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Estimation of static parameters based on dynamical and physical properties in limestone rocks

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ABSTRACT

Due to the importance of uniaxial compressive strength (UCS), static Young's modulus (E_S) and shear wave velocity, it is always worth to predict these parameters from empirical relations that suggested for other formations with same lithology. This paper studies the physical, mechanical and dynamical properties of limestone rocks using the results of laboratory tests which carried out on 60 the Jahrum and the Asmari formations core specimens. The core specimens were obtained from the Bazoft dam site, hydroelectric supply and double-curvature arch dam in Iran. The Dynamic Young's modulus (Ed) and dynamic Poisson ratio were calculated using the existing relations. Some empirical relations were presented to estimate uniaxial compressive strength, as well as static Young's modulus and shear wave velocity (V_s). Results showed the static parameters such as uniaxial compressive strength and static Young's modulus represented low correlation with water absorption. It is also found that the uniaxial compressive strength and static Young's modulus had high correlation with compressional wave velocity and dynamic Young's modulus, respectively. Dynamic Young's modulus was 5 times larger than static Young's modulus. Further, the dynamic Poisson ratio was 1.3 times larger than static Poisson ratio. The relationship between shear wave velocity (V_s) and compressional wave velocity (V_p) was power and positive with high correlation coefficient. Prediction of uniaxial compressive strength based on V_p was better than that based on V_s. Generally, both UCS and static Young's modulus (E_S) had good correlation with Ed.

1. Introduction

Most engineering projects related to the rocks such as tunnels, foundations and slopes, petroleum reservoir geomechanics (well bore stability analysis, reservoir compaction survey, and prediction of optimum drilling mud pressure), as well as modeling the behavior of rocks and estimation of in situ stresses are required the static and dynamic properties of the rocks (Chang et al., 2006; Abdulraheem et al., 2009; Alemdag et al., 2015).

Measuring static and dynamic properties of the rocks, especially UCS and E_S are time consuming processes, tedious, expensive and require well prepared rock cores. In addition, obtaining these parameters of rocks are difficult and not accessible, especially deep drilling and geomechanical purposes. Therefore, indirect methods such as ultrasonic and physical tests are often used to predict the UCS and E_S.

Indirect tests, especially none destructive tests (ultrasonic tests), are easier to carry out because they necessitate less or no sample preparation and testing equipment is simple. Also they can be used in the field. As a result, in comparison to the uniaxial compression test, indirect tests are simpler, faster and more economical.

Some researchers have investigated the dynamical, mechanical and physical properties of carbonate rocks. Some of these studies were listed at below.

Najibi et al. (2015) established some empirical relations between strength and static and dynamic properties of limestone rocks. The relationship of compressional wave velocity (V_p) with Young's modulus, density and UCS of carbonate rocks were investigated. Results showed that there were strong relationships between wave velocities and properties of limestone rocks (Kahraman and Yeken, 2008; Yasar and Erdogan, 2004; Concu et al., 2014). The relationship between the petrographic and geomechanical properties of pyroclastic rocks was studied by Korkanç and Solak (2016).

Stan-Kłeczek (2016) investigated the relationship of bulk, shear

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and elastic modulus as well as Poisson's ratio with compressional wave velocity in limestone rocks. Castagna and Backus (1993) presented empirical polynomial relations for estimating shear wave velocity (V_s) from V_p depending on data derived from sonic log.

The relationship of the compressional wave velocity (V_s) and stress of the different rock types was investigated by Chen and Xu (2016). Also, the relationship of uniaxial compressive strength and point load was investigated by Ozturk and Altinpinar (2017).

Pappalardo (2015) presented some linear relationships of the compressional wave velocity with UCS and physical properties in limestone rocks. Likewise, the relationship of compressional wave velocity with physical and mechanical properties of different rocks was investigated by Khandelwal (2013). Tamrakar et al. (2007) studied the relations between mechanical and lithological properties of different rocks. İnce and Fener (2016) and Ceryan (2014) presented a model for estimation of the uniaxial compressive strength.

The effect of porosity on the tensile and compressive strength of the porous gypsum was investigated by Palchik and Hatzor (2004). In addition, Palchik (2011) found the relationship of the UCS and static Young's modulus of carbonate rocks.

The association of the UCS and point load index of the 38 different rock types was examined by Kahraman et al. (2005). Vasarhelyi (2005) also studied the influence of water content on the strength of the limestone rocks.

Palchik (2006) presented a model to predict stress–strain relationships for weak to strong carbonate rocks.

Chang et al. (2006) suggested 31 empirical equations between p-wave velocity, Young's modulus, specific gravity and friction angle with UCS for limestone, shale, dolomite and sandstone.

Table 1 lists some empirical relations between UCS, E_S, density, water absorption (W_a) and V_s with dynamic and static data.

The main objective of this study was to predict UCS and E_S of limestone rocks. To achieve this goal, the uniaxial compression test, ultrasonic tests, physical tests such as water absorption, porosity and density, carried out on 60 limestone core specimens of the Jahrum and the Asmari formations. The core specimens were obtained from the Bazoft dam site. The dynamic young's modulus (E_d) and Poisson's ratio were calculated based on related equations. Some empirical correlations between UCS and E_S with Ed, porosity, density, water absorption (W_a), V_p and V_s for the Jahrum and the Asmari limestone were established. Also, the correlation of V_s and V_p as well as UCS and E_S were investigated. In addition, some suggested empirical equations about the literatures of this paper were adjusted with using the present data (measured values).

2. Bazoft dam site

Bazoft dam is a hydroelectric supply and double-curvature arch dam with a height of 211 m located in Chaharmahal and Bakhtiari province of Iran. The bedrock of the dam site consists of the Asemari formation (limestone), and the Jahrum formation (limestone). Figs. 1 and 2 show pictures of the Jahrum and the Asmari formations in dam site.

Fig. 1. A view of the Jahrum formation.

3. Thin section investigations

The Asmari formation age is related to Oligo-Miocene period which is the main formation at the south west of Iran. The Asmari formation was studied at the Bazoft dam site.

According to the results of the petrographic examinations, the limestone samples were dominantly calcite. Limestone of the Asmari formation includes benthic Foraminifera microfossils. In addition, the frequency of these microfossils showed that the Asmari formation precipitated in lagoon environment (Fig. 3).

More than 56 thin sections of the Jahrum formation were analyzed under the petrographic microscope (Fig. 4). The Jahrum formation consists of limestone, which includes *bioclast* wackestone to packstone. These microfossils showed that the Jahrum formation deposited in lagoon environment. Due to the great diversity and abundance of large benthic foraminifera (including miliolides and textularids), the age of the Jahrum formation is related to the Paleocene-Eocene period.

The particles size and fossils of the microscopic sections showed that the Jahrum formation was more fine-grained limestone as compared to the Asmari formation. As shown in Tables 2 and 3, the average values of static properties (UCS and E_S) of the Jahrum

Table 1
Some empirical relations between UCS, V_s and E_S with dynamic data (for carbonate rocks).

Equations	Descriptions	R^2	Lithology	References
$E_S = 74*Ln(V_p) - 572$	V_p in m/s, E_S in MPa	0.74	carbonate rocks	Stan-Kłeczek, 2016
$UCS = 31.5*Vp - 63.7$	UCS in MPa, V_p in Km/s	0.80	carbonate rocks	Yasar and Erdogan, 2004
$E_S = 10.67*V_p - 18.71$	E_S in GPa	0.86	carbonate rocks	Yasar and Erdogan, 2004
$V_p = 4.3183*\rho - 7.5071$	V_p in Km/s, ρ in gr/cm^3	0.81	carbonate rocks	Yasar and Erdogan, 2004
$UCS = 11.05*E_S$	UCS in MPa, E_S in GPa	0.79	limestone	Najibi et al., 2015
$UCS = 3.67*V_p$	V_p in Km/s	0.81	limestone	Najibi et al., 2015
$UCS = 12.8*\left(\frac{E_d}{10}\right)^{1.32}$	E_d in GPa	0.88	limestone	Najibi et al., 2015
$E_S = 0.169*V_p$		0.90	limestone	Najibi et al., 2015
$E_S = 0.014*E_d$		0.87	limestone	Najibi et al., 2015
$UCS = 25.1*E_S$	E_S in GPa, UCS in MPa	–	dolomite	Chang, 2004
$V_S = -0.055*V_p + 1.017*V_p - 1.031$	V_s and V_p in Km/s	–	Limestone and Dolomite	Castagna et al., 1993
$W_a = -2.248*V_p + 13.76$	V_p in Km/s	0.90	carbonate rocks	Kahraman and Yeken, 2008