Modern Soil Stabilization Techniques

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ABSTRACT

Successful modern soil stabilization techniques are necessary to assure adequate subgrade stability, especially for weaker or wetter soils. It is widely recognized that the selection between the cementitious stabilizing agents cement and lime is based on the Plasticity Index (PI) of the primary soil type being improved. A PI of 10 is considered by many as the threshold that justifies the cost for use of Portland cement compared with lime. Application rate of the selected stabilizing agent is important, both for durability and for cost considerations.

The use of bituminous stabilizing agents is somewhat less common, but worthy of consideration. Working with bituminous emulsions requires close attention to application rate. Both anionic and cationic emulsions show compatibility with cold, moist materials; break and curing time are important for desirable mix performance. For stabilization of deeper layers, cationic emulsions are preferred. Foamed bitumen is a developing technology that shows excellent performance. Iowa State University (ISU) studies in the mid-1950s led to Mobil Oil technology developments and introduction of a production foamed bitumen system by Wirtgen in 1996.

In the comparison of cement versus bitumen for stabilization, similar advantages and disadvantages as Portland Cement Concrete (PCC) versus Hot Mix Asphalt (HMA) pavements are recognized. Cement stabilization offers worldwide availability and ease of application. Bituminous stabilization provides material flexibility and resistance to cracking. Depending upon regional availability, cost for construction is variable.

1 Introduction

1.1 Background

The stabilization of naturally-occurring or native soils has been performed for millennia. It was recognized before the Christian era began that certain geographic regions were plagued with surface materials and ambient conditions that made movement of men and materials difficult, if not impossible, over the paths between villages and towns. The Mesopotamians and Romans separately discovered that it was possible to improve the ability of pathways to carry traffic by mixing the weak soils with a stabilizing agent like pulverized limestone or calcium. This was the first chemical stabilization of weak soils to improve their load-carrying ability.

It was further discovered, through trial and error, that as long as the improved soil bases were protected against the damaging effects of excessive moisture content, they remained stable and capable of carrying increasing traffic volume and heavier loads in the carts and wagons. The use of stone slabs as the wearing surface over these conditioned soil bases was perfected by these technologically-advanced civilizations. In fact, a few sections of roadways built by the Romans are still in remarkably good condition 2000 years following their construction.

Obviously, throughout history, there have been a number of improvements in the equipment and technology employed for the material stabilization application. This paper will present an overview of some of the design features of modern soil stabilizers. In addition, additive selection criteria will be reviewed.

1.2 Objectives

This presentation has been developed to assist attendees to the TAC (Transportation Association of Canada) 2007 Annual Conference understand the state-of-the-industry for modern soil stabilization techniques. A few recent, larger-scale field projects will be discussed. General cost data for the various additives used in soil stabilization will be presented. Explanation of the technology utilized for introduction of the stabilizing agent into in-situ soil will be provided and a pictorial record of one of a typical project will be depicted. At the end of the presentation, appropriate references for contemporary technical assistance with this technology will be identified.

1.3 Definitions and Terminology

Asphalt emulsion – Asphalt emulsion is a mixture of asphalt binder and water that contains a small amount of emulsifying agent to cause the asphalt to become mixed with or suspended in the water. Asphalt emulsion may be either anionic with electronegatively charged asphalt globules or cationic with electro-positively charged asphalt globules, depending upon the emulsifying agent.

Atterberg Limits – The Atterberg Limits are a basic measure of the nature of a fine-grained soil. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. In each state the consistency and behavior of a soil is different and thus so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behavior. These limits were created by Albert Atterberg, a Swedish chemist, in the late 1800s. They were later refined by Arthur Casagrande.

Bitumen – Bitumen is a class of black or dark-colored cementitious substances (either natural or manufactured) composed principally of high-molecular weight hydrocarbons, of which asphalts, tars and pitches are typical.

Cement – Portland cement is hydraulic cement made by heating a limestone and clay mixture in a kiln and pulverizing the resulting material.

Clay – Clay is a cohesive soil type composed of very fine material particles; clay is one of the fine-grained soils defined by the Unified Soil Classification System.

CQS (Cationic Quick Setting) emulsion – CQS is a quick-setting cationic slurry emulsion used for a variety of construction applications.

CTB (Cement-Treated Base) – CTB is a mixture of aggregate material and/or granular soils combined with measured amounts of Portland cement and water that hardens after compaction and curing to form a durable paving material.

Density – Density is the measure of the relative weight of any material compared to its occupied volume, expressed in kilograms per cubic meter (pounds per cubic foot). The increase in density is limited only by the degree of solidity that can be achieved in a material by total elimination of voids between the particles in the mass.

Fly ash – Fly ash is fine particulate ash created by the combustion of a solid fuel, such as coal, and discharged as an air born emission, or recovered as a byproduct for various commercial uses. Fly ash is used chiefly as a reinforcing agent in the manufacture of bricks, concrete, et cetera. There are two major classes of fly ash, C and F. Class F is produced from burning anthracite or bituminous coal; it usually has cementitious properties in addition to pozzolanic properties. Class C is produced by burning sub-bituminous coal and lignite, and is rarely cementitious when mixed with water alone.

Foamed Asphalt or Foamed Bitumen – Foamed asphalt or bitumen is expanded in volume and softened through controlled addition of air and water in an expansion chamber. The foam mixture then distributed (in controlled volume) through spray nozzles into the mixing chamber of a mobile mixer where the bitumen attaches itself to fines in the mix, creating spot "welds" rather than uniform particle coating.

Gravel – Gravel is a granular material type composed of particles predominantly retained on the 4.75 millimeter (number 4) sieve; gravel is one of the coarse-grained materials identified by the Unified Soil Classification System.

Impermeability – Impermeability is the relative resistance to the passage of air or water into or through a material or pavement layer.

Lime – Lime is a white or grayish-white, odorless, lumpy, very slightly water-soluble solid, CaO, that when combined with water forms calcium hydroxide (slaked lime). Calcium hydroxide is used chiefly in mortars, plasters, and cements.
LL (liquid Limit) – The liquid limit of a fine-grained soil is the boundary between the liquid and plastic states of that particular soil, expressed as a moisture content percentage (by weight).
PI (Plasticity Index) – PI is the numerical difference between the liquid limit and the plastic limit of a fine-grained soil.
PL (Plastic Limit) – The plastic limit of a fine-grained soil is the boundary between the plastic and semi-solid states for that particular soil, expressed as a moisture content percentage (by weight).
QA (Quality Assurance) – QA is the activity of providing evidence needed to establish confidence among all concerned, that quality-related activities are being performed effectively.
QC (Quality Control) – QC is a process for maintaining proper standards in construction or manufacturing by employing systems to ensure that products or services are designed and produced to meet or exceed customer requirements.
Sand – Sand is granular material type composed of particles predominantly passing the 4.75 millimeter (number 4) sieve but retained on the 0.075 millimeter (number 200) sieve; sand is one of the coarse-grained materials identified by the Unified Soil Classification System.
Soil – Soil is sediment or other unconsolidated accumulation of solid particles produced by the physical and/or chemical disintegration of rock; soil may or may not contain organic material.
SL (Shrinkage Limit) – The shrinkage limit of a fine-grained soil is the boundary between the semi-solid and solid states for that particular soil, expressed as a moisture content percentage (by weight).
Stabilizing additive – A stabilizing additive is a mechanical, chemical or bituminous additive (or other material) used to maintain or increase the strength and durability, decrease the moisture sensitivity, or otherwise improve the engineering properties of a soil or other material used in construction.

2 Soil Stabilization Process

2.1 Current stabilizing technology


Figure 2.1-1 soil stabilizer at work

The currently-employed technologies for soil stabilization include multiple alternatives. One choice involves the pulverization and homogenization of existing materials in-place, without the addition of an additive to change or improve the characteristics of the material. This technique is typically performed when the in-situ material is suitable and when FDR (Full Depth Reclamation) can create a new stabilized base of sufficient thickness and strength for the intended traffic loads. Of course, a surface of some type must be placed over the stabilized base to protect it.

A second technique for stabilization includes the addition of a single additive such as lime, cement or bitumen. Less common additives include fly ash and mineral fillers. Addition of this stabilizing agent was historically done dry. In recent years, however, emphasis on environmental considerations has led to more frequent utilization of liquid slurry additive applications. The dry stabilizing agent is premixed with water to form slurry which has water content at or slightly below the optimum moisture content for the material being stabilized. Not only does the use of slurry dramatically reduce the occurrence of dust during the mixing process but it also permits more accurate and uniform application and blending of the additive into the material being stabilized. When the stabilizing agent is able to be added during the pulverization pass of the stabilizer, a corresponding reduction in production costs and time can also be realized.

Another more expensive, but effective, stabilization technique involves use of multiple additives to achieve superior results. In these instances, it may be necessary to spread one of the additives onto the surface to be stabilized (in either a dry or wet state) and to add another in a slurry form through the stabilizer's on-board additive system. In some instances, multiple stabilization passes will be needed to thoroughly blend the combined additives into the in-situ material. Each project must be operated with 'best practices' for its unique site conditions and desired end results.

Figure 2.1-2 lime stabilization

A few of the more modern stabilizers actually incorporate on-board storage for one additive to eliminate the need for additional transport vehicles on site. These pieces of equipment have become very specialized. Their integrated spreader is able to distribute lime or cement in precise amounts for efficiency, using a cellular wheel to spread the lime or cement over the full working width immediately in front of the pulverizing and mixing rotor. Depending upon the size of the project, the additive storage bin has sufficient capacity to add between 1 to 2 percent dry cement or lime for stabilization. The hopper

Figure 2.1-3 Wirtgen WR 2500 SK

capacity of the machine shown in the photograph below, figure 2.1-3 is 4 cubic meters (5.2 cubic feet). On higher volume projects or where greater than 2 percent of additive is required, it is recommended that the cement or lime be stored in a transport that is connected by umbilical hose to the stabilizer. This will permit uninterrupted operation of the stabilization process for higher efficiency and lower operating costs. Actual additive volume is determined, of course, by laboratory testing of the materials to be treated during the stabilization application.

The depth to which stabilization is possible depends, in part, upon the construction of the stabilizer itself. In addition, however, thickness of the unsuitable material is also a determining factor. Keep in mind that one of the more common reasons for stabilization is to dry materials that are in excess of their optimum moisture content, and to reduce their moisture sensitivity. The total thickness of the improved sub-grade and/or sub-base layers is determined by calculations made during the design process.

2.2 Stabilization with lime

The use of lime to dry, modify or stabilize soils has been documented in studies as much as fifty years old. Many state agencies developed specifications or procedures for lime stabilization of fine-grained and/or mixed soils when the United States interstate highway system was being constructed in the 1960s.

Figure 2.2-1 lime slurry stabilization

In 1999, the National Lime Association commissioned Dr. Dallas Little to evaluate the structural properties of lime and to develop practical lime stabilization MDTP (Mixture Design and Testing Procedure). His work outlined that seven steps may be necessary for mixture design and testing of lime stabilized soils. The seven tests are identified by Dr. Little are as follows:

1. Initial soil evaluation
2. Determination of approximate lime demand
3. Determination of OMC (Optimum Moisture Content) and MDD (Maximum Dry Density) of lime-treated soil
4. Fabrication of UCS (Unconfined Compressive Strength) specimens
5. Curing and conditioning of ICS specimens
6. Determination of UCS of cured and moisture-conditioned specimens
7. Determination of change in expansion characteristics of specimens (only done for expansive soils)

2.3 Stabilization with cement

2.3.1 CTB (Cement-Treated Base)

According to the PCA (Portland Cement Association), CTB (Cement-Treated Base) has provided economical, long-lasting pavement foundations for over seventy years. These structures have combined soil and/or aggregate with cement and water which is then compacted to high density. The advantages of cement stabilization are several:

Figure 2.3-1 Wirtgen WM 1000 slurry mixer

1. Cement stabilization increases base material strength and stiffness, which reduces deflections due to traffic loads. This delays surface distress such as fatigue cracking and extends pavement structure life.
2. Cement stabilization provides uniform, strong support, which results in reduced stresses to the sub-grade. Testing indicates a thinner cement-stabilized layer can reduce stresses more effectively than a thicker un-stabilized layer of aggregate. This reduces sub-grade failure, pothole formation and rough pavement surfaces.
3. Cement stabilized bases have greater moisture resistance to keep water out; this maintains higher strength for the structure.
4. Cement stabilization reduces the potential for pumping of subgrade fines.
5. Cement stabilized base spreads loads and reduces sub-grade stress.

CTB is a cemented, rigid material that distributes load over a larger area due to its slab-like characteristics and high beam strength (see Figure 2.3-2). CTB is practically impervious; it resists freezing/thawing cycles, rain or high ground water tables and spring-weather damage. CTB continues to gain strength with age, even under traffic loading.

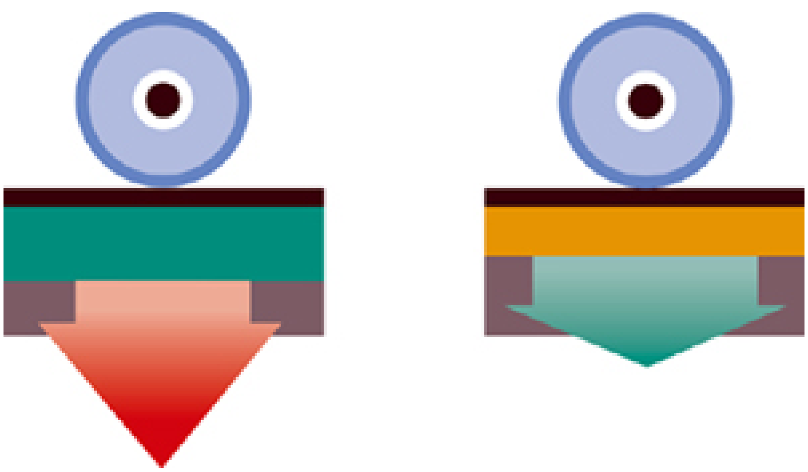

Figure 2.3-2 load distribution

2.3.2 CMS (Cement-Modified Soil)

According to the Portland Cement Association, CMS is a soil material that has been treated with a relatively low proportion of Portland cement. In general, the volume of cement is less that that required for CTB or soil-cement. The objective of CMS is to mitigate the undesirable properties of materials that are sub-standard in quality or engineering value so that they can be made suitable for construction. The amount of improvement that can be expected is dependent upon the quantity and quality of cement used as well as the type of soil being treated. The engineering properties that can be improved include the following:

1. The soil's Plasticity Index can be reduced.
2. The soil's CBR (California Bearing Ratio) can be increased.
3. Material shearing strength can be increased.
4. Shrinkage or swelling characteristics for the soil can be decreased.
5. The amount of fine-grained material particles (silt and clay) can be reduced.

CMS materials are typically classified into two primary groups, according to the predominant particle size of the soil. Silt-clay soils contain more than 35 percent fine-grained material content (material passing the 0.075 millimeters or number 200 sieve). Granular soils are those containing less than 35 percent fine-grained material content, as defined previously. Their modification is done to meet requirements for pavement base or sub-base layers.

The equipment used to produce CTB or CMS bases ranges from the very simple mixer to the sophisticated self-contained slurry portable plant (as shown in Figure 2.3-3). Regardless of the equipment utilized, the use of cement as a stabilizing agent is wide-spread around the world. Its usage is increasing annually.

Figure 2.3-3 cement slurry mobile plant

2.4 Stabilization with bitumen

2.4.1 Additive selection

Figure 2.4-1 foamed bitumen stabilization

Soil stabilization with bitumen can be done with either of two additives. Depending upon project conditions, the choice is made between using an asphalt emulsion or using foamed bitumen as the additive. For example, extremely wet soil conditions might dictate the use of foamed bitumen rather than a standard asphalt emulsion to compensate for the high field moisture content. Emulsion might be chosen for projects where high-performance emulsions are readily available. Therefore, cost and product availability are practical considerations for stabilization with bitumen, just as with other construction activities.

2.4.2 Use of multiple additives

Figure 2.4-2 foamed asphalt being rolled

It is not uncommon for certain materials or project conditions to require that more than a single additive be utilized to achieve the required strength and stability for the new base design. For example, when using foamed bitumen, it is often the practice to also utilize cement or lime to help increase the compressive strength of the base material, or to assist in drying out materials that have field moisture contents greatly exceeding optimum moisture content (OMC).

When more than a single additive is selected, the first additive to be applied may be added in the dry state or as slurry. When added in the bulk state, it is not uncommon for the agent to be spread onto the surface of the material and then either bladed, disked, scarified or otherwise distributed prior to final stabilization. As slurry, it may be applied by a truck distributor, or mixed directly into the soil through an additive system incorporated into the stabilizer's mixing chamber.


Figure 2.4-3 wetting lime and soil

There are also many projects where the in-situ material field moisture content is not sufficient for proper activation of the chemical reaction of the cement or lime. For these projects, it is necessary to wet the treated soil prior to mixing. Dry spreading of cement or lime in arid regions is often discouraged due to the creation of dust during the process.

3 Texas LNG terminal site project

3.1 Site details

A major Texas-based construction firm was contracted to complete soil stabilization on the site of a massive liquid natural gas (LNG) receiving terminal south of Houston on the Texas Gulf Coast. The site contains approximately 348,000 square meters (86 acres), situated between 0.9 to 1.2 meters (3 to 4 feet) below the ground water table elevation. The entire site is situated on a dredge spoil area which includes a variety of materials including fat clay, silt, sand and organic matter from ship channel dredging operations during the past. The contractor was charged to build up the site elevation by up to 4.3 meters (14 feet) plus build levees up to 6.4 meters (21 feet) tall to self-contain the site and protect it from flooding.

Soil from off-site is being trucked in, with 40 to 50 truck loads arriving daily; volume of material being placed varies between 4590 to 5350 cubic meters (6,000 to 7,000 cubic yards) per day. The total amount of soil that needs to be moved for this project is 688,100 cubic meters (900,000 cubic yards).

3.2 Construction

Lime is the stabilizing medium for the soil on this project. The contractor needs to truck in more than a dozen 22.7 tonne (25 ton) truck loads each day. Some of the material is being reclaimed from the actual dredge spoil area; other soil is coming in from an offsite borrow pit. Pelletized lime is being used to reduce fugitive dust, to prevent environmental issues. The lime is dumped from the belly-dump haul trucks into windrows and then spread by motor grader, laid at about 5 percent volume. Water (drawn directly from the Gulf) is then sprayed onto the pelletized lime and soil for slaking. About 37,850 liters (10,000 gallons) of water are needed for each 22.7 tonne (25 ton) truck load of lime. After slaking is completed, the stabilizers go to work.

Figure 3.2-1 multiple mixing passes

According to the contractor's representative, the soil is mixed "back and forth a couple of times"; once the mix is ready, "they start compaction with sheepsfoot and smooth drum compactors". Following stabilization, curing time is between two and three days, depending upon ambient conditions.

3.3 Performance

Two Wirtgen model WR 2000 soil stabilizers (shown in Figure 3.2-1) are working together on this project. The contractor is able to mix approximately 15,050 square meters (18,000 square yards) of material each day with this equipment. One of the features of these machines that is appreciated by the contractor is the ability to mix whether working forward or reverse in direction; this eliminates the need to turn around the stabilizers at the end of each mixing pass. The four wheel drive design of the machines also prevents the units from becoming stuck in bad material. The contractor is still working on this project, which is scheduled for completion in early 2008.

4 Stabilization with fly ash

Figure 4.1-1 blending in fly ash with subgrade

4.1 Description of work in Iowa

In May 2006 an Iowa contractor was challenged to quickly stabilize a series of tennis courts in the southeastern portion of the state. Iowa is known for fine agricultural soils…loamy, high-organic materials. However, construction projects often encounter material changes from glacial till to sand and many other soil types. Contractors find that the glaciers seem to have deposited material in layers that, as cuts are made through them, have pockets of different materials within.

For this reason, fly ash was chosen as the agent to stabilize these highly variable soil types to produce a stable base for reconstruction of the new tennis courts' surfaces.

Figure 4.1-2 fly ash mixing process

Type C fly ash was spread by distributor truck at an application rate of (59 pounds per square yard). The fly ash was mixed with the existing subgrade to a depth of 300 millimeters (12 inches); water was used to activate the ash's bonding with the in-situ subgrade materials. The stabilized material was then compacted with a pad foot vibratory compactor, and graded to proper profile. A smooth drum vibratory compactor reduced material air void content to about 3 percent. The tennis courts were then capped with about 50 millimeters (2 inches) of reclaimed mix from the original courts.

4.2 Description of work in Illinois

Figure 4.2-1 175 mm mixing depth

Champaign County, Illinois County Road 9 was the site of an experimental project where fly ash was used as a second additive during stabilization using foamed bitumen. The contractor had designed the mix and construction procedure to suit the application. The existing pavement surface had been milled off from an adjacent section of this farm-to-market road and was placed onto the second segment of the project. This RAP was then rolled to make it sufficiently stable to support the weight of the stabilizer. This 100 millimeters (4 inches) thick lift of material and the underlying surface were mixed together to a depth of about 175 millimeters (7 inches) while the stabilizer's integrated spray systems injected water and penetration-graded asphalt cement (to produce the foamed bitumen) plus 1 percent Class C fly ash as a pozzolanic additive that met the requirement for a minus 0.075 millimeters (number 200 sieve) material. The fly ash had been spread on top of the RAP and chip seal surface in multiple segments approximately (1000 feet) in length, ahead of the Wirtgen WR 2500 S being used for stabilization. Three side-by-side stabilizing passes were made to cover the complete width of the roadway.


Figure 4.2-2 mixing foamed bitumen with fly ash

The total project foam stabilized 41,135 square meters (49,200 square yards) of roadway; the project was 6 kilometers (3.75 miles) in length and 6.7 meters (22 feet) wide. The mix design required 2.5 percent liquid asphalt, PG 64-22. The contractor selected County Road 9 for this test project for its combination of moderate traffic volume but heavy loads.

5 Future considerations

5.1 Importance of soil stabilization

Throughout the Americas, agencies and contractors have experienced recurring pavement failures actually due to weakness of the sub-grade soil or sub-base material beneath the pavement. Many regions of the western hemisphere include geographies where expansive soils are encountered. Others places are plagued by periods of heavy rainfall and high ground water tables that can weaken the supporting layers beneath pavements. In some cases, poor construction techniques and inattention to details during construction creates further difficulties.

5.2 Shoulder stabilization

Another growing application for stabilization is shoulder stabilization. The need for increased bearing capacity from roadway shoulders has led to reconstruction efforts that include stabilization of existing shoulders. By adding agents that will increase the compressive strength of the naturally-occurring shoulder materials, these shoulders can be upgraded to contemporary traffic standards. The ability of the stabilizer to be operated in an off-set steering mode enhances its utility for this application. This keeps a portion of the weight of the machine on the improved grade and provides better traction and more precise control of slope. For other applications, this off-set steering capability may also provide other benefits such as helping to prevent pre-compaction of the stabilized material by the rear tires of the stabilizer. Regardless of the application,

Figure 5.2-1 stabilizing on a slope

machines with this capability offer greater flexibility to the contractor to do a wider variety of applications. This often helps to justify the initial investment in capital equipment and to spread ownership and operating costs over a greater number of projects for lower cost per cubic meter (cubic yard) of material treated.

5.3 Growth of foamed bitumen

The use of foamed bitumen as a stabilizing agent is one of the newer applications, having been first utilized as a secondary and local road improvement technique in the late 1950s in the United States of America (Iowa).The original process of foaming utilized steam; the process was soon patented by Mobil Oil Company for use in North America. In 1968, Mobil Oil of Australia modified the process to use cold water rather than steam to create the foaming process. This made the technique more economical and more acceptable to agencies and specifiers, as well as for contractors doing the stabilizing work.

Figure 5.3-1 foamed bitumen stabilization

There has been fairly dramatic growth in the application of using foamed bitumen as a stabilizing agent. Part of this growth has been due to the improvements in the technology, through use of water rather than steam as the foam-inducing agent. A greater reason for growth may be the improvements made in the equipment utilized for the application, however. Several manufacturers have developed foam injection systems for installation onto their soil stabilizers which provide excellent reliability as well as high productivity. In addition, popularity of foaming has increased due to the ability to utilize a variety of asphalt cements, including neat asphalts with a range of penetration grades, depending upon local availability.

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7 Additional Information

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