Cyprus University of Technology

Faculty of Engineering and Technology

Doctoral Dissertation

REDUCING STATISTICAL UNCERTAINTY IN GEOTECHNICAL ENGINEERING DESIGN RELYING ON TARGETED FIELD INVESTIGATION: A RANDOM FIELD APPROACH

Panagiotis Christodoulou

Limassol, May 2020

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Chapter Abstract

Chapter 1 – A comparative assessment of the methods-of-moments for estimating the correlation length of one-dimensional random fields

Due to geological processes, soil properties vary in vertical and horizontal directions which is defined as inherent uncertainty of soil. This type of uncertainty may seriously affect the reliability of all geotechnical structures. The inherent uncertainty of soil properties is modelled as a random field, which is described by the mean, standard deviation and correlation length (also known as scale of fluctuation, θ) of soil properties. In this Chapter, the effectiveness of eight methods-of-moments for estimating the correlation length θ is investigated. This is done by generating samples of one-dimensional random fields for pre-defined values of the correlation length, which is then estimated by the different methods. For each method, the influence of the sampling domain length D and sampling interval d_x on the estimation of θ were investigated, and the results are quantified in the form of errors over the parameter space, defined by the dimensionless ratios D/θ and θ/d_x. Through the present analysis, one is able to assess the reliability of θ estimations obtained in practice, by mapping the conditions of any given experiment i.e., sampling domain, interval and estimated correlation length, onto the parameter space. The expected error associated with each method used is also quantified. Through this analysis a comparative assessment of the methods is also obtained.

Chapter 2 – Spatial Correlation Length of Soils in Practice

This Chapter is a study on the spatial correlation length of soils in practice. On this basis, a series of Dynamic Probing Light (DPL) penetrations were carried out in cohesive and cohesionless soils in various sites in Cyprus. The reliability of θ estimations obtained were assessed by mapping the conditions i.e., sampling domain, the interval and estimated correlation length, into the findings of Chapter 1. Continuous sampling and laboratory tests on undisturbed samples (referring to clays) also took place. The findings verify that even the so-called "homogenous soils" can be far from uniform. Indeed, the spatial correlation length θ of the soils examined was found to be as low as a few tens of centimeters. These values are far from the $\theta = \infty$ value that might be used in a simplistic probabilistic analysis.

Chapter 3 – The effect of targeted field investigation on the reliability of axially loaded piles

This Chapter deals with the practical problem of the effect of targeted field investigation on the reliability of axially loaded piles, aiming at an optimal serviceability and ultimate limit state design. This is done in a Random Finite Element Method (RFEM) framework properly considering sampling in the analysis; the RFEM method combines finite element analysis with the random field theory. In this respect, the freely available program called RPILE1D has been modified as to consider sampling of soil and pile properties. In each RFEM realization, failure is considered to have occurred when the calculated shaft resistance of pile considering spatially uniform properties (average of sampled values from the soil and pile random fields), is greater than the respective one considering spatially random properties for both soil and pile. The necessary numerical demonstration of the proposed methodology is done by considering two sampling strategies: a) sampling from a single point and b) sampling from a domain, both along the pile, whilst the various parameters governing the statistical uncertainty of the problem are examined. As shown, by adopting the proper sampling strategy (defined by the number and location of sampling points along the pile), the statistical error can be minimized or even, eliminated. The error is quantified by the difference in the probability of failure comparing different sampling scenarios. Another main finding is that, the optimal horizontal sampling location is at location where the pile is going to be constructed. In addition, it was observed that, the benefit from a targeted field investigation is much greater as compared to the benefit gained using characteristic soil property values.

Chapter 4 – The effect of targeted field investigation on the reliability of earth retaining structures

This Chapter introduces the concept of targeted field investigation on the reliability of earth-retaining structures in both active and passive state, which is implemented in RFEM framework. The open source RFEM software REARTH2D was used and modified suitably in order to accommodate the purposes of the present research. Soil properties are modelled as random fields, and measurements are modelled by sampling from different points of the field domain. Failure in the active state is considered to have occurred when the “actual” resultant earth pressure force on the retaining wall (calculated using the friction angle random field) is greater than the respective “predicted” force (calculated using an homogenous friction angle field characterized by the mean of the values sampled from the respective random field). For the passive state the failure is considered to have occurred when the “actual” resultant earth pressure force is less than the respective “predicted” one. Two sampling strategies are investigated, namely, sampling from a single point and sampling from a domain, through an extensive parametric analysis. As shown, the statistical uncertainty related to soil properties may be significant and can only be minimized by performing targeted field investigation. Among the main findings is that the optimal sampling location is immediately adjacent to the wall face and half wall height away from the wall face for the active and passive state respectively. In addition, it is advisable that the entire wall height be considered in sampling for both states. Finally, it was observed that the benefit from a targeted field investigation is much greater as compared to the benefit gained using characteristic values in a Load and Resistance Factor Design framework.

Chapter 5 – Reducing statistical uncertainty in elastic settlement and bearing capacity analysis of shallow foundations relying on targeted field investigation

The present Chapter deals with the practical problem of reducing statistical uncertainty in elastic settlement and bearing capacity analysis of shallow foundations relying on targeted field investigation aiming at an optimal design. In a targeted field investigation, the optimal number and location of sampling points are a priory known. As samples are taken from the material field (i.e. the ground), which simultaneously is a stress field (stresses caused by the footing), the coexistence of these two fields allows for some points in the ground to better characterize the elastic settlement and the ultimate bearing capacity of foundation. These points are identified herein through an extensive parametric analysis of the factors controlling the magnitude of settlement and bearing capacity. This is done in an advance probabilistic framework using the RFEM properly considering sampling of soil properties. In this respect, the open source RSETL2D and RBEAR2D programs, has been modified as to include the function of sampling of soil property values from the generated random fields and return the failure probability of footing against excessive settlement and bearing capacity respectively. Two sampling strategies are examined: a) sampling from a single point and b) sampling a domain (the latter refers to e.g. continuous Cone Penetration Test data). As shown, by adopting the proper sampling strategy (defined by the number and location of sampling points), the statistical error can be significantly reduced. The error is quantified by the difference in the probability of failure comparing different sampling scenarios. Finally, from the present analysis it is inferred that, the benefit from a targeted field investigation is much greater as compared to the benefit from the use of characteristic values in a Limit State design framework.