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A PRACTICAL APPROACH FOR MODELING TWIN-TUNNEL EXCAVATION IN HO CHI MINH CITY

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Abstract. The prediction of ground settlement under tunnel excavation is still challenge. Almost engineer uses Mohr-Coulomb model in practice due to the conventional geotechnical investigation data. This paper describes the study of tunnel lining behaviors and ground surface settlement under tunneling process with a typical case study of twin tunnels excavation in Ho Chi Minh city, Vietnam. The advanced material model namely Hardening Soil model is used to investigate the proposing twin-tunnel with numerical approach. The internal forces of tunnel lining and ground settlement, which achieved from Hardening Soil model and the available results from Mohr-Coulomb model, are then made comparison between two models which yields some important differences for analysis. Since the experimental works for qualifying stiffness parameters in Hardening Soil model are missed in the Metro Line 1 project in Ho Chi Minh city, an empirical formula is proposed in the paper as a guide for estimating the required data in modelling process

Keywords: twin-tunnel, Soil modelling, ground surface settlement, Excavation

1. INTRODUCTION

Tunnel construction for transport routes is becoming increasingly important worldwide. Constructing a tunnel is one of the most complex challenges in the field of civil engineering. Tunnel linings differ from others structural systems due to the consideration of structure itself and surrounding ground integrally. Since their interaction affects structural behavior, stability and overall load carrying capacity, it is significantly important to model the tunneling process. The Ho Chi Minh city Metro Line, Vietnam is a planned rapid transit network which was first proposed in 2001 as part of a comprehensive public transport network plan, with the aim of avoiding the severe traffic congestion problems. However, underground metro is generally large, deep excavation, so understanding the tunnel behavior as well as monitoring carefully is challenging now. Tunnel behavior and building settlement due to tunnel excavation in literature show that the excess pore pressure generated by tunnelling excavation process dissipates with time. Also the tunnel has typically zero pressure inside, the new water pressure conditions will be created which leads to soil consolidation, especially in case of twin-tunnel with complicate interaction [1]. Moreover, one of the most important considered factors in designing a tunnel is the internal forces induced in segmental tunnel lining. Some studies [2-3] have been developed for investigating this aspect with calculation methods include empirical methods, analytical methods and numerical methods which yield different results. The settlement of buildings adjacent to tunnel excavation and the induced internal forces of Metro Line thence need to be studied more and clarifed due to the complexity of strata profile in Ho Chi Minh City.

The implementation of Mohr-Coulomb model for the soil behavior in the calculation sheet provided by Contractor [4] may create argument when considering tunnel soil behavior as explained in some articles [5-6]. Thus the other soil model is proposed in this study, i.e. the Hardening Soil model, to make comparision with Mohr-Coulomb model, which could result in some differences for analysis. In practice, it is necessary to carry out some laboratory tests as well as in-situ tests for the determination of stiffness parameters for Hardening Soil model: the triaxial loading stiffness (E_{50}^{ref}), based on the results of triaxial pressure test; the triaxial unloading stiffness (E_{ur}^{ref}), based on the results of triaxial unloading pressure test; and the oedometer loading stiffness (E_{oed}^{ref}), based on the results of a one-dimensional consolidation test [5]. In Ho Chi Minh project, the input data for Hardening Soil model are lacked due to budget limitation. For this reason, some correlations derived from existing data need to be set up.

This paper focuses on the differences of lining behaviors and ground settlement under tunnel excavation when investigating the two soil models: Mohr-Coulomb and Hardening soil models, with the help of numerical approach (Finite Element Method). The empirical formulas for estimating stiffness paramteters in Hardening Soil model are also suggested for purpose of design and elastic-related solutions.

2. PRACTICAL APPROACH FOR MODELING TUNNEL EXCAVATION BY HARDENING SOIL MODEL

2.1. Methodolody of determining Hardening Soil paramters

Hardening Soil model is an advanced model for simulating the behavior of different types of soil, both soft soils and stiff soils [7]. The Hardening Soil model accounts stress-dependency of stiffness moduli which means stiffnesses increase with pressure. As shown in Figure 1, the Mohr-Coulomb model is a perfect linear elastic-plastic model. Contrast to the Mohr-Coulomb model, the strains (elastic and plastic) in the Hardening Soil model are calculated based on the stiffness of the surface tension and this stiffness is different for the initial loading and unloading/loading [8]. In this model, the behavior of material is nonlinear, behavior is determined based on Mohr-Coulomb strength parameters (c, φ). However, soil stiffness in Hardening Soil model is described much more accurately by defining three more different stiffnesses corresponding to the loading conditions: the triaxial loading stiffness (E_{50}^{ref}), the triaxial unloading stiffness (E_{ur}^{ref}), and the oedometer loading stiffness (E_{oed}^{ref}) [9].

As mentioned in former section, since the stiffness parameters for Hardening Soil model are often difficult to determine experimentally, some relationships have been established. Figure 2 illustrates the sequences of the determination of input parameters for the Hardening Soil model: from the available Standard Penetration Test (SPT) value, determine the value of the elastic modulus, thereby determining the oedometer unloading stiffness (Eoed) by means of using relationship (1). The other required stiffness parameters are then met by using relationships (2), (3) and (4), as proposed by Chanaton et al [10].

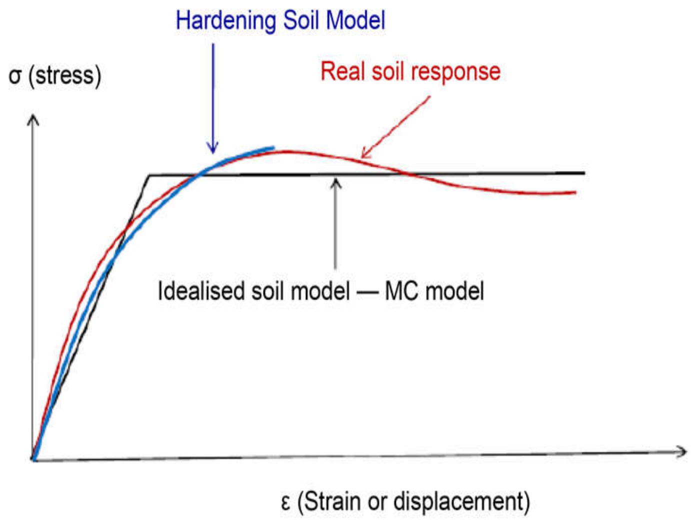


Figure 1. Respones of different soil models [7].

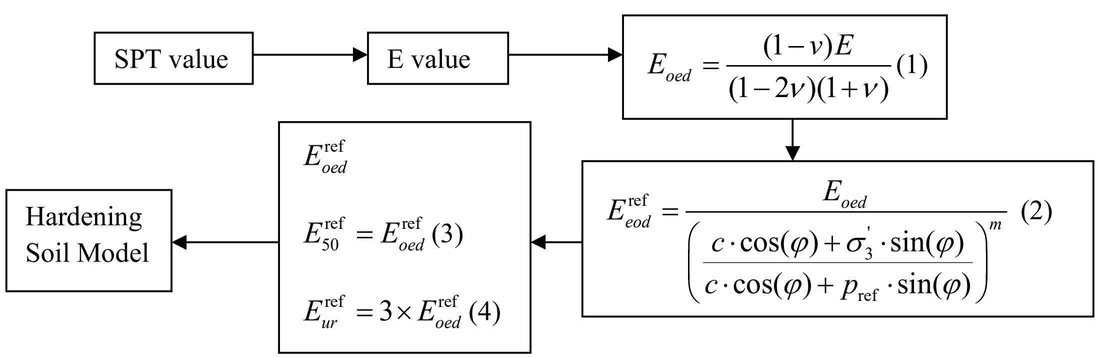


Figure 2. Calculation steps for the input parameters of Hardening Soil model [10].

As given in Figure 2, E_{50}^{ref} is a reference stiffness modulus corresponding to the reference stress pref. In Plaxis software, pref equals to 100 kN/m2 as a default setting. The actual stiffness depends on the minor effective principal stress $\sigma_3^{'}$. Note that $\sigma_3^{'}$ is positive in compression. Moreover, the amount of stress dependency is represented by the power m. As Soos von [11] proposed a range values of m from 0.5 to 1 in different soil types, this study considers m = 0.5 (normally for dense sand) in calculating process.

A major problem here is the determination of elastic modulus from available SPT value. The empirical equations of modulus of elasticity have been collected from El-sayed Abdelfattah El-kassaby [12] and examined to see which gives reasonably reliable results.

2.2. Empirical correlations of modulus of elasticity

Empirical correlations of modulus of elasticity (Es) with the standard penetration number (N) are collected from literature as shown in Table 1. A number of investigators have attempted to correlate the modulus of elasticity with the conventional results obtained during field exploration programs, specifically, the SPT values. These formulas provide well estimation among wide ranges of different soil types. The modulus of elasticity therefore can be derived effectively by applying the relations in Table 1

Table 1. Empirical correlations of modulus of elasticity.

No	Formula	Unit	Reference documents
1	E_s=41600+1090N	kPa	[13]
2	E_s=1200(N+6)	kPa	[14]
3	E_s=(15200 to 22000)ln(N)	kPa	[15]
4	E_s=1200(N+6) if N<15	kPa	[16]
	E_s=4000+1200(N-6) if N>15	kPa	[16]

3. CASE STUDY OF METRO LINE 1 IN HO CHI MINH CITY

3.1. Introduction of metro line 1 in Ho Chi Minh City

Metro Line 1 in Ho Chi Minh City runs for 19.7 km from Ben Thanh market, underground for 2.6 km past the Opera House, Ba Son shipyard, and then cross the Saigon river on an elevated track, passing through district 2 on the way to Suoi Tien park and the terminus in Long Binh in district 9. In total, Line 1 includes 14 stations sketched in Figure 3, with three of these being underground [17]. Based on the Technical Design Report [4], the underground route includes two tunnels of 6.35m diameter, namely, upper tunnel - West Bound Track (WBT) and lower tunnel - East Bound Track (EBT), with rail elevation being 12.74 (m) and 24.94 (m), respectively. The twin bored tunnels were completed in the middle of 2018, and the entire project is expected to be operated by the end of 2020.

A critical section, namely A-A section, is located at CH0+860, between Opera House and Ba Son shipyard as shown in Figure 3. This section has the heaviest building load according to Technical Design Report [17]. Hence, A-A section is under investigated as a typical section to take the settlement effects of existing buildings into account and calculate the induced internal forces in segmental tunnel linings of Project Metro Line 1. The geotechnical parameters of this section are presented in Table 2. Figure 4 represents the strata profile at A-A section. The geological profile is mainly comprised of fill, alluvium and diluvium materials with the water level equalled to the ground. The first layer of soil comprises of fill with an average depth of approximately 2 m. The next layer of Alluvium is approximately 30 m deep, which comprises of soft clayey silt, silty fine sand layer 1 and sand layer 2. Diluvium clayey silt and silty sand are found below the alluvium layer [17].

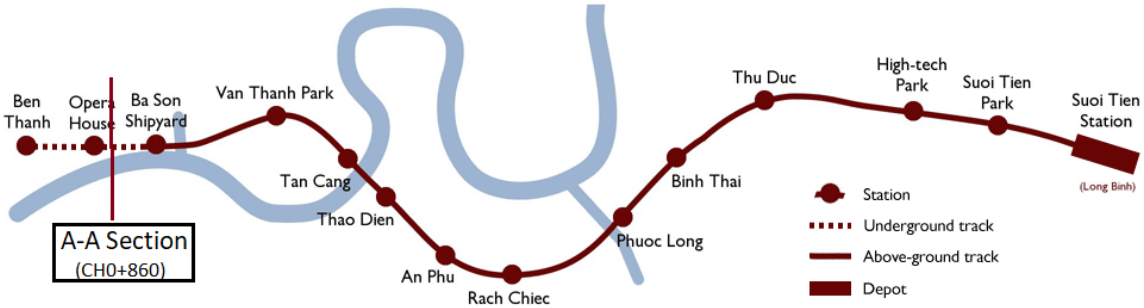


Figure 3. Metro Line 1 of Ho Chi Minh City [4].

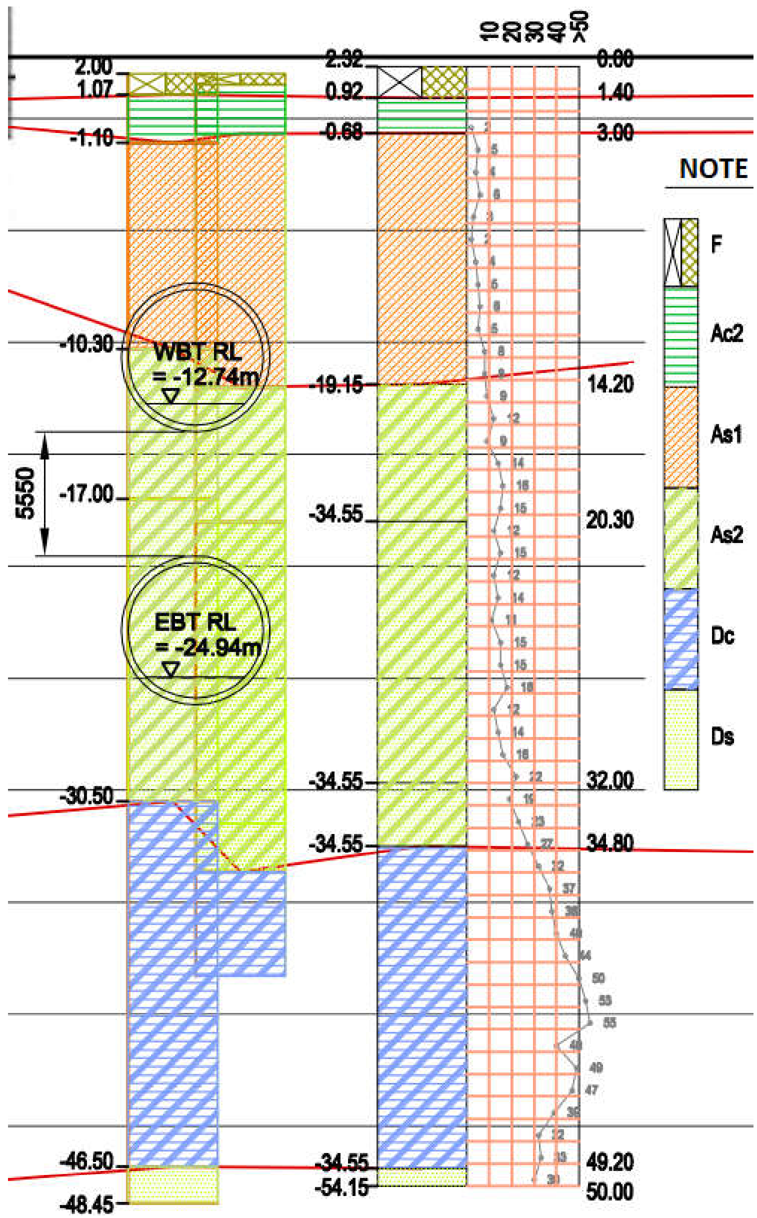


Figure 4. Stratigraphy at A-A section (CH0+860) [4].

Table 2. Geotechnical parameters of A-A Section.

Soil layer	Unit weight, γ (kN/m^3)	SPT – N value (Blows/30cm)	Effective cohesion, c' (kN/m^2)	Effective friction, φ' (degree)
Fill (F)	19.0	4	10	25
Clay Layer 2 (Ac2)	16.5	2	10	-
Silty Fine Sand Layer 1 (As1)	20.5	5	0	30
Sand Layer 2 (As2)	20.5	15	0	33
Hard Clayey Silt (Dc)	21.0	34	170	-
Dense Silty Sand (Ds)	20.5	36	0	35

Table 3. Soil parameters for Mohr-Coulomb model.

Description	Unit	Soils layers					
		F	Ac2	As1	As2	Dc	Ds
Drainage type	-	Drained	Undrained	Drained	Drained	Undrained	Drained
Unit weight (γ)	kN/m^3	19	16.5	20.5	20.5	21	20.5
Elastic modulus (E)	kPa	10000	3000	12500	37500	136000	90000
Poisson's ratio (υ)	-	0.3	0.3	0.3	0.3	0.3	0.3
Permeability cofficient (k)	m/sec	8.64×10^{-3}	8.64×10^{-5}	8.64×10^{-3}	8.64×10^{-5}	8.64×10^{-4}	8.64×10^{-4}
Cohesion (c')	kPa	10	10	0	0	170	0
Friction angle (φ)	degree	25	0	30	33	0	35
Dilatancy angle (ψ)	degree	0	0	0	0	0	0
Interface factor	-	0.67	0.5	0.67	0.67	0.67	0.5

3.2. Hardening soil parameters

The methodology presented in the section 2 is used to determine the elastic modulus parameters for Hardening Soil model by means of substituting the average SPT values of A-A section into the empirical formulas mentioned in Table 1. The results of elastic modulus for specific layers of A-A section are shown in Table 4. As can be seen in Table 4, the different empirical correlations presented in literature give different values for modulus of elasticity.

Table 4. Elastic modulus derived from empirical formulas (kPa).

Soil Layer	1	2	3	4	5	6
Formula	F	Ac2	As1	As2	Dc	Ds
D'Appolonia et al (1970)	45960	43780	47050	57950	78660	80840
Boweles (1974)	12000	9600	13200	25200	48000	50400
Trofimenkof (1964), 15200ln(N)	21072	10536	24463	41162	53601	54469
Trofimenkof (1964), 22000ln(N)	30498	15249	35408	59577	77580	78837
Begemann (1974)	12000	9600	13200	14800	37600	40000
Min	12000	9600	13200	6700	12400	13000
Max	45960	43780	47050	59577	78660	80840
Proposed value	21072	10536	24463	59577	77580	78837

Table 5. Soils parameters for Hardening-Soil Model.

Description	Unit	Soils layers					
		F	Ac2	As1	As2	Dc	Ds
Drainage type	-	Drained	Undraine d	Drained	Drained	Undrained	Draine d
Unit weight (γ_{sat})	kN/m^3	19	16.5	20.5	20.5	21	20.5
Secant Stiffness (E_{50}^{ref})	kPa	57793	29650	36977	52155	50133	45466
Tangent Stiffness (E_{oed}^{ref})	kPa	57793	29650	36977	52155	50133	45466
Unloading stiffness (E_{ur}^{ref})	kPa	173379	88950	110931	156465	150399	136398
Poisson's Coefficient	-	0.3	0.3	0.3	0.3	0.3	0.3
Permeability (k)	m/sec	$8.64x10^{-3}$	$8.64x10^{-5}$	$8.64\ x10^{-3}$	$8.64x10^{-5}$	$8.64x10^{-4}$	$8.64x10^{-4}$
Cohesion (c')	kPa	10	10	0	0	170	0
Friction angle (φ)	degree	25	0	30	33	0	35
Dilatancy angle (ψ)	degree	0	0	0	0	0	0
Interface permeability	-	0.67	0.5	0.67	0.67	0.67	0.5

The minimum, maximum and average values are also computed to figure out the possible range of elastic modulus. The results derived from the formula of Trofimenkof seem to give the closest values in comparison with the average values. Specifically, using 15200ln(N) for SPT values N < 15 and 22000ln(N) for SPT values N > 15 give the most reliable results. Hence, Trofimenkof formula [15] is proposed to estimate the modulus of elasticity for modelling the Hardening Soil models. Table 5 shows all the required input parameters for Hardening Soil model, with the three stiffness parameters (E_{50}^{ref} , E_{ur}^{ref} , E_{oed}^{ref}) derived from the sequence described in Figure 1.

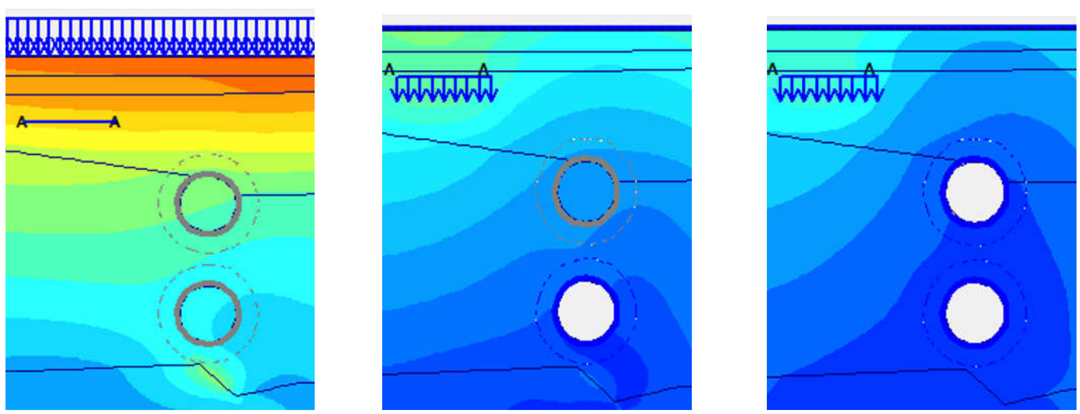
3.3. Case study problem

The result of determining Hardening Soil parameters by the proposed methodology in this paper is used to investigate tunnel behavior of Metro Line 1 in Ho Chi Minh City. The assumed conditions for this case study are as follows:

1. The problem aims at determining the ground settlement due to tunnel excavation, therefore, it is necessary to consider the existing building load and surcharge load. The surcharge load is taken as 15 kPa, and the existing building load is calculated by 15kPa plus the number of story [4].

2. During the tunneling process, there is no water in the tunnel, so the pore pressure around the tunnel is considered zero during the tunneling process.

The calculation is then carried out to estimate the ground settlement in both Mohr-Coulomb and Hardening Soil models. For the execution of the two mentioned models, it is required to applying the sequences as presented in Figure 5: (a) Phase 1- apply the surcharge (15kPa); (b) Phase 2- apply building load, bore through East Bound Track and install lining; (c) Phase 3- bore through West Bound Track and install lining.



(a) Phase 1 (b) Phase 2 (c) Phase 3

Figure 5. Sequences of modeling tunnel excavation process: (a) Phase 1- Apply the surcharge (15kPa); (b) Phase 2- Apply building load, bore through East Bound Track and install lining; (c) Phase 3- Bore through West Bound Track and install lining.

Plaxis software, which offers a convenient option to create circular and non-circular tunnels composed of arcs and lines [7], is used to investigate the stability and settlement of project Line 1 in Ho Chi Minh city and to simulate behavior of the soil surrounding the tunnel. Models of soil layers, building loads, surcharge load and tunnels are shown in Figure 6 where the ground level (GL) is being 2.73 m whereas the water table (WT) is being 1.93 m. As given in the Figure 6, the load of building No. 42 with 8m distance and 45A with 15m distance have the values of 85 kPa and 150 kPa, respectively. In addition, a surcharge load of 15 kPa is distributed on the ground. The upper tunnel is WBT with the rail level being 12.74 m and the lower tunnel is EBT with the rail level being 24.94 m, as mentioned in Section 3.1.

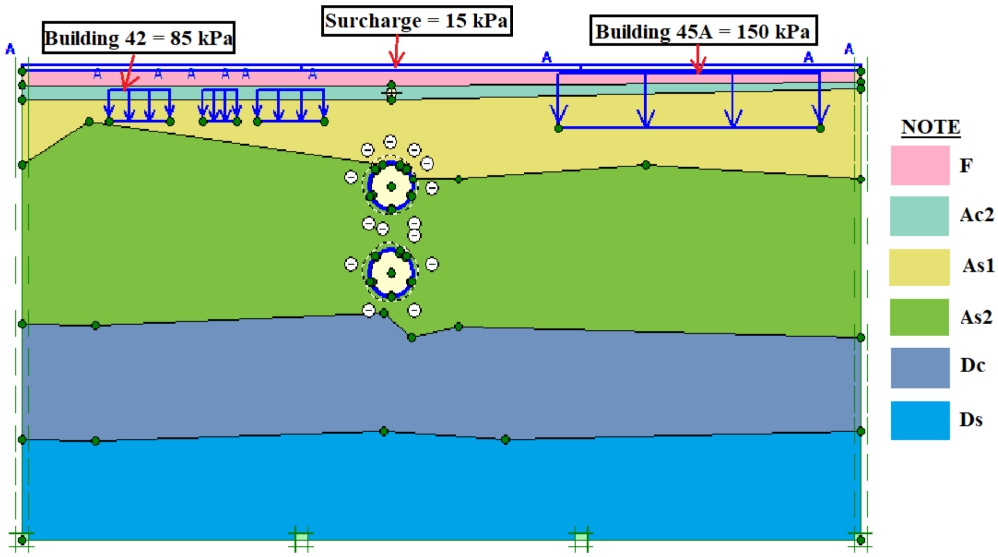
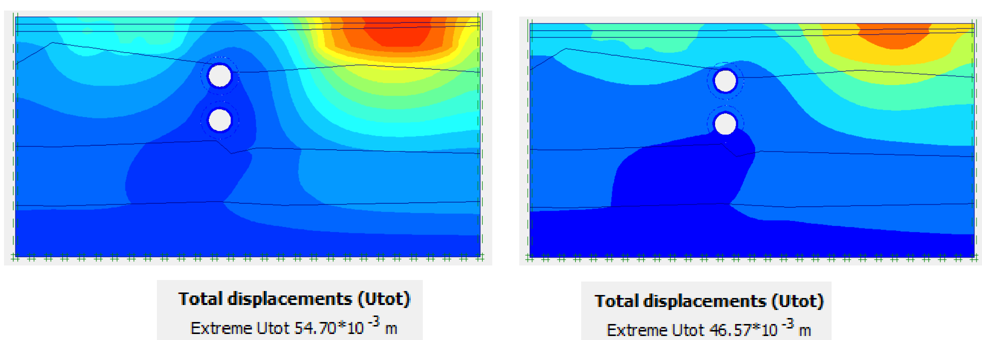


Figure 6. Model of soil layers and building load in Plaxis for section A-A of Metro Line 1.

3.4. Modelling results



(a) (b)

Figure 7. Result of Phase 3 for (a)Mohr-Coulomb Model and (b) Hardening-Soil Model.

Figure 7 illustrates the total displacement (ground settlement) after Phase 3 of Mohr-Coulomb (a) and Hardening Soil (b) models in Plaxis. The total displacement for the Mohr-Coulomb model is 54.70 x 10^{-3} m and 46.57 x 10^{-3} m for that of the Hardening Soil model. The average difference between two results is approximate 15%. The diagrams of axial forces, shear forces and bending moments from two models for WBT and EBT are shown in Figure 8 - 9. Also the extreme values of each diagram is presented in these figures. There is a similarity in shape of diagrams between Mohr-Coulomb and Hardening Soil models, with the average difference approximately 19%. Generally, the analyses of two material models pointed out some differences in terms of ground settlement as well as internal forces in tunnel lining. This can be explained by the increase of stiffness moduli in Hardening Soil model; however, these differences are not too large. The empirical relationship used for adequating the elastic modulus data in modeling process of Hardening Soil model in this case study thereby could be a reference to solve the current problem of modeling tunnel excavation in some projects.

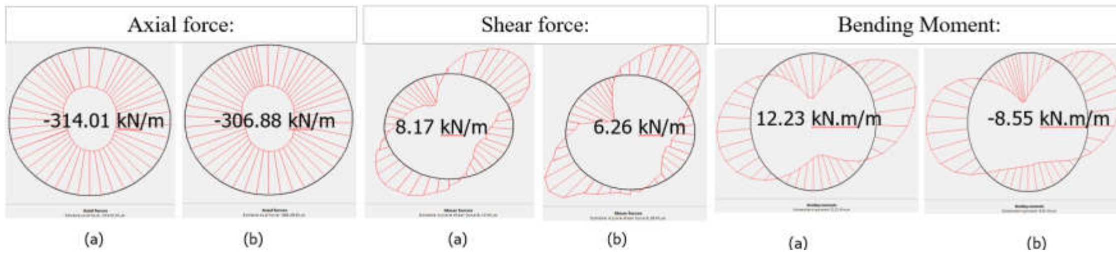


Figure 8. Internal forces of West Bound Track with extreme values (a) Mohr-Coulomb model; (b) Hardening Soil model.

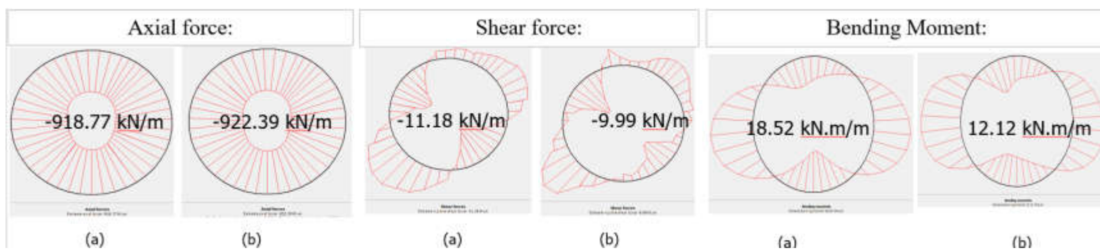


Figure 9. Internal forces of East Bound Track with extreme values (a) Mohr-Coulomb model; (b) Hardening Soil model.

4. CONCLUSION

This paper has presented a practical study for estimating the ground settlement and internal forces of tunnel lining due to tunnel excavation. A typical section of twin bored tunnels of the Metro Line 1 in Ho Chi Minh city has been investigated as a case study with numerical approach when comparing the results of Hardening Soil and Mohr-Coulomb models. As presented in section 3, the result of total displacement obtained from Hardening Soil model is smaller than that obtained from Mohr-Coulomb model which reveals that the suggested formula is the secant stiffness modulus in Hardening Soil. Since all formulas were established based on reality strata profiles, they could be recommended to apply in further projects with similar geological properties in case of limitation in executing field or laboratory tests.

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REFERENCES

[1] S. Soga, R.G. Laver, Z. Li, Long-term Tunnel behaviour and Ground movements after Tunnelling in Clayey soils, Underground Space, 2 (2017) 149-167. https://doi.org/10.1016/j.undsp.2017.08.001.

[2] E. Almog, M. Mangione, G. Cachia, Ground Relaxation in Segmental Lining Design using the Convergence-Confinement method, Proceedings of the Underground Design and Construction Conference, 2015, IOM3 Hong Kong Branch, pp. 335-345

[3] N.A Do., D. Dias, P. Oreste, I. Djeran-Maigre, Comparison between Design Methods Applied to Segmental Tunnel Linings, Geotechnical Engineering of the SEAGS & AGSSEA, 45 (2013) 64-70.

[4] Shimizu-Maeda, Technical Design Report (Third Submission), Ho Chi Minh City Urban Railway Construction Project Ben Thanh - Suoi Tien Section (Line 1), Simizu Maeda joint adventure, 2016

[5] S. Celik, Comparison of Mohr-Coulomb and Hardening Soil Models' Numerical Estimation of Ground Surface Settlement Caused by Tunneling, Iğdır Univ. J. Inst. Sci. & Tech., 7 (2017) 95-102

[6] A. Gaur, A. Sahay, Comparison of Different Soil Models for Excavation using Retaining Walls, SSRG International Journal of Civil Engineering (SSRG – IJCE), 4 (2017) 40-45. https://doi.org/10.14445/23488352/IJCE-V4I3P110

[7] R.B.J. Brinkgreve, W. Broere, D. Waterman , Version 8.5 Finite-Element Code for Soil and Rock Analyses, Plaxis, 2007.

[8] R.F. Obrzud, A. Truty , The Hardening Soil Model: A Practical Guidebook, ZSoil manual, 2018.

[9] K.N Vakili, T. Barciaga, A.A. Lavasan, T. Schanz , A Practical Approach to Constitutive Models for The Analysis of Geotechnical Problems, The Third International Symposium on Computational Geomechanics (ComGeo III) At: Krakow, Poland, Volume: 1, 2013.

[10] S. Chanaton, L. Suched, W. Darius, B. Arumugam, O. Erwin, G. Hong, Stiffness and strength parameters for hardening soil model of soft and stiff Bangkok clays, Soils and foundations, 52 (2012) 682-697. https://doi.org/10.1016/j.sandf.2012.07.009

[11] P. Soos von, Properties of Soil and Rock (in German), Grundbautaschenbuch, vol. 1, 6th Ed., Ernst and Son, Berlin, 2001, pp. 117-201

[12] El-sayed Abdelfattah El-kassaby, Estimation of Guide Values for the Modulus of Elasticity of Soil. Bulletin of Faculty of Engineering, Assiut University, 19 1991

[13] D.J. D'Appolonia, E. E. D'Appolonia, R.F. Brissette Closure to Settlement of Spread Footings on Sand, Journal of the Soil Mechanics and Foundations Division, 94 (1968) 735-762

[14] J.E. Boweles, Analytical and Computer Methods in Foundation Engineering, McGraw-Hill Publisher, 1974.

[15] Y.G. Trofimenkof, Field Methods for Testing the Structural Properties of Soils, Building Literature Publishing House, Moscow (in Russian), 1964

[16] H.K.S. Begemann, General Report for Central and Western Europe. In Proceedings, European symposium on penetration testing, Stockholm, 1974.

[17] Nguyen A.T., Tran D.C., Nguyen T.D., The Application of Jet Grouting Technology to Reduce Ground Deformation of Construction the Metro Line in Ho Chi Minh City, Strength of Materials and Theory of Structures, 97 (2016) 121-134