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Impact of bearing plates dimensions on interaction of mine workings support and rock mass

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ABSTRACT

The aim of the research presented in this article is to assess the impact of bearing plates dimensions on the interaction of steel arch support and rock mass. The analysis of the bearing plates was based on laboratory tests and numerical calculations using the FLAC3D program (a finite difference method) and the strain-hardening/softening model based on prescribed variations of Mohr–Coulomb properties. The article presents the results of laboratory tests on selected bearing plates and the results of numerical analysis of the interaction between the bearing plates and rock mass with coal, clay stone and sandstone properties.

1. Introduction

The proper interaction of the steel arch support and rock mass involves, inter alia, transferring roof loads to the floor, which largely depends on the type of foot support. Activities aiming at increasing the load-bearing capacity of the working support are justified only if proper foot support to the frame is provided. Additional intermediate elements are applied due to the small cross-sectional area of the V profiles in order to increase the contact surface area of the steel arch support and the floor, the so-called bearing plates. The appropriate transfer of forces from the support's foot to deeper layers of rock mass has a considerable role in determining the interaction of the entire support with the rock mass. In the case of weak floor rock wooden or concrete bearing plates are used. Wooden and concrete plates are characterized by high rigidity and the relatively large surface of its elements. However, due to transport difficulties such bearing plates are virtually unprecedented (Fig. 1).

Currently, bearing plates are made of steel of varying thickness (8–12 mm) and varied contact surface with the floor (200–300 mm^2). In many cases the steel arches are only placed on the plates. However, in order to improve the contact between the arches and the plates, there are different designs of bearing plates available, especially those with varied hitches for mounting specific profiles of steel arches (Fig. 2).

It is essential to determine the optimal size of the surface area and thickness (stiffness) of the bearing plate both in technical and economic terms, in order to ensure proper load-bearing capacity of the working support. Too small a surface area may cause damage to the floor structure and a successive process of support punching, as shown in Fig. 3. In such a case, it is not possible to obtain the controlled yielding of the steel arch by means of butted connections, this leads to further roof delamination and to an increased load acting on the support. In turn, an unnecessarily large area of the steel bearing plate is undesirable for economic reasons.

Due to the limited use of bearing plates and steel arch support in underground coal mines, there is a limited amount

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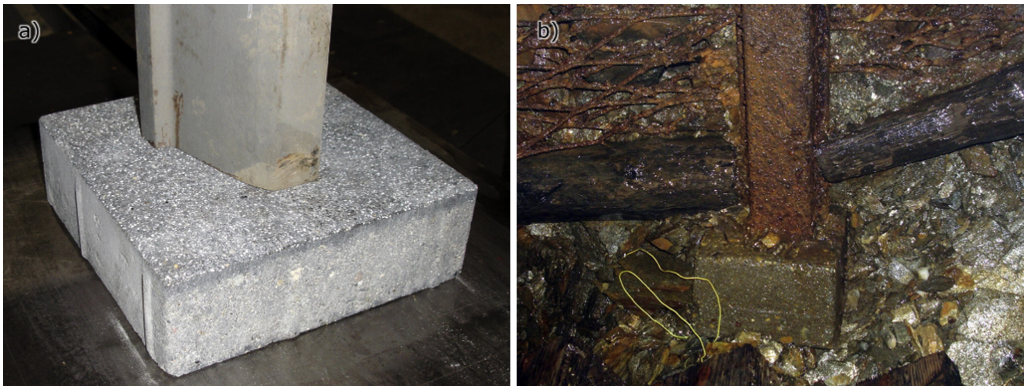

Fig. 1 – Bearing plates made of concrete a) concrete bearing plate prepared for stand test, b) concrete bearing plate in an old mine working.

of data from prior laboratory and numerical research. In most cases, previous studies were focused on the use of regular and irregular shaped plates for the estimation of the bearing capacity of a weak floor (Fig. 4). It enabled the classification of the rocks and the study of the phenomena occurring in the process of destroying the floor rocks on the surface and in underground conditions (Afrouz, 1975; Barry & Nair, 1970; Gadde & Peng, 2009; Hansen, 1968; Jenkins, 1955; Konopko & Marszałek, 1969; Lee, 1961; Mandel & Salencon, 1969; Motyczka & Stałęga, 1974; Prandl, 1920; Platt, 1956; Śmieja & Skóra, 1974; Terzaghi, Peck, & Mesri, 1996; Vesic, 1975).

2. Bearing plates – stand testing

Bearing plates are subjected to laboratory tests in a system similar to the natural conditions of their work, based on the methodology developed in the Central Mining Institute in Katowice (Pytlik, 2013). A bearing plate is placed on properly prepared rock body and then a load is applied to the bearing plate through the V section aiming at punching the plate into the surface. The test determines the characteristics of the entire system in relation to plate load versus plate displacement. The bearing plate should not be destroyed (cracked) under the test load of P = 600 kN. The rock body is prepared from pre-compacted loose coal and clay stone grains to simulate the condition of destroyed structure of floor in underground workings. The test schemes are shown in Figs. 5 and 6. Fig. 7 shows an example of the characteristics obtained from testing bearing plates produced by a Polish manufacturer. Fig. 8 shows a deformed plate after a test.

The graphs (Fig. 7) show that the load increases in all cases despite the plate displacement and destroyed rock structure under the plate. Due to the fact, that the rock body was formed by the compaction of loose grains of coal and clay stone, the failure of the rock and the way this failure occurred was not analysed further. It must be stated, however, that the displacement of grains and further compaction of the rock body may be one of the reasons for the variation of the obtained curves. Despite the small differences in the results obtained, the general tendency is the decrease of displacement caused by the test load along with the increase of the thickness and area of the plate.

3. Analysis of the interaction between bearing plate and floor

To determine the forces in the system: steel support – bearing plate – floor, a numerical analysis was carried out using the FLAC3D software developed by Itasca Consulting Group, based on the finite difference method. In order to accomplish this purpose the research team designed a model of the rock mass in the form of a cube with dimensions of 2.0 × 2.0 × 1.0 m. The following elements were placed on the model: a bearing plate with variable dimensions and a part of the support from the V36 section as a load factor. An example of the model adopted in the calculations is presented in Fig. 9.

The stress state of the rock mass was calculated based on the Mohr–Coulomb failure criterion with the post-failure properties of the rock mass. The Mohr–Coulomb failure criterion is based on the relationship binding the shear strength with the angle of internal friction and cohesion:

$$\tau = c + \sigma_n tg\varphi \tag{1}$$

τ – shear stress at failure, MPa,
σ_n – effective normal stress, MPa,
c – cohesion, MPa,
φ – angle of internal friction.

where:

Calculations were carried out in three variants for a homogeneous rock mass with different geotechnical parameters. For the determination of the parameters of the rock mass, the GSI classification was used, which is based on research conducted by Hoek (Hoek, 1999; Hoek, Kaiser, & Bawden, 1995). Parameter values for numerical calculations are based on literature review (Kalamaras & Bieniawski, 1995) and relations (2, 3, and 4). Due to the lack of laboratory tests of modelled rock samples, the values of post-peak failure parameters were determined based on previous research (Bukowska, 2012,