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The observational method applied to a high embankment founded on sulphide clay

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ABSTRACT

Since its introduction, Eurocode 7 has acknowledged the observational method as a valid design approach for geotechnical structures. The observational method is defined in five paragraphs. Although several case studies have concluded that the observational method is useful, the method is still sparsely used. This study compares the actual implementation of the observational method in the Veda embankment project according to the definitions given in Eurocode 7. The outcome of the observational method as a design approach, and the major deviations compared to the definitions in Eurocode 7 are discussed. It is concluded that the design of a multi-staged embankment, where the building process is governed by consolidation in the subsoil, can only partly be adapted to the observational method as defined in Eurocode 7. Furthermore, when this is the case, the possibility of combining "design by calculations" and the observational method is discussed.

Notation

C_c	compression index
C_α	creep index
c_v	vertical coefficient of consolidation
c_h	vertical coefficient of consolidation
CPTu	cone penetration test with pore pressure measurement
CRS	constant rate of strain oedometer test
COV	coefficient of variation
d_h	deformation in the horizontal direction
d_s	deformation in the vertical direction (crest settlement)
FC	fall cone test
FS	factor of safety
FVS	field vane test
γ	unit weight of soil
k_h	hydraulic conductivity in horizontal direction
OCR	overconsolidation ratio
OM	observational method
PVD	prefabricated vertical drain
s_u	undrained shear strength
SLS	serviceability limit state
u	pore water pressure
ULS	ultimate limit state
w_n	water content
w_L	liquid limit
σ'_p	pre-consolidation pressure
σ'_v	effective vertical stress

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1. Introduction

The design and construction of geotechnical structures often involve a wide range of uncertainties, which are generally associated with the interpretation and assessment of geotechnical properties from a limited set of data. In projects with a high level of uncertainty and when the geotechnical behaviour is difficult to predict, the observational method (OM) defined by Peck (1969) is recommended. This design method enables the engineer to address the uncertainties by continuously predicting, observing and altering the design during construction. Traditionally, the OM is used in projects where a design based purely on preconstruction calculations would render a conservative, expensive design as a result of dealing with the associated uncertainties.

Since Peck (1969) first formulated the design philosophy of the OM, the method has been refined and improved. In Eurocode 7 (EC7) for Geotechnical Design (CEN, 2004), the OM is defined in five paragraphs as one of four design alternatives for geotechnical structures. The major principles of the OM are to initially assess acceptable limits of behaviour and the range of possible behaviour for a structure, subsequently followed by monitoring and evaluation of the actual behaviour. During the design phase, it is of great importance that prospective deviations in geotechnical behaviour and associated failure mechanisms are identified so that appropriate actions can be devised in the early stage of the design process. In case of deviation from initial assessments and established limits during construction, actions have to be performed according to the plan elaborated in the design phase (CEN, 2004).

Despite its many advantages, the method is rarely used as a design approach in Sweden, and case studies about the implementation of the OM in design as defined in EC7 are few. Case studies have recently been presented by Moritz and Schubert (2009) and Spross and Larsson (2014), both focusing on the implementation of the OM in tunnelling projects. Case studies regarding the design of embankments on soft clay that include discussion of the OM have been presented by Choa (1994), Tan and Liew (2000) and Wu (2011). Studies on the same land reclamation project as in Choa (1994) have also been presented by, e.g., Arulrajah et al. (2004) and Bo et al. (2007), both of which discuss soil improvement by the use of prefabricated vertical drains (PVDs) and an observational approach for settlement evaluation and prediction using Asaoka's method (Asaoka, 1978) and the hyperbolic method (Tan, 1993). However, regarding the design of embankments, no studies with particular focus on the use of the OM as defined in EC7 can be found in the literature.

Several authors (e.g., Powderham, 2002 and Kadefors and Bröchner, 2008) have implied that the OM is significantly underused and that the industry's major objections to and concerns about the method are due to contractual issues and fear of increased economic risk as a result of altering the design during construction. According to Wu (2011), the OM should allow a design to be altered during the construction phase, within the economic framework, considering possible consequences in terms of both construction time and material cost. It is of utmost importance that this is understood by the key stakeholders and that the contract is adjustable to account for these consequences (Chapman and Green, 2004). If the OM is used correctly, the method has the potential to provide great savings in both time and money.

This paper presents a case study on how the OM was adopted in the design and building process for the Veda embankment project. In the study, the outcome of the OM as a design approach compared to the definitions in EC7 is presented and discussed. Furthermore, if the OM is not fully applicable, the possibility given in EC7 to combine “design by calculation” and the OM is discussed as a more suitable design approach. The OM is only schematically defined in EC7. One way to increase the method's use might be to define the OM in categories, revised for different types of geotechnical structures.

The primary source of information in this paper comes from Müller (2010, 2013). The Veda embankment has been the main subject of research presented in Müller (2010, 2013), Müller and Larsson (2008), Müller and Larsson (2012) and Müller et al. (2013b).

2. Project description

The Veda embankment is situated approximately 400 km north of Stockholm, the capital of Sweden, near the outlet of the Ångermanälven River into the Gulf of Bothnia (Figure 1a). The embankment is part of a newly constructed railway section and spans an approximately 300-m-wide valley where deposits of loose sediment (silt, clay, sulphide clay and sand) dominate the geology (Figure 1b).

The embankment is constructed by crushed rock-fill and is at most 16 m high. Due to the immense embankment load and hence the imposed stress increase in the subsoil, both stability and deformation problems had to be addressed during the design of the embankment. Supporting berms consisting of till fill were designed as counterweights to address the stability problem. Additionally, the embankment was built using staged construction to account for the strength increase in the clay layers due to consolidation effects, which addresses both the stability and the deformation problems. To accelerate the consolidation, PVDs were also installed beneath the embankment. A plan and a typical section of the Veda embankment are presented in Fig. 2.

The construction process was divided into seven stages according to Fig. 3, where the 6th and 7th stages represent the loading and unloading, respectively, of a surcharge designed to reduce creep settlements. Until the completion of stage 5, construction work was intended to proceed continuously. Thereafter, before applying the surcharge (stage 6), a 6-month pause was required to ensure a sufficient increase in strength. The surcharge was designed to be in place for one year to

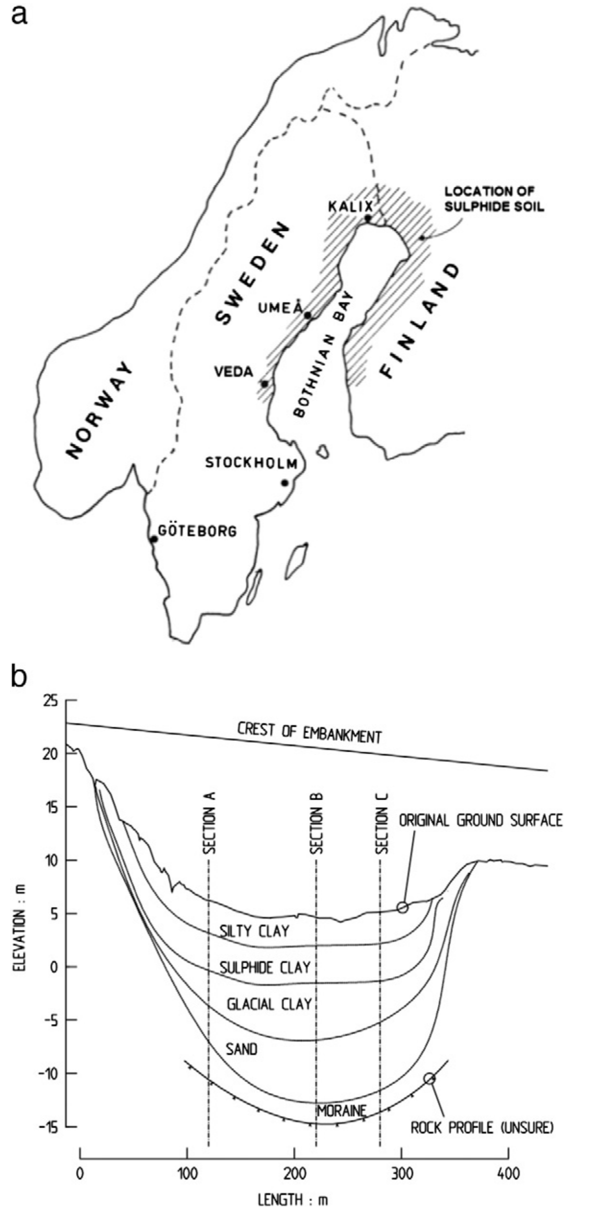

Fig. 1. Veda area: (a) location plan (partly from Schwab, 1976); (b) profile through the centre of the embankment (modified after Müller et al., 2013b).

reach near-100% consolidation in the clay layers. During the initial stages (1–3), supporting berms were intended to be constructed simultaneously with the embankment before initiating stage 4, when the embankment would rise above the supporting berms.

In the Nordic countries, sulphide clay predominates along the coast of Bothnia. The uncertainties concerning the strength and the deformation and consolidation characteristics of the sulphide clay and its interaction with the PVDs were considered significant. These uncertainties motivated an extensive investigation plan, including construction and instrumentation of a trial embankment. The investigation plan utilised undisturbed samples to determine the index parameters (natural water content w_n, liquid limit w_L, unit weight γ), consolidation characteristics (compression index C_c, creep index C_α, vertical coefficient of consolidation c_v) and pre-consolidation pressure (σ'_p) in the clay layers. The consolidation characteristics and σ'_p were determined via constant rate of strain (CRS) consolidation tests and standard incremental load oedometer tests. Fall cone tests (FC) were also performed on samples that had undergone incremental load oedometer tests and K_0-consolidated undrained direct simple shear tests to