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HANOI GEOENGINEERING 2022

Innovative Geosciences, Circular Economy and Sustainability

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OPTIMIZING CUT-OFF JETGROUTING WALL PARAMETERS FOR PROTECTING HISTORICAL BUILDINGS WHEN TUNNELLING IN SOFT SOIL CONDITIONS IN HO CHI MINH CITY

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Abstract: The protection of important nearby buildings is an essential work in the tunnelling design when starting a tunnel project in density urban areas, especially in soft soil conditions. In Ho Chi Minh Metroline No.1 project, a cut-off jetgrouting wall was applied for minimizing effects induced by the tunnelling work on the Saigon Opera House and showed an effective protection. In this paper, an investigation on input parameters of the cut-off wall has been carried out in order to optimize the efficiency of the wall. A comparison to observed data at the site shows a good agreement with the study results. Based on the results, engineers can easily select jetgrouting cut-off wall parameters for protecting nearby existing buildings in near future tunnelling projects in Vietnam.

Keywords: Tunnelling; Jetgrouting; Cut-off wall; Ho Chi Minh Metroline No.1; Saigon Opera House.

1. INTRODUCTION

The rapid economic development and the increasing urban population in Ho Chi Minh city leads to urban living issues of traffic congestions and air pollutions. Infrastructure construction becomes a vital development for a better living condition. Since the space on the surface in the city becomes expensive and limited, the underground space is a solution for transportation space. Although the construction cost of tunnels is high when comparing the construction cost of road and bridge, urban underground development is unavoidable in urban areas.

Based on the city planning development, there are eight metro lines that will be built in Ho Chi Minh city. The Ho Chi Minh Metroline No.1 construction was started in 2012 and the underground construction work was completed in 2020. This metroline is considered as a pilot metro line in Ho Chi Minh city from the Ba Son station to Suoi Tien park. With a length of 2.6 km underground construction with soft soil conditions and under a density area with many historical buildings, the tunnelling work was carried out with a careful monitoring and protection plans for minimizing effects on existing buildings.

One of the most important tasks of tunnelling design is the selection of protection methods for nearby important buildings from negative impacts caused by tunnelling process. When tunnelling in soft soil conditions in urban areas and especially under historical areas, there might be a risk of damage to buildings from settlements induced by the tunnelling process. In the case of Ho Chi Minh Metroline No.1, the tunnel alignment is designed at the location closed to historical buildings and under a density area. The geocondition of the project is soft soil conditions of silty and clay soil layers leading to sensitive protecting methods for the building.

The paper presents an analysis of the cut-off wall constructed by jetgrouting technique with a purpose of minimizing effects of the tunnelling work in the Ho Chi Minh Metroline No.1 project on the Saigon Opera House. Effects of input parameters of the cut-off wall are investigated in order to obtain optimal cut-off wall parameter values for protecting nearby buildings.

2. REDUCING EFFECTS OF TUNNELLING ON EXISTING BUILDINGS BY CUT-OFF WALL IN HO CHI MINH METROLINE NO.1

2.1. Methods for minimizing effects of tunnelling

Shield tunnelling is often applied in constructing underground infrastructure in cities due to the ability to limit settlements and damage to existing buildings. However, in an urban environment with soft overburden and building foundations such as the Metroline No.1 project in Ho Chi Minh city, there is a tendency to design the tunnel well below the surface in order to reduce interaction between tunnelling process and building foundations.

From analyzing empirical data of many shield tunnels, Peck (1969) firstly presented the settlement trough on the surface induced by tunnelling in soft soils as a Gaussian distribution as shown in Figure 1. The result is also confirmed by other authors (Cording and Hansmire, 1975; Mair et al., 1993; Ahmed and Iskander, 2010). Based on the results from centrifuge test and empirical data, Mair et al. (1993) showed that the subsurface settlement profile distributes as the Gaussian curve also. The width of settlement trough at the depth z depends on the depth of the tunnel and a coefficient K depending on depth. Other studies by Moh et al. (1996), Grant and Taylor (2000) and Jacobsz (2003) based on Mair et al. (1993) proposed a limited change of K in various kinds of soil.

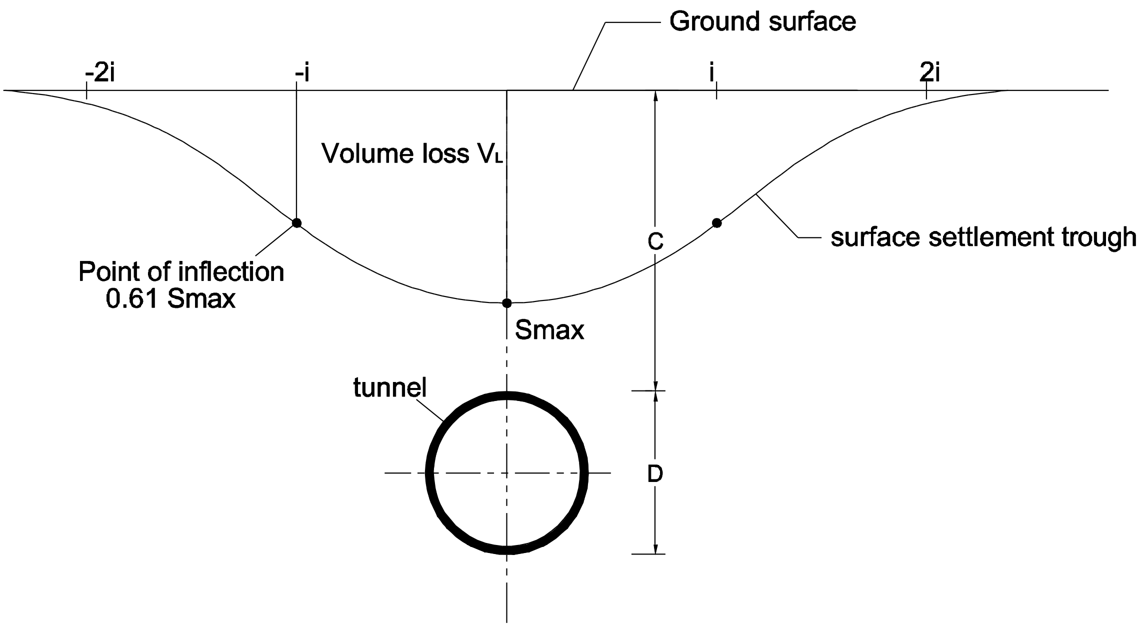


Figure 1. Transverse settlement trough due to tunnelling (Peck, 1969).

Assessing impacts of tunnel construction on existing structures is essential in the tunneling design. The stability of nearby buildings is often assessed by the ground movements around tunneling, the surface settlement trough, and the distance between the tunnel and the buildings (Vu et al., 2017). Thus, the influence zone induced by tunneling should be determined in order to minimize the effects on the existing structures. The assessment of the impacts of tunneling excavations on existing buildings and the responses of buildings have been studied by authors all over the world including Rankin (1988), Boscardin and Cording (1989), Mair et al. (1996), Burland et al. (2001), Franzius (2004); Netzel (2009) and Giardina (2013).

In tunnel design and construction, the selection of mitigating measures often depends on the cost of projects, the speed of carrying out the work, the reduction of uncertainties between design and construction, and the safety when tunneling. In order to reduce the effect of tunnelling and protect existing buildings, there are four categories of protecting methods as follows:

- Strengthening existing structures: existing buildings can be reinforced to resist the impact of ground movement induced by tunnelling. With recent design computer programs, deformations and internal forces of buildings can be easily determined. Based on these analyses, reinforcement methods will be carried out for possible damage elements of the buildings. According to Burland et al. (2001), reinforcement methods can be applied to improve the capacity of building foundations, to stiffen the structure and to maintain the work ability of the structure for examples by installing jacks between the building elements, adding tie bars, ring beams and preparing good maintenance plans.

- Reducing settlement by changing soil properties: the analysis of the impact of soil parameters on the extent of zones influenced by tunneling with various relative distance x/D in Vu et al. (2017) shows that with a given distance from the tunnel axis to an existing nearby building, the settlement can be achieved less than a given allowable settlement by changing parameters of the surrounding soil. On the basis of the result, following ground improvement methods with the aim of improving the soil properties can be applied in practice: permeation grouting, jetgrouting, soil mixing and ground freezing.

- Compensating settlement without changing soil properties: compensation grouting or fracture grouting is often used for decreasing building settlements and distortions to allowed values, which are indicated in Rankin (1988) and Boscardin and Cording (1989); or eliminating previous settlements of structures induced by tunnelling. In this method, a grout slurry is injected into the soil between building foundations and the tunnel lining by sleeve pipes (for an example, TAMs), which are often installed with a drill dig. Compaction grouting is a technique that the soil is compressed by the grout around the injection point. In this case, the grout does not fill the soil pores but remains as a mass to compact the soil around. In tunneling, the purpose of this technique is to compensate for previous settlement induced by tunneling by increasing the soil density and stress in the soils to heave the structures. Compaction grouting can be used for compensating the settlement of consolidation or relaxation induced by tunneling.

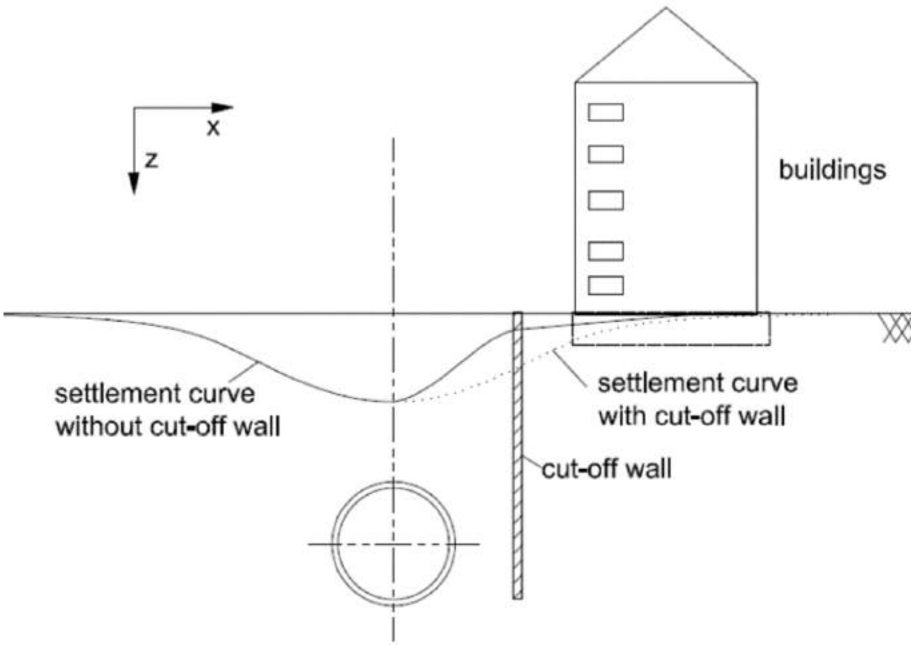
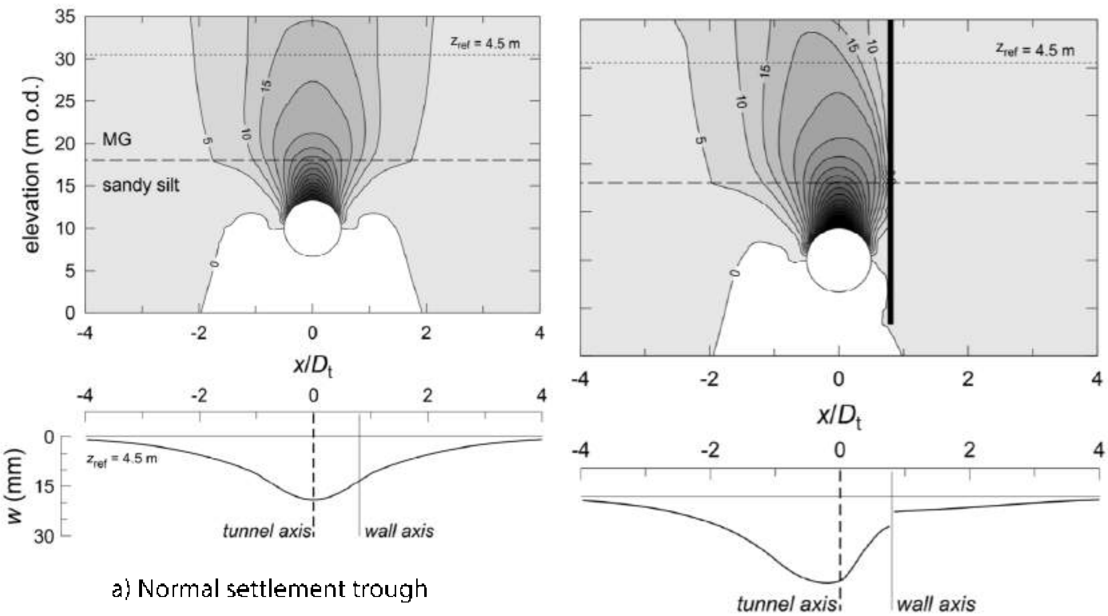


Figure 2. Cut-off wall method in reducing settlements induced by tunnelling.



a) Normal settlement trough

b) After cut-off wall applying

Figure 3. Settlement trough is changed in both shape and depth (Bilotta, E. 2008).

Cut-off wall technique uses a wall in the distance between the buildings and the tunnel in order to minimize the ground movement induced by tunneling, which leads to the settlement of nearby existing buildings, as can be seen in Figure 2. The cut-off wall also reduces the change of groundwater when tunneling below the water table. The cut-off wall can be formed by steel sheet-piling, slurry trench walls, concrete diaphragm walls, bored pile walls, grout barriers, mix-in-place barriers or artificial ground freezing (Chen et al., 1998; Oteo et al., 1999; Sola et al., 2003; Gens et al., 2006). The effectiveness of the cut-off wall in tunnelling depends not only on geometrical features such as depth and location, but also on its stiffness and, to some extent, on the properties of its interface with the soil. In Bilotta, E. (2008), a series of centrifuge tests were performed in which a diaphragm wall was embedded to one side of a tunnel with various of locations, lengths, thickness of the wall and the roughness of the wall-soil interface. The study shows that the diaphragm wall modifies the pattern of ground movements induced by tunnelling in a soft soil (Figure 3). In this paper, the cut-off wall constructed by jetgrouting technology in the Ho Chi Minh Metroline No.1 is discussed.

2.2. An application of the cut-off wall created by jetgrouting technology in Ho Chi Minh Metroline No.1

Ho Chi Minh Metro Line 1, completed in 2021, is the first metro line built in Vietnam. The project was launched in 2012 and the underground work was finished in 2019. This metroline is of 19.7 km length including 2.6 km underground length below density areas of Ba Son shipyard, the Saigon Municipal Opera House and the Saigon river and 17.5 km length on the surface. Fourteen stations are located along this metroline from the Ben Thanh station to the Long Binh deport. In the project, the tunnel was constructed under many historical buildings and density areas with an Earth Pressure Balance Tunnel Boring Machine (EPB TBM) tunnelling at the depth varying from 11 to 30 meters below the surface. Requirements on settlements and other effects on existing buildings on the surface thus are very strict.

Table 1. Soil layers at Ho Chi Minh Metroline No.1 project

Layer	**Properties**
Backfill	Mainly composed of a mixture of clay, sand, rocks, organic materials
Ac2	Mainly gray-brown clay, very soft hard soil
Ac3	Mainly fine sandy clay, soft to hard. Seen as an intermediate layer separating As1 and As2
As1	Mainly very liquid clayey sand with medium density, reddish brown
As2	Mainly fine to medium grain sand, reddish brown to golden brown
Dc	Mainly brown to light gray clay, medium to very hard hardness
Ds	Mainly composed of light gray mixed sand, the density is very high.

Table 2. Geological input parameters at the Saigon Opera House location

Layer	d (m)	γ (kN/m³)	c (kN/m²)	ϕ (deg.)	E (kN/m²)	v
Backfill	1.1	18	0	28	2500	0.35
Ac2 and Ac3	1.6	16	14	0	10000	0.48
As1	14	19.5	0	31	16000	0.33
As2	17	19.5	0	31	35000	0.33
Dc	15.6	21	220	0	101000	0.45
Ds	5.7	21	0	34	77500	0.31

The geo-profile of the tunnel alignment comprises of Fill, Alluvium and Diluvium materials as shown in Table 1. The Fill layer depth is of about 2 meters. The deeper layers- Alluvium layers with the depth of 30 meter involve Soft Clayey Silt layer, Silty Fine Sand Layer 1 and Sand layer 2. The deeper layers are Diluvium clayey silt and silty sand layers.

Table 2 describes geotechnical parameters at the Saigon Municipal Opera House location.

The Saigon Municipal Opera House was built between 1901 and 1911 with the designed architectural style as the Opéra Garnier in Paris, France. There are a main seating floor and two above seating levels with an accommodating capable of 1,800 people. There is a capacity 500 seats in this opera house. Since the Saigon Municipal Opera House has important roles as an historical building and a famous tourist destination of the city, a protection from any impact on the house from tunnelling excavation works had been carried out.

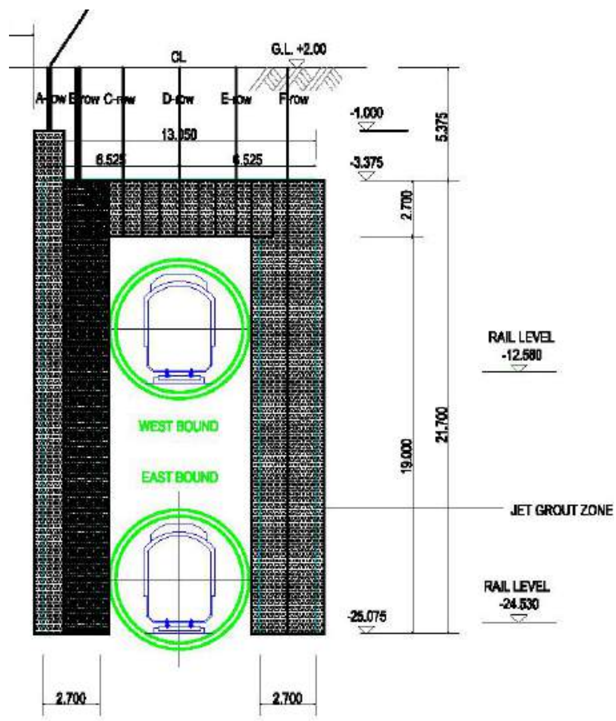


Figure 4. Crosssection view of jet grouting wall at the Saigon Opera House location (Vu et al., 2021).

Due to the historical role of the opera house as described, much effort had been used to find out a suitable method for protecting the house because the tunneling works were carried out in a soft soil condition with a short distance between the house and the tunnel alignment. In the protection design of this project, a cut-off wall created by jet grouting technique in the distance between the house and the tunnel alignment was proposed for minimizing the ground displacement induced by tunneling. In this design, two tunnel alignments are mostly surrounded by jet grouting walls in both sides and above the tunnel crown, as can be seen in Figure 4. By this, the soil displacements were minimized not only in the house direction but also with the surface settlement. This wall also decreased groundwater variation under the house foundation. In fact, this design is extremely safe for the building and the tunnelling process.

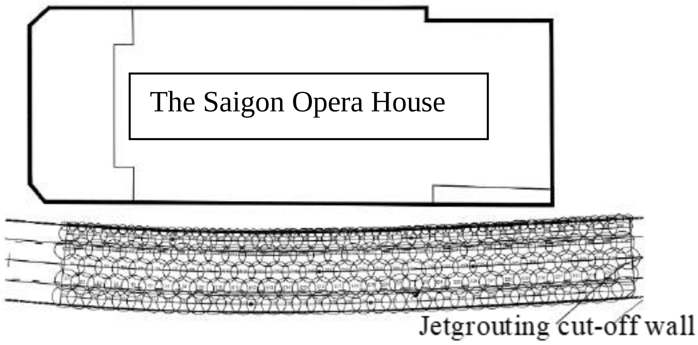


Figure 5. Jet grouting plan at the Saigon Opera House (Vu et al., 2021).

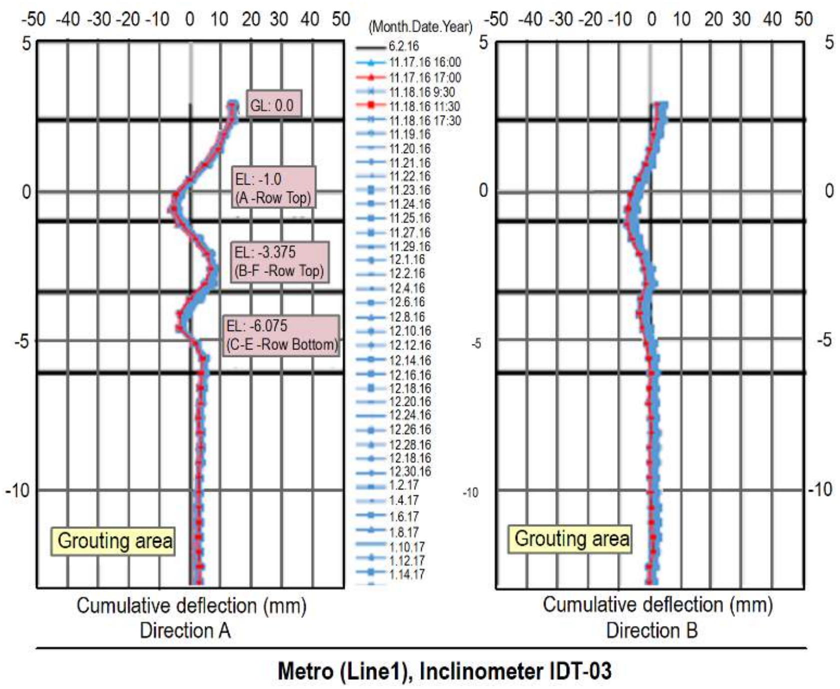


Figure 6. Observed data of IDT-03 inclinometer behind the jet grouting wall near the Saigon Opera House (in mm) (Vu et al., 2021).

The cut-off wall was constructed by 239 jet grouting holes including 66 jet grouting holes with 1400 mm in diameter, 47 jet grouting holes with 3000 mm in diameter, and 126 jet grouting holes with 3500 mm in diameter. The layout of jet grouting work at the Opera House site is shown in Figure 5.

The observed data of soil displacements by an inclinometer named as IDT-03 is presented in Figure 6. In the "A" direction, the soil displacements have varied with the maximum value of 15 mm is at the top of the wall, closed to the surface where no jet grouting applied. The maximum displacement along the part of the wall without jet grouting is only about 6 mm. Along the jet grouting part, the maximum displacement is only less than 4 mm from the level -6 m and becomes smaller with deeper depths. In the "B" direction, the observed data in Figure 6 show that at the zone without jet grouting (above the level of -6 m), maximum soil displacement is only about 8 mm while only small deformation (less than 4 mm) was recorded in the jet grouting zone. This means that the jetgrouting cut-off wall, in this case, protected the important building effectively from the tunneling impact. Thus, the role of the jet grouting cut-off wall in reducing the settlement induced by tunnelling and protecting the historical building is clearly shown in this case.

3. OPTIMIZING THE CUT-OFF WALL PARAMETERS FOR PROTECTING A HISTORICAL BUILDING WHEN TUNNELLING IN HO CHI MINH CITY SOFT SOIL CONDITIONS

The underground construction in Ho Chi Minh Metro Line No.1 was completed. The observation of soil displacements has been continued, and no damage has been recorded at this building up to now. These small observed data show that the cut-off wall is a sufficient way for protecting existing buildings when tunneling in soft soils, in particular, the jetgrouting cut-off wall in this case.

As discussed above, eight metrolines will be constructed in Ho Chi Minh city in the near future. Moreover, the other eight metrolines will also built in Hanoi with same soft soil conditions. A further study in effects of the cut-off wall created by jetgrouting technique will derive a deeper understanding and a better benefit of the cut-off wall both for the design and the construction cost.

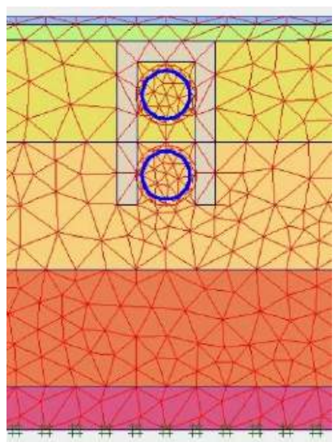


Figure 7. The Plaxis 2D model for analyzing the effects of the jetgrouting wall parameters.

In this study, an analysis the relationship between the surface settlement and the input parameter of the cut-off wall designed as the case of Ho Chi Minh Metroline No.1 is carried out. An analysed model is created in Plaxis 2D as shown in the Figure 7 with a "green-field" condition. The bottom boundary is fixed in both horizontal and vertical directions. The geo-condition parameters are shown in Table 2. The geological parameters used in the analysis is created with the Mohr-Coulomb model.

In order to investigate the effect of the thickness of the wall on the settlement induced by tunnelling, an analysis with various of the wall thickness is carried out. In this analysis, the elastic modulus of the wall is of 100 MPa. The thickness of the wall changes from 0.5 to 3.5 m.

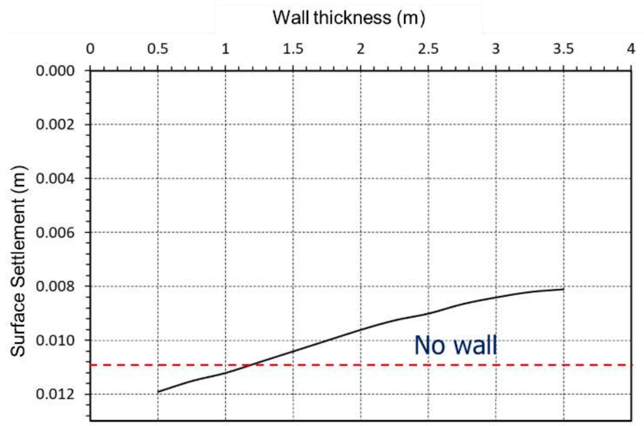


Figure 8. Relationship between surface settlement and thickness of wall system.

Figure 8 shows the analysis results. It shows that the relationship between wall thickness and settlement is almost linear. It can be explained that the wall system works as beams on a horizontal elastic foundation. When increasing the thickness of the wall system (height in the horizontal direction), the value of the modulus of resistance to the wall system also increases leading to smaller horizontal deformations of the wall. The settlement of the soil behind the wall system will be improved theoretically.

Investigating effects of the elastic modulus of the wall, an analysis was carried out with values of modulus of variation from 10 MPa to 2000 MPa with the case of the wall thickness of 1.5 meters. The study result is shown in Figure 9.

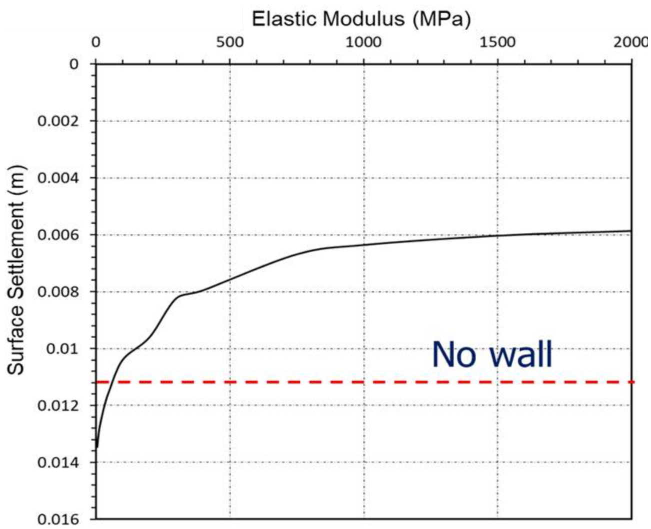


Figure 9. Relationship between surface settlement and modulus of wall system.

Figure 9 shows that when the value of elastic modulus of the wall system increases to 50 MPa, the settlement at the survey site tends to increase. This phenomenon can be explained because the original soil with specific gravity of 19.5 kN/m^3 is replaced by soil mixed with spray mortar with γ = 22 kN/m^3, which increases the self-weight of the subsoil, while the modulus of the wall system is not large enough to prevent soil movement. When the value of elastic modulus of the wall system increases from 70 MPa to 750 MPa, the surface settlement tends to decrease rapidly from 11.2 mm down to 6.7 mm for surface settlement. When the value of elastic modulus of the wall system increases from 750 MPa to 2000 MPa, the settlement decreases lightly. In fact, it is difficult to archive a high strength jet grouting with these elastic modulus values. Therefore, the value of 750 MPa seems as an optimal value of elastic modulus in the jetgrouting cut-off wall design for minimizing the settlement induced by tunnelling in soft soil conditions in Ho Chi Minh city.

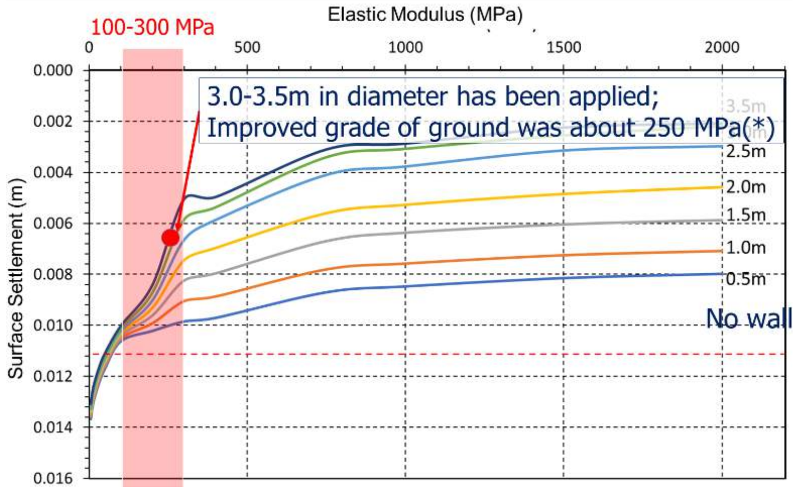


Figure 10. The efficiency of the HCM application is in the effective range.

Figure 10 shows a good agreement between the study results with the cut-off wall design in Ho Chi Minh Metroline No.1 which applied the elastic modulus of 250 MPa for 3-3.5 jetgrouting columns of the wall. Comparing to the observed data in Figure 6, the surface settlement about 6.2 mm behind the wall is also in line with the research results in Figure 10.

4. CONCLUSIONS

The development of traffic and urban population in Ho Chi Minh city along with limited surface space result in the necessity for underground construction, especially metroline systems. Tunneling in soft soil conditions in urban areas leads to negative effects on existing utility systems and nearby buildings. The paper presents a study on the application of cut-off wall in protection historical buildings from impacts induced by tunnelling in Ho Chi Minh Metroline No.1 project. The study results shows that the cut-off wall created by jetgrouting technology reduces soil displacements when tunnelling closed to the Saigon Opera House. A further investigation on effects of jetgrouting cut-off wall parameters shows that the surface settlement decreases in line with the thickness of the wall and an optimal value of elastic modulus of jetgrouting wall is about 750 MPa. Based on the study result, engineers can obtain a better design for the cut-off wall in protection of existing buildings from negative effects of tunnelling process in next metroline projects.

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