PB87-134409

SOIL STABILIZATION FOR LOW-VOLUME ROADS

VOL. 1: EXECUTIVE SUMMARY

Research, Development, and Technology
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Federal Highway Administration

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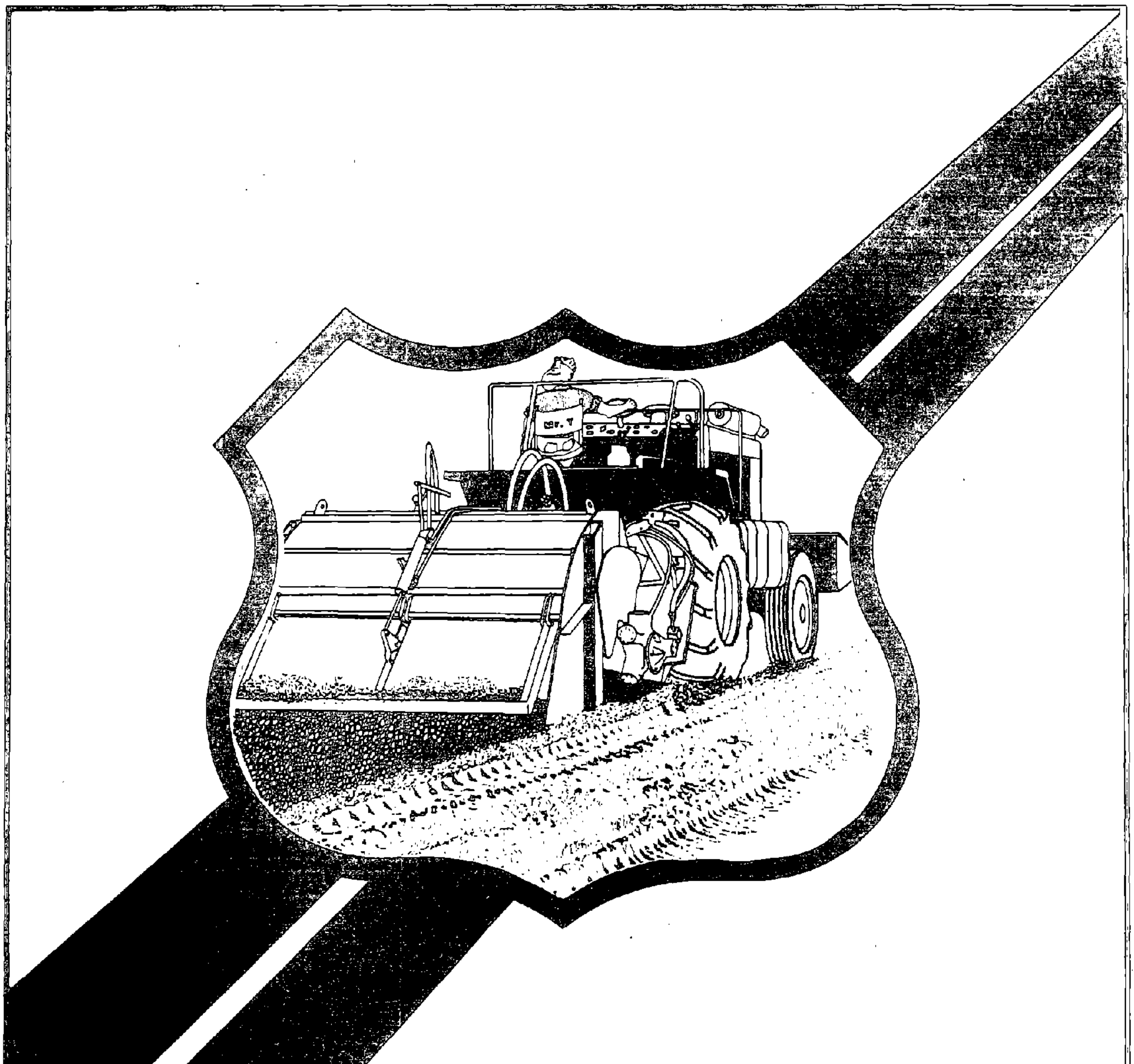

FOREWORD

This report, FHWA/RD-86/096, summarizes the results of research conducted by Sheladia Associates, Inc. for the Federal Highway Administration (FHWA), Office of Research, under Contract DTFH61-81-C-00004. The work was part of FCP Project 5M, "Rehabilitation and Maintenance of Low-Volume Roads." Volume 1--Executive Summary presents technical information described in Volumes 2 and 3 in a manner that can provide those in non-technical areas an understanding of the processes involved in construction of highways.

The information summarized includes discussions on climate, traffic, soil, and stabilizer selection, among others. These factors are interrelated and require consideration if a successful design is to be achieved. Types of stabilizers are described with reference to the soil conditions necessary for their use to achieve the desired result. Quality control and equipment requirements are also discussed.

Volume 2--Road Engineer's Guide (FHWA/RD-86/097) and Volume 3--Road Builder's Guide (FHWA/RD-86/098), pertaining to engineering and construction practices respectively, are available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161. In addition, Volume 4--Cost Benefit Analysis (FHWA/RD-86/099) is available describing the economic considerations of soil stabilization. Volume 1 and Volume 4 will be given widespread distribution by FHWA to Technology Transfer Centers under the Rural Technical Assistance Program. Additional copies may be obtained from NTIS along with Volumes 2 and 3.

Richard E. Hay

NOTICE

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16. Abstract

Volume 1, contained herein, is an Executive Summary for administrators to provide help in understanding the factors involved in using soil stabilization for low-volume roads. The decision making factors such as traffic, soils, climate, stabilizer selection, design procedures, construction equipment, and quality control have been outlined.

Volumes 2 and 3 are guide booklets for road engineers and road builders respectively. 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 documents the use and cost-benefits of these four stabilization treatments used in the construction of low-volume roads.

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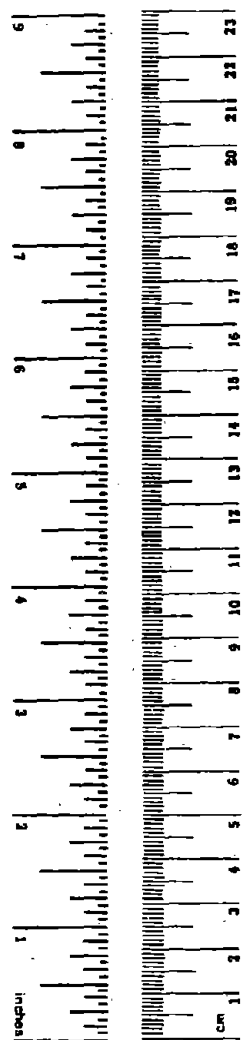
METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

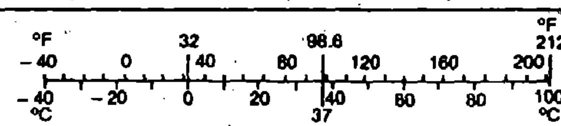
NOTE: Volumes greater than 1000 L shall be shown in m³.

Symbol	When You Know	Multiply By	To Find	Symbol
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectares (10 000 m²)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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INTRODUCTION

This publication was written to help county and local elected officials and non-engineering administrators understand the factors involved in using soil stabilization for low-volume roads. The official's or administrator's (decision maker's) main concerns are to provide for public's needs in a cost effective way. To do this, the decision maker must have enough data about such factors as traffic, soils, climate, stabilizer selection, design procedures, construction equipment, and quality control to make informed judgments about the different types of road improvements.

This booklet offers assistance in the identification and evaluation of each of these factors. It outlines the proper procedures to follow in applying the results of the evaluation process to the selection of a compatible stabilizer, the stabilizer's application rate, and specific construction requirements. The economic analysis procedure is documented in Volume 4 - Cost-Benefit Analysis of this four-volume report. Administrators who need or want a more complete treatment of soils stabilization technology will find more information in Volume 2 - Road Engineer's Guide, and Volume 3 - Road Builder's Guide, published together with this booklet. 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 (5) (9).

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. Soil stabilization 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.

The definition of low-volume roads, as adopted in this booklet, is stated in Figure 1. Low Volume Roads Definition, on page 19. Low-volume roads are for the use of the people living or working in the local area; the roads carry only the types of vehicles 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.

Traffic damages low-volume roads through repeated axle load applications. This damage to low-volume roads means increased maintenance costs. Stabilized soil base courses can reduce costs for traffic damage and maintenance. This assumes selecting the appropriate stabilizer, the correct application requirements, and the proper construction technology. The use of stabilized soil therefore requires engineering evaluations of the soil to be stabilized and of the climatic factors affecting the durability of the road.

Soil stabilization improves the structural capability of many subgrade soils and improves many borrow materials that otherwise would be unacceptable for use as base course material for low-volume roads. Stabilizing agents must be compatible with the speciifc soil to be stablilized. The same unique chacteristics that cause each soil type to react differently to stress and environment in its natural state affect that soil's response to different stabilizers. 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 also hold true for other stabilizing agents used for low-volume road soil stabilization.

Current design methodology for low-volume roads does not include repeated traffic loadings as a structural failure criteria. Instead engineers use high-volume road technology to evaluate stablized soil bases. The results are therefore very conservative because the failure criteria for high-volume roads is a predetermined surface roughness which is usually acceptable for use on the low-volume roads defined in the fourth paragraph in this booklet.

Preliminary consideration to use a stablized base course must include an evaluation of the volume and type of traffic, the soil classification of the subgrade, the climatic conditions, and the stabilizing agents and construction methods that may be used. This evaluation should determine the proper thickness of the stabilized base course for a certain stabilizer at a reasonable (economic) cost. This report outlines these evaluation methods and describes the evaluation procedure. Volume 4 describes the economic principles involved. Any evaluation should also include other viable options to build or improve the road. Stabilized soil should be used only when it is a cost-effective long term investment.

The best design of a stabilized base will result only after the options selected during the preliminary design phase are developed and considered. Final design should include detailed evaluation of the soils involved and the stabilized mixture, and an accurate estimate of construction costs. The administrator must also decide if the project should be constructed by public or contracted workers, and assign a specific individual the responsibility for proper construction procedure performance.

The following sections address each topic of the evaluation, design, and construction procedures in more detail. They are described in the order in which they should be evaluated, beginning with traffic considerations, then following through soil and environmental evaluations, stabilizer selection, preliminary and final design activities, and finishing with short sections covering construction equipment and quality control.

TRAFFIC

Pavement design consists of selecting the proper composition and thickness of a pavement material to withstand the anticipated traffic volume loadings. The traffic volume is generally expressed as annual average daily traffic (ADT) (Ref. 1) (References begin on page 31). Technically, pavement design is based on a total number of specific axle loadings anticipated during the pavement's design life time; the type of soil under the pavement; and environmental conditions such as temperature, topography and rainfall (Ref. 2). Pavement design takes into account the estimated number and type of traffic (i.e. automobiles, buses, trucks by size) that will travel over the pavement during its service life. Estimating traffic for a long time period is more difficult than estimating the short term vehicles per day (vpd) or ADT on low-volume roads.

All axle loads do not stress the pavement to the same degree. Their individual effect is characterized by the Traffic Equivalence Factor (Ref.2). This factor equates the number of the various axle loadings to a single axle loads, each equivalent to an 18,000 pound (18-kip) axle load. Generally, 18-kip axle loadings occur on the rear axle of loaded vehicles with gross weights in the 27,000 pound range, such as 5-yard dump trucks and 60 passenger school buses. The total loading imposed by such vehicles (on both axles) is equivalent to 1.08 18-kip axle loadings; in other words, (100/1.08 or 92) such loaded vehicles produce about the same accumulated damage as 100 standard axle loadings. Tandem rear axles cause less distress to the pavement than single axles with the same loading because the load is distributed over a larger area.

For example, pickup trucks and vans and all lighter vehicles have axle loads of less than 2,000 pounds (2-kips) when empty. It would require approximately 5,000 of these axle loadings to cause the same effect as a single 18-kip design axle loading. Vehicles with a gross vehicle weight of 10,000 pounds usually have less than 8,000 pounds weight on their heaviest axle and can be ignored when calculating low-volume road pavement life.

Traffic projections (i.e. the traffic anticipated at some future time) are often inaccurate, especially for low-volume roads. They are sensitive to unforeseen changes in local traffic from such causes as the future construction of a housing subdivision. Normally the overall traffic growth on low-volume roads is influenced by the specific area served rather than by general trends.

SOILS

Before any soil can be stabilized, it needs to be evaluated in order to select both the type and amount of stabilizer to be used. Soils consist of a series of layers called soil horizons. The uppermost layer, or 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 which, or on which, to build roads.

The next lower layer is made of non-organic material that can be sub-divided into four major soil components: gravel, sand, silt, and clay. These materials were formed over the centuries from the bottom layer or horizon material of parent rock, also called ledge or bed rock. The zone between each layer may be indistinct, especially the area between A and B horizons. Roadbuilders work primarily with material from the intermediate layers between the organic and parent rock materials.

Engineering soils (those in the intermediate layer) need to be evaluated more closely than by merely dividing them into the principal components of gravel, sand, silt and clay. Each soil is a mixture of materials. The relative amounts of the principal components present in the mixture influences the physical properties of the total mixture. The physical properties of soil mixtures of most importance for road construction are:

1. Permeability (how easily the water can flow through the soil) after the soil is compacted;

2. Shearing strength (the ability of the soil to support a load) when compacted and saturated with water;

3. Frost susceptibility (the likelihood that water below the frost line will be drawn up into the road structure to cause frost heaves and subsequent "spring breakup"); and

4. Compaction properties (the type of roller needed to properly compact the soil at the correct moisture content).

Soils evaluation is begun by identifying the existing soil as a member of a recognized soil group. Two groups are commonly used to identify road soils, the American Association of State Highway and Transportation Officials (AASHTO) System and the

Unified Soils Classification System. Although the AASHTO classifications pertain specifically to the soil's suitability as a highway material, most civil engineers working at the local level are more familiar with the second system which is therefore described in this booklet.

The Unified Soils Classification System divides soil mixtures into 15 soil groups, each having different soil properties and therefore 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. 3), on page 20, shows the names of the soil groups and describes their characteristics.

The classification of the soil to be stabilized will normally be supplied by the engineer developing input for the decision making process. Other sources for soil classifications include: state, county, or consulting soils engineers; state or county agriculutural agents; and university departments. No intelligent evaluation of the soil stabilization process is possible without a soil classification.

A preliminary determination of soil types can be made from simple observations in the field. Gravel is pea size or larger. Sand particles are visible to the naked eye. Well-graded material contains enough different size particles to make a tight, dense, stable mass. Silty and clayey gravel and sand contain mostly coarse material, but include enough fine particles (individually invisible to the naked eye) to affect the properties of the soil mixture. These soils are termed dirty gravel or sand. Wet dirty material stain one's hand. Dry dirty materials form a dust cloud when poured from the hand. Fine sand feels gritty, silts and clays feel soft like flour. Dry silt can be easily broken and rubbed into powder. Dry lumps of clay require more effort to break and are much more difficult to pinch into powder. Wet clay can be rolled between the hands into long, thin, worm-like ribbons, while wet silt will form short threads at best. Peat and muck have a distintive odor.

Coarse grained materials gain their strength by mechanical interlocking while silts and clays depend on cohesion (sticking together) for strength. Plastic fine soils (plasticitiy is the putty-like trait of being flexible enough to change shape in any direction without breaking apart) can seriously reduce the desirability of any soil as a road building material, even when only a small amount of plastic fines is present. Soil stabilization attempts, among other things, to improve the undesirable qualities of the fine grained portions of native soils. Therefore it is important to make a correct evaluation of the soils to be stabilized so the proper stabilizing agent, application rate, and construction method can be selected. Otherwise the stablized soil will not stand up to the climatic conditions to which it is exposed.

CLIMATE

The environment affects the curing time, durability and performance of a stabilized soil. Water, in some form, is the most important environmental factor affecting most low-volume roads. Rainfall must be removed from the road surface as soon as possible by means of a sufficient crown and adequate side ditches. Water penetration of the roadbed material must be controlled by using a water resistant surface material, proper sized culverts, interceptor drainage, or subdrains. In some cases drainage improvements will eliminate the need for soil stabilization, and in all cases adequate drainage is necessary for successful soil stabilization.

Frost damage is caused by the presence of water in frost susceptible soil and freezing temperatures. Table 1. <u>Frost</u>

Design Soil Classification (Ref. 11), on page 24, shows a list of soils divided into four Frost Groups, the first group being the least frost susceptible. Figure 3. Six Climatic Regions in the United States for use in Highway Technology, on pages 21 and 22, divides the U.S. into areas of hard freeze, freeze/thaw cycling, and no freeze.

The northern areas suffer severe winters with a high potential for subgrade (the material on which the road is built) frost penetration. The middle areas have moderate winters with a high potential for freeze/thaw activity throughout the winter. Since low-volume roads suffer the most damage during the thawing period, due to a high moisture concentration trapped under the road surface at that time, the middle zones often experience worse frost damage than northern areas. Running a snowplow on a dump truck carrying a full load of sand over a partially thawed road surface can be the major cause of damage to many low-volume roads.

Frost damage to low-volume roads 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 for the full depth of frost penetration, but this is often uneconomical. The cost and feasibility of a deep layer (or several layers) of stabilized soil is a function of the stabilizing agent selected, the subject of the next section.

STABILIZER SELECTION

There can be several reasons for stabilzing soils. Subgrade soils may be stabilized to provide enough strength to support construction equipment, to reduce their expansive capabilities, and/or to reduce frost heaves, as well as to increase their long term stuctural strength. Each of these factors contributes not only to the road's durability and performance under traffic, and its life span, but also affects its construction and maintenance costs, and consequently its economic benefits.

Specific stabilizing agents (asphalt, cement, lime, and lime-fly ash) do not react equally well with each soil classification. However, there is a considerable overlap in the ability of each stabilizer to react with specific soils (Ref 5). A few soils can be stabilized with any of the agents, while other soils are best suited to one or two specific additives. When more than one option exists, stabilizing agent cost considerations and construction equipment availability may not favor the additive requiring the smallest application. The state highway department may be the best source for information about using stabilizing agents, however some states do not use certain additives that may be suitable for local use. Private contractors and additive industry representatives are possible sources of information although they can not be considered impartial advisors. Many consulting engineers have soil specialists on their staffs.

Stabilizing agents should be selected on the basis of the plasticity or clay content of the material to be stabilized. That soil may be in situ material (soil presently on the ground at the location where stabilization is proposed), consisting of either naturally occurring soil (subgrade material) or some previously imported soil; or it may be soil imported specifically to be stabilized. Imported soil is any material that has been excavated elsewhere (borrowed) and delivered to the site. In some cases the in situ material may be removed (wasted) and replaced by the imported material, in other cases the imported material may be placed directly on top of the in situ soil.

Bituminous (asphaltic) stabilization works best on granular soils with low plasticity, including many well graded gravels classified in Figure 2, on page 20, as GW, GM, and GC; and many sands in the SW, SP, SM, and SC groupings. Asphalt may be applied as a cutback (asphaltic cement diluted with a petroleum solvent) or as an emulsion (asphaltic cement diluted with water), but it's design quantity is determined as the percent of asphaltic cement by weight of dry aggregate (soil) being stabilized. The solvent or water acts as a carrying agent that evaporates without providing any cementing properties. Table 2. Selection of Asphalt Cement Content, (Ref. 5), on page 25 shows the approximate quantities of asphaltic cement required for bituminous stabilization. It should be noted that many jurisdications have sanctions against the use of cutback asphaltic material, in those areas only the information about emulsions is applicable. If sanctions exist, any reputable local supplier will be aware of them.

Portland cement is suitable for stabilizing a wide range of soils with low to moderately high plasticity. Table 3. Cement Requirements for Various Soils, (Ref. 6), on page 26, 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. 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. 7), on page 27, shows the estimated cement content needed to stabilize several such materials.

Lime stabilization works best on 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.

In certain soils, termed reactive soils, a pozzolanic reaction also occurs. This reaction introduces increasing strength and durability over a period of several years. The cured 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. 5). Table 5. Approximate Lime Contents, (Ref. 6), on page 28, shows ranges of applications for both hydrated lime and quicklime to certain soil types. The reactivity and exact lime content required must be determined in the laboratory for each individual soil. Suitable laboratories are located in state highway departments, in some universities, and in private testing concerns.

Lime-fly ash stabilization works best with coarse grained material such as some gravels, sands, and several types of slags. Some fine grained materials, such as silt and fine sands, have also been successfully treated. Fly ashes (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. Lime fly-ash is usually proportioned so that all of the fly ash reacts with all of the lime. 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. 5).

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 is pulled out) under traffic, and often develop small cracks during the curing process which allows water to seep into the subgrade. An asphaltic surfacing membrane is therefore necessary to resist traffic abrasion, assist in the curing process, and to insure a water proof surface.

Stabilized bases can be applied in lifts (layers) as thin as four inches under properly controlled conditions. However most projects involving low-volume roads do not include a supervisory force large enough to provide precise measurements, so many agencies specify a minimum thickness of six inches. This thickness can be easily managed by the roadmix machines currently in use, however much thicker designs may need to be placed in two or more layers. If heavy vehicles are expected to use the road, an engineering evaluation of the traffic, soils, and environment is needed to determine the proper thickness of the stabilized base during the preliminary design activity outlined in the next section. However, Table 6. Minimum Total Equivalent 18-kip Single Axle Load Applications per Lane, on page 29, used in conjunction with Figure 4. Contours of Equal Regional Factors, (Ref. 4), on page 23, will give very conservative limits of equivalent axle loadings for trouble free usage.

PRELIMINARY DESIGN

Preliminary design is an engineering activity aimed at determining the feasibility and approximate cost of stabilizing a low-volume road. It includes an attempt to estimate the current traffic demand, the type of soil on which the road will be built (the subgrade material), the type of soil to be stabilized, the type or types of stabilizing agents that are available and suitable, the method to be used to stabilize the soil (in place or in a mixing plant), and the road construction activities and costs.

Often, traffic evaluation consists of a file review if any sort of traffic records have been developed. If no traffic data is available, residents in the area can be interviewed, as well as any developers who may own property nearby. If a road improvement is to be made in response to an application for a permit to develop an area, the developer's engineer should be required to submit traffic estimates. These estimates should be independently reviewed even if the developer is required to build the road.

Soil types can be determined from soils maps of the area. Various state and federal agencies work with these maps all the the time and should be able to convert the classification system used on the soils map to the Unified Soil Classification System in the area of interest. State highway employees and local contractors usually know the location of local borrow pits (material sources). The state highway department can also supply the regional factor (a correction to the normal total axle loadings in the design of a pavement to account for environmental conditions) for local use.

Local suppliers of stabilizing agents can provide literature about the application of their products, as well as the cost and delivery methods available. Any local contractors who have had experience in stabilizing soils usually feel it is in their best interests to assist in evaluating proposed projects, but they should be warned that any assistance they may provide does not obligate the local government in any way.

The purpose of this preliminary engineering is to determine the most economical solution to the stabilization problem. All alternatives must therefore be evaluated, including both the use of government personnel and equipment, if available, and the use of contractors. It may be possible to contract out only those portions of the work that the local government is unable to do with its own resources, such as providing and operating a travelling roadmix machine or stationary plant mixing equipment. Any such evaluation should include the fair rental cost of any government owned equipment (trucks, graders, etc.) and government employees wages, benefits, and overhead if a true cost comparision is desired before final design is authorized.

FINAL DESIGN

Final design should only be authorized if the preliminary design has determined that soils stabilization is the most cost effective solution to the public's needs. It should begin with the sampling and testing of the project's in-place material and the underlying subgrade soils to determine the percentage of gravel, sand and fines; the gradation (if predominantly coarse grained); the plasticty of fines; and the CBR (California Bearing Ratio - a load-capacity indicator figure) (Ref. 8).

Plasticity is found by testing the soil for its liquid limit (LL = the moisture content at which the soil passes from a plastic to a liquid state) and it's plastic limit (PL = the moisture content at which the soil passes from a semisolid to a plastic state). The numerical difference between the LL and the PL is called the plasticty index (PI). The PI denotes the range in moisture content at which the soil is in a plastic condition. These three values together are called the soil's Atterberg Limits and play an important part in selecting the proper stabilizing agent.

The CBR test is used to indirectly determine a Soil Support Value (SSV). This value is used in the formula to determine the total equivalent axle loads a pavement structure can support. The greater the subgrade's bearing capacity, as determined by the CBR tests, the more axle loads any specific thickness of stabilized material can support before it reaches design life or physical failure. The regional factor (an environmental correction mentioned above) is included in the same formula and usually reduces the total acceptable loadings.

Final design should include tests to determine the correct amount of stabilizing agent. These tests can include an evaluation of the stabilizer itself, the reactivity of the soil to be stabilized, strengh and durability (freeze-thaw and wet-dry) tests, and moisture-density tests (to determine the water content required to achieve maximum density during compaction).

These sampling and testing procedures are not simply an exercise to increase construction costs. They determine the compatibility between the construction process chosen and the equipment available. They also assure both reduced maintenance costs and the stabilized soil's capability to act as an engineered base or subbase under any high type of pavement, such as asphaltic concrete or portland cement concrete, that may be required in the future.

EQUIPMENT REQUIREMENTS

Equipment requirements vary according to the construction method chosen. The three most commonly used methods are:

1. Mixed-in-place (the soil is spread on the subgrade, the stabilizer is spread on the soil, and the combination is mixed);

2. Travelling plant (the soil is bladed or dumped into a windrow or long continuous heap which is picked up by a moving mixer that adds stabilizer, mixes the combination, and discharges the mixture from the rear); and

3. Stationary plant (the soil is trucked to a permanently installed mixing plant where the stabilizer is added and mixed, after which the mixture is hauled to the site and spread).

Equipment can include standard highway construction machinery or simple farm equipment such as harrows and plows. In any case the equipment must be sufficient to carry out the five steps necessary to construct a stabilized base, namely: soil preparation, stabilizer application, pulverization and mixing, compaction, and curing. Table 7. Equipment Typically Associated with Mixed-in-Place Subgrade Operations, (Ref. 9), on page 30, outlines the types of equipment used and offers comments on weather and seasonal constraints, mixing constraints, and safety procedures. The enforcement of these constraints and safety measures is called field inspection or quality control.

QUALITY CONTROL DURING CONSTRUCTION

Quality control (proper inspection and testing) is necessary for all roadbuilding operations to insure the result will function as planned. The field control of stabilization activities includes inspection of the subgrade preparation, stabilizer content, moisture content, mixing operations, spreading activities, compaction effort, and curing technique (Ref. 10). Quality control is usually exercised by placing inspectors from the local highway agency or from a consulting engineer on contractor built projects.

However quality control is no more an exercise to increase construction costs than is proper design. It should therefore also be practiced when the local government's own highway crew is building a stabilized base. Quality control does not have to be an adversary relationship, its real purpose is to assign specific individuals the responsibility for following proper construction procedures, thereby protecting the taxpayer's investment.

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			COMPACTION EQUIPMENT		
		PERMEABILITY	LOAD CARRYING ABILITY	FROST SUSCEPTIBILITY		BASE COURSES	WEARING COURSES
Well-Graded Gravel	GW	Pervious	Excellent	Alone to very slight	Virbratory Rubber tire slight wheel	Excellent to good	Fair
Poorly Graded Gravel	GP	Very Pervious	Good	None to very slight		Fair	-----
Silty Gravel	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	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 nearing surfaces or roads with less than 100 vehicles per day.
5. Trawler tractors can be used as virbratory 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.

FIGURE 3

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

As defined by University of Illinois

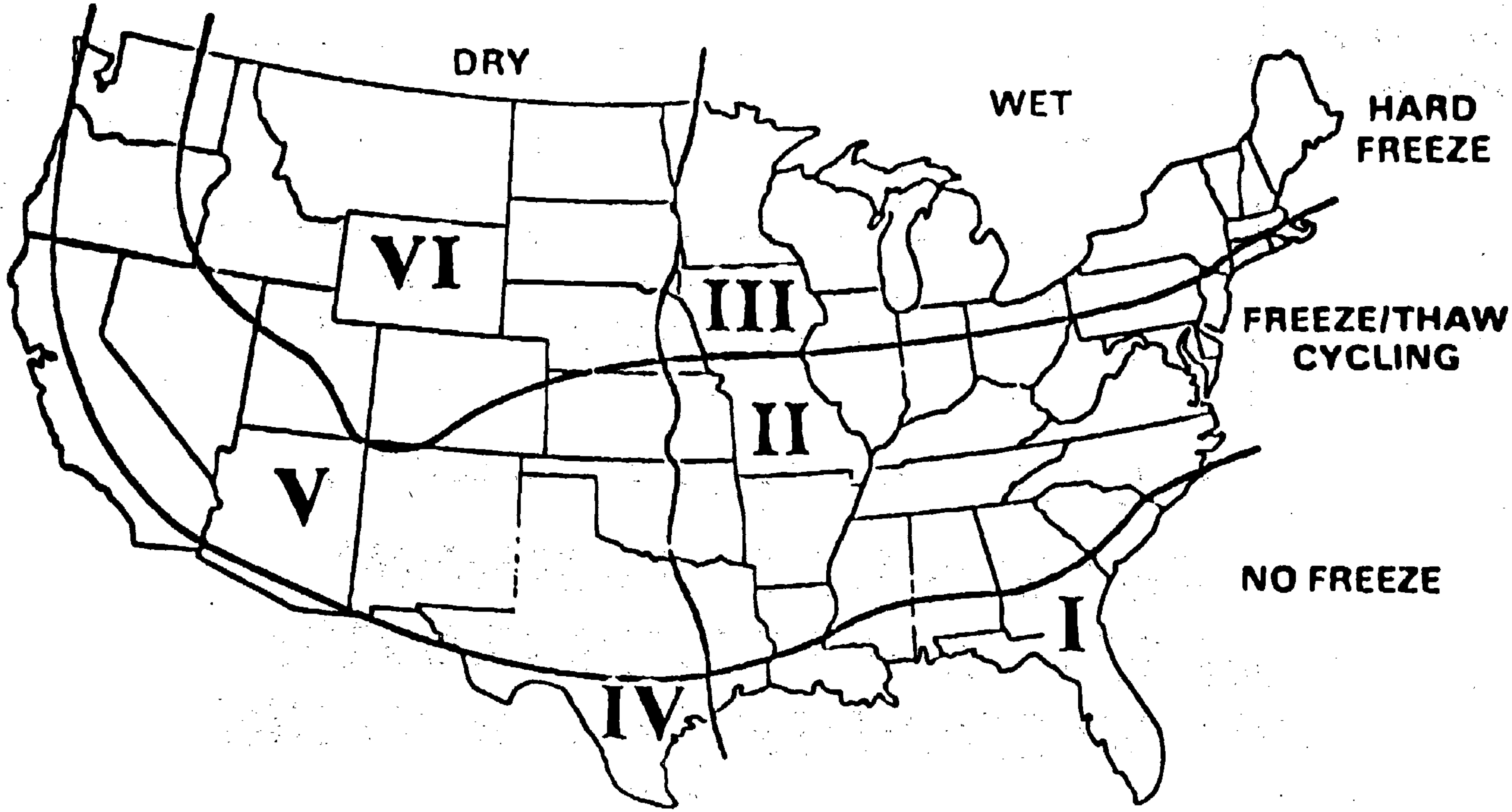

FIGURE 3

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

Thornthwaite Index = Zero (boundary between WET and DRY)

Freezing penetrates 5 inches (boundary between NO FREEZE and FREEZE/THAW CYCLING)

Freeze Index endures 60 days per year (boundary between FREEZE/THAW CYCLING and HARD FREEZE)

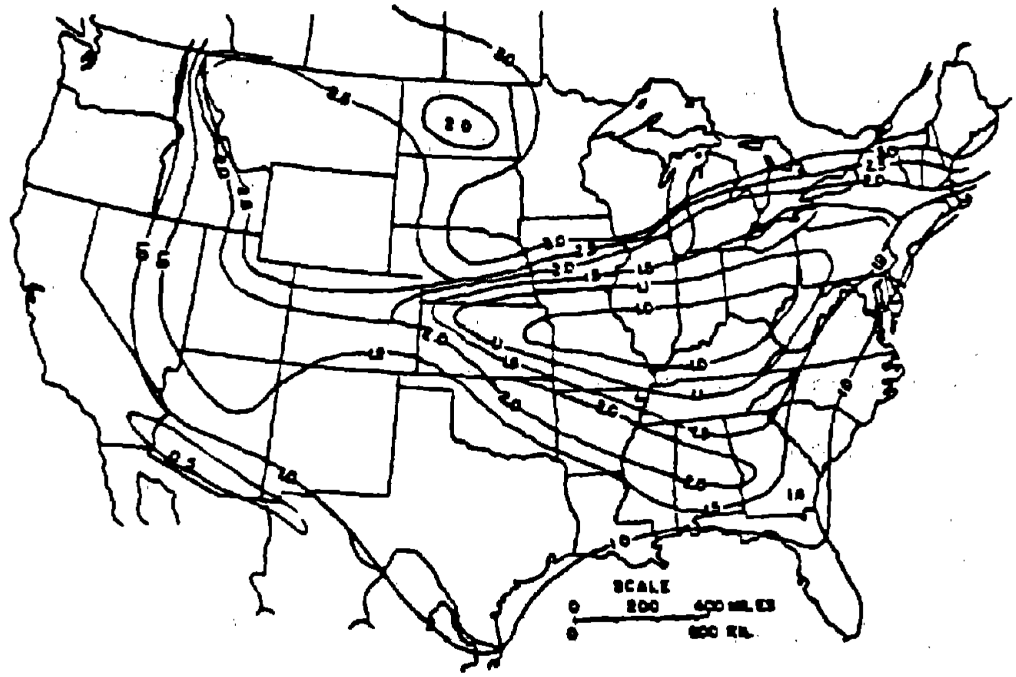

FIGURE 4: CONTOURS OF EQUAL REGIONAL FACTORS

SOURCE: (4)

Table 1: Frost Design Soil Classification

Frost Group	Kind of Soil	Percentage Finer than 0.02 mm by Weight	Typical Soil Types Under Unified 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: (11)

Table 2: 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 in field based on observation of mix and engineering

Source: (5)

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: (6)

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: (7)

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: (6)

Table 6. Minimum Total Equivalent 18-Kip Single Axle Load Applications Per Lane

Subgrade Soil Group	Layer Thickness	Equiv. Axles Per Lane
GW	6-inches	72,500
	8-inches	341,000
GWd(*)	6-inches	36,500
	8-inches	172,000
GP	6-inches	20,100
	8-inches	94,400
GMu(*), GC, SW, and SMd(*)	6-inches	15,500
	8-inches	73,000
SP, SMu(*), SC	6-inches	6,600
	8-inches	31,000
	10-inches	115,000
ML, CL	6-inches	2,360
	8-inches	11,100
	10-inches	41,300
OL, MH	6-inches	1,540
	8-inches	7,200
	10-inches	26,900
	12-inches	83,600
CH, OH	6-inches	1,000
	8-inches	4,700
	10-inches	17,500
	12-inches	54,500

(*) Suffix d is used when liquid limit is 25 or less and and plasticity index is 5 or less; the suffix u is used otherwise.

The above figures do not include any correction for evnrionmental differences. For approximate corrections, go to Figure 4. Contours of Equal Regional Factors, to interpolate the proper regional factor for your area. Divide the answer found in the above table by your regional factor (as interpolated from Figure 4), on page 23, to determine the total equivalent 18-kip single axle loads on the type of subgrade being investigated. The number found will indicate the total number of equivalent axle loadings in the design life of a high volume road which is a very conservative estimate of trouble free usage for low-volume roads.

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: (9)

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH, DEVELOPMENT, AND TECHNOLOGY

The Offices of Research, Development, and Technology (RD&T) of the Federal Highway Administration (FHWA) are responsible for a broad research, development, and technology transfer program. This program is accomplished using numerous methods of funding and management. The efforts include work done in-house by RD&T staff, contracts using administrative funds, and a Federal-aid program conducted by or through State highway or transportation agencies, which include the Highway Planning and Research (HP&R) program, the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board, and the one-half of one percent training program conducted by the National Highway Institute.

The FCP is a carefully selected group of projects, separated into broad categories, formulated to use research, development, and technology transfer resources to obtain solutions to urgent national highway problems.

The diagonal double stripe on the cover of this report represents a highway. It is color-coded to identify the FCP category to which the report's subject pertains. A red stripe indicates category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, and green for category 9.

FCP Category Descriptions

1. **Highway Design and Operation for Safety**
   Safety RD&T addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act. It includes investigation of appropriate design standards, roadside hardware, traffic control devices, and collection or analysis of physical and scientific data for the formulation of improved safety regulations to better protect all motorists, bicycles, and pedestrians.

2. **Traffic Control and Management**
   Traffic RD&T is concerned with increasing the operational efficiency of existing highways by advancing technology and balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, coordinated signal timing, motorist information, and rerouting of traffic.

3. **Highway Operations**
   This category addresses preserving the Nation's highways, natural resources, and community attributes. It includes activities in physical maintenance, traffic services for maintenance zoning, management of human resources and equipment, and identification of highway elements that affect the quality of the human environment. The goals of projects within this category are to maximize operational efficiency and safety to the traveling public while conserving resources and reducing adverse highway and traffic impacts through protections and enhancement of environmental features.

4. **Pavement Design, Construction, and Management**
   Pavement RD&T is concerned with pavement design and rehabilititation methods and procedures, construction technology, recycled highway materials, improved pavement binders, and improved pavement management. The goals will emphasize improvements to highway performance over the network's life cycle, thus extending maintenance-free operation and maximizing benefits. Specific areas of effort will include material characterizations, pavement damage predictions, methods to minimize local pavement defects, quality control specifications, long-term pavement monitoring, and life cycle cost analyses.

5. **Structural Design and Hydraulics**
   Structural RD&T is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highway structures at reasonable costs. This category deals with bridge superstructures, earth structures, foundations, culverts, river mechanics, and hydraulics. In addition, it includes material aspects of structures (metal and concrete) along with their protection from corrosive or degrading environments.

9. **RD&T Management and Coordination**
   Activities in this category include fundamental work for new concepts and system characterization before the investigation reaches a point where it is incorporated within other categories of the FCP. Concepts on the feasibility of new technology for highway safety are included in this category. RD&T reports not within other FCP projects will be published as Category 9 projects.

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