Soils and Foundations 2015;55(4):866–880

HOSTED BY

ELSEVIER

CrossMark

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf

Reliability analysis of strip footing considering spatially variable undrained shear strength that linearly increases with depth

Dian-Qing Li[a,*], Xiao-Hui Qi[a], Zi-Jun Cao[a], Xiao-Song Tang[a], Wei Zhou[a], Kok-Kwang Phoon[b], Chuang-Bing Zhou[c]

[a]*State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, 8 Donghu South Road, Wuhan 430072, PR China*
[b]*Department of Civil and Environmental Engineering, National University of Singapore, Blk E1A, 07-03, 1 Engineering Drive 2, Singapore 117576, Singapore*
[c]*School of Civil Engineering and Architecture, Nanchang University, Nanchang 330031, PR China*

Received 13 October 2014; received in revised form 4 February 2015; accepted 19 April 2015
Available online 21 July 2015

Abstract

This paper aims to investigate the reliability of strip footing in the presence of spatially variable undrained shear strength that linearly increases with depth. A non-stationary random field is used to model the spatially varying undrained shear strength. A strip footing example is presented to investigate the effect of spatially variable undrained shear strength on the performance of strip footing. The results indicate that the mean bearing capacity for spatially variable undrained shear strength is smaller than that obtained from a deterministic analysis. Both the mean and standard deviation of bearing capacity increase with increasing autocorrelation length. Ignoring the trend of undrained shear strength linearly increasing with depth will significantly overestimate the probability of failure of the strip footing. A factor of safety significantly below 3.0 may be used for designing strip footings if the trend of undrained shear strength linearly increasing with depth is considered properly.

Key words: Strip footing; Bearing capacity; Spatial variability; Random field; Reliability analysis

1. Introduction

In geotechnical engineering, both the deterministic approach and probabilistic approach have been used to evaluate the bearing capacity of a shallow foundation. Soil parameters generally vary spatially in both the horizontal and vertical directions (Li et al., 2011, 2015c; Cao and Wang, 2014; Jiang et al., 2015). Due to this nature, the probabilistic approach to evaluate the bearing capacity considering spatial variability in soil parameters has received more attention recently. A number of studies investigated the effect of spatial variability in soil properties on bearing capacity of shallow foundations (e.g. Fenton et al., 2008; Popescu et al., 2005; Kasama et al., 2012; Soubra and Mao, 2012; Teixeira et al., 2012; Wang and Cao, 2013).

The assessment of the stability of shallow foundations highly depends on the selection of a proper random field model for describing the spatial variability in soil properties. In the literature (e.g. Ching and Phoon, 2013a,b; Cho and Park, 2010; Griffiths et al., 2006, 2011; Jiang et al., 2014; Le, 2014; Lloret-Cabot et al., 2014; Low et al., 2007; Phoon et al., 2003; Zhu and Zhang, 2013; Zhu et al., 2013), the stationary random field model has been widely used to describe the spatial variability of soil parameters. In this model, a spatially variable parameter is customarily decomposed into a trend function and

*Corresponding author. Tel.: +86 27 6877 2496; fax: +86 27 6877 4295.
E-mail address: dianqing@whu.edu.cn (D.-Q. Li).
Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2015.06.017
0038-0806/

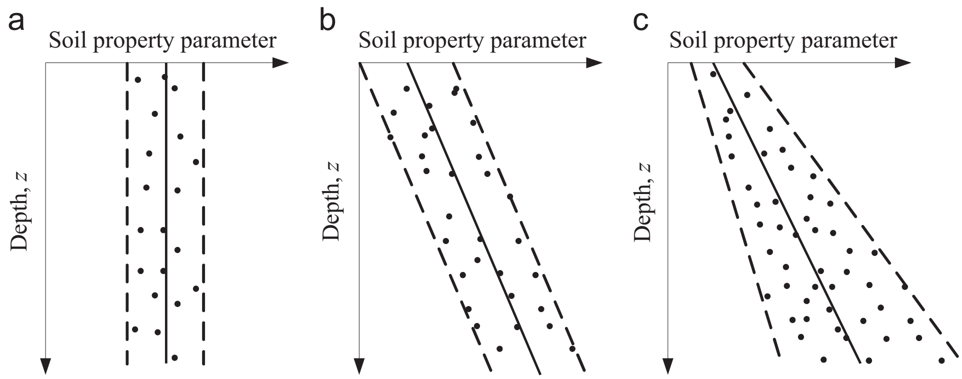

Fig. 1. Different types of spatial variability of soil property.

a fluctuating component (Phoon and Kulhawy, 1999). Note that the stationarity refers to as a weak or second-order stationarity. In other words, the mean and standard deviation of soil parameter do not vary with depth, and the covariance between the fluctuating components at two different depths is a function merely of their separation distance instead of the absolute position. Some data from in situ tests, however, reveal that the stationarity does not always characterize the spatial variability of soil property (e.g. Asaoka and A-Grivas, 1982; Haldar and Sivakumar Babu, 2009; Kulatilake and Um, 2003; Lumb, 1966; Li et al., 2014; Sivakumar Babu et al., 2006). Therefore, it is necessary to investigate the effect of spatially variable soil properties on shallow foundation reliability using a non-stationary random field model.

In view of the non-stationary characteristic underlying the spatial variability of soil properties, a number of researchers have paid attention to the non-stationary random field of spatially variable soil parameters(e.g. Kulatilake and Um, 2003; Sivakumar Babu et al., 2006; Srivastava and Sivakumar Babu, 2009). For example, Kulatilake and Um (2003) evaluated the variance and correlation distance of cone tip resistance (q_c) using two different random field models, namely one random field model with a constant trend function (stationary) and the other random field model with a linear trend function (non-stationary). They pointed out that the stationary random field model may produce misleading correlation distance. Sivakumar Babu et al. (2006) modeled the spatial variability of q_c using a non-stationary random field with a quadratic trend function, which was further used for the reliability analysis of a shallow foundation. Srivastava and Sivakumar Babu (2009) adopted a non-stationary random field with a linear trend function to describe the spatial variability of q_c associated with shallow foundation and slope stability problems. However, the non-stationary random field of undrained shear strength (s_u) where both the mean and standard deviation of s_u linearly increase with depth as reported in Lumb (1966) has not been investigated. Additionally, it is recognized that the coefficient of variation (COV) of s_u also varies with depth in the non-stationary random field of s_u. For convenience, however, a COV of s_u at the depth of influence zone is often adopted to represent the overall COV of s_u in geotechnical reliability problems (e.g. Sivakumar Babu et al., 2006; Srivastava and Sivakumar Babu, 2009). The resultant errors caused by this simplification are not clear. To validate this simplification, it is necessary to compare the reliability results obtained from a constant COV and a non-constant COV underlying the spatially variable s_u.

Table 1
Statistics of soil strength properties with depth z (modified from Lumb (1966)).

Soil	Property	Mean (μ)	Standard deviation (σ)	COV (%)
Marine clay in Hong Kong	s_u (kPa)	$1.04z+1.89$	$0.19z+0.35$	18.4
London clay	s_u (kPa)	$22.1z$	$3.58z$	16.2

This paper aims to investigate the reliability of strip footing in the presence of spatially variable undrained shear strength that linearly increases with depth. A non-stationary random field where both the mean and standard deviation of s_u linearly increase with depth is used to model the spatial variability of s_u, which is discretized by Karhunen–Loeve (KL) expansion (e.g. Phoon et al., 2002). Monte Carlo simulations are carried out to evaluate the statistics of bearing capacity and reliability of strip footing. For comparison, the corresponding results obtained from the stationary random field of s_u are also provided. A strip footing example is presented to investigate the effect of spatial variability on the statistics of bearing capacity and the reliability of strip footing.

2. Spatial variability of undrained shear strength

Soil is a complex engineering material that has been formed by a combination of various processes, such as geologic, environmental, and physical–chemical processes (Tang et al., 2013, 2015). Soil properties in situ exhibit spatial variability due to the effect of these natural processes. After examining the statistical properties of London Clay and four types of soils in Hong Kong, Lumb (1966) divided the spatial variability in soil property into the following three types (see Fig. 1): (a) mean and standard deviation of soil parameter constant with depth; (b) mean of soil parameter linearly increasing with depth while standard deviation of soil parameter constant with depth; (c) both mean and standard deviation of soil parameter