

The choice of soil models in the design of deep excavation in soft soils of Viet Nam

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Abstract. The use of diaphragm wall to protect the depth excavation is quite common in Viet Nam. Prediction of diaphragm wall deformations is required to choose the method of construction, and also for control of process of erection of an underground construction. Currently, there are many programs to calculate the deformation of the diaphragm wall, including software Plaxis. This paper considers the choice of a computational model for soils in the Hanoi - Viet Nam region of Mohr Coulomb (MC) and Hardening Soil (HS) and comparison of the calculation results with the measured data. Such investigations were conducted first.

1 Introduction

In larger cities of Viet Nam, such as Hanoi and Ho Chi Minh City, the volume of high-rise buildings with underground part is also getting bigger. The need for underground space is increasing. Construction of underground structures has a significant impact on the surrounding buildings. It is necessary to use computational methods to assess the impact of underground construction on neighboring buildings. The geological conditions of these areas and models for the calculation were studied [1-9]. The main soil models for geotechnical calculations are Mohr Coulomb, Hardening Soil.

2 Numerical simulation in the finite element program Plaxis 2D

2.1 The Mohr-Coulomb model (MC)

This model represents a “first-order” approximation of soil or rock behaviour. Although the increase of stiffness with depth can be taken into account, the MC model does neither include stress-dependency nor stress-path dependency of stiffness or anisotropic stiffness. The linear elastic perfectly-plastic MC model involves five main parameters: elastic young modulus, E , Poisson's ratio, ν , the cohesion, c , friction angle, φ , and the dilatancy angle, ψ . [8, 10-13]. The MS model is suitable for many practical applications. To select a suitable calculated model of soil behavior, a series of numerical calculations of horizontal displacement of diaphragm walls using supported structures (i.e. anchors, struts of steel

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pipes, reinforced concrete floors) are performed. The calculated results are compared with the data of field observations.

2.2 The Hardening soil model (HS)

This is an improved model of massive soils that uses the theory of plasticity instead of the theory of elasticity, taking into account the characteristics of the soil. The relationship between axial strain and shear stress can be described by a hyperbolic curve. This model is devoid of the disadvantage of the MS model in describing the behavior of the soil during unloading and loading operations.

The HS model considers separately the modulus of deformation of soil under deviatoric loading (E_{50}^{ref}), the deformation modulus at compression (E_{oed}^{ref}), and module unloading and re-loading of the soil (E_{ur}^{ref}). Three-axis tests are required to obtain these parameters [10-15]. In fact, most often the designer has the results of stabilometric tests only for a few soils from the entire section, lying, as a rule, at a depth of more than 20 m. Other characteristics are set based on the recommendations of the developers of Plaxis [11].

2.3 Drainage type

Drained behavior: Using this setting no excess pore pressures are generated. This is clearly the case for dry soils and also for full drainage due to a high permeability (sands) and/or a low rate of loading [10, 12].

Undrained behavior for saturated soils. All clusters that are specified as undrained will indeed behave undrained, even if the cluster or a part of the cluster is located above the phreatic level [10,12,14,16].

There are three different methods of modeling the untrained behavior of the soil.

Undrained A: this is an analysis with effective stiffness as well as effective strength parameters. It can be used in combination with the most effective parameters φ' and C' to simulate the undrained shear strength of the soil. Figure 1. illustrates an example using the Mohr-Coulomb model.

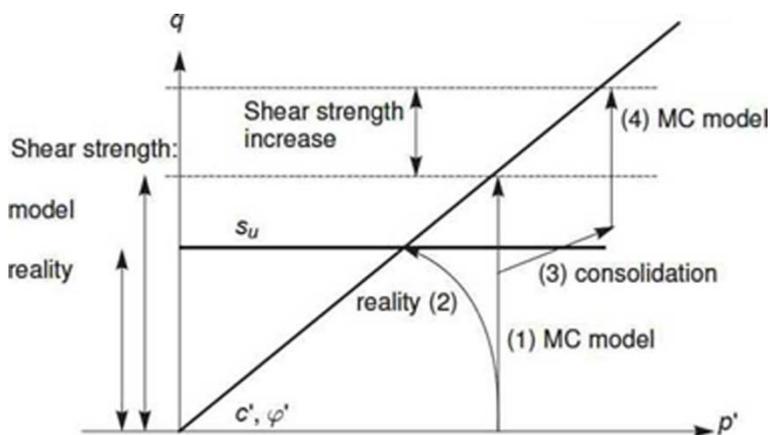


Fig. 1. Illustration of stress; reality vs. MC model

Fig. 1 illustrates an example using the Mohr-Coulomb model. When the Drainage type is set to undrained (A), the model will follow an effective stress path where the mean effective stress, p' , remains constant all the way up to failure (1). It is known that especially soft soils, like normally consolidated clays and peat, will follow an effective stress path in undrained loading where p' reduces significantly as a result of shear induced pore pressure (2)[10].

Undrained B: represents the undrained effective stress analysis with effective stiffness parameter and undrained strength parameters. Shear strength (s_u) is the input parameter ($\varphi=\varphi_u=0^\circ$; $c=c_u$).

Undrained C: the analysis of the undrained total stress with all the options. Model C includes Young's modulus of elasticity E_u and the Poisson's ratio ν_u , the strength is modeled using the shear strength s_u and ($\varphi=\varphi_u=0^\circ$). Typically, the Poisson's ratio is taken to be close to 0.5 (between 0.495 and 0.499).

Non-porous behavior: when using this setting, neither initial nor excessive pore pressure will be taken into account in clusters of this type. Nonporous behavior is often used in conjunction with a linear elastic model.

3 Analysis of application of soil model in geotechnical modelling in soft soils of Viet Nam

3.1 Description of studied structure

To analyze the applicability of soil models for the excavation of deep pits in Viet Nam conducted numerical geotechnical modeling for the building with two basements, which were constructed in Dong Da in Hanoi. The selected structural solution is the use of diaphragm walls for resisting the deep excavations $H_k=8\text{m}$ (H_k - depth of pit)

3.2 Input parameters

The thickness of the diaphragm wall was equal to 0.8 m, the parameters of the model: $EA=2.304 \times 10^7$ kN; $EI=1.23 \times 10^6$ kNm²/m, Poisson's ratio $\nu=0,18$. There were three methods for the construction of basements, which are: struts of steel pipes, anchors and concrete slabs (top-down). The calculations were performed using two soil models: MC and HS [17]. Concrete B40 has $EA=6.5 \times 10^6$ kN. Struts of steel pipes have: $EA=2.51 \times 10^6$ kN; spacing $L_s=1\text{m}$;

For the using anchor method, anchors are arranged uniformly along the length of the diaphragm wall with an interval of 2m, the tensile strength $EA=2.0 \times 10^5$ kN; The anchor is modeled by geotextile element with a stiffness of 1.91×10^6 kN/m;

The loadings of surrounding buildings are calculated as a pressure $q=20$ kN/m on the ground surface. This load is located at distances from excavation $0.5H_k$, $1.0H_k$, and $1.5H_k$.

The ground-water level is at a depth of -6m from the ground surface. The parameters of the soil models are presented in table 1 and table 2.

Table 1. MC model parameters

The type of soil		Loams	Loams	Loams	Sands	Sands
Layer thickness		3,3 m	11,2m	4,5m	9,0m	5,5m
γ_{unsat}	kN/m ³	12	15	15	17	17
γ_{sat}	kN/m ³	17	19	19	20	20
C [']	kPa	14	16	23	1	1
ϕ	°	11	14	18	31	32
E _{ref}	kPa	5362	6128	10724	30640	55918

Table 2. The parameters of the model HS

The type of soil		Loams	Loams	Loams	Sands	Sands
Layer thickness		3,3 m	11,2m	4,5m	9,0m	5,5m
γ_{unsat}	kN/m ³	12	15	15	17	17
γ_{sat}	kN/m ³	17	19	19	20	20
C [']	kPa	14	16	23	1	1
ϕ	°	11	14	18	31	32
E ₅₀ ^{ref}	kPa	5362	6128	10724	30640	55918
E _{oed} ^{ref}	kPa	5362	6128	10724	30640	55918
E _{ur} ^{ref}	kPa	16086	18384	32172	91920	167754

Geotechnical model of the object is shown in fig. 2.

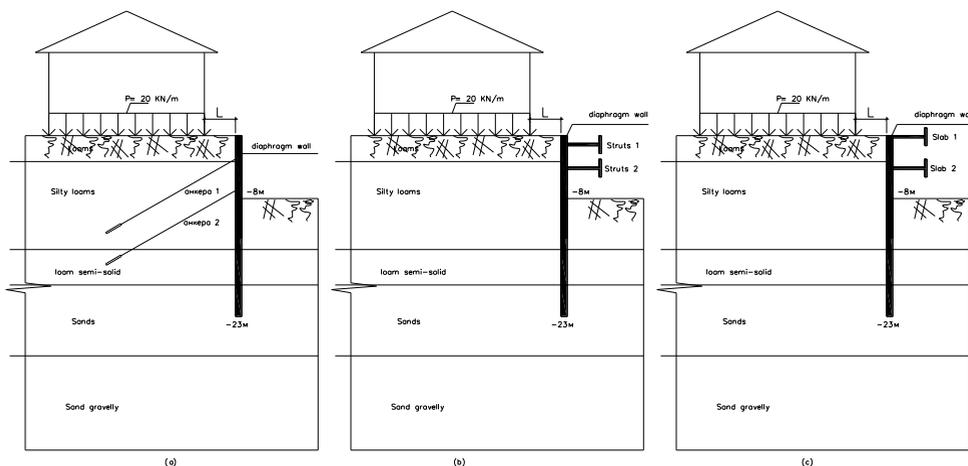


Fig. 2. Geotechnical model of the construction object with support structures: a) anchors, b) struts of steel pipes, c) reinforced concrete floors.

The finite element code Plaxis 2D is used for all analyses. The following computational steps have been performed [18]:

- Stage 1: activation of diaphragm walls
- Stage 2: excavation step 1 (to level -2.9m)
- Stage 3: Construct slab 1 (0.0m)
- Stage 4: excavation step 2 (to level -4.5m)
- Stage 5: Construct slab 2 (-4.3m)

- Stage 6: groundwater lowering and excavation step 3 (to level -8.0m)

4 Result of calculation

Geotechnical calculations were carried out using two types of soil behavior (drained and undrained A) in two soil models (MC and HS) to identify the features of soil base deformations from weak water-saturated soils of Viet Nam that contain underground structures. Given the limited data on the physical-mechanical properties of soils, the type of soil behavior undrained was considered.

Graphs of horizontal displacements of diaphragm wall (U_h , mm) at three types of fastening of depth excavation using two soil models (MC and HS) and two types of soil behavior (drained and undrained A) are shown in fig. 3.

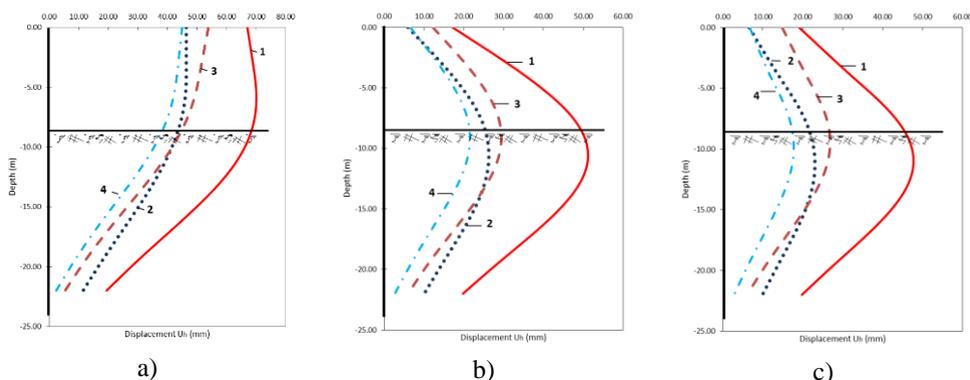


Fig. 3. Horizontal displacements of the diaphragm wall U_h , with $f=0.5$ when the spacer structures in the form of: a) anchors b) struts of steel pipes, c) reinforced concrete floors; 1 - MC undrained A; 2 - MC drained; 3-HS undrained A; 4 - HS drained

The values of U_h at the bottom of the pit (-8m) determined using HS and MC, drained and undrained A are presented in table 3:

Table 3. U_h , horizontal displacements of the diaphragm wall in the ground at a depth of -8 m

Distance from the depth excavation	$f=0,5$		$f=1,0$		$f=1,5$			
Calculation model	MC Drained	MC undrained(A)	HS Drained	HS undrained(A)	MC undrained(A)	HS undrained(A)	MC undrained(A)	HS undrained(A)
Anchor's (mm)	44.43	69.15	39.43	46.03	68.79	45.06	68.40	44.19
struts of steel pipes (mm)	24.81	48.55	21.25	29.06	48.32	28.57	48.03	28.06
Reinforced concrete floors (mm)	21.47	44.43	17.02	26.40	44.21	25.32	43.93	24.88

Where: $f = \frac{L}{H_k}$ (L - distance from the depth excavation, m ; H_k – the depth of the pit, m)

From the results shown in table 3, it follows that the maximum horizontal displacements of diaphragm wall gives the calculation of the model undrained MC A. Value U_h model undrained A more than the model MC drained at 55.6% (using anchors), 95.7% (using the horizontal braces of steel pipes) and 106.9% (with concrete slabs). The results of the horizontal displacement calculation of diaphragm wall using the model HS undrained A are 16.7% more than the model HS drained for anchors, 36.8% for steel pipe struts and 55.1% reinforced concrete floors. Therefore, for the Hanoi condition, where weak water-saturated clay soils are deposited, the undrained type of soil behavior should be used.

Comparison of the U_h values calculated by MC and HS models (undrained conditions) with measured values is given in table 4 and fig.4.

Table 4: Comparison of calculated and measured values of horizontal displacements of the diaphragm wall at the bottom of the pit U_h

Stage of construction	The maximum horizontal displacement U_h (mm)			Comparison with observations (%)	
	MC undrained A	HS undrained A	Measured	MC undrained A	HS undrained A
	(1)	(2)	(3)	(4)	(5)
To level -2.9 m	14.63	7.65	5.95	145.88	28.57
To level -4.5m	36.78	20.21	18.30	101.00	10.43
To level -8.0m	44.43	26.40	19.83	124.05	33.13

Where: (4)= ((1)-(3))*100/(3); (5)= ((2)-(3))*100/(3)

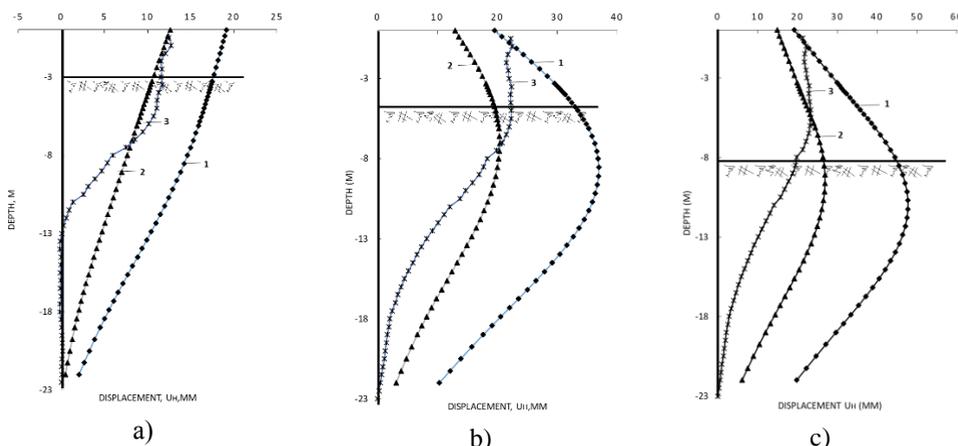


Fig. 4. Calculated and measured horizontal displacement of diaphragm wall at the depth: a) -2.9 m; b) -4.5 m; c) -8.0 m; (1-MC undrained A; 2-HS undrained A; 3- measured values)

From the analysis of table 4 and fig. 4 it can be concluded that the results of calculations of the diaphragm wall horizontal displacement using the HS undrained A model give the best convergence with the measured values.

5 Summary

1. A quantitative assessment of soil mass stress-strain state is conducted for the weak water-saturated soils in Vietnam. Calculations were made for three types of diaphragm wall supported structures : anchors, struts of steel pipes, and reinforced concrete floors. Two soil models HS and MC and two kinds of soil behavior were considered. Such investigations were conducted first.

2. The comparison of calculated results and data from field observations demonstrates that the soil model, HS undrained A, should be used for evaluating the deep excavations in urbans of Vietnam with weak water-saturated soils.
3. The forecast of horizontal displacement of diaphragm wall based on model HS undrained A allows to choose a safe method of construction and also to avoid accidents at deep excavation.

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