UDC 539.3

ANALYSIS OF THE EFFECT OF THE HO CHI MINH CITY TUNNEL SETTLEMENT ON THE ADJACENT BUILDINGS

Nguyen Anh Tuan[1],
PhD, Lecturer, Faculty of Transportation Engineering,

Tran Duc Chinh[1,2],
DSc, Prof.

Nguyen Thanh Dat[1]
PhD, Associate Prof.

[1]*Hochiminh City University of Transport, Hochiminh City, Vietnam*
[2]*Academician of ABU Academy, Ukraine*

The paper aims to studying the effect of settlement of the Ho Chi Minh City Tunnel in soft soil condition on the nearby buildings due to tunneling by the Finite Element Method using Plaxis 3D Tunnel.

Keywords: Tunnel, soft soil, settlement, Finite Element Method.

1. Introduction

Nowadays, the population of the Ho Chi Minh City has grown quickly. The traffic facilities of Ho Chi Minh City therefore have been continually upgraded but they are still weak and cannot satisfy the traffic needs. Therefore, the city needs a modern public passenger transport network to ensure that the citizens can travel quickly, safely and conveniently. Tunneling not only provides high-speed transportation in rush hours but also carries a large number of passengers. Besides, it doesn't cause any pollution so it satisfies the sustainable long-term development of the Ho Chi Minh City.

This is the first time in Vietnam to build the tunnel. Hence, we are lack of experience, technology and construction management. Besides, there are many projects have been built on the ground so the study on the settlement effect of tunnel construction to nearby buildings in the Ho Chi Minh City is very essential. The Ho Chi Minh City Tunnel - part of Ben Thanh - Suoi Tien has been selected for the study of ground surface settlement due to underground tunnel construction and the effect of settlement on the nearby buildings.

2. Content

2.1. Project description

Fig. 1 describes the cross section of the Ben Thanh - Suoi Tien Tunnel and the Tunnel balanced construction model by TBM is shown in Fig. 2.

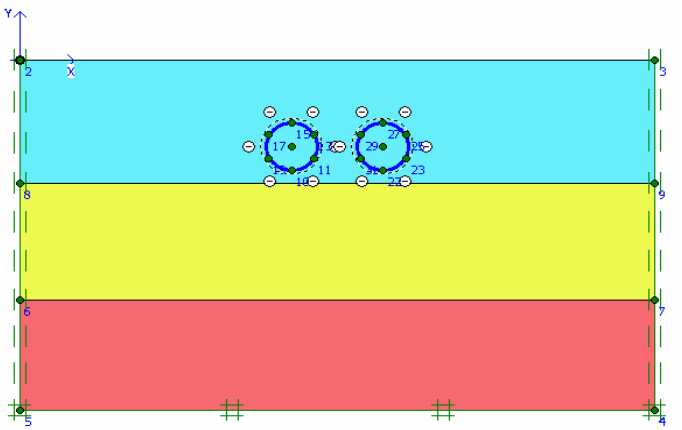

Fig. 1. Cross section of the Ben Thanh - Suoi Tien Tunnel

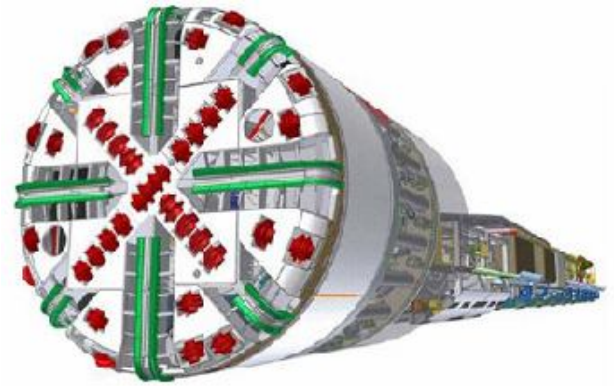

Fig. 2. Tunnel balanced construction model by TBM

Construction overview: Ben Thanh - Suoi Tien tunnel route is 19,7 *km* long. It includes 2,6 *km* underground tunnel and 17,1 *km* rail on ground.

Cross section of tunnel: Rounded tunnel, Diameter (D) = 6,65m and Thickness (d) = 0,3*m*.

Tunnel construction method: According to the soft soil condition in Ho Chi Minh City, it's believed that the Tunnel Boring Machine (TBM) is the most suitable method to execute the tunnel.

2.2. Model of tunnel construction in Plaxis 3D Tunnel

Table 1

Parameters of soil properties

	Layer 1 Organic clay	Layer 2 Clayey sand	Layer 3 Sandy Clay	Unit
Layer's thickness	16.7	16	15	*m*
Material model	MC	MC	MC	-
Natural density γ_{unsat}	15.8	20.2	20.9	kN/m^3
Saturation density γ_{sat}	16.1	20.4	21.02	kN/m^3
Elastic module E_{ref}^{50}	1040	15330	12105	kN/m^2
Poisson coefficient ν	0.35	0.27	0.32	-
Cohesive force c'	7.3	14.1	80.4	kN/m^2
Angel of interior friction φ'	5.72	27.58	21.3	^{0}
Permeability *k*	$1.83x10^{-5}$	$0.5x10^{-5}$	$1.36x10^{-5}$	*m/s*

Plaxis 3D Tunnel program is based on the finite element method. The program can calculate internal forces, analyze stability and deformation of geotechnical constructions. Plaxis 3D Tunnel, has simple interface, allows user to build construction models and provides fairly accurate results.

The soil properties is summarised in Table 1. Model of the tunnel in Plaxis 3D Tunnel is shown in Fig. 3.

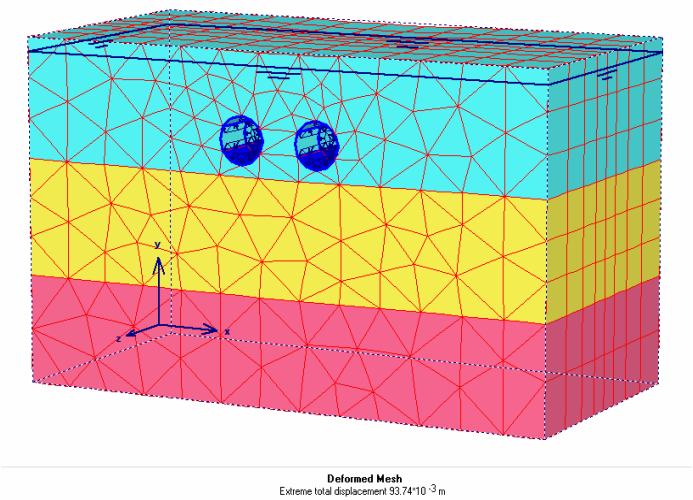

Fig. 3. Model of the tunnel in Plaxis 3D Tunnel

2.3. Analysis of results

2.3.1 Effect of burial depth on ground settlement

Results of the ground settlement around the tunnel corresponding to the different burial depths of the tunnel are summarised in Table 2 and Fig. 4.

Table 2

Results of the ground deformation around the tunnel

Ground settlement	Burial depth, *m*			
	15	20	25	30
U_z, *cm*	9.37	6.33	4.75	2.56
U_x, *cm*	2.17	1.21	0.79	0.48

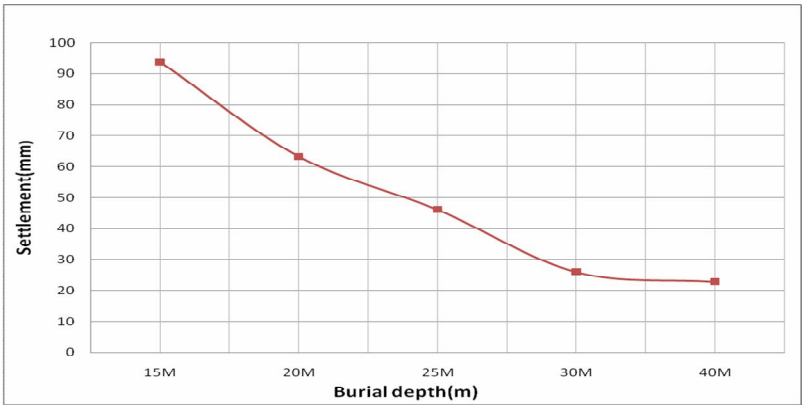

Fig. 4. Settlement values corresponding to burial depth

Analysis of the 6.65 *m* diameter tunnel shows that if the burial depth increases then the ground surface settlement decreases. The settlement is negligible when the burial depth reaches a particular value.

If twin tunnels are constructed alternately, the ground surface settlement on the 2nd tunnel is greater than the 1st one. After construction of two tunnels, the center line of settlement groove on the ground between the two tunnels is not symmetric. The deeper the tunnel is, the fewer tunnels settlement is. When the burial depth is 30 *m*, two tunnels bear forces independently and sunk relatively evenly.

When the bottom of the tunnel is placed at the depth of 15 *m* of soft soil area, the value of displacement and deformation is relatively large. The largest vertical settlement is above and below the tunnel.

2.3.2 Case study of the distance between two tunnels

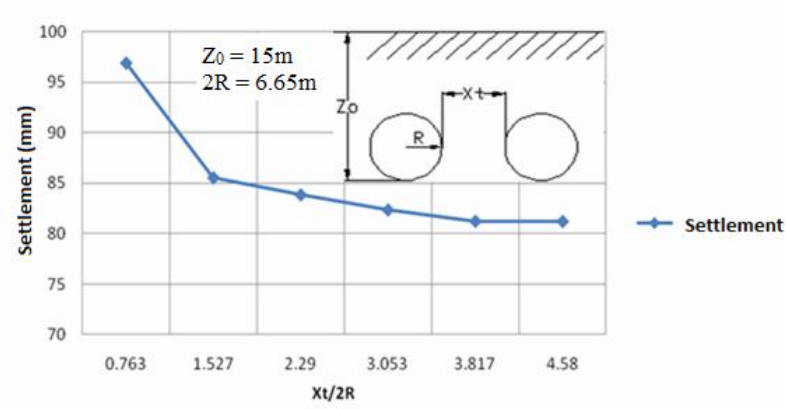

Fig. 5. Effect of distance between two tunnels on largest ground deformation

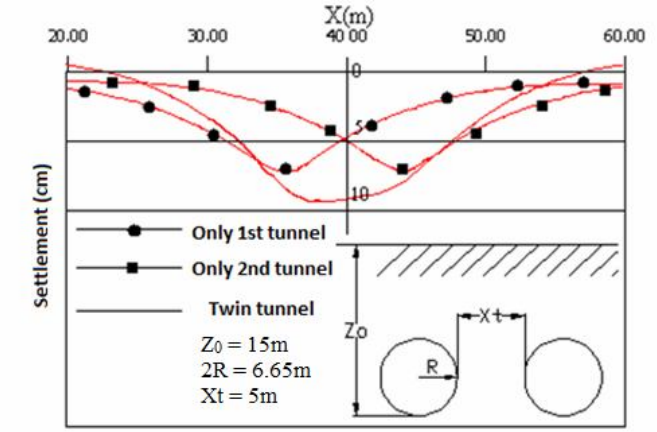

Fig. 6. Ground settlement for single tunnel and twin tunnel at a depth of 15*m*

Building the 2nd tunnel effects increases the stress on the 1st tunnel. According to the Fig. 6, it's clear that the 2nd tunnel has a large effect on ground settlement which leads to the whole settlement of twin tunnels greater than single tunnel.

According to the Fig. 5, it's clear that the further the distance between two tunnels is, the less the largest settlement is. When the ratio of $X_t/2R$ reaches a particular value, the effect of each tunnel on the other one is negligible. In this case, the settlement line is unaltered when $X_t/2R > 3$.

Vertical settlement of ground due to metro construction can cause danger to nearby buildings. Therefore, this analysis can be applied to find the optimum

distance between tunnels in order to satisfy both economical and technical purposes.

2.3.3 Effect of metro construction on nearby buildings

Ground settlement causes deformation of buildings which are located in affected settlement zone. The degree of settlement effect depends on the ground settlement and the shape, size, position, and condition of building.

Buildings located on the center area of deformation zone are affected heavily by the ground settlement. Therefore, buildings' deformations develop primarily from the roots to the low floors of the buildings.

The primary affects of vertical settlement on buildings are bending and angularity. Horizontal deformations only effect on buildings' structure through force of friction at buildings' bottom and sides of foundation. In general, effectiveness of horizontal deformation is much less than vertical one.

2.3.4 Reasonable burial depth for minimizing the effect of Ben Thanh - Suoi Tien tunnel construction on nearby buildings

There are many methods to assess the ground settlement affecting on houses such as methods of Prof Wahls (1981), and Prof Attewell (1986). [1]

According to Attwell's research, destruction of structures on the ground is divided into 4 groups depending on the inclination and ground settlement as shown in Table 3.

Table 3

Destruction grouping of structures on the ground

Type	Ground settlement	
	Max settlement, *mm*	Inclination, *mm/m*
Negligible	0-50	0-5
Medium	50-75	5-20
Much	>75	>20

This paper focuses on the influence of vertical settlement, the most influence factor to nearby buildings.

Table 4

Ground settlement. Burial depth: 15*m*, distance between 2 tunnels: 5*m* to 30*m*

Distance, *m*	5	10	20	25	30
Settlement, *mm*	96.89	85.54	83.85	82.36	81.24

Table 5

Ground settlement. Burial depth: 20*m* to 40*m*. Distance between 2 tunnels: 5*m*.

Burial depth, *m*	20	25	30	40
Settlement, *mm*	65.34	48.99	27.15	24.51

According to the comparison of the above tables against the Attewell's table, if the burial depth is 15m then the degree of ground settlement is significant. Therefore, it is needed to take measures to minimise the damage that may occur to the nearby buildings.

If the burial depth is deeper than 20m then the degree of ground settlement is medium and it does not cause serious impact on the nearby buildings.

3. Conclusions

Metro tunnel construction causes the change of stress state and natural deformation of land. Therefore, it creates fading deformation field around the land masses.

Reasonable burial depth for Ben Thanh – Suoi Tien tunnel is from 15m to 20m (about 2D to 3D where D is tunnel's diameter)

Vertical settlement badly effects on nearby buildings. The damage degree depends on the structure condition and factors of ground deformation field. It sometimes requires measures to protect nearby buildings.

Choosing reasonable burial depth and distance between 2 tunnels both not only can satisfy the technical requirement but also save the capital on construction.

REFERENCES

[1] Attewell, P. B., Yeates, J. & Selby, A. R. 1986. *Soil movements induced by tunnelling and their ef ects on pipelines and structures*, Blackie and Son Ltd, UK.

[2] JG Wang, SL Kong and CF Leung (2003), *Twin tunnel induced ground settlement in soft soils*.

[3] L.V. Makopski (2004), *Underground construction in urban area,* Ha Noi.

[4] Le Van Thuong et all, (1981), *Principle of designing underground construction.*

[5] Paul Sweeney (2006), *A study of interaction effects due to bored tunnels in clay,* Massachuset Institute of Technology.

Нгуєн Ань Туан, Чан Дик Тінь, Нгуен Тхань Дат

АНАЛІЗ ВПЛИВУ ПРОКЛАДКИ ТУНЕЛЮ У МІСТІ ХОШИМІН НА СУСІДНІ СПОРУДИ

В останні роки з розвитком потужних обчислювальних інструментів чисельні методи домінували в розрахунку проблем поверхневої деформації, викликаних туннелюванням. Чисельні методи використовуються не тільки для прогнозування деформації грунту навколо тунелю, але і для всього процесу проектування та будівництва тунелів, включаючи моделювання процесу виїмки і будівництва тунелі між грунтом - оболонкою тунелі, взаємним впливом між сусідніми тунелями, проникністю і ущільненням. Одним з найбільш точних чисельних методів є метод скінченних елементів (МСЕ). Метою даної роботи є дослідження впливу прокладки тунелю в слабкому грунті в районі Хошиміну. МСЕ, реалізований в програмі Plaxis 3D Tunnel, використовується для прогнозування зміщення грунту і аналізу впливу процесу тунелювання на сусідні споруди. Результати досліджень дозволяють визначити глибину прокладки тунеля і відстань між двома тунелями, які відповідають вимогам безпеки будівель.

Ключові слова: тунель, слабкий грунт, осад, метод скінченних елементів.

Nguyen Anh Tuan, Tran Duc Chinh, Nguyen Thanh Dat

ANALYSIS OF THE EFFECT OF THE HO CHI MINH CITY TUNNEL SETTLEMENT ON THE ADJACENT BUILDINGS

In recent years, with the advent of powerful computing tools, numerical methods have prevailed to the problem of ground deformation induced by tunneling. Numerical methods are applied not only to the ground settlement prediction but also to the entire tunnel design procedures, including simulation of the excavation sequence and placing of the lining, soil - tunnel lining interaction, effects of nearby tunnels, seepage, and consolidation. One of the more refined numerical methods is the Finite Element Method (FEM). The paper is aimed at studying the effect of settlement of the Ho Chi Minh City Tunnel in soft soil condition on the nearby buildings. The Finite Element Method using Plaxis 3D Tunnel is introduced to predict the ground settlement and to analyse the settlement effect of the tunnel during construction on the surrounding buildings. The reasonable depth and distance between the two tunnels can be suggested for satisfy construction requirements.

Keywords: Tunnel, soft soil, settlement, Finite Element Method

Нгуен Ань Туан, Чан Дык Тинь, Нгуен Тхань Дат

АНАЛИЗ ВЛИЯНИЯ ПРОКЛАДКИ ТОННЕЛЯ В ГОРОДЕ ХОШИМИН НА СОСЕДНИЕ СООРУЖЕНИЯ

В последние годы с развитием мощных вычислительных инструментов численные методы доминировали в расчете проблем поверхностной деформации, вызванных туннелированием. Численные методы используются не только для прогнозирования деформации грунта вокруг туннеля, но и для всего процесса проектирования и строительства туннелей, включая моделирование процесса выемки и строительства туннели между грунтом - оболочкой туннели, взаимным влиянием между соседними туннелями, проницаемостью и уплотнением. Одним из наиболее точных численных методов является метод конечных элементов (МКЭ). Целью данной работы является исследование влияния осадок при строительстве тоннелей в слабом грунте в районе Хошимина. МКЭ, реализованный в программе Plaxis 3D Tunnel, используется для прогнозирования смещения грунта и анализа влияния процесса туннелирования на соседние сооружения. Результаты исследований позволяют определить глубину прокладки туннеля и расстояние между двумя туннелями, которые соответствуют требованиям безопасности зданий.

Ключевые слова: туннель, слабые грунты, осадки, метод конечных элементов.

УДК 539.3

Нгуєн Ань Туан, Чан Дик Тінь, Нгуєн Тхань Дат. **Аналіз впливу прокладки тонелю в місті Хошимін на сусідні споруди** // Опір матеріалів і теорія споруд. – 2017. – Вып. 99. – С. 142 – 150.

Метою статті є вивчення впливу прокладки тунелю в м'яких грунтах на довколишні будівлі за допомогою тунелювання методом скінченних елементів з використанням Plaxis 3D.

Табл. 3. Іл. 6. Бібліогр. 37 назв.

UDC 539.3
Nguyen Anh Tuan, Tran Duc Chinh, Nguyen Thanh Dat. **Analysis of the effect of the Ho Chi Minh City Tunnel settlement on the adjacent buildings** // Opir materialiv i teoria sporud (Strength of Materials and Theory of Structures). – 2017. – Issue. 99. – P. 142 – 150.
The paper aims to studying the effect of settlement of the Ho Chi Minh City Tunnel in soft soil condition on the nearby buildings due to tunneling by the Finite Element Method using Plaxis 3D Tunnel.
Table 3. Fig. 6. Ref. 37

Нгуен Ань Туан, Чан Дык Тинь, Нгуен Тхань Дат. **Анализ влияния прокладки тоннеля в городе Хошимин на соседние сооружения** // Опір матеріалів і теорія споруд. – 2017. – Вып. 99. – С. 142 – 150.
Целью статьи является изучение влияния прокладки тоннеля в мягких почвах на близлежащие здания с помощью туннелирования методом конечных элементов с использованием Plaxis 3D.
Табл. 3. Ил. 6. Библиогр. 37 назв.

Автор (вчена ступень, вчене звання, посада)*:*

Nguyen Anh Tuan, *PhD, Lecturer, Faculty of Transportation Engineering, Hochiminh City University of Transport, No. 2, D3 St., Ward 25, Binh Thanh Dist., Hochiminh City, Vietnam.*
Phone: *(+84) 917.863.898.*
Email: tuankct@hcmutrans.edu.vn

Tran Duc Chinh, *DSc, Prof. (Viet Nam), Academician of ABU Academy, Ukraine.*
Phone: *(+84) 1688.997.750.*
Email: td_chinh07@hcmutrans.edu.vn

Nguyen Thanh Dat*, PhD, Associate Prof. (Viet Nam), Hochiminh City University of Transport, No. 2, D3 St., Ward 25, Binh Thanh Dist., Hochiminh City, Vietnam.*
Phone: *(+84) 989.051.723.*
Email: nguyenthanhhoaitu@yahoo.com