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AN INVESTIGATION OF MECHANICAL PROPERTIES OF JET GROUT APPLICATIONS FOR ALLUVIAL SOILS IN THE KAHRAMANMARAŞ REGION

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M.Sc. Thesis

In

Civil Engineering

Hasan Kalyoncu University

Supervisor

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by

Oktay ÇİÇEK

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Oktay ÇİÇEK

ABSTRACT

AN INVESTIGATION OF MECHANICAL PROPERTIES OF JET GROUT APPLICATIONS ON ALLUVIAL SOILS IN THE KAHRAMANMARAŞ REGION

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The jet grout method, which is among the methods commonly used in the design, decking, and decking of building foundations in our country, is among the most preferred methods. It was observed that there was a decrease in seating, permeability, and an increase in carrying power and against liquefaction with ground strengthening performed by the Jet grout method. Within the scope of the thesis, the mechanical properties of jet injection were examined with different literature studies and in this context, parameters were determined in the production of jet grout column and 3 columns were manufactured. Manufactured jet grout columns are made with different injection pressure and water/cement ratio with a single fluid (Jet1) system on the compressed alluvial ground. Jet grout application was made at the construction site of the Turkoglu fire building, which is planned to be made on behalf of the Metropolitan Municipality of Kahramanmaras, which is located in the Turkoglu District of Kahramanmaras province, Turkoglu (Center) District, 88 Islands, and 21 parcels. A total of three types of bar pressure were used during the application of Jet grout.

• 300 bar
• 400 bar
• 450 bar

A soil sample was taken at a depth of one meter in the area of the manufactured columns. Plastic Limit, liquid Limit test, and sieve analysis were performed with the samples taken. In the research, the water/cement ratio of the columns formed with 300 bar and 400 bar from 3 columns manufactured was determined as 1. In the column formed with 450 bar, the water/cement ratio was determined as 0.8. In addition, the pull (30 V (cm/min)) and rotation speeds (15/20 D (rpm)) of the manufactured 3 columns, the diameter of the nozzle used (2.2 mm), and the number (2 pieces) were kept constant. After the jet grout columns were completed, significant differences were observed in the diameter top-up made and removed from the ground. In addition, core samples were taken from the columns in a ratio of one to two and free pressure experiments were conducted. As a result of the experiments, it was observed that the strength of the column increases as the time to receive pyresis increases

Keywords: Jet grout, strength, pressure, diameter, alluvial.

ÖZET

KAHRAMANMARAŞ BÖLGESİNDE ALÜVYON ZEMİNLERDE JET GROUT UYGULAMALARININ MEKANİK ÖZELLİKLERİNİN İNCELENMESİ

ÇİÇEK, Oktay

Yüksek Lisans Tezi, İnşaat Mühendisliği Bölümü

Tez Yöneticisi(leri): Prof. Dr. Hanifi ÇANAKÇI

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60 sayfa

Ülkemizde yapı temellerinin tasarımında yaygın olarak kullanılan yöntemler arasında yer alan jet grout yöntemi, bina temellerinin zemin güçlendirmesinde en çok tercih edilen yöntemler arasındadır. Jet grout yöntemi ile yapılan zemin güçlendirmesi sonucu oturma, geçirgenlik ve sıvılaşmada azalma, taşıma gücünde ise artış olduğu görülmüştür. Tez kapsamında jet enjeksiyonun mekanik özellikleri farklı literatür çalışmaları ile incelenmiş, bu kapsamda jet grout kolon üretiminde parametreler belirlenmiş ve 3 kolon imal edilmiştir. Üretilen jet grout kolonları, sıkıştırılmış alüvyon zemin üzerinde farklı enjeksiyon basıncı ve su/çimento oranında tek akışkan (Jet1) sistemi ile yapılmaktadır. Kahramanmaraş ili Türkoğlu ilçesinde bulunan Kahramanmaraş Büyükşehir Belediyesi adına yapılması planlanan Türkoğlu İtfaiye Binası şantiyesinde jet grout imalatı yapılmıştır. Jet grout uygulaması sırasında üç farklı bar basıncı kullanılmıştır.

- 300 basınç
- 400 basınç
- 450 basınç

Üretilen kolonların bulunduğu bölgede bir metre derinlikte toprak örneği alınmıştır. Alınan numuneler ile Plastik Limit, Likit Limit ve Elek Analiz deneyleri yapılmıştır. Araştırmada üretilen 3 kolondan 300 bar ve 400 bar ile oluşturulan kolonların su/çimento oranı 1 olarak belirlenmiştir. 450 bar ile oluşturulan kolonda su/çimento oranı 0,8 olarak belirlenmiştir. Ayrıca imal edilen 3 kolonun çekme (30 V (cm/dk)) ve dönüş hızları (15/20 D (rpm)) ile kullanılan nozül çapı (2,2 mm) ve sayısı (2 adet) sabit olarak imal edildilmiştir. Jet grout kolonları imal edildikten sonra zeminden çıkarılmıştır. Çap ölçümleri yapılarak farklılıklar gözlemlenmiş. Ayrıca kolonlardan yaklaşık olarak bire iki oranında karot numuneleri alınmış ve serbest basınç deneyleri yapılmıştır.

Anahtar Kelimeler: Jet grout, güç, basınç, ölçü, alüvyon.

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SYMBOLS AND ABBREVIATIONS

CCP	ChamicalChurning Pile
CE	ConformitéEuropéene
Cem	Cement
cm	Cantimeter
cm2	Cantimsquare
Cpt	ConePenetration Test
D	Diameter
D	RotationSpeed(rpm)
E	ElasticityModulus
EN	Europen norm
gr	gram
Hp	Horsepower
Jcb	JosephCyrilBamford
JG	Jet grout
JSG	Jumbo Special Grouting
Kg	Kilogram
Kgf	Kilogram Force
kPa	Kilopascal
Lt	Liter
m	Meter
m2	Metersquare
m3	Cubicmeter
Min	Minute
Mj	MegaJoule
mm	Milimeter
MPa	Megapascal
Nm	Newtonmeter
P	Pressure
PT	PlatinumGroup
R	Radius
Rpm	Revolutionsper Minute

Spt	StandartPenetration Test
SSM	Super Soil Stabilization Management
V	Shrinkagespeed
W/C	Water/Cementratio.

CHAPTER 1

INTRODUCTION

Today, as a result of the increase in population density in the city centers, it is decreased by the grounds that will carry the foundations of the basics of the buildings to be built and the loose sands, soft clays, peat, and softer alluvium floors and under groundwater levels are high in the ground and similar fields. The physical and mechanical properties of the floor should be determined, and if the physical and mechanical properties of the ground will be determined, also a problematic ground in terms of transportation and seating

- Refill and compression with a granular other material carrying the weak ground in the present and the engineering angles.
- Conforming the design of the existing site to ground properties and carrying capacity of the current site
- Replacing the land area of the structure, (Özdemir, A. and Özdemir, M., 2006).

Although solutions are given, it also affects the manecaneavrability of engineering structures, together with due to physical and public boundary conditions, and leads to important problems. To make the desired project in poor ground pitches, it is necessary to strengthen the ground strength properties and to carry the capacity to carry permanent loads, as well as to be able to transfer movable traffic loads smoothly. For this reason, various floor improvement methods have been developed with rapid and continuously growing ground technologies. Floor improvement methods are directly related to secure, high-quality, functional, and economic solutions. Therefore, strengthening the problematic floors with the appropriate improvement technique; provides more successful results. Floor improvement methods have been developed to be difficult to construct depending on technology and to improve problem areas and to be conducive to the construction. Ground improvement methods can be classified as superficial floor improvement methods and deep ground improvement methods. Stabilization with cement and stabilization with cement for superficial floor improvement can be applied to stabilization, compact, drainage, and bitumen. Preloading and dynamic compaction for deep ground improvement, Vibro-compaction, deep mixing, stone columns, injection, floor studs, jet grout, vertical drains, and fore pile can be used (Doğu, 2005).

Within the scope of this thesis, three specially designed jet grout columns were manufactured in the construction site of the Kahramanmaraş Metropolitan Municipality, located in the Türkoğlu (Center) District of Kahramanmaraş province Türkoğlu district, which is located in the 1st earthquake zone of Turkey. The research is also determined as the water/cement ratio of 3 columns created with 300 bar and 400 bar. In the column created with 450 bar, the water/cement ratio was 0.8. In addition, the drawing of the 3 columns manufactured (30 V (cm/min) and rotation speeds (15/20 D (RPM)), the nozzle diameter (2.2 mm) used (2 units) were kept constant. After the jet grout columns were completed, significant differences were observed in the diameter top-up made and removed from the ground. In addition, core samples were taken from the columns in a ratio of one to two and free pressure experiments were conducted. As a result of the experiments, it was observed that the strength of the column increases as the time to receive pyresis increases. Manufactured jet grout columns are printed with 300,400,450 bar, water/cement with these columns, the program of experiments and the construction of experiments are explained extensively.

1.1 History of The Jet Grout Method

It can be seen that the first traces of the jet grout method were encountered in the medieval period, using the erosion power of water to break up the ground, making ground excavations and mining activities.

Even though the jet grouting method was first introduced in England in the 1950s, it was first used in Japan for geotechnical engineering purposes. (Doganışık, 2010) .

When successes were realized in the field of geotechnical engineering, it started to be used in Italy and various European countries towards the end of the 1970s. In our country, it was used in the construction of the Ayvansaray tunnel mirror in the Golden Horn Collectors Project (Çınar ve Akkaya,19940). It is aimed to have fragmentation of grounds that are improved or were partially improved by using chemical injection with jet grout technology using water jet at the first times. Afterward, cement-based chemical mixtures were delivered to the fragmented areas and impermeable areas were formed. Later, the Jet Grouting method was used to make thin sealing curtains (Moseley and Kirsch, 2004).

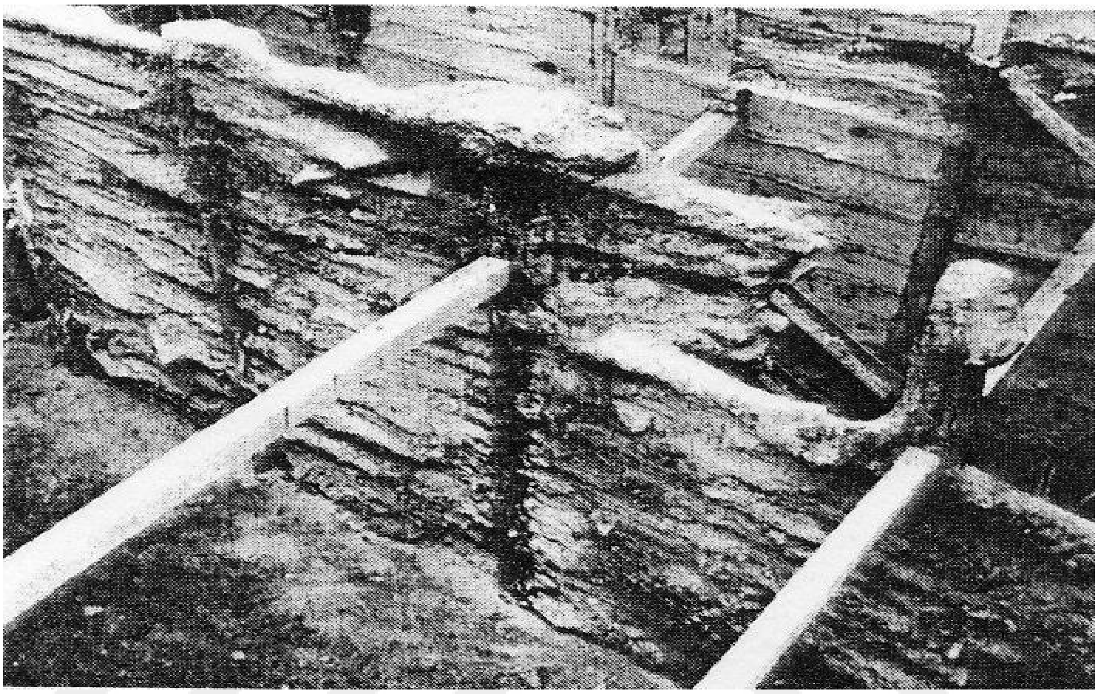


Figure 1.1 Thin impermeability curtain formed with Jet grout (Moseley and Kirsch, 2004)

This method aims of is to increase the mechanical strength values of the soil. Therefore, the bearing capacity and modulus of elasticity of the soil increase, and its permeability decreases. With the jet grouting method, it is possible to rehabilitate very wide and different types of soils with different characteristics such as clay or sand-gravel.

To have soil structures with better engineering properties, especially to provide reinforcement and stabilization of soils, to reduce the permeability of soils, and to support excavations, the jet grouting method is used. This method is accomplished by a high-energy grout jet breaking up the ground. In this way, it is ensured that the soil-cement mixture column, which is defined as the jet grout column, is in a better condition in terms of tension, durability, and permeability compared to the condition of the ground before the improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 General Literature Study

This section includes important studies on the behavior, design, and application of the jet grout columns. Up today, some of the studies in the literature on the methods of manufacturing jet grout columns are summarized below.

As a result of the studies carried out by the author, it was emphasized that the ground reinforcement method with jet grout is new and this method has not been developed. Since it is among the pioneering studies in which compressive strengths that can be obtained for different types of ground are given, it should be considered as an important study. He mentioned that the application is economical and effective in soil improvement problems. However, experimental research on the method should be done for more effective use.

After the researcher revealed the ground improvement method with Jet grout method, examples of certain problems regarding geotechnical engineering processes where the jet grout method is used were examined. In the study, effective factors relating to ground improvement with Jet grout were listed as items and they were also examined. (Lunardi, 1977).

- Suitability of method as per different ground types
- Design criteria
- Observation during construction
- Most recent technological developments relating to the method
- Jet grout method in construction and environmental engineering works
- Certain cases and their analyzes

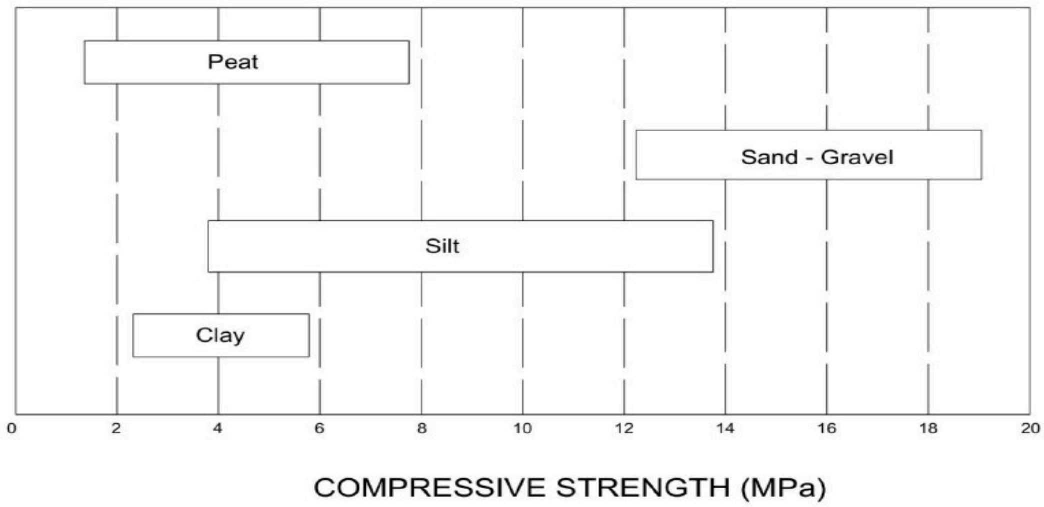


Figure 2.1 Compressive strengths obtained as per certain types of ground (Lunardi, 1977)

In studies, on different floors reinforced with jet grout arms, changes in uniaxial compressive strength were studied depending on the ratio of water/cement used during column construction. In samples taken from jet grout columns applied to seven different floors, the unconfined compressive values obtained according to the different water/cement ratios are shown in the chart.

In the study realized by Baumann (1984), the changes in uniaxial compressive strength were researched depending on the water/cement ratio used during the construction of the column in different soils reinforced with jet grout columns. Unconfined compressive values obtained according to different water/cement ratios in the samples taken from the jet grout columns applied to seven different soils are shown in the table. (Baumann, 1984).

Table 2.1 Unconfined compressive strength values of column depending on the water-cement ratio (Baumann, 1984)

Soiltype	Gravel	Sand	Plate/ Clay	Organic Soil	Gravel/ Sand	Sand/ Plate	Plate/ Clay
Column No	1	2	3	4	5	6	7
w/c 0.67	< 20	< 15	<12	< 3	12-18	10-14	6--10
w/c:1	< 20	< 15	<12	< 3	6-10	5-7	3-5

The study is important for providing detailed strengths of Jet Grout columns made in different ground conditions in the field. As per the data in the study, it has been observed that the compressive strengths obtained in sandy and gravelly soils are higher than those of clayey, silty, and organic soils, and the compressive strength of pebbly sandy, sandy silty, silty clayey soils also increases with the increase in the amount of cement (Baumann 1984).

Mechanical properties of Boston blue clay, properties of which were improved by forming jet grout columns, were investigated. Cement ratios of 12-45% were used in the study. Cement percentage is the ratio of cement weight to the total weight of the mix. Different water/cement ratios were used. They specified that the compressive strength of the formed columns decreased as the water/cement ratio increased. The results obtained are shown in Figure 2.4 (Kauschinger et al., 1992).

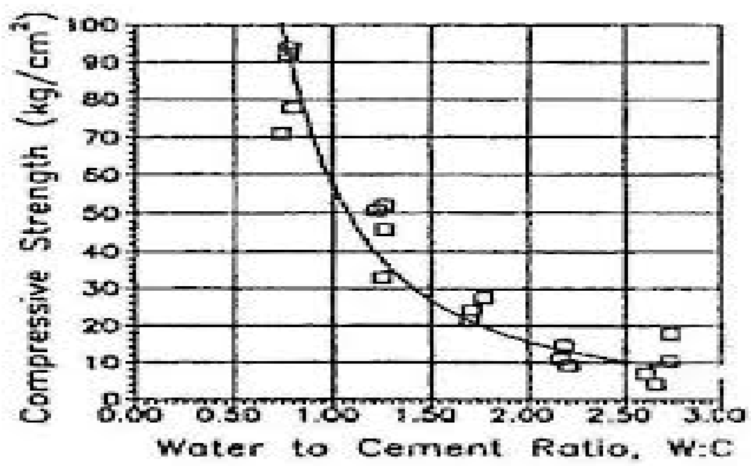


Figure 2.2 Correlation between water/cement ratio and compressive strength (Kauschinger et al, 1992)

Graphs given in Figure 2.5 showed the relationship between column diameter and injection pressure. Increasing the injection pressure has a positive impact on the column diameter. However, Melegary and Garassino (1997) alleged that the residence time is also important to create a homogeneous column and he has revealed the graph in Figure 2.6 showing the relationship between injection pressure - residence time and column diameter. (Xanthakos, 1994).

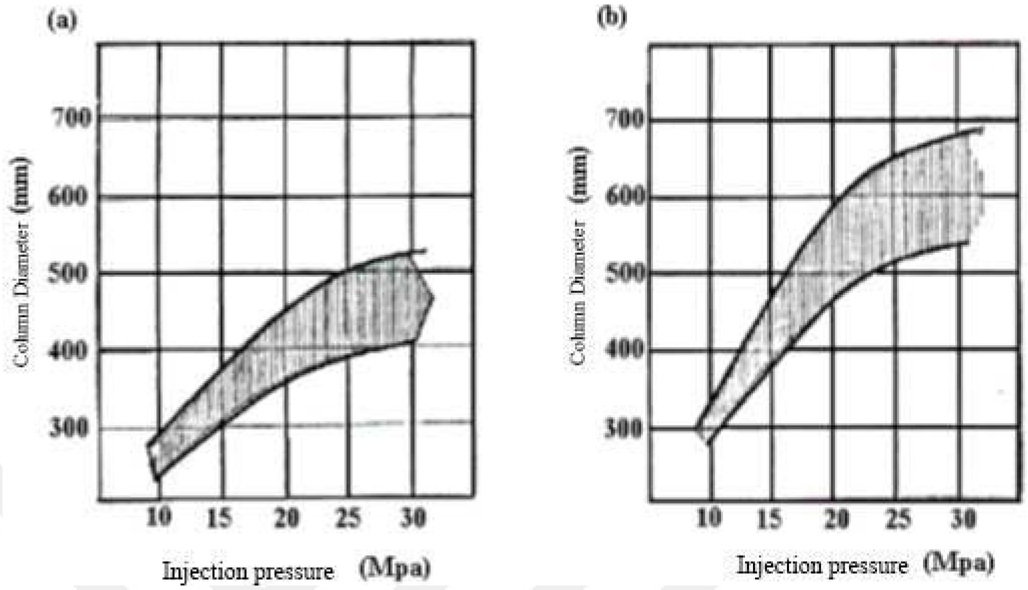


Figure 2.3 The relationship between the formed column diameters and the injection pressure; (a) soft fine-grain soil, (b) medium-tight rough grain non-cohesive soils (Xanthakos et al., 1994)

Grout pressure is one of the most effective parameters for forming the column diameter that is desired to be obtained, and there is a relationship between the injection pressure and the column diameter. As the pressure increases, the diameter of the column increases. But to obtain a homogeneous column of the desired diameter to be reached, the pressure value is required but alone is not sufficient. Because other parameters, i.e. tensile and rotational speeds, are also related to time, the formation of columns of the same diameter and homogeneity is also associated with the time factor (Melegary and Garassino, 1997).

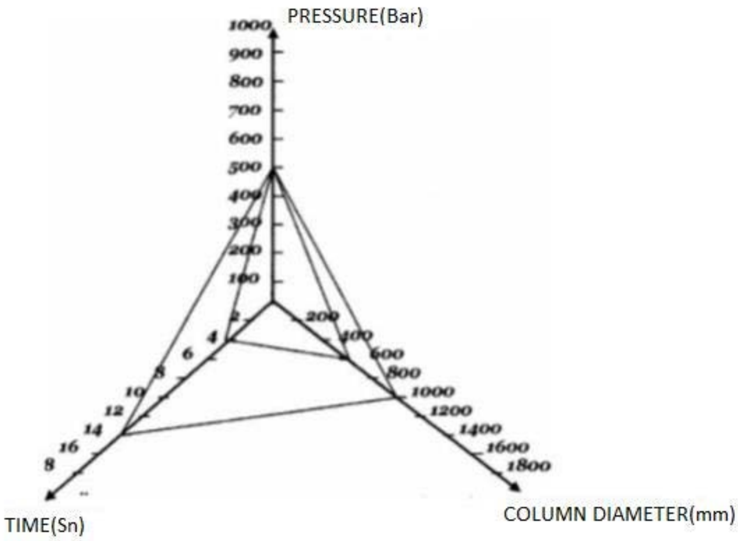


Figure 2.4 Relationship between Injection Pressure-Injection Time-Column Diameters (Melegary and Garassino, 1997)

Uniaxial compressive strength test, Brazilian split tensile test, and ultrasonic tests were realized to determine the mechanical properties of jet grout columns. Experiments have been carried out by using samples taken from the columns formed on the road route built on silty sand and silty clay soil units. Experiment results showed that density, modulus of elasticity, split tensile strength and P wave velocity of soil mass increased with increases in uniaxial compressive strength. Uniaxial compressive strength changes as a function of depth are also shown in Figure 2.5. also shown (Fang et al., 1994).

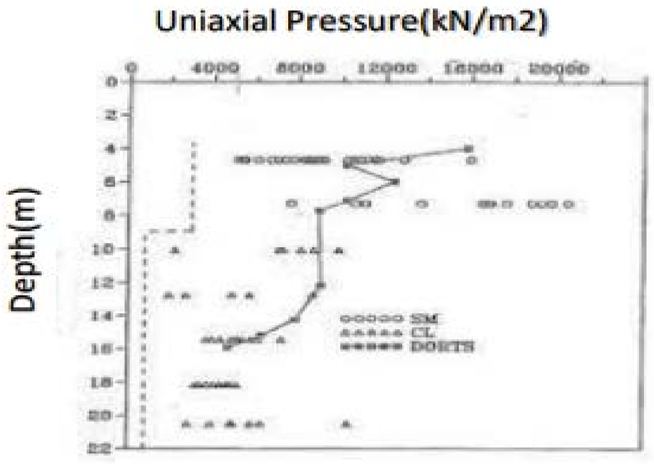


Figure 2.5 Single-axis compressive strength change in Jet grout columns (Fang et al, 1994).

In this research, the relationship between the modulus of elasticity and the uniaxial compressive strength of jet grout columns was investigated. In experimental studies, samples that were taken from Jet Grout columns formed on silty and silty sandy soils were used. As a result of the studies, the graph in Figure 2.6 was obtained and it was reached to the conclusion that the strength of the jet grout column is directly proportional to the modulus of elasticity. (Trevi, 1994).

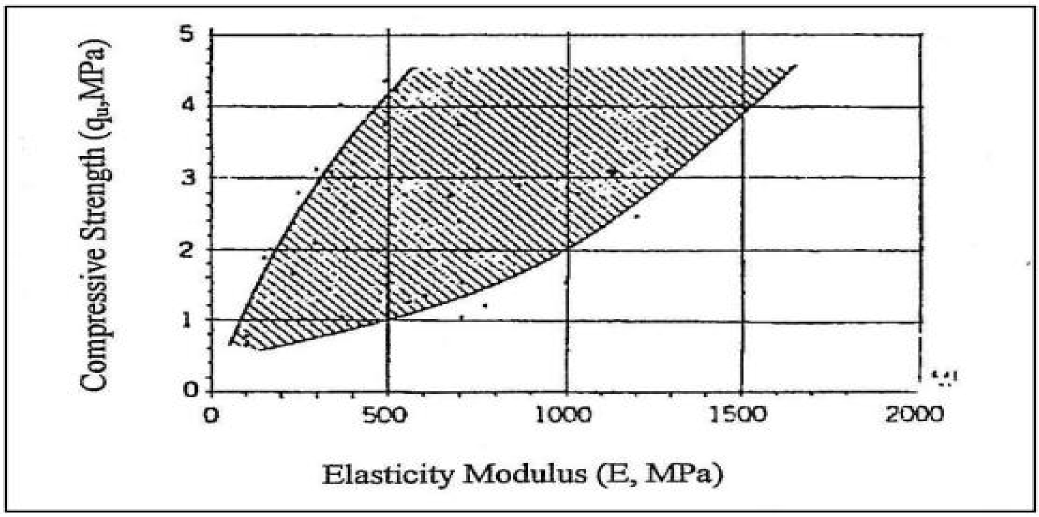


Figure 2.6 Elasticity Module- Single Axis Compressive Strength relationship (Trevi,1994)

Estimated column diameter – tensile velocity correlation obtained in his study is seen. As per Figure 2.7, there is a decrease in the diameter of the column as the rod withdrawal speed increases (Moseley, 1993).

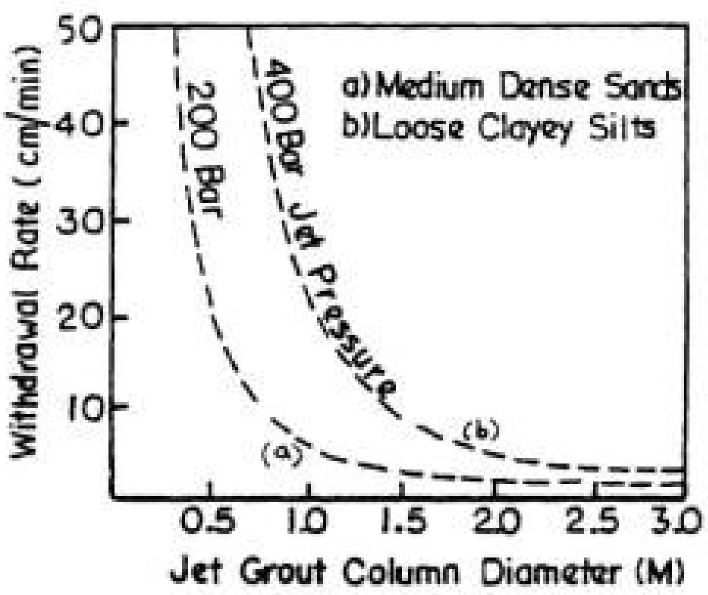


Figure 2.7 Correlation of estimated column diameter- rod lifting speed **(**Moseley 1993)

In this study, uniaxial pressure tests were realized in the laboratory on core samples taken from super jet columns. In the experiments, the compressive strengths of 3, 7, 14, and 28 days of 76 x 150 mm cylindrical samples were determined and the graph in Figure 2.8 was obtained. (Bell et al., 2003).

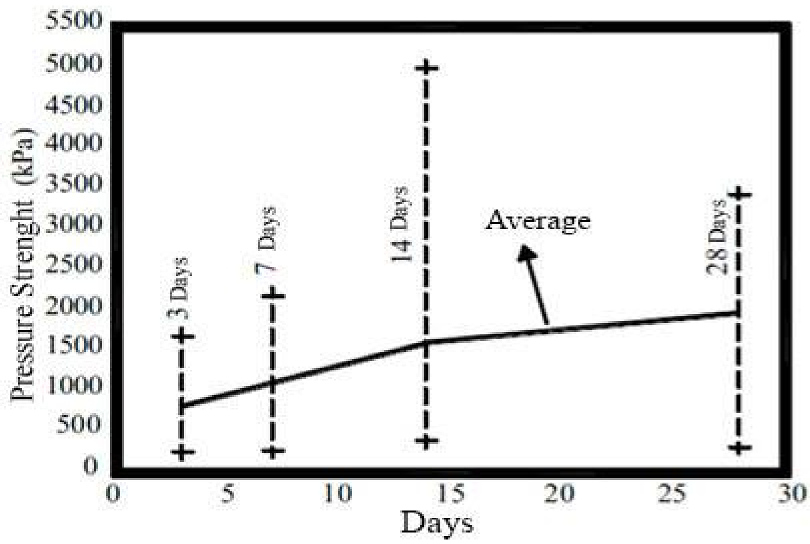


Figure 2.8 Compressive strength of column samples (Bell et al., 2003)

According to Figure 2.8, it was determined that the superjet column strengths increased with time and the real strength was reached on the 28th day.

Important experiments have been carried out to find the relationship between wear and energy flow for the development of the practical jet grout method, which is used to form column diameters exceeding 5 meters in their studies. Fluid energy, which is the product of flow rate and dynamic pressure, determines the tearing distance. Hence, by dividing the unit volume of the ground with great energy, it causes ruptures at greater distances with the jet. Researchers stated that the purpose of their basic experiments was to clarify the requirement for the flow energy level in the jet stream to form an improved ground skeleton with a diameter of 5 meters. Experiments were realized by pouring water jets into the prepared artificial ground in-ground tanks with a capacity of 24 and 100 cubic meters. 90% of the artificial soil is placed by compaction of sandy soil containing sand. For each flow rate of 75, 150, 300 lt/min, experiments were carried out at discharge pressures of 27,37 and 47 Mpa, and the tearing time (for the calculation of the tearing characteristics in the ground) was determined by a constant flow rate from the jet. measured when it reaches the point.

In their study, researchers suggested a new method in addition to the traditional method in creating a large-scale jet grout column. This method, which they proposed, was applied in the field as well as the experimental application, and the results were listed:

- Basic specifications were proposed for explaining the relationship between fluid energy and the sheer distance of the jet in the experiments, and they proved the requirement for fluid energy of at least 8 GPa lt/min to create an improved column with a diameter of 5 meters.
- The requirement for the geometry of the jet for the development of construction tools and equipment was revealed from the experiment carried out to explain the effect of the correction coefficient on the spread of the jet passing through the curved pipe.
- Trial constructions on clayey and sandy soils have been realized based on basic specifications to improve 5 meters in diameter (figure 2.9) (Shibazak et al., 2003).

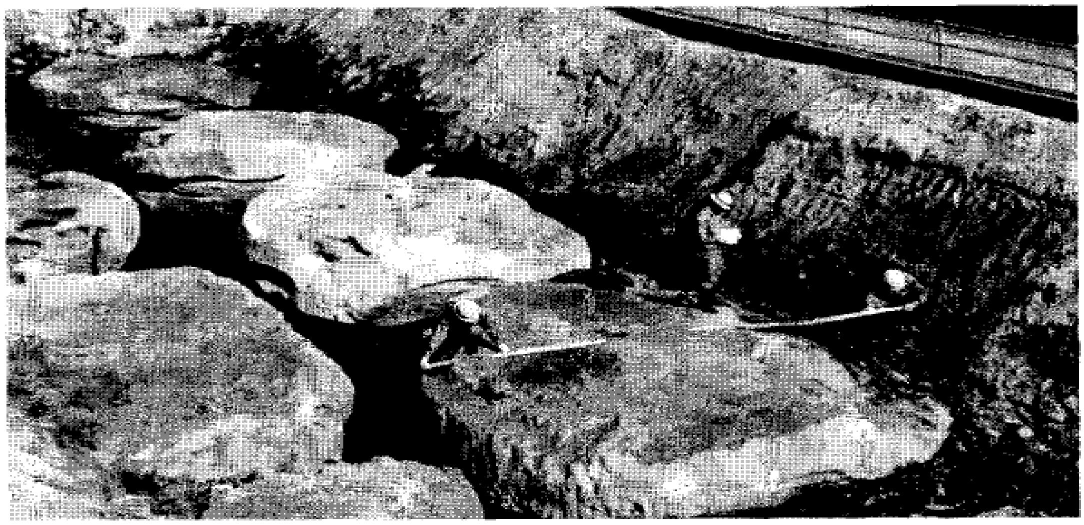


Figure 2.9 Jet grout columns having a diameter of 5 meters (Shibazak et al., 2003)

In his study, the researcher examined the advantages and disadvantages of the Jet Grout method. The researcher emphasized put emphasis on the fact that the jet grout method is a soil improvement method, that is becoming increasingly common around the world, and compared these existing methods, and specified the most used parameters. In his study, methods and parameters have been analyzed, in-depth details of different soil types were compared, and some recommendations were presented with regards to Jet Grout methods. The most common jet grouting methods are Single Fluid (Grout), double fluid (Grout and air), Three Fluid (grout+air+water) methods. The researcher stated that it is very difficult to tear in the intervals from gravelly to sandy soils with jet grout, whereas less tearing occurs in clay soils with high plasticity. The researcher said that the rupture of the soil is all about energy and emphasized that the kinetic energy of the high-speed fluid hitting the ground disrupts the soil structure. The energy used depends on the dynamic pressure of the fluid jet, fluid mass, fluid viscosity, air content, rotational and shrinkage speed, and fluid velocity. The researcher has stated general aspects of advantages and disadvantages of x-jet applications having three fluid methods enabling improvement with controlled diameter and uniform particularly regarding the super jet method that has a double fluid system that can be increased up to diameter of 5 m about private equipment and high injection that can separately be sufficient with regards to single, double and three fluid grout methods. Table 2.2 (Burke, 2004).

Table 2.2 Jet Grout System advantages and disadvantages Burke (2004)

System	Advantages	Disadvantages
With single fluid	-Simple equipment and system -Vertical joints can be tightly sealed -Gives good results on the cohesionless ground	- Small geometry construct - Shooting control is difficult -Quality control is difficult in cohesive soils
With double fluids	- A very common system -Tools and equipment are available -High energy and good geometry are provided -More experience is available -Often very economical	- Gravity control is difficult on cohesive soils -Residue heap is difficult to handle -Not usually considered for foundation reinforcement
With three fluids	- It is the most controllable system -High quality on problem floors -Best base booster abuse -Easiest to check for shooting and residue stack	- It has complex equipment and system -Requires significant experience
Superjet System	-Lowest fee per healing volume -The best mix is achieved	- Requires special tools and equipment -Draft control is difficult on cohesive soils -The pile of residues is plentiful -It cannot be operated on the edges without support -It causes too many logistic problems
X-Jet System	-Safe geometry - Controlled material cost -Gives best results on soft cohesive soils	- Very specialized equipment that requires daily calibration -There is little experience

In the study carried out by the researcher, it has been stated that jet grout technology was started to be used in many different projects with the rapid increase in subway construction, tunnels, and high-rise structures in Shanghai in the last 10 years. The particular reason for the application of jet grout technology in the projects he researched was the formation of water impermeability curtains and foundation improvement. The improvement depth has reached from 20-30 m to 50 m. The arrangement of jet grout columns in excavation pits depends on soil conditions and construction characteristics, including wall types, single-pile type, and slab type. The improvement interval is estimated based on recent calculations and experience. The researchers listed the general construction parameters of the jet grout as generally rotating speed of 10-20r/min and pulling speed of 5-30 cm/min. The researchers stated that the quality of the jet grout is directly related to the selection of the construction parameters and the quality control during the construction phase. (Wang et al., 2009).

Figure 2.10 Width section of Jet Grout column formed (Wang et al., 2009)

2.3 Jet Grouting Method

If the properties of the soil are insufficient according to the soil bearing capacity, liquefaction, permeability, settlement, or stability criteria, deep foundation systems application or soil improvement is required. By selecting a suitable method according to the soil parameters, improving the soil and as a result, the bearing capacity increases, settlements and impermeability decrease, and liquefaction resistance increases. With the development of technology, the jet grouting method has become an effective method in solving many geotechnical engineering problems today.

Welsh, Rubright, and Coomber described the jet grouting method in their general definition as "the controlled and simultaneous injection of cement instead of the ground cut with high-pressure water jets" (Welsh et al., 1986).

This method is mainly the process of systematically injecting cement-based injection material prepared in different mixed ratios with special equipment instead of the cut ground with high-pressure water jets. While the injected cement and water mixture causes the ground to break down due to the high pressure, on the other hand, the cement and water mixture mixes with the ground grains, resulting in the formation of Jet Grout columns.

The Jet Grouting method was used on granular floors in the early days of its development, and with the development of technology, it can be implemented on almost all kinds of floors. Compared to other improvement methods (ground filling, stone column, dynamic compaction, etc.), this method can achieve faster, reliable, permanent, and economical results.

As the amount of grout to be injected into the floor is calculated before starting with the production in the Jet Grout method, it is possible to calculate the unit and total cost of the application.

With Jet Grout method, among Geotechnical Engineering problems confronted with;

• To provide more bearing capacity for vertical loads and to limit absolute and differential settlements in the ground under foundation and fill,

• To provide support against lateral ground thrusts in excavation works such as tunnels and shafts,

• To use as a sealing element to control the groundwater that may come from the excavation base to the excavation and to prevent the spread of polluted water in the solid waste sites to the environment,

• To use as a ground reinforcement element to provide stability on slopes is aimed (Durgunoğlu, 2004).

2.4 Basic Principles of Jet Grout Method

The Jet Grout method is constituted of two stages mainly being drilling and injection.

2.4.1 Drilling

The drilling method is selected by considering the characteristics of the ground to be drilled. This method is applied as rotary method or pulsed-rotary method depending on the soil feature. External hammer systems are the most common of the percussion-rotary method. Many different fluids are used to cool the bit set during drilling, to facilitate the drilling process, and to prepare the ground for injection. These can be listed as bentonite grout, air, water, cement grout. The bit used as a drill pipe is Jet Grout rods. These materials are resistant to high pressure and are produced with different manufacturing techniques. In the connection (additional) sleeves, elements that provide sealing and can withstand 500-600 bar are used (Çınar and Akkaya, 1994). The drilling machine and the drill bit are seen in Figure 2.11

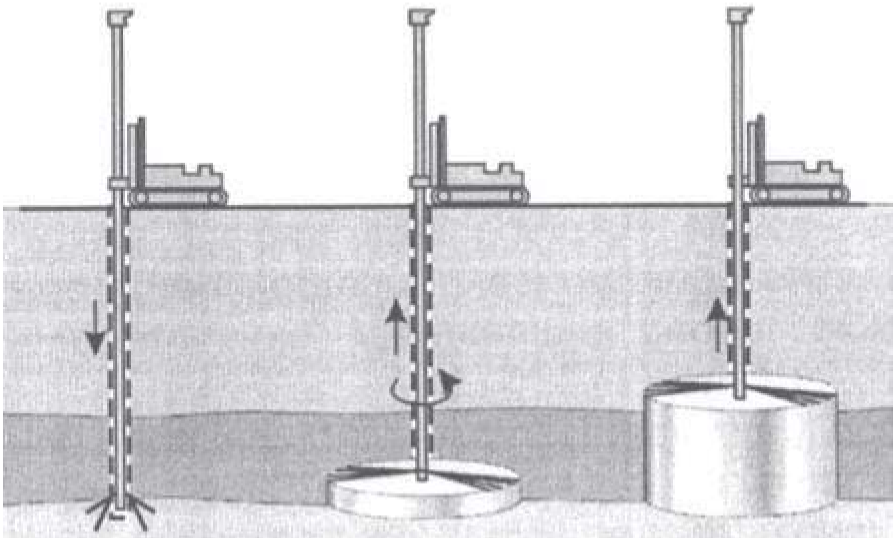


Figure 2.11 Drilling, forming a mixture with the ground, and column establishment (Tunçdemir, 2004).

2.4.2 Injection

In the study, when the determined depth is reached, the drilling and flooding process becomes ended. Hig- pressure Jet Grout syrup gains high speed while passing through nozzles. The Jet Grout syrup, which reaches high speed, tears the ground and mixes with the ground. The mixture, which is pressed by the rotary movements of the drilling tool, is formed in the shape of a column with a circular cross-section. In this way, a mixture (silcrete) with a very different structure from the natural ground will be obtained. A structure consisting of vertical circular columns or columns is formed by carrying out the rotational movement created by the drilling tool together with the previously planned and backward pulling movement provided at a constant speed (Çınar and Akkaya, 1994). The dimensions of the columns to be formed vary according to the characteristics of the soil, the rotation and withdrawal speed of the grouting set, the pressure of the injected grout, the flow rate of the grout, the nozzle diameter, and the number of nozzles (Çınar and Akkaya, 1994).

Figure 2.12 An image of the Jet Grout work performed in the study area.

2.5 Jet Grout equipment

Jet Grout equipment is constituted of a drilling machine, pump unit, mixer unit, and cement silo.

2.5.1 Jet Grout Drilling Machine

The punching machine must be capable of going down to the desired depth in the application project and forming the Jet Grout column in the desired dimensions (Çınar and Akkaya, 1994) (Figure 3.4). They are vehicles with high torque and pressure power, consisting of hydraulic systems. The drilling machine is selected as per soil properties with the known rotary and impact-rotary methods. As a bit set, “tritone” bits are used on hard floors and clay bits are generally used on soft floors. Jet grout drilling pipe (tige) is used for drilling and these rods are manufactured with high-pressure resistant material. Sealing elements resistant to 500 and 600 bar are also used in connection (additional) sleeves.

Figure 2.13 Drill pit for jet grout column production.

Figure 2.14 Punching machine for jet grout column

2.5.2 Jet Grout mixer unit

It consists of a mixer and a proofer that will electronically weigh and mix the injection mixture at the specified mixing ratio with sufficient capacity to feed the Jet Grout pump unit (Çınar and Akkaya, 1994) (Figure 2.11). The cement/water mixture ratio determined in the project is prepared and the mixing and resting process is performed. The prepared grout is kept in the resting boiler.

Figure 2.15 An image relating to jet Grout mixer unit.

2.5.3 Jet grout pump unit

It is a pump unit that can produce high pressure that can press the water and cement mixture to the ground with the pressure that can form a jet grout column of the desired diameter (Kauschinger et al., 1992) (Figure 2.16). After the drilling process is completed, a steel ball is sent to the rod. With this process, the direction of the grout is turned to the tool called "monitor" and carries the jet grout nozzles. It also sends the grout to the ground with the help of high-pressure injection pumps. The continuity of the pressure produced by the pump unit of the prepared grout creates high pressure by the suction and compression processes of the python mechanism, allowing the grout to pass through the nozzles and mix with the ground by breaking the natural structure of the ground.

Figure 2.16 An image relating to the jet grout pump unit

With the grout material given by pressure, which tearing and mixing with the ground, a circular section column is formed by the rotation and pulling action of the drilling tool. With this method, a column with high modulus and very different mechanical values is obtained compared to the natural soil. The rotation and lifting speed of the drilling tool is predetermined according to the column diameter and strength determined in the project. The dimensions of the columns you want to create depend on the characteristics of the ground, as well as;

- Nozzle diameter and quantity,
- Grout flow,
- Grout pressure,
- Lifting speed,
- Rotating speed

Jet grouting also depends on system parameters. During injection, a certain amount of injection material overflows from the periphery of the drill set (Figure overflowing nozzle). This situation creates excessive pressure of the grout mixed with the ground for the columns to be created, and this causes the excess pressure to come out between the diameter of the drill pipe and the hole diameter. This situation causes discontinuity in the dimensions of the columns to be created and problems in the construction of existing structures. To avoid such problems, in practice;

- Reduction of flow amount,
- Decreasing the injection pressure,
- Drilling with the pre-washing process especially on massive clay grounds,

and similar measures would be helpful if they are taken. The amount of grout material overflowing during the pressure grouting process depends on the type and permeability of the soil.

To be able to obtain the desired Jet grout columns, it is sent to the ground medium through nozzle holes whose numbers are between 1-4 and whose diameters vary between 1-3 mm. Nozzle diameter and number are among the parameters that significantly affect the column diameter. Figure relating to the nozzle:

2.5.4 Cement silo

Cement silo can store bulk cement with a capacity of at least 50 tons, which can feed the Jet Grout mixer unit at the level of need (Çınar and Akkaya, 1994).

Figure 2.17 An image relating to cement silo

To realize daily targeted production quantities and to achieve planned production quality;

- It must be smooth and dry to ensure that the construction site and machinery and personnel work efficiently,
- The area where the production will be carried out must be arranged in such a way that the drilling machine, concrete mixer, crawler crane, concrete pump, and heavy-duty machines do not sink more than 10 cm.
- For this purpose, it should be ensured that the production area remains dry by establishing a suitable surface drainage system, if necessary (Erkan Doctorate thesis, Konya 2013)

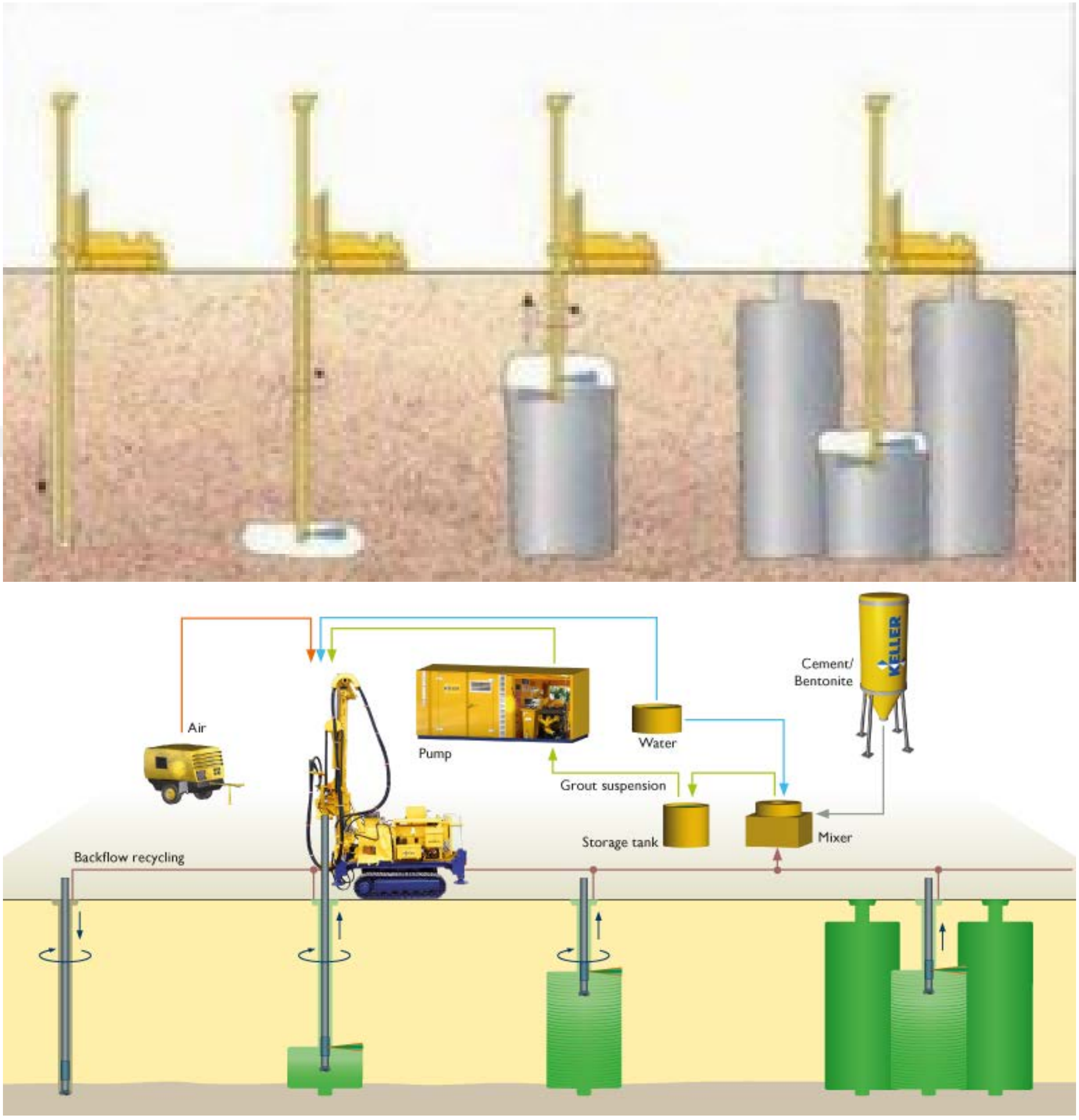


Figure 2.18 General picture of Jet and system

2.6 Jet Grout Application Methods

The jet grout method is divided into three according to the equipment features and the number of fluids used during soil improvement. These are named as a single fluid system (jet 1), double fluid system (jet 2), and three fluid systems (jet 3). Although these systems are similar to each other in terms of working principle, the different apparatus and mixture materials used constitute the main features that distinguish the systems from each other. During the selection of the system to be used in soil improvement; It is decided by considering factors such as soil properties, application purpose, application area, column diameter to be created, compressive Strength, and permeability.

2.6.1 Single Fluid System (Jet 1)

In the single fluid system, prepared injection material passes towards the ground with high pressure from injection pumps via rods, monitors, and nozzles and tears the floor with cement injection and as a result, relevant application method used for jet grout columns formed by pulling the rod using rotating while the injection is made and the injection continues is named as a single fluid system (jet1). It is the simplest injection system and its schematic illustration is given in Figure. One or two pieces of nozzles with varying diameters are used. Less number of nozzles causes for reduction of energy loss.

It can be easily implemented on soft and cohesionless substrates. Depending on the soil strength properties and selected parameters, small diameter columns are obtained. In this system, jet grout columns are formed around 100 cm on sandy and gravelly soils, and around 60-80 cm on soft clay soils.

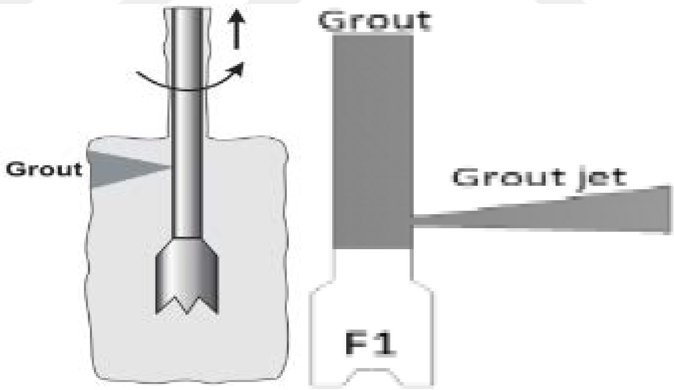


Figure 2.19 Single jet grouting system, F1 (HBI 2004; B Nikbakhtan 2007; B. Nikbakhtan, Aghababaei, and Pourrahimian 2007; B Nikbakhtan and Ghoshtasbi 2008; B Nikbakhtan and Osanloo 2009; B Nikbakhtan and Pourrahimian 2006)

2.6.2 Dual Fluid System (Jet2)

This method is different from the single fluid system (Jet1), where a second-rod kit is placed in the red thread used in the Jet 1 method and the cement injection sent from the injection pump passes through the inner rod. Compressed air produced at a pressure level of 5-12 bar is sent from the second rod through the compressor. Cement injection and air are simultaneously sprayed onto the floor from the nozzles. The applied air-jet- increases the efficiency of the system by reducing energy losses. The diameters of the jet columns formed by this method are 55-75% larger than the jet1 method. In the Jet 2 method, one air nozzle is generally used. This is because it is difficult for the operator to notice if one of the nozzles is clogged. The diameters of the jet grout columns created by this method are greater than 1000 mm in medium dense soils and greater than 1800 mm in loose soils. A general scheme of the method is given in Figure.2.20

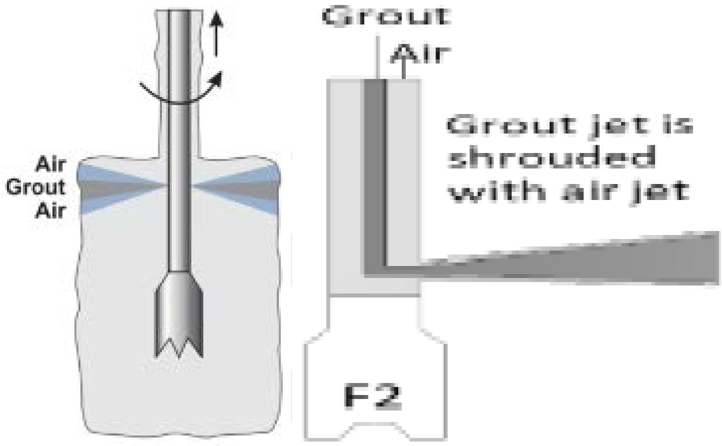


Figure 2.20 Single jet grouting system, F2 (HBI 2004; B Nikbakhtan 2007; B. Nikbakhtan, Aghababaei, and Pourrahimian 2007; B Nikbakhtan and Ghoshtasbi 2008; B Nikbakhtan and Osanloo 2009; B Nikbakhtan and Pourrahimian 2006)

2.6.3 Three Fluid System (Jet3)

The three-fluid system is more complex and advanced than other jet grout systems. There are three intertwined rods. Jet grout injection mixture passes through these rods from the inside to the outside, the water sent at the level of 30-80 bar, and the air sent at the level of 5-12 bar through the compressor through the outer rod. Air and water are injected from the same nozzle, and cement injection is injected into the ground from a different nozzle. Jet grout columns obtained by this method can reach diameters greater than 2m. The most effective method in cohesive soils is the Three Fluid (Jet3) method. The schematic representation of this method is given in Figure 2.21

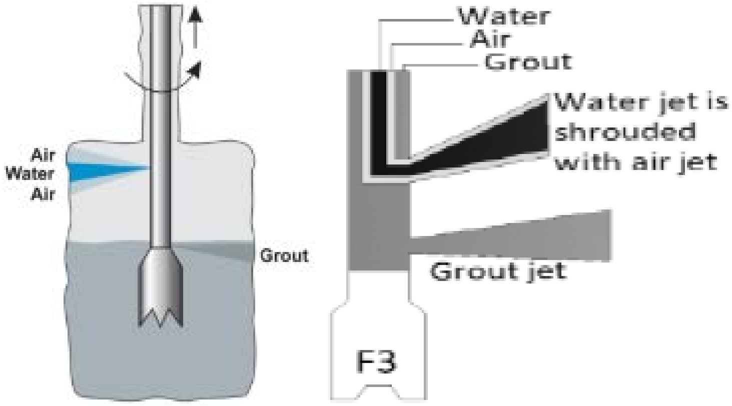


Figure 2.21 Single jet grouting system, F3 (HBI 2004; B Nikbakhtan 2007; B. Nikbakhtan, Aghababaei, and Pourrahimian 2007; B Nikbakhtan and Ghoshtasbi 2008; B Nikbakhtan and Osanloo 2009; B Nikbakhtan and Pourrahimian 2006)

The column diameter and strength properties are obtained according to the type of soil on which the jet grout systems can be applied and the jet system applied is seen.

Table 2.3 Comparison of jet grout systems (Yıldırım, 2019)

Ground Type	**Column Diameter**	**JG column endurance**
jet 1 system	60cm-90cm	
sand and pebble	110 cm	70-250 kg/cm2
clay	60cm-90cm	20-100 kg/cm2
jet 2 system	90 cm-180 cm	
sand and pebble	300 cm	35-140 kg/cm2
clay	90 cm-150 cm	10-70 kg-cm2
jet 3 system	150 cm-240 cm	35-105 kg/cm2
sand and pebble	90 cm-180 cm	10-50 kg/cm
clay		

2.7 Productıon Parameters of Jet Grout Column

With regards to the working parameters in jet grout column manufacturing, there are several parameters vary based on the type of soil, the chosen grout method, the state of the layer, the capacity of the machinery and elements to be used, the length of the column to be manufactured, the diameter of the column, and the column carrying capacity. The main ones out of these parameters are; injection pressure, dosage, withdrawal, and rotational speed. Generally, the selection of suitable parameters is made based on previously applied studies on soils (Fook-Hou Lee, 2005).

Before starting the jet grout column production, different parameters should be determined and trial columns should be made. By examining the columns made, the design parameters that are suitable for the structure of the ground, the diameter of the column, and the compressive strength determined in the project, the desired length, and discontinuity of the column are provided, and economical design parameters should be preferred as manufacturing parameters. A study of these parameters is given in the chart.

Table 2.4 Production parameters of Jet Grouting method (Lunardi, 1977)

System	Injection Type	Pressure (bar)	No of nozzles and dia (no, mm)	Pulling speed (cm/min)	Rotation speed (rpm)	Water/Cement rate	Pump capacity (lt/min)
JET1	Cement	400 - 550	1-2 x 2-5	15-100	5-15	1.0-1.5	70-600
JET2	Cement	400 - 550	1-2 x 2-5	10-30	4-8	1.0-1.5	70-600
	Air	10 - 12	-	10-30	-	-	4,000 – 10,000
JET3	Cement	50-100	1-2x4-5	6-15	4-8	1.2-1.5	80-200
	Air	10-12	-	6-15	-	-	4.000-10.000
	Water			6-15	-	-	40-100

"The variation of the strength values of jet grout columns in various soil types with the applied manufacturing parameters by Stoel (2001) is given in Table 2.5". In this section, the parameters that are effective in the creation of jet grout columns are explained.

Table 2.5 Change of jet column resistance values with production parameters (Stooel 2001)

Ground Type	Free Compressive Strength (MPa)	
	Lower Limit	Upper Limit
Organic Soil	1	6
Clay	3	7
Silt	5	15
Sand	10	40
Pebble	10	40

Different change graphics were obtained between jet energy and column diameters in case different production methods are tried depending on the ground type.

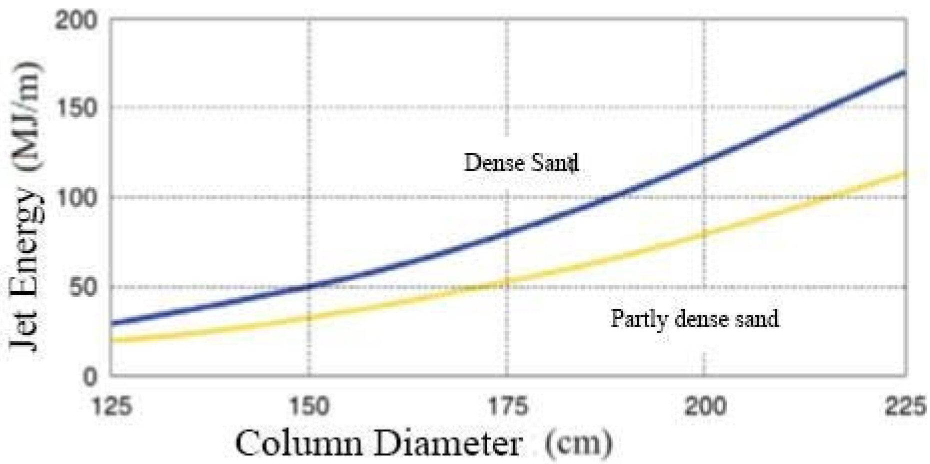


Figure 2.22 Graph of jet energy and column diameter (SoletancheBachy company)

Shape Jet Energy-Colon Diameter Relations on cohesion-free Floors (Soletanche Bachy).

It is seen that on grounds with no cohesion column diameter increased within the increase in jet energy.

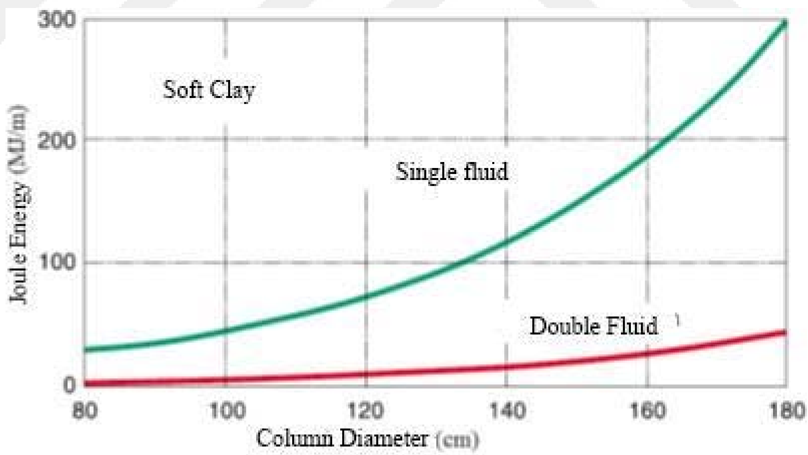


Figure 2.23 Jet Energy-column diameter relationship in cohesive soils (SoletancheBachy company)

In soft clays, more energy is needed to form a large diameter column with a single fluid system than with a dual fluid system.

2.7.1 Injection Pressure

Injection pressure is one of the most effective parameters during manufacturing in obtaining the diameter of the jet grout column. Jet grout manufacturing can be divided into three parts according to the injection pressure value.

•Low-pressure injection in 150 – 250 bar interval

• Medium pressure injection in 250–350 bar interval

• High-pressure injection in 400 – 600 bar interval

There is a direct relationship between the injection pressure and the diameter of the column as seen in Figure. As the pressure increases, the column diameter also increases. Pressure is necessary but not sufficient to obtain a homogeneous column diameter desired to be manufactured. To obtain the desired homogeneous column and diameter, the tensile and rotational speeds are also effective in the formation of the column as it is time-related. (Figure 2.4) (Melegary and Garassino, 1997)

2.7.2 Rod Lifting and Rotating Speed

Rod rotation speed and rotating speed are among the parameters that affect jet grout column manufacturing and design. It is formed by lowering the rods to the desired depth of the designed jet grout columns and lifting them from the bottom with the rotation of the rods around their axis at a certain speed. For the column to be manufactured to be formed, the rotation speed must be at a certain value and the speed of the rod drawing must be adjusted to ensure continuity in the entire column to be manufactured. The rotation speed of the rod can be up to 5-30 rpm. In some special projects, this value can be up to 35rpm. The drawing process is done in two different ways depending on the characteristics of the drilling machine. These are Gradual pull and continuous pull. Some machines may have both features. To achieve the best result in gradual lifting, it is obtained by moving 4 cm in each step and waiting 5-11 seconds. In the continuous drawing, the rods are pulled from the bottom up with a constant drawing speed adjusted on the drilling machine. (Melegary and Garassino 1997, See 2007)

Due to the low tear resistance of cohesionless soils with the jet grout method, the mixing of the grout material with the ground occurs in a short time and the column to be formed is manufactured in a shorter time. On the other hand, in cohesive soils, it takes longer for the grout material coming out of the nozzles to tear the ground and to obtain a homogeneous column by mixing. Therefore, the selection of drawing and rotational speeds depends on the soil properties and the amount of grout material to be injected. The selection of shrinkage and rotational speeds depends on the condition of the ground to be improved, water content, consistency, and the type of jet grout to be applied. Therefore, in Jet2 and Jet3 methods, a longer time is needed as larger diameters are targeted and therefore larger volumes need to be rehabilitated. In the jet grout study conducted by Nikbakhtan et al. (2010), the relations between rod drawing speed and uniaxial compressive strength are given.

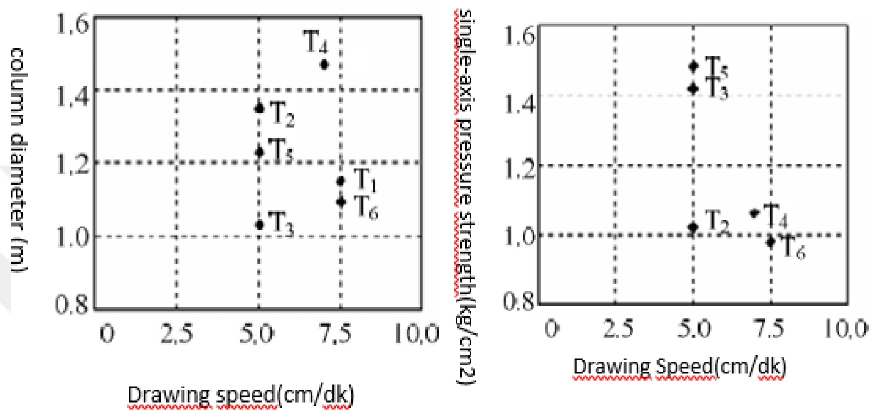


Figure 2.24 Impact of pulling speed on jet grout column diameter and single-axis compressive strength (Nikbakhtan et al 2010)

2.7.3 Water/Cement (W/C) ratio

Jet grout injection mixtures are defined as the water/cement ratio (W/C) on a weight basis, and this ratio varies between 0.6 and 1.3 in practice. The water/cement (W/C) ratio is taken as 1.0 as a standard. The specific gravity of the prepared injection material is in the range of 1410-1570 kg/cm^3. The amount of cement in 1 m3 of improved soil varies between 350-700 kg/m^3. It can be taken as 440kg/m^3 on average. This ratio may vary according to the selected jet grout method and the final strength of the columns. It is possible to add some additives into the injection mixture. For example, it is not considered appropriate to decrease the W/C ratio below 0.7, except in the case of using bentonite in the mixture for the formation of waterproof plastic grout curtains. (Melegary and Garassino, 1997).

Table 2.6 Jet grout column bearing capacities on different types of soils (Melegary and Garassino, 1997)

Ground Type	**Jet grout column carriage capacities on the ground (kg/cm^2)**
Organic Ground	3
Clay	18-30
Silt	30-45
Sand	60-90
Gravel	100

2.8 Application Place of Jet Grout Columns

Ground reinforcement with the Jet Grout method is used in many different areas. It is an important improvement method in bringing this method to the capacity to carry the desired service loads in different engineering problems. The usage areas of the jet groud method are listed below.

- Bearing capacity and displacement control under foundations, vertical loads, high spring loads.
- Capacity to carry service loads and displacement control as a pressure element under the areas to be filled
- In pools, underground water tanks, and water structures, it is used as a pulling element by being equipped with reinforcement to neutralize the buoyancy force that may occur under the foundation.
- It is used to carry vertical ground thrusts by being equipped with reinforcement in the areas to be excavated.
- It is used in anchorage structures and excavations with special reinforcement as an anchoring element.
- It is used as a cofferdam closing element between carrier elements in excavations where the underground water level and ground permeability are high.
- It is used as a buttress element in excavations to be made in soft clays to form the excavation base level before excavation.
- It is used as a plug element for the control of groundwater that may come from the foundation level to the foundation in places where the groundwater level is high.
- It is used as a ground reinforcement element to provide stability on slopes.

- It is applied to improve the ground of the upper part of the tunnel in tunnels to be built close to the surface on soft soils.
- Increasing the number of safety in places with liquefaction potential is also applied as a result of limiting the vertical and lateral displacements that may occur as a result of earthquakes by carrying a significant part of the shear stresses on the ground. (Durgunoglu, 2004).

Jet grout application pictures are given in Figures 2.25 and 2.26

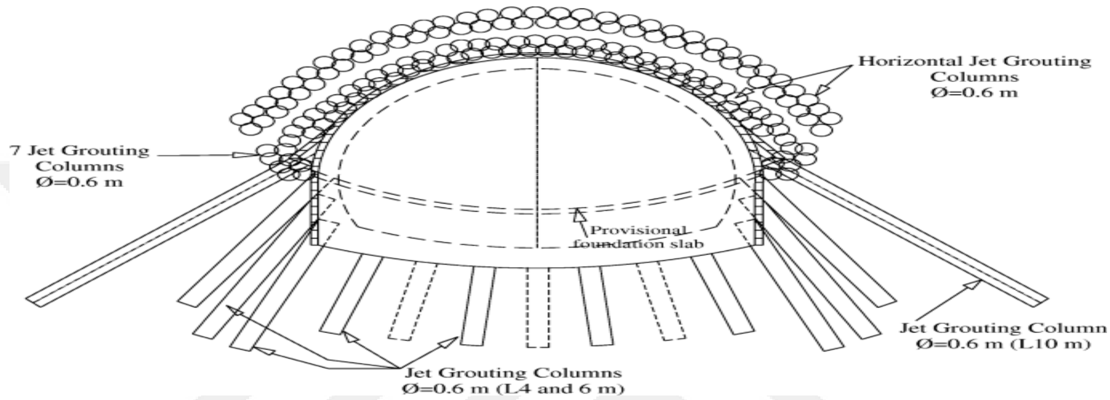


Figure 2.25 Application areas of the figure Jet grout column (Soletanche Bachy)

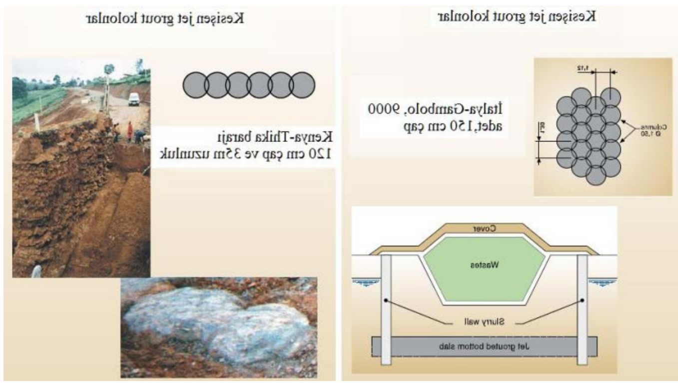


Figure 2.26 Application Areas of Shape Jet Grout Column (Soletanche Bachy)

CHAPTER 3

MATERIALS AND METHODS

3.1 Site description

The place where the study was carried out is the construction site of Kahramanmaraş Province Türkoğlu District Metropolitan Municipality Türkoğlu Fire Department. Jet 1 method was preferred in the ground reinforcement of the Fire Brigade Construction area and 3 columns were manufactured with the jet1 method on the alluvial fill ground in the same region.

Figure 3.1 Study area

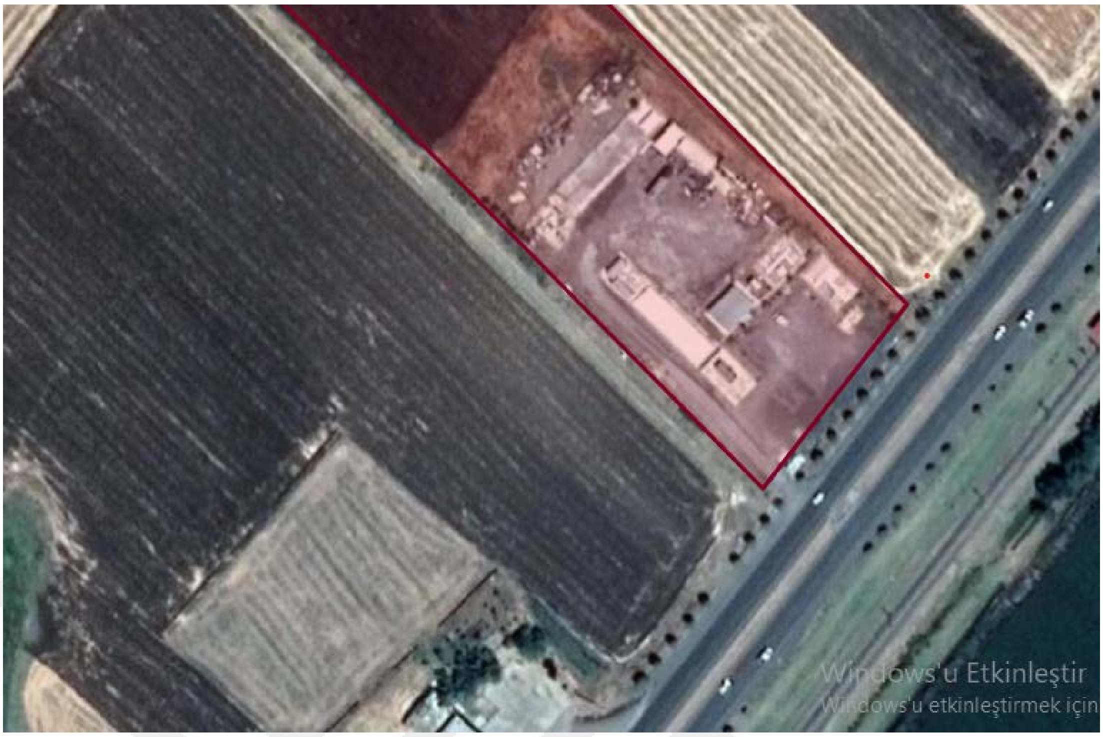


Figure 3.2 Area of testing

3.2 Testing Program

As mentioned in the literature summaries, manufacturing is affected by parameters such as pressure, rotation speed, drawing speed, the water-cement ratio in jet grout column manufacturing. For this reason, the table of the study is shown in the figure.

Table 3.1 Testing program

	Pressure P (bar)	**Water/Cement Ratio w/c**	**Lifting Speed (cm/min.)**	**Rotational Speed (rpm)**
Alluvial Soil	300	1	30	15/20
Alluvial Soil	400	1	30	15/20
Alluvial Soil	450	0.8	30	15/20

3.3 Features of Machine Used in Production of Jet Grout Column

The fire brigade construction area working field was tried to be kept neat and dry so that the machinery and personnel could work, as a result of which the planned daily production amount could be made and the production quality was achieved. The MDT MC 160 B machine that we will manufacture is used. By providing fast and reliable solutions being technically innovative for improving maneuvre capacity, reliance, and high productivity regarding the drilling tower of the machine it is reliably enabled for project completion. In the project designing phase active and passive safety devices at maximum reliance were stipulated in the project. It is enabled to meet site needs regarding operator and other personnel using design options for MDT MC 160 B.

It is the 2007 model MDT 160 B machine we use in the field. The intended use is for jet grout drilling and ground improvement. The machine has 240 HP engine power, 6 cylinders, and a turbocharger. A pallet with a diameter of 650 mm and a length of 11 m is used for safe movement in the field. The diameter of the drill rod is 90 mm. The maximum performance depth is 21 m and the drilling speed is 0.01 m/s. To ensure the regular operation of the machine, the operator using the drill and the operator of the pump machine should work in coordination.

Figure 3.3 Jet grout testing machine

3.4 Features Of Cement Used In Jet Grout Production

Portland Composite Cement- 42.2 R CEM I was used. According to the TS EN 197-1-2012 standard, only portland cement consists of clinker and gypsum. It is suitable for general use and is also preferred in cold weather.

Figure 3.4 Picture of cement

3.5 Sieve Analysis

It is important in determining the grain sizes of soils, in their classification, in determining the uniformity and gradation coefficients, in soil mechanics, in the selection of core and filter materials in dams. Determining the percentage of grains (gravel, sand, silt, clay) in the soil also provides important information about the other engineering properties of the soil.

As a result of the sieve and hydrometer analysis, the weight percent of the grains of different sizes that make up the material are determined and the "Grain Size Distribution Curve" is drawn by using the "grain size" on the logarithmic axis and the "percent under sieve weights" on the arithmetic axis. By using this curve, the amounts of gravel, sand, clay, and silt that make up the material are determined and soil classification is made for different uses.

The dry sample mass of the sample we took was weighed as 2572.63 gr. The dry sample remaining after washing was weighed 2274.62 g. The sieve range we have chosen is 3" with No 200. After sieving the sample for at least 15 minutes for each sieve, the sample taken was divided into two as the dry sample remaining on the sieve and the sample that passed, and it was written in the form of a table below.

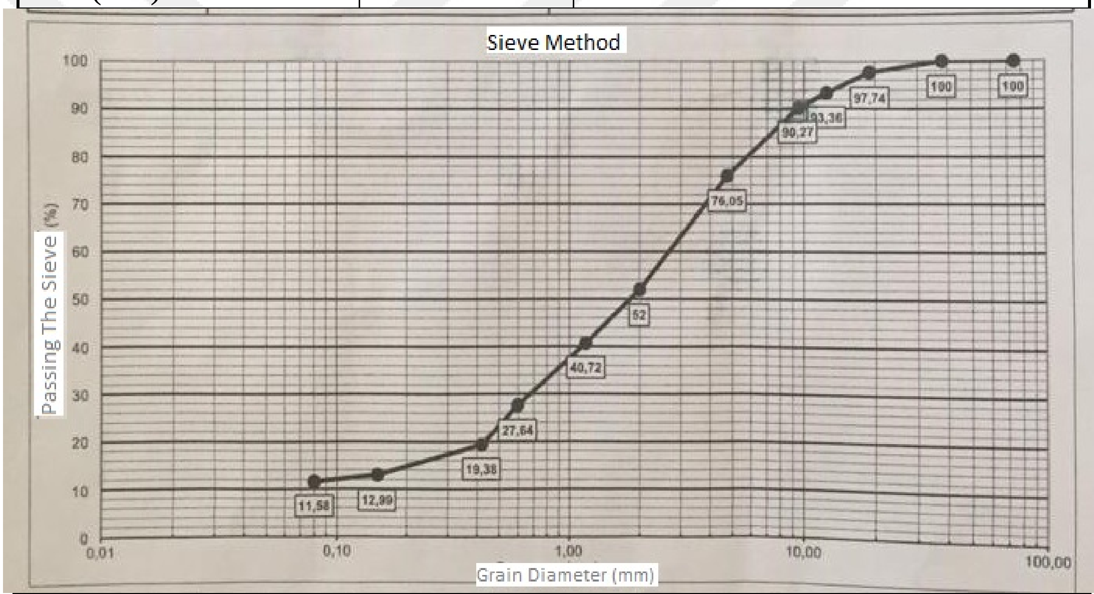
Table 3.2 Sieve Analysis Test Form (With Washing)

Sieve Analysis Test Form (With Washing)					
Dry sample mass (gr)		2572.63			
Dry sample after washing (gr)		2274.62			
Sieve Name	**Sieve aperture**	**Sample remaining on the sieve**	**Remainder**	**Total remaining**	**Total passing**
	0.7	**(gr)**	**(%)**	**(%)**	**2.25**
3"	75.000	0.000	0.00	0.00	100.00
11/2"	38.100	0.000	0.00	0.00	100.00
3/4"	19.100	58.250	2.26	2.26	97.74
1/2"	12.500	112.560	4.38	6.64	93.36
3/8"	9.500	79.450	3.09	9.73	90.27
No. 4	4.750	365.980	14.23	23.95	76.05
No. 10	2.000	618.640	24.05	48.00	52.00
No.16	1.180	290.260	11.28	59.28	40.72
No.30	0.600	336.350	13.07	72.36	27.64
No.40	0.425	212.460	8.26	80.62	19.38
No. 100	0.150	164.550	6.40	87.01	12.99
No. 200	0.075	36.120	1.40	88.42	11.58
Rubble (%)	0.00		Sand (%)	64.46	
Gravel (%)	23.95		Thin (%)	11.58	
Total (%)	100.00				
D10 (mm)	0.08		Uniformity coefficient, Cu = D60/D10		38.80
D30 (mm)	0.70		Coefficient of continuity, Cr = (D30D30)/(D60D10)		38.81
D60 (mm)	2.91				

We determined the sieve analysis curve as per the above table and we made ground classification accordingly.

Table 3.3 Sieve Analysis Curve Form (With Washing)

Sieve Analysis Curve Form (With Washing)			
Rubble (%)	0.00	Sand (%)	64.46
Gravel (%)	23.95	Thin (%)	11.58
Total (%)	100.00		
D10 (mm)	-	Uniformity coefficient, Cu = D60/D10	-
D30 (mm)	-	Coefficient of continuity, Cr = (D30D30)/(D60D10)	-
D60 (mm)	-		



Sieve	3"	11/2"	3/4"	1/2"	3/8"	No. 4
Aperture Size (mm)	75.000	38.100	19.100	12.500	9.500	4.750
The Remainder (%)	0.00	0.00	2.26	4.38	3.09	14.23
Total Passing(%)	100.00	100.00	97.74	93.36	90.27	76.05
Sieve	No. 10	No. 16	No.30	No.40	No. 100	No. 200
Aperture Size (mm)	2.000	1.180	0.600	0.425	0.150	0.075
The Remainder (%)	24.05	11.28	13.07	8.26	6.40	1.40
Total Passing(%)	52.00	40.72	27.64	19.38	12.99	11.58

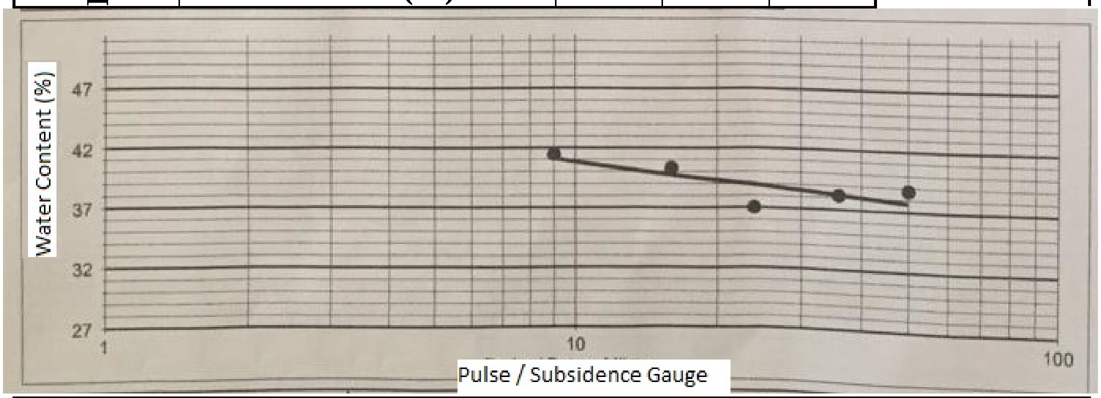
In our sieve analysis, the soil classification is such that gravel has a ratio of 23.95%- and has a ratio of 64.46%, and fine material has a ratio of 11.58%. The uniform coefficient (Cu) determined by the grain diameters is 38.80 and the continuity coefficient (Cr) is 2.25.

3.6 The trial of the consistency limit and the water content on the floor

After determining the consistency limit, liquid limit, and plastic limit, I set them in the table below.

Table 3.4 Atterberg limits test form

Atterberg Limits Test Form						
Liquid Limit		Casagrande Method				
		1	**2**	**3**	**4**	**5**
	Cup No	10	31	8	86	98
	Pulse (number)	50	36	24	16	9
	Wet Sample + Cup (gr)	47.110	45.580	47.970	44.950	39.840
	Dry Sample + Cup (gr)	42.230	40.550	42.980	39.440	35.220
	Water Content (gr)	4.880	5.030	4.990	5.510	4.620
	Cup (gr)	29.470	27.200	29.310	25.60	23.940
	Dry Sample (gr)	12.760	13.350	13.670	13.840	11.280
	Water Content (%)	38.2	37.7	36.5	39.8	41.0
Plastic Limit		**1**	**2**	**3**		
	Cup No	34	80	102		
	Wet Sample + Cup (gr)	47.560	36.770	42.160		
	Dry Sample + Cup (gr)	44.080	33.740	39.180		
	Water Content (gr)	3.480	3.030	2.360		
	Cup (gr)	30.850	23.950	26.370		
	Dry Sample (gr)	13.230	9.790	13.430		
	Water Content (%)	26.3	31.0	17.6		



Liquid Limit	38.47
Plastic Limit	24.94
Plasticity Limit	13.53

I found water content a percentage difference between wet samples and dry samples and I got information about physical and mechanical features of the ground.

Table 3.5 Water content test form

Water Content Test Form			
	1	**2**	**3**
Cup No	26	-	-
Wet Sample + Cup (gr)	1397.130	-	-
Dry Sample + Cup (gr)	1341.560	-	-
Water Content (gr)	55.570	-	-
Cup (gr)	191.650	-	-
Dry Sample (gr)	1149.910	-	-
Water Content (%)	4.830	-	-
Mean Water Content (%)	4.83		

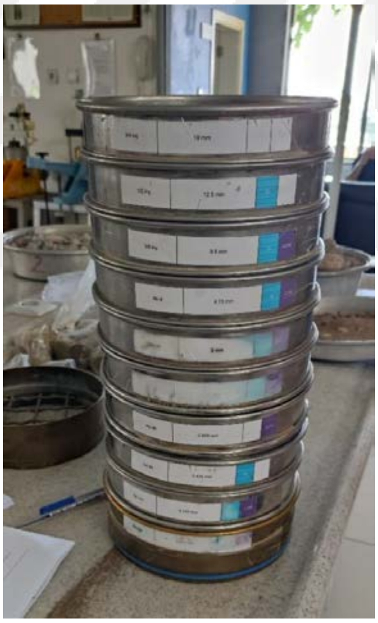


Figure 3.5 Picture of sieves

Figure 3.6 Picture of the weighted sample

3.6.1 Plastic Limit

The boundary water content of the soil from the plastic form to the semi-solid form is called the plastic limit. Cylinders with a diameter of 3 mm and a length of up to 10 cm are formed by kneading some soil with water. These are rolled on a frosted glass or flat tile. Thus, partially dehydrated cylinders can no longer continue in motion due to the reduced plasticity of the ground and are split into various pieces to break. The water content of the soil in this state is called the plastic limit. I determined the consistency limit in the table below after determining the liquid limit and the plastic limit.

Figure 3.7 Plastic limit test

3.6.2 Liquidity Limit

The liquid limit is the water content at the moment when the fluidized soil turns into a plastic state. The diameter of the place where the liquid limit cup hits should be less than 10 mm. The drop height of the liquid limit container should be 10±2 mm.

The geometry of the sample inside the liquid limit container must be the same as the geometry of the water in the container. The experiment was carried out by paying attention to these substances.

Figure 3.8 Liquid limit test

3.7. Removing and Sampling the Column

The manufactured columns were removed with the help of JCB and the core sample was taken by making height measurements and diameter measurements. Columns are manufactured in 3 meters. The manufactured columns are divided in half from the middle point to be about 1.5 m. The division was named as points A, B, C, and D from the top of the column to the ground. In addition, three core samples taken from each point were named A1,A2,A3,B1,B2,B3,C1,C2,C3 and D1,D2, D3 from left to right.

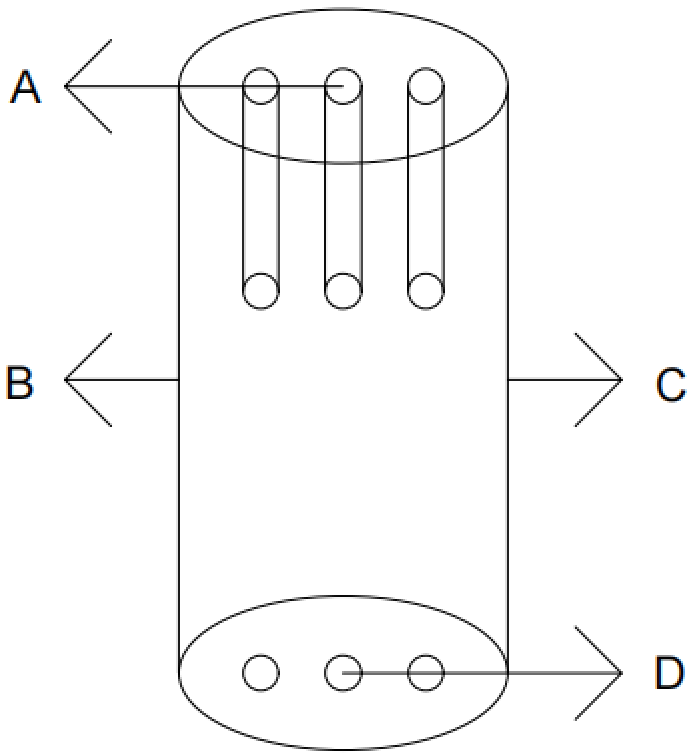


Figure 3.9 Schematic image of manufactured JG column

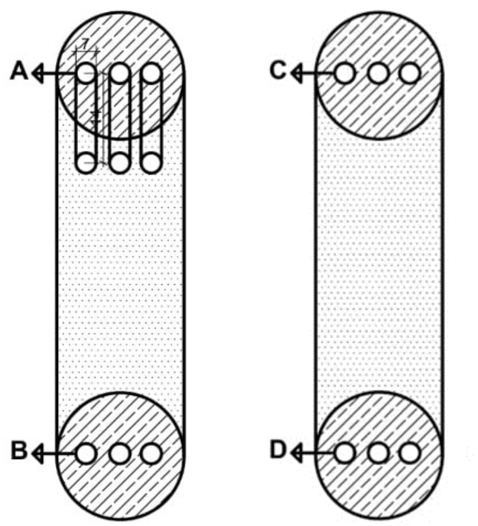


Figure 3.10 Separation of manufactured JG columns from the middle

CHAPTER 4

TEST RESULTS AND DISCUSSION

The production stages of jet grout columns produced by the research program, measuring the diameter and height of each column, taking core samples, performing unconfined compressive strength tests on the core sample, evaluating the geometry of jet grout columns are explained below.

4.1 Production and Extraction Process of Jetgrout Columns

After the necessary preparations were completed for the production of the JG columns of three different combinations, which were decided according to the design table, on the field, the production phase was started. It is shown in Table 4.1. As seen in the manufacturing design table, injection material was prepared for two different water/cement(W/C) ratios (0.8 and 1.0). With the help of the prepared grouting material driller, the rod was descended four meters from the ground, and the production of the column was started by keeping the different pressure (300, 400, 450 bar) and the lifting speed (30 V) and rotational speeds (15/20 cm/min) the same, and the production was completed when one meter remained to the ground. A distance of 220cm to 230cm is left between each column.

As described above, three jet grout columns were manufactured with different injection pressure, water/cement ratio, drawing speed, and rotational speed.

Table 4.1 Column production parameters

	Pressure P (bar)	**Water/Cement Ratio w/c**	**Lifting speed V (cm/min.)**	**Rotation Speed (rpm)**
Alluvial Soil	300	1	30	15/20
Alluvial Soil	400	1	30	15/20
Alluvial Soil	450	0.8	30	15/20

Figure 4.1 JG column production stages

After the Jet Grout columns were formed, it was waited for 28 days to ensure sufficient setting. No treatment was applied to the columns during curing. At the end of 28 days, the columns were removed from the ground with the help of JCB. The condition of the columns after they are removed from the ground can be seen in Figure 4.2

Figure 4.2 Extraction of samples

4.2 Measurement of Diameter of Jet Grout Columns

At the end of the 28-day waiting period, the diameter and height of the jet grout columns removed from the ground were measured. The diameters of the produced columns are shown in Table 4.3 with 300 bar, in Table 4.3 with 400 bar, and in Table 4.4 with 450 bar. The manufactured JG columns were divided into two at a medium distance (1.5 m). Diameter measurements were made in the upper part, middle part, and lower part.

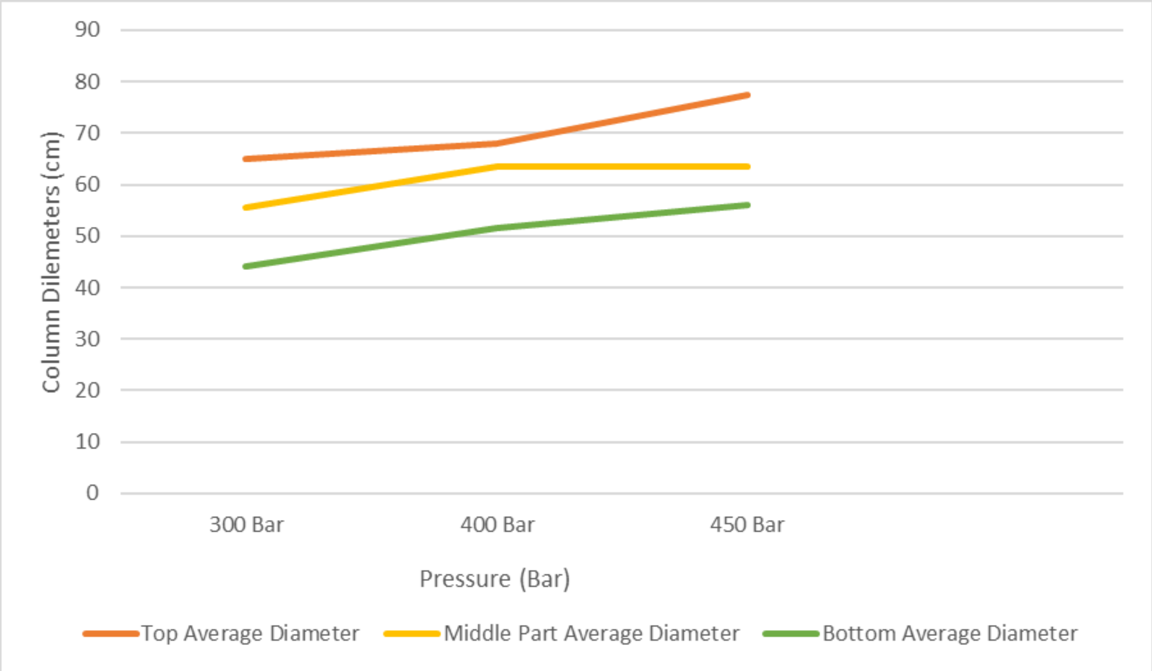


Figure 4.3 JG column diameter averages produced with 300,400,450 bar

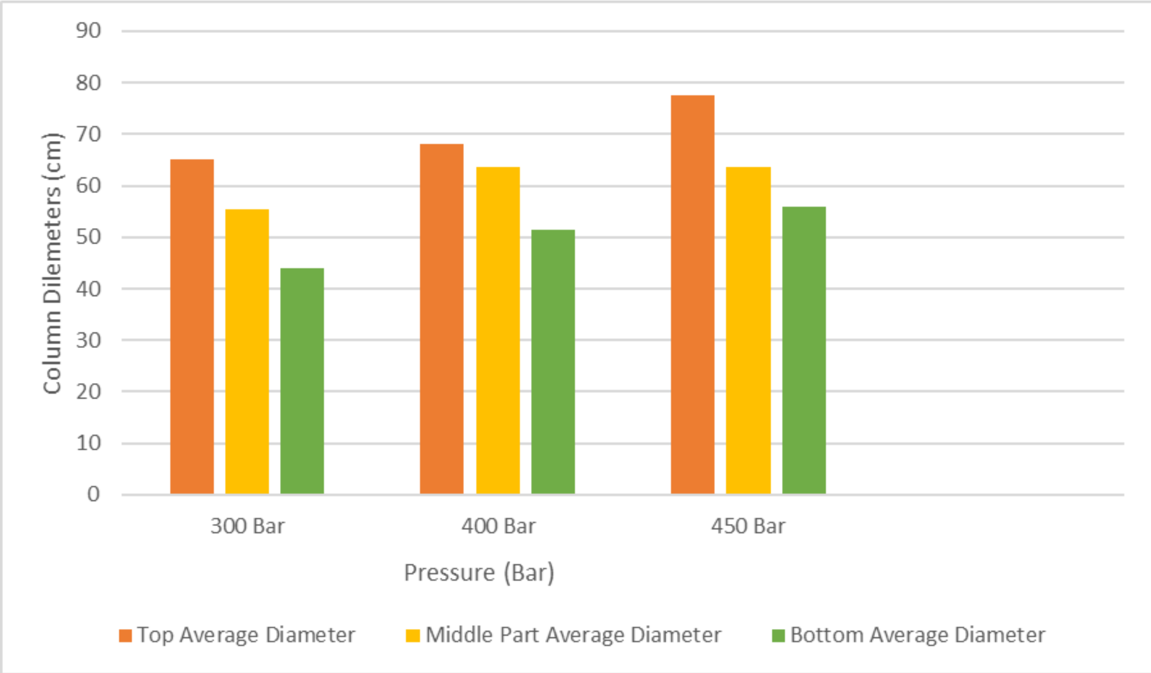


Figure 4.4 Average diameter measurement of JG columns

Table 4.2 JG column diameter produced with 300 bar

Point A	Horizontal 64 cm	Vertical 66cm	Average 65 cm
Point B	Horizontal 56cm	Vertical 55cm	Average 55.5 cm
Point D	Horizontal 46cm	Vertical 46 cm	Average 44 cm

Table 4.3 JG column diameter produced with 400 bar

Point A	Horizontal 67 cm	Vertical 69cm	Average 68 cm
Point B	Horizontal 62cm	Vertical 65cm	Average 63.5 cm
Point D	Horizontal 51cm	Vertical 52 cm	Average 51,5 cm

Table 4.4 JG column diameter produced with 450 bar

Point A	Horizontal 77 cm	Vertical 78cm	Average 77,5 cm
Point B	Horizontal 65cm	Vertical 62cm	Average 63,5 cm
Point D	Horizontal 55cm	Vertical 57 cm	Average 56 cm

Figure 4.5 Diameter measurement of the vertical and horizontal column

It is observed that the diameter of manufactured jet grout columns also increases with increasing injection pressure. It has also been observed that the diameter of the column increases from the bottom to the top. It is believed that the upward pressure of the ground decreases as a reason for this. As mentioned in the literature, as the military and Garassino noted (1997), as the pressure and injection waiting time increase, the diameter of the column also increases. Study of the researcher; it was observed that the diameters of the jet grout columns that we manufactured with 450, 400, 300 bars were close to the values specified by the researcher (Figure 2.4).

In the comparison of the Jet grout systems mentioned in the literature section, it was noted that the column diameters manufactured with the Jet 1 system are between 60 cm and 90 cm inline within the study.

As mentioned in the literature, the relationship between column diameter and pull speed is observed. Moseley's research also observed that as the rate of withdrawal of rod increases, there is a decrease in Column diameter, and in our study, there is no decrease in Colon diameter because the rate of withdrawal is constant, and we think that this coincides with the study with the Melegary and Garassino research.

When we examine the manufactured columns, it is seen that the column made with 450 bar has a more homogeneous diameter and a more compact structure than the other columns. A column made with 300 bars was formed in the form of a spiral (leaf) column, which could not provide homogeneity in its structure and diameter. This indicates that pressure is very important in the performance of jet grout columns.

Figure 4.6 JG column manufactured with 450 bar

Figure 4.7 JG column manufactured with 300 bar

4.3 Taking Core Samples in JG Columns and Free Pressure Experiments

After taking the necessary photographs to measure the diameter of the manufactured JG columns, the columns were divided into two equal parts. The ends of the dividing columns are named A, B, C, and D. A total of 3 core samples were taken from each section, 12 core samples from each column, and 36 core samples in total. The core samples taken were carefully cut with a height/diameter ratio of two or close to two and subjected to unconfined pressure tests. Free pressure experiments were subjected to free pressure experiments in the KSU laboratory.

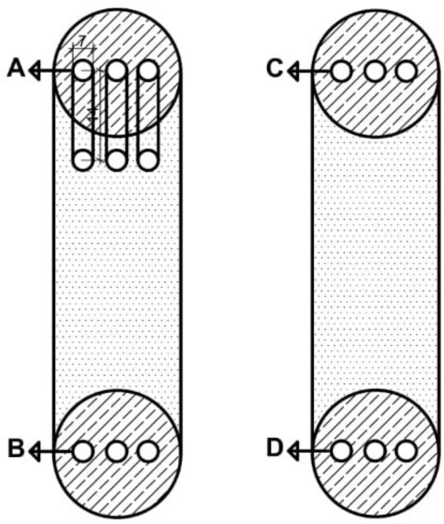


Figure 4.8 JG Illustration of sample taking places of columns

Samples taken from manufactured jet grout columns were named A1, A2, A3, B1, B2, B3 at point a, C1, C2, C3 at Point C, and D1, D2, D3 at the point from left to right.

Figure 4.9 Taking core samples of JG columns

The samples we took were tested for 28 and 90 days of unconfined pressure. Samples were taken from A1, A3, B1, B3 at point A, and D1, D3 at point D in figure 4.6, which were subjected to a 28-day free pressure experiment. Samples subjected to a 90-day free pressure experiment were taken from points C1, C2, C3 of 3 columns manufactured after the JG column in Figure 4.6 was divided into two. In addition, samples taken from points A2, B2, and D2 were subjected to 90-day curing.

4.3.1 28 and 90-day free pressure test results

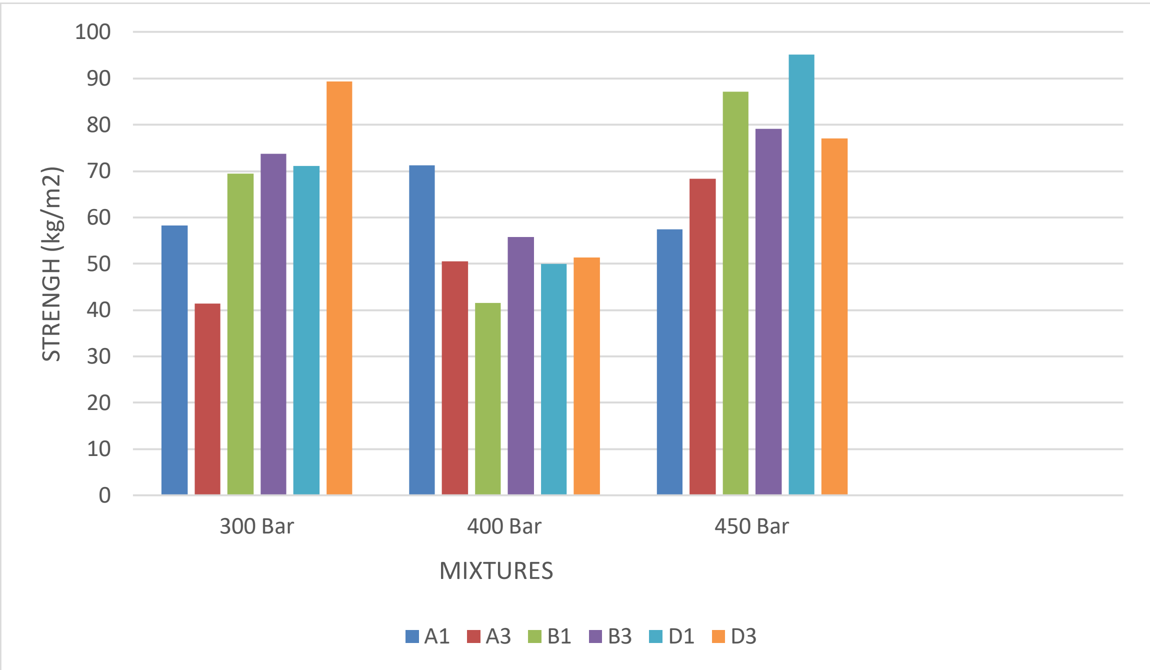


Figure 4.10 28-day pressure experiments of JG columns

Manufactured columns when the results of the 28-day free pressure experiment were examined, the compressive strength increased in the JG column with 300 bar when it landed east from above to the bottom of the column. It is observed that the compressive strength of the column printed with 400 bar is approximately the same. The water/cement ratio, tensile and rotational speeds of the columns manufactured with 300 and 400 bar are manufactured in the same way. Compared to the two columns, it is seen that the pressure resistance of the column manufactured with 300 bar is greater. It is believed that this is because the floor is less mixed into the column due to the lack of bar.

Samples taken from Point C were subjected to a free pressure experiment taken from points C1, C2, C3 and A2, B2, D2, and their results are given in the table below.

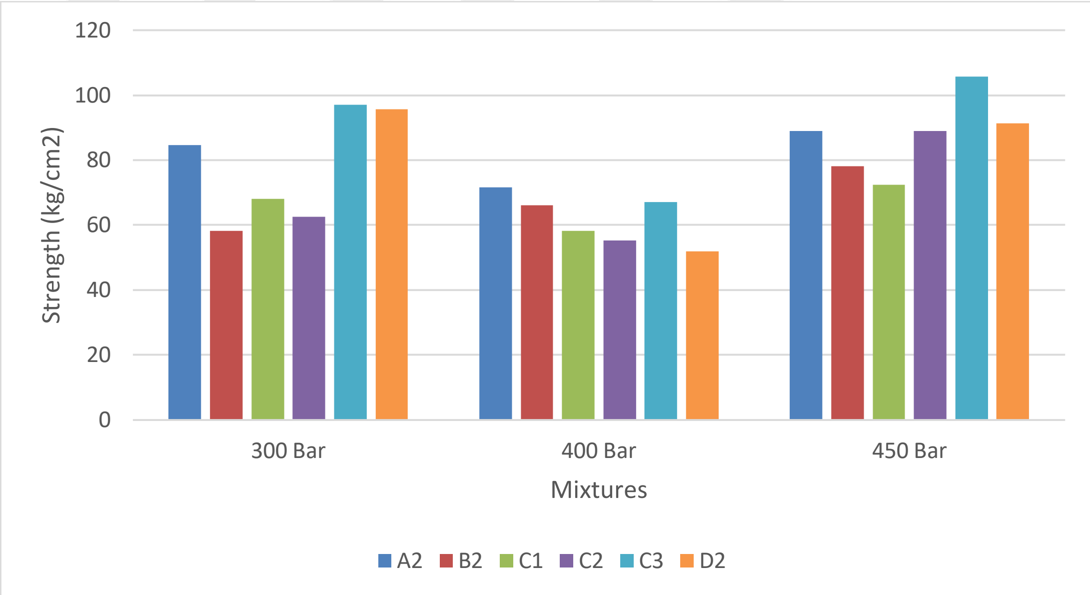


Figure 4.11 90-day pressure experiments of JG columns

When the results of the 90-day unconfined compression test were experiment were examined, it was observed that the compressive strength increased. It is believed that this is because the columns receive an outlet. It is seen that the column manufactured with 300 bar has more compressive strength than the column manufactured with 400 bar It is seen that the bearing power of the column printed with 450 bar is greater than that of the other two columns. The reason is that the water/cement ratio is thought to be 0.8. As mentioned in the literature, Bauman mentioned that there is a compressive strength of 6-10 MPa on gravelly sandy floors, close to his study, and approximately

55-95 kg/cm^2 values are observed as a result of our study. The water/cement ratio of the column manufactured with 450 bar was determined as 0.8. Approximately the same conclusions were reached with Baummann's study. In addition, Melegary and Garassino observed that the results within the values specified in the studies of jet grout column carrying capacities formed on different types of floors were achieved.

When the diameter measurements of the JG columns manufactured with 300 to 400 bar, which are the same as the water/cement ratio, lifting speed, and rotation speeds, were examined, the diameter of the column manufactured with 400 bar was greater. The reason for this is thought to be related to the height of the bar pressure of the gorot injected into the ground. In addition, when the compressive strength was examined, it was found that the column manufactured with 300 bars had more compressive strength than the column manufactured with 400 bars. It is believed that the Grot injected with high pressure breaks the ground further, entering the column, causing the column's compressive strength to drop.

When the columns are manufactured with 300, 400, and 450 bars are examined; As the bar increases, the diameters of the columns are increasing. When pressure strengths are examined, it is seen that the column manufactured by 4150 bar is 0.8, which is 0.8, it is seen that the pressure is more than 0.8 compared to other columns. Cause Cement ratio is considered to discard the pressure resistance.

Table 4.5 Change of strength values of jet columns with manufacturing parameters (Stoel, 2001)

Ground Type	**Free Compressive Strength (MPa)**	
	Lower Limit	**Upper Limit**
Organic Soil	1	6
Clay	3	7
Silt	5	15
Sand	10	40
Pebble	10	40

Figure 4.12 General appearance of samples subjected to free pressure experiment

CHAPTER 5

CONCLUSIONS

In the thesis study, full-scale jet grout columns were manufactured in the field to investigate the effect of injection pressure and w/c ratio on the diameter of the column and compressive strength. Tests were made on fine-grained soil with three injection pressure and two w/c ratios. Following results were obtained from the experimental work entered.

1- The results indicated that unconfined compressive strength of the silcrete increased with increased injection pressure
2- It was observed that injection pressure has an important effect on the dimeter of silcrete columns manufactured in the field. Higher the pressure larger the diameter for the same soil type.
3- It was also found that diameters of the column manufactured with the same injection pressure were not the same at all depth. It is larger at the near ground surface; but smaller at higher depth.
4- Test results showed that curing time has an important effect on the unconfined compressive strength of the hardened jet grout column. Longer the curing time higher the compressive strength as expected. The 90-day compressive strength value of the JG column is greater than the strength values of 28-day cured samples.
5- It has been observed that as the pressure of JG columns increases, the diameter of the column also increases.
6- Higher strength was observed as the water/cement ratio was increased along with the bar.
7- Injection mixture is defined as water/cement ratio (w/c) based on weight, and in practice, this ratio varies between 0.6 and 1.3 Dec. 0.8 and 1.0 water/cement ratios were used in manufactured columns. It is estimated that the high w/c ratio throws away the potential for erosion (grinding and dispersing) of the ground, but can cause low column compressive strength.
8- In Jet grout columns manufactured with 300 and 400 bar with water/cement ratio 1.0, it is seen that the compressive strength is the column manufactured with 300

bar. It is thought that the reason for this is because the ground is less mixed with the grout.

9- It was observed that the compressive strength of the column manufactured with 300 bar is more than the compressive strength of the 90-day compressive strength of the 28-day compressive strength. It is believed that this is because samples subjected to a 90-day free pressure experiment have completed their press. In addition, it is believed that samples taken from points A2, B2, D2 of the columns of 90 days are the middle part of the JG column, so the floor of the manufactured column is more mixed.

10- When free pressure experiments of the column manufactured with 400 bar are examined, it is seen that the pressure strength of the column is more than 90 days.

11- When free pressure experiments of the column produced with 450 bar are examined, it is seen that the 90-day compressive strength is excessive.

12- When the diameter measurements of the JG columns manufactured with 300 to 400 bar, which are the same as the water/cement ratio, lifting speed, and rotation speeds, were examined, the diameter of the column manufactured with 400 bar was greater. The reason for this is thought to be related to the height of the bar pressure of the gorot injected into the ground. In addition, when the compressive strength was examined, it was found that the column manufactured with 300 bars had more compressive strength than the column manufactured with 400 bars. It is believed that the Grot injected with high pressure breaks the ground further, entering the column, causing the column's compressive strength to drop.

13- When the columns are manufactured with 300, 400, and 450 bars are examined; As the bar increases, the diameters of the columns are increasing. When pressure strengths are examined, it is seen that the column manufactured by 4150 bar is 0.8, which is 0.8, it is seen that the pressure is more than 0.8 compared to other columns. Cause Cement ratio is considered to discard the pressure resistance.

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