A case history of jet grout column application in Turkey

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ABSTRACT: This paper briefly reports the case history of a large jet grouting application in Turkey. The execution of jet grouting was for the foundation improvement against settlement of a 4-storey shopping center that includes 1-storey basement in capital city, Ankara. The paper describes the design, construction and performance of the jet grouting process.

Soil modeling, settlement of the raft foundations under superstructural loads and alternative improvement systems are discussed. The choice of jet grouting as a soil improvement solution and its advantages are pointed out. In application of jet grouting, type of treatment, application procedure and operational parameters are discussed. Grout properties and type of equipment are also given.

Full control of jet grouting process including monitoring all jet grouting phases, making a trial excavation, the coring of soilcrete to determine the resulting compressive strength and pull-out tests to determine the load capacity of the jet grout columns are all mentioned.

1 INTRODUCTION

Migros/Ankara (GIMAT) Hypermarket and Shopping Center was constructed by Garanti-Koza Inşaat A.Ş. in Yenimahalle/Ankara. Soil improvement work was implemented by jet grouting method. Total construction area was 60,000m^2 and consisted of a 4-storey shopping center including 1-storey basement as the main building and a carpark. According to the settlement analysis, excessive settlements were determined under the raft foundations of shopping center building and jet grouting technique was chosen as a solution for this problem to improve approximately 25,000m^2 of land. The complete improvement work was executed only in 67 days by continuous 24-hour two shifts utilizing three sets of equipment.

The soil was modeled as a result of extensive field and laboratory field testing. Based on the geotechnical model, the settlement of the shallow foundations under superstructural loads was estimated. Two alternative systems were recommended in order to limit the excessive settlements, i.e. pile foundations and jet grout columns. The latter solution was preferred due to its inherent advantages of low cost and low construction time in comparison to classical pile foundations.

In order to determine the column bearing capacity, twenty-five Cone Penetration Tests (CPT) were employed and factor of safety under superstructural loads was assessed. In the mentioned construction, totally 2,233 jet grout columns were constructed that had 14-m length and 80-cm diameter. Type of treatment, application procedure and operational parameters are discussed. In addition to this, type of equipment and workmanship data are considered.

Full control of jet grouting application was maintained by monitoring all jet grouting phases carefully. The resulting diameter of the jet grout columns was evaluated on randomly excavated areas. The coring of soilcrete and resulting compressive strength were determined by means of testing on carefully obtained core samples. Large-scale pull-out (tension) tests were employed in order to determine the load capacity of the resulting jet grout columns. The results of each quality control work are discussed.

2 SUBSOIL CONDITIONS AND FOUNDATION ENGINEERING EVALUATIONS

The construction site was located in northwest of Ankara. The area existed in the valley bottom of Ankara Stream. The alluvial soils encountered in this flat area were gray-green, medium stiff to stiff clay layers containing thin gravel bands at the top levels and clayey-sandy gravel layers at the lower levels. In the subject site, nine borings were performed that had 20-m average length. Standard Penetration Tests (SPT) were carried out in every 1.5 meters of the borings. Average SPT/N values for the encountered low plasticity clays were calculated as N=11 for the first 12 meters from the excavation elevation and N=16 for the next 4.5 meters.

The soil was modeled as a result of extensive field and laboratory soil testing. The modeled section was determined by correlation from the SPT/N values and by undrained shear strength values that were obtained directly from the laboratory tests. Because of the high compressibility of the encountered clay layers and the variable subsoil conditions, allowable soil pressure was determined by settlement analysis. For the shopping center building, the net soil pressures acting on the foundations was taken as σ_f= 110 kPa based on the superstructural loads and the analyses were realized according to this value by Janbu Tangent Modulus. The amount of settlement was estimated to be 22-cm for the shopping center building foundation. Due to excessive settlements expected under the raft foundations, two alternative systems were recommended for the foundation system as raft foundations constructed on jet grouted soil (i.e. subsoil improvement) and deep foundations by piles.

As a result of detailed study, jet grout column technique was preferred due to its inherent advantages of low cost and low construction time in comparison to classical pile foundations. In addition to these, two technical advantages of jet grouting were considered:

- the length of jet grout columns would be smaller,
- vertical subgrade reaction of the subsoil would significantly increase and consequently the depth of the raft foundations would be smaller due to the extensive soil improvement offered by jet grouting (ZETAŞ. 1997).

According to the design, the ultimate load capacity of the columns was determined to be 100 tons and appropriate column configuration was designed due to superstructural loads. In order to calculate the load capacity of the columns, twenty-five Cone Penetration Tests (CPT) were performed. Based on CPT data, 100-ton column capacity was maintained with the column dimensions of L=14m and ϕ=80cm and was provided all over the site with a factor of safety between 1.9 and 2.7 that the average was 2.3. as given in Table 1 (ZETAŞ. 1998).

Table 1. Summary of jet grout column capacity evaluations based on CPT data (ϕ=80cm and L=14m)

	Ultimate tip resistance (kN)	Skin friction (kN)	Total capacity (kN)	Factor of safety
Minimum	295.2	1,125.4	1,864.8	1.9
Maximum	1,732.9	2,022.8	2,742.2	2.7
Average	739.4	1,590.0	2,268.4	2.3

3 JET GROUTING APPLICATION

3.1 Type of treatment and application procedure

In the mentioned project, the adopted jet grouting technique was single fluid system (JET1 or mono jet). Single fluid system is the type of treatment that both drilling and injection stem consists in one rod. Injection pressure may vary between 300-600 bars. The diameter of the resulting columns are generally 60-80 cm in clay and 60-100 cm in gravel (Melegari and Garassino, 1997).

Jet grout columns were formed by drilling a hole of 10-cm diameter up to the required depth at the site and then injecting the water-cement grout under high pressure that was prepared in the jet grouting equipment. In the applied procedure, the mixer was filled with water and cement with electronic scale. The grout was mixed until having a homogenous mixture and then transferred into the agitator in order to hold the mixture at rest for a short period. While this process went on, the drilling was being completed at the site. Drilling was realized by a drilling-injection rig at the site by water injection through the clay bit. The compressive effect of water pressure allowed reaching to the required depth. Then the drilling system was made ready for injection. This was realized by inserting a metal sphere into the monitor to plug the monitor tip. Therefore, the mixture was forced to go out of the nozzles. Then the grout slurry was transferred to the pump and the exact injection pressure was maintained. Meanwhile, the drilling machine was adopted for jet grouting process and operational parameters such as rotation and lifting speed of the rods were ensured. The grouting process was completed 20-cm below the working platform. After forming the soilcrete column, injection hose and the drilling rods were all cleaned by water to get rid of the slurry before starting to drill the new hole (Eker. 1999).

3.2 Operational parameters

In jet grouting, the operational parameters are injection pressure, number and diameter of nozzles, rotation and lifting speed of the rods. These parameters are set according to appropriate calculations and as a result the required column diameter is tried to be fixed. These parameters may be modified due to:

- subsoil conditions,
- desired column diameter,
- desired soilcrete bearing capacity,
- applied jet grouting technique.

In this project, the operational parameters were predetermined before the application due to above criteria and then set for the whole treatment after performing the quality control works by means of the trial excavation (Table 2).

Table 2. Operational parameters

Operational parameter	Unit	Value
Injection pressure	bar	500
Number of nozzles	n.	2
Diameter of nozzles	mm	2.4
Rotation speed of nozzles	RPM	24
Lifting speed of rods	cm/min	34

Throughout the application, Portland Cement (PC) 42.5 was used and water/cement ratio by weight (w/c) was kept constant to be one. The specific gravity of the grout was approximately 1500~1510 kg/m^3. The flow rate per nozzle was approximately 69~70 lt/min.

3.3 Equipment and workmanship information

Jet grouting application plant was consisted of jet grouting and drilling equipment and cement silos.

Jet grouting equipment (Tecniwell TWM-20) was consisted of two main units and special jet grouting apparatus such as monitor, nozzles, and etc. The units were:

- the mixer unit containing the mixer, the agitator and the control panel
- the pump unit containing the pump and the engine

The capacity of the mixer and the agitator was 1,300-lt and 2,600-lt respectively. Cement transfer was maintained from the silos of 60 and 80 tons and water was obtained from a water well. The control unit functioned in electronic scaling of the grouting materials. In the control panel, the cement-water filling and discharging were regulated automatically and the required water/cement ratio was maintained by the help of the digital panel.

The high-pressure pump had three pistons and involved electronic gear system. The pump capacity was 800 bars. The pressurized grout was transferred to the drilling machine by the injection hose of 1-inch diameter.

The drilling and injection process in the site was performed by Soil Mec SM 400 drilling machine. For drilling, a clay bit of 10-cm diameter was used. The drilling process was made by compression technique of water pressure of 100 bars. Both for the drilling and injection phases, three rods having 8-cm diameter and 4-m length were used. Injection process was made by means of a specially designed apparatus called as monitor that was located between the drill rods and the clay bit and had 40-cm length. On the monitor, each nozzle was located laterally at the opposite sides and had 2.5-cm vertical distance relative to each other.

The total time for execution of one jet grout column was recorded as approximately one-hour (Table 3).

Table 3. The average periods of jet grouting application phases

Application phase	Average period (minute)
Mobilization of drilling equipment	7
Preparation for drilling	5
Drilling	8
Preparation for injection	2
Injection	35

Throughout the application, one set of equipment was used 30 days, two sets of equipment were used 27 days and three sets of equipment were used 10 days. The whole improvement work was successfully completed in 67 days by continuous 24-hour two shifts and totally 2,233 jet grout columns were constructed that had 31,262m length. Considering the workmanship, jet grouting process was thought to involve two crew that were mixer-pump crew and drilling-injection crew. Under a site engineer control, in each shift, two operators and three workers were involved in the job. Depending on the increase in the number of equipment, the number of employees was also increased and reached up to twenty-five persons (Eker. 1999).

4 JET GROUTING QUALITY CONTROL WORKS

All jet grouting phases were monitored carefully and the operational parameters were controlled for each column. For each column, a daily report was prepared including execution number and date, cement and water consumption quantities and duration of drilling and grouting phases.

Throughout the project, three methods were employed for the quality control of jet grout column application:

4.1 Trial excavation

Within the first days of the application, some test columns were formed and a trial excavation was made in order to trace the following concepts (Figure 1):

- to inspect the jet grout columns visually,
- to perform resulting diameter control,
- to control the column verticality,
- to assess the column configuration at the site (control of the distance between the columns).

Figure 1. Trial excavation of jet grout columns (Eker. 1999)

Under such difficult conditions, the results of the trial excavation were successful. The constructed test bodies showed that the combination of the predetermined operational parameters resulted in obtaining the required project diameter (80-cm) in the subject cohesive soils. Also, in randomly excavated areas of the site, the required diameter of the columns was maintained.

In addition, the column verticality was observed as satisfactory. It was assessed that the project configuration was successfully applied and distance between the columns was appropriate.

4.2 Determination of compressive strength of jet grout columns

In order to determine the resulting compressive strength of jet grout columns, ten core samples were obtained from the test bodies of the trial excavation area.

The compressive strength values are summarized in Table 4. The values were compared with the proposed compressive strength values for clay (18-30kg/cm^2) given in the literature (Melegari and Garassino, 1997) and six of them were found to be in this range and four of them were found to be higher.

Table 4. Compressive strength values from core sampling

Test number	Sample diameter (cm)	Sample length (cm)	Failure load (kgf)	Compressive strength (kg/cm^2)
1	9.2	20.5	1,500	23
2	9.2	21.0	2,200	33
3	9.2	21.0	2,500	38
4	9.2	21.0	2,500	38
5	9.2	20.5	1,500	23
6	9.2	21.0	1,650	25
7	9.2	20.8	2,000	30
8	9.2	20.8	1,950	29
9	9.2	20.8	1,900	29
10	9.2	20.8	1,850	28

4.3 Determination of load capacity of jet grout columns by pull-out tests

According to the project requirements, nine pull-out tests were employed in order to determine the load capacity of the columns. Before the test, a reinforced concrete foundation was constructed for each test column and at least 30-cm distance was provided between the test column and this foundation. An anchorage tendon formed of 10 steel rods of 0.6-inch diameter was placed inside the test columns. In addition, reaction beams for the axial loads, hydraulic jack, hydraulic pump, manometer, and other measurement tools were placed conveniently in the test area (Figure 2).

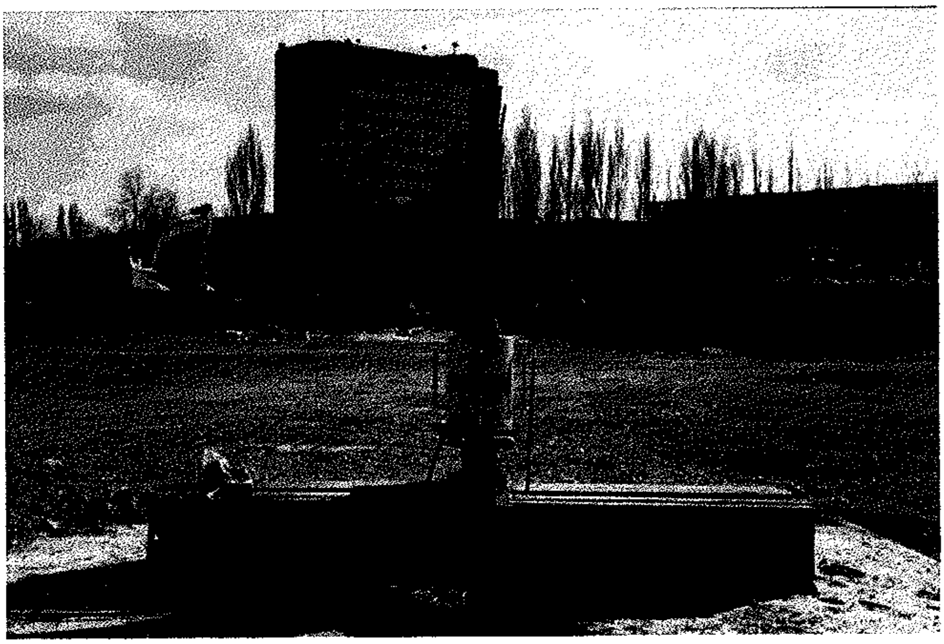

Figure 2. Pull-out test configuration (Eker. 1999)

In the test, by the hydraulic pump, the static tension load was transferred to the hydraulic jack that was placed over the column head and the reaction beams under certain pressure levels. Because of the rigid system, the column moved vertically under loading. These displacements in the column were measured independently from the column and other pressure components.

The column loading was performed in two cycles. The test load was determined to be 100 tons. In the first cycle, it was reached to 50 tons by 25 per cent load increments with 60-minute periods and then the load was discharged with 15-minute intervals. In the second cycle, it was tensioned up to 50 tons by 25 per cent load increments again and then it was tensioned up to 100 tons with 60-minute intervals with the same increments. The load was again discharged with 15-minute periods (ZETAŞ. 1999).

In order to inspect the column behavior more effectively and observe the permanent displacements, loading was tensioned up to 175 tons in six columns, 165 tons in one column and 162.5 tons in two columns. Consequently, it was tried to determine the column behavior under a load of nearly 70 per cent higher than the test load.

According to the test loads, the maximum permanent displacement was recorded as 4-mm. This displacement value was obtained under 162.5 tons that was 62.5 per cent higher then the test load so the column was determined to be safe under 100 tons that was the project load. It was also observed 0.5-mm and lower displacement values in six columns (Eker. 1999).

Table 5. Summary of the pull-out test results

Test number	Displacement (mm) load = 100 tons	Displacement (mm) Load = max. tons	Displacement (mm) load = 0 ton
1	7.00	6.00 (1625.5 tons)	4.00
2	0.00	1.00 (175 tons)	0.50
3	0.50	0.50 (1625.5 tons)	0.10
4	6.00	5.00 (175 tons)	3.00
5	1.00	1.50 (165 tons)	0.50
6	0.50	1.00 (175 tons)	0.30
7	1.00	4.00 (175 tons)	2.00
8	0.50	0.50 (175 tons)	0.10
9	1.20	2.20 (175 tons)	0.10

5 CONCLUSIONS

Migros/Ankara (GIMAT) Hypermarket and Shopping Center Project was one of the first examples of the massive soil improvement work in Turkey by extensive treatment of bearing jet grout columns. As a result soil improvement, the settlement of raft foundations was proved to be below the proposed design value of 5-cm.

In the project, jet grouting application as a soil improvement method was completely satisfactory by means of its low cost and low construction time. The high speed of jet grouting application allowed the other construction phases take place immediately such as lean concrete works, drainage, isolation, raft foundations and etc.

The effective use of jet grouting in wide range of subsoil conditions was proved in this project that the clayey soil that is not possible to inject was easily grouted under high pressure. The appropriate selection of the operational parameters resulted in a successful treatment that was proved by technical methods such as trial excavation, core sampling and pull-out tests.

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7 REFERENCES

Eker Fırat Ş. 1999. Jet Grouting Technique and Case Studies. MS Thesis. Boğaziçi University. Istanbul

Melegari Cesare & Garassino Angelo L. 1997. Seminar on Jet Grouting. Singapore: THL Foundation Equipment Pte Ltd

ZETAŞ Earth Technology Corp. 1997. Migros/Ankara (GIMAT) Hypermarket and Shopping Center Soil and Foundation Engineering Evaluations Report. Istanbul

ZETAŞ Earth Technology Corp. 1998. Migros/Ankara (GIMAT) Hypermarket and Shopping Center Jet Grout Column Loading Test Technical Specifications and CPT Results. Istanbul