LIME-TREATED SOIL CONSTRUCTION MANUAL

LIME STABILIZATION & LIME MODIFICATION

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Foreword

This manual is written for construction contractors developing project bids, planning jobs, and conducting construction activities; for engineers preparing lime stabilization construction specifications; for project inspectors; and for civil engineering students.

This publication was originally written by the American Road Builders Association Subcommittee on Lime Stabilization and published in 1959 as ARBA Technical Bulletin 243. The National Lime Association assumed publication rights in 1965. This eleventh edition was significantly revised in 2003. About 90,000 copies of previous editions of this manual have been distributed.

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Table of Contents

CHAPTER I:
INTRODUCTION

The long-term performance of any construction project depends on the soundness of the underlying soils. Unstable soils can create significant problems for pavements or structures (Figure 1). With proper design and construction techniques, lime treatment chemically transforms unstable soils into usable materials (Figure 2). Indeed, the structural strength of lime-stabilized soils can be factored into pavement designs.

Figure 1: Extreme example of pavement failure from unstable soils

Figure 2: Comparing untreated plastic clay to lime-treated clay after initial mixing and mellowing

Lime can be used to treat soils to varying degrees, depending upon the objective. The least amount of treatment is used to dry and temporarily modify soils. Such treatment produces a working platform for construction or temporary roads. A greater degree of treatment--supported by testing, design, and proper construction techniques--produces permanent structural stabilization of soils.

Before beginning any construction project, project plans and specifications must be developed. For highway pavements, the design must accommodate expected traffic volumes along with environmental, site, and material conditions. All structural designs should be based upon laboratory tests and mix designs that fit the demands of the particular project and provide the most economical alternative for the planned use. This manual focuses on the subsequent *construction* aspects of treating soils with lime. The *testing and design* of stabilized soil layers is addressed elsewhere. For example, see the mix design and testing protocol at http://www.lime.org/SOIL3.PDF .

This manual was originally written for highway pavement applications, and this revised edition maintains that focus because most lime for soil treatment is used in highway construction. However, the use of lime for soil drying, temporary modification, and permanent stabilization is not limited to highway construction--see Chapter V for more information.

What is Lime?

Lime in the form of quicklime (calcium oxide – CaO), hydrated lime (calcium hydroxide – $Ca[OH]_2$), or lime slurry[1] can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone – $CaCO_3$) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. It is hydrated lime that reacts with clay particles and permanently transforms them into a strong cementitious matrix.

Most lime used for soil treatment is “high calcium” lime, which contains no more than 5 percent magnesium oxide or hydroxide. On some occasions, however, "dolomitic" lime is used. Dolomitic lime contains 35 to 46 percent magnesium oxide or hydroxide. Dolomitic lime can perform well in soil stabilization, although the magnesium fraction reacts more slowly than the calcium fraction.

Sometimes the term “lime” is used to describe agricultural lime which is generally finely ground limestone, a useful soil amendment but not chemically active enough to lead to soil stabilization.

“Lime” is also sometimes used to describe byproducts of the lime manufacturing process (such as lime kiln dust), which, although they contain some reactive lime, generally have only a fraction of the oxide or hydroxide content of the manufactured product. In this manual, “lime” means quicklime, hydrated lime, or hydrated lime slurry.

[1] Lime slurry, a suspension of hydrated lime in water, can be made from either hydrated lime or quicklime.

Lime Stabilization of Soils

Soil stabilization significantly changes the characteristics of a soil to produce long-term permanent strength and stability, particularly with respect to the action of water and frost (Figure 3).

Figure 3: Lime-stabilized layer (see arrow) bridging an erosion failure illustrates strength

Lime, either alone or in combination with other materials, can be used to treat a range of soil types. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop. In general, fine-grained clay soils (with a minimum of 25 percent passing the #200 sieve (74mm) and a Plasticity Index greater than 10) are considered to be good candidates for stabilization. Soils containing significant amounts of organic material (greater than about 1 percent) or sulfates (greater than 0.3 percent) may require additional lime and/or special construction procedures.

Subgrades (or Subbases): Lime can permanently stabilize fine-grained soil employed as a subgrade or subbase to create a layer with structural value in the pavement system. The treated soils may be in-place (subgrade) or borrow materials. Subgrade stabilization usually involves in-place "road mixing," and generally requires adding 3 to 6 percent lime by weight of the dry soil.[2]

Bases: Lime can permanently stabilize submarginal base materials (such as clay-gravel, "dirty" gravels, limestones, caliche) that contain at least 50 percent coarse material retained on a #4 screen. Base stabilization is used for new road construction and reconstruction of worn-out roads, and generally requires adding 2 to 4 percent lime by weight of the dry soil. In-situ "road mixing" is most commonly used for base stabilization, although off-site "central mixing" can also be used. Lime is also used to improve the properties of soil/aggregate mixtures in "full depth recycling."

[2] Lime percentages should be determined by an engineer using a mix design and test protocol. A chart to convert lime percentages to weight appears in Appendix D.

Lime Modification & Soil Drying

There are two other important types of lime treatment used in construction operations:

First, because quicklime chemically combines with water, it can be used very effectively to dry wet soils. Heat from this reaction further dries wet soils. The reaction with water occurs even if the soils do not contain significant clay fractions. When clays are present, lime's chemical reaction with clays causes further drying. The net effect is that drying occurs quickly, within a matter of hours, enabling the grading contractor to compact the soil much more rapidly than by waiting for the soil to dry through natural evaporation.

"Dry-up" of wet soil at construction sites is one of the widest uses of lime for soil treatment. Lime may be used for one or more of the following: to aid compaction by drying out wet areas; to help bridge across underlying spongy subsoil; to provide a working table for subsequent construction; and to condition the soil (make it workable) for further stabilization with Portland cement or asphalt. Generally, between 1 and 4 percent lime will dry a wet site sufficiently to allow construction activities to proceed.

Second, lime treatment can significantly improve soil workability and short-term strength to enable projects to be completed more easily. Examples include treating fine-grained soils or granular base materials to construct temporary haul roads or other construction platforms. Typically, 1 to 4 percent lime by weight is used for modification, which is generally less than the amount used to permanently stabilize the soil. The changes made to lime-modified soil may or may not be permanent. The main distinction between modification and stabilization is that generally no structural credit is accorded the lime-modified layer in pavement design. Lime modification works best in clay soils.

The Chemistry of Lime Treatment[3]

When lime and water are added to a clay soil, chemical reactions begin to occur almost immediately.

1. Drying: If quicklime is used, it immediately hydrates (i.e., chemically combines with water) and releases heat. Soils are dried, because water present in the soil participates in this reaction, and because the heat generated can evaporate additional moisture. The hydrated lime produced by these initial reactions will subsequently react with clay particles (discussed below). These subsequent reactions will slowly produce additional drying because they reduce the soil's moisture holding capacity. If hydrated lime or hydrated lime slurry is used instead of quicklime, drying occurs only through the chemical changes in the soil that reduce its capacity to hold water and increase its stability.

[3] For a more detailed discussion of the chemistry of stabilization, see Little, *Stabilization of Pavement Subgrades and Base Courses with Lime*, 1995.

2. Modification: After initial mixing, the calcium ions (Ca^{++}) from hydrated lime migrate to the surface of the clay particles and displace water and other ions. The soil becomes friable and granular, making it easier to work and compact (Figure 4). At this stage the Plasticity Index of the soil decreases dramatically, as does its tendency to swell and shrink. The process, which is called "flocculation and agglomeration," generally occurs in a matter of hours.

Figure 4: Lime flocculating clay

3. Stabilization: When adequate quantities of lime and water are added, the pH of the soil quickly increases to above 10.5, which enables the clay particles to break down. Determining the amount of lime necessary is part of the design process and is approximated by tests such as the Eades and Grim test (ASTM D6276). Silica and alumina are released and react with calcium from the lime to form calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates (CAH). CSH and CAH are cementitious products similar to those formed in Portland cement. They form the matrix that contributes to the strength of lime-stabilized soil layers. As this matrix forms, the soil is transformed from a sandy, granular material to a hard, relatively impermeable layer with significant load bearing capacity. The process begins within hours and can continue for years in a properly designed system. The matrix formed is permanent, durable, and significantly impermeable, producing a structural layer that is both strong and flexible.

Lime-Pozzolan Mixtures for Soils with Low Amounts of Clay

Lime by itself can react with soils containing as little as 7 percent clay and Plasticity Indices as low as 10. If the soil is not sufficiently reactive, lime can be combined with an additional source of silica and alumina. Such "pozzolans" include fly ash and ground blast furnace slag. The additional silica and alumina from the pozzolan react with the lime to form the strong cementitious matrix that characterizes a lime-stabilized layer. Properly proportioned mixtures of lime and pozzolans can modify or stabilize nearly any soil, but are typically used for soils with low to medium plasticity.

Fly ash is the most commonly used pozzolan. It is the finely divided residue that results from the combustion of pulverized coal in power plant boilers, which is transported from the combustion chamber by exhaust gases.

Use of lime kiln dust (LKD) is an increasingly popular alternative. LKD is the finely divided residue that results from the combustion of coal and the processing of limestone into lime in a lime kiln, and which is removed from kiln exhaust gases. LKD usually contains a significant amount of lime, alumina, and silica--it is in essence a preblended mix of pozzolan and lime. The amount of lime, silica, and alumina in LKD varies, primarily depending on the limestone, fuel, and kiln operations used during the lime manufacturing process.

CHAPTER II:
OVERVIEW AND COMPARISON OF CONSTRUCTION PROCEDURES

Construction Overview

Because lime can be used to treat soils to varying degrees, the first step in evaluating soil treatment options is to clearly identify the objective.

The construction steps involved in stabilization and modification are similar. Generally, stabilization requires more lime and more thorough processing and job control than modification. Basic steps include

- scarifying or partially pulverizing soil,
- spreading lime,
- adding water and mixing,
- compacting to maximum practical density, and
- curing prior to placing the next layer or wearing course.

When central (off-site) mixing is employed instead of road (in-place) mixing in either stabilization or modification, only three of the above steps apply: spreading the lime-aggregate-water mixture, compacting, and curing.

Advantages and Disadvantages of Different Lime Applications

The type of lime stabilization technique used on a project should be based on multiple considerations, such as contractor experience, equipment availability, location of project (rural or urban), and availability of an adequate nearby water source.

Some of the advantages and disadvantages of different lime application methods follow:

Dry hydrated lime:

Advantages: Can be applied more rapidly than slurry. Dry hydrated lime can be used for drying clay, but it is not as effective as quicklime.

Disadvantages: Hydrated lime particles are fine. Thus, dust can be a problem and renders this type of application generally unsuitable for populated areas.

Dry Quicklime:

Advantages: Economical because quicklime is a more concentrated form of lime than hydrated lime, containing 20 to 24 percent more “available” lime oxide content. Thus, about 3 percent quicklime is equivalent to 4 percent hydrated lime when conditions allow full hydration of the quicklime with enough moisture. Greater bulk density requires smaller storage facilities. The construction season may be extended because the exothermic reaction caused with water and quicklime can warm the soil. Dry quicklime is excellent for drying wet soils. Larger particle sizes can reduce dust generation.

Disadvantages: Quicklime requires 32 percent of its weight in water to convert to hydrated lime and there can be significant additional evaporation loss due to the heat of hydration. Care must be taken with the use of quicklime to ensure adequate water addition, mellowing, and mixing. These greater water requirements may pose a logistics or cost problem in remote areas without a nearby water source. Quicklime may require more mixing than dry hydrated lime or lime slurries because the larger quicklime particles must first react with water to form hydrated lime and then be thoroughly mixed with the soil.

Slurry Lime:

Advantages: Dust free application. Easier to achieve even distribution. Spreading and sprinkling applications are combined. Less additional water is required for final mixing.

Disadvantages: Slower application rates. Higher costs due to extra equipment requirements. May not be practical in very wet soils. Not practical for drying applications.

CHAPTER III:
DETAILED DESCRIPTION OF CONSTRUCTION STEPS

The following construction recommendations apply to the use of hydrated lime and quicklime in the stabilization or modification of subgrade (subbase) and base courses and are intended as a general guide for contractors, inspectors, and specification writers. Quality assurance/quality control considerations are presented throughout the chapter.

Delivery

Dry Lime

Dry quicklime or hydrated lime is usually delivered in self-unloading transport trucks (Figure 5). Commonly, each load of dry lime delivered to a jobsite carries a weigh ticket certifying the amount of lime on board. In addition, some agencies require certification of the chemical characteristics of the lime delivered.

Figure 5: Example of tanker trucks typically used for dry lime delivery

Quicklime is occasionally delivered to jobsites in dump trucks. Tightly-fitting tarpaulin covers are required for dump trucks to prevent dust loss during transit.

Slurry

Slurry lime can be produced from quicklime or hydrated lime. It can be delivered from a central mix plant or produced on site. Slurry preparation facilities should be approved by the project engineer. Regardless of location, slurry created from quicklime is hot because the chemical reaction between quicklime and water is exothermic. Slurries created by mixing hydrated lime and water are not hot.

Slurry may be prepared in a mixing tank, with agitation for mixing lime and water provided by integral paddles, compressed air, and/or recirculating pumps. Portable jobsite slaker tanks typically handle 20 to 25 tons of quicklime at a time (Figure 6).

Figure 6: Portable lime slaker tanks for preparing lime slurry on-site

A second method of slurry production, which eliminates batching tanks, involves the use of a compact jet slurry-mixer (Figure 7). Water at 70 psi pressure and hydrated lime are charged continuously in a 65:35 (weight) ratio into the jet mixing bowl, where slurry is produced instantaneously. The slurry is pumped directly into trucks for spreading on the construction site. The mixer and auxiliary equipment can be mounted on a small trailer and transported to the job readily, giving great flexibility to the operation.

In the third type of slurry set-up, measured amounts of water and lime are charged separately into the tank truck, with the slurry being mixed in the tank either by compressed air or by a recirculating pump mounted at the rear. The water is metered and the lime proportioned volumetrically or by means of weigh batchers.

Lime slurries have lime solids contents up to 42 percent. The percent of lime solids can be tested using a simple specific gravity device (pycnometer) to insure that the correct quantity is spread throughout the project.

Figure 7: Jet slurry mixer

Subgrade (or Subbase) Stabilization

1. *Scarification and Initial Pulverization*

After the soil has been brought to line and grade, the subgrade can be scarified to the specified depth and width (Figure 8) and then partially pulverized. It is desirable to remove non-soil materials larger than 3 inches, such as stumps, roots, turf, and aggregates.

A scarified or pulverized subgrade offers more soil surface contact area for the lime at the time of lime application. If the slurry method is being employed, scarification will also lessen runoff from the treatment area.

In the past it was common practice to scarify before spreading. Today, because of the availability of superior mixers, lime is often applied without scarification. Lime trucks can also negotiate the roadway more readily if it is compacted, rather than scarified, particularly on wet soils. The main disadvantage of this procedure, however, pertains to weather conditions; when lime is placed on a smooth surface, there is greater chance for loss due to wind and runoff, particularly if mixing is not started immediately. To eliminate runoff to the sides, a small soil windrow can be constructed along each side, using material from the roadbed (Figure 9).

Figure 8: Scarification before lime application

Figure 9: Soil windrow used to contain lime before mixing

If quicklime is to be discharged in windrows, a smooth surface is desired so that uniform spreading by motor grader blade can be achieved. Therefore the soil should not be scarified before quicklime is applied in this manner.

Equipment: Grader-scarifier and/or disc harrow for scarification; rotary mixer for initial pulverization.

2. *Lime Spreading*

Quicklime

There are two ways that dry quicklime can be applied. First, self-unloading trucks or trailers can distribute quicklime pneumatically or mechanically the full width of the truck. Because granular and pebble quicklime flow is more controllable than hydrated lime, it is a common practice to use trucks with built in aggregate-type spreaders (Figure 10).

For use of a pneumatic spread bar, the quicklime is typically fine sized (¼" by 0) to flow freely. A mechanical spread auger on the end of a truck, trailer, or a separate spread box can handle larger sized quicklime--typically up to ½" size. The subbase can be uneven or scarified for this type of application. This application works well in very wet soil conditions.

Figure 10: Dry lime application with mechanical spreader[4]

To insure that the correct quantity of lime is spread, a pan or cloth of known area can be placed on the ground between the wheels of the spreader truck as it drives across the site. The collection container with the lime in it is weighed to insure that the quantity of lime is correct.

A second way that dry quicklime is applied is through a gravity drop into a windrow. Bottom dump tankers and clam shell bottom drop trailers are commonly used. A motor grader/ maintainer is used to spread the quicklime evenly. Larger-size lime up to ¾" can be used. This method requires the area be level and dry enough so that the soil will not rut under the truck tires, which prevents uniform spreading. It is difficult to measure the application rate of lime when it is spread using a motor grader. The best method is to mark off an area in which a known quantity of lime will be spread and observe the grader to insure that it is spread evenly.

Regardless of the method used, the amount of lime applied to a site should not exceed the amount that can be mixed into the soil during the day of application.

[4] Photo courtesy of Mt. Carmel Sand & Gravel.

Dry Hydrated Lime

Hydrated lime should be uniformly spread at the specified percentage from suitably equipped trucks (Figure 10). An approved spreader is preferable for uniform distribution. The application rate of dry hydrated lime can be measured using the same method as described above for quicklime.

Dry hydrated lime should not be spread under windy conditions because of excessive dusting. Under windy conditions, in populated areas, or adjacent to heavy vehicle traffic, slurry application or proper quicklime applications can minimize dust related problems.

Equipment for dry hydrated lime application: For truck shipments, self-unloading bulk tanker trucks are most efficient for transporting and spreading lime because no rehandling is involved. Unloading is conducted pneumatically or by one or more integral screw conveyors. Spreading can be accomplished by a mechanical spreader attached to the rear, or through metal downspouts or flexible rubber boots extending from each conveyor or air line.

If live bottom trailers are used, the bodies should be enclosed to prevent dusting during transit to the job and during spreading. Spreading from live bottom trailers should be conducted by means of a mechanical spreader attached to the rear. Tailgate spreading of hydrated lime and leveling with a grader are not recommended.

Slurry

In this application, the soil is generally scarified and the slurry is applied by distributor trucks (Figure 11). Because lime in slurry form is much less concentrated than dry lime, often two or more passes are required to provide the specified amount of lime solids. To prevent runoff and consequent non-uniform lime distribution, the slurry is mixed into the soil immediately after each spreading pass.

The actual proportion used depends upon the percent of lime specified for the type of soil, and the percent of lime solids in the slurry. Solids in the slurry generally range between 30 and 35 percent, although technology exists to increase the solids to above 40 percent to reduce the number of passes made by the spreading trucks. The solids contained in the slurry (and, consequently, the quantity of lime available) can be easily measured in the mixing tanks or trucks using a specific gravity device. Once the solids content of the slurry is known, loads can be spread over measured areas to ensure the correct application rate.

Equipment for slurry application: Distributor trucks with recirculation capabilities are recommended to keep slurry in suspension. If the transit time is short, trucks without recirculating pumps can be employed. Spreading from the tank trucks is conducted by gravity or by pressure spray bars. Pressure distributors are preferred because they provide more uniform application.

Figure 11: Example of lime slurry application

3. Preliminary Mixing and Watering

Preliminary mixing is required to distribute the lime throughout the soil and to initially pulverize the soil to prepare for the addition of water to initiate the chemical reaction for stabilization. This mixing can begin with scarification (Figure 12). Scarification may not be necessary for some modern mixers, however. During this process or immediately after, water should be added (Figure 13).

Figure 12: Scarification after lime spreading

Figure 13: Adding water after dry lime application[5]

Rotary mixers should be employed to ensure thorough mixing of the lime, soil, and water (Figure 14). With many rotary mixers, water can be added to the mix drum during soil-lime processing (Figure 15). This is the optimum method to add water to dry lime (quicklime or hydrated lime) and soil during the preliminary mixing and watering stage.

Figure 14: Rotary mixer used for initial mixing

[5] Photo courtesy of Mt. Carmel Sand & Gravel.

Figure 15: Rotary mixer with water truck attached

Regardless of the method used for water addition, it is essential that adequate water be added before final mixing to ensure complete hydration and to bring the soil moisture content 3 percent above optimum before compaction.

To hydrate dry quicklime, additional water may be needed. The balance of the quicklime stabilization operation is similar to that using hydrated lime or slurry. A key requirement when using quicklime is to ensure complete hydration before mixing is completed and compaction starts. The soil should also be spot checked with a shovel to ensure that no pockets of unhydrated quicklime remain. Where excessive amounts of quicklime are present (e.g., due to poor distribution), additional wetting and mixing are necessary to ensure complete hydration and a quality stabilization project.

To ensure that the stabilized section is the correct depth, small holes can be dug at random and the soil can be sprayed with a pH indicator such as phenolphthalein. Phenolphthalein changes from clear to red between pH 8.3 and 10. The color change indicates the location of the bottom of the mixing zone. Other pH indicators can measure higher pH levels if there is reason to suspect that inadequate lime has been mixed into the soil.

Where heavy clays are being stabilized, it is generally necessary to mix the lime-clay layer in two stages, allowing for an intervening 24 to 48 hour mellowing period. During this mellowing period the clay becomes friable so that pulverization can be readily attained during final mixing.

After mixing is complete, the lime-treated layer should be shaped as close to the final section as possible and lightly compacted with a roller in order to minimize evaporation loss or excessive wetting from possible rains during mellowing.

Equipment: Rotary mixer, water truck, and light sheepsfoot or pneumatic roller.

4. *Mellowing Period*

The lime-soil mixture should mellow sufficiently to allow the chemical reaction to change (break down) the material. The duration of this mellowing period should be based on engineering judgment and is dependent on soil type. The mellowing period is typically 1 to 7 days. After mellowing, the soil should be remixed before compaction. For low Plasticity Index soils, or when drying or modification is the goal, mellowing is often not necessary.

5. *Final Mixing and Pulverization*

To accomplish complete stabilization, adequate final pulverization of the clay fraction and thorough distribution of the lime throughout the soil are essential (Figure 16). Mixing and pulverization should continue until 100 percent of non-stone material passes the 1-inch sieve and at least 60 percent of non-stone material passes the number 4 sieve.

Figure 16: Mixing and pulverization

If quicklime is used, it is essential that all particles have hydrated and have been thoroughly mixed. For dry quicklime only, after final mixing, prior to compaction, visually inspect the soil to ensure thorough mixing has been achieved. Use of dry quicklime often produces light specks in the soil, which are grit or core that are not of concern; they are not unhydrated particles. If in doubt, place a sample of these particles in water. If they do not dissolve, they are harmless inert particles. If they do dissolve, they are lime particles, which indicates that additional mixing is needed before final compaction.

Additional water may be required during final mixing (prior to compaction) to bring the soil to 3 percent above optimum moisture content of the treated material.

If it is certain that the above pulverization requirement can be met during preliminary mixing, then the mellowing and final mixing steps (#4 and #5) may be eliminated.

Equipment: Rotary mixer for pulverization.

6. Compaction

The lime-soil mixture should be compacted to the density required by specification, typically at least 95 percent of the maximum density obtained in the AASHTO T 99 (Standard Proctor) test. The density value should be based on the Proctor curve from a representative field sample of the lime-soil mixture – not the untreated (raw) soil.

Compaction should begin immediately after final mixing. If this is not possible, delays of up to four days should not be a problem if the mixture is lightly rolled and kept moist until compaction can be conducted. For longer delays, it may be necessary to incorporate a small amount of additional lime into the soil.

Equipment: To ensure adequate compaction, the equipment should be matched to the depth of the lift. Compaction can be accomplished in one lift using heavy pneumatic or vibratory padfoot rollers or a combination of the sheepsfoot and light pneumatic vibratory padfoot rollers or tamping foot rollers (Figure 17). Typically, the final surface compaction is completed using a steel wheel roller (Figure 18).

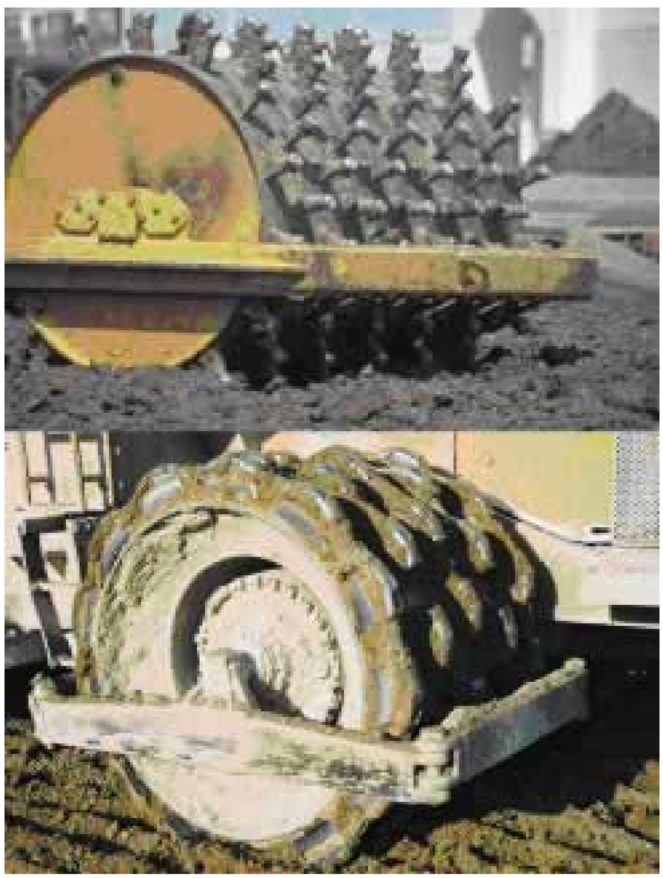

Figure 17: Sheepsfoot (above) & padfoot (below) rollers

Figure 18: Steel roller

7. Final Curing

Before placing the next layer of subbase (or base course), the compacted subgrade (or subbase) should be allowed to harden until loaded dump trucks can operate without rutting the surface. During this time, the surface of the lime treated soil should be kept moist to aid in strength gain. This is called "curing" and can be done in two ways: (a) *moist curing*, which consists of maintaining the surface in a moist condition by light sprinkling and rolling when necessary, and (b) *membrane curing*, which involves sealing the compacted layer with a bituminous prime coat emulsion, either in one or multiple applications (Figure 19). A typical application rate is 0.10 to 0.25 gallons/square yard.

Figure 19: Prime coat emulsion for curing

Base Stabilization

Lime often works well for stabilizing roads being reconstructed using "full depth reclamation." In addition, it can be used to improve marginal aggregate base materials, particularly those containing excess clay fines. The use of lime in both of these applications can contribute to the use of materials that would otherwise be wasted, transforming them into high quality structural materials.

Full Depth Reclamation

Full depth reclamation is an attractive alternative when roads having inadequate base material need reconstruction. By pulverizing the surface course and mixing it with the existing base and subgrade, an improved structural base can be constructed in place to receive a new wearing course. Often the addition of a small percentage of lime (generally 2 to 3 percent) can dramatically improve the properties of the reclaimed base by reacting pozzolanically with clay contaminants and cementing the section together. In some cases, lime kiln dust or fly ash with lime is used to increase pozzolonic activity.

Construction procedures are similar to those above:

1. *Scarification and Pulverization* – Typically, a rotary mixer is used to break the existing pavement and mix it with the base and subgrade materials to the full design depth. Depending upon the thickness of the pavement, more than one pass with the mixer may be required to reduce the pavement surfacing to a suitable size for mixing. Most specifications require that the asphalt surface course be pulverized so that 100 percent passes a 2-inch sieve; this necessitates the use of a rotary mixer. On occasion, the road may first be scarified using a motor grader, tractor-ripper, sheepsfoot roller, or crawler-tractor. Large, modern reclaiming machines can pulverize thicker asphalt without first breaking up the surface.

2. *Lime Spreading* – See discussion above (see p. 16).

3. *Mixing and Watering* – It is important to mix the lime thoroughly throughout the new base section. Sufficient water must be added to ensure that lime is hydrated (in the case of quicklime) and that it can react with the clay in the mixture. The mixing drums of most rotary mixers are equipped with hose fittings to connect to water trucks. This is a common way to introduce water into the full depth of the newly mixed layer. If that feature is not available, the reclaimed layer should be mixed, after which the surface should be watered and the section remixed. More than one application of water and additional mixing may be necessary. The final moisture content should be at least 2 percent above optimum to provide sufficient water for the lime/soil chemical reactions. This percentage differs from that discussed above, because there is a lower percentage of fine material in full depth reclamation than in clay stabilization.

4. *Compaction* – Initial compaction is usually performed as soon as possible after mixing, using a sheepsfoot type roller or a vibratory padfoot roller. After the section is shaped, final compaction can be accomplished using a smooth drum roller. The equipment should be appropriate for the depth of the section being constructed.

5. *Curing* – As with any lime-stabilized structural layer, the surface of the reclaimed base section should be kept moist until it is covered by the wearing course. The moist curing or membrane curing methods described above should be used. The layer should be cured until loaded construction equipment can drive over it without leaving ruts.

Aggregate Base Course – Central Mixing

Small percentages of lime (generally 1 to 2 percent) can be added to aggregate base courses containing excessive fines, often transforming marginal or non-specification materials into superior bases. If the excess fines are clays, lime reacts with them pozzolanically to transform them into cementitious agglomerations. With non-reactive fines, the recarbonation of the lime will often cement the fines into larger particles that contribute to the structural strength of the aggregate base.

1. *Mixing*– Lime can be metered onto the cold feed belt conveying the aggregate base, immediately followed by a spray of water to hydrate the lime (in the case of quicklime) and to promote its chemical reaction with the clays or other fines. The aggregate should then be conveyed into a pugmill to ensure adequate blending before stockpiling.

2. *Placing Material* – The treated aggregate base should be placed on the roadway using standard methods.

3. *Compaction* and *Curing* - See discussion above (this page).

Lime for Drying & Modification

Generally, lime treatment of <u>granular base</u> materials for drying and modification occurs at a central mixing location. For drying and modification of <u>fine-grained subgrade</u> materials, lime and soils are usually road mixed in place.

Base Materials – Where central mixing is used, the same steps as outlined for central mixing of aggregate base courses apply, namely: distributing the lime-aggregate mixture with a spreader box, compacting, and curing. With road-mixing, the five steps presented for full depth reclamation apply (see p. 24). However, the curing period for lime-modified bases may be waived, since it is not paramount that the treated layer develop as great a strength as with conventional base stabilization.

Subgrade Materials – The same construction steps as described for subgrade stabilization apply (see p. 14), with the exception that the mellowing period can be eliminated, and thus compaction can follow immediately after mixing. The fine degree of pulverization required in stabilization is not as essential for modification. Because of this, disc harrows alone may be adequate for mixing in extremely wet situations, although rotary mixers are still preferred for heavier soils. Because the objective of the treatment is to lower soil water content and/or temporarily improve workability and strength, compaction requirements may be reduced below 95 percent density, subject to the project engineer's approval. This is particularly true where lime modification is employed for producing a working table; in this case, driving heavy construction equipment on the surface (commonly referred to as "proof rolling") may be all that is required.

Where lime is used to condition a heavy clay soil for stabilization with cement or asphalt, the general procedure is to mix the lime and soil, seal the layer, mellow for 24 to 48 hours, remix, then apply the second additive, remix, compact, and cure for up to 7 days.

CHAPTER IV:
ADDITIONAL CONSIDERATIONS

The following factors should be considered by both engineers and contractors in the design and construction of lime-stabilized roads.

Maintaining Traffic

The ideal solution to the problem of maintaining traffic during lime stabilization construction is to re-route traffic around the construction until a part of the wearing surface has been applied. If traffic must be accommodated during curing and before application of the wearing surface, there is less chance of damage to the stabilized layer if the number and weight of vehicles can be minimized. Although trucks carrying 25-ton loads have been adequately supported by one-day-old, well-compacted lime-clay subbases, heavy wheel loads may cause spot rutting in freshly compacted bases. Such rutting usually reveals inadequate compaction. These ruts or soft spots can be reworked and recompacted.

Need for Wearing Surface

All lime-stabilized bases require a wearing surface of at least a bituminous seal coat because an unprotected lime-stabilized base has poor resistance to the abrasive action of continued traffic. Temporary access construction haulage roads are a potential exception. However, if these roads are to be used heavily longer than a year, a seal coat is recommended.

Climatic Limitations

Lime stabilization takes time and requires some warm weather to harden properly. As a general rule, the air temperature should be 40 degrees F. in the shade and rising for lime stabilization. Where lime is used solely to dry up wet soils for compaction and not for permanent stabilization, the operation can be carried out in colder weather. In no case, however, should lime be applied to frozen soil.

Freezing Contingencies

When premature freezes occur or when jobs have been badly delayed into cold weather, damage from frost can be minimized by the following procedures:

1. Reroll the freshly compacted lime-treated aggregate base the day after a freeze. Experience has shown that subsequent intermittent freezes have little effect on the base. The first freeze usually causes some "puckering " or distortion in the top 1 inch.

2. If spring "breakup" occurs as a result of late fall construction, distressed sections can be reworked and recompacted into permanent, durable sections. Most of the lime is still active and "free," and will readily react during the ensuing warm spring weather. In reworking, it may be desirable to add lime to compensate for a possible decrease in soil pH.

3. In the event of a winter shutdown, newly stabilized subgrades should be protected with a layer of suitable cover material, e.g., borrow soils.

Early Spring Start

The use of lime lengthens the spring construction period by allowing operations to start much earlier – just as soon as the frost is out of the ground. Subsequent freezes are generally not damaging since they are short-lived. In early spring, construction can proceed with lime even when the ground is saturated with moisture. This is due to lime's drying effect, which ultimately allows the saturated soil to be worked without heavy equipment bogging down. Without lime, the contractor must wait for nature's drying action, causing weeks of lost construction time.

Construction Flexibility

Flexibility in construction is also possible because soil-lime mixtures can be retempered and reworked if contingencies cause delays while lime stabilization is in progress. This is true even after the cementing or hardening action begins.

Rain Not Detrimental

During light rains, lime spreading, mixing, and compaction can continue normal operation. Spreading of dry lime by motor grader in the rain can be difficult if not done quickly as the lime becomes wet. Also, rain can create alkaline runoff if the lime is not contained by scarified soil or berms and quickly incorporated into the soil. Once the lime is mixed with soil, however, light rains reduce the amount of sprinkling needed for compaction.

Following compaction, the lime-treated layer is largely impervious to moisture and it sheds rainwater similar to a paved road. This means that even with hard rains, there are usually only minimal delays before the surfacing can be applied (or in case of subgrade stabilization, the base course placed).

Lime Safety Precautions

The safety guidelines below are general in nature. Precautions for the specific lime product used can be found in its Material Safety Data Sheet (MSDS), which is available from the lime producer or supplier.

Worker Safety

Lime, particularly quicklime, is an alkaline material that is reactive in the presence of moisture. Workers handling lime must be trained and wear proper protective equipment. Soil applications can create exposure to airborne lime dust, which should be avoided.

Eye Hazards—Lime can cause severe eye irritation or burning, including permanent damage. Eye protection (chemical goggles, safety glasses and/or face shield) should be worn where there is a risk of lime exposure. Contact lenses should not be worn when working with lime products.

Skin Hazards—Lime can cause irritation and burns to unprotected skin, especially in the presence of moisture. Prolonged contact with unprotected skin should be avoided. Protective gloves and clothing that fully covers arms and legs are recommended. Particular care should be exercised with quicklime because its reaction with moisture generates heat capable of causing thermal burns.

Inhalation Hazards—Lime dust is irritating if inhaled. In most cases, nuisance dust masks provide adequate protection. In high exposure situations, further respiratory protection may be appropriate, depending on the concentration and length of exposure (consult MSDS for applicable exposure limits).

Product Safety

Care should be taken to avoid accidental mixing of quicklime and water (in any form, including chemicals containing water of hydration) to avoid creating excessive heat. Heat released by this reaction can ignite combustible materials or cause thermal damage to property or persons.

Lime dust can be removed from vehicles using rags dampened with dilute vinegar. After applying dilute vinegar, vehicles (especially chrome surfaces) must be washed with water.

First Aid

The Material Safety Data Sheet (MSDS) for the specific lime product should always be consulted for detailed first aid information. The following guidelines are general in nature.

If skin contact occurs, brush off dry lime and then wash exposed skin with large amounts of water. If skin burns occur, administer first aid and seek medical attention, if necessary.

If lime comes in contact with the eyes, they should first be flushed with large amounts of water. Seek medical attention immediately after administering first aid.

For inhalation, remove exposed person to fresh air. Seek medical attention immediately after administering first aid.

For further steps, consult the MSDS and follow the instructions of medical personnel.

Dry Lime – Bags

Bagged lime is sometimes used to create a working platform for equipment on poor soils (particularly for jobsite entrance and exit points) and for smaller projects. This method is rarely used on mainline roadway construction.

Bags are delivered in dump or flatbed trucks and evenly spaced for the required distribution. To simplify the spacing calculations, refer to Figures 25 and 26. A hypothetical example illustrating the use of these graphs follows: Assume that the project involves 1 foot of stabilization (compacted depth), 4 percent lime, a soil having a compacted density of 110 pounds/cubic foot, and a construction site or smaller roadway of 16-foot width. Using Figure 25, it can be seen that approximately 40 pounds of hydrated lime is required per square yard. Using the information in Figure 26, it can be seen that the 50-pound bags should be spaced on 18-inch centers in one line along the middle of the roadway (or in two lines, with bags spaced on 36 inch longitudinal centers). Generally, with windrow mixing by a grader, one or two lines of bags are used; with rotary mixing, several lines are employed, i.e., checkerboard fashion. As a rule of thumb, for a 1-foot stabilized layer of most soils, 1 percent hydrated lime corresponds to about 10 pounds/square yard; 2 percent to 20 pounds/square yard; etc. However, this may vary from 8 to 14 pounds/square for 1 percent application, depending on the soil type.

After the bags are properly placed, they are slit with a knife or shovel and the lime is dumped into piles or into transverse windrows across the roadway. The lime is then leveled by using a motor grader/maintainer to ensure uniform spreading of the predetermined spacing. On very small jobs, hand raking or the use of a spike-tooth harrow or drag pulled by a tractor or truck may be used to level the lime. Generally, two passes are required. Immediately thereafter, the lime is sprinkled with water.

Disadvantages of the bag method over the dry bulk and slurry methods include higher cost of lime (due to costs of bagging), greater labor costs due to considerable extra physical handling, and slower operation. Despite these disadvantages, however, bagged lime may still be practical for small projects, such as city streets or sidewalks (provided dust is controlled), secondary roads, smaller areas of commercial projects, and maintenance (patching).

Bulk Density

Lime additions to soil are usually specified by percent weight of the dry soil density, rather than volume. Hydrated lime is rather light and bulky, having bulk densities ranging between 30 and 40 pounds/cubic foot (35 pounds/cubic foot on average). Specific gravities of high calcium hydrated lime are 2.3-2.4, and of normal dolomitic hydrated lime 2.7-2.9. Soil typically weighs 100 to 120 pounds/cubic foot, thus, hydrated lime weighs about one-third as much as the average soil. An application of 3 percent of hydrated lime by <u>weight</u> is equivalent to 9 percent hydrated lime by <u>volume</u>.

Quicklime is heavier than hydrated lime, weighing 55-60 pounds/cubic foot in pebble form and having a specific gravity of 3.2-3.4. Quicklime sized ¼-inch or less typically weighs 65 pounds/cubic foot.

Use of Other Stabilizers with Lime

Base Stabilization

In clay areas devoid of base material, lime has been used jointly with other stabilizers--notably Portland cement, bituminous emulsions, or foamed asphalt--to provide base courses for secondary roads and residential streets. Because these other additives cannot be mixed successfully with plastic clays, lime (generally 2 to 3 percent) is first incorporated into the soil to make it friable, thereby allowing the cement or asphalt to be mixed adequately.

In asphalt stabilization of base materials in place, a small percentage of lime (generally up to 2 percent) is often used to dry up wet material, so that the asphalt can be properly mixed, and the particles coated.

Lime-Fly Ash or Lime Kiln Dust Subgrade Construction

When added in the proper quantity, lime alone will effectively stabilize most clay soils. When the soil is not sufficiently reactive, however, additional silica and alumina may be needed for stabilization. Use of lime kiln dust (LKD) or lime and fly ash are two alternatives.[6]

Alumina, silica, and lime are three of the principal constituents of lime kiln dust. With proper design, this material can be used for soil modification, including modification of soils with lower clay concentrations.[7] If adequate lime (and silica and alumina) are present, LKD can also be used for soil stabilization. Construction procedures are essentially the same as those used for dry quicklime (see p. 16).

Fly ash contains significant amounts of alumina and silica. Lime-fly ash (LFA) combinations can be added to the soil in two ways:

The lime and dry fly ash can be pre-blended to the proper proportions, transported to the job site, then spread and mixed into the soil. If quicklime is used, the maximum particle size is often limited to ⅛ or ¼ inch to ensure that the fine-grained fly ash does not unduly segregate from the lime.

Lime and fly ash can also be spread and mixed into the soil in two separate operations. Typically, the lime is spread first and mixed into the soil with adequate moisture to bring the soil moisture content to 3 percent above optimum. If necessary, the soil is allowed to mellow. Then, fly ash is added at the prescribed rate and additional water is added as needed for final mixing. After final mixing, the treated soil is compacted, graded and cured.

Fly ash can be spread in two forms – dry or moisture-conditioned. Moisture-conditioned ash typically contains 10 to 25 percent water (by weight of dry fly ash), making it virtually dust-free. Generally, only non-self cementing Class F fly ash meeting the requirements of ASTM 618 is suitable for use in the moisture-conditioned state. When mixed with water, most Class C fly ash is self-cementing and cannot be easily spread onto the soil.

Dry ash is spread using the same equipment used to spread dry hydrated lime or fine quicklime (see p. 16). Moisture-conditioned Class F fly ash can be spread with asphalt paving machines (Figure 20) or with specially-modified mechanical spreading trucks (to ensure that the moist ash will not plug during spreading). Because fly ash is normally proportioned by dry weight, it is important to properly account for the weight of water when using moisture-conditioned fly ash. The balance of construction procedures are essentially the same as those used for dry quicklime (see p. 16).

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[6] The variability of composition should be considered in design and use of any by-product material.
[7] General guidelines for use of LKD appear in ASTM standard D5050 (see Appendix A).

Figure 20: Asphalt paving machine used to spread moist fly ash

Sulfates

The presence of soluble sulfate salts can present problems when soils are stabilized with any calcium-based additive (e.g. lime, Portland cement, fly ash). Sulfates are most common in the western United States, due to the presence of naturally-occurring gypsum, although soils contaminated with industrial sulfates or synthetic gypsum base materials can also lead to problems. Sulfates in the soil combine with calcium and alumina from clay, and with water, to form the minerals ettringite and thaumasite in a highly expansive reaction. The formation of these minerals after compaction can result in significant pavement heaving and loss of strength.

Soil sulfate concentrations of less than 3,000 ppm (0.3 percent) are unlikely to cause problems. Concentrations of 3,000 to 5,000 ppm (0.5 percent) can be readily stabilized if care is taken to follow good construction practices such as using plenty of water and allowing ample time for the lime and soil to mellow between mixings. Concentrations greater than 5,000 ppm are often treated with two applications of lime, the first before the first mixing and the second after the mellowing period. The moisture content of the soil is raised to 5 percent over optimum during a multi-day mellowing period to solubilize as many sulfates as possible and to force ettringite to form before compaction.[8] Once formed, ettringite is relatively stable and is unlikely to cause future problems. After the mellowing period additional lime is added to the soil and construction proceeds normally.[9]

Sulfates are rarely distributed evenly throughout a construction site, but are found in isolated seams and pockets. Research is currently being conducted to improve methods for locating sulfate concentrations in the field in order to reduce the risk of problems and facilitate construction.

[8] However, recent research on treating sulfates up to 7,000 ppm to reduce swell suggests using moisture contents 2% above optimum with a single application of lime (http://www.trb.org/am/ip/Practical_Papers.asp#1577).
[9] Additional information is available at http://www.lime.org/sulfate.pdf .

CHAPTER V:
NON-HIGHWAY APPLICATIONS

Lime treatment is used in a number of non-highway applications for both modification and stabilization. Non-structural applications (modification) are designed to dry up mud and create working platforms in a variety of construction settings. Structural applications (stabilization) include non-highway pavements, such as airports, parking lots, secondary roads, and racetracks; and other applications such as building foundations and embankment stabilization. The lime treatment construction techniques used are essentially the same as those described above for lime stabilization and lime modification in highway construction.

Airports

Lime has an extensive history as a soil treatment option for airport construction. Examples include the Denver International, Dallas Ft. Worth, and Newark airports. Many airports in the United States are expanding by lengthening runways, taxiways, and parking aprons. New and expanded terminals are also under construction (Figure 21).

Figure 21: Lime stabilization project at an airport

Most airports build on existing properties or purchase adjacent properties, and therefore have little control over terrain and soil conditions. If marginal or poor soil conditions are encountered, the owner can choose to remove and replace the existing soils or treat them. Construction techniques for lime treatment of soils in airport construction are essentially the same as those for roads. However, the Federal Aviation Administration (FAA) has specifications for construction and soil treatment methods.[10]

[10] See, for example, the FAA's Advisory Circular for Standards for Specifying Construction of Airports, AC 150/5370-10A, Part 2, Item P-155 "Lime Treated Subgrade."

Soil Stabilization: Creating sound foundations beneath runways is critical. Slurry lime is becoming the most often specified lime-based treatment option due to the potential for dry lime dusting of airplanes and mechanical equipment.

Soil Drying and Modification: Airport construction often proceeds under time constraints. The use of lime to dry and modify marginal and poor soils can assist in keeping projects on schedule during wet weather by providing a working table that sheds water and allows return to work more quickly after rain events.

Commercial

New construction of large stores or shopping centers with the accompanying parking areas is an increasingly common application for lime stabilization or modification. Location of these facilities tends to be based on customer accessibility, not on soil characteristics. Unstable soils may be present. Sites may be in wet, low-lying areas. Rarely are sites level or on grade. The contractor must cut and fill the site and compact soils to prescribed soil densities. Stabilization/modification techniques are generally the same as those described for highway construction.

Lime Stabilization: Material excavated for building pads can be limed in lifts as it is removed and stored in a stockpile for a few weeks. These treated soils should have a water content 1 to 3 percent above optimum to ensure that the lime reaction has enough water for completion. This practice saves construction time as the mellowing is occurring in the material stockpile. The treated and mellowed material can then be compacted in lifts without delay as it is returned to the building pad.

Roadways and parking areas need to be designed to accommodate the expected vehicle traffic. Ignoring the nature of the underlying soils creates the potential for pavement failures. Lime stabilization can provide sound pavement foundations and reduce the thickness of the overlying layers.

Lime Modification: Completion time for commercial projects is a prime constraint. Projects tend to focus on opening dates that correspond with seasonal purchases, such as holidays and summer landscaping. On many occasions the contractor finds he has to work during rainy weather. Lime can be used to dry overly wet soil prior to compaction. Lime modification can be used to maintain a firm working table that sheds moisture. This will assist in keeping workers, equipment, and materials out of the mud, reduce weather-related delays, and assist in keeping the project on schedule.

Housing

The development of subdivisions begins with the establishment of access roads and related utilities, followed by the construction of sidewalks, driveways, and homes. Lime stabilization can be used to create structural foundations for building pads, sidewalks, and streets. Lime modification offers a convenient construction technique for minimizing the effects of weather and marginal soils. Often, housing construction continues through all seasons, wet or dry, because borrowed money makes maintaining construction schedules paramount. The ability to reduce delays is one way to increase profits. Soil treatment procedures are similar to those described earlier.

Subdivision Streets: The contractor begins by laying out streets and utilities. The streets are rarely without crews digging utility trenches for sewer, water, gas, and electric. With all of this digging and filling it is small wonder the streets tend to be areas of deep mud and at many times impassable. One way to mitigate this problem is to use lime in the beginning phase of construction to modify the soil and then to use additional treatments for drying trench fills. Stabilized soils can also be used as a foundation for the final pavement (Figure 22). Soils beneath sidewalks can also be stabilized to minimize sinking and buckling.

Figure 22: Compacting lime stabilized soil for base of street in housing subdivision

Individual Home Sites: The contractor can use lime to modify and stabilize the driveway area and building pad, which will create a work area free of mud to receive building materials and set up equipment. When construction is complete, the home will have a driveway and foundation that is less likely to settle and crack.

Embankment Stabilization

Often, inferior or overly wet borrow materials are used to construct embankments. Lime treatment can be used to stabilize these soils either when they are first constructed, or as part of repairing failed embankments. Usually the unstable soil is moved to a mixing area where construction equipment can be used to conduct the operations described above (Figure 23). For soils with high clay content, lime is used; whereas for soils with low clay content, lime-pozzolan (e.g., fly ash) mixtures are used. These treated soils should have a water content 1 to 3 percent above optimum to ensure that the lime reaction has enough water for completion. After mixing, watering, and mellowing, the material is returned to the embankment, shaped, and compacted to specification (Figure 24). Construction time is saved as the mellowing occurs in the material stockpile. Limed material is compacted without delay in lifts as it is returned to the embankment.

For embankments where soil drying is the primary goal, the soil is often treated with lime after it is brought into the embankment location. The untreated soil is placed in lifts, typically 8 to 12 inches thick. Each lift is treated with lime and thoroughly mixed, lowering the soil moisture content. The lift is then compacted, another lift of soil is placed and the process is repeated until the embankment is complete. Again, it is important to ensure that adequate moisture exists or is added, particularly if quicklime is used. If quicklime is used, it is essential that all particles have undergone hydration.

Figure 23: Preliminary mixing of lime and embankment soils in mixing area

Figure 24: Returning treated soils from mixing area to embankment

APPENDICES

Appendix A: Specifications[11]

Materials:

1. **ASTM C977 Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization**
2. **AASHTO M216 Lime for Soil Stabilization**
3. **ASTM C593 Standard Specification for Fly Ash and Other Pozzolans for Use With Lime (applies to soil stabilization and building lime)**
4. **ASTM C618 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete**
5. **ASTM D5050 Guide for Commercial Use of Lime Kiln Dusts and Portland Cement Kiln Dusts**

Testing & Sampling:

6. **ASTM D6276 Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization**
7. **ASTM D3155 Standard Test Method for Lime Content of Uncured Soil-Lime Mixtures**
8. **ASTM D5102 Test for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures**
9. **ASTM D 698 Test Methods for Laboratory Compaction of Soil Using Standard Effort**
10. **ASTM D 1557 Test Methods for Laboratory Compaction of Soil Using Modified Effort**
11. **AASHTO T 99 Standard Proctor Test**
12. **AASHTO T 180 Modified Compaction Test**
13. **AASHTO T 294 Conventional Resilient Moduli Test**
14. **ASTM D4318-00 Test Methods for Liquid Limit, Plastic Limit, & Plasticity Index of Soils**
15. **ASTM D3551 Lab Preparation of Soil-Lime Mixtures Using a Mechanical Mixer**
16. **ASTM D3668 Test Method for Bearing Ratio of Laboratory Compacted Soil-Lime Mixtures**
17. **ASTM D3877 Standard Test Methods for 1-Dimensional Expansion, Shrinkage, & Uplift Pressure of Soil-Lime Mixtures**
18. **ASTM D5093 Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring (can be used for soil-lime mixtures)**
19. **ASTM D6236 Standard Guide for Coring and Logging Cement- or Lime-Stabilized Soil**

Other:

20. **ASTM E1266 Standard Practice for Processing Mixtures of Lime, Fly Ash, and Heavy Metal Wastes in Structural Fills and Other Construction Applications**

[11] The specifications listed are national or international. State specifications are not included, but should be considered if applicable to the project. In 2003, the Federal Highway Administration created a website for access to state and federal highway specifications at http://fhwapap04.fhwa.dot.gov/nhswp/index.jsp .

Appendix B: NLA Soil Stabilization Publications (updated Sept. 2004)

More information is available in the following reports and from lime company representatives:

"Lime Stabilization and Mechanistic-Empirical Pavement Design," by Jagannath Mallela, Harold Von Quintus, and Kelly Smith: Manual to provide guidance on how to consider and include lime-stabilized layers in pavement designs being evaluated with mechanistic-empirical (M-E) tools (2004, 40 pp.), *http://www.lime.org/MechEmpPavement.pdf* .

Evaluation of Structural Properties of Lime-Stabilized Soils and Aggregates by Dallas N. Little:

- Volume 1, "Summary of Findings": tabulated format summarizing lab and field documentation of the structural properties of lime-stabilized soils (1999), *http://www.lime.org/SOIL.PDF* .
- Volume 2: data & supporting information for Volume 1 (hard copy only, 1999), *http://www.lime.org/publications.html* .
- Volume 3, "Mixture Design and Testing Protocol (MDTP)": systematic design and testing procedures for lime stabilization to better assure structural properties are achieved (2000), *http://www.lime.org/SOIL3.PDF* .
- Volume 4, "Example Illustrating the MDTP": a case history illustrating mechanistic design and analysis using the Volume 3 MDTP to address structural properties of lime-treated subgrade, subbase, and base layers (2001), *http://www.lime.org/AMDTP.pdf* .

"Stabilization of Pavement Subgrades & Base Courses with Lime": advanced text on geotechnical uses of lime stabilization, reaction mechanisms, engineering properties, and life cycle costs. Includes research findings from major universities (hard copy only, 1995), *http://www.lime.org/publications.html* .

"Technical Memorandum: Guidelines for Stabilization of Soils Containing Sulfates": detailed discussion and guidelines for using lime in sulfate-bearing soils (2001), *http://www.lime.org/sulfate.pdf* .

"Lime Dries Up Mud": Tech-brief brochure on drying up wet soil to form a stable working table that will resist further wetting (1998), *http://www.lime.org/mud.pdf* .

"Fact Sheet on Lime Stabilization and Modification": Overview of lime soil treatment procedures and benefits (updated 2001), *http://www.lime.org/soil2.pdf* .

For access to these publications, see *http://www.lime.org/publications.html*. For lime company contact information, see *http://www.lime.org/usstate.html* .

Appendix C: Plasticity Index (PI)

The Plasticity Index (PI) is a measure of how much water a soil can absorb before dissolving into a solution. The higher the number, the more plastic and weaker the material. Plastic soils containing clay have PIs of 10 to 50 or more. Generally, lime will react with such soils to significantly reduce the PI and create material with structural strength. Soils with PIs less than 10 generally do not react as readily with lime, although there are exceptions.

The PI is measured by two of the most simple tests in soil mechanics: the liquid limit and the plastic limit; the difference between the two is the Plasticity Index—see ASTM D4318-00 “Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.” The tests are performed on material passing the 425-mm (No. 40) sieve. Each test measures the moisture content of the soil under certain conditions. Laboratory equipment such as a drying oven and weighing scales are required for both tests. The liquid limit test uses a simple apparatus. The plastic limit test requires hand rolling a thread of soil, kneading it, rolling it again, and repeating the procedure until the soil thread crumbles. The moisture content at this stage is the plastic limit.

Appendix D: Charts (converting percent to weight & bag spacing)

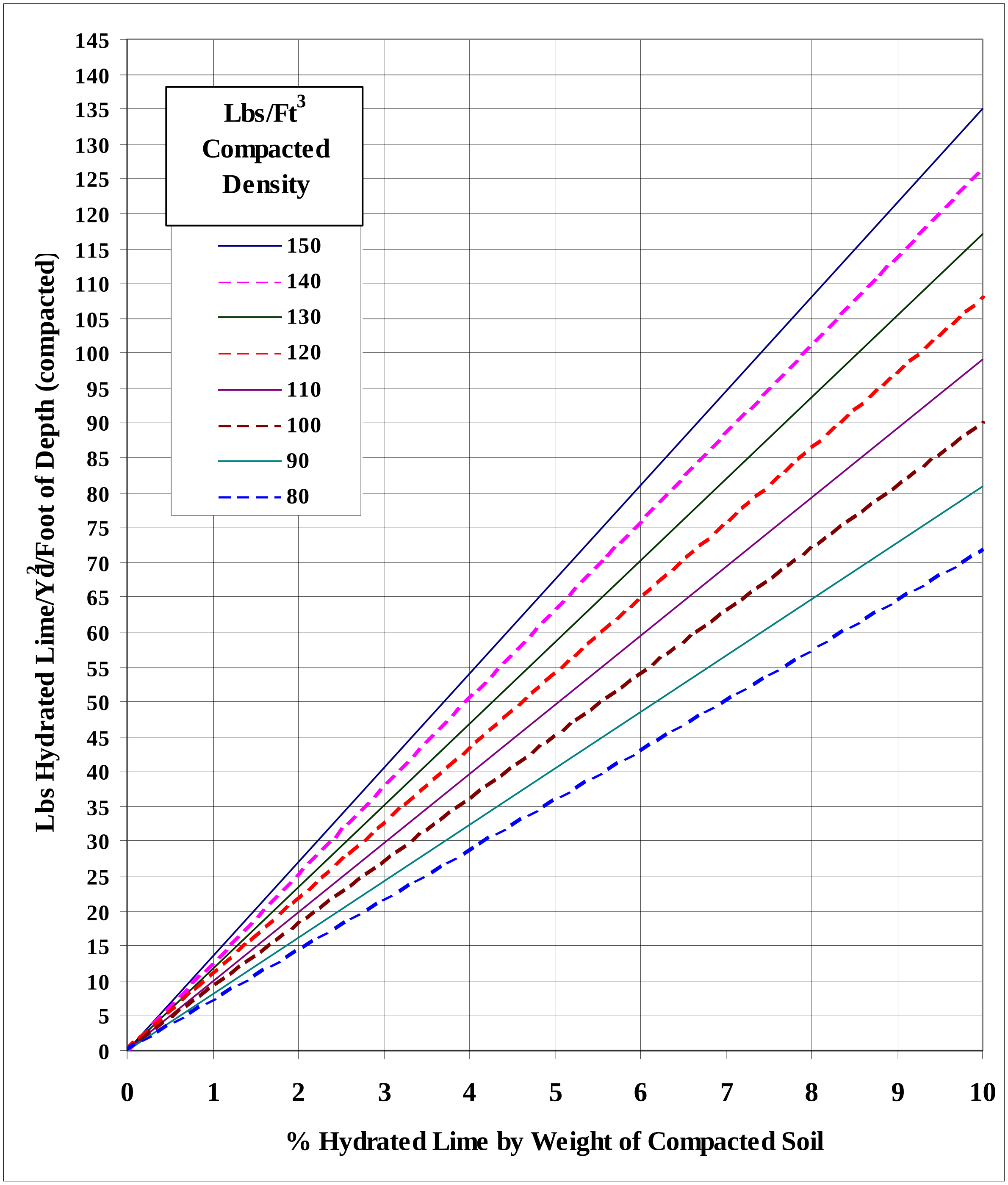

Figure 25: Graphical Conversion for Hydrated Lime Application Rates

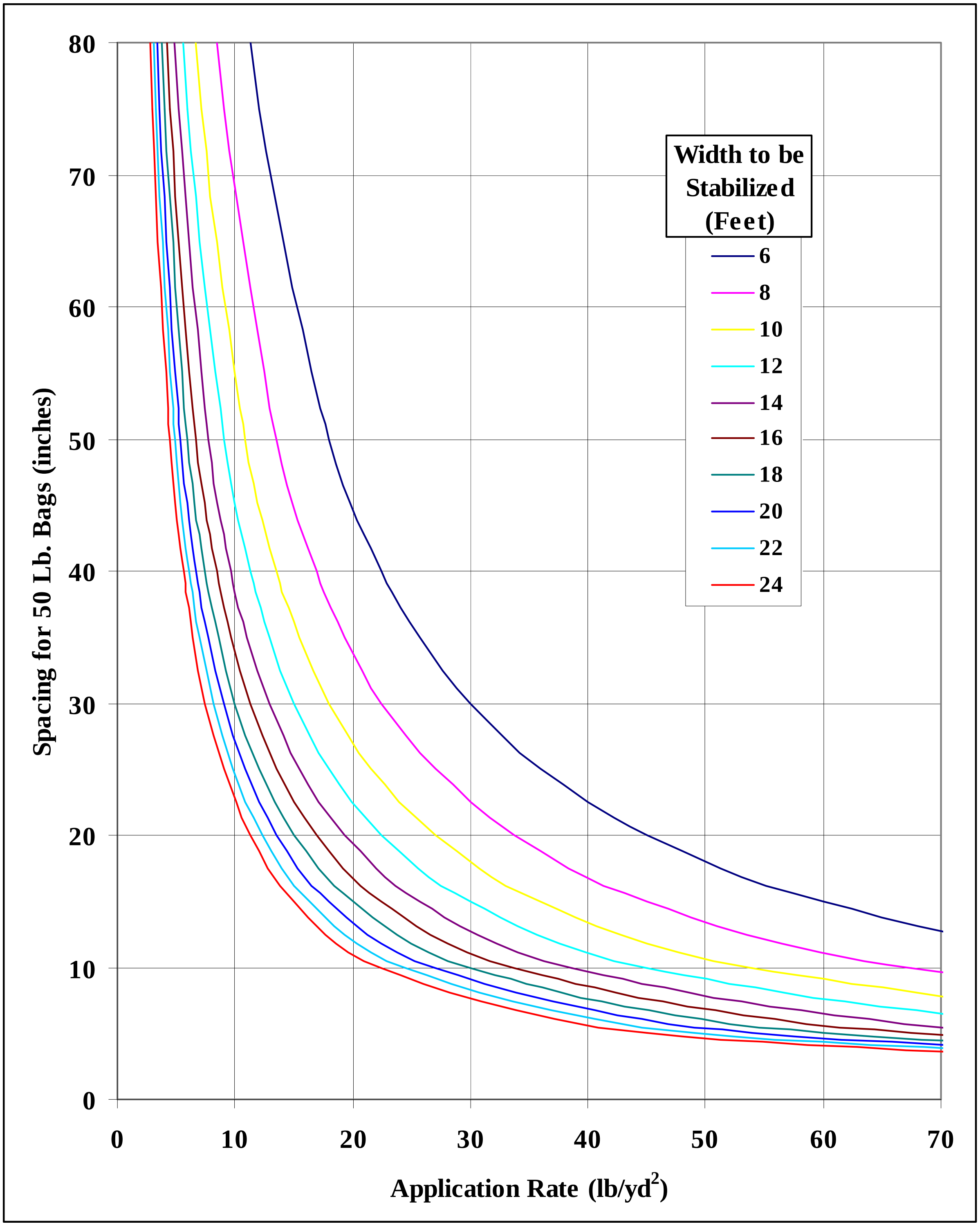

Figure 26: Bag Spacing