JET GROUTING SOFT GROUND IMPROVEMENT TECHNIQUE FOR BUILDING FOUNDATION- A CASE STUDY, DHAKA, BANGLADESH

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ABSTRACT

Construction of road embankments, bridge approaches, retaining wall and building foundations on soft soil deposits is a major concern due to excessive settlement both in short term and long-term conditions. Wide ranges of ground improvement techniques (e.g., vertical drain, jet grouting, deep soil mixing, controlled modulus column, dynamic compaction, stone column, dynamic replacement) are preferred these days to mitigate these settlement problems, as conventional piling is expensive and in some cases are not feasible as well. Among all the ground improvement techniques, jet grouting is one of the most popular ground improvement techniques due to its applicability in almost all soil types.

Local Government Engineering Department (LGED) has taken a pilot project for a six storied primary school building (WAKUP Government primary school of Dristy Nandan project in Mirpur, Dhaka) foundation treatment using jet grouting columns. Three jet grout columns having approximately 1m diameter and 11m long were designed and constructed to carry a building column load. This project has investigated feasibility of jet grouting system as compared to the conventional pile for the building foundation. Bearing capacity and settlement is assessed from unconfined compressive strength (UCS) and modulus (E_s) of the jet grout coring samples after 28 days and 6 months curing. This paper presents some preliminary UCS and modulus results obtained from seven field cored samples, and assessed bearing capacity and settlement of the building foundation. Based on the UCS test results, it is found that jet grouting ground treatment has increased the allowable bearing capacity of untreated soil significantly and is in the range of 1 to 3MPa. The allowable design bearing capacity for the column load investigated was 1MPa. Hence, jet grout column foundation satisfied the bearing capacity requirements without pile foundation.

In addition to the bearing capacity, jet grout columns were also designed to satisfy 25mm settlement criteria for the building foundation. After the evaluation of the field cored samples, it was observed that cored samples were not retrieved after 6m depth of the jet grout columns due to the presence of cement-clay lumps. It is believed that this is due to the significant disturbance of jet grouting operation causing the machine stopped several times due to rain and other mechanical faults. Hence, a revised settlement analysis considering higher E_s values of the column as per Table 3 for the upper 6m and lower E_s values for the bottom 5m of cement-clay lumps is required. In the revised settlement analysis, building column's load distribution along the length of the jet grout column to be considered as well. Furthermore, detail design of load transfer platform (LTP) is underway, and a plate load test is planned to verify the bearing capacity and settlement of the jet grout foundation. This further investigation will ensure that the jet grout foundation can take a column load from six storied building.

Keywords: *Unconfined compressive strength, Elastic Modulus, jet grouting, bearing capacity, settlement*

1. INTRODUCTION

Construction of road embankments, bridge approaches, retaining wall and building foundations on soft soil deposits is a major concern due to excessive settlement both in short term and long-term conditions. Wide ranges of ground improvement techniques (e.g., consolidation and semi-rigid inclusion techniques) are preferred these days to mitigate these settlement problems, as conventional piling is expensive and in some cases are not feasible as well. Among all the ground improvement techniques, jet grouting is one of the most popular ground improvement techniques due to its applicability in almost all soil types. It is a sustainable and hazard free technology of soil improvement for new as well as old structure. The jet grouting method is frequently used to improve the soft ground in many parts of the world (e.g., Singapore, Malaysia, Thailand, Australia, Japan, USA, Europe etc.) especially in road construction, deep excavation, shield tunneling and foundation treatment in recent years (Cheng et al. 2017; Kamruzzaman, 2001; Kamruzzaman 2022; Kamruzzaman; 2023, Hiroaki et al. 2014). This technology is based on the high-velocity injection of one or greater fluids (single/double/triple tubes using cement grout, air, water) into the ground. In this system, the fluids are injected through small-diameter nozzles fitted at the bottom of the pipe. At first, the soil is drilled up to the desired depth of improvement, and then the pipe having small-diameter nozzles lifted at a constant speed and turned around the ground at the time of jet grouting until up to the ground surface. Finally, a treated soil-cement body is formed in the ground either as a "mass" or "column" with high strength and low compressibility foundation.

Jet grouting technique in Bangladesh is relatively new, in particular for building foundation treatment. Local Government Engineering Department (LGED) has taken a pilot project for a six storied primary school building (WAKUP Government primary school of Dristy Nandan project in Dhaka) foundation treatment using jet grouting columns. Double tube jet grouting method is used in this project to treat up to 11m of soft clay with organic content presence in layers. This project has investigated feasibility of jet grouting system as compared to the conventional pile for the building foundation. Bearing capacity and settlement is assessed from unconfined compressive strength (UCS) and modulus (E_s) of the jet grout coring samples after 28 days and 6 months curing using the method described in Kamruzzaman (2022, 2023) and Swedish Geotechnical Guide- SGF (1997). This paper presents some preliminary UCS and modulus results obtained from seven field cored samples, and assessed bearing capacity and settlement of the building foundation. Further studies including plate load test and as constructed columns/soil-cement behavior is on process, and will be presented elsewhere.

2. SOIL CONDITIONS

The Dhaka area is flat and close to the mean sea level. Two boreholes (BH) and one Cone Penetration Test (CPT) were carried out for this site as shown in Figure 1. Stratification of soil layer is shown in bore logs (BH) and Cone Penetration Test (CPT) plot respectively in Figure 2. From BH-01 and BH-02, generally soft silty Clay/clayey Silt with some organic and sand lenses materials are observed up to a depth of about 9m, and then the soil stratification changes to firm clayey Silt followed by medium dense to dense silty Sand up to the depth of 18m. The CPT plot is also showing similar trend of soft Clay layers followed by medium dense to dense silty Sand layers. A summary of shear strength properties at various depths is provided in Table 1.

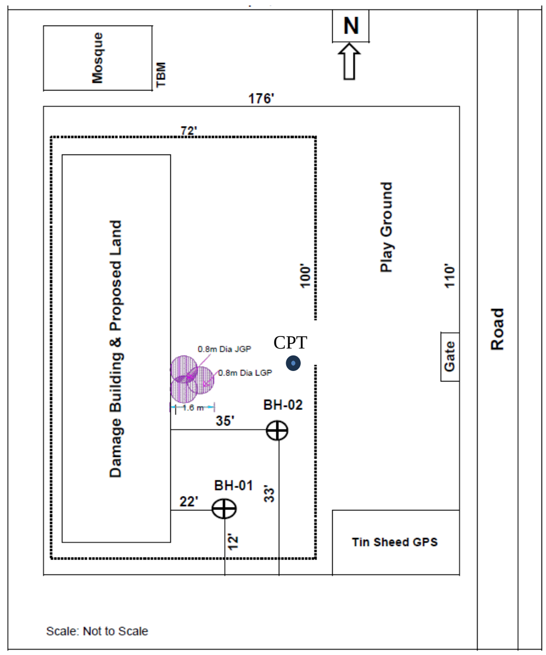

Figure 1: Borehole, CPT and JGP location

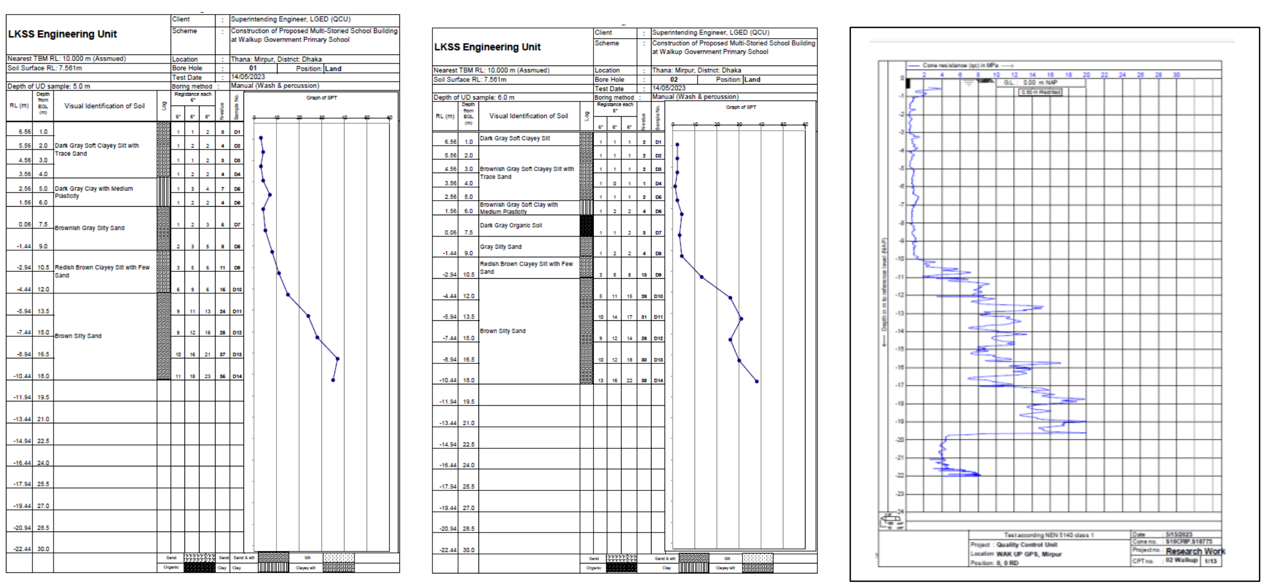

Figure 2: Borehole and CPT logs

Table 1. Shear strength properties of soil from CPT and SPT data

Soil Type	Thickness (m)	Undrained Shear Strength (kPa)	Cone resistance (qc) in MPa	Sleeve friction (fs) in MPa	SPT
Soft clayey Silt	1.0 – 5.0	10-30	0.4-0.7	0.01-0.03	02-04
Soft silty Clay with sand lenses	5.0 – 9.0	10-30	0.7-1.0	0.01-0.03	03-04
Firm clayey Silt	9.0 – 10.5	20-100	1.0-2.0	0.02-0.11	04-11
Medium dense to dense silty Sand	10.5 – 18	N/A	4.0-15.0	0.10-0.20	24-38

3. PROJECT DESCRIPTION

Dristy Nandan Project of LGED at Mirpur, Dhaka used in this study. Drishti Nandan scheme is under the Directorate of Primary Education, but Primary Education Infrastructure Development Wing of LGED is the implementing authority. The duration of the project is from January 2020 to December 2024, and about 356 schools in Dhaka city are planned to implement under this scheme by LGED. All 356 schools are being provided with foundations of six-story buildings each. Based on the soil conditions, pile foundations have been provided for almost every building in this project, which has increased the cost. Following the evaluation of geological condition and six storied building loading at the Mirpur site, ground improvement using jet grouting columns is considered for the details feasibility of the system, which is aimed to improve bearing capacity and mitigate both short term and long-term settlement of the foundation. Furthermore, jet grouting columns are proposed to reduce the cost of the foundation compared to the conventional pile foundation.

4. METHODOLOGY OF JET GROUTING

Double tube jet grouting system as shown in Figure 4 is used in this project. The jet grouting method utilizes a high-pressured grout slurry to erode and mix in-situ soil to form soil-cement mixture columns with a diameter up to approximately 2m (Kamruzzaman, 2001; Makovetskiy, 2016; Nikbakhtan and Osanloo, 2009). The main characteristics of double nozzle jet grout system and its influence on the mechanical characteristics of soilcrete are highlighted in Figure 4. According to Sarkar et al. (2022), the double fluid system is quite like a single system. The only variation is to add an air cover to the grout jet. By adding air to the grout jet, the cutting energy is increased to allow a higher distance to erode, mainly if there is no water table. Table 2 summarizes the jet grouting operating parameters for the double-tube grouting system used in this project.

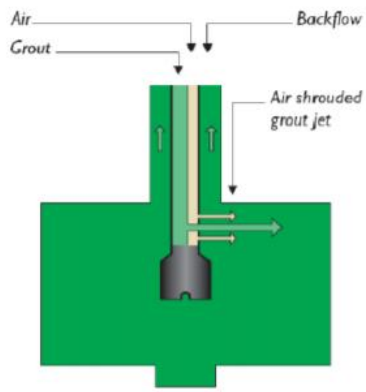

Figure 4: Double fluid system (K.G. GmbH, 2002)

Table 2. Jet grouting operating parameters for the double-tube grouting system

Parameter	Unit	Value	Parameter	Unit	Value
Grout pressure	MPa	22 – 25	Grout flow rate	l/min	
Air pressure	MPa	0.7 – 0.7	Cement	bags	64 (800kg/m^3)
Lifting speed	cm/min	12 – 15	W: C	….	1:1
Water pressure	MPa	8 – 10	Grouting density	t/m^3	

Using the above jet grout parameters, 11m long and approximately 1 m diameter columns with 100mm overlapped were constructed and they are shown in Figure 5. The columns were constructed in a triangular pattern, and at least 0.5m were socketed into the medium dense to dense sandy materials as recommended in many overseas projects (e.g. Kamruzzaman et al. 2023).

Figure 5: Three Jet Grouted Columns (11m long, approximately 1m diameter and 100mm overlapped)

4.1 Design of Jet Grout Column for Building Foundation

Jet grout columns are designed as an improved soil-cement mass, and is in accordance with Kamruzzaman et al. (2023), Kamruzzaman (2022) and SGF (1997). Unconfined compressive strength (q_u) of 1MPa and elastic modulus (E_s) of 150MPa in 28days curing (using the relationship of $E_s = 150\ q_u$) are used for the targeted 25mm settlement of the foundation. In the 1-D settlement calculation, jet grouted improved soil-cement mass is considered to act as a drain element in accordance with many literatures review (Kamruzzaman et al, 2009, Chew et al, 2004, Bergado 1996), and thus primary settlement is expected to occur within the first 3months of the construction. No creep settlement of the jet grout columns is also expected as it works as a drain and elastic mass.

Upon completion of the jet grout columns and at least after 28days of curing, a load transfer platform (LTP) is also to be constructed to transfer the building column load uniformly on the jet grout mass. A preliminary design of LTP considered 500mm thick well graded select fill materials along with 300kN/m high strength geofabric. Detail design of LTP is yet to be completed.

4.2 Strength and modulus determination from field jet grout cored samples

Field coring samples were collected from the site after 28days and 6months of curing using 73mm diameter core barrel as shown in Figure 6. Following the coring, the samples were kept in a wooden box to maintain the field moisture content of the jet grout samples. Keeping the moisture content constant for the jet grout samples are critical as it affects significantly on the UCS results. The UCS samples were then prepared in the laboratory and tested in accordance with ASTM D2166 for the determination of q_u and E_s.

Figure 6: Core sample collection using core drill and sampling method

Unconfined compressive strength (q_u) and modulus of elasticity (E_s) are the two critical parameters that must be evaluated in jet grouting applications as mentioned by many researchers (e.g. Sarkar et al, 2022; Kamruzzaman, 2001; Kamruzzaman et al. 2019; JJGA 2017; Hiroaki et al. 2014). However, because of soil heterogeneity and variability of jet-grouting controlling parameters, good core recovery and determining q_u and E_s are complex. The field cored samples were prepared in the lab from two columns and seven UCS tests were completed. Following the cored samples from two columns and subsequent UCS testing results, third column was not cored as results from two columns were very similar. Typical UCS test results of a cored jet grout sample and test setup is shown in Figure 7. Elastic modulus (E_s) is determined from the stress-strain plot of the UCS test results. Local Government Engineering Department laboratory has provided all unconfined compressive strength (UCS) test results.

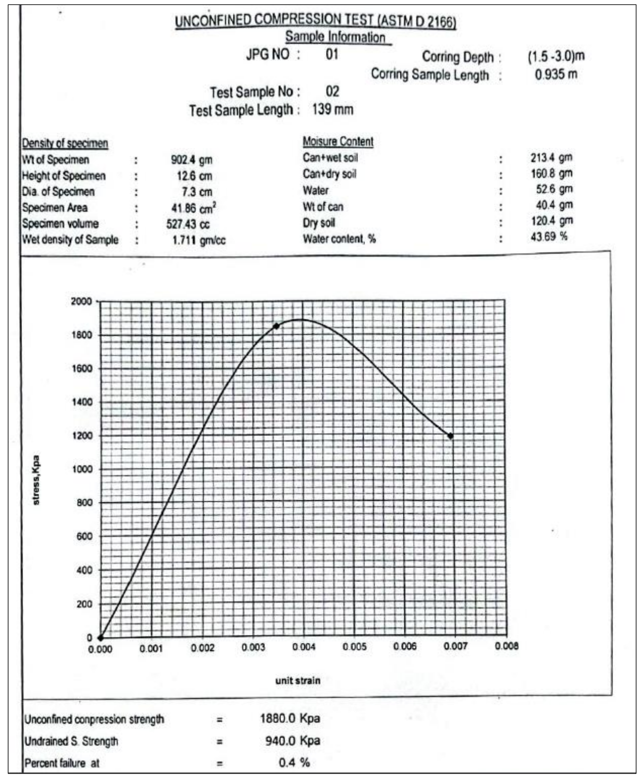

Figure. 7 Typical unconfined compressive strength test of cored jet grout sample in the laboratory

5. RESULTS AND DISCUSSIONS

Unconfined compressive strength (q_u) and modulus of elasticity (E_s) values along with other sample parameters from two columns (column 1 and 2) are presented in Table 3 below. As can be seen, all test results exceeded the design strength and modulus requirements (q_u = 1MPa and E_s = 150MPa). Literature review suggests that, over the time both q_u and E_s are going to increase due to curing effect and the pozzolanic reaction between cement and clay (Kamruzzaman et al. 2022; Kamruzzaman 2001; Hayashi et al. 2003; Ikegami et al. 2005). It should be noted that cored samples were not retrieved after 6m depth of the jet grout columns due to the presence of cement-clay lumps. It is believed that this is due to the significant disturbance of jet grouting operation at site causing the machine stopped several times due to rain and other mechanical faults. Hence, a revised settlement analysis considering higher E_s values as per Table 3 for the upper 6m jet grout columns and lower E_s values for the bottom 5m of clay-cement lumps is required. In the revised settlement analysis, building column's load distribution along the length of the jet grout column to be considered as well. Additionally, a load test is planned to conduct for the verification of bearing capacity and settlement of the jet grout foundation.

Figure 8 shows UCS results of Japanese soil developed by JJGA (Japan Jet Grout Association). As can be seen, for clayey Dhaka soil, UCS results of the jet grout samples are within the Japanese practice. According to the JJGA specification, majority of the UCS values are ranging from 1 to 4MPa for clayey soil. Results from the current study also ranges from 1.3 to 3.5MPa.

Table 3. Unconfind compression strength and elastic modulus results at 6 months curing

Scenario No	Jet Grout Pile No.	Coring Depth (m)	Coring Sample Length	Test sample Number	Test sample Length(mm)	Moisture Content (%)	Wet Unit Weight (gm/cc)	Unconfind Compression Strength (MPa)	Modulus of Elasticity (MPa)
1	JPG No 1	1.5-3.0	0.935	01	146	39	1.809	1.32	480.0
2	JPG No 1	1.5-3.0	0.935	02	139	44	1.711	1.88	600.0
3	JPG No 1	0.0-1.5	0.900	01	200	45	1.765	2.7	250.0
4	JPG No 1	0.0-1.5	0.900	02	245	33	1.707	3.5	225.0
5	JPG No 1	0.0-1.5	0.900	03	125	40	1.748	2.45	500.0
6	JPG No 2	1.5-3.0	1.17	02	145	23	1.756	3.2[1]	420.0
7	JPG No 2	3.0-4.5	0.970	03	145	33	1.694	1.8[1]	195.0

Note: 1. 28 days curing

As per the JJGA guideline, the jet grouting system is a double tube nozzle system, and cement quantity used was 750 kg/m^3. For this study, with a double tube nozzle system, 800 kg/m^3 cement was used. Following the results from Table 3 and comparing from JJGA practice, it is expected that a lower cement content with a double nozzle system can be used in Dhaka Clayey soil to meet the strength and deformation requirements of the jet grout samples. A field trial along with foundation load must be assesed before confirming this cement doses.

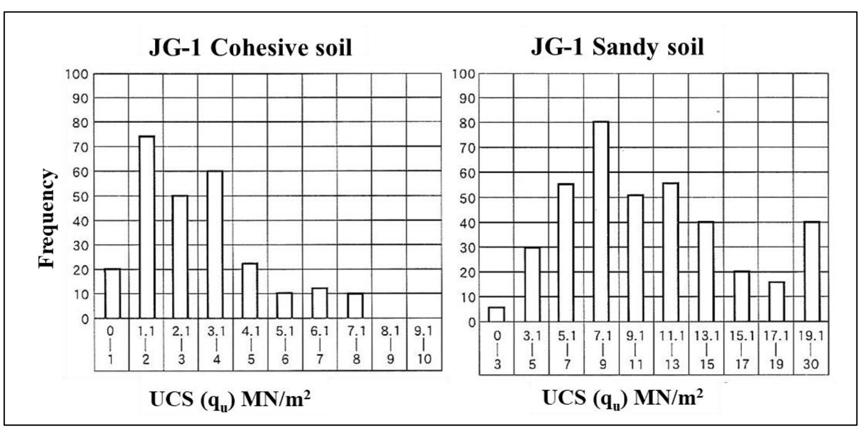

Figure 8: UCS for clayey soil of Japanese soil developed by JJGA (Japan Jet Grout Association).

6. CONCLUSIONS

Local Government Engineering Department (LGED) has taken a pilot project for a six storied primary school building (Wak-Up Government primary school of Dristy Nandan project in Mirpur, Dhaka) foundation treatment using jet grouting columns. Three jet grout columns having approximately 1m diameter and 11m long were designed and constructed to carry a building column load. This project has investigated feasibility of jet grouting system as compared to the conventional pile for the building foundation. Bearing capacity and settlement is assessed from unconfined compressive strength (UCS) and modulus (E_s) of the jet grout coring samples after 28 days and 6 months curing. This paper presents some preliminary UCS and modulus results obtained from seven field cored samples, and assessed bearing capacity and settlement of the building foundation. The following conclusions are made from this study:

- Undrained shear strength of untreated clay at the Wak-Up Government Primary School site is about 20kPa (i.e., UCS and allowable bearing capacity of about 40kPa). Without ground treatment or pile foundation, a six storied building would not be constructed on this ground. Jet grouting ground treatment has increased the bearing capacity significantly and is in the range of 1 to 3MPa. The design bearing capacity for the column load investigated was 1MPa. Hence, jet grout column foundation satisfied the bearing capacity requirements without pile foundation.

- In addition to the bearing capacity, jet grout columns were also designed to satisfy 25mm settlement criteria for the building foundation. After the evaluation of the field cored samples, it was observed that cored samples were not retrieved after 6m depth of the jet grout columns due to the presence of cement-clay lumps. It is believed that this is due to the significant disturbance of jet grouting operation causing the machine stopped several times due to rain and other mechanical faults. Hence, a revised settlement analysis considering higher E_s values of the column as per Table 3 for the upper 6m and lower E_s values for the bottom 5m of cement-clay lumps is required. In the revised settlement analysis, building column's load distribution along the length of the jet grout column to be considered as well.

- Detail design of load transfer platform (LTP) is underway, and a plate load test is planned to verify the bearing capacity and settlement of the jet grout foundation. This will ensure that the jet grout foundation can take a column load from six storied building.

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