The Evaluation of Stone Column and Jet Grouting Soil Improvement by Conducting a Comprehensive Experimental Program

Arshiya Abadkon and Erol Güler

Abstract Ground improvement is an important requirement in today‘s construction industry as land reclamation is becoming increasingly popular. Many different ground improvement techniques have been developed over the past few decades to treat weak soil deposits. Two of commonly used techniques are jet grouting and vibro-stone column. The goal of this study is to investigate the advantages and disadvantages of both techniques using in-situ tests such as cone penetration testing, standard penetration testing, seismic wave velocity measurements and laboratory tests including direct shear tests, density and void ratio measurements on undisturbed samples obtained from the soil between produced columns. A test area including 25 jet grout columns with 1.8 m spacing and diameter of 60 cm was prepared to investigate the effectiveness of jet grouting method. A test area with same dimensions as it was for jet grout columns was prepared for stone columns. 25 stone columns with diameter of 1 m and spacing of 1.8 m were produced in the test area. Vibroflotation technique was used to produce stone column with top feeding method. In-situ and laboratory tests were carried out for these test areas to investigate the advantages and disadvantages of both techniques. The most important result obtained from in-situ tests was the better improvement of soil mass between stone columns than that of jet grout columns which plays a key role in reducing seismic risks and liquefaction hazards. Laboratory tests on undisturbed samples obtained from the soil between produced stone columns and jet grout columns also approved the findings from in-situ tests.

Keywords Ground improvement · Field study · Stone column · Jet-grout columns

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1 Introduction

Ground improvement is an important requirement in today's construction industry as land reclamation is becoming increasingly popular. Many different ground improvement techniques have been developed over the past few decades to treat weak soil deposits [1]. Two of commonly used techniques are the installation of jet grout columns and vibro-stone columns. Jet grouting soil improvement method was used since early 1970s. The technique of jet grouting uses high pressure/velocity jet fluids to erode the existing soil and then to mix the cuttings with cement slurry to form soilcrete columns. It is effective across the widest range of soil types of any grouting system. However, if the native soil is not completely mixed with slurry the resulting columns will have soil inclusions which can reduce the strength of the column. Also the achieved diameter of the column depends on the soil type and density of the soil [2].

Stone column method refers to columns of compacted, gravel size stone particles constructed vertically in the ground to improve the performance of soft or loose soils. This technique was invented in Germany in the early 1960s and is possibly the most natural foundation system in existence as it consists entirely of a gravel column that is formed in the subsoil. In addition stone columns are also more durable than most of the other soil improvement systems which involve use of cement or steel (Barksdale and Bachus 1983).

The goal of this study is to investigate the advantages and disadvantages of both techniques using in-situ tests such as cone penetration testing, standard penetration testing, seismic wave velocity measurements and laboratory tests including direct shear tests, density and void ratio measurements on undisturbed samples obtained from the soil between produced columns. Since there is liquefaction risk on this site, these evaluations were crucial. Literature cites that jet-grout columns can mitigate liquefaction risk [3]. Still the Engineer had several questions regarding the effectiveness of jet grouting techniques especially in seismic areas. In this paper seismic test results are also presented for stone column soil improvement technique.

2 Experimental Study

Experimental program in this study was conducted during soil improvement works of Ashgabat International Airport Project in Turkmenistan. Existing soil at the side consisted of mostly loose silty sand with thin clay layers. Due to weak soil conditions bearing capacity and settlement problems were foreseen during geotechnical evaluation of the project for structures transferring high loads to the ground such as Main Terminal, Cargo Terminal, Aircraft Hangars and etc. In addition, because of the cohesionless structure of the existing soil and high groundwater level liquefaction risk at the site was very high. Therefore, jet grout columns with 16 m length and 0.6 m diameter and stone columns with 16 m length and 0.8 m diameter were designed to remove the mentioned risks for the soils below the foundation of the

Table 1 Existing soil profile at test site

Depth (m)	Soil type
0–4.5	Silty sand
4.5–7.5	Lean clay
7.5–12.0	Silty sand
12.0–13.5	Lean clay
13.5–16.0	Silty sand

structures. Experimental study was carried out based on details provided by the alternative designs for the same site. Two test areas in the same region was established and in-situ and laboratory tests for the test areas including jet grout and stone columns were conducted. The existing soil profile at test areas is shown in Table 1. Both test areas have dimensions of 7 × 7 m, each including 25 columns with spacing of 1.8 × 1.8 m.

2.1 Experimental Study for Jet Grout Columns Test Area

A test area including 25 jet grout columns with 1.8 m spacing and diameter of 60 cm was prepared to investigate the effectiveness of jet grouting method. Single fluid jet grouting technique was used to produce jet grout columns. Slurry was injected to the ground with 400 bar pressure and water to cement ratio of one. Prior to production of jet grout columns one standard penetration test and one cone penetration test were conducted. Same tests were done after jet grout columns production in the same area in order to compare the results before and after improvement. Schematic plan of the test area and test points are given in Fig. 1.

Fig. 1 Plan of jet grout test area

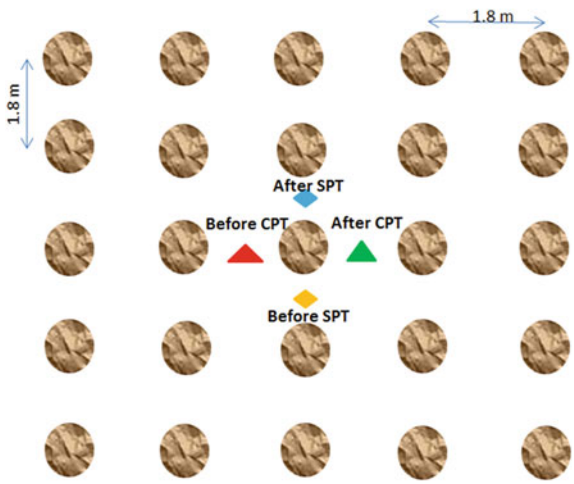

Fig. 2 Excavation around jet grout columns

After post production tests soil around the jet grout columns was excavated to measure the diameter of the columns (Fig. 2). In addition full length coring was conducted on some of the produced jet grout columns to check the integrity of the produced columns.

2.2 Experimental Study for Stone Column Test Area

A test area with same dimensions as it was for jet grout columns was prepared for stone columns. 25 stone columns with diameter of 1 m and spacing of 1.8 m were produced in the test area. Vibroflotation technique was used to produce stone column with top feeding method. Before stone column soil improvement SPT and CPT tests were conducted in the predetermined locations. Mentioned tests were done also after improvement in the same location to investigate the effect of stone column technique on the soil between the columns. Test plan is shown in Fig. 3.

Moreover, after conducting in-situ tests undisturbed sample (Shelby Tube) was obtained from the soil between the columns for laboratory tests. Shear strength parameters of the soil before and after stone column improvement were checked.

Seismic reflection tests were also conducted on this test area to compare the shear wave velocity of the soil before and after improvement (Fig. 4).

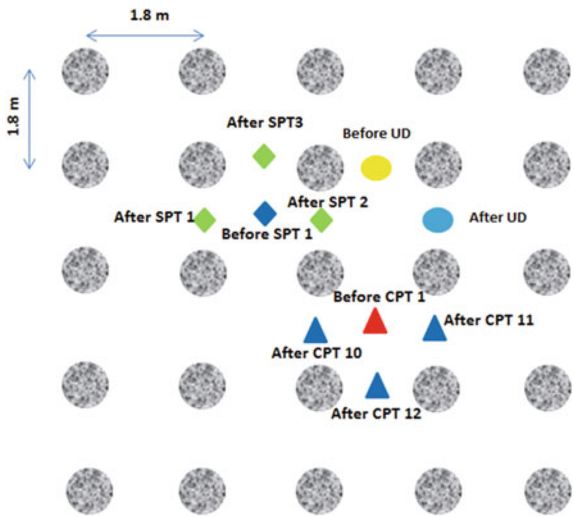

Fig. 3 Plan of stone columns test area

Fig. 4 Produced stone columns in test area

3 Test Results Study

3.1 *Jet Grout Column Test Area Results*

SPT and CPT test results showed almost no change in the strength of the soil between columns before and after jet grouting improvement. Results of SPT tests are shown in Fig. 5.

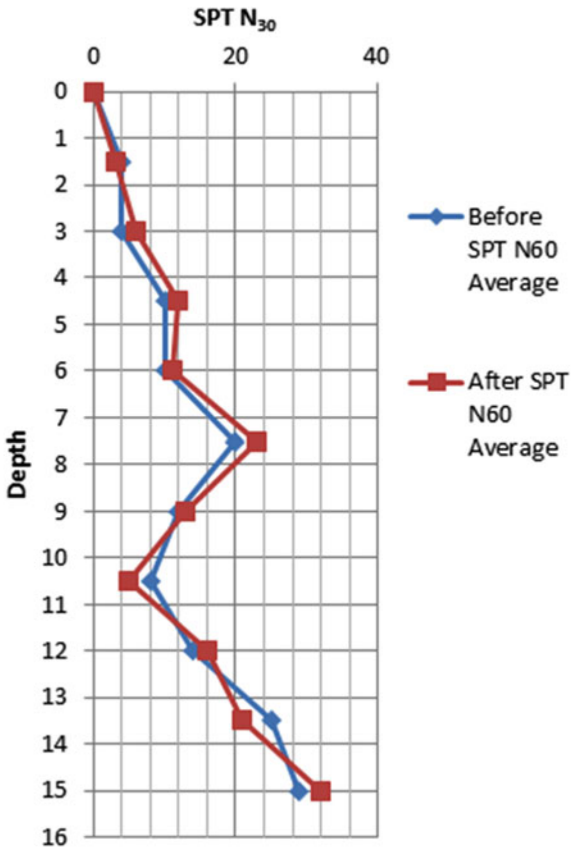

Fig. 5 SPT results for jet grout area

Results showed that there is not a homogeneous structure in the whole length of jet grout columns. Moreover, in some columns there were soil inclusions resulting from existence of hard clay which avoided jet grout slurry to mix with soil and produce the soil-crete columns. This might cause bearing capacity and settlement problems for the geotechnical design.

3.2 Stone Column Test Area Results

Standard penetration test results showed a slight increase in average SPT N60 values after stone column soil improvement which indicated that in addition to the area of the stone column itself, soil mass between columns has also been improved (Fig. 6). This plays a key role in reducing seismic risks and liquefaction hazards. CPT results also showed that strength parameters of the soil mass between stone columns have increased. The purpose was to determine the liquefaction risk before and after soil improvement. The avarage values of the cone resistance are given in Fig. 7. Also the soil classification determined from the CPT test prior to stone column installation are given in the same figure.

In addition, direct shear and density tests were conducted on undisturbed soil samples obtained from soil between stone columns. Test results showed an important increase in friction angle of the soil and decrease in void ratio which confirms the in-situ test results. Results of laboratory tests are shown in Table 2.

Moreover, seismic tests as seen in Fig. 8 was conducted on site. The seismic tests showed that shear wave velocity of the soil increased from 170.4 m/s before improvement to 250.7 m/s after improvement which indicates a 47% increase. Average value of shear wave velocity until depth of 30 m was increased from 290 to 370 m/s after improvement.

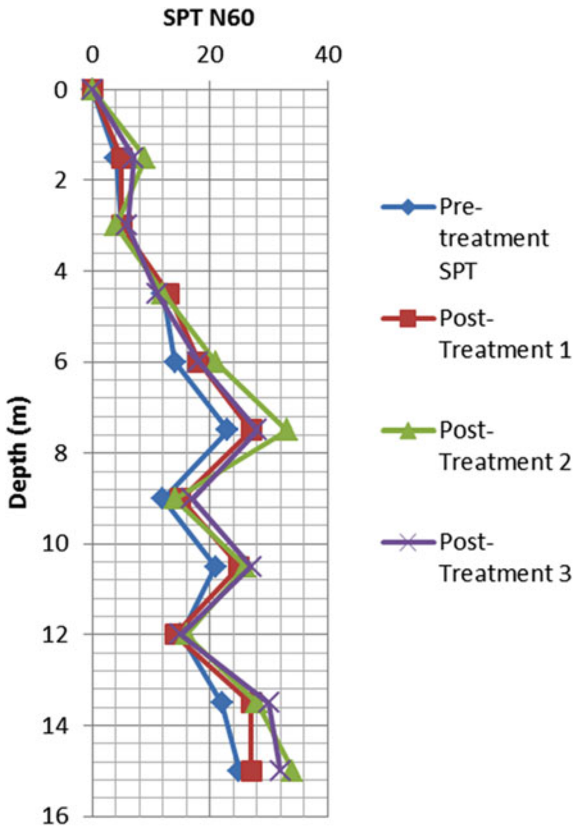

Fig. 6 SPT results for stone column area

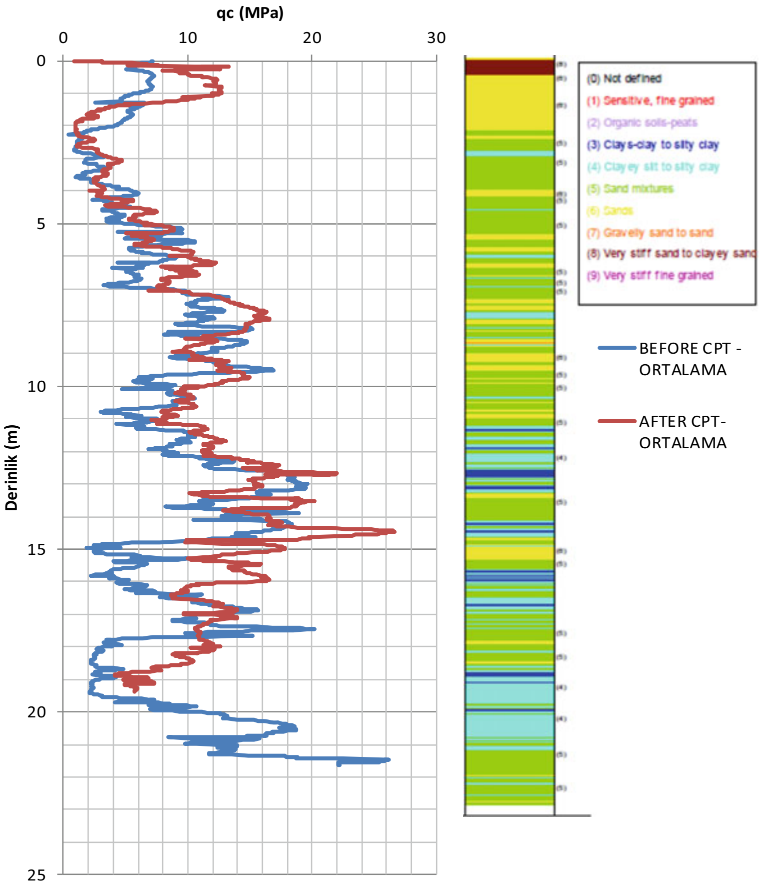

Fig. 7 CPT test results for stone column test area

Table 2 Laboratory tests results for soil between stone columns

	Wet density ρ_s (ton/m^3)	Dry density ρ_d (ton/m^3)	Specific gravity (Gs)	Void ratio (e)	Peak internal friction angle φ (^{o})
Before improvement	19.6	16.6	2.70	0.59	12.3
After improvement	21.3	17.9	2.71	0.54	29.4

Fig. 8 Seismic test for stone column test area

4 Discussion and Conclusions

In this paper jet grouting and stone column soil improvement techniques were evaluated by conducting in-situ and laboratory tests. Especially soil mass between jet grout and stone columns was tested to measure the effect of these methods on the improvement of the area between columns.

Post treatment test results show significant increase in friction angle of the soil between stone columns. This is because the soil is cohesionless and consists mainly of silty sand and is therefore affected by the vibration of the probe during stone column Installation. This increase in internal friction angle means a denser soil which leads to reduction of liquefaction hazard especially for loose saturated soils. It was also observed that that the structure of the soil obtained from post treatment Shelby tube is in general different than the soil obtained before improvement. In summary it can be said that there is an increase in density and internal friction angle of the soil in-between the stone columns. This indicates that stone columns provide a very efficient soil improvement in granular soils.

Another indication of the increased density was the significant increase in shear wave velocity by the use of stone column technique. Similarly the increase in shear wave velocity is an indication of a decrease in the risk of liquefaction hazards.

In case of jet grout columns practically no improvement was observed in the soil in-between the columns. Also full length coring results for jet grout columns showed that there is a risk of soil inclusion or discontinuities within jet grout column length due to ground conditions.

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References

1. Kirsch K, Bell A (2009) Ground improvement
2. Grace P, Flora A (2014) Jet grouting: technology, design and control
3. Martin JR, Olgun CG, Mitchell JK, Durgunoglu HT (2004) J Geotech Geoenviron Eng 130(6):561–571
4. Stark TO (2009) Soil inclusions in jet grout columns. DFI J 1(1)