Cement Soil Mixing in Soft Ground

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Abstract

History

Various methods of soil mixing, mechanical, hydraulic, with and without air, and combinations of both types have been used widely in Japan for about 20 years and more recently have gained wide acceptance in the United States. The soil mixing, ground modification technique, has been used for many diverse applications including building and bridge foundations, retaining structures, liquefaction mitigation, temporary support of excavation and water control. Names such as Jet Grouting, Soil Mixing, Cement Deep Mixing (CDM), Soil Mixed Wall (SMW), Geo-Jet, Deep Soil Mixing, (DSM), Hydra-Mech, Dry Jet Mixing (DJM), and Lime Columns are known to many. Each of these methods has the same basic root, finding the most efficient and economical method to mix cement (or in some cases fly ash or lime) with soil and cause the properties of the soil to become more like the properties of a soft rock.

At the present time, the total volume of soil mixing work performed annually in Japan is about 5,000,000 million cubic meters. This includes CDM, SMW, DJM and Jet Grouting. Total Yen (Dollar) volume annually is on the order of $2 Billion performed by over 500 rigs in all categories operating throughout the country. In contrast, in the United States, currently there are about 10 traditional soil mixing rigs operating, plus about another 10 jet grouting rigs, and total of soil treated in any one year has not exceeded approximately 30,000 cubic meters. Japan has a population of about 1/2 that of the United States and a land area smaller than the state of California. Therefore, their need to utilize all available space has made reclamation of soft soils along their coastline critical to providing the needs of their population. Much of their soil mixing has been to treat soft bay muds in coastal areas, developing strengths of 5-20 kg/cm^2(75-300 psi).

At about the same time as the use of soil mixing was expanding in Japan (mid 1970'S), independent progress was being made in Scandanavia with a lime column technique for the stabilization and reinforcement of very soft, cohesive soils. This technology has evolved in Sweden and Finland to the present time where production of what is now lime-cement columns ranges between 3 and 4 million lineal meters per year. This production is mainly for reduction of settlements and improvement of stability for the construction of new roads and railroads. Almost all this production is constructed using dry reagents that are introduced by compressed air and mixed mechanically with the soft soils.

Some typical applications for which soil mixing has been used in the United States, Scandinavia and in Japan are shown in Figure 1.

Treated Soil Characteristics

As stated, the intent of most soil mixing is to modify the soil so that it's properties become similar to that of a soft rock such as a clay shale or lightly cemented sandstone. The modulus of elasticity and unconfined compressive strengths are typically 1/5 to 1/10 that of normal concrete. Almost all soil types are amenable to treatment; however, soils containing more than 10% peat must be tested thoroughly prior to treatment. Mixing of soft, clay soils must be carefully controlled to avoid significant pockets of untreated soils. However, there are methods readily available to insure competent mixing and methods of testing to insure that adequate mixing and treatment has been achieved.

Soil mixing is also commonly used as a stabilization or in-situ fixation method for containing hazardous wastes and sludges. Containment walls can be constructed with permeability of approximately $5x10^{-7}$ cm/sec, similar to that achieved by most slurry wall techniques.

See Table 1 for typical strength and permeability characteristics of treated soils.

Construction Methods & Construction Equipment

Mechanical soil mixing is typically performed using single or multiple shafts of augers and mixing paddles. The auger is slowly rotated into the ground, typically 10-20 rpm, and advanced at 0.5-1.5 meters per minute. As the auger advances, cement slurry is pumped through the hollow stem of the shaft(s) feeding out at the tip of the auger. Mixing paddles are arrayed along the shaft above the auger to provide mixing and blending of the slurry and soil. (See Figure 2 for typical multiple stem auger and mixing paddles). The slurry helps to lubricate the tool and assists in the breaking up of the soil into smaller pieces. Since fluid volume is being introduced into the ground, spoils must come to the surface. These spoils are a combination of the cement slurry and soil particles, typically with a similar cement content as what remains in the ground. After final depth is reached, the tools remain on the bottom of the hole, rotating for about 0.5 to 2 minutes for complete mixing. At this point, the tools are raised while continuing to pump slurry at a reduced rate. Withdrawal is typically at twice the speed of penetration, 1-3 meters per minute.

Other methods of mixing cement with soil consist of jet grouting. Here, high-pressure cement slurry (4-7000 psi) is pumped through horizontal ports in a drill string above the drill bit. The high velocity and pressure of the cement jets cuts and mixes the soil insitu (Figure 3). This is termed single fluid jet grouting. In double fluid jet grouting, a shroud of compressed air (10-15-bar pressure) is pumped to surround the slurry jet thus enhancing the penetrating ability of the jet. In triple fluid jet grouting, the cement is pumped at low pressure at the bottom of the hole while high pressure water, surrounded by a shroud of compressed air, cuts and removes the soil during the withdrawal of the tools.

Other methods of introducing and mixing cement with soil involve such methods as Hydra-Mech, utilizing both hydraulic (jet) and mechanical energy to cut and mix the soil and cement. A different method not utilizing slurry is the DJM (Dry Jet Mixing) or Lime Column method. Here, compressed air carries lime and/or cement powder to the bottom of the hole where mixing paddles blend the dry reagent with the soil. This method can only be used in high moisture content, soft soils.

Treatment of the soil can be done to a replacement ratio of 100% wherein all the soil inside a particular block is treated to a specified strength by mixing with cement. Other patterns, as shown in Figure 4, can be employed to achieve the desired result. Recently a prototype retaining wall was constructed at the National Geotechnical Experimentation Test Site at Texas A & M University that employed a less than 100% treatment ratio to achieve a composite behavior of a block of soil. In this test, a replacement ratio of approximately 35% cement treated to native soil ratio was used to force a composite action of the soil cement columns and native soil. This gravity wall, installed in May 1998, 11 meters high, containing no steel reinforcing, has performed well to date with total movements of 30 mm (Figure 5).

Quality Control and Testing

Since the aggregate being used in producing the engineered "low strength" concrete insitu is the native soils, pre-construction soil borings, testing of the mix design with the in-situ soils is a must. One to two cubic feet of the soils is sufficient to run the required laboratory, pre-production tests on the soil cement mix. Various water cement ratios are considered, usually between 1:1 and 1.5:1 (by weight). The amount of cement, again by weight, is typically 5-15% of the weight of the soil to be treated.

Proper injection of slurry, mixing and blending of the cement slurry and soil is verified by several means. Initially, during installation, wet grab samples are taken from different elevations in the mixed columns after the tools are withdrawn. Remote closing tubes are inserted, filled with the wet, mixed soil and slurry, a closure lid secured and the sample brought to the surface. The slurry is poured into cylinders for later laboratory testing. In addition, core sampling of the completed columns may be performed. It is wise to wait at least until 28 days after installation to perform coring, and then only with triple tube coring equipment, as the sample may be difficult to retrieve intact because of it's low strength.

Figure 1. SOIL MIXED GRAVITY WALL APPLICATIONS

TABLE 1

Soil Type	Cement Usage	UCS	Permeability
Sludge	240 to 400 kg/m^3 (400 to 700 lbs/cy)	70-350 kPa (10-50 psi)	1x10^{-6} cm/sec
Organic silts and clays	150 to 260 kg/m^3 (260 to 450 lbs/cy)	350-1400 kPa (50-200 psi)	5x10^{-7} cm/sec
Cohensive silts &	120 to 240 kg/m^3 (200 to 400 lbs/cy)	700-2100 kPa (100-300 psi)	5x10^{-7} cm/sec
Silty sands and sands	120 to 240 kg/m^3 (200 to 400 lbs/cy)	1400-3500 kPa (200-500 psi)	5x10^{-6} cm/sec
Sands and gravels	120 to 240 kg/m^3	3000-7000 kPa	1x10^{-5} cm/sec

	(200 to 400 lbs/cy)	(400-1000 psi)	

FIGURE 2

FIGURE 3

If you have any questions, please contact **Dr. C.Vipulanandan**