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The subsidence prediction due to load characteristics of underground structures in soft soil in Ho Chi Minh City

Dự đoán lún bề mặt do tải trọng đặc trưng khi thi công công trình ngầm trong đất yếu ở TP Hồ Chí Minh

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ABSTRACT

Metro line No. 6 in Ho Chi Minh City is the stage of preparation for construction investment. Ho Chi Minh City has weak geology which construction can cause surface subsidence affecting the surrounding buildings above. Studying and forecasting of subsidence of the surrounding ground surface when constructing underground is an important issue for engineers. The article presents predicting land subsidence in the influence of external load such as pile foundation, increased load due to construction or change of transport infrastructure to twin tunnels to analytical and numerical methods.

Keywords: Twin tunnel; surface settlement; Plaxis; soft soil.

TÓM TẮT

Tuyến metro số 6 TP.HCM đang trong giai đoạn chuẩn bị đầu tư xây dựng tại TP.HCM trong môi trường địa chất tương đối yếu, việc thi công có thể gây sụt lún bề mặt ảnh hưởng đến các công trình xung quanh phía trên. Nghiên cứu và dự báo độ lún của mặt đất xung quanh khi thi công công trình ngầm là một vấn đề quan trọng đối với các kỹ sư. Bài báo trình bày tính toán dự đoán lún nền đất dưới tác động của ngoại lực như móng cọc, tải trọng gia tăng do thi công hoặc chuyển đổi hạ tầng giao thông thành hầm đôi bằng phương pháp giải tích và phương pháp số.

Từ khóa: Hầm đôi; lún bề mặt; Plaxis; đất yếu.

1. BACKGROUND

Today underground projects are increasingly being built in big cities like Hanoi and Ho Chi Minh City to minimize ground space. The projects can be shopping centers, underground stations, car parks, and subways. The underground constructures being built can cause deformation of the surrounding ground, and the subsidence of the ground surface. So, when constructing underground metro lines in soft soil or saturated soil, it is necessary to pay more attention to the influence of displacement and deformation of the ground around the underground constructures during and after the construction process. Surface subsidence depends on parameters such as influence range, direction and speed of development, which can affect the state of these structures; change their functions and more seriously may destroy the structure, causing instability. The study of surface settlement prediction is a very important issue that needs to be considered when building tunnels, especially in urban areas. For example, in crowded areas in Ho Chi Minh City and Hanoi, there are a lot of buildings and technical infrastructure where the tunnel is located underground.

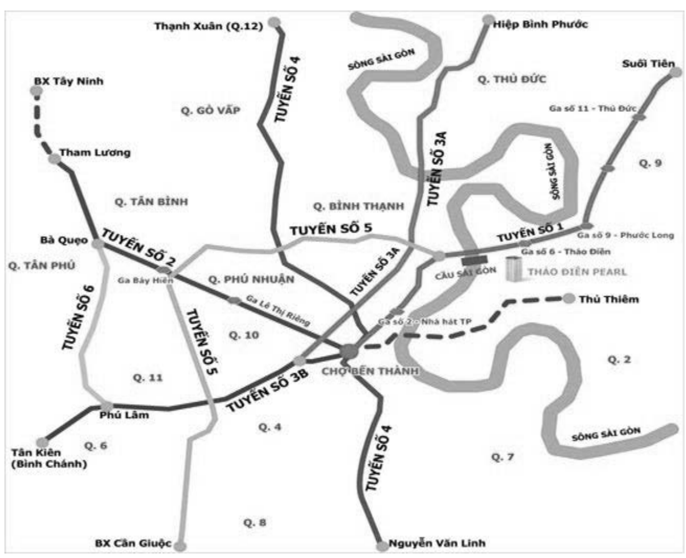

Figure 1. The Map of metro line.

2. CALCULATION METHOD

Calculating the stress state and predicting the surface settlement of the ground around the metro helps engineers to design, predict and prevent unexpected incidents in the construction. The calculation of stress state - soil surface deformation has been determined by scientists Peck and Schmidt, Cording and Hansmire, Atkinson and Potts, Attewell and Woodman, O'Reilly and New, etc ... In terms of surface settlement prediction, most authors have proposed to assume the settlement funnel has the form of a standard distribution curve.

a. Prediction of surface settlement for single tunnel construction

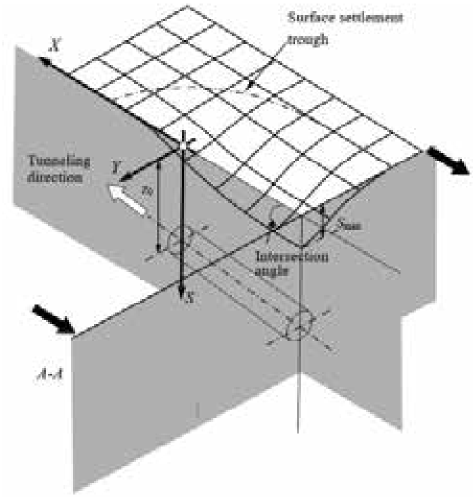

Figure 2. The shape of the surface settlement due to construction of a single tunnel [1].

The form of the surface settlement funnel during the construction of a single tunnel is shown in Figure Figure 3. The surface settlement (S) determined based on theoretical calculation is often assumed as a Gaussian error function or distribution curve standard as shown in Figure 2 [1].

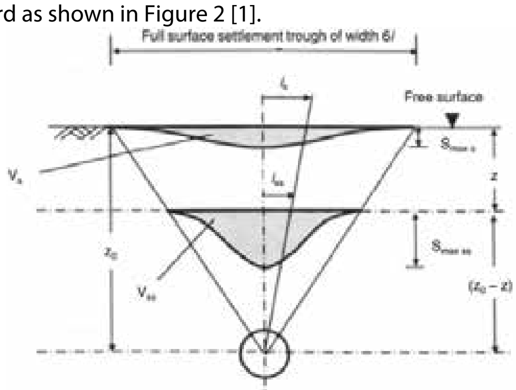

Figure 3. The graph depicts the surface settlement funnel shape when constructing a single tunnel [1].

$$S = S_{max} exp\left(\frac{-y^2}{2i^2}\right) \quad (1)$$

where:

exp - logarithmically e^x;

y - the horizontal distance from the center of the tunnel to the point where settlement is required;

i - the standard deviation of the settlement curve, which is the distance from the bending point of the settlement chute to the center of the tunnel, also called the settlement chute width parameter; "i" is calculated by Equation [1].

$$i = k.z$$

with: "z" is the vertical level of the tunnel axis and "k" is depending on the geotechnical characteristics of the ground;

S_{max} - maximum surface settlement, above the tunnel shaft;

S_{max} is determined through settlement funnel volume [9]. This value depends a lot on the geo-mechanical conditions of the soil mass such as strength, hardness, permeability, groundwater elevation, etc., geometrical parameters of the tunnel: tunnel diameter (D), tunneling depth (H), construction method, construction technical level;

$$S_{\max} = \frac{V_L}{i.\sqrt{2\pi}} = \frac{V_L}{2,5.i} \quad (2)$$

where:

V_L - total volume loss, which is the free space between the cut edge and the outer edge of the shield, the space u_1 is taken equal to 3cm, Figure 3.

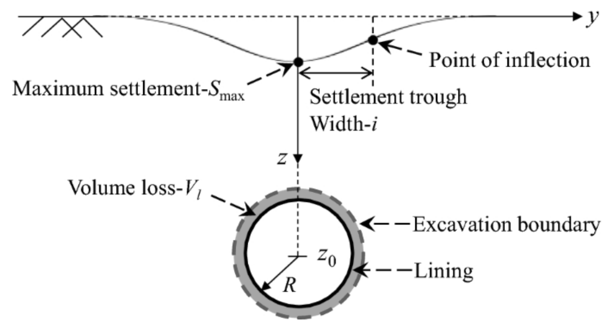

Figure 4. Total loss volume V_L [9].

Values of "i" are mainly formulas obtained from field observations. Accordingly, the value of "i" depends on the size (diameter) of the tunnel, geological conditions and especially the tunneling depth (z_0); (i) can be determined by:

i = 0,43. z_0 + 1,1 (with consolidated soil);

i = 0,28. z_0 – 0,1 (for unconsolidated soil).

where: z_0 - depth of the tunnel's centerline above the ground.

b. Prediction of twin tunnels construction surface settlement

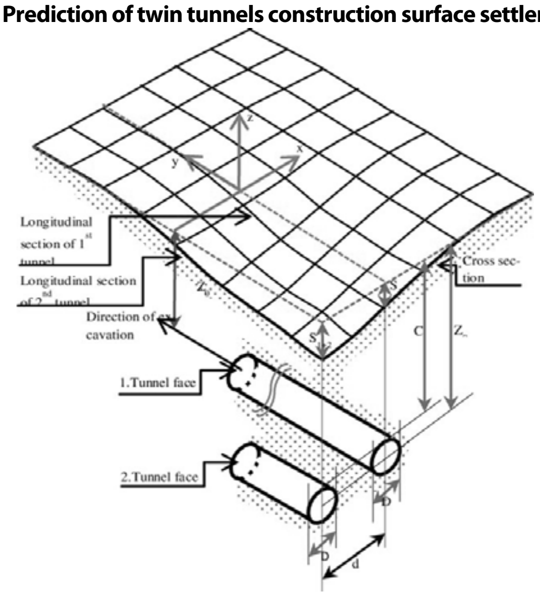

Figure 5. The shape of surface settlement due to construction of twin tunnels [9].

According to the scientists Peck (1969) [9], O'Reilly & new (1982), and Mair et al. (1993) [5] predicted surface subsidence caused by the construction of twin tunnels with a larger and larger distribution of surface settlement compared to the case of a single tunnel Figure 4.

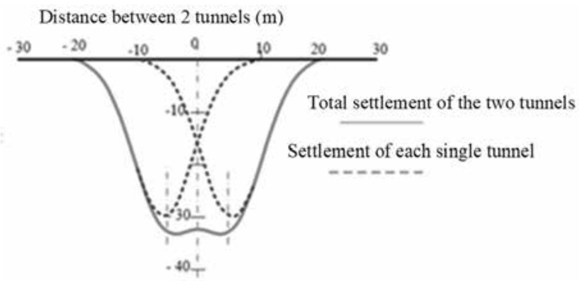

Figure 6. Surface settlement curve when constructing twin tunnels [9].

Surface settlement (S_v) during construction of twin tunnels is determined

$$S_v = S_{\max}\left[\exp\left(-\frac{x_A}{2.i^2}\right)+\exp\left(\frac{\left(x_A-d\right)^2}{2.i^2}\right)\right] \qquad (3)$$

where:

x_A - the horizontal distance from the center of the first tunnel to the point where settlement is required;

d - the horizontal distance between the two tunnel centers.

And $S_{\max} = 4,71.\left(\gamma_n.z_0+\sigma_s\right).\left(D^2/\left(3i+L\right).E\right)$

with:

D - tunnel diameter, (m);

σ_s - the top surface load, (T/m^2);

L - the distance between the two tunnel axes, (m).

Nowadays, the science of developing numerical methods is becoming more and more dominant. The finite element method is the most popular numerical method in estimating surface settlement due to construction of underground structures. The numerical model represents node systems, elements, and boundary conditions. Elements are used to model soil masses and structures, and nodes to position and link elements. Boundary conditions will re-describe the model's connection with the ambient space. The necessary conditions to model the surface settlement by numerical model need input data such as: geometric size; material properties of the support system, construction methods, and geological conditions, ... Currently, there are much geotechnical analysis software such as Abaqus, Plaxis, ... The article uses Plaxis software deformation calculation and surface settlement prediction. Depending on design calculations we choose the appropriate method.

3. CALCULATING THE STRESS-STRAIN STATE AND PREDICTING SETTLEMENT OF THE SURROUNDING GROUND SURFACE DURING THE CONSTRUCTION OF METRO LINE 6 IN HO CHI MINH CITY

In fact, along metro line 6, there are many low-rise architectural buildings, high-rises and technical infrastructures being built before. Some buildings were built on shallow foundations, some high-rise buildings are built on deep foundations... The construction process of the metro line will cause surface subsidence and affect the neighboring buildings above. The author presents the study of subsidence of the surrounding ground surface during the construction of metro line 6 at the distance of km6+700.

3.1. Project Overview

Metro Line 6 has relatively good geological features at the beginning of the line and gradually weakens at the end. There are 5 boreholes on the whole line, representing the beginning to the end of Nguyen Van Luong Street. Process km 6+700 to calculate the parameters of soil are shown in Figure 7 [7].

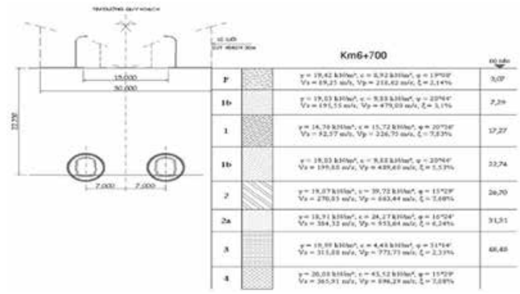

Figure 7. Cross-section of metro line 6 and parameters of soil [7]

Dimensions of tunnel cover are shown in Table 1. Tunnel location is described as two cross-sections representing the route as shown in Figure 5.

Table 1. Geometrical dimensions of metro tunnel line 6 [7].

Type of tunnel	circle	Unit
Dimensions of lining	6,0/6,6	m
Elastic modulus of concrete	3,5E+7	kPa
Poisson's coefficient of concrete	0,2	
The interface coefficient considers the interaction of lining - ground (concrete in the soft soil layer), R_{int}	0,7	

3.2. Calculation diagram and numerical model

Modeling plane geometry problem, using Plaxis 2D CE V20 software to calculate the displacement of surface settlement. The compaction method in Plaxis will consider the effect of volume loss due to tunnel construction by the TBM (Tunnel Boring Machine) method, which considers the reduction of the tunnel cross-sectional area. The degree of compression (%) is the ratio of the reduced area to the original cross-sectional area and is chosen to be 2%. Standard Boundary Condition: This boundary condition restricts the horizontal displacement for two vertical boundaries (Ux=0) and restricts the displacement in both directions (Ux=0 and Uy=0) for the bottom boundary of the model.

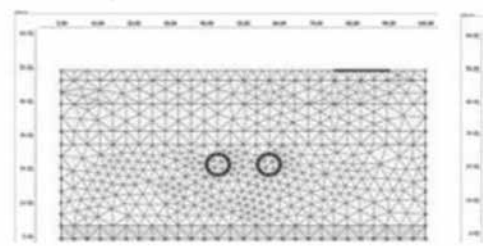

Figure 8. Finite element meshing model

3.3. Result

a. Stress-deformation field and displacement of soft ground around the double tunnel at a depth of 27,250m, the distance of two tunnels is 14m.

The results of the calculation of stress and deformation of soil mass around the double tunnel are shown in Table 2.

Table 2. Results of stress, deformation and displacement of double metro line

Results	The numerical method	The analytical method	unit
Displacement of vertical	3,12x10^{-2}	4,24x10^{-2}	m
Displacement of horizontal	3,03x10^{-2}		m
Shear strain, (Maximum)	1,89		%
Maximum stress	453,55		kPa

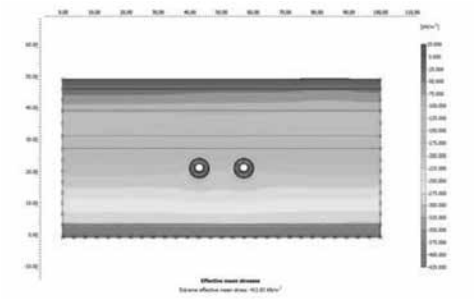

Figure 9. Strain field of twin tunnels.

b. The effect of the surface load when increasing the surface load from 0 kPa to 30kPa.

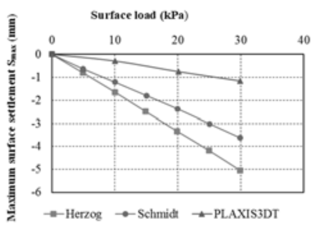

Figure 10. Effect of ground load on the maximum settlement due to single tunneling by shield digging.

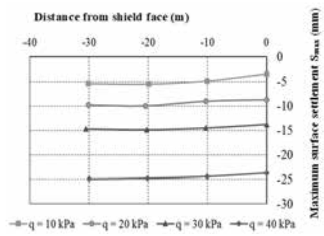

Figure 11. Effect of the top load on the maximum settlement due to single tunneling with a shield.

The analytical results for surface loads are shown in Figure 10 and Figure 11 shows the largest variation of ground settlement according to surface load by numerical and experimental methods (Herzog (1985) and Schmidt (1981) for a tunnel located at a depth of 20,8m. PLAXIS 2D results show that an increase in surface load from 0 to 30 kPa leads to an increase in ground settlement of about 1mm. Figure 10 shows settlement curves along the tunnel axis for four values of surface load. The results show that the ground settlement along the tunnel axis increases as the surface load increases.

c. Influence of the pile foundation

The problem model to consider the effects of the above works when there is no pile foundation and the pile foundation system on the ground settlement due to digging a single tunnel with a shield dug in soft soil has been established. Conduct ground settlement analysis when changing the tunneling depth, corresponding to different depths, the calculation results are shown in Figure 12 and Figure 13.

In case the building above has a pile foundation, the horizontal displacement (S_h) of the tunnel structure changes less than that without the pile foundation and corresponds to each tunneling depth. In this case, the case surface settlement value also corresponds to the set depth.

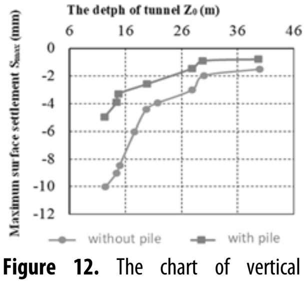

Figure 12. The chart of vertical displacement value according to the tunneling depth corresponds to the case without pile foundation and with pile foundation above.

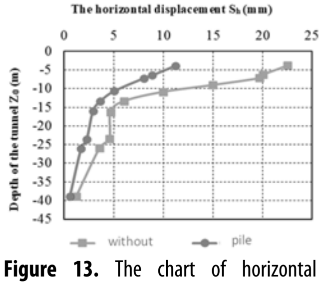

Figure 13. The chart of horizontal displacement values according to the tunneling depth corresponds to the case without pile foundation and with pile foundation above.

Thus, the construction of structures underground that affect existing buildings on the ground is inevitable and the greatest degree of impact is when tunneling right below the existing structure on the ground. With a tunnel located 15m deep in the geological area of Ho Chi Minh City. it is recommended that the works above the tunnel work should have appropriate assessment and treatment measures before tunnel construction.

4. COMMENTS AND RECOMMENDATIONS

Calculation of surface settlement prediction during double-line metro construction can be done by different methods such as the analytic method and numerical method.

The Gaussian curvature is typical of the calculation of surface settlement caused by tunnel construction. The analytical method for calculating surface settlement in the case of double tunneling is based on the superposition principles of two settlement curves. This approach ignores any interaction between two adjacent tunnels. The analytic method is simple. The downside cannot consider all important factors such as the complex behavior of stress and strain, construction details and complex geological conditions.

The numerical method helps the design engineer to calculate to consider many influencing factors, and environmental parameters and at the same time consider the structural interaction - the working environment and should give the value compatible with the model's realistic working texture.

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