Assessment of Stabilization Methods for Soft Soils by Admixtures

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***Abstract*—Soil stabilization by admixture was developed in Japan during 1970s and 1980s. The treated soil has greater strength, reduced compressibility and lower hydraulic conductivity than the original soil. The original technique known internationally as the deep mixing method (DMM) was developed simultaneously in Sweden and Japan in the mid-1970s. It is an in-situ soil treatment technology whereby the soil is blended with cementitious and/or other materials. Jet Grouting is suitable to be used as the injection method for the DMM. It utilizes a fluid jet (air, water and/or grout) to erode and mix the in-situ soft or loose soils with grout. The grouting method is one of the ground improvement methods suitable for the soft soil. Chemical stabilization is the effective method to improve the soil properties by mixing additives to soils. Selecting the right method for soil stabilizing however, depends on several conditions like; soil type and layering, magnitude of the load, situation and type of the project, among others. In this paper, the authors have investigated and compared the different methods used according to their characteristics. By utilizing this information and their inter-relationship, it is expected that the geotechnical engineers will be in a better position to select a suitable method to improve the soft soils and overcome their difficulties.**

***Keywords*—Injection; Jet Grouting; Chemical grouting; Deep mixing method; Stabilization.**

I. INTRODUCTION

The world population growth of human is increasing day by day and the suitable soil to sustain loading from buildings or structure are becoming scarce. Due to the scarcity of land, the development of the swampy areas, mountainsides and landfill areas become the alternate places for the people to live. Hence, soil stabilization has become one of the useful solutions to treat the soil in such areas to achieve the required engineering properties and specification so that structures can be placed safely without undergoing large settlements.

Soil stabilization is defined as a technique to improve the engineering characteristics in order to improve the parameters such as shear strength, compressibility, density, hydraulic conductivity. The techniques of soil stabilization can be classified into a number of categories such as vibration, surcharge load, structural reinforcement improvement by structural fill, admixtures, and grouting and other methods. There are many techniques that can be used for different purposes by enhancing some aspects of soil behavior and improve the strength and properties of soil [1]. The important features of ground treatment includes: improving the bearing capacity of the ground, reducing the potential for total and differential settlement, reducing the time during which the settlement take place, reducing potential for liquefaction in saturated fine sand or hydraulic fills, reducing the hydraulic conductivity of the ground, removing or excluding water from the ground. The conventional method of soil improvement is to replace the soft soil by suitable imported fill materials. However, this practice is naturally very expensive due to the cost of excavation, dumping and the filling material. This paper aims to review the use of different chemical grout for the stabilization of soft soils.

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II. SOIL STABILIZATION BY ADMIXTURE

Soil stabilization by admixture was developed in Japan during 1970 and 1980. It uses rotating mixer shafts, paddles, or jets that penetrate into the ground while injecting and mixing Portland cement or some other stabilizing agent. These techniques include deep cement mixing, soil mix walls, deep mixed method and other. The treated soil has greater strength, reduced compressibility and lower hydraulic conductivity than the original soil [2]. The use of admixture such as lime, cement, oils and bitumen is one of oldest and most widespread method for improving soil. When mixed with soil, it forms a material called soil-cement. The objective of admixture is to provide artificial cementation, thus increasing the strength and reducing both compressibility and hydraulic conductivity. Admixture treated soil also have been used as erosion protection on the face of the earth dams, levees and channels. The disadvantage of this method is that specialized equipment is usually required to achieve a sufficient thorough mixing. If the mixing is inadequate, the resulting product will consist of alternating over treated hard spot separated by untreated soft spot, a situation that may be worse than no treatment at all [3].

III. DEEP MIXING METHOD (DMM)

The Deep Mixing Method can be applied in most soft soils. The mechanized process of mixing is by using a rotating mixing tool, drilling the tool into the soil. After this, the drilling rotation is reversed, extracting it and at the same time as the dry binder is injected and mixed into the soil. Through the rotating movement, the soil is

mixed with the binder and an immediate reaction starts. The improved soil acquires the share of a column [4]. The column so formed can have diameters ranging from 0.5 to 1m and the lengths up to 25 m. The columns can also be interlocked to provide cellular structure of in-situ wall or the entire mass cab be stabilized. Dry mixing is a highly effective ground treatment system used to improve the load performance of soft soils. By varying the proportion of lime, cement and admixtures, a range of strength gains can be achieved. The greatest improvements can be achieved in inorganic soils with low moisture content [5].

The original technique known internationally as the deep mixing method (DMM) was developed simultaneously in Sweden and Japan in the mid-1970s. Now, DMM is a ground treatment, improvement, and support method of global application and increasing popularity and value [6]. Compared with other similar ground improvement methods, the Deep mixing Method (DMM) is the method specially designed to treat the soft soils. DMM are divided into three systems namely, SSM (Shallow Soil Mixing), DSM (Deep Soil Mixing) and JGS (Jet Grouting Systems) [7].

Deep mixing method is an in-situ soil treatment technology whereby the soil is blended with cementitious and/or other materials. The deep mixing method is often classified into two methods: dry and wet method, based on the type of binder, the mechanism of bleeding in rotary or jet assisted, and the vertical extent over which blending is accomplished [8]. The former utilizes the dry powdered binder whereas the latter utilizes the water-binder slurry. Naturally, there are some differences in the execution machines between dry and wet methods. However, there is no substantial difference in the characteristics of treated soils between them. The apparent difference in the design procedure and application comes from the purpose of improvement, which in turn gives rise to the difference in the installation patterns and in the order of strength required [9].

Deep mixing method emphasizes on column type techniques using lime/cement. It is a soil improvement method, which is performed to improve the strength, deformation properties and hydraulic conductivity of the soil. It is based on mixing binders, such as cement, lime, fly ash and other additives, with the soil by the use of rotating mixing tools in order to form columns of a hardening material since pozzolanic reactions between the binder and the soil grains are developed.

The main advantage of these methods is the long-term increase in strength, especially for some of the binders used [10]. Pozzolanic reaction can continue for months or even years after mixing, resulting in the increase in strength of cement stabilized soil with the increase in curing time [11].

IV. GROUTING AND INJECTION METHOD

Typically, grouts that are continually moving will turn into a gel less quickly, and the penetration from continuous injection will be greater than that from the same volume of grout used in batch injection. When gelling occurs before pumping is halted, the last injected grout typically moves to the outside of the grouted mass, and both large and small openings are filled. Jet Grouting is suitable to be used as the injection method for the deep mixing method (DMM). It utilizes a fluid jet (air, water and/or grout) to erode and mix the in-situ soft or loose soils with grout. It utilizes high velocity, 28 to 42MPa backpressure and jet to hydraulically shear the soil and adding suitable binder to form a column. The result is significantly increased shear strength and stiffness of the soil [6]. The first patent regarding jet grouting was applied for in England in the 1950s; however, the actual development of jet grouting was in Japan during 1960s and 1970s. Jet grouting is the newest method compared with other methods. In the mid 1970s, jet grouting was exported to Europe and has become popular worldwide. This technology was initially aimed at improving the effectiveness of water tightness, in chemical grouting, by eroding the untreated or partially treated soil, which was then ejected to the surface for disposal being replaced with cement-based slurry for imperviousness [12].

Jet grouting is the construction of hard, impervious column in the ground by the enlargement of a drill hole using rotating fluid jets to liquefy and mix grout with, or to excavate and replace, soil [2]. Jetting and grouting are carried out during controlled withdrawal and rotation of the drill string and the jetting head from the hole. There are several variations depending on the nature and pressure of the jetting and grouting the in-situ soil may be mixed with the grout, partly mixed and partly removed or wholly replaced. In general, as shown in Fig. 1, there are four basic jet grouting systems which are widely used and classified as Single phase (grout injection only), Dual phase (grout + air injection), Triple phase (water + air injection and followed by grout injection), Super Jet Grouting (air injection + drilling fluid by grout injection) [7].

The grouting method is one of the ground improvement methods suitable for the soft soil. Modern grouting began in the mining industries, concerned with the seepage and strength control in mines, tunnel and shaft, then was taken up by civil engineering. Various functions of grouting available depend on the intention and the condition of the site. It includes permeation grouting, compaction grouting, hydro fracture grouting, jet grouting, rock grouting, compensation grouting, cement grouting and fracture grouting. Because of the various functions of grouting, the differences between grout characteristic and differences between the soil type to be grouted need to be addressed. Therefore, the generalization about the grouting equipment and method are difficult to achieve [13]. A grout is also simply defined as a material used for grouting [14].

Selecting the right method for deep soil stabilizing however, depends on several conditions like the type and alternative layers of soil, load size, the situation and type of project, among others [6]. Grouting generally is used to fill voids in the ground (fissures and porous structures) with the aim to increase resistance against deformation, to supply cohesion, shear-strength, compressive strength and finally to reduce hydraulic conductivity or interconnected porosity in an aquifer [15].

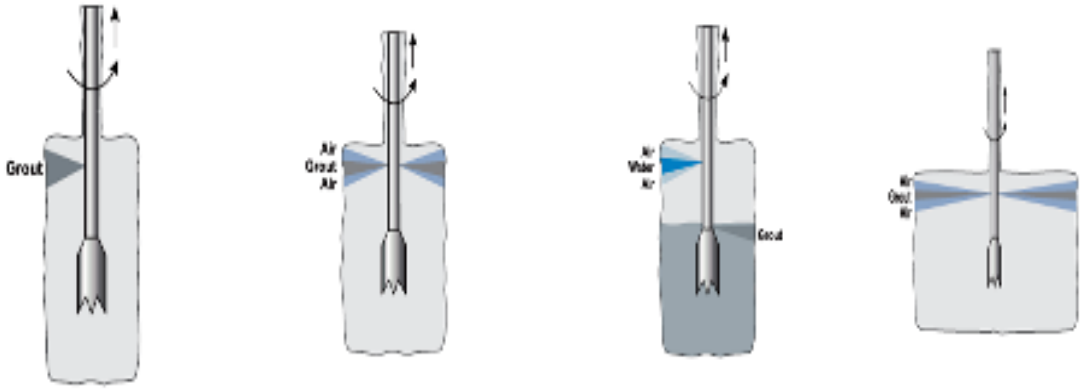

Figure 1. The system in jet grouting [7].

The mechanism of grout can be explained in the process of pressure filtration of grout in which the grout is injected under pressure into the soil and the mix will loose water into the surrounding ground. This loss of water will cause a thickening and reduction in volume of the mix. As a result of generation of internal friction, increased viscosity and yield of the grout will finally block the flow or movement of grout into the soil. Through the theoretical and experimental considerations, as soon as internal friction in a particulate mix occurs, grouting will be stopped. This pressure filtration phenomenon state that when the cement grains are not transported freely by the fluid but come into contact, friction between the particles will develop and will cause the grouting process to be terminated [6].

Generally, the grouting method is classified as suspension type grout and solution type grout. The suspension type grout includes soil, cement, and lime asphalt and emulsion, while the solution type includes a wide variety of chemicals such as silicate based grout, resins and epoxy [16].

For selecting the method for soil stabilization, as it mentioned earlier, applying each of DMM methods cause to get very homogeneously soil mixed with binder in the short time and the down side of some of DMM methods (e.g. super jet grouting method) is the high cost of them. Anyway, except the cost issue which is not consider in the mega-projects and important projects, all DMM methods are suggested for stabilization of soft and very soft soils.

V. Chemical and Cementation Grouts

Chemical stabilization is the effective method to improve the soil properties by mixing additives to soils. Usually the additives are cement, lime, fly ash and bituminous material. These additives enhance the properties of soil. Generally, two major reactions for the chemical stabilization are cation exchange reaction and cementation [17]. The common chemical agent for cementation process is Portland cement, lime, fly ash, sodium silicate polyacrylamides and bituminous emulsion.

Many of chemical grouts are based on the combination of sodium silicate and a reagent to form gel. The Joosten process used in coarse granular soils uses calcium chloride as a reagent. Other reagents are organic ester, sodium aluminates and bicarbonates. The reagent and the proportion can be chosen to control the gel time, the initial viscosity and the order of strength of the grouted soil.

Chemical grouts are injected into voids as a solution, in contrast, to cementitious grouts, which are suspension of particle in a fluid medium. The difference between chemical grout and cementitious grout is the chemical grout can be used to fill the finer voids of soil particles up to 10 to 15ηm in diameter. In other word, it has better penetration ability than the cementitious grout [18].

Chemical grout can be classified in single step and two step processes. In one step process, all the ingredients are premixed prior to injection, the system are designed that the reaction takes place in-situ. In the two step process, the initial chemical is injected into soil mass then follow by the second chemical material to react with the first in-situ and to stabilized the mass. There are several types of chemical grouts, each type of grout have different characteristics and different applications. The most common are sodium silicate, acrylate, lignin, urethane, and resin grouts [13].

In order to choose a grout type, several properties of grout should be concerned such as rheology, setting time, toxicity, strength of grout and grouted soil, stability or permanence of the grout and grouted soil and the penetrability and water tightness of the grouted soil [16]. Moreover, the spreading of grout plays an important role in the development of grouting technology. In the actual filed, the grouting method requires a extensive consideration on the grout hole equipment, distance between boreholes, length of injection passes, number of grouting phases, grouting pressure and pumping rate [13]. According Table I and [4], some clue can get for selecting the grouts and the advantage and disadvantages of grouting methods.

The crucial issue of applying chemical grouts is if it is safety and environmental compatibility or not? As it can

be seen in the Table I, the grout with low toxicity and high strength like silicate grout is the best for very soft soils. By applying some plasticizers the viscosity will be decreased and the inject ability of grout will be increased and the cost decreased as well.

TABLE I.
RANKING BASED TO TOXICITY, VISCOSITY AND STRENGTH [13].

Grouts	Toxicity	Viscosity	Strength
Silicate			
Joosten process	Low	High	High
Siroc	Medium	Medium	Medium-High
Silicate –Bicarbonate	Low	Medium	Low
Lignosulphates			
Terra Firma	High	Medium	Low
Blox- All	High	Medium	Low
Phenoplasts			
Terramier	Medium	Medium	Low
Geoseal	Medium	Medium	Low
Aminoplasts			
Herculox	Medium	Medium	High
Cyanaloc	Medium	Medium	High
Acrylamides			
AV-100	High	Low	Low
Rocagel BT	High	Low	Low
Nitti- SS	High	Low	Low
Polyacrylamides			
Injectite 80	Low	High	Low
Acrylate			
AC- 400	Low	Low	Low
Polyurethane			
CR-250	High	High	High

VI. CONCLUSIONS

Soil stabilization has become one of the useful solutions to treat the weak soils to achieve the required engineering properties and specification so that structures can be placed safely without undergoing large settlements. The treated soil has greater strength, reduced compressibility and lower hydraulic conductivity than the original soil. Selecting the right method for deep soil stabilizing however, depends on several conditions like the type and alternative layers of soil, load size, the situation and type of project, method of stabilizing, selection of binders, cost, and etc.. Compared with other similar ground improvement methods, the DMM is the method specially designed to treat the soft soils with low cost and high efficiency. The main advantage of these methods is the long-term increase in strength, especially for some of the binders used. By applying DMM method with chemical grout, the soil will be mixed by binders homogeneously and the strength of soil stabilized will be higher than conventional methods, which is recommended for important project and mega-project because of some cost issues. Using some chemical grouts with low toxicity and high strength by injection method (one kind of DMM method) help to get the milestones for soft soil improvement easily.

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