STUDY OF NEW GROUTING TECHNIQUES IN REPAIR AND STRENGTHENING OF SOFT SOILS

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ABSTRACT
Demands for soft land strengthening and contaminated soil solidification have been increased due to the explosion population, development of technology, industry, and transportation systems. Deep mixing methods (DMMs) are conventional methods for strengthening the soft soils. Cement (or binder) with soil have being mixed in this method. Injection of cement and additives with a high pressure and displacing the gases and liquids from within soil grains in combination with DMMs is a new wedding technique for increasing the efficiency of soil stabilization. In this paper, different kinds of deep mixing methods (conventional and new techniques) were studied. By considering the type and alternative layers of soil, load size, the situation, cost and type of project selecting the right stabilizing method for repair and strengthening of soft soils recommended and it is believed that it could prompt engineers to resolve soil strengthening difficulties from the geotechnical view point.

Keywords: grouting, stabilizing, injection, mixing, soft soil, cement and binder

1. INTRODUCTION
1.1. Deep Mixing Methods (DMMs)
The DMMs refers to the rotary methods for the penetration of soil or rock and mixing of soil with suitable binder and at times with pneumatically dry or wet end for enough depth. This technique has been used for construction of tunnels by injecting binder in the rock too. Based on design requirements, site conditions, soil layers, restraints, and economics, the use of DMMs is increasingly spreading. The demand for improving and stabilizing land for different purposes is expected to increase in the future and the best way to fulfill it is by using DMMs. The main advantage of these methods is long term increase in strength, especially for some of the binders used. It has been mentioned that DMMs is the best way to improve soils and rocks. The following are the characteristics of the improved soils and rocks when these methods are employed [1]:
(i) Reduction of settlements, (ii) increase of stability, (iii) increase of bearing capacity, (iv) prevention of sliding failure, (v) reduction of vibration, (vi) liquefaction mitigation, and (vii) remediation of contaminated ground. The Federal Highway Administration has suggested that these techniques can be
classified based on [2]:
1) Method of additive injection (i.e. wet or dry injection).
2) Method by which additive is mixed (i.e. rotary, mechanical energy or by high pressure jet).
3) The location of the mixing tool (i.e. near the end of the drilling rods or along a portion of the drilling rods).

Majority of the companies which are working in these fields agree that the DMMs can be divided into three common techniques [9]:
1. Shallow soil mixing (SSM), which uses a single mechanical mixing auger located at the end of the drilling tool (Kelly bar).
2. Deep soil mixing (DSM), which utilizes a series of overlapping augers and mechanical mixing shafts.
3. Jet grouting which can be considered a type of soil mixing. In order to inject a liquid into voids within a structure, it is necessary to displace the gases and liquids from within these. This utilizes high velocity ranges from 28 to 42 Mpa backpressure and jets to hydraulically shear the soil and blends a cement grout or suitable binder to form a soil-cement column or column with soil and special binder.

Table 1 clearly names the methods which are utilized in each part. The explanation and comparison of each part will be made subsequently.

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The researchers have come up to four basic jet grouting systems to be used, which are [4]:
(i) Single phase (grout injection only), (ii) dual phase (grout + air injection), (iii) triple phase (water+air injection and followed by grout injection), and (iv) super jet grouting (air injection+drilling fluid by grout injection). Figure 1 shows the sketches of the jet grouting systems.

![Figure 1. The systems in jet grouting.](image-url)
2. SHALLOW SOIL MIXING (SSM)

2.1. Ras-Columns

Ras-Columns are one of the most common soils mixing in DDMs which are based on mechanical soil mixing technology. This method has been used for improving shallow soils and seldom in deep mixing. The mixing head is combined with blades which can rotate inversely. In other words, in bottom auger the mixing blades rotate clockwise and in the upper auger, the mixing blades rotate anti clockwise [3]. This technique causes the cement to mix with soil homogeneously, and thus produces higher quality soil-cement columns. The first step of this method is Rig positioning. This is followed by penetration whereby after passing dry excavation zone, injecting slurry without any jetting should start. The third step is churning or moving the head up and down to mix homogenous thoroughly. Finally is the completion step, where the head is withdrawn and soil column cement is completed (Figure 2).

![Figure 2. The steps in ras-columns system [3].](image)

2.2. Advantages and Main Points

1. Ability to produce soil-cement column of 1.4 to 2.5 m diameter.
2. Applicable to a wide range of soils hence providing excellent quality improvement.
3. Uniform mixing and homogenous product quality due to counter-rotation mechanism (in comparison with traditional equipment).
4. Low noise and low vibration system.
5. Computer-based control and monitoring system ensures quality improvement (in some latest ones).

3. DEEP SOIL MIXING (DSM)

3.1. Cement Deep Mixing System (CDM)

The second method which is related to deep soil mixing and is one of the DMMs is CDM. As mentioned before, in this method a series of overlapping augers and mechanical mixing shafts are applied. Figures 3(a) and 3(b) show CDM machines with 2 and 3 augers respectively. CDM is normally utilized in soft soil that contains mineral soils such as clay or sand. In some conditions where mineral soils are absent, sand should be added before mixing in cement slurry. CDM is a soil stabilization method which mixes cement slurry with soft soil in situ to attain a required strength. Soft soil is
stabilized by the 2-phase chemical reaction. A hydration reaction occurs and an ettringite of capillary crystals is generated when the cement mixes with water. Then a pozzolanic reaction follows, as the age grows, where the hydration product reacts with the clay minerals in the soil [3].

Figure 3: (a) The CDM machine with 2 augers (b) The CDM machine with 3 augers

3.2. Advantages and Main Points
1. CDM is a drilling and mixing operation with low noise and low vibration, and does not generate dust.
2. CDM method mixes soft soil in situ with cement slurry without any jetting. The soil should have mineral soils like sand and clay for hydration product with cement.
3. Because of a series of overlapping augers, it saves soil mixing time and labor while maintaining efficiency in comparison with previous method.
4. Computer-based control and monitoring system ensures quality improvement (in some latest ones).

4. JET GROUTING SYSTEMS
Jet grouting systems, which is the third part of DMMs, have some similarities with the previous methods. Apart from having the same mixing tools, this method also applies the same process whereby the in-situ soil will be cut and broken by high pressure jet of slurry and produce homogenously improved zone around the mechanically mixed core.

In addition, for underwater applications, it is desirable to have highly flowable grout that can resist water dilution and segregation, and spread readily into place. The slump of concrete or grout is a good measure of the consistency and flow characteristics of a concrete or grout mixture. This equates (to) a mid range slump. A very high slump grout gives maximum water dilution. A very low slump grout results in little or no flow characteristics. For underwater grout, the slump flow is influenced (in order of influence) by the anti-washout admixture concentration and the binder content, the water-cementitious material ratio, and the water reducer concentration [10, 11].
4.1. Single Phase
4.1.1. Maxperm Grouting System

It has been mentioned that the jet grouting is divided into 4 phases. The first part which is single phase has 4 common methods. One of the newest methods in jet grouting system is Maxperm grouting system. This method is commonly utilized around the world by several names such as dual-tube double-packer grouting system.

In this method, the contractor can inject several materials in the soil which has several layers with different characteristics. On the other hand, the ground is made up of alternative layers, consisting of different particle sizes, and permeability can be stabilized by this method. The pre-defined region is improved and its sketches are shown in Figure 4.

![Figure 4. Pre-defined region can be improved by maxperm grouting system.](image)

The following are the steps that take place in this method which are also shown subsequently in Figure 5[3]:

2. Apply casing drilling ($\phi=100$ mm to a pre-defined depth).
3. Install the grout pipe with special sleeve packers and strainers then withdraw the casing.
4. Install the dual-wall inner tube equipped with double packer which inflates the
5. Inject grout through the strainer section. Re-install the dual-wall inner tube equipped with double packer.

4.1.2. Advantages and Main Points
1. Cost-effective and labor saving alternative, because it can be separated and cause large borehole spacing.
2. Special layers, regions, any pre-defined point, a narrow area and ground with underground obstacles in soil can be improved by this method.
3. Large size improvement.
4. A pre-defined zone is homogenously stabilized by injecting grout from discrete injection points.
5. The system allows repetitive grouting at the same injection point with different grout materials even after the work is completed.
6. This method can be used as a remedial method for structures.

4.1.3. Navigational Drilling System
The second method in single phase jet grouting is navigational drilling system. This is a new method which is broadly used. By using 3D navigational drilling system, horizontal grout holes can be installed from the surface without excavating a shaft.

The bit locator system monitors exact location of the drill bit with special locator sensors free from magnetic disturbance. The system gives the operator in real time such information as direction and inclination of drill bit, tool face orientation, and deviation from preplanned alignment. Figure 6 shows the schematic representation of the flexible borehole alignment.

Figure 6. The schematic representation of the flexible borehole alignment which can be made by navigational drilling system [3]

Below are the steps that take place in this method:
1. Operator starts drilling while monitoring bit location (with the tool face oriented to the goal).
2. Withdraw the inner steel rod.
3. Install a grout pipe.
4. Withdraw the outer pipe.

Figure 8 clarifies the steps that take place in the navigational drilling system.
4.1.4. Advantages and Main Points
1. Drills of this method are the most flexible among injection and grouting tools (it can carve with various radiuses, e.g. 20)
2. Drills are able to drill at a long-distance.
3. Drills can solve the underground obstacle problems with special bit locator system.
4. Enable ground improvement and soil remediation under or behind existing structures with out affecting operation or damaging underground structures
5. This method can be used as a remedial method for structures.

4.1.5. Vacuum Grouting Injection
It is worth pointing out that pressure injection may be less successful when the pressures needed to dispel gases and liquids from the voids are so high as to risk disrupting the structure. For instance this may happen when the voids consist of many fine interstices and are not always interconnecting (which may result in the need for a very large number of injection points), when complete filling is very difficult to achieve, or when it is difficult to confine the grout to the area to be injected.

The third part of single phase of jet grouting is Vacuum Grouting Injection. In this technique a partial vacuum is first established in a portion of the structure (or the whole of the structure if it is small enough), drawing off gases and liquids from the voids and interstices.

This vacuum holds the structure together, rather than exerting any potentially disruptive forces as in pressure injection. After achieving a stable vacuum, the injection liquid is introduced either through injection pipes set at appropriate intervals and depths or, over the surfaces and into the structure through cracks, fissures and porous areas [6]. In Figure 7 the proceeding of Vacuum Grouting Injection and its instrument are displayed.

![Figure 7: The proceedings of vacuum grouting injection.](image)

4.1.6. Advantages and Main Points
1. It can be used for filling small, essentially air-tight voids through a single hole, where difficult access complicates the provision of vent holes (like Dam's concrete) [7].
2. It has been employed for filling small voids under steel liners, as well as defects in the original grouting of post-tensioning ducts. In other words, it can
fill off closely spaced fine defects in concrete or masonry.
3. It can be seen clearly which part of the voids are filled by grouting (in part 2). Whenever the plastic cover saturates the entire area under plastic sheeting, all air will be sucked in including any void space as well (Figure 8).
4. This method can be used as a remedial method for structures.
5. The mixing machine used is mobile and can be easily relocated to the next soil mixing location at/on site.
6. This method can be used as a remedial method for structures.

Figure 8. The plastic cover is used for all air to be sucked into any void spaces as well [12]

5. DUAL PHASE SYSTEM

5.1. Dry jet Mixing System (DJM)
The second part of jet grouting systems is dual phase system. The DJM is a highly effective ground treatment system used to improve the load performance characteristics of soft clays, peats and other weak soils. The concept of using dry binder for deep soil mixing was first presented in Scandinavia in 1967 by Mr. Kjeld Paus from Sweden. A period of thirty years has passed since then but the technique has been evolved considerably. The method is based on injecting dry binder carried by compressed air into soil [8]. The DJM uses mixing blades to mix dry reagents, such as cement or lime, with in-situ soils for remediation. In this method, the process employs the effects of both hydration and the bonding of soil particles to increase the shear strength and reduce the compressibility of the soil mass [4].

Advantages and Main Points
1. The use of air instead of water to transport the binder in pipes and hoses is a big advantage where the temperature drops below the freezing point many months of the year or in the high ground conditions [8].
2. Additives to cement and lime can be used with particles of sizes less than 5 mm [3].
3. DJM does not need water or slurry preparation. Operation without water keeps the site clean.
4. Little dust is introduced into air and the operation is safe with minimum noise.
and minimum ground vibration.
5. The mobility and automatic monitoring system (the latest one) of mixing machine records help in getting high quality performance and saves on labor.
6. Soil mix column with diameters of 600mm to 1000mm can be constructed to controlled height and depth. The amounts of binder agents commonly used are 80-100 kg/m$^3$ in soft clay and 150-200 kg/m$^3$ in peat [4].

5.2. Triple Phase
5.2.1. Jumbo Eco Pile System (JEP)
The next part of JEP is triple phase system. It can be said that the JEP is the most popular method in this system. Most frequently, the applications of JEP, which is also named soilcrete-jet grouting, are: underpinning, tunnel protection, foundation restoration and modification, shaft supports, deep foundation, earth pressure relief, panel walls, vault slabs, column walls, sealing cover, dam sealing, joint sealing, sealing slabs, and groundwater exits. Figure 9 shows the steps of this method.

This method is also recognized as cement soil stabilization. With the aid of high pressure cutting jets of water or cement suspensions having a nozzle exit velocity $\leq 100 \text{ m Sec}^{-1}$; eventually the air shrouding the soil around the borehole is eroded [4]. It has been suggested that when the cohesion of the ground exceeds 50 kNm$^{-2}$ a separate study is required. A separate study is also required for the sand and gravel layer [3].

Advantages and Main Points
1. Large diameter column improvement from double jet monitors.
2. Double jet shortens construction time.
3. Tow jet crosses and cuts soil to smaller size, thus producing high quality product.
4. In comparison with the conventional method, this method is more cost-effective and time saving alternative.
5. The compressive strength of JEP system is from 2-25Mpa.
5.3. Super Jet Grouting
5.3.1. Ras-Jet System
Ras-Jet System is used in super jet grouting method. This method is the same as the Ras-Columns which have been elaborated in the first part of this paper. However, in Ras-Jet System, while the mixing blades are rotating; the same slurry is jetted simultaneously. With this system, the homogenous soil-cement column mass of a large diameter will be installed underground.

Grout slurry, air, and drilling fluid are pumped through separate chambers in the drill string. Upon reaching the designed drill depth, jet grouting is initiated with high velocity, coaxial air and grout slurry to erode and mix with the soil, while the pumping of drilling fluid is ceased. This system uses opposing nozzles and highly sophisticated jetting monitor specifically designed for focus of injection media [4]. Figure 10 shows the soil cement columns which are produced by Ras-Jet system.

Advantages and Main Points [3]
1. Applicable to a wide range of soils, providing excellent quality improvement.
2. Large diameter column improvement of diameter (1.6 - 2.0m, excluding the jet grouting part).
3. Uniform mixing and homogenous product quality due to counter-rotation mechanism.
5. Super high pressure jet of slurry cuts and breaks in-situ soil and produces homogenously improved zone around the mechanically mixed core.

Figure 10. The soil cement columns which have been made by ras-jet system

6. CONCLUSIONS
1. The DMMs which are applied to stabilize and improve soils are spreading increasingly and have been accepted worldwide as a soil improvement method. DMMs are based on mixing binders such as cement, and/or lime and other additives with soil grains, using rotating mixing tools or jetting, simultaneously.
2. These methods have been suggested and applied for soil and rock stabilizing, slope stability, liquefaction mitigation, vibration reduction (along the railway),
roads and railroads bridge foundations, embankments, construction of excavation support systems or protection of structure close to excavation sites, solidification and stabilization of contaminated soils, and remedial grout injection of building.

3. Based on conditions such as the types of soil and rock layers, time table of project, location, importance of project, and the economic situation, the use of multiple-auger or single auger deep mixing methods, jet grouting methods, or a combination of several methods may be required.

REFERENCES