Stabilization of Soils with Lime, Lime-Flyash, and Other Lime Reactive Materials

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The purpose of this report is to discuss desirable testing and construction techniques to be used for construction of successful lime stabilization projects. The report discusses the history of the process, the composition and characteristics of the limes used, and the types of lime stabilization generally used. A brief discussion of some of the chemical reactions explains why and how lime changes physical characteristics of soils. A portion of the report pertains to testing of mixtures and to interpretation of test results.

Discussion of construction practice covers such subjects as application of lime, mixing, compacting, curing, and reworking. Recommendations with regard to these practices and their relationship to cracking and permanence are made. A number of tests to be made subsequent to construction are suggested and the benefits of lime as a stabilizer and of properly constructed lime stabilized projects are summarized.

● LIME STABILIZATION, as applied to present day highway construction, is an outgrowth of ancient practices which have been modified by laboratory and field tests to fulfill a variety of stabilization requirements. Since all varieties of this type of stabilization are not entirely satisfactory for all job requirements, and since different construction techniques are necessary for use with various job requirements, a discussion of this subject is indicated. It is the purpose of this report to clarify some of these points by setting forth some of the best concepts and practices known to date. It is believed that this report will provide both background and specific information to those who, for the first time, are employing lime stabilization by presenting some of the history of the process and by explaining why and how soil-lime mixtures have stabilizing characteristics. Since this type of stabilization is growing rapidly, and the present knowledge of the subject is constantly being enlarged upon in both the field and the laboratory, one may expect to elaborate upon this report considerably in the future.

HISTORY

Broadly speaking, the use of lime stabilization preceded the beginning of clearly recorded history. Perhaps its use in constructing the pyramids of Shensi in the Tibetan-Mongolian Plateau is one of the oldest. These pyramids are much larger and older than the Egyptian pyramids and were constructed of compacted mixtures of clay and lime. They were considered so very old that little was known about them when their first history was recorded over 5,000 years ago.

China and India also have used lime stabilization in various ways throughout their long history. Chinese engineers have used lime-stabilized clay-gravel for massive bridge footings and underground chambers. Engineers from India tell of using lime-clay-sand mortars in construction of tall masonry dams. In their country, this treatment is noted for the prevention of weeping of dams. The use of lime in subbases of the Roman roads dates back more than 2,000 years. The practice had probably existed in this area long before construction of the Roman roads.

Many of these and other countries have continued such practices right up to the present time. One very noticeable point is that in many instances the practice was and still is a family art handed down from father to son. For this reason there were practically no written procedures or specifications available for modern use; therefore, considerable experience in testing and constructing actual experimental projects is required to adapt techniques to modern day road building. These techniques covered such items as desirable methods for mixing, compacting and curing.

The Texas Highway Department has utilized some of the art known by ancient races in development of lime stabilization for use in present practices of road building. Like many other organizations they have carried out laboratory tests on soil-lime mixtures for the last 25 years, but the first 13 years were spent without observable success. The development of laboratory compaction and triaxial compression methods of testing made it possible to better evaluate such mixtures as early as 1945. In highway work, laboratory experiments without field experiments are usually inconclusive and one without the other can often be misleading. Prior to 1945, field experiments were conducted in a number of states (including the midwest) without consideration of control of mixing, compacting and curing. Most of these jobs were used as open surfaced roads and resulting performances were disappointing. One such job in Texas probably delayed development of lime stabilization in that state for ten years. These same materials that failed on one job in this state, when used on another nearby job, have given splendid performance under medium heavy traffic for a period of 14 years to date. Several hundred miles of this granular type of lime stabilization are giving good service. Treatment of clays with lime started about seven years ago and has increased in demand so rapidly that several hundred miles of this type of stabilized subbase now can be found on this state's highway system. The use of lime for stabilization purposes in this one state alone has reached an average of 9 to 10 thousand tons monthly and is increasing. The percentages of lime used have varied from 1 to 8, based on dry weight of soil, and costs in the southern states exclusive of surfacing have varied from 22 to 50 cents per sq yd for a 6-in. depth. Many other states and countries are building lime stabilization projects which should contribute greatly to the knowledge on this subject.

TYPES OF LIMES USED

Most of the lime used for road stabilization to date has been hydrated lime (calcium and/or calcium-magnesium hydroxide) although some quicklime (calcium and/or calcium-magnesium oxide) and waste lime have been used with success. Both high calcium and dolomitic or magnesium limes have been used successfully. Hydrated limes have been applied both in the powder and slurry forms. So far as is known, quicklime has been applied only in the powder form and has been known to burn some workman who were not properly protected. In order to overcome this difficulty, quicklime probably could be slurried sufficiently to avoid severe burns, but for best mixing the lime particles after slurrying should be as finely divided as hydrated lime. Waste lime may contain both quicklime, hydrated lime and impurities, and its use has been limited to small experimental jobs. It is difficult to plan on the use of such limited and erratic sources for stabilization on a scale of any considerable magnitude.

The chemical constituents of lime are quite definite and there should be no doubt as to what lime is; however, the words "lime" and "limestone" have been so loosely used that many people, including engineers, mistake limestone dust or screenings for lime. Limestone is calcium-carbonate and not calcium-oxide or lime; it cannot become a lime except by having its carbon dioxide removed by heating. Some metamorphic limestones may have a trace of free lime available in them due to their past geological history, but their lime content cannot be expected to produce stabilization results which are comparable to those obtained when commercial lime is used.

Some control of the purity of lime to be purchased should be exercised in order to avoid buying inert materials. Lime for soil stabilization has generally been purchased under ASTM Designations C-6-49 or 207-49 with plasticity requirements deleted. The ASTM tests for this purpose, if strictly interpreted, have been found by some to be too complicated and too slow for control of large quantities expected to be transported on short notice. One state has its own test procedure and specification for control of lime quality. When lime stabilization is used frequently in a given state or area, it may become desirable for control samples to be taken at the lime plants in lieu of samples from individual truck or rail shipments. This can avoid the embarrassing situation of having sub-standard lime on or in the job and wondering what to do about it.

TYPES OF LIME STABILIZATION

Generally, there are two main types of lime stabilization which can be accomplished out of a variety of combinations. One consists of treating granular or aggregate bearing materials for final course of base upon which a wearing course or surfacing is to be placed. Such mixtures usually contain less than 50 percent soil binder and are treated with from 2 to 4 percent lime based on dry weight of soil aggregate material. The other consists of treating soil materials to serve as subbase. Usually, clay soils are treated for this purpose by the addition of from 4 to 8 percent lime based on dry weight of soil. Due to the effects of weathering conditions, clay-lime mixtures which are adequate for subbase purposes probably will not prove to be satisfactory if used as final course of base upon which a thin surfacing is to be placed. Many types of soils react favorably to lime stabilization regardless of whether they are acid or alkaline.

The treatment of granular soils for final course of base to be surfaced, which do not react well with lime alone, can be enhanced by the addition of flyash, expanded shale fines, volcanic ash, portland cement and bituminous materials. A class of high type pavements probably could be opened up by pursuing the use of aggregates treated with lime and flyash or expanded shale (burned clay) or some volcanic ashes. This type of stabilization could probably be pursued further by using dolomitic or magnesium lime in conjunction with calcium chloride or gypsum to form oxychloride or oxysulphate cementation. If adequate methods of injecting carbon dioxide after completion of compaction could be developed, a different type of hardening and increase in strength could be accomplished.

CHEMICAL REACTIONS

There are many chemical reactions which take place in soil-lime mixtures and the following discussion probably covers only a few of them. The first reaction which takes place is of a base exchange nature which lowers the plasticity index of the soil and gives the soil a loose friable appearance. Various small amounts of mixing, depending on the nature of the soil, are required to obtain this consistency. This texture is similar to good tilth in farm land and will remain friable unless compacted. If compacted, however, another reaction is believed to be effected which consists of calcium reacting with available silica and alumina (colloidal sizes) to form complicated compounds of non-slaking monocalcium silicates and aluminates. This is a form of slow setting cement which continues to gain strength over long periods of time and is commonly referred to as a pozzolanic reaction. The rate of this cementation varies a great deal with the type of soil being treated and with climatic conditions. The third reaction is the slowest and involves the absorption of carbon dioxide from the air so as to react with the calcium hydroxide to form calcium carbonate or limestone. For either of these last two reactions to produce effective hardening by cementation, the mixture must be thoroughly compacted prior to time of reactions.

TESTING OF SOIL-LIME MIXTURES

In running tests on such mixtures, it is important to always use a fresh supply of good lime. The soil constants of highly plastic, clay material to be treated with lime should be run as an indication of the degree of mixing required. If lime will not lower the PI of a heavy clay effectively, mixing difficulties may be anticipated. If lime hardens a low PI material, it is not necessary to require a decrease in PI.

The strengths of soil-lime mixtures are usually evaluated by such tests as the CBR, unconfined compression, resistance value, triaxial, etc. In attempting to evaluate the test results, it should be kept in mind that the mixes which are hardest at an early age are not necessarily the best, because some of the differences in strength may be due only to the rate of setting having been speeded up. It should also be kept in mind that if a mixture has sufficient hardness, strength or toughness to withstand the climates and extensive repetitions of the stresses imposed, it may serve just as well as a much stronger layer. There is a need for fast-setting mixtures where the lack of detours makes it necessary to carry heavy traffic over existing roads. There is danger that such mixtures under heavy traffic may be susceptible to cracking. Regardless of the type of strength test used, it is common practice to plot strength versus percent lime, as shown in Figure 1.

In this case, plotting test results by the aforementioned methods would seem to indicate an optimum lime content of 5, 7 and 9 percent for 7, 21 and 60 day old specimens, respectively. The strength values for the 180 day old specimens show that there really is no optimum lime content to be gained from such an analysis. Strength tests are necessary to see if a proposed mixture will harden sufficiently but experience and good judgment are also essential tools for selecting percentage of lime to be used. There is also a noticeable discrepancy between road and laboratory strengths of clay-lime mixtures. Laboratory strengths may indicate a Class 1 mix but the same clay-lime mix may not obtain such strengths in the road due to delayed mixing, compacting and weathering. Cores cut from old roads consisting of old, lime-granular soil mixtures show that field strengths are higher than are found from laboratory tests on specimens up to 60 days old. In selecting the percentage of lime for use, it should be kept in mind that some lime will be lost in construction operations by blowing, carbonation, etc., so it is advisable to use a little more lime than short-time tests indicate to be sufficient. It will be very advantageous to have some extra lime in mixtures which have to be reworked. Very low percentages of lime are practical to use for temporary effects on haul roads and detours. Of any combination of materials selected for use as base course, Texas test method THD-82 suggests a minimum unconfined compressive strength of 100 psi after 7 days moist curing and 10 days soaking or capillary wetting at room temperature. Mixtures that set slower than this may be difficult to handle, particularly during cold or adverse weather conditions. Laboratory personnel often observe a fast rate of wetting in moist-cured, partially dried specimens. This should not be mistaken as an indication of a high rate of permeability. Capillarity and permeability are two different things. Compacted lime mixtures are particularly effective for repelling water percolation.

CONSTRUCTION METHODS

The quality and behavior of soil-lime stabilization mixtures are highly dependent

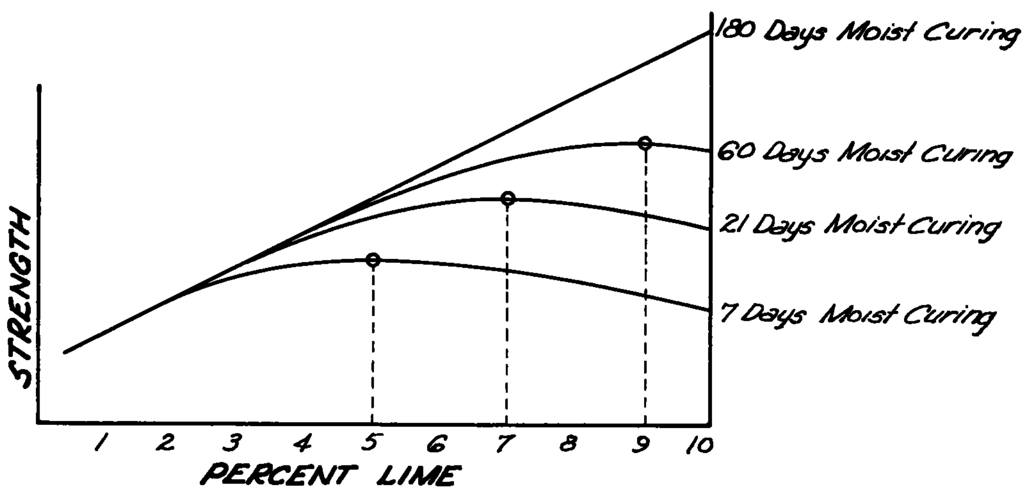

Figure 1. Effect of lime content on strength of soil-lime mixtures.

upon the technique used during construction. If the material to be treated is in place, some scarification and pulverization, prior to addition of lime, are indicated. Rooters, disc harrows and rotary speed pulverizers are very useful tools for these types of operation.

Application of Lime

As stated before, lime may be added in either the powder or slurry form. The choice of which to use often depends upon the moisture content of the soil to be treated and location of the project with respect to creating a dust hazard to homes and business establishments. Powdered lime may be added by proper spacing of bags or by mechanical spreaders, or with transport trucks equipped with auger unloaders and flexible downspouts. Hydrated lime slurries have been made by blending water to lime with pugmills, compressed air, and circulating pumps as stirring devices. Blending may be effected during or prior to loading truck tanks. The cost of satisfactory plants of this type have ranged from 3 to 7 thousand dollars which becomes a small item if used on several jobs or if parts are converted to other uses. It has been found that lime slurry can be handled through ordinary water tank truck spray bars when 2 or 3 lbs or more of water per lb of hydrated lime are properly blended. Occasionally, truck tanks not equipped with circulating devices will accumulate a layer of lime sediment in the bottom of such tanks. Compressed air is usually effective in stirring up these sediments so the tanks can be flushed out.

Mixing

In the case of sandy or aggregate bearing soils, lime is usually added to the surface and mixed with motor patrol graders or rotary speed pulverizers. In case lime slurry is being added, thin layers are bladed aside as each increment of slurry is added by sprinkling until windrows are formed. After windrows are bladed back across the road, the mix is usually ready for compaction if its moisture content is near optimum. If the moisture content is below optimum moisture when spread, additional water will need to be added by sprinkling and blade mixing. If the mixture is too wet to roll, further aeration is indicated. This can be accomplished by additional blading or by use of rotary speed pulverizers fixed so as to throw the material into the air. In the case of mixing dry lime with clay soils it is often necessary to blade part of the soil to be treated into windrows and form a sandwich by adding the lime, sprinkling, and covering with soil from the windrows. This procedure protects the lime from the elements and at the same time does not delay application of lime. A delay of mixing for two days when necessary will help to mellow extremely lumpy clays and decrease difficulty of mixing. The remainder of mixing and adding of water may be carried out by sprinkling, and mixing with blade and/or rotary pulverizers over a period of time not to exceed four days.

Although the pugmill type road mixer has not been used frequently in lime stabilization, it is possible that this type of mixer will help to eliminate unequal transverse distribution of lime. Clay-lime mixtures should be pulverized to pass the 1-in. screen and at least 60 percent to pass the $\frac{1}{4}$-in. screen (No. 4 sieve) prior to compaction.

Compaction

Delay of compaction of thin windrows of all types of soil-lime mixtures which dry and become carbonated probably will decrease hardening of the mix subsequent to compaction. For best hardening results, compaction to high density at the proper time is essential for all lime mixtures. Naturally, close control of moisture content will be of great aid to density control. Experience has shown that a few rules for compaction of soil-lime mixtures have been helpful when followed. All soil-lime mixtures, except lime-treated heavy clays, may be compacted promptly after mixing or at any time within two days. Ordinarily, such soil aggregate bearing lime mixtures should not be recompacted if previous rolling is over four days old without adding new water, lime and/or soil. There are two exceptions to this rule: one is when the mixture contains a high percentage of lime and the other is in the case of stabilizing heavy plastic clays treated with high percentages. In the latter case some delay in compaction after mixing can be advantageous but this delay should not be in excess of four days. Mixtures may be compacted with various types of pneumatic, tamping or vibratory rollers in various layer thicknesses. The layer thickness and weight of roller will usually depend upon the type of soil being stabilized and the supporting power of the various sublayers. Reworking of clay-lime mixtures which have been compacted for more than 7 days should be avoided unless additional lime and/or soil in incorporated.

Curing

Proper curing is an essential step in obtaining hardening effects. The lime stabilized base can be cured satisfactorily by sprinkling for 7 days or by sealing with a bituminous treatment within one day after final rolling. Since lime stabilized soils absorb very small amounts of asphalt, the usual quantities of prime used for untreated bases probably will be excessive. Generally, the application of heavy loads should be avoided for a period of 7 days after completion of rolling. If it is necessary to haul over a stabilized layer during this period, least damage will occur if loads are applied immediately after compaction. Treated subbase layers may be sprinkled for periods of time exceeding 7 days or until covered with subsequent material. Light rolling is usually applied during this period to keep the surface knitted together.

Cracking

Any good, well compacted semi-flexible or cemented mixture is generally more susceptible to cracking than are good flexible bases. This defect becomes increasingly noticeable in the surfacing with time. Much can be done during design and construction to minimize such defects. Causes for cracking may be due to any one or more of the following reasons: (a) swelling of clay subgrade; (b) shrinkage of clay subgrade especially when inadequate shoulders are used; (c) use of inadequate design thicknesses; (d) application of heavy loads from hauling or rolling during curing period; and (e) natural shrinkage of the mixture. The first three causes listed above are common to all types of pavements and every reasonable effort should be made to minimize high volume change characteristics and use of base depths which are too thin. The last two causes listed above become more readily noticeable than the others and are often referred to as shrinkage cracks. Prior to application of asphaltic concrete, the use of a single asphalt surface treatment instead of a prime seems to reduce the seriousness of this problem, perhaps because penetration asphalt does not run down crevices in the base and prevent rehealing as much as a prime or asphaltic emulsion will. Surface treatments also prevent raveling and pot holing prior to paving. This so-called shrinkage type of cracking has occurred on a few lime stabilized jobs. Where it was most severe the base consisted of low PI (8 or less) materials. Higher PI materials when treated with lime appear to be less troublesome in this respect. It is theorized that aggregate bearing mixtures consisting of high PI materials and lime are less fragile and can support loads with less cracking during curing than can low PI or more fragile mixtures. Lime mixtures for base course which are susceptible to cracking probably should be "tight bladed" and sealed promptly after compacting. If such mixtures have already cracked extensively, they probably should be reworked using lime water. If a base is properly designed and constructed, transverse cracks may occur at fairly large distance intervals and they should be so minute that they are difficult to observe.

Permanence

The history of ancient lime mortars and pozzolanic mixes, such as were used in construction of Roman roads, indicates that some lime mixtures have a high degree of permanence. Like many other mixtures the permanence of such mixtures depends upon good design and construction practices. Design includes the careful selection of good mixtures and adequate thicknesses to withstand repetitional stresses imposed upon or below their surfaces. Proper uses of triaxial, CBR, and resistance value test methods should be very useful in selecting thicknesses of layers to be used. The percentage of lime used may also be found to influence the life of such roads. Many jobs in south central states up to 14 years old are still in excellent condition. A few jobs in New Mexico and California have withstood severe climatic conditions for several years without damage from freezing and thawing. Final conclusions with respect to this matter will depend upon future experience. It should be emphasized that extensive vertical movements due to swelling or heaving of deep layers of soils are not overcome by lime-treatment or any other treatment applied in thin layers.

TESTS TO BE MADE ON COMPLETED ROAD

There are a number of tests which will reveal interesting data on roads as they age under traffic, several are listed as follows:

1. Deflection tests by use of Benkelman beam or plate loading.
2. In place CBR.
3. Compression tests of undisturbed cores.
4. Flexural tests on sawed beams.

BENEFITS OF LIME STABILIZATION

There are several characteristics of lime that make it a good stabilizer:

1. It is easy to mix with soil.
2. It quickly reduces the plastic properties of soil when wetted.
3. It sets slowly, the time interval between mixing and compacting is not critical, especially if the mixture is not allowed to remain spread in a thin windrow for long periods of time.
4. Compaction can be done over a period of two or three days, bases need not be rolled all at once allowing time for base to adjust to subgrade.
5. Costs are reasonably low.

There are also a number of benefits being derived from clay-lime subbase treatments. Some are as follows:

1. The lime-treated subbases form a working table upon which contractors can continue construction of pavements shortly after rains.
2. Wetting operations for such treatments transfer enough water into subgrade soils to cause their subgrade to lose some of its swelling characteristics.
3. The treated layers form a water barrier to prevent excessive shrinkage cracking of subsoils due to drying or infiltration of water during rainy weather.
4. Last, but not least, such lime-treated layers form a subsection of the total depth of pavement.