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# Evaluation of the wall deflections of a deep excavation in Central Jakarta using three-dimensional modeling

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ABSTRACT

This paper presents a case study and numerical simulations regarding a large-scale deep excavation in Central Jakarta, Indonesia, and its three-dimensional (3D) effects on wall deformation. The soil profile in Central Jakarta is generally soft to firm alluvial clay overlying stiff to hard alluvial and diluvial clay. In this study, the geotechnical engineering properties of soil (i.e., undrained shear strength and modulus) were established using data from a site investigation, in situ and laboratory tests, and empirical correlations with standard penetration numbers (SPT-N). A summary of simplified soil input properties for subsurface soil in Central Jakarta was provided. To analyze the deep excavation case, a 3D finite element model was developed by considering a top-down construction method, a supporting system of concrete slabs, and the influence of the soil modulus. The numerical results indicated that the hardening soil model with the soil modulus obtained from in situ pressuremeter tests yields reasonable predictions for excavation-induced wall deformation. The applicability of 3D finite element analyses to capturing the 3D corner effect on the wall deformation was validated. According to the parametric study, the plane strain ratio (PSR) was determined for the excavations in Jakarta clay. Compared with the PSR developed for Taipei clay, this study revealed that the PSR value was influenced not only by the 3D corner effect but also by the stiffness of the subsurface soil. In addition to PSR, the wall deflection path was also affected by the 3D corner effect and soil modulus.

## 1. Introduction

Jakarta is the capital and largest city of the Republic of Indonesia. With a population of 10 million and limited urban public transport services, additional underground space is required for transportation nerworks, for which deep excavation is crucial. Many studies have evaluated the effect of deep excavations on the behavior of walls (Clough and O'Rourke, 1990; Ou et al., 1996, 2000; Ou, 2006; Kung et al., 2007; Lin and Woo, 2007; Hsiung, 2009; Schweiger, 2009; Wang et al., 2010; Likitlersuang et al., 2013; Khoiri and Ou, 2013; Finno et al., 2015; Orazalin et al., 2015; Hsieh et al., 2015; Hsiung et al., 2016), but limited studies have reported excavation cases in Jakarta, Indonesia. Furthermore, explorations of soil properties are limited, and few of the large-scale deep excavations in the city have been well documented. Most of the available information is documented mainly in the local language. All of these factors increase the difficulty of studying deep excavation in Jakarta area.

In engineering practice, two-dimensional (2D) finite element (FE) analysis is generally performed because of time and budget limitations, although three-dimensional (3D) FE analysis has already been used to study 3D wall behavior. The concept of plane strain ratio (PSR), proposed by Ou et al. (2006), is used to accurately quantify 3D excavation-induced behaviors from the output of 2D FE analysis. The PSR is the ratio of the maximum wall deformation of a section of a wall at a distance *d* from the corner to the maximum wall deformation of the section under plane strain conditions. The PSR was adopted in this study to quantify the 3D wall behavior of an excavation in clay in Central Jakarta.

This paper presents a unique and well-documented case of a large-scale deep excavation in clay in Central Jakarta. The excavation was nearly completely embedded in thick layers of clay. Detailed background information regarding the subsurface soil conditions, in situ and laboratory soil tests, construction sequences, and monitoring data are introduced and discussed. The input soil parameters were estimated and interpreted from in situ and laboratory triaxial tests. Moreover, the determined soil parameters were compared with the estimated values using several empirical correlations with the standard penetration number (SPT-N) to confirm the reliability of the parameters that were

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used in the analyses. A 3D FE analysis was then conducted to model the selected deep excavation in Central Jakarta and to verify the applicability of 3D FE models in predicting a 3D excavation-induced wall displacement (also known as a 3D corner effect). The results of the numerical analysis and field observations were compared and discussed. Finally, a PSR chart for excavations in Central Jakarta was developed through a series of parametric studies with several excavation aspect ratios. The proposed PSR chart provided an alternative approach to transfer the wall displacement from a 2D analysis to one considering the 3D corner effect. Thus it enabled a practical design (typically 2D) to account for the 3D effects of an excavation on wall deformation.

## 2. Project background

A deep excavation in Central Jakarta, Indonesia was selected for the case study and numerical simulation. The length of the excavation was 430 m and the width varied from 22 to 30 m in different sections. The construction was performed using a top-down method with five excavation stages, supported by four-level reinforced concrete slabs with various thicknesses. The maximum excavation depth was 18.9 m in the final excavation stage. The excavated pit was retained using a 1.0-m thick and 24.1-m deep diaphragm wall. Figs. 1 and 2 show the cross section and photograph of the excavation, respectively.

To increase the stiffness of the retaining wall system, 414 × 405 × 18 × 28 steel H-beams were installed as kingposts in the middle of the excavation area at 3.0-m intervals. The kingposts bore the weight of concrete floor slabs and the possible lateral loading from the diaphragm wall, which was transferred to the slabs. The H-beams were inserted 4.0 m into bored piles with a diameter of 1.0 m and an embedded length of 14.5 m.

The diaphragm wall and kingposts were constructed before the soil was excavated to ground level (GL) − 1.5 m. In the next phase, a deck slab with a thickness of 0.4 m was installed. The second excavation stage involved removing the soil to GL − 5.08 m and then constructing a top slab at GL − 4.18 m. Subsequently, the soil was excavated to GL − 11.18 m and a middle slab with a thickness of 0.4 m was placed at GL − 10.48 m. The fourth and fifth excavation stages were conducted similarly. In the final construction phase, the bottom slab with a thickness of 1.0 m was installed at GL − 18.13 m. Table 1 details the construction phases and sequences of the excavation.

## 3. Instrumentation and observations

To monitor the performance of the diaphragm wall during construction, several monitoring instruments were installed around the excavation site, including inclinometers, surface settlement points, observation wells, rebar stress transducers, and kingpost strain gauges. All monitoring data were carefully reviewed and only reliable and representative data were selected for further analysis and discussion. Inclinometers were installed at several cross sections of the site to measure the lateral movement of the diaphragm wall. The inclinometers were installed on the left and right sides of the diaphragm wall. Fig. 3 displays the locations of the inclinometers at five

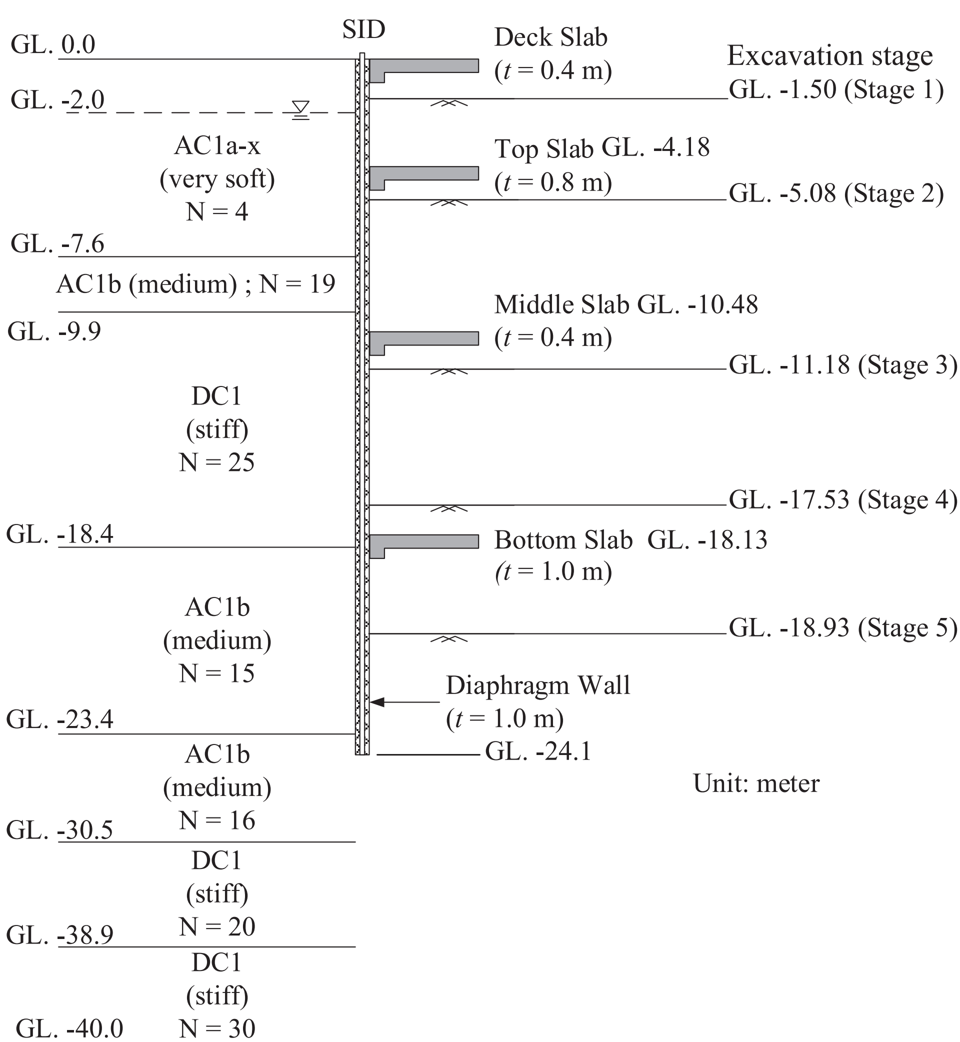


**Fig. 1.** Cross section and soil profile of the excavation.