3rd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering,
28-30 June 2012, Near East University, Nicosia, North Cyprus

Lateral Displacement of Temporary Retaining Wall as Jet Grouting Pile Installation in Singapore

Eun Chul Shin
Professor, Dept. of Civil & Environ. Engrg., Univ. of Incheon, Republic of Korea, ecshin@incheon.ac.kr

Young Jin Park
Ph.D. Student, Dept. of Civil & Environmental Engineering, University of Incheon, Republic of Korea

Jeong Jun Park
Research Professor, Dept. of Civil & Environmental Engineering, Univ. of Incheon, Republic of Korea

KEYWORDS: Jet grouting pile, lateral displacement, temporary retaining wall, earth pressure

ABSTRACT: The JGP(Jet Grouting Pile) installation works have been performed by following the designed parameters and the same work procedures which were used in the previous JGP work, particularly at the Block D in the Marina Coastal Expressway. However, the lateral displacement of temporary retaining wall was occurred at the installed depth from 22m to 24.5m. The characteristics of displacement at the Block D is different from that of the other already constructed retaining wall. It is influenced on the bending of retaining wall and the magnitude of displacement is somewhat over the control value. Therefore, we would like to find out the actual reasons through the investigation of the field construction and design related documents, especially soil boring data and designed parameters of each staged for JGP pile construction works. The results of detailed studies disclosed that the initial injection water pressure at the time of JGP installation and unrecoverable pressure, release of passive earth pressure due to excavation of underground soil and dewatering at the "Slip Road" construction site, are the main causes of lateral displacement of temporary retaining wall at the Block D.

1 INTRODUCTION

The site location and Block D section for the Jet Grouting Pile(JGP) work is shown in Figure 1. The JGP installation works have been performed by following the designed parameters and the same work procedures which were used in the previous JGP work, particularly at the Block D. However, the lateral displacement of temporary retaining wall was occurred at the installed depth from 22m to 24.5m. The characteristics of displacement at the Block D is different from that of the other already constructed retaining wall. It is influenced on the bending of retaining wall and the magnitude of displacement is somewhat over the control value. Therefore, we would like to find out the actual reasons through the investigation of the field construction and design related documents, especially soil boring data and designed parameters of each staged for JGP pile construction works and the investigation by the site visit.

Figure 2 shows the cross-section of pressure release pipe installation. The role of this pipe is reduced the residual pressure after stop working in Stage 1. The first of all, steel casing pipe with a diameter of 1,400mm was installed from the ground surface to the top of the upper improved layer, and drill the hole from the top of upper improved lay to the bottom of lower improved layer as shown in Figure 3. The hole made was filled up by the bentonite to release the pressure built up due to the formation of JGP (Personal communication with field engineers, 2011).

In this case tubular pipe's displacement is greater than that of the control value. JGP pile size and jet grouting pressure was reduced and monitoring the lateral displacement during the repetition of JGP piling work. Finally main purpose of this investigation is to fine out suitable installation method of JGP through analyzing of geotechnical conditions at the present JGP piling work site.

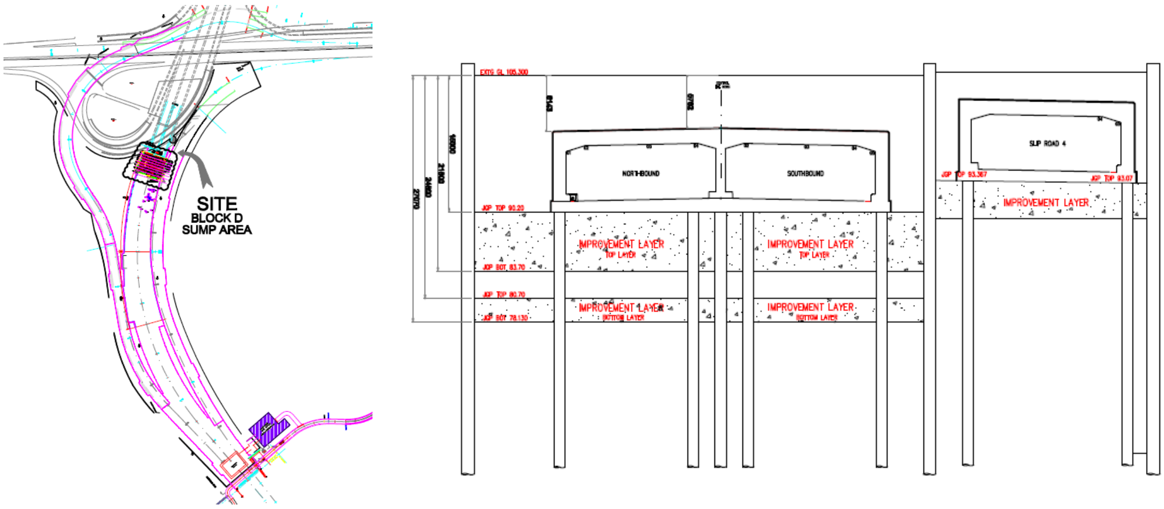

Figure 1. Site location and cross-section of JGP installation at Block D

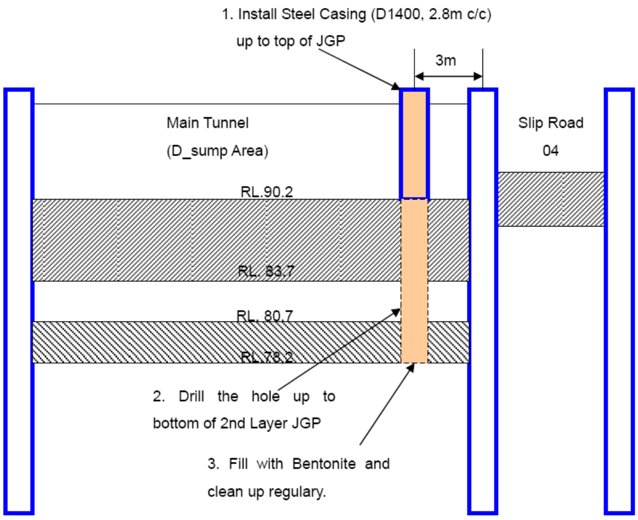

Figure 2. Installation of JGP pressure release pipe

2 METHOD AND SITUATIONS OF CONSTRUCTION

JGP is one type of soil improvement methods using by high pressure grout mix or water jetting that is using for breaking soil and mixing with original soil for forming of JGP pile in the ground.

JGP method is consisted of single tube, double tubes and triple tubes depending on the injection mechanism, equipment used and jet pressure. In this site, a double tube injection type was used that is injection with grout and air for cutting ground and rod is rotating/lifting up for forming of JGP pile. After the detail investigation of design drawing and field work condition, overall construction state can be described as below with consideration of field performance.

In this site, JGP method is being drilled into the below ground to reach the desire depth and injected high pressure air from the nozzle at the bottom part of double tube to break the ground as tabulated in Table 1. At that time, the rotation of rod per minute is 1 or 1.5 and withdrawing speed of rod is ranged of 3.2~8.3m/min. Base on these parameters, the diameters of JGP pile, φ2,000, φ1,500 and φ1,000mm are formed in the ground by following the working schedule, respectively.

Working process of each stage is described in Table 2, in working Stage 1(2011.1.1~2011.2.28), the casing was installed down to GL-14m by following the upper layer design specification to make a forming of JGP with 2,000mm diameter under the jetting pressure of 400 bar. The proposed design specification was both the upper layer with the casing installation depth of GL-14m and lower layer with casing installation depth of GL-24m.

However, from the working Stage 2(2011.4.8~2011.5.13), the casing was installed down to GL-14m and GL-24m by following the design specification. The diameter of JGP pile was reduced as 1,500mm under the jetting pressure of 300bar. The lateral displacement of retaining was observed continuously in spite of reduction of JGP pile diameter and the jetting pressure.

The lateral displacement was begun prior to installation of JGP pile(August 2010) by the observation of field instrumentation. So, intuitively, we recognized that engineering problems were occurred. Consequently the installation of JGP pile was stopped because the lateral displacement of the retaining wall was reached beyond the control limited value during the JGP piling work. Even if there was no JGP piling work, the lateral displacement was continued. Since then the JGP piling work was repeatedly continued and stopped with the analysis of field measurement of lateral displacement.

Based on the analysis of soil profile, the soil layers F1(Fluvial Sand, SPT N=15~50) and F2(Fluvial Clay, SPT N=0~20) are existed between upper improved layer and lower improved layer, that is, GL-21m~GL-24m. It was assumed that this layer is too hard enough to be cutted by air jetting. Therefore, the ground improvement work by JGP installation was separately proceeded at the upper layer and at the bottom layer, respectively. The occurrence of lateral displacement in between constructed JGP pile and original ground for Block D can be potentially notified by the prediction of stress potential.

Table 1. Design specification of JGP

Diameter of pile (mm)	2,000	1,500	1,000
Pile volume (m^3/m)	3.140	1.766	0.785
Injecting quantity (l/min)	300± 30	240± 24	196± 19
Water cement ratio	1:1	1:1	1:1
Injecting pressure (bar)	400± 40	300± 30	200± 20
Withdrawing rate (min/m)	8.3± 1	5.9± 1	3.2± 1
Diameter of nozzle (mm)	3.8	3.8	3.8

Table 2. JGP installation parameters with each stage for Block D

Stage	Period	JGP dia. (mm)	Pressure (bar)	Casing		
				Use	Depth	Specification
Stage 1	2011.1.1 ~2011.2.28	2,000	400	○	GL -14m	upper layer
Stage 2	2011.4.8 ~2011.5.13	1,500	300	○	GL -14m GL -24m	upper and lower layers
Stage 3	2011.5.21 ~present	1,000	200	○	GL -14m GL -24m	nearby measuring instrument
		1,500	300	○	GL -14m GL -24m	under construction

3 SOIL CONDITIONS AND FIELD MEASUREMENT AT THE SITE OF THE INCIDENT

The major drawing and the working condition of JGP installation which provided by the construction site office are investigated to figure out the main cause of the large displacement for Block D. The detailed results of technical investigation are described in the concluding remark.

The locations of soil boring holes(ABH-20, ABH-34) are shown in Figure 3. The soil stratification with the SPT-N value where the lateral displacement was happened is shown in Figure 4 with respect to the soil depth. The summary of soil characteristics and JGP ground improvement works are tabulated in Table 3.

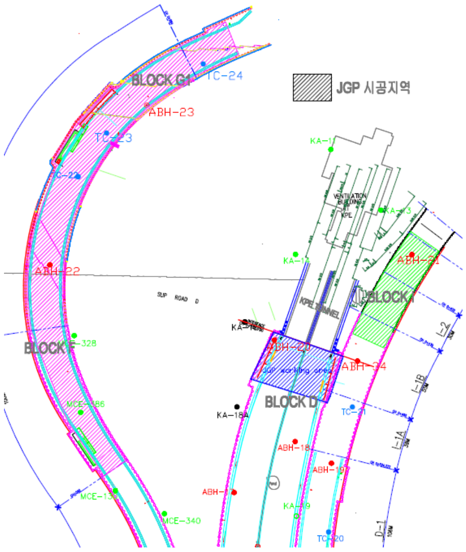

Figure 3. Location of soil boring holes

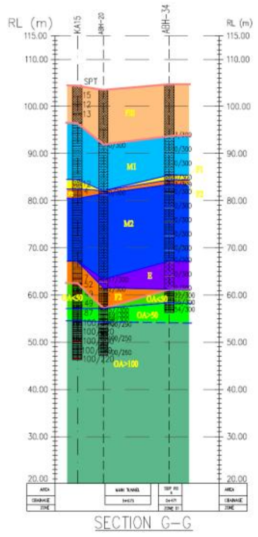

Figure 4. Soil profile for Block D

Table 3. Summary of soil characteristics and JGP ground improvement works

Block	Borehole No.	Improvement upper (GL.m)	Improvement Lower (GL.m)	Thickness (m)	Soil description	Soil type (BS)	SPT N value/mm
D	ABH 20	89.89	85.89	4.0	M1 very soft bluish grey clay	C	0/300 0/300 0/300
I	ABH 34	94.74	90.74	4.0	FILL & M1 very soft, greenish grey clay	MS & C	3/300 0/300
I	ABH 21	99.29	97.29	2.0	FILL medium stiff, very sandy silt	MS	6/300
F	ABH 22	90.84	85.28	5.56	FILL silty sand	SM	4/300, 23/300 10/300
F	TC 23	90.92	82.92	8.0	FILL Medium stiff, very sandy silt	MS	12/300, 6/300 11/300, 13/300 14/300, 11/300
F	ABH 23	90.93	85.47	5.47	FILL clayey sand	SC	8/300, 9/300 12/300, 12/300 2/300
G1	TC 24	86.5	77.0	9.5	FILL & M1 bluish grey clay	MS & C	11/300, 14/300 0/300

The field monitoring instrumentation was installed for both upper improvement layer and bottom improvement layer and the locations of instrumentation IW7I101 and IW7I103 to measure the lateral displacement as shown in Figure 5.

Table 4 describes the installation of field instrument and additional field instrument at Block D. The magnitudes of lateral displacement and the maximum lateral displacement with the relevant soil depth for each working stage are also presented in Table 4.

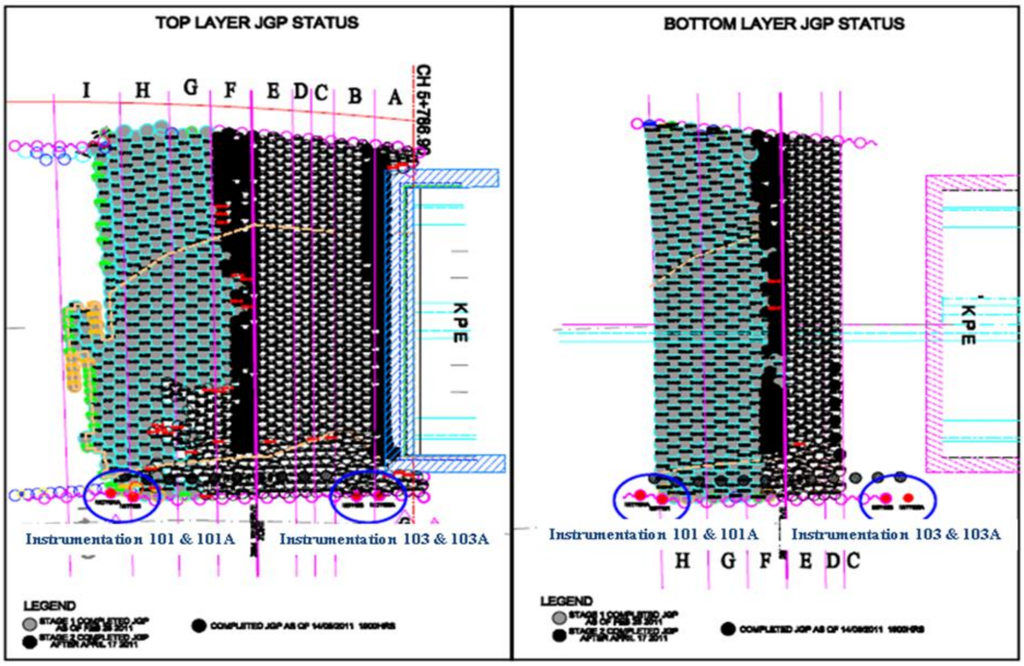

Figure 5. Location of field monitoring instrumentation at upper and bottom JGP improved layers

Table 4. Analysis field monitoring at Block D

Date	Detail work	IW7I101		IW7I101A		IW7I103		IW7I103A	
		Value (mm)	Max. dis. Depth(m)	Value (mm)	Max. dis. Depth(m)	Value (mm)	Max. dis. Depth(m)	Value (mm)	Max. dis. Depth(m)
2010.8.10	Monitoring	5.0	-			2.0			
2010.11.2	JGP before 2 month	11.2	23.0			4.7	22.0		
2011.1.1	Stage 1 work start	18.4	23.0			8.5	22.0		
2011.3.1	Stage 1 standby	74.6	24.0			56.9	22.0		
2011.4.8	Additional installation	120.9	24.0	0.9	33.5	106.9	24.5	0.0	0.0
2011.4.18	Stage 2 work start	120.2	24.0	1.1	0.5	106.1	24.5	1.7	4.5
2011.5.13	Stage 2 standby	122.6	24.0	2.8	12.0	145.4	24.0	30.0	24.0
2011.5.21	Stage 3 work start	122.0	24.0	4.1	9.5	138.9	24.0	23.8	24.5
2011.6.10	Stage 3 under const.	122.5	24.0	7.5	9.0	147.2	24.0	30.2	24.5

4 INFLUENCE OF EXCAVATION AND DEWATERING WORKS IN THE ADJACENT CONSTRUTION WORK SITE

The underground excavation work for the construction of the adjacent "Slip Road" construction work site as shown in right side of Figure 2 has been carried out prior to the launching of the JGP installation work at Block D.

This underground excavation work was influenced on the lateral displacement of temporary retaining wall. The evidence of this phenomenon can be seen from the field monitoring result of lateral displacement which is shown in Figure 6.

Figure 7 shows the plan view of the directions of lateral displacement in the temporary retaining wall. The results of field measurement with the elapsed time are listed in Appendix.

The all the directions of lateral displacement are toward to the one location, that is, "Slip Road" construction site. The JGP installation work was stopped on Feb. 28, 2011 due to the continuously increasing of lateral displacement of temporary retaining wall. However, Figure 6 indicates that the lateral displacement was further greatly increased with the elapsed time during the standby period of Feb. 28~April 18, 2011.

It is clearly shown that this trend of lateral displacement could be triggered by the external environment. Since the underground excavation work and dewatering work were preformed at the right adjacent "Slip Road" construction work site, the large lateral displacement is closely related to the performance of "Slip Road" construction work. The excavation of underground soil at Slip Road construction site could reduce the passive earth pressure to the temporary retaining wall.

The dewatering of underground water at the "Slip Road" construction site makes a high hydraulic gradient between the underground water level in the Block D site and that of "Slip Road" site. Therefore, the underground water flows to the direction of "Slip Road" site from the Block D site. The excavation of underground soil and dewatering of underground water at the "Slip Road" are the one of main reasons of the large lateral displacement of temporary retaining wall.

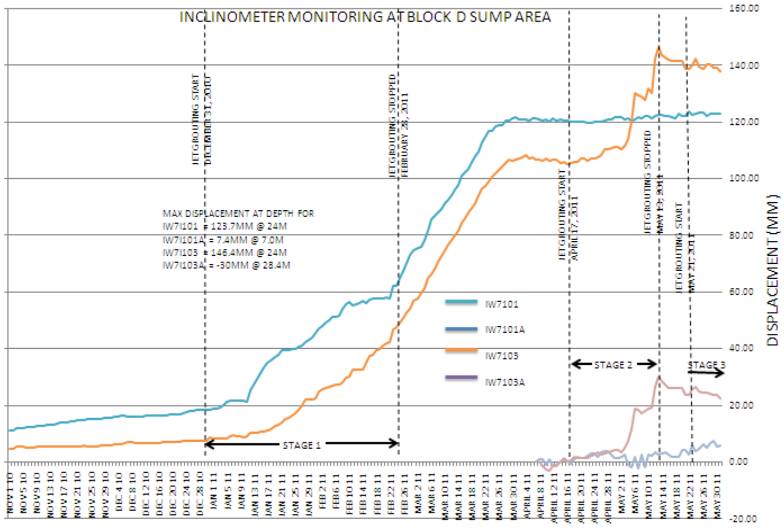

Figure 6. Inclinometer readings at Block D

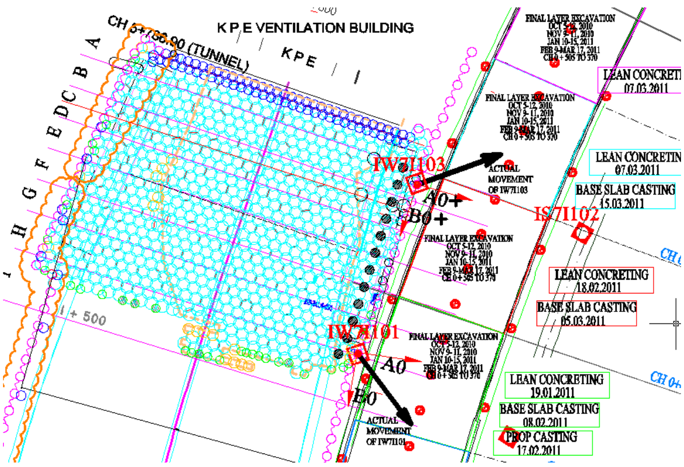

Figure 7. Direction of temporary retaining wall lateral displacement

5 CONCLUSIONS

With the analysis of field monitoring results for lateral displacement and the soil boring data, some engineering comments can be made. In the beginning of JGP installation work at the site, the earth pressure was built up at the interface between high jet pressurized water and soil ground (Brill et. al, 2003; Shirlaw, 2003). This mobilized water pressure is being continuously increased, then sometimes later this pressure could be greater than the shear strength of soil at the site. Thus, the soil is lost its shearing resistance. Simultaneously the pore space in between soil particles is fully saturated with water, and then pore water pressure is built up due to the reaction of jet water pressure in the pore of soil particles. So far forementioned reason, hydraulic fracture pressure could be generated by the injecting water during the installation of JGP pile in the very soft clay ground condition. The stiffness of soft clay for Block D has zero SPT-N value.

All things taken into account and also based on the geotechnical mechanism, the primary reason of lateral displacement is the soil condition of Block D that has the very low undrained shear strength of soft clay and high ground water level. The high injection water pressure during the installation of JGP is also influenced on the hydraulic fracturing of low bearing pressure of soft ground and this applied pressure on soft soil is beyond the shear strength of soil. The zone of ground relaxation was expanded and affected to the plastic collapse of soil. Thus, these mechanisms are the main caused of lateral displacement of the temporary retaining wall(steel pipe pile+sheet pile). It was noted that the ground displacements were inelastic and did not return to their original positions after completion of JGP works (Ho and Tan, 2003; Shibazaki, 2003) .

From the field monitoring results of lateral displacement of temporary retaining wall shown in Figure 7 and the directions of lateral displacement of temporary retaining wall shown in Figure 8 the lateral displacement of temporary retaining wall at the Block D was occurred by the release of passive earth pressure at the side of Slip Road construction site due to the excavation of underground soil and high hydraulic gradient between at the Block D site(high water level) and at the Slip Road site(low water level) due to dewatering of underground water at the Slip Road site.

REFERENCES

Brill, G.T., Burke, G.K. and Ringen, A.R. (2003) A Ten-Year Perspective of Jet Grouting: Advancements in Applications and Technology, Geotechnical Special Publication No. 120, Grouting and Ground Treatment, Proc. of The Third International Conference, New Orleans, Louisiana, published by ASCE, pp.218-235.

Ho, C.E. and Tan, C.G. (2003) Stabilization of Deep Open Excavations in Soft Soil by Jet Grouting, Geotechnical Special Publication No. 120, Grouting and Ground Treatment, Proc. of The Third International Conference, New Orleans, Louisiana, published by ASCE, pp.269-280.

Personal communication with field engineers (2011) JGP Installation Work for Singapore Marina Coastal Expressway C487 Block D.

Shibazaki, M. (2003) State of Practice of Jet Grouting, Geotechnical Special Publication No. 120, Grouting and Ground Treatment, Proc. of The Third International Conference, New Orleans, Louisiana, published by ASCE, pp.198-217.

Shirlaw, J. N. (2003) Jet Grouting Soft Clays for Tunneling and Deep Excavations - Design and Construction Issues, Geotechnical Special Publication No. 120, Grouting and Ground Treatment, Proc. of The Third International Conference, New Orleans, Louisiana, published by ASCE, pp.257-268.