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Soil classification analysis based on piezocone penetration test data — A case study from a quick-clay landslide site in southwestern Sweden

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ABSTRACT

Cone penetration test (CPT) and piezocone penetration test (CPTu) methods can be effective in site characterization and are important for soil profiling and classification. Extensive experience exists that relates CPT and CPTu results to soil type/state and these are often the preferred in-situ tools for subsurface investigations, soil exploration and the evaluation of different engineering soil properties, compared with conventional laboratory testing. In this study, eight methods, consisting of traditional and nontraditional ones, for soil classification and prediction of soil type and state using CPTu data were examined and tested. The CPTu data not only provide valuable information on soil types, but also can be used for deriving correlations with engineering soil properties for the purposes of hazard analyses and design of foundations. We carried out and established a region-specific correlation between CPTu data and soil properties for three location test points in southwestern Sweden at a quick-clay landslide site. First, an analysis of the available CPTu data was performed and then classification of the soils was made. After determination and identification of the soil profiles, the results were further evaluated using the Unified Soil Classification System (USCS) and converted to CPT–SPT charts. We summarize results from each of these methods, including a description of the available charts and their performance for soil classification. From CPTu data, we provide high-resolution soil profiles from the three test points. Our work allowed the detection of potential sensitive fine-grained clays, which are responsible for landslides in the study area, however, in most cases occurring above coarse-grained materials. These materials were also detected in the CPTu data and show good correspondence with available reflection seismic profiles from the site.

1. Introduction

Soil classifications (type and/or state) into groups that have similar geotechnical behavior can provide useful guidance for geotechnical engineers. The conventional method for determining a soil type is by laboratory classification of samples retrieved from boreholes (Cai et al., 2011). However, in the field, and in practice, the Standard Penetration Test (SPT) and the cone penetration test (CPT) are two commonly used in-situ tests for assessing and classifying soil types. The CPT has proven to be the more reliable, cost effective and valuable tool in characterizing subsurface conditions and in assessing various soil properties, including the estimation of the liquefaction potential at a particular site. If a CPT device is also capable of simultaneously measuring pore water pressure, then the measurements are referred to as a piezocone penetration test (PCPT) or CPTu (Baligh et al., 1980; Tumay et al., 1981; Zuidberg et al., 1982; Lunne et al., 1997; Cai et al., 2010).

Advocates of the CPT method argue its capacity to define a continuous depth profile and its repeatability (Robertson, 2004). Its ability to detect thin layers makes the CPT method superior to the SPT method. Although, there are several classification-based algorithms to predict the soil type and state using CPT or CPTu data (e.g., Begemann, 1965; Douglas and Olsen, 1981; Jones and Rust, 1982; Senneset and Janbu, 1985; Robertson et al., 1986; Olsen and Malone, 1988; Campanella and Robertson, 1988; Robertson, 1990, 2009; Jefferies and Davies, 1991, 1993; Olsen, 1994; Olsen and Koester, 1995; Olsen and Mitchell, 1995; Eslami and Fellenius, 1997; Robertson and Wride, 1998; Jefferies and Been, 2006; Jung et al., 2008; Schneider et al., 2008; Cetin and Ozan, 2009), the proposed charts by Robertson et al. (1986) and Robertson (1990) have been popular and widely used (Long, 2008; Cai et al., 2011). The non-normalized charts by Robertson et al. (1986) define 12 Soil Behavior Type (SBT) zones, whereas, the normalized charts by Robertson (1990) define 9 zones. This difference has generated some confusion among geotechnical engineers and led Robertson (2010, 2012) to provide an update of the charts.

In this paper we aim to classify soil types in a quick-clay landslide site in southwestern Sweden on the basis of CPTu data. Our ultimate goal is to determine and identify sensitive fine-grained clays, which may be responsible for landslides. The study area (Fig. 1) has been the subject of several geophysical studies, such as reflection and refraction seismic (Malehmir et al., 2013a, 2013b; Adamczyk et al., 2013, 2014; Lundberg et al., 2014) and electromagnetic (Shan et al., 2014) investigations, as

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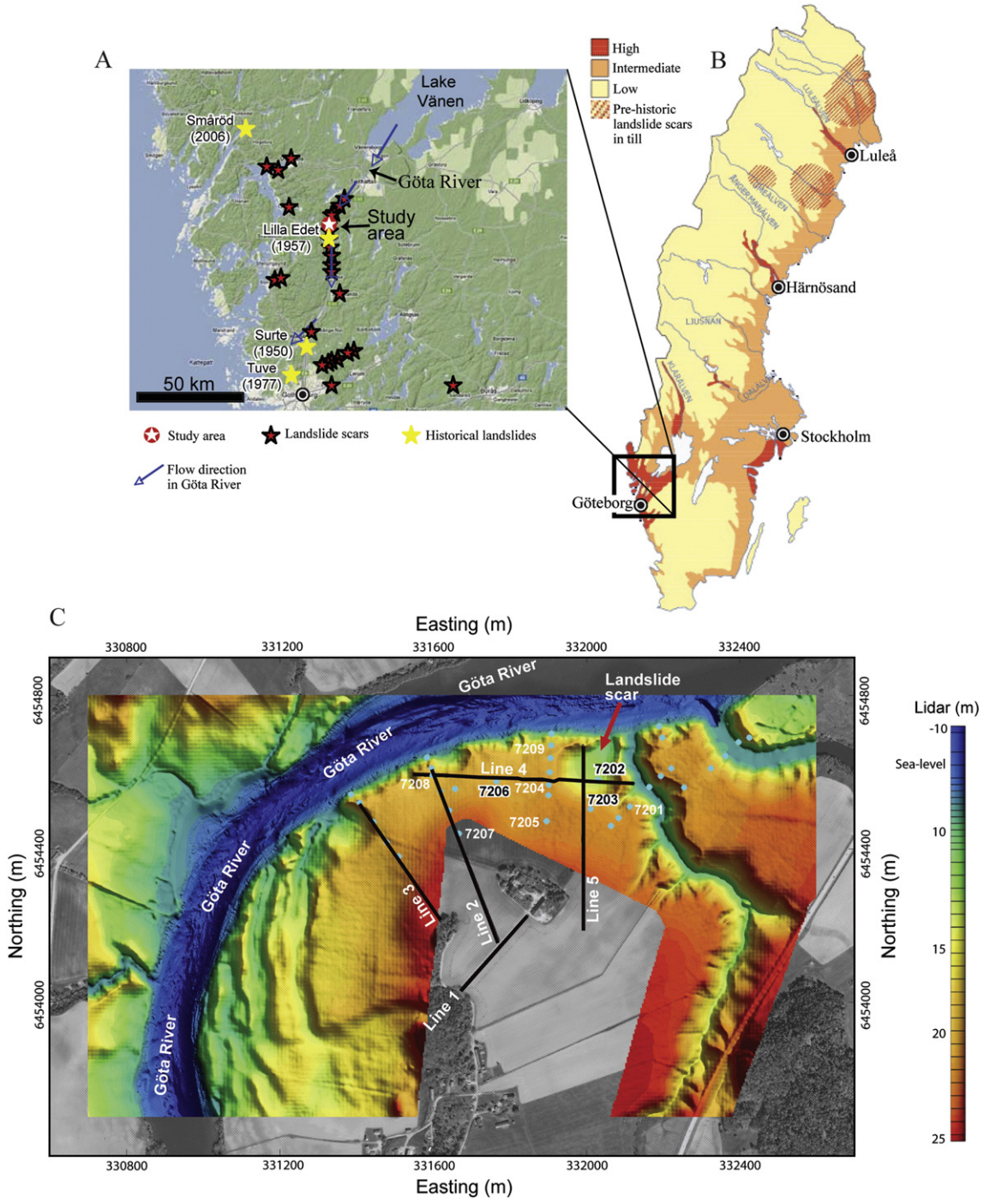

Fig. 1. (A) Location map of the study area, (B) landslide risk map of Sweden showing the location of major landslides and (C) the location of the test points in our study area. CPTu data from 7202, 7203 and 7206 are used in this study. CPT point 7202 occurs within a major quick-clay landslide scar (noticeable in Lidar data). Black lines show the location of existing geophysical profiles. Reflection seismic data from lines 5 and 4 are presented and compared with our results in this study. Modified from Malehmir et al. (2013a, 2013b).

well as geoelectrical and CPT measurements (Löfroth et al., 2011). We use the CPT data presented by Löfroth et al. (2011) in this study. In order to provide insight on the applicability of the various soil classification methods for assessment of soil types and states using CPTu site investigations we tested eight CPT based classification methods. Our objective was to determine which one(s) provide the highest resolution soil profile and if detection of sensitive clay is possible. After the analysis we compared the results of each method with the laboratory Unified Soil Classification System (USCS) provided by Löfroth et al. (2011). We show that among the tested methods, the proposed ones by Robertson et al. (1986), Robertson (2010), Brouwer (2007) and Zhang and Tumay (1999) give good results, but the original method proposed by Robertson et al. (1986) has the highest quality.

2. Soil type classification methods

In this study the proposed methods by Robertson et al. (1986), Robertson (1990), Olsen and Mitchell (1995), Swedish National Report (1995), Eslami and Fellenius (1997), Jefferies and Been (2006), Brouwer (2007) and Robertson (2010) have been used and tested. We provide here the basic ideas behind each of the mentioned soil classification methods and the various formulas employed by them. Note that