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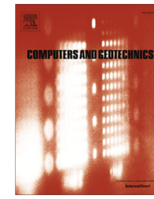

Research Paper

Assessment of strut forces for braced excavation in clays from numerical analysis and field measurements

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A B S T R A C T

One important consideration in the design of a braced excavation system is to ensure that the structural bracing system is designed both safely and economically. The forces acting on the struts are often determined using empirical methods such as the Apparent Pressure Diagram (APD) method developed by Peck (1969). Most of these empirical methods that were developed from either numerical analysis or field studies have been for excavations with flexible wall types such as sheetpile walls. There have been only limited studies on the excavation performance for stiffer wall systems such as diaphragm walls and bored piles. In this paper, both 2D and 3D finite element analyses were carried out to study the forces acting on the struts for braced excavations in clays, with focus on the performance for the stiffer wall systems. Subsequently, based on this numerical study as well as field measurements from a number of reported case histories, empirical charts have been proposed for determining strut loads for excavations in stiff wall systems.

1. Introduction

Construction of a basement structure using a braced retaining wall system will inevitably result in wall deflections and ground settlement. Excessive ground settlement will frequently cause damage to adjacent properties in urban areas. The total amount of ground settlement associated with deep excavations is closely related to the type of support system, the properties of the in situ soils, and the excavation procedure. For excavations in clays, basal heave stability also needs to be considered.

Another important design issue is to ensure the structural safety of the bracing system. The forces acting on the struts are often determined using empirical methods such as the Apparent Pressure Diagram (APD) method. Terzaghi and Peck [22] and Peck [20] recommended the widely used APD, to estimate the magnitude and distribution of prop loads. They proposed different APDs for braced excavation in sands, stiff fissured clays, and soft to medium clays. This method was developed based on field measured data for braced excavations with flexible wall systems.

Ou [18] summarized Peck [20]'s work on APD to estimate the magnitude and distribution of strut loads in different clays as shown in Fig. 1, where the Rankine's coefficient of lateral active earth pressure K_a is expressed as:

$$K_a = 1 - m\frac{4c_u}{\gamma H_e} \quad (1)$$

where c_u is the soil undrained shear strength (in kPa), γ is the soil unit weight (in kN/m^3), H_e is the depth of the excavation (in meter) and m is an empirical coefficient. Most of the commonly used empirical methods that were developed from either numerical results or field studies have been for excavations with flexible wall systems such as sheetpile walls. To date, there have been limited studies on the excavation performance for stiffer wall systems such as diaphragm walls and bored piles.

Chang and Wong [4] proposed a modified APD for diaphragm walls in deep clay deposits. The research was based on a case study and a parametric finite element study. Their research showed that strut loads computed using the Peck's APD underestimated the strut loads significantly. By introducing a strut force exceedance ratio α, as functions of the soil stiffness ratio and undrained shear strength, a modified APD was proposed. They commented that the amended APD was derived from the cases with T/B ratio greater

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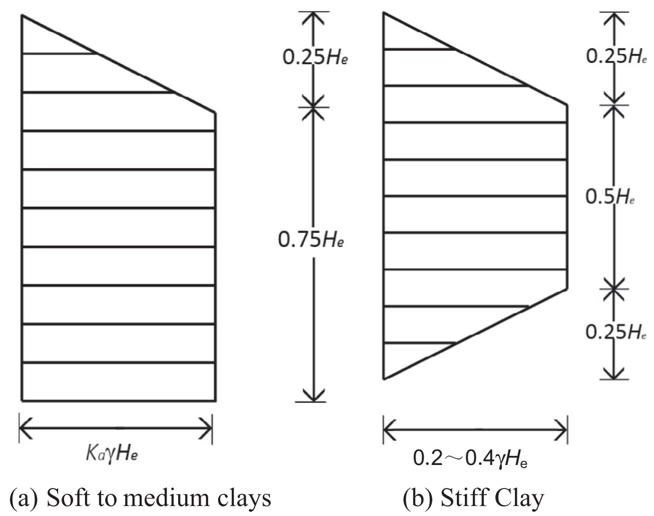

Fig. 1. APD for design of struts in: (a) soft to medium clays; (b) stiff clays (adapted from [20]).

than 1 (where T is the clay thickness below the final excavation level, and B is the excavation width, as illustrated in Fig. 2). If T/B is less than 1, they inferred that there would be strong restraining effect from the hard stratum reducing the strut force.

Hashash and Whittle [8] compared Peck's conventional APD with their FE results which considered undrained strength anisotropy and strength non-homogeneity. Their research indicated that the conventional APD was smaller than the finite-element results for diaphragm wall, especially for deep excavations. Also, the wall stiffness plays an important role in the apparent earth pressures. As the wall stiffness decreased, the apparent earth pressure decreased.

Hsiung et al. [10] reported the well-instrumented strut behavior of a 16-m deep excavation with seven level struts restrained by a diaphragm wall in Taipei. They found that the Peck's APD underestimated the measured apparent pressure for this case. Sze [21] carried out a series of centrifuge tests to investigate the apparent earth pressure for an undrained excavation. According to Sze's test results, Peck's APD underestimated the measured apparent pressure by 30 % for the case of excavations supported by diaphragm walls. Wong et al. [25] observed that for the construction of a major Singapore underground expressway project, most of the data were within the vertical boundary of the apparent earth pressure diagram proposed by Terzaghi and Peck [22]. However, they recommended that the vertical pressure diagram should extend to the ground surface instead of decreasing to zero to fit all the measured data.

Twine and Roscoe [23] enhanced Terzaghi and Peck's work and introduced the Distributed Prop Load (DPL) method based on 81 case histories and field measurements of prop loads. However, of the 81 case histories, 28 cases are for flexible walls in soft to medium clays (denoted as class AF) while only 2 cases are for stiff walls (class AS). In addition, although there are 10 reported cases for stiff walls in stiff clays (class BS), 5 of them are singly propped while 2 cases have two strut levels and only the remaining 3 cases have three levels of struts. In view of these limited published data, it is therefore relevant to reassess the DPL method for the class AS and class BS excavation types.

All these studies outlined earlier generally indicated that Peck's APD under-predicted the apparent earth pressure of the braced excavations, especially for those involving diaphragm walls and large excavation depths. As various factors are likely to influence the APD such as the clay thickness, soil strength and stiffness, wall stiffness, excavation width, and strut stiffness, this paper explores the performance of the strutting system, including the apparent earth pressure, through a series of plane strain and three-dimensional finite element analysis. Some differences were observed between the numerical results and Peck's APD.

As discussed previously, for the case of excavations in stiff wall systems, the proposed distributed prop loads (DPL) by Twine and Roscoe [23] were based on only very limited measured data. The main contribution from this paper is to propose updated APD for stiff wall systems based on extensive numerical analyses supplemented by additional measured data (8 cases in soft clays and 8 cases in stiff clays, with up to five levels of struts).

2. Details of numerical models

For this study, the finite element analyses were carried out using the geotechnical software PLAXIS 2D (V9.0) and PLAXIS 3D Foundation [1]. Fig. 2 shows a typical cross-section and plan view

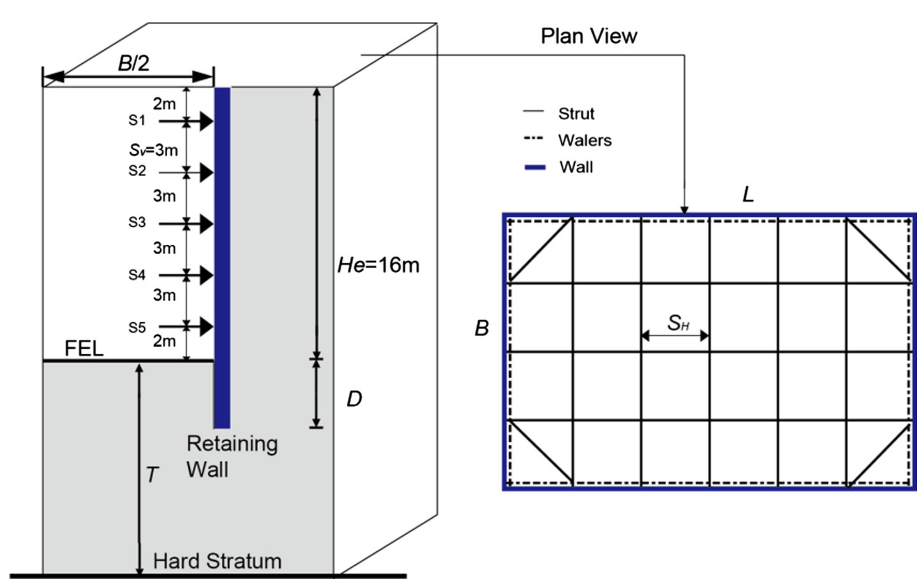

Fig. 2. Cross-section and plan view of the model for braced excavation.