A Review of Soil Improvement Methods for Tunneling Projects in Urban Areas and Their Application at the Hochiminh Metroline No. 1,Vietnam

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Abstract. When tunneling in cities with soft soil conditions, it can lead to unexpected impacts on existing buildings on the surface. Buildings locating on influence zones induced by tunneling might be damaged in the case of no mitigating method applied. The scope of the influenced zone when tunneling is represented in this paper in association with a review on recent soil improvement methods for reducing the effects of tunneling. Possible mitigating solutions applied in tunneling design and construction processes are discussed, including improving surrounding soil and/or compensating settlements, as well as protecting existing building solutions. A soil improvement application with jet grouting technique in a recent tunneling project in Hochiminh city for reducing effects of tunneling on surround buildings and the tunneling process is also analyzed.

Keywords: Tunneling · Influence zones · Mitigating methods · Ho chi minh city · Vietnam

1 Introduction

In recent decades, transportation space has been in high pressure due to economic development and population growth. Since the surface space becomes more and more expensive and restricted, underground space development has seemed like a vital solution in cities. In the underground construction, tunneling with TBMs (tunnel boring machines) has been popular in urban areas with advantages of safe and rapid construction and reduction of influences on existing buildings [21]. Especially when tunneling in soft soil conditions with shallow depths, it has to face difficulties of sensitive and complex foundations and urban utility systems.

In cases that nearby buildings are forecast with large settlements, additional methods should be applied in order to ensure safety. Finding an appropriate solution in tunneling

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is actually necessary because this work affects safety when tunneling, construction cost, and the stability of surrounding areas. A summary of soil improvement methods applying in tunneling projects in this paper will help engineers to obtain an overview of mitigating methods and to have an ability to decide a sufficient solution in both technical and economic factors. Recent case studies of applying jet grouting technology for protecting a historical building and starting/arriving TBM areas in the tunneling process in a tunneling project in Hochiminh city, Vietnam are also introduced in this paper.

2 A Review of Soil Improvement Methods in Tunneling

2.1 The Scope of Influence Zones Induced by Tunnelling

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 [24]. 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) [20]; Boscardin and Cording (1989) [1]; Mair et al. (1996) [13]; Burland et al. (2001) [2]; Franzius (2004) [7]; Netzel (2009) [16] and Giardina (2013)[8].

In an investigation of ground movements induced by shallow tunneling, Vu et al. (2015) [21] proposed a model for predicting effects of tunneling on existing surface structures, as shown in Fig. 1. Based on the model, the minimum distance x from the building to tunnel axis is estimated by an allowable settlement u_{max} and the volume loss V_L as follows:

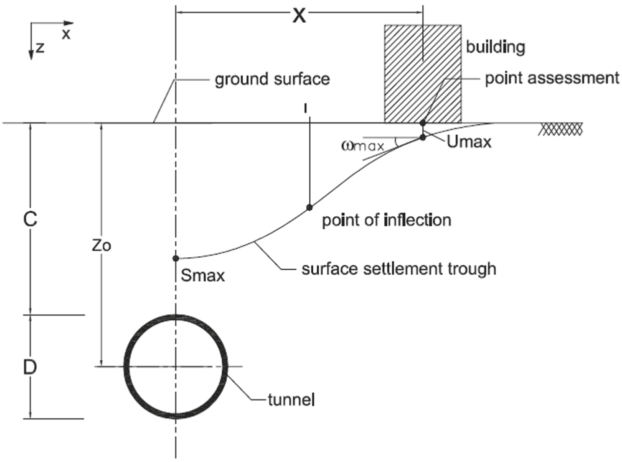


Fig. 1. Model of assessing the influence of tunnelling on existing buildings [21].

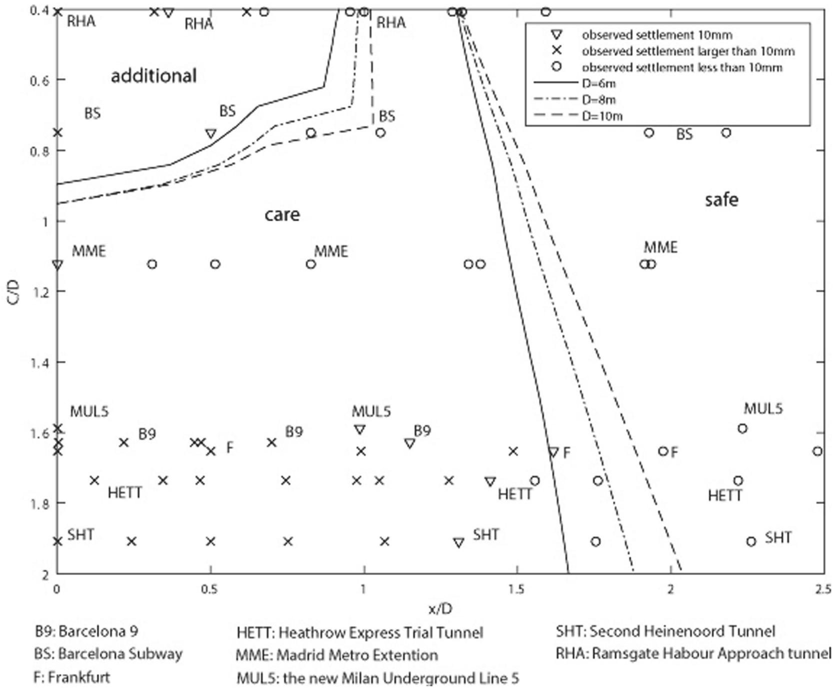


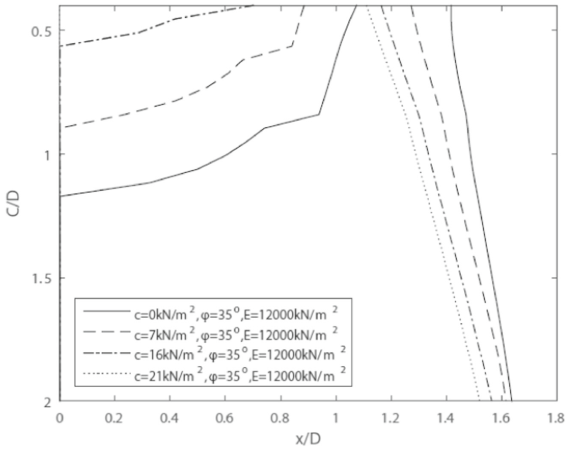
Fig. 2. Scopes of influence zones induced by tunnelling with various tunnel diameters and case studies [24]

$$x = \sqrt{-2i^2 \ln\left(\frac{u_{\max}}{S_{v,\max}}\right)} = \sqrt{-2i^2 \ln\left(\frac{u_{\max} i 4\sqrt{2}}{V_L D^2 \sqrt{\pi}}\right)} \quad (1)$$

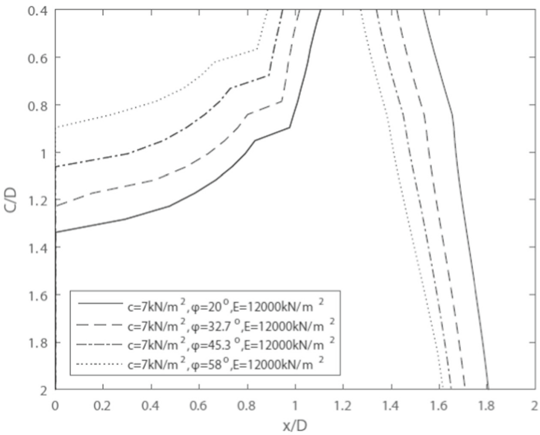
$$x = \frac{\omega_{\max} i^3 \sqrt{2}}{\sqrt{\pi} V_L D^2 LambertW\left(-\frac{32\omega_{\max}^2 i^4}{\pi V_L^2 D^4}\right)} \quad (2)$$

where, the allowable settlement $u_{\max}$ and allowable slope $\omega_{\max}$ are indicated in technical standards [17] and the volume loss V_L value depending on the tunnelling process can be obtained from [23].

Figure 2 shows that the scope of influence zones caused by tunnelling with various tunnel diameters. In this figure, the "safe" zone means that if the building location (x/D ratio) and the tunnel depth (C/D ratio) are in this zone, the building can be in safe when tunnelling. If the building location (x/D ratio) and the tunnel depth (C/D ratio) are in the "care" zone, the building can be protected without mitigating methods but the tunnelling process should be in a careful monitoring. The "additional" zone means that mitigating solution should be applied if the building location (x/D) and the tunnel depth (C/D) are estimated in this zone. On the basis of these analyses, engineers can predict and assess damage risks of existing buildings in the tunnelling process based on their locations and



(a)



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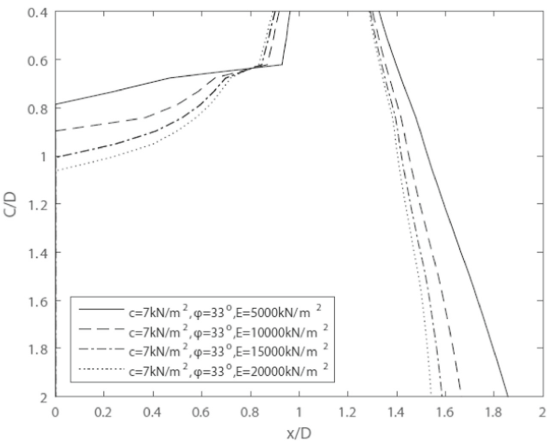


(c)

Fig. 3. Effects of soil properties on the scope of influence zone [25] (a)Effects of the cohesion c; (b) Effects of friction angle φ; (c) Effects of the modulus of elasticity E.

geo-conditions and decide to have a suitable monitoring and/or apply soil improvement methods.

In a study on shallow tunneling, Vu (2016) [25] also investigated the effect of soil parameters on the scope of the influence zone. Figure 3 shows the effects of the cohesion c, the Angle of internal friction φ and the values of elasticity modulus E on the scope of the influence zone. It can be seen in the Figs. 3a and 3b that when increasing the cohesion c and the friction angle φ, the relative distance x/D reduces. This means that tunneling impacts on surrounding structures can be minimized by changing the cohesion c and the friction angle φ. Meanwhile, the scope of influence zone seems no change when increasing the modulus of elasticity E values. Based on these analyses, it shows that the influence scope of tunnelling can be controlled by soil improvement methods.

2.2 Settlement Compensation 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) [25] 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 is the oldest grouting technique. The first application was in 1802 [26]. The principle of this method is filling voids in soil with an injection grout without changing the soil structure. The grout is pumped into a high permeable, granular soil to saturate and cement soil particles together in order to archive a stabilized soil zone for tunneling.

In this technique, the grout can be pumped from the surface and/or from the tunnel section itself, ahead of the excavation face or from dedicated grouting/pilot galleries by sleeved pipes (tube à manchette, or TAM). In injection, the coarse injection grout should be used first, and then the fine injection grout. This technique with the TAM can inject different grouts in the same hole at different times (Fig. 4). The pressure used in this technique must not exceed the value h where h is the overburden pressure and $\alpha$is an empirical factor with the value h $= 0.3 \div 3$ depending on soils ([11]). Permeation grouting technique is suitable for sands and gravels. In tunneling, permeation grouting has been applied in many projects, such as Turin Railway Interchange, Roma, and Napoli metro projects.

Jet Grouting. In this technique, water or grout is injected with high pressures in order to disrupt the ground for improving [10]. The first application of this technique was in England in the 1950s, but the first real practical application was in Japan. In the early 1970s, rotating jet grouting developed in Japan in the case of various thickness and somewhat fragile strength. In the middle 1970s, jet grouting was introduced in Europe and has become popular [15]. Jet grouting can be used to reinforce almost all soil types, except for peat. In the procedure of jet grouting, firstly, a jet tube is injected into the soil by using a boring machine, then, the grout mix is injected with the sufficient pressure in order to erode and mix with the soil. There are three installation methods of jet grouting depending on geometry, as can be seen in Fig. 3: the single system injects only grout, the double system injects grout combined with air, the triple system includes three components: grout, jetting water, and compressed air. Jet grouting has been used in many projects, for example, Galleria Valsesia Milan, Turin railway junction, Panel Grouting building pit Binnenrotte, Aechertunnel, Hochiminh Metro Line 1.

Soil mixing measures are based on turning an auger into and out of the soil, while continuously adding injection fluid under pressure through the hollow core of the soil to make the soil-concrete mixture. There are three different techniques often applied: Soil Mixed Wall (SMW), Deep Soil Mixing (DSM), and Shallow Soil Mixing (SSM). This technique is normally applied for improving bearing capacity, decreasing settlement, and increasing stability for structures and embankment. For example, the railway and road embankment in Malaysia, Japan, and Sweden. This technique also applied for improving the bearing capacity of the foundation for high buildings, and highway-bridge in Poland, as well as excavation control in Japan.

Ground freezing is the technique to make the soil impermeable and increase the stiffness of the soil by freezing the soil for stability. This technique can be applied for a wide range of soil types, especially fully saturated soils and in difficult ground conditions. The advantage of this technique is the ability to control the geometry of ground improvement zones by using flexible angles and length of freezing pipes. However, ground freezing requires refrigeration of massive soil volumes over a long time, so this technique is expensive comparing to other methods. When using liquid nitrogen in order to save time, the cost much increases. The other disadvantage is the expansion volume of frozen water, which can lead to unexpected heave. Therefore, it requires careful monitoring in the ground freezing process. In tunneling, ground freezing has been applied for some projects such as Copenhagen Metro, Denmark (Fig. 5).

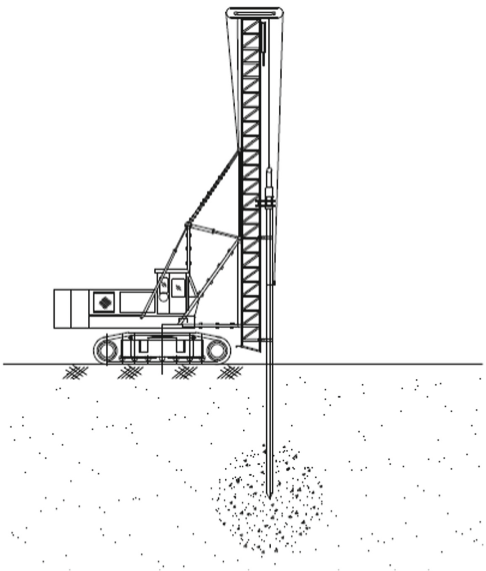


Fig. 4. Principle of permeation grouting

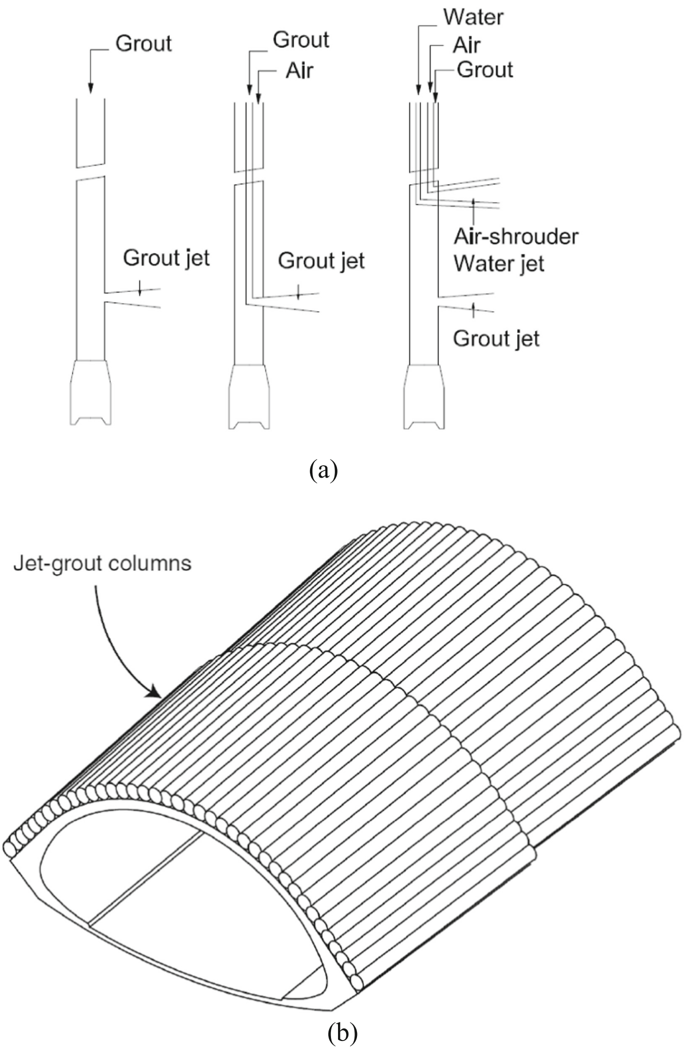


Fig. 5. Jet grouting technique in tunnelling (a) Systems in jet grouting [15] and (b) Jet grouting arch umbrella in Aeschertunnel, Switzerland

2.3 Reducing 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 [22] 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 (normally, TAMs), which are often installed with a drill dig (Fig. 6). In this method, the control of grouting operations works on ground and structure movements. When fracturing under the foundation, the monitoring should be accurately controlled both for the settlements of the buildings and the injection performance. Based on hydraulic fracturing theory, this technique can be performed in any soil type.

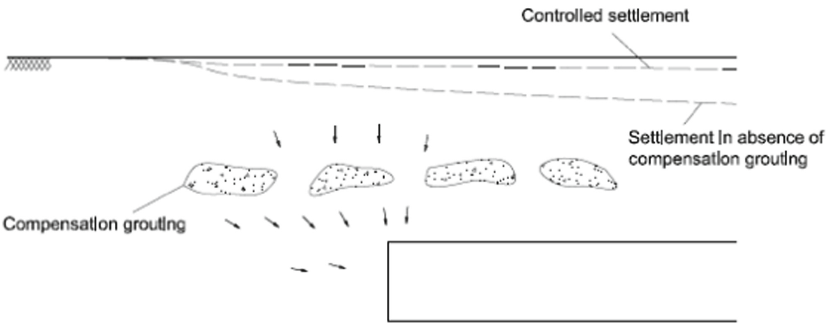


Fig. 6. Compensation grouting in tunneling [12]

A large number of applications show that compensation grouting can be applied in challenging soil conditions such as soft and organic soils and peat. Compensation grouting design requires one to identify geotechnical conditions, expected heaves or settlements, and possible injection points. In tunneling, compensation grouting was used firstly in 1974 after the collapse of 23 m railway tunnel below a building in Canterbury in England in order to prevent further settlements. In the construction of the Bolton Subway Tunnel in Baltimore, the United States of America (USA), from 1977 to 1980, compensation grouting was used to prevent the settlement during tunneling. This method has been successfully applied in tunneling in Waterloo Stations, London [9], Antwerp Central Station [6], Jubilee Line Extension, London, and the North-South Line in Amsterdam.

Compaction grouting is a technique that the soil is compressed by the grout around the injection point. The grout does not fill the soil pores but remains as a mass to compact the soil around (Fig. 7). 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. In these cases, this technique is applied behind the TBM, from the analysis in Vu et al. (2016) [25].

Compaction grouting was firstly used in the early 1950s and then has become widely used in construction as an improvement technique in USA. In 1990, compaction grouting was exported to Japan and used extensively to repair structures that experienced settlement and tilting due to earthquakes. Although this technique has been used for more than 6 decades, there has been little research on the fundamental theory. Only some successful observation results have been published such as the drain tunnels in Phoenix and Bolton [4].

Micropiles. A micropile system is often used for transferring the structural load to competent bearing strata. Micropiles were introduced in Italy in the 1950s in the renovation of historic buildings that had been damaged during World War II. Then, this technique became popular in Europe, especially in the 1980s. Micropiles have been used with

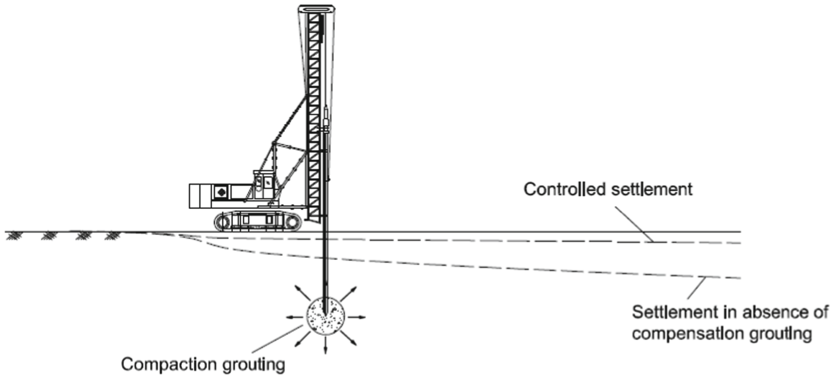


Fig. 7. Principle of compaction grouting ([12])

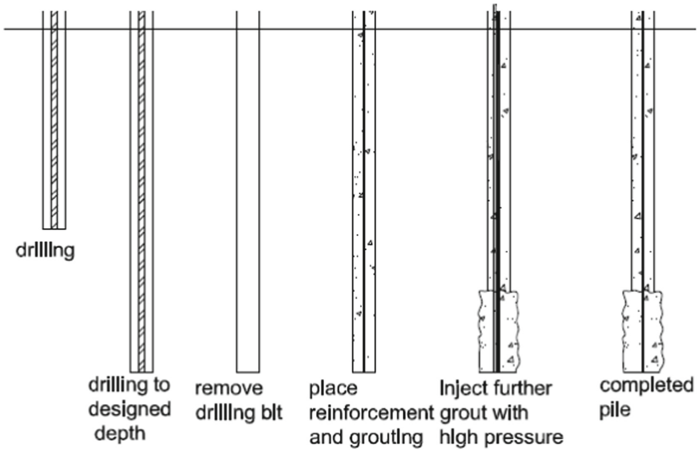


Fig. 8. Micropile construction

drilling rigs, grout mixing, and a pump for jetting the grout. The method of installing micropiles can be seen in Fig. 8. Firstly, a drilling rig drills a hole to designed depths. Then, reinforcements are placed in the hole. The grout is injected to the hole by pumping. The pile can be injected with further grout under high pressure to create a larger bearing capacity at the lower part of the pile. In tunneling, this technique can be used for reinforcing foundations above the tunnel.

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 Fig. 9. 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.

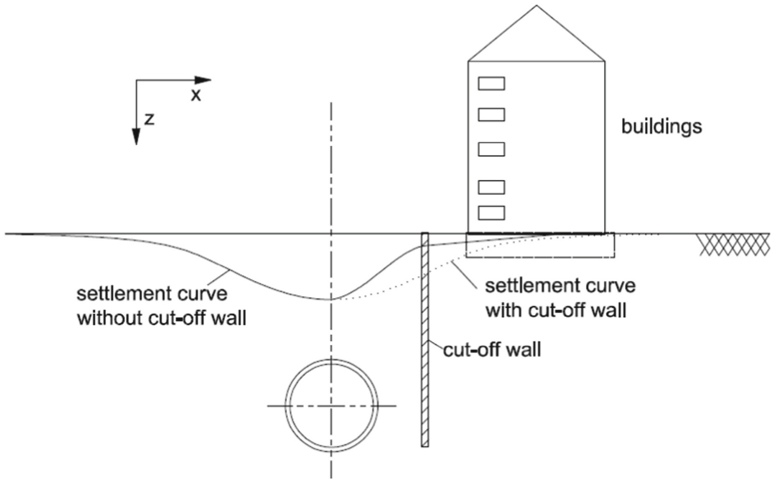


Fig. 9. Principle of the cut-off wall [3]

2.4 Mitigating Measure Selection for Tunneling Projects

In tunnel design and construction, the choice 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. The selection of soil improvement methods in tunneling projects is a summary of the assessment of ground improvement on the flexibility, feasibility, durability, and the speed of carrying out of work [18].

In the case of tunneling in peat and soft clay, as investigated in [23], the volume loss of the tunneling face, along with the shield, at the tail and in consolidation might be very large. The ground improvement methods combined with reinforcement methods for the tunneling face are recommended to be applied in these cases. Careful control when tunnelling is also recommended in these cases.

The mitigating measures for improving the soil properties are often applied before tunneling, and the injected grout quantity can be estimated in the laboratory in order to achieve the required soil parameters before actually being applied in projects. Meanwhile, the measures of compensating settlement without changing the soil properties are usually applied to compensate for the settlement induced by tunneling. The cavity expansion methods indicated in [27] and [23] can be used to estimate the quantity of required grout in these measures.

3 A Case Study at Hochiminh Metroline No. 1, Vietnam

The Metro Line 1 in Hochiminh city is the state-of-the-art metro line built in Vietnam with 19.7 km length comprising 2.6 km underground under density areas of Ba Son shipyard, the Saigon Municipal Opera House and the Saigon river (Fig. 10). There are 14 stations along this metroline from the Ben Thanh station to the Long Binh deport.

The Hochiminh Metro Line 1 project was started in 2012 and the underground work was finished in 2019. The tunnel is constructed under many historical buildings and density areas, thus allowable settlements and other effects on existing buildings on the surface are very strict. An Earth Pressure Balance Tunnel Boring Machine (EPB TBM) was used for tunneling from 11 to 30 m depths.

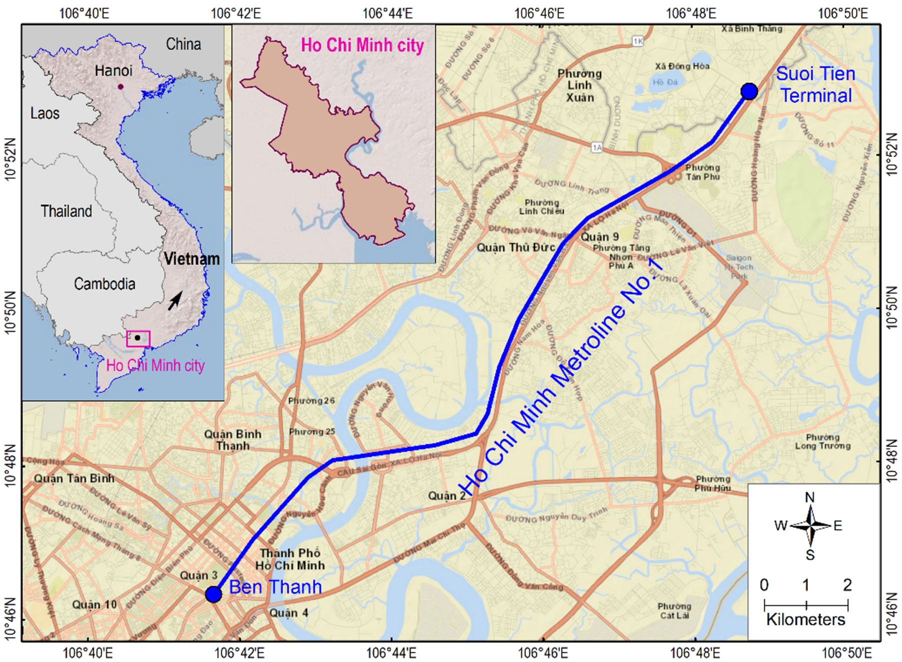
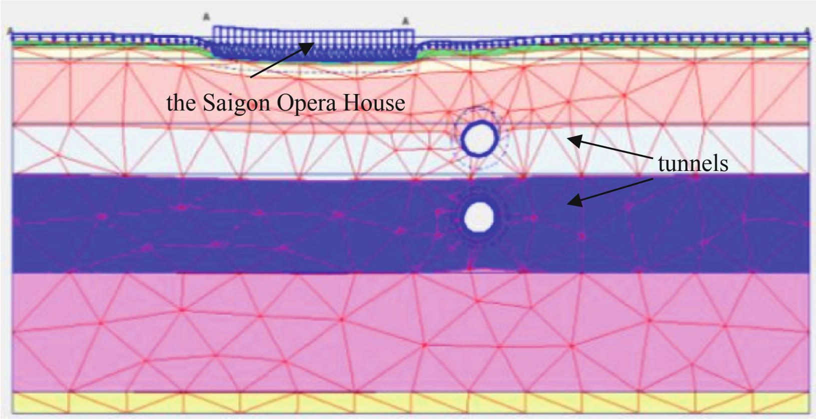


Fig. 10. Plan of Hochiminh Metro Line No1 in Vietnam

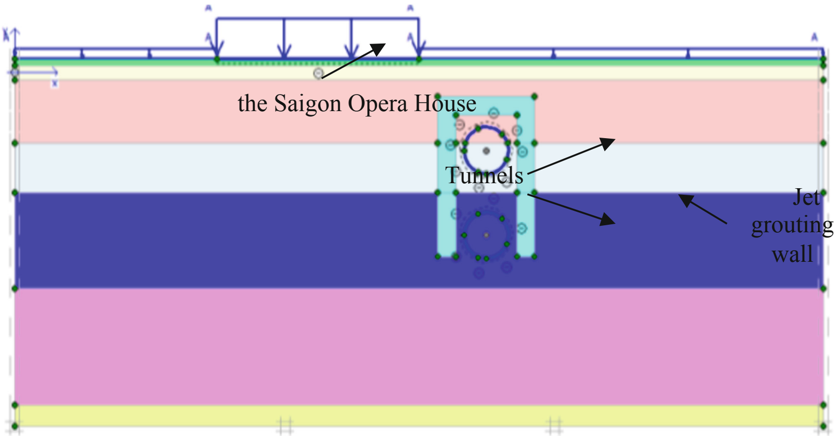
Table 1. Soil parameters at the Saigon Municipal Opera House, Hochiminh city, Vietnam

Layer	Thickness (m)	Unit weight γ (kN/m^3)	N-value	Cohesion c (kN/m^2)	Friction angle φ degree	Young modulus αE_0 kN/m^2	Poisson's ratio ν	Permeability coefficient k (m/sec)
Fill	1.1	18.0	1	0	28	2,500	0.35	1×10^{-6}
Ac2 and Ac3	1.7	16.0	1	14	0	10,000	0.48	1×10^{-9}
As1	13.9	19.5	6	0	31	16,000	0.33	5×10^{-5}
As2	17.0	19.5	13	0	31	35,000	0.33	5×10^{-5}
Dc	15.6	21.0	43	220	0	101,000	0.45	1×10^{-10}
Ds	–	21.0	31	0	34	77,500	0.31	7×10^{-6}

The soil-profile at the Saigon Municipal Opera House location is shown in Table 1. There are three soil materials including Fill layer at the top, Alluvium layers and Diluvium materials at lower depths. The Fill layer is of about 2 m. Alluvium layers are of about 30 m depth comprising Soft Clayey Silt (Ac2 and Ac3), Silty Fine Sand Layer 1 (As1) and Sand layer 2 (As2). Diluvium layers shown in Table 1 include Diluvium clayey silt (Dc) and silty sand layer (Ds).



(a)



(b)

Fig. 11. Settlement analysis in Plaxis 2D for the Saigon Municipal Opera House in Hochiminh Metro Line 1 [19] (a) In the case of no protection solution (b) In the case of using jetgrouting wall

3.1 Jet-Grouting Wall for Protecting a Historical Building

The Saigon Municipal Opera House is one of the most important buildings in Hochiminh city with French architectural shape like the Opera Garnier. The house was designed smaller than Hanoi Opera House with a specific characteristic of French Third Republic. All the design drawings, decorations and furnitures were sent from France. This house was built for a decade from 1901 to 1911 with 1800 seats. The opera house has a main seating floor with two seating levels. After some reparations, the opera house now has only a capacity of 500 seats. Since the tunneling works were carried out in a soft soil condition with a short distance between the house and the tunnel alignment, the house was predicted to have a significant influence if no protection method would be applied. Thus, finding protection methods of any damage to the house during the excavation process is necessary for the project design.

Due to the historical role of the house, much effort had been carried out to study a sufficient method for protecting the house. Figure 13 shows the locations of twin tunnels at this location at levels of about −12.5 m and −24.5 m. Thus, tunnels are in the As1 and As2 layers, as can be seen in Table 1. A prediction of the house settlement carried out in Plaxis 2D was shown in Fig. 11a with a maximum settlement of 61.04 mm [19]. This means that the house would have large damage if no additional method would have been applied. In this project, a solution of using jet grouting technique was proposed.

In this protection design, the tunnel alignment is mostly surrounded by jet grouting walls in both sides and above the tunnel crown, as can be seen in Fig. 13. The jet grouting wall was created by jet grouting technique in the distance between the house and the tunnel alignment for minimizing the ground displacement induced by tunneling. With this solution, the soil displacement is minimized not only in the house direction but also with the surface settlement. This wall also decreases groundwater variation under the house foundation. Therefore, this method can reduce potential damages to the building in the most safe way.

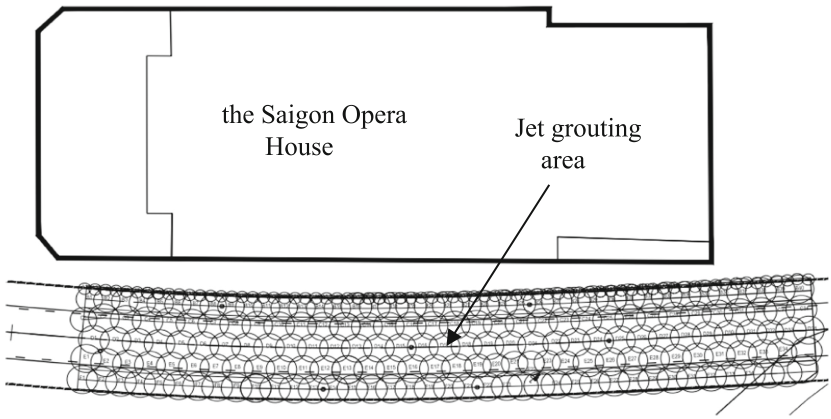


Fig. 12. Jet grouting plan at the Saigon Opera House

An analysis by Plaxis 2D was also carried out for this case, as can be seen in Fig. 11b. It was shown that settlements of the house are predicted from 10 to 12 mm when jet grouting wall applied with a depth of 2.7 m [19].

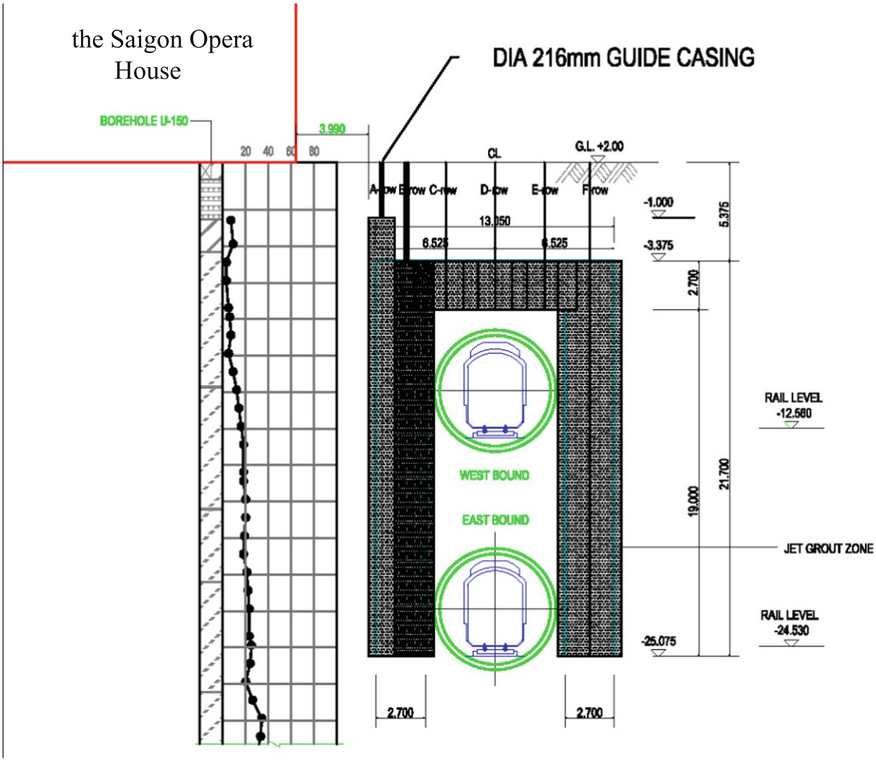


Fig. 13. Crosssection view of jet grouting wall at the Saigon Opera House location

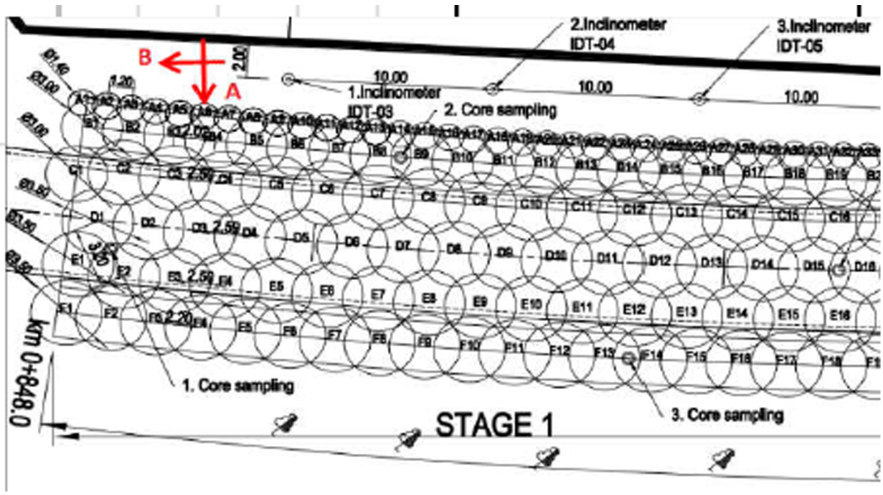


Fig. 14. Inclinometer locations for monitoring at the Saigon Opera House

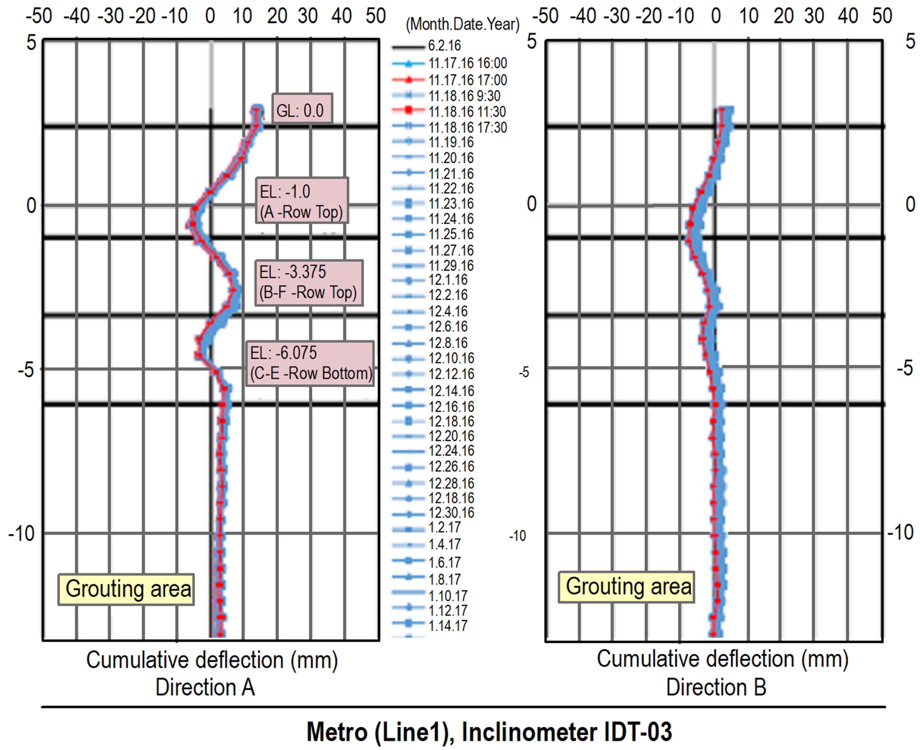


Fig. 15. Observed data of IDT-03 inclinometer behind the jet grouting wall near the Saigon Opera House (in mm)

A layout of jet grouting work at the Opera House site is shown in Fig. 12. A total of 239 jet grouting holes comprising 66 jet grouting holes (1400 mm in diameter), 47 jet grouting holes (3000 mm in diameter), and 126 jet grouting holes (3500 mm in diameter) was constructed at the field.

On-site, the grout was continuously mixed by a mixing machine with the combination per cubic meter comprising 760 kg PCB40 cement plus 750 water liters. This slurry combination was pumped with a pressure of about 40 MPa and 300 L/min discharge rate. The rotational speeds of the triple rod were 12 rpm for jet grouting holes with 3500 mm in diameter, and 14 rpm for jet grouting holes with 3000 mm in diameter. The pulled up speeds of the rod were 9 min/m for 3500 mm jet grouting hole and 7 min/m for 3000 mm jet grouting hole. The depth of the jet grouting wall is at the level of −25 m with a width of 2.7 m (see Fig. 13).

Four inclinometers were installed at the site for measuring ground displacements in the space between the jet grouting wall and the Saigon Municipal Opera House as shown in Fig. 14.

The observed data of soil displacements at the location of IDT-03 is presented in Fig. 15. The role of the jet grouting wall is clearly shown in this case. The soil displacements have fluctuated with the maximum value of 15 mm is at the top of the wall, near the surface in the "A" direction, where no jet grouting applied. The maximum displacement along the part of the wall without jet grouting is only about 6 mm. Meanwhile, at 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 data 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 wall, in this case, protected the important building effectively from the tunneling impact.

The tunnel construction in Hochiminh Metro Line 1 has already been completed. The observation of soil displacements has been continued, and no damage has been recorded at this building. 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 jet-grouting wall in this case.

3.2 Strengthening the Tunneling Process

When the TBM starts/arrives shafts, there is a transformation from the concrete structure to the soil environment at the boundary of shaft areas. Practically, the soil in these areas is always improved in order to avoid possible damage that appeared on surrounding structures and the TBM due to large settlements. In the case of Hochiminh Metro Line

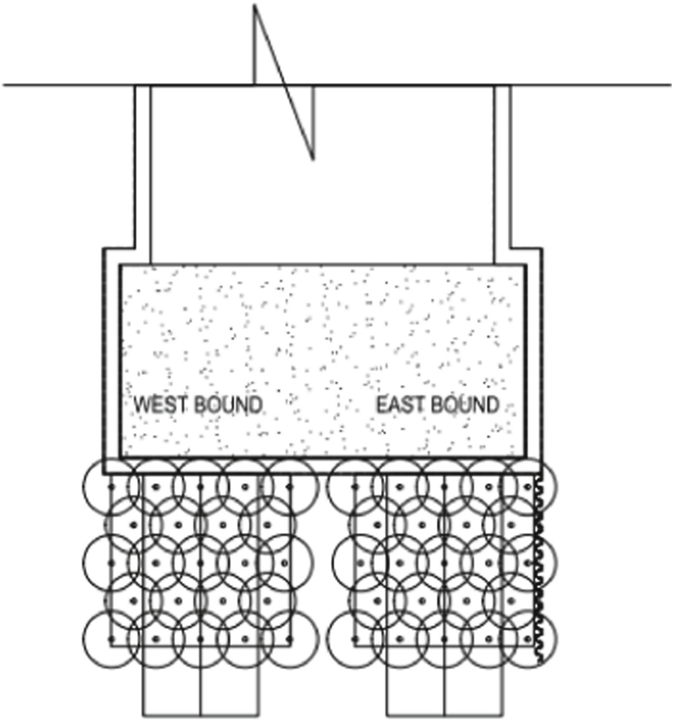


Fig. 16. Jet grouting plan at the starting area at Ba Son Station

1, at shaft areas, the tunneling was carried out with shallow overburdens and soft soil conditions. Thus, if high supporting pressures had been applied at the tunneling face, blow-out and fracturing accidents would have also occurred in the tunneling process. On the basis of these situations, the jet grouting method was selected to improve the soil surrounding launching/arriving shafts in this project.

Figure 16 presents a jet grouting plan at the starting shaft at Ba Son station. The starting areas at both East Bound and West Bound are designed with 23 jet grouting holes with 3500mm in diameter. The slurry components per cubic meter also include 760 kg PCB40 cement plus 750 water liters. A pressure of 40 MPa was used for pumping the slurry combination with the 300 L/min of discharge rate when jet grouting at the site. The triple type rod of the jetgrouting machine was hitched with a speed of 9 min/m and rotated with a speed of 12 rpm.

The soil around the arrival shaft at the Opera House Station was improved by 27 jet grouting columns with 3500 mm in diameter and 7 jet grouting columns with 3000 mm in diameter (Fig. 17). The same mixing proportion, pumping pressure and discharge rate with the jet grouting work at the starting shaft at the Ba Son station was applied. For the jet grouting columns with 3500 mm in diameter, a rotational speed of 12 rpm and a pulling up speed of 9 min/m were applied. For the jet grouting columns with 3000 mm in diameter, slower rotational and pulling up speeds of 14 rpm and 7 min/m were used. At

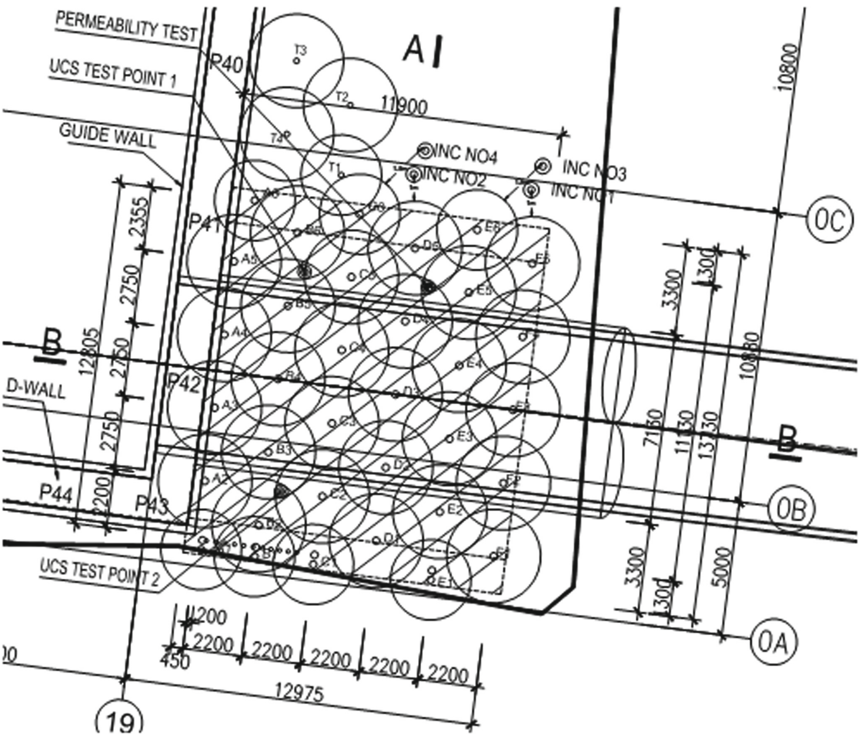


Fig. 17. Layout of soil improvement at the arrival area by jet grouting technique at the Opera House Station

this location, there are 4 inclinometers (INC N01, INC NO2, INC NO3 and INC NO4) were installed at the site for monitoring soil displacements as can be seen in Fig. 17.

Figure 18 shows sample test results, including unconfined compression tests of a sample from a jet grouting column after 7 days (Fig. 18a) and core samples from a jet grouting column after 14 days (Fig. 13b) of jet grouting column in this project. In detail, after 7 days, the unconfined compressive strength q_u is measured of about 3000 kPa while the secant modulus at 50%q $E_{s,50}$ is measured of around 870 MPa.

With core samples from a jet grouting column after 14 days, the unconfined compressive strength q_u is measured of about 2450 kPa and the secant modulus at 50%q $E_{s,50}$ is 1758 MPa. These recorded values with jet grouting with large diameter technology used in the Hochiminh Metro Line 1 project are double than the values of normal jet grouting with smaller diameters. As above discussed, the scope of influence zones at these areas is minimized with highly improving soil properties.

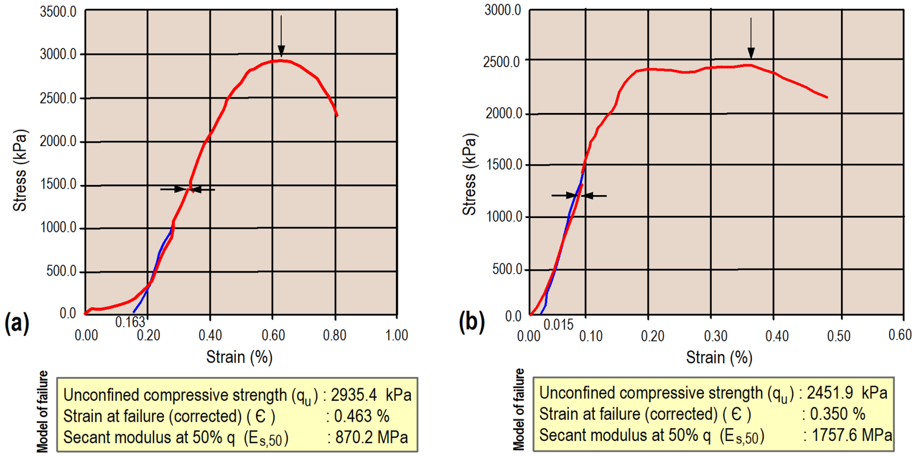


Fig. 18. Results of sample tests for jet grouting columns in Metro Line No.1 Project in Hochiminh city: (a) Unconfined compressive test for a jet grouting sample after 7 days and (b) a core sample test for a jet grouting sample after 14 days

The underground construction in the Metro Line No 1 project in Hochiminh city has been finished and no problem at starting and arriving shafts of the project has been occurred. This success means that the jet grouting technique is a sufficient soil improvement method when tunneling in soft soil conditions, especially at sensitive zones of starting/arriving TBM.

4 Conclusions

Population and infrastructure development in line with limited surface space lead to the high demand for underground construction. Tunneling in soft soils in urban areas has to face complex existing utility systems and geotechnical issues. The study shows that the scope of the influence zone induced by tunneling can be controlled by improving the soil properties. This paper reviews possible soil improvement methods applied in tunneling for ensuring the tunneling process in safe and protecting nearby buildings, including methods of changing soil properties and compensating tunneling effects. A case study of Hochiminh Metro Line 1 in this study shows that jet grouting technique applied at launching/arrival shafts for successful tunneling work and protecting the historical Saigon Municipal Opera House is a sufficient solution for future metro lines in Vietnam.

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