Applied Soft Computing 18 (2014) 223–231

Contents lists available at ScienceDirect

Applied Soft Computing

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

Estimating of the Dry Unit Weight of Compacted Soils Using General Linear Model and Multi-layer Perceptron Neural Networks

Ersin Kolay*, Tugce Baser

Department of Geological Engineering, Bozok University, Yozgat, Turkey

ARTICLE INFO

Article history:
Received 28 September 2012
Received in revised form
19 December 2013
Accepted 22 January 2014
Available online 1 February 2014

Keywords:
Relative compaction
General linear model
Multi-layer perceptron neural networks
Earth fill
Standard Proctor test
Dry unit weight

ABSTRACT

Compaction of earth fill is a very important stage of construction projects. Degree of compaction is defined by relative compaction. The relative compaction of a compacted earth fill is calculated by dividing the dry unit weight obtained from in situ tests by-into the maximum dry unit weight obtained from laboratory compaction tests. This rate represents compaction quality in the field. Numerous test methods such as sand cone, rubber balloon, nuclear measurements, etc., are available to determine the maximum dry unit weight of soils in the field. It is well known that these methods have disadvantages as well as advantages. This study focused on estimation of dry unit weight of soils depending on water contents and P-wave velocities of compacted soils. The multi-layer perceptron (MLP) neural networks and general linear model (GLM) were used in this study to estimate the dry unit weight of different types of soils. Results of the MLP neural networks were compared with the GLM results. Based on the comparisons, it is found that the MLP generally gives better dry unit weight estimates than the GLM technique. The laboratory experiments and modeling studies showed that a new method for compaction control can be developed depending on P-wave velocity to estimate of the dry unit weight of compacted soils.

1. Introduction

The compaction theory advocates that the weight of solids per unit volume of soil can be increased by reducing the volume of voids through mechanical application. Compaction is carried out to optimize soil properties in the field. During the course of an appropriate compaction process, as the strength of soil increases, settlement potential, hydraulic conductivity and void ratio decrease [1]. Thus, the compaction is of paramount importance for all varieties of earth structures such as earth dams, highway embankments, compacted clay liners and retaining walls.

Compaction parameters ($\gamma_{d\text{-max}}$ and w_{opt}) of soil are firstly determined in the laboratory. Soil is then compacted in the project site according to these parameters. The compaction is generally performed by the standard Proctor [2] equipment in the laboratory. The aim of these tests is to determine the optimum water content (w_{opt}) and the maximum dry unit weight ($\gamma_{d\text{-max}}$), two key parameters of soils for earth structures. During the test, the soil is compacted at different molding water contents (w) through a particular and standardized compaction effort to obtain these parameters. A compaction curve is generally characterized by a peak point at which the soil density is the highest, which in turn depends on the $\gamma_{d\text{-max}}$ and corresponding w_{opt}. Soil is compacted in field having the same water content which is equal to w_{opt} during the construction and particular percentage of $\gamma_{d\text{-max}}$ is desired to achieve. For a wide variety of earth structures, the minimum acceptable dry density is usually specified at 95 percent of the $\gamma_{d\text{-max}}$ for the standard Proctor compaction [3].

Another critical issue pertaining to compaction is controlling the compaction parameters in the field. Relative compaction (RC) is defined by the equation below:

$$RC = \frac{\gamma_{d\text{-field}}}{\gamma_{d\text{-max-lab}}} \times 100 \quad (1)$$

RC value in the range of 95–98 percent indicates a successful compaction. There are numbers of test methods to determine the dry density of the compacted earth fill, such as nuclear density measurement, sand cone, rubber balloon, seismic velocity, and plate loading tests, but the most preferred methods are the nuclear and sand cone tests. Although the nuclear density method is more practical and faster, more reliable results are obtained by destructive and time-consuming techniques such as the sand cone and balloon methods [4]. During the course of sand cone test, vibrations in the vicinity of the test area and moisture content of material largely affect the results. The measurements obtained from nuclear densitometers are significantly affected by the grain size distribution

* Corresponding author. Tel.: +90 3542421112; fax: +90 3542421005.
E-mail address: ersin.kolay@bozok.edu.tr (E. Kolay).

1568-4946/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.asoc.2014.01.033

(gradation), and extreme care must be displayed during the application in the field because of radioactivity [4].

Accurate, easy and quick determination of density of soil constructed in field is important for calculation of RC. It was indicated above that dry density of soils determined by methods such as nuclear density measurements and sand cone test have some disadvantages. The disadvantages of these common methods gave rise to this study to determine the γ_d of the compacted soil with new method. The objective of this study is to establish preliminary relationships for estimating γ_d with the assistance of w and P-wave velocity (V_p). For this purpose, the standard Proctor test and V_p measurements were performed under laboratory conditions. In order to estimate the γ_d of compacted soils, GLM and MLP neural network models were established using the w, γ_d and V_p values. Finally, outputs of the GLM and MLP were compared with experimental test results.

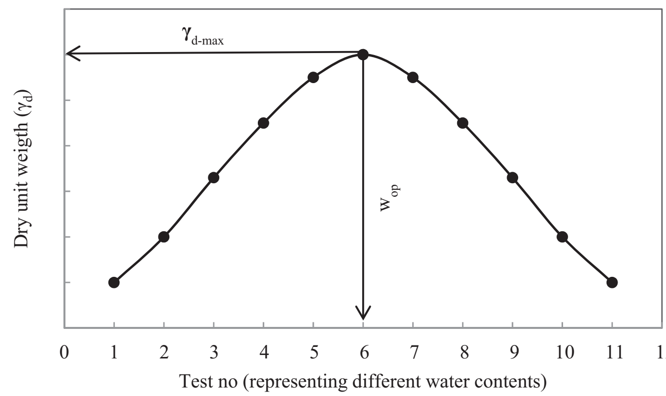

Fig. 1. Design of the test steps (test numbers) of standard Proctor tests.

2. Materials and test procedure

There are studies in the literature focused on relationships between grain components, plastic features, compaction energy and $\gamma_{d\text{-max}}$ and w_{opt} of soils [5–11]. These relationships were examined with regression equations. Several researchers used the ANN approach for estimating the w_{opt} and $\gamma_{d\text{-max}}$ of soils with consistency limits, unit weight and other index parameters of soils [12,13]. Sinha and Wang [14] modeled $\gamma_{d\text{-max}}$ of various compacted soils using density of solid phase, fineness modulus, effective grain size, plastic limit, and liquid limit via ANN models. They concluded that ANN prediction models can be used to predict the $\gamma_{d\text{-max}}$. The purposes of these studies are to reveal relationships between compaction parameters and other properties of soils and estimate $\gamma_{d\text{-max}}$ and w_{opt} from the estimation models without Proctor test. Different from those, in the present study, during Proctor tests V_p measurements and γ_d calculations were conducted on each w values and potential relations were examined between V_p, w, and γ_d. By means of constructed GLM and MLP models associated with laboratory data, estimation of $\gamma_{d\text{-field}}$ is aimed for calculation of RC using w and V_p values regarding soil compacted in field.

This study used eight natural soil samples taken from different locations in Yozgat (Turkey) province. The symbol *F* denotes fine-grained soils and symbol *C* is used for coarse-grained soils. Soils used in the study were classified according to Unified Soil Classification System (USCS) using consistency limits (W_L, W_P) and sieve analysis results. The samples were sieved using a #4 mesh size before the standard Proctor test.

According to the standard Proctor test, results of the four tests conducted with different water contents are sufficient to determine $\gamma_{d\text{-max}}$ and w_{opt}. In this study, standard Proctor tests were performed with eleven different water contents for each soil sample in order to investigate the relationship between V_p, w and γ_d, of the compacted soils. The tests were numbered according to increasing water content (Fig. 1). The tests numbered 1 through 5 are located on the dry side (left side) of w_{opt}, while the tests numbered 7 through 11 are located on the wet side (right side) of w_{opt}. Finally, the test number 6 was carried out at w_{opt} for all soil samples. Therefore, eleven distinct points for each soil sample were obtained on the compaction curve. Afterward, V_p, w and γ_d were measured for all the test points during standard Proctor tests.

In this study, an ultrasonic test device was used to measure the P-wave velocity of the compacted soil and in accordance with the direct method. P-wave velocities of the soils were measured at the completion of each compaction by smearing a sufficient amount of jelly on both transducers and then placing these transducers on surfaces of the compacted soil in a standard Proctor mold (Fig. 2a). Lastly, V_p was calculated dividing the length of the soil by transit time.

Also, effect of the compaction mold on P-wave velocity measurements was investigated. In order to understand if there is any difference between V_p value measured in the mold and V_p value measured outside of the mold, V_p measurements were obtained without compaction mold (Fig. 2b). While there is no change in transit time through soil (as shown in Fig. 2), travel times for a few soil increased about 1%. This can be attributed relaxation and disturbance of soils due to extraction process. One may conclude that there is no compaction mold effect for V_p measurements. Consequently, there is no harm to obtain V_p values of soils in the compaction mold.

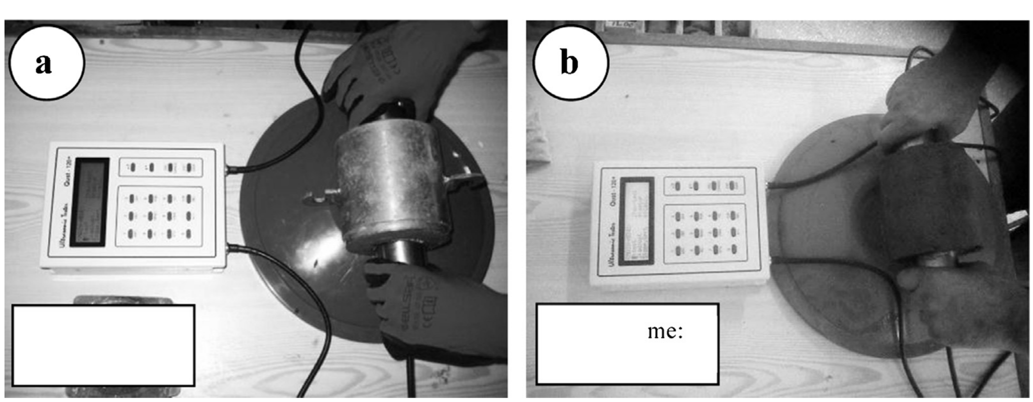

Fig. 2. Measurement of V_p of compacted soil using the portable device.