Probability Distributions of Geotechnical Parameters of a Silty Spoil Material

Alexandros I. Theocharis, Ioannis E. Zevgolis and Nikolaos C. Koukouzas

Abstract

During coal and lignite mining, vast amounts of overburden sterile materials (particularly in surface operations) are excavated to reach the deposits. These materials are characterised as waste and are dumped inside or outside the mine pit. Nowadays, sustainable waste management is a global priority, and thus, considerable efforts are made to exploit spoil heaps properly. Given that dumps were often not constructed with future valorisation in mind, they consist of randomly dumped mixed soils that result in a challenging construction environment (highly random, variable, and heterogeneous). The authors recently made a systematic analysis in order to quantify the uncertainty of the geotechnical properties of a Greek spoil heap. A database based on laboratory test results was established and statistically analysed; the results revealed and quantified the significant spoil material variability. In the present work, the focus is on the probability distributions of significant physical and engineering parameters. Due to the large variability of spoil materials, a reliability analysis rather than a deterministic one should be considered. For that purpose, the probability distributions of the parameters involved are essential and are thus, presented and analysed herein.

Keywords

Spoil heap · Spoil pile · Waste dump · Geotechnical properties · Probability distributions · Reliability analysis

A. I. Theocharis · N. C. Koukouzas
Centre for Research and Technology Hellas, Chemical Process and Energy Resources Institute, Athens, Greece

I. E. Zevgolis (✉)
School of Mining and Metallurgical Engineering, National Technical University of Athens, Athens, Greece
e-mail: izevgolis@metal.ntua.gr

1 Introduction

Coal and lignite (brown coal) mining has been an enormous industry aiming at extracting coal resources from the ground. During surface mining, the overburden of the lignite (primarily soil rather than rock) is removed and usually dumped as waste in spoil heaps (also referred to as spoil dumps, spoil piles, or waste embankments). Nowadays, significant consideration is given to properly exploiting spoil heaps within the framework of cyclic economy and sustainable management of mines and wastes. In Masoudian et al. (2019), a tentative overview of the geotechnical characteristics of European spoil heaps was presented, while in Zevgolis et al. (2018, 2020), the authors presented an in-depth statistical analysis of an important Greek heap. It was concluded that spoil materials present remarkable variability, significantly larger than natural soils, and a challenging scenario for engineering purposes.

For the efficient exploitation of spoil heaps, it is of utmost importance to understand and quantify the geotechnical properties of the spoil material. The present work refers to a massive spoil heap located in northern Greece, composed of soils from two adjacent surface lignite mines; it measures 5 km in length and more than 150 m in height. A laboratory campaign on the spoil material of this heap led to the creation of an extensive database of geotechnical parameters (Zevgolis et al., 2020). In this work, the distributions of the spoil's physical and engineering properties were analysed to gain an in-depth understanding of the properties' variability and provide input for reliability analysis.

2 Probability Distributions

Physical and engineering parameters were evaluated in terms of their probability distributions. Based on several observations in Zevgolis et al. (2020), a general stratigraphy

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or even characterisation of layers cannot be identified. Given the disordered structure of the spoil material, a statistical treatment of the heap can be employed considering a single material with significant inherent variability; this approach is used in Zevgolis et al. (2020) and for the following analysis. Herein, only normal and lognormal distributions were examined versus the laboratory results; mean value, standard deviation, and coefficient of variation (COV) are mentioned as calculated in Zevgolis et al. (2020). Finally, the goodness of fit is estimated based on Anderson–Darling statistical test (Stephens, 1974), and *p*-values of each fit are calculated; if $p > 5\%$ (as frequently assumed), then the null hypothesis (indicating that the data come from a normal- or lognormal-distribution) is accepted. Only the best out of the two fits (normal or lognormal) is mentioned in each figure.

Liquid limit (LL) and plastic limit (PL) are the two main physical parameters used for fine-grained soil characterisation (Fig. 1). LL (Fig. 1a) presents a high peak at 55–60%, larger than the mean value, and larger relative frequencies for high plasticity materials ($LL > 50\%$). Additionally, it presents a significant tail on low plasticity materials ($LL < 50\%$); the *p*-value is very low and normal distribution is not accepted as an accurate fit. Furthermore, PL (Fig. 1b) presents two high peaks at 15–25 and 35–45%. The normal distribution, in this case, cannot describe the first peak at 15–25%. However, most of the measurements (approx. 60%) still lie within one standard deviation, and the *p*-value is greater than 5%, denoting an acceptable normal fit.

Further frequently employed physical parameters and indexes are the liquidity index (LI) and the moisture (or water) content (w), and Fig. 2 presents their distributions. LI has a relatively normal distribution (with $p >> 5\%$) around its mean value—equal to 0.3—and exhibits values from 0 to 0.8, denoting a soil that behaves plastically; most cohesive soil deposits have LI values within this range. Moisture content cannot be accurately represented from a normal or a lognormal distribution as it exhibits two peaks at 20–25 and 40–45% and a large tail on values from 50 to 85%.

The two major investigated engineering parameters are the effective friction angle and the cohesion of the spoil. These two parameters define a failure surface for the material and are characteristic of its strength (Fig. 3). Effective friction angle (Fig. 3a), although having some gaps, can be represented by a normal distribution around its mean value of 25.2° (with $p > 5\%$). However, due to the peculiarities

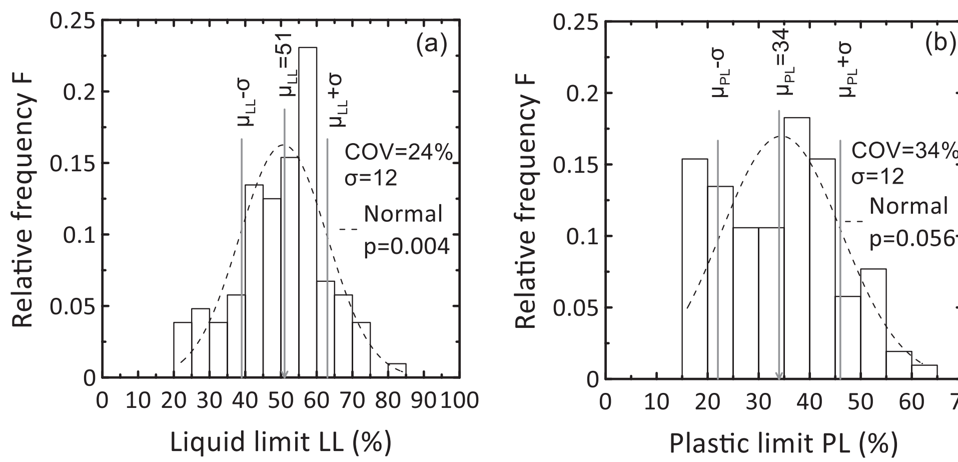

Fig. 1 Probability distributions of **a** liquid limit (LL) and **b** plastic limit (PL)

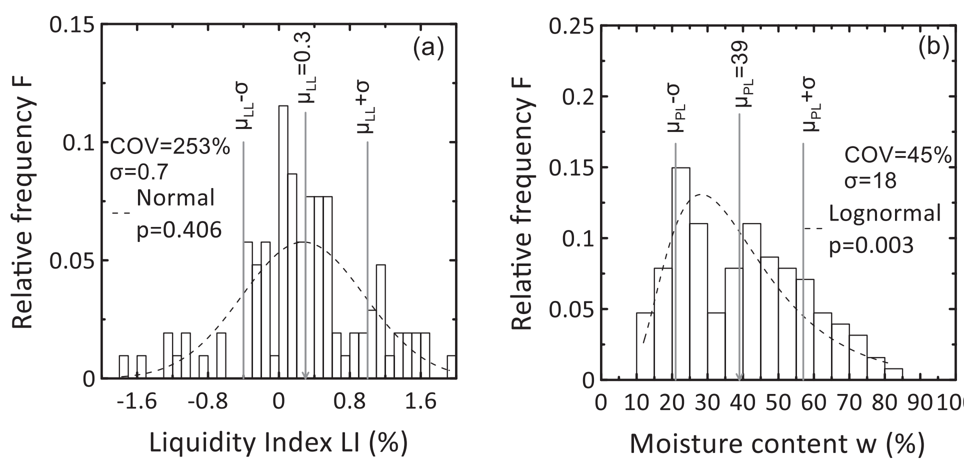

Fig. 2 Probability distributions of **a** liquidity index (LI) and **b** moisture content (w)

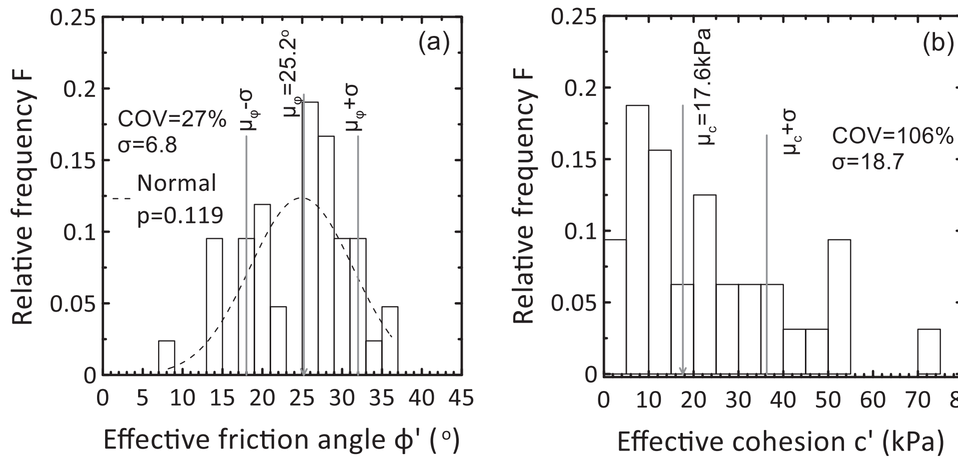

Fig. 3 Probability distributions of **a** effective friction angle (φ) and **b** cohesion (c)

illustrated in Fig. 3a, the normal fit should be applied cautiously. Additionally, 37% of the results lie outside one standard deviation of the mean value. Cohesion presents a distribution challenging to fit, as many samples have low or zero cohesion, and a large tail goes up to 80 kPa. This difficulty is also identified by the COV that is equal to 106%.

3 Conclusions

Geotechnical properties of spoil material from lignite mines generally present large variability. So, when it comes to stability or deformation analysis of spoil heaps, reliability analysis should be considered as an additional tool to the conventional deterministic analysis. For this purpose, the probability distributions of the major geotechnical parameters are essential and have been, herein, presented and analysed. Based on a standard statistical test and by testing the normal and the lognormal distribution for each case, the liquid limit, the liquidity index, and the effective friction angle could be accurately approximated by a normal distribution. Peculiarities in the distribution of the other examined parameters (plastic limit, moisture content, and cohesion), such as gaps, large tails, and two peaks, propose complex distributions that should be further analysed.

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