International Case Studies of Peat Stabilization by Deep Mixing Method

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ABSTRACT

The purpose of this paper is to advance the knowledge on peat soil stabilization by critically examining and documenting the current state of practice. Deep mixing method is emphasized on column type techniques using lime/cement. This paper is essentially a comprehensive review of available academic literature on deep soil stabilization utilizing this approach. Deep mixing with lime or lime-cement columns and methods of combined soil stabilization with vertical columns are discussed. Furthermore, applications of these methods are illustrated in a variety of conditions and several case histories are presented.

KEYWORDS: Deep mixing, Peat soil, Soil stabilization, Dry jet mixing, Lime-cement columns, Mixed-in-place method.

INTRODUCTION

Problematic peat soil exhibits high compressibility, medium to low permeability, low strength and volume instability. Consequently, it is widely regarded as the worst foundation soil for supporting man-made structures. Under such circumstances, deep soil stabilization technique is often an economically attractive alternative to removal of deep peat or use of piles as deep foundation (Hebib and Farrell, 2003).

The deep mixing method is today world-wide accepted as a ground improvement technology in order to improve the permeability, strength and deformation properties of the soil. Binders, such as lime or cement are mixed with the soil by rotating mixing tools. The stabilized soil, often produced column shapes, has higher strength, lower compressibility and lower permeability than the original soil. Experience has been positive and the method has great development potential. The method is undergoing rapid development, particularly with regard to its applicability, cost effectiveness and export potential (Larsson, 2003).

OBJECTIVES

The objectives of this paper are as follows:

1) To review the various deep mixing techniques applied for stabilizing peat soil in construction industry.
2) To examine some case histories of application of deep mixing methods in various conditions.
3) To discuss some advancements for the future application of deep mixing stabilization of peat soil.

DEEP MIXING METHOD

Deep mixing was developed as a soft ground soil improvement method in Japan during the 1970s. In the

Accepted for Publication on 15/7/2011.

Japanese Geotechnical Terminology Dictionary, "deep mixing method of soil stabilization" was described as a "generic term for soil improvement involving mixing by force together with chemical stabilizers such as lime or cement within the deep ground on site". As a rule, the improved soil has better strength and deformation properties than the surrounding untreated soil. The mechanical mixing is generally done by rotating impellers of paddle or helical type auger. A range of methods have been developed which today have names such as "deep mixing (method)" (Terashi, 1997; Porbaha, 1998). There is no clear distinction between surface stabilization and deep mixing. However, CEN TC 288 specifies deep mixing as treatment of the soil to a minimum depth of 3m.

Figure 1: Mixing method with (a) on board binder silo; (b) separate binder silo

Figure 2: (a) Deep wet mixing plant; with (b) separate mixing and holding tanks and pumps

Lime and Lime-Cement Columns

Lime and lime cement columns are installed using the deep soil mixing technique, in which a hardening binder such as lime, cement or a mixture of lime and cement is mixed with the soil using mixing tools. This technique was developed and independently put into practice in the middle of the 1970s in Sweden and Japan. It is distinguished between dry mixing and wet mixing.

In dry mixing (Figure 1), compressed air is used as the medium for the transport of dry binder powder from the tank to the soil. The use of compressed air as the medium for transporting the binder has the advantage that it takes a relatively small amount of binding agent to achieve the requisite strength gain. Given that loose soils, especially peat soil, already contain a lot of water, it appears logical not to add still more water to the soil, as is done when the wet method is employed. However, the addition of air adds to the difficulty of the mixing process in a material, soft soil, the rheological properties of which are already very complex. In the mixing process, an air-borne binder complicates the dispersion process with regard to the wetting of lime and cement particles and the breaking up of agglomerates. In wet deep mixing method (Figure 2), the binder, usually cement, is premixed with water to form slurry, thus distributing the binder to the soil in liquid form. This is the dominant technology in Japan and elsewhere.

Research and practical applications in Europe have shown that organogenic and organic soils can be stabilized with lime cement columns (Holm, 2002; EuroSoilStab, 2002). Holm, Andréasson, Bengtsson and Eriksson (2002) reported a successful application of lime cement columns in very soft organic soil (gyttja) and clays for the stabilization of a low railway embankment in Sweden. A binder consisting of unslaked lime and cement in an amount of 120 - 150 kg/m^3 was used. Despite an organic content of up to 20% and an embankment height of only 1.4 m, a settlement reduction factor of 5 at low train speeds and of up to 15 at train speeds of 200 km/h was achieved. More positive experiences with lime cement columns in very soft cohesive soils with organic admixtures are reported for instance by Sondermann and Wehr (2002).

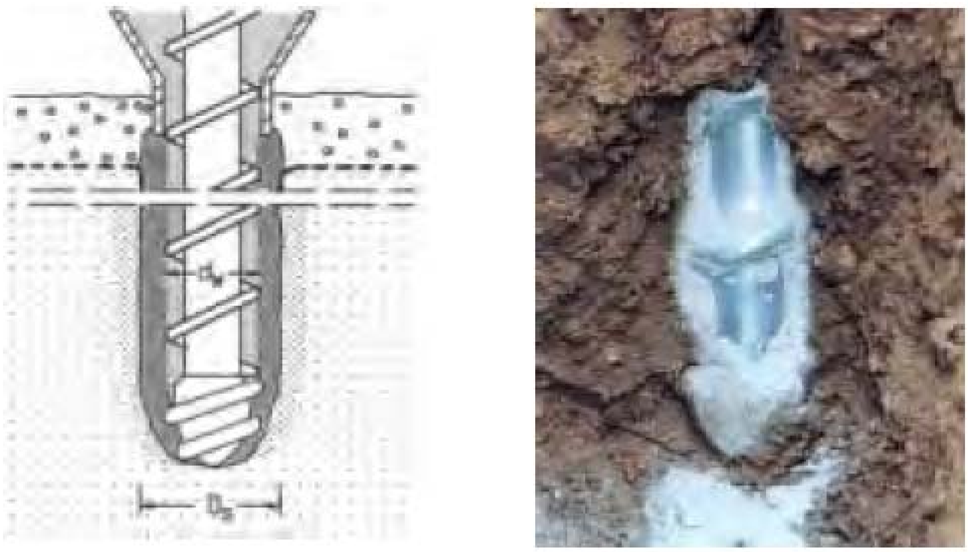

Figure 3: (a) The installation process; (b) exposed auger during material transport (Courtesy: Bauer Construction Company)

CSV-METHOD

Combined soil stabilization with vertical columns (CSV) is a technique, whereby small diameter columns consisting of a binder or binder mixture are installed in a close grid. Cement and lime are usually included as binder materials. The columns with a diameter of 12 to 18cm are arranged at a centre to centre distance of 0.5 to 1.5m in a quadratic or triangular grid system. The CSV-method can be used in very soft to stiff cohesive soils, loose granular soils and organic soils (Reitmeier and Scheller, 2000). By hardening of the stabilization material, rigid columns can be formed. In Germany, a dry cement-sand-mixture is used as binder which is installed into the soft soil by the displacement method using a continuous auger (so-called Coplan-Stabilization-Method) (Figure 3). Basic guidelines for the calculation and design are given in DGGT (2002). For the verification of the safety against fracture of the column, it is generally assumed that all loads are carried by the CSV columns.

CASE HISTORIES

Hamburg–Berlin Railway Line: Reinforced Embankment on Pile-like Elements

As part of upgrading the railway line Hamburg-Berlin by the German Rail Company, the Buechen-Hamburg and the Paulinenaue-Friesack part of the railway line were upgraded in 2003 to allow a train speed of 230 km/h. Because of the very soft organic soil (peat and mud) layer with insufficient bearing capacity, stabilization of the embankment foundation was necessary at these two parts. The part of this line with a total length of 625m was near the railway station Buechen. The soft underground was stabilized with columns installed using Mixed-in-Place Method (MIP) and the embankment was reinforced with geogrids at its base on the top of the columns. The MIP belongs to the wet deep mixing methods. The underground consists of a 3 to 5 m fill of silty and gravely medium dense sand with slag and organic mixtures underlain by a 0.5 to 2 m thick layer of very soft peat and mud. The peat soil has a water content of 80% to 330% and an organic content between 25% and 80%. Beneath the soft layer, a medium dense and slightly silty sand layer with a thickness up to 8 m is encountered followed by a boulder clay with soft to stiff consistency and a water content of 10% to 20%. The MIP-columns were installed using a single axis auger. A cement slurry was continuously injected into the soil during the penetration as well as during the retrieval of the auger. Due to the rotation of the auger, the cement slurry is mixed with the soil. The MIP-technique is free of vibrations and displacements and therefore had no effect on the ongoing railway traffic on the other track. The cement columns (diameter 0.63 m) were installed in a square grid of 1.5x 1.5 m.

City Road Trasa Zielona in Lublin-Polen: Wet Deep Soil Mixing

The weak soil found at a depth of 3 to 8 m consists of loose anthropogenic fill, underlain by 1 to 4 m thick peat and organic clay. The embankment height was 1.3 to 2.5 m and the equivalent live load was 30 kPa. A triangular column grid with 2m spacing was selected, resulting in soilcrete design strength of 480 to 676 kPa. The required unconfined compression strength was 1.5 Mpa. Altogether, 2402 columns with a total length of 15,532 m had been constructed. The final embankment was reinforced with two layers of Tensar geogrid, resulting in the so-called Load Transfer Platform design.

Tomei Highway Expansion Project

Tomei Freeway which connects Tokyo and Nagoya has been the artery of Japanese culture and economy since the 17th century. Even with the addition of railroads and bullet train rails, the traffic volume along the Tomie Freeway continues to increase. Therefore, the expansion project was carried out to expand the four-lane freeway into a six lane freeway-three lanes in each direction. The section near Isebara, located along the foothill of the Tanzawa ridge, is underlain by consecutive sections of ridges and valleys. The ridges consist of organic clays with peat. Excessive total and differential settlement and embankment instability were expected, if the new embankments were placed without improving the strength and compressibility of the organic soils.

Dry Jet Mixing (DJM) method, which has been used in numerous projects for treating organic soils and peat with satisfactory results, was selected to treat. Staged construction at 3 elevations was used for soil treatment. Two mix designs were used. Lower cement injection rates, 100 kg to 120 kg cement per m^3 of target soil, were used in the existing embankment zone to maintain the strength of soil-cement at 0.8 kgf/cm^2 (Editor's note: this old-metric/pre-SI unit is approximately equal to 100 kPa) – the average strength of the existing embankment soils. The higher cement injection rate, 170 kg to 230 kg cement per m^3 of target soil, was used in the organic clays to obtain a minimum unconfined compressive strength of 7 kgf/cm^2 after treatment.

A total of 50,215 m^3 organic clay, peat and fill were treated for use as foundations of the new embankment, retaining walls and box culvert. Two sets of DJM rig were used. The deep mixing was commenced in April 1994 and completed in November 1994 without interrupting the use of the four-lane freeway. Staged construction procedure was used to perform the soil treatment within a limited working space. In addition to the foundation treatment for the new embankment, DJM also improved the foundation for the retaining wall and the box culvert and eliminated the mobilization of pile driving equipment to the congested work zone parallel to an existing freeway.

Dutch High Speed Railway Link

In Dutch high speed railway link, an alternative design has been made using deep soil stabilization. The design was tested on a test site. The embankments for this substructure of the rail system are constructed on 9 meter very compressible subsoil. The subsoil consists of organic clay and peat. The compressible layers lie on a stiff and bearing sand layer. The test-embankment has a high part and a low part. The high part is 5 meter high and the low part is 1 meter high. The high part of the embankment ends at an imaginary piled bridge foundation. In the sub-structure system, the designers incorporated a transition zone to control the differential settlements of structure and embankment. The foundation of the embankment consists of stand-alone stabilized soil columns and panels in the high part and a combination of mass stabilization on the top of stand-alone columns in the low part. The mass stabilization (performed as overlapping short columns) was made to a depth of 2 meters. The columns were made down to the bearing sand layer. The tip of the column is fixed. The columns have a diameter of 600 mm and were installed in a square pattern. The centre to centre distance varies from 1.0 m for the high part of the embankment near the imaginary bridge up to 1.6 m under the mass stabilization for the low embankment.

DICUSSION AND RECOMMENDATIONS

Water content of peat soil is very high. Water content of existing soil in "Hamburg–Berlin railway line" project is varying from 80% to 330%. When a method of deep mixing is chosen, water content of unstabilized soil is to be considered. As the soil already has a high water content, required water for soil-cement reaction comes from the soil. So Dry Jet Mixing (DJM) method is effective for peat soil stabilization instead of Wet Mixing method. On the other hand, due to features of mixing dry powders, DJM provides the flexibility of reagent selection for the treatment of various soils that slurry type deep mixing technologies are inefficient or uneconomical to treat (Yang et al., 1998).

Organic clay and gyttja give good results when stabilized with cement by deep mixing method. But special attention should be given for peat soil. Due to its high water content, adding some sand improves strength and bearing capacity. Research findings indicated that the engineering properties of peat can be improved with the inclusion of Portland cement and ground granulated blast furnace slag (a byproduct of iron manufacturing) with siliceous sand acting as filler (EuroSoilStab, 2002; Åhnberg, 2006). When mixed with cement in the soil, slag, fly ash, bentonite or other secondary products which contain silica, alumina and reactive lime are activated, and this can accelerate the reactions of cement in peat improving the stabilization effect. Siliceous sand can be used as filler to increase the number of solid particles in peat soil.

In CSV method, the surrounding soil acts as a casing for the transport of dry mix when dry binders or binder-sand mix are inserted into the ground using a continuous flight auger. If the soil is not firm enough to fulfill this task, the quantity of material input will be adjusted to create the necessary casing for a smooth and satisfactory transport of the dry material. Peat soil is a very soft soil with high water content and casing problems may arise, because when the auger rotates, the surrounding soil breaks down and inturupts uniform soil mixing, and this problem can be solved by mixing bentonite with binder which can help build a firm layer at the surrounding of the soil-cemnt column.

Ahnberg et al. (2006) conducted a laboratory experiment concerning the effect of initial loading on the strength of stabilized peat. The test results revealed that an initial loading during curing greatly influences the strength of the stabilized peat. It is important that this fact is taken into account and utilized in the design and execution of stabilization in the field. In the field, the initial load should be evenly applied, using the same thickness of fill. This should be done after the installation of the column as early as possible. An even and early loading is important to improve the homogeneity as well as the strength of the stabilized soil. In case of peat soil stabilization by Deep Mixing Method, back filling work of certain height can be done after the installation of the soil-cement column to ensure the initial load.

CONCLUSIONS

From the above discussion, one can draw the following conclusions:

- Due to high water content, Dry Jet Mixing (DJM) method is effective for the stabilization of peat soil.
- Using fly ash, blast furnace slag, bentonite or another secondary product can accelerate the reaction rate during stabilization.
- Adding some portion of well graded sand, which acts as filler material, is also effective for soil-cement stabilization.
- Using some initial load after the installation of the soil-cement column can also increase the strength of treated soil.

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