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A New Prediction Model for Soil Deformation Modulus Based on PLT Results

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Summary

In this study, a new empirical model was developed to predict the secant soil deformation modulus (E_s) using linear genetic programming (LGP). The best LGP model was selected after developing and controlling several models with different combinations of the influencing parameters. The experimental database used for developing the model was established upon a series of plate load tests (PLT) conducted on different soil types. A sensitivity analysis was carried out to determine the contributions of the parameters affecting E_s. The proposed model gives precise estimations of the soil deformation modulus.

KEYWORDS: Soil deformation moduli; Soil physical properties; Linear genetic programming; Nonlinear modeling.

1. INTRODUCTION

The modulus of soil deformation is an important parameter for the behavior analysis of substructures. The soil modulus can be obtained from a stress-strain curve. According to the theory of elasticity, the strains experienced by the soil are linearly related to the stresses applied. This is not in practice true for soils since both elastic and plastic deformations occur during the loading. Because of the elasto-plastic behavior of soils, different moduli can be derived from the stress-strain (load-settlement) curves of laboratory or field test results [1, 2]. The soil deformation moduli are usually evaluated by laboratory or field methods. The field test results have been found to be more reliable than those of the laboratory methods [3]. Among different field tests, plate load tests (PLT) has been a traditional in-situ method for estimating the soil moduli. Using the results obtained from this test allows minimization of the effects of the scale factor and soil sample

disturbance [4]. Several researches have shown that the plate load test provides reliable predictions of the soil modulus [5]. Despite reliability of this testing method, little attention is devoted to developing empirical solutions relating the deformation moduli obtained from the plate load test results to the physical properties of soils. In this context, Reznik [3] proposed analytical expressions describing dependence of the plate load deformation moduli of collapsible soils on void ratio and moisture content. Nearly all of the developed empirical correlations for the soil moduli prediction have been established based on regression analysis [6]. The significant limitations the traditional statistical techniques strongly affect the prediction capabilities of the derived equations.

The main purpose of this paper is to obtain a new empirical relationship for determining soil secant modulus (E_s) utilizing linear genetic programming (LGP) method. Various predictor variables included in the analysis were coarse and fine-grained contents, grains size characteristics, liquid limit, moisture content, and soil density. The proposed model was developed based on several plate load tests performed in this study.

2. LINEAR GENETIC PROGRAMMING

Genetic programming (GP) [7] is a symbolic optimization technique that creates computer programs to solve a problem using the principle of Darwinian natural selection. The breakthrough in GP came in the late 1980s with the experiments on symbolic regression [7]. GP is an extension of genetic algorithms (GAs). This classical GP technique is also referred to as tree-based GP [7]. The main difference between the GA and GP approaches is that in GP the evolving programs (individuals) are parse trees rather than fixed-length binary strings.

Linear genetic programming (LGP) [8] is a subset of GP with a linear representation of individuals. In contrast with traditional GP, application of LGP in the field of civil engineering is totally new and original [9].The main characteristic of LGP in comparison with traditional tree-based GP is that expressions of a functional programming language (like LISP) are substituted by programs of an imperative language (like C/C++) [8, 10]. Figure 1 presents a comparison of the program structures in LGP and tree-based GP. A linear genetic program can be seen as a data flow graph generated by multiple usage of register content. That is, on the functional level the evolved imperative structure denotes a special directed graph. In tree-based GP, the data flow is more rigidly determined by the tree structure of the program [10, 11].

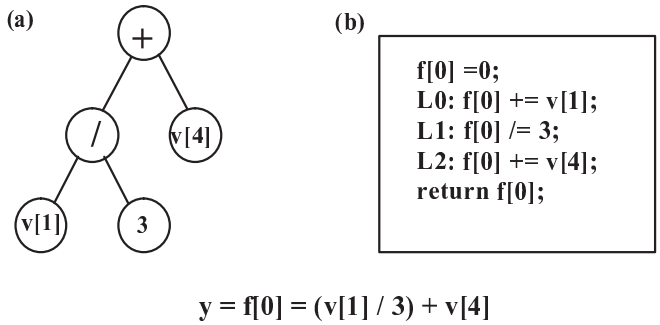

Figure 1. Comparison of the GP program structures. (a) Tree-based GP (b) LGP (after Alavi et al. [11]).

Almost all computer architectures represent computer programs in a linear fashion. In other words, computers do not naturally run tree-shaped programs. Hence, slow interpreters have to be used as part of tree-based GP. Conversely, by evolving the binary bit patterns in LGP, the use of an expensive interpreter (or compiler) is avoided. Consequently, LGP can run several orders of magnitude faster than comparable interpreting systems. The enhanced speed of LGP permits conducting many runs in realistic timeframes. This leads to deriving consistent, high-precision models with little customization [12, 13]. In the LGP system described here, an individual program is interpreted as a variable-length sequence of simple C instructions. The instruction set or function set of LGP consists of arithmetic operations, conditional branches, and function calls. The terminal set of the system is composed of variables and constants. The instructions are restricted to operations that accept a minimum number of constants or memory variables, called registers (r), and assign the result to a destination register, e.g., $r_0 := r_1 + 1$.

Here are the steps the LGP system follows for a single run [8]:

I. Initializing a population of randomly generated programs and calculating their fitness values.

II. Running a Tournament. In this step four programs are selected from the population randomly. They are compared and based on their fitness, two programs are picked as the winners and two as the losers.

III. Transforming the winner programs. After that, two winner programs are copied and transformed probabilistically into two new programs via crossover and mutation operators.

IV. Replacing the loser programs in the tournament with the transformed winner programs. The winners of the tournament remain without change.

V. Repeating steps two through four until termination or convergence conditions are satisfied.

Crossover occurs between instruction blocks. During this operation, a segment of random position and arbitrary length is selected in each of the two parents and exchanged. If one of the two children would exceed the maximum length, crossover is aborted and restarted with exchanging equally sized segments [10]. The mutation operation occurs on a single instruction set. Inside instructions, mutation randomly replaces the instruction identifier (a variable or a constant) by equivalents from valid ranges. Comprehensive descriptions of the basic parameters used to direct a search for a linear genetic program can be found in [8].

3. MODELING OF SOIL DEFORMATION MODULUS

In order to provide accurate assessment of the soil modulus, the effect of several influencing factors should be incorporated into the model development. It is well-known that the soil deformation moduli are affected by the basic soil properties (fabric characteristics), the state of the soil, and its consolidation history [1]. The main purpose of this study is to derive new relationships for the soil secant (E_s) modulus using LGP. The most important factors representing the soil deformation moduli behaviors were detected based on the literature review [1-4] and after a trial study. Consequently, E_s (kg/cm^2) was considered to be a function of several parameters as follows:

$$E_s = f\left(\frac{CC}{FC}, D_{10}, D_{30}, D_{60}, C_u, C_c, LL, W, \gamma, \gamma_d\right) \quad (1)$$

where,

CC (%): Coarse-grained content

FC (%): Fine-grained content

D_{10} (mm): Grain size for which 10 percentage of the sample is finer

D_{30} (mm): Grain size for which 30 percentage of the sample is finer

D_{60} (mm): Grain size for which 60 percentage of the sample is finer

C_u: Coefficient of uniformity (D_{60} / D_{10})

C_c: Coefficient of curvature ((D_{30})^2 / (D_{60} × D_{10}))

LL (%): Liquid limit

W (%): Moisture content

? (gr/cm^3): Soil bulk density

?$_d$ (gr/cm^3): Soil dry density

(Note: 1.0 kg/cm^2 = 0.1 MPa, 1.0 g/cm^3 = 0.1 KN/m^3)