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Incorporating the Site Variability and Laboratory/In-situ Testing Variability of Soil Properties in Geotechnical Engineering Design

INTRODUCTION

The subsurface soil conditions usually subjected to significant degree of variability in terms of soil type, layering, and their properties. The soil borings and in-situ tests are carried out at fixed locations, and laboratory tests are conducted on samples retrieved from discrete depths, which can increase the variations of soil properties. The soil variability is a complex phenomenon that arises from different sources of uncertainties. The inherited spatial variability of soil during deposition, random measurement error, statistical uncertainty, and model bias uncertainty. The first source of uncertainty results from natural geologic processes that change the characteristics of soil properties. It is described as a random field with mean (μ), coefficient of variation (COV), and scale of fluctuation. Measurement error is caused by equipment- and/or operator-induced variation, which can take place from one test to another. Equipment error arises from variations when tests are set up and loads are delivered. Operator-induced variation occurs when personal judgement is required to read scales (take measurements). Statistical uncertainty is associated with choosing the best correlation required to interpret data from a range of equations. The bias model uncertainties are due to variations between model's predictions and measured values.

Several techniques were proposed to evaluate the site variability, such as Geographic Information Systems (GIS), geostatistical methods, and multivariate statistical analysis. The GIS with different spatial interpolation methods, including inverse distance and Kriging, was used in many engineering applications. The Sequential Gaussian Simulation (SGS) can be used to generate variable maps and reproduce actual statistics, histograms, and variograms of the spatial variability for the data without smoothing effect.

OBJECTIVES

- Evaluate the operator-induced and equipment-induced variations on design soil properties;
- Evaluate the site spatial variations of design soil properties;
- Evaluate the best spatial interpolation method to generate synthetic CPT profiles and soil boring data from the existing CPT and soil boring data of the specific site;
- Incorporate special site variability into LRFD design of pile foundations; and
- Incorporate special site variability into different geotechnical engineering applications.

SCOPE

In this study, the site variability was evaluated through conducting in-box, laboratory, and field tests to evaluate variability of measured strength/stiffness parameters from different devices and the variability of the different soil properties in addition to evaluating the spatial site variability from soil borings and/or in-situ tests for many geotechnical engineering problems.

The in-box tests included constructing and testing several sections using different devices, such as dynamic cone penetrometer (DCP), light falling weight deflectometer (LFWD), Geogauge, plate load test (PLT), nuclear density gauge (NDG), E-gauge, and dirt seismic portable analyzer (D-SPA). The field tests were conducted using Geogauge, LFWD, and DCP on several sections from different projects. The tests were conducted by different operators at different locations. The operator- and location-related variabilities in terms of COV were evaluated.

Typical laboratory tests that included Atterberg limits, unconsolidated undrained (UU) triaxial, direct shear, consolidation, and California bearing ratio (CBR) tests were conducted on specimens of various soil types using different operators to evaluate the specimen- and operator-related variability of different soil properties in terms of COV.

Several geostatistical methods, such as semivariogram, probabilistic approach, Bayesian analysis, Fenton and Griffiths method, and Naghibi and Fenton method, were used to evaluate the spatial site variability from soil borings with laboratory data and/or in-situ cone penetration test (CPT) data for incorporating the effect of specific site variability into many geotechniocal engineering applications such shallow foundation, deep foundations, and slope stability analysis.

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METHODOLOGY

Several approaches were used to evaluate the different sources of geotechnical variability and variability of soil properties. This includes conducting in-box and field tests on different sections using different devices such as DCP, LFWD, Geogauge, PLT, NDG, E-Gauge, and D-SPA; conducting laboratory tests such as UU, direct shear, and consolidation tests on different type soil specimens; and evaluating the site variability from soil borings with lab tests and/or in-situ CPT data. The tests were performed by several operators on different locations/specimens.

Different geostatistic methods were used to evaluate site variability from soil borings with lab tests and/or CPT tests to incorporate its effect in several geotechnical applications, such as pile and shallow foundations and slope stability analysis. This included X-Bar/R, ANOVA, second moment analysis, spatial correlation and semivariogram modeling, Bayesian technique, probabilistic approach, Fenton and Griffiths modeling, and Naghibi and Fenton modeling.

The results of in-box, field, and typical lab tests were statistically analyzed using the X-Bar/R and ANOVA to evaluate the mean value and COV of the testing measurements.

The semivariobram approach was used to evaluate site variability for 10 sites with multi CPT tests and multi soil borings. The COV due to spatial variability (COVRspatial) was determined for each site and used to calibrate the specific site resistance factor for LRFD design of piles.

The Bayesian analysis was used to update μ, standard deviation, and COV of the measured/ predicted pile capacity of site from national/state data and using the pile load tests of new site. The updated variables were used to calibrate the resistance factors for LRFD design of piles.

The probabilistic approach was used to analyze the CPT tests performed at LA 1 using the SGeMS program. The software provides confidence intervals (CI) to the estimated data between test points. The operator can then choose from a range of confidence limits (0 to 100%).

The effect of spatial variability on slope stability analysis was evaluated using a two-layer embankment model that was run for different scenarios for drained and undrained conditions. The effect of COV of different soil properties on the factor of safety was evaluated using the Slide 2018 2D software (Figure 1).

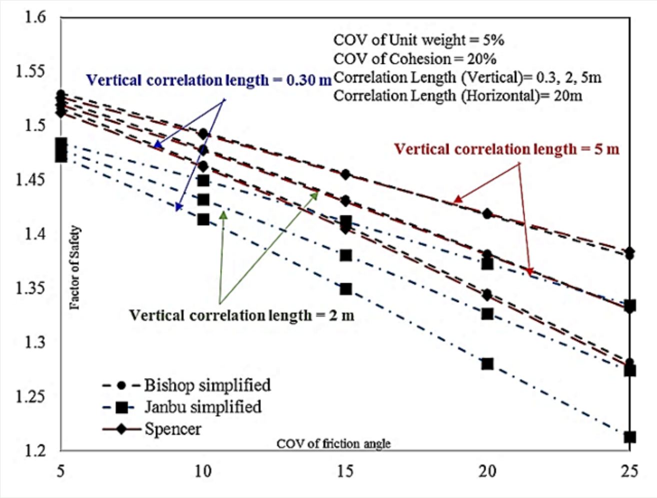

Figure 1. Factor of safety vs COV of Φ at different vertical variability levels of drained condition

The Naghibi and Fenton method was used to incorporate the variability in soil properties for cohesive and cohesionless soils in terms of COV and the distance from soil boring(s) for analysis and design of deep foundations. The resistance factors of pile foundations was evaluated using the Slide 2018 2D software.

The Fenton and Griffiths method was used to incorporate the effect of variability in soil properties in terms of COV and distance from soil boring(s) for analysis of shallow foundations. The resistance factors of shallow foundations was evaluated using Rbear2D software.

CONCLUSIONS

- The COV of laboratory tests (UU, Atterberg limits, direct shear tests, consolidation, CBR) ranged from 0.5 to 30.6%. The COV for the different devices (DCP, LFWD, Geogauge, PLT, NDG, E-Gauge,D-SPA) ranged from 1.6 to 25.5.1%.
- The effect of site variability can be implemented into LRFD design of pile foundations through evaluating the spatial COV and/or total COV of the site using the semivariogram.
- For sites with lower site variability than the design method variability, the total COV decreases and the corresponding resistance factor increases. Hence, giving a credit to low variability sites as compared to high variability sites.
- The Bayesian analysis can be used to update the mean (μ) and COV of measured/predicted pile capacity of new specific site, and hence update the resistance factor for the specific site.
- The factor of safety for slope stability analysis decreases with increasing the COV of either cohesion and/or friction angle and increases with increasing the vertical correlation length.
- The resistance factor of shallow and deep foundations decreases with increasing the COV of cohesion/friction angle and with increasing the distance between foundation and soil boring.

RECOMMENDATIONS

- It is recommended to use the variability of soil properties evaluated in the laboratory and AMRL for geotechnical engineering analysis and design.
- It is recommended to consider the variability of measurements by the different devices (DCP, Geogauge, LFWD, NDG, E-Gauge, D-SPA) in different geotechnical applications.
- It is recommended to implement the semivariorgam analysis to evaluate the site variability from multi-CPT tests and/or multi soil borings for use in different geotechnical applications.
- It is recommended to apply the Bayesian analysis to incorporate site variability to update the resistance factor for the new specific site.
- It is highly recommended to consider variability in soil properties in evaluating the slope stability analysis of slopes, embankments, and MSE walls.
- It is recommend to explore the Fenton and Griffiths method to incorporate variability in soil properties and distance from soil boring(s) for analysis and design of foundations.