Determination of soil stiffness parameters at a deep excavation construction site in Kenny Hill Formation

Law Kim Hing , Siti Zulaikha Othman , Roslan Hashim , Zubaidah Ismail

The demand for underground space such as deep basement car-park, road and railway tunnels has increased substantially in highly urbanized areas due to scarcity of the land. A major concern in these developments is the ability of the geotechnical engineers to predict accurately the wall and ground movements associated with the construction activities during the design stage. Nowadays, numerical analysis such as finite element method (FEM) has been assuming an increasingly important role in the prediction of ground and wall deformations as highlighted by Lee et al. [1].

A general overview of the Kuala Lumpur and Ipoh geological settings is given by Tan [2] where the engineering geologic problems in these two cities were discussed. Several studies in the past have been conducted to examine the soil parameters like stiffness. Tests for the stiffness of soil at very small strain were conducted in a hydraulic tri-axial cell fitted with bender elements and with local axial gauges for characterizing the non-linear stress–strain behavior of soil for monotonic loading required for analyses of the dynamic and small strain cyclic loading of soils was studied by Viggiani and Atkinson [3]. Simple expressions were obtained which described the variation of strain in terms of the current stress and over consolidation ratio. The parameters in these expressions were found to depend on plasticity index. The influence of layered soil in soil–structure interaction was also estimated. The method offers a practical method that does not require complex calculations. Another simple and practical method for estimating the horizontal dynamic stiffness of a rigid foundation on the surface of multi-layered soil was proposed by Nakamura [4]. In this method, waves propagating in the soil are traced using the conception of the cone model, and the impulse response function can be calculated directly and easily in the time domain with a good degree of accuracy.

Lipin´ ski and Wdowska [5] predicted the soil stiffness with a focus on Quaternary heavy over-consolidated stiff sandy clay. Series of tri-axial tests on reconstituted and natural material were carried out which provided data for setting up formula for calculation of Young's modulus in a wide range of strain 10–2/1.0%. A series of tri-axial tests was also conducted by Powrie et al. [6] on samples of speswhite kaolin, to investigate the stress–strain relations appropriate to diaphragm walls in clay. The results of the tests highlight the influence of the recent stress history on the behavior of the soil. In particular, the recent stress history imposed during wall installation was found to have significant effect on the stiffness of the soil during the subsequent excavation stage. Although the pre-excavation stress state of the soil may be closer to the passive than the active condition, the reversal in the direction of the stress path at the start of the excavation stage means that the response of the soil behind the wall will probably be very stiff. Shafiee et al. [7] conducted an experimental study investigating the prefailure and failure characteristics of compacted sand-clay mixtures under monotonic compression and extension loading paths. Results revealed that pore pressure, secant modulus, undrained shear strength and angle of shearing resistance increase when sand content was raised in both compression and extension. It was also found that the tested materials were over-consolidated by the fact that normalized shear strength depends on initial confining stress.

The fiber Bragg grating (FBG) sensor has been widely used in the measurement of temperatures and moisture [8–10]. Jackson et al. [11] examined the feasibility of using inexpensive wireless nanotechnology based devices for the field measurement of soil temperature and moisture. In their study, the design, validation, and application of a new flexible fiber Bragg grating (FBG) sensing beam are presented for effectively measuring dynamic lateral displacements inside soil mass in a shaking table test. The dynamic lateral displacements at different depths of the soil mass in the shaking table box throughout time history are calculated by differential and integral methods Xu et al. [12].

In the past, the performance of deep excavations in Kenny Hill Formation was mainly evaluated using 2D finiteelement back-analyses as exemplified by studies by Liew and Gan [13], Sofiana and Hooi [14] and Tan et al. [15]. Approximation is commonly needed in 2D numerical model to represent the real situations and this could lead to uncertainty in the interpretation and validity of the results as shown by Simpson et al. [16]. The correlation of soil stiffness parameters with standard penetration test (SPT) N value, which was calibrated based on 2D back-analyses results may not be representative of actual condition at the site. Field data clearly indicated that the stiffening effect of corners lead to much smaller wall and ground movements at the corners as compared to that measured near the middle of the excavation wall as shown by Lee et al. [17], Ou and Shiau [18] and Ou et al. [19]. In this case, when back analyses were performed to calibrate the 2D model, the soil stiffness would have to be increased in order to match the observed wall deflection. Therefore, 3D geometrical or corner effect needs to be considered when back-analyses were performed in order to get a meaningful empirical correlation to be adopted in the future in same soil conditions.

A common problem in the analysis of deep excavation in residual soils is the soil tests data often limited or low quality due to the difficulty in obtaining undisturbed in situ soil samples. Very often, acceptable data on strength properties of soil could be obtained through laboratory tests but not on its modulus value. Therefore, information from back-analyses of the Young’s modulus based on local case histories, if available, are often very useful for engineering judgment in the estimation.

This study examined the soil stiffness parameters for a deep excavation supported by diaphragm wall in weathered residual soils of Kenny Hill Formation. An elastoplastic isotropic Hardening Soil (HS) model following Schanz et al. [20], as implemented in commercial finite element program PLAXIS, was employed in this study. The objective is to provide data for the determination of horizontal displacements which can also be generally applied to other excavation works in soil conditions similar to the Kenny Hill Formation.

Material and methods

The study project is located at Lebuh Ampang, Kuala Lumpur city center. It is a 24-storey office building with 5 levels of basement car-park. The construction of basement involved 18.5 m deep of excavation, approximately 30 m wide and 35 m long, in weathered residual soils of Kenny Hill Formation. The excavations were performed using the bottom-up method. The diaphragm wall of

23 m deep and 0.8 m thick was supported by three levels of H-section steel struts with 3.5 m horizontal spacing on average. A double steel section was used for 2nd and 3rd layers strut to provide sufficient resistance against high horizontal earth pressures at these levels. At the contact point between the strut and diaphragm wall, I-section walers supported by angle brackets were installed to provide better load transfer between the retaining wall and struts.

The ground condition at the site generally consists of residual soils and weathered rocks of the Kenny Hill Formation. This formation is also referred by Komoo [21] as meta-sedimentary, considering that the sedimentary rocks (e.g. sandstone, siltstone) have been partly metamorphosed into quartzite and phyllite. The weathering process of the rock material which is rather complex have been described by Raj [22].

The soil profile at this project site consists of an upper 6 m of recent alluvium underlined by Grade IV to VI residual soils of Kenny Hill Formation up to depths of about 30 m. Highly fractured and weathered Siltstone with Rock Quality Designation (RQD) of 0% is encountered beyond 30 mdepth. Grading analysis revealed that the residual soil mainly consists of sandy silt and clayey silt material. Standard penetration test (SPT) blow counts were low in the alluvium layer but increases beyond 50 blows/300 mm from depth exceeding 10.5 m. The high SPT-N values exceeding 150 blows/300 mm were probably due to the presence of quartz veins or phyllite fragments encountered in the boreholes. The bulk density of residual soil layers are generally ranged from 19 kN/m^3 to 22 kN/m^3 with depth. The moisture content of residual soil layers are close to plastic limit with plasticity index generally lying in between 15% and 30%. The groundwater table is located at depth of 4.5 m below ground surface.

The movements of the diaphragm wall, the ground and the adjacent buildings were monitored during excavation using standard monitoring devices. Fig. 1 shows the excavation site along with the instruments for monitoring locations. Eight inclinometer casings (I-1 to I-8) were installed inside 800 mm thick diaphragm wall to monitor the lateral displacements of diaphragm wall. All the inclinometer casings were installed to a depth of 3 mbelow diaphragm wall toe level, so that the toe movement of the diaphragm wall can be measured.

Six water standpipes (P-1 to P-6) were also installed outside the excavation area to monitor the fluctuation of groundwater table during the entire excavation process.

Mesh and boundary conditions

The excavation geometry of the case history was carried out for a plan area of approximately 30 m by 35 m. The ratio of excavation length to width is about 1.2 suggesting that a plane strain 2D model may not be appropriate due to corner effect of the excavation [6–8]. The numerical back analyses of this case history have therefore been conducted by 3D finite element analyses using the program PLAXIS 3D FOUNDATION Version 2.2.

Fig. 2 shows the finite element mesh adopted in the numerical back analyses. The side boundaries of the mesh are prevented from movement in the horizontal plane but are free to move vertically and the bottom boundary of the mesh is fully fixed. The 0.8 m thick diaphragm wall was modeled with isotropic linear elastic plate elements. Soil elements are 15-node wedge elements which are created by projection of 2D, 6-node triangular elements. Supporting steel struts were modeled with isotropic linear elastic beam elements. The diaphragm wall was assumed to be ‘‘wished-in-place’’. The installation effect of diaphragm wall was not considered.

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