Soil-Cement Construction Handbook

ENGINEERING BULLETIN

PCA
Portland Cement Association

Foreword

The procedures given here for building soil-cement base courses represent over 50 years of field experience in the construction of many million square yards (square meters) of soil-cement.

To construct soil-cement, certain basic requirements must be met: thorough pulverization and mixing, adequate cement content, proper moisture content, adequate compaction, and proper curing. It is the intent of this publication to show how high-quality soil-cement can be built rapidly and easily under a wide variety of conditions by fulfilling these requirements.

Detailed information on soil surveying and sampling is available in PCA *Soil Primer*. Procedures for testing soil materials for soil-cement are available in *Soil-Cement Laboratory Handbook*. General specifications are given in *Suggested Specification for Soil-Cement Base Course*. Field inspection steps to control construction are described in *Soil-Cement Inspector's Manual*. All are Portland Cement Association publications.

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WARNING: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause skin Irritation, Severe Chemical Burns (THIRD DEGREE), or Serious Eye Damage. Frequent exposure may be associated with irritant and/or allergic contact dermatitis. Wear waterproof gloves, a long-sleeved shirt, full-length trousers and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete mortar, cement or cement mixtures from your skin immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

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SOIL-CEMENT CONSTRUCTION HANDBOOK

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CHAPTER 1

Soil-Cement—Applications, Properties, Laboratory Tests, and General Construction Procedures

Fig. 1. Typical soil-cement paving operation including mixer, compactor, and grader. Local traffic is maintained throughout construction.

Soil-cement is a mixture of pulverized soil material and measured amounts of portland cement and water, compacted to high density. As the cement hydrates, the mixture becomes a hard, durable paving material. A bituminous wearing course is placed on the soil-cement base to complete the pavement.

The soil material in soil-cement can be almost any combination of sand, silt, clay, and gravel or crushed stone. Local granular materials (such as slag, caliche, limerock, and scoria) plus a wide variety of waste materials (such as cinders, fly ash, and screenings from quarries and gravel pits) can be used to make soil-cement. Also, old granular-base roads, with or without their bituminous surfaces, can be recycled to make good soil-cement.

Soil-cement is sometimes called cement-treated base or cement-stabilized-aggregate base. Regardless of what it is called, the principles governing its composition and construction are the same.

SOIL-CEMENT APPLICATIONS

Soil-cement is used primarily as a base course for:

- Roads
- Streets
- Airports
- Shoulders
- Parking areas

It is also used for:

- Subbase for rigid pavements*
- Subbase for flexible and soil-cement pavements
- Road widening
- Storage areas
- Reconstruction and recycling of failed flexible pavements
- Slope protection for earth dams and embankments
- Foundation stabilization
- Reservoir and lagoon linings
- Channel and ditch linings
- Stabilized subgrades

TYPES OF SOIL-AND-CEMENT MIXTURES

There are two primary types of soil-and-cement mixtures:

- Soil-cement
- Cement-modified soil

Soil-cement is a hardened material which contains sufficient cement to satisfy established weight-loss criteria based on standard freeze-thaw and wet-dry tests.** Other terms such as cement-treated base, cement-stabilized soil, and cement-stabilized aggregate base are sometimes used.

Cement-modified soil can be a hardened, unhardened or semihardened mixture of soil and cement. When relatively small quantities of portland cement and moisture are added to a soil material, the chemical and physical properties of that soil material are improved. The soil's plasticity and volume-change capacity are reduced and its bearing value increased.

*Cement-treated granular subbase material used for rigid pavements is called cement-treated subbase. The methods used to mix, place, compact, and cure cement-treated subbases are the same as described in this handbook for soil-cement bases.

**Standard laboratory tests are described in *Soil-Cement Laboratory Handbook*, Portland Cement Association.

The degree of improvement depends on the quantity of cement and the type of soil material used. In cement-modified soil, only enough cement is used to change the physical properties of the material to the desired degree. Cement-modified soil is not intended to withstand standard freeze-thaw and wet-dry tests.

The use of cement to produce a cement-modified soil can be applied both to silt-clay soils and to granular soils. In highway construction, modification of silt-clay materials is used to improve unsuitable subgrade and fill materials; modification of granular soil materials is used to increase the bearing values and reduce or eliminate plasticity of base and subbase materials. Cement-modified soils and their use are discussed further in Chapter 5.

For the purposes of this handbook, all compacted mixtures of soil and cement are classified as soil-cement or cement-modified soil, without regard to the type of soil or other material. Other Portland Cement Association publications describing soil-cement for specific uses are *Soil-Cement for Facing Slopes and Lining Reservoirs, Channels and Lagoons and Soil-Cement Slope Protection for Embankments: Construction.*

ENGINEERING PROPERTIES OF SOIL-CEMENT

During its construction, soil-cement is compacted to a high density. As the cement hydrates, the mixture hardens in this dense state and becomes a structural slablike material. It does not consolidate further under traffic nor does it rut or shove during spring thaws. Soil-cement can bridge over local weak subgrade areas. It is little affected by water or freezing and thawing.

Since soil-cement is a structural material, it possesses engineering properties of a magnitude dependent primarily on type of soil, curing conditions, and age.

Depending on the soil material, 28-day compressive strength of saturated specimens at the minimum cement content meeting soil-cement criteria is generally between 300 and 800 psi (2 and 6 MPa). The 28-day modulus of elasticity is about 1 million psi (7000 MPa). These properties increase significantly with increases in curing time.

As shown in Fig. 2, a direct relationship exists between modulus of rupture and compressive strength—the modulus of rupture being about 20% of the compressive strength.

The cement in soil-cement continues to hydrate over a long period of time even under traffic. Cores taken from roads after many years of use show appreciably greater strength than samples tested at 7 and 28 days (Fig. 3). This means that soil-cement has a reserve of strength to accommodate increases in volume and weight of traffic.

Because of soil-cement's slablike character it has high load-carrying capacity (Fig. 4). A thickness design procedure for soil-cement roads, streets, parking areas, and other pavements subject to single- and tandem-axle loading configurations of conventional trucks is described in *Thickness Design for Soil-Cement Pavements.* For heavy industrial vehicles refer to *Thickness Design of Soil-Cement Pavements for Heavy Industrial Vehicles,* and for light aircraft refer to *Soil-Cement Pavements for Light Aircraft.* All are published by the Portland Cement Association.

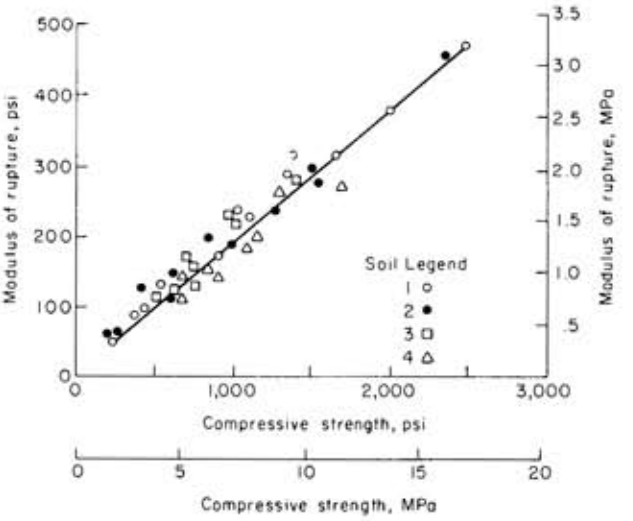

Fig. 2. Relationship between moduli of rupture and compressive strength of soil-cement.

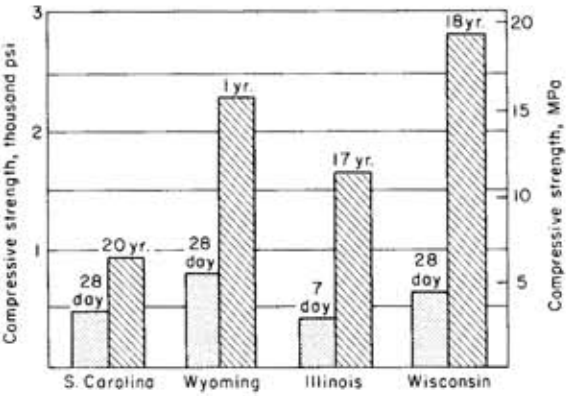

Fig. 3. Comparison of laboratory compressive strengths and strengths of projects in service.

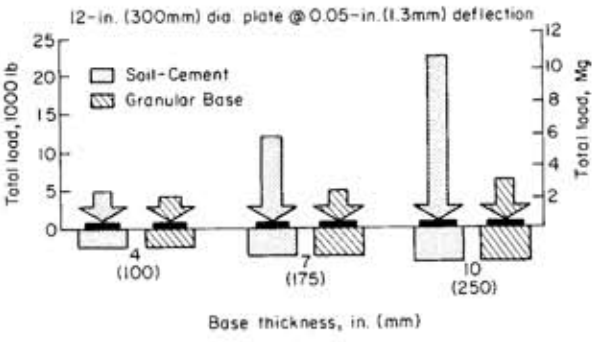

Fig. 4. Load-carrying capacity of soil-cement and granular base.

MATERIALS FOR SOIL-CEMENT

Only three basic ingredients are needed for soil-cement: soil material, portland cement, and water. Low first cost is achieved mainly by using inexpensive local materials. The soil material, which makes up the bulk of soil-cement, is either in place or obtained nearby, and the water is usually hauled only short distances.

The soil in soil-cement can be a wide variety of materials. The material that occurs on the road, street, or other area to be improved is commonly used—with or without its bituminous surfacing. Some materials that have been used include fine-textured soils; sandy materials; glacial materials that are variable mixtures of sand, gravel, silt, and clay; granular materials that have local names of caliche, limerock, disintegrated granite, ash, cinders, scoria, and red dog; well-graded granular materials such as crushed rock and crushed gravel; waste products from aggregate production; and poorly graded and dirty sands from gravel pits.

The quantities of portland cement and water to be added and the density to which the mixture must be compacted are determined by standardized tests. The water serves two purposes: it helps to obtain maximum compaction (density) by lubricating the soil grains and it is necessary for cement hydration, which hardens and binds the soil into a solid mass. Properly built soil-cement contains enough water for both purposes.

Portland Cement

Any type of portland cement may be used that complies with the latest specifications for portland cement (American Society for Testing and Materials ASTM C150, Canadian Standards Association A5-M, or American Association of State Highway and Transportation Officials, AASHTO M85) or blended hydraulic cements (ASTM C595 or AASHTO M240). Portland cement Types I and II are most commonly used.

Water

The water used in soil-cement should be relatively clean and free from harmful amounts of alkalies, acids, or organic matter. Water fit to drink is satisfactory. Sea water has been used satisfactorily when fresh water was unobtainable.

Soil Materials

Since soil-cement obtains its stability primarily by the hydration of cement and not by cohesion and internal friction of the materials, practically all soil materials and combinations of materials can be hardened with portland cement. The general suitability of soil materials for soil-cement can be judged, before they are tested, on the basis of their gradation and their position in the soil profile.

Gradation

On the basis of gradation, soil materials for soil-cement can be divided into three broad groups:

1. *Well graded sandy and gravelly materials* with about 10 to 35% of non-plastic fines have the most favorable characteristics and generally require the least amount of cement for adequate hardening. Glacial and water-deposited sands and gravels, crusher-run limestone, caliche, limerock, and almost all granular materials work well if they contain 55% or more material passing the No. 4 (4.75-mm) sieve and 37% passing the No. 10 (2.00-mm) sieve. These sands and gravels are readily pulverized, easily mixed, and can be built under a wide range of conditions.

   Coarsely graded crushed stone and gravel base course materials with more than 45% retained on the No. 4 (4.75-mm) sieve are being used successfully. However, because of their coarse gradation, these materials may require additional non-plastic fines or higher cement contents than less coarsely graded materials. When these coarse-graded aggregates are used in soil-cement it is important, as it is for all soil-cement materials, that the mix design not be based exclusively on compressive strength, but be based on the ASTM or AASHTO standard freeze-thaw and wet-dry tests.
2. *Sandy materials deficient in fines*, such as some beach, glacial, and windblown sands, make good soil-cement, though the amount of cement needed for adequate hardening usually is slightly greater than with the materials in the first group. Because of poor gradation and absence of fines in these sands, construction equipment may have difficulty in obtaining traction. Traction can be vastly improved by keeping the sand wet and by using track-type equipment. These materials are likely to be tender and to require special procedures during final compaction and finishing to obtain a smooth, dense surface.
3. *Silty and clayey soils* make satisfactory soil-cement, but those containing high clay contents are harder to pulverize. Generally, the more silty and clayey the soil, the higher the cement content required to harden it adequately. Construction with these soils is more dependent on weather conditions. If the soil can be sufficiently pulverized, it is suitable for use in soil-cement.

Soil Profile

A soil profile is a vertical cross section of the earth's surface that exposes the different soil horizons or layers. Each soil horizon is generally of a different gradation (texture), structure, and color. Color indicates the soil's chemical makeup. In some instances, gradation of the soil is secondary to chemical makeup insofar as the soil's reaction with portland cement is concerned. For instance, a red soil indicates the presence of iron and generally reacts exceptionally well with cement. Conversely, a black farmland soil may react rather poorly with cement because of the presence of organic material.

In some locations in northern glaciated areas and in eastern and southeastern coastal areas, there are some sandy soils that require exceptionally high cement factors. Two alternative corrective measures can be considered: (1) replacing or blanketing the poorly reacting sand with a normally reacting soil; or (2)

adding to the sandy soil a small percentage of calcium chloride, a friable, clayey soil, or a calcareous material such as limerock or limestone screenings. Sodium chloride, seawater, and other chemicals may also be effective.*

Soils formed from similar parent material and under similar conditions of climate, topography, drainage, and vegetation are similar and have similar profiles. These soils have been identified according to soil series by the U.S. Department of Agriculture's Natural Resources Conservation Service. Many areas have been surveyed and mapped according to this classification system; and the maps and accompanying reports are a valuable aid in soil survey work. Studies have shown that soils of the same soil series and horizon and of similar texture, wherever they are found, will require the same amount of cement.**

Old Roadway Material

The materials usually found in old gravel or stone roads and streets make excellent soil-cement. They are generally friable, mix easily, and require only a minimum amount of cement. Frequently the old bituminous mat, if present, can be salvaged by pulverizing it and mixing it with the old base-course material for processing with cement. The reuse of these materials with cement is an economical way to strengthen and rebuild wornout granular base pavements. Chapter 4 provides further details on recycling failed flexible pavements.

Borrow Materials

From a construction or cost standpoint, it is sometimes advantageous to use a borrow material instead of the soil in place. The existing soil or the soils encountered in cut sections may have a very high clay content and require a relatively high cement factor. Also, a considerable effort may be required to pulverize these soils properly. Deposits of friable or granular materials that require much less cement and very little pulverizing can often be found nearby and can be used to blanket the existing soil or can be combined with it. Selective grading often is used to place the most favorable soils at the top of the grade. Comparative cost estimates will indicate the most economical materials or combination of materials to use.

*Additional details are given in the Portland Cement Association publication, *Soil-Cement Laboratory Handbook*; and in "Effect of Soil and Calcium Chloride Admixtures on Soil-Cement Mixtures," by Miles D. Catton and E.J. Felt, Highway Research Board, *Proceedings of the Twenty-Third Annual Meeting*, Vol. 23, 1943, pages 497-529. A field test to identify poorly reacting sands is described in "Development of a Test Identifying Poorly Reacting Sandy Soils Encountered in Soil-Cement Construction," *Soil Stabilization by Admixing Portland Cement*, Highway Research Board Bulletin 267, 1960.

**Refer to "Use of Agricultural Soil Maps in Making Soil Surveys," by L.D. Hicks, *Engineering Use of Agricultural Soil Maps*, Highway Research Board Bulletin No. 22, 1949, pages 108-116. Also, "Soil Series as a Basis for Determining Cement Requirements for Soil-Cement Construction," by J.A. Leadabrand, L.T. Norling, and A.C. Hurless, *Soil Series Requirements*, Highway Research Board Bulletin 148, 1957.

LABORATORY TESTS

Before construction starts, the soil materials that will be treated with cement should be identified and representative samples of each type forwarded to a laboratory for testing.† These tests determine the minimum cement content required to harden each material adequately and the approximate optimum moisture content and density values for use in construction.

The optimum moisture content and maximum density for molding laboratory test specimens are determined by the moisture-density test for soil-cement (ASTM D558 or AASHTO T134). The required amount of cement is determined by laboratory wet-dry and freeze-thaw tests. (ASTM D559 and D560 or AASHTO T135 or T136.)

Short-cut test methods have also been developed to determine the cement content required for granular soils. State highway department laboratories and many commercial testing laboratories are equipped to run the soil-cement tests.

In some areas special test methods and criteria have been developed specifically for local conditions. For the particular soil materials and climate involved, these locally developed tests methods have proved satisfactory.

Table 1 gives the normal range of cement requirements for soils of the various AASHTO soil groups. Table 2 gives average cement requirements for a number of miscellaneous materials and special types of soil. These average cement requirements can be used for rough cost estimates and then confirmed or revised as laboratory test results become available.

A proper cement content is the primary requirement for soil-cement construction. In the discussions that follow, it is assumed that cement factors and boundaries of the various soil materials have been determined for the area to be constructed.

TABLE 1. Normal Range of Cement Requirements for B- and C-Horizon Soils*

AASHTO Soil Group	Cement, percentage by weight of soil	Cement, pounds per cubic foot of compacted soil-cement	Cement, kilograms per cubic metre of compacted soil-cement
A-1-a	3-5	5-7	80-110
A-1-b	5-8	7-8	110-130
A-2-4			
A-2-5	5-9	7-9	110-140
A-2-6			
A-2-7			
A-3	7-11	8-11	130-180
A-4	7-12	8-11	130-180
A-5	8-13	8-11	130-180
A-6	9-15	9-13	140-210
A-7	10-16	9-13	140-210

*A-horizon soils (topsoils) may contain organic or other material detrimental to cement reaction and thus require higher cement factors. For dark grey to grey A-horizon soils, increase the above cement contents 4 percentage points (4 lb/cu ft [60 kg/m³] of compacted soil-cement); for black A-horizon soils, 6 percentage points (6 lb/cu ft [100 kg/m³] of compacted soil-cement).

†*PCA Soil Primer*, Portland Cement Association, gives considerable information on soil survey and sampling methods. Testing, including short-cut methods, is described in *Soil-Cement Laboratory Handbook*, Portland Cement Association.

TABLE 2. Average Cement Requirements of Miscellaneous Materials

Material	Cement, percentage by weight of soil	Cement, pounds per cubic foot of compacted soil-cement	Cement, kilograms per cubic metre of compacted soil-cement
Caliche	7	8	130
Chat	7	8	130
Chert	8	8	130
Cinders	8	8	130
Limestone screenings	5	7	110
Marl	11	10	160
Red dog	8	8	130
Scoria containing plus No. 4 material	11	11	180
Scoria (minus No. 4 material only)	7	8	130
Shale or disintegrated shale	10	10	160
Shell soils	7	8	130
Slag (air-cooled)	7	8	130
Slag (water-cooled)	12	9	140

GENERAL CONSTRUCTION STEPS

In soil-cement construction the objective is to obtain a thoroughly mixed, adequately compacted and cured material. Construction methods are simple and follow a definite procedure:

1. Initial preparation
   a. Shape the area to crown and grade.
   b. Correct unstable subgrade areas.
   c. If necessary, scarify, pulverize, and prewet the soil.
   d. Reshape to crown and grade.
2. Processing
   a. Mixed-in-place method
      (1) Spread portland cement and mix.
      (2) Apply water and remix.
   b. Central mixing plant
      (1) Mix soil material, cement and water.
      (2) Haul mixed soil-cement to placing area.
      (3) Spread soil-cement uniformly over area.
3. Compact.
4. Finish.
5. Cure.

Most soil-cement is built from materials that require little or no preliminary pulverizing. If pulverization is required, it is usually done the day before actual processing. Processing operations are continuous and must be completed the same working day.

TYPES OF MIXING EQUIPMENT

Soil, cement, and water can be (1) mixed in place using traveling mixing equipment, or (2) mixed in a central mixing plant. The types of mixing equipment are as follows:

1. Traveling mixing equipment
   a. Flat-transverse-shaft type
   b. Windrow-type pugmill
2. Central mixing plants
   a. Continuous-flow-type pugmill
   b. Batch-type pugmill
   c. Rotary-drum mixers

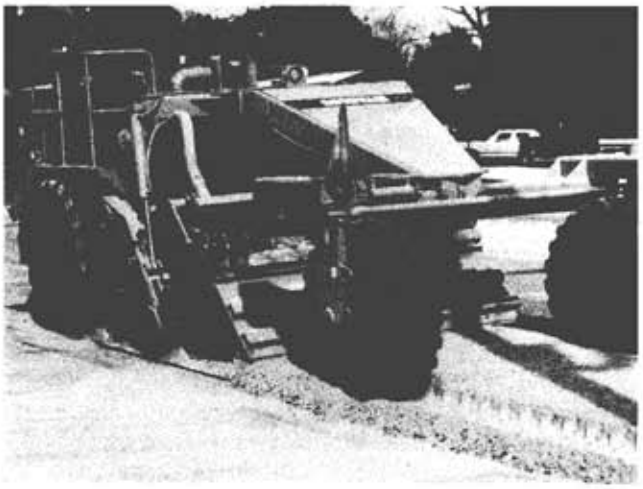

Fig. 5. Transverse single-shaft mixer processing soil-cement in place. Multiple passes are required.

Fig. 6. Windrow-type traveling pugmill mixing soil-cement from windrows of soil material.

Fig. 7. Continuous-flow central mixing plant.

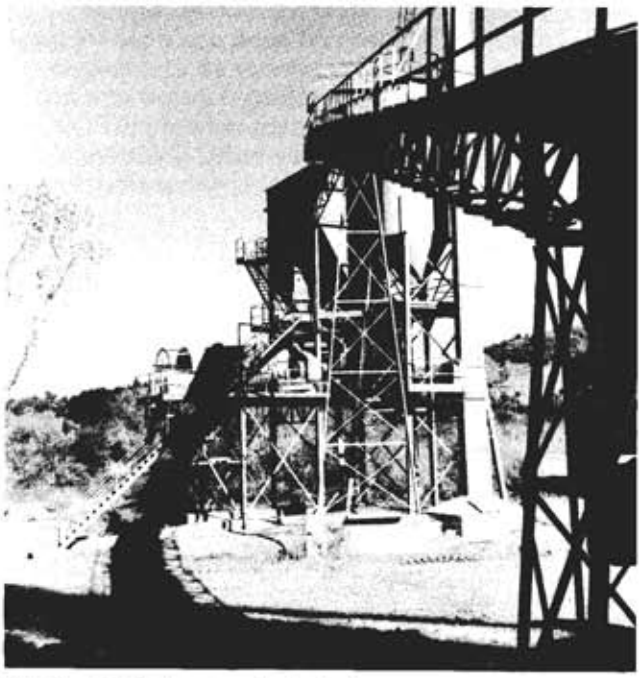

Fig. 8. Batch-type central plant.

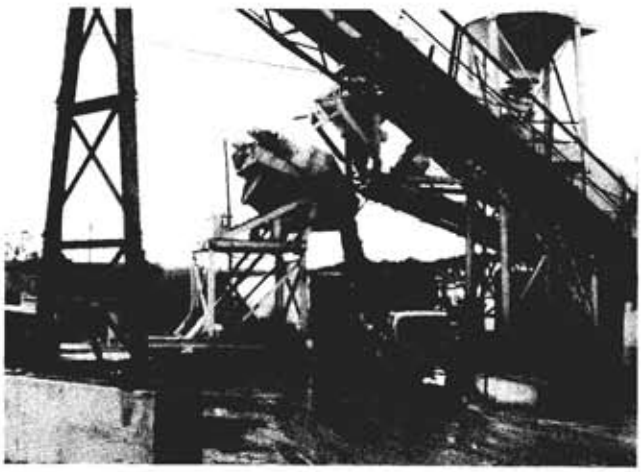

Fig. 9. Rotary-drum central mixing plant.

Whatever type of mixing equipment is used, the general principles and objectives are the same. Modern mixing machines are very efficient and give high daily production at a low cost.

Some soil materials cannot be sufficiently pulverized and mixed in central mixing plants because of their high silt and clay content and plasticity. Transverse-shaft mixers are capable of mixing all types of soil materials, from granular to fine grained soils. Material containing large amounts of highly plastic clays may require several passes with the mixer to obtain adequate pulverization.

Traveling pugmills can be used for non-plastic to slightly plastic granular soils. For coarse, non-plastic granular materials, a rotary-drum mixer can provide a suitable mix; however, if the material includes a small amount of slightly plastic fines, mixing may not be adequate.

INSPECTION AND FIELD CONTROL

The purpose of field inspection and control of soil-cement construction is to ensure that the results set out in the plans and specifications are obtained. Field inspection involves the control of five basic factors:

- Cement content
- Moisture content
- Mixing
- Compaction
- Curing

A complete description of inspection steps and appropriate tables and charts for use by the inspector are given in the Portland Cement Association's *Soil-Cement Inspector's Manual*.

BITUMINOUS SURFACE

A bituminous surface should be placed on the completed soil-cement base course as soon as practical. Although it is not unusual for several weeks to elapse between completion of the soil-cement and placement of the wearing course, it can be placed immediately.

The type and thickness of surfacing depend on traffic volume, availability of materials, cost, and local practices. In general, the required thickness of the wearing course on a soil-cement base is less than required on a granular-type base. A common type of wearing course for lightly traveled roads, streets, and airports is a double surface treatment about 3/4 in. (19 mm) thick. For greater traffic volumes, thicker, high-quality surfacings are warranted. Where snowplows are likely to be used, a minimum 1-1/2 in. (38 mm) bituminous surface is common.

Local experience and practice will dictate the specific details of construction. Good construction practices such as thorough cleaning of the base course should always be followed when the surfacing is placed.

There are special uses of soil-cement, such as coal-storage and compost paving areas, where bituminous surfaces are not required.

THICKNESS OF SOIL-CEMENT BASE

Most soil-cement base courses are constructed 6 in. (150 mm) thick, but they may be reduced to 5 in. (125 mm) for light traffic and good subgrades. For higher traffic volume, a thickness of 8 in. (200 mm) or greater may be needed.*

SPECIFICATIONS

Suggested Specifications for Soil-Cement Base Course is available from the Portland Cement Association as an aid in preparing job specifications.

SHRINKAGE CRACKS

Sometime after construction, transverse shrinkage cracking occurs in the soil-cement base course. Such shrinkage cracking is a natural characteristic of soil-cement and does not materially affect the performance of the base course. It is evidence that cement hydration is producing a hardened base. The vertical faces of the cracks are irregular; as a result, there is effective load transfer. Cracks are wider at the top than at the bottom. Some appear the first few days after construction and more may appear during the first few months.

The amount of shrinkage of soil-cement base is mainly dependent on the soil type and the moisture content at time of compaction.

From an appearance standpoint, it may be worthwhile to minimize the number of cracks that show through the surface. Experience has shown that fewer shrinkage cracks will show through a bituminous surface treatment than through a thin hot plant-mix surface. Delaying placement of the bituminous surface until the cracks have formed is also beneficial.

Fig. 10. Reflective cracks in asphalt surface constructed on a soil-cement base.

Often reflective cracks are minimized by placing a bituminous surface treatment first and adding a plant-mix surface at a later date. A crack inhibiting fabric placed between the soil-cement and asphalt surface is another technique for minimizing reflective cracking. Plant-mix surfaces at least 4 in. (100 mm) thick have exhibited very little reflective cracking.

From a performance standpoint, it is not necessary to seal fine shrinkage cracks. Sealing fine cracks is not effective and usually detracts from the appearance of the pavement. In many cases, periodic resealing of the asphalt surface will cover fine cracks.

Cracks wider than about 1/8 in. (3 mm), however, may require filling, depending on local weather conditions. The cracks should be cleaned thoroughly and all spalled pieces of the surface removed. The cracks are then filled, using a hand squeegee and broom, with an asphalt-emulsion slurry or light grade of liquid asphalt mixed with fine sand. The crack should be sealed with liquid asphalt. An asphalt kettle, hand-pouring pot, and hand squeegee are most commonly used. Special nozzles or attachments are helpful in more closely controlling the flow of material into the crack. An application of sand over the bitumen will prevent pickup by traffic. Joint sealing compounds and heavier bodied asphalt materials are also used to fill large cracks.

*Design information is given in *Thickness Design for Soil-Cement Pavements*, *Thickness Design of Soil-Cement Pavements for Heavy Industrial Vehicles*, and *Soil-Cement Pavements for Light Aircraft*, Portland Cement Association.

CHAPTER 2

SOIL-CEMENT CONSTRUCTION

This chapter will address in detail the two methods for mixing soil-cement—mixed-in-place and mixed in a central mixing plant. Also discussed will be information on other aspects of soil-cement construction including special construction concerns.

MIXED-IN-PLACE CONSTRUCTION

Preparation

Before construction begins, the crown and grade of the roadway should be checked and any fine grading should be completed. Since there is little displacement of material during processing, grade at the start of construction will determine final grade to a major extent. If borrow material is to be used, the subgrade should be compacted and shaped to proper crown and grade before the borrow is placed. Any soft subgrade areas should be corrected.

Fig. 11. Unstable subgrade areas must be corrected before soil-cement processing begins. Without proper support for compaction equipment, adequate density in the soil-cement base cannot be obtained.

To avoid later costly delays, all equipment should be carefully checked to ensure it is in good operating condition and meets construction requirements of the job.

Guide stakes should be set to control the width and guide the operators during construction.

Arrangements should be made to receive, handle, and spread the cement and water efficiently. The number of cement and water trucks required depends on length of haul, condition of haul roads, and anticipated rate of production. For maximum production, an adequate cement and water supply is essential.

The limits of the different materials and their corresponding cement requirements should be established by the project engineer.

Prewetting by adding moisture before cement is applied often saves time during actual processing.

Fig. 12. Since there is little displacement of the soil material during processing, the roadway should be at proper crown and grade at start of construction. This practice will also permit rapid runoff of water during heavy rains.

Friable granular materials, which are most commonly used, require little or no scarification or pulverization. Silty and clayey soils may require extra effort to pulverize them, particularly if they are too dry or too wet. Soils that are difficult to pulverize when dry and brittle can be broken down readily if water is added and allowed to soak in, whereas sticky soils can be pulverized more easily when they have been dried to near optimum moisture content.

Most specifications require that the soil material be pulverized sufficiently so that at the time of compaction 100% of the soil-cement mixture will pass a 1-in. (25-mm) sieve and a minimum of 80% will pass a No. 4

Fig. 13. If prepared roadbed has become compacted and hard, the soil material should be loosened with a scarifier on a motor-grader before cement is spread.

(4.75 mm) sieve, exclusive of any gravel or stone. Gravel or stone should be no more than 2-in. (50-mm) maximum size. The final pulverization test should be made at the conclusion of mixing operations.

Single-Shaft Traveling Mixer

The basic objective of any type of mixing equipment is to provide a thorough mixing of soil, cement and water with single-shaft mixers more than one mixing pass is usually required.

Prewetting the soil material is common practice. Applying water at this stage of construction saves time during actual processing operations because most of the required water will already have been added to the soil material. In poorly graded granular materials, prewetting prevents cement from sifting to the bottom of the mix by causing it to adhere more readily to the sand and gravel particles.

Mixing the soil material and cement is easier if the moisture content of the raw material is two or three percentage points below optimum. However, very sandy materials can be mixed even if the moisture content is one or two percentage points above optimum. Moisture should be applied uniformly during prewetting. By mixing it into the soil material, evaporation losses are reduced. Because of the hazard of night rains, some prefer to do the prewetting in the early morning. After scarifying and prewetting, the loose, moist soil material is shaped to crown and grade.

Fig. 14. Prewetting helps pulverization of dry, hard soils and saves time during processing.

Handling and spreading cement

Bulk cement is normally trucked to the jobsite in bulk transport trucks or shipped to the nearest railroad siding in enclosed hopper cars. Compressed air or vibrators are used to loosen the cement in the hopper cars during unloading. Transfer to cement trucks is done pneumatically or by a screw or belt conveyor. The trucks are usually enclosed or fitted with canvas covers. The cement is weighed in truckloads on portable platform scales or at a nearby scale.

Fig. 15. Bulk portland cement being transferred pneumatically from a bulk transport truck to a job truck.

Soil materials that contain excessive amounts of moisture will not mix readily with cement. Sandy soils can be mixed with a moisture content at optimum or slightly above, while clayey soils should have a moisture content below optimum when cement is spread. Cement should not be applied onto puddles of water. If the soil material is excessively wet, it should be aerated to dry it before cement is applied.

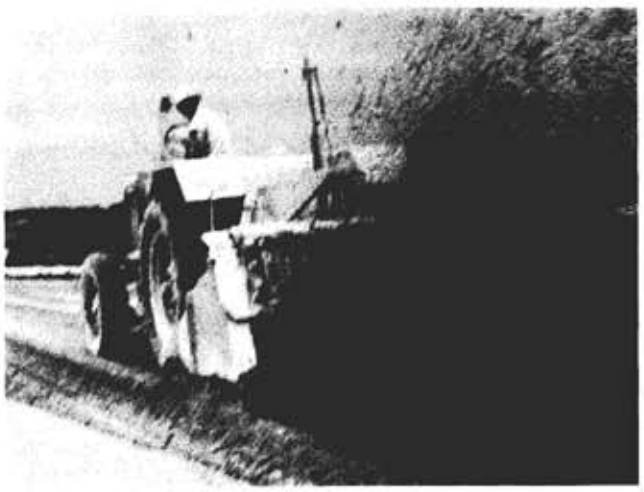

Fig. 16. Wet soil can be aerated by operating a single-transverse-shaft mixer with the back of the hood in a raised position.

Cement is spread by a mechanical cement spreader or from bags. Mechanical spreaders are often attached to the back end of dump trucks. As the truck moves forward, cement flows through the spreader, which regulates the quantity of cement placed on the prepared soil. To obtain a uniform cement spread, the spreader should be operated at a constant, slow speed and with a constant level of cement in the hopper.

Fig. 17. Mechanical cement spreader attached to a job dump truck spreading cement in regulated quantities. To obtain a uniform cement spread, the spreader should be operated at a constant, slow speed with a constant level of cement in the hopper.

Fig. 18. Mechanical cement spreader with spreader fins to increase width of spread, attached directly behind a bulk cement transport truck. The cyclone dissipates the air of the pneumatically conveyed cement.

Fig. 19. Cement spreader distributes dry cement uniformly over the prepared area.

The mechanical spreader must have adequate traction to produce a uniform cement spread. Traction can be aided by wetting and rolling the soil material before spreading the cement. When operating in loose sand or gravel, slippage can be overcome by the use of cleats on the spreader wheels or by other modifications; sometimes the spreader is mounted on the back of a dozer.

The mechanical cement spreader can also be attached directly behind a bulk cement truck. Cement is then moved pneumatically from the truck through an air separator cyclone that dissipates the air pressure, and falls into the hopper of the spreader. Forward speed must be slow and even. Sometimes a motor grader or dozer pulls the truck to maintain this slow, even forward speed.

Pipe cement spreaders attached to cement transport trucks have been used in some areas with variable results. It is important that whatever type of spreader device is used, the distribution of cement be uniform.

Fig. 20. Slippage of cement spreader wheels in loose sand or gravel can be overcome by the use of cleats.

Fig. 21. Towing bulk transport truck at constant speed as cement is being spread assures uniform coverage.

Fig. 22. Pipe spreader attached to bulk transport truck.

The amount of cement required is specified as percentage of cement by weight of oven-dry soil material, or in pounds of cement per cubic foot (kilograms per cubic meter) of compacted soil-cement.* Fig. 23 can be used to convert from one to the other if the maximum dry density of the compacted soil-cement is known.

Fig. 24 and Table 3 can be used to determine quantities of cement per square yard (square meter) of pavement or per linear foot (meter).

EXAMPLE:

Determine the linear distance a truckload of cement should travel to spread the required amount of cement.

GIVEN:

Required cement content . . . 6.9 lb per cubicfoot (110 kg/m³)
Depth of compacted soil-cement . . 6 in. (150 mm)
Width of spread . . . . . 8 ft (2.4 m)
Weight of truckload of cement . . . . . .15,400 lb (6990 kg)

PROCEDURE:

Enter Fig. 24 on the top edge at 6.9 lb of cement per cubic foot (110 kg per cubic meter) and proceed vertically to the 6-in. (150-mm) depth line; proceed horizontally to intersection with line representing 8-ft (2.4-m) width of spread; then proceed vertically to the bottom edge and read the quantity cement per unit length required: 27.6 lb per foot (41.1 kg/m)

ANSWER:

The required distance of travel for the 15,400-lb (6990 kg) truckload of cement to obtain the specified cement spread equals the total weight of cement on the truck divided by the pounds (kilograms) per linear foot (meter) required:

$$\frac{15{,}400}{27.6} = 558 \text{ ft } (170 \text{ m})$$

Methods used to check the amount of cement spread are given in *Soil-Cement Inspector's Manual*, published by the Portland Cement Association.

When bags of cement are used on small jobs, a simple but exact method for properly placing the bags is necessary. The bags should be spaced at approximately equal transverse and longitudinal intervals that will ensure the proper percentage of cement. Positions can be spotted by flags or markers fastened to chains at proper intervals to mark the transverse and longitudinal rows.

When the bags are opened, the cement should be dumped so that it forms fairly uniform transverse windrows across the area being processed. A spike-tooth harrow, a nail drag, or a length of chain-link fence can be used to spread the cement evenly. The drag should make at least two round trips over the area to spread the cement uniformly.

*Previous editions of this handbook used percentage of cement by volume as an alternate method of expressing cement content. This was based on a 94-lb (43-kg) U.S. bag of cement.

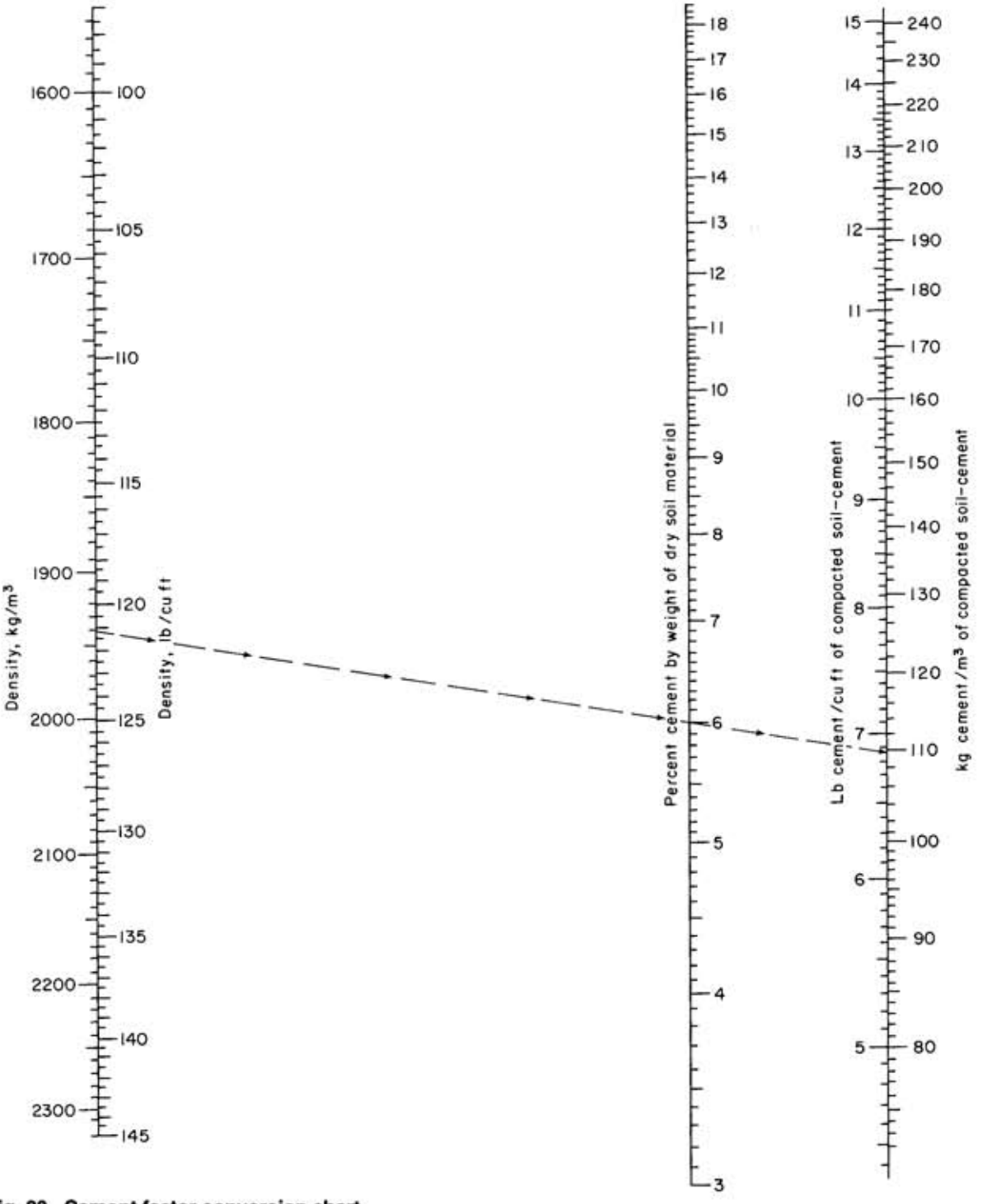

Fig. 23. Cement factor conversion chart.

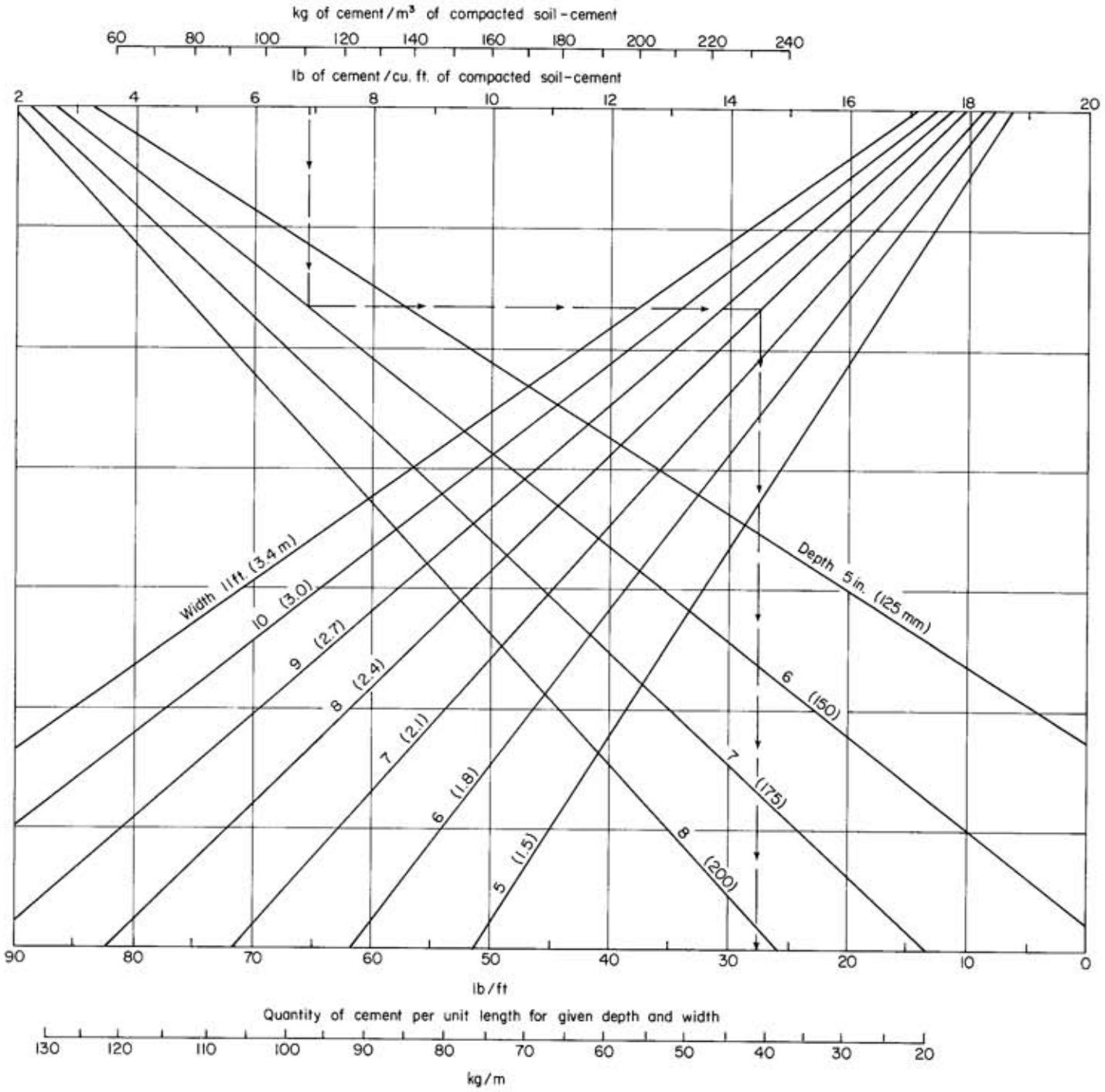

Fig. 24. Quantity of cement per unit length for given depth and width of treatment for specified cement contents.

TABLE 3. Cement Spread Requirement, Pounds per Square Yard per Inch of Compacted Thickness (kg/m² per 10 mm)

Cement content, pounds per cubic foot of compacted soil-cement	Cement spread, pounds per square yard per inch of thickness of compacted soil-cement	Cement content, kilograms per cubic metre of compacted soil-cement	Cement spread, kilograms per square metre per 10 mm of thickness of compacted soil-cement
4.5	3.38	72	0.72
5.0	3.75	80	0.80
5.5	4.13	88	0.88
6.0	4.50	96	0.96
6.5	4.88	104	1.04
7.0	5.25	112	1.12
7.5	5.63	120	1.20
8.0	6.0	128	1.28
8.5	6.38	136	1.36
9.0	6.75	144	1.44
9.5	7.13	152	1.52
10.0	7.50	160	1.60
10.5	7.88	168	1.68
11.0	8.25	176	1.76
11.5	8.63	184	1.84
12.0	9.0	192	1.92
12.5	9.38	200	2.00
13.0	9.75	208	2.08
13.5	10.13	216	2.16
14.0	10.50	224	2.24
14.5	10.88	232	2.32
15.0	11.25	240	2.40
15.5	11.63	248	2.48
16.0	12.0	256	2.56

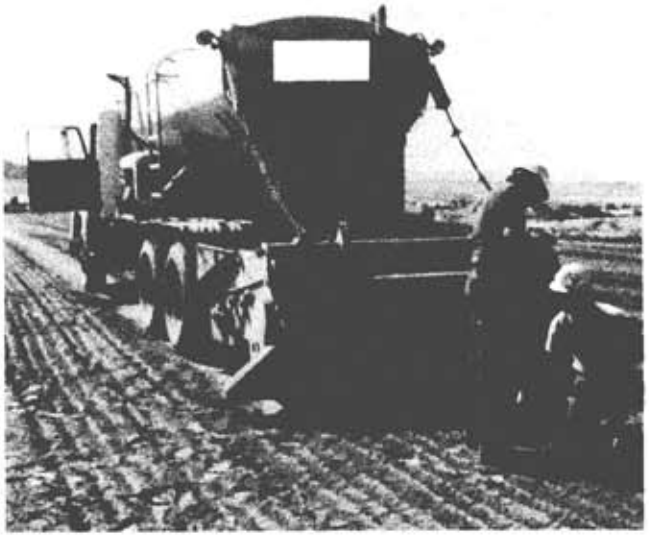

Fig. 25. Checking quantity of cement spread by weighing cement collected on a square yard (m^2) of canvas.

Fig. 26. If the prepared area becomes partially compacted by equipment before and during cement spread, reloosening it with scarifier on motor-grader will hasten mixing. Cement should flow between the scarifier teeth and not be carried forward by the frame.

Fig. 27. Cutting in the cement during first pass of single transverse-shaft mixer. Water truck in foreground supplies water for mixing.

Fig. 28. Mixing chamber for typical single transverse-shaft mixer.

Fig. 29. Worn and broken mixing tines should be replaced; otherwise adequate mixing may not be achieved.

Fig. 30. Soil-cement at optimum moisture casts readily when squeezed in the hand and can be broken into two pieces without crumbling.

Mixing and application of water

Procedures for applying water and mixing depend on the type of mixing equipment used. A thorough mixture of pulverized soil material, cement, and water must be obtained. Uniformity of the mix is easily checked by digging trenches or a series of holes at regular intervals for the full depth of treatment and inspecting the color of the exposed soil-cement mixture. Uniform color and texture from top to bottom indicate a satisfactory mix; a streaked appearance indicates insufficient mixing. Proper width and depth of mixing are also important. These items are easily checked, as described in *Soil-Cement Inspector's Manual.*

Occasionally the prewet soil material becomes compacted by cement-spreading equipment. In such cases, mixing can be hastened by loosening the material again after cement is spread, usually with the scarifier on a motor grader. The scarifier teeth should be set so that the cement will flow between them and not be carried forward or displaced by the scarifier frame.

The mixer picks up the soil material and cement and mixes them in place. Water, supplied by a tank truck, is usually applied to the mixture by a spray bar mounted in the mixing chamber, or it can be applied ahead of the mixer by water pressure distributors. The soil material and cement must be sufficiently blended when water contacts the mixture to prevent the formation of cement balls. The number of mixing passes depends on the type of soil material and its moisture content and on the mixing capability of the mixer.

Water is supplied to the mixer by tank trucks. A small reserve water tank on the mixer permits continuous operation while the water trucks are being switched. The quantity of water required per unit length or per minute for 1% moisture can be determined by using Fig. 31.

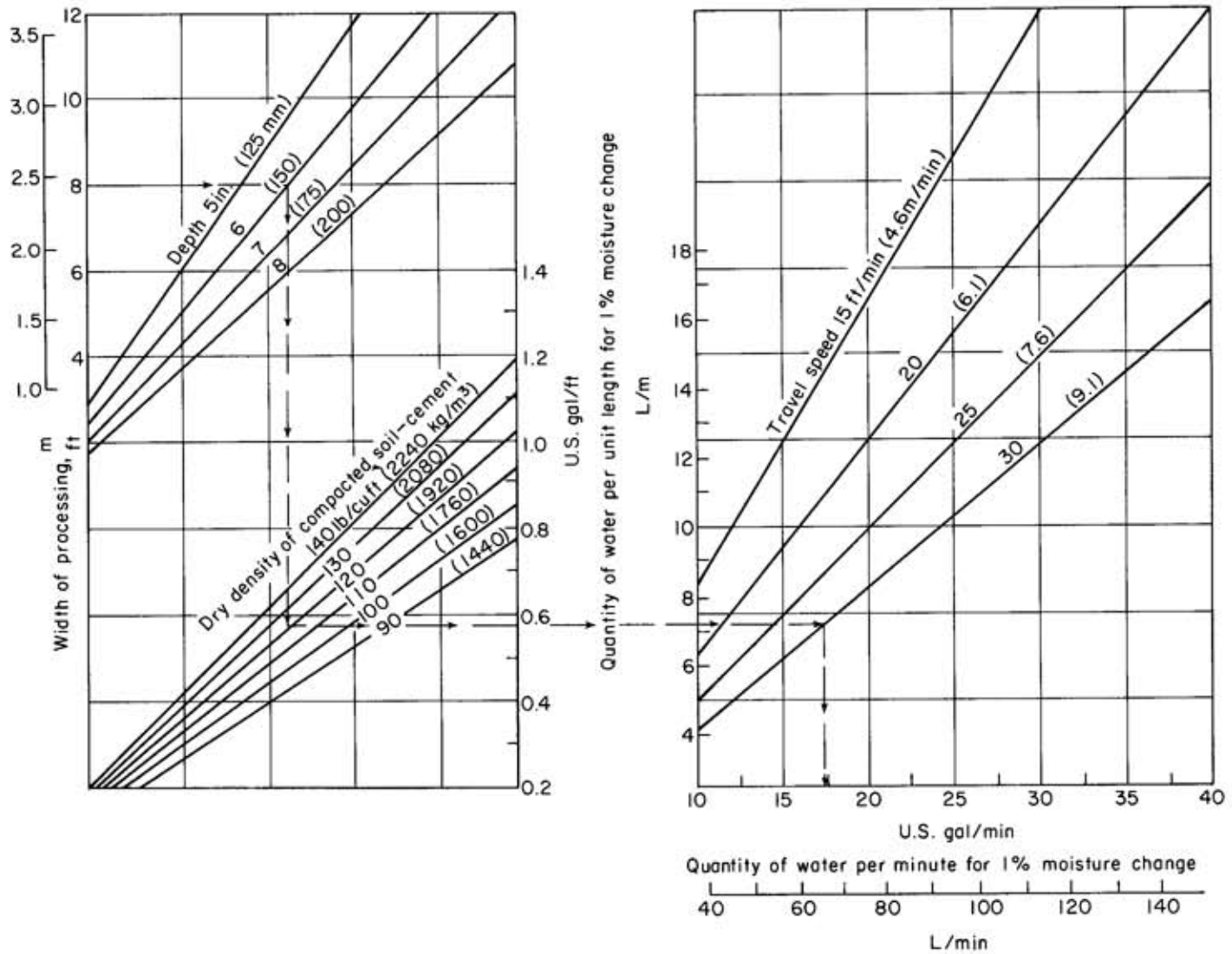

Fig. 31. Quantity of water required per minute to raise moisture content of soil-cement mixture 1 percentage point.

EXAMPLE:

Determine water required.

GIVEN:

In-place moisture content of raw soil material 5.5%
Optimum moisture content 11.5%
Maximum density ..... 121.2 lb per cubic foot (1941 kg/m³)
Compacted depth ..... 6 in. (150 mm)
Mixing width ..... 8 ft (2.4 m)
Mixing rate ..... 30 ft per minute (9. 1 m/min)

PROCEDURE:

1. Percentage of moisture required equals the difference between the optimum moisture content and the moisture content of the raw soil material,plus 2% of the total mixture to compensate for evaporation 11.5 - 5.5 + 2 = 8%
2. Enter Fig. 31 at left edge at 8-ft (2.4-m) width of processing and proceed horizontally to the 6-in. (150-mm) depth line; then proceed downward until the 121.2-lb (1941-kg) density line is intersected; proceed horizontally to the right and read gallons per linear foot (L/m) for 1% moisture approximately 0.58 U.S. gal per foot (7..2 L/m).
3. Multiply gallons per linear foot (L/m) by the 8% moisture required: 8 X 0.58 = 4.6 U.S. gal per foot (8 X 7.2 = 58 L/m)
4. Continue on Fig. 31 horizontally from gallons per linear foot (L/m) for 1% moisture until the travel speed line of 30 ft per minute (9.1 m/min) is intersected; then proceed downward and read gallons per minute (L/m) for 1% moisture change: 17.4 U.S. gal (65.9 L).
5. Multiply gallons per minute (L/m) for 1% moisture change by the 8% moisture required: 17.4 X 8 = 139 U.S. gal per minute (526 L/min).

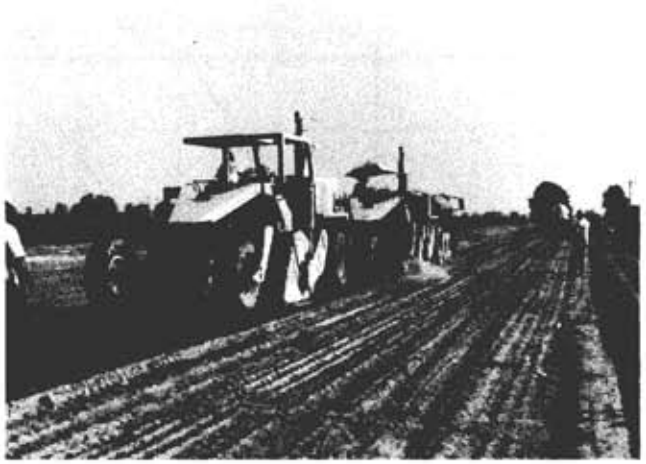

Fig. 32. Single transverse-shaft mixers working in tandem to complete mixing operation in one pass.

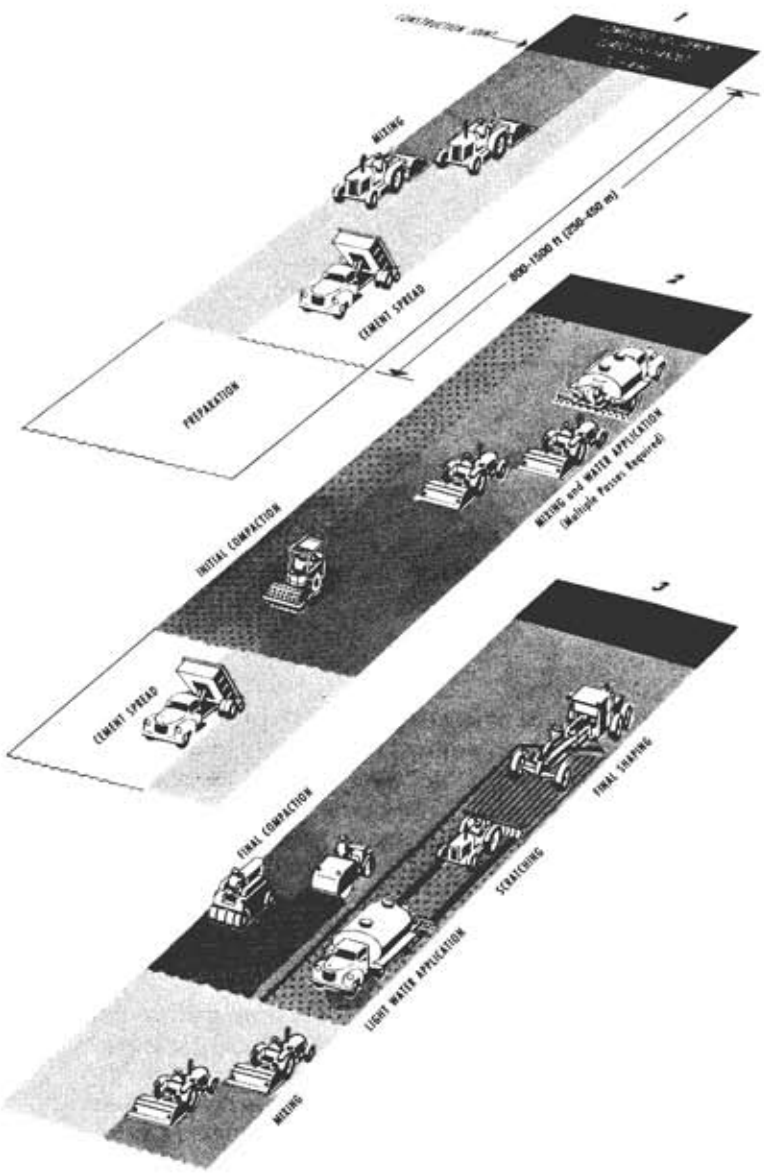

Fig. 33. Sketch of soil-cement processing operations with single transverse-shaft mixers.

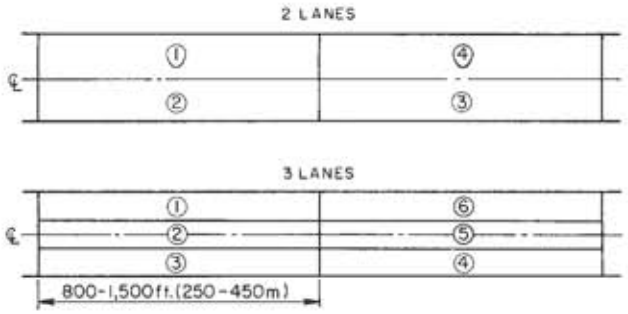

Fig. 34. Plan for processing with single transverse-shaft mixers.

Construction steps and typical equipment required for construction with single-shaft traveling mixers are summarized as follows:

CONSTRUCTION STEPS

1. Preparation:
   a. With in-place soil or failed flexible pavement:
      Scarify existing soil or recyclable pavement material.
      Pulverize if necessary.
      Shape area to crown and grade.
      Prewet as needed.
   b. With borrow material:
      Shape subgrade to crown and grade.
      Compact subgrade.
      Place borrow material.
      Shape borrow material.
2. Soil-cement processing:
   Spread portland cement.
   Mix.
   Apply water and remix as needed.
   Compact.
   Finish.
   Cure.

TYPICAL EQUIPMENT REQUIREMENTS

1. Preparation:
   1 motor grader or dozer with scarifier.
   Single-shaft traveling mixers for initial pulverization.
   1 water truck with pressure spray bar for prewetting.
2. Handling bulk cement:
   1 or more cement trucks as require.
   1 portable truck scale, if necessary.
   1 mechanical cement spreader.
3. Mixing and water application:
   Single-shaft traveling mixers (same as above).
   1 water pump at source.
   2 or more water pressure distributors or water supply trucks as needed.
4. Compaction:
   See section "Compaction" in this chapter.
5. Finishing:
   See section "Finishing" in this chapter.
6. Curing:
   See section "Curing" in this chapter.

Windrow-Type Pugmill

Although not commonly used today, windrow-type pugmills are an effective method for processing soil-cement. This type of equipment is generally limited to non-plastic, easily pulverized soil material. The process begins by blading the soil into uniform windrows. If necessary, a proportioner is pulled over the windrow to provide a uniform cross section. When borrow materials are used, a windrow spreader can be used to proportion the material. Nonuniform windrows cause variations in cement content, moisture content, and pavement thickness. The number and size of windrows needed depend on the width and depth of treatment and on the capacity of the mixing equipment.

Cement is spread on top of the partially flattened or slightly trenched, prepared windrow. The mixing equipment then picks up the soil material and cement and dry-mixes them with the first few paddles in the mixing drum. At that point water is added through spray nozzles and the remaining paddles complete the mixing. A strikeoff attached to the mixing equipment spreads the mixed soil-cement.

If a motor grader is used to spread the mixture and a tamping roller is used for compaction, the mixture should first be loosened to ready it for compaction. If two windrows have been made, the mixing equipment progresses 350 to 500 ft (100 to 150 m) along one windrow and then is backed up to process the other windrow for 700 to 1,000 ft (200 to 300 m).

The cement spreading operation is kept just ahead of the mixing operation. Water is supplied by tank trucks. A water tank installed on the mixer will permit continuous operation while the tank trucks are being switched. As soon as the first windrow is mixed and spread on one section of the roadway, it is compacted. At the same time a second windrow is being mixed and spread. It in turn is then compacted. Then finishing of the entire roadway is completed in one operation.

Fig. 35. To produce uniform cement and moisture content, windrows of soil should be of uniform cross section.

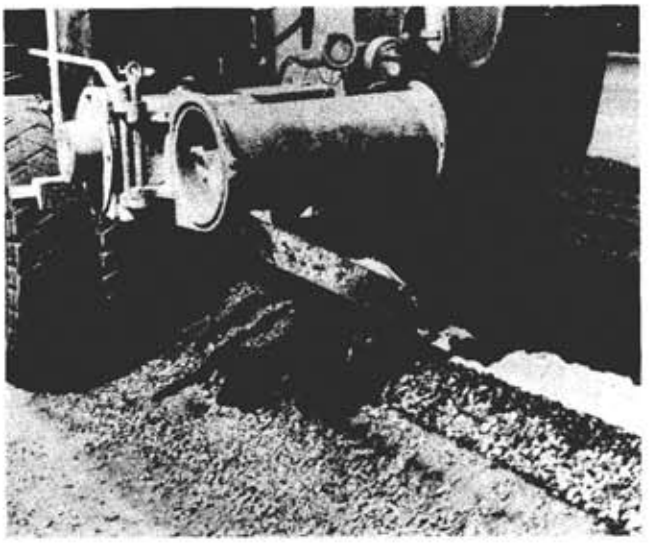

Fig. 36. Windrow-type mechanical spreader is used to place cement on the top of a slightly flattened windrow of borrow soil material.

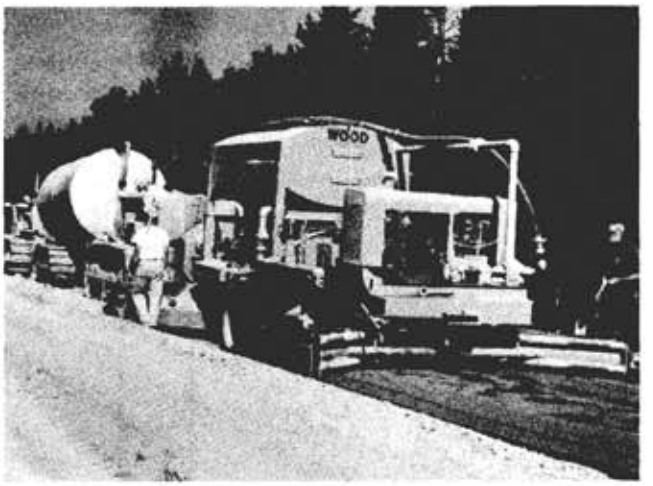

Fig. 37. A strikeoff attached to the windrow-type mixer can be used to level the mixed soil-cement.

CENTRAL PLANT MIXING

Central mixing plants are often used for projects involving borrow materials. Friable granular borrow materials are generally used because of their low cement requirements and ease in handling and mixing. Clayey soils or materials containing clay should be avoided because they are difficult to pulverize in a central plant mixer.

There are two basic types of central plant mixers—pugmill mixers, either continuous flow or batch and rotary drum mixers. Although batch pugmills and rotary drum mixers have been used successfully, the most common central plant mixing method is the continuous flow pugmill mixer.

A diagram of a continuous-flow pugmill plant is shown below. A typical plant consists of a soil bin or stockpile, a cement silo with surge hopper, a conveyor belt to deliver the soil and cement to the mixing chambers, a mixing chamber, a water-storage tank for adding water during mixing, and a holding or gob hopper to temporarily store the mixed soil cement prior to loading.

A pugmill mixing chamber consists of two parallel shafts equipped with paddles along each shaft. The twin-shafts rotate in opposite directions, and the soil cement is moved through the mixer by the pitch of the paddles.

Material feed, belt speed, pugmill tilt, and paddle pitch are adjusted to optimize the amount of mixing in the pugmill. Thorough blending in the mixer is very important, and the length of mixing time is used to control this factor. Some specifications dictate the minimum blending time. Usually 30 seconds is specified, although satisfactory blending has been achieved in shorter periods, depending on the efficiency of the mixer.

The correct proportion of materials entering the mixing chamber is important. Cement is usually metered onto the soil aggregate feeder belt or directly into the mixing chamber. Variations in moisture and in gradation of the soil aggregate will result in variations in the amount of material being fed into the mixing chamber. An adequate surcharge in the soil hopper will help to maintain a more uniform flow through the soil material feeder.

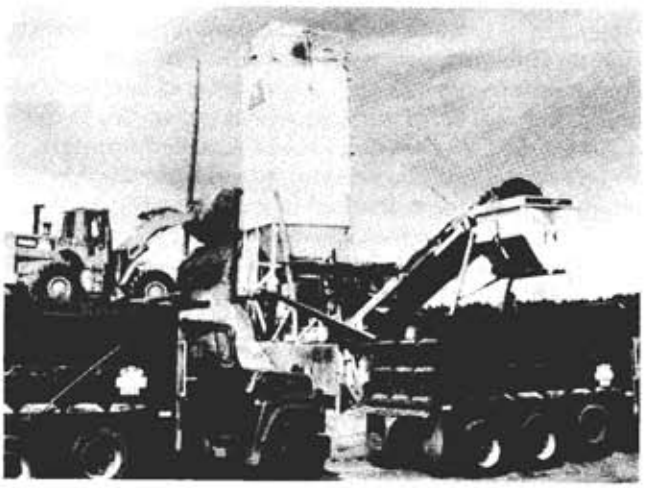

Fig. 39. Typical continuous-flow central mixing plant.

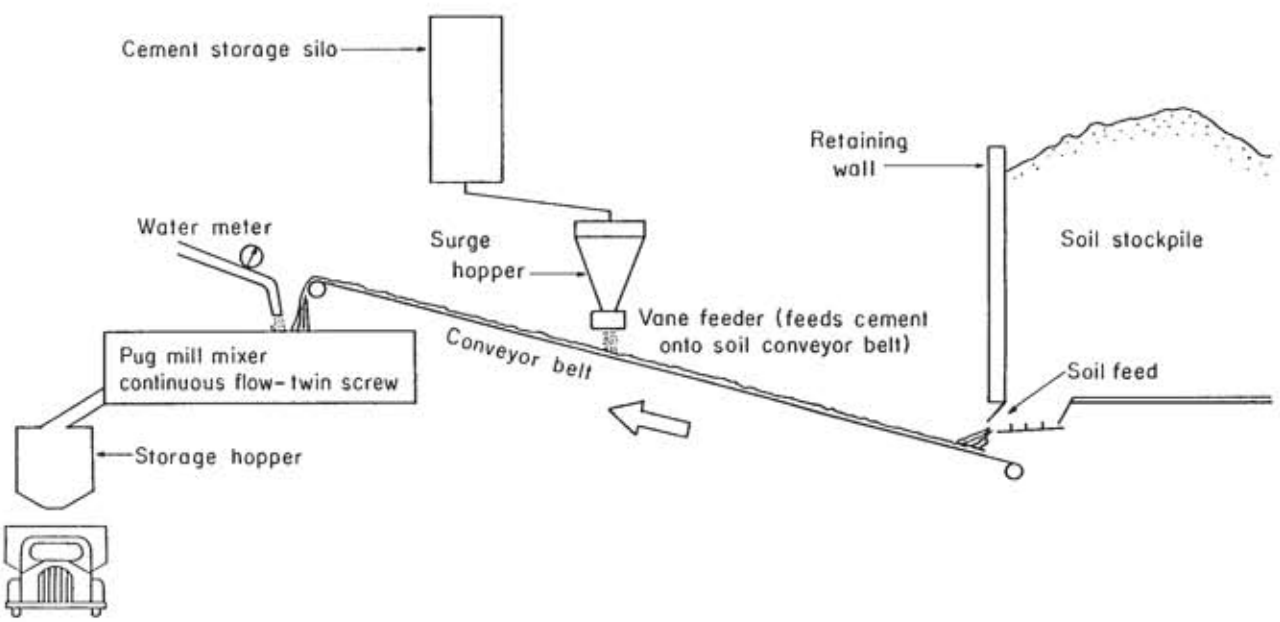

Fig. 38. Diagram of continuous-flow central plant for mixing soil-cement.

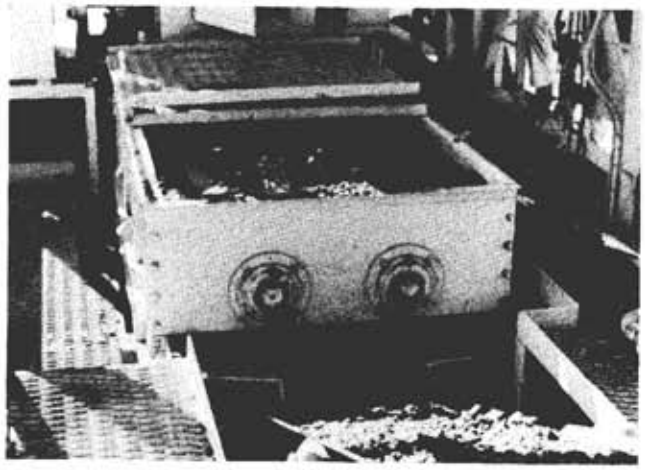

Fig. 40. Mixing action of a twin-shaft pugmill for continuous-flow, central mixing plant.

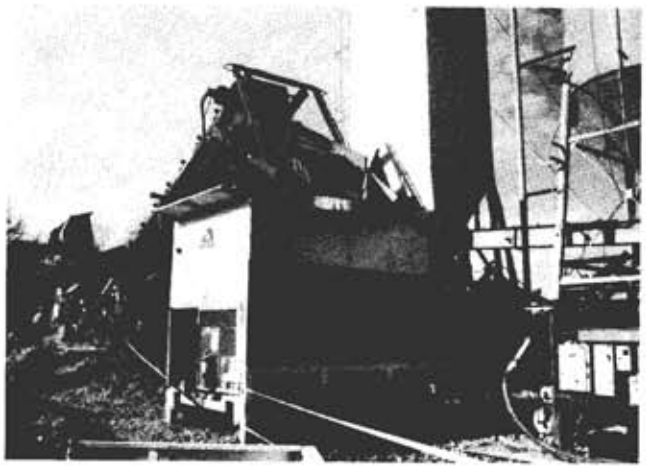

Fig. 42. Vibrating screen removes oversize material from soil feed prior to mixing.

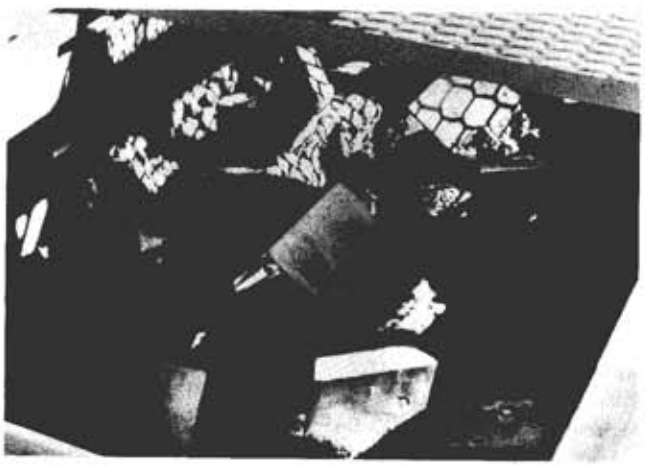

Fig. 41. Mixing paddles for twin-shaft pugmill.

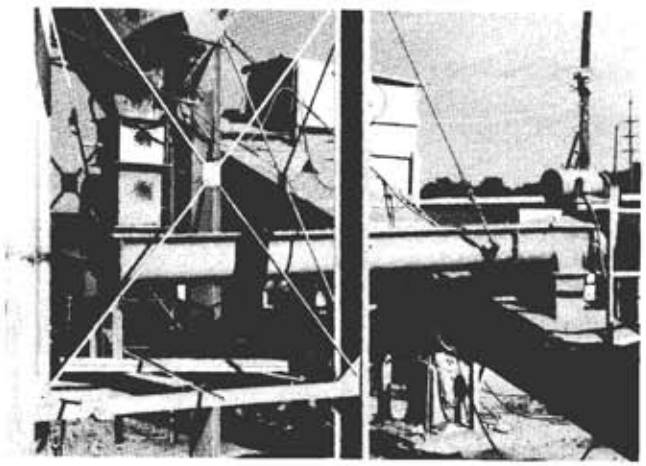

Fig. 43. Screw auger for transferring cement from cement silo to soil-cement conveyor belt. Note cover over conveyor belt to reduce dusting.

One of three types of cement meters—belt, screw, or vane—can be used to proportion the cement on a volumetric basis. Many cement metering devices require a 450- to 750-lb-capacity (200- to 340-kg) surge tank or hopper between the cement silo and the cement feeder. This tank maintains a constant head of cement for the feeder, thus providing a more uniform cement discharge. Compressed air of 2- to 4-psi (14- to 28-kPa) pressure should be used to prevent arching of cement in the silo and the surge tank. Portable vibrators attached to the surge tank can be used instead of air jets. A positive system should be included to stop the plant automatically if the cement flow suddenly stops.

When cement is added to a soil aggregate feeder belt, a simple method for minimizing cement loss due to wind is to use a small plow attachment to form a furrow for the cement in the soil aggregate. After the cement is added, a second plow attachment a little further up the main feeder or belt closes the furrow and covers the cement. Another method of minimizing material loss due to wind is to cover the entire feeder belt.

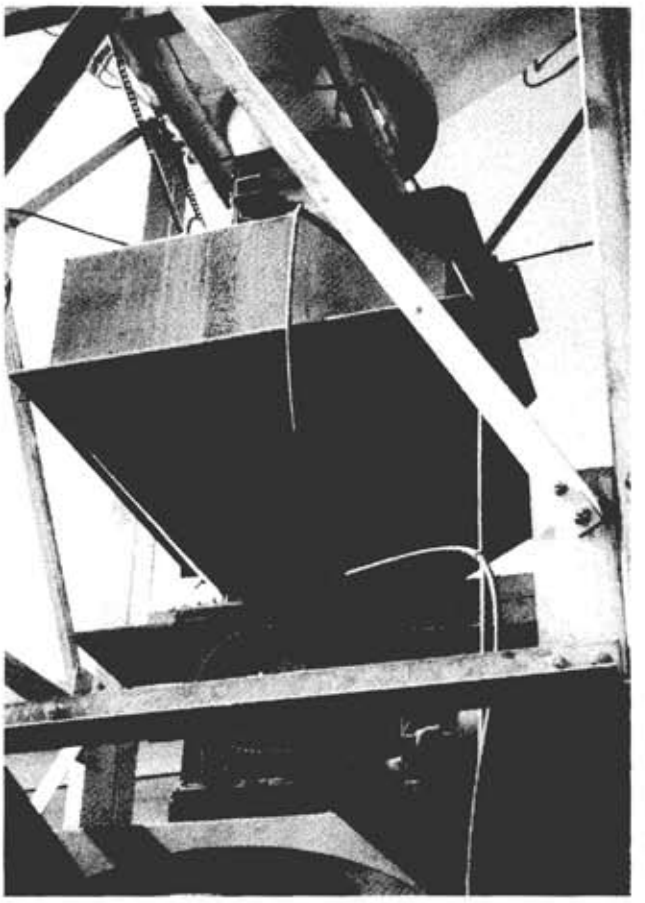

Fig. 44. Surge hopper placed between cement silo and vane feeder maintains a constant head of cement for feeder, thus providing a more uniform cement discharge.

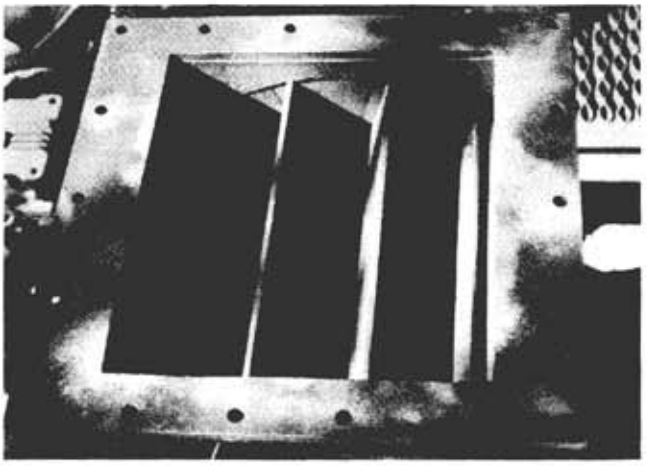

Fig. 45. Close-up view of the inside of a cement vane feeder.

Fig. 46. V-shaped plow devise provides furrow in soil for cement.

Plant Calibration

The correct proportion of cement, soil material, and water entering the mixing chamber must be determined by calibrating the plant before mixing and placing operations begin.

One method of calibrating the plant is first to run the soil material through the plant for a given period of time and collect it in a truck. This should be done for specific periods of time, such as 1, 2, and 3 minutes, to determine the uniformity of flow and the quantity of soil material going through the plant. The quantity of moist soil per hour divided by 1 plus the moisture content expressed as a decimal will give the quantity of dry soil per hour.

EXAMPLE:

Moist soil material going through the plant per hour: ..... 500 tons (454 Mg)
Moisture content of material: 5.5%
Delivery rate of dry material:

$$\frac{500}{\left(1.0+\frac{5.5}{100}\right)} = 474 \text{ tons per hour (430 Mg / h)}$$

Cement is calibrated in a similar manner by diverting it directly from the cement feeder into a truck or suitable container while soil material is going through the plant. A diversion chute directs the cement from the cement meter to the container (Fig. 48). The plant is run at full capacity during calibration so that operations will be comparable to those of actual running conditions and power drawdown will not affect calibration results during cement trials. Generally, periods of 15, 30, and sometimes 45 seconds are used to determine the uniformity of feed and the quantity of cement delivered.

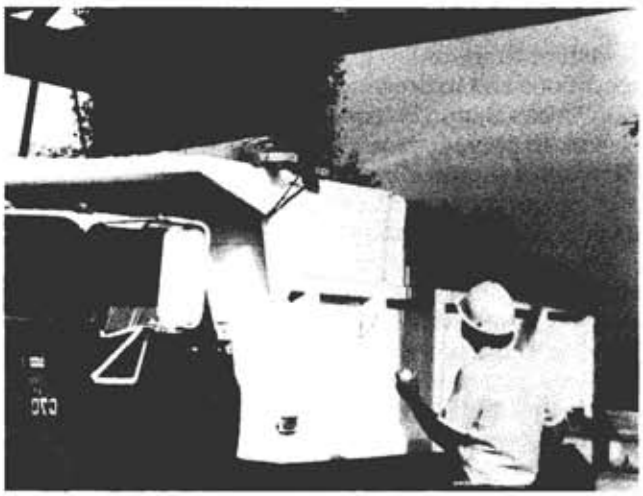

Fig. 47. Calibrating central mixing plant by first determining quantity of soil passing through plant for a specific period of time.

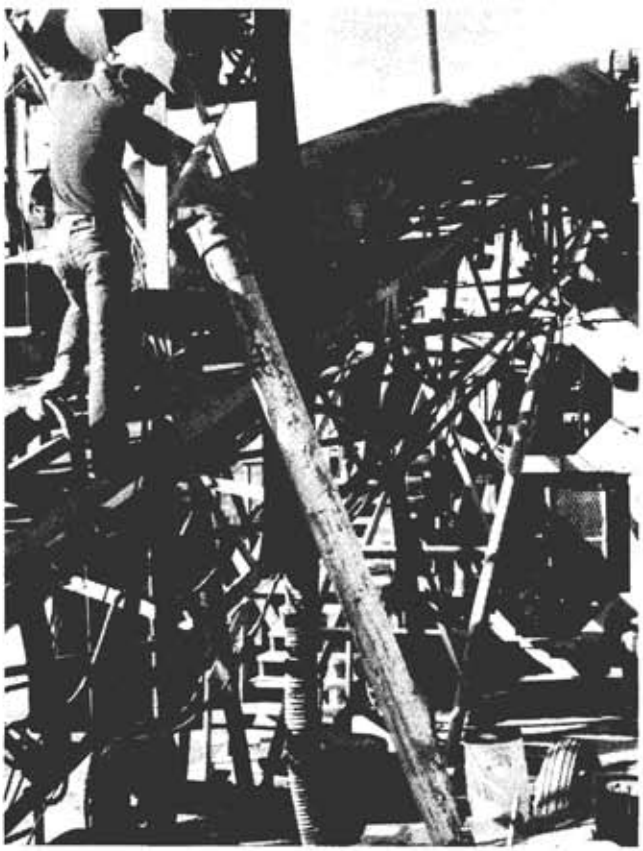

Fig. 48. Calibrating cement feed with the aid of a discharge chute.

EXAMPLE:

Determine cement quantity per unit time.

GIVEN:

Cement content by weight of dry soil material: 6.0%

PROCEDURE:

From previous example: 474 tons per hour (430 Mg/h) of dry soil material requires 474x0.06 = 28.4 tons of cement per hour (25.8 Mg/h), or

$$\frac{28.4 \times 2{,}000}{60} = 948 \text{ lb (430 kg) of cement per minute}$$

Rather than arbitrarily adjusting the cement feeder until the correct amount of cement is being discharged, the relationship between various feeder gate openings or revolutions per minute (depending on type of feeder) and amount of cement discharged can first be determined. By plotting this relationship, the gate openings or revolutions per minute for the required amount of cement can be determined. The cement meter can also be calibrated by determining separately the amount of cement and soil material on a selected length of conveyor belt and adjusting the cement feeder if necessary. Once the plant is properly calibrated, only one check a day is usually necessary. A cement batch weigher between the silo and holding hopper will keep track of cement used. The cement used should also be checked occasionally against bulk transport weights by completely emptying the silo.

Water is calibrated theoretically by weighing the amount discharged for one minute and comparing it with the meter on the mixer that measures rate of flow.

EXAMPLE:

Determine quantity of water needed for the mixture.

GIVEN:

Optimum moisture content: 11.5%
Add for evaporation loss: 2%
Moisture in soil material: 5.5%

PROCEDURE:

1. From previous example, dry soil material: 474 tons per hour (430 Mg/h)
2. From previous example, cement: 28.4 tons per hour (25.8 Mg/h)
3. Water in soil material: 474 x 0.055 = 26.1 tons per hour (23.7 Mg/h)
4. Soil material and cement: 474 + 28.4 = 502.4 tons per hour (455.8 Mg/h)
5. Water required: 502.4 x 0.135* = 67.8 tons per hour (61.5 Mg/h)
6. Water to add: 67.8 - 26.1 = 41.7 tons per hour (37.8 Mg/h), or

$$\frac{41.7 \times 2{,}000}{8.33 \times 60} = 167 \text{ U.S. gal per minute (632L/min)}$$

*Percentage of moisture required equals the optimum moisture content (11.5%) plus 2% for evaporation.

Coarse, non-plastic granular materials are sometimes mixed with cement in a rotary-drum mixer. The aggregate material and cement is batch-weighed and transferred to the mixer drum; water is added volumetrically. Production may be slightly less than for concrete. If fines are present in the soil-aggregate material there may be buildup on the mixer blades that must be loosened and removed.

When soil-cement is mixed in a batch-type pugmill or rotary-drum mixing plant, the proper quantity of soil material, cement, and water for each batch is weighted before being transferred to the mixer.

EXAMPLE:

Calculate the correct proportions for a 2,000-lb (907-kg) batch of soil-cement to be mixed in a batch-type pugmill or rotary-drum mixing plant.

GIVEN:

Cement content by weight of dry soil material: ... 6%
Optimum moisture content by weight of soil material plus cement: 11.5%
Evaporative loss ..... Add 2%
Moisture content of raw soil material: 5.5%

PROCEDURE:

1. Weight of dry soil material plus cement per batch:

$$\frac{2{,}000}{1.135^*} = 1{,}762 \text{ lb (800 kg)}$$

2. Weight of dry soil material:

$$\frac{1{,}762}{1.06} = 1{,}662 \text{ lb (754 kg)}$$

3. Weight of cement:
   1,762 - 1,662 = 100 lb (45 kg)
4. Weight of moist soil material:
   1,662 x 1.055 = 1,753 lb (795 kg)
5. Weight of water in soil material:
   1,753 - 1,662 = 91 lb (41 kg)
6. Weight of water needed:
   2,000 - 1,762 = 238 lb (108 kg)
7. Weight of water to add:
   238 - 91 = 147 lb (67 kg)
   or 17.6 U.S. gal (67 L)
8. Batch weights corrected for moisture in soil material:

Cement	100 lb (45 kg)
Water	147 lb (67 kg)
Moist soil material	1,753 lb (795 kg)
	2,000 lb (907 kg)

In batch-type pugmill or rotary-drum plants the soil material and cement should be dry-mixed before water is added.

*Percentage of moisture required equals the optimum moisture content (11.5%) plus 2% for evaporation.

Hauling and Spreading

To reduce evaporation losses during hot, windy conditions and to protect against sudden showers, haul trucks should be equipped with protective covers. To prevent excessive haul time, not more than 60 minutes should elapse between the start of moist-mixing and the start of compaction. Haul time is usually limited to 30 minutes.

The mixed soil-cement should be placed on the subgrade without segregation in a quantity that will produce a compacted base of uniform density conforming to the specified grade and cross section. On roadway construction the mixture should be spread to full width either by one full-width spreader or by two or more spreaders operating in staggered positions across the roadway. Less preferable is the use of one piece of spreading equipment operating one lane at a time in two or more lanes. No lane should be spread so far ahead of the adjoining lane that a time lapse of more than 30 minutes occurs between the times of placing material in adjoining lanes at any location. The subgrade should be damp when the soil-cement is placed.

There is a wide variety of spreading devices and methods. Using a motor grader or spreader box attached to a dozer are the most commonly used means. Spreading may also be done with asphalt-type pavers. Some pavers are equipped with one or more tamping bars, which provide initial compaction. Soil cement is usually placed in a layer 25 to 50 percent thicker than the final compacted thickness. For example, a 8 to 9 in. (200 to 230 mm) loosely placed layer will produce a compacted thickness of about 6 in. (150 mm). This relationship varies slightly with the type of soil, method of placement and degree of compaction. The actual thickness of the loosely spread layer is determined from contractor experience or trial-and-error methods.

Fig. 49. Spreaders working in staggered position across roadway to minimize longitudinal cold joints.

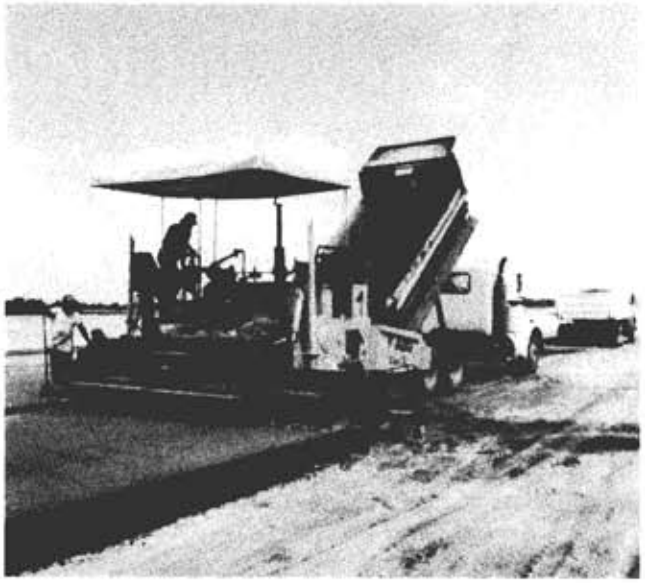

Fig. 50. Soil-cement being placed with heavy-duty paver equipped with rear dual tamping bars.

Construction steps and typical equipment required for central mixing plant construction are summarized as follows:

CONSTRUCTION STEPS

1. Preparation:
   - Shape subgrade to crown and grade.
   - Compact subgrade.
2. Soil-cement processing:
   - Mix soil material, cement, and water in plant.
   - Haul to placement area and spread.
   - Compact.
   - Finish.
   - Cure.

TYPICAL EQUIPMENT REQUIREMENTS

1. Preparation:
   - Motor grader.
   - Rollers.
2. Mixing:
   - One central mixing plant, continuous-flow or batch type pugmill or rotary drum, with facilities for storing, handling, and proportioning soil material, cement, and water.
3. Placing:
   - Haul trucks as needed.
   - Two mechanical spreaders.
4. Compaction:
   - See section "Compaction" in this chapter.
5. Finishing:
   - See section "Finishing" in this chapter.
6. Curing:
   - See section "Curing" in Chapter 1.

COMPACTION

The principles governing compaction of soil-cement are the same as those for compacting the same soil materials without cement treatment. The soil-cement mixture at optimum moisture should be compacted to maximum density and finished immediately. Optimum moisture and maximum density are determined by AASHTO T134 and ASTM D558. Moisture loss by evaporation during compaction, indicated by a greying of the surface, should be replaced with light applications of water.

Tamping rollers are generally used for initial compaction except for the more granular soils. Self-propelled and vibratory models are also used.

To obtain adequate compaction, it is sometimes necessary to operate the rollers with ballast to give greater unit pressure. The general rule is to use the greatest contact pressure that will not exceed the bearing capacity of the soil-cement mixture and that will still "walk out" in a reasonable number of passes. Friable silty and clayey sandy soils will compact satisfactorily using rollers with unit pressures of 75 to 125 psi (520 to 860 kPa). Clayey sands, lean clays, and silts that have low plasticity can be compacted with 100- to 200-psi (690- to 1380 kPa) rollers. Medium to heavy clays and gravelly soils require greater unit pressure—150 to 300 psi (1030 to 2070 kPa) with most self-propelled compaction equipment.

Compacted thicknesses up to 9 in. (230 mm) can easily be compacted in one lift. Greater thicknesses can be compacted with equipment designed for deeper lifts.

When tamping rollers are used for initial compaction, the mixed material should be in a loose condition at start of compaction so that the feet will pack the bottom material and gradually walk out on each succeeding pass. If penetration is not being obtained, the scarifier on a motor grader or a traveling mixer can be used to loosen the mix during start of compaction, thus allowing the feet to penetrate.

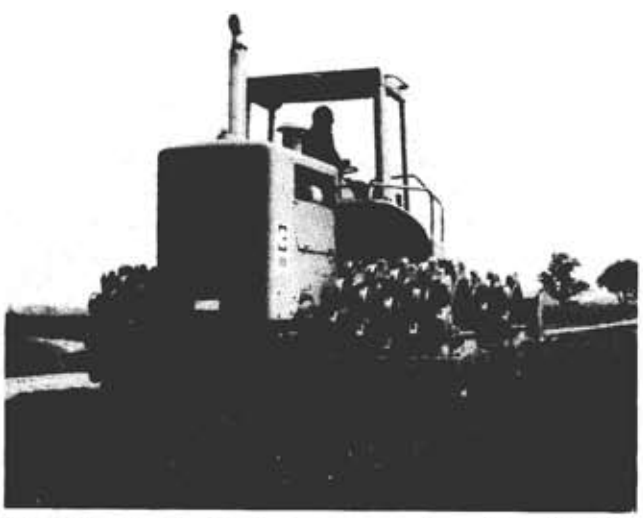

Fig. 51. Tamping rollers are commonly used for initial compaction of most non-granular soil-cement mixers.

Vibratory-steel-wheel rollers are typically used to compact soil-cement made of granular soil materials. Vibratory-plate jumping jack type compactors are used for hand compaction on nonplastic granular materials.

Pneumatic-tire rollers can be used to compact coarse sand and gravel soil-cement mixtures with very little plasticity and very sandy mixtures with little or no binder material, such as dune, beach, or blow sand. Some permit rapid inflation and deflation of the tires while compacting to increase their versatility.

Pneumatic-tire rollers pulled by track-type tractors equipped with street plates can be used to compact cohesionless sand mixtures. The weight and vibration of the tractor aid in compaction.

Heavy three-wheel steel rollers can be used to compact coarse granular materials containing little or no binder material. Gravelly soils that contain up to about 20% passing the No. 200 (75 mm) sieve and have low plasticity are best suited for compaction with these rollers.

Tandem-steel-wheel rollers are often used during final rolling to press down or set rock particles and to smooth out ridges.

There are two general types of pavement cross section: trench and featheredge. Both can be built satisfactorily with soil-cement. In trench-type construction the shoulder material gives lateral support to the soil-cement mixture during compaction. In the featheredge type of construction, the edges are compacted first to provide some edge stability while the remaining portion is being compacted. The edge slope should not be steeper than 2:1 to facilitate shaping and compacting. Shoulder material is placed after the soil-cement has been finished.

Occasionally during compaction and finishing a localized area may yield under the compaction equipment. This may be due to one or more causes: (1) the soil-cement mix is much wetter than optimum moisture; (2) the subsoil may be wet and unstable; or (3) the roller may be too heavy for the soil. If the soil-cement mix is too damp, it should be aerated with a cultivator, traveling mixer, or motor grader. After it has dried to near optimum moisture, it can be compacted.

For best results, compaction should start immediately after the soil material, cement, and water have been mixed. Required densities are then obtained more readily; there is less water evaporation; and daily production is increased. Final compaction should be completed no more than four hours from the start of mixing. Minimum density requirements for soil-cement range from 96% to 100% of the maximum density determined by a representative field sample taken from the moist mix at the time compaction begins (AASHTO T134 or ASTM D558). Details of moisture-density control are given in *Soil-Cement Inspector's Manual*.

Fig. 52. Vibratory-steel-wheel rollers are used to compact soil-cement made of granular materials.

Fig. 53. Pneumatic-tire rollers are used for compaction of sand, gravel and non cohesive soil-cement mixtures. They also are used during finishing operations to seal the surface.

Fig. 54. Checking compacted density of soil-cement using a nuclear density meter.

FINISHING

There are several acceptable methods for finishing soil-cement. The exact procedure depends on equipment, job conditions, and soil characteristics. Regardless of method, the fundamental requirements of adequate compaction, optimum moisture, and removal of all surface compaction planes* must be met to produce a high-quality surface. The surface should be smooth, dense, and free of ruts, ridges, or cracks.

When shaping is done during finishing, all smooth surfaces, such as tire imprints and blade marks, should be lightly scratched with a weeder, nail drag, coil spring, or spiketooth harrow to remove cleavage or compaction planes from the surface. Scratching may be done on all soil-cement mixtures except those containing appreciable quantities of gravel.

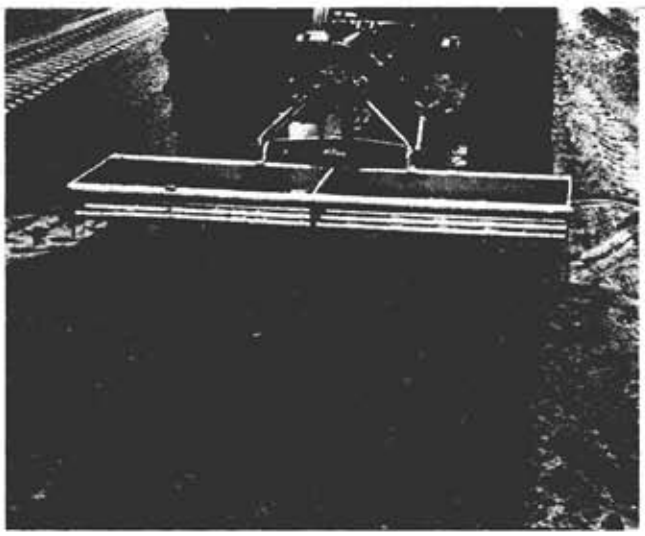

Fig. 55. During finishing operations, a hydraulically controlled scratcher removes possible surface compaction planes. The area is then rerolled with steel-wheel or pneumatic-tire roller.

The surface should be kept damp during finishing operations. Steel-wheel rollers can be used to smooth out ridges left by the initial pneumatic-tire rolling. Steel-wheel rollers are particularly advantageous when rock is present in the surface. A broom drag can sometimes be used advantageously to pull binder material in and around pieces of gravel that have been set by the steel-wheel roller. Instead of using a steel roller, surfaces can be shaved with the motor grader

Fig. 56. Surface of the soil-cement should be kept moist during finishing operations in order to provide adequate water for cement hydration.

and then rerolled with a pneumatic-tire roller to seal the surface. Shaving consists of lightly cutting off any small ridges left by the finishing equipment. Only a very thin depth is cut and all material removed is bladed to the edge of the road and wasted. The final operation usually consists of a light application of water and rolling with a pneumatic-tire roller to seal the surface. The finished soil-cement is then cured.

Outlines of several of the methods used for finishing soil-cement follow. All will produce satisfactory compaction and surface finish if fundamentals are adhered to.

Fig. 57. Motor-grader shaves the surface as necessary and is followed by a steel-wheel or a pneumatic-tire roller to seal the surface.

*Surface compaction planes are smooth areas left near the surface by wheels of equipment or by motor-grader blades. A thin surface layer of compacted soil-cement may not adhere properly to these areas and in time may fracture, loosen, and spall. For good bond, the area must be rough and damp. A scratcher, such as a weeder, nail drag, or spiketooth harrow, can be used to remove potential surface compaction planes. This scratching operation may not be necessary for mixtures that contain appreciable quantities of gravel.

METHODS OF FINISHING

Method 1.

For soil-cement mixtures made of fine-grained soil materials without much gravel and compacted with tamping roller:

1. Remove compaction planes with weeder, nail drag, coil spring, or spiketooth harrow while shaping with motor grader.*
2. Roll with pneumatic-tire roller.
3. Shave with motor grader.**
4. Roll with pneumatic-tire roller.†

Method 2.

For soil-cement mixtures containing appreciable quantities of gravel, having some plasticity, and compacted with tamping roller, heavy pneumatic-tire roller, or vibratory-steel-wheel roller:

1. Shape with motor grader.
2. Roll with steel-wheel roller.
3. Use broom drag.
4. Roll with pneumatic-tire roller.*

Method 3.

For very sandy mixtures containing little or no fines†† and compacted with pneumatic-tire roller and track-type tractor with street plates, or steel-wheel roller.

1. Remove compaction planes with weeder, nail drag, coil spring, or spiketooth harrow while shaping with motor grader.*
2. Roll with pneumatic-tire roller and drag with broom.
3. Use broom drag.*
4. Roll with pneumatic-tire roller.*

Method 4.

For coarse granular mixtures containing less than 20% material passing the No. 200 (75 mm) sieve, with low plasticity index,††† and compacted with vibratory-steel-wheel roller, or vibratory-plate compactors:

1. Shave high areas with motor grader.
2. Roll with pneumatic-tire roller.*

CURING

Compacted and finished soil-cement contains sufficient moisture for adequate cement hydration. A moisture-retaining cover is placed over the soil-cement soon after completion to retain this moisture and permit the cement to hydrate. Most soil-cement is cured with bituminous material, but other materials such as waterproof paper or plastic sheets, wet straw or sand, fog-type water spray, and wet burlap are entirely satisfactory.

The types of bituminous materials most commonly used are RC-250, MC-250, RT-5, and emulsified asphalt SS-1. Rate of application varies from 0.15 to 0.30 U.S. gal per square yard (0.7 to 1.4 L/m²). At the time of application, the soil-cement surface should be free of all dry loose, and extraneous material. The surface should also be moist when the bituminous materials are applied. In most cases a light application of water is placed immediately ahead of the bituminous application.

Fig. 58. Proper curing is essential to the hardening of soil-cement. Here a bituminous material is used to cure soil-cement base. To allow local traffic to use the base immediately, the bituminous cure coat is sanded to prevent pickup.

CONSTRUCTION JOINTS

After each day's construction a transverse vertical construction joint must be formed by cutting back into the completed soil-cement. This is usually done the last thing at night or the first thing the following morning, using a motor grader blade. The joint must be vertical, full depth and perpendicular to the centerline.

Before continuing soil-cement operations the joint must be cleaned of all dry and unmixed material and retrimmed if necessary. Mixed moist material is then bladed into the area and compacted thoroughly. The joint is left slightly high until final rolling when it is trimmed to grade with the motor grader and rerolled.

Joint construction requires special attention to make sure the joints are vertical and the material in the joint area is adequately mixed and thoroughly compacted.

When bituminous material is used as a curing agent, it should be applied right up to the joint and sanded to prevent pickup.

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*Light application of water as needed.

**Broom drag is sometimes used to level ridges.

†Tandem-steel-wheel roller is sometimes used prior to final rolling with pneumatic-tire roller.

††Such as cohesionless dune or blow sand containing 0% to 10% minus No. 200 sieve (75mm) material.

†††Only for very coarse granular mixtures containing appreciable quantities of gravel. Not recommended for other soil-cement mixtures. Material must be level and approximately to crown and grade before compaction.

Fig. 59. A vertical transverse construction joint perpendicular to centerline of road is made at the end of each day's construction by cutting back into completed work.

MULTIPLE-LAYER CONSTRUCTION

When the specified thickness of soil-cement base course exceeds the depth that can be compacted in one layer, usually greater than 10 in. (250 mm), it must be constructed in multiple layers. No layer should be less than 4 in. (100 mm) thick. The lower layer does not have to be finished to exact crown and grade, nor do surface compaction planes have to be removed since they are too far from the final surface to be harmful. For mixed-in-place construction the lower layer can be cured with the moist soil that will subsequently be used to build the top layer with mixed-in-place construction, care must be taken to eliminate any raw-soil seams between the layers.

Bonding Successive Layers

For effective bonding of successive layers of soil-cement it is essential that each completed surface remain clean and moist, but not wet, until it is covered. Mud and debris tracked onto a surface will significantly reduce bonding. Methods which can be used to improve bonding include:

1. Minimize time between placement of successive layers. This time will vary depending on the characteristics of the soil-cement and climatic conditions.
2. Use of either dry cement or cement slurry. Dry cement may be applied at about 1 lb/yd^2 (0.54 kg/m^2) to a moistened surface immediately prior to placement. The cement slurry mix should have a water-cement ratio of about 0.70 to 0.80.
3. Provide a roughened surface texture on the lower soil-cement layer by brushing the surface with a power broom after the soil-cement has set. Also use of a tamping sheepsfoot type roller for final compaction of the lower layer will provide indentations in the surface of the layer.
4. Use of chemical retarding agents in the soil-cement.

Fig. 60. Bonding soil-cement layers by spreading dry cement over completed soil-cement layer immediately prior to placement of subsequent layer.

SPECIAL CONSTRUCTION CONSIDERATIONS

Handling Traffic During Construction

A small volume of traffic can be handled through the construction area. If side ditches or shoulders are flat, traffic can be diverted to these areas. In extreme cases, where traffic volume is large and detours are not feasible, half-width construction may be employed, but this is not the vest practice since a longitudinal construction joint must be built. Loads of less magnitude than that of the equipment used in building the soil-cement will not harm the freshly constructed base provided the subgrade is stable. Traffic must be controlled since high-speed traffic may mar the "green" surface. Where traffic is to be maintained, provisions should be made to keep the curing material in place. Bituminous material can be sanded to prevent its pickup by traffic.

Rainfall

Attention to a few simple precautions before processing will greatly reduce the possibility of serious damage from wet weather. For example, any loose or pulverized soil should be crowned so it will shed water, and low places in the grade where water can accumulate should be trenched so the water will drain off freely.

As shown by the construction of millions of square yards of soil-cement in all climates, it is unlikely that rainfall during actual construction will be a serious problem to the experienced engineer or contractor.

Usually construction requires the addition of water equivalent to 1 to 1-1/2 in. (25 to 28 mm) of rain. If rain falls during cement-spreading operations, spreading should be stopped and the cement already spread should be quickly mixed into the soil mass. A heavy rainfall that occurs after most of the water has already been added, however, can be serious. Generally, the best procedure is to obtain rapid compaction by using every available piece of equipment so that the section will be compacted and shaped before too much damage results. In such instances it may be necessary to complete final blading later; any material bladed from the surface is wasted.

Wet Soil Material

Excessively wet material is difficult to mix and pulverize. Experience has shown that cement can be mixed with sandy materials when the moisture content is as high as 2% above optimum. For clayey soils, the moisture content should be below optimum for efficient mixing. It may be necessary to dry out the soil material by aeration. This can be done by using single-shaft traveling mixers with the hood in a raised position, or by cutting out the material with the top of a motor grader blade and working and aerating with a disc.

The maintenance of good crown and surface grade to permit rapid runoff of surface water before soil-cement processing is the best insurance against excessive amounts of wet material.

Soft Subgrade

Proper compaction is one of the fundamental requirements of soil-cement construction. If the subgrade is soft and cannot properly support the compaction equipment, adequate density of the soil-cement will not be obtained. Therefore, soft areas should be located and corrected before processing begins. These areas can generally be detected by observing their stability under the wheels of the motor grader as it shapes the area prior to soil-cement processing.

Shallow, soft subgrade areas are usually due to poor maintenance of the grade prior to soil-cement processing. Such areas can usually be stabilized by aerating and recompacting the soil. When deep unstable areas are encountered, it is usually necessary to remove the underlying wet soil and replace it with stable material, or the area can be subprocessed with soil-cement or cement-modified soil.

In subprocessing, the top layer of material is bladed aside and the exposed soil is mixed with cement and compacted to the best possible density. The drying action of the cement and its hydration will harden the area sufficiently so that the top layer of material can be replaced and processed in the usual manner.

Springs, seepage areas, and differential frost-heave areas should be located and corrected.

In some instance soft subgrades will not show up until compaction of the soil-cement has been partially completed. In cases where minor distress is indicated by cracking and shoving, the rollers should be removed and final rolling done with a lightweight roller.

Cold Weather

Soil-cement, like other cement-using products, hardens as the cement hydrates. Since cement hydration practically ceases when temperatures are near or below freezing, soil-cement should not be placed when the temperature is 40°F (4°C) or below. Moreover, it should be protected to prevent its freezing for a period of 7 days after placement by a suitable covering of hay, straw, or other protective material.

CHAPTER 3

STREETS, SHOULDERS, AIRPORTS AND PARKING AREAS

STREETS

The same principles of construction and the same basic control factors apply in construction of soil-cement streets as apply in soil-cement roadway construction. Proper cement content, moisture content, density, and curing are essential. Laboratory testing of representative soil samples to establish an adequate cement content is a prerequisite to construction. Simple field control tests during construction eliminate guesswork and ensure quality.

Fig. 61. Soil-cement being constructed on street paving project from curb to curb in one continuous operation.

Curbs, Gutters, and Manholes

Concrete curbs and gutters should be built before soil-cement paving is started.

Soil materials should be balanced carefully and shaped to proper crown and grade before soil-cement processing is begun. Crown and grade should conform to any existing or planned structures such as curbs and gutters, manholes, driveways, and street intersections. This procedure simplifies and speeds up final finishing.

Most engineers and contractors prefer to remove manhole covers and frames before processing. A heavy wooden plank or metal plate is placed over the manhole just below the depth to be processed, the soil material is replaced over it, and its location is marked. This permits work to proceed without difficulty. After final finishing and before the soil-cement has hardened, the temporary cover is removed, the manhole frame and cover are replaced, and soil-cement is hand-tamped tightly around the structure. Concrete can be used instead of soil-cement to fill in around structures such as manholes.

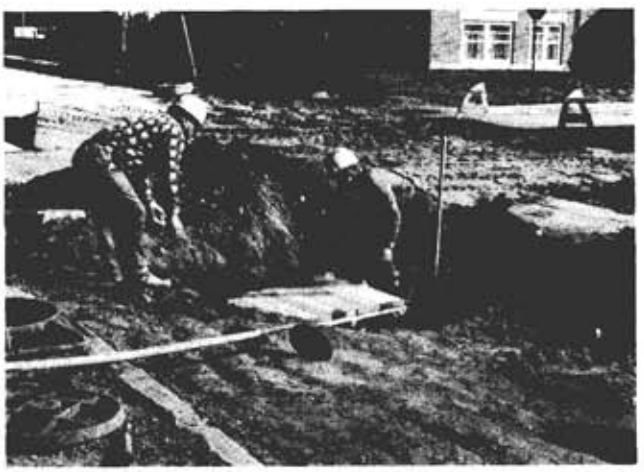

Fig. 62. Soil-cement processing is hastened by removing manhole covers and frames, covering the holes with wooden planks or metal plates just below the depth to be processed.

Fig. 63. Covering the wooden plank with soil. It is important to mark the location of the manhole so that it can be easily located after soil-cement processing is completed.

If it is expedient to process around manholes, their locations should be marked clearly with flags or barricades to avoid damage by construction equipment. Other utility structures should be marked carefully before processing so that equipment can be lifted over or guided around them.

Processing should be organized so that the full street width is completed each day. To speed construction and to avoid the need for longitudinal joints, processing is done in successive construction lanes—usually some multiple of the mixing equipments width—until the full street width is mixed.

Special attention to mixing adjacent to curbs, gutters, and utility structures is necessary to ensure that it is thorough. All soil and cement should be cleaned away from the gutter section for the full depth of processing. The point of the motor-grader blade or special cleaning devices are used for this purpose. Some final cleaning with flat-end shovels may be needed.

Fig. 64. After the cement is spread, the soil and cement is pulled away from curbs, gutters and other tight areas to allow for thorough mixing.

Fig. 65. Mixing soil-cement with single transverse-shaft mixer.

Fig. 66. Compacting soil-cement immediately adjacent to gutter.

Preliminary and final shaping of the section should be carefully done to obtain proper grade adjacent to curbs and gutters, manholes, driveways, and street intersections. During shaping, a special guide can be attached to the end of the motor grader blade so that, when it is resting on the gutter, it maintains the proper depth for the subsequent bituminous surface. If no curbs and gutters exist, it is important to build the edges of the paving on line and at uniform grade to facilitate the placing of curbs and gutters or utility structures at some later time.

The moist soil-cement must be compacted thoroughly adjacent to curbs, gutters, and utility structures. The rear wheels of a motor grader can be used to obtain additional compaction along the gutter line.

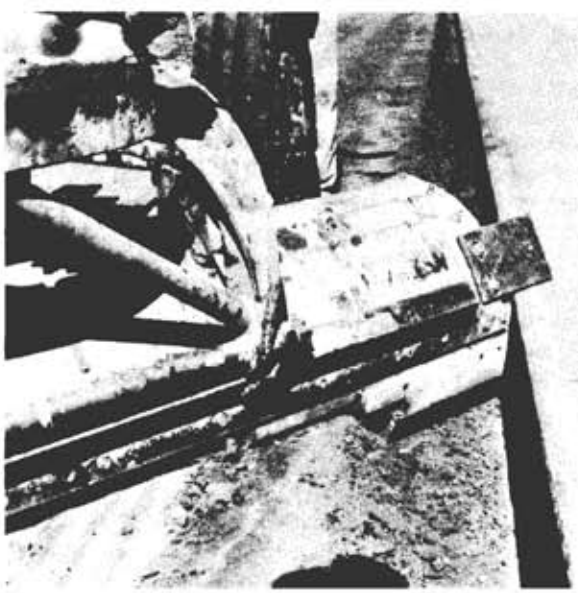

Fig. 67. Steel plates attached to grader blade can be used to clean gutter line.

Intersections

Generally, construction should be planned so that the turnaround area for equipment is at the end of the block within the street intersection. Construction joints should be located at the end of the block being paved, but not within the intersection unless paving is to end there. Sometimes the soil-cement paving is extended a few feet (meters) beyond the intersection and cut back when the cross street is paved. The entire intersection is then paved as a part of the construction of the intersecting street. Miscellaneous areas to be paved, such as corners of intersections and approaches to alleys or unpaved streets, require separate mixing and finishing, but are usually handled without undue delay at the time the street is built.

Surface Course

The type of bituminous surface to be used depends on the factors discussed in Chapter 1. A double bituminous surface is a common-type wearing surface for residential streets. Higher-type surfaces, either road-mixed or plant-mixed, are more costly but are sometimes justified. Where snowplows are likely to be used, a minimum 1-1/2-in. (38-mm) surface depth should be specified.

The bituminous surface course can be placed as soon as the bituminous curing material has dried. Often all streets scheduled for construction are processed first. Then all surfacing can be placed in one continuous operation. The soil-cement base can be opened to local traffic immediately after construction and before the surface course is placed provided the base has hardened sufficiently to prevent marring or distortion of the surface and provided the curing material is not damaged.

WIDENING AND SHOULDERS

Equipment used for constructing soil-cement pavement widening and shoulders are basically the same as those for soil-cement road construction except that equipment must conform to a more limited space. Thorough mixing and compaction of the soil-cement along the roadway pavement edge are essential.

Widening

Pavement widening is generally designed to be thicker than ordinary pavement because it is subjected to greater stresses. Soil-cement widening varies in thickness from 6 to 12 in. (150 to 300 mm), depending on traffic and subgrade conditions.

In cases where edges of the old roadway are found to be weak, the edge material should be ripped up and pulverized; then both edges and widening are processed in a single operation. Widening of 4 ft (1.2 m) or more can be processed in place; however, some modification of equipment and of processing methods may be necessary.

For narrow widening, the material can be bladed or trenched out onto the surface of the existing roadway for processing. It should be mixed there with a traveling mixer, bladed back into the trench, and compacted and finished.

When the in-place soil is not suitable, borrow material should be used. The area to be widened is trenched and the excavated material put aside to be used later for widening the shoulder. Borrow material, cement, and water can be mixed in the trench or on the surface of the existing roadway; or it can be mixed in a central mixing plant, hauled to the site, and dumped through a spreader box into the trenched area. If a spreader box is not available, the mix can be dumped into a windrow on the edge of the existing pavement and bladed into the excavated area with a motor grader. When the mixture is in place, it is compacted and finished. Single-drum tamping rollers, trench rollers, or the dual rear wheels of heavily loaded trucks can be used for compaction in the narrow areas.

The completed widening should be cured and surfaced with a suitable bituminous mixture. Frequently the entire old roadway and the new widened area are surfaced in one operation.

Shoulders

In contrast with widening that is designed to carry continuous traffic, shoulders are improved to provide better pavement performance and a safe emergency stopping area. Improved shoulders increase the safety and traffic capacity of a road.

Soil-cement shoulders are stable under all weather conditions, do not consolidate under traffic, resist erosion and growth of vegetation, and provide rapid runoff of surface water. High concentrations of deicing salt are detrimental to soil-cement shoulder bases and should be drained from the pavement as rapidly as possible.

Fig. 68. Spreading plant-mixed soil-cement from truck onto prepared shoulder area.

Depending on type and volume of traffic, soil-cement shoulders should be built 5 to 8 in. (125 to 200 mm) thick. Bituminous surfaces range from single surface treatments to plant-mix surfaces 2 in. (50 mm) or more thick. In frost areas a minimum 1-1/2-in. (38-mm) surface is recommended to provide protection against snowplow damage.

Vertical movement of shoulders from frost heave or expansive soils under the shoulder can be minimized by proper and effective sealing of the longitudinal joint between pavement and shoulder. Asphalt and asphalt-filler mixtures have been used successfully. A rolling cutter attached to a motor grader can be used to produce a joint that is filled with cold-applied joint sealer. The longitudinal joint can also be formed by sawing with a conventional concrete power saw equipped with a diamond segmented blade.

Construction methods for soil-cement shoulders are the same as those for widening. The width of construction dictates the procedure used and what modification of equipment is required.

It is very important to obtain thorough mixing and compacting of the shoulder materials along the roadway pavement edge. This can be done by the same methods used for mixing and compacting soil-cement next to curbs and gutters in street work.

AIRPORTS

The same principles of construction and the same fundamentals of control that apply to soil-cement road construction apply to soil-cement airport pavements as well. A few details, however, require emphasis. They are (1) shaping the soil material to proper crown and grade before processing; (2) preparing a workable plan for processing; and (3) construction joints.

Shaping Material to Crown and Grade

Since there is little longitudinal and transverse displacement of the soil material during processing, accurate grading before construction begins will save time and make finishing easier. This is particularly true of large areas such as airport runways. A system of grade stakes should be used for grade control.

Plan for Processing

The most practical plan for processing soil-cement airport pavements is one that reduces longitudinal and transverse construction joints to a minimum and permits finishing to be done longitudinally—thus providing a smoother surface. This can be done by dividing the area into processing sections of convenient length and width. It is important that the end of each longitudinal section be built to grade. After each day's construction, the material next to the end should be loosened to prevent its hardening.

Joint Construction

Three types of joints are needed with soil-cement airport pavements: (1) a longitudinal joint adjacent to partially hardened soil-cement, that is, adjoining the preceding day's construction; (2) a longitudinal joint adjacent to hardened soil-cement, that is, adjoining soil-cement processed three or four days previously; and (3) a transverse construction joint at turnaround areas adjoining hardened soil-cement.

The material next to all joints must be thoroughly pulverized, mixed with cement, moistened, and tightly compacted. Compaction next to a joint can be done with motor grader wheels and by operating the compaction rollers as close to the joint as possible. The location of all joints should be properly marked by stakes and string lines or by pegs so that streaks of unprocessed material will not occur along the joints. Special attention should be given all joint construction to ensure a vertical joint, adequately mixed material, and compaction up against the joint.

A longitudinal joint adjacent to partially hardened soil-cement can be constructed with transverse shaft mixers by merely cutting back a few inches (millimeters) with the mixer into the previously constructed area. The amount of overlap is determined by digging back into the completed work until solid material and proper crown and grade are reached. Guide stakes should be set for cement spreading and mixing.

When longitudinal and transverse joints are built after the soil-cement has hardened too much for mixing equipment to cut it, the joint face must be prepared at the end of the day of construction of the completed lane or the following morning by cutting to a string line with the edge of a motor grader blade. Some hand trimming with ax and shovel may be needed. A disc mounted on the end of a blade makes a good edge cutter. With a windrow-type mixing machine, and central plant mixers, this method of joint construction is used for all joints.

Construction joints are formed by cutting back into the completed work to form a vertical face, free of loose and shattered material. See also "Construction Joints" in Chapter 2.

Regardless of the method of construction, all joints must be cut back to solid soil-cement and the material next to a joint must be properly pulverized, mixed with cement, moistened, compacted, and finished level with the adjoining section. Care must be taken to maintain proper grade.

Thickness Design

A guide to the thickness design of runways, taxiways, and aprons is given in *Soil-Cement Pavements for Light Aircraft*, Portland Cement Association.

PARKING AND STORAGE AREAS

The same basic procedures and controls apply to the construction of soil-cement parking and storage areas as apply to construction of soil-cement roads. Accurate grading before processing starts and good grade control during processing will provide for rapid runoff of water and prevent puddles. Large areas should be processed in the same way as outlined for airport runways. For small projects, a processing plan that permits the fullest use of equipment in rather confined areas should be used.

Parking areas are surfaced with bituminous material. Storage areas for coal and similar materials can be left unsurfaced except in traffic lanes. If the soil-cement is to be left unsurfaced, the cement factors should be increased to provide additional abrasion resistance. This increase should be 2% for granular soils containing less than 50% silt and clay, and 4% for other soils.

Thickness design for heavy-duty industrial use such as contained ports, rail and truck terminals, and log-sorting yards present unique problems. Procedures for these pavements are given in *Thickness Design of Soil-Cement Pavements for Heavy Industrial Vehicles*, Portland Cement Association.

Fig. 69. Large open areas can be effectively water cured using a sprinkler system arrangement.

CHAPTER 4

RECYCLING FAILED FLEXIBLE PAVEMENTS

One of the most important uses of soil-cement is in recycling and reconstructing granular base courses that have failed. The old, failing flexible pavements contain basically good material that can be reused to conserve materials and money. Incorporating portland cement with base-course materials, often including the old bituminous surface, provides an economical means of salvaging and strengthening wornout pavements.

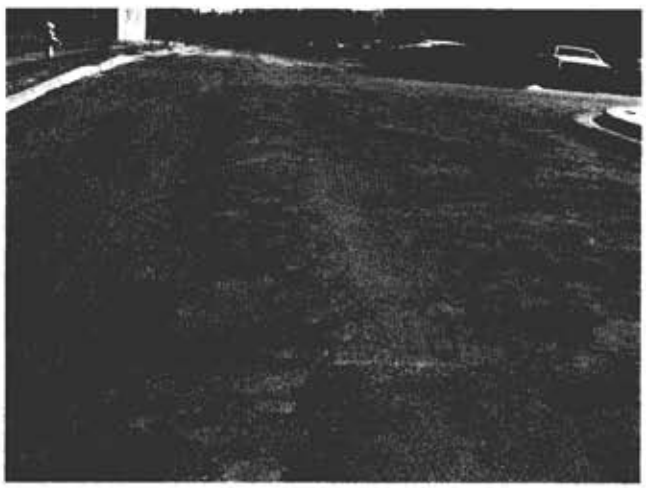

Fig. 70. Badly deteriorated asphalt street is in need of major reconstruction.

Cement binds the granular particles together to form a paving material capable of withstanding moisture infiltration and frost action and of bridging over localized soft spots in the subgrade. Cement increases the strength of the base without the need for removing the old material and hauling in large quantities of expensive new materials. Existing grade lines and drainage can be maintained.

Portland cement has been used with gravel, crushed stone, caliche, limerock, clay-gravel mixtures, sand-clay mixtures, and similar granular-type materials to produce hardened soil-cement of more than average load-carrying capacity and serviceability. These materials require only a minimum of cement for adequate hardening.

INCORPORATING OLD SURFACING

If the old bituminous mat is practically dead, that is, has lost most of its flexibility and can be readily pulverized, it can be considered satisfactory for inclusion in the soil-cement mixture. If, on the other hand, the mat is alive, that is, the bituminous material retains most of its original viscosity, it should not be incorporated in the mixture, but should be removed. It may be worthwhile to reclaim it and use it to surface the soil-cement, with the addition of new materials as needed.

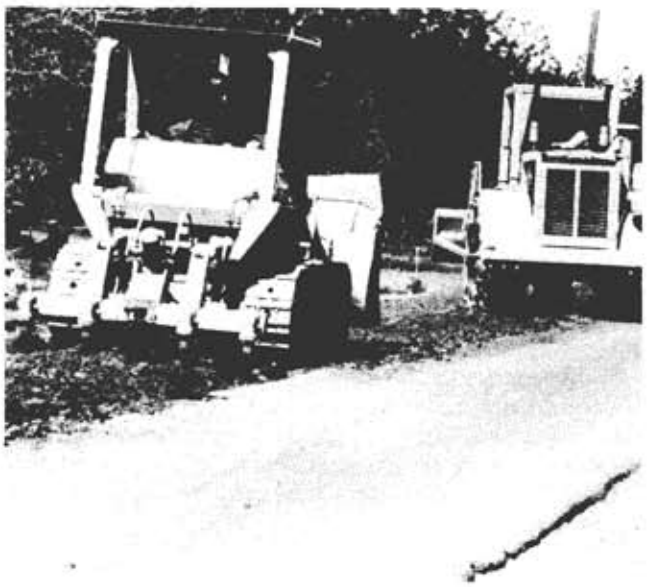

Fig. 71. Recycling begins by ripping up the old asphalt surface.

Relatively thin surface treatments present no particular construction problem and can usually be readily scarified, broken up, and pulverized. Thick, heavy mats are more difficult to handle, but can be adequately pulverized with the proper equipment. The old mat must be pulverized sufficiently so that it meets the soil-cement gradation requirement of 55% passing a No. 4 (4.75-mm) sieve. The amount of old surfacing included in the soil mixture should generally not exceed 50% of the total. The largest pieces of mat in the pulverized mixture should not exceed 2 in. (50 mm).

Fig. 72. The old asphalt surface is crushed into small pieces using a pavement braker such as this one.

The granular material in some old bases may be deficient in fines and may contain variable amounts of oversize material, that is, over 2 in. (50 mm). These large pieces should be broken up so that all the material will pass a 2-in. (50-mm) sieve.

Once the old base material and bituminous surface have been pulverized and the area brought to proper crown and grade, soil-cement processing should be carried out as already described.

Fig. 73. The old asphalt surface and base materials are further broken down using a single transverse-shaft mixer.

CONSTRUCTION EQUIPMENT

Construction equipment used to scarify, break up, and pulverize old surfacings includes rippers, motor grader scarifiers, traveling hammer mills, traveling mixing machines, disc harrows, and various types of rollers. The hardness, thickness, and type of surface will dictate the choice of equipment for a specific job.

The specific procedure followed for recylcing failed flexible pavements with cement is:

1. Initial preparation:
   a. Scarify and pulverize old mat.
   b. Scarify and break up old base material.
   c. Prewet the prepared material..
   d. Shape area to approximate crown and grade.
2. Soil-cement processing:
   a. Spread portland cement.
   b. Mix thoroughly.
   c. Apply water, if necessary, to achieve optimum moisture content and remix.
   d. Compact.
   e. Finish.
   f. Cure.
3. Apply new surface course.

Additional information is given in *Recycling Failed Flexible Pavements with Cement*, Portland Cement Association.

CHAPTER 5

CEMENT-MODIFIED SOILS

A cement-modified soil (CMS) is a soil material that has been treated with a relatively small proportion of portland cement—less cement than is required to produce hardened soil-cement. The objective of the treatment is to amend undesirable properties of problem soils or substandard materials so that they are suitable for use in construction. With the small quantities of cement generally used, CMS becomes caked or slightly hardened. However, it still functions essentially as a soil, although an improved one. The degree of improvement depends on the quantity of cement used and the type of soil. Therefore, by the addition of varying amounts of cement, it is possible to produce cement-modified soils with a wide range of engineering properties. The improvement in engineering properties of a soil due to the addition of small quantities of cement can be measured in several ways including:

- Reduction in plasticity characteristics as measured by the plasticity index (PI).
- Reduction in the amount of silt and clay size particles.
- Increase in the California Bearing Ratio (CBR).
- Increase in shearing strength.
- Decrease in volume-change properties.

Cement-modified soils are usually classified into two groups according to the predominant grain size as follows:

- **Cement-modified silt-clay soils** (soils containing more than 35% silt and clay*). The general objective is to improve soils that are otherwise unsuitable for use in subgrades or subbase layers. Specific objectives may be to decrease plasticity and volume change characteristics, to increase the bearing strength, or to provide a stable working platform on which pavement layers may be constructed.
- **Cement-modified granular soils** (soils containing less than 35% silt and clay**). The usual objective is to alter substandard materials so that they will meet requirements specified for pavement base or subbase layers.

CEMENT-MODIFIED SILT, CLAY SOILS

Cement-modification improves the properties of certain silt-clay soils that are unsuitable for use in subgrade construction. The objective is to reduce the ability of the soil to retain moisture, while at the same time increasing its strength. CMS can transform a wet, soft subgrade into a surface that will support construction equipment.

One common and simple way of measuring the improvement of a silt-clay soil is by the reduction in its plasticity characteristics as measured by the plasticity index. The plasticity index (PI) is a measure of a soil's cohesive properties and is indicative of the amount and nature of clay in the soil. Soils with a high PI may be difficult to work with in construction because of their instability and stickiness when wet.

High PI soils also have potential for detrimental volume changes during wetting and drying, which can lead subsequently to pavement roughness. Experience has shown that soils with PI's less than about 15 usually cause no problems.

Table 1 gives examples of the effect of cement-modification on three clay soils. The substantial reduction of PI's and increase in shrinkage limits*** indicates not only an improvement in the volume change characteristics but also modification of the soils into more stable and workable materials. In many cases, reducing the PI to a value in the range of 12 to 15 serves as the criteria for selecting a cement content.

Subgrade Stabilization for Flexible Pavements

Poor quality subgrade soils are improved by cement modification. The primary purpose is to provide supporting power and a firm, stable working table for pavement construction. Cement-treated subgrades also provide an effective solution to the problem of fatigue failures caused by repeated high deflections of asphalt surfaces where a weak subgrade exists in the pavement structure. Field tests and experience in areas of resilient subgrades, micaceous soils for example, show a marked decrease in deflection when subgrades are stabilized with cement. Performance indicates the cost of subgrade stabilization is well worth the modest cost involved.

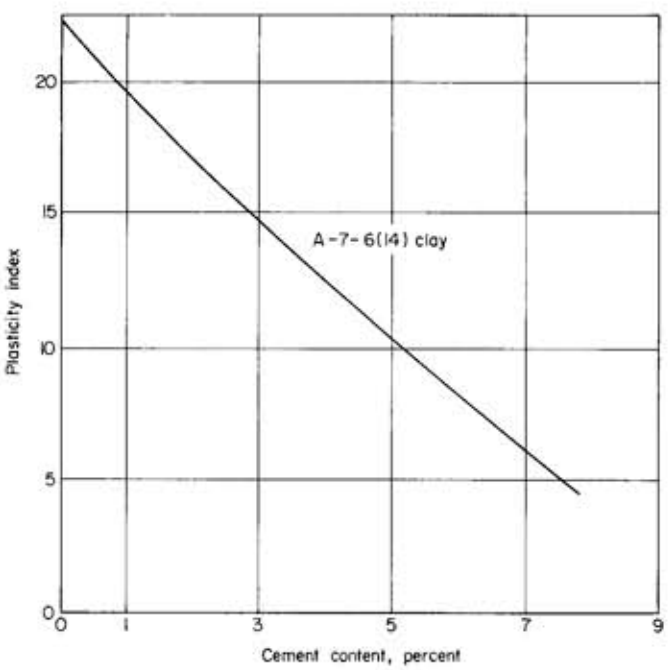

Fig. 74. Plasticity index versus cement content.

*"Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils," ASTM D4318.

**Combined silt and clay defined as material passing a No. 200 sieve.

*** The shrinkage limit indicates how much moisture (percent) the soil can absorb without swelling; the higher the value, the less potential for expansion.

TABLE 1. Effect of Cement Treatment on Properties of Clay Soils

Soil Type	Cement Content, percent	Plasticity Index	Shrinkage Limit, percent
Clay A-7-6 (20)	none	30	13
	3	13	24
	5	12	30
Clay A-7-6 (18)	none	36	13
	3	21	26
	5	17	32
Clay A-7-6 (20)	none	43	14
	3	24	24
	5	16	31

Additional data on a total of 11 different clay soils are given in *Cement Modification of Clay Soils*, Portland Cement Association.

Cement-modified silt-clay soils have been used as subbases for soil-cement pavements. Generally, the subgrade soil is treated with enough cement to provide a firm foundation for compacting the base course above it. A soil-cement base constructed on top of the cement-modified subbase may be made of the same material but treated with sufficient cement to produce hardened soil-cement, or it may be hardened soil-cement built with granular borrow soil.

Correcting Unstable Subgrade Areas

Sometimes, localized soft spots of very wet and unstable subgrades are encountered unexpectedly during construction. In addition to the difficulty of operating construction equipment, adequate compaction of base and subbase layers placed on top of these soft areas may not be possible.

These areas may be corrected by cement modification. Cement is spread and mixed into the soil to the best extent possible. If the material is too wet or cohesive to use a traveling mixer, it may be processed by several passes of a disc harrow or grader using its scarifier teeth. Then the material is compacted to whatever density can be achieved. The drying action of the cement and its hydration for two or three days will stabilize the area sufficiently so that construction may proceed.

Base for Pavements

Cement-modified silt-clay soils are ***not*** recommended for use as pavement bases. Small quantities of cement do not improve silt-clay soils sufficiently to make them satisfactory as base materials. The most effective means of utilizing such soils for base materials is to add sufficient cement to make fully hardened soil-cement.

Construction

For silt-clay soils that are not excessively cohesive or wet, the construction operations are essentially the same as those for soil-cement. However, some additional effort may be required in the pulverization and mixing operations. A pulverization requirement of 100% passing a 1-1/2 inch (38 mm) sieve and a minimum of 60% passing a No. 4 sieve is common.

Wet cohesive soils may require discing to cut in the cement and do the initial mixing before a rotary mixer is used. If the soil is dry, prewetting and allowing the water to soak in, may facilitate pulverization.

Cement may be spread by dry placement methods similar to normal soil-cement operations or it may be spread in slurry form. Where slurry placement is to be used, the solids content of the slurry should be the same as if dry placement methods were used. Also the distributor truck for slurry placement should be equipped with an agitator which will keep the cement and water in a uniform mixture.

In contrast to normal soil-cement construction, there is no time limit between mixing and compacting; although all the operations are completed in the same day. Applying an asphalt cure coat is usually not required.

CEMENT-MODIFIED GRANULAR SOILS

Substandard granular soils, that is, granular soils not acceptable for use as pavement base materials because of slightly excessive plasticity index or poor gradation, can be modified with portland cement to reduce or eliminate plasticity and to increase bearing values to a point where they are acceptable. Fig. 75 shows a permanent reduction in PI as measured over a 10-year period at the Hot Springs (Ark.) Municipal Airport.*

Base Course for Flexible Pavements

Cement-modified granular soils are being used extensively as flexible pavement bases for highways and streets. To meet specification requirements for these uses, the materials to be treated generally

*J.F. Redus, *Study of Soil-Cement Base Courses on Military Airfields*, Bulletin 198, Highway Research Board, 1958, pages 13-19.

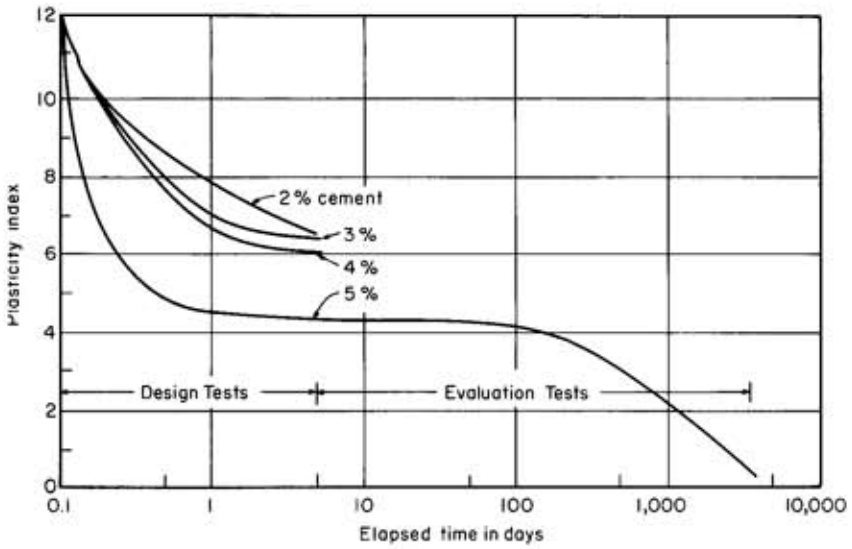

Fig. 75. Plasticity index versus time for various cement contents.

require only a small degree of improvement. The primary objective in most cases is to reduce the plasticity index and increase the bearing value.

By the addition of relatively small quantities of portland cement, substandard granular materials can be improved and made usable. The resulting product, however, is still primarily a granular base material with all the characteristics of that type of construction. A much stronger and more durable base course would be obtained by adding the additional amount of portland cement needed to harden the materials into soil-cement.

Subbase for Concrete Pavements

In a rigid pavement layer system, the subbase for concrete pavement is defined as the layer immediately beneath the concrete pavement. For light-traffic facilities, a subbase is not required and the concrete may be constructed directly on a properly prepared subgrade if it is capable of supporting construction equipment and is not highly expansive. Otherwise, the subgrade may be made suitable by cement modification.

Where heavy loads and volumes of truck traffic are anticipated, cement-modified silt-clay soils are ***not*** recommended for use as a subbase because they do not meet the requirements of a non-pumping subbase material. However, cement-modified granular soil subbases can be used to:

1. Prevent consolidation of the subbase under heavy traffic,
2. Increase the bearing capacity of the subbase,
3. Provide a firm support for paving operations; this is especially important when a slip-form paver is used, and
4. Prevent intrusion of subgrade soil into the granular subbase.

The use of cement-treated granular soil as subbase is recommended where good quality granular subbase materials do not exist or are very expensive. Substandard granular subbase materials can be treated with just enough cement to reduce the PI and/or upgrade the materials sufficiently to meet standard subbase specifications, such as AASHTO M 155 or ASTM D 1241.

Granular materials to use for cement-modified subbases under concrete are restricted to AASHTO Soil Classification Groups A-1, A-2-4, A-2-5 and A-3.

Construction

With a few exceptions, these base and subbase courses are constructed in essentially the same manner as soil-cement. The steps include:

- For initial preparation, shape the area to crown and grade and correct any soft subgrade areas.
- Add specified amounts of cement and water, and mix thoroughly; this is done in a central mixing plant or with mix-in-place equipment.
- Compact, and finish to crown and grade.

In contrast to normal soil-cement construction, there is no time limit between mixing and compacting. The material usually is spread and compacted the same day it is mixed. Often, it is not cured, although curing with a moist spray is suggested to provide maximum benefit from the cement.

For more information on Cement-modified soil refer to *Properties and uses of Cement-Modified Soil*, Portland Cement Association.

KEYWORDS: aggregates, backfills, cement-modified soils, cements, compacting, construction, construction equipment, curing, density, finishes, inspection, joints, pavements, recycling, sampling, shoulders, site preparation, soil cement, soil cement processing, soils, subbases, subgrades, surfacing, tests.

ABSTRACT: Describes procedures for constructing, under a wide variety of conditions, high quality soil-cement base courses for roads, streets, airports, and parking and storage areas. Includes inspection and field control, recycling flexible pavement, and a discussion of cement-modified soils.

REFERENCE: *Soil-Cement Construction Handbook* (EB003.10S), Portland Cement Association, 1995.

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