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A comparative assessment of rock mass deformation modulus

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ABSTRACT

Deformation modulus of a rock mass (E_m) is one of the most important design parameters in construction of rock engineering projects such as underground excavations. However, difficulties are frequently encountered during in-situ tests which are also time-consuming and expensive for determining this parameter. Although E_m is often estimated indirectly from proposed equations by different researchers, many of these equations cannot be used in case of problematic rock conditions (thinly bedded, highly jointed rock masses, etc.) as high quality core samples are required. This study aims to explore more practical and useful equation for E_m estimation using Rock Quality Designation (RQD) and point load index values. Comparisons were made between available empirical equations and the proposed E_m equation in terms of the estimation capacity. Multiple comparison tests (ANOVA) showed that E_m can be reliably estimated using proposed equation especially at the preliminary stages of projects.

1. Introduction

Deformability is known as one of the most crucial parameters governing the behavior of rock masses. Since the deformation modulus (E_m) is the best representative parameter of the pre-failure mechanical behavior of a rock mass, it is a significant parameter and of vital importance for successful execution of geotechnical projects [1]. The deformation modulus of a rock mass is measured by in-situ tests, such as plate bearing, flat jack, and borehole jacking and dilatometer tests. However, field tests to determine this parameter directly are time-consuming, expensive and the reliability of the results of these tests is sometimes questionable [2,3]. It is generally known that in-situ tests of the deformation modulus of rock masses could be subjected to measurement errors, from equipment, test site preparation and blasting damage in the test void [4]. These measurements also involve limited volumes of the rock mass [5]. Palmstrom and Singh stated that good site characterizations of the rock mass and use of an appropriate indirect method may in many cases give better results than expensive in-situ measurements [4]. Due to the difficulties and uncertainties encountered during in-situ tests, E_m of a rock mass is often estimated indirectly from correlations with classification indices such as the Rock Quality Designation (RQD), Rock Mass Rating (RMR), Q-system (Q), Rock Mass Index (RMi) and Geological Strength Index (GSI) [6–11].

Its a well-known fact that the Uniaxial Compressive Strength (UCS) of rock material has been used as an input parameter in some classification systems such as RMR and RMi. Additionally, some equations necessitate young modulus (E_i) of intact rock for obtaining E_m parameter. However, performing the UCS and E_i are mostly expensive and required high-quality core samples and considerable time, especially the preparation of rock samples for testing [12,13]. Further, obtaining core samples of the desired geometry cannot often be extracted from soft/weak, highly jointed rock masses, thinly bedded and/or block-in-matrix rocks [14,15]. Therefore, the purpose of this study is to present a trial/proposed empirical approach which is thought to be easier to use for indirect estimation of deformation modulus of rock masses. To compare the proposed equation, E_m was also predicted using seven empirical equations recommended in the literature.

2. Site description and geology

Eastern Black Sea Region is an efficiency basin in terms of small hydroelectric powers because of important surface water potential. A total of 213 hydroelectric power plant (HEPP) projects are being constructed and planned to establish in the region apart from the other engineering projects such as road tunnels and mining [16]. In addition to these, there have been new projects to be planned for HEPP and other applications in the region since 2008.

The study area (Çambaşı HEPP site) is located 83 km away from the city of Trabzon in the northeast of Turkey (Fig. 1). Along the tunnel route, geological formations consisting of volcanic,

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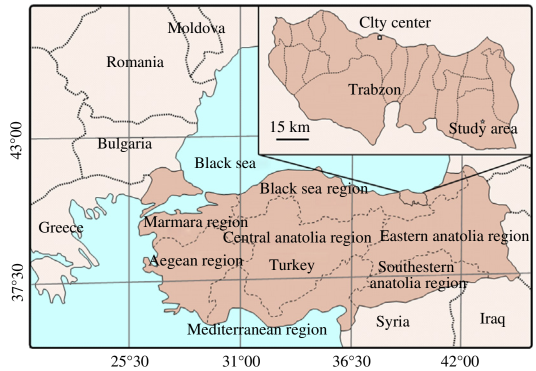

Fig. 1. Location map of the study area.

metamorphic and sedimentary rocks were observed. The lithology of the tunnel route mainly consists of basalt, metabasalt, limestone, dacite, volcanic breccia. The oldest and youngest lithological units belong to Jurassic (Hamurkesen Formation) and Quaternary (alluvium), respectively. Hamurkesen Formation is mainly composed of basalt, metabasalt and rarely seen maroon-colored limestone having a thickness of 3–5 m. This formation extends widely along the tunnel alignment. Hamurkesen Formation is chiefly overlain by the Berdiga Formation. The Upper Jurassic-Lower Cretaceous aged Berdiga Formation is represented by mainly gray-white color, medium-thick layer clayish–sandy limestone.

The study area is in the center of eastern Black Sea Region; thus, it shows similarities in terms of the rock types and surface features. Since the determination of rock mass deformation modulus is quite difficult and expensive especially at the preliminary stage of designing a structure, this study aims to suggest a useful and practical equation for the estimation of deformation modulus for the rock masses having similar properties to the researchers. Additionally, many equations proposed in the literature cannot be used for E_m estimation in problematic rock conditions (thinly bedded, highly jointed rock masses, etc.), as the high quality core samples are required. For these reasons, this study aims to explore more practical and useful equation for estimation of E_m.

3. Field and laboratory studies

Within the framework of the present study, rock samples were collected from various locations throughout the Çambaşı tunnel, 24 of which were volcanic, 8 were metamorphic, and 5 were sedimentary (Table 1). Laboratory and field studies were carried out on these 37 rock samples/masses representing 7132 m long lithology. Laboratory experiments involved the UCS, young modulus (E_i) and point load index ($Is_{(50)}$) tests. The field studies included the orientation, spacing, opening, roughness, the degree of weathering, filling of discontinuities in the rock masses and ground water conditions for rock mass classification systems. These parameters are important for quantitative descriptions of the rock masses. The most well-known classification systems such as RMR_{89}, Q and RMi were utilized in this study. The RMR_{89} system calculates an index by summing the ratings for six main factors: UCS, RQD value, spacing, condition and orientation of discontinuities, and ground water conditions. The Q system is defined in terms of RQD, the function of joint sets (J_n), discontinuity roughness (J_r), joint alteration (J_a), water pressure (J_w) and stress reduction factor (SRF). As for the RMi system, it is a volumetric parameter indicating the approximate Uniaxial Compressive Strength of a rock mass by combining UCS and a jointing parameter (*JP*). The *JP* presents the block volume (V_b) plus the joint condition (*jC*). The *jC* can be estimated by joint roughness (*jR*), joint alteration (*jA*) and joint size (*jL*) [17]. Further details of RMR, Q and RMi systems can be found elsewhere [8,18,19].

UCS and E_i were conducted on the intact core samples (NX-size, 54.7 mm) according to the ISRM (2007). Each block sample was inspected for macroscopic defects as to provide test specimens to be free from fractures and cracks. In order to obtain the exact results as well as the best comparison, the experiments were carried out under the same (natural) conditions. One of the important parameters affecting the strength of the rocks is anisotropy. However, volcanic rocks have shown no prismatic, pillow lava and flow structure. Additionally, metamorphic rocks (metabasalts) contain no anisotropy such as schistosity and foliation.

The UCS tests were carried out on unweathered rock samples which have a length-to-diameter ratio of 2.5. The UCS tests were performed using a servo-controlled testing machine, having a load capacity of 300 tons. The stress rate was applied at 0.75 MPa/s during the tests. Mean UCS values were obtained by averaging the strength values of 5 core samples for each rock type. In order to determine the Young's modulus, lateral and vertical strain gages (Kyowa) were attached and glued (using cyanoacrylate) onto each core sample used in the UCS tests. Axial point load tests were carried out on NX-size core samples in accordance with the ISRM procedure [20]. Ten samples were subjected to the experiment and the mean value was calculated discarding the lowest and highest two values and averaging the rest. The name, location and average results of the related properties of rock material/masses are given in Table 1.

4. Estimation of deformation modulus and methodology

The empirical relations which are thought to be more practical and easier for E_m estimation, given in Table 2, were used along the tunnel route for 37 segments/locations (Table 3). As shown in Table 2, most researchers have proposed equations relating rock mass modulus to classification systems such as RMR, Q, RMi [4,6–8,21,22]. Some engineering properties of intact rock materials were also used as input parameters to estimate E_m such as P-wave velocity (V_p), E_i and the UCS [1,8,10,23,24]. Zhang et al. utilized the RQD and E_i parameters for estimation of E_m [24–26].

Empirical relations are applicable in the initial stages of projects, especially in the site selection process, for which the data are limited [27]. It is well known that the direct tests such as UCS and E_i cannot mostly be performed during the preliminary design stage of underground structures when representative rock blocks were not obtained from exploration core. The experiments are also expensive, troublesome and time-consuming, especially for during the initial stages of projects. Since discontinuity characteristics and the strength (UCS) of rock materials are the most important contributors to rock deformability, the trial empirical model was aimed to propose considering RQD (discontinuity characteristic) and $Is_{(50)}$ in this study [27]. $Is_{(50)}$ is closely related to strength of rock material (i.e. UCS) according to the literature [28,29]. $Is_{(50)}$ is used widely in practice due to its testing ease, simplicity of sample preparation, and possible field applications, and is much easier to apply compared to the UCS and E_i. Contrary to some existing equations, $Is_{(50)}$ is also thought to be more suitable for formulation since it exhibits a narrower range of data (generally between 0 and 10 MPa and occasionally 10–15 MPa in the literature) [28].

In the current study, $Is_{(50)}$ and RQD (easy and simple to perform) were projected to give reliable E_m estimations based on site experience and observations. Therefore, the following relation was generated for rock masses studied by using the excel computer program. Multiple comparison statistical analysis (ANOVA) was also performed to confirm the relation used for estimation of E_m.

$$E_m = Is_{(50)} \times 10^{(0.01 \times RQD - 0.25)} \quad (1)$$