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Finite element study of deep excavation construction processes ☆

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Abstract

Excavations for deep basements in urban areas present complex design questions, *e.g.* related to the selection of retaining systems and the specification of construction processes. Consideration must be given to the design of structural systems to support the excavation and the mitigation of any impact that the construction might have on any nearby infrastructure. The finite element analysis is routinely used (in design and research) for the analysis of this type of complex soil-structure interaction problem. Care is needed to ensure that representations of the construction processes, soil and structural behaviour are incorporated in the finite element model at an appropriate level of detail. This paper addresses the implementation of construction procedures in a finite element analysis of a deep excavation in Shanghai. Initially, an analysis is developed to model the construction processes actually employed in the project. The results of this model compare favourably with data measured during construction. The model is then developed to investigate the influence of certain aspects of the construction processes on the computed results. The results indicate the following: (i) the construction sequence for the floor slabs does not have a significant influence on the computed deformations in the retaining walls or the nearby ground at the end of construction; (ii) earth beams (used as temporary supports) are effective in reducing the computed wall and ground movements, and (iii) neglecting the presence of openings in the floor slabs may lead to unconservative calculations of the retaining wall and ground movements.

Keywords: Deep excavations; Finite element analysis; Openings; Construction sequence; Floor slabs; Earth berms

1. Introduction

Deep excavations are routinely employed in urban development projects. The performance of an excavation is affected by various factors, including the local ground conditions, the structural support systems, and the construction processes. The finite element (FE) analysis has been widely used to model deep excavation construction processes (*e.g.*, Dong et al., 2016; Whittle et al., 1993; Zdravkovic et al., 2005). However, the development of FE procedures that provide reliable data for design purposes is challenging, particularly when the excavation is of irregular geometry or where innovative construction processes are proposed. Recent studies (Dong, 2014; Dong et al., 2016) demonstrate the importance of considering a range of issues in the analysis of excavations, including small-strain soil nonlinearity, construction joints in the retaining walls, post-cure thermal behaviour of concrete floor slabs and the detailed nature of the initial ground stresses. The current paper extends this previous work to a case study of a complex deep excavation, the North Square Centre, which forms part of the Shanghai South Railway Station, completed in 2005. Initially, an FE analysis is developed to model the construction processes that were actually employed in this project. This model is then

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modified to investigate the influence of aspects of the construction procedure on the computed results.

In projects involving top-down construction methods (such as the North Square Centre), the floor slabs are typically cast, sequentially, in independent sections. However, the performance of the excavation may depend on details of the construction sequence. Questions exist about the appropriate level of detail for modelling the construction operations to achieve results that are sufficiently reliable for design purposes. In this paper, these questions are investigated.

Earth berms are often used within deep excavations to provide temporary lateral support to the retaining wall, maintaining stability during construction (Clough, 1977; Georgiadis and Anagnostopoulos, 1998; Gourvenec and Powrie, 2000; Daly and Powrie, 2001; Powrie and Daly, 2002; Smethurst and Powrie, 2008). However, earth berms inevitably add complexity to the construction. It is not clear whether berms need to be included in an FE model of the construction process. The analysis described here is focussed on the effectiveness of the berms used in the North Square Centre project in reducing deformation in the retaining wall and the neighbouring ground.

In top-down construction, temporary openings in the floor slabs are used to provide access. Because these openings reduce the effectiveness of the propping action of the slabs, an increase in wall deflections and local ground movements may occur. The size and distribution of openings needs to be carefully considered when top-down construction is employed. In FE models of top-down excavations, the openings are typically included in the analysis, approximately, by artificially reducing the stiffness of the lateral support system (*e.g.*, Simpson, 1992; St. John et al., 1993). This simplification may not capture the excavation behaviour well, especially when the geometry of the retaining system is complex. We describe an FE study on the influence of temporary openings on the deformations in the retaining wall and the surrounding soil.

2. The north square centre

2.1. General description

The Shanghai South Railway Station was constructed to increase the capacity of existing passenger terminals, forming the basis of a major urban development project. The Station integrates subways, a light rail system, aboveground public transport, an elevated freeway and a passenger interchange. The project included an underground shopping centre, the North Square Centre (NSC). The excavation for the NSC, to the north of the Main Station (Fig. 1), forms the basis of the finite element modelling presented here.

The NSC required a deep excavation, constructed using a top-down method. Site investigation data were reported by Xu (2007). Extensive field monitoring data were collected during construction (Xu, 2007; Hou et al., 2009). The excavation is 12.5 m deep, and covers an area of about 40,000 m^2. The structure has two basement levels and is supported on a piled raft foundation. The soil retaining system uses a diaphragm wall, propped by the floor slabs. The geometry of the excavation is irregular: roughly 400 m long and 100 m wide. Construction of the NSC began in 2003 and was completed in 2005.

The NSC excavation is close to several current and planned underground transportation links. To the east is the new LRT (Light Rail Transit) Line 1 (within 3 m of the diaphragm wall), and the Interchange Station for the new Metro Lines R1 and LRT Line L1. The Main Station and the relocated Metro Line R1 (within 2 m of the diaphragm wall) are to the south. To the north is the operational Metro Line R1 (with a minimum distance of 3 m to the diaphragm wall). The excavations for these neighbouring developments were completed before the start of the NSC excavation.

The NSC excavation has several distinctive features: (i) it is close to adjacent infrastructure, so care was

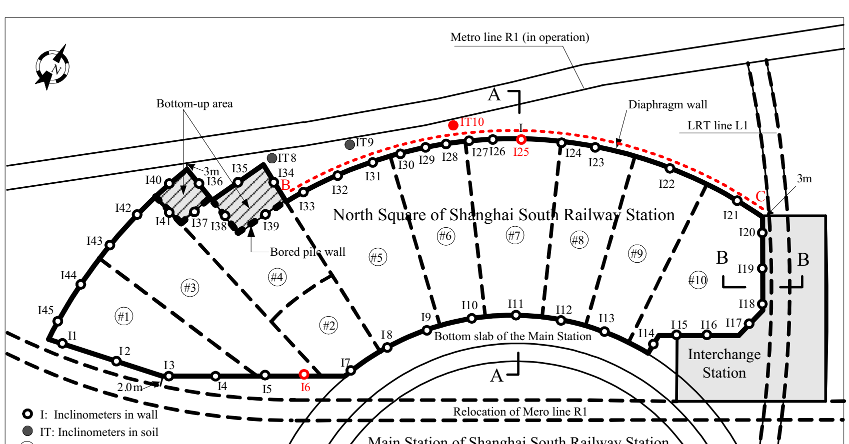

Fig. 1. The North Square Centre excavation plan and instrumentation (Xu, 2007). (The measurement locations used to compare with numerical analyses are indicated in red).