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16. Abstract

Volume 1 and 2 of this report are guide booklets for administrators and road engineers respectively. Volume 3, contained herein is a guide booklet for road builders. These guide booklets were developed to provide information on the use of four stabilization treatments, i.e., lime, asphalt, cement, and lime-fly ash in the construction of low-volume roads. Volume 4, of this report documents the use and cost benefits of the above referenced four soil stabilization treatments used in the construction of low-volume roads.

Volume 3 addresses each important topic the road builder should know about stabilizing soils. The topics reviewed in this booklet includes drainage requirements, soil and additive measurements, soils, stabilizer selection, climate, construction, and maintenance of stabilized soil roads.

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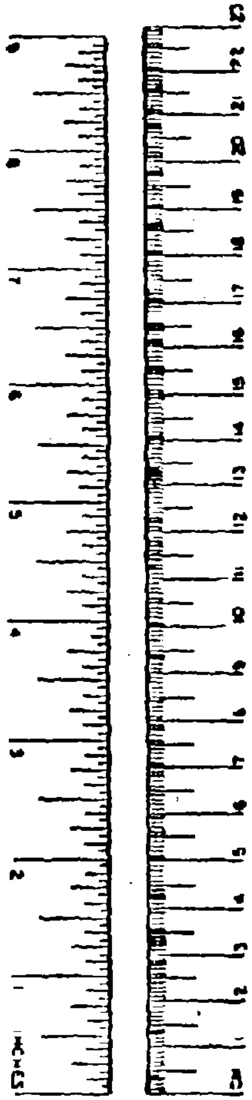
METRIC CONVERSION FACTORS

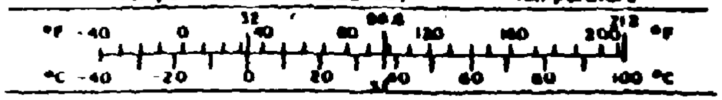
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

This publication was written to assist local and county construction supervisors understand and control the making and placing of stabilized soil as a part of low-volume road pavements. The definition of low-volume roads, as adopted in this booklet, is stated in Figure 1. Low Volume Roads Definition, on page 24. Low-volume roads are for the use of the people living or working in the local area; the roads carry only the types of vehciles normally used in the local area; and the roads are usable and safe through-out the year, at slower speeds and on a less smooth surface than required on high-volume highways.

Soil stabilization is accomplished by controlled mixing and compaction of an additive (asphalt, cement, lime, etc.) with a local soil. Proper soil stabilization can strengthen the soil and the road surface to make them usable during and after rain storms and frost thaws. However, it is not an economical substitute for replenishing a gravel road surface if good gravel is inexpensive and readily available; except when the gravel surface may be expensive to maintain or objectionable to the users. It is primarily used when proper granular materials are unavailable or too expensive; but can also be used to eliminate objectionable qualities such as flying stones, noise, and dust. However, when dusting is the only problem, there are frequently less costly solutions than using the additives described in this booklet.

Soil stabilization with asphalt, portland cement, lime, and lime-fly ash is within the capabilities of most local and county construction crews, once their supervisor understands the principles of stabilization. Many of these principles, which are discussed step by step in this booklet, also hold true for other stabilizing agents used for low-volume road soil stabilization. Interested road supervisors can read more about soil stabilization in the other three volumes in this report: Volume 1 - Executive Summary, Volume 2 - Road Engineer's Guide, and Volume 4 - Cost-Benefit Analysis. A more technical treatment of soil stabilization can be found in another recently published FHWA two volume document titled: Soil Stabilization in Pavement Structures - A User's Manual (2) (10).

All stabilization projects must start with a review and correction of any drainage problems likely to trap moisture in the stabilized soil or its subgrade. These are the same type of drainage problems road supervisors face in their daily work, but the first step in any stabilization project must be a further conscientious effort to protect the investment in soil stabilization through drainage improvement.

Soil stabilizaton involves blending soil and stabilizing agent. The amount of agent required is defined as a weight of stabilizing agent expressed as the percentage of dry weight of the soil requiring stabilization. Since the road builder needs to know how to equate these weights with the volumes of materials he or she usually works with, this booklet also reviews measurement principles.

Various soils react differently with specific stabilizing agents. Some soils only react to one or two agents, other soils require different quantities of alternative agents to achieve the same results. Simple clues can frequently help the road builder identify specific soils to confirm stabilizer selection, however the correct type and amount of stabilizing agent for a specific soil should first be determined by an engineer or soil technician. A road builder who understands the principles of stabilizer selection is often more comfortable with specifications developed for a specific project and can identify any unusual circumstances encountered in stabilizing the particular soil involved.

Weather considerations play an important part in soil stabilization. Frost damage is a constant concern to road builders in the northern and central United States, and frequently causes trouble in southern areas. All road builders need to know both the proper construction seasons for the various stabilizers and the weather constraints on their application. An appreciation of the principles behind these general rules can help the road supervisor cope with unusual circumstances.

Soil stabilization can be broken down into a series of specific tasks. Some activities differ depending on whether the soil and stabilizer are mixed on the road, in a travelling plant, or in a stationary plant, but otherwise the construction principles are similar: the subgrade must be firm enough to permit compaction of the stabilized material, the materials must be placed in the proper amount and manner, they must be properly mixed and compacted, the stabilized soil must be protected during the curing period, and it must receive some sort of surfacing to protect it from traffic abrasion before it is put into service.

Maintaining soil stabilized low-volume roads is relatively simple. The drainage systems protecting the road should oprate properly. However, the integrity of the surface must be maintainted to prevent raveling, pothole development, and water intrusion through the pavement into the subgrade. If the drainage systems are monitored regularly and the surface is patched promptly and renewed periodically, stabilized low-volume roads can provide years of satisfactory service.

The following sections address each important topic the road builder should know about stabilizing soils. The first section reviews drainage requirements. Soil and additive measurements are then reviewed, followed by soils information, stabilizer selection, weather factors, construction techniques, and a few comments about maintaining stabilized soil roads.

DRAINAGE CONSIDERATIONS

There are certain considerations common to all road pavement construction. Drainage is of prime importance because most pavement failures are caused by the combination of moisture and traffic. Poor drainage will therefore reduce the useful life of a stabilized soil. The need to stabilize a soil can sometimes be eliminated with drainage improvements such as adequate ditches properly sloped, correctly sized culverts, underdrains, etc. Consequently, the first step before constructing or strengthening a pavement is to confirm that the drainage system is at the most effective level possible.

The shape of the pavement surface is also a drainage consideration. Road crowns are designed to remove surface water before seepage through any pavement cracks or holes weakens the subgrade. Generally, conventional pavement design requires a cross slope of 1/4 inch per foot, however high grade pavement construction usually implies careful engineering measurements. Without such controls, low-volume road cross slopes in the order of 1/2 inch per foot are less likely to puddle from construction irregularities.

Similarly, water that seeps into the pavement should not become trapped in the subgrade. In-place subgrades should be crowned and compacted before placing the top stabilized layer. Shoulder material should be free draining to guarantee water will not be trapped in any gravel beneath the road surface. A high water table will weaken the pavement subgrade and produce frost heaves in freezing climates. Deep side ditches or underdrains will lower the water level beneath the pavement.

SOIL AND ADDITIVE MEASUREMENTS

Soils and additivies are measured in several different ways. This booklet uses several measurement terms that have specific meanings in soil stabilization. Construction supervisors sometimes use other methods of measuring the same things. Therefore, this section describes the relationships between different ways of measuring soils and stabilizing additives so the following sections will not appear more confusing than they really are.

Three different soil volumes are commonly used:

1. Bank measurement indicates the volume of material in its natural state. It can be determined by surveying a borrow pit before and after material is excavated and calculating the volumetric difference. Its most common usage is estimating available quantities.

2. Loose measurement indicates the volume of material in a an uncompacted state. It can be measured in a truck if the material is level with the top of the body, or computed by measuring a material's depth, width and length after it is spread but before it is compacted.

3. In-place measurement indicates the volume of compacted material on the roadway. It is computed by measuring a material's depth, width and length when all work on the material is completed.

Additives are also measured by volume, such as sacks of cement and lime or gallons of liquid additives. However, when soils and additives are mixed, the mixtures are desribed in terms of a percentage of <u>dry weight measure</u> of the soil to eliminate the differences in volume measurements described above.

Most road builders work only in volume measurements. However, the loose volume dry weight of a soil can be determined by drying a container of soil in a kitchen oven after measuring a known volume of soil into the container. The container and soil are weighed after the soil is dry. Once the weight of the empty container is subtracted, the dry weight of the measured volume of soil is known.

Usually design engineers convert dry weight measurements to volumes in their instructions to the road builder. There are other ways to determine these weights however. The conversion factor from dry weight to material volume is generally known for state approved pits. Local agricultural or conservation agents may be able to provide the conversion factor for local soils. A representative of the additive supplier may be able to assist in this determination. A local college or high school teacher may also be helpful. Once the dry weight of the actual soil and additive are known, they are usually not changed unless there is a visible change in the material.

The design application of asphaltic material is always determined as the weight of asphaltic cement content at a base reference temperature of 60 degrees Fahrenheit. This weight is usually converted to gallons of <u>asphaltic cement</u> in application instructions. Since asphlatic materials are usually applied at a higher temperature, both the proper application temperature and the conversion factor for the temperature difference must be determined. The proper conversion factors can be found in any asphalt handbook. Usually the distributor driver has a conversion table in his truck.

Cut-back and emulsified asphalts are manufactured by diluting asphaltic cement with a petroleum derivative or water. There are restrictions on the use of cut-back asphalts in some jurisdictions at this time, so the local administrator should be consulted before any cut backs are applied.

The conversion of gallons of cut-back or emulsified asphaltic materials to gallons of asphaltic cement must be made separately from the application temperature corrections. It must be made to account for the solvent or water that will evaporate after the mixture is sprayed on the road. For example, if one gallon of asphaltic cement per square yard of road surface is required, and an asphaltic emulsion consisting of 55% asphaltic cement is specified, the proper application is 1.0 divided by 0.55 = 1.82 gallons of asphaltic emulsion per square yard at the base temperature. It is extremely important that each delivered load of cut-back or emulsion is certified to contain the right amount of asphaltic cement.

SOILS

Soil is the principle ingredient in the soil stabilization procedure. The ground consists of a series of layers called soil hoirzons. The uppermost layer, called the A horizon, contains organic living matter and is capable of supporting plant life. This layer, which is usually dark colored, is the dirt in which people plant gardens and lawns. It is not a suitable material with, or on which, to build roads.

The next lower layer, or B horizon, is non-organic material consisting of four major soil components: gravel, sand, silt, and clay. These components were formed through centuries of disintegration from the bottom layer or horizon material of parent rock, also called ledge or bed rock. The dividing line between each layer is generally not distinct, especially the division between the A and B horizons.

Engineering soils in the second horizon need to be classified more exactly than as individual groupings of the principal gravel, sand, silt, and clay components. Each soil is a mixture of these components. The relative amount of each component influences the physical properties of the mixture and indicates the stabilizing agent that may be effective.

The Unified Soils Classification System has been developed to sub-divide soil mixtures into 15 basic soil groups having different soil properties and behaving differently as road building materials. The system is used to evaluate soil samples after the large stones are removed. Figure 2. Soil Use Chart, (Ref. 1), on page 25, includes the names of the soil groups, their symbols in the Unified Soil Classification System, and their characteristics as road building materials.

Coarse grained materials, gravel and sand, gain strength from mechanical interlocking. Silts and clays depend on cohesion, the ability to stick together, for strength. Plasticity, the putty-like trait of being flexible enough to change shape in any direction without breaking apart, seriously reduces the desirability of any soil containing even a small amount of plastic fines. Soil stabilization attempts, among other things, to improve the undesirable qualities of the native soil's fine grained portions.

Figure 3. Soil Identification Procedures (Ref. 1), on page 26, shows a simplified procedure for determining soil types. Basic identification procedures are not a replacement for engineering testing, but do give a good indication of soil classification. A brief description of the procedure follows (Ref. 1):

Step 1. Collect about a pail full of the soil to be classified.

Step 2. Spread a representative sample, about a quart can full, out on a flat surface and discard any stones larger than 3 inches. If the sample is dark brown, dark grey or black; has the odor of decay; and consists of the decomposing remains of organic material it is peat or muck (Pt) and no further steps are necessary.

Step 3. Make an estimate of the percentage of individual particles that can be seen by the naked eye. It may be necessary to dry the sample to see individual particles. Soils with more than 50% visible particles are coarse grained. Soils with less than 50% are fine grained and do not require Steps 4 through 6.

Step 4. Make an estimate of the various amounts of larger and smaller particles in the coarse grained sample to decide if the space between the larger particles can be filled by smaller particles to make a dense mass. If so, the material is well graded, a condition seldom occurring in nature. If the materials is composed of mainly one size of visible particles, it is uniformly graded; if one or more sizes are missing, it is gap graded.

Step 5. Dry and pass the sample through a piece of 1/4-inch mesh hardware cloth. If more than 50% passes, the material is sand, otherwise it is gravel.

Step 6. Drop a large handful of dry material passing through the hardware cloth about 18 inches onto a hard surface. If a small dust cloud forms, the material is dirty; if little or no dust appears the materials is clean. To confirm this observation, moisten some of the same material and squeeze a handful, dirty material will discolor the hand.

Step 7. If the material tested in Step 6 is dirty, as most natural soils are, sieve a dry portion of the material passing the hardware cloth in Step 5 through a piece of window screen. The portion of fine grained material from Step 3 which passes through hardwear cloth should be dried and sieved through a piece of window screen.

Step 8. Wet and knead a handful of the material passing the window screen until it is in a good, moldable condition. If it sticks to the hand, it is too wet and must be reworked until it no longer sticks. Make a roll about 1/2 to 3/4 inch in diameter and 3 to 5 inches long. Very carefully try to squeeze the roll into a vertical ribbon 1/8 to 1/4 inch thick.

Step 9. Classify coarse grained soil silty if no ribbon can be made. Coarse grained soil is classified as clayey if a ribbon is formed. Fine grained soils are classified silt if no ribbon is formed or as low plastic clay, or silty clay, if the ribbon's own weight causes it to break at a length less than 8 inches. Ribbons over 8 inches in length are classified as high plastic clay.

Step 10. Return to the unwet portion of the sample in Step 8 if the material has been classified as a fine grained soil. Try to break some of the lumps. If the lumps powder, they confirm the silt classification. If tiny mica flakes can be seen in the powder, the soil is micaceous silt. If the powder is dark, it is organic silt.

Step 11. When a sample classified as clay has a dark color and smells like muck, the sample site should be revisited. If the site is a low, undrained, or poorly-drained basin area and the clay is light weight and has a soft, spongy feel it is organic clay.

STABILIZER SELECTION

There can be several reasons for stabilizing the soil types identified in the previous section. Subgrade soil may be stabilized to support construction equipment, to reduce its expansive capabilities, and/or to reduce frost heaves. Soils may also be stabilized to increase their long term structural strength.

Specific stabilizing agents (asphaltic, cement, lime, and lime-fly ash) do not react equally well with each soil classification. However, often more than one stabilizer has the capability to react with a specific soil (Ref. 2). A few soils can be stabilized with any of the agents, while other soils are best suited to only one or two specific agents.

Bituminous (asphaltic) stabilization works best on granular soils with low plasticity including many well graded gravels classified in Figure 2., on page 25, as GW, GM, and GC; and many sands in the SW, SP, SM, and SP groupings.

Asphalt may be applied as a cutback, where permitted, or as an emulsion, but its design quantity is always determined as the percent of asphaltic cement by weight of dry aggregate or soil being stabilized. The solvent or water permits easy application but evaporates without providing any cementing properties. Table 1. Selection of Asphalt Cement Content (Ref. 2), on page 31, shows the approximate quantities of asphaltic cement required for bituminous stabilization. Table 2. Asphalt Cutback Composition, (Ref. 3), on page 32, shows the percentage of solvents for each type and grade of cutback.

Portland Cement is suitable for stabilizing a wide range of soils. Table 3. Cement Requirements for Various Soils, (Ref. 3), on page 33, indicates many soils in all classifications except OL and Pt may react with cement. However soil-cement, which is a structurally improved cement stabilized mixture, is most economically produced from well-graded granular materials with low to moderately high plasticity. Many unique materials such as caliche, chert, cinders, shale, etc. have also been stabilized with cement. Table 4. Average Cement Requirements of Miscellaneous Materials, (Ref. 4), on page 34, shows the estimated cement content needed to stabilize several such materials.

Lime stabilization works best with many of the fine grained soils with moderate to high plasticity in the ML, MH, OL, CL, CH, and OH groups; and on coarse grained soils with 10 - 12% clay or more, such as GM or GC gravels and SM or SC sands.

Soils may be stabilized with either quick or hydrated lime. These burnt limes introduce several immediate reactions which reduce the soil's plasticity and improve its workability, uncured strength and load-deformation properties. These immediate reactions modify the soil since they do not substantially improve the soil's strength. Agricultural lime is not suitable for lime stabilization.

In certain soils, termed reactive soils, a pozzolanic reaction also occurs. This reaction introduces increasing strength and durability over a period of several years. These "curing" effects vary according to the soil type, lime type, lime percentage, compacted density, and the time-temperature curing conditions. Non-reactive soils will not develop pozzolanic strength regardless of the lime type, percentage, or time- temperature conditions (Ref. 2). Table 5. Approximate Lime Contents, (Ref. 3), on page 35, shows application rate ranges of both hydrated lime and quicklime for certain soil types. The reactivity and exact lime content required for each individual soil are laboratory determinations.

Lime-fly ash stabilization works best with coarse grained material such as gravels, sands, and several types of slags. Some fine grained materials, such as silt and fine sand, have also been successfully treated.

Fly ashes, which are very small, separate particles collected from smoke stacks of plants burning coal or lignite, act as a pozzolan. Since all fly ashes do not have the same characteristics, laboratory tests are required to evaluate both the fly ash and the lime-fly ash mixture. The most common ratios of lime to fly ash are 1:3 or 1:4. Typical proportions are 2-1/2 to 4 percent lime and 10 to 15 percent fly ash (Ref. 2). Lime-fly ash stabilized soil "cures" in the same manner as lime stabilized materials.

All of the above stabilized soils act as a base course material. They add strength and durability to the treated soils. However they are prone to ravel, some of the material being pulled out under traffic, and sometimes develop curing cracks which allow seepage. Therefore an asphalt seal coat is always applied to insure proper curing, durability, and protection against climatic factors.

CLIMATE

Climatic factors influence both a stabilized soil's construction and its ultimate durability. Water, in all of its forms, is the most important environmental factor affecting most low-volume roads. Temperature and topography are other important environmental considerations.

Frost damage requires the presence of water in frost susceptible soil and freezing temperatures. Table 6. Frost Design Soil Classification, (Ref. 5), on page 36, divides soils into four Frost Groups, the first group being the least frost susceptible. Figure 4. Six Climatic Regions in the United States for use in Highway Technology, on pages 27 and 28, divides the U.S. into areas of hard freeze, freeze/thaw cycling, and no freeze.

The northern areas (VI and III) in Figure 4 suffer severe winters with a high potential for subgrade frost. The middle areas (V and II) have moderate winters with a high potential for freeze/thaw activity throughout the winter. Since thaw periods present the greatest frost damage potential for low-volume roads, due to a high concentration of moisture trapped under the surface, the middle areas often experience worse frost damage than northern areas. Snowplows mounted on dump trucks with full loads of sand, operating during intermittent thaws, are often the dominate factor in early pavement failures.

Low-volume road frost damage can be prevented by closing the roads to traffic during thaws, by removing the frost-susceptible soil, or by stabilizing the soil to change its frost-susceptibility characteristics. Stabilization does not change the frost-susceptibility of the natural soil below the stabilized layer. Ideally the soil should be stabilized to the full depth of frost penetration.

Climatic conditions influence the construction season and introduce construction constraints to successful stabilization. Asphaltic mixed-in-place stabilization should be scheduled for a time of the year when weather conditions are likely to be hot and dry during, and for some weeks after, the work. Asphalt should not be applied to the aggregate when the temperature in the shade is less than 50 deg. F. Work should be suspended during rain or when the mix is wet (Ref. 6). Hot plant mix stabilization follows the same rules that apply to any asphalt hot mix application.

Soil cement hardens as the cement hydrates. Since cement hydration practically ceases when the temperature is near or below freezing, soil cement should not be placed when the temperature is 40 deg. F. or below. It should be protected to prevent its freezing for a period of 7 days after placement and until it has hardened, by a suitable covering of hay, straw or other protective material. If rain falls during the cement application of a mix-in-place operation, the spreading should stop and the mixing should begin at once. If rain falls after most of the water has been applied, the mix should be compacted immediately (Ref. 7).

Lime stabilization is relatively slow setting and requires some warm weather to harden properly. The temperature should be 40 deg. F. in the shade and rising before the lime is placed. Ideally lime or lime-fly ash construction should be followed by at least two weeks of warm to hot weather. The recommended seasons are: hard freeze area, April through mid-September; freeze/thaw area, mid-March through early October; no freeze area, all year. Except for possible heavy rain storms no restriction on lime stabilization construction is necessary in rainy weather (Ref. 8).

Weather also plays an important role in surface treating stabilized bases. Surface treatment should never start while the surface is wet, or when it is threatening to rain. The weather should be hot and dry during, and for some weeks after, treatment. The air temperature should be at least 50 deg. F. in the shade before operations begin, but better results are often achieved if the temperature is above 80 deg. F (Ref. 9).

CONSTRUCTION

Successful soil stabilization requires a thorough mixture of pulverized soil with the correct amount of stabilizer and enough moisture to obtain maximum compaction. The stabilized soil must be protected from traffic to prevent abrasion and to permit curing. The curing process must include favorable temperature and moisture conditions for strength to develop.

Either mixed-in-place or central plant mixing are viable options for combining soil and stabilizer. Mixing method selection depends on local job conditions an equipment availability. Figure 5. Soil Stabilization Construction Equipment. (Ref. 10), on page 29, identifies the various types of mixing equipment available. Table 7. Equipment Typically Associated with Mixed- In-Place Subgrade Stabilization Operations, (Ref. 9), on page 37, outlines equipment requirements for on-site soil stabilization, with comments and safety procedures for specific stabilizing agents.

Stabilized soil base material construction is well documented in previous publications. Reference 6 describes asphalt stabilization; Reference 7 describes portland cement stabilization; References 8 and 11 describe lime stabilization; and References 12 and 13 describe lime-fly ash stabilization. All stabilizing activities follow the same general procedures outlined in Reference 10:

1. Subgrade preparation, if stabilized material is to be imported, either plant mix or soil to be mixed-in-place.

2. Soil preparation, if the soil is to be mixed-in-place.

3. Stabilizer application, for mixed-in-place operations.

4. Pulverizing and mixing, for mixed-in-place operations. Steps 2 through 4 can also take place in a central mixing plant. The plant mix material is then hauled to the site and spread, the remaining steps are the same for both cases.

5. Stabilized material compaction.

6. Stabilized material curing.

Subgrade Preparation - The subgrade must be shaped to shed water and compacted before material is imported to be mixed-in-place or as plant mixed soil and stabilizer.

Soil Preparation - The soil must be brought to the proper line and grade when stabilizing subgrade soil. It must then be scarified to the proper depth and width using a grader-scarifier and/or disc harrow. All stumps, roots, turf and stones larger than 3 inches must be removed. The scarified soil is initially pulverized with a disc harrow or a rotary mixer. Plows, various types of cultivators, and other types of agriculutural equipment can also be used. If the existing road surface is to be stabilized, a preparizer may be used to used to break up old pavement and base which contain oversize material.

Additional material may be blended with the subgrade material either by mixing with motor graders and pulverizing with disc harrows or single- or multiple-shaft flat type mixers, or by windrowing both materials and mixing with a windrow type mixer.

Imported material, placed on top of the subgrade for stabilization, can be pulverized with a hopper type pugmill travel plant. If the soil is very dry, water can be added to aid pulverization. Very wet soil can be aerated with a disc harrow or rotary mixer.

Stabilizer Application - Asphalt can be sprayed from a distributor or directly by the mixing equipment. When asphalt is sprayed ahead of a rotary mixing machine or grader, more than one mixing pass is usually required with asphalt added in increments of about 1/2 gallon per square yard until the required amount is added.

Cement and lime can be distributed dry by spotting bags on the roadway or by self-loading bulk haulers either spreading the stabilizer over the roadway or onto a windrow. Mechanical spreaders may also be used. Lime may be spread as a slurry through tank truck spray bars. The usual slurry mix is one ton of hydrated lime to 500 gallons of water. When fly ash is to be combined with lime, the lime is usually spread first by normal methods, damp fly ash is then delivered in open dump trucks and spread by grader, spreader box, or mechanical spreader.

Pulverizing and Mixing - Single - and multilple-shaft rotary (flat type) mixers and windrow type mixers can be used to pulverize and mix all types of stabilized soil, although windrow mixers are not usually used to stabilize subgrade soil. Motor graders and farm equipment are also used, often producing uneven mixing. Since in-place mixing efficiency is less than laboratory and stationary plant mixing, stabilizer content is usually increased or rounded up by one to two percent.

Asphaltic stabilization requires repeated mixing. The surface should be maintained to true grade and cross section during the mixing operation, which should take place immediately after the asphalt is applied. Mixing must continue until all the aggregate is thoroughly coated as indicated by a uniform color. The mix may have to be aerated by grading it back and forth across the road until the volatile material or water has been reduced before it is compacted.

Portland cement stabilized soil is pulverized and mixed before water is added. However prewetting the soil before applying the cement will assist in the final mixing operation. The soil cement mixture should be less than one inch in size and 80% should pass through a piece of 1/4 inch mesh hardware cloth, exclusive of any gravel or stone, before mixing is complete. A uniform color and texture from top to bottom of a series of test holes also indicates sufficient mixing.

The amount of water needed after a soil cement mix is pulverized should be checked using a quick method such as the speedy moisture meter to determine the present moisture content of the mixture. The optimum moisture content for a soil cement mix is often approximately 2% above the optimum moisture for the untreated soil. A soil cement mixture near or at optimum moisture content is just moist enough to dampen the hand when squeezed into a tight ball. The ball can be broken into two pieces with little or no crumbling. Mixture above optimum will leave excess water on the hand, mixture below optimum will tend to crumble easily (Ref. 14).

Both blade and rotary mixing can be used to add lime to granular soils, but rotary mixing is generally required for highly plastic soils. Blade mixing is accomplished by forming two windrows, dumping dry lime between them, and covering the lime with the windrows. Mixing is completed by blading the dry mix back and forth. Properly mixed material has a uniform color. After dry mixing is completed, water is added to slightly above optimum moisture content, and at least three more complete movements of the mixture are required.

Before using high speed rotary mixers or one pass travel plant mixers, lime is spread evenly on the roadway. Water is added during the mixing to obtain optimum moisture content. Complete mixing can be achieved in one to three passes, depending on the type of equipment and the type of soil. Lime-fly ash stabilization follows the same procedures.

Subgrade lime stabilization, using rotary mixers, consists of preliminary mixing, moist curing for one to two days, and final mixing. The first mixing distributes the lime throughout the soil to facilitate the lime's "mellowing" action. The clay should be broken into less than two inch lumps in the preliminary mixing. The surface should be sprinkled to bring it up to 5% above optimum moisture and lightly rolled prior to the first curing period. The final pulverizing and mixing should continue until all lumps are broken down to less than one inch in size and 60% of the mixture passes through a piece of 1/4 inch hardware cloth (Ref. 8).

Compaction - Asphalt stabilized soil should be compacted as soon as it is properly aerated. Earlier compaction causes rutting and shoving under the roller. Cutbacks are properly aerated when their volatile content is reduced about 50% in graded granular material or about 33% in fine grained materials. Emulsified asphalt stabilized soils can be rolled when the emulsion begins to break, indicated by a color change from brown to black. Pneumatic tired rollers, with or without steel wheeled rollers, are usually used for compacting asphalt stabilized soils.

Soil cement compaction should be carried out as quickly as possible. Sheepsfoot rollers often provide initial compaction. Pneumatic or smooth-wheeled rollers usually complete the compaction after a grader has fine graded the surface. It is esential to keep the length being constructed short enough so that the construction process can be completed before the cement takes its initial set. The initial set is sometimes considered as taking place in about an hour. The longer the time period from adding water and mixing to final rolling, the more compactive effort is is required to get the same density.

The Portland Cement Association (Ref. 7) outlines methods for processing soil cement with different traveling mixers (windrow, multiple-shaft, and single shaft). Figure 6. <u>Sketch of Soil-Cement Processing Operations with Single-Shaft Mixers</u>, on page 30, is taken from that publication.

Lime-soil mixes and lime-fly ash-soil mixes with granular soils are generally compacted as soon as possible after mixing, although delays of up to two days are not harmful if the soil is kept moist. Lime stabilized clay subgrades can also be compacted soon after final mixing, although delays of up to four days are acceptable. The most common compaction method for lime stabilized soils is to "walk out" a sheepsfoot roller before using a 10-ton pneumatic roller. A flat wheeled roller is used for finish rolling.

<u>Curing</u> - Proper curing of asphalt stabilized soils involves further loss of the carrying agent. If traffic must travel over these stabilized materials during the curing period, a sand or aggregate seal should be placed over the uncured mixture. The final asphalt seal or wearing surface should not be placed for at least seven days as it will slow the evaporation process.

Proper curing of cement, lime, and lime-fly ash stabilized soils involves a strength gain that is dependent on time, temperature, and the presence of moisture. The stabilized layer may be sprinkled with water at frequent intervals to prevent moisture loss. However, the preferred method is to seal the damp surface with a single application of cutback asphalt (at

0.10 to 0.25 gal./sq. yd.) within a day of final rolling. Emulsified asphalt sealing must be done incrementally during the curing period. A sand coat must be applied to the curing membrane before traffic is allowed, and the traffic limited in weight and speed.

The final asphalt surface treatment, which is required to prevent raveling and promote waterproofing, can be applied instead of the curing membrane described above. However, during the first week of the stabilizer's curing period, no traffic heavier than a pneumatic roller should be allowed on the surface treatment.

MAINTENANCE

No road is maintenance free. Low-volume roads are often stabilized without knowing how the traffic will increase in the future. This "wait and see" approach is often called staged construction. Proper maintenance will prolong the period before the next stage is required and, more importantly, will prevent structural failure of the stabilized soil from causes other than traffic.

Structural failure is often caused by a lack of support due to water in the subgrade rather than by failure of the stabilized soil base. The drainage system is critical after soil is stabilized. It protects any subgrade soil which may weaken rapidly in the presence of moisture. Standing water in roadside ditches is an invitation to roadbed moisture. Ditches should be checked frequently and cleaned, enlarged, or realigned if the water does not flow properly.

Water can also enter the subgrade through the road surface. The surface treatment should be checked periodically after a rain to look for standing water or areas that stay damp or wet looking when the rest of the surface dries. These wet areas are the first warning of reflective cracks from the stabilized soil, poor utility trench patching, future surface raveling, and potholing. Prompt resealing of small cracks will prevent serious stabilized soil structural failures from developing and ensure years of satisfactory service.

Low-Volume Roads Definition

Low-Volume Roads are Service Roads in a Particular Area

Designed and Constructed with Minimum Serviceability Requirements

As Necessary and Sufficient to Enable All Vehicles Common to the Area

To Travel Unassisted and Safely with Reduced Priority for Speed and Comfort

Figure 1

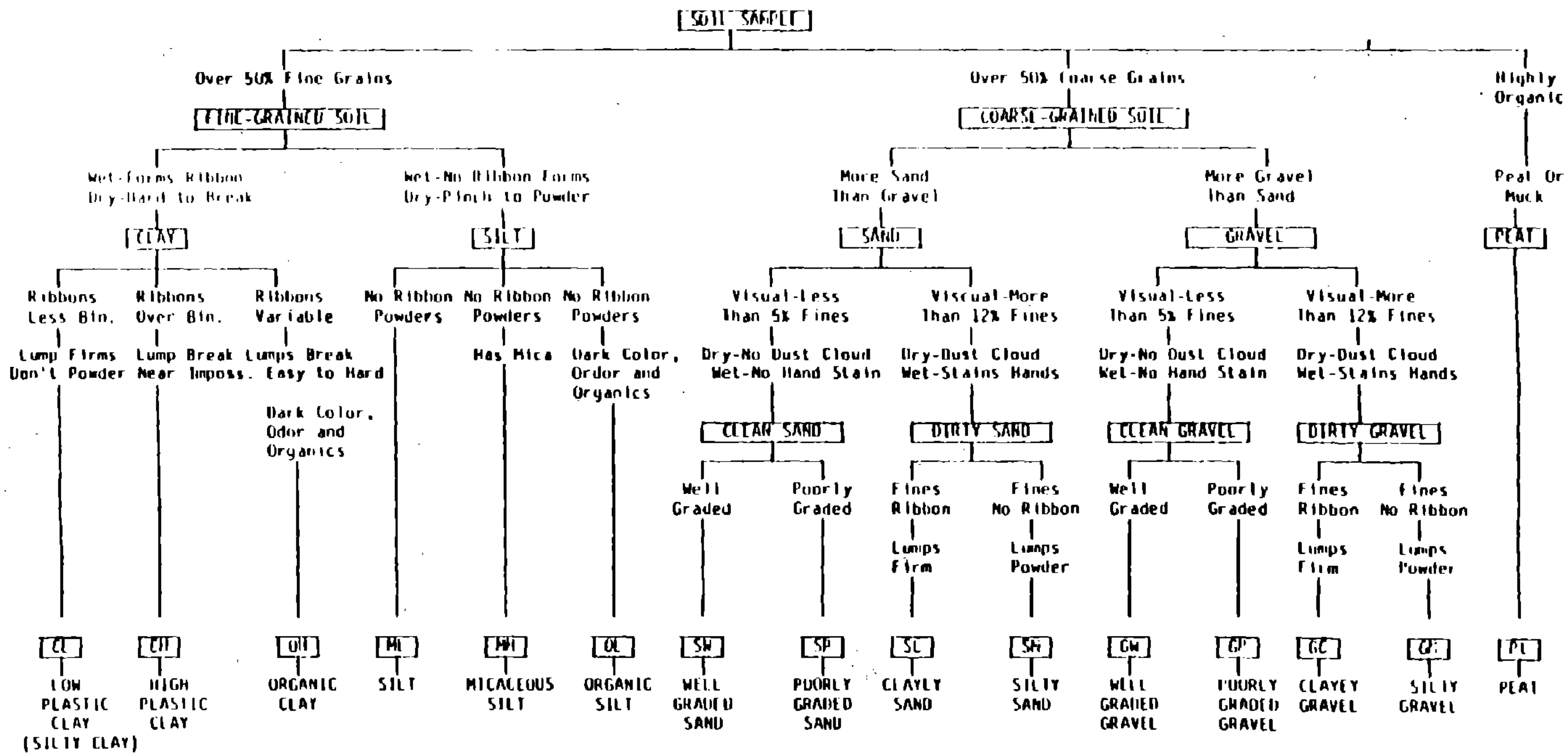
Figure 2: SOIL USE CHART
(Numbers in the Chart refer to footnotes)

SOILS	SYMBOL	PROPERTIES[1]			COMPACTION EQUIPMENT[2]		
		PERMEABILITY	LOAD CARRYING ABILITY	FROST SUSCEPTIBILITY		BASE COURSES[3]	WEARING COURSES[4]
Well-Graded Gravel	GW	Pervious	Excellent	Alone to very slight	Vibratory[5] Rubber tire slight wheel[6]	Excellent[7] to good	Fair
Poorly Graded Gravel	GP	Very Pervious	Good	None to very slight		Fair	-----
Silty Gravel [8]	GM	Semi-pervious to impervious	Good to fair	Slight to medium	Vibratory Rubber Tire Sheepsfoot Steel wheel	Excellent to fair	Good to fair
Clayey Gravel [8]	GC	Impervious	Good to fair	Slight to medium		Good to poor	Excellent to good
Well Graded Sand	SW	Pervious	Excellent	None to very slight	Vibratory Rubber tire Steel wheel	Poor	Fair
Poorly Graded Sand	SP	Pervious	Good	None to very slight		Poor	-----
Silty Sand	SM	Semi-pervious to impervious	Good to fair	Slight to high	Vibratory Rubber tire Sheepsfoot Steel wheel	Fair to poor	-----
Clayey Sand	SC	Impervious	Good to fair	Slight to high		Fair to poor	Good to fair
Silt	ML	Semi-pervious to impervious	Fair	Medium to very high	Rubber tire Segmented wheel Steel wheel		
Micaceous Silt	MH		Fair to poor				
Organic Silt	OL		Poor				
Silty Clay	CL	Impervious	Fair	Medium to High	Rubber tire Sheepsfoot Steel wheel		
High Plastic Clay	CH		Poor	Medium			
Organic Clay	CH		Very poor	Medium			
Peat and Muck	Pt	Remove from subgrade					

1. Qualitative values listed below are for properly compacted soils.
2. Equipment listings are in order of efficiency - first is best.
3. Qualitative values listed are for bases on high traffic roads.
4. Gravel road wearing surfaces or roads with less than 100 vehicles per day.
5. Trawler tractors can be used as vibratory equipment - other types are listed in text.
6. Steel-wheel rollers are best used as grade finishers.
7. Well-graded gravels are usually very difficult to compact.
8. These materials cover a considerable quality range -- from a low percentage of lines 15%-12% and well graded to a high percentage of fines (over 12% to about 20%) and poorly graded.

Source: (1)

Figure 3. SOIL IDENTIFICATION PROCEDURE



Source: (1)

FIGURE 4

SIX CLIMATIC REGIONS IN THE UNITED STATES FOR USE IN HIGHWAY TECHNOLOGY

As defined by University of Illinois

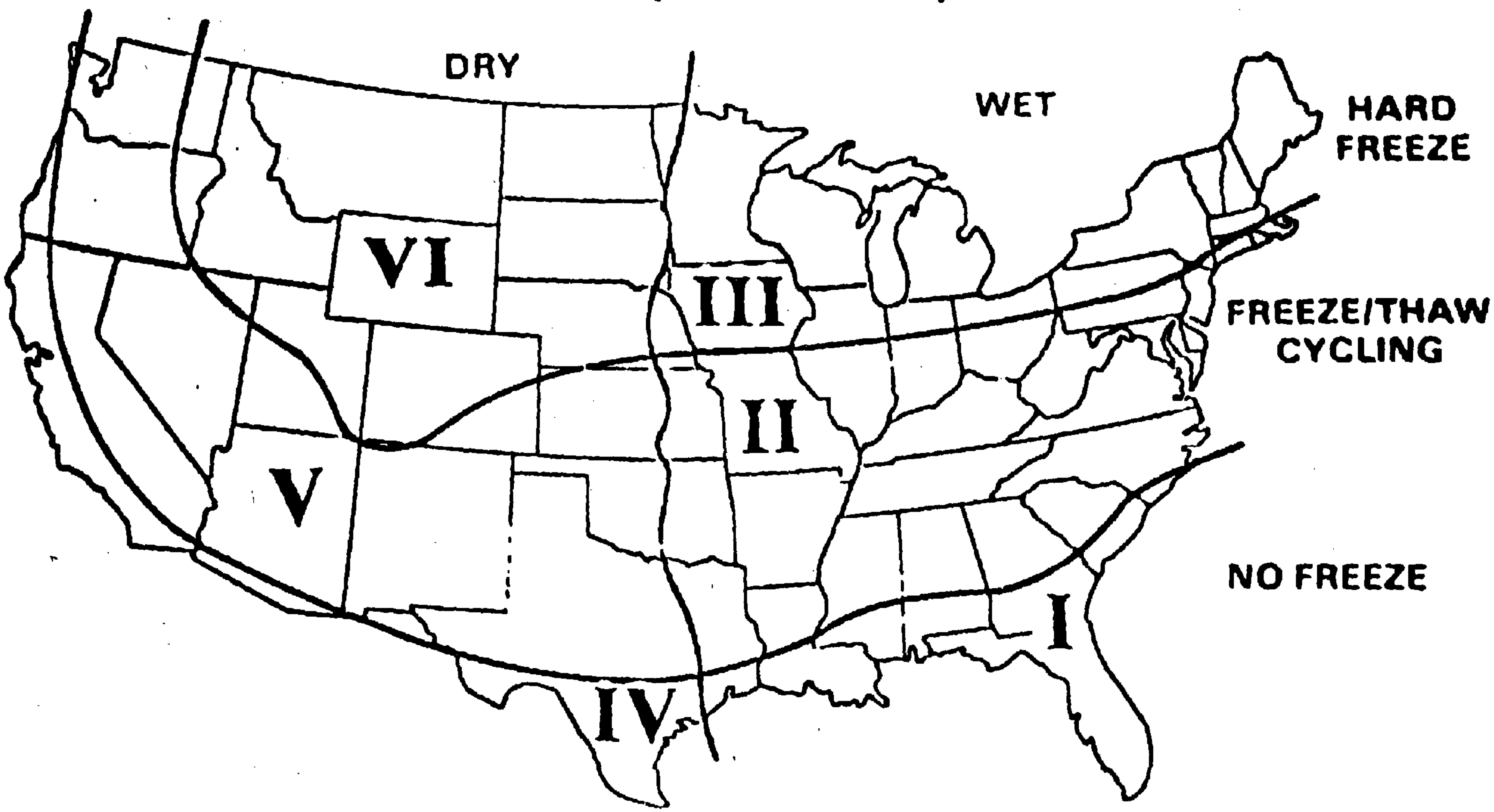


FIGURE 4

SIX CLIMATIC REGIONS IN THE UNITED STATES FOR USE IN HIGHWAY TECHNOLOGY

As defined by University of Illinois

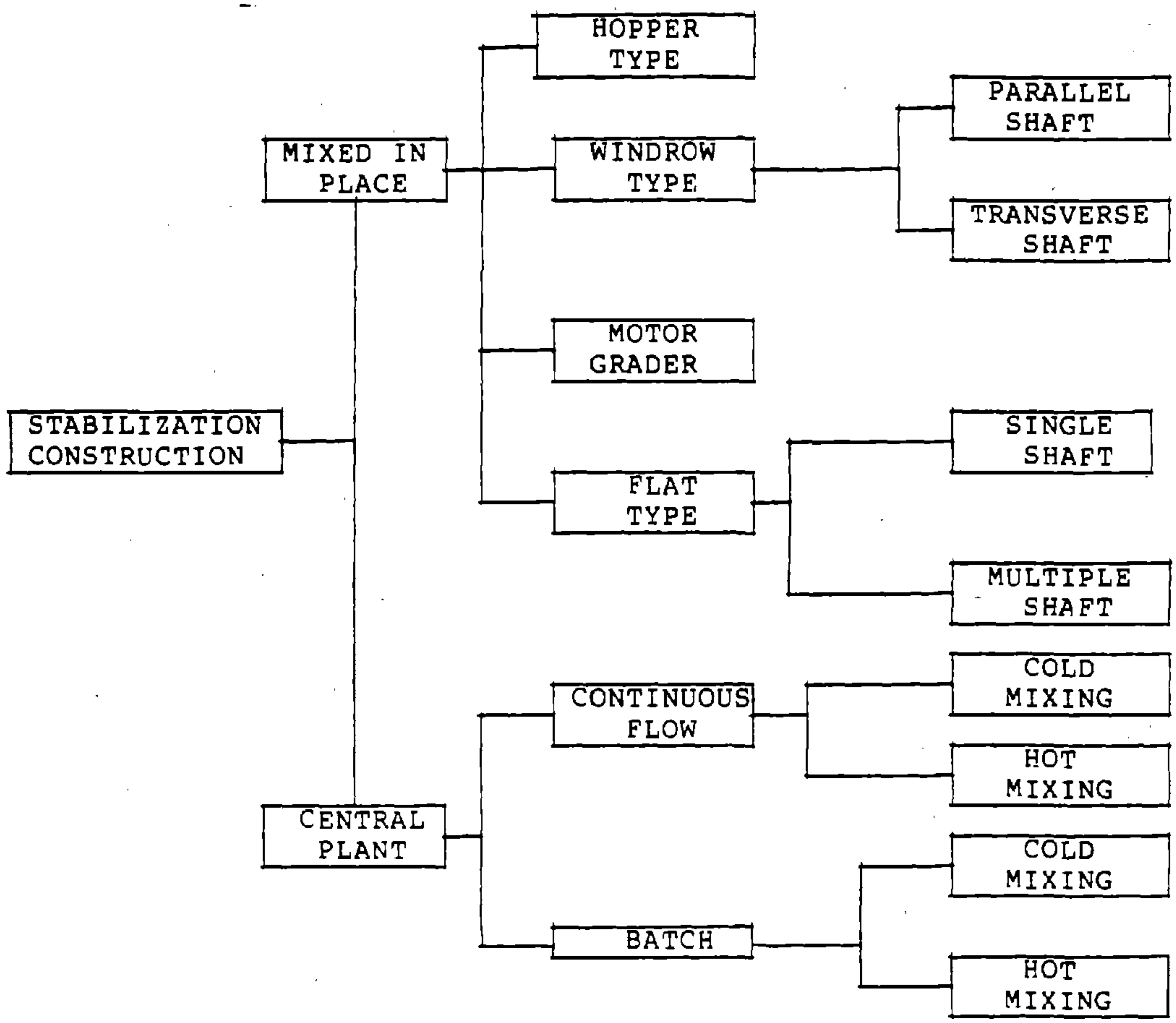
	NO FREEZE	FREEZE/THAW CYCLING	HARD FREEZE
WET	I	II	III
DRY	IV	V	VI

Boundary between WET and DRY: **Thornthwaite Index = Zero**

Boundary between NO FREEZE and FREEZE/THAW CYCLING: Freezing penetrates 5 inches

Boundary between FREEZE/THAW CYCLING and HARD FREEZE: Freeze Index endures 60 days per year

Figure 5: Soil Stabilization Construction Equipment.



Source: (2)

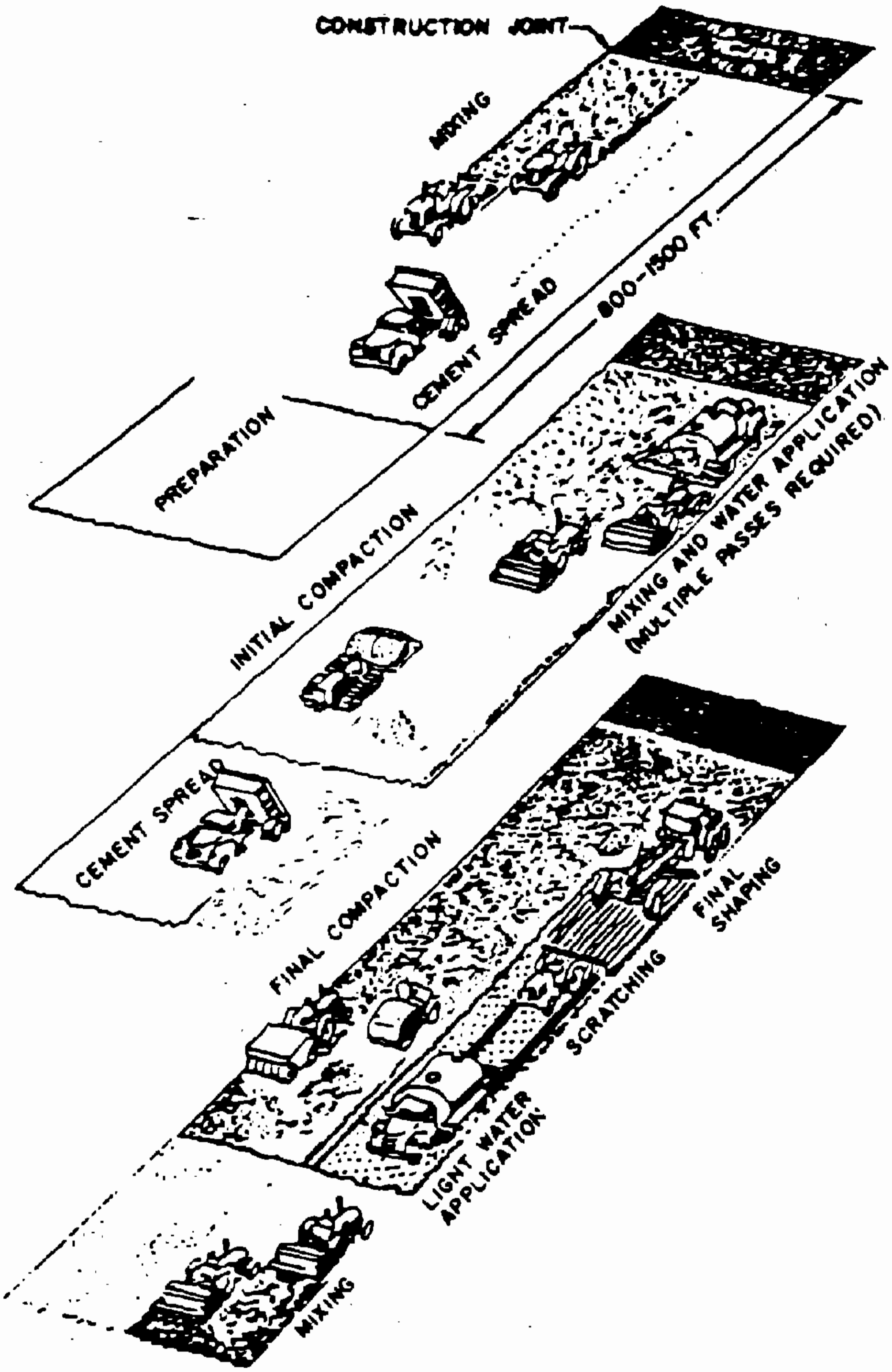


FIGURE 6 SKETCH OF SOIL-CEMENT PROCESSING OPERATIONS WITH SINGLE-SHAFT MIXERS

Source: (7)

Table 1: Selection of Asphalt Cement Content

Aggregate Shape and Surface Texture	Percent Asphalt By Weight of Dry Aggregate*
Rounded and Smooth	4
Angular and Rough	6
Intermediate	5

*Approximate quantities which may be adjusted in field based on observation of mix and engineering judgment.

Source: (2)

Table 2: Asphalt Cutback Composition

Type of Cutback	Solvent	Percent Solvent for Particular Grades				
		30	70	250	800	3000
RC	Gasoline or Naptha	--	35	25	17	13
MC	Kerosene	46	36	26	19	14
SC	Fuel Oil	--	50	40	30	20

Source: (3)

Table 3: Cement Requirements for Various Soils

Unified Soil Classification*	Usual Range in cement requirement**	
	percent by vol.	percent by. wt.
GW, GP, GM, SW SP, SM	5 - 7	3 - 5
GM, GP, SM, SP	7 - 9	5 - 8
GM, GC, SM, SC	7 - 10	5 - 9
SP	8 - 12	7 - 11
CL, ML	8 - 12	7 - 12
ML, MH, CH	8 - 12	8 - 13
CL, CH	10 - 14	9 - 15
OH, MH, CH	10 - 14	10 - 16

*Based on correlation presented by Air Force
**for most A horizon soils the cement should be increased 4 percentage points, if the soil is dark grey to grey, and 6 percentage points if the soil is black.

Source: (3)

Table 4: Average Cement Requirements of Miscellaneous Materials

Type of miscellaneous material	Estimated cement content and that used in moisture-density test	
	percent by vol.	percent by wt.
Shell soils	8	7
Limestone screenings	7	5
Red dog	9	8
Shale or disintegrated shale	11	10
Caliche	8	7
Cinders	8	8
Chert	9	8
Chat	8	7
Mart	11	11
Scoria containing material retained on the No. 4 sieve	12	11
Scoria not containing material retained on the No. 4 sieve	8	7
Air-cooled-slag	9	7
Water-cooled slag	10	12

Source: (4)

Table 5: Approximate Lime Contents

Soil Type	Approximate Treatment, Percent by Soil Weight	
	Hydrated Lime	Quicklime
GC, GM-GC	2-4	2-3
CL	5-10	3-8
CH	3-8	3-6

Source: (3)

Table 6: Frost Design Soil Classification

Frost Group	Kind of Soil	Percentage Finer than 0.02 mm by Wt.	Typical Soil Types Under Soil Classification System
F1	Gravelly soils	3 to 10	GW, GP, GW-GM, GP-GM
F2	(a) Gravelly soils	10 to 20	GM, GW-GM, GP-GM
	(b) Sands	3 to 15	SW, SP, SM, SW-SM, SP-SM
F3	(a) Gravelly soils	Over 20	GM, GC
	(b) Sands, except very fine silty sands	Over 15	SM, SC
	(c) Clays PI>12	-	CL, CH
F4	(a) All silts	-	ML, MH
	(b) Very fine silty sands	Over 15	SM
	(c) Clays, PI<12	-	CL, CL-ML
	(d) Varved clays and other fine-grained, banded sediments	-	CL and ML: CL, ML, and SM; CL, CH, and ML; CL, CH, ML, and SM

Source: (5)

Table 7: Equipment Typically Associated with Mixed-In-Place Subgrade Stabilization Operations

STABILIZER	CONTRUCTION OPERATION				
	SOIL PREPARATION	STABILIZER APPLICATION	PULVERIZATION AND MIXING	COMPACTION	CURING
Lime[1]	-Single-shaft rotary mixer (flat type) -Motor grader, -Disc Harrow -Other agriculutural-type equipment	-Dry-bagged -Dry bulk -Slurry -Slurry thru mixer	-Single- and multi-shaft rotary mixers -Motor graders -Other agricultural-type equipment	-Sheep's foot -Pneumatic -Steel wheel	-Asphalt membrane -Water sprinkling
Lime or cement, Fly ash[2]	-Single-shaft rotary mixer (flat type) -Motor grader -Disc harrow -Other agricultural-type equipment	-Separate application -Lime--dry or slurry -Fly ash--conditioned -Combined application -Dry-bagged -Dry bulk	-Same as lime	-Steel wheel -Pneumatic -Vibratory	-Asphalt membrane -Water sprinkling
Cement[3]	-Single-shaft rotary mixer (flat type) -Motor grader -Disc harrow -Other agricultural-type equipment	-Dry-bagged -Dry bulk	-Same as lime	-Sheep's foot -Pneumatic (clay soils) -Vibratory (granular soils)	-Asphalt membrane -Water sprinkling
Asphalt[4]	-Motor grader -Single-shaft rotary mixer (flat type)	-Asphalt spray distributor -During mixing process	-Single- and multi-shaft rotary mixer (flat type) -Motor grader	-Pneumatic -Steel wheel -Vibratory	-Volatiles should be allowed to escape and/or the pavement to cool

COMMENTS	SAFETY PROCEDURES
[1]Double application of lime may be required to facilitate mixing. The soil and air temperature should be greater than 40°-50°F to insure adequate strength gain. Construction should be completed early enough in summer or fall so that sufficient durability will be gained to resist freeze-thaw action.	Lime spreading should be avoided on windy days. Proper clothing should be worn so that Workmen can avoid skin contact with quicklime. Workmen should avoid prolonged contact with lime and breathing lime dust.
[2]Fly ash must be conditioned with moisture prior to distribution to prevent dusting. Mixing and compaction should be completed shortly after stabilizer application. The soils and air temperature should be greater than 40°-50°F to insure adequate strength gain. Construction should be completed early enough in summer or fall so that sufficient durability will be gained to resist thaw-freeze action.	Fly ash, lime and cement spreading should be avoided in windy days. Workmen should avoid prolonged contact with the stabilizers and breathing the the stabilizers.
[3]Mixing and compaction must be completed shortly after stabilizer application. The soil and air temperatures should be greater than 60°F to insure an adequate rate of strength gain. Construction should be completed early enough in summer or fall so that sufficient durability will be gained to resist freeze-thaw action.	Cement spreading should be avoided on windy days. Workmen should avoid prolonged contact with cement and breathing the cement dust.
[4]Proper soil moisture content must be achieved to aid distribution and mixing. Stabilized material should be properly aerated prior to compaction. The soil and air temperature should be above 40°F to allow for proper curing and sufficient time for compaction if hot mix processes are utilized. Thick lifts of hot, asphalt cement stabilized materials can be placed below 32°F.	Proper clothing should be worn so that workmen can avoid skin contact with quickline.

Source: (2)

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