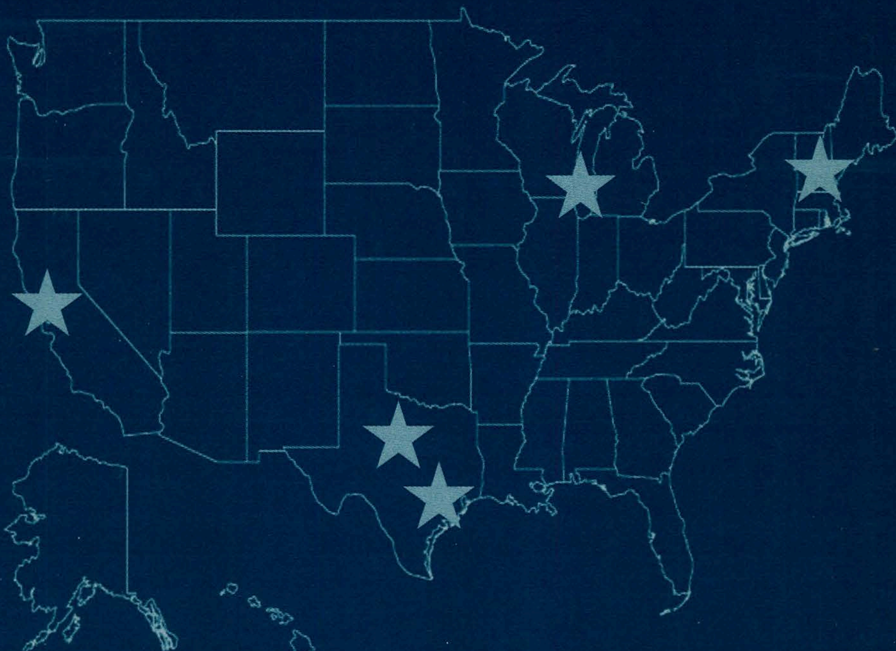
Geotechnical Special Publication No. 121

# Probabilistic Site Characterization at the National Geotechnical Experimentation Sites



Edited by
Erik VanMarcke
Gordon A. Fenton

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# Probabilistic Site Characterization at the National Geotechnical Experimentation Sites

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Abstract: The papers in this Geotechnical Special Publication explain and demonstrate a broad range of methods of probabilistic site characterization using soil data obtained at one or more National Geotechnical Experimentation Sites (NGES), in particular the NGES locations at Texas A&M University, Treasure Island Naval Station, University of Massachusetts at Amherst, University of Houston and Northwestern University. Among the topics covered are statistical estimation procedures based on homogeneous random field theory, with as parameters the mean, coefficient of variation and scale of fluctuation, as well as two alternate fractal representations of spatial variation in soil deposits, a neural network model, and an approach to correlating soil properties based on the concept of fuzzy subsets. There are results for both horizontal and vertical variation of measured soil properties, under different assumptions about trend removal and layering at a site, or about the validity of combining data from non-contiguous soil deposits. The aim of this publication is to provide both a state-of-the-art assessment of statistical methods of soil profile modeling and a set of baseline statistics, representative of the well-documented NGES, intended to serve as *a priori* information for probabilistic site characterization.

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# Preface

This Geotechnical Special Publication consists of a series of papers presenting a wide range of methods of probabilistic site characterization and demonstrating them using soil data obtained at the National Geotechnical Experimentation Sites (NGES), in particular the sites at Texas A&M University, Treasure Island Naval Station (California), the University of Massachusetts at Amherst, the University of Houston and Northwestern University. An earlier volume in this series, Geotechnical Special Publication No. 93, provides relevant background material on the layouts of borings and cone penetrometer test (CPT) soundings, the geological setting, and the types of field and laboratory tests performed at each site.

Among the topics covered in this publication are, in sequence, statistical estimation procedures based on homogeneous random field theory, with as principal parameters the mean, the coefficient of variation and the scale of fluctuation (O'Neill and Yoon; Wu; Akkaya and Vanmarcke), two different fractal representations of spatial variation in soil deposits (Kulatilake and Um; Fenton and Vanmarcke), a neural network model (Juang and Jiang), and a new approach to correlating CPT data with soil type and engineering properties based on the concept of fuzzy subsets (Zhang and Tumay). There are results for both horizontal and vertical variation of measured soil properties – most often CPT data -- under various assumptions about trends-in-the-mean and layering by soil type, or about the validity of combining, for statistical analysis purposes, data from similar non-contiguous soil deposits (e.g., data on variation-with-depth of CPT tip resistance from different clay layers at one site or from all layers at all five sites).

Useful perspectives on the different sources of uncertainty of soil properties is offered, in this volume, by Kulatilake & Um and Akkaya & Vanmarcke. Equations for the variogram and several equivalent representations of second-order statistics of homogeneous (or stationary) one-dimensional random variation, can be found in the papers by O'Neill & Yoon and Kulatilake & Um. The paper by Fenton and Vanmarcke focuses on alternative spectral representations. The results for the various second-order descriptors (correlation functions, variograms, spectral density functions) and their parameters (like the scale of fluctuation) differ greatly depending on whether (and how) trends-with-depth or layering-by-soil-type are modeled, as informed either by the site-specific measurements or by information about site geology. The papers by O'Neill and Yoon (using data from the University of Houston NGES) and Wu (integrating new data from the Northwestern University NGES) report stable estimates for coefficients of variation and scales of fluctuation based on analyses of either the raw data originating from nominally homogeneous domains or normalized data (obtained from measured values by first subtracting trends or layer-specific means and perhaps dividing residuals by a local standard deviation).

When trends and other site-specific information are ignored in the data processing, evidence of fractal behavior, implying fluctuations across a range of spatial scales, appears in the second-order statistics (Fenton and Vanmarcke, Kulatilake and Um); the sampling interval and the size of the domain sampled or analyzed also affect the parameter estimates. Transformation of the raw data prior to statistical analysis, for example by first calculating the logarithms of the measured CPT tip resistance values (Fenton and Vanmarcke), further complicates interpretation of the results. The paper by Akkay and Vanmarcke reports estimated coefficients of variation and scales of fluctuation for many different soil properties at the Texas A&M NGES sand and clay sites. Kulatilake and Um concentrate on statistical analyses of cone tip resistance data from the Texas A&M NGES clay site, while Fenton and Vanmarcke aggregate all the CPT data from the five NGES, disregarding trends and other site-specific information. Only Zhang and Tumay's paper deals explicitly with cross-correlation between measured values, focusing on how CPT data inform about soil type and engineering properties.

Knowledge about the inherent variability of soil properties is of critical importance in reliability analysis of geotechnical facilities, risk assessment for decision support or regulatory control, and planning and optimization of site-specific exploration and testing. The dual aim of this publication is to present an overview of traditional and novel statistical methods of soil profile modeling and provide a set baseline statistics, representing the well-documented NGES, that can serve as *a priori* information, in a Bayesian sense, about pattern of spatial variation of soil properties in probabilistic site characterization worldwide.

The papers in this volume, having been accepted for publication by the editors based on a process of peer review in accordance with the standards of ASCE and the Geo-Institute, are eligible for discussion in the Journal of Geotechnical and Geo-Environmental Engineering and for ASCE awards. Early versions of most of the papers were presented, discussed and criticized at a workshop held in conjunction with the Geo-Institute Conference in Seattle, WA (1998) and sponsored by the G-I Committee on Risk Assessment and Management.

The Federal Highway Administration (FHWA) and the National Science Foundation (NSF) provided funding for the NGES program during the 1990's. Support for the project on probabilistic site characterization at the NGES, conducted by the G-I Committee on Risk Assessment and Management, and for related research by Dr. Akkaya and co-editor Dr. Fenton during extended visits to Princeton University, came from FHWA through the Geo-Institute of ASCE. Special thanks are due to Albert F. DiMillio of FHWA for his leadership in the NGES program and to Carol Bowers of the Geo-Institute for critical project management support.

Erik Vanmarcke, Princeton University
and
Gordon Fenton, Dalhousie University

# Contents

# Spatial Variability of CPT Parameters at University of Houston NGES

Michael W. O'Neill[1] and Gil Lim Yoon[2]

## Abstract

Cone penetrometer test (CPT) records for the University of Houston National Geotechnical Experimentation Site were analyzed for variability using simple statistical methods. The site, which comprised approximately 4000 $m^2$ in area, consisted of generally insensitive clays interbedded with seams and layers of fine sand and clayey silt that were overconsolidated in Pleistocene times by desiccation. CPT records were examined by (a) simple direct comparison, (b) computation of depthwise means and coefficients of variation, (c) estimation of the probability distribution model, (d) determination of vertical and horizontal variograms and correlation distances, and (e) development of Kriging surfaces for the CPT tip and sleeve resistance values across the site. Together, these results constitute an appropriate, practical geostatistical characterization of the CPT test results at the site.

## Introduction

The University of Houston National Geotechnical Experimentation Site (NGES-UH) was operated from 1979 - 2000 by the senior author. Its primary use was the testing of full-scale shallow and deep foundations — particularly the effects of construction methods and technologies on the geotechnical and structural performance of foundations. However, during the course of its operation many *in situ* soil tests were performed on the site, including a large number of cone penetrometer tests (CPT's). Selected CPT records from two series of tests are considered herein to document the general statistical characteristics of the soil at the site, which is geologically typical of many Pleistocene terrace sites in the southeastern United States.

The NGES-UH consisted of soils from two Pleistocene terrace (sedimentary) deposits, as indicated in Fig. 1. The older and deeper deposit, termed locally the

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