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Lessons learnt from a deep excavation for future application of the observational method

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ABSTRACT

This paper draws lessons learnt from a comprehensive case study in overconsolidated clay. Apart from the introduction of the case study, including field measurements, the paper draws on the observations and a three-dimensional (3D) numerical analysis to discuss the implications of observations in the application of the observational method (OM) in the context of the requirements of EUROCODE 7 (EC7). In particular, we focus on corner effects and time-dependent movements and provide initial guidance on how these could be considered. Additionally, we present the validation of a new set of parameters to check that it provides a satisfactory compliance with EC7 as a set of design parameters. All these findings and recommendations are particularly important for those who want to use the OM in similar future projects.

1. Introduction

As a design and construction framework, the observational method (OM) was introduced by Peck (1969) and has since seen many applications over the years (e.g. Glass and Powderham, 1994; Powderham, 1994, 2002; Powderham and Rutty, 1994; Peck, 2001; Sakurai et al., 2003; Chapman and Green, 2004; Finno and Calvello, 2005; Yeow and Feltham, 2008; Nicholson et al., 2014; Spross and Johansson, 2017).

OM can be approached in multiple forms. However, within the context of this paper, we focus on the philosophy of EUROCODE 7 (EC7) Clause 2.7 (British Standards Institute, 2004) to provide a framework for our discussion against an established design standard. EC7 states the following requirements for the application of the OM before construction starts:

(1) *Acceptable limits of behaviour shall be established.*

(2) *The range of possible behaviour shall be assessed and it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits.*

(3) *A plan of monitoring shall be devised, which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage, and with sufficiently short intervals to allow contingency actions to be undertaken successfully.*

(4) *The response time of the instruments and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system.*

(5) *A plan of contingency actions shall be devised, which may be adopted if the monitoring reveals behaviour outside acceptable limits.*

In particular, we will provide a commentary of the observed behaviour of a deep excavation and its impact on the first four EC7 requirements as shown above. A methodology of how to set the trigger values or a set of action plans is not covered in this article but is thoroughly presented by Spross and Johansson (2017). In this paper, the focus is on the behaviour that may affect the general application of OM in relation to the above requirements.

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The commentary includes some initial guidance on how to overcome this behaviour for the future application of OM in similar conditions.

The complexity of current deep excavations, due to the congested urban environments, means that sophisticated analyses are needed to satisfy the requirements of all stakeholders involved in these projects which, in cities, also include the third-party neighbours. These analyses are typically three-dimensional (3D) numerical models that require adequate constitutive relationships to characterise soil behaviour. In the case covered in this paper, we focus on the use of the BRICK soil model (Simpson, 1992), which has been validated for characteristic parameters (defined in the next section) and provides adequate design parameters for deep excavations in undrained London Clay (Ng et al., 1998; Long, 2001; Yeow et al., 2006).

To date, however, a validation of most probable (also defined in the next section) BRICK soil model parameters has not yet been carried out and it is a necessity for future applications of the OM using BRICK soil model. Furthermore, it is known that excavations present 3D effects, particularly around their corners, as well as time-dependent effects that need to be considered when setting the trigger values. This is particularly necessary to avoid situations where measured movements exceed those triggers. Therefore, this paper has three main objectives:

(1) Validate a set of most probable parameters for BRICK soil model in 3D, using undrained analysis for a case study in London Clay; given that in conjunction with the already validated characteristic parameters, it can provide a sufficient range of behaviours for the application of OM.
(2) Observe the corner effects of the case study in relation to providing guidance of how these can be considered within the operation of OM.
(3) Observe the time-dependent movements and provide guidance of how these could be included in the predictions within the operation of OM.

2. Observational method – design parameters

The EC7 requirements presented above are very broad and have been approached in multiple ways by different authors. Of particular interest are the works (Prästings et al., 2014; Spross et al., 2016) applied to other types of geotechnical structures. In the context, the focus is on the design parameters and the behaviour of the retaining wall, following the recommendations of Nicholson et al. (1999). EC7 requirements 1 and 2 of the list above are related to the definition of a range of behaviours. Nicholson et al. (1999) recommended the use of two sets of design parameters to do this: 'most probable' and 'characteristic'. The former, with such name introduced by Powderham (1994) and Nicholson et al. (1999), defined it as: "a set of parameters that represent the probabilistic mean of all possible set of conditions. It represents, in general terms, the design condition most likely to occur in practise". As other authors have done in the past (e.g. Yeow and Feltham, 2008; Nicholson et al., 2014), we define them as those parameters that provide the closest response to reality in terms of displacements (i.e. monitoring data). The second set agrees with the terminology used in EC7 (British Standards Institute, 2004) and is defined as: a cautious estimate of the value affecting the occurrence of the limit state. Hence, both sets of parameters differ in their degree of cautiousness with the 'characteristic' being a more cautious set of parameters. Both sets allow the prediction of two separate trigger values that give a range to dictate when actions are required (i.e. point 5 of the EC7 requirements). In order to fulfil EC7 requirements 3 and 4, both sets also need to provide a range of behaviours that can be easily differentiated and also monitored timely. For this, Nicholson et al. (1999) recommended that both sets of parameters are validated against real case studies using similar sites, which is what this paper provides for deep excavations.

3. Site description

3.1. Site and existing structures

The site is located in the vicinity of Aldgate Station in London, UK. The site is bounded to the southeast by St. Botolph Street, to the southwest by Houndsditch, and to the northwest by Stoney Lane (Fig. 1). White Kennett Street forms the northern site boundary with the London Underground (LUL) District and Metropolitan lines running along the eastern site boundary through a cut and cover tunnel. The site dimensions are approximately 90 m × 65 m (length × width). Ground level around the site rises from approximately +14 mOD to +15.5 mOD in the north/south direction, where mOD stands for metres above Ordnance Datum.

The site was occupied, before the project started, by two buildings: St. Botolph's House and Ambassador House as shown in Fig. 1. St. Botolph's House was designed and built in the 1960s. It was an 8-storey concrete frame building on pad foundations with a single basement; the basement occupied most of the site footprint and its level was typically at +11.0 mOD. Ambassador House was built in the 1980s and occupied the northern part of the site. It was a 12-storey concrete frame building with a single basement founded on a raft. The basement was used as a car park with a ramped access off St. Botolph Street, parallel to an LUL tunnel (Fig. 2). The basement level was typically at +10.5 mOD.

3.2. Adjacent structures

The LUL Circle and Metropolitan underground lines run alongside the eastern site boundary through a former open cut, which was subsequently capped in the early 1990s to form a pedestrians-only zone. A reclined retaining wall separates the LUL tunnels from the existing structure. A subway passage exists beneath St. Botolph Street and Houndsditch, to the south corner of St. Botolph's House. The location of both structures is shown, approximately, in Fig. 2, together with the footprint of the proposed building.

The new St. Botolph's development includes demolition of the existing Ambassador House and St. Botolph's House buildings and the construction of a new commercial office development. The newly built structure has fourteen storeys above two levels of basement. This means a retained height between 10.5 m and 11.5 m.

3.3. Ground investigation and conditions

The ground investigation (see Fig. 2) was carried out between 4 October and 14 December 2006, using the following investigative tools:

(1) Three boreholes drilled by cable percussive methods to an average depth of 45 m below ground level;
(2) Four observation pits excavated to a maximum depth of 2.1 m to investigate areas of potential contamination;
(3) Six horizontal concrete cores to investigate existing basement walls;
(4) Six vertical cores to investigate the existing basement structure;
(5) Four inclined cores and one vertical core drilled using a Beretta T41 track mounted rotary rig to investigate the geometry and composition of the LUL reclined wall and to