Large soil-cement column technique for urban underground projects in Vietnam

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ABSTRACT

Almost all big cities in Vietnam are often located in the river deltas, therefore the ground conditions are mostly soft soil. As a result, the soil strengthen works are mandatory in order to prevent the harmful to the third parties and tunnel structure itself in urban tunnel projects in Vietnam. This paper particularly introduces the large diameter jet-grouted column (LSCC) technique that has been recently successfully applied in Ho Chi Minh Metro Line 1 in Vietnam. The success application of this technique for protecting a historical sensitive building and for water cutoff objective of launching and arriving shafts in the urban tunnel project will be analyzed from construction process, quality control and lessons learnt. From this situation, the large diameter jet-grouted column technique can extent to another urban tunnel projects in Vietnam and other countries which have similar soft soil conditions.

Keywords: Large Diameter, Jet Grouting, Ground Improvement, Urban Tunnel proceedings;

1 INTRODUCTION

The demand for infrastructure in cities is increasing rapidly due to economic developments and the urban population growth. In developing countries, particularly in Vietnam, cities have faced to a rapid growth in transport-related challenges, including traffic congestion, noise and air pollutions, and environmental degradation. Almost all big cities in Vietnam are often located in the river deltas and therefore the ground conditions are mostly soft soils. The tunneling work in poor soil conditions is typically achieved by combining various soil improvement methods and soil support techniques, for example, grouting, jet grouting and micro-piles. In principle, each technique is best suited for particular soil types and seepage conditions. The construction procedure can be thus customized, for each particular case, allowing also for rapid changes on site in case unforeseen conditions were encountered. As a result, the soil strengthen works are mandatory in order to prevent the harmful to the third parties and tunnel structure itself in urban tunnel projects.

Japanese specialists can be considered as the pioneers in the jet grouting technology. They have developed jet grouting since the 1970s, with the name CCP-Chemical Churning Pile when chemical binders were applied. Then, these products were replaced by water-cement grouts. Another method referred to as the ‘Jet Grout’ method was developed at the same time by other Japanese specialist group (Yahiro et al. 1974), in which treatment included eroding the soil with high-speed jets of water afterward filling the remoulded material with cement grout injected from a lower nozzle (Croce et al.,2014). Nowadays, the available jet grouting techniques can be classified into three main systems comprising of single, double and triple fluid, depending on the number of fluids injected into the soil (grout, air and grout, and water plus air and grout).

This paper presents an application of the large soil-cement column in Hochiminh Metro Line 1 (HCM MRT Line 1), Vietnam where a variety of jet-grout treatments were performed to protect a historical building and to ensure the tunneling process in safe.

2. LARGE SOIL-CEMENT COLUMN TECHNIQUE (LSCC)

In jet-grouting development, manufactures have attempted to improve the performance of the jet grouting process, for example minimizing the curvature of curved parts of the fluid conduit and improving the working of nozzles from a single to a double and, then, to a triple system. Figure 1 shows a triple rod system in jet grouting. By this, soil remoulding and cementation are divided into two processes. Firstly, a high-velocity water jet is used to separate the soil through a nozzle on the upper part of the rod. Then, the water-cement grout is injected from a lower nozzle in order to cement the remoulded soil. Recently, with the development of technology, the jet grouting can reach extremely large diameters of the columns by using powerful pumps and efficient supply system. An example is a well-known “SuperJet” which can have a 5m diameter of jet grouting column (Yoshida et al. 1996). In Vietnam, a company, namely as FECON Underground Construction Jsc. in a co-operation with Raito Kogyo

Co.,Ltd. also has a jet grouting technology with large diameters called “Big Diameter Jet Grouting”. Here, this technique is called the large soil-cement column (LSCC). LSCC has many advantages in comparing to conventional grouting methods. The first is the high speed construction due to the reduction of the column number (equals 1/10 of conventional grouting methods) in a particular construction area. The other benefit is the grouting linear length, LSCC linear length only equals 1/18 to conventional grouting methods. Thirdly, this technique creates high quality products because the rod in LSCC is thicker so the rigidity of the rod is much better than the rod used in conventional jet grouting methods. This leads to the more accuracy when drilling. In-situ soil is cut into smaller pieces while two jets rotates and crosses in the ground. The final benefit is that it avoids the impact to existing pipelines because wide spaces between jet grouting holes. A typical sequence of jet grouting is described in Figure 2. Firstly, the machine is located to the pile location which was determined previously. In the second step, the rod will be drilled to the designed depth. Next, grout slurry is injected into the soil in order to harden the surrounding soil. Finally, carrying out jet grouting to the top of the improved zone and finishing.

Fig.1. Jet grouting triple type rod used in HCM MRT Line 1

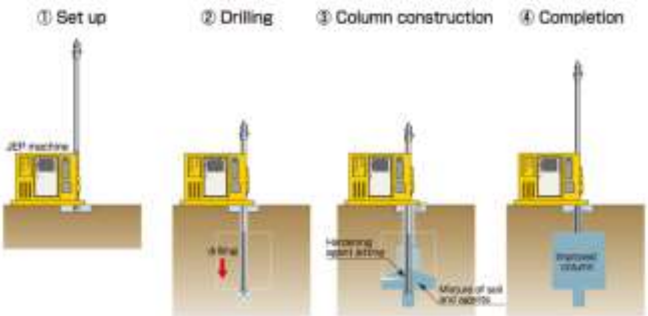


Fig. 2. A typical sequence of Jet Grouting Work (Raito, 2019)

3. CASE STUDIES IN HO CHI MINH METRO LINE 1 PROJECT

Hochiminh Metro Line 1 is a first metro line in Vietnam, which was tunnelled with an EPB TBM. This metro line is of 19.7 km composed of 2.6 km underground pass the Ba Son shipyard and the Opera House, crossing the Saigon River (Figure 3). Within this corridor, the tunneling project might impact adjacent existing structures and buried infrastructure utilities (Le, H. Q., & Hsiung, B. C. B.,2014). The soil condition of the tunnel includes Fill, Alluvium and Diluvium materials. The surface Fill layer has a depth of about 2 m. The next around 30 m Alluvium layer includes Soft Clayey Silt layer, Silty Fine Sand Layer 1 and Sand layer 2. Diluvium clayey silt and silty sand layers are in deeper depths. Large soil-cement column technique was applied in this project in order to prevent damages in tunneling excavation and also existing buildings. In this paper, two case studies are presented for the application of LSCC. The first is the soil improvement for protecting at the Opera House and the second is at launching and arrival areas of the TBM.

Fig. 3. A plan view of Hochiminh Metroline 1 project

3.1. Soil improvement for the protection of the Saigon Municipal Opera House

The Opera House was built between 1901 and 1911. It was designed with architectural style as the Opéra Garnier in Paris by a French artist and sent from France. There are a main seating floor and two above seating levels with an accommodating capable of 1,800 people. Due to the historical importance of the Opera House, a protection solution for avoiding any impact on the house from tunnelling excavation works is essential. In this case, a cut-off wall with LSCC technique as a grout barrier was built for minimizing the ground movement induced by tunnelling. A deep cut-off wall here not only decreases the settlement but also reduces the change of ground water which might lead to damage of the foundation of the Opera House. In this area, a careful monitoring was designed in order to recognize any risk for the building appeared.

Figure 4 shows the layout of jet grouting in the Opera House area. There are 239 jet grouting holes including 66 holes with the diameter of 1400mm, 47 holes with the diameter of 3000mm, and 126 holes with the diameter of 3500 mm. Jet grouting slurry was mixed continuously on site with the mixing proportion of 760kg PCB40 cement and 750 litter of water per a cubic meter. The grout was pumped with about 40MPa pressure and about 300litters/min rate, rotational speed was 12rpm and 14rpm for holes with diameter 3500 and 3000mm,respectively.

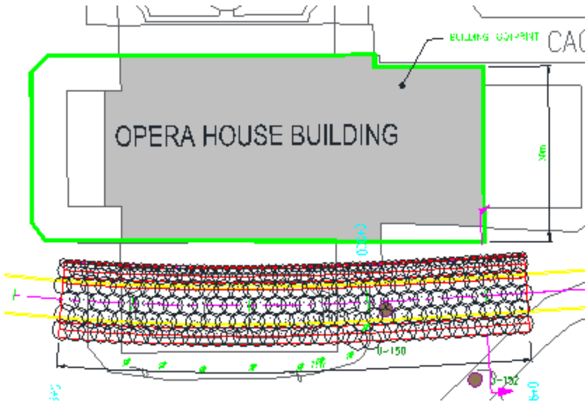


Fig. 4. Jet Grouting Layout for protecting the Opera House

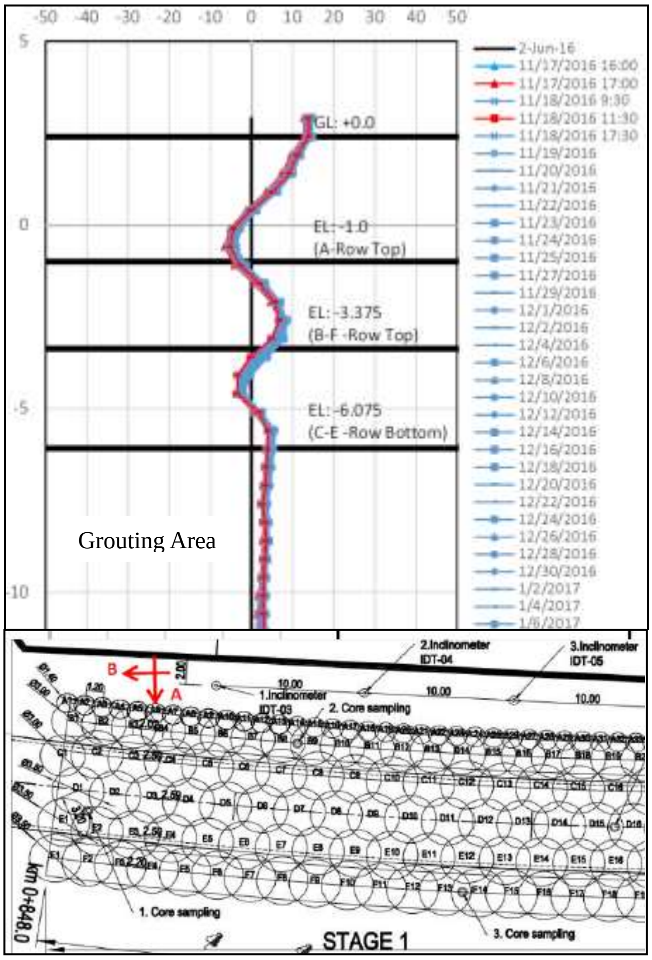


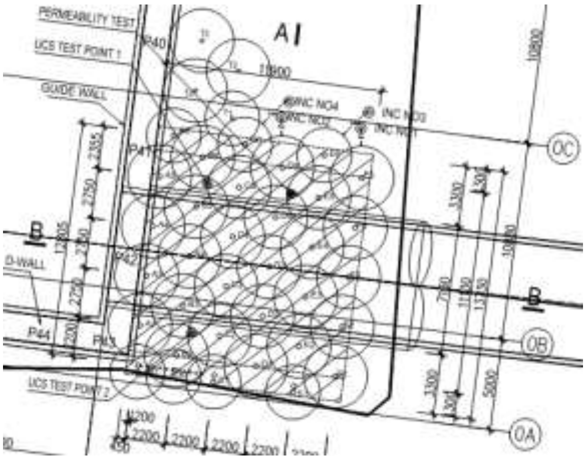
Fig. 5. Observed cumulative deflection (mm) in Direction A at IDT-03 inclinometer

The pulling up rate was 9 mins/m for jet grouting diameter 3500, and 7 mins/m for jet grouting diameter 3000mm. Clearly, from the jet grouting plan, it presents advantages of the LSCC. In the case of large areas required high improved soil quality with a purpose of having better soil parameters such as cohesion, friction angle values for reducing the scope of influence zones induced by tunneling (Vu et al.,2015), LSCC is a more effective solution than the conventional methods with smaller jet grouting diameters when reducing a huge number of jet grouting holes in order to obtain a full jet-grouted area. The construction schedule in this case therefore was on track. In the distance from the jet grouting wall to the Opera House, there were 4 inclinometers for observing the ground movement behind the cut-off wall which can influence on the Opera House foundation. Based on the observed data from an IDT-03 inclinometer near the jet grouting wall, Figure 5 shows that the soil displacement in the jet grouting zone is much smaller in comparing to the ground displacement in the area without jet grouting. The maximum ground displacement was about 5mm in the grouted area, meanwhile this value was about 15mm in the "A" direction at the soil area on the top of jet grouting column near the surface. It means that jet grouting has an advantage in preventing existing buildings from influence induced by tunnelling.

HCM MRT Line 1 tunnelling work has been finished and only small soil displacements were observed behind the LSCC wall. This means that the Opera House was protected from influences induced by tunnelling. The LSCC application as a protection barrier at the Opera House area shows a successful solution for protecting historical buildings in urban areas when tunnelling.

3.2. Method statement for jet grouting at launching/arrival areas for TBM

At arrival/launching areas where exist a change from soil conditions to concrete structures, it is often observed unusual settlements. This might lead to risks of damages on tunnel machines and tunnelling process. In HCM MRT Line 1, the depth of overburden above the tunnel lining when tunnelling closely to stations is shallow with soft soil conditions. In order to prevent influences on surface buildings, risks of blow-out and/or fracturing, LSCC was also applied at these areas. An arrival area of the Opera House station and a launching area at Ba Son station are examples of LSCC application in this metro project. A layout of LSCC in Figure 6a is shown for the arrival area at the Opera House station. There were 27 jet grouting holes with the diameter of 3500mm and 7 jet grouting holes with the diameter of 3000mm. Mixing proportion here was the same proportion as large diameter columns of jet grouting applied at the Opera House. Jet grouting slurry was also mixed continuously on site with the same mixing proportion. The grout was pumped by a triple rod with a high pressure of about 40MPa with the rate of about 300 litters/min, rotational speed was 12rpm and 14rpm and pulling up rate was 9 mins/m and 7 mins/m for jet grouting with diameters of 3500 and 3000mm, respectively. Four inclinometers were also installed. Figure 6b shows a picture of jet grouting site. Although it was observed a small fracture occurrence with small air burbles appeared on the road surface when raining, no damage was recorded. This might be explained by the existence of air in jet grouting areas.



(a)Jet grouting layout

(b)Jet grouting site

Fig. 6. Jet grouting at arrival area at Opera House Station

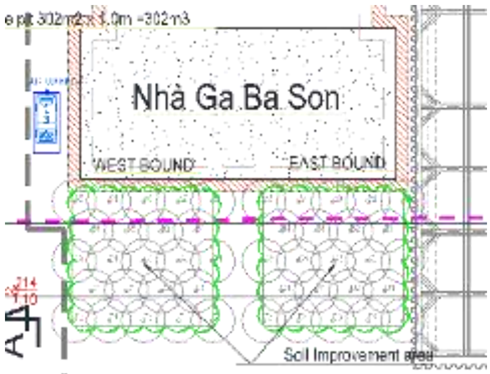


Fig.7. Jet grouting at launching area at Ba Son station

Figure 7 shows another application of LSCC technique at the launching area at Ba Son station including 23 jet grouting holes for East Bound and 23 jet grouting holes for West Bound. All holes have a diameter of 3500mm. The same mixing proportion for cement grout and other technical parameters of jet grouting work are applied at this area. Figure 8 shows test results of jet grouting columns with unconfined compression tests after 7 days. It can be seen that the unconfined compressive strength q_u of the jet grouting column can reach nearly 3000kPa and secant modulus $E_{s,50}$ is near 870 MPa after 7 days. These values are nearly double normal values reaching by other soil improvement methods even jet grouting with smaller diameters. The reason is the higher soil improvement quality of LSCC in comparing with smaller diameters of jet grouting column when using higher grout pressures and larger jet grouting areas.

At the construction stages of HCM MRT Line 1, no damage at these areas was recorded. This means LSCC technique is an effective solution when tunnelling in urban areas with soft soil conditions for protecting existing buildings and at sensitive areas such as arrival and launching TBM areas.

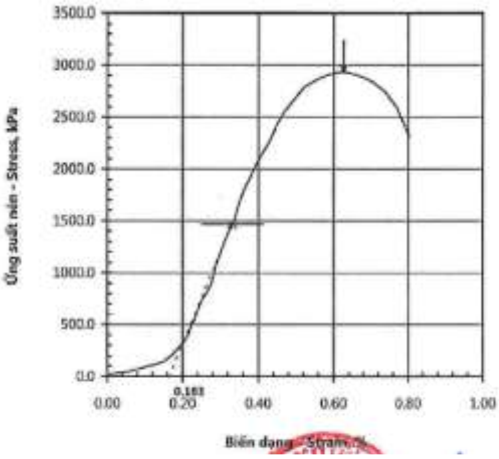


Fig.8. Unconfined compressive test results after 7 days

4. CONCLUSION

Jet grouting technology with large diameter column has many benefits with high quality products, short construction time and economy benefit. In this paper, case studies in Hochiminh Metro Line 1 have been reviewed with the application of LSCC in the Opera House protection and arrival/launching TBM areas. These cases show that LSCC is an effective solution for minimizing the effects induced by tunneling in urban areas not only in tunneling excavation but also in protection of existing buildings.

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