Expert Systems with Applications 36 (2009) 7749–7757

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

# Modelling damping ratio and shear modulus of sand–mica mixtures using genetic programming

Abdulkadir Cevik *, Ali Firat Cabalar

*Department of Civil Engineering, University of Gaziantep, Gaziantep, Turkey*

ARTICLE INFO

*Keywords:*
Leighton buzzard sand
Mica
Resonant column testing
Genetic programming

ABSTRACT

This study presents two Genetic Programming (GP) models for damping ratio and shear modulus of sand–mica mixtures based on experimental results. The experimental database used for GP modelling is based on a laboratory study of dynamic properties of saturated coarse rotund sand and mica mixtures with various mix ratios under different effective stresses. In the tests, shear modulus, and damping ratio of the geomaterials have been measured for a strain range of 0.001% up to 0.1% using a Stokoe resonant column testing apparatus. The input variables in the developed NN models are the mica content, effective stress and strain, and the outputs are damping ratio and shear modulus. The performance of accuracies of proposed NN models are quite satisfactory ($R^2$ = 0.95 for damping ratio and $R^2$ = 0.98 for shear modulus).


## 1. Introduction

The damping ratio (D) and shear modulus (G) of soils are usually determined using dynamic tests. A widely used way to determine dynamic properties of the soils is the resonant column test method, where the soils are loaded harmonically. In this method the wave propagation in cylindrical soil specimens is studied. The testing procedures and the data reduction for the tests are described in many studies (e.g., ASTM D4015-92, 2000; Drnevich, Hardin, & Shippy, 1978; Toki, Shibuya & Yamashita, 1995). In the resonant column technique, a column of cylindrical soil sample is contained within a membrane, and an effective stress is applied during the test. After a specimen in the apparatus is prepared, it is isotropically consolidated, and then a cyclic loading is commenced. The loading frequency is first set at low value, and then increased until the response reaches the maximum value. The frequency is a parameter of the certain characteristics of the apparatus (i.e., interaction between the magnets and coil, fixity between the specimen and drive system, resonance of the other part of the apparatus) as well as the small-strain stiffness of the soils (Richart, Hall, & Woods, 1970).

In many cases it is necessary to obtain data for damping ratios and shear modulus over a range of confining pressures. This can be accomplished by (a) a multistage test, where a specimen is tested at a confining pressure and subsequently retested at other confining pressure values or by (b) several single stage tests, where a specimen is subjected to a confining pressure and then tested at a range of shear strain amplitudes. Although the former procedure is more economical, the question arises if microstructural changes caused by repeated strain cycles, particularly at the higher strain amplitudes, can alter the dynamic properties of the specimen tested (Chung, Yo Kel, & Drnevich, 1984).

This paper provides an alternative approach for the modelling of damping ratio and shear modulus of sand–mica mixtures using Genetic Programming (GP). GP based equations are proposed for damping ratio and shear modulus of sand–mica mixtures. The GP models are based on an experimental database, which was conducted to document the behaviour of saturated Leighton buzzard sand and mica mixtures in Stokoe resonant column apparatus. Following the readily available studies on the influence of particle shape on the behaviour of geomaterials (i.e., Dodds, 2003; Theron, 2004; Vermeulen, 2001), a series of stress-controlled multi stage tests were performed in parallel on various mix ratios. The predictions of GP models developed to explore the cyclic behaviour of the mixtures are found to be quite accurate.

## 2. Theoretical background

The first use of the resonant column testing technique dates back to the late 1930s (Iida, 1938, 1940). The technique was considerably refined by a number of researchers in 1960s and 1970s (e.g., Hardin & Richart, 1963; Drnevich & Richart, 1970). The parameters of G and D determined in the laboratory with resonant column equipment are widely discussed in one of the recent studies by Stokoe, Hwang, Lee, and Andrus, (1994). The Stokoe device is provided with instrumentation to excite and measure the response of a cylindrical soil specimen in both torsional shear and resonant column modes of a testing. The apparatus is of the fixed-free type, with the bottom of the specimen fixed and torsional excitation

* Corresponding author. Tel.: +90 342 317209; fax: +90 342 3601107.
*E-mail address:* akcevik@gantep.edu.tr (A. Cevik).

0957-4174/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2008.09.010

employed to the top as shown in Fig. 1. During torsional tests, four pairs of coils are connected in series so that a torque is applied to the soil column. To apply flexural vibrations, only two pairs of coils are used by applying a horizontal force to the soil column inducing bending excitation.

The resonant column test is based on theoretical solutions relate the dynamic modulus of the column to its resonant frequency. Various forms of physical systems subject to vibrations yield the wave equation expressed by the following partial-differential equations, which is one of the fundamental equations of mechanics.

$$\frac{\partial^2 u}{\partial t^2} = v^2 \frac{\partial^2 u}{\partial x^2} \tag{1}$$

where $\upsilon$ is the wave-propagation velocity.

The shear modulus can be related to the fundamental frequency by the procedure below. Consider a specimen in resonant column apparatus with height '*h*' fixed against rotation of its base, and with polar moment of inertia '*I*', subjected to sinusoidal harmonic torsional loading. The elastic resistance of the specimen leads a torque at its top, which can be written as,

$$T = gI_P \frac{\partial \theta}{\partial x} \tag{2}$$

where *g* is shear modulus (modulus of rigidity), $I_P$ is polar moment of inertia of the cross-section and $\frac{\partial \theta}{\partial x}$ is angle of twist per unit length of rod.

Assuming that the rotations of the specimens are also harmonic, they can be identified by

$$\theta(z,t) = \Theta(z)(C_1 \cos \omega t + C_2 \sin \omega t) \tag{3}$$

where $\Theta(z) = C_3\cos kz + C_4\sin kz$. The zero rotation boundary condition at the base of the specimen requires $C_3 = 0$, and the compatibility of Eqs. (1) and (2) needs, at the fundamental frequency, $\omega_n = k_n v_s$, so that

$$G\frac{I}{\rho}C_4 k_n \cos k_n h(C_1 \cos \omega_n t + C_2 \sin \omega_n t) = -I_0 h(-\omega_n^2 C_4 \sin k_n h)(C_1 \cos \omega_n t + C_2 \sin \omega_n t) \tag{4}$$

which can be written as follows:

$$\frac{I}{I_0} = \frac{\omega_n l}{v_s} \tan \frac{\omega_n l}{v_s} \tag{5}$$

I, $I_0$, and *h* in Eq. (5) are generally known at the time that cyclic loading commences for a given specimen. The fundamental frequency is determined experimentally, and then $v_s$ is calculated by using Eq. (5). The shear modulus is then obtained using $G = \rho v_s^2$. Damping ratio can be calculated from curve of frequency response using the logarithm decrement by placing the specimen in free vibration or from the half-power bandwidth method (Richart et al., 1970, Kramer, 1996).

## 3. Experimental study

### 3.1. Materials

The aim of the experimental study was to evaluate the influence of various proportions of platy fines on the behaviour of rotund particles. Two different geomaterials were used in all the tests, Leighton buzzard sand and mica.

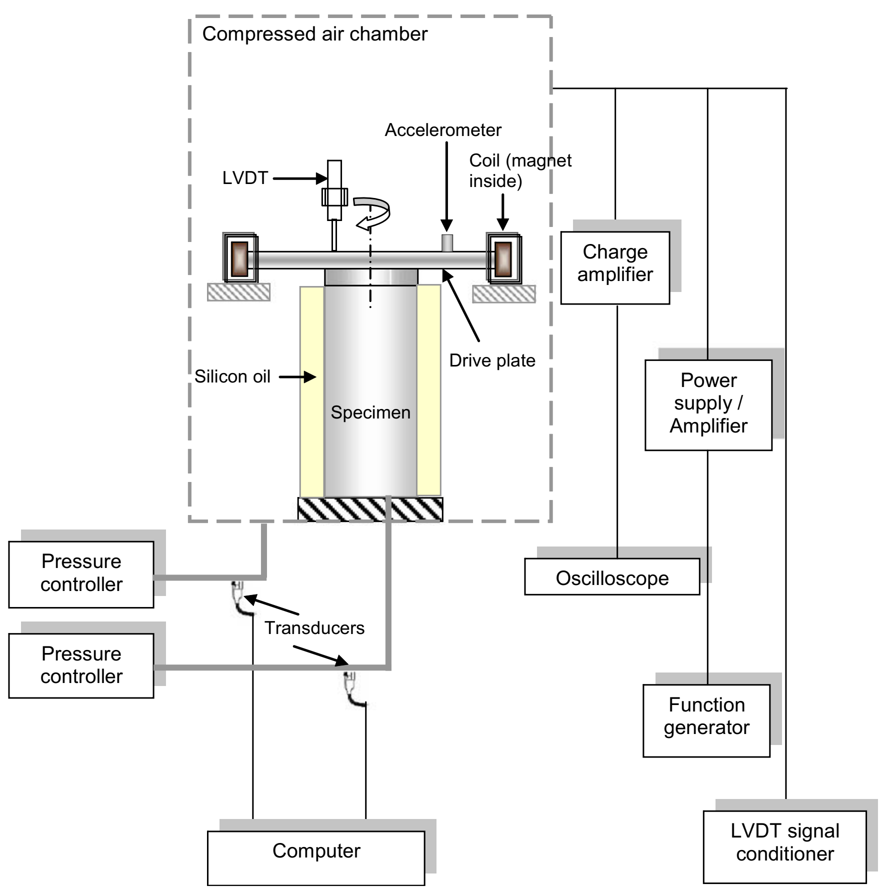


**Fig. 1.** Simplified diagram of the resonant column testing apparatus used in the experimental study.