Deep soil improvement technique using combined deep mixing and jet grouting method

Technique d'amélioration des sols combinant les méthodes de mélange des sols à grande profondeur et de Jet Grouting

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ABSTRACT

When dealing with deep soil improvement, there are two widely known methods, Deep Soil Mixing and Jet Grouting. The Combined Deep Mixing and Jet Grouting method (DMJG) is a relatively new technique integrating the two traditional methods into a single operation to form a solid treated column. This integration has resulted in a larger treatment column diameter, which could not be easily achieved by either of the conventional methods carried out individually. This advantage has led to a faster, cheaper and more efficient means of soil improvement. The construction procedure, treatment parameters and results of a case study in Singapore are presented in this paper.

RÉSUMÉ

Traditionnellement, les deux méthodes utilisées pour améliorer les sols à grandes profondeurs sont le mélange des sols à grande profondeur et le jet grouting. La méthode combinée de mélange des sols à grande profondeur et du jet grouting (DMJG) est une technique relativement nouvelle intégrant les deux méthodes traditionnelles en une seule opération pour former une colonne de sol renforcé. Cette technique permet l'obtention d'une colonne de sol traité de diamètre plus important qu'avec les deux méthodes traditionnelles. Ceci permet d'assurer une amélioration des sols plus rapide, moins onéreuse et plus efficace. La mise en place et l'utilisation de la méthode, les paramètres de traitement et les résultats d'une étude de cas à Singapour sont présentés dans cet article.

Keywords : soil improvement, deep soil mixing, jet grouting

1 INTRODUCTION

There are two widely known methods in dealing with deep soil improvement namely, Deep Soil Mixing and Jet Grouting. The Combined Deep Mixing and Jet Grouting Method (DMJG) is a relatively new technique integrating the two traditional methods into a single operation to form a solid treated column.

This paper presents the principle of DMJG technique and a case study of the New Nicoll Highway MRT Station project in Singapore, where the DMJG technique was applied. The diameter of the treatment column in this project is generally 2.8 m with treatment depth below existing ground surface ranging from 21 to 29 m at the main station area. The thickness of the DMJG treated columns varies from 3 to 5 m at the Entrance area and 7 m at the Main Station area. A total of 1374 columns of DMJG have been successfully installed in this project.

2 COMBINED DEEP MIXING AND JET GROUTING METHOD

DMJG is essentially an enhancement of the Deep Soil Mixing (DSM). The main advancement feature in this technique is the incorporation of double tube jet grouting system at the tip of the DSM auger.

In principal, the improvement process in this technique consists of drilling and mechanically mixing the in-situ soil with cementitious grout, while at the same time high pressure jet grout is discharged through the nozzle located at the auger tip.

Through integration of the two methods, the DMJG combines both advantages of DSM method and Jet Grouting method, which are homogenous treated soil mass and tight contact to existing structure. The integration also enables a larger diameter of improved column, which in turn increases the treatment productivity. In addition, it creates lesser heave problem compared to the conventional Jet Grouting due to bigger and stiffer rod which creating bigger pressure relief path.

2.1 *DMJG Improvement Mechanism*

As shown in Figure 1, the improvement mechanism of DMJG consists of a mechanical mixing part and a jet grouting part where high-pressure slurry is jetted into the in-situ soil.

The rod has a considerably large diameter of 457mm and it is stiffer compared to the traditional jet grouting rod of 200mm, which will provide better drilling verticality.

2.2 *Characteristic of DMJG*

The characteristic of DMJG lies in its mechanical part and jet grouting part. The characteristic of each part can be uniquely identified as follows:

Mechanical mixing part:

- Dual rotation auger mechanism, by which an auger and mixing blades turn in opposite directions at a high rotation rate, eliminates the problem of soil and mixing blade turn together, resulting in poor mixing. Through this special mixing mechanism, a homogenous product can be obtained.
- Auger and blades are attached to the high torque motor. It enables to treat wide range of soil types including hard soils.

Jet grouting part:

- High pressure jet of cement slurry cuts and breaks the in-situ soil bond and constructs a homogenous improved column.
- Treated soil mass follows the geometry of adjacent underground structures and contacts tightly to the surface due to blast effect of jetting.
- Very large diameter improvement can be achieved with the high pressure cement slurry jet discharged at the tip of large-diameter rotating blade.

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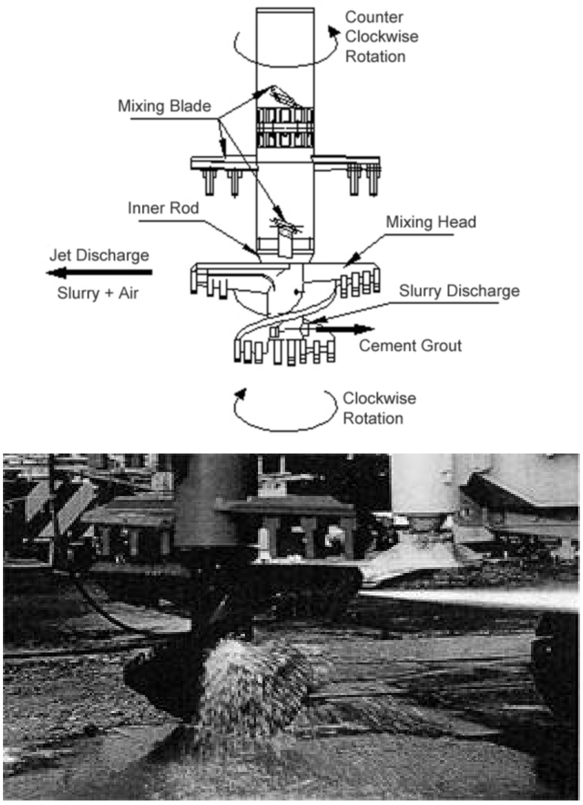

Figure 1. DMJG improvement mechanism (Raito Kogyo, 2005).

2.3 *DMJG Improvement Procedure*

In DMJG system, cement based hardening agent is discharged, mechanically mixed and churned with in-situ soil by rotating mixing blades, at the same time the cement slurry is jetted from the nozzle located at the tip of the mixing blade in order to form an outer collar part of the homogenous improved column mass.

As shown in Figure 2, DMJG procedure involves 5 main steps:

1. Penetration / Drilling
   The process starts with penetration through non improvement zone with discharging water only.
2. Cement Grout Injection and Mixing (Mechanical Part)
   Upon reaching the top of improvement zone, the cement slurry is discharged and the penetration is continued coupled with mechanical mixing of in-situ soil.

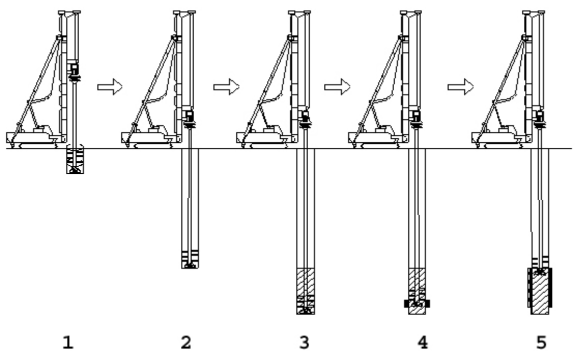

Figure 2. DMJG improvement procedure.

3. Churning
   When the treatment depth is reached, the slurry discharge is stopped. However, the mixing is continued for several minutes in order to get homogeneous blend of soil and cement slurry.
4. Withdrawal with Jetting and Mixing
   Process is then continued through withdrawing the drilling rod. Concurrently, the cement slurry is discharged through the jet nozzle.
5. Withdrawal with Mixing
   When the withdrawal reaches the top of improvement zone, the main parts of soil improvement process is completed. The remaining process is merely withdrawal of the drilling mast to the surface while discharging a small amount of slurry.

3 CASE STUDY

For the recent development of Singapore Mass Rapid Transport (MRT) Circle Line Phase 1, DMJG was utilized as the ground improvement method in C828 Project at the New Nicoll Highway (NCH) Station. The project was a new alignment replacing the previous NCH Station abandoned due to the infamous collapse in 2004. The DMJG was carried out by specialist contractor Raito Kogyo Co., Ltd. from Japan with a system called Ras-Jet. The application of DMJG in the project was a first application of the method on such a large scale in Singapore and possibly in South East Asia.

3.1 *Site Overview*

The main NCH Station is about 24m wide and 165m long excluding entrances and vent shafts. The sub-soil condition of the station is characterized by the presence of very thick (about 40m thick) poor alluvial soil comprising predominantly very soft marine clay (M-layer) inter-bedded with very soft estuarine/organic peaty clay (E-layer) and loose fluvial sand (F1-layer). These layers are underlain by medium weathered old alluvium (O-layer) with N-SPT value of more than 100.

The construction scheme adopted for the NCH Station was a top-down method with DMJG ground improvement. 1500 mm thick diaphragm wall was installed to support the station excavation and also as a permanent wall to the main station area. Strutted sheet pile wall system was utilized as a supporting system for the excavation of entrances as well as the vent shafts areas.

The excavation support system of the main station consists of 3-layers of temporary steel struts, permanent roof slab, concourse slab and 7m thick soil improvement layer (DMJG layer) underneath the permanent base slab.

3.2 *Detail of DMJG at NCH Station*

Through a series of detailed ground improvement trials carried out on the actual site of NCH Station, DMJG with total column diameter of 2.8m (including 1.6m diameter of mechanical part) was adopted for the actual treatment. The detail DMJG treatment parameters are shown in Table 1, whereas typical DMJG column arrangement is shown in Figure 3.

Consuming Ordinary Portland Cement of about 27,000 ton, a total of 1374 DMJG columns were constructed. 837 of them were installed in the main station area with the 7m thick improvement zone from 21.5 to 29.4m below ground level. The remaining columns were ranging from 3m to 5m thick and installed in the entrances and vent shafts area at shallower depth ranging from 12.5m to 17.5m.

Using 2 machines, the DMJG work was carried out from January 2006 to August 2006 with a peak productivity of 6 columns per day per machine in 24 hours operation.

Table 1. DMJG treatment parameters adopted in NCH Station.

Blade Diameter (Mechanical Part)	1,600 mm		
Column Diameter	2,800 mm		
Water Cement Ratio	100%		
Mechanical Mixing Part	**Cement Dosage**	**For E Layer**	600 kg/m^3
		For Other Layers	400 kg/m^3
	Number of Blade Cuts		400 times/m
Jet Grouting Part	**Slurry Discharge Rate**	**For F2 Layer**	300 L/min
		For Other Layers	300 L/min
	Withdrawal Speed	**For F2 Layer**	8 min/m
		For Other Layers	7 min/m

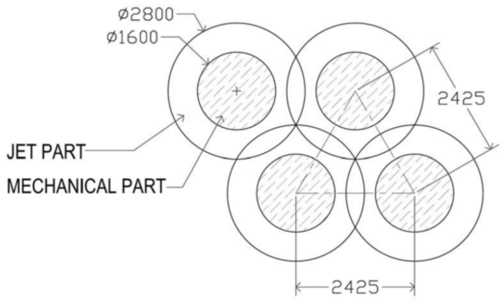

Figure 3. Typical DMJG column arrangement.

3.3 *Quality Control*

During the treatment process, the soil improvement quality was ensured through the utilization of computerized quality control system to monitor and record improvement depth, penetration and withdrawal rate, and slurry discharge rate at every meter of depth.

For the final product, i.e. treated soil uniformity and properties, an extensive coring and laboratory test regime were carried out for the mechanical part as well as the jet grouting part. Figure 4 illustrates the coring locations for both mechanical and jet grouting parts.

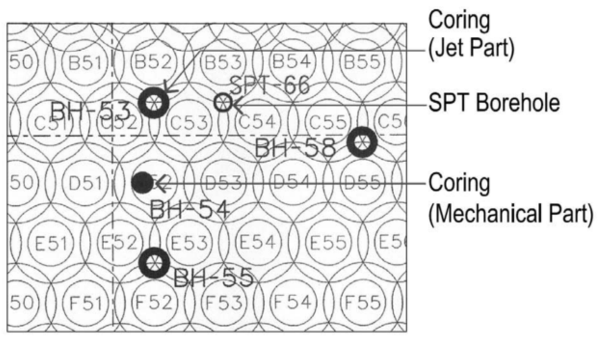

Figure 4. Coring locations of mechanical and jet grouting parts.

The quality of coring was examined in accordance to Singapore Land Transport Authority (LTA) material and workmanship (M&W) specification, which requires Total Core Recovery (TCR) to be minimum 85%. In addition, core samples were sent to laboratory for Unconfined Compression Test. The acceptance criteria were based on the design requirements that specified stiffness (E_{50}) of 90 MPa and Unconfined Compressive Strength (q_u) of 900 kPa at 28 days.

In total, the corings were carried out at 107 locations with 36 cores for the mechanical part and 71 cores for the jet grouting part. In addition, 87 boreholes of Standard Penetration Test (SPT) were also carried to provide in-situ strength check of the treated soil mass complying to LTA M&W Specification.

3.4 *DMJG Treatment Results*

The corings and laboratory tests results from the treated soil specimens had met all requirements of the soil improvement criteria. The results showed drastic improvement of the original soil properties. Table 2 presents the soil parameters comparison of before and after DMJG treatments.

Table 2. Soil properties comparison of before and after treatment.

	Original Soil Properties			
SOIL TYPE	**Depth (m)**	**Average c_u (kPa)**	**Average N-SPT (blows/300mm)**	**E_{50} (kPa)**
E	≥ 10	15 +1.2 (z-10)	0 ~ 1	300Cu
M	≥ 10	15 +1.2 (z-10)	0 ~ 1	300Cu
F1	≥ 10	N/A	3 ~ 17	1500N

	DMJG Treated Soil Properties			
SOIL TYPE	**Depth (m)**	**Average q_u (MPa)**	**Average N- SPT (blows/300mm)**	**Average E_{50} (MPa)**
E	≥ 10	2.8	> 100	390
M	≥ 10	3.8	> 100	548
F1	≥ 10	3.3	> 100	523

As shown in Figure 5 and 6, the laboratory tests of DMJG core samples show both mechanical part and jet grouting part share similar statistical trends in terms of strength represented by the Unconfined Compressive Strength (q_u) and stiffness (E_{50}). The mean of q_u and E_{50} for mechanical part are 3.89 MPa and 565 MPa, whereas for jet grouting part are 3.56 MPa and 544 MPa respectively.

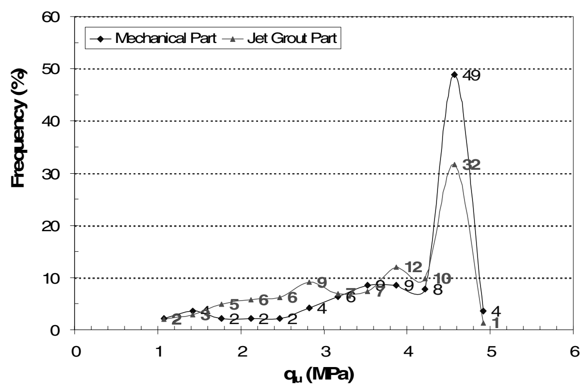

Figure 5. Statistical distribution of q_u of all DMJG core samples.

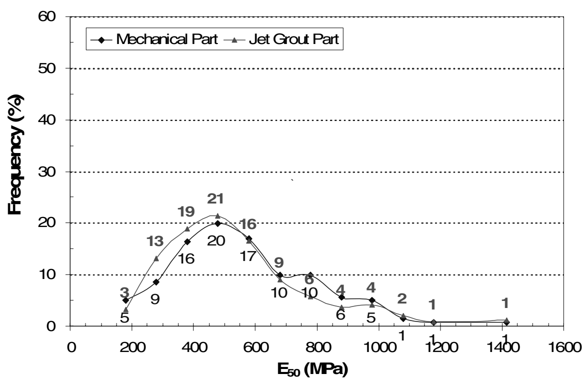

Figure 6. Statistical distribution of E_{50} (stiffness) of all DMJG core samples.

The correlation between compressive strength (q_u) and E_{50} is presented in Figure 7. After treatment, the soil stiffness increases to a range between 52.5 q_u to 187.5 q_u, with mean of 117.5 q_u + 119 MPa.

Similar to the strength and stiffness data of the improved materials, the core samples of mechanical part and jet grouting part also show a similar range of dry density, which varies from 0.9 to 1.35 Mg/m^3 as illustrated in Figure 8.

The coring and laboratory tests have provided evidence that both mechanical soil mixing part and jet grouting part provide similar treated soil properties. Therefore, the integration of the two methods in the DMJG are able to produce uniform treated soil mass.

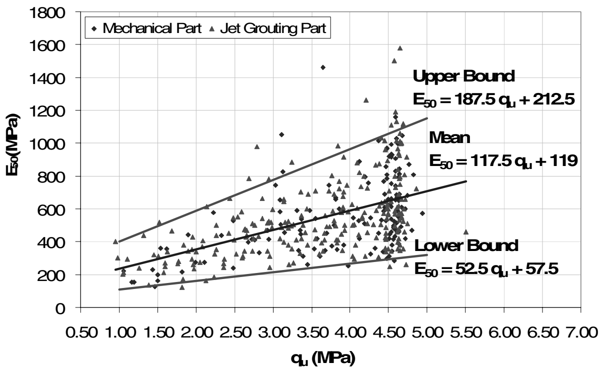

Figure 7. Correlation of q_u and E_{50} of all DMJG core samples.

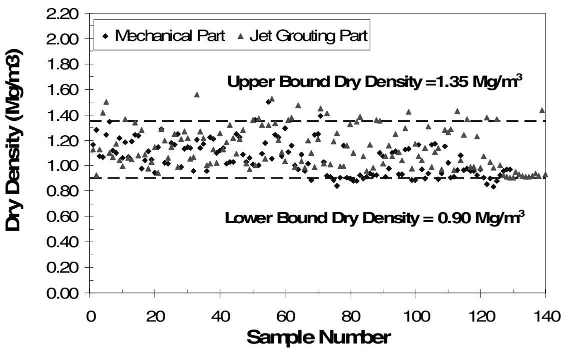

Figure 8. Dry density of all DMJG core samples.

4 CONCLUSION AND RECOMMENDATION

The conventional techniques of deep mixing and jet grouting have their own advantageous and disadvantageous. The integration of the two methods can combine the advantages of both techniques and reduce the disadvantageous technically and economically.

Based on the case study results, both mechanical mixing part and jet grouting part are able to produce reasonable treatment character similarities in terms of density, strength and stiffness, therefore the integration of these two deep soil improvement techniques can produce a solid combination and relatively better final product compared to the individual conventional techniques.

There are significant advantages in DMJG as compared to its conventional parent techniques. Firstly, it enables the field improvement works faster due to the bigger treated column diameter can be achieved, therefore the total number of DMJG treatment columns in one area is significantly less compared to conventional Jet Grout pile. Secondly, the DMJG is relatively cheaper as compared to the Jet Grouting method since the Deep Soil Mixing cost is normally much cheaper than Jet Grouting method for the same diameter of treated column.

DMJG gives better quality since the center of the treated column is more homogeneous compared to Jet Grout pile and the verticality of the treated column is more controllable, due to utilization of bigger and stiffer drilling rod than conventional Jet Grouting.

Comparing DMJG with conventional Jet Grouting for a similar treated column diameter, the quality of jet part in DMJG is reasonably better since the edge of the treated column of DMJG is closer to the jet nozzle compared to the conventional Jet Grouting. Therefore the density and the strength of the collar part of DMJG column produced by jet grouting part are higher than the perimeter of the conventional Jet Grout pile.

The disadvantage of this technique is on the equipment itself, which has not yet been standardized. Hence, a detailed trial test prior to the real application in a project is essential and the trial results should be evaluated in advance. However this problem can be mitigated with the provision and use of a comprehensive quality control specification such as the Singapore LTA M&W Specification, which enforces and details trial requirements prior to any actual improvement work.

As the product of DMJG is an unseen product buried deep underground, the quality control during operation and verification with coring check afterward plays a very important role. DMJG is a relatively new technique in Singapore, therefore there is no specific quality control standard governing it. So far the QA/QC for DMJG is adopted from Deep Mixing and Jet Grouting in LTA M&W Specification. For better quality verification on site, the corings at the boundary/perimeter between the Deep Mixing part and Jet Grouting part and at the center of the treated column are recommended. In addition, the criteria of the successful DMJG treatment should not be merely based on the TCR of the coring and Unconfined Compressive Strength / Elastic Modulus of laboratory test results, but it would be more meaningful to include the Rock Quality Designation (RQD) and Solid Core Recovery (SCR). Through these criteria, the quality of the soil-cement mixtures of the treated mass can be evaluated more accurately.

As the higher stiffness of the treated DMJG layer between the retaining wall will create higher bending moment and shear force of the wall, the mix-design of the cement content in DMJG needs to be done cautiously to ensure the final product of the treated soil stiffness does not exceed far beyond the required stiffness, so that the unexpected design complication can be avoided. It is recommended that a construction stiffness specification is given in a range of upper and lower bounds values instead of one specific lower bound value only.

Last but not least, the contractor who carries out DMJG should work with responsible attitude and the quality control supervisor, i.e. Qualified Person for Supervision has to work professionally adhering to the specified standards. Otherwise, the advantageous highlighted above will be meaningless.

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