REPORT NO. FRA/ORD-77/30

PB 272721

HANDBOOK FOR RAILROAD TRACK STABILIZATION USING LIME SLURRY PRESSURE INJECTION

REVISED

APRIL 1979

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington, D.C. 20590

NOTICE

Technical Report Documentation Page

1. Report No. FRA/ORD-77/30	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Handbook for Railroad Track Stabilization using Lime Slurry Pressure Injection		5. Report Date June 1977, revision April 1979 6. Performing Organization Code
7. Author(s) Original by James R. Blacklock and Chris H. Lawson, revised by Richard H. Ledbetter		8. Performing Organization Report No.
9. Performing Organization Name and Address Graduate Institute of Technology, P. O. Box 3017, 1201 McAlmont, Little Rock, Arkansas 72203 Revised by U. S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, P. O. Box 631, Vicksburg, Mississippi 39180		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DOT-OS-40107 13. Type of Report and Period Covered Handbook
12. Sponsoring Agency Name and Address Federal Railroad Administration Office of Research and Development Improved Track Structures Research Division Washington, D. C. 20590		14. Sponsoring Agency Code

15. Supplementary Notes
Prepared in cooperation with the Federal Railroad Administration, and the Transportation Systems Center and with the aid of the Railroad Industry.

16. Abstract

This handbook includes chapters dealing with the technology of lime injection, surface and subsurface soil exploration and laboratory testing, environmental considerations and safety precautions. In addition, there are appendices which provide state-of-the-art specifications for lime slurry injection and laboratory soil testing procedures. A lime slurry section gives a complete description of the present state of the art of Lime Slurry Pressure Injection (LSPI). This handbook hopefully will provide the railroad industry with existing information and guidance in the selection and use of the LSPI method of roadbed stabilization.

This handbook has been revised by the U. S. Army Engineer Waterways Experiment Station in accordance with recent tests and findings dealing with LSPI soil stabilization. The major revisions are concerned with injection techniques and with field and laboratory testing to evaluate a subgrade soil's potential for dispersal of the injected slurry and improvement of stability by LSPI.

Vertical line denotes change

17. Key Words Railroad Track Track Maintenance Lime Slurry Pressure Injection Roadbed Stabilization Laboratory Tests	18. Distribution Statement Document is available to the public from the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	87	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The modern method of lime slurry pressure injection (LSPI) is potentially useful for the rehabilitation or improvement of certain types of railroad subgrade soils and has been employed by several major railroads for track maintenance since 1971. The Graduate Institute of Technology (GIT) of the University of Arkansas, under contract to the Federal Railroad Administration, U. S. Department of Transportation, has performed an initial research study for the "Improvement of Problem Track Subsoil by the Lime Slurry Pressure Injection Method." The information contained in this handbook was collected or developed during this research project to assist railroads and injection contractors to obtain more effective and economical applications of lime injection. Because this method of soil treatment is constantly undergoing modification and improvement, this handbook is far from definitive and provides only the existing information on the state of the art of soil stabilization--including the lime injection process, soil testing and evaluation, and project management of the process. It is anticipated that this handbook will be revised as better information becomes available.

The GIT was awarded the Federal Railroad Administration research contract in 1974 to examine the ability of the LSPI method to improve the subgrade soils of problem roadbeds. The railroad research team at the GIT has conducted an engineering and chemical analysis and laboratory testing program and has evaluated and documented data generated by the contractors and several rail lines covering many aspects of LSPI. Indications are that LSPI is proving to be a valuable method for stabilizing certain problem roadbed soils and is substantially reducing the maintenance cost on many sections of track.

This handbook has been revised for the U. S. Department of Transportation/Transportation Systems Center in 1979 by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under Reimbursable Agreement 76-41. Revisions are based on recent tests and findings dealing with Lime Slurry Pressure Injection (LSPI) soil stabilization. The major revisions are concerned with injection techniques and with field and laboratory testing to determine those railroad subgrade materials in which the injected slurry can be effectively dispersed and stability improved by LSPI. This handbook will provide the railroads with information and guidance in the selection and use of the LSPI method of roadbed stabilization. Additional information may be obtained from the references in the Bibliography.

Vertical line denotes change

The railroad engineer who is considering the use of LSPI stabilization for the first time will find the entire handbook to be helpful, especially the section on Surface and Subsurface Soil Exploration and Testing. This section will be most valuable when trying to develop the initial project plan for a particular problem section of track. It is essential to consider the soil-testing and -exploration items in the decision process.

The sections on Safety Precautions and Environmental Considerations are provided to enable the railroad engineer to gain knowledge quickly about these specialities as they relate to LSPI.

The Lime Injection Technology section gives a complete description of the present state of the art of LSPI. The equipment, procedures, and techniques discussed in this section have been developed by soil engineers, railroad personnel, and the contractors over the past six years of LSPI roadbed stabilization. As lime injection continues to grow, it is anticipated that new equipment, procedures, and techniques and better materials will be forthcoming. The bulk of the material in the handbook, however, is not likely to change appreciably.

Various types of fine-grained soils with low permeability may present problems to LSPI, and the permanency of stabilization has not been proven. LSPI field tests* on the Rock Island Railroad north of Memphis, Tennessee, and on a test track at the WES in clays and silty clays of low plasticity showed that essentially no lime or supernatant liquid was forced into the clayey soils. However, the more permeable ballast mixtures at both test sites were stabilized and showed significant strength increases. Under train traffic and seasonal environment changes, the life of the stabilization is not known.

This handbook addresses the use of lime slurry pressure injection at depths less than or equal to 20 feet as a method of correction or improvement of the performance of railroad roadbeds that are unstable due to causes related to combinations of high wheel load, heavy traffic, unstable materials, and/or ground water problems. The handbook does not apply to problems related to slope failure or to settlements that are deep-seated or are primarily related to gravitational loadings.

---

* A DOT report is to be published in 1979 on the field test results.

Vertical line denotes change

TABLE OF CONTENTS

Vertical line denotes change

LIST OF FIGURES

Vertical line denotes change

LIST OF TABLES

Vertical line denotes change

GLOSSARY OF TERMS

Accelerated Cure -- See Curing.

Adsorption -- Attraction of lime particles to surfaces of clay particles.

Carbonation -- Formation of calcium carbonate, $CaCO_3$, by reaction of calcium hydroxide, $Ca(OH)_2$, with carbon dioxide, CO_2, in the atmosphere.

Cementation -- Hardening action in which calcium silicates and aluminates are the main products of the chemical reactions of lime slurry with the principal soil components, namely, silica, alumina, and alumino-silicates.

Consolidation -- A measure of the reduction in the size of a soil mass under a compressive load, due to water ejection. This is a time-dependent process in which excess pore pressure dissipation results in void ratio reduction.

Curing -- Process of maintaining a soil mass or sample for a specific period of time under specific conditions of temperature and relative humidity so as to allow internal reactions in the soil to take place up to a satisfactory stage.

Normal Cure -- The soil is sealed in a plastic bag and placed to cure at room temperature (22-25^{o} C). The soil is effectively curing in its own atmosphere. It is good practice to place the sealed sample in a controlled-humidity chamber (100% relative humidity) to prevent moisture loss in case of poor sealing.

Accelerated Cure -- The soil is sealed in plastic bag and placed to cure at a temperature of 45-60^{o} C. A good quality plastic must be used to prevent deterioration and subsequent moisture loss. The soil is effectively curing in its own atmosphere.

Deteriorating Track -- Track which is experiencing a progressive reduction in its capacity to carry traffic at predetermined operational characteristics (for example, speed).

Expansive Clay Soil -- A predominatly clay soil that undergoes large volumetric changes with variations in moisture content.

Grouting -- Pumping of a cement-sand grout into the railroad subgrade soil through grouting spuds either driven or drilled into the ground. Typical grouting projects in the general construction field--which include slide stablilzation, dam sealing, tunnel construction, and void filling--require the *in situ* injection of large solid masses of hardenable structural materials. There is some overlap between the terms injection and grouting, and sometimes the terms are used interchangeably.

Injection Pressure -- The lime slurry pumping pressure in pounds per square inch (psi) in the injection rods. The gage pressure (in psi) at which the lime slurry is injected into the soil. The pressure is usually in the range of 50-200 psi.

Injection Spacing -- Longitudinal distance along the track between each injection hole.

Lime Blending Truck -- Hy-rail truck equipped with a mixing tank and agitation device to mix and haul lime slurry on a job site.

Lime, Hydrated -- A material (calcium hydroxide) obtained by hydrating quicklime with water. It is purchased according to standard materials specifications.

Lime Injection -- The process whereby lime slurry is pumped under pressure into the ground in large quantities at regular spacing intervals to specified depths to treat problem subgrade soils.

Lime Injection Nozzle -- The nozzle portion of the injection rod, usually constructed of machined hard steel several inches long with a suitable 360-degree hole pattern for slurry distribution.

Lime Injection Rod -- Hollow steel pipe used to inject lime into the ground, usually 10-20 feet long.

Lime Injection Truck -- Hy-rail truck equipped with a slurry-holding and -agitation tank; a high-volume, high-pressure pump; hydraulic injection mechanisms for pushing injection rods; and necessary hoses and controls.

Lime Reactive Soil -- Soil that is significantly modified by lime-soil chemical reactions.

Lime Seams -- Thin sheet-like layers of lime slurry injected into cracks present within the soil mass.

Lime Slurry -- A liquid mixture of hydrated lime and water with or without additives.

Lime Slurry Additives -- Any chemical added to the lime slurry mixture, usually to act as a pozzolan, to accelerate curing or to act as a wetting agent (see Surfactant).

Lime Slurry Tank -- A large tank for storage of dry lime and for mixing, holding, and dispensing lime slurry on a job site.

Lime Transport Truck -- Truck for hauling dry hydrated lime from a lime plant to the job site, generally 18-24 tons in capacity.

Lime-Water Ratio -- The amount of dry lime in pounds added to each gallon of water to form a slurry.

Moisture Content -- The amount of water contained in a soil mass, expressed as a percentage of the oven dry weight of soil as determined by a closely defined test procedure.

Normal Cure -- See Curing.

Plasticity Index (PI) -- An indicator number which is numerically equal to the difference between the liquid limit and the plastic limit of a soil specimen. An expansive clay would have a "high PI." Low PI soils are generally more stable and have less volumetric change that do high PI soils.

Post Hole Method -- Lime stabilization using pre-drilled post holes filled with lime slurry. It has seldom been used.

Pozzolanic Reaction -- Mineralo-chemical reaction between lime and the clay minerals of the soil or any other pozzolanic component (such as hydrous silica) to form a tough, water-insoluble gel of calcium silicate that cements the soil particles together. In time, this gel gradually crystallizes into well-defined calcium silicate hydrates, such as tobermorite and hillebrandite.

Pumping Soil -- A soil failure characterized by a water-bed effect that provides an unstable support for the track. Mud pockets under the ties and fouled ballast are often the result of pumping soils.

Railroad Roadbed -- That portion of the trackway below the ties that includes ballast, subballast, and subgrade soils.

Railroad Track System -- System including rails, fastenings, ties, ballast, subballast, and subgrade as an integral part.

Refusal -- Most of the slurry that is being injected is escaping to, and flowing freely on, the surface from surface breakouts.

Silty-Clay Soil -- A soil containing substantial amounts of silt and clay. Such soils are usually associated with low strength and are sensitive to low percentages of moisture.

Soil Exploration -- Surface inspection and subsurface soil drilling to obtain information on soil stratification and samples for laboratory tests and classification.

Soil Tests -- Field and laboratory tests conducted on soil samples obtained during soil exploration.

Spot Treatment -- The use of lime injection or other techniques to improve short trouble spots along a track.

Squeeze -- A roadbed soil failure characterized by the presence of subsurface clay soils extruded to the surface through the ballast (similar to a pumping soil).

Stabilization -- Modifying or changing the properties of a soil mass to improve its serviceability under existing load and environmental conditions.

Subgrade Soil -- Soil below the ballast and subballast in the roadbed.

Supernatant Liquid -- Saturated solution of $Ca(OH)_2$.

Surface Breakout -- The slurry that is being injected begins flowing rapidly back out of the ground at one or more points. The breakout(s) may occur around the injection rods, out of previous injection holes, or through fractures in the soil.

Surfactant -- Chemical added to decrease the viscosity or lower the surface tension and thus to increase the flow characteristics of lime slurry in certain soils.

Treated Soil -- Soil which has been lime injected or otherwise chemically modified.

Untreated Soil -- Soil which has not been lime injected or chemically modified.

Volumetric Change -- The swell or shrinkage of a soil mass brought about by changes in moisture content.

Water-Sensitive Soil -- A soil with the adverse characteristic of losing strength rapidly when brought in contact with extra moisture.

Water Transport Truck -- Truck for hauling clean water to the job site.

Wet-Dry Cycles -- Natural climatic cycles that cause a soil to alternately gain and lose moisture.

INTRODUCTION

This edition of FRA/ORD-77/30 is a revision of the handbook dated June 1977. Based on new recent test results and findings, Section II concerning injection techniques and Section III dealing with soil exploration and testing have been extensively revised. Section III includes a new evaluation and testing methodology that leads to more decisive answers concerning the use of lime slurry injection stabilization.

One of the major problems facing the American railroads is the overall rising cost of track maintenance, a large percentage of which is made necessary by unstable problem roadbed soils. One method the railroads have used to combat the rising cost of track maintenance and halt the deterioration of track subsoils is stabilization of the roadbed with lime slurry pressure injection (LSPI).

For certain combinations of in situ soil conditions and permeability, in-place treatment with hydrated lime slurry has the potential to economically render <u>some</u> expansive and low-strength clays and some other fine-grained roadbed subsoils more stable possibly by improving volumetric stability or increasing usable shear strength or both. Stabilization of ballast pockets, if the materials are chemically reactive with lime, is more easily achieved than is stabilization of fine-grained soils because the ballast pockets have higher permeabilities which allow dispersion (i.e., reasonably intimate mixing with the ballast) of sufficient quantities of lime slurry.

The thin lime slurry--a blend of high-purity hydrated lime, clean water, and sometimes a surfactant--is injected into the ground through hydraulically operated rods mounted across the rear of an injection truck. Normally three rods are used, one at the track center line and one on each side of the track approximately 5 feet from the center line. The slurry is injected into the soil at close intervals down to the maximum injection depth. The amount of slurry used will usually vary depending on soil types and conditions.

The injected slurry follows the paths of least resistance, moving principally along soil separation planes, seams, and fractures, if they exist. The lime slurry divides to form (1) thin sheets of lime in the seams and (2) supernatant liquid, which, depending on the soil permeability, may saturate the soil adjacent to the lime seams. With an injection spacing of 5 feet, and under certain soil conditions, an overlapping network of a high concentration of lime seams may be achieved.

In heavy clay soils, the sheet-like seams, if they occur in sufficient quantity and extent and if the soil is chemically reactive with lime, may react with the adjacent soil to form moisture

Vertical line denotes change

barriers that tend to stabilize the moisture content of the soil. In most instances when heavy clay soils are to be injected, they should be treated when the moisture content of the soil is at a low point for the year, so cracks and fissures have the best chance of being present and open.

The dispersal of lime into soils may provide overall gains in soil strength and stability if cation exchange and pozzolanic reaction occur. In some instances, the soil may require drainage prior to injection, although generally the more granular soils may be injected even when very wet.

Although many aspects of the mechanism of stabilization by lime injection remain unexplained, there are several benefits which may be expected from LSPI under favorable soil conditions, soil chemical reactivity, and permeability. They include:

Dewatering. Experience on many jobs has shown that the injected lime slurry actually cuts off the flow of subsurface water. In tracks with deep ballast layers that act like underground rivers, the flow of subsurface water in wet seasons contributes to many roadbed problems. Flow of water in the ballast will generally be reduced since the lime fills voids in the ballast material and may significantly reduce the permeability of the ballast if a high degree of saturation with lime slurry is achieved.

Moisture Content Control. The principal benefit of LSPI in many instances may be in stabilizing the moisture content of the soil mass. Under certain soil conditions, if lime can be deposited in a sufficient concentration of seams, it may form moisture barriers which tend to impede the movement of moisture within the soil mass. This benefits the roadbed because there is less degradation from seasonal moisture changes. Long dry spells or long wet spells will not have such devastating effects on control of track geometry.

Reduced Volumetric Change. Under certain soil conditions, and if a significant amount of lime can be impregnated per cubic foot of soil (intimately mixed), swelling and shrinkage of clays may be reduced by changing the basic soil characteristics.

Increased Strength. Tests made on laboratory injected samples have shown that there is usually an increase in strength in treated clay soils if, and only if, the soil chemistry is such that it will chemically react with lime. However, it should be pointed out that impregnation of laboratory samples with lime may (depending on soil type) in no way reflect in situ lime impregnation. Since the shear strength of a soil is generally inversely proportional to its moisture content, stabilization of the moisture content at a lower level effectively increases the strength.

The only way to know if the above benefits have a possibility of occurring and providing improvements is through certain laboratory and field tests. Soil samples should be obtained and

Vertical line denotes change

laboratory tests conducted in order to determine if the soil is chemically reactive with small amounts of lime, such as 1 to 2 percent. If the soil is not chemically reactive, no pozzolanic reaction or strength increase will occur. Either laboratory or field permeability tests should be conducted to determine if the soil is permeable enough to allow dispersion of the supernatant liquid during the field pressure injection process. If the soil is relatively impermeable and has few fracture surfaces or cracks in situ, slurry liquid will not travel into the soil in sufficient amounts to cause changes or chemical reactions in reactive soil. The soil should be classified and grain-size distribution should be determined (except for clays when the answer is obvious), because the soil can filter out lime particles and prevent dispersion of the lime slurry. At the present time, the only way to judge if soils are injectable is to conduct field pump tests with an injection rod and lime slurry. Undisturbed* samples must be obtained and inspected to determine if the soil is being impregnated, if a sufficient number of lime seams are forming, and if sufficient lateral dispersion is occurring to cover the space between injection points (injection points are normally spaced at 5-foot intervals).

If roadbed subsoils prove to be nonreactive and not injectable, consideration can be given to LSPI stabilization of the lower ballast layers and pockets. When field pump tests are conducted, they should also include tests on the ballast materials. Chemical reactivity of the ballast materials should also be checked. Recent field tests have shown that stabilized ballast layers are the chief source of increased roadbed stability and strength in the case of lean clay subgrades. Stabilized ballast will also help prevent water infiltration into the roadbed subsoils and pockets and will reduce load-induced stress in the subsoil. LSPI stabilization of lower ballast and subballast materials only should be considered as economically and technically sound at sites either where subsoils do not permit good dispersion of the slurry or where the largest gain in stability and strength is most effective.

Excessive moisture is one of the primary causes of subgrade instability, and every railroad engineer knows the importance of good drainage. However, in many areas, good drainage is difficult to maintain because of soil conditions and the track geometric layout. In these areas, it may be necessary to provide wells or other means of drainage rather than standard gravity-flow side

---

* Laboratory test sample quality is not necessary; however, the soil stratifications and structure must be preserved and no mixing should have occurred.

Vertical line denotes change

ditches. Lime injection should always be used in conjunction with good drainage practices.

When the subgrade is unstable, maintenance work on the ties, ballast, and rails often merely buys time. Corrective techniques that have been used by railroads for roadbed repair--such as cement grouting, pole driving, and ballast dumping--often have not produced the desired long-term improvement. In fact, many areas that have been successfully stabilized and improved through LSPI had previously been treated unsuccessfully with driven poles, cement grout, or other means of remedial maintenance. However, this does not mean LSPI is a cure-all; some applications of LSPI have not been successful. This points out the fact that, to achieve the best results with any subgrade maintenance program, a thorough engineering study should be conducted first. Each individual soil problem then should be treated specifically with the best methods available, whether they involve chemical stabilization, mechanical modification, or other treatments.

Historically, the greatest portion of railroad maintenance-of-way funds has been spent on top of the roadbed--for new ties, rails, and ballast and for maintenance functions related to these components. Today, subgrade failures and soil-related problems are occurring more frequently than ever as a result of higher wheel loads. This, coupled with the recent shortage of roadbed maintenance funds, has contributed to the increasing number of miles of track in need of substantial subgrade improvement. The LSPI method of roadbed improvement is potentially one method for reducing maintenance costs and providing safer railroads when certain favorable soil types and conditions exist.

Vertical line denotes change

I. BACKGROUND

Modern railroad lime injection stabilization began with work on two independent projects, both involving areas of track requiring extremely high maintenance. In the fall of 1971, the Frisco Railroad used rubber-tired forklift injection units that had been developed for the civil building industry to treat sections of track near Denton, Texas. A few months later, in the spring of 1972, the Southern Railroad treated areas near Greensboro, North Carolina, using the first on-track, self-contained injection truck with hydraulic lime injectors. (Figure 1 shows a modern lime injection truck and related equipment.)

After about one year of observing the Denton test sections, the Frisco reported that maintenance had been reduced on all of the treated track except for areas with deep-ballast pockets. The 10-foot-deep injections, the maximum obtainable at that time, had not penetrated through the deep ballast into the underlying problem clay subsoils. The Southern reported three years after injection that its treated track, which was resurfaced three months after injection, had resisted formation of new squeezes and that the existing problem squeezes had not reappeared.

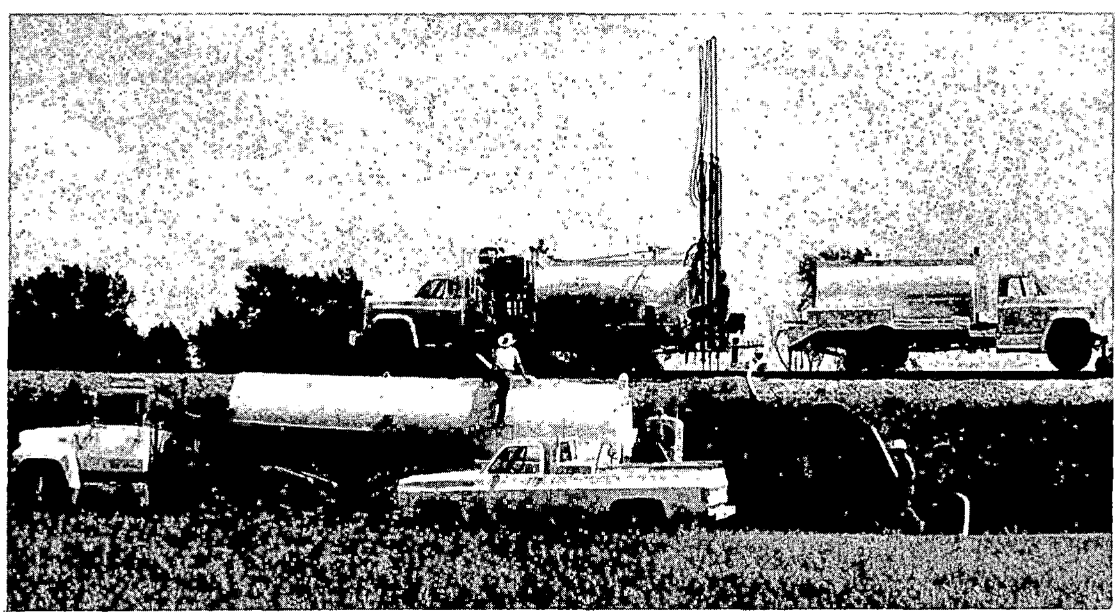


Fig. 1. Modern lime injection equipment. On the track are a lime injection truck (left) and a slurry haul truck. The large truck (lower left) is a slurry transport.

The apparent success of these projects encouraged the railroads to proceed with LSPI treatment of other sections of track; and since those initial projects, lime injection has been used in approximately 20 states by many of the major railroad companies. Many new and challenging applications of lime slurry injection have been tried, and at least two contractors operate fleets of self-contained, semiautomatic injection units and related equipment built especially for railroad lime injection.

II. LIME INJECTION TECHNOLOGY

The immediate physical goal of lime injection is to achieve economically a uniform dispersal of the lime slurry throughout the treated soil mass. During the past few years of actual railroad LSPI stabilization operations, a step-by-step technology for efficient injection of roadbeds has been developed with this goal in mind. The railroads and lime injection contractors are continuously refining this technology to attain more uniform coverage economically, and future LSPI roadbed projects should utilize better injection technology through improved equipment, procedures, inspection, and quality control.

The current railroad LSPI technology includes criteria for materials, equipment, mixture control, injection techniques, and injection records and inspection. Proper control of each of these items contributes to the success of any particular lime injection project; therefore, the use of a properly prepared plan that includes engineering specifications is recommended for each stabilization project. General specifications developed by GIT and the contractors during this program are included in this Handbook as Appendix A. These specifications and the discussion below will help provide a solid foundation for a successful, efficient lime injection project directed toward roadbed stabilization.

MATERIALS

Lime is sold commercially in two forms: quicklime and hydrated lime. Quicklime, CaO, which is produced by burning limestone, $CaCO_3$, in kilns to drive off carbon dioxide, is considered to be hazardous for use in railroad LSPI stabilization projects and, therefore, has seldom been utilized.

Hydrated lime, $Ca(OH)_2$, is manufactured by grinding quicklime, mixing with water, and drying and pulverizing the mixture into a flocculent powder. Hydrated lime is relatively safe to use and economical to purchase and, therefore, is utilized in the large majority of the LSPI projects. Hydrated lime should be purchased according to a standard materials specification for construction-grade hydrated lime. State highway departments can supply such specifications, as well as a list of qualified material suppliers. Also, the lime can be purchased according to ASTM D C-207, Type N, except that the calcium hydroxide content must be not less than 90 percent and the requirements for popping, pitting, and water retention shall not be applicable. The supplier of the lime shall be prepared to furnish certified evidence of the quality of his product. A physical and chemical analysis for a typical suitable hydrated lime is shown in Table I.

TABLE I

Example Material Analysis for Hydrated Lime

Components	Weight (%)
Free Moisture	0.30
Chemically Combined Moisture	23.39
Silicon Dioxide	0.11
Iron Oxide	0.20
Titanium Oxide	0.01
Manganese Dioxide	< 0.001
Aluminum Oxide	0.22
Calcium Oxide	73.98
Magnesium Oxide	0.17
Sulfur Trioxide	0.04
Phosphorus Pentaoxide	< 0.01
Insoluble (Less Silica)	0.16
Carbon Dioxide	1.11
% Passing 200 Mesh	95
% Passing 325 Mesh	87

Carbonation of hydrated lime is caused by absorption of carbon dioxide, CO_2, from the air. Excess water used in forming the lime paste evaporates and is gradually replaced by CO_2, causing any free lime hydrate to revert to the original $CaCO_3$ [i.e., $CA(OH)_2 + CaCO_3 + CO_2 \rightleftarrows CaCO_3 + H_2O$]. Hydrated lime will carbonate rapidly when exposed to air. Carbonation of the hydrated lime is not desirable and should be prevented prior to injection because the carbonated lime will not react with the soil minerals to form the necessary soil-cementing agents.

The subject of waste, or reclaimed, lime currently is of interest to several of the railroads because of substantial reductions in purchase price over new certified hydrated lime.

The use of waste lime is considered to be outside of the scope of this handbook, and handbook statements are not to be considered as applicable to stabilization using lime other than that purchased under acceptable specifications. Some of the injection work performed in the infancy of the LSPI method utilized waste lime. Virtually all of those jobs were considered to be failures, probably due not only to the use of waste lime but also to the inadequate hand injection methods that were available prior to the development of hydraulic equipment.

In addition to certified hydrated lime, materials for lime injection include water and, possibly, a surfactant (wetting agent). Water used in mixing lime slurry shall be clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials, or other substances that may be deleterious to the desired lime-soil reaction. If nonpotable water is proposed for use and if there is any doubt concerning compliance with the above statement, then laboratory tests should be conducted to compare the lime-soil reaction of specimens incorporating the nonpotable water with the reaction of similar specimens incorporating potable water.

A surfactant may be used as indicated by the particular soil conditions of the injection site. The surfactant, which should be used according to the manufacturer's recommendations, helps reduce surface tension between fine-grained soil particles and the lime slurry, thus allowing further penetration into the soil mass.

EQUIPMENT

The equipment used for modern railroad lime injection stabilization was designed and engineered for precisely this one function. It was the development of this special equipment for the railroads that made LSPI stabilization economically feasible and routinely practical. The on-track, self-contained semi-automatic injection truck (Figure 2) equipped with a hydraulic injection system is an essential part of the present high-production LSPI capability. Currently, at least two lime injection contractors own and operate lime injection equipment designed for railroad applications.

An injection fleet typically comprises a storage tank, a slurry mixing unit, slurry transports, and the hy-rail injection truck. The fleet normally is operated by three or more crewmen.

The lead crewman, who is experienced in lime injection, is trained to supervise the lime injection sequence and to look for and troubleshoot problems. In addition, he is responsible for customer coordination, ordering materials, accepting deliveries, and keeping field records.

Fig. 2. Lime injection truck.

One or two men handle the slurry mixing and hauling, and one crew member operates the injection truck. From his location at the rear of the truck (Figure 3), the operator can see the area around each injection rod, enabling him to visually ascertain its progress.

BULK STORAGE

Lime transport trucks are used to transfer the dry hydrated lime from a lime plant to the job site. Water transport trucks are used if water of the required quality is not available at the job site. The lime may be stored at the site in the transports or in large wet or dry holding tanks. The wet holding tanks, called lime slurry tanks (Figure 4), are utilized both as storage tanks and as mixing units. The dry tanks are equipped with a pneumatic blower system to transfer the lime to the equipment that mixes the slurry.

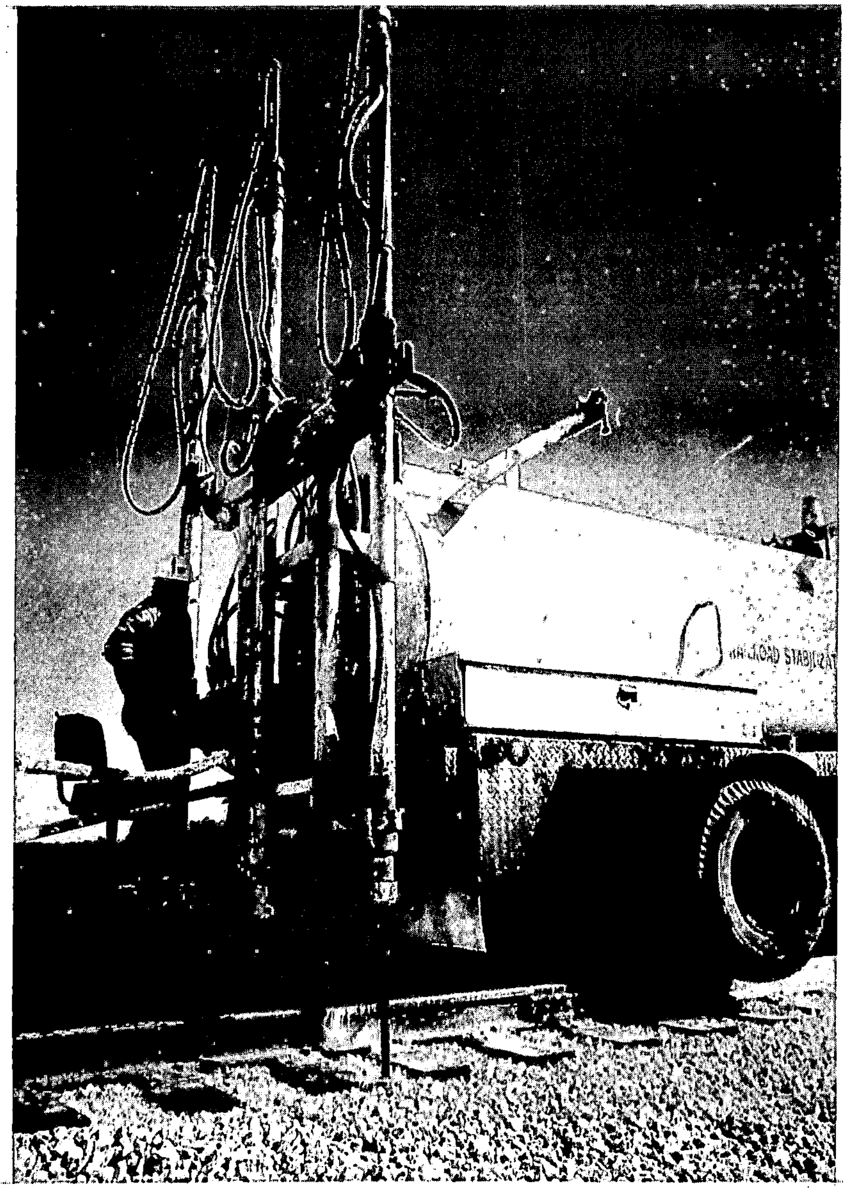


Fig. 3. Operator and injection rods.

MIXING EQUIPMENT

Currently, there are two slurry-mixing systems. In one system, the large lime slurry tank is used to mix lime slurry in bulk. In the other system, lime is transferred from the dry

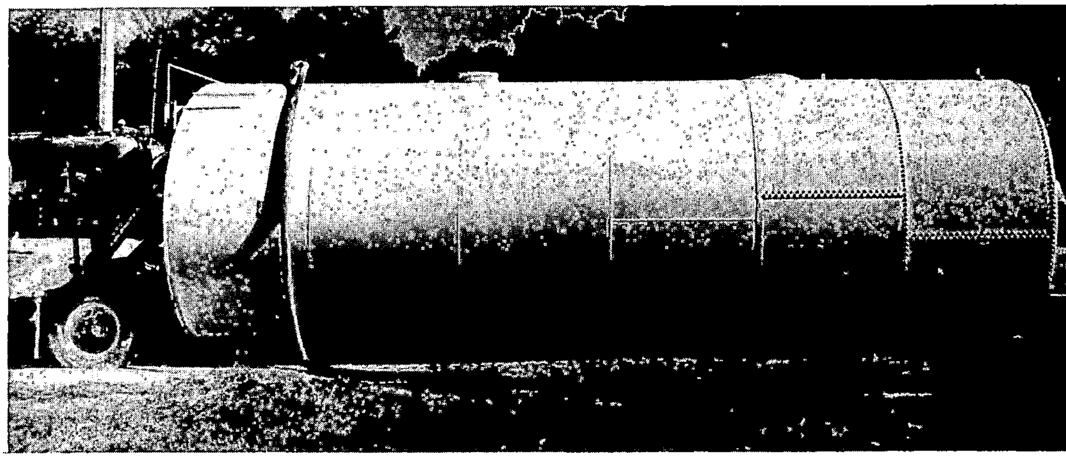


Fig. 4. Lime slurry tank.

holding tanks to small blending trucks. Each system is used to mix dry lime and water and to agitate the solution to form a slurry. The main difference between the two systems is size.

The lime slurry tank is capable of producing up to 17,000 gallons of slurry in one batch. The tank, which is equipped for road travel when empty, has a centerline paddle-wheel agitator to insure uniform suspension of the lime.

The blending truck is used to mix 1500 to 2000 gallons of slurry at one time. Blending trucks are equipped with pump or paddle-wheel agitation systems, and some have hy-rail wheels.

ON-TRACK HAUL TRUCK

The link between the mixing system and the injection rig is the on-track haul truck (Figure 5). Equipped with hy-rail wheels, these trucks are capable of accompanying the injection rig as it moves along the track from one injection site to the next. Each haul truck has a slurry tank capable of holding 1500 to 2000 gallons, an agitation system, and a transfer pump.

When the lime slurry tank is used, the slurry may be pumped directly to the on-track haul truck if it is possible to locate the tank near the track. Otherwise, the slurry is transferred from the tank to the haul truck via a slurry transport truck. When the blending truck is used, the slurry may always be pumped directly to the on-track haul truck; however, in some cases, the blending truck may double as the haul truck.

Fig. 5. On-track slurry haul truck.

LIME INJECTION TRUCK

The basic item of equipment for the LSPI process is the lime injection truck, which is equipped with hy-rail wheels for on-track operation (Figure 6). The injection truck also is equipped with a suitable agitation system, slurry tank, high-pressure pump, and three hydraulic injection rods.

The three injection rods are spaced 5 feet apart across the rear of the injection truck with the center rod at the track centerline. Each injection rod is made of steel pipe that is threaded on the lower end so that an injection nozzle may be attached. The machined-steel nozzle is perforated so that the slurry is properly distributed in a 360-degree arc into the soil (Figure 7).

PNEUMATIC DRILL TRUCK

A relatively new piece of equipment for lime injection is the pneumatic drill truck (Figure 8), which is equipped with rock drills, compressors, and hy-rail wheels. The rock drills are aligned to produce a hole pattern that matches the hole pattern of the standard injection truck. The drill truck is used to perforate cement-stabilized soil or other previously placed hard-surface grouts prior to injection.

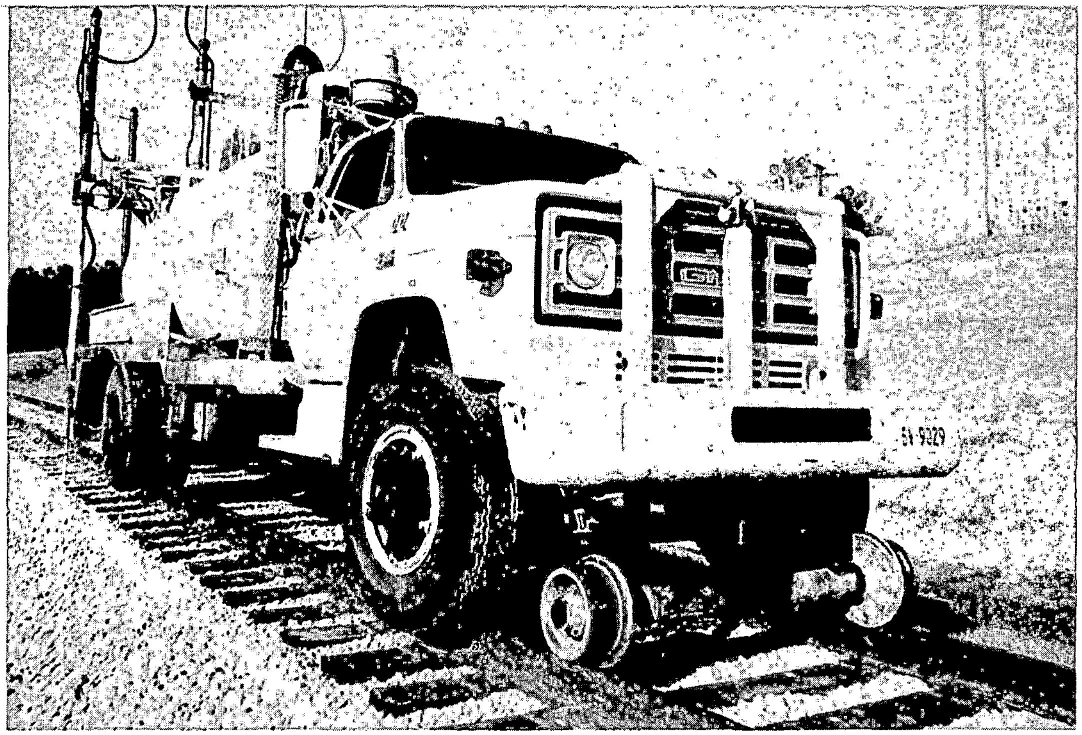


Fig. 6. Lime injection truck on hy-rail wheels.

SLURRY MIXING

The on-site mixing of lime slurry is one of the more difficult steps in the injection process. According to information obtained from the contractors' weekly report forms, the average amount of lime used per railroad mile in 1975 was 158 tons. When mixed with water, this would yield approximately 125,000 gallons of slurry per mile. The logistics of obtaining water and lime in such large quantities on a rigid time schedule and in remote areas sometimes are very taxing. The operation requires durable equipment and considerable prior planning.

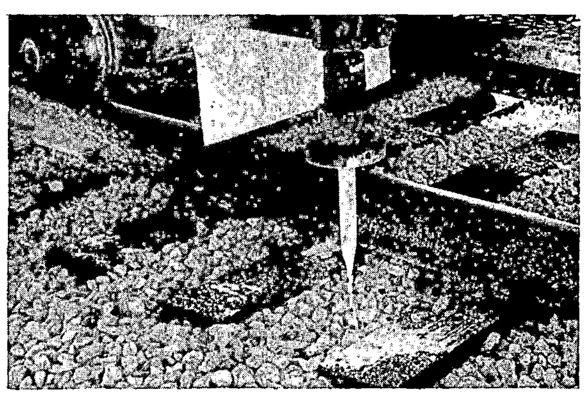


Fig. 7. Lime injection nozzle.

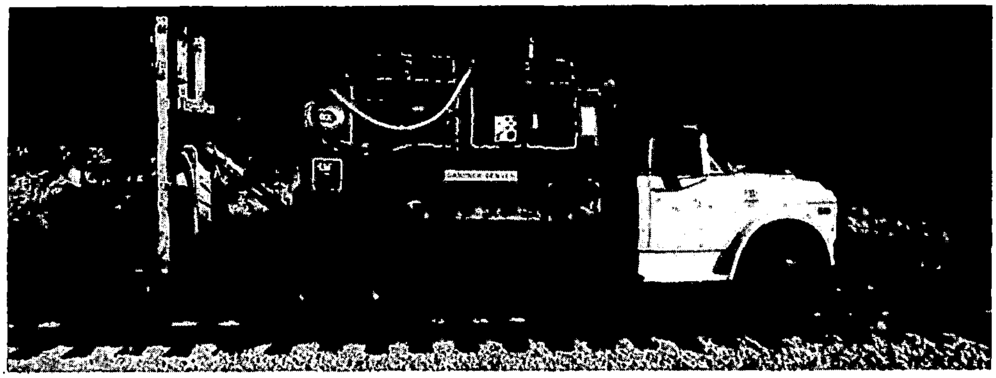


Fig. 8. Pneumatic drill truck.

In addition to the physical difficulty of on-site mixing, there is the requirement that the lime slurry be proportioned and maintained at the proper consistency. Field experience with applying LSPI to roadbeds has shown that the optimum range for the lime-water ratio is usually 2½ to 3 pounds of lime per gallon of water. Site conditions will require that the contractor adjust the ratio within this range. In some instances, it may be necessary to increase or reduce this range; however, the lime should never exceed 4 pounds per gallon of water.

Achieving the proper slurry consistency is relatively simple when the lime slurry tank is used. After 20 to 24 tons of lime (the capacity load of a bulk transport) have been transferred to the tank, the tank is filled with water to a prescribed level, producing slurry of the desired ratio of lime per gallon of water.

More care must be taken when using the smaller blending trucks. The tank of the truck is first filled with water, and then dry lime is pumped from the bulk storage truck until the proper consistency is obtained. Because it is not possible to weigh the lime as it is transferred into the blending truck, another method of proportioning the lime to the water must be used.

Two methods have been recommended for checking the consistency of the lime slurry: the hydrometer method and the Baroid Scale method. While both methods have been used in the past, it is felt currently that the Baroid Scale method is the more accurate. The Baroid Scale is not sensitive to temperature changes, requires less skill to operate, and has the same accuracy for thick and thin mixtures. The gravest difficulty with the hydrometer method is that, with varying techniques, the tester can obtain a wide range of specific-gravity readings, especially for a thick mixture.

Figure 9 compares the total slurry weight (Baroid Scale method) and the specific gravity (hydrometer method) with the lime-water ratio. The Baroid Scale, which was developed for measuring the density of oil field mud, can be ordered from Baroid Division, N L Laboratories, Inc., P.O. Box 1675, Houston, Texas 77001.

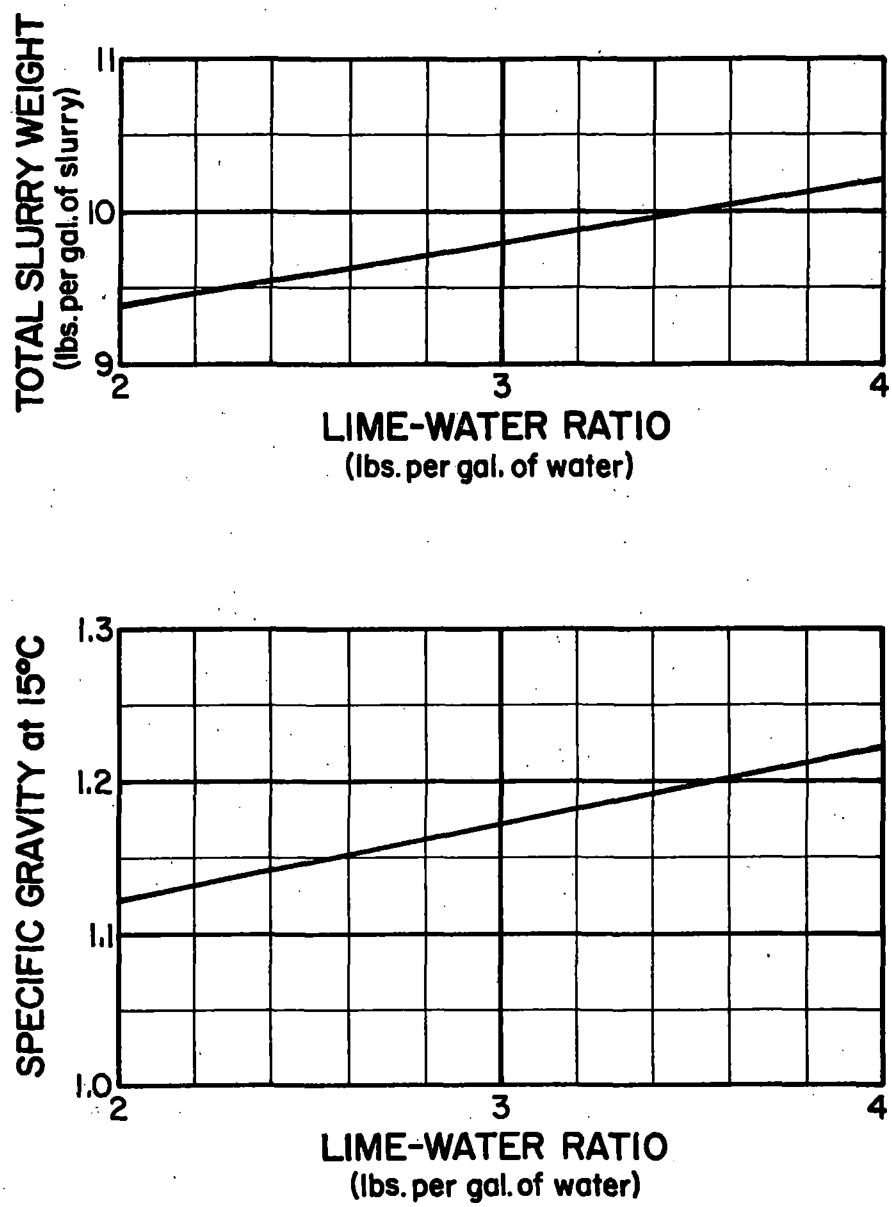


Fig. 9. Lime-Water Ratio Curves.

Injection

The injection procedures for any particular track section will vary with the roadbed condition and engineering considerations. For example, when injecting a high embankment in arid Wyoming soils (Figure 10) it may be necessary to use a thin slurry mixture of approximately 2 pounds of lime per gallon of water. However, when injecting a deep cut with standing water in side ditches (Figure 11) it may be necessary to inject a thicker mixture of perhaps 3 pounds of lime per gallon of water. It is necessary to have sufficient water in the slurry to carry the lime particles into the ground and then be available to support the chemical reactions.

The injection operator sits or stands at a control console on the rear of the injection truck with a clear view of the equipment, which is necessary for accurate control and quick reaction (Figures 12 and 13). The operator carefully positions

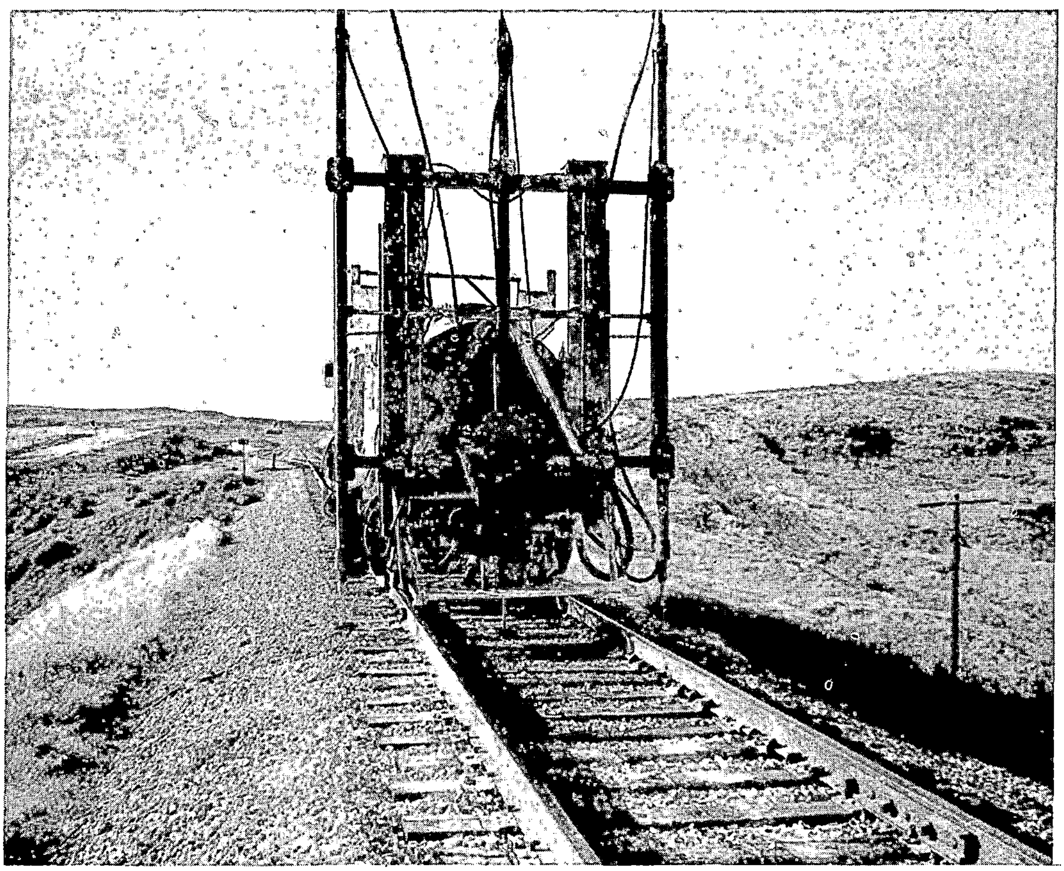


Fig. 10. Lime injection in progress in Wyoming.

Vertical line denotes change

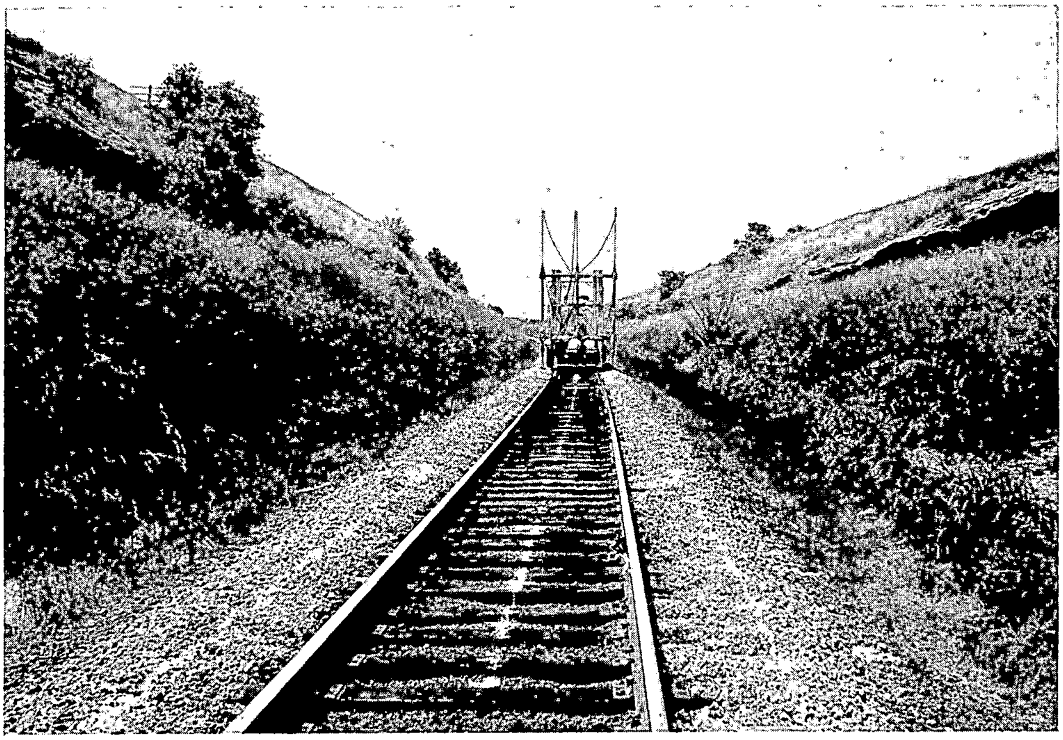


Fig. 11. Lime injection in a typical deep cut problem area in Oklahoma.

the truck at each injection set-up point. He then operates a hydraulic valve to lower the injection rod to the proper depth and operates the flow valve to allow the slurry to be pumped into the soil from the holes in the injection nozzle. Each rod is lowered farther and the slurry flow continued until the injection at that set-up point has been completed. The flow is then stopped and each injection rod raised so that the truck may be advanced to the next set-up point. The operation at each set-up point is conducted in a somewhat continuous manner, with first one injection rod being lowered a bit and then the next and so on until the total depth is reached on each rod. Studies have shown that each injection setup requires from 3 to 5 minutes, depending on the operator and soil conditions. Of this time, 10 to 15 seconds are required to move the truck the distance forward to the next set-up point. Recent studies have indicated that the injection technique in certain fine-grained soils may need to be modified. By turning the slurry flow off before advancing to each depth interval, the soil will tend to seal around the injection rods better than if a continuous flow is maintained. Also, controlling the slurry pressure in a manner that increases it slowly

Vertical line denotes change

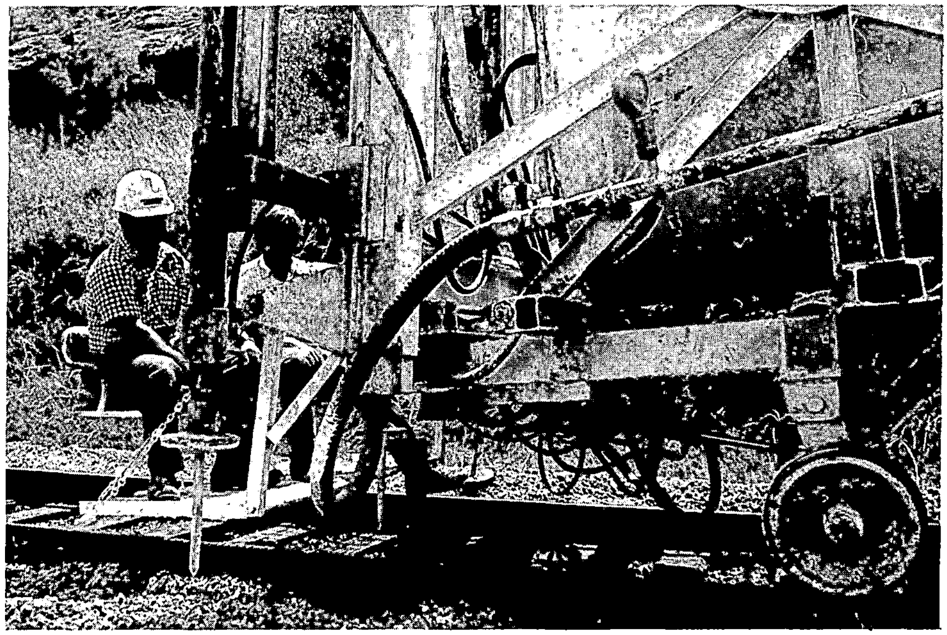


Fig. 12. Side view of operator's position at rear of injection truck.

at each depth will tend to increase hydraulic fracture and the opening of seams or bedding planes in the soil. When continuous high pressure is constantly maintained, the slurry may only jet a hole along the path of least resistance and permit the slurry to escape to the surface or to a more permeable material such as a ballast layer. Modification of the injection technique will of course add to the operation time. Field pump tests using an injection rod and lime slurry will indicate the best technique to be used in a particular soil.

To gain the most benefit from lime injection, it is essential that the injection operator be given technical directions specifying the depths to inject and the quantity of slurry to pump. The nature of injection equipment makes it easier to inject more slurry at deeper levels because there is less chance of a surface breakout. This may be exactly what should be prescribed if the injection area involves a weak or unstable deep problem and a strong, stable upper roadbed. In many cases, however, the problem soils are near the surface and the deep soils require little or no treatment.

Both surface and subsurface soil exploration and soil testing are usually necessary to determine where the problem soil is located and to define the soil layers to be injected. With information from a soil exploration program, the soils engineer,

Vertical line denotes change

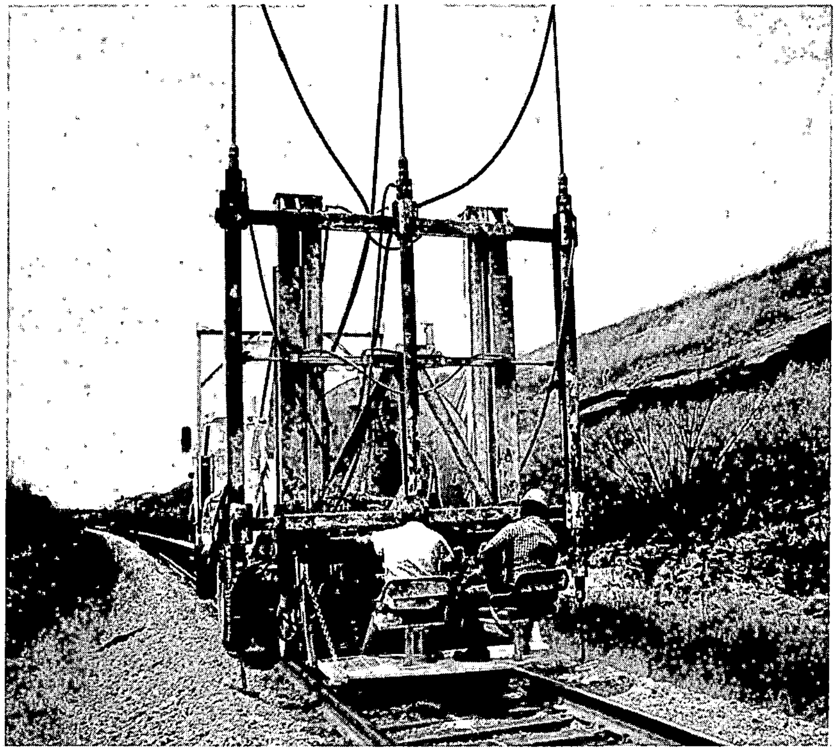


Fig. 13. Rear view of operator's position on injection truck.

the railroad engineer, and the contractor working as a team should prepare the injection plan. Each member of the team should study the problem and all available related data prior to developing the plan, which will include the injection specification. The specification will include data for the control of the depth of injection and the quantity of lime to be injected. The plan should not only indicate the total depth; it should specifically indicate which soil layers are to be injected and with how much slurry of what consistency. This degree of accuracy will be difficult to achieve in most cases, but it should be the goal of those writing the specification and instructions to be as specific as practical.

The other injection parameters--such as spacing, interval, pressure, and flow rates--will need to be adjusted to achieve the above prescribed depths of injection and quantity of injected lime.

The injection spacing, which is usually set at every second or third tie, should be varied to achieve the proper quantity of lime slurry at the proper depth. In some cases it may be necessary to "double inject" to place the desired amount of lime at that depth. The procedures for double injection have not been thoroughly documented; however, various methods have been tried with some success. Perhaps the method most used is that of staged injections, i.e., after the initial injection to refusal, the contractor waits a minimum of 48 hours and then re-injects between the original injection holes. The other methods are:

1. Inject every other tie to full depth and to refusal for a distance of 200 or more feet and then back up and repeat the injections for the in-between tie spaces.
2. Inject every other tie to a shallow depth only and return a few days later for full-depth injections.
3. Inject every second or third tie as a normal operation and return months later to re-inject. (This obviously would be much more costly.)
4. For the shallow problem only, inject a limited amount of slurry--not to refusal--and then, hours or days later, repeat until the proper amount of slurry has been injected into the soil.

The vertical injection interval is a much maligned term. In the early literature on lime injection, it was generally stated as varying from 12 to 18 inches. The optimum distance for the injection interval depends to a great extent on the soil structure and how quickly the soil will reseal itself around the injection rod after the rod is advanced. However, it may not be necessary to control this parameter as long as there is strict control of the prescribed quantity of lime slurry injected at each proper depth within the unstable soil layers and if the lime slurry is dispersing well and impregnating the soil. If the problem soil is uniformly distributed to the total depth and if the lime slurry is dispersing well, then a small, uniform interval such as 18 inches would need to be prescribed and adhered to. It then would be necessary to inject approximately the same quantity of lime at each interval and to adjust the injection procedure to achieve the specified total amount of slurry to be injected per track foot. Dispersal and soil impregnation can only be determined by inspection of undisturbed* samples or by trenching and should be determined before full-scale injection of large track sections. Where the length of truck to be injected is so small that the cost of determining whether dispersal and impregnation are occurring is about as large as the cost of the injection, the optimum course of action may be to inject and "gamble" on dispersion. If dispersal and soil impregnation are poor, injection intervals as close as 6 inches may be desired.

Standard injection procedures use pumping pressures within a

---

* See footnote at bottom of page 3.

Vertical line denotes change

range of 50 to 250 pounds per square inch (psi). However, recent field tests have indicated that in certain fine-grained soils, better results are achieved if pumping pressures below 25 psi are used along with the modified injection technique discussed on page 5. In the recent cases mentioned, high pressure tended to blow the slurry upward to the surface along the injection rod. Considering that in situ vertical total pressure at a depth of 5 feet is about 5 psi and at 10 feet is about 10 psi, injection pressures need to be only slightly greater in order to open seams or bedding planes and to hydraulically fracture the soil. The most effective pump pressure to employ can be determined from field pump tests and inspection of samples or cut trenches.

One other critical item concerns the technique of injecting slurry to refusal. Does the operator stop the flow at the first trickle of lime or wait for more signs of lime breakouts and for the lime to flow freely on the surface? The manner in which this is handled will greatly affect the quantity of lime placed unless the inspector requires the operator to adhere to a predetermined specific quantity of lime to be injected. In any case, it will be found that different roadbed soils react differently and trial-and-error injections will be necessary to determine the best procedure.

Records

A major contribution of the contractors and railroads to the success of a recent research project was the continuous preparation of written records of important injection data for each project performed between October 1974 and July 1976. Two basic record forms (Forms 1 and 2) were developed for this purpose. Sample blank forms are given in Appendix B of this report. Much of the data from the forms has been entered monthly in a data-collection, -storage, and -retrieval computer system. Figure 14 is an example of the contractor's weekly injection reports. These data have been used for economic analysis and various parameter studies. It is recommended that each railroad compile similar records to monitor and evaluate its LSPI activities.

Inspection

The careful inspection by trained technical personnel of certain important lime injection parameters is advisable for each roadbed stabilization project. The inspector should be aware that, due to the many variables of the "normal" railroad track site, an unyielding set of "exact" guidelines for inspection is impossible to formulate. However, one should also be aware that

Vertical line denotes change

LIME STABILIZATION CONTRACTOR'S
WEEKLY WORK REPORT
W.E. 11/10, 19 74

R.R. Name ______________ Region ______________

R.R. Division Engineer ______________ Location ______________

R.R. Inspector or Flagman ______________ Location ______________

Job Location: Fayetteville State North Carolina

	MON	TUES	WED	THURS	FRI	SAT	SUN
DATE	4	5	6	7	8	9	10
Temperature Daily (high and low)	60-80	60-78	50-71	41-59	34-55	34-56	off
Precipitation Daily (inches of rainfall)	none	none	none	none	none	none	
Location of Area Worked (mile post, etc.)	30.2	29.9	29.8	29.6	29.5	29.4	
Track Injected (feet)	429	429	468	624	468	468	
Injected Spacing (cribs)	2/3	2	2	2	2	2	
Injection Depth (feet)	10	10	10	10	10	10	
Injection Pressure (psi)	75	75	75	75	75	75	
Lime Delivered Per Day (tons)	20.1	16.1	15.1	18.2	17.0	16.6	
Lime Water Ratio (lbs. per gallon)	2.5-3	2.5-3	2.5-3	2.5-3	2.5-3	2.5-3	
Customer Delays (hours)	none	none	none	none	none	none	
On Track Work Time (hours)	10	10	10	10	10	10	
Total Hours All Employees on job per day	35	32	33	36	35	33	
Site Description (cut, fill, level, etc.)	fill	fill	fill	fill	fill	fill	
Soil Description (general terms)	clay, clay,	pipe gumbo	and sand	same	same	same	

Lime Supplier and Location ______________

Contractor's Injection Unit Number 69-18 Haul Truck Unit Number 68-16

Method of Mixing Lime and Water Slurry tank with mechanical agitator

Type of Surfactant Wet-it Ratio 1 gal. to 6500 gal.

Any Unusual Conditions Monday middle injector stuck in ground. Worked with it and got it out.

Fig. 14. Sample contractor's weekly work report.

there are numerous items of the lime injection process that can and should be carefully controlled.

For example, the density of the lime slurry can be controlled to within a certain stipulated measurable tolerance (±10 percent). Also, the injection interval, the total depth of injection, and the average gallons of slurry injected per track foot at the proper depth can be controlled. The inspector should insure that all items in the lime injection plan and specification are followed by the contractor and railroad and that good workmanship and safe construction procedures are enforced.

Because post-injection performance criteria have not been established for lime injection stabilization, the recorded eyewitness report of the technical inspector will usually constitute the only record of the compliance of the injection contractor. The current typical injection contract requires that bulk hydrated lime and clean water be placed into the roadbed soils, but only the amount of lime being placed is normally controlled through purchase records. A positive measure for cross-reference of both of these bulk materials is very important. This can be accomplished by measuring and recording the number of gallons of water utilized, as well as the amount of lime. These data, in addition to the regular checks on slurry consistency, will insure adherence to agreed-upon lime-water ratios.

The inspector should have some knowledge of the roadbed soil profile and be aware of the total plan for stabilization. This is necessary to assure that the lime slurry is placed at the proper depth below the track to best treat the problem-causing soils. For example, if the site to be treated contains a problem soil layer at the 3- to 7-foot level, then most of the lime must be injected at this level. A continuous active attempt must be made to place the slurry at the proper depth. Sometimes this will be very difficult at the predetermined spacing; but usually experiments with different spacings (e.g., every second tie rather than every third tie), flow rates, pressures, and densities will indicate how the desired results can be achieved.

These are the major items that the inspector should check; however, it should be stressed that the inspection process is often a full-time proposition because there are so many items that need to be checked that will go wrong if not properly controlled.

To obtain the best results, the railroad inspector should receive specialized training by attending railroad, contractor, or university seminars; and he should have access to expert advice regarding injection problems in his particular soil formation. He should be trained to the point where he comfortably understands the factors involved in the control of a successful lime injection stabilization project.

Evaluations

It is recommended that each railroad compile performance records for every lime-injected area and maintain the records on each site for a minimum of five years. A suggested format of pertinent information is shown in Appendix B, Form 3. By compiling performance records, each railroad will be forming its data base for making economical decisions concerning when to best use LSPI stabilization as remedial and/or upgrading measures. Also, the data contained in Form 3 will eventually provide the railroad a data base for knowing which materials and conditions on their lines are injectable, are not injectable, have specific injection interval requirements, have specific injection technique requirements, and produce the largest benefits from LSPI treatment. By having the above data base, the field pump and laboratory tests for many sites along a railroad line could be eliminated; thereby, producing significant cost savings and still maintaining a high probability of success of LSPI treatment.

One summary of pertinent facts that each railroad should continue to fill is in a table such as Table II. Table II would summarize the injectability of soil types (Unified Soil Classification, ASTM D 2487). The injectability would be determined by field pump tests, and the in situ moisture content and density prior to pump testing should be listed. A material type with large differences in moisture content and density between sites may be found to have differing injectability behavior; however, this has not been investigated. At the present time, only part of the table could be filled in due to lack of adequate information on injected areas.

Vertical line denotes change

TABLE II

Injectability of Soil types

	Injectability
GW	
GP	
GM	Good injectability* w = 4% γ_d = 123 pcf
GC	Non-injectable* w = 7 to 20%, γ_d = 109 to 125 pcf
SW	
SP	
SM	
SC	
ML	Non-injectable*, ** w* = 22 to 30%, γ_d* = 90 to 100 pcf, w** = 25 to 45%
CL	Non-injectable silty clay to slight injectable lean clay with poor impregnation*,** w*,** = 17 to 33%, γ_d* = 85 to 104 pcf
OL	Organic soils do not have good soil-lime chemical reactivity
MH	
CH	Non-injectable** w** = 43 to 53%
OH	Organic soils do not have good soil-lime chemical reactivity
P_t	Organic soils do not have good soil-lime chemical reactivity

NOTES: w = in situ water content
γ_d = in situ dry density

* From the U. S. Army Engineer Waterways Experiment Station Test Sites in Vicksburg, Mississippi.
** From the Rock Island Railroad Test Site, Forrest City, Arkansas.

Vertical line denotes change

III. SURFACE AND SUBSURFACE SOIL EXPLORATION AND TESTING

Application of the LSPI method of stabilization to a section of problem track should be based upon a thorough soil investigation, including both surface and subsurface exploration. A detailed surface exploration often will provide preliminary identification of the problem. Subsurface exploration (drilling), soil sampling, and laboratory testing will help verify the identity of the problem and indicate whether LSPI has the potential to improve the roadbed soils. If the use of LSPI is indicated, the data obtained from exploration and testing will serve as a basis for preparing the injection specification.

SURFACE EXPLORATION

Most squeezes, differential soil movements, and embankment failures can be broadly classified as resulting from two different, but often related, problems: low strength and volumetric instability of the embankment soils. The information obtained during a surface exploration together with historical data from railroad maintenance records will help indicate if there is a strength problem or a volumetric stability problem or both. Subsurface exploration will aid further in identifying the nature of the problem.

Surface exploration should include a detailed visual inspection of the problem track area and the surrounding terrain features (e.g., embankment, drainage ditches, adjacent fields). The engineer should look for squeezes, mud pumping, foul ballast, washouts, side-slope failures, ponded water, and horizontal and vertical track movement. Photographic records and detailed sketches of the problem track area should be prepared. A series of cross-sectional elevation measurements at intervals close enough to describe the important changes in topography provide additional important information. Figure 15 is an example of what an embankment cross section might look like. The points of interest, which are indicated in the figure by circled numbers, include:

(1) The drainage ditches are too shallow, are overgrown, and contain water.

(2) The lower bulges may be berms or the result of either up-slope erosion or embankment slope failure. Visual inspection indicates slope failure.

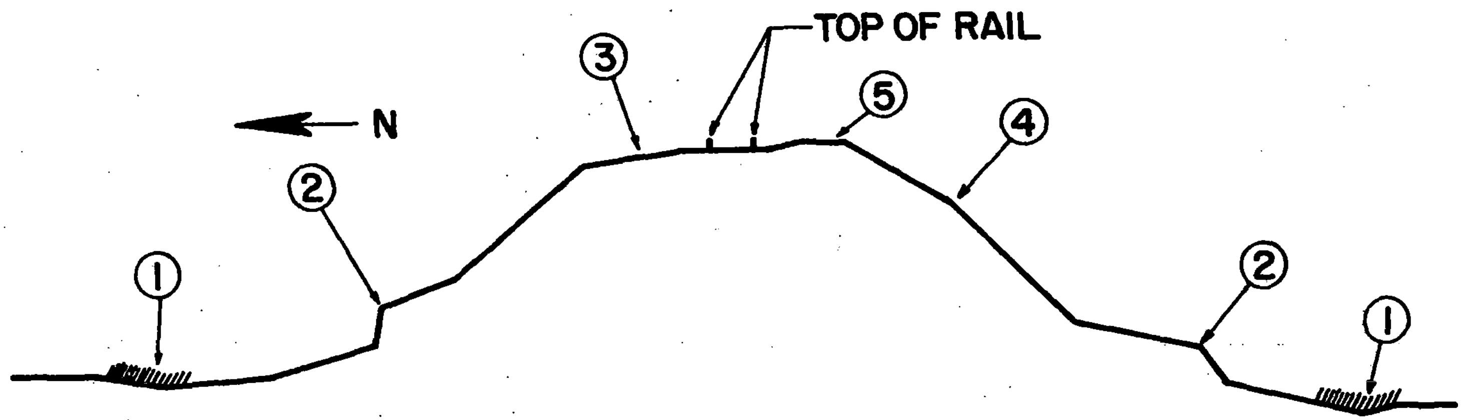


Fig. 15. Embankment cross-section.
(Note: See text for circled-number description.)

(3) The flat grade (flatter than that generally used by railroads) could be further evidence to support the slope-failure conclusion.

(4) The mid-embankment bulge could be the result of down-slope erosion or slope failure, or it could be caused by settlement of the embankment.

(5) The upper bulge could indicate that there is a squeeze on the south side of the embankment or that the north side is moving due to settlement or slope failure, leaving the south side undisturburbed.

The overall conclusions from this surface exploration would be:

(1) The embankment is suffering from a strength problem as evidenced by the various embankment failures on the slopes.

(2) The track elevation is sinking relative to the surrounding countryside. This could be related to the strength problem.

(3) This section of track was investigated because its poor condition was indicated by a poor riding quality. It is possible that this is strength related.

SUBSURFACE EXPLORATION

Laboratory testing of soil samples obtained by drilling will indicate the nature and engineering properties of the roadbed soils. Soil drilling usually can be best accomplished with a standard highway-type drill truck equipped with hy-rail wheels (Figures 16 and 17). In some instances, drilling can be accomplished with a rubber-tired truck; however, for general mobility, the hy-rail vehicle has proven best.

Before beginning subsurface exploration, the soils engineer must determine how many borings will be necessary. The number of borings and the number of samples required may vary depending on the nature of the problem. Table III is a general guide for estimating the scope of the drilling and testing program.

TABLE III

Estimated Borings per Length of Track

Length of Problem Track	Number of Borings
0 - 1000 ft.	2 + Length/250
1000 - 4000 ft.	6 + (Length - 1000)/300
4000 - 10000 ft.	16 + (Length - 4000)/400

The locations of the borings also must be selected. There are few established guidelines for locating the borings other than that the borings will be taken on the track center line if a hy-rail drill rig is used and that they should be spaced as evenly as possible to give overall subsurface information but grouped where necessary to give detailed information. The choice of the precise locations thus rests on the soils engineer's evaluation of all the data available at the time and should be flexible for modification as sampling and testing progress.

In locating borings, the soils engineer also should consider the value of allocating extra borings to an adjacent stable section of track. The resultant capability of comparing the two sections may prove invaluable in determining why the problem area is unstable.

Another initial decision concerns the termination depth for each boring. The borings should be no deeper than about 20 feet and should determine:

(1) if the water table is within the 20-foot depth and its position;
(2) within the top 20 feet, all interface depths of ballast, subballast, ballast mixtures, soil layers, and natural ground; and
(3) if drainage ditches or ponding areas are within the top 20 feet.

Low-strength material below about a 10-foot depth is train loaded fairly uniform with low pressures and a large spread

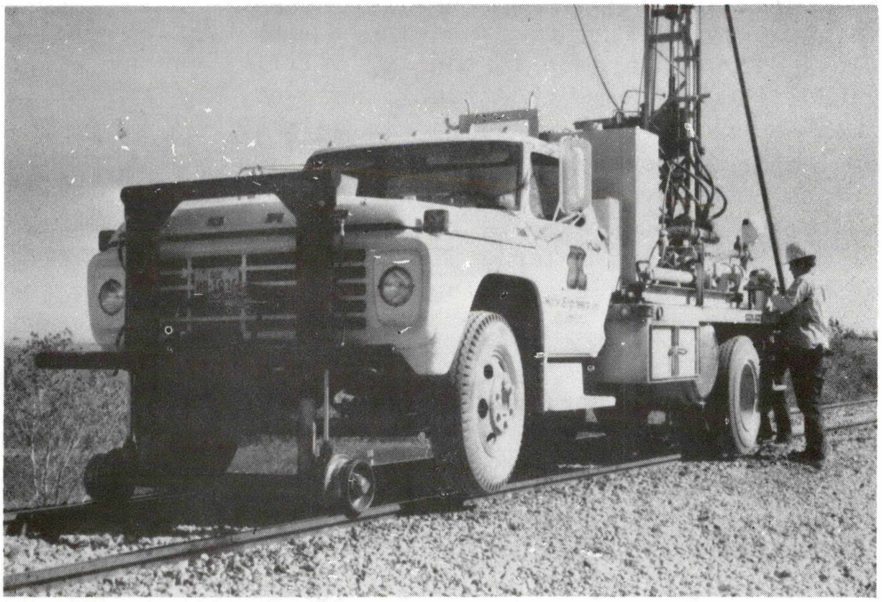


Fig. 16. Drilling rig mounted on hy-rail wheels.

Vertical line denotes change

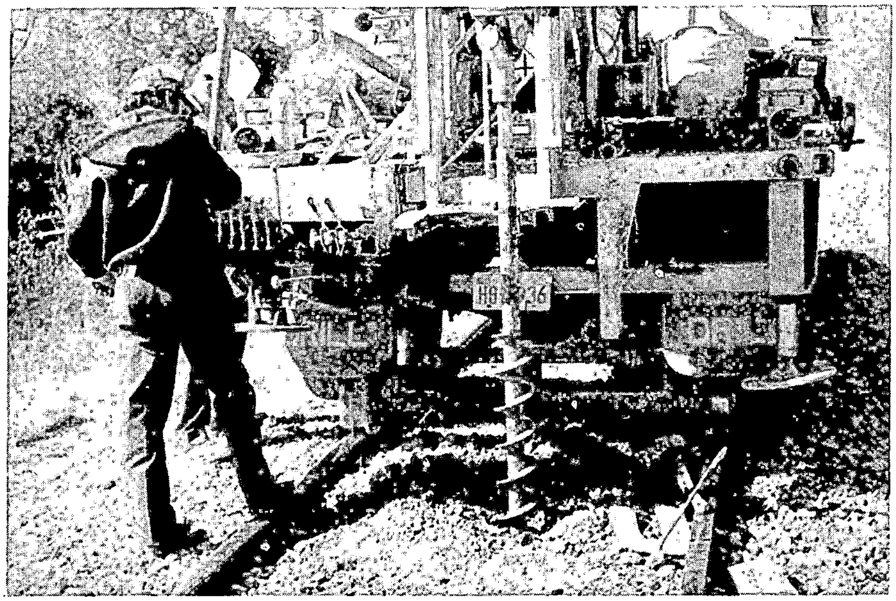


Fig. 17. Drilling in progress.

distribution such that load-induced deformations should generally be negligible. If train load-induced deformations do occur in material below about 10 feet, they will result in large spread uniform movement at the surface and will not cause extensive differential movements.

It often is a good rule to locate the first boring in the middle of the problem section. The engineer can closely monitor the boring and determine, based on the above guidelines, a reasonable depth at which to terminate the subsequent borings. Subsequent borings should extend about 2 to 5 feet below the anticipated maximum injection depth.

For the actual drilling operation, it is considered good practice to:

(1) Obtain undisturbed samples according to ASTM D 1587-74.

(2) Obtain continuous undisturbed samples for a distance of 5 feet just under the ballast and at regular or selected intervals to completion of the boring. A 5-inch inside diameter (ID) fixed-piston sampler is recommended for use in very soft to stiff clays and silts both above and below the water table. The sampler moves with respect to the piston within it only during the actual push; this creates a vacuum that helps suspend the sample in the tube and retains it after the push is made. A 6-inch ID core barrel sampler, such as a Denison sampler, for use in the ballast and any gravelly

Vertical line denotes change

layers is recommended as the sample tube in the fixed-piston system and may be bent in pushing through crushed stone. However, the fixed-piston sampler may be tried in the degraded and mixed ballast layers.

(3) Obtain bag samples wherever it is not possible to obtain undisturbed samples.

(4) Determine the elevation of the water table.

(5) Determine penetration values in the materials with a standard tool, such as the Dutch cone or Standard Penetration Test blow count. (These values can be used as a guide in achieving a subjective determination of the nature of the problem at the site.)

(6) Never use the washed-boring method of drilling unless absolutely necessary.

(7) Install perforated pipe in a few selected borings to monitor water level fluctuations.

Close study of the extrusion of the samples from the sample tubes will yield important information. The extrusion process should be supervised by a soils engineer or technician experienced in identifying sand or silt lenses, seams, cracks and fissures, root lines, voids, slickensides, and other means by which the slurry could be expected to travel extensively through the soil mass. This information is essential in making the final decision regarding injection.

If the undisturbed samples are extruded in the field, they should be processed and handled carefully to ensure that they remain in an undisturbed state. Samples to be taken to the laboratory should be sealed in containers of either cardboard or metal, 1 inch greater in diameter and 1-1/2 to 2 inches greater in length. The containers, with samples inside, must be completely sealed with a mixture of 1-to-1 of melted paraffin and microcrystalline wax. This wax mixture will not become brittle when cold. When applied to the soil sample, the wax mixture should be approximately 20°F above the melting point to prevent penetration into soil pores and cracks. Samples that are just wrapped and sealed in some manner do not remain undisturbed due to handling, transporting, storing, etc. Moisture and density samples may then be obtained in the laboratory from the inside of the field-extruded samples. It is important to obtain a moisture-content profile for each boring and, subsequently, for the entire site.

The next step of subsurface exploration is the preparation and interpretation of soil and moisture-content profiles. The soil profile should be plotted to scale, showing all important surface features and each soil layer. The plotting of a moisture-content profile, either on the soil profile or as an overlay to the soil profile, is good practice. Such a profile is a ready reference for determining zones of elevated moisture content in relation to the soil profile and will help to determine the

Vertical line denotes change

injection depths when writing the injection specifications. Figure 18 is an example of a soil profile showing the moisture contents and other soil test results.

The soils engineer should select the samples for laboratory testing very carefully. The economic factor will determine the size of the testing program; therefore, the amount of funds allocated to this area should reflect the realistic needs of the railroad to improve its track and should be flexible to allow the engineer to adjust the number of samples for adequate investigation of the problem.

Soil Testing

Soil testing for LSPI stabilization of roadbeds can best be described as a developing technology. The purpose of the testing program is to determine whether LSPI will improve the roadbed soils and to guide in preparing injection specifications. Although the suggested laboratory tests will give some data that will, in effect, indicate the soil improvement, it is not possible at the present time to obtain a one-to-one correlation between laboratory results and the degree of success in the field. The development of yes-no laboratory tests for the use of LSPI is still in the preliminary stage. Presently, the only way to determine the behavior and possible success of LSPI for improvement of roadbed materials is to conduct a field-pump test and obtain undisturbed* samples for inspection or cut open a trench. The pump test will indicate if roadbed materials are injectable and the spacings and depth intervals that should be used. For roadbed materials that are not injectable, the following laboratory tests need not be conducted. Also, if the soil is not chemically reactive with lime, intimately mixed slurry and soil strength testing is meaningless.

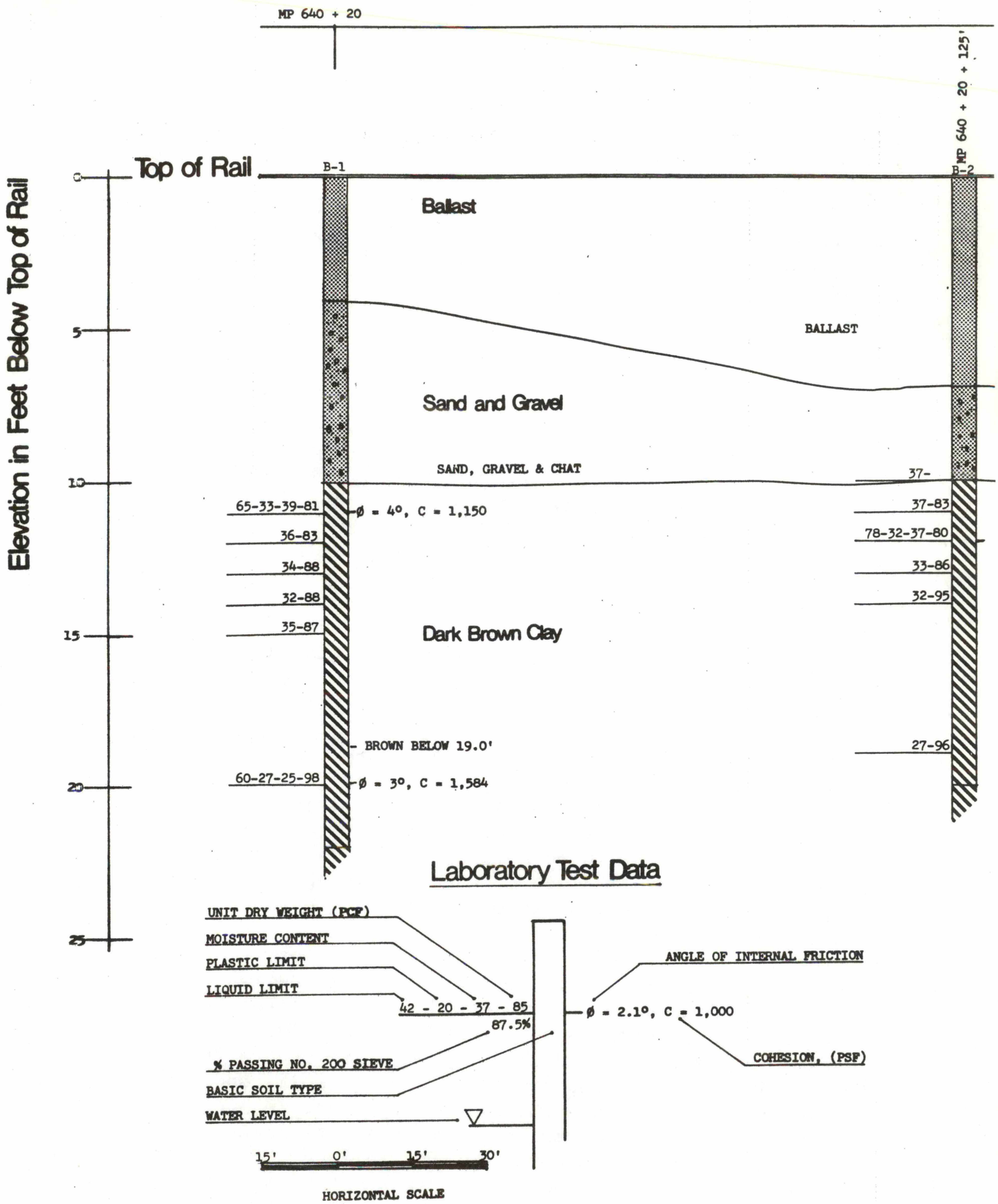
The amount of lime recommended for laboratory testing is 1 percent of the soil dry weight. This has been estimated to be the amount of lime generally injected during railroad LSPI operations, based on injections on 5-foot centers. Just as it may be necessary in the field to double inject or to reduce the space between injections to compensate for certain soil conditions, it may be necessary to modify the laboratory tests to account for the same conditions by increasing the percentage of lime.

The tests that are recommended for railroad LSPI stabilization evaluations are described below and presented in tabular form in Table IV. Other LSPI stabilization-evaluation tests that provide supporting information to the ones in Table IV but should not be

---

* See footnote at bottom of page 3.

Vertical line denotes change


MP 640 + 20
MP 640 + 20 + 125'
Elevation in Feet Below Top of Rail
Top of Rail
0
5
10
15
20
25
B-1
B-2
Ballast
BALLAST
Sand and Gravel
SAND, GRAVEL & CHAT
37-
65-33-39-81
ø = 4°, C = 1,150
36-83
34-88
32-88
35-87
37-83
78-32-37-80
33-86
32-95
Dark Brown Clay
BROWN BELOW 19.0'
27-96
60-27-25-98
ø = 3°, C = 1,584
Laboratory Test Data
UNIT DRY WEIGHT (PCF)
MOISTURE CONTENT
PLASTIC LIMIT
LIQUID LIMIT
42 - 20 - 37 - 85
87.5%
ANGLE OF INTERNAL FRICTION
ø = 2.1°, C = 1,000
COHESION, (PSF)
% PASSING NO. 200 SIEVE
BASIC SOIL TYPE
WATER LEVEL
15' 0' 15' 30'
HORIZONTAL SCALE

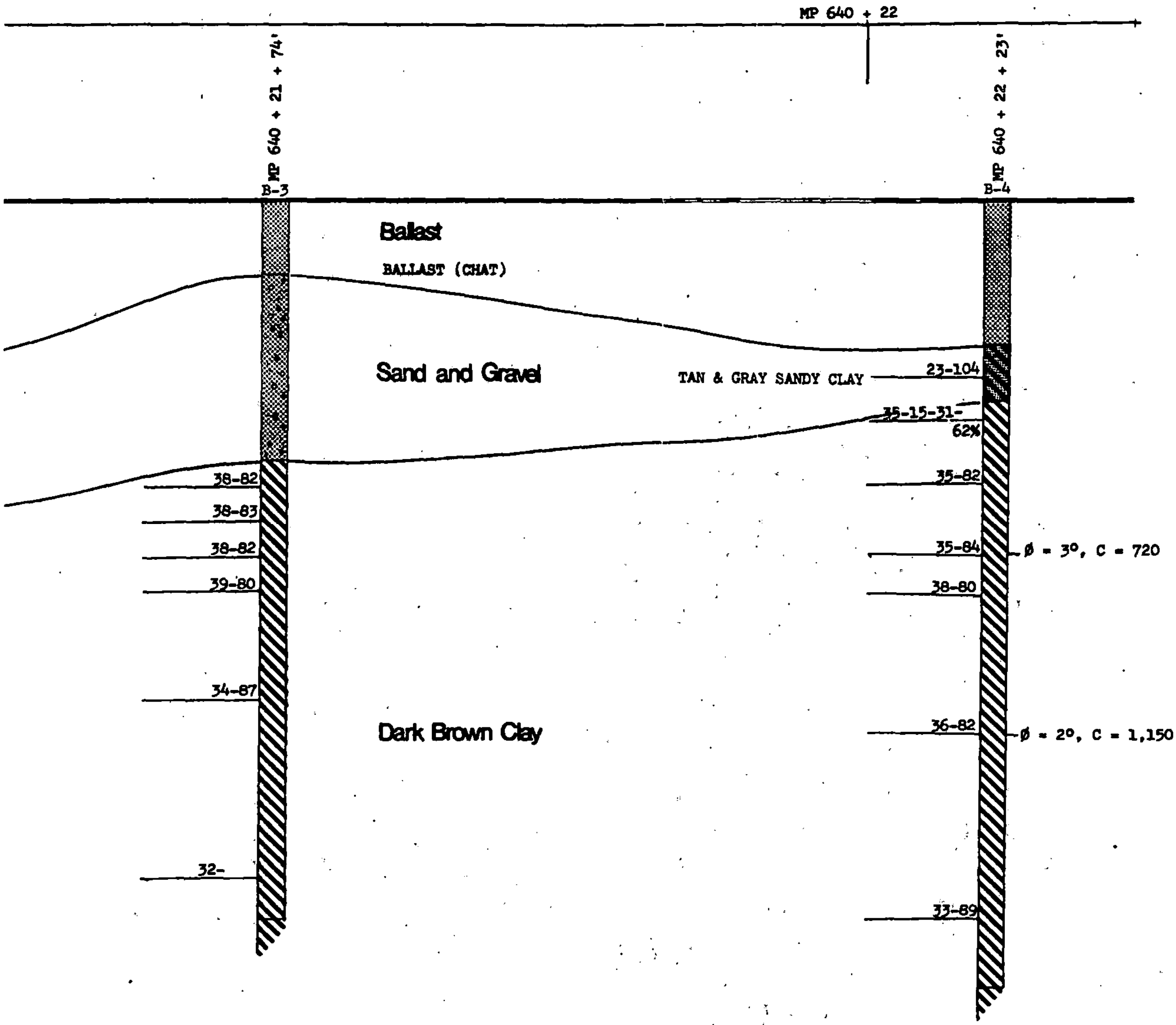


Fig. 18. Soil Profile.

TABLE IV

LSPI Soil Tests with Positive Results

Group	Test	Positive Result for LSPI
Preliminary	Atterberg Limits	Decrease in Plasticity Index
	Field-Pump Test	Injectable plus good dispersion and impregnation
	Soil-Lime Chemical Reactivity	Reactive at pH 12.4
	Gradation and Classification	
Strength	Natural Triaxial	No positive results; data give the untreated strength conditions
	Unconfined Compression	Increase in average peak strength and in slope of stress-strain curve
Volumetric Stability	Volumetric Shrinkage	Decrease in the amount of shrinkage

Vertical line denotes change

considered as necessary or mandatory can be found in the works of Thompson, Blacklock, and others in the Bibliography. The minimum test program that should be conducted includes:

(1) Field-pump test.
(2) Soil-lime chemical reactivity.
(3) Unconfined compression (remolded samples).
(4) Atterberg limits.
(5) Volumetric shrinkage.
(6) Gradation and classification.

Combined results from the above tests will define whether LSPI can or cannot be used to effect positive changes in roadbed materials. Strength determinations for analytical evaluations of the injected subgrade should be made from laboratory tests on specimens taken from post-injection undisturbed samples or preferably determined by in situ testing techniques. Appendix C includes the standards, specifications, and procedures for the recommended LSPI evaluation tests. In the following discussion, the tests are divided into three groups, viz., preliminary, strength, and volumetric stability.

PRELIMINARY SOIL TESTS

The four preliminary tests should be performed according to standard specifications, except that the treated samples containing 1 percent by weight of intimately mixed dry lime are compared with control samples containing no lime. The field-pump tests and soil-lime chemical reactivity tests will dictate if further soil tests are desirable and should be the basis for deciding whether or not to inject any of the roadbed materials.

Field-Pump Test. Field-pump tests can be performed by the same drill rig and crew that obtain the initial soil samples. Lime slurry and an injection rod with a tip similar to those used by LSPI companies should be used. The purposes of the field-pump tests are to determine (1) those roadbed materials (including lower ballast materials) that are injectable, (2) if a sufficient amount of lime seams and lime-filled cracks are forming, (3) if sufficient lateral dispersion is occurring to cover the space between injection rods, and (4) if the soil is being impregnated with slurry or supernatant liquid. Positive results would be saturation of a material with either slurry or supernatent, closely spaced (a few inches) lime-filled seams or a web of lime-filled cracks, lateral dispersion of the lime-filled seams and cracks to at least half the distance between normal injection rod spacing, and impregnation of the soil around each seam or crack for at least a few inches. The best method for injection can be determined in terms of injection intervals with depth (including the omission of noninjectable materials), injection rod spacing,

Vertical line denotes change

injection pump pressures, and whether continuous pressure and flow should be used. The roadbed materials that are noninjectable can be eliminated from any further tests or sampling in the field or laboratory.

Soil-Lime Chemical Reactivity. The roadbed materials that are injectable with positive results from the field-pump tests should be checked for chemical reactivity. Unless the soil and lime are chemically reactive, no cation exchange and pozzolanic reaction will occur and the soil will not gain in strength or stability. A positive result from this test is that about a pH 12.4 must be achieved in lime and soil mixtures with 1 to 2 percent lime. Roadbed materials that are not chemically reactive with lime, even though they are injectable, can be eliminated from strength gain testing. However, if the materials have positive results from the field-pump tests and a significant amount of lime can be impregnated per cubic foot of soil but have negative chemical reactivity tests, injection may still be worthwhile if swelling and shrinkage are a problem. Volumetric stability testing can be used to evaluate the effects of lime on shrinkage and swell characteristics. Also, materials that have good positive field-pump test results, even though they are not chemically reactive, may be injected to form moisture barriers. The concentration of lime-filled seams and cracks will tend to stabilize any moisture fluctuations. However, it should be pointed out that infiltration of water from the surface can be significantly reduced by filling the lower ballast materials with slurry.

Gradation and Classification. Gradation curves should be determined for each material except those that contain negligible material in the sand-size range. Also, each material should be classified according to the Unified Soil Classification System.

Atterberg Limits. A positive result from this test, which is a combination of the Liquid Limit and Plastic Limit tests, is a reduction of the Plasticity Index (PI). Generally, the liquid limit can be lowered by no more than approximately 2 percent, so the major change must occur in the plastic limit. There are no criteria for ascertaining how great a reduction in PI is necessary before it may be termed a significant improvement. Whether the improvement is significant will depend upon the type of soil, the other test results, and the judgment of the engineer. Reductions in PI ranging from 5 to 15 have been obtained in soils judged reasonable responsive, based on laboratory testing, to LSPI treatment.

SOIL STRENGTH TESTS

The following strength tests should be conducted only if a material is chemically reactive with lime. An exception is the

Vertical line denotes change

natural triaxial test that determines the in situ strength conditions to aid in analysis of the roadbed problems.

Natural Triaxial. Triaxial compression tests on natural, undisturbed samples (unconsolidated, undrained) are suggested in order to ascertain the in situ strengths of the roadbed materials. The soil strength must be compared with the stresses caused by train loads and overburden pressures. If there is no accurate way to determine soil stresses, through either calculations or field tests, the results can be interpreted only subjectively as to whether the soil has a low, medium, or high strength with respect to imposed loadings. However, this is necessary and useful information for determining whether the materials have the strength to support the loads or whether the track system needs to be strengthened.

Unconfined Compression. This test, comparing remolded samples using either (1) supernatant liquid from lime slurry or (2) lime slurry with remolded samples at the in situ moisture content, has the advantage of requiring less soil than some of the other tests. A strength increase of 50 psi or greater is a positive result. However, if the addition of lime to a remolded sample produces no improvement in laboratory test results over results from untreated remolded samples, then LSPI, which in no way can duplicate the intimate mixing possible in remolded samples, will not produce field strength increases.

VOLUMETRIC STABILITY TESTS

Volumetric Shrinkage. For this test, samples intimately mixed with 1 percent dry lime are compared with untreated samples. Any reduction of shrinkage detected in this test is a positive result. Generally, reductions of 5 to 10 percent indicate that LSPI has a good chance of reducing shrinkage in the field.

THE DECISION PROCESS

Based on the surface and subsurface explorations of a problem area, the soils engineer should identify the cause of the problem and consider all possible solutions. For example, problems may be caused by more and heavier traffic on inherent low-strength material, by strength loss due to increased water content, by differential movements caused by swelling clays, by pumping and movements caused by degraded fowled ballast, inadequate embankment side slopes, etc. Possible solutions could include such approaches as LSPI for strength increase and/or moisture control, thicker ballast depth to decrease load-induced stresses, closer spaced ties, or other methods for decreasing load effects, improving drainage ditches, and/or installing drains into the embankment, clean

Vertical line denotes change

ballast, flatter embankment side slopes, chemical grouts other than lime, etc. The costs associated with each possible solution should be compared.

If LSPI appears to be the best approach, the engineer is then faced with: Will the injection of lime slurry make a positive improvement in the roadbed materials? In compiling the data on which to base his answer to this question, the engineer must make numerous decisions, beginning with the surface exploration of the site and culminating in the evaluation of all the data, especially the information obtained from the field-pump tests. The flow chart in Figure 19 has been devised to guide the engineer through this decision process.

If the field-pump tests have positive results, and after the laboratory tests have been performed, the engineer will be faced with making a yes-no decision on the use of LSPI based on the test results and all other available data. In assessing the laboratory test results, the engineer should credit as a "yes" any positive improvements. If no improvement is detected by a test, a "no" should be registered. While a "no" result does not indicate that LSPI will be bad for the site, it does mean that the laboratory test gives no encouragement for the prospects of positive soil improvement. In most cases, several "no" answers will lead the engineer to conclude that LSPI should not be recommended; and if all treatment-type tests give no indication of improvement, LSPI definitely should not be recommended. Clearly, materials shown to be noninjectable with the field-pump test should not be LSPI-treated. If, based on the evaluations, LSPI should not be used, an alternate approach will have to be chosen from the possible solutions and evaluated.

Because of the large number of possible variables in the LSPI type of testing, statistical analysis of the data is often of considerable benefit. Because statistics is a broad subject, it will not be covered in this handbook. Those not familiar with the use of statistics in soils engineering analysis should seek assistance in this area or, if none is available, simply rely on their own experience and engineering judgement for evaluation of the test results.

INTERPRETATION OF RESULTS

Interpretation of the data obtained from the laboratory tests is not a simple task because the mechanisms by which LSPI stabilizes the soil are not totally understood.

The particle size of the soil (i.e., clay, silt) and the existence of fissures and cracks must be considered because it is unlikely that lime particles will be transported into the soil mass if the soil is a heavy or fat clay and if no flow paths exist.

Vertical line denotes change

Furthermore, any improvement shown in the laboratory tests is only an improvement in the quantities measurable in a laboratory on a laboratory-sized soil sample. The soil sample is not an exact model of the soil mass. No decision should be made solely on the basis of the data from the Atterberg limits and volumetric shrinkage tests.

The following hypothetical example indicates how the test results can be weighed in determining whether LSPI will stabilize the soil.

Preliminary exploration indicates the soil is volumetrically unstable. The appropriate tests outlined in the flow chart (Figure 19) were performed with the following results:

Field-Pump Test: Positive with good impregnation
Soil-Lime Chemical Reactivity: Positive
Unconfined Compression: Strength increase greater than 50 psi
Atterberg Limits: No change
Volumetric Shrinkage: 6% reduction

The conclusion to be drawn from these results is that the addition of lime decreases the volumetric instability and increases strength. Therefore, the laboratory tests indicate that lime injection may be recommended.

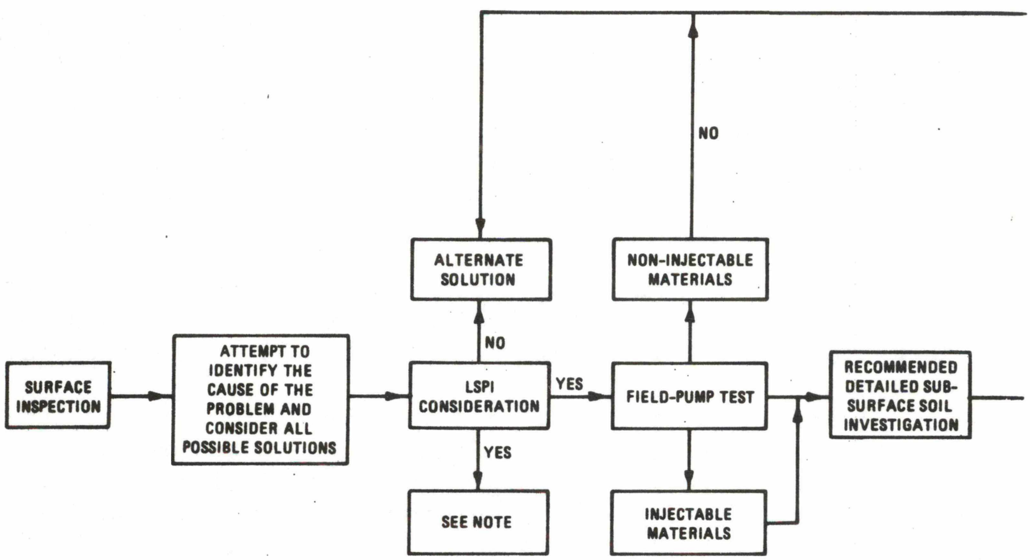
The preceding example shows a data combination that is reasonably simply to interpret. It often will be more complex.

When the laboratory results give no clear indication of the appropriate conclusion, a soils engineer experienced in data interpretation in the LSPI field should be consulted. He would then consider the results of the laboratory tests and all other factors involved in the investigation.

In cases where considerable doubt exists as to the practicality of LSPI treatment, it may be feasible to consider injecting only a small test section, perhaps one mile, of track. This method would be cost effective if (1) other sections of track were being injected and (2) the railroad could wait for an extended period of six months to a year to determine whether LSPI improved the soil mass. If this method is selected, an evaluation plan that fully considers the actual source of track improvements must be prepared. For example, a tie-and-surfacing operation often precedes or follows an LSPI treatment. The tie-and-surfacing operation alone provides a better track surface for a period of time, and it may sometimes prove difficult to separate the beneficial effects of that operation from those attributable to LSPI.

Today there is no simple method of obtaining a yes-no answer for all possible LSPI sites. Further research may provide more answers. The surface and subsurface soil explorations and the tests outlined in this handbook will aid in obtaining more effective and economical utilization of the LSPI method of track stabilization if used as an integrated whole.

Vertical line denotes change



NOTE: IN SOME INSTANCES (e.g., SPOT TREATMENT), IT MAY BE MORE ECONOMICALLY VIABLE TO BASE THE DECISION TO USE LSPI PURELY ON THE BASIS OF THE SURFACE INSPECTION. THIS IS RECOMMENDED ONLY WHEN THE COST OF THE LABORATORY ANALYSIS IS COMPARABLE WITH, OR EXCEEDS, THE COST OF INJECTION. HOWEVER, THIS APPROACH IS RISKY.

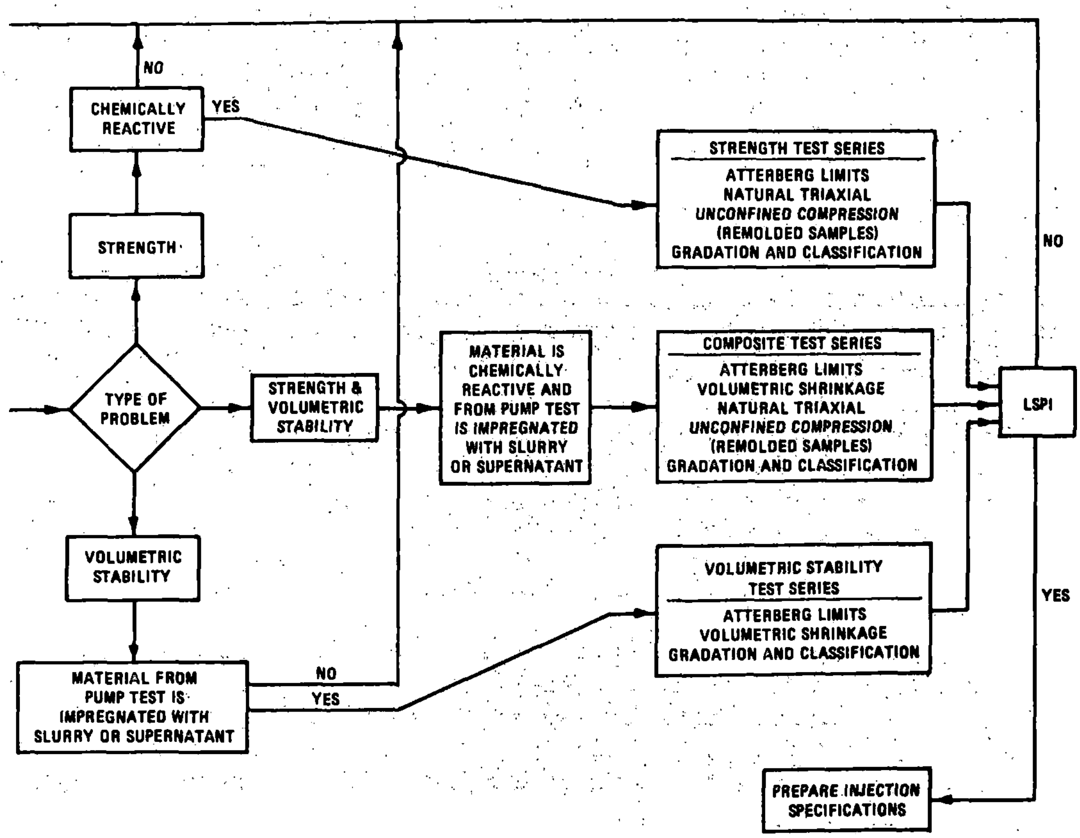


Fig 19. Decision flow chart.

IV. ENVIRONMENTAL CONSIDERATIONS

The LSPI method of roadbed stabilization possesses only a small potential for adverse environmental effects. If reasonable care and precautions are exercised, the possibility of a serious problem developing will be minimal.

The potential adverse effects are included in three overlapping divisions: physiological, aquatic, and botanical. For example, the injection of fluids into the ground can result in contamination of a well used to supply water for human consumption. In addition, the right-of-way may be denuded as a result of alteration of the pH of the soil. Spillage of lime slurry into local waterways may result in fish kills because of the introduction of toxic materials or through drastic adjustment of the pH of the water. Also, the phosphate contained in lime slurry could contribute to the triggering of an algae bloom.

Currently, there is public concern over the quality of drinking water, as reflected in the passage of Safe Drinking Water Act, Public Law 93-523. Public-interest groups and water utilities will not hesitate to bring suit against contractors if there is suspicion that they have endangered local water supplies. To guard against contamination of water supplies, care must be taken in handling the lime slurry, particularly when wetting agents are used.

The lime contains trace materials that are of concern. Analyses obtained from vendors list the presence of arsenic and flouride. The current Safe Drinking Water Standards under Public Law 93-523 are 0.05 milligrams per liter for arsenic and a maximum level of 1.4-2.4 milligrams per liter for flouride, depending upon water temperatures. While the levels reported in commercial hydrated lime are low--0.368 milligrams per liter for arsenic and 0.260 milligrams per liter for flouride before dilution with water--careful handling is required to protect local supplies of drinking water.

The lime slurry also has been found to contain barium, cadmium, lead, selenium, silver, zinc, and manganese; however, none of these materials have been found in a sufficient quantity to present a significant problem of ground water contamination at the current levels of lime use in LSPI railroad treatments.

Lime contains sulfates, which can be reduced in anaerobic environments to hydrogen sulfide, H_2S, and cause objectionable odors in well water. The sulfates are reduced in the presence of organic substrates that are oxidized in the process and act as hydrogen acceptors. This will be a problem if organic contamination is present in the ground water for oxidation by microbial respiration.

The polyvalent cations in the slurry will displace monovalent cations in the clay. There will be increases in dissolved sodium and potassium in the ground water around the injection site; however, the hardness of the ground water will not be appreciably affected in the area surrounding the injection site. Current data on the epidemiological significance of moderately hard waters compared with soft waters suggest a slight increase in hardness will have a beneficial effect. In total, the change in mineral content of well water adjacent to the site would be negligible.

The addition of surfactants to lime slurries poses some additional problems. Care must be exercised in the selection of the additive because a number of surfactants have undesirable physiological effects. The use of any chemical should be preceded by an initial check of the Toxic Substance List compiled by the National Institute of Occupational Safety and Health for known carcinogenic, mutagenic, teratogenic, or toxic effects. Suspicious chemicals should be avoided. Time spent on determining what is in the additives can save a contractor or railroad from extended litigation.

The potential visible effects of LSPI on the environment are fish kills, algae blooms, and destruction of vegetation. These effects, which are highly visible and are likely to lead to immediate reaction in the local community, can be avoided by limiting the amount of excess pumpage of lime and by careful disposal of excess lime from the slurry tanks.

The lime contains approximately 0.1 percent phosphate, equivalent to about 1000 milligrams per liter. The current concentration accepted for the limitation of algae blooms in a waterway is 0.01 milligrams per liter phosphorous. Thus, there apparently are significant amounts of phosphorous in the slurry. The phosphate problem can be compounded by the use of commercial detergents, which have a phosphate content in excess of 50 percent as builders and wetting agents. Spillage of lime slurries into surface waters can potentiate eutrophication of these waterways. For example, the Arkansas State Standard is 0.001 milligrams per liter phosphorous in streams and less than 0.05 milligrams per liter in lakes. Assuming a 23 percent lime slurry (approximately 2 pounds of dry lime per gallon of water), it would require approximately 150 gallons of dilution water per gallon of slurry to stay below the state lake standard with regard to soluble phosphorous. Fortunately, most of the phosphate will exist as insoluble hydroxylapatite, a calcium precipitate.

Fish kills can occur in streams adjacent to LSPI sites due to increased pH levels. A pH of 10 or above will cause an immediate problem. Excessive pumping of the lime slurry to refusal or beyond and careless dumping of excess lime slurry can cause problems with fish kills. Most states have financial penalties for discharges that result in fish kills.

The Safe Drinking Water Act contains provisions for regulating subsurface chemical injection. The provisions and regulatory programs of this act require that a permit program be established for subsurface chemical injection by December 17, 1978. The permit program can be administered by the state if it submits a program that the Environmental Protection Agency approves. The eventual provisions of this program will carry civil penalties of up to $5,000 per day of violation or, for willful violators, $10,000 per day of violation. The impact of this act and its regulatory provision on the LSPI technique is difficult to assess at this point. The specifics of the programs called for are not available but will be effective in less than two years.

V. SAFETY PRECAUTIONS

Hydrated lime (calcium hydroxide), like most materials or chemicals in common use, is not dangerous to work with provided that precautions are exercised. While the danger of severe skin burns caused by lime is remote, it generally is desirable to prevent hydrated lime from coming into contact with a worker's skin. Prolonged contact of hydrated lime with skin damp with perspiration and chafed by tight clothing can produce bad burns. Thus, particular care must be taken to avoid the presence of lime slurry inside shoes or boots. Hot, humid weather tends to heighten the caustic effect of hydrated lime on the worker's skin. Also, persons with particularly sensitive skin have developed forms of skin irritation through prolonged contact. There is no urgency in removing hydrated lime dust from open skin areas, but it should be flushed off with water as soon as convenient.

If the following recommendations are followed, there is little possibility that workers will suffer skin burns or irritation. In a closed mixing system, the dangers from lime dust are avoided, and dust-related precautions are not necessary except during the transfer operation, when the workers should exercise care in protecting their eyes.

Clothing

1. Wear at least one shirt, preferably with long sleeves.
2. Wear high-top shoes or boots.
3. Wear long trousers over shoe or boot tops.
4. Wear hat or cap to protect scalp from accumulated lime dust.
5. Do not wear clothes that bind too tightly around the neck or wrists because chafing may cause lime dust to be more irritating to skin.
6. When conditions are quite dusty, a light-weight filter mask should be worn during open lime-transfer operations.

Eye Protection

Although goggles or safety glasses with side shields are recommended while working with lime, they are seldom worn by injection workers. It is important therefore, that the contractor have eye-wash kits readily available in the event of a hose break or other occurrence causing lime slurry to be sprayed into the worker's eyes. This is the most common cause of worker injury, and eye damage can be caused if the worker rubs the eye which has been sprayed with lime or if it is not washed immediately.

Skin Protection

Workers should bathe or shower after a workday to cleanse the body entirely of lime. When necessary, a solution of vinegar applied to the hands, feet, or other nonsensitive body parts will neutralize any lime which remains on the body after washing.

First Aid

Skin burns. Wash thoroughly with soap and warm water and vinegar to remove all lime. Apply a standard burn ointment used for heat or caustic burns and cover with sterile bandages. Keep bandaged during healing to prevent infection.

Lime in the eyes. DO NOT RUB THE EYE! Hold worker's eye open and flush with water immediately. Eye-wash kits should be carried on each vehicle.

Report all serious burns from lime or cases of lime in eyes immediately so that medical attention can be provided if necessary.

General Precautions

Generally, the workers most vulnerable to lime dust burns and the ones who should practice rigorously the above precautions are those handling bagged lime and those operating bulk-transfer equipment. In general, greater care should be exercised in bag applications than in bulk. Since the greatest danger is to the eyes, all workers emptying bags of lime must be equipped with close-fitting goggles. If a stooping worker should drop an open bag on the ground, the impact could cause a dense cloud of lime dust to arise directly into the worker's face. If his eyes were unprotected by goggles, loss of sight might result from lime burns. Workers in the vicinity of dry lime transfer and mixing operations should wear goggles to prevent a blast of lime dust from hitting their eyes.

The least hazard from lime burns is encountered in handling the lime slurry. Only workers with unusually sensitive skins are adversely affected by slurry splashing on their bare skin. But the same rigid care should be exercised to prevent lime slurry from getting into the eyes and shoes or soaked into clothing.

The above precautions are largely intended for contractors who are using lime for the first time. Contractors experienced with lime have learned to deal with these safety items. However, "an ounce of prevention" is important; so all contractors should carefully brief each worker, inspectors, and others at the job site on lime precautions and, most important, check to see that the worker abides by these few simple safety rules. Practically speaking, hydrated lime or slurry is no more dangerous to the skin than cement; lime is simply lighter and finer than cement and more prone to blow. Because the slurry is under high pressure, there is an added element of danger due to possible hose breaks.

SELECTED BIBLIOGRAPHY

Ahlf, Robert E., "M/W Costs: How They Are Affected by Car Weight and the Track Structure," Railway Track and Structure, 71, No. 3; p. 34 (March 1975).

Ballentime, George D., "Deep-layer Pavement Stabilization," The Military Engineer (May-June 1975).

Blacklock, James R., "Analysis of Lime Injected Roadbeds," Proceedings of Roadbed Stabilization Lime Injection Conference, August 21-22, 1975, FRA-OR&D-76-137 (Nov. 1975).

Blacklock, James R., "Evaluation of Railroad Lime Slurry Stabilization," Report No. FRA/ORD-78/09, U. S. Department of Transportation, Federal Railroad Administration, Office of Research and Development, Washington, D. C. (June 1978).

Boynton, Robert S., "Lime Stabilization Construction Manual," National Lime Association, Washington, D. C., Fifth Edition (1972).

Building Research Advisory Board, "Chemical Soil Stabilization," National Academy of Science, Washington, D. C. (1969).

Dunlap, et al., "U. S. Air Force Soil Stabilization Index System--A Validation," Technical Report AFWL-TR-73-150, Kirtland Air Force Base (Jan. 1975).

Farris, J. B., "Lime Injected Roadbed Stabilization Project Experiences," Proceedings of Roadbed Stabilization Lime Injection Conference, August 21-22, 1975, FRA-OR&D-76-137 (Nov. 1975).

Fohs, D. G., and Kinter, E. B., "Migration of Lime in Compacted Soil," Public Roads, 37, No. 1 (June 1972).

Harris, H. P., "Relation Between Ballast Type, Subgrade and Stability--Including Length of Maintenance Cycle," Committee Report presented to Roadmasters and Maintenance of Way Association of America, Sept. 1975.

Hay, W. W., "'Engineered' Track, Part 1: Effective Subgrade and Ballast," Progressive Railroading (March 1975).

Hay, W. W., "'Engineered' Track, Part 2: Ballast Stability and Prolonged Rail Life," Progressive Railroading (April 1975).

Heath, D. L., Shenton, M. J., Sparrow, R. W., and Waters, J. M., "Design of Conventional Rail Track Foundations," Institution of Civil Engineers Proc., London, 51 (Feb. 1972).

Higgins, C. M., "High Pressure Lime Injection," Louisiana Department of Highways Research Report No. 41 (June 1969).

Ingles, O. G., and Metcalf, J. B., Soil Stabilization--Principles and Practice," Wiley, New York (1973).

Lundy, H. L., Jr., and Greenfield, B. J., "Evaluation of Deep In-Situ Soil Stabilization by High Pressure Lime-Slurry Injection," 47th Annual Meeting Highway Research Board, Washington, D. C. (Jan. 1968).

McNutt-Schneller, Inc., "Evaluating Pressure Lime Injection by Factorial Analysis of Varience," McNutt-Schneller, Inc., Engineers, Little Rock, Arkansas, June 15, 1975.

Robnett, Q. L., Jamison, G. F., and Thompson, M. R., "Technical Data Base for Stabilization of Deep Soil Layers," Technical Report AFWL-TR-70-84, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (April 1971).

Robnett, Quentin L., "Alteration of Soil Properties as Effected by Various Lime Treatment Procedures," Proceedings of Roadbed Stabilization Lime Injection Conference, August 21-22, 1975, FRA-OR&D-76-137 (Nov. 1975).

Robnett, Q. L., Jamison, G. F., and Thompson, M. R., "Stabilization of Deep Soil Layers," University of Illinois, Technical Report AWFL-TR-71-90 (Jan. 1972).

Rone, C. Ronald, "Soil Exploration on Railroad Tracks - Why Necessary?" Proceedings of Roadbed Stabilization Lime Injection Conference, August 21-22, 1975, FRA-OR&D-76-137 (Nov. 1975).

Sheaff, David F., "Selected Case Studies of Lime Injected Railroad Track," Proceedings of Roadbed Stabilization Lime Injection Conference, August 21-22, 1975, FRA-OR&D-76-137 (Nov. 1975).

Thompson, Marshall R., "Lime Reactivity of Illinois Soils," Journal of Soil Mechanics and Foundations Division, 92, No. SM5; pp. 67-92 (Sept. 1966).

Thompson, Marshall R., "Factors Influencing the Plasticity and Strength of Lime-Soil Mixtures," Vol. 64, No. 100, Engineering Publication Office 112 Engineering Hall, University of Illinois, Urbana, Illinois, 61801 (April 1967).

Thompson, Marshall R., "Field Evaluation of Pressured Injection Lime Treatment for Strengthening Subgrade Soils," Proceedings of Roadbed Stabilization Lime Injection Conference, August 21-22, 1975, FRA-OR&D-76-137 (Nov. 1975).

Thompson, Marshall R., and Robnett, Q. L., "Pressure Injection Lime Treatment of Swelling Soils," Transportation Research Board Annual Meeting, Washington, D. C. (Jan. 1975).

Townsend, Frank C., and Donaghe, Robert T., "Investigation of Accelerated Curing of Soil-Lime and Lime-Flyash-Aggregate Mixtures," Technical Report S-76-9, Soils and Pavements Laboratory, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi (Aug. 1976).

Vickers, Albert F., "Environmental Considerations," Proceedings of Roadbed Stabilization Lime Injection Conference, August 21-22, 1975, FRA-OR&D-76-137 (Nov. 1975).

Wright, Paul J., "Lime Slurry Injection Tames Expansive Clays," Civil Engineering - ASCE, 43 (Oct. 1973).

Wright, Paul J., "Lime Injection Production Equipment and Techniques," Proceedings of Roadbed Stabilization Lime Injection Conference, August 21-22, 1975, FRA-OR&D-76-137 (Nov. 1975).

Note: FRA-OR&D-76-137 indicated in many of the above references may be obtained from NTIS as PB251681.

APPENDIX A

GENERAL SPECIFICATIONS FOR LIME SLURRY INJECTION

MATERIAL

1. The lime slurry shall consist of clean fresh water and hydrated lime (calcium hydroxide). A nonionic surfactant (wetting agent) may be used according to the manufacturer's recommendations.

2. The hydrated lime shall conform to the following requirements as to chemical composition (percent by weight):

Hydrate alkalinity, $Ca(OH)_2$	Min.	90.0%
Unhydrated lime content, CaO	Max.	5.0%
"Free water" content, H_2O	Max.	5.0%

3. The percent by weight of residue retained shall conform to the following requirements:

Residue retained on a No. 6 sieve	None	
Residue retained on a No. 10 sieve . . .	Max.	1.0%
Residue retained on a No. 30 sieve . . .	Max.	2.5%

4. Under no circumstances shall waste (reclaimed) lime be used.

5. The lime slurry shall be agitated continuously to insure uniformity of the mixture. A positive method of determining and controlling the density of each batch of lime slurry shall be provided by the contractor.

EQUIPMENT

1. The contractor shall provide one hy-rail injector truck equipped with three hydraulic injection rods. Injection rods shall be individually controlled and of the maximum necessary length. The injector unit shall be equipped with a 1500- to 2000-gallon slurry tank and a slurry pressure pump capable of pumping slurry at the required pressure, density, spacing, and depth at a rate of approximately 1500 to 2000 gallons per hour of track operational time.

2. The contractor shall supply one hy-rail slurry supply truck equipped with an agitation system and slurry tank capable of transferring lime slurry to the injector unit to support the specified pumping requirements.

3. The contractor shall provide at least one storage unit capable of holding 20 tons of hydrated lime and the necessary equipment for hauling water and for mixing and handling the lime slurry.

APPLICATION

1. Injection of lime slurry shall be continued until "REFUSAL" (i.e., until the soil will not take any more and slurry is running freely on the surface either around the injection rod(s), out of previous injection holes, or has fractured the ground).

2. The injection rod(s) shall penetrate the soil in _____* intervals, injecting to refusal at each interval for total depth of _____* feet (measured from top of tie) or until impenetrable material is reached, whichever occurs first. The lower portion of the injection rod shall consist of a hole pattern that will uniformly disperse the lime slurry throughout the entire depth.

3. Injection pressures should be adjusted to inject the quantity of slurry as specified herein within a pressure range of _____* to _____* pounds per square inch pump pressure.

4. The injection technique of (A or B)* shall be used:
   (A) Maintaining continuous flow and pressure.
   (B) Stopping flow and pressure at each depth interval before advancing to the next depth.

5. Longitudinal spacing for the injections shall not exceed _____* feet on center, with one injection rod at the center line of the track and two injection rods spaced approximately 5 feet to either side.

6. The lime slurry mix will be proportioned within the rate of _____* pounds of hydrated lime per gallon of water.

---

*Each of the blanks underlined are parameters that will be determined by the technical team, and they shall be adjusted on each project based on engineering data and primarily on the field-pump test results to obtain the maximum cost-effective benefits of the slurry injection stabilization procedure.

Vertical line denotes change

APPENDIX B

REPORT FORMS

The two sample report forms (1 and 2) included in this appendix were developed in the fall of 1974 with the advice and approval of the two lime injection contractors and representatives of the railroad industry. These forms, which were used for two years, were very helpful in providing construction data on approximately 80 miles of lime-injected railroad tracks. They are included as a guide to encourage and help others to document future important lime injection projects. The understanding of several items of practical benefit was made possible through the monitoring and recording of the data contained in these forms. Form 3 is a suggested format of pertinent information for performance records of each LSPI site.

Vertical line denotes change

LIME STABILIZATION CONTRACTOR'S
WEEKLY WORK REPORT
W.E. ____________, 19___

R.R. Name ______________________ Region ______________________

R.R. Division Engineer ______________ Location ______________

R.R. Inspector or Flagman ____________ Location ______________

Job Location: ____________________ State ______________

	MON	TUES	WED	THURS	FRI	SAT	SUN
DATE							
Temperature Daily (high and low)							
Precipitation Daily (inches of rainfall)							
Location of Area Worked (mile post,etc.)							
Track Injected (feet)							
Injected Spacing (A,B or C)*							
Injection Depth (feet)							
Injection Pressure (psi)							
Lime Delivered Per Day (tons)							
Lime Water Ratio (lbs. per gallon)							
Customer Delays (hours)							
On Track Work Time (hours)							
Total Hours All Employees on job per day							
Site Description (cut,fill,level,etc.)							
Soil Description (general terms)							

Lime Supplier and Location ______________________________

Contractor's Injection Unit Number __________ Haul Truck Unit Number ______

Method of Mixing Lime and Water ______________________________

Type of Surfactant ______________________ Ratio __________

Any Unusual Conditions ______________________________

____

*A. Every Tie
B. Every 2nd Tie
C. Every 3rd Tie

Signature, R.R. Representative

Signature, Contractor

Form 1

Vertical line denotes change

LIME STABILIZATION RESEARCH REPORT

WEEKLY WORK REPORT
W.E. ____________, 19 ___

R.R. Name ______________________________ Division ____________________

Job Location: __________________________ State _______________________

Contractor's Name ______________________ Foreman _____________________

Location of Area Worked
(mile post, etc.) ____

____

Why was this particular track area selected for LSPI? ________________

____

Subgrade soil classification, type or description. (Use standard classification nomenclature, i.e. Unified, ASSHO, etc.) ______________

____

Yearly gross tons on this track 1972 ____________, 1973 ____________

Heaviest monthly traffic in tons _________________ Month? _____________

Weight of Rail ________________, welded or bolted, ballast type? _______

Maximum Time Card Speed Limit of this track? ___________________

Slow orders in effect before injection __________ after injection _______

Type of maintenance work performed past three months? (M.P. to M.P.)

____

____ Estimated Man Hours _______

Type of maintenance work performed past year? (M.P. to M.P.) __________

____

____

____ Estimated Man Hours _______

Grouting or stabilization history of this track area __________________

____

Will track be reworked after injection __________ New Track? __________

Reballasted? _____________ Resurfaced? _____________

Any Unusual Conditions: ____

____

____
Signature, R. R. Engineer

Form 2

Vertical line denotes change

LIME STABILIZATION RESEARCH REPORT

R. R. Name ______________________________ Division ____________________

Job Location: ___________________________ State ______________________

Contractor's Name _______________________ Foreman ____________________

Location of Area Worked
(mile post, etc.) ____

____

Why was this particular track area selected for LSPI? ________________

____

Tests conducted and results to determine applicability of LSPI
stabilization

____

____

____

Site description:

How deep fill ___________, How high cut ___________, Level __________

Drainage conditions (depth and condition of ditches): ________________

____

Is water table in upper 20 ft of depth and at what position? __________

____

Depths of:

Ballast __________, Ballast mixtures __________, Subballast __________,

Ballast pockets ___________, Subsoil stratifications ________________,

Ballast and subballast types ____.

Injected materials and depths: ______________________________________

____

Form 3

Vertical line denotes change

Noninjected materials and depths? ________________________________

____

Injection depth intervals and technique used for each material? ________

____

Roadbed material classification, type, and description. (Use standard classification nomenclature, Unified) ________________________

____

Yearly gross tons on this track. Past ____________, Present __________ Future __________

Heaviest monthly traffic in tons ______________ Month? ____________

Weight of Rail ______________, Welded or Bolted? ______________

Maximum time card speed limit of this track before and after injection?

____

Slow orders in effect before injection ________ after injection ______

____

Type of maintenance work performed the year before injection (M.P. to M.P.)

____

____

________________________________ Estimated Manhours ____________

Type of maintenance work performed for 5 years after injection ________

____

________________________________ Estimated Manhours ____________

Grouting or stabilization history of this track area ______________

____

Was track reworked after injection __________ New track? __________ Reballasted? __________ Resurfaced? ________ Drainage? __________

Any unusual conditions: ____

Form 3

____
Signature, R. R. Engineer

Vertical line denotes change

APPENDIX C

SOIL TEST PROCEDURES

The standards, specifications, and procedures for the soil tests described in Chapter III are presented below. The grouping of the tests (preliminary, strength, and volumetric stability) and the order used in the chapter are retained.

In the following discussion, a test soil containing no lime is referred to as the control sample, and a test soil that is mixed with some form of lime is referred to as the treated sample. Where a standard test is used, its reference designation is given.

PRELIMINARY SOIL TESTS

FIELD-PUMP TEST

Equipment

Grout pump or pump capable of pumping lime slurry under pressures at least in the range of 10 to 100 psi.

Injection rod (an injection rod can be made from a 1-inch outside diameter (OD) pipe with a closed pointed tip and with four or more 1/4-inch-diameter perforations in the pipe wall from 1 to 2 inches above the tip).

Drill truck and sampling tubes (5-inch-diameter sampling tubes are recommended).

Barrel or tank for mixing lime slurry and for slurry reservoir when pumping.

Testing

Conduct a minimum of one exploratory boring to at least a depth of 10 feet and determine type and location of the various material layers including the ballast mixtures. Spray the various materials with phenolphthalein indicator (turns shades of red in contact with lime, lime slurry, or supernatant liquid) to determine if lime is already present. If there is no reaction, it can be used as an indication of lime in the injection samples. If chemicals exist in the soils such that the indicator turns a shade of red on the untreated materials, it cannot be used on the injected materials.

Push the injection rod with the drill truck into each material, including the lower ballast materials, and inject lime slurry under pressure. Pump slurry until it comes to the surface or until several gallons (such as 10) have been injected. Use a

Vertical line denotes change

slurry mixture of 2-1/2 to 3 pounds of hydrated lime per gallon of water. The lime should be as specified in Appendix A.

The most common injection technique is to maintain continuous flow and pressure (50 to 100 psi) while injecting and while pushing to the next depth. Trial of a second injection test in which the flow and pressure are stopped before pushing to the next depth is also recommended. When the next depth is reached, the flow and pressure are then increased slowly to and then held at 15 to 20 psi. The purpose of the two techniques is to determine which one produces the best results of injecting lime slurry into the materials. In some fine-grained soils, the continuous flow method has only hydraulically jetted a hole, and the slurry has been pumped back to the surface along the outside of the injection rods. Depending on the materials present, both techniques could be used at a site. In other words, one type material may best be injected with one technique, and another material, in the same profile, may respond best to the other technique.

Take continuous undisturbed* samples (5-inch-diameter is recommended) in each injected material adjacent to, 1 foot offset from, and 3 feet offset from the injection hole. Be sure to get continuous samples from the ballast materials, or excavate a small trench to determine the degree to which the ballast can be injected. Samplers are discussed in the Subsurface Exploration Section of Chapter III.

Extrude the samples as sampling progresses, and slice them lengthwise into quarters. If the phenolphthalein indicator does not turn a shade of red on the untreated materials, spray the quartered, injected samples. Inspect the samples for lime-filled seams and cracks or for lime slurry saturation in granular materials, such as the ballast mixtures. The red phenolphthalein will indicate minute cracks and the degree of slurry or supernatant impregnated into the soil around each seam and crack. Be careful that the indicator is not indicating smeared slurry from the slicing action. Carefully wipe or scrape smeared slurry off the exposed sample surfaces. Materials that are saturated or have very good impregnation of lime slurry or supernatant will be immediately obvious when sprayed with phenolphthalein. Specifically notice, for each material layer, the lateral dispersion and impregnation characteristics determined by comparing the sample adjacent to the injection hole with the sample from the 3-foot offset. Unless lime slurry or supernatant is traveling 2-1/2 to 3 feet laterally from the injection rod, good overlap at the common 5-foot injector rod spacing will not occur.

---

* Laboratory test sample quality is not necessary, but the soil stratifications and structure must be preserved and no mixing should have occurred.

Vertical line denotes change

SOIL-LIME CHEMICAL REACTIVITY

The following test procedures are taken from the U. S. Air Force Academy Report No. FJSRL-TR-76-0006.

Weigh to nearest 0.01 gram, five representative samples of air-dried soil passing No. 40 sieve equal to 20 grams each of oven-dried soil.

Use the following formula and moisture content, MC, (ASTM D2216) to establish the required amount of soil:

$$\text{Weight of natural soil required to approximate 20 grams of oven-dry soil} = 1 + \frac{MC}{100} \times 20 \text{ grams}$$

Place soil samples in 150- to 200-millilitre bottles insuring that no soil is lost in the transfer.

Add percentages of lime (specified in Appendix A), weighed to nearest 0.01 gram, to the soil samples (use lime percentages equal to 0, 1, 2, 4, and 5 percent based on dry weight).

Add 100 millilitres of water to each bottle. The water should be that which would be used for mixing lime slurry for the problem roadbed.

Shake each mixture vigorously for a minimum of 30 seconds or until there is no evidence of dry material on the bottom of the bottles.

Shake the bottles for 30 seconds at 10-minute intervals for one hour. At the last interval, shake each bottle and immediately transfer the mixture into a clean 250-millilitre beaker.

Using a calibrated pH meter, take readings in each beaker after swirling for 50 seconds.

Record the pH for each of the soil-lime mixtures.

Make a graph of percent lime versus pH.

ATTERBERG LIMITS

Two tests--the liquid limit (LL), ASTM D 423, and the plastic limit (PL), ASTM D 424, tests--are required to determine the plasticity index (PI). The tests should be repeated with fresh samples to ensure accuracy.

Sample Preparation

Obtain enough soil, as specified by ASTM, for two complete PI determinations. Divide the soil into two equal parts.

To one portion add 1 percent (by weight in comparison with the oven-dry weight) dry lime and mix thoroughly. This is the treated sample. The other portion is the control sample.

Vertical line denotes change

Place each portion in a porcelain (or similar) dish and add sufficient water to reach approximately the liquid limit. The water should be that which would be used for mixing lime slurry for the roadbed. Cover the dishes and store for 24 hours.

Testing

Perform LL and PL tests on both the treated and control samples. The measure of plasticity (PI) for each sample is the numerical difference between the LL and PL for each sample:

$$PI = LL - PL.$$

The results may be reported in two ways:

$$PI_C, PI_T, PI_C - PI_T$$

or

$$PI_C, PI_T, (PI_C - PI_T)/PI_C,$$

where the subscripts C and T refer to the control and treated samples, respectively. The terms $PI_C - PI_T$ and $(PI_C - PI_T)/PI_C$ are measures of improvement.

GRADATION AND CLASSIFICATION

The gradation of the particles and the engineering classification of the materials shall be determined in accordance with ASTM D 422 and D2487, respectively. Only conduct sieve analysis on portion retained on No. 200 sieve (hydrometer analysis on portion passing No. 200 sieve not necessary).

SOIL STRENGTH TESTS

NATURAL TRIAXIAL

The unconsolidated, undrained tiaxial compression test, ASTM D 2850, generally is used to determine the existing strength of the soil. Natural or undisturbed representative samples are tested strictly according to ASTM. Test specimens of granular materials shall have a height-to-diameter ratio between 2 and 3 with sample diameter a factor of 4 or 6 larger than the largest particles.

UNCONFINED COMPRESSION

The treated samples for this test may be mixed with either

Vertical line denotes change

(1) supernatant liquid from lime slurry or (2) lime slurry. A minimum of six control and six treated samples is required. This number should be raised to ten each if possible. The water to be used in this test should be that which would be used for mixing lime slurry for the roadbed.

Preliminary Calculations

Determine the sample specifications for remolding from the natural undisturbed samples:

Dry-density (DD), e.g., 95 pcf.

Water content (WC), e.g., 27% (ASTM D 2216).

Determine the established data:

Volume of mold (VM), e.g., for a 1.35" dia × 3.00" long mold, VM = 4.2942 in^3 or 70.3687 cm^3.

Air-dry water content of soil before molding (WA), e.g., 4%.

Calculations

The calculations involved when the supernatant liquid is used vary from those involved when lime slurry is used.

(1) Supernatant Liquid Calculations

Weight of oven-dry soil (WO):

$$WO = DD(70.3687/62.4271)$$
$$= DD(1.1272)$$
$$= 107.1 \text{ gm}$$

Weight of air-dry soil (WAS):

$$WAS = DD(70.3687/62.4271)(1 + WA) \text{ gm}$$
$$= DD(1.1272)(1 + WA) \text{ gm}$$
$$= 111.4 \text{ gm.}$$

Total weight of wet soil (WWS):

Vertical line denotes change

$$WWS = DD(1.1272)(1 + WC) \text{ gm}$$

$$= 136.0 \text{ gm.}$$

Volume of water (VL) to be added to bring the soil to the in situ moisture content (WC):

$$VL = WWS - WAS$$

$$= 136.0 - 111.4 \text{ cm}^3$$

$$= 24.6 \text{ cm}^3$$

The slurry to be used in the field of S pounds of lime per gallon of water (e.g., 2.5 lb/gal).

Percentage of lime (L) to be added to sample, e.g. 1%.

Weight of lime to be added to sample (WL).

$$WL = WO(L)/100 \text{ gm}$$

$$= 1.07 \text{ gm}$$

Volume of supernatant liquid (VSL) to be added:

$$VSL = WL/(0.1198)S \text{ cm}^3$$

$$= 3.57 \text{ cm}^3$$

Accounting for losses:

Weight of air-dry soil required for molding (WAS):

$$WAS = 111.4 \text{ gm} + \text{approx. } 1 \text{ gm}$$

$$= 112 \text{ gm.}$$

Volume of liquid to be added (VL):

$$VL = 24.6 \text{ cm}^3 + \text{approx. } 1 \text{ cm}^3$$

$$= 25.5 \text{ cm}^3.$$

Volume of supernatant liquid to be added (VSL):

Vertical line denotes change

$$VSL = 3.57\ cm^3 + \text{approx. } 0.1\ cm^3$$

$$= 3.7\ cm^3$$

Weight of lime (WL):

$$WL = 1.07\ gm + \text{approx. } 0.05\ gm$$

$$= 1.1\ gm$$

(2) Lime Slurry Calculations

Weight of oven-dry soil (WO):

$$WO = DD(70.3687/62.4271)$$

$$= DD(1.1272)$$

$$= 107.1\ gm.$$

Weight of air-dry soil (WAS):

$$WAS = WO(1 + WA)$$

$$= 111.4\ gm.$$

Total weight of wet soil (WWS):

$$WWS = WO(1 + WC)\ gm$$

$$= 136.0\ gm.$$

Volume of water to be added (WWA) to bring the soil to the in situ moisture content (WC):

$$WWA = WWS - WAS\ cm^3$$

$$= 24.6\ cm^3.$$

Slurry to be used in field of S pounds of lime per gallon of water (e.g., 2.5 lb/gal).

Percentage of lime (L) to be added to sample, e.g., 1%.

Weight of lime to be added to sample (WL):

Vertical line denotes change

$$WL = WO(L)/100 \text{ gm}$$

$$= 1.07 \text{ gm.}$$

Volume of water to be added in slurry (WSL):

$$WSL = WL/(0.1198)S \text{ cm}^3$$

$$= 3.57 \text{ cm}^3.$$

Accounting for losses:

$$WAS = 111.4 + \text{approx. } 1 \text{ gm}$$

$$= 112 \text{ gm.}$$

$$WL = 1.07 \text{ gm} + \text{approx. } 0.05 \text{ gm}$$

$$= 1.1 \text{ gm.}$$

$$WSL = 3.57 \text{ cm}^3 + \text{approx. } 0.1 \text{ cm}^3$$

$$= 3.7 \text{ cm}^3.$$

$$WWA = 24.6 \text{ cm}^3 + \text{approx. } 1 \text{ cm}^3$$

$$= 25.5 \text{ cm}^3.$$

Soil Preparation

Soil preparation involves mixing the appropriate liquid with the air-dry soil before placing it in the mold. The method of preparation differs depending upon whether supernatant liquid or lime slurry is used.

(1) Supernatant Liquid Preparation

The supernatant liquid is a saturated solution of calcium hydroxide, $Ca(OH)_2$. It is generally prepared by decanting from a slurry mixed in the lime-water ratio to be used in the field (e.g., 2.5 to 3.0 pounds of lime per gallon of water that would be used for mixing lime slurry for the roadbed). The slurry should be allowed to stand in a tall container for 24 hours before the clear supernatant liquid is drawn from the container and placed into an airtight jar.

Weigh out the appropriate amount of air-dry soil (WAS) per sample.

Vertical line denotes change

Measure the appropriate volume of water (VL) per sample.

Measure the appropriate volume of supernatant liquid (VSL) per sample.

For the control samples, thoroughly mix only the water into the soil. Treated samples are formed from soil thoroughly mixed with both water (VL) and supernatant liquid (VSL).

(2) Lime Slurry Preparation

To every sample (WAS gm) of air-dry soil, add WWA cm^3 of water and mix thoroughly.

Seal each sample in a plastic bag and leave to equilibrate for 24 hours in a stable atmosphere (preferably 100% relative humidity and 22-25°C).

Control test samples are formed from part of the above-prepared soil.

For treated samples, mix a slurry of WL gm of lime and WSL cm^3 of water. Add this to the above-prepared soil and mix thoroughly.

The soil is now ready for molding.

Molding

The molding procedure is known as "static molding."

Grease the mold with a high vacuum silicone grease. Only a very light application is necessary.

Place the prepared soil into the mold as indicated by Step 1 in Figure C-1. It may be necessary to use a tamper to ensure that the soil is placed evenly and that all the soil goes into the mold. A piece of 1/8-inch-diameter aluminum rod rounded at one end and pointed at the other works well. The end to be used will depend on the soil and the preference of the technician.

As shown in Step 2 of Figure C-1, place one piston on top of the soil.

Reverse the mold as in Step 3 of Figure C-1 and replace the cap with the other piston.

Move the pistons to the "closure" position using a hydraulic jack. (Figure C-1, Step 4.)

Extrude the sample using the extruder shown in Figure C-2 and a hydraulic jack.

Wrap the sample in plastic, mark it, and place it in the curing chamber.

To eliminate the effects of skill and weather changes, it is generally best to prepare and test samples in random sequence.

The most frequently used sample size is that used in the Harvard Compaction Test. Common examples of sample size are 1.40 inches in diameter by 2.80 to 3.00 inches long and 1.35 inches in

Vertical line denotes change

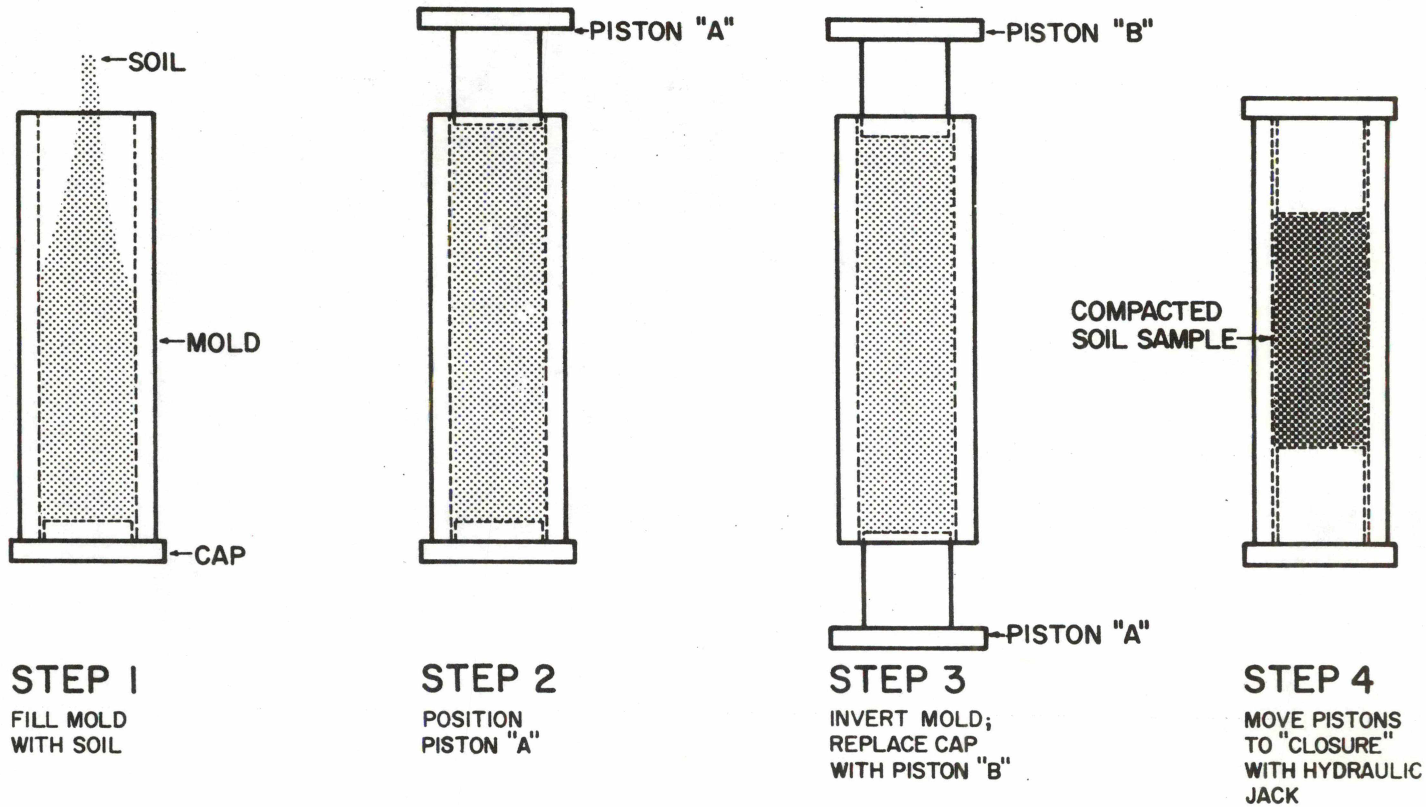


Fig. C-1. Static molding procedure.

Vertical line denotes change

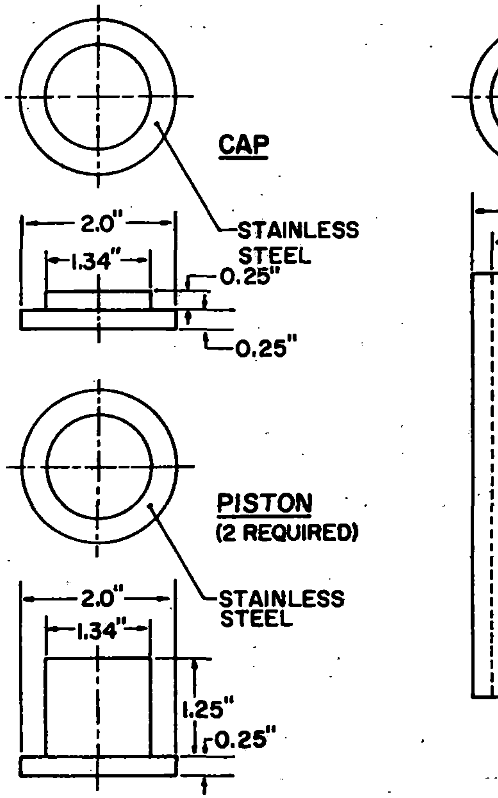
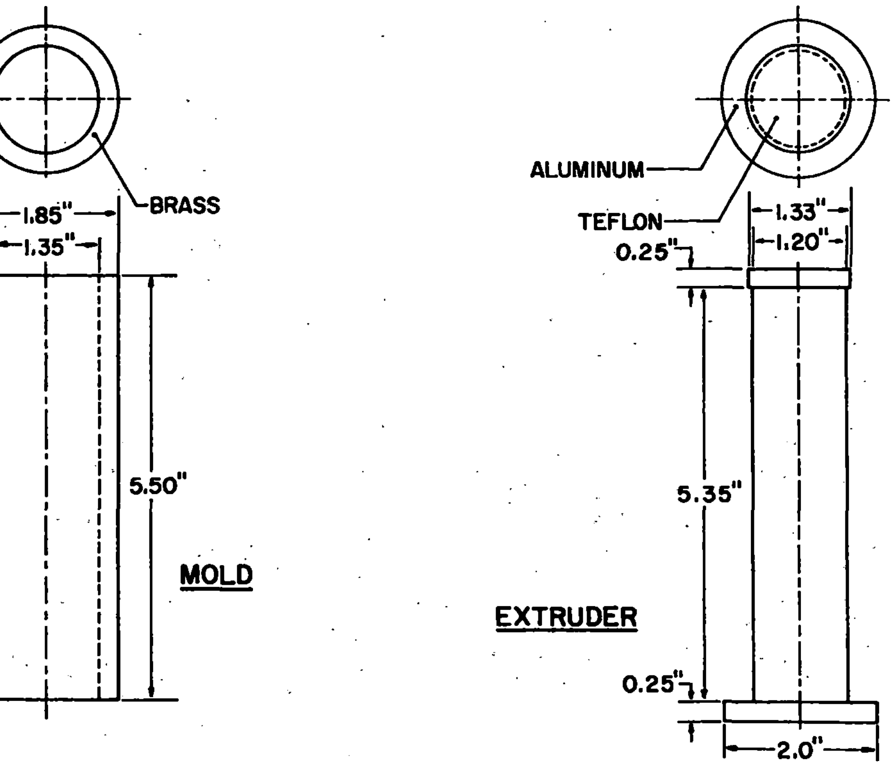


Fig.

Vertical line denotes change



C-2. Static miniature mold.

diameter by 2.70 to 3.00 inches long. The aspect ratio (height to diameter) should be between 2.00 and 2.25.

Curing

Two types of curing are used in practice: (1) normal cure for no less than 28 days and (2) accelerated cure for 4 to 6 days. Accelerated curing temperature should be 105°F in a controlled oven. (For effects of accelerated curing, see U. S. Army Engineer Waterways Experiment Station Technical Report S-76-9.)

Testing

The compression test used is the unconfined (ASTM D 2166).

VOLUMETRIC SHRINKAGE STABILITY TEST

Sample preparation is the only way in which this test differs from ASTM D 427. It is necessary to know the liquid limit before performing this test. A minimum of four (preferably at least six) tests with the control soil and the same number of tests with the treated soil are required. Inconsistent results should be rejected and the test repeated. The water to be used in this test should be that which would be used for mixing lime slurry for the roadbed.

Weigh out enough soil for the complete series of tests. Divide the soil into a sufficient number of portions to conduct two volumetric shrinkage tests. Divide each of these portions into two equal parts.

To one part add 1 percent (by weight in comparison with the oven-dry weight) lime and mix thoroughly. This is the treated soil. The other part is the control soil.

To the control soil add water to bring it to or just above the liquid limit. Enough water should be added to make the soil pasty.

Add the same volume of water to the treated soil and mix thoroughly. Should the treated soil not be workable at this water content (this is not uncommon), add more water until it is.

The two samples are now ready to be placed in the dishes, and the test may proceed according to ASTM. The other portions will be prepared in the same way as the first.

Comparisons should be made between treated and untreated samples.

Vertical line denotes change

Handbook for Railroad Track Stabilization using Lime Slurry Pressure Injection (Revised, 1979

US DOT, FRA