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Full Length Article

Influence of groundwater drawdown on excavation responses – A case history in Bukit Timah granitic residual soils

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A B S T R A C T

Performances of a braced cut-and-cover excavation system for mass rapid transit (MRT) stations of the Downtown Line Stage 2 in Singapore are presented. The excavation was carried out in the Bukit Timah granitic (BTG) residual soils and characterized by significant groundwater drawdown, due to dewatering work in complex site conditions, insufficient effective waterproof measures and more permeable soils. A two-dimensional numerical model was developed for back analysis of retaining wall movement and ground surface settlement. Comparisons of these measured excavation responses with the calculated performances were carried out, upon which the numerical simulation procedures were calibrated. In addition, the influences of groundwater drawdown on the wall deflection and ground surface settlement were numerically investigated and summarized. The performances were also compared with some commonly used empirical charts, and the results indicated that these charts are less applicable for cases with significant groundwater drawdowns. It is expected that these general behaviors will provide useful references and insights for future projects involving excavation in BTG residual soils under significant groundwater drawdowns.

1. Introduction

In recent years, a large number of transportation tunnels and mass rapid transit (MRT) stations have been constructed in densely built-up and populated area of Singapore to meet the requirement of urbanization and continuing population growth. As the fifth MRT line in Singapore, the Downtown Line (DTL) is a major MRT line that links downtown area with the northern and eastern parts of Singapore directly. The DTL is being implemented in 3 stages and the stage 2 (DTL2) with 16.6 km twin tunnel and 12 underground stations was completed in December 2015. Fig. 1 shows the route of DTL2 and distribution of main geological formations in Singapore.

A key challenge of construction in sensitive areas is to assess and control the impact of construction activities on surrounding buildings and infrastructures. Bukit Timah granitic (BTG) residual soil is the main geological formation in the area where DTL2 stations and tunnels were constructed. However, some studies have confirmed that the BTG residual soil properties have a great spatial variability (Rahardjo et al., 2011, 2012; Qian et al., 2016; Moon et al., 2017; Zhang et al., 2018). Due to the hot and humid tropical climate in Singapore, the weathering process of the Bukit Timah granite is extensive and rapid. The large amount of rainfall combined with relative high temperature facilitates the weathering of the bedrock to a vertically varying degree, and the regional nature of bedrock and climatic and topographic conditions result in the degree of weathering of residual soil varying from region to region (Rahardjo et al., 2004). Therefore, the hydromechanical properties of BTG residual soil are complicated.

In Singapore, the groundwater level is about 1–3 m below the ground surface due to the considerable precipitation and the low elevation. Abundant groundwater exerts considerable hydraulic pressure on the underground supporting structure and even flooding accident takes place during underground constructions. Moreover, excessive ground settlement due to dewatering measures of excavation is one of the main reasons for damage of nearby buildings and roads. Some studies focused on underground excavations in permeable strata and analyzed the leakage and seepage

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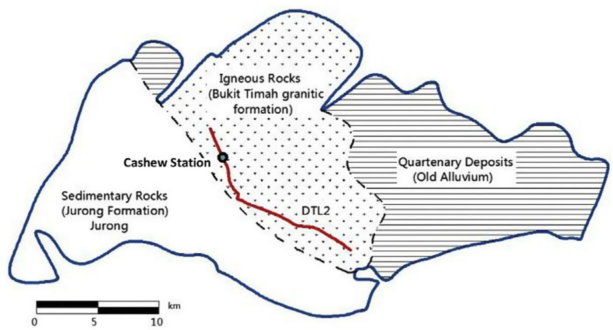

Fig. 1. Simplified geological map of Singapore and the location of Cashew station.

problems (Zheng et al., 2014, 2018; Goh et al., 2017a,b; 2018; Shen et al., 2017; Tan and Lu, 2017; Tang et al., 2017; Zhang et al., 2017; Zeng et al., 2018; Xiang et al., 2018), but history cases with significant water level drawdown outside the pit were rarely reported.

Specially, Zhang and Goh (2016) reported an excavation construction of Cashew station (as indicated in Fig. 1), which is one of the 12 stations of DTL2 and subjected to significant groundwater drawdown during construction. Meanwhile, they presented the instrumentation results of measured wall deflections and profiles, ground surface settlements, and groundwater level changes. However, the influences of groundwater drawdown on the wall deflections and ground surface settlements were not systematically and numerically back-analyzed. Based on the reported responses, this paper back-analyzes the most typical cross-sections for plane-strain calculations. Numerical model is developed and calibrated according to the instrumentation results. Subsequently, parametric studies of groundwater drawdown influences on excavation responses are carried out. It is expected that both the instrumentation data and the numerical results obtained in this paper will provide helpful references and insights for future projects involving excavations in the BTG residual soils, especially when subjected to significant groundwater drawdowns.

2. Project overview

2.1. Site conditions

The excavation is about 225 m long, up to 60 m wide, and 20 m deep. As shown in Fig. 2, the Cashew station is located at the intersection of Cashew Road and Upper Bukit Timah Road, with several adjacent buildings.

The ground consists mainly of the man-made fill (denoted as fill), Kallang formation (F1 and F2), BTG residual soil (G VI), completely weathered Bukit Timah granite (G V), highly weathered Bukit Timah granite (G IV), moderately to slightly weathered Bukit Timah granite (denoted as G III and G II, respectively), and fresh rock (represented by G I). According to borehole data, the thickness of fill varies from 1 m to 5 m, and the distribution of the Kallang formation is fragmentary. The residual soil, most concerned in this study, is typically described as soft to stiff sandy silt with thickness of 5–25 m, below which lies the G V layer of 5–15 m in thickness. The G IV layer is a transition zone and is less frequently encountered. The top of G III layer is the rockhead together with the G II and G I layers, and they are regarded as the rock bed. Fig. 3 shows the typical strata profiles with field and laboratory test data. Shear strength parameters were obtained by triaxial tests, and permeability was measured using variable-head single-packer test.

2.2. Supporting and monitoring systems

To prevent the damage of surrounding buildings and roads caused by excavation, the earth retaining support system (ERSS) which consisted of 1 m-thick diaphragm wall with the average length of 29 m, 4 layers of HY 700 struts and double waler beam HY700 with bracket HY400 was utilized. Fig. 4 plots the layout of the supporting system.

Field instrumentations were also installed to monitor the excavation responses. The monitoring system, as shown in Fig. 5, included settlement markers (monitoring ground settlement), in-wall inclinometers (monitoring lateral wall deflection), and vibrating wire piezometers (monitoring pore water pressure).

2.3. Excavation activities and groundwater response

The main construction activities and the corresponding dates, as well as the construction days, are summarized in Table 1. Construction day 1 denotes the day of June 3, 2011, corresponding to the beginning of the excavation of the first level soil at the project site.

During excavation, it was observed that the piezometer head sharply dropped and a large amount of groundwater discharged into the pit from both the leakage points of the diaphram wall and the bottom of the excavation. Fig. 6 shows the recorded piezometric level changes versus the construction day. For GWV2009 and

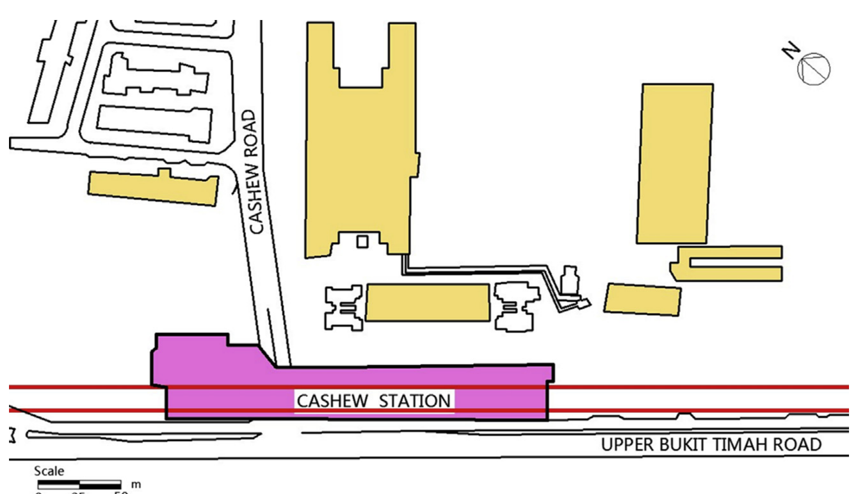

Fig. 2. Plan layout of Cashew station and its surroundings.

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