International Journal of Rock Mechanics & Mining Sciences 72 (2014) 92–99

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

Characterization of intensely jointed rock masses by means of in situ penetration tests

R. Fernandez-Rodriguez [a], C. Gonzalez-Nicieza [b,*], F. Lopez-Gayarre [c], E. Amor-Herrera [d]

[a] Research Group of Ground Engineering, Mining Engineering School, University of Oviedo, Oviedo, Asturias, Spain
[b] Dept. of Exploitation and Prospecting Mines, Mining Engineering School, University of Oviedo, Oviedo, Asturias, Spain
[c] Dept. of Construction and Manufacture Engineering, Engineering School of Gijon, Campus de Viesques, Asturias, Spain
[d] SAHVL, Leon, Spain

ARTICLE INFO

Article history:
Received 26 June 2013
Received in revised form
7 May 2014
Accepted 23 June 2014

Keywords:
Jointed rock mass
In situ test
Penetration test
Back analysis

ABSTRACT

The task of characterizing a highly fractured rock mass correctly is often complex due to errors produced by the "scale effect" in the majority of laboratory tests. Furthermore, current methods of in situ characterization pose logistical, technical, or even economic problems, while geomechanical classifications are not precise enough for this kind of ground. This makes the stability analysis of jointed rock mass slopes a complex undertaking that is generally far from reliable.

This paper proposes a new method of in situ analysis to characterize this type of highly fractured rock mass accurately, applied here to the case of the large-scale slopes of an open-cast coal mine. The method is based on carrying out a novel in situ penetration test to obtain the strength properties of the ground as a whole. The results are calibrated by means of numeric simulation. Further, back analysis of the current slopes in the mine was carried out using classical methods to test the reliability of the results obtained using this technique.

1. Introduction

Knowledge of the rock mass strength and deformation behaviours is required for the design of many engineering and mining structures in or on rock, such as foundations, slopes, tunnels, underground caverns, drifts, and stopes mining. A better understanding of the strength behaviour of the rock mass, including the peak and residual strengths, will facilitate the cost-effective design of such structures [1].

Determination of the global mechanical properties of a jointed rock mass remains one of the most difficult tasks in rock mechanics. Many researchers have developed constitutive models to describe the strength and deformation behaviours of jointed rock masses [2–4]. Because there are so many parameters that affect the deformability and strength, it is generally impossible to develop a universal model that can be used to predict the strength of the rock mass a priori. Traditional methods to determine these parameters include for example plate-loading tests for the deformation modulus and in-situ block shear tests for strength parameters. These tests, and others that we will summarize later, can only be performed when the exploration adits are excavated and the cost of conducting in situ tests is high. Few attempts have been made to develop methods to characterize the jointed rock mass to estimate the deformability and strength indirectly.

The main purpose of this work is to develop an analytical methodology to find out the properties of intensely jointed rock masses and enhance the security of open pits in poor quality rock masses. In the in situ determination of the cohesion and friction angle of rock mass, direct shear tests on joints [5] and triaxial tests [6–8] are employed. They are very efficient, although their methodology, the necessary logistics for their application and their cost mean that their implementation is limited to ambitious plans. There is also a direct shear in situ test to determine the friction in materials of dams of breakwaters [9]. Other in situ tests used to analyse the deformability of rock mass are pressuremeters [10], flatjacks [11], load plates [12,13], and seismic methods [14,15]. They all are affected by the scale effect and are far from cost-effective.

Geomechanical classifications are another widely used method to characterize rock masses [16–19]. Some years ago, the Hoek–Brown failure criterion [20–23] was adapted to the RMR (Rock Mass Rating) classification scheme [16] to analyse the shear strength of surface rock masses. This methodology has been used by other authors [24–27] in diverse analyses of slope stability. The SMR (slope mass rating) proposed by Romana [28] uses more or less the same parameters as the RMR, but provides indications regarding the failure of slopes. Whatever the case may be, classifications of this type continue to be suitable for solid rock

* Corresponding author.

http://dx.doi.org/10.1016/j.ijrmms.2014.06.016
1365-1609/

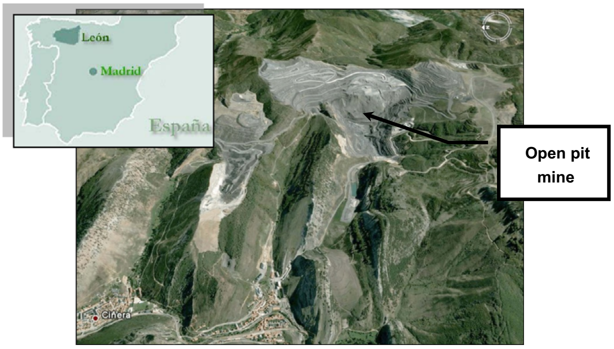

Fig. 1. Location of the area under study.

masses or for those with well-defined fractures, but are not considered reliable for intensely fractured rock masses.

In order to solve the outlined disadvantages, a tool and a methodology for carrying out in situ tests to characterize intensely fractured rock masses have been developed. The methodology has some advantages over the conventional assays: the information obtained for the characterization of the rock mass is of high quality, and the cost is lower since the realization of the methodology only requires the excavation of a trench.

2. Geological—Lithological description of the area under study

The open-cast coal mine analysed here is located at the north of the province of León, between Pola de Gordón and Ciñera. Fig. 1 shows the location and extension of the open-cast mine. It comprises a large-scale open-cast mine made up of alternating layers of shale, sandstone, and coal seams distributed heterogeneously over four slopes that form the open pit. These slopes are large in scale, with total heights between 100 and 350 m. The benches of the mine are 10 m in height and the berms between 5 and 6 m wide. Although coal mining was performed using opencast workings, there is underground mining of some coal layers of the south slope.

The development of coal mining works entails designing the expansion of the mine in the near future. This expansion will include the redesign and enlargement of the current slopes. To carry out this design appropriately, it is very important to know the strength properties of the rock mass. To this end a new in situ test methodology has been applied [29].

The mine under study is located in a synclinorium whose axis extends 15 km in the E–W direction. Its width is 5 km in the N–S direction. At its western edge, where work is currently taking place, there are three main synclinal structures (Vegacervera, Matallana, and Llombera), separated by their corresponding anticlines (Fig. 2).

Stratigraphically the coalfield is divided into seven distinct formations (Training San Francisco, Pastora, Gravel, Roguera, San Jose, Welcome, and Matallana). The set reaches a thickness of 1500 m. Of these, the Pastora Formation has the greatest economic interest. It provides the total coal production in the existing mining centres. On the northern edge of the Llombera syncline is the Competidora layer. It is the main layer of coal and has a highly variable thickness of between 2 and 15 m. The dip is nearly vertical with a W–E direction. This layer is made up of a succession of small, highly fractured strata of shale and sandstone intercalated with coal.

Besides being highly fractured, these materials are also affected by subsidence resulting from underground coal mining works, situated below the open-cast mine under study, which have been carried out in the past and which persist at the present time. It has been measured a maximun subsidence in the area of study of 9 m. On the other hand, piezometric data have also shown that the groundwater level varies substantially within these materials, undergoing a very substantial increase during the rainy season.

Sporadic points suffering sliding and/or incipient fissures have been located throughout the mine under study. These areas shall be studied to determine the reliability of the results of the in situ characterization tests performed.

3. Development and methodology of the penetration tests

A test device was developed to characterize in situ the materials in this open-cast mine in a way that is both reliable and simple. The device is based on the application of a load to the ground by means of a hydraulic cylinder, thereby allowing penetration tests to be performed. The stress displacement curve of the tested ground may be obtained from these tests. This curve may then be used to determine diverse material parameters.

By the use of the simple penetration tests, the stress displacement curve of the ground can be obtained, the strength of each material can be established, and the possible residual strength can be analysed. The device is equipped with automatic pressure and displacement sensors to obtain the corresponding curves (Fig. 3).

Penetration tests are pressure–displacement tests that consist in applying pressure to the ground by means of hydraulic cylinder and then measuring the penetration (displacement) produced as a result of the applied pressure. Before carrying out the test, a trench of approximately 1.5 m width, in which the equipment is to be placed, must be excavated in the material. The cylinder must be aligned perpendicular to the walls of the trench. Once the cylinder has been positioned in the materials under study, pressure is applied and gradually increased. This pressure is transmitted through the piston rod perpendicular to the ground thanks to the ball-and-socket joint. The pressure increases until it causes failure of the ground.

The failure of the ground translates as an abrupt decrease in the applied pressure and in the penetration of the ball-and-socket joint and/or the piston rod into the ground. Usually, numerous cracks also appear and propagate rapidly, leading to collapse of the trench walls.

The equipment contains a hydraulic device which provides a pressure of up to 25 MPa via a variable hydraulic pump with A10VSO axial pistons. This pressure is transmitted to the cylinder, 1.5 m in length, with a 500 mm piston stroke [30], by means of high-pressure hoses.

The pressure and displacement sensors provide an electrical signal. This signal is automatically recorded on a data acquisition module. The frequency with which the data are captured is regulated by means of the computer application employed. The data measured in situ are subsequently transferred to a laptop to be treated and interpreted off-site.

This type of in situ test allows the pressure–displacement curve of the ground to be obtained at a real working scale, with a data capture interval of 2 s. The failure pressure of each analysed material can then be calculated from this curve and the peak and residual strength may be estimated. The penetration of the hydraulic cylinder when under load may also be estimated until failure of the ground occurs. These values are of great importance when analysing the properties of the materials in the mine and when designing future slopes, as they quantify the failure strength of the materials and the residual strength that these can support after failure has occurred. Fig. 4 shows one of the graphs obtained in a penetration test. Four different phases can be distinguished: a first phase or horizontal area, which corresponds to the stroke of the piston until the hydraulic cylinder enters into contact with the