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Tunnel behaviour and support associated with the weak rock masses of flysch

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ABSTRACT

Flysch formations are generally characterised by evident heterogeneity in the presence of low strength and tectonically disturbed structures. The complexity of these geological materials demands a more specialized geoengineering characterisation. In this regard, the paper tries to discuss the standardization of the engineering geological characteristics, the assessment of the behaviour in underground excavations, and the instructions–guidelines for the primary support measures for flysch layer qualitatively. In order to investigate the properties of flysch rock mass, 12 tunnels of Egnatia Highway, constructed in Northern Greece, were examined considering the data obtained from the design and construction records. Flysch formations are classified thereafter in 11 rock mass types (I–XI), according to the siltstone–sandstone proportion and their tectonic disturbance. A special geological strength index (GSI) chart for heterogeneous rock masses is used and a range of geotechnical parameters for every flysch type is presented. Standardization tunnel behaviour for every rock mass type of flysch is also presented, based on its site-specific geotechnical characteristics such as structure, intact rock strength, persistence and complexity of discontinuities. Flysch, depending on its types, can be stable even under noticeable overburden depth, and exhibit wedge sliding and wider chimney type failures or cause serious deformation even under thin cover. Squeezing can be observed under high overburden depth. The magnitude of squeezing and tunnel support requirements are also discussed for various flysch rock mass types under different overburdens. Detailed principles and guidelines for selecting immediate support measures are proposed based on the principal tunnel behaviour mode and the experiences obtained from these 12 tunnels. Finally, the cost for tunnel support from these experiences is also presented.

1. Introduction

Since the last decades of the 20th century, there has been a rapid development in various stages of geotechnical design, analysis and computational methods. Yet, regardless of the capabilities offered by the numerical tools, the results can still involve uncertainties when parameters are used directly without considering the actual failure mechanism of the rock mass in tunnelling. Understanding the rock mass behaviours in tunnelling can ensure selecting appropriate design parameters (for rock mass and/or discontinuities) and failure criteria to be used in numerical analysis and consideration of the principles in association with tunnel support.

Engineers can design reinforced concrete or steel structures using certain checks for specifically predefined failure mechanism. Specifically, design should consider bending moment, axial force, shear, penetration and deflection (serviceability limit state). In tunnelling, however, there is no specific procedure to check against a predefined failure mechanism. This paper points out that the first step is not to start performing numerous calculations (probably misleading or useless), but to define what the potential failure mechanisms are and to qualitatively consider the support theories to account for them. This process is thus applied for the heterogeneous rock masses of flysch (Fortsakis, 2014).

Rock mass behaviour evaluation in tunnelling and its relation with the design process have been significantly reported. Goricki et al. (2004), Schubert (2004), Potsch et al. (2004) and Poschl and Kleberger (2004) have studied rock mass behaviours with respect to design and construction experiences of Alpine tunnels and Palmstrom and Stille (2007) from other tunnels. Flysch rock is

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composed of varying alternations of clastic sediments associated with orogenesis, since it ends the cycle of sedimentation before the paroxysm folding process. Intense folding and heavy shearing with numerous overthrusts thus characterise the environment in areas of flysch formations. It is characterised mainly by rhythmic alternations of sandstone and pelitic layers (siltstones, silty or clayey shales), where the thickness of sandstone or siltstone beds ranges from centimetres to metres. Consequently, conglomerate beds may also be included. The main thrust movement is associated with smaller reverse faults within the thrust body. The overall rock mass is highly heterogeneous and anisotropic, and thus may be affected by extensional faulting producing mylonites. The tectonic deformation drastically degrades the quality of the rock mass, a reason that flysch is characterised by diverse heterogeneity (Fig. 1) and the presence of low strength and tectonically disturbed structures (Fig. 2). Such formations are classified into 11 rock mass types (I–XI) according to the siltstone–sandstone proportion and their tectonic disturbance.

The design of tunnels in weak rock masses such as disturbed and sheared flysch presents a major challenge to geologists and engineers. The complex structure of these materials, resultant from their depositional and tectonic history, means that they cannot easily be classified in terms of the commonly used characterisation schemes.

The variety of geological conditions under different in situ stresses, in both mild and heavy tectonism examined here, provided significant amount of information regarding the engineering geological conditions and geotechnical behaviour of several flysch rock mass types. These behaviours were analysed and evaluated so as to define the geotechnical characteristics for each flysch type.

This study is based on experiences obtained from the design and construction of 62 mountainous twin tunnels of the Egnatia Highway in Northern Greece. The cross-section of these tunnels is 100–120 m^2, constructed conventionally using the top heading and bench method. In this context, a database named “Tunnel Information and Analysis System” (TIAS) was created (Marinos, 2007; Marinos et al., 2013). Using this database, the evaluation of huge geological and geotechnical data from the design and the construction of 12 tunnels is presented. These cases comprise tunnelling up to 500 m of overburden depth.

The data processed by TIAS are obtained from geological mapping (design and face mapping records), boreholes, laboratory tests, site testing, geotechnical classifications (design and construction records) and designation of design parameters. Data were also collected and processed in view of the geotechnical behaviour, such as deformations, overbreak, structural failures and groundwater inflow. Data from detailed information on temporary support measures and tunnel construction cost were also included. The processing and evaluation of this information contributed to assessing the correlations between behaviours of the ground and the formulation and the temporary support requirements. The use of TIAS database enabled then the determination of the possible rock mass types of flysch and the engineering geological characterisation in terms of properties and their behaviour in underground construction (Marinos et al., 2013).

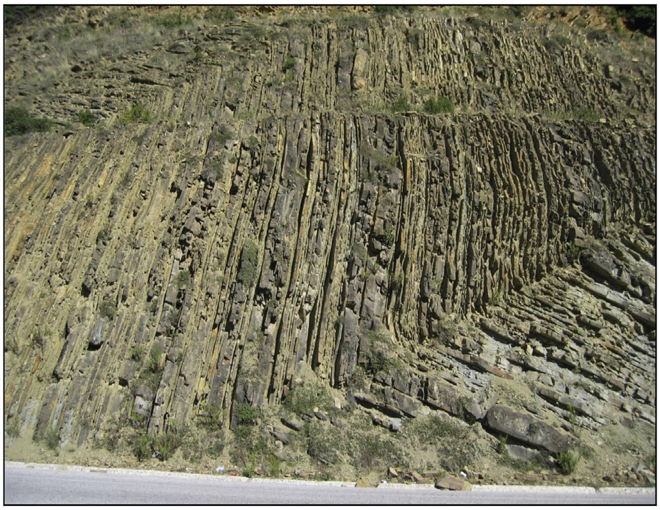

Fig. 1. Moderately disturbed rock mass with sandstone and siltstone alternations in similar amounts.

Fig. 2. Tectonically disturbed sheared siltstone with broken deformed sandstone layers. These layers have almost lost their initial structure, almost a chaotic structure.

2. Geotechnical properties

The development of powerful microcomputers and of user-friendly software prompted a demand on data related to rock mass properties required as inputs for numerical analysis or close-form solutions for designing tunnels. This necessity preceded the development of a different set of rock mass classifications, where the geological strength index (GSI) is such a classification. The Hoek–Brown failure criterion (Hoek et al., 2002) is closely connected to the GSI, covering a wide range of geological conditions affecting the quality of the rock masses, including heavily sheared weak rock masses (Hoek et al., 1998). The GSI considered as such a tool for assessment was initially introduced by Hoek (1994) and developed by Marinos and Hoek (2000). Marinos et al. (2005) further discussed its applications and limitations.

The GSI system was extended to heterogeneous rock masses, such as flysch, by Marinos and Hoek (2001), and then modified by Marinos (2007), and Marinos et al. (2007, 2011a) with adjustments in values and additions of new rock mass types. Flysch formations are thus classified into 11 rock mass types (I–XI) according to the siltstone–sandstone proportion and their tectonic disturbance. Hence, a new GSI diagram for heterogeneous rock masses such as flysch has been presented, where a certain range of GSI values for every rock mass type is proposed (Fig. 3). It is highlighted again that the Hoek–Brown failure criterion and consequently the GSI value should be used when the rock mass behaves isotropically.

The case in the presence of better quality blocks along with the sheared mass may improve the “overall” rock mass strength,