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Numerical Simulation for a Shallow Braced Excavation of Campus Building

Sao-Jeng Chao, Wen-Cheng Chen, Wei-Humg Lu

***Abstract*—**In order to prevent encountering unpredictable factors, geotechnical engineers always conduct numerical analysis for braced excavation design. Simulation work in advance can predict the response of subsequent excavation and thus will be designed to increase the security coefficient of construction. The parameters that are considered include geological conditions, soil properties, soil distributions, loading types, and the analysis and design methods. National Ilan University is located on the LanYang plain, mainly deposited by clayey soil and loose sand, and thus is vulnerable to external influence displacement. National Ilan University experienced a construction of braced excavation with a complete program of monitoring excavation. This study takes advantage of a one-dimensional finite element method RIDO to simulate the excavation process. The predicted results from numerical simulation analysis are compared with the monitored results of construction to explore the differences between them. Numerical simulation analysis of the excavation process can be used to analyze retaining structures for the purpose of understanding the relationship between the displacement and supporting system. The resulting deformation and stress distribution from the braced excavation cab then be understand in advance. The problems can be prevented prior to the construction process, and thus acquire all the affected important factors during design and construction.

***Keywords*—**Excavation, numerical simulation, rido, retaining structure.

I. Introduction

GEOLOGICALLY speaking, Ilan area can be classified as the conjunction region of Hsuehshan Mountain Range, Central Mountain Range, and Lanyang Plain. The campus of National Ilan University is located in Lanyang Plain. Lanyang Plain is composed of river alluvial soil, primary the clayey material and silty sand layers deposited interactively. Responding to the needs of modern construction and design of the contemporary society, as well as the development of increasing demand for the bustling population, the demanded space in a limited area must accommodate more people. However, considering Lanyang Plain young geological age, subsoil in loose to moderate dense state, and groundwater table quite close to the surface, all the circumstances give the idea that the process of excavation requires especially carefulness.

Several studies [1]–[3] have been performed for the performance of excavation in soft clay. This paper focuses on discussing the excavation construction in Ilan area. Specifically, we take the advantage of campus building excavation project, which provides shallow excavation monitoring data to study RIDO numerical simulation. By means of comparison of monitoring data and numerical simulation, excavation construction can be studied more comprehensively.

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II. Excavation Sequence of the Study Site

Yilan City, with the average height of 7.38 m above the sea level, is the core city and transportation hub in Yilan County. The campus of National Ilan University is located in the southwest corner of Yilan City. Excavation Construction of the study site is shown in Fig. 1. This new excavation project is a five-floor building with basement. The excavation construction uses steel sheet pile with three levels of security strut as retaining structures. The length of the sheet pile is about 19 m, while the security strut uses H-350×350×12×19 type steel with the length of 50 m. The total depth of the excavation is GL-9.6 m with four phases of excavation. The first phase of the excavation is to the GL-1.6 m; the second phase of the excavation is to the GL-4.5 m; the third phase of the excavation is to the GL-7.5 m; and the fourth stage of excavation is made at the GL-9.6 m. Excavation construction of the building is shown in Fig. 2. The way for dewatering of this project is to bury the suction pipe inside of sheet piles, so the outer part of the water level can be kept unchanged. Dewatering process follows the rule step by step with the excavation level, i.e. every excavation depth is lower than the excavation level for 0.5~1 m.

Fig. 1 Excavation construction site

Fig. 2 Excavation construction support

III. Geological Data and Safety Monitoring System

According to the geological drilling information, the main composition from ground level to 1.7 m is the backfill of clay bricks, concrete blocks, gravel, and other components. The soil material between depth of 1.7 to 19.8 m is composed of gray clay layered with silty sand; between depth of 19.8 to 30.3 m of gray silty sand with thin clay layer; between depth of 30.3 to 34.8 m of fine sand with gray gravel; and between depth of 34.8 to 40.0 m of gray silty clay with thin sand layer. Simplified soil layer with parameters are illustrated in Table I.

In order to secure the implementation of the excavation construction project, a safety monitoring system is arranged as an aid to achieve engineering facilities safe purpose. The main feature of the project monitoring system can be considered as inclinometer monitoring. Precisely, there are four inclinometer holes installed inside the excavation construction base for retaining structure tilting observation as shown in Fig. 3.

TABLE I
SIMPLIFIED SOIL LAYER WITH PARAMETERS OF THE STUDY SITE

D (m)	USCS	γ_t (t/m^3)	c (t/m^2)	ϕ(。)	N-value
1.7	SF	1.76	0	26	3
19.8	ML	1.76	1.6	22	3~10
30.3	SM	1.86	3.5	30	21~28
34.8	SM	2.16	4.3	40	54~65
40	ML	1.76	3	35	15~18

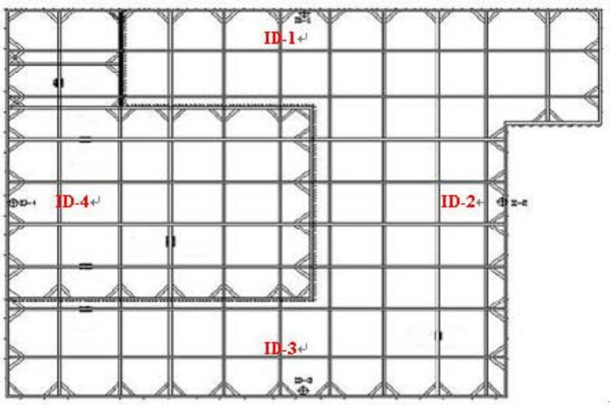

Fig. 3 Configuring of inclinometer location

- TILTMETER ID-1: The lateral displacement for first layer excavation was observed a maximum value of 2.7 cm, while the lateral displacement for the fourth layer excavation recorded a maximum value of 15.5cm. The amount of lateral displacement is in the boundary of the acceptable range of safety concern. The historical displacement observations are shown in Fig. 4.

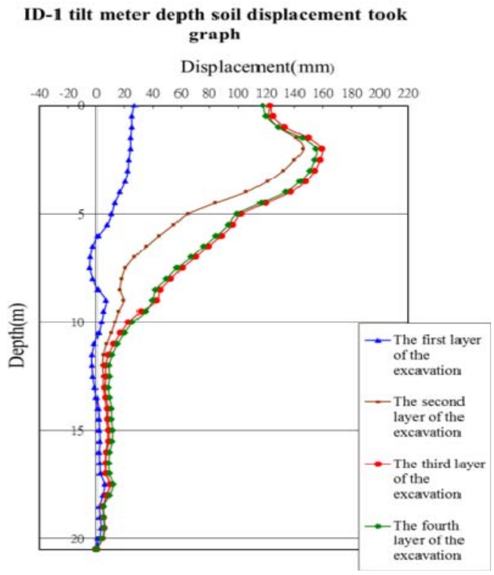

Fig. 4 TILTMETER ID-1

- TILTMETER ID-2: The lateral displacement for first layer excavation was observed at a maximum value of 5.3 cm, while the lateral displacement for the fourth layer excavation recorded a maximum value of 11.5 cm. The historical displacement observations are shown in Fig. 5.

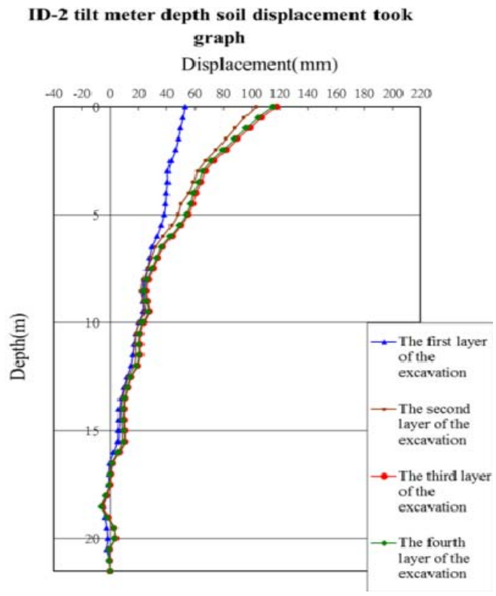

Fig. 5 TILTMETER ID-2

- TILTMETER ID-3: The lateral displacement for first layer excavation was observed at a maximum value of 1.3 cm, while the lateral displacement for the fourth layer excavation recorded a maximum value of 2.3 cm. The historical displacement observations are shown in Fig. 6.

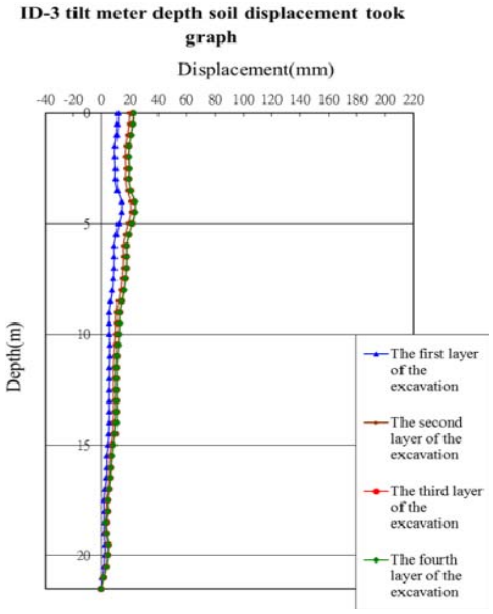

Fig. 6 TILTMETER ID-3

- TILTMETER ID-4: The lateral displacement for first layer excavation was observed at a maximum value of 2.7 cm, while the lateral displacement for the fourth layer excavation recorded a maximum value of 9.3 cm. The historical displacement observations are shown in Fig. 7.

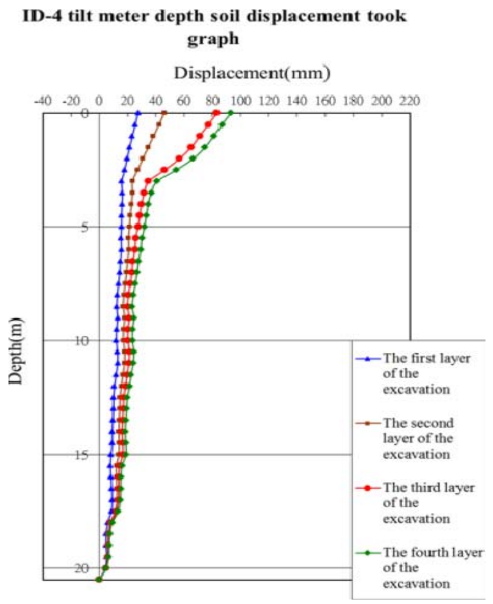

Fig. 7 TILTMETER ID-4

IV. RIDO Finite Element Analysis

RIDO finite element computer program was first developed in 1983 by Robert Fages Logiciels [4] using elastoplastic equilibrium in accordance Winkler spring [5] to simulate the hypothesis retaining wall at the time of each stage of excavation. The retaining walls to withstand bending moment, shear force, and deformation can be calculated during the excavation process. This study uses finite element program RIDO version 4.11.

RIDO is available for retaining wall and foundation pile for a variety of different types of soil in the elastoplastic equilibrium calculations. Taking the process of stress change in the soil mass during the construction stage into consideration, especially the irreversible characteristics of soil behavior, as well as the influences from the applied structure loading and/or the external surcharge force, the calculation procedure of RIDO can be performed as a staged simulation based on the construction sequence.

A. RIDO Program Composition and Instruction Description

The most critical part of running RIDO finite element program is the input for the pre-treatment program. All the basic information for the study case needs to be entered step by step to make sure that the correct model been established.

The most important part for RIDO finite element program is the pre-processing section. Excavation elevation, retaining structure, the layer of soil, groundwater surface, and construction sequence are contributed in the calculation for the purpose of accurate simulation. They can be described as follows:

1. Excavation elevation: This line instruction inputs the initial elevation before excavation.
2. Retaining structure: This line instruction inputs retaining structure elevation profile and rigid stiffness (EI).
3. Soil stratification: This line instruction inputs soil layer elevation and the characteristics of soil stratification.
4. Groundwater surface: This line instruction inputs elevation of the groundwater table setting.
5. Construction sequence: This line instruction inputs elevation of the construction sequence according to the actual excavation situation and its corresponding input.

B. Fundamental Assumptions of RIDO

1. The Stress-Strain Behavior of Soil

RIDO program basically assumed that the soil on both sides of the retaining structure is a linear elastic-plastic material, and can be represented by a group of spring system, which is independent of each other side, to simulate the soil behavior. When the soil pressure reaches the active and passive earth pressure, it is set to perform a non-reversible behavior. The earth pressure limit - active and passive soil pressure system is in accordance with (1) and (2):

$$q_a = K_a P + \frac{c}{\tan\phi}\left(\frac{\cos\delta - \sin\phi\cdot\cos\gamma}{1+\sin\phi} e^{-(\gamma-\delta)\tan\phi}\cdot\cos\delta - 1\right) + S_b \tag{1}$$

$$q_p = K_p P + \frac{c}{\tan\phi}\left(\frac{\cos\delta - \sin\phi\cdot\cos\gamma}{1+\sin\phi} e^{-(\gamma-\delta)\tan\phi}\cdot\cos\delta - 1\right) + S_b \quad (2)$$

where K_a = Coefficient of active earth pressure, K_p = Coefficient of active earth pressure, p = Effective overburden pressure, *c*, ϕ = Cohesion, Friction mobilization, δ = Effective angle of internal friction, $\gamma = \sin^{-1}(\sin\delta / \sin\phi)$, S_b = Boussinesq theory calculation of lateral force caused by the surcharge load.

2. Support or Ground Anchor

Strut support or ground anchor system is assumed to be the spring force with pre-stress in RIDO program. The engagement with type retaining structures can be roller connected, hinge connected, or rigid connection. It is also noted that strut support or ground anchor system can be input or removed in any analysis phase at any node.

C. Parameter Determination for RIDO Analysis

1. Soil Parameters

Soil parameters used in RIDO analysis are: soil unit weight (γ_t), active lateral earth pressure coefficient (K_a), lateral earth pressure at rest coefficient (K_o), passive lateral earth pressure coefficient (K_p), cohesion (c), internal friction angle (ϕ), delta/phi for active pressure (δ_a/ϕ), delta/phi for passive pressure (δ_p/ϕ), subgrade reaction modulus (R_e), second reaction coefficient (R_p). Wherein, the level of subgrade reaction can be expressed as:

$$K_h = R_e + R_p \times P \quad (3)$$

2. Lateral Earth Pressure

Elastoplastic model analysis and design of deep excavation retaining structure should adopt practical soil pressure. The so-called practical earth pressure actually refers to a theory of soil ultimate failure at active or passive earth pressure condition.

3. Stiffness of Retaining Structure and Strut Support

To conduct stress analysis of retaining structures, the stiffness retaining structures should consider appropriate amount of reduction based on the type, excavation method, construction quality, and material integrity.

Retaining structure usually withstands great moment in time and results to crack within the service life; therefore, the value of retaining structure stiffness is multiplied by a value from 0.5 to 0.7 as the reduction factor in general. Besides, the stiffness of H-beam strut support system generally uses a reduction factor between 0.3 and 0.7, considering the construction quality and material aging factor.

V. Simulation Results from RIDO

The analysis of this study case for the campus building basement excavation includes four-stage excavation, three-stage strut support, and dewatering with each stage process. RIDO finite element computer program simulates actual construction process, in accordance with the empirical formula of the input parameters to make the appropriate reduction or amended.

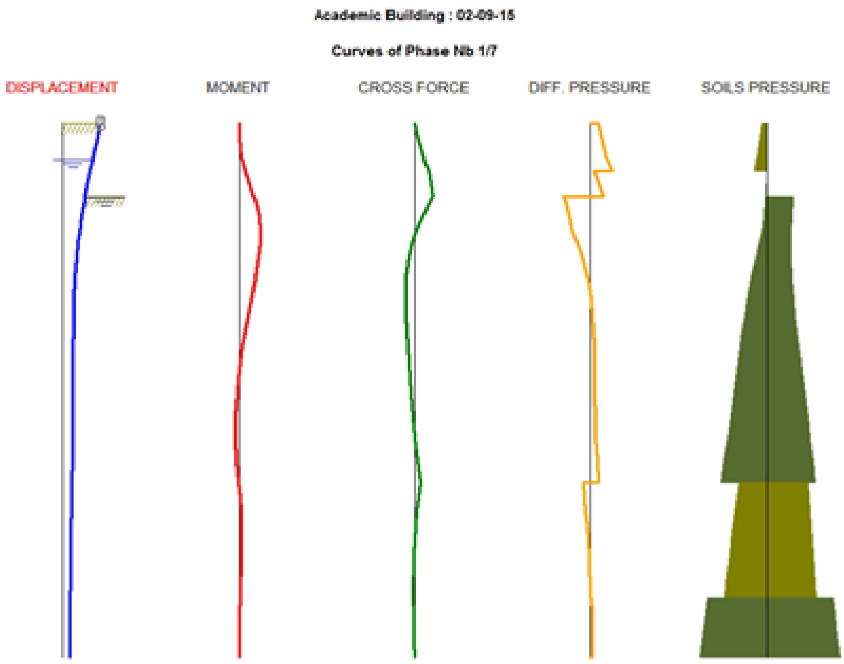

Fig. 8 Excavation to the first layer

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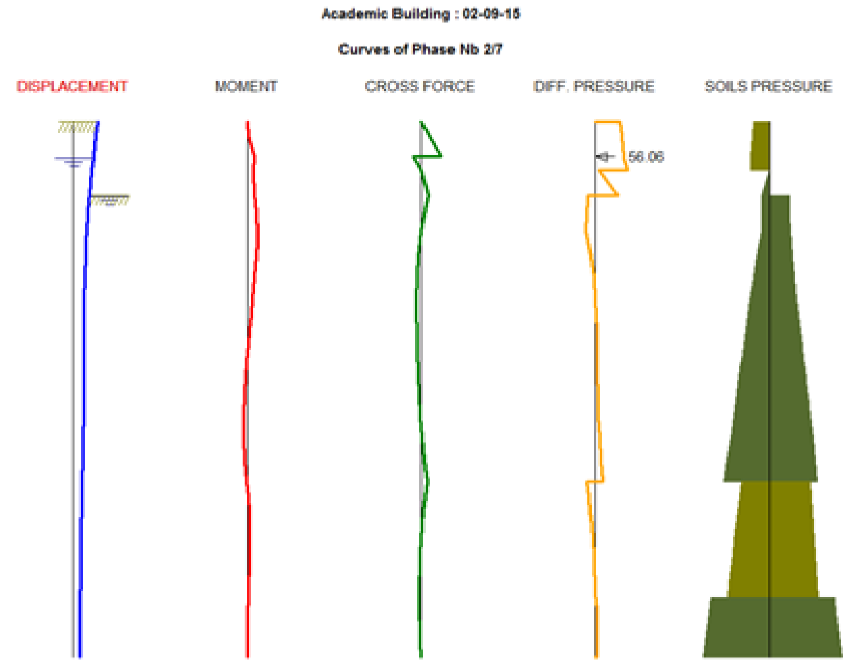

Fig. 9 First strut support set

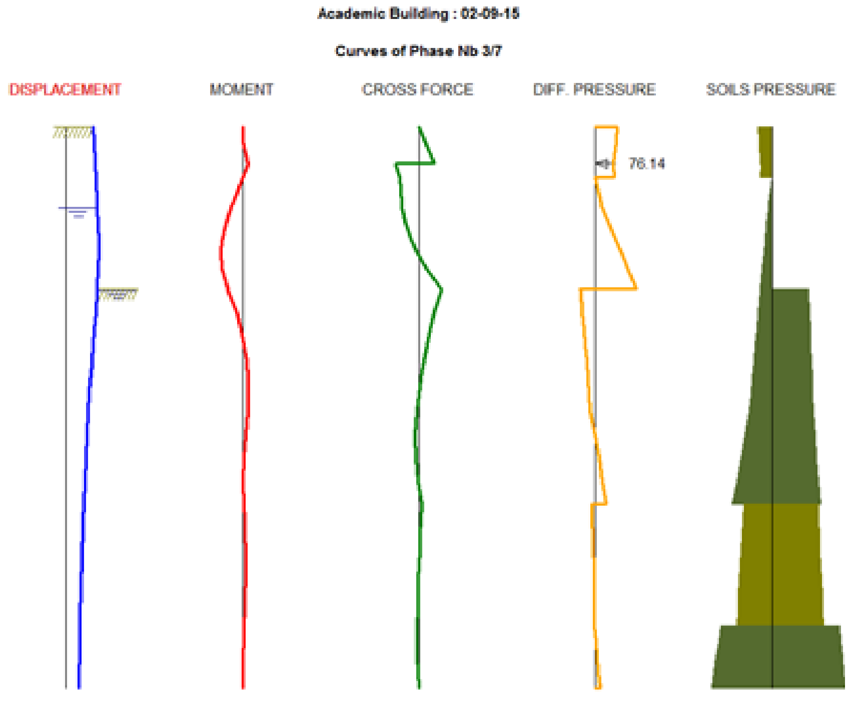

Fig. 10 Excavation to the second layer

The predicted results from RIDO for the TILTMETER ID-3 show the case when the excavation of the first layer gives the maximum displacement of 1.0 cm located at the elevation of ground surface (Fig. 8). The first layer of strut support provides the maximum displacement amount of 0.7 cm, also on the ground surface elevation (Fig. 9). When the excavation reaches to the second layer, the maximum displacement amount is predicted as 0.9 cm at the depth of 4.25 m from the ground surface (Fig. 10). After setting the second layer of strut support, the maximum displacement is 0.7 cm at the depth of 5.55 m from the ground surface (Fig. 11). When the excavation reaches to the third layer, the maximum displacement amount is 1.8 cm at the depth of 7.95 m underground (Fig. 12). After setting the third layer of strut support, the maximum displacement is 1.7

cm at the depth of 7.95 m from the ground surface (Fig. 13). Finally, when the excavation reaches to fourth layers, the maximum displacement amount is 2.2 cm at the depth of 9.07 m from the ground surface (Fig. 14).

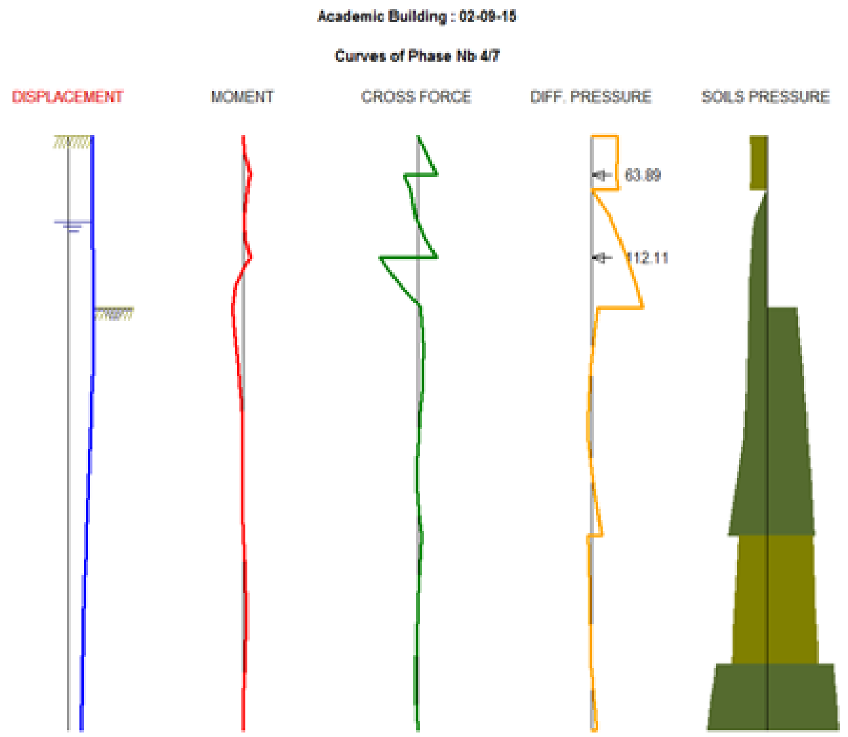

Fig. 11 Second strut support set

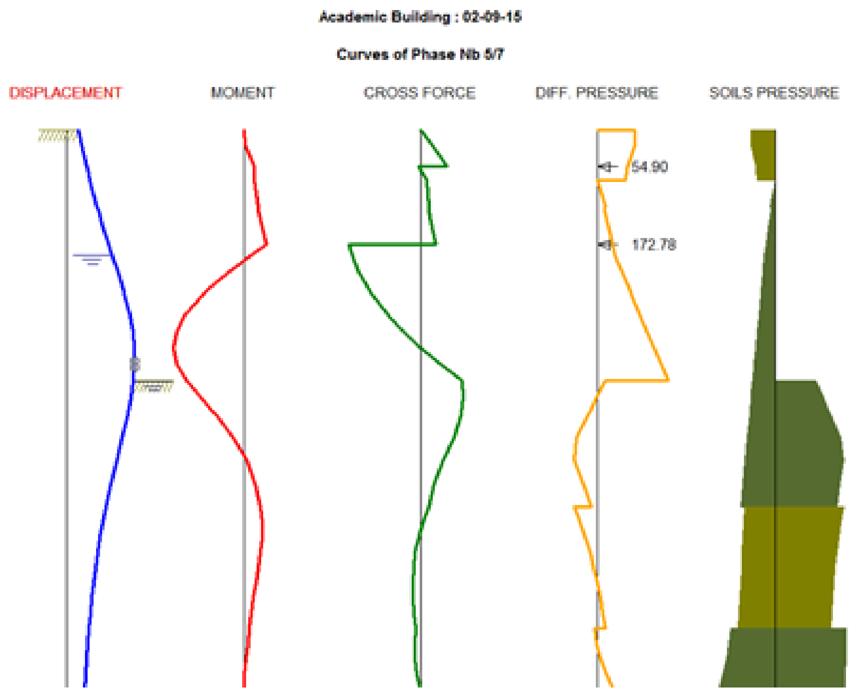

Fig. 12 Excavation to the third layer

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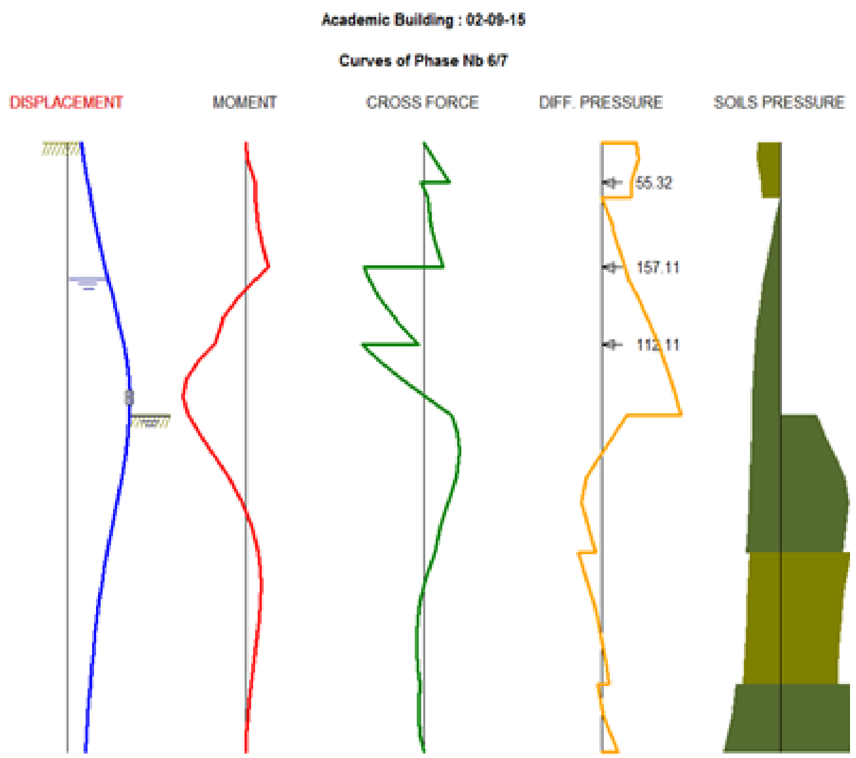

Fig. 13 Third strut support set

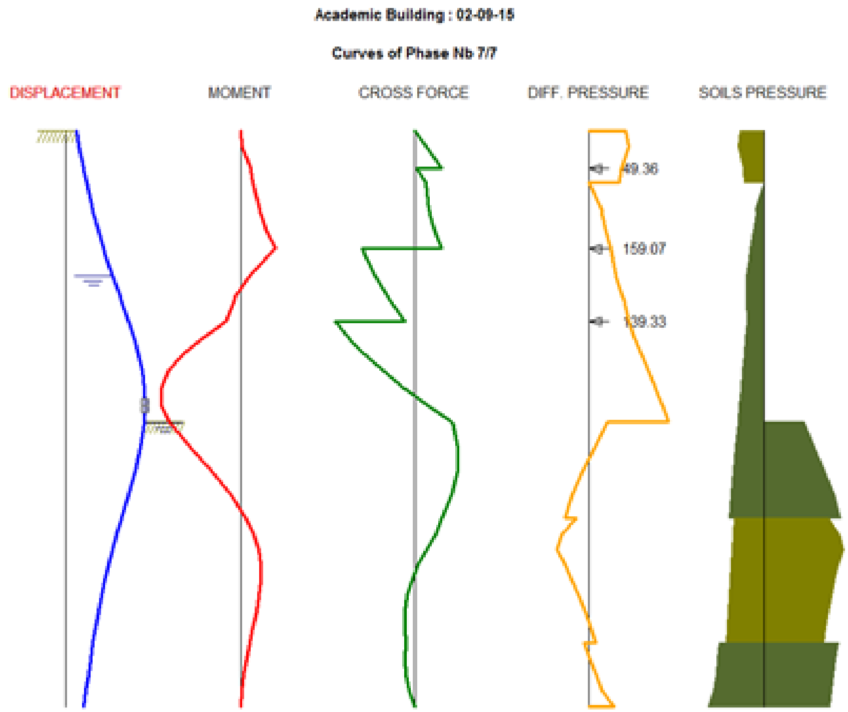

Fig. 14 Excavation to the fourth layer

VI. Conclusions

This paper describes the excavation reactions of a campus building in details from both the monitoring program as well as computer simulation. It is found that the predicted results from RIDO finite element method program can be compared with the observed data from the monitoring program pretty well at

TILTMETER ID-3, which is considered as the most reasonable results of the monitoring program. Thus, the excavation construction is under control in advance by employing numerical simulation for the engineering practice. Furthermore, it is recommended that prior to the excavation project, the numerical simulation results not only can be used to predict the field condition, but also can provide knowledge in advance for the details that are needed to pay attention and improve excavation safety.

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