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Research Paper

Numerical calculations of shield support stress based on laboratory test results

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A R T I C L E I N F O

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A B S T R A C T

This article presents the results and analyses of numerical calculations and laboratory tests performed on a two-legged shield support. The shield was placed on a special device (hydraulic cushion) that can simulate the ground with different load-bearing capacities. Applying the hydraulic cushion allows for laboratory testing of the shield for various base support configurations. Over 60 laboratory tests of the shield were conducted for different patterns of loading in accordance with the PN-EN standard 1804-1+A1. To reproduce the results of the laboratory tests, a 3D numerical model of the shield placed on the hydraulic cushion was developed. Numerical calculations were performed using the finite element method (FEM). To simulate the performance of the hydraulic cushion, SPRING-type elements of adjustable yield capacity were applied, which enabled a highly accurate reproduction of the results of the laboratory tests. The laboratory tests and numerical calculations showed that the type of base support influences the stress distribution in the shield. When the entire base was supported with all the active hydraulic cylinders, the stress values in the base decreased by 32% compared with the stress when the base was supported according to the PN-EN standard 1804-1:2004 (with only the outermost cylinders active). Moreover, a comparison of the results obtained for the different types of base supports indicated that when the base was supported over its entire length, the load on the ground at the front part of the base was reduced by approximately 45%. The numerical calculation method presented here can be useful for designing a shield support for specific geo-mining conditions.

1. Introduction

Underground hard coal mining is conducted by various methods worldwide, although the room-and-pillar and longwall methods predominate. In the longwall method, the basic equipment includes a shield support (usually consisting of a two- or four-legged shield), a shearer to cut the coal face and an armoured face conveyor (AFC). After the shearer cuts, the shield support is lowered (Fig. 1a) and then advanced towards the coal face (Fig. 1b). In the next step, the shield is set against the roof, where it begins to engage the roof strata. At this stage, pressure in the hydraulic legs increases to the set pressure value (Fig. 1c). In the final stage, the shield is loaded by the rock mass (Fig. 1d). In extreme situations when the roof convergence is intense, the pressure in the hydraulic legs may reach their yield pressure. Yield pressure refers to the maximum load capacity of the shield support and is determined by a pre-set yield valve in the legs of the support.

A number of countries have developed various methods for shield selection in different mining conditions. Properly selected shields should ensure a planned volume of coal production and provide safe working conditions during the longwall operations [1–7]. The load-bearing capacity of the floor strata is a particularly important, albeit frequently underestimated, aspect of assessing shield performance in geo-mining conditions. In the case of floor rock of relatively low strength, significant disturbances in longwall advancement may occur as the shields begin to sink into the floor. Various research methods have been devised to assess the parameters of the floor strata and select the most appropriate type of support [8–15].

To assess the construction and performance of a shield support before it is used in collieries, laboratory (rig) tests are conducted. During such tests, various arrangements of the elements installed either on the canopy or under the base of the shield support can be used to obtain symmetric and asymmetric patterns of shield loading [16–19]. The tests are conducted following various

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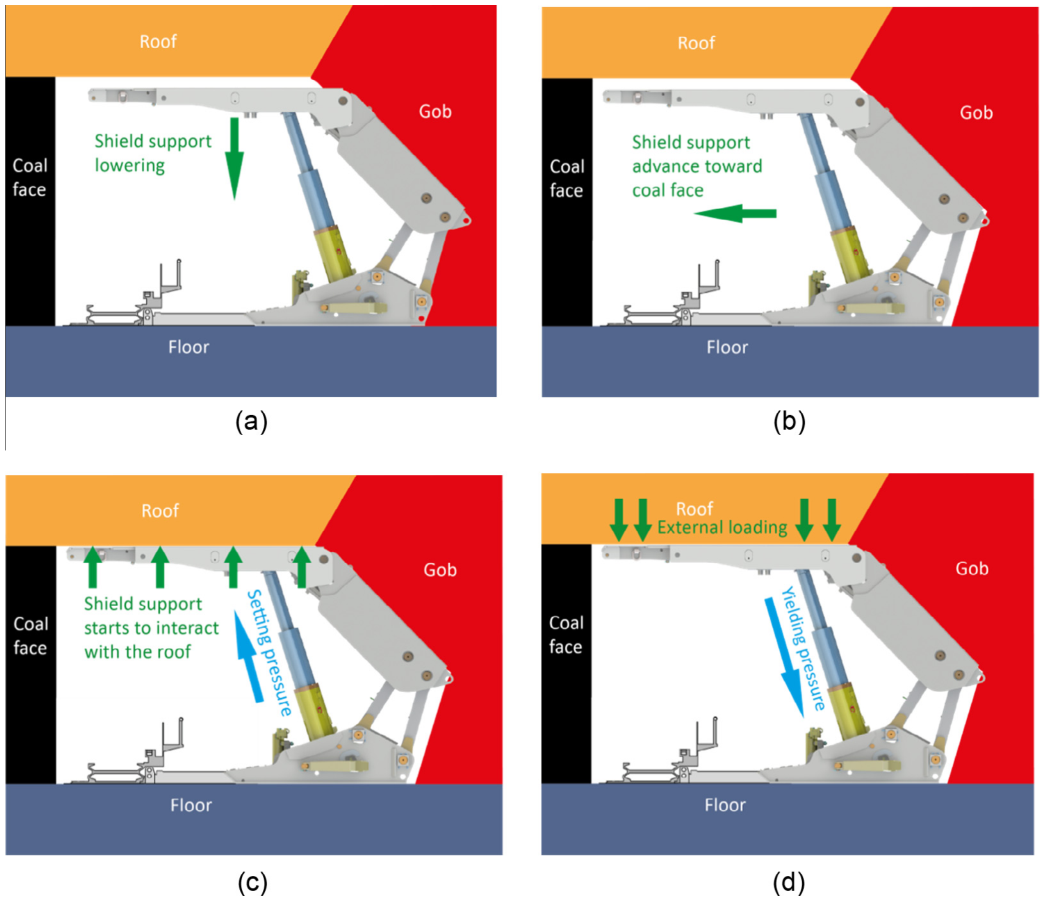

Fig. 1. Stages of shield support during longwall operations: (a) lowering, (b) advancing, (c) setting, and (d) external loading.

standards and methodologies [20–22], and they generally do not consider the floor load-bearing capacity [19]. One of the first laboratory tests of a shield that considers ground parameters appears to have been conducted in the US [23].

The development of computer-assisted design (CAD) software, especially in the area of numerical calculations based on the finite-element method (FEM), has allowed numerical calculations of new shield support designs to replace costly laboratory tests. The calculations are most often performed by engineers and designers of shield supports who are interested in new support structures or optimising existing structures. In discretized models, stress can be determined at specific control points on a shield support and for all the construction elements of the analysed shield support [24–29]. Numerical calculations can also be used to determine the base load distribution exerted on the ground (floor) for various operational patterns of the shield support [30,31]. For numerical calculations concentrating on one element of a shield, the computational model can be simplified so that it copies only the geometry of the tested shield element, such as the base, caving shield, or canopy [32–34].

This article presents the results of laboratory tests conducted on a two-legged shield within the framework of the project titled "Geomechanics and Control of Soft Mine Floors and Sides" (abbreviated GEOSOFT). The project was performed at the Central Mining Institute (GIG) between 2010 and 2013 and co-financed by the Research Fund for Coal and Steel (RFCS) [35]. Within the framework of the research performed as part of the project, a special hydraulic cushion was designed and constructed. This cushion enabled us to conduct laboratory testing of shields with variable ground parameters. In underground collieries, such conditions occur for floor rocks of variable strength. This article describes the research methodology and presents selected results of the laboratory tests performed on a shield placed on a hydraulic cushion. Furthermore, a method of numerical modelling for the shield laboratory tests using ANSYS software and the FEM is described.

2. Laboratory tests of shield support (BW 16/34 POz) using a hydraulic cushion

Becker-Warkop's two-legged shield support (BW 16/34 POz) was tested under laboratory conditions. The tests were conducted in Poland at the test rig (station) located at the Institute of Mining Technology KOMAG (ITG KOMAG). The basic technical parameters of the tested shield support are presented in Fig. 2. During the laboratory tests, the shield was loaded by the action of the upper plate of the test rig, which simulated shield loading by the roof strata in longwall workings. Basic laboratory tests of the shield were conducted for both a symmetric load and an asymmetric load of the canopy following the guidelines of the PN-EN standard 1804-1 +A1. In addition, non-standard tests of the shield were conducted, in which the load was exerted across the entire surface of the canopy.

During the laboratory tests, the shield was placed on a hydraulic cushion (Fig. 3b and c), which consisted of a steel frame with 24 hydraulic cylinders (Fig. 3a) and was specially designed and manufactured for the shield laboratory tests. The special construction of the hydraulic cushio allowed for the simulation of strata with different load-bearing capacity (i.e., floor strata of variable strength parameters). The load-bearing capacity of the floor with the hydraulic cushion was simulated by setting the pressure value for the yield valve of each of the hydraulic cylinders in the cushion.