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Determination of mechanical properties of flysch using laboratory methods

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ABSTRACT

The paper deals with the determination of the mechanical properties of heterogeneous rocks in the laboratory and proposes a methodology for predicting the rock mass strength of flysch formations consisting of siltstone–sandstone alternations in different proportions. In order to simulate such formations, composite specimens comprising superimposed disks of intact sandstone and siltstone material with different thickness ratios were prepared. Wave velocity (P and S), uniaxial and triaxial compressive strength and Young's modulus of the composite samples were determined in the laboratory. According to the laboratory results, the uniaxial compressive strength and Young's modulus decrease with the increase of the siltstone percentage in the specimens, and yield the strength of siltstone when the siltstone percentage in the rock is equal to 37%. Additionally, the triaxial compression tests on composite samples revealed a significant decrease of the m_i parameter for a siltstone percentage of only 17%. A comparison is made between the results of the present study with similar laboratory and empirical references from literature. Finally, it was possible to suggest how the relation between uniaxial compressive strength, σ_{ci}, and siltstone percentage, sl, may differ according to the ratio of the compressive strength of the two main rocks, weak and strong, which comprise the heterogeneous rock.

1. Introduction

Heterogeneous or composite rock masses can be characterized as formations, which consist of at least two lithological units with different engineering behaviors and properties. Heterogeneous rock masses exhibit a structure of alternating layers of hard and weaker rocks with varying thickness and they are usually of sedimentary origin.

Flysch and molasse are typical examples of such rocks. They are characterized by rhythmic alternations of sandstone and pelitic (fine grained) rocks such as siltstones, marls, shales and clay shales. Conglomerates and limestones can also be present.

A number of engineering projects like tunnels, foundations and rock slopes are constructed in heterogeneous rock masses in countries (e.g. Greece) where such rock masses are common. Due to the highly anisotropic behavior that they exhibit, the engineering uncertainties and risk increase disproportionately, often leading to highly conservative engineering judgment and overpriced solutions. Determining the mechanical properties of heterogeneous formations both in uniaxial and triaxial conditions is vital for the selection of characteristic values for the design and construction of such works.

In the present study, an attempt is made to estimate the intact rock properties of heterogeneous flysch rock (alternations of sandstone and siltstone) using composite rock specimens for laboratory tests.

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2. Literature review

Although the determination of properties of heterogeneous rock masses constitutes a challenging engineering problem, the available literature is relatively limited. Only in the last decade, owing to the increasing underground infrastructure projects, there has been interest in the research on such rock masses.

Duffault (1981) published a study on modeling and simulating heterogeneous rock masses introducing the term “sandwich (single or multiple) rock mass”.

Greco et al. (1992) and Greco (1994) conducted a study for determining the strength and failure mechanism of composite rocks in the context of the stability analysis of the columns and masonry walls of a Cathedral, built with stones of different rock types.

Goodman (1993) had emphasized that any combination of more than one lithological types of rock exhibiting different properties imposes a complex geotechnical engineering problem.

Marinos and Hoek (2001) and Hoek et al. (2005) suggested empirical charts for estimating GSI, σ_{ci} and m_i for heterogeneous rock masses, based on the lithology, structure and discontinuity surface conditions.

Vlasov and Merzlyakov (2004) studied the deformability of the stratified rock mass considering it as a transversally isotropic medium using the asymptotic method of averaging, whereas Lydzba et al. (2003) studied the conditions at failure of a layered sandstone/claystone rock mass formation.

Liang et al. (2007) conducted laboratory experiments on natural layered specimens consisting of rock salt and anhydrate concluding that the overall strength is determined by the behavior of the weaker component. Zainab et al. (2007) conducted tests on composite specimens consisting of highly weathered sandstone and siltstone from Kuala Lumpur, Malaysia. The laboratory method that they have proposed is similar with the one that is used in the present study.

Saroglou and Steiakakis (2010) investigated the variation of uniaxial compressive strength of flysch intact rock samples, which presented layering due to existence of thin siltstone and sandstone alternations.

Budetta and Nappi (2011) have assessed the rock strength of a heterogeneous formation, comprised of sandstones with argillaceous marls, using the sandstone/pelite ratio (S/P) and the classification of GSI proposed by Marinos and Hoek (2001).

3. Laboratory testing

3.1. General

The laboratory method comprises the preparation and testing of rock specimens that were made up of superimposed disks of intact sandstone and siltstone material. The disks were formed in different thickness ratios of siltstone–sandstone (sl–st) material so as to simulate different siltstone and sandstone proportions in the flysch formation as presented in Fig. 1 (Tziallas, 2010).

The proportion of siltstone to sandstone in heterogeneous rock formations in the field is not directly analogous to the proportion of siltstone to sandstone in the laboratory, due to the lack of continuity of the alternations of siltstone to sandstone in the specimens. Thus, heterogeneous formations in the field with a specific proportion (defined by thickness of alternating layers) of siltstone and sandstone, will have a lower proportion in the laboratory specimens, since the alterations of layers in the specimen result in more sandstone than siltstone layers. For example, a heterogeneous rock mass with equal proportions of siltstone to sandstone (sl:st = 1:1) will have a percentage of siltstone equal to 30% in the laboratory specimen, as shown in Specimen B in Fig. 1. The siltstone percentage is indicated as sl and sandstone percentage as st (Tsiambaos, 2010).

The heterogeneous rock mass types with different proportions of siltstone to sandstone (equal to 1:5, 1:1, 3:1, 5:1) most commonly encountered in nature are shown in Fig. 1. These rock mass types were modeled in the laboratory and the proportion of siltstone to sandstone is shown in Fig. 1.

The composite specimens with varying siltstone–sandstone ratio were subjected to wave propagation tests, uniaxial compression tests with determination of elasticity modulus as well as triaxial compression tests.

All the laboratory tests were determined according to the ISRM (2007) procedures.

3.2. Description of materials

The samples that were used for the laboratory tests were collected from Kalydona tunnel of the Ionia Odos Highway, in the area of Evinochori village in central Greece, where the Ionian flysch of the Gavrovo–Tripoli geotectonic unit is encountered. The samples were either prepared from intact sandstone and siltstone blocks or from borehole cores. More specifically: a) Light gray to gray, medium to coarse grained, fresh, sandstone with no signs of anisotropy. Siltstone intercalations in the form of lenses were encountered in the sandstone but did not exceed 1–2% of the specimen volume. The mean unit weight of the sandstone specimens was $\gamma_{st} = 25.4$ Mg/m^3.

The siltstone used was gray-green to dark gray, homogeneous and fresh, sensitive to water, and displayed macroscopically swelling and shrinkage and loosening finally leading to slaking. Siltstone samples with thin sandstone intercalations were rejected during the selection of disks for the preparation of the composite specimens. The mean unit weight of the siltstone specimens was $\gamma_{sl} = 24.4$ Mg/m^3.

3.3. Preparation of the specimens

Generally, the greater difficulty on testing heterogeneous rock masses is to obtain "intact" core samples for determining the uniaxial or triaxial compressive strength in the laboratory. Moreover, laboratory tests carried out on natural heterogeneous samples often result in a lower strength value due to sampling and preparation disturbance (Saroglou and Steiakakis, 2010). Marinos and Hoek (2001) suggest that using the results of such tests in the Hoek–Brown criterion "will

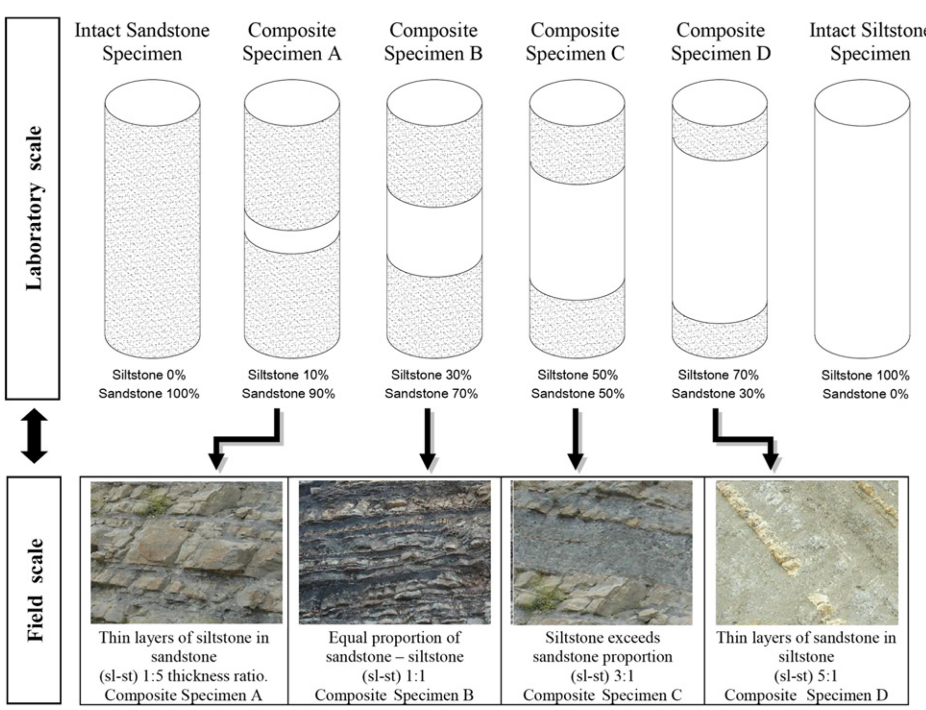

Fig. 1. Heterogeneous flysch with different proportions of siltstone and sandstone in the field and laboratory.