IOP Conference Series: Earth and Environmental Science

Classification of the technical condition of steel arch supports in dog headings with a long-term service life

IOP Conf. Series: Earth and Environmental Science **261** (2019) 012009 doi:10.1088/1755-1315/261/1/012009

Classification of the technical condition of steel arch supports in dog headings with a long-term service life

G Dyduch

Silesian University of Technology, Faculty of Mining and Geology, 2 Akademicka Street, 44-100 Gliwice, Poland

E-mail: Grzegorz.Dyduch@polsl.pl

Abstract. A large number of dog headings is made and maintained in Polish underground mines that extract hard coal. These headings are often used for many years. However, a gradual deterioration of the technical condition of the supports occurs over all those years, which may pose a serious threat to the safe use of the heading. Therefore, in order to prevent dangerous situations, it is necessary to conduct an ongoing assessment of the technical condition of mine headings and, based on it, make decisions regarding the need to carry out protective and maintenance works. For this purpose, the classification of the technical conditions of steel arch supports suggested in this article can be used. It allows to assess the support conditions according to homogeneous criteria and is a convenient tool to carry out diagnostics of dog headings throughout the entire period of their use. It also gives the possibility to compare different support designs which are used in similar conditions and to verify the developed technical forecasts, regardless of the methodology used to calculate the support.

1. Introduction

The conduct of underground mining activity is connected with the necessity of building a large number of dog headings. Some of them are then maintained for many years. Under the conditions of Polish underground mines that extract hard coal, the longest-maintained ones are access openings, such as cross headings, drifts or main galleries as well as special headings (e.g. chambers). Most often, they are equipped with yielding steel arch supports.

Over time, the support elements are subject to gradual wear, which is the result of, among others, limited durability of the materials used, quality of the construction, its way of use, as well as operational conditions [1, 2]. This may pose a serious threat to the safety of the excavation, with recent years as an example and such cave-ins as in "Wieczorek" (2009, 2012), "Borynia-Zofiówka-Jastrzębie" Ruch "Jas-Mos" (2015), "Pniówek" (2016), "Piast-Ziemowit" (2016), or "Ruda" Ruch "Halemba" (2017, 2018) mines. One of the main reasons for the occurrence of the above mentioned cave-ins was the weakening of the supports caused by excessive corrosion of its structural elements [3]. Therefore, it is extremely important to conduct ongoing supervision of the technical condition of dog headings, especially in the case of aggressive mining environment, in order to limit the possibility of recurrence of similar events.

In order for such supervision to be possible, it is necessary to have appropriate tools to carry it out. “Tools” herein not only means the appropriate measuring instruments, but also a proper technique of making measurements, carrying out the necessary calculations and the possibility of classifying the support in terms of technical condition, as well as making further decisions regarding the possible need for securing the excavation. To this end, measures have been taken to create a classification of the technical condition of dog heading arch supports, which will allow it to be assessed according to homogeneous criteria and will be a convenient tool for the diagnosis of dog headings throughout their entire lifecycle.

2. A contribution to create the classification

The necessity of ongoing supervision of the technical condition of dog heading mining supports with a long service life results not only from the necessity of work safety in the mine, but also from ensuring the continuity of the mining process. Any failure of the support, in particular within the main headings, is not only a threat to employees but also causes complications from the point of view of transport and ventilation. In addition, reconstruction of collapsed sections of excavations belongs to the group of the most dangerous mining works and generates high costs. All this means that the principle of "*morbum evitare quam curare facilius est*" known from medical sciences (attributed to Hippocrates), finds a new reference here, because, as we know, prophylaxis is usually an easier and cheaper solution than removing the effects of adverse events that could not be prevented.

The necessity of periodic inspections of the mining support conditions in dog headings was also included in the current Polish mining regulations [4]. Pursuant to the Ordinance of the Minister of Energy of 23rd November, 2016 regarding detailed requirements for underground mining operations (§ 121, item 2), supervision of supports "*in the main transportation and ventilation routes is carried out once a quarter by a person who supervises mining plant operations and who has been designated by the head of operations of the said mine*". However, these regulations do not contain any guidelines as to the methodology of conducting this type of inspection and interpretation of its results.

Therefore, an attempt was made to create a classification of the technical condition of dog heading mining supports with a long-term service life, based on the degree of wear of its elements, which in turn is determined on the basis of the examination carried out in the excavation and macroscopic observations made therein.

3. Research on the degree of wear of dog heading mining supports

In order to develop the technical conditions of the classification of steel arch supports in dog headings and its adaptation for practical purposes, a study was carried out on the degree of wear of the support elements in 37 excavations located in 6 mining plants in the Upper Silesian Coal Basin. These excavations were made at a depth of approx. 350 m to 1050 m, in a rock mass with varying mining and geological conditions. As part of selected excavations, 44 measurement sections with a total length of 8257 m and a different degree of corrosion of support elements were distinguished [1].

The study was preceded by a detailed analysis and identification of factors exerting a decisive influence on the course of wear of the support components. In the course of the study, it was found that one of the main reasons for the deterioration of the technical conditions of the steel arch supports, especially in the case of long-term service excavations, is corrosion of its structural components. This process contributes to lowering the load capacity of the structure, as a result of changes in geometrical and static parameters of the steel sections from which the support elements were made and changes in the performance characteristics of the yielding joints [1, 5].

The conducted study demonstrated that the most frequently observed course of deterioration process in steel arch supports can be described as electrochemical corrosion running in a liquid environment (most often in the presence of mine water) or in an atmospheric environment of a general nature. Less frequently observed cases included slitting or pitting, locally stimulated by stress accumulation in the structural elements [1].

Determination of the degree of corrosion of individual elements of steel arch supports included a measurement of their thickness in the underground conditions. The tests were performed by ultrasonic echo method, with the use of SONO M610 ultrasonic thickness gauge by Metrison [1, 6, 7]

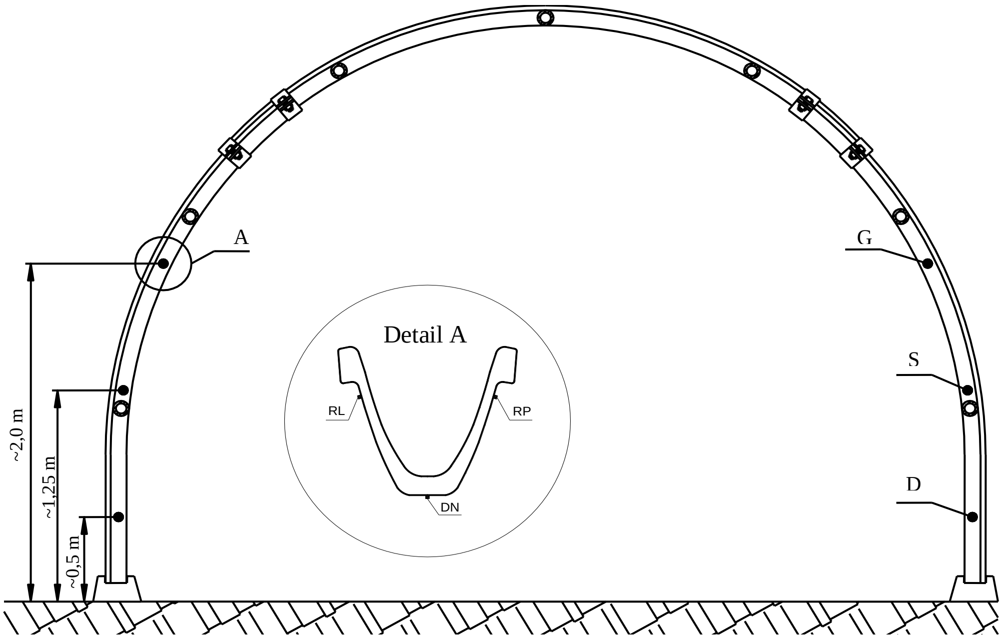

Figure 1. Diagram of test stand: D, S, G – testing locations on the arch support, RL, RP, DN – measuring points on the section walls.

Measurements of individual arches were usually performed on both curves, usually in three places - at a distance of about 0.5 (so-called bottom measurement), about 1.25 m (so-called middle measurement) and about 2.0 m (so-called upper measurement) from the floor of the excavation (figure 1). Each time, the wall thickness of the right arm (RP), bottom (DN) and left arm (RL) was determined. (figure 2, figure 3).

Figure 2. An example of thickness measurement of a section wall performed "in situ".

Figure 3. An example of thickness measurement of a section bottom performed "in situ".

Some difficulties in the measurements occurred while examining the scope of corrosion damage to strut walls and steel bars of mining grids. Due to the low stiffness and small cross-sectional dimensions of these elements, attempts to clean them from corrosion could lead in most cases to their damage. This may affect not only the correct operation of these elements but also the load-bearing capacity of the entire support structure, causing a hazard to the safety of the excavation, which is why the housing accessories were assessed only visually [1, 6].

In addition to the measurements of corrosion damage, the tests included identification of the type of support and if the assembly of its individual components was correct, as well as the analysis of corrosive factors present in the excavation and the ways in which corrosion distributed on the perimeter of the support. Inventory of damages in the form of perforation, pitting, exfoliation, de-bonding and other surface defects was also carried out.

4. Assessment of technical wear of arch supports in dog headings

Based on the results of the corrosion testing of yielding steel arch supports, it is possible to determine the amount of its technical wear and to assess the technical condition of the supports in the excavation. Both the macroscopic observations and the measurements of the thickness of the support elements were analyzed.

On the basis of the macroscopic evaluation of the excavation, it is possible to assess the course and degree of the aggressive environmental impact on the support elements and to identify features of high material stress, which may result in reaching the ultimate limit state by the structure.

The obtained results of wall thickness measurements allow to run a statistical analysis of the scope and distribution of corrosion in the perimeter sections of the support and along the length of the excavation [8]. As the conducted tests and the analysis show, not only the amount of corrosion but also its asymmetrical distribution affects the load-bearing capacity of the support, especially within the arm sections [1]. This leads to a significant reduction in the section strength index against bending and needs to be taken into account when analyzing the measurement results.

On the basis of the conducted analysis, the average and minimal expected (computational) values of geometrical and static parameters of the support sections were determined. For calculation of the current bearing capacity of the support, design values were adopted, which were determined for a probability level of 0.95 [1].

The load-bearing capacity of a yielding steel arch support, exposed to eccentric compression, having taken into account buckling, the lifetime of the excavation and the extent of corrosion, may be determined on the basis of the limit state method, with the use of the following formula [1, 9]:

$$P_t = \frac{f_d \cdot (m_s + n_1)}{d \cdot \left[\frac{M_{max}}{W_x^t} + \frac{N_{odp}}{\varphi \cdot A^t}\right] \cdot m_1} \cdot 1\text{m} \quad (1)$$

where:
P_t –load-bearing capacity of a yielding steel arch support after the time *t*,
M_{max} – value of the maximum bending moment on the perimeter of the arch support for an equal load of 1 kN/m,
N_{odp} – value of the axial force at the place of occurrence of the maximum bending moment on the perimeter of the arch support for an equal load of 1 kN/m,
W^t_x – value of the bending strength index for the element relative to the main central inertia axis of the arch support section after the time *t*,
φ – value of the buckling coefficient according to PN-B-03200:1990 standard,
A^t – value of the cross-sectional area of the steel arch support element after the time *t*,
f_d – tensile and compressive design strength of steel,
m_s – coefficient depending on the shape of the profile,
n_1 – Schaefer's material coefficient,
m_1 – conditional coefficient of support operation,
d – distance between arch support frames,
t – current lifetime of the excavation.

IOP Conf. Series: Earth and Environmental Science **261** (2019) 012009 doi:10.1088/1755-1315/261/1/012009

The conducted tests and the observations performed underground showed that the occurring corrosion processes block the frame slip, therefore the criterion of load capacity of the joints was omitted in the analysis [1, 5].

Having assumed that the frames are the main structural elements of the support and having excluded the accessories from the analysis, it is possible to determine the amount of technical wear of the support (s_z), understood as the amount of loss of load capacity of the frame during its operation in relation to their initial bearing capacity, which is calculated with the following formula [1, 10]:

$$S_z = \left(1 - \frac{P_t}{P_0}\right) \cdot 100\% \tag{2}$$

where:

P_0 –initial load capacity of the element ($t = 0$), MPa,

P_t – load capacity of the element in the period $0 < t < T$, MPa,

t – current lifetime of the object (element), in years,

T – expected total lifetime of the object (element), in years.

The presented method is based on measurable quantities that can be obtained using relatively simple research tools. It also allows for individual assessment of each excavation or its individual sections, which depends on the needs identified in that area by previous visual tests (local density of the measuring network, increase in the number of measuring points, etc.).

5. Development of the classification of the technical condition of steel arch supports in dog headings with a long-term service life

As a measure of the technical wear of steel arch supports in dog headings, a decrease in the load capacity of the supports was assumed due to the ongoing corrosion process in its main structural elements. Therefore, it became necessary to determine the acceptable scope of technical wear, the excess of which may cause the emergence of dangerous conditions, threatening not only the stability of the support structure, but also the safety of the heading or even the whole excavation. According to the formula (1), the assumed design bearing capacity is about ⅓ lower than the nominal capacity, which is calculated on the basis of the limit states method. This takes into account coefficient m_1 referred to as *the support operating conditions coefficient*. The recommended value of coefficient m_1 = 1.5 for a yielding steel arch support frame with a long-time service life [9, 11, 12]. The coefficient plays the role of a safety factor and its value results from the uncertainty of information available during the design of the excavation, possible shortcomings that may occur during manufacturing of the support or if underestimation of its load should occur [13]. Therefore, it is the maximum acceptable range of technical wear of the support, beyond which it falls into a potentially dangerous state, which threatens the safety of its further use. Achieving a dangerous (emergency) level is usually not an emergency situation and operations continue in an uninterrupted manner, although with varying intensity, which depends on the environmental conditions and the mode of use of the excavation. However, it is possible to distinguish certain stages of technical wear which predestine the construction to reach a potentially dangerous state.

On the basis of theoretical analyzes and sub-tests of the technical wear of the support elements, a classification of the technical condition of steel arch supports in dog headings was created (Table 1). Adopted classes of technical condition, based on the conducted tests are assigned to the intervals of technical wear of the support and the corresponding macroscopic symptoms which are most often observed in dog headings.

Table 1. Classification of technical condition of dog heading supports with long-term service life, depending on the scope and signs of wear [1].

Technical state	Scope of wear (%)	Macroscopic signs of wear
very good	$s_{z\,obl} \leq 3$	No visible signs of corrosion or local occurrences, slight surface corrosion of steel elements of the support.
good	$3 < s_{z\,obl} \leq 10$	Small surface corrosion of steel support elements, locally intensified in places of water condensation from the rock mass or in the bottom of the excavation. Despite the small surface corrosion of the support frame, locally increased corrosion of steel cladding grids and/or steel struts is observed.
average	$10 < s_{z\,obl} \leq 20$	Surface corrosion of steel support elements, locally with a significant degree of intensity, especially in places where water from the rock is condensing. In places of corrosion, visible peeling and delamination of the surface of the sections. Locally, heavily corroded steel cladding grids and/or steel struts.
bad	$20 < s_{z\,obl} \leq 30$	Excessive corrosion of steel support elements with visible exfoliation and delamination in large areas of the sections. Strongly corroded steel cladding and/or steel struts. Locally visible losses in cladding made from mining grids, damage and bending of the struts due to excessive corrosion and slight deformation of the support frame.
emergency	$s_{z\,obl} > 30$	Very strong corrosion of steel support components with visible exfoliation and delamination on the whole surface of the sections. Local perforations of profile walls occur spontaneously as a result of corrosion or when attempting to clean surfaces before testing. Sections damaged with cracks and fractures. Significant losses in cladding made from mining grids, extensive damage and bending of struts due to their excessive corrosion and significant deformation of the support frame, which often requires additional protection.

Note: In the case of pitting corrosion in a form of perforation of section walls, the support should be classified as having the highest degree of wear technical condition class.

Class thresholds were established with the assumption that the amount of technical wear for a given class would occur with a probability of 0.95.

The threshold level of 30% was assumed as the upper limit of technical wear. Exceeding this limit puts the support in a technical condition known as *an emergency*.

While determining the size of the lowest class interval, the maximum permissible dimensional deviations of the support sections were assumed in accordance with PN-H-93441-3:2004 standard. On this basis, the minimum bearing capacity of the support for non-corrugated profiles was determined [14]. The load capacity for the most frequently used sections and sizes of the support frame was not lower than 3% in relation to the base load capacity calculated for the nominal dimensions of the sections. The technical condition of the support which technical wear does not exceed 3%, can therefore be considered as *very good*.

As indicated by the conducted tests, the technical wear of support which does not exceed 10% is usually observed in the initial period of exploitation of the excavation and is connected with the occurrence of small surface corrosion on its elements. This usually does not pose a serious threat to the safe use of the excavation, so the technical condition of the housing can be described as *good*.

The range includes the average value of the adopted, maximum range of technical wear, which qualifies the technical condition of the support as *average*. Local surface corrosion of support elements is usually observed here, with a significant degree of severity, especially on sections that remain in constant contact with water leaking from the rock mass.

The progressive corrosion processes cause a gradual increase in the technical wear of the support, up to the adopted limit value, beyond which it passes into a potentially dangerous state, jeopardizing the safety of its further use. The range of technical wear that immediately precedes the transition into a dangerous state qualifies the support to be in *poor* technical condition. At the same time, it indicates the need to take appropriate protective measures to prevent the load carrying capacity from reaching the ultimate limit state.

In order to assess the suitability of the proposed classification for practical applications, the assessment of the technical condition of the support in the analyzed sections of the excavations was carried out in accordance with the guidelines contained in table 1. The results of the assessment are shown in figure 4.

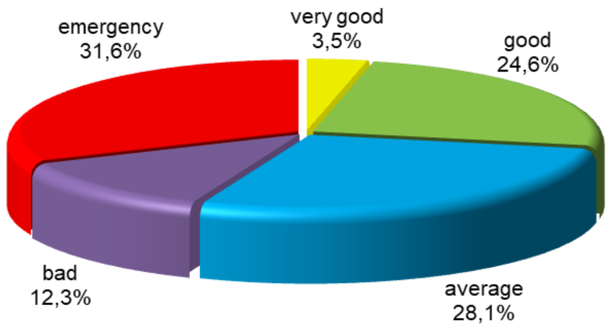

Figure 4. Results of the classification of the technical condition of the support of the analyzed sections of excavations

As a result of the assessment carried out within the analyzed sections of the excavations, all classes of technical condition of the support were represented, with their percentage share being different. The obtained results coincide with the performed tests and macroscopic signs of wear observed in the surveyed headings. This confirms the usefulness of the developed classification of the technical condition of dog headings for practical applications.

6. Conclusions

The issue of the technical state of supports in dog headings, particularly those with long-term service life, is still a crucial and important issue from the point of view of occupational safety in the mining plant. This is evidenced by numerous recent occurrences of cave-ins in various coal mines whose main cause was the weakening of the support caused by excessive corrosion of its structural elements.

In order to prevent dangerous situations, an assessment of the technical condition of supports in all kinds of excavations should be carried out on an ongoing basis and decisions should be made on this basis as to the need for conducting protective and reinforcement works. For this purpose, the presented classification of the technical condition of steel arch support frames can be used. It allows for an assessment of the support structures carried out according to homogeneous criteria and is a convenient tool to perform diagnostics of dog headings throughout their entire lifetime. It also enables the possibility to compare different support designs installed in similar conditions and to verify previously developed technical forecasts, regardless of the methodology used to calculate the support design.

7. References

[1] Dyduch G 2011 *Wpływ korozji na zmianę właściwości technicznych stalowej obudowy odrzwiowej wyrobisk korytarzowych o długim okresie użytkowania.* Praca doktorska (Gliwice: Biblioteka Główna Politechniki Śląskiej) p 251
[2] Niedbalski Z and Majcherczyk T 2018 *Journal of Sustainable Mining* **17** 131
[3] www.wug.gov.pl
[4] Rozporządzenie Ministra Energii z dnia 23 listopada 2016 r. w sprawie szczegółowych wymagań dotyczących prowadzenia ruchu podziemnych zakładów górniczych (Dz.U. 2017, poz. 1118) p 393
[5] Bocheński W, Pacześniowski K, Rułka K and Sawka B 1993 *Zabezpieczanie stalowych obudów odrzwiowych przed korozyjnym działaniem środowiska kopalnianego* vol 782 (Katowice: Prace Naukowe Głównego Instytutu Górnictwa)
[6] Chudek M, Duży S, Dyduch G, Głuch P and Kleta H 2012 *Diagnostyka wyrobisk górniczych czynnikiem optymalnej ich eksploatacji i zachowania bezpieczeństwa w kopalniach podziemnych* Zagadnienia wybrane Monografia (Gliwice: Katedra Geomechaniki Budownictwa Podziemnego i Zarządzania Ochroną Powierzchni Wydziału Górnictwa i Geologii Politechniki Śląskiej) p 148
[7] Chudek M, Duży S and Dyduch G 2017 *Systemy Wspomagania w Inżynierii Produkcji* **6**. (3) 35
[8] Chudek M Duży S and Dyduch G 2005 *Budownictwo Górnicze i Tunelowe* **3** 7
[9] Chudek M, Duży S, Kleta H, Kłeczek Z, Stoiński K, and Zorychta A 2000 *Zasady doboru i projektowania obudowy wyrobisk korytarzowych i ich połączeń w zakładach górniczych wydobywających węgiel kamienny*. (Gliwice - Kraków - Katowice: Wyd. KGBPiOP Pol. Śl.) p 161
[10] Orłowicz R and Leleń S 2002 *Kwartalnik Warstwy – dachy i ściany* **2** 41
[11] Wypchol N, Mateja J, Rułka K, Lachman K and Jasnowski M 1978 *Projektowanie i obliczenia statyczne obudów kapitalnych wyrobisk korytarzowych i komorowych* (Mysłowice: Praca Naukowo-Badawcza OBRGBG Budokop) p 40
[12] Janas P. and Janas K. 2016 *Calculation of load capacity of closed steel supports for galleries made from steel profiles TH29, TH34 (31Mn4 and 31Mn4+Qt) and K24 (H60U). User manual, version 1. Prepared for the Premegovnik Mine (Velenje) in Slovenia*. (Ostrava: VŠB - Technical University of Ostrava, Faculty of Civil Engineering, Department of Structural Mechanics) p 46
[13] Duży S 2007 *Studium niezawodności konstrukcji obudowy i stateczności wyrobisk korytarzowych w kopalniach węgla kamiennego z uwzględnieniem niepewności informacji* vol 277 (Gliwice: Zeszyty Naukowe Pol. Śl. s. Górnictwo) p 221
[14] PN-H-93441-3:2004 *Kształtowniki stalowe walcowane na gorąco dla górnictwa. Kształtowniki typu V. Wymiary.* P 7