of a heading drill show a specific, numerical range of errors committed in the excavation process and a comprehensive assessment taking into account the conditions of its exploitation.

If it is necessary to repair incorrectly made parts of the excavation and after removing any irregularities committed during the excavation, the next inspection should be carried out in the same way, the test should be started by shifting one more support hatch to increase the effectiveness of the inspection.

3 Example of evaluation of the 4W pavement performance quality

The 4W heading was drilled in the 504 seam at 920 - 1010 m depth. The drilling took place using mechanical rock excavation using the AM-50 harvester. The width of the excavation in the light of the support was 5.0 m and the height 3.5 m. The support was made of flexible steel arch support. In the ancestors of the above-mentioned workings, tests of the quality of their drilling were carried out. The tests included measurements of 12 sizes, namely: the heading breach width, the heading breach height, the heading useful width, the heading useful height, the angle of inclination of arch, the horizontal offset of arch (direction), the vertical offset of arch (cancellation), distance between mine roadway support, the arch set overlap length, the tightening torque of clamps screws and development of struts and dadding.

For example, the selected measurement results are shown in Figures 1-12, and the results of the evaluation of the quality of the excavation performance in Table 4.

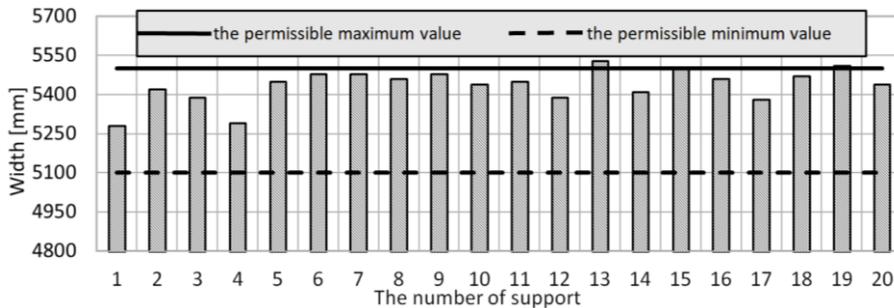


Fig. 1. Results of measurements of the 4W heading breach width

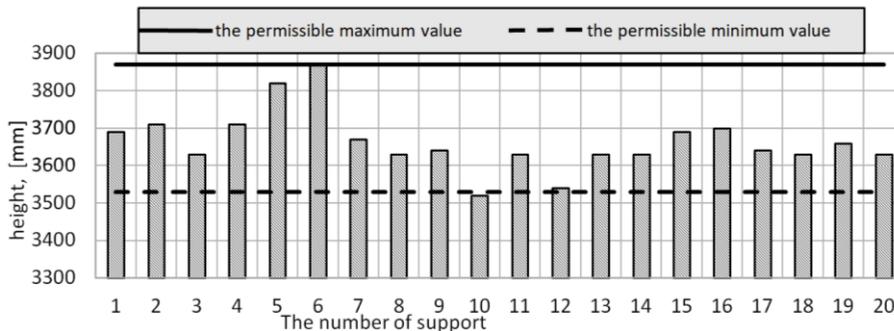


Fig. 2. Results of measurements of the 4W heading breach height

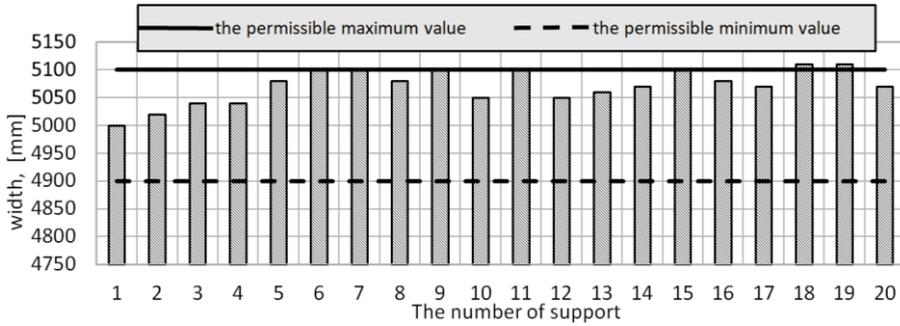


Fig. 3. Results of measurements of the 4W heading useful width

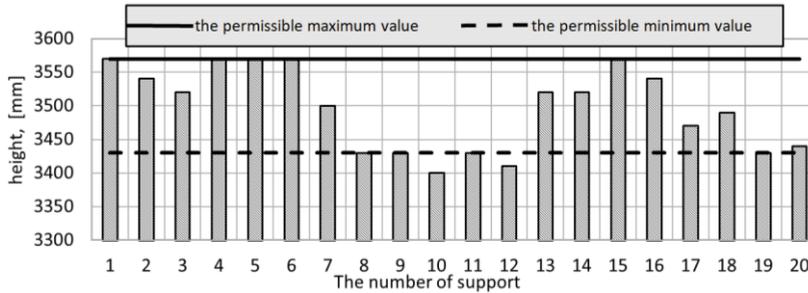


Fig. 4. Results of measurements of the 4W heading useful height

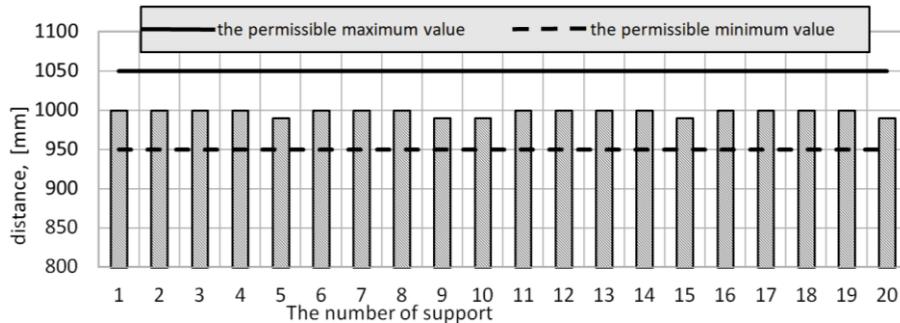


Fig. 5. Results of measuring the distance between mine 4W heading support

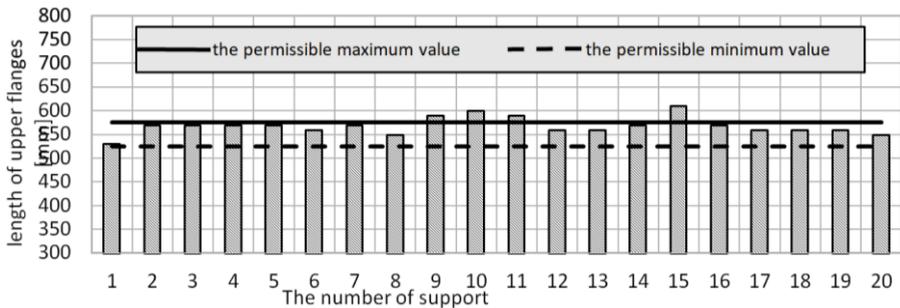


Fig. 6. Results of measurements of the upper the arch set overlap length

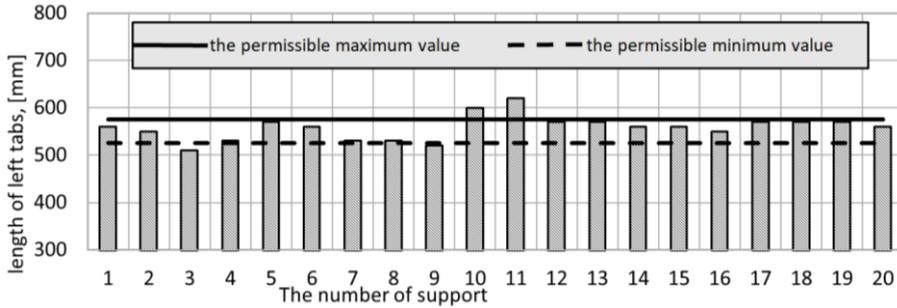


Fig. 7. Results of measurements of the left the arch set overlap length

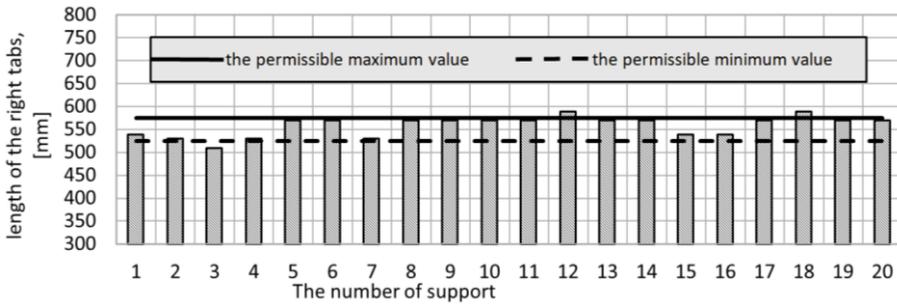


Fig. 8. Results of the measurements of the right the arch set overlap length

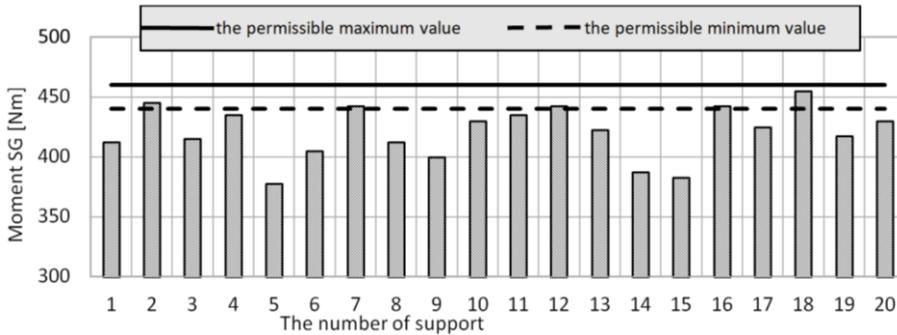


Fig. 9. The results of the tightening torque of upper clamps screws

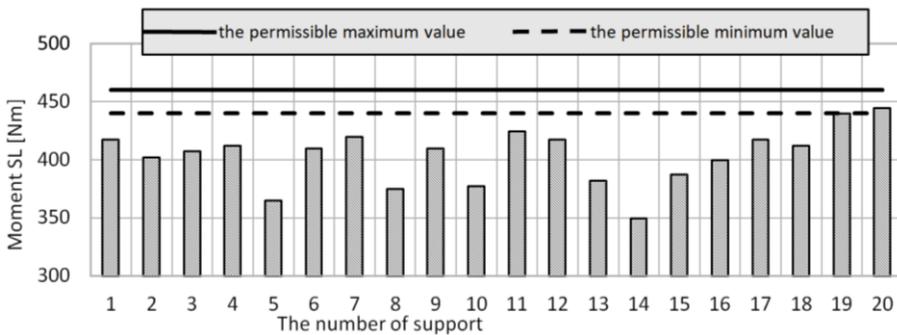


Fig. 10. The results of the tightening torque of left clamps screws

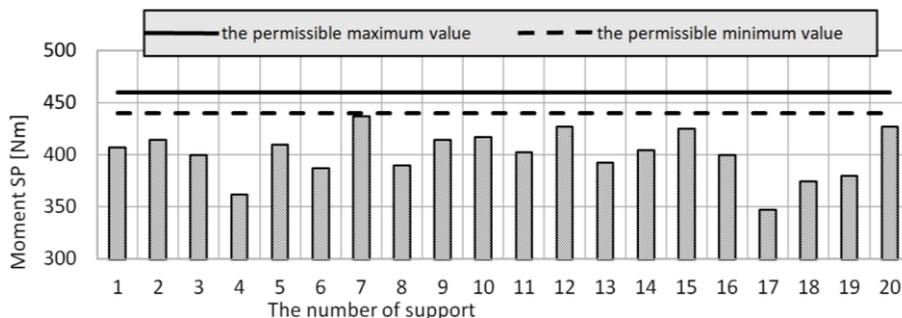


Fig. 11. The results of the tightening torque of right clamps screws

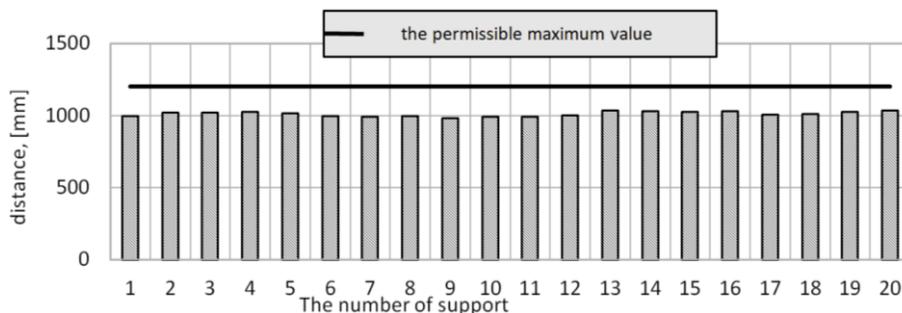


Fig. 12. Results of the measurements of the development of struts

The 4W pavement, according to the developed quality assessment method, obtained 109 points out of 120 possible and was classified to the second category of excavation quality – an excavation of good quality that could be approved for use, with acceptance of the elements of the excavation deviating from the required, after its intended use and planned time of use or before being accepted for use requiring some adjustments to the elements of the lowest quality, which are very important in given conditions.

The pavement was designed as a ventilation pit in a place affected by exploitation and its duration was planned for less than 1 year. The lowest point was the quality of the implementation of the opinion and this is the only element requiring correction due to the planned movement of the crew in this excavation. Due to the low defectiveness, the scope of repair of this element is very small.

Table 4. Evaluation of the performance quality of the 4W heading

4W excavation	Limits of tolerance, [mm]	Average value, [mm]	Standard deviation, [mm]	Non-compliance class	The value of AQL , [%]	Qualifying constant k	upper Q_U quality statistics	Lower quality statistics Q_L	Compatibility with the $Q_U > k$ criterion and $Q_L > k$	Q_N times to k	number of points
The heading breach height	3870 3530	3663,5	79,16	B	10	0,917	2,61	1,69	YES		10
The heading breach width	5700 5000	5435,5	62,25	B	10	0,917	4,25	7	YES		10
The heading useful height	3570 3430	3496	61,08	B	10	0,917	1,21	1,08	YES		10
The heading useful width	5100 4900	5071,5	30,83	B	10	0,917	0,92	5,56	YES		10
The angle of inclination of arch	6 -6	1,2	2,46	B	10	0,917	1,95	2,93	YES		10
The horizontal offset of arch	100 -100	22	75,51	B	10	0,917	1,03	1,62	YES		10
The vertical offset of arch				B	10	0,917					
Distance between mine roadway support	1050 950	997,5	4,44	B	10	0,917	11,82	10,7	YES		10
The arch set overlap length	630 570	613,17	23,91	B	10	0,917	0,7	1,81	NO	0,23	9
The tightening torque of clamps screws	410 390	408,58	23	B	10	0,917	0,06	0,81	NO	0,93	7
Development of struts	1200	912,75	78,85	B	10	0,917	3,64	11,58	YES		10
Dadding	0	0,3	0,47	B	10	0,917	-0,64		NO	1,7	3
The contact of support with rock strata	90	89,5	9,45	B	10	0,917		9,47	YES		10
											109

4 Summary

The impact of the human factor on the accuracy of the excavation of the headings justifies the need and purposefulness of the quality control of the excavation as an important condition for maintaining its stability.

Based on the results of the tests carried out and the analysis of their results, a new method for assessing the quality of the excavation work performance in the underground hard coal mine was proposed. The new tool for controlling and assessing the quality of the excavation proposed in this work should to a large extent order and facilitate this process. The method includes 13 parameters characterizing the quality of excavation performance, namely: the heading breach width, the heading breach height, the heading useful height, the heading useful width, the angle of inclination of arch, the horizontal offset of arch (direction), the vertical offset of arch (cancellation), distance between mine roadway support, the arch set overlap length, the tightening torque of clamps screws, development of struts, dadding and the contact of support with rock strata.

The proposed new way of assessing the quality of heading performance is based on the basis of statistical data analysis. This tool gives a clear picture of the quality of the excavation work with a detailed visualization of the quality of each of its elements separately. The results of such a control allow for a quick response and indicate in a transparent way the scope of the necessary adjustment. The final assessment defines the quality of the excavation and indicates, using specific values, the scale of the shortcomings of those elements of the excavation that do not meet the assumed requirements.

The new method of assessing the quality of excavation workplaces offers simple research plans and uses simple mathematical relationships to determine the quality of excavation performance, thanks to which it is a tool that can be successfully used in practice.

References

1. Chudek M., Duży S., Głuch P., Kleta H., Cholewa M., Winch M., *Stateczność wyrobisk korytarzowych warunkiem efektywnej eksploatacji i bezpieczeństwa pracy w kopalniach podziemnych*. Gliwice (2011).
2. Duży S., *Studium niezawodności konstrukcji obudowy i stateczności wyrobisk korytarzowych w kopalniach węgla kamiennego z uwzględnieniem niepewności informacji*. ZN Politechniki Śląskiej, s. Górnictwo, z.277. Gliwice (2007)
3. Norma polska PN-ISO 3951. *Kontrola wyrywkowa procentu jednostek niezgodnych na podstawie liczbowej oceny właściwości; procedury i nomogramy*.
4. Cholewa M., *Metoda oceny jakości wykonania wyrobiska korytarzowego w podziemnej kopalni węgla kamiennego*. Praca doktorska, Politechnika Śląska, Gliwice (2015)
5. Norma polska PN-G-06011:1990, *Wyrobiska korytarzowe poziome i pochyle w kopalniach. Wyrobiska obudowane odrzwiami z kształtowników korytkowych. Wymagania i badania przy odbiorze*, (1990)
6. Norma polska PN-ISO 2859-2: 1996. *Procedury kontroli wyrywkowej metodą alternatywną. Plany badania na podstawie jakości (LQ) stosowane podczas kontroli partii izolowanych*, (1996)