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ScienceDirect
Expert Systems with Applications 35 (2008) 111–123
Expert Systems with Applications
www.elsevier.com/locate/eswa

# Prediction of compressive and tensile strength of limestone via genetic programming

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Received 23 December 2006; accepted 1 June 2007

**Abstract**

Accurate determination of compressive and tensile strength of limestone is an important subject for the design of geotechnical structures. Although there are several classical approaches in the literature for strength prediction their predictive accuracy is generally not satisfactory. The trend in the literature is to apply artificial intelligence based soft computing techniques for complex prediction problems. Artificial neural networks which are a member of soft computing techniques were applied to strength prediction of several types of rocks in the literature with considerable success. Although artificial neural networks are successful in prediction, their inability to explicitly produce prediction equations can create difficulty in practical circumstances. Another member of soft computing family which is known as genetic programming can be a very useful candidate to overcome this problem. Genetic programming based approaches are not yet applied to the strength prediction of limestone. This paper makes an attempt to apply a promising set of genetic programming techniques which are known as multi expression programming (MEP), gene expression programming (GEP) and linear genetic programming (LGP) to the uniaxial compressive strength (UCS) and tensile strength prediction of chalky and clayey soft limestone. The data for strength prediction were generated experimentally in the University of Gaziantep civil engineering laboratories by using limestone samples collected from Gaziantep region of Turkey.


*Keywords:* Genetic programming; Prediction; Limestone; Strength of materials

## 1. Introduction

The uniaxial compressive strength (UCS) and tensile strength of rocks are widely used in the design stage of geotechnical structures. There are basically two methods for determining these strength properties, one of the approaches is to collect and test the specimens in the laboratory or making use of the previously derived empirical equations from the literature. The first approach is the direct approach and the second approach can be called as indirect approach. Testing procedures for the direct approach have been standardized by ASTM D 2938-95, ASTM D 3967-95a and ISRM (1981). Due to simpler, faster and more economical solution aspects, indirect methods for UCS and tensile strength predictions are frequently required to be driven particularly at the conditions of limited laboratory facilities. In the indirect approach the empirical equations for strength are usually derived from simple tests such as Schmidth rebound number, point load tests, impact strength and sound velocity (Fener, Kahraman, Bilgil, & Gunaydin, 2005; Singh, Singh, & Singh, 2001). Soft computing based techniques especially artificial neural networks (ANN) are also gaining a considerable attention in estimating both UCS and tensile strength (Meulenkamp, 1997; Meulenkamp & Alveraz Grima, 1999; Nie & Zhang, 1994; Singh et al., 2001). ANN being recently more popular especially at the circumstances of

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0957-4174/$ - see front matter 
doi:10.1016/j.eswa.2007.06.006

less correlation coefficient of regression equations required more input variables to completely define rock characteristics and more flexible operations between input and output variables (Garret, 1994; Huang & Wänstedt, 1998). ANN is a fundamentally different approach which has to learn and generalize interactions among many variables. Because of this ability, ANN technology has a big potential in modeling the material behaviour from experimental data (Ellis, Yao, & Zhao, 1992; Ghabousi, Garret, & Wu, 1991). In the literature, Meulenkamp and Alveraz Grima (1999), Meulenkamp (1997) applied ANN for the prediction of compressive strength on the rock samples containing sandstones and granodiorites. Singh et al. (2001) used ANN to predict both UCS and tensile strength for schistose rocks. All those past studies showed that using neural network models for the prediction of strength properties concluded more accurate predictions than conventional statistical models. However, the problem with ANN is their black box like working characteristic. It is not easy to relate inputs of an ANN with its outputs in an analytical equation form. Another branch of soft computing approaches from the family of evolutionary programming that is known as genetic programming is also a promising candidate for solving complex prediction problems. The main advantage of genetic programming based approaches is their ability to generate prediction equations which can be easily manipulated in practical circumstances. Genetic programming based approaches are not yet applied to the prediction of UCS and tensile strength of limestone in the literature. In this research paper a promising set of genetic programming techniques, which are known as multi expression programming (MEP), gene expression programming (GEP) and linear genetic programming (LGP) approaches are applied to the UCS and tensile strength of chalky and clayey soft limestone. The limestone samples which are used to produce data sets for genetic programming techniques were collected from Gaziantep city of Turkey (see Fig. 1).

The rock characteristics which function as the training input of genetic programming are ultrasonic pulse velocity (UPV), density, water absorption, dry density, saturated density and bulk density, while the corresponding UCS and tensile strength are the outputs for which prediction equations are derived by using LGP, GEP and MEP. The present study makes also a contribution by comparing these three effective genetic programming techniques on a real life problem.

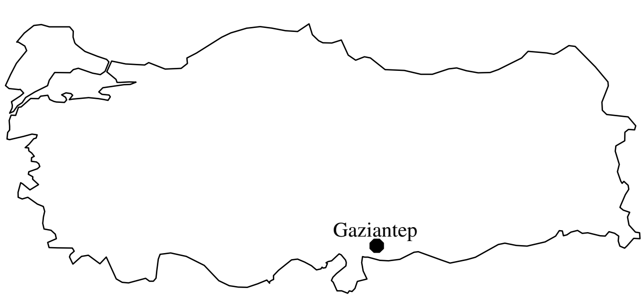


Fig. 1. Location of Gaziantep city in Turkey where the limestone specimens are collected.

## 2. Geological setting of limestone

The limestone particularly within the Gaziantep region has extensively two main geological formations which are Fırat formation (Tmf) and Gaziantep Formation (Tmga) (see Fig. 2). Fırat formation was basically composed of reefal limestones. Gaziantep formation is mainly constituted with clayey limestone and chalky limestone. In the consideration of geological time, limestone with Fırat formation are created in the lower middle oligocene and limestones with Gaziantep formation are assembled within the middle upper Eocene. Both formations are included within the tertiary. In addition, the mineralogy of the limestone is chemically described in Table 1. The mineralogy indicates that limestone is almost pure with totally 97% ($CaO + CO_2$). Furthermore, $SiO_2$, MgO and $Al_2O_3$ components shows significant variations in their total amounts.

## 3. Experimental study and test results

Limestone samples which are used in the experiments are obtained from borings and collected from rock blocks, within Gaziantep region. The core barrel designation NX size samples with cylindrical shape are taken from the borings. In addition, using core drilling machine at the laboratory (University of Gaziantep civil engineering labs.), NX size core samples have been prepared from the collected rock blocks. The conducted areas of borings and collected rock blocks are shown in Fig. 3.

In the experimental study, UCS, tensile strength, ultrasound pulse velocity, water absorption, dry density, saturated density and bulk density tests are conducted. Specimens are prepared and experiments are performed in accordance with the procedures given in ISRM (1981). In order to develop a reliable predictive model with genetic programming techniques, laboratory tests are conducted by a sufficient population of samples. In the genetic programming techniques, ultrasonic pulse velocity, water absorption, dry density, saturated density and bulk density are used as input features. In addition, two main strength properties, UCS and tensile strength are considered as the outputs.

Two sets of samples are arranged for the experimental study. In the first set, a total of 106 samples are prepared for UCS test. Before conducting UCS, ultrasonic pulse velocity, water absorption, dry density and saturated density tests are carried out for those samples. In the second set, a total of 118 samples are prepared for tensile strength test by Brazilian method. Before executing tensile strength tests, ultrasonic pulse velocity, water absorption, dry density and saturated density tests are also performed for the second set of samples. UCS and tensile strength values are measured in oven dried samples.