



Large soil-cement column applications in Vietnam

Minh Ngan Vu

Hanoi University of Mining and Geology, Hanoi, Vietnam. E-mail: vuminhngan@gmail.com

Quang Hanh Le

Fecon Underground Construction Jsc., Hanoi, Vietnam. E-mail: hanhquangle@fecon.com.vn

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ABSTRACT: Industrial and infrastructure projects in Vietnam are often constructed with soft soil conditions, thus many soil improvement methods are usually used. Large Soil-cement Column (LSCC) is one of state-of-the-art soil improvement techniques recently applied in construction in Vietnam. Successful applications in industrial zones (Hoa Phat steel plant and Duyen Hai thermal power plant) and tunnelling projects (Hochiminh Metro Line 1 CP1a & CP1b) showed a huge benefit of this method. With advantages of safety, lower costs, shorter construction time and high quality products, LSCC is predicted to become a popular soil improvement method in Vietnam where a significant increase of the industrial and infrastructure project number is foreseen. Looking back the LSCC approach and its applications, technical lessons are derived in order to improve LSCC work for future projects.

1. INTRODUCTION

In order to adapt high demands of economic developments and the growing urbanization, improving infrastructure systems and developing industrial zones is essential, particularly in developing countries as Vietnam. Increasing population in cities leads to congestions, air pollutions and environmental degradations while surface space is limited. Thus, underground infrastructure is a sustainable and safe solution even high construction costs.

Infrastructures and industrial zones have recently been constructed with soft soils conditions in Vietnam since almost all big cities are located in the river deltas. Ensuring the safety of the buildings and preventing the harmful to the third parties, various soil improvement methods and soil support techniques, for example, grouting, jet grouting and micro-piles are often considered in design and construction process. Depending on soil types and construction conditions, a suitable soil improvement method can be selected on careful

economic and technical considerations. This paper introduces a recent popular ground improvement method, namely as Large Soil-cement Column or Jet-grouting with big diameters in infrastructure and industrial projects in Vietnam.

Jet grouting technology has been innovated and developed by Japanese specialists since the 1970s, with the name CCP-Chemical Churning Pile. Firstly, chemical binders were used. Then, these products were changed to a slurry of water and cement combination. Another method referred to the 'Jet Grout' method was developed at the same time by other Japanese specialist group (Yahiro et al., 1974). This method includes eroding the ground with high pressured water jets, then filling the remoulded material with cement grout by injecting with a lower nozzle (Croce, 2014). In the first generation, with a purpose of only creating vertical cement column, nozzles were put down and then pulled up without rotation. The next generation of jet grouting technology in Japan was known as the 'Kajima' method which named from

a Japanese company or the Column Jet Grout (CJG). This method consists of simultaneously pulling up and also rotating the rod in order to obtain a better quality cement-grout column. The lower part of the rod involves two nozzles which are used for injecting water and compressed air into the surrounding soil at the upper part and for ejecting cement grout at the lower part (Yahiro et al., 1974).

Since the 1980s, jet grouting has been applied as an effective geotechnical solution for foundations, tunnels, excavations and water barriers in Europe. With good results, this method has been popular in ground improvement work in European countries. Although there was a slow beginning in the early 1980s in United State of America, jet grouting has widely used as a practical and cost-effective geotechnical soil improvement method, especially in difficult situations such as ground-water barrier and slope stabilization. In South America countries, this technique has been common in soil improvement work.

The recent jet grouting technique can be categorized into three main systems including single, double and triple fluid. Corresponding to the fluids injected into the soil as grout, air and grout, and water plus air and grout, a suitable system can be selected. In application, jet grouting can be used for many purposes including cut-off walls, bottom plugs and tunnel canopies.

In this paper, reviewing of recent applications of jetgrouting in industrial zones such as Hoa Phat steel plant and Duyen Hai thermal power plant and tunneling projects (Hochiminh Metro Line 1 CP1a & CP1b) is carried out in order to obtain experiences and lessons for future infrastructure and industrial projects in Vietnam.

2. LARGE SOIL-CEMENT COLUMN (LSCC) TECHNIQUE

In jet-grouting technology, attempts for improving the jet grouting performance have been made by many manufactures including minimizing the curvature of the fluid conduit and/or modifying the work of nozzles from a single to a double and to a triple system in order to optimize the effectiveness of this ground improvement method. Figure 1 shows a state-of-the-art jet grouting technique with a triple system which has been used in Hochiminh Metro Line 1. By this, remoulding process and cementation of the soil are divided into two processes as follows: a high-velocity and high-pressured water is jetted into the surrounding soil

for separating the soil by a nozzle on the rod and the grout of water and cement is pumped afterward from a lower nozzle on the rod for cementing the surrounding soil.



Figure 1. LSCC rod used in Hochiminh Metro Line 1

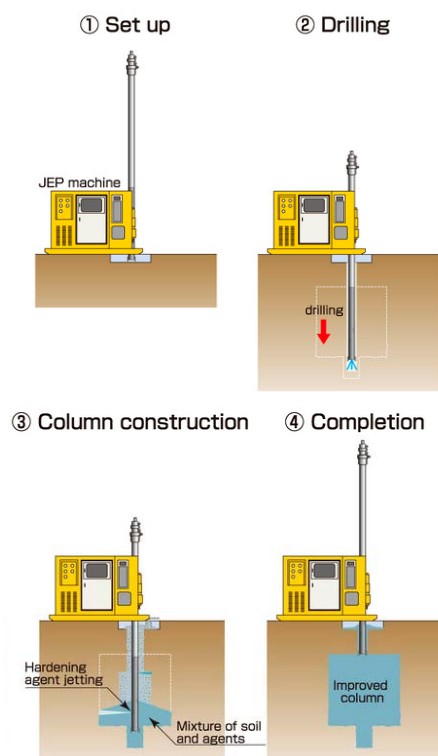


Figure 2. A typical sequence of Jet Grouting Work (Raito Company 2019)

A typical jet grouting sequence is shown in Figure 2. Firstly, jet grouting machine is located on the place determined previously. In the next step, the rod will be drilled to the depth estimated in the design. Then, the cement grout is pumped into the soil with high pressure in order to remould and cement the surrounding soil. Finally, jet-grouting to the top of the improved zone as designed and

continuously jet-grouting next piles. There are two sequences can be adopted, named “fresh in fresh” and “fresh in hard”, as can be seen in Figure 3, depending on application purposes. With the fresh-in-fresh sequence, new columns are constructed with short time intervals, without waiting for grout hardening. With the fresh-in-hard sequence, new column is built only after waiting for grout hardening of the previous columns.

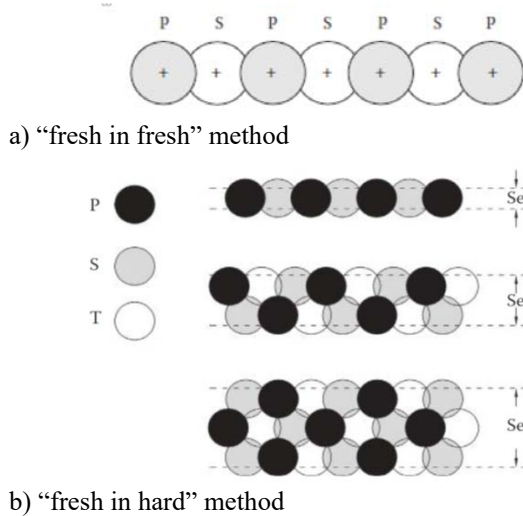


Figure 3. Sequence of jet grouting groups of overlapped columns (P, S and T, respectively, for primary, secondary and tertiary columns). (Croco, 2014)

In jet-grouting, the diameter of the jet grouting column varies with a large range from 0.5 m to 5 m and has a larger trend. The diameter of jet grouting column depends on geo-conditions and construction technology. Supporting with recent technology development, the jet grouting column diameter can reach extremely large diameters with

powerful pumps and efficient supply systems. A well-known “SuperJet” which can have a 5m diameter of jet grouting column (Yoshida et al., 1996) is an evidence.

In Vietnam, FECON Underground Construction Jsc. Company (FCU) in cooperation with Raito Kogyo Co.,Ltd, a company based in Japan, have developed a jet grouting technology with large diameters and higher strength of jet-grouting column namely as “Big Diameter Jet Grouting”. This technique is also called the large soil-cement column (LSCC) in this paper.

Comparing to conventional grouting methods, LSCC has many benefits in construction time, scope of soil improvement area, quality of jet grouting and less impact on existing structures. Firstly, the number of LSCC column is about 1/10 the number of conventional grouting methods in a particular jet grouting area. The soil improvement time thus is reduced significantly in total construction schedule of the project. The second advantage is the reduction of required grouting length for improving the foundation and/or ground areas. In experience, the required LSCC length only equals 1/18 to the required grouting length in conventional grouting methods. The other benefit is that the LSCC technique creates higher quality products than conventional methods. This is due to the thicker rod used in LSCC which has the higher rigidity. Thus, jet-grouting with LSCC is more accuracy. In LSCC technique, surrounding soil is cut into smaller pieces when two jets rotate and cross in the soil. Moreover, the LSCC method can limit impacts to existing pipelines because of large spaces between jet grouting holes (Raito, 2019).

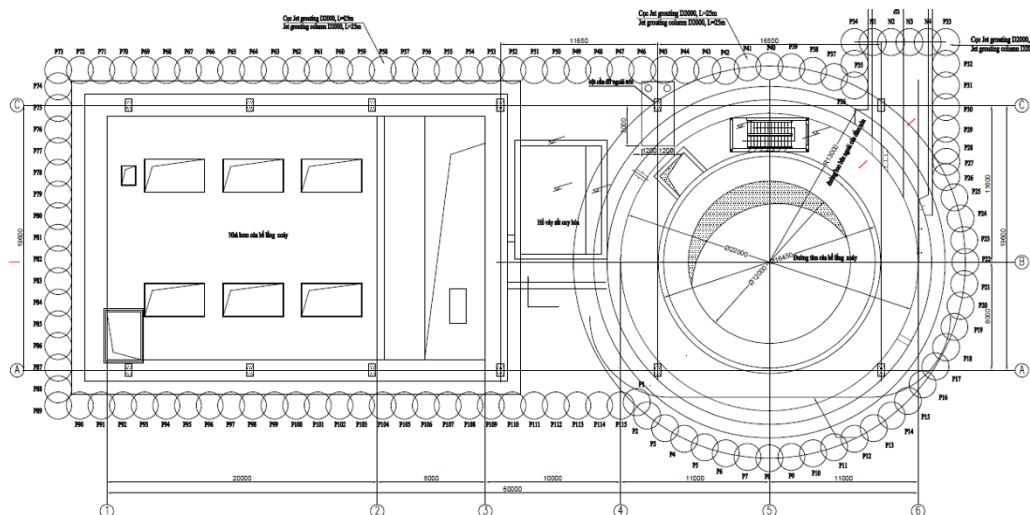


Figure 4. Jet grouting for a waste tank in Hoa Phat Dung Quat Iron and Steel Complex Project

3. APPLICATIONS IN INDUSTRIAL ZONES

3.1 At Hoa Phat steel plant project

Hoa Phat Dung Quat Iron and Steel Complex Project in Quang Ngai, Vietnam including a deep-water port system allows 200,000-ton ships to dock in order to transport materials and products. The project has been divided into two phases. The first phase was implemented in 24 months from February 2017 with a capacity of 1 million tons of long construction steel and 1 million tons of high quality long steel per year. The second phase of producing 2 million tons of hot rolled flat steel for mechanical engineering has been implemented from August 2017. The whole project is expected to complete and put into production in early of 2020.



Figure 5. Jet grouting work in Hoa Phat Dung Quat Iron and Steel Complex Project

The jet grouting carried out by FCU in this project was designed for reducing horizontal pressures on a retaining wall and waterproofing for a pit when constructing a waste tank as can be seen in Figure 4. There were 119 jet grouting piles constructed with the drilling depth of about 28.0 m and the grout jetting depth of about 25.0 m. All piles have a diameter of 2000 mm. In this project, the jetting pressure was about 40MPa with the rate of grouting 300 liters per minute, the rate of pulling rod was about 4 minutes per meter and the rate of pulling rod was from 10 to 20 rpm. The mixing proportion was 760 kg of PCB40 cement and 750 liters of water per cubic meter. The application of LSCC in this project shows that LSCC can be applied as a protect structure for minimizing damage on buildings.

3.1 At Duyen Hai 3 Thermal Power Plant

Duyen Hai 3 Thermal Power Plant is one of four power projects built at Duyen Hai Power Centre in Duyen Hai Town, Tra Vinh Province, Vietnam with a combined generation capacity of 4348 MW as outlined in the Vietnam's power development master plan between 2011 and 2020 with vision towards 2030. Figure 6 shows a jet grouting layout in this thermal power plant with a purpose of increasing strength and stability for surrounding soil at the bottom of a CW 3800 mm pipeline. 52 jet grouting piles with a diameter of 3000 mm were drilled to the depth of 28.0 m for improving length of 25.0 m as designed in Figure 7. The jetted grouting pressure was about 40 MPa, the discharge rate of slurry was about 300 liters per minute. The mixing proportion was 760 kg of PCB40 cement and 750 liters of water per cubic meter. The rod used in this project was a triple system with rotational speed of about 40rpm and pulling up rate of 7 mins/m. Figure 8 shows the jet grouting work carried out in the site.

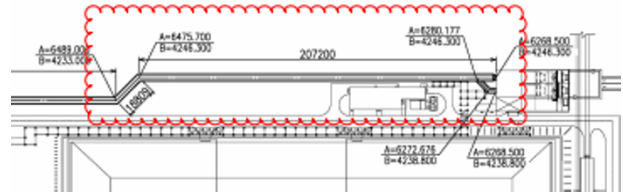


Figure 6. Location of jet grouting at Duyen Hai 3 thermal power plant

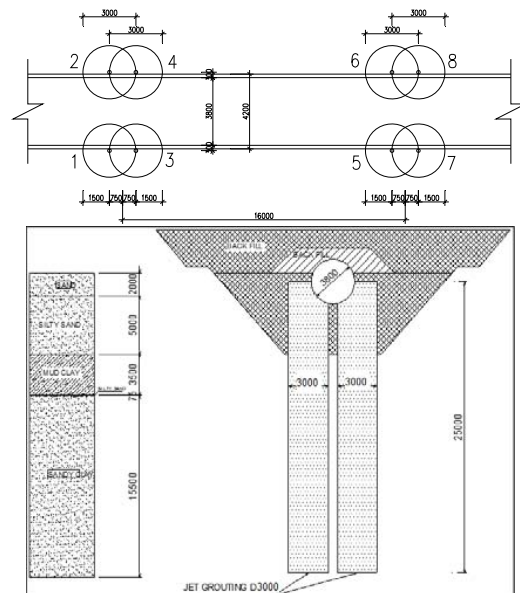


Figure 7. Layout of Jet Grouting underneath the existing CW pipe



Figure 8. Jet grouting work in Duyen Hai 3 Thermal Power Plant

4. APPLICATIONS IN HOCHIMINH METRO LINE 1 TUNNELLING PROJECT

Hochiminh Metro Line 1 is the first metro line in Vietnam with a length of 19.7 km including 2.6 km underground pass Ba Son shipyard and the Opera House crossing the Saigon River (Figure 9). The soil profile of the tunnel alignment comprises of Fill, Alluvium and Diluvium materials. The Fill layer of about 2 m is on the Alluvium layers of around 30 m including Soft Clayey Silt layer, Silty Fine Sand Layer 1 and Sand layer 2. The deeper layers are Diluvium clayey silt and silty sand layers. The tunnel was excavated by an Earth Pressure Balance Tunnel Boring Machine (EPB TBM) supplied by Shimizu Corporation in depths varying from 11 to 30 meters. The tunnel alignment passes a density area of Hochiminh city with soft soil conditions. Thus, the tunneling project might impact adjacent existing structures and buried infrastructure utilities. Meanwhile, requirements on settlements and other effects on existing buildings on the surface are strict. In the construction time, LSCC was applied in some sensitive locations and no serious damage was recorded. Looking back on LSCC applications in this project can obtain some lessons and experience for future tunnelling projects in Hanoi and Hochiminh city in Vietnam.

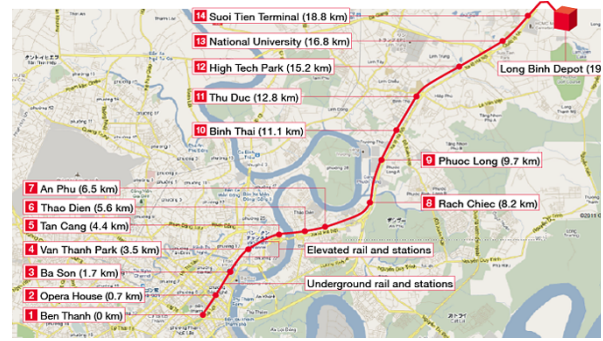


Figure 9. Hochiminh Metroline 1 project

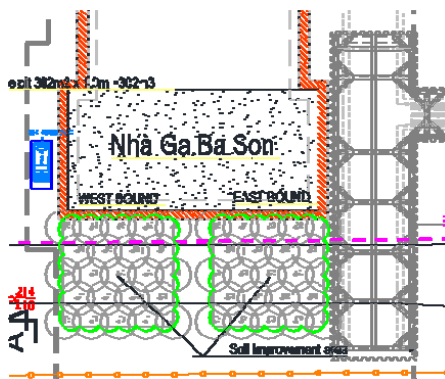
4.1 Applications of LSCC at arriving/launching shaft areas

In tunnelling, arriving/launching shaft areas exist a change from soil conditions to concrete structures, so unusual settlements can be observed in these areas. These settlements might lead to damages on the TBM and existing structures. When tunnelling closed to arriving/launching shafts, the overburden above the tunnel lining is shallow and has soft soil conditions. Risks of blow-out and fracturing can occur in tunnelling process and results in unexpected settlements of surrounding structures. In this paper, the applications of LSCC at arriving/launching shafts at Ba Son station and the Opera House station are reviewed.

Figure 10 shows the application of LSCC at the launching area at Ba Son station both for two tunnel lines. There are 23 jet grouting holes for East Bound and the same number of jet grouting holes for West Bound with a diameter of 3500 mm. The mixing proportion of jet grouting slurry was 760 kg PCB40 cement and 750 liters of water per cubic meter. The pumping pressure applied for injecting grout slurry into the soil was of about 40 MPa with the discharge rate of 300 liters/min. The jet grouting rod applied in this project was a triple type. The rod had a rotational speed of 12 rpm and the pulling up velocity of 9 mins/m.

Table 1. Design parameters of soil layers for jet grouting design at Saigon Municipal Opera House

Layer	Thickness (m)	Unit weight γ (kN/m ³)	N-value N	Cohesion c (kN/m ²)	Friction angle ϕ (deg.)	Young modulus αE_0 (kN/m ²)	Poisson's ratio ν	Coefficient of permeability k (m/sec)
Fill	1.1	18.0	1	0	28	2500	0.35	1x10 ⁻⁶
Ac2 and Ac3	1.7	16.0	1	14	0	10000	0.48	1x10 ⁻⁹
As1	13.9	19.5	6	0	31	16000	0.33	5x10 ⁻⁵
As2	17.0	19.5	13	0	31	35000	0.33	5x10 ⁻⁵
Dc	15.6	21.0	43	220	0	101000	0.45	1x10 ⁻¹⁰
Ds	-	21.0	31	0	34	77500	0.31	7x10 ⁻⁶

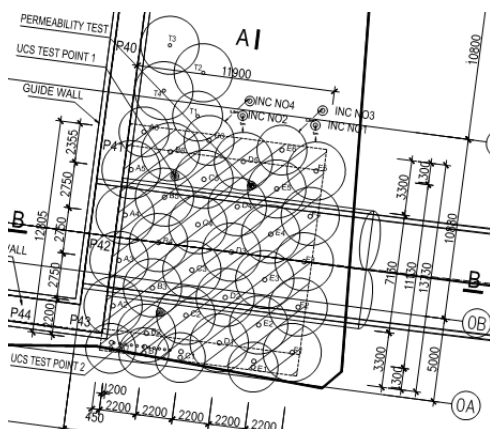


(a) Jet grouting plan



(b) Jet grouting site

Figure 10. Jet grouting at Ba Son Station

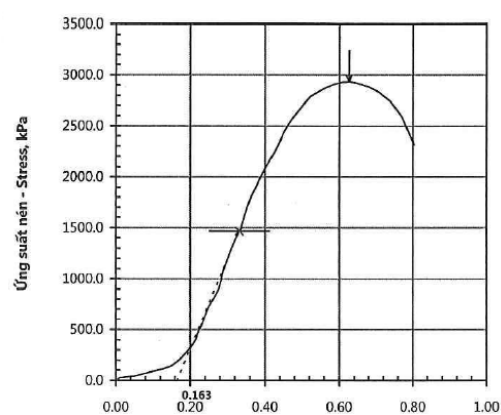


(a) Jet grouting layout



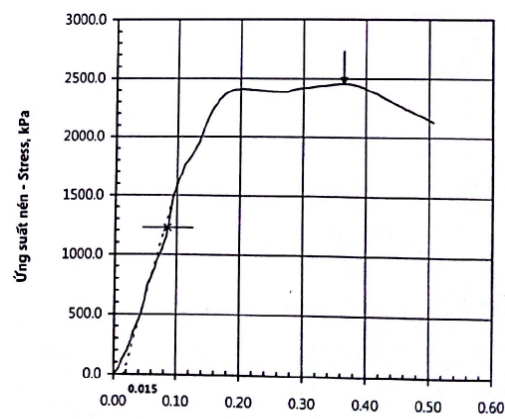
(b) Jet grouting site

Figure 11. Jet grouting at arrival area at Opera House Station Km 0+850.



Mode of failure	Cường độ kháng nén	q_u	2935.4 kPa
	Unconfined compressive strength		
	B. dạng khi phá hủy (đã hiệu chỉnh)	ϵ	0.463 %
	Strain at failure (corrected)		
	Môđun đàn hồi ở 50% q_u	$E_{s,50}$	870.2 MPa
	Secant modulus at 50% q_u		

(a) Unconfined compressive test after 7 days



Mode of failure	Cường độ kháng nén	q_u	2451.9 kPa
	Unconfined compressive strength		
	B. dạng khi phá hủy (đã hiệu chỉnh)	ϵ	0.350 %
	Strain at failure (corrected)		
	Môđun đàn hồi ở 50% q_u	$E_{s,50}$	1757.6 MPa
	Secant modulus at 50% q_u		

(b) a core sample after 14 days

Figure 12 Test results of a jet grouting column in Hochiminh Metro Line 1

Figure 11a shows a layout of LSCC for the arriving area at the Opera House Station. 27 jet grouting holes with the diameter of 3500 mm and 7 jet grouting holes with the diameter of 3000 mm were constructed in this area. For the mixing proportion, jet grouting slurry was also mixed continuously on site with the same mixing proportion of 760 kg PCB40 cement and 750 liters of water per cubic meter. The pumping pressure here was also of about 40 MPa with the discharge rate of about 300 liters/min. The triple rod was rotated with speeds of 12 rpm and 14 rpm and pulling up speeds of 9 mins/m and 7 mins/m for jet grouting diameters of 3500 and 3000 mm, respectively. Figure 11b shows jet grouting work at the construction site. Despite small air burbles appeared on the road surface when raining after jet grouting, no problem was recorded at the site. This can be explained by the existence of air in jet grouting areas. For soil displacement monitoring, 4 inclinometers (INC N01, INC N02, INC N03, INC N04) were set up as described in Figure 11a.

The results of sample tests for jet grouting columns are shown in Figure 12. There are unconfined compression tests after 7 days and core samples after 14 days. It can be seen that the unconfined compressive strength q_u of the jet grouting column can reach nearly 3000 kPa and secant modulus $E_{s,50}$ is near 870 MPa after 7 days. After 14 days, these values are about 2450 kPa and 1758 MPa, respectively. Based on our experience in ground improvement, these values are nearly double than values reaching by other soil improvement methods, especially by jet grouting with smaller diameters. It can be explained by the higher quality of LSCC in comparison to the soil improvement quality of jet grouting column with smaller diameters when using higher grout pressures and larger jet grouting diameter.

In the construction time at the Metro Line 1 in Hochiminh city, no damage at arriving/launching areas was observed. It shows that LSCC technique is an effective soil improvement solution at sensitive areas such as arriving/ launching areas when tunneling by the TBM in soft soil conditions.

4.2. Protection of historical buildings

The Saigon Municipal Opera House built from 1901 to 1911 is an important historical building in Hochiminh city. This building with an architectural style as the Opéra Garnier in Paris was designed by a French artist. The house has a main seating floor and two above seating levels with an

accommodating capable of 1800 people. Nowadays, the capacity of the opera house is 500 seats. Constructed on the soft soils, it was predicted that the opera house would have a large impact when tunnelling in this area in the case of no protection solution. Therefore, applying protection methods for preventing any damage on the house from tunnelling excavation is essential in the project. Table 1 describes geotechnical parameters for jet grouting at the Saigon Municipal Opera House. A “cut-off” wall built by LSCC technique with a role as a grout barrier for minimizing the ground displacement when tunnelling was proposed. In this case, the cut-off wall reduced the settlement induced by tunnelling. Moreover, this wall minimized the change of ground water under the Saigon Municipal Opera House foundation. Thus, the house was protected from impacts induced by tunnelling.

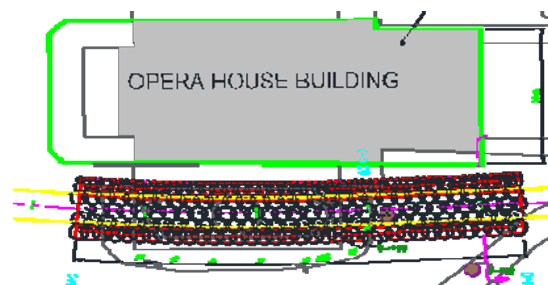


Figure 13. Jet Grouting layout for protecting the Saigon Opera House as a cut-off wall



Figure 14. Jet Grouting work at Saigon Opera House

Figure 13 shows a jet grouting layout at the Opera House area. 239 jet grouting holes including 66 holes with the diameter of 1400 mm, 47 holes with the diameter of 3000 mm, and 126 holes with the diameter of 3500 mm were built. The jet grouting layout shows advantages of the LSCC method. When improving large soil areas required high qualities of soil parameters such as cohesion,

friction angle values, LSCC is more effective than conventional methods with smaller jet grouting diameters due to significantly reducing the number of jet grouting holes. The construction time of improving soil decreases by this way.

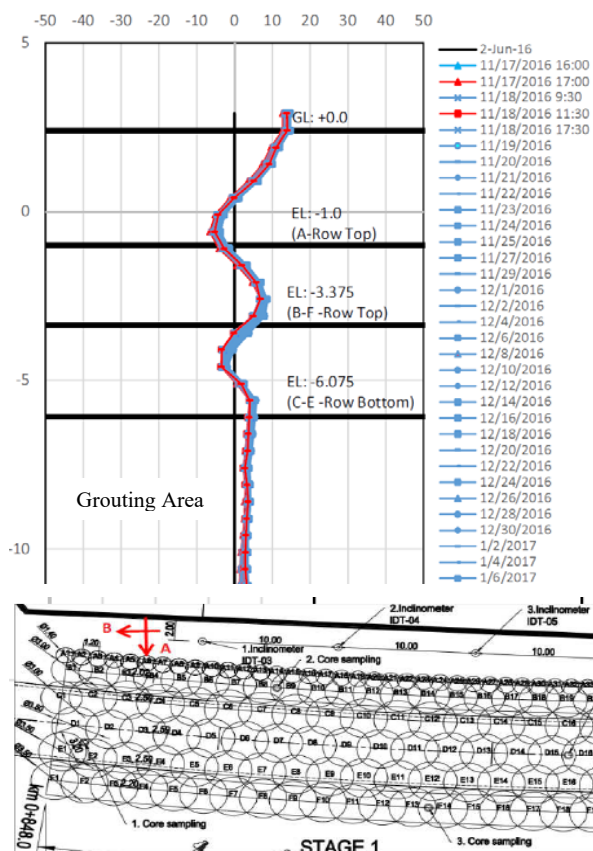


Figure 15. Observed cumulative deflection (mm) in Direction A at IDT-03 inclinometer

In this project, slurry was mixed continuously on site with the proportion of 760 kg PCB40 cement and 750 liters of water per cubic meter. The grout pumping pressure was of about 40 MPa with the discharge rate of about 300 liters/min. The triple rod had rotational speeds of 12rpm and 14rpm for diameter 3500- and 3000-mm holes, respectively. The rod was pulled up with velocities of 9 mins/m and 7 mins/m for jet grouting diameters 3500 and 3000 mm.

For monitoring ground displacements near the house, measuring instruments were installed behind the jet grouting wall. Four inclinometers for observing ground movements were set up in the distance from the jet grouting wall to the Saigon Municipal Opera House. Figure 15 shows the observed data from an inclinometer at the location of IDT-03. It can be seen that the ground displacement in the upper area without jet grouting is much larger than the ground displacement in the

jet grouting zone at deeper depths (below the level of about -6m). In detailed, the maximum displacement was about 15 mm in the A" direction at the soil area on the top of jet grouting column near the surface. In the grouted area, the maximum ground displacement was only about 5mm. These observation measurements show that using LSCC technique can reduce significantly impacts induced by tunnelling on existing buildings.

The tunnel excavation in Hochiminh Metro Line 1 has been successfully finished. With the small soil displacements observed behind the jet grouting wall, it means that LSCC technique applied in the project of Hochiminh Metro Line 1 as a "cut-off" wall protected the Saigon Municipal Opera House from influences induced by tunnelling.

5. CONCLUSIONS

Jet grouting technology with large diameter columns has been a common soil improvement method in the world with many advantages of high quality products, short construction time and economy benefits. Applications of LSCC in industrial zones such as Hoa Phat and Duyen Hai industrial projects have shown that this soil improvement technique can be applied as a supporting structure for reducing soil pressures on main structures and ground improvement. By reviewing applications in Hochiminh Metro Line 1 in Saigon Municipal Opera House protection and arriving/launching TBM areas, LSCC technique is an effective solution for minimizing influences induced by tunnelling in urban areas not only in tunnelling excavation but also in protection of existing buildings.

6. REFERENCES

- Croce, P., Flora, A. and Modoni, G. (2014). Jet grouting: technology, design and control. CRC Press.
- Raito (2019). www.raitoinc.com/technologies/jet-grouting/
- Yahiro, T., H. Yoshida, and K. Nishi. (1974). Soil improvement utilizing a high-speed waterjet and air jet. *Proceedings of the 6th Inter. Symp. on Water Jet Technology, Cambridge, UK*, August 30-31: 397-428.
- Yoshida, H., S. Jimbo, and S. Uesawa. (1996). Development and practical applications of large diameter soil improvement method, *Proceedings of the Conf. on Grouting and Deep Mixing, Tokyo, Japan*, May 14-17, 1996: 721-726.