DECEMBER 2020 M.Sc. Thesis in Civil Engineering EMRE İHSAN AKSOY

HASAN KALYONCU UNIVERSITY

NATURAL AND APPLIED SCIENCES

MECHANICAL PROPERTIES OF JET GROUTING FOR TWO DIFFERENT SOIL TYPES AND DIFFERENT PRESSURES

M.Sc. THESIS IN

CIVIL ENGINEERING

EMRE İHSAN AKSOY

DECEMBER 2020

Mechanical Properties of Jet Grouting For Two Different Soil Types And Different Pressures

M.Sc. Thesis

In

Civil Engineering

Hasan Kalyoncu University

Supervisor

Assist. Prof. Dr. Muhammet ÇINAR

by

Emre İhsan AKSOY

September 2020

I declare that all information contained in this document has been received and presented in accordance with academic rules and ethical behavior. I also declare that, in accordance with these rules and practices, I have fully cited and mentioned all materials and results that are not original for this work.

Emre İhsan AKSOY

ABSTRACT

Mechanical Properties of Jet Grouting for Two Different Soil Types and Different Pressures

AKSOY, Emre İhsan

M.Sc. in Civil Engineering Department Supervisor:

Assist. Prof. Dr. Muhammet ÇINAR

SEPTEMBER 2020

61 pages

Jetgrout method, which is among the soil improvement methods widely used in our country, is one of the most preferred methods. This thesis has been compared with different literature studies by examining the mechanical properties of jet injection on two different soils and at different pressures using the jetgrout method. While this comparison was made, studies were conducted on the jet injection application directly in the field and in the factory construction site in the 5th organized region of Gaziantep. During the jet grout application, a total of three types of bar pressure were used. There are;

- 300 bar
- 350 bar
- 400 bar

It has been applied to three different types of soil. There are;

- Clayey soil
- Sandy soil
- Wetsandy soil

Clayand sand samples were taken from the area where the experiments were carriedout, and plastic limit, liquid limit test and sieve Analysis were performed on these samples. Thus, it was aimed to reach realistic results in comparison of the materials used in the experiment with other experiments.

In the experiments, a total of seven jet grout columns were made. A total of three, 300 bar, 350 bar and 400 bar, were applied to the clayey soil. A total of two, 350 bar and 400 bar, applied in Sandy ground. Two applications, 350 bar and 400 bar, were applied on wet sand ground.

After the jet grout columns were completed, cores were taken from the column sand pressure tests were performed on these columns.

As a result of these tests, it was observed that the diameter of the columns made on clayey soil was smaller than the diameterof made in wet and dry sandy soils. No significant difference was observed between the diameter of the column applied on wet sandy soil and the column applied on dry sandy soil.

Interms of compressive strength, it has been observed that columns applied on clay soil show lower compressive strength than column sapplied on dry Sandy soil and wet sandy soil.

Keywords: Jet grout, sand, clay, strength, pressure, diameter

ÖZET

İki Tür Zeminin Farklı Basınçlarda Jet Grout ile Mekanik Özelliklerinin Belirlenmesi

AKSOY, Emre İhsan

Yüksek Lisans, İnşaat Mühendisligi Bölümü
Tez Yöneticisi: Dr. Öğr. Üyesi Muhammet ÇINAR
Eylül 2020
61 sayfa

Ülkemizde yaygın olarak kullanılan zemin iyileştirme yöntemlerinin arasında olan jetgrout yöntemi en çok tercih edilen yöntemlerdendir. Bu tez jetgrout yöntemi kullanılarak iki farklı zeminde ve farklı basınçlarda jet enjeksiyonu'nun mekanik özellikleri incelenerek farklı literature çalışmalarıyla kıyaslanmıştır. Bu kıyaslama yapılırken direk sahada jet enjeksiyon uyguluması, Gaziantep in 5. Organize bölgesin' deki fabrika inşaatı sahasında çalışmalar yürütülmüştür.

Jet grout uyguluması sırasında toplam üç tip bar basınç kullanılmıştır. Bunlar;

- 300 bar
- 350 bar
- 400 bar

Zemin olarak üç farklı tip zemine uygulanmıştır. Bunlar;

- Killi zemin
- Kumlu Zemin
- Islak kumlu zemin

Deneylerin yapıldığı alandan kil ve kum numuneleri alınarak, bu numunelere plastic limit, likit limit testi ve elek analizi yapılmıştır. Böylece deneyde ki kullanılan materyallerin diğer başka yapılmış olan deneylerle kıyaslamada gerçekci sonuçlara ulaşmak amaçlanmıştır.

Deneylerde toplam yedi adet jet grout kolonu yapılmıştır. Killi zemine 300 bar,350 bar ve 400 bar olmak üzere toplam üç adet uygulanmıştır. Kumlu zemine 350 bar ve 400 bar olmak üzere toplam iki adet uygulanmıştır. Islak kumlu zemine 350 bar ve 400 bar olarak iki adet uygulama yapılmıştır. Jet grout kolonları tamamlandıktan sonar kolonlardan karotlar alınarak , bu kolonlara basınç testi yapılmıştır.

Bu testlerin sonucunda killi zeminde yapılan kolonların çap ölçüsü ıslak ve kuru kumlu zeminde yapılan kolanların çapına oranla daha küçük olduğu gözlenmiştir. Islak kumlu zeminde uygulanan kolon ile kuru kumlu zeminde uygulanan kolonun çapı arasında önemli bir fark gözlemlenmemiştir.

Basınç dayanımların da ise killi zemine uygulanan kolonlar, kuru kumlu zemin ile ıslak kumlu zeminde uygulanan kolonlara oranla daha düşük basınç dayanımı gösterdiği gözlemlenmiştir.

Anahtar Kelimeler: Jet grout, kum, kil, güç, basınç, ölçü

To My Family…

ACKNOWLEDGEMENTS

First of all I would like to express my deepest gratitude to my supervisor of Assist. Prof. Dr. Muhammet ÇINAR, Assoc. Prof. Dr. Eren GÜLŞAH and Assist. Prof. Dr. Nurullah AKBULUT. Also, I would like to express my sincere appreciation to Assist. Prof. Dr. Muhamet ÇINAR for the support, guidance and insights that he has provided me throughout the study. I would like to thank my family**.**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

SYMBOLS AND ABBREVIATIONS

W/C	Water / Cementratio.
MPa	Megapascal
E	ElasticityModulus
m	Meter
cm	Cantimeter
kPa	Kilopascal
mm	Milimeter
m^2	Metersquare
cm^2	Cantimsquare
m^3	Cubicmeter
Kg	Kilogram
gr	gram
PT	PlatinumGroup
CCP	ChamicalChurning Pile
JSG	Jumbo Special Grouting
SSM	Super Soil Stabilization Management
Lt	Liter
Min	Minute
Rpm	Revolutionsper Minute
Mj	MegaJoule
Kgf	Kilogram Force
D	Diameter
Cpt	ConePenetration Test
Spt	StandartPenetration Test
V	Shrinkagespeed
P	Pressure

D	RotationSpeed(rpm)
Jcb	JosephCyrilBamford
CE	ConformitéEuropéene
Hp	Horsepower
Nm	Newtonmeter
EN	Europen norm
Cem	Cement
R	Radius

CHAPTER 1

INTRODUCTION

1.1 General Overview

Soils appear as a carrier layer and construction material under the foundations of the buildings built on them. The engineering properties of the soil, which differ from each other, vary within a wide range depending on the type of the soil as well as the terrain conditions (such as the degree of compactness, water content, and consolidation pressure, loading and drainage conditions). Soils may not always have the desired properties. Alteration of the area on which a building is constructed or use of more suitable soils instead of the soils that do not have the desired properties are often not considered as effective solutions for technological and economic reasons. In such cases, it is adopted to determine the limitations arising from the ground features in the field and improvement of the ground in a way to provide design, increasing the strength of the ground, reducing the permeability of the ground are preferred. Jet grouting method, which has emerged with the advancement of technology today, is a very effective soil improvement method that is used in situations where there is a problem related to the soil after construction as well as providing the stabilization of the new structure. Especially in loose soils where the groundwater level is high, it is often preferred as it is economical and fast compared to the pile method. Jet grout method is based on the principle of cutting the soil with high pressure water from the millimetric holes in the probe and forming a column in the ground by pressing this cylindrical cavity (water-cement) when the probe is taken back when the projected depth is reached (Essler and Yoshida, 2004). The purpose of the method is to prevent the liquefaction that may occur on the soil, as well as to increase the mechanical strength of the ground, namely the bearing capacity and elastic modulus, and to reduce the soil permeability(Schaefer, 1997). The jet grouting method that emerged in Japan in 1965 has become an increasingly common area of use. In this thesis, the jet grouting method, which is one of the methods to provide soil improvement and stabilization, will be discussed in detail, and the effect of this application on different soils will be examined and its application under different pressure effects will be compared.

Jet grout column, 300 - 600 bar, usually 400-450 bar pressure sprayed water and cement mixture of the ground. It is obtained by filling the gaps and compressing. High pressure means the grout. It provides a high kinetic energy while passing through the nozzles. The speed of the water-cement mixture reaches 250m / sec values. by reaching, tearing the grout floor and joining with the floor, a cemented floor structure-soilcrete- is formed. Parameters determining the properties of jet grout; type of ground, fluid pressure in the jet injection rod, jet the fluid flow rate in the injection rod (nozzle diameter), the composition of the injection grout, the drawing of the jet injection rod is the speed.

In this comparison, the mechanical properties of creek sandy ground, wet creek sandy ground and clayey ground were investigated. By making comparison, it was investigated how the strength of the same soil at different pressures was when applying the jet grout column and that the column diameters were cm. After the jet column application was completed, they were taken to the laboratory and core samples were taken from various parts of the column and fracture test was applied to these samples. Then, by measuring the column diameters, information is given on which ground and how to reach the column diameter. During the application, the cement / water ratio was taken the same in the column samples. The reason for this is to better understand the mechanical properties of the column in different soils.

All column casting applications were made on the same day so that the time and weather conditions were the same during the application. Thus, the weather conditions showed the same effect on all columns.

Jet grout importance is much lower as a soil improvement method compared to similar ones. Another aim of this study is to minimize the costs by making a suitable jet grout column for the suitable soil. Thus, to obtain the best floor at the most appropriate cost. In the following sections of the study, you will see how many cm in diameter the jet grout column is on which ground is given in the average information. The contribution of this measurement aims to calculate more diameters and extract costs more easily. Jet grout pricing is generally based on the length of the drill made in meters. Jet grout pricing during the process, the geological structure of the ground, the amount of work, the length of the drilling, the working conditions are the most important factors that determine the price. In ground conditions where drilling is difficult, the daily production amount decreases, thus the unit price increases. In works where the total amount of production is small, a lump price is generally given. Because the drill you carry with 3 trucks machine, cement silo, cement mix container, transport, placing, work of jet grout pump container, it takes high cost and time to bring it back at the end.

1.2 Structure of the Thesis

Chapter 1-Introduction: Chapter 1 is a brief introduction to the research topic. This section reports on the setting of the overall scope and specific objectives. An overview, purpose and structure was presented to the study.

Chapter 2-Literature review: This section is a literature review of the mechanical properties of jet injection at different soils and different pressures.

Chapter 3-Methodology: Chapter 3 is the section describing how the materials and machines used in the construction site are used in the site.

Chapter 4-Results and discussion: This chapter is about the results of the development and analysis of the field of study.

Chapter 5-Conclusions: General results about general results are explained

CHAPTER 2

LITERATURE REVİEW

2.1 General Literature Study

In this section, important studies on the behavior, design and application methods of jet grout columns, which have been in the literature up to now, are summarized below. Changes in uniaxial compressive strengths of different types of soils improved with jet grout columns were investigated depending on resulting the water / cement ratio after column formation. In Figure 1.1 compressive strength values of jet grout column samples taken from seven different soil types are shown according to different water / cement ratios.

Table 2.1. Free compressive strength values of column depending on 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 research is important in terms of providing comprehensive strengths of JG columns produced in different soil conditions in the field. According to the results of the research, it has been observed that the compressive strength obtained in sandy and gravelly soils is much higher (3-4 times more) compared to clayey, silty and organic soils, and also that the compressive strength increases in gravelly, sandy, silty, silty clayey soils as the amount of cement increases. The relationship between the modulus of elasticity and the uniaxial compressive strength of jet grout columns has been studied by (Trevi, 1994).

Samples taken from Jet grout columns formed on silty and silty sandy soils were used in experimental studies. It was concluded that the jet grout column strength is directly proportional to the modulus of elasticity

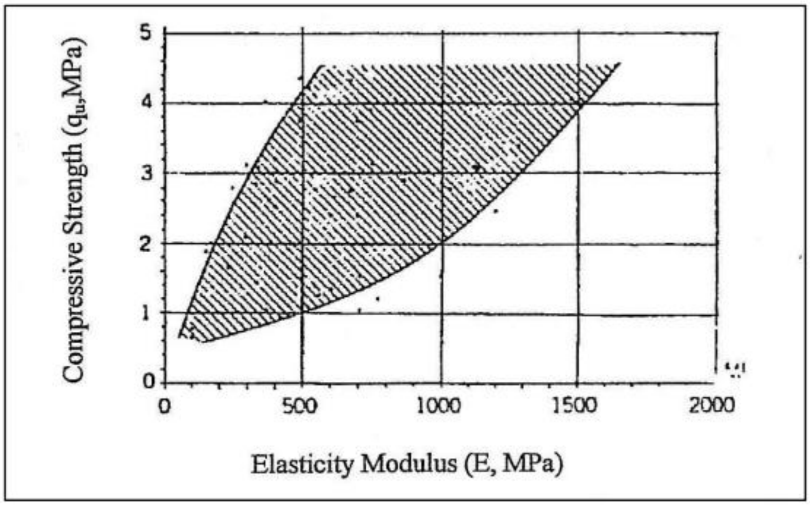


Figure 2.1 Modulus of elasticity-uniaxial compressive strength relation (Trevi, 1994)

In an 18000 m2 foundation excavation in an art center in Singapore, it has been shown that the side surfaces of the excavation supported by the sheet pile wall and diaphragm wall are strengthened with jet grout columns and deformations in the direction of the excavation are reduced with jet grout columns (Wong vd.,1999). It was stated that there was groundwater 2.5 - 3.0m below from the ground surface. Ground section of jet grouting application made in sand fill on sea clay is shown in Fig 2.2.

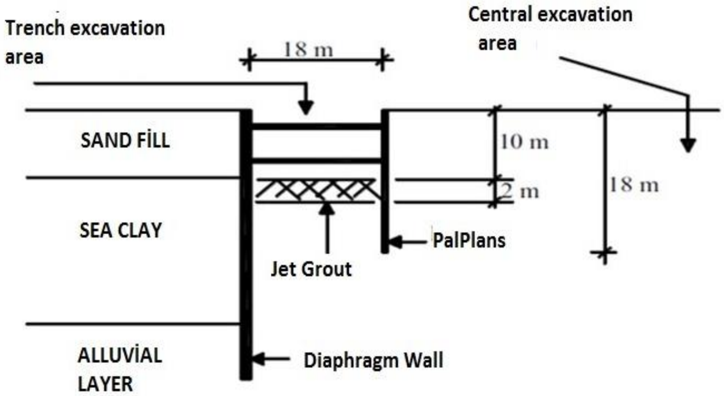


Figure 2.2 Jet grouting application cross section (Wong et al., 1999)

It was emphasized that the production of jet grout columns in the ground section was obtained by Jet-2 method. In the study, it was stated that the undrained shear strength before the improvement of the soil was 300kPa and the elasticity modulus was 150kPa, while the undrained shear strength reached 1150kPa and the elasticity module reached

350kPa after the jet grout soil improvement.

Recent jet grouting applications from Turkey are given below. The factors affecting the performance of jet grout columns in application were also explained by the authors. They stated that the purpose of the use of jet grout columns is to reduce the ground settlements and to reduce the risk of liquefaction (Sağlamer, vd.,2002).

It is stated that the jet grouting method has been developed in recent years and is mostly applied for soil improvement and provides effective solutions against many geotechnical problems. The author defined this method as compacting the cement-water mixture by injecting it into the soil under very high pressure. In this study, the strength properties of jet grout columns of five different field studies are evaluated and the results are researched by taking the historical, theoretical and practical background of soil improvement into consideration (Gümüş,2002).

Uniaxial pressure tests were carried out in the laboratory on the core samples taken from the super jet columns. In the experiments, 3, 7, 14 and28dayscompressive strengths of 76 x 150mm cylindrical specimens were measured. It was determined that the super jet column strength increased with time and the actual strength was reached on the 28th day (Bell vd.2003).

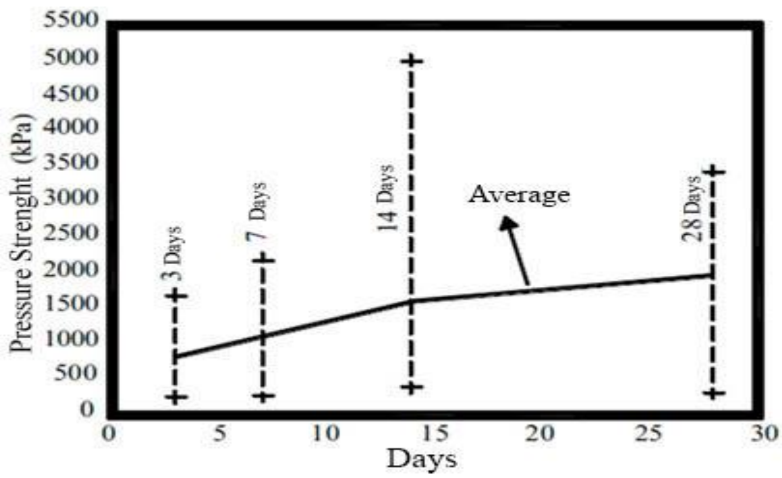


Figure 2.3 Compressive strength of Jet grout column samples (Bell et al., 2003)

In another study, it was emphasized that excessive wall deflections and soil settlements are common problems in deep excavations for soft clay soils, and they cause significant damage, especially for adjacent structures. It was stated that the ground is generally improved by jet grout or deep compaction method to reduce wall deflections or soil settlements. However, three dimensional finite element method was used in this study, since there are some problems in the analyses performed by two dimensional finite element method and the real condition cannot be fully reflected. After comparing the measured wall deformations with the deformations obtained from the analysis, it was seen that there was a very good agreement between them (Ouvd.,2007).

In different study, by the consideration of the historical, theoretical and practical background of the jet grout technique, which is an on-site soil improvement technique, the types, design, application, parameters, application areas, advantages and disadvantages of this technique are explained. The researcher presented the Jet grout application under a railway that is settled due to poor soil conditions as a case study (Küçükali,2008).

Another researchers investigated the effect of jet grout pressure and grout flow on the physical and mechanical properties of jet grout columns. For this purpose, 6 Jet grout columns with different grout pressures and different flow rates were built in the Shahriar dam site (Iran). From these columns, Cube samples were taken from different distances from the center of the columns formed by core and cylindrical samples. 5 different experiments were conducted in the laboratory on the samples taken. These are uniaxial pressure, triaxial pressure,direct shear, Brazilian indirect tension, and Schmidt hammer experiments. According to laboratory results and numerical studies, UCS (uniaxial compressive strength) increases logarithmically with the increase of grout pressure and flow (flow). In addition, the jet grouting process greatly increases features such as cohesion and internal friction. (Nikbakhtan et al.,2009)

They shared the results of laboratory experiments on sample JG columns manufactured in different parameters at the Shahriar dam site. They chose the manufacturing parameters of 6 sample columns produced for this purpose differently. These parameters are determined as tij pull rate, tij rotation rate, water/cement ratio, grout pressure, grout flow rate, water pressure and flow rate, air pressure and flow rate. ,

The relationship of the diameter and free compressive strength of jet grout columns formed as a result of experimental and field studies with these parameters has been given. (Nikbakhtan et al.,2010)

It studied the performance of the jet grout column under the influence of vertical loads in the jet grout columns created on non-cohesive soils and the way the stresses formed in the column are distributed. As a result of this research, he aimed to create a model that is close to the behavior of jet grout columns under loads in real life, which will be designed using the finite element method, and to create resources for similar studies. (Doğanışık, 2010)

2.2 Soil Improvement

As a result of population growth and urbanization, urbanization was forced for soils that did not have sufficient carrying capacity. For this reason, soil improvement methods have been applied to make usable useless soil that does not have sufficient features. With technological advances in Soil Mechanics, many soil improvement techniques have been developed to understand geotechnical problems and analyze soil behavior. The aim of soil improvement techniques is to increase the carrying capacity in general, that is, to reduce seismic hazards by increasing the rigidity of the soil and to make it useful by preventing liquefaction. Improvement methods vary according to the soil profile and the property of the structure to be built on it (Kramer, 1996). Foundations must safely transfer loads affecting structures to the soil. In there are conditions for staying within the limits of the condition of safety, the condition of carrying power and the allowable seating values? The type of soil, carrying power, etc. considering its characteristics, the basic project is dominated by a seating condition or a carrying force condition (Ayan 2009).In the process, which begins with the detection of the soil with carrying power, seating, liquefaction, permeability, stability, bulking and collapsing problems, there are many options for choosing a method of soil improvement after the decision to make a soil improvement has been made. Some of them are blasting method, vibro compaction method, preloading method and jet grouting. Implementation of special construction techniques for each project may also become a need. In addition, solutions can be created against economic problems even in structures that will be made in difficult conditions with soil improvement. It is possible to divide all these soil improvement methods into various groups. In this study, soil improvement methods and jet grout are briefly described below.

2.2.1 Blasting Method

This method is a soil improvement method in which the material that forms the soil on soft soils is compressed by converting it into smaller pieces. A limited amount of explosives placed inside the improved soil layers are detonated with successive ignitions, thus creating fast pressure waves that ensure the compression of the soil. By blasting technique, consolidation of organic, peat and very soft soils and deep compaction of granular soils can be done. If granular soils suitable for vibro flationation are fully saturated under underground water level, a 6% decrease in volume and a 35% -85% increase in relative density can be achieved during compaction by the pating technique. For this reason, 50% -75% depth of the soil to be compressed and 3-10 m intervals of holes are opened and 1-12 kg or 10-30 g of explosives for each m3 of soil to be compressed are detonated after placing.TNT, dynamite, etc., another case in which explosives are active is throws made 1-3 m above the loose soil under water. 18 m. it has been reported that the surface can be collapsed by 25 cm at 20 kg of TNT at 2.5 m high in underwater gravel sand (Önalp1983).

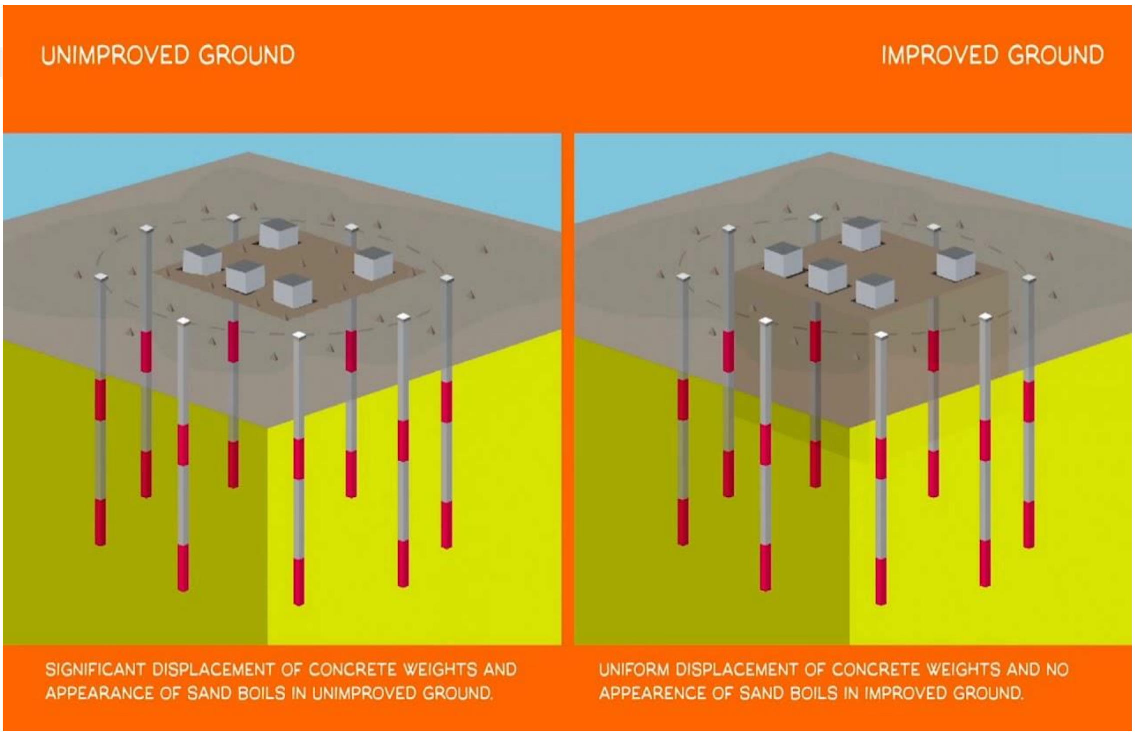


Figure 2.4 Blasting Method

2.2.2 Vibro compaction Method

Vibro compaction deep and cohesive soils are compressed by the high energy vibrations of a probe placed on the soil. For this purpose, vibrator hammers that can penetrate the soil are used. The vibro-wing, Terraprope and Franki y-Prope types are most commonly used in vibrocompaction technique. In vibrocompaction, compaction is performed at 1-2 m intervals. The Vibro-wing apparatus penetrates the soil to the desired depth with a vibrator blow, and the soil is also compressed as it is gradually pulled upwards. Deep, loose and cohesive soils are compressed by the high energy vibrations of a probe placed in the soil. In this technique, a cylindrical probe with a diameter of 40 cm is lowered to the soil by vibrating together with vibration and spraying water with high pressure through holes at the bottom of the probe. At the desired depth, the flow of water is reduced, and the direction of some of the squirt is turned above the probe, causing the filling material to descend to the extreme point of the ground with the upward flow of water. Drilling around 2.50 - 3.00 m over time as the filling process continues. a region in diameter is compressed. With this method, 10-15 m deep soil layer is compressed.

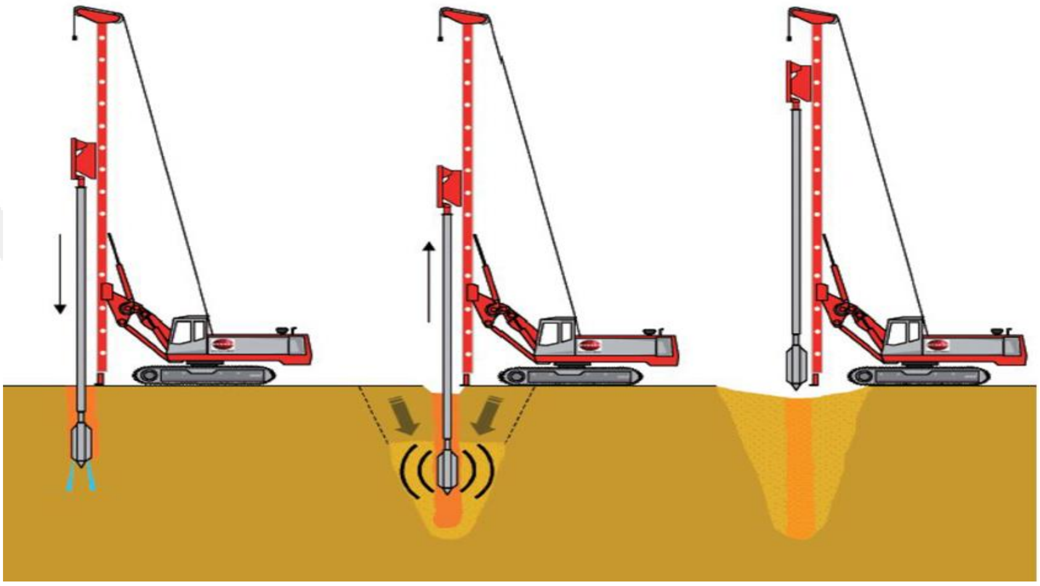


Figure 2.5 Vibrocompaction method

2.2.3 Compaction Piles Method

A compaction pile is a displacement pile that is nailed to the loose layer of sand to increase the density of the soil. In reducing the plastering potential of fine sand and reducing the use of soft sediments, silts, etc. it is widely used in increasing carrying power. The density of the soil can be increased by hammering large displacement piles into the soil, such as pre-cast concrete piles or empty steel piles with one end closed. The soil is compressed by both the actual displacement of the soil and the soil vibration that occurs during the ramming process. The piles are left in place. In order to ensure a reasonable level of compression of the soil between the piles, the piles must have a relatively close span. Sand piles are formed by plating pipe along with an easily detachable base plate. Then, gradually, the sand filling material inside the pipe is compressed with the retraction of the coating pipe. The Franki pile is an effective method. Franki type caisson piles can safely carry very large pressure and pulling forces. This method is convenient for quick use of sand piles. In there, the compression of the soil occurs both by spraying during the pipe's ramming and by dynamic effect. On sand soils, this effect occurs most when the sand is fully saturated or dry with water. The distance between sand piles usually ranges from 1.0-1.5 m. Compaction piles are a more suitable method than vibroflot and terraprobe probes in terms of cost and suitability on fine-grained soils. It is also a very effective method on water-saturated soils (Kauschingervd., 1992).

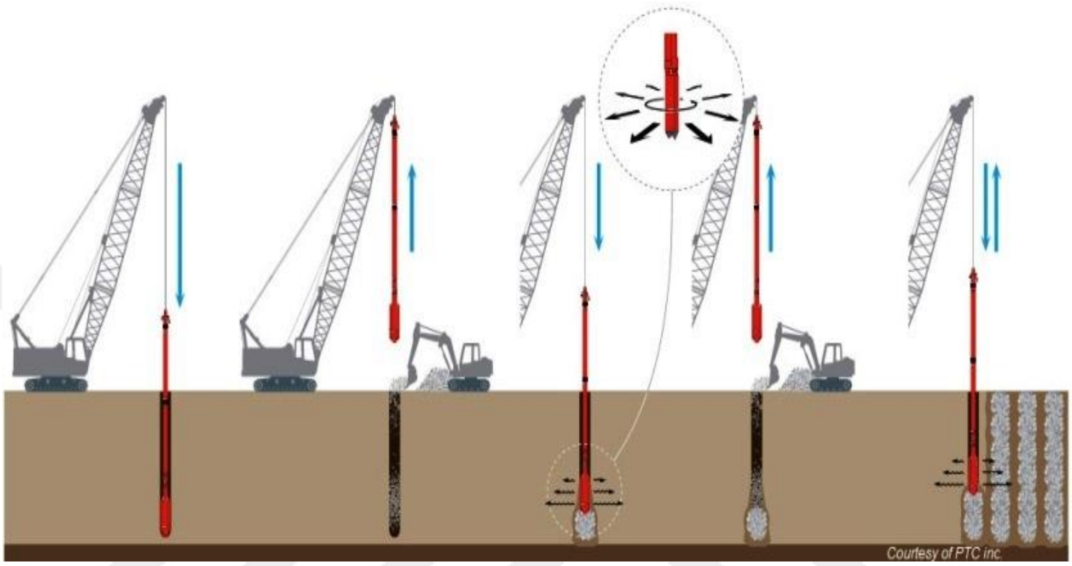


Figure 2.6 Compaction pile method

2.2.4 Preloading Method

It takes many years for consolidation to sit due to the stresses that flow from the structure on a compressible soil. Sometimes it can be to the extent that it can damage the structure on the sitting that occurs. For this purpose, an additional load more than the construction load is applied to the soil before the construction of the structure, and time-dependent sit-ups are accelerated with increases in stress. After the desired amount of seating occurs, the additional load on the soil is removed. In this way, unwanted sessions that will occur depending on the time after the start of use of the structure are prevented and close to the entire final sitting occurs. Accelerated consolidation technique with this method, very successful results are achieved if the soil on which the structure sits is clay, soft and excessively compressible. Placing vertical sand drainage columns or artificial drainage boards inside the soil to reduce the waiting time for preloading gives good results. In this case, the water inside the soil is removed from the soil by means of drainage channels, moving not only in the vertical direction but also in the horizontal direction. Thus, the consolidation of the soil layer accelerates the groove. Although it is relatively more economical than other methods, the time required to complete the sessions is longer. In this method, the additional load applied must be easily drained granular material (sand and gravel) to speed up sitting on soft soil. During consolidation, it should be ensured that the water that will come from the trapped soil will be drained immediately. It can be successfully applied on all clay soils, usually organic or not, and even on Moorish soils of the PT group and even on soils with a water content of 20% -3000%.

2.2.5 Sand Drains

Sand drain is a clean sand filter column created by drilling a pile into the soil and removing the soil by drilling or Auger. Consolidation sessions with the preloading method usually take a very long time. In order to accelerate consolidation, vertical sand drains are built in the soil to be consolidated, ensuring rapid drainage of water in the soil. In clay with low permeability, consolidation can increase the rate by using sand drains, reducing the drainage path in the clay. Sand filters placed in drain wells must have a high drainage ability and a suitable gradient to have a capillary cavity, and they must be sufficiently compressed during their placement. In addition, the filter material should not be blocked by the fine grains of the floor during the drainage of the soil. Otherwise, the ability to drain will decrease or disappear. For this reason, it would be appropriate to wrap the sand drain material with geotextile material into a sheath. Sand drains should be used in conjunction with the preloading method, as they do not cause consolidation sitting alone. In practice, sand drains are generally designed with Square or triangular shapes with a diameter of 30-45 cm and intervals of 1.5-3 meters.

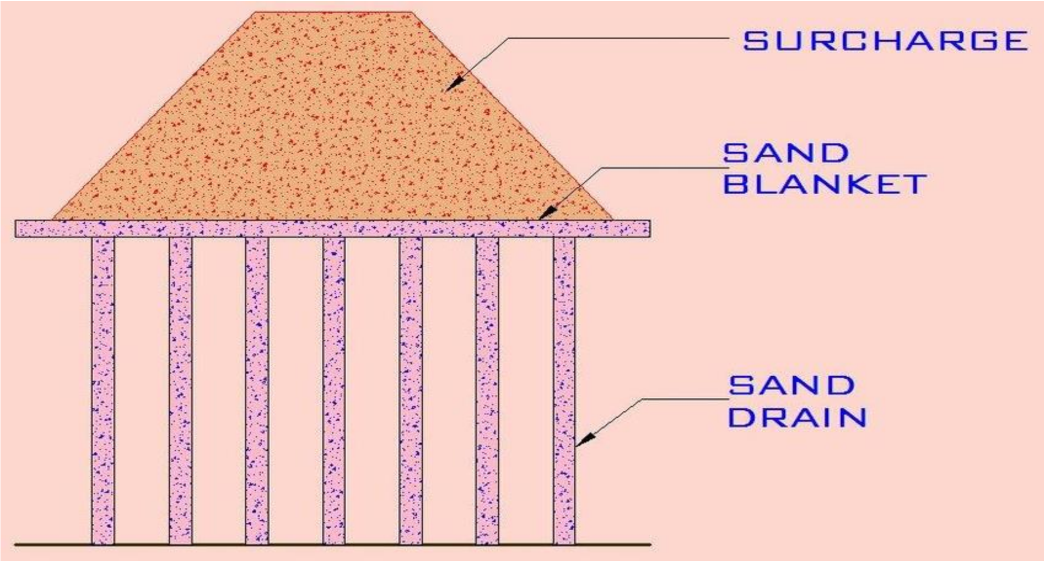


Figure 2.7 Sand drains

2.2.6 Stone Columns

Stone columns are a useful method of healing soft and loose soils. Stone columns and superstructure project loads, site and soil conditions depending on the carrying capacity ofthe soil is increased, the seating time is reduced and the soils that liquefy or lose strength in the event of an earthquake are strengthened. Stone columns are generally preferred on soft and medium solid clay soils, in conditions where the problematic floor layer thickness is usually less than 10 m. With the application of stone columns, seating problems can usually be reduced by 50-60%, while carrying capacity can be increased too much higher levels. It is generally recommended that the ends of stone columns be seated on a solid base soil. Depending on the superstructure project loads and soil conditions, 75-100 cm diameter stone columns are designed in a triangular or square layout plan. Stones used in manufacturing should be made clean, usually 10-50 cm in size and with materials with a thin ratio of 5-10%. Stone columns soil with water jet and floor after placing coarse granular material directly into it, it is obtained by compression by vibration. Due to the fact that the soils reclaimed by this method are compressed by vibration effect, an increase in density is achieved, an increase in transport strength, shear strength and Drain ability can be achieved (Özkök 2006).

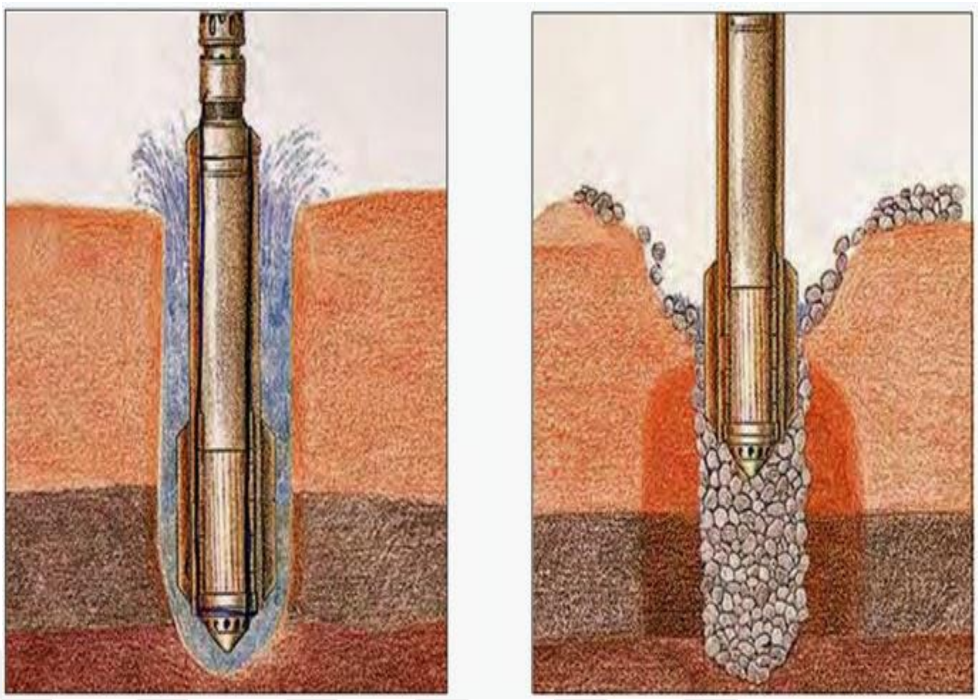


Figure 2.8 Stone column method

2.2.7 Deep Mixing

The aim of the deep mixing method is to increase the shear strength of the soil, reduce its permeability or improve its resistance to harmful substances. This method is based on the use of jets or augers to physically mix the soil with deep mixing stabilizing material (Goby 2004). In the deep mixing method, soil reclamation works are carried out using cement, flyash, blast furnace slag, lime, various additives or their combinations as binding agents. The binding agent used must be up to 20-30% of the volume of the soil to be improved, depending on the type of soil. Application areas can be listed as supporting excavation pits, impermeability curtains, and dock structures, supporting the tunnel soil, reinforcing the foundation and preventing liquefaction. In order to ensure optimal improvement after the application of the pre-manufacturing method, it is necessary to determine the binding agent suitable for the type of energy and soil to be used by land and laboratory experiments.

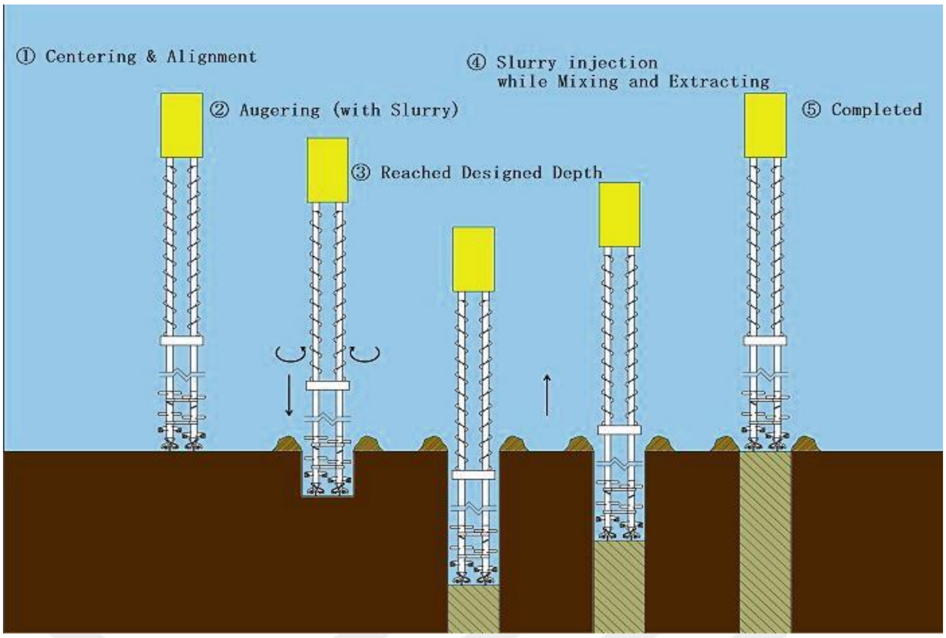


Figure 2.9 Deep mixing method

2.2.8 Soil Injection

Soil injection is basically the injection of fluid materials into cavities inside the soil under pressure. In order for the soil to carry superstructure loads in a healthy way, the engineering properties of the soil must be improved. In this context, the permeability of the soil resistance is increased by clamping the grains through injection. This improvement is achieved by changing the mechanical properties of the soil such as stress deformation and strength and hydraulic properties such as permeability. Floor injections have been used to prevent harmful sitting on the surface or in nearby structures due to tunnel excavation in the last 15-25 years, to reduce the liquefaction potential of loose, water-saturated granular soils that can liquefy during an earthquake, and to increase the transport capacity of soils. According to the size of

the gaps in the soil and the purpose of the injection, the appropriate injection material must be determined. Different injection techniques have also been developed depending on the way the injection material is placed in the soil and the characteristics of the soil. Injection material and injection parameters (injection pressure, injection speed, injected volume, etc.) soil conditions (grain diameter distribution, relative tightness, geostationary stresses, etc.) and should be designed for the purpose of application. For successful application of soil injections with such different application areas, it is necessary to know the injection techniques, the types of injection mortar, the properties of filling materials and the behavior that the floor will show against injection (Uzuner, 2006).

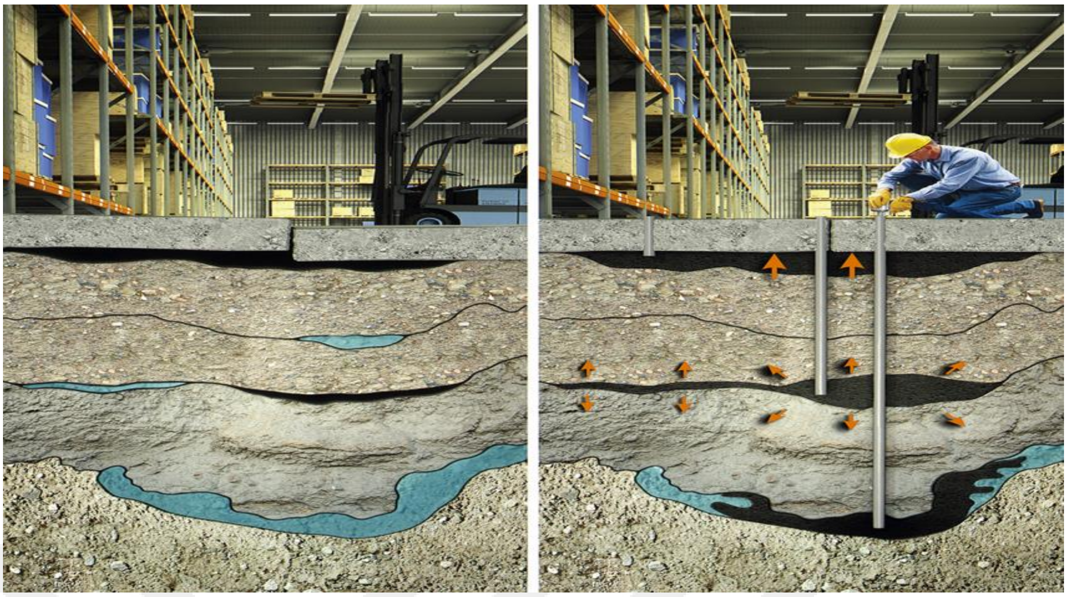


Figure 2.10 Ground injection method

2.2.9 Jet Grouting

Quite expensive, and a new method of jet injection, a homogeneous mixture of cement or bentonite, which is a very good syrup turned into a drilling machine after the desired depth is reached with a very high pressure (400-700 bar) pump by way of spraying and blend the floor into the soil and tore into the soil to ensure that. This spraying process is done from injectors at the end of drilling Tijs inserted into the soil. Preparation of the mixture, injecting it into the soil is done with the help of fully automatic machines and with an experienced equipment group.

Figure 2.11 Jet injection method

2.3. JET GROUT

2.3.1 Jet Grout History

The idea of improving the soil by cutting the soil with high-speed mixing, and the work on this issue, was first implemented in Japan by the Yamakado brothers in 1965, and two different jet injection techniques were developed in the early 1970s. Nakanishi and company (N.T.In the jet injection technique developed by I), Chemical and cement mixtures are used and a punch is injected at very high pressure from the injection cybobs of tijin. During the injection of the mixture, tijin is rotated around itself and pulled up, creating piling-like floor cement columns. For this reason, this type of jet injection technique is called “CCP Jet grouting” (Chamical Churning Pile) chemical shaking pile (Yilmaz 2003). Almost at the same time, Yahiro and his colleagues made a new development called the “Jet Grout” method. Later, these and similar methods were always referred to as the jet grout method. This method also opens a half on the soil using a high-speed water jet, and then this slit starts from below and is petrified by a cement mortar jet (East 2005). Other application techniques were used in Japan in the mid-1970s. A jumbo Jet special Grout called “JSG” was developed using the CCP jet injection system. These columns are 1.5 – 2 times larger than CCP columns. After that, Yahiro and his colleagues added the jet injection columns to a water jet

system wrapped in an Air jet using a similar principle. The anvil soil is torn off by an

Air jet, and the resulting gaps are filled and mixed by injection (Yilmaz 2003) . In 1980, the Super Soil stabilization method "Super Soil Stabilization Management (SSM-man)" was developed by the CCP group. In this system, the purpose is to create very large columns. The opening space is measured by supersonic wave technique and filled by injection. With the SSM-man technique, large volumes of solidified structures up to 4.0 m in diameter can be created, especially on non-cohesive soils (Yilmaz 2003) . After the introduction of the Jet grouting method in Japan, this technology quickly spread to Western Europe, especially Italy, Germany and Brazil. In North America, it was implemented in the 1980s (Euphrates 2001) . In recent years, with the development of technology, the equipment has also been developed and fluidized pumps have been produced at high pressures and speeds.

Figure 2.12 Jet grout

2.3.2 Jet Grout Method

The soil-cement mixture is a mixture of cemented chemicals and causes significant increases in floor shear strength in particular. Substances such as fly ash and sodium sulfate were also added to the mixture to increase the effect of these mixtures created by high-pressure injection. Currently, in parallel with technological developments, injection speeds and injection pressures have increased according to project needs, preparatory work and time spent during construction have been reduced, productivity has increased and human needs have decreased, jet grouting method has spread rapidly around the world with more reliable work tools (Cinar, 2014).

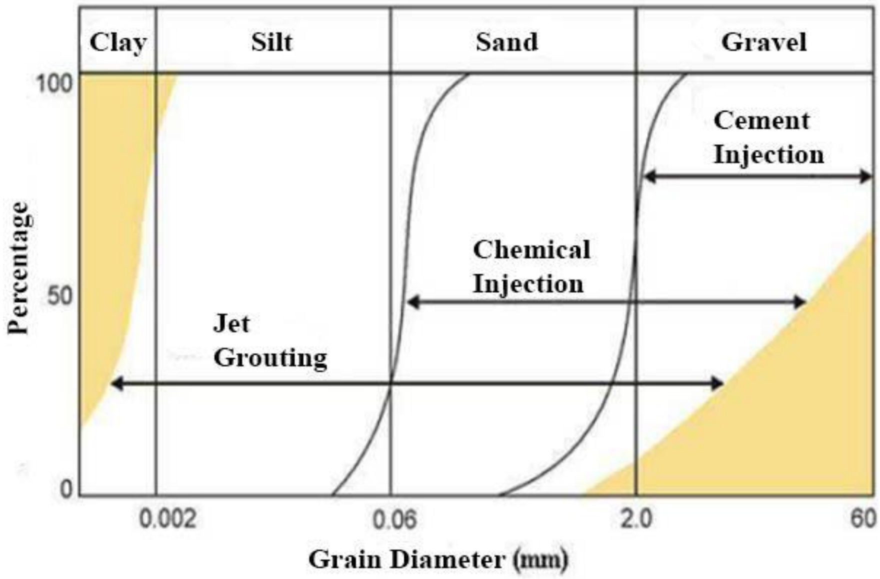


Figure 2.13 Injection types according to grain distribution

In general, the jet grouting method is the case of drilling a well from a rotating injection pipe at a certain speed under the influence of a horizontal jet of high-pressure air or water, and mixing cement sorbet horizontally under high pressure into this well (Durgunoglu, 2004). This method, applied upwards from the base level of the well, can be built underground walls and diaphragms along with other jet grout columns, which are applied next to it, so that the column we create does not leave a gap between them without getting a socket.

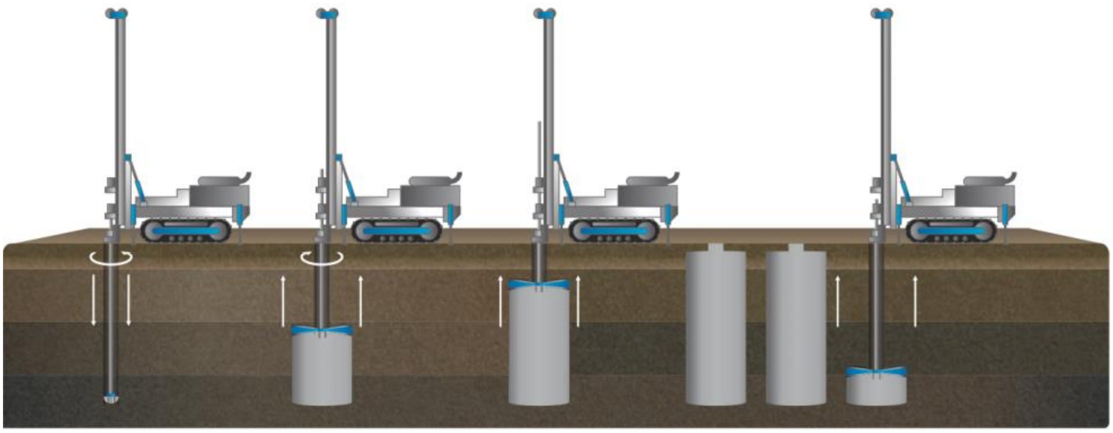


Figure 2.14 Jet grout animation view

The mechanical and geometric properties of these columns, which will be formed by the Jet grouting method, depend on the soil parameters that will be applied, how we will perform the application, and also depend on the variable parameters and method properties in these methods. When the Jet grouting method is applied properly, loads caused by both superstructure and seismic hazards are carried by with column-ground.The Jet grouting method increases the carrying capacity of the soil, the modulus of elasticity; it also reduces the compressibility of the soil, as it will reduce the permeability, resulting in a more rigid soil. This resulting soil is also protected from liquefaction, seating and seismic hazards. Jet grouting method is used in almost all kinds of weak soil and sand, clay, gravel etc. it is a highly preferred method of soil improvement due to its applicability in soil structures formed by natural soils, as well as providing a more economical, permanent, fast and reliable solution than other methods of improvement. The jet grouting method distinguishes it from other classical injection methods by determining the amount of material to be used before application in the soil to be applied, and calculating soil parameters such as carrying strength, deformation modulus and permeability of the soil after application.

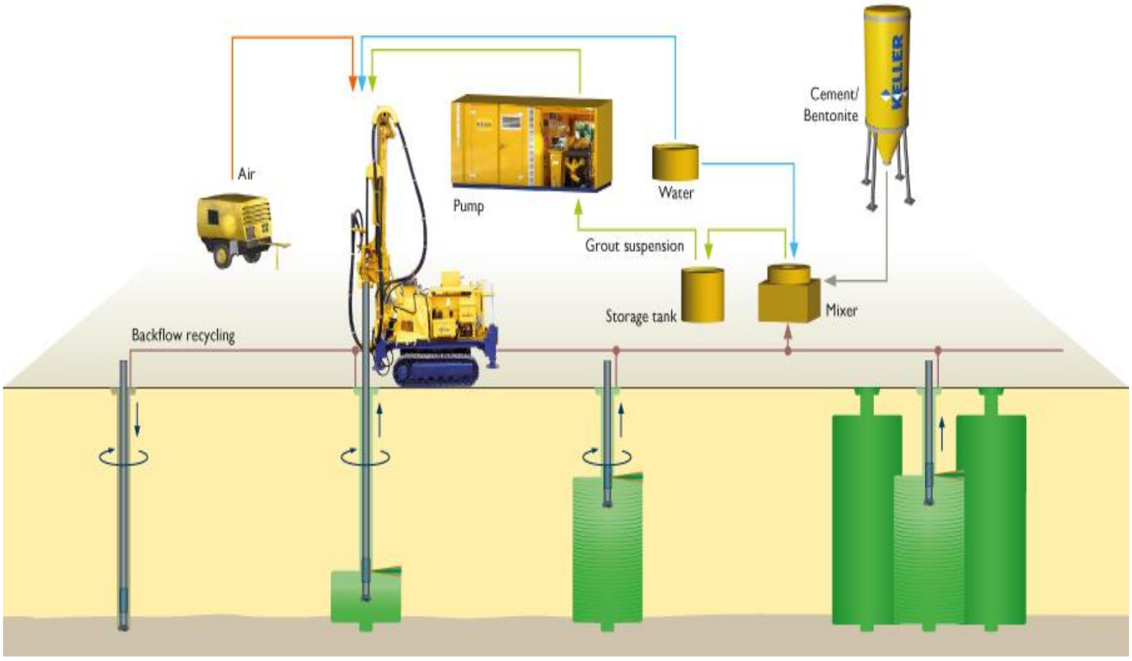


Figure 2.15 Jet grout application method

2.3.3 Jet Grouting Systems

The Jet grout method is divided into three: single-fluid, double-fluid and triple-fluid according to the fluids injected into the soil. The system to be used is decided according to the type of soil, the diameter of the column to be manufactured and the volume of the soil to be reclaimed.

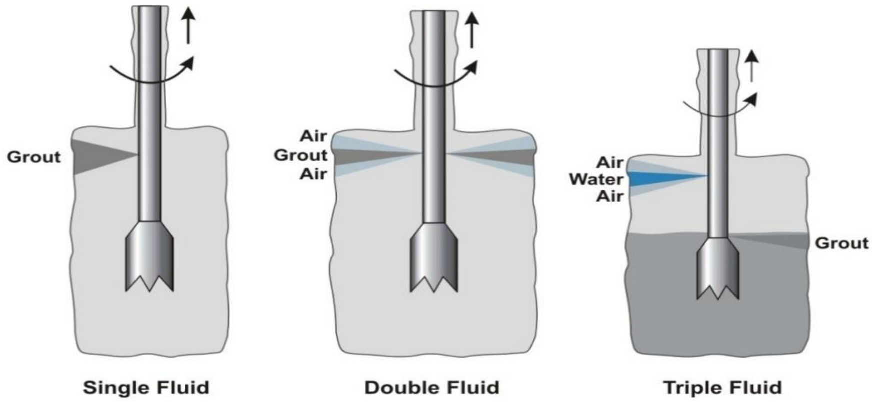


Figure 2.16 Jet grout systems (Keller, 2009)

2.3.3.1 Single-Flow System (JET-1)

The single-flow jet grout method is the simplest among the three systems. The reason for this simplicity is that there is a single jet stream that performs the functions of cutting, eroding and mixing soil and injection. The system has one or several spray mouths with a diameter of 2.0 – 4.0 mm, on which the injection is transmitted and close to the bottom end. Cement injection is sprayed at a 90° angle with the system, so that the soil is removed from one side, while the cement injection with the floor removed at the same time is replaced. During the process, the monitor with the spray mouths is retracted at constant speeds (rotating if necessary) depending on the soil layers, and thus the jet grout element is formed from the cement injection mixture with the dismantled soil (in cylindrical geometry, if it is rotated back). The properties of this mixture, consisting of soil grains by injection of cement 12, determine the improved soil properties (Fırat 2001). The diameters of the columns formed on the soil vary depending on the property of the soil and the parameters used to create the column. With this method, columns with diameters of 600 – 800 mm are created in clays and 1000 mm on gravel soils (Doğu 2005).

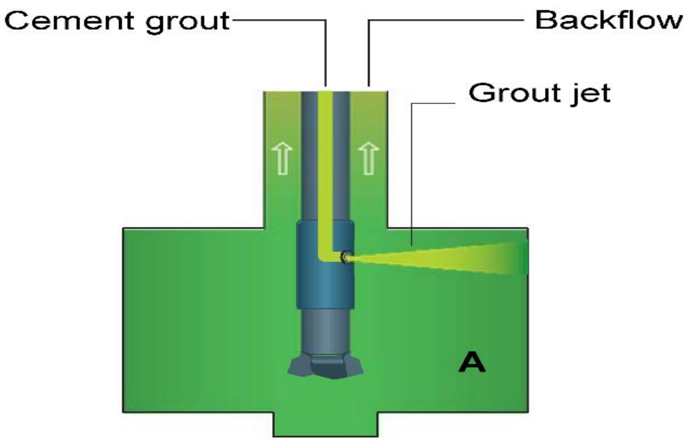


Figure 2.17 Single fluid system cross section view

2.3.3.2 Double-Flow System(JET-2)

The double-flow jet grouting system is a more complex and advanced system than the single-flow system. The most defining feature of the double – fluid jet grouting system is that the high-speed injection jet is sprayed with a compressed 2-15 bar and the air cone surrounding the injection. As a content, this system can be considered as a modified form of a single-fluid system. This compressed air jet added to the system greatly increases the corrosive effect of cement injection, and there is an almost 2 times increase in the diameters of the formed column-type jet grout elements compared to the single-fluid system. The main reasons for this increase in the size of the created elements can be listed as follows. Thanks to the air cone, the cut ground is prevented from falling into the jet stream, thus reducing the energy loss in the turbulent jet stream to a minimum. Cut ground particles can be removed from the cutting area more efficiently with the effect of bubbles and removed to the soil surface thanks to the air cone. Compressed air acts as a buffer between the jet stream and existing underground water. Therefore, the jet stream can perform cutting and etching at a distance of twice as long as the system in which compressed air is not used. In a double-fluid system, the injection spray mouths and the outlet mouth of the compressed air jet are arranged to be on the same axis (Fırat 2001).

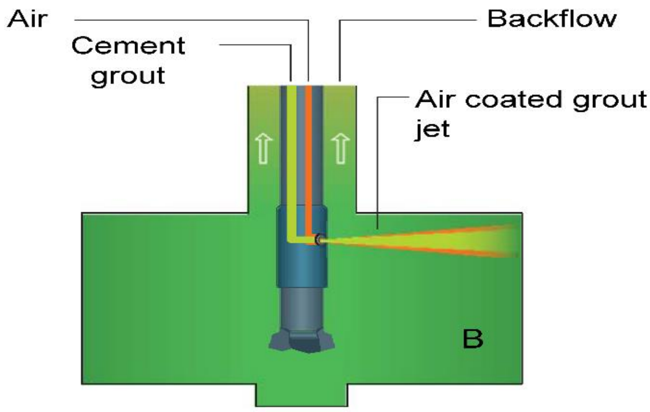


Figure 2.18 Double fluid system cross section view

2.3.3.3 Triple-Flow System(JET-3)

The triple-fluid system is the most complex of jet grout systems. In the system, the removal of the soil is done by a water jet surrounded by a compressed air cone, and cement injection is sprayed alone from the spray mouth, which is located some way down from this jet (several decimeters) with the same axis. A triple-fluid system is usually the system in which the largest-sized elements are created. With this system, column-type jet grout elements up to 300 cm in diameter can be created on non-cohesive soils, and column-type jet grout elements up to 150 cm in diameter can be created on cohesive soils (Fırat 2001).

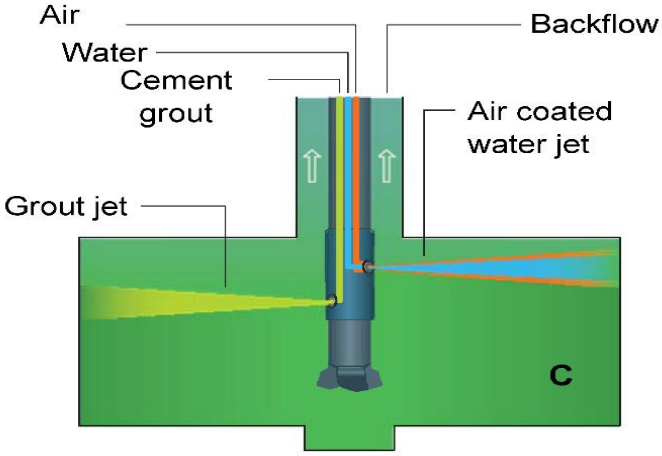


Figure 2.19 Triple-fluid system cross section view

2.4 Jet Grouting Manufacturing Parameters

The Jet grouting method is a soil improvement method that can be applied in all soil types, where cement injection is injected into the soil and reclaims the properties of the soil that are problematic. Studies from the first years of the method have shown that certain parameters determine the diameters of columns formed by fluid injected into the soil, and these parameters are determined according to the diameter of the soil grain, the binding rate of the soil and many other soil properties. Operating parameters; it is selected according to soil characteristics, the diameter of the column to be created, the desired column carrying capacity, and the selected jet grouting system. The manufacturing parameters used in the Jet grouting method are as follows (Ergun 2007).

- Jet grouting system (JET-1, JET-2, JET-3)
- Injection pressure (bar)
- Pump capacity (lt / min)
- Nozzle number and diameter
- Water / cement ratio
- Tij rotation speed (rpm)
- Tij pull speed (cm / min)

Since high-pressure injection is sent into the soil in the Jet grout method, the high etching energy released from the moment the high-pressure injection comes into contact with the soil ensures the formation of columns. If the resulting high etching energy is tested in different soil types and different manufacturing methods, it varies between the applied jet energy and the diameter of the column. Accordingly, it was observed that the diameter of the column formed with increased jet energy on non-cohesive soils increased logarithmically. However, more energy is needed in soft clays than in the JET-1 method to create a large diameter column. Because of this, it shows that the JET-2 system means creating a larger diameter column with less energy in soft clays. But the JET-1 method is more economical if small diameter columns are designed in soft clays.

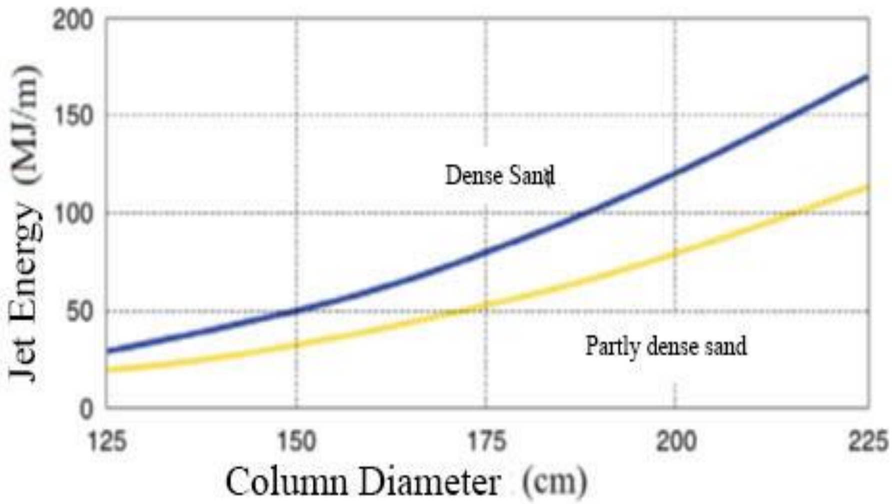


Figure 2.20 Jet Energy-column diameter relationship in non-cohesive soils (SoletancheBachy company)

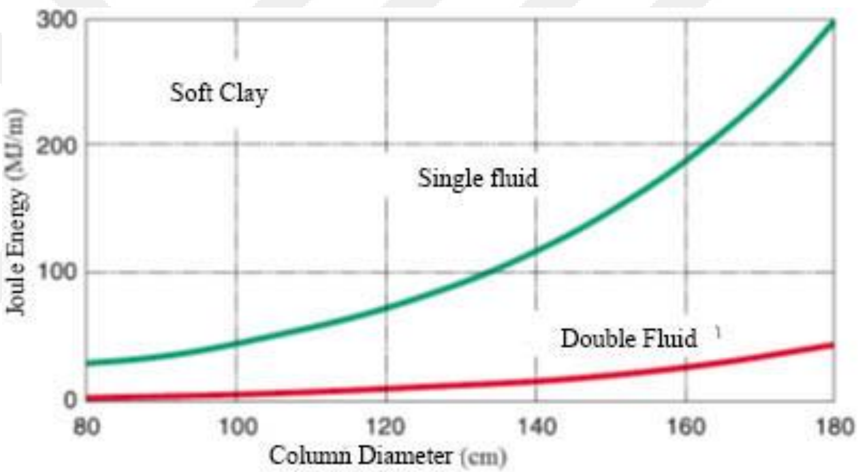


Figure 2.21 Jet Energy-column diameter relationship in cohesive soils (SoletancheBachycompany)

2.4.1 Injection Pressure

The parameter that plays the most important role in achieving the desired column diameter is the injection pressure parameter. If the injection pressure is classified;

- Low pressure 200-300 bar
- Medium pressure 300-400 bar
- High pressure 400-700 bar

Generally, higher injection pressure is required to achieve higher column diameters. But the increase in injection pressure does not always reach the desired column diameters. The reason for this situation is that the connection between the injection pressure and the diameter of the column is not directly, it is a function in which time is also involved. In addition, increasing the time taken to create the column increases the homogeneity of the jet injection columns (Xanthakos, P. Et al, 1994). Another consideration when selecting the injection pressure is that 5% to 10% of the injection pressure will be lost due to friction in the hoses, pipe and neuzule. (Langbehn, 1986)

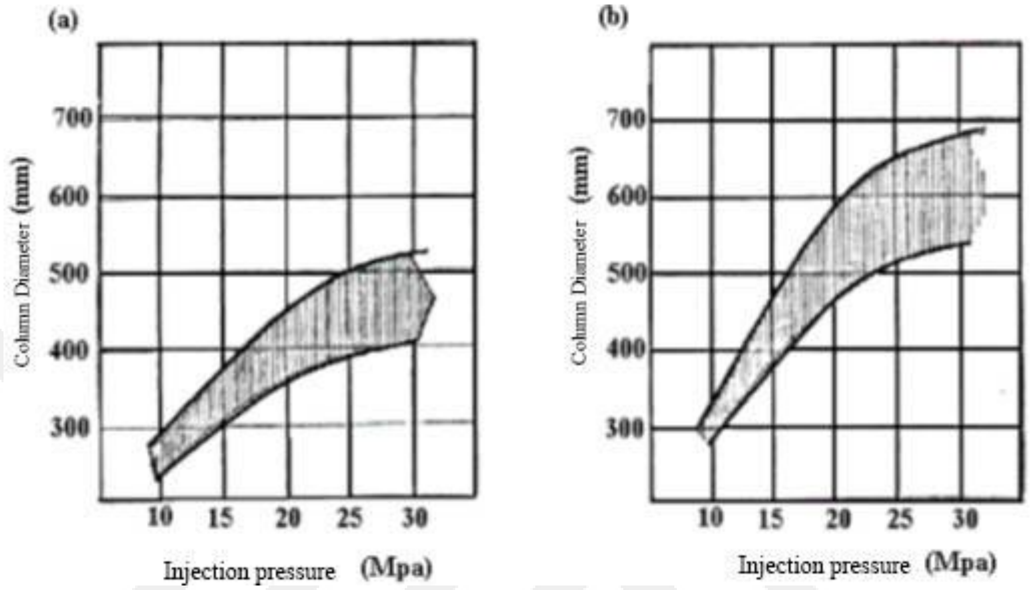


Figure 2.22 The relationship between the formed column diameters and the injection pressure; (a) soft fine grain soil,(b) medium-tight rough grain non-cohesive soils (Xanthakos, P. Et al, 1994)

Grout pressure is one of the most effective parameters in 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. However, in order to obtain a homogeneous column of the desired diameter to be reached, the pressure value is necessary, 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, maintenance 2007).

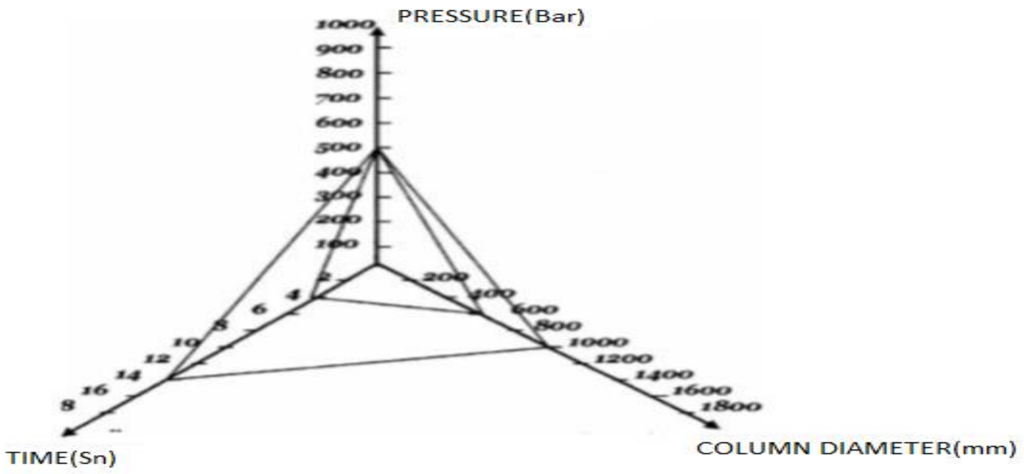


Figure 2.23 Relationship between Injection Pressure-Injection Time-Column Diameters (Melegary&Garassino, 1997)

2.4.2 Pull and Rotation Speed of Tij

Controllable parameters that affect the design and manufacture of Jet grout columns include pull speed of tij and rotation speed. In order for the jet grout columns to form, the Tijs in the drilling machine, which are lowered to the desired depth, rotate around their axis at a certain speed, and the Tijs must also be pulled from the bottom up. In order for the soil and grout material to mix homogeneously and form a jet grout column, the rotation speed of the Tijs must not exceed a certain value, and the pulling speed of tij must also be adjusted to ensure continuity throughout the entire column to be manufactured. The rotation speed of tij usually ranges from 5-30 rpm. In cases where the desired diameter is not too large, it can be removed up to 35 rpm. Drawing can be done in two different ways according to the apparatus in the punching machine. These are gradual pulling and continuous pulling. After the tij is lowered to the desired quota, it begins to pull up at a certain speed with one of these two methods. In gradual pulling, 4 cm progress at each stage and 5-11 seconds standby provide the best result. In continuous pulling, the Tijs are pulled from the bottom up with a constant pulling speed set in the Punch machine (Melegary and Garassino 1997, Bakım 2007). Because of the low tear resistance of loose soils cohesionless, grout tearing and mixing the soil can occur in a short time. But cohesive soils usually require longer periods of time for the injection material coming out of the nozzles to tear the soil and mix it to form a homogeneous column. Therefore, the choice of tensile speed and rotational speeds depends on the properties of the soil and the amount of grout to be injected into the unit volume. Optimum adjustment of thetensile and rotational speeds depends on the class, firmness, consistency of the soil to be improved and the type of jet grout to be applied.

2.4.3 Water / Cement Ratio

In Jet grout manufacturing, water / cement (S/O) ratio can be taken as 1.0 as standard. The specific gravity of the prepared injection material can be in the range of 1410-1570 kg/m^3. Research shows that as the S/O ratio increases, the compressive strength of the column decreases. These ratios may vary according to the selected jet grout manufacturing method, depending on the type of soil in the applied area and the intended final compressive strength in the columns. The amount of cement in the widely improved 1m^3 soil varies between 300 - 750 kg/m^3. 440 kg/m^3 can be taken on average. It is also possible to add some additives to the injection mixture. For example, in cases with high flow ground water, the addition of sodium silicate at 1-3% may be recommended to speed up the outlet. Or, in order to save cement and reduce the cost, various chemical resins can be added to fly ash or mixture water as much as a certain amount of cement percentage.

2.4.4 Injection Mortar

The injection mortar is basically created by obtaining a mixture of water and cement in a ratio of 1:1 and 1:1.5. Its specific density ranges from 1410-1570 kg/m^3. Research shows that as the water/cement ratio increases, the compressive strength of the column decreases. These ratios may vary according to the type of soil in the application area and the final pressure forces targeted in the columns according to the selected jet grout production method. Generally, cement ranges from 300-750 kg/m^3 in 1m3 developed soil. It is also possible to add some additives to the injection mixture. For example, when there is high-flow groundwater to speed up the mixture, the addition of 1-3% sodium silicate may be recommended, or different types of chemical resin or flying ash may be added to the mixing water in the percentage amount of cement to save the cement and reduce costs (Öz, 2015).

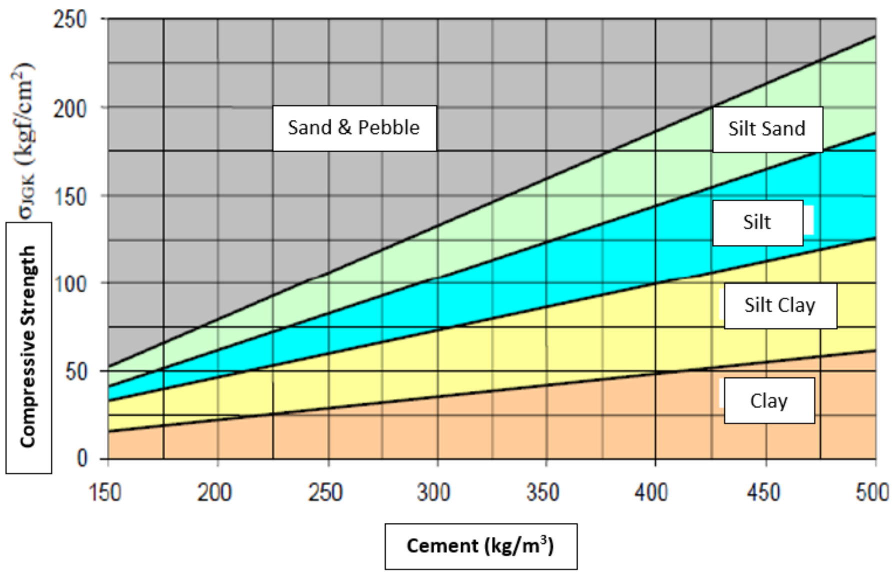


Figure 2.24 Cement quantities for compressive strength in various Ground types (Öz, M.Y., 2015)

In soils with organic content, the cement dose can be increased from 450 kg / m3 to 700 kg / m3. This is because some of the cement used is spent on the neutralization of acids in the organic medium, which removes the bonding property of the cement from the medium. Soil developed by Jet Grout method also improves the properties of unprocessed soil. With this second effect of the Jet grout method, the SPT values of the improved soil increased by 20-25% compared to the natural soil (and the results of other improvement methods) (Öz, 2015).

2.4.5 Number and Diameter of Nozzles

In order for Jet grout to be applied to the soil, the number of nozzles that will spray the fluid and the diameter of the nozzles are also of great importance. Because liquids that will be injected into the ground at a certain pressure come out of these spray mouths, known as nozzles, and meet the soil. In this case, the energy and flow rate of the injection mortar are related to the injection pressure, as well as to the number and diameter of the nozzle. As the diameter of the nozzle decreases, the amount of spread of the spray mortar also increases.

Table 2.2 Relationship between nozzle diameter and pressure

	FLOW (LITER/MIN)													
	NOZZLE DIAMETER(mm)													
PRESURE	1,4	1,6	1,8	2,0	2,2	2,4	2,5	2,6	2,8	3,0	3,2	3,5	4,0	4,5
(bar)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
300	18	24	30	37	45	53	58	63	73	83	95	114	148	188
350	20	26	32	40	49	58	63	68	79	90	103	123	160	203
400	21	27	35	43	52	62	67	72	84	96	110	131	171	217
450	22	29	37	45	55	65	71	77	89	102	116	139	182	230
500	23	31	39	48	58	69	75	81	94	108	123	147	192	242
550	25	32	41	50	61	72	79	85	98	113	129	154	201	254
600	26	34	42	52	64	76	82	89	103	118	134	161	210	266

2.5 Jet grout manufacture on various soils

In order for soil reclamation to be successful with the jet grout column to be created in the soil, the operating parameters must be selected consciously. The pressure value and injection time should be determined according to the resistance of the natural soil. He summarized the relationship between the element to be formed on the ground and the type of soil as follows (Welsh et al., (1986)

The volume reclaimed by Jet grout is most affected by injection or water pressure and withdrawal rate. With the increase of the clay content, the volume of the soil reclaimed at the rate of withdrawal of the spray body with the mortar injected at any pressure decreases. In very solid and hard clays, it is difficult to obtain columns with a diameter of 1.5 m using typical mortar pressure and water pressure.

The volume reclaimed by Jet grout is not significantly affected by the grain size distribution of the soil if the uniform coefficient of the soil (D60/D10) is equal to or greater than 8. If the uniform coefficient is less than 8, the column diameters can reach up to 3 meters using typical operating parameters.

If the content of the soil in the size of gravel is more than 50%, the penetration of the mortar into the soil decreases and the element to be manufactured becomes irregular.

2.5.1 Cohesive Soils

In order for the elements to be formed on the soil to be formed uniform, small spray nozzles are used. The number of spray nozzles used varies between two and 1.6/2.0 mm in diameter. The pressure to be used ranges from 500 to 600 bar. At these pressures, it is necessary to reduce the quantity of the mortar to be injected to prevent the soil from breaking and breaking. Because the broken soil creates excessive material, it cannot be drained between the drill pipe and the drill pipe. Under Normal conditions, the mortar and soil rise to the surface through the drilling well with pressure under the surface. This pressure actually increases the density of the soil around the formed columns, which is an advantage for soil improvement studies. As the drainage becomes irregular, there is a possibility of bearing around the piercing pipes. Excessive pressure begins to break and fluid size the soil by gathering around the spray nozzles due to the lack of drainage. As a result, the effect of the mortar on the soil and the mixture with the soil is lost. With this formation, discontinuity in the columns and breakages under pressure in the upper sections of the soil or vertical or horizontal bearings are formed in weak areas of the soil. If difficulties are encountered when breeding on cohesive soils, it is recommended to install a single spray mouthpiece instead of a double spray mouthpiece. In this way, energy loss at high pressure can be controlled by a single spray nozzle. A pre – reclamation work can be done for reclamation work to be done by pre-washing in 250-300 bars on such soils.

They can also be called gravels and granular soils. Operating parameters are different compared to cohesive soils. Injection pressure varies between 400 and 500 bar on such soils. The diameter of the spray nozzles is between 2.5 and 3.0 mm, so that a large amount of mixture can be injected into the soil. All jet grout systems can be applied on such soils. Below is information about the systems that will be applied on such soils. Single fluid system: Usually one or two spray nozzles are used. Equal breeding areas are formed due to less energy loss when using a smaller number of spray nozzles. When using smaller diameter spray nozzles, the loss of energy affects the output of the injection from the spray nozzles and its spread around. By increasing the diameters of the spray nozzles, there is a decrease in the spread of the injection around. Double fluid system: A spray nozzle is mainly used. Because when two spray mouthpieces are used, air can come out of one of these two spray mouthpieces, and the operator may not be aware of this situation. In this case, the soil may not be wetted as needed. The diameter of the spray nozzles used in this method is larger than the single-fluid system. Diameter dimensions 2.5 mm. with 4.5 mm. it ranges from. Triple-fluid system: All considerations that apply in two-fluid systems apply in this method. The success of soil reclamation by Jet-grout method depends on very careful selection of application parameters. Pressure value and injection time are determined according to the strength value of the natural soil to be reclaimed. In order for the Jet grout technique to be applied and the most appropriate jet grout technique to be selected, some research needs to be done. These; SPT in the land can be counted as data obtained from CPT experiments and determination of relative tightness, grain distribution of non-cohesive soil samples, water content, determination of saturated unit volume weights, determination of consistency limits of cohesive soils. According to these data, the most appropriate jet grout technique is revealed. On clay soils, a small diameter nozzle should be used to obtain a smooth column. Generally, the number of nozzles used is 2, and the diameters are 1.6 - 2.0 mm. Pressure at 500-600 bar and high, and grout flow should be kept low to prevent frequent soil breakages (Melegary and Garassino, 1997). If the ground has properties that are difficult to form a mixture, such as consolidated clay, the number of nozzles should be reduced to one. In this way, the friction losses of the kinetic energy obtained by high pressure can be controlled - in this case, the amount of grout injected should be low and the waiting time at the stage should be long. 250 - 300 bar pressurized water injection (pre-wash) is recommended in order to reduce the density of sand on such clay soils. In gravelly and usually granular soils, operating parameters are different compared to clay soils. Injection pressure is usually between 400-500 bar and nozzle diameters between 2.5-3.0 mm, providing greater grout injection to the soil (Özturan, 2017).

CHAPTER 3

METHODOLOGY

3.1 Testing Local Area

The area where the test was conducted is in the 5th organized industrial zone of Gaziantep and it is an area in where factories are located. Indeed, it is in commercial area. The site is in the northern part of Gaziantep. The name of the region is called as Yukarı beylerbeyi.

Figure 3.1 Study area

Figure 3.2 Area of testing

3.2 Materials used testing programme

As can be understood from the summary of the literature, considering the grout pressure (P), shrinkage speed (V), rotation speed (D) and water/cement ratio (w/c), which are among the most important parameters affect jet grout column manufacturing. An experimental program was prepared to investigate these effects. The test program is shown in Table 3.1.

Table 3.1 Testing programme

	Pressure P (bar)	Water/Cement Ratio w/c	Tensile Speed V (cm/min.)	Rotational Speed D (rpm)
Dry Sandy Samples	300	1.0	30	10
Dry Sandy Samples	400	1.0	30	10
Cured Sandy Sample	300	1.0	30	10
Cured Sandy Sample	400	1.0	30	10
Wet Sand Samples	300	1.0	30	10
Wet Sand Samples	400	1.0	30	10
Cured Wet Sand Samples	300	1.0	30	10
Cured Wet Sand Samples	400	1.0	30	10
Clayey Samples	300	1.0	30	10
Clayey Samples	400	1.0	30	10
Cured Clay Samples	300	1.0	30	10
Cured Clay Samples	400	1.0	30	10
Dry Sandy Samples	350	1.0	30	10
Cured Clay Samples	350	1.0	30	10

3.3 Construction of jet grout columns

First of all, environmental issues and area of construction site are taken into consideration for the determination of testing area in order to prevent any type of harm to the environment and the site during jet grout process. Two places were selected on the area. Thereafter, these places were excavated and they were filled with river sand. The sand is a natural river sand and is obtained from Narlı (a village in Kahramanmaraş). A special excavator (jcb 3cx) was used for excavation. Excavation was not carried out for the clayey soil, since the soil was already clayey. Both excavation dimensions are 2m x 4m x 3m (width x length x height

Figure 3.3 Picture of Excavation Machine

Figure 3.4 Excavation

River sand was poured into the excavated area. The land where the river sand has been poured was compacted with a compactor to ensure that there is no gap in the sand as much as possible. Then, one of the areas is watered and the sand became wet. Sieve analysis of the sand and the clay was made in the laboratory.. The sieves whose sizes are between 8 inch(200 mm) and 3/8 inch (9.5 mm) were used for sieve analysis. Normally used are the standard 8 inch (200 mm) sieves. With Fine Aggregate the coarse sieve or the 3/8" (9.5 mm) sieve at the top; each sieve below is finer; and the finest sieve, a No. 200 (75 µm) is at the bottom.

Figure 3.5 Picture of weighted sample

Figure 3.6 Picture of sieves

Figure 3.7 Sieving of wet clay sample

Figure 3.8 Liquid limit test

Figure 3.9 Plastic limit test

The results of the tests are given in the tables 3.2, 3.3, 3.4 and 3.5.

Table 3.2 Sieve analysis of clay

SIEVE NO	SIEVE OPENING	SIEVE RETAINED (g)	CUMULATIVE RETAINED (g)	RETAINED (%)	CUMULATIVE RETAINED (%)	CUMULATIVE PASSING (%)
3''	76.2			0	0	100
11/2''	38.1		0	0	0	100
3/4	19.1		0	0	0	100
3/8	9.52		0	0	0	100
4 NO	4.76	11	11	0,88	0,88	99,12
8 NO	2.38	67	78	5,36	6,24	93,76
16 NO	1.19	43	121	3,44	9,68	90,32
30 NO	0.59	18	139	1,44	11,12	88,88
50 NO	0.297	22	161	1,76	12,88	87,12
80 NO	0.18	18	179	1,44	14,32	85,68
100 NO	0.149	23	202	1,84	16,16	83,84
200 NO	0.075	19	221	1,52	17,68	82,32

Table 3.3 Specifications of clay

1	Liquid Limit	42
2	Plastic Limit	22
3	Plasticity Index	20

Table 3.4 Proportions of Sieve analysis

Gravel %	6,24
Sand %	11,44
Plate-Clay %	82,32

Table 3.5 Table of LL-PL

	LL			PL	
	1	2	3	1	2
Number of Strokes	44	30	22	-----	-----
Container No	118	132	113	133	138
Container Weight (gr)	20,1	21,1	21,1	21	21,1
Container + Wet Sample Weight (gr)	46,38	42,81	49,07	37,12	39,43
Container + Dry Sample Weight (gr)	41,11	37,02	40,31	33,99	36,71
Dry Sample Weight (gr)	21,01	15,92	19,21	12,99	14,18
Water Weight (gr)	5,27	5,79	8,76	3,13	2,72
Water Content %	25,1	36,4	45,6	24,1	19,2

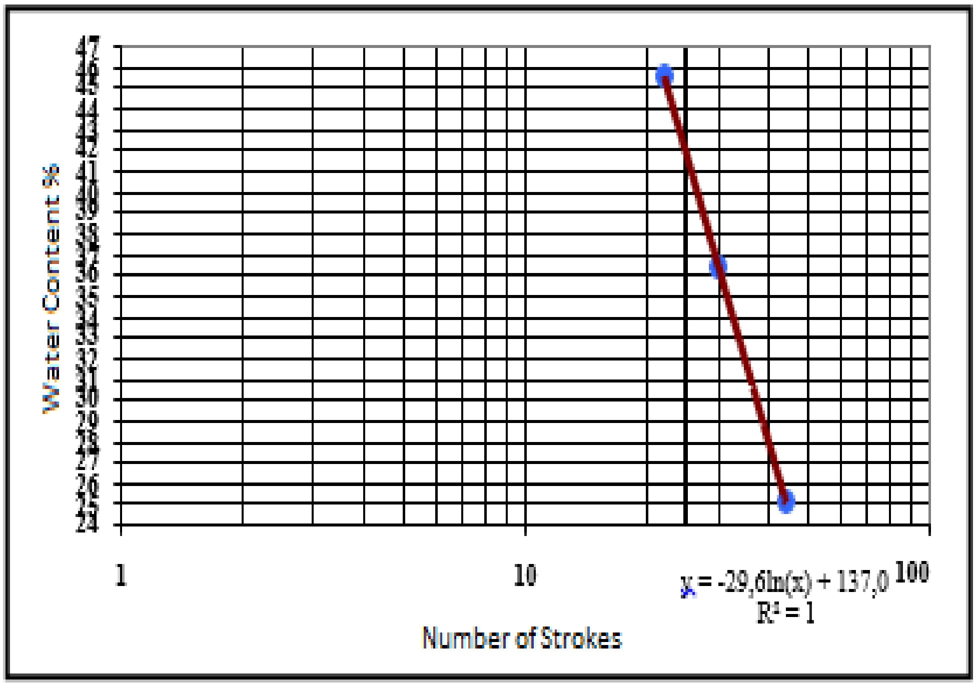


Figure 3.10 Graphic of Water Content and Number of Strokes

Table 3.6 Sieve Analysis of sand

FINE AGGREGATE SIEVE ANALYSIS					
DRY WEIGHT OF THE DRY SAMPLE RECEIVED				1250 g	
SIEVE mm	REMAINING ON THE SIEVE (gr)	CUMULATIVE WEIGHT (gr)	PERCENT REMAINING ON THE SIEVE	CUMULATİVE % RETAINED	CUMULATİVE % PASSING
8					
5.6					100
4.0	7	7	0.56	0.56	99.44
2.0	21	28	1.68	2.24	97.76
1.0	139	167	11.12	13.36	86.64
0.50	227	394	18.16	31.52	68.48
0.250	247	641	19.76	51.28	48.72
0.125	368	1009	29.44	80.72	19.28
0.063	84	1093	6.72	87.44	12.56
No: 0.063'den geçen					
Numune Ağırlığı					

After the sand loading work was completed, jet grout column was started. While making the jet grout column, MDT 140 b was used as the machine. MDT 140 B is in the middle segment of multidirectional drill rigs, it is designed especially for heavy job-site works and is characterized by excellent manoeuvrability, reliability and high productivity level - all this thanks to adoption of many innovative technical solutions. Active and passive safety devises were foreseen at the design stage to ensure maximum safety to the operator and other rig personnel. Design choices foreseen for MDT 140 B were made in view of the necessities of the job site, to make possible carrying out different types of work using the same machinery. Therefore, using this drill rig it is possible to carry out drilling works like consolidated piles through jet grouting consolidation method, micropiles, anchors and consolidation tie rods.

High stability on the way and during placing to the advantage of safety and manoeuvrability, even when the rig is equipped with lattice extensions installed for Jet Grouting injections for maximum useful drilling depth of 16 m.

162 hp engine for excellent performance and application of rotary head of 32000 Nm, double rotary head and Top Hammer. The engine is equipped with electronic Exchange that always keeps the engine functioning under control, giving alarm in case of abnormalities.

Remote control panel connected with cable, or radio control upon request, for overall vision of the work area and considerable speed up of movement and placing operations, practicable in most safe conditions, especially during loading and unloading operations. All the functions of traverse-placing, mast positioning and drilling process are remote-controlled from remote electric control panel with cable or radio control.

Automatic power division system in order to improve the drilling rig’s performance and maintain productivity at a high level.

Automatic devices’ application facilitates the use of the rig even by less experienced personnel.

Ample oversizing of structural parts in view of prevention of possible critical conditions due to possible operator’s mistakes. Technical solutions suited to guarantee rock-bottom operating costs and maximum easiness of maintenance servicing. The drill rig meets the CE norm, the UNI EN 791 in particular

Figure 3.11 Jet grout testing machine

Portland Composite Cement - 32,5 R; The cement is produced by grinding at least one type of mineral additive (pozzolana) prescribed by standards (max. %55) with portland clinker byaddition of a certain amount of retarder (generally gypsum). The product delivers the strength values respectively in late periods compared to CEM I and CEM II types. Water/cement ratio is respectively higher. It is much more resistant to alkali and aggregate reactions. It is best for repairing works, foundation filling and used in stucco and building chemicals manufacturing.

Table 3.7 Properties of cement physical characteristics

	Çimko cement	Standard	Unit
Solidification Start/End	190	min. 75	minute
Solidification End	234	-	minute
Volume Expansion	1	max. 10	cm
Specific Surface (Blaine)	5170	-	cm2/g
Liter Weight	862	-	g/l
2-day Resistance	14.7	min. 10	MPa
28-day Resistance	36.2	min./max. 32.5/52.5	MPa

Figure 3.12 Picture of cement

Suspensions with one water/cement ratio were prepared. The mixtures with water/cement ratios of 1.0, by weight were used in the experiments. Since the speed of the mixer and the mixing time are extremely important for the suspension, the mixing process was carefully carried out to avoid agglomeration and premature hydration of the particles. If the mixing time is kept too long, the suspension temperature may rise too high and early hydration may be seen. The speed of the mixer is also important to prevent agglomeration. For the mixing time and cycle number, the issues specified in the manufacturer's information catalog have been taken into account. After the sand was filled, 40 cm of the excavation was filled with hard filling in order to ensure the correct results of the samples.

Figure 3.13 Picture of loaded sand

Jet grout columns applied to 3 selected areas with three different materials. These are; wet river sand, dry river sand and clay soil.The samples were constructed with a ratio of w/c= 1 for each test.Three jet grout column samples were made on each material at 300, 350 and 400 bar pressures.

Figure 3.14 Jet grouting of wet river sand soil

Figure 3.15 Jet grouting of dry river sand soil

Figure 3.16 Jet grouting of clay soil

All jet grout samples were tested after 28 days of curing time. The prepared samples have been removed by an Excavator machine.

Figure 3.17 Excavation around of Jet grout column

Jet grout columns were removed from the ground surface with the help of an Excavator and coring samples were taken from the field. Diameter of coring samples were 6 cm and the height was 12 cm. The height is twice the length of the diameter.

Figure 3.18 Taking coring samples on jet grout

Figure 3.19 Taking coring samples from Jet grout columns

Finally, the jet grout columns made to the laboratory of the Hkü University for further research were taken with the help of a crane.

Figure 3.20 Pictures of jet grout columns

CHAPTER 4

RESULTS & DISCUSSION

This study is important in terms of providing strengths of jet grout columns produced in sand soil and clay soil conditions in the field. According to the results of the study, it has been observed that the jet grout colum samples compressive strength obtained in sandy soil much higher compared to clayey soil. Also tha tthe compressive strength in creases in both types of soil as the days of curing time increases. According litareture Baumann (1984) and Trevi (1994) found same result. Themixing of sandy soil with grout creates a solid product like concrete. Therefore, it has been observed that its compressive strength is higher than clayey soil. With the curing effect, the cement formed more solid bonds as time passed and the compressive strength increased over time.

4.1 Diameter of the jet grout columns according to the type of soil

During the application, the diameters of the jet grout column of different soil type were measured under the same conditions. The same weather conditions, the same water / cement ratio (water/cement ratio: 1) and the same machine have been used. The purpose of this is to determine more accurately the diameter of the jet grout column in different soils. There are a total of three different soil types in this experiment.These are;

- Clayey Soil
- Sandy Soil
- Wet Sandy Soil

Figure 4.1 Measure of jet grout columns diameter

The diameters of jet grout columns in different soil types are shown on table 4.1 Jet grout columns diameter of different soil types below. Jet grout columns are generally 3 meters in height and the diameter of the columns have been measured in the middle of the samples.

Table 4.1 Jet grout columns diameter of different soil types

JET GROUT COLUMNS	Pressure (bar)	DIAMETER (cm)
Clayey Samples	400	74
	350	54
	300	49
Sandy Samples	400	98
	350	84
Wet Sandy Samples	400	97
	350	82

It has been observed that the diameters of clay soils are smaller than in sandy soils.No major differences were observed between wet sandy soil and dry sandy soil.Sandy soil samples have a bigger diameter than clayey samples. Dry and wet sand samples had bigger diameters than clayey samples. This could be because of the water-cement injection works better with non-cohesive materials than cohesive. Sand samples had a higher void ratio while the clay samples have very low void ratios. These voids have been filled by injection and affected the diameter of the jet grout columns.Sand has a high binding with w/c solution than clay.

It has been observed from the results of Table 4.1 that the diameter of the jet grout columns increases as the pressure increases.These solutions are the same as Xanthakos, P. Et al, 1994 stated in the literature.

Typical column diameters formed ranged from 0.9 m to 0.5 m, with decreasing trend from gravelly soil to clayey soil, as shown in Figure 3 (Croce and Flora, 2000).

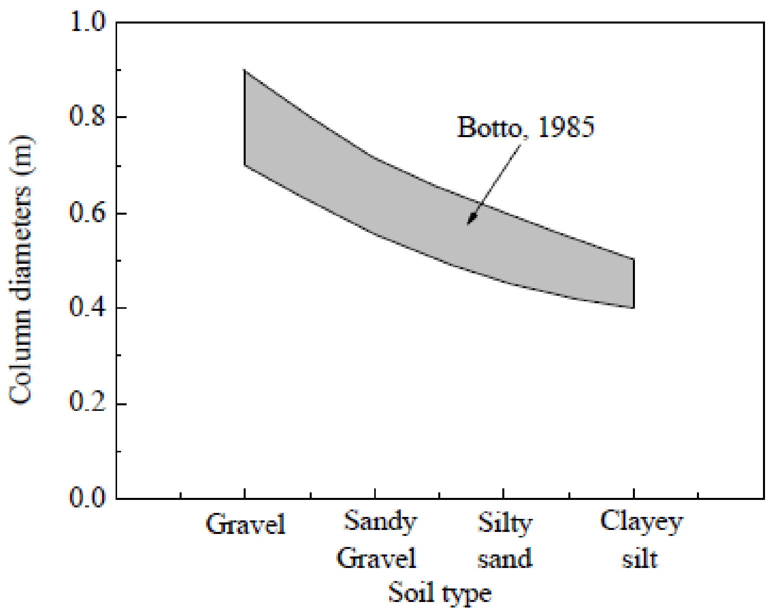


Figure 4.2 Variation of column diameters with soil type for single fluid system (after Croce and Flora, 2000)

4.2 Compressive strength of jet grout columns to soil type

Figure 4.2shows a photo of the dry sand sample which was prepared at 400 kPa of injection pressure. The coring sample had a diameter of 8 cm and a length of 16 cm. The UCS results showed that the 7 days cured sample had a strength of 15.0 kPa and the 28 days cured sample had 20.3 kPa of strength. These results showing that the curing period have a significant effect on strength characteristics. MelegaryandGarassino, 1997 reported in the literature study, same parallel results.

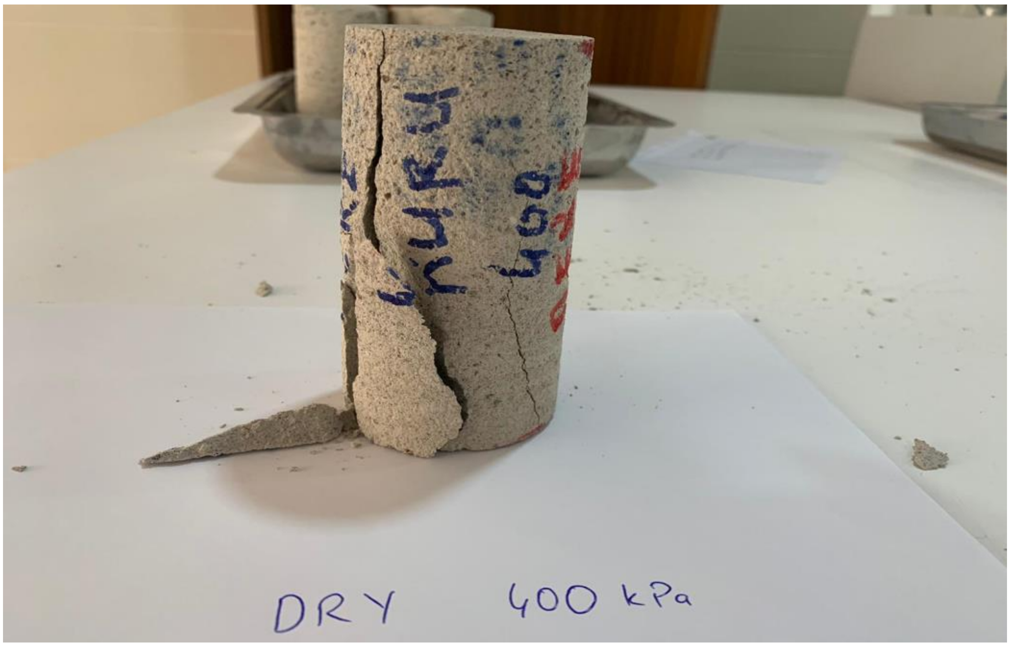


Figure 4.3 Picture of dry sand for 400 kPa pressure

On the other hand, Figure 4.3 shows a photo of the clay sample which was prepared at 400 kPa of injection pressure. The coring sample had also a diameter of 8 cm and a length of 16 cm. The UCS results showed that the 7 days cured sample had a strength of 3.0kPa and the 28 days cured sample had 4.7kPa of strength. Curing period have also an important effect on strength characteristics of clay samples but the increment in strength is less than sand samples. Clay samples have a lower strength than sand samples. This could be due to the w/c binding solution. The solution reacts easier with sand than clay.

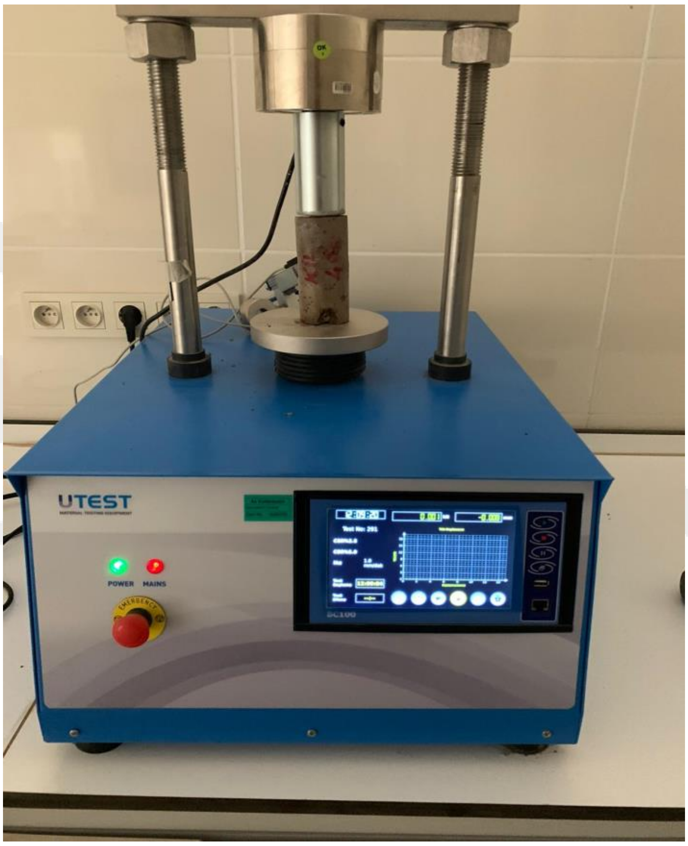


Figure 4.4 Picture of clay sample for 400 kPa pressure

An increase in pressure for both 7- and 28-days samples resulted in a decrease in strength. Also, the strength increased with curing time. After 28 days, the strength increase were about 1.5 times than the 7 days sample values (see Table 4.2).

Table 4.2 Testing results of UCS Test for clay soil

Mixtures	Pressure (bar)	Strength (kN)
Clayey Samples (7 days)	300	6,1
	350	4,2
	400	3
Clayey Samples (28 days)	300	9,9
	350	6,8
	400	4,7

For the dry sandy samples, the pressure increases for both 7- and 28-days samples resulted in a decrease in strength. Also, the strength of sandy soils increased with curing time. After 28 days, the increase in strength values were about 20% higher than the 7-day sample values(see Table 4.3).

Table 4.3 Testing results of UCS test for dry sand

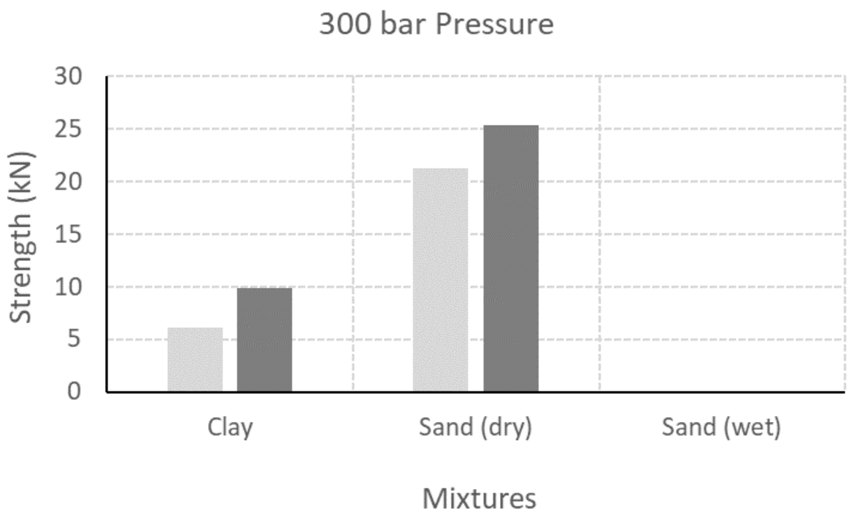
Mixtures	Pressure (bar)	Strength (kN)
Sandy (dry) Samples (7 days)	300	21,2
	350	15,9
	400	15
Sandy (dry) Samples (28 days)	300	25,4
	350	21,3
	400	20,3

Moreover, for the wet sandy samples, pressure increases for both 7- and 28-days samples resulted in a decrease in strength for wet sandy samples. Also, the strength of wet sandy soils increased with curing time. After 28 days, the increase in strength values were about 20% higher than the 7-day sample values.Wet sandy samples couldn’t examine the 300 bar tests. This were because of the high-water content inside the sample.

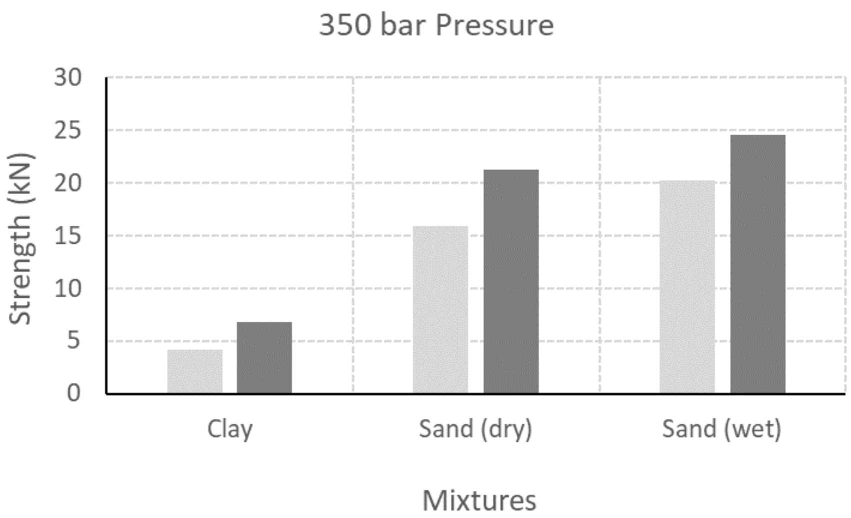
Table 4.4 Testing results of UCS test for wet sand

Mixtures	Pressure (bar)	Strength (kN)
Sandy (wet) Samples (7 days)	350	20.2
	400	17,3
Sandy (wet) Samples (28 days)	350	24.6
	400	21,5

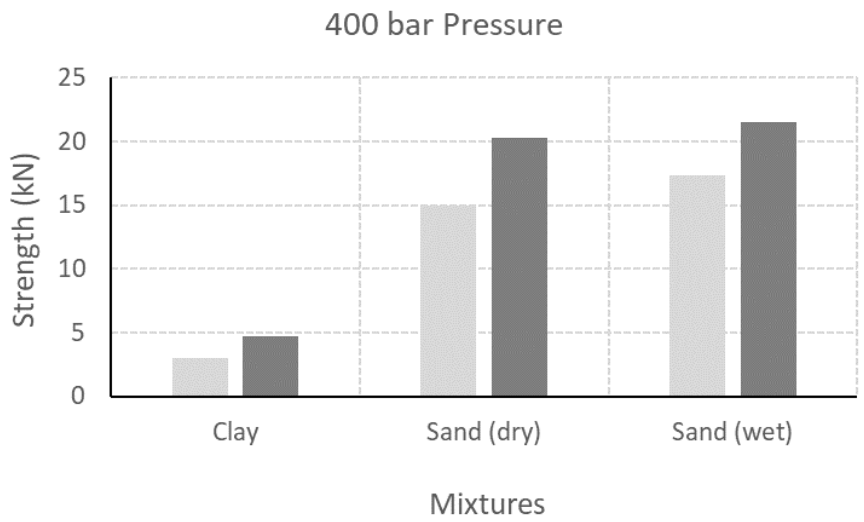
It was observed that curing time have an important effect on the unconfined compressive strength of jet grout columns. Clayey samples had the lowest UCS results. Preparing the sand samples dry had a negative effect on the unconfined compressive strength results. Wet samples had a higher strength than the dry samples. The unconfined compressive strength was maximum at the dry sand cured samples.



(a)



(b)



(c)

Figure 4.5 Strength results of samples for 7 days (light) and 28 days (dark) of curing period

From the bar view on Figure 4.4a, it can be seen that the wet sand tests could not be examined at 300 bar pressure. This could be because of the low pressure. At higher pressures, the jet grout injection has been achieved. Also, it can be pointed out from the results that the curing period increased the strength by 50% for clay samples. On the other side this increment was lesser (20%) for dry sand samples. Furthermore, clay samples had the lowest strength values in all bar figures. As the pressure increased the strength have been decreased for all samples (see Figure 4.4 a-b-c). Wet sand samples had the highest strength values for all pressures.

CHAPTER 5
CONCLUSIONS AND DISCUSSION

This thesis aimed to study the effect of soil type and pressure on jet grouting. The study is significant regarding providing strengths of jet grout columns produced in sand and clay soil conditions in the field. The primary objectives of this research can be summarized as:

1. According to the results of the study, it has been observed tha the jet grout colum samples compressive strength obtained in Sandy soil much higher compared to clayey soil.
2. Also, the compressive strength increases in both types of soil as the days of curing time increases.
3. Themixing of Sandy soil with groutcreates a solid product like concrete. Therefore, it has been observed that its compressive strength is higher than clayey soil.
4. With the curing effect, the cement formed more solid bonds as time passed and the compressive strength increased over time.
5. The strength values of 28 days samples were about 20% higher than the 7-day wet sand and dry sand samples.
6. The UCS strength values of clay samples were about 3.0 kPa for 7 days of time period while the 28 days cured sample had a 4.7 kPa of strength. Clay samples showed a very low strength comparing to sand samples. This could be because of the w/c solution binding.
7. As the pressure has increased, the diameter of all sample types has also increased. This increment was at least 10-15 cm.
8. Dry and wet sand samples had bigger diameters than clayey samples. This could be because of the water-cement injection works better with non-cohesive materials than cohesive. Sand samples had a higher void ratio while the clay samples have very low void ratios. These voids have been filled by injection

9. and affected the diameter of the jet grout columns.

10. Sand samples had a better binding affect with the w/c solution than clay.

REFERENCES

Ayan, E.(2009). Derin Zemin İyileştirme ve Uygulamadan Örnekler. Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, İnşaat Mühendisliği ABD, İstanbul, Türkiye

Baumann,V. 1984.Das Soilcrete - Verfahren in der Baupraxis. Vortrage der Baugrundtagung, Duesseldorf: DGEG.

Bell, K. R., Clemente, J., L.M., Gularte, Francıs B., Lopez, Roberto A., 2003, Superjet Grouting Reduces Foundation Settlement for La Rosita Power Plant in Mexicalli, Mexico, New Orleans:Woodhead.

Croce,P., Flora, A., (2000), *Analysis of single-fluid jet grouting. Géotechnique 50,*No 6 ,739-748

Doğanışık,S.K., 2010, "Jet Grout Kolonundaki Gerilme Dağılışının İncelenmesi", Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, İnşaat Mühendisliği ABD, 95s, İstanbul.

Doğu, O.(2005). "Jet Grouting Tekniği ile Zemin Islahı", Yüksek Lisans Tezi, İ.T.Ü., İstanbul.

DOĞU O., YILDIRIM H., DURGUNOĞLU A. T., 2006. "Zeminin İnce Dane Oranı ve SPT Vuruş Sayısının Jet Grout Kolonların Mukavemetine Etkisi", Zemin Mekaniği ve Temel Mühendisliği On birinci Ulusal Kongresi, K.T.Ü., Trabzon.

Essler, R., and Yoshida, H. (2004). Jet grouting. Ground Improvement (Second Edition), Spon Press, pp160-196

Fırat, A.T. (2001). Jet Grouting Yöntemi ile Temel Takviyesi. Yüksek Lisans Tezi, İ.T.Ü, İstanbul, Türkiye.

Gümüş, G. (2002). Jet Grouting technique and strength properties of jet grout columns. Yüksek lisans tezi, Boğaziçi üniversitesi, İstanbul, Türkiye

Kauschinger, J. L., Perry, E.B., Hankour R., 1992, Jetgrouting: State of the Practice. Proceedings of the Conference of Grouting Soil Improvement and Geosyntetics, New Orleans, Louisiana, 25-28 Februrary 1992, 1, 169- 181, ASCE, New York.

Küçükali, N. (2008). Demiryolu altyapısının jet enjeksiyon yöntemi ile iyileştirilmesi, Yüksek lisans tezi, Karadeniz Teknik Üniversitesi, Trabzon.

Langbehn,W.K. (1986). The jet grouting method: applications is slopestabilization and land slide repair, Master of enginnering report, University of california, Berkeley, USA.

Melegari, C. and Garassino A. L., 1997. Seminar on Jet Grouting, CI-Premier Pte. Ltd., Singapore.

Nikbakhtan,B.,Osanloo,M.(2009). Effect of grout pressure and grout flow on soil physical and mechanical properties in jet grouting operations, *International Journal of Rock Mechanics&Mining Sciences* , 46, 498-505p.

Nikbakhtan, B., Osanloo, M. (2010). Estimation of jet grouting parameters in Shahriar dam, Iran, *Mining Science and Technology* ,20, 0472-0477p.

Ou,C.Y.,Teng,F.C.,Wang, I.W.(2007). Analysis and Design of Partial Ground İmprovement in Deep Excavations, *Computers and Geotechnics*, 35, 576 – 584p.

Önalp,A., 1983, İnşaat Mühendislerine Geoteknik Bilgisi. Cilt II, Karadeniz Üniversitesi Yayın No:3, Trabzon, 1225s

Özturan, M. (2017). Enjeksiyon Yöntemi ile Zemin İyileştirme Yöntemi, Yüksek Lisans Tezi, Pamukkale Üniversitesi Fen Bilimleri Enstitüsü, İnşaat Mühendisliği Anabilim Dalı, Denizli.

Öz, M.Y.(2015). Sıvılaşmaya karşı jet grouting yöntemi ile örnek bir iyileştirme uygulamasının incelenmesi, Yüksek Lisans Tezi, Pamukkale Üniversitesi Fen Bilimleri Enstitüsü, Denizli.

Özkök, E.(2006). Adapazarı Ovasındaki Zeminlerin Gene Dağılımı ve Uygun Zemin İyileştirme Yöntemlerinin Belirlenmesi, Yüksek lisans tezi, Sakarya Üniversitesi, Sakarya.

Sağlamer A., Düzceer R., Gokalp A., Yılmaz E., 2002, “Ground Improvement by Jet Grout Columns for the Foundations of an Automobile Plant in Turkey” Deep Foundations, Proceedings of the International Deep Foundations Congress, Orlando, Florida, GSP No. 116.

Schaefer,V.R., 1997, Ground Improvement, Ground Reinforcement, Ground Treatment Developments Proceedings of Sessions Sponsored bythe Committee of Soil Improvement sand Geosyntetics of the Geoinstitute of the ASCE, Geotechnical Special Publication, 69.

Trevı K., 1994, ColumnarTreatment, Illustrative Report, Cesena

Uzuner B.A. 2006, Temel Mühendisliğine Giriş, 3. Basım, Derya Kitabevi, Trabzon.

Welsh,J.P., Rubright,R.M., Coomber,D.B., 1986, Jet grouting – uses for soil improvement, ASCE conference on grouting for support of structures, Seattle, Washington.

Wong K.S.,Lı J.C., Goh. A.T.C., Poh K.B., Oıshı E., 1999, Effect of Jet Grouting on Performance of DeepExcavation in SoftClay', Proceedings of the 5th International Symposiom on FieldMeasurements in GeomechanicsFMGM99, Singapure.

Xanthakos,P.P., Abramson,L.W., Bruce, D.A., 1994, Ground control and improvement, John Wiley, New York.