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The development of a coal measure classification (CMC) and its use for prediction of geomechanical parameters

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Abstract

Many studies have been performed to predict the strength and deformation moduli for both rock masses and discontinuities. However, in most empirical equations in the literature that have been proposed for the estimation of the strengths and deformation moduli, the rock mass is assumed isotropic. Although it is known that the strength and deformation of a stratified rock mass varies depending on the loading direction in relation to the orientation of the lamination planes, there exists at present no commonly accepted method for characterising this anisotropy. This paper outlines the development of a rock mass rating system for coal measure rock masses that can be used to empirically predict the engineering properties of stratified rock masses. The output from the classification system is two numerical ratings representing the different engineering properties of the strata in directions parallel and perpendicular to stratification.

A detailed description on the methodology used to develop the classification system has been given and the derivation and rating of the various rock mass parameters is outlined. The methodology of deriving the in situ stratified rock mass input parameters and geomechanical computational analysis is illustrated for the case of two rock bolted roadways within a representative deep UK coal mine. The model predictions were validated against the actual in situ monitoring data of displacements within the immediate roof of the roadway.

Keywords: Rock mass classification; Longwall mining; Geomechanical modelling; Empirical equations

1. Introduction

Field-validated geomechanical computational modelling of longwall coal mine excavations has been applied to roadway support design [1,2] mining stress interactions analysis, coal pillar design [3], analysis of the effect of geological features such as faults, the affect of earthquakes on mine stability [4,5], in methane drainage design [6] and surface subsidence prediction [7,8]. Common to all of these diverse applications is the need to construct a geomechanical model of the coal measure rock mass. However, the direct measurement of the mechanical properties of the rock mass in situ is rarely possible due to cost and the difficulty of gaining access to the different strata horizons [9].

Rock mass classifications are now commonly used to predict the engineering performance/response of rock mass for a wide range of civil and mining engineering environments [10]. Typically, engineering rock mass classification systems quantify five or six parameters of the rock mass which are considered to have the most significant affect on the response to engineering operations. The two most popular geomechanical classifications used today are the 'Q' Index [11] and the rock mass rating (RMR) system [12]. Initially both types were used as empirical design tools in tunnelling but have subsequently been extended to other applications such as rock slopes, ground rippability assessments and foundations [13].

However, detailed design and characterisation or engineering application is needed the mentioned systems are

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too general to be used. In other words, although anisotropic rock masses, particularly, stratified rock masses, can be classified by using RMR or Q systems, it is not possible to predict the variation in the strength and deformation characteristics due to the stratification. In mining engineering applications this has lead to modification of existing classifications and the development of new classifications for use in the design of both hard rock mining and in 'soft rock' coal measure environments [14–16]. The classification systems developed for coal measure rock environments have been mainly used directly for the prediction of roof and pillar stability and the empirical design of excavation support systems [14,15]. More recently the use of geomechanical computational models in coal mine design has lead to the requirement of the determination of the strength and deformation parameters for the rock mass. The incorporation of sophisticated constitutive laws that govern the geomechanical behaviour of the rock mass within such models requires a range of engineering parameters for each distinctive strata horizon to be specified. It is therefore desirable to have a classification system developed specifically for the empirical prediction of the in situ rock mass parameters required in constitutive material models that represents the stratified coal measure rock mass.

2. Development of a rock mass classification system for coal measures rock masses

In this study, the UK coal measure's were selected as an investigation material during the development of the coal measure classification (CMC) system. The geomechanical response of the stratified rock mass surrounding underground coal mines is a manifestation of the interactions between the rock mass, the high in situ stress environment due to the depth of mining, and the disturbances created by the long wall mining process itself. Characteristically, the UK Coal Measure's comprise a distinctive sequence of strata layers known as a cyclothem [17]. The cyclothem represents the cycle of deposition on a subsiding delta and is typified by a coarsening upwards sequence above the coal seam. This forms distinctive strata units varying from fine grained mudstones and claystones to coarse conglomerate sandstones. The sub-horizontal sedimentary layering represented by the bedding, lamination planes and shaleyness imparts an engineering anisotropy upon the rock mass [18–20]. Structurally the coal measure rock strata within the UK also contain two mutually perpendicular joints sets which have a steep or vertical dip, formed as a result of tectonic movements in the geological past. In general each of the different rock horizons forming the cyclothem has different engineering characteristics.

2.1. Conceptual models of deformation and failure in coal measure rock masses

Several parameters of a coal measure rock mass influence the engineering response of the rock mass to disturbances in the stress field induced by long wall mining. It has been stated that the parameters that are most significant are those that have the greatest effect on the modes of deformation and failure that occur due to the imposition of the disturbance [21]. Romana [22] claimed that any effective classification system has to cope with the different possible modes of failure, implying that a successful classification system has to include and quantify the rock mass parameters that have the greatest significance in these modes. However, there are limitations to rock mass classification systems in certain circumstances. For instance slope failure is sometimes governed by a 'special' joint set that exhibits a significantly lower shear strength than does a typical joint. This joint set will then determine the behaviour of the rock mass rather than the characteristics of the rock mass as a whole and the application of classification system like Romana's would be misleading in such a case.

To identify the most significant modes of deformation and failure that occur in the stratified rock mass

Table 1
Conceptual mechanisms of strata deformation [23]

Roadway floor	Roadway roof	Coal face	Pillar/Rib
Buckling by horizontal stress (Fig. 1a)	Buckling of roof beds due to horizontal stresses (Fig. 2a)	Dilation of face and spalling of coal face (Fig. 3a)	Side wall spalling by tensile cracking (Fig. 4a)
Swelling of seatearth floor (Fig. 1b).	Self weight sagging of roof beds (Fig. 2b).	Bearing capacity failure of floor beneath powered supports (Fig. 3b)	Side wall movement by coal cleat dilation (Fig. 4b)
Shear failure and deformation along shear planes (Fig. 1c)	Shear failure of roof beds (initiating from the roadway corners) (Fig. 2c).	Collapse of immediate roof in front of supports (Fig. 3c).	Shear failure and movement into roadways along shear planes (Fig. 4c)
Extrusion of seatearth into roadway floor (Fig. 1d)	Shear joints/parting plane failure (Fig. 2d).	Cantilevering of beds over the goaf (Fig. 3d)	Wedge/ block failure in pillar sides (Fig. 4d).
Bearing capacity failure (Fig. 1e)	Wedge/block failure (Fig. 2e)	Wedge/ block failure in front of supports (Fig. 3e)	Yield zone development (Fig. 4e)