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A simple regression based approach to estimate deformation modulus of rock masses

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ABSTRACT

Rock mass characterization has a crucial importance in rock engineering applications including foundation design, slope design, support design and others. For these purposes, it is necessary to determine some input parameters for design, such as deformation modulus (E_m), uniaxial compressive strength (σ_{ci}) and Poisson ratio (υ). The E_m is an important input parameter and the practical and economical way to determine this parameter is to apply a rock mass classification system and estimate using the rock mass properties. Data from four different sites were used in the study. The values of E_m were calculated using the existing empirical equations based on the Rock Mass Rating (RMR_{89}) system. Furthermore, pressuremeter tests were carried out to determine the E_m in one of the sites. The relationship between the RMR_{89} and the E_m was obtained via simple regression analysis using the E_m calculated from empirical equations based on RMR_{89} system. Afterwards, performance of the equation obtained from regression analyses was examined and compared the predicted E_m values with experimental values with respect to the R^2 values using the data of fourth site. Overall R^2 value was found to be as 0.75.

1. Introduction

The earth's surface is continuous and is shaped according to various forces. Ground movements consist of divergent–convergent plate displacements and crustal deformations. Many parameters such as tectonic, hydrogeological processes and geological conditions affected crustal deformations. Large number of investigations has been carried out in this field of study (Sandu et al., 2009; Kamberis et al., 2012). Measurements of ground displacements are widely used to get an insight into the earth's deformation and to increase the understanding of the forces of nature. Many methods are available to measure ground movements. For instance, Global Positioning System (GPS) for geodetic observations provides accurate three-dimensional measurements of ground displacements at sparse locations and for the same areas various image analysis methods are used which were used in particular by some investigators during the planning of urban environment in terms of natural hazards (Bathrellos et al., 2012; Apostolidis and Koukis, 2013; Bathrellos et al., 2013; Papadopoulou-Vrynioti et al., 2013). On the other hand, the deformation modulus (E_m) of the rock and soil mass which make up the earth's crust are determined in small scale engineering investigations.

The E_m is an important parameter that is often estimated by designers for design applications. The parameter is necessary for design of foundation, underground openings and slopes. The best estimate of E_m of a rock mass can only be made through large size field testing of the rock mass. However, most in situ measurements are time-consuming and costly and may be operationally difficult. Comparatively, empirical equations for indirect estimation of the E_m are simple and may be cost-effective in many applications. As a result, E_m is estimated indirectly from classification systems such as Rock Mass Rating (RMR), Rock Mass Quality (Q), Rock Mass Index (RMi) and Geological Strength Index (GSI) (Bieniawski, 1978; Hoek and Brown, 1988; Palmström and Singh, 2001; Barton, 2002; Hoek and Diederichs, 2006).

Different researchers suggested several empirical equations for estimating the E_m based on the values of RMR, Q, RMi and GSI. These empirical equations have been used by designers to estimate the deformation modulus of rock masses (Rashed and Sediek, 1997; Gurocak et al., 2008; Alemdag et al., 2008, 2014; Kaya et al., 2011; Gurocak and Alemdag, 2012; Kang et al., 2012; Chai et al., 2013; Zhang et al., 2014; Alemdag, 2015; Karaman et al. 2015). One of the major difficulties in using the existing empirical

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equations arises from the fact that different results are obtained by using these empirical equations. A designer often prefers to use the average design values obtained from several equations.

Many of the equations suggested in literature (Bieniawski, 1978; Serafim and Pereira, 1983; Isik et al., 2008; Alemdag, 2010) can be used for certain types of rock masses which poses a significant limitation. The objective of this study is to eliminate this limitation and find a new expression which can be used for rock masses of different types. Therefore, different types of rock masses were preferred as subject of study and siltstone was specially selected as a validation unit. Because, the expression that can be used for siltstone indicates that there is no limitation on the use of the expression suggested in this paper.

2. Methodology

The regression model developed here is based on the RMR_{89} system that is used frequently by different researchers. Efforts are made to evaluate the relationships between the RMR_{89} and E_m. For these purposes, laboratory and field data obtained from four different sites in Turkey have been utilized. These sites are Boztepe (Malatya) dam site, Kapikaya (Malatya) dam site, Atasu (Trabzon) dam site and southeast Elazig (Fig. 1).

The E_m values at these sites (Boztepe, Kapıkaya and Atasu dam sites) were estimated using existing empirical equations based on the RMR_{89} and pressuremeter tests were performed to determine in-situ E_m in the fourth site (southeast Elazig).

Simple regression analysis was performed to obtain the relationship between the RMR and E_m using the data from three sites. The RMR and in-situ E_m values of the fourth site were used to control the performance of equation obtained from regression analysis. The strengths and weaknesses of the developed equation were examined by comparing the estimated E_m values with the experimental E_m values with respect to the R^2 values. The proposed regression model is expected to be useful in future design applications.

2.1. Development of a database

To develop a data base, field and laboratory studies carried out in four different areas in Turkey, namely Boztepe (Malatya) dam site, Kapikaya (Malatya) dam site, Atasu (Trabzon) dam site and southeast Elazig.

First study area is the Boztepe (Malatya) dam site which is mainly covered by basalts and tuffites. The basalts are dark colored. Joints within the basalts are well-developed. The tuffites are dirty white – light grey in color. They have well-developed bedding surfaces and thicknesses of bedding varies from 50 to 600 mm. The tuffites contained rarely-developed joint sets (Gurocak, 1999).

According to ISRM (2007), the joint sets in the basalts have close-very close spacing, low persistence, and moderate width, rough and moderate weathered character. The joint sets and bedding surfaces in tuffites have close spacing, medium to high persistence, moderate width, and rough and weathered character.

Second study area is the Kapikaya (Malatya) dam site which is mainly covered by diabases that are light grey in color. The joint sets in the diabases were described accordance with ISRM (2007) criteria. They have close spacing, low persistence, and moderate width as well as rough and moderate weathered character.

Third study area is the Atasu (Trabzon) dam site which is mainly covered by basalts. Rock mass properties of the basalts are investigated in this study. Fresh surface of basalts are black and dark grey colored and altered surfaces are yellowish and brownish colored (Alemdag, 2004). According to ISRM (2007), the joint sets in the basalts have close spacing, low persistence, and moderate width with a rough and slightly weathered character.

Fourth study area is located in southeast Elazig. This area is mainly covered by siltstones which are dirty light grey in color and well-developed bedding surfaces and bedding thicknesses varies from 3 to 150 cm. The siltstones have joint sets and they are moderately altered, filled with calcite having 20–30 mm thickness. The joint sets and bedding surfaces in the siltstones have moderate spacing, medium persistence, open to moderate width and have a rough and slightly weathered character.

Uniaxial compressive strength (σ_{ci}), elasticity modulus (E_i) and unit weight (γ) of the intact rocks in the study areas were determined in accordance with the test methods suggested by ISRM (2007). The test results are summarized in Table 1.

In addition to laboratory studies, pressuremeter tests performed to determine in-situ deformation modulus of rock mass in the fourth (southeast Elazig) study area. The pressuremeter test developed by Ménard (1956), is a in-situ test preferred by

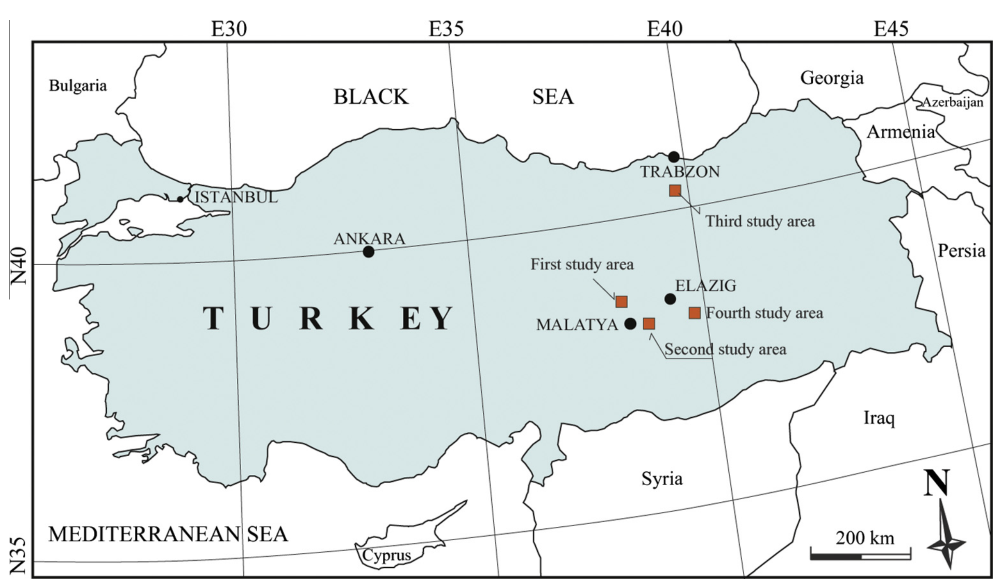

Fig. 1. The location map of study areas.