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Soil-Cement Stabilization for Roads

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SOIL - CEMENT STABILIZATION FOR ROADS

BY

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This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

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D. S. D.

INTRODUCTION

The purpose of the manuscript is twofold: First, to explain some of the basic factors which must be considered by individuals dealing with soil-cement stabilization, and second, to present the application of the principles involving the basic factors to design problems. It is assumed that the reader has a knowledge of the fundamentals of soil mechanics and concrete.

To accomplish these two purposes an extensive examination of published sources was made. Material from the Highway Research Board, Bureau of Public Roads, Portland Cement Association and other sources was assembled and summarized in Chapters 2 to 6. It is believed that by bringing together this scattered material into one place it may be a useful contribution. Beyond this, an effort was made by means of a questionnaire to assemble performance records from a number of highway departments which built roads using this technique approximately twenty five years ago. This material was then analyzed in view of existing conditions such as traffic and wheel load.

It has been a major consideration to discuss the factors underlying these concepts. It is inevitable that the factors can best be illustrated by referring to present day practices.

An attempt has been made to balance theory and practice by dividing the manuscript into several chapters. In the first chapter the fundamental principles of stabilization are discussed, such as: adsorption, film moisture in soil, effect of water film character on properties of soil, type of soil stabilization, admixtures affect soils in a number of ways, admixtures of portland cement and bituminous materials. In the second chapter the methods for soil survey and soil sampling are analyzed. In the third chapter all soil cement tests are discussed and described. They are moisture-density test, description of moisture density test method, percent cement by volume at maximum density, field moisture density checks, determination of optimum moisture by wet-dry and freeze-thaw tests, conducting wet-dry test, calculations, conducting freeze-thaw test, determination of optimum moisture by compressive strength tests and estimation of cement requirements. In the fourth chapter soil cement road construction is discussed, under such headings as: initial scarifying, pulverizing, spreading portland cement, raw soil moisture samples, mixing soil and portland cement, soil cement moisture samples, water spreading and mixing, moisture-density control and compaction procedures. In the fifth chapter some important problems related to soil-cement stabilization are discussed. They are the stabilization of heavy clay soils with cement, effect of organic matter in soil cement stabilization, discussion of calcium chloride tests, gumbotil soil by lime and portland cement admixtures, curing of soil cement bases, chemical determination of cement content of soil cement mixtures from cement hardened bases. In the sixth and last chapter the questionnaire replies are analyzed and discussed.

It has been impossible to discuss all the applications of soil cement stabilization which might arise. For example, use of long time mixing for high clay content soils to increase the strength of soil cement stabilization can be applied to many high clay content soils, but only one application is discussed. There is also an analysis of the mechanics of stabilization. Thus if the reader establishes firmly in his mind the stabilization process, he can fit this information into special problems as they arise.

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CHAPTER I

CONSIDERATIONS IN THE STABILIZATION OF SOIL

Many soil mixtures commonly used for road surfaces, at some moisture content, are highly stable. This is true of cohesionless beach sands, friable glacial silts, and highly plastic clays. Because of this every possible combination of sand, silt and clay may be used as the aggregate in stabilized soil, that is if the right binder is used to cement the soil particles together. Along with the right binder, the moisture which binds soil mixtures into masses stable enough to withstand great abrasion must have surface tension and viscosity greater than those of free water. On the above two facts is based the entire theory of soil stabilization.

Without trying to evaluate the practical aspects or the relative values of the different methods, the underlying principles involved in soil stabilization and the possible means of its accomplishment will be discussed. Particularly stressed is the application of the colloidal phenomena showing the affects of adsorption and base exchange on: (a) particles of soil, sand, crushed rock, gravel, slag coated with films of air, water, soluble chemicals, and binders not soluble in water; (b) the relative adhesion between solids and films; and (c) the effects of the chemical composition of aggregate and binders and the ions on the surfaces of the solid particles.

Types of treatments are as follows:

1. Graded soil mixtures
2. Calcium chloride
3. Sodium chloride
4. Asphalt emulsion
5. Asphalt, sub-oiling method
6. Asphalt, mixing method
7. Tar
8. Portland cement
9. Sulfite liquor
10. Molasses
11. Calcium silicate
12. Electro-chemical treatment
13. Application of heat

Adsorption

Some soil particles have high attraction for air, and under proper conditions, become coated with air films. Other soil particles have high attraction for moisture and, under proper conditions, become covered with moisture films. Strong masses may be formed by dried soil clods which retain enough moisture to bind the particles into these masses. On the other hand, air may be adsorbed on soil solids so strongly during a period of drought that drops of rain will roll along on dust without wetting it. Adsorption of one solid by another is the quality that plastic clays possess. It is this power that gives them the ability of retaining their plasticity when mixed with sand or other non-plastic material. The clay is not distributed uniformly through the pores or interstices of the coarse particles.

In order for soil particles to get wet, the water or other binder must displace the air coating on the particles. This means that the soil particles must attract the liquid more strongly than they attract the air. In this same manner, clay adsorbs different liquids to different extents. Clay's power of adsorption is selective and under suitable conditions, one liquid will displace another in contact with the clay.

Film Moisture in Soil

In completely saturated soil, every particle is covered with a film of moisture attracted to it more strongly than by the force of gravity. Until enough water is added to the soil to balance the condition of equilibrium between attraction of gravity and of the soil particles for water, all the moisture is arranged around the particles as films, with the interstices between the films filled with air.

Chemical composition of soil is indicated by the ratio of silica to the combined iron and aluminum oxides. This ratio is termed the silica sesquioxide ratio and is designated by the symbol, $\frac{SiO_2}{R_2O_3}$. Clays high in silica, termed "podsols", consist principally of the highly water-absorbent, scale-like particles productive of high plasticity and shrinkage. Soils high in iron and alumina, termed "laterites", consist more of the bulky or spherical particles which do not attract water so strongly.

A colloid which holds hydrogen adsorbed on its surface is termed a hydrogen-ionized or H-colloid. One with calcium adsorbed on its surface is termed a calcium-ionized or Ca-colloid. If a substance like hydrated lime, $Ca(OH)_2$ is leached through soil containing H- colloids, the calcium replaces the hydrogen to form Ca-colloids, and the hydrogen thus released combines with the $(OH)_2$ to form water. Such exchange of ions is termed "base exchange".

The potassium ion is representative of those ions which undergo small volume change when alternately wetted and dried. It has a true diameter of (9×10^{-9}) in. and in suspension becomes associated with 16 molecules of water, thus attaining an apparent diameter of (21×10^{-9}) in. The lithium ion is representative of those ions which undergo great volume change when alternately wetted and dried. It has a true diameter of (6×10^{-9}) in. and becomes associated with more than 120 molecules of water thus attaining an apparent diameter of (40×10^{-9}) in. Between potassium and lithium other of the more common metallic ions can be arranged in the order of their attraction for water (36). Therefore, a potassium clay would be expected to undergo the least, and a lithium clay the greatest, volume change under climatic variations. Change of ions on the surfaces of the clay and colloidal particles effects a change in shrinkage, swell, and like properties on which the stability of the soil depends.

The concentration of the hydrogen ions determines the relative acidity or alkalinity. It is indicated by the pH-value which may be defined as the reciprocal of the logarithm of the grams of ionized hydrogen per liter of solution or suspension. The lower the pH-value is below 7.0, the greater is the acidity of the liquid and the greater is its base-exchange capacity.[1]

The thickness of film on the colloids is controlled by the moisture content of the clay. This, in turn, determines the density to which a particular pressure will compact the soil. The relation between dry-weight density per cubic foot of samples compressed at equal pressures, to the moisture contents in percentage of the total soil and moisture volumes, consists of a series of straight lines with different slopes, as shown by the full lines in Figure 1. By the broken line in Figure 1 is shown the relation the density would have to moisture content if the samples contained more air. The difference in moisture contents indicated by the two lines represents the percentage of moisture,

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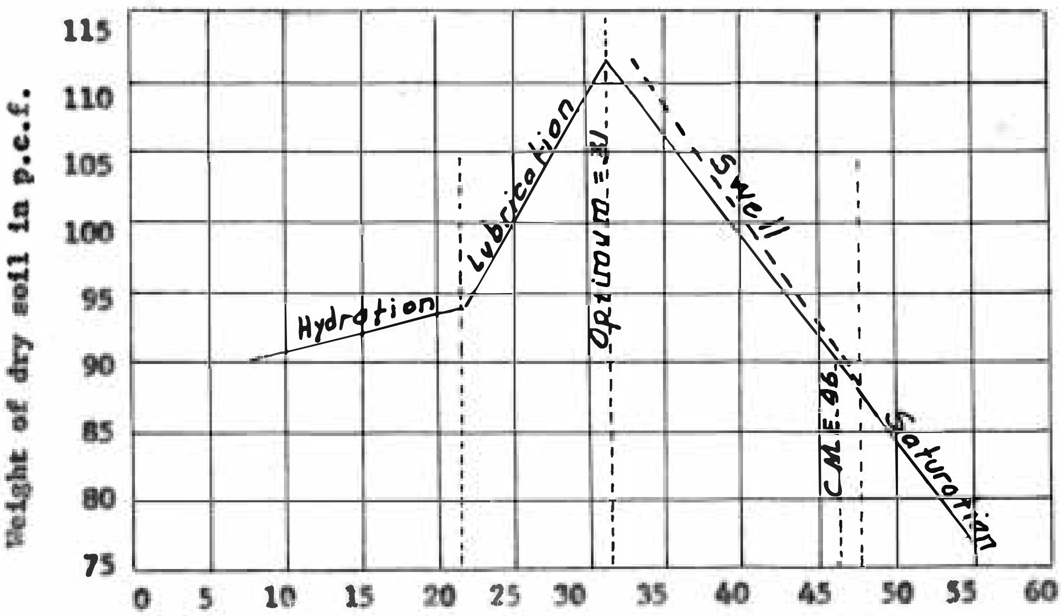
[1]C. A. Hogentogler, and E. A. Willies, Transactions of The American Society of Civil Engineering, vol. 103, 1165, 1938.

by volume at any density required to replace the contained air. The limits of four distinct stages of wetting which the compressed samples undergo before their pores become completely filled with water, is indicated by the moisture contents at which the straight lines intersect. Wetting up to a moisture content of approximately 21% (Figure 1) may be called the state of Hydration. During hydration, part of the contained water is absorbed by the soil particles, and the remainder is adsorbed on their surfaces in the form of cohesive films. The stage of "lubrication" is indicated by moisture contents ranging from approximately 21% to 31%. To facilitate the re-arrangement of particles being compacted without excluding all the air, part of the contained moisture acts as a lubricant. Water in excess of approximately 31% causes the soil mass to "swell", because the air content decreases very little whereas the moisture content increases to 48%. The state of "saturation", during which practically all the air is displaced, is reached at moisture contents approximately between 48% and 54%.

The moisture content (31% in this case) at which maximum density is reached is the optimum suggested by R. R. Proctor, for use in connection with the construction of earth embankments and dams. During cold weather the adsorbed films are usually thicker than in warm weather. This makes temperature an important factor.



Moisture Content, in Percentage by Volume

Figure 1. Relation Between Density and Moisture Content

Source: C. A. Hogentogler and E. A. Willies, Transactions of the American Society of Civil Engineering, vol. 103, 1938.

Effects of Water Film Character on Properties of Soil

The water which fills the interstices remaining between the outer surfaces of the adsorbed moisture films and not the pores between the surfaces of the soil particles is called free or pore water. The flow of the water through soil likewise occurs between the films adsorbed on the particles. As a result of this flow, the speed at which water percolates through soil, varies wherever the thickness of the adsorbed film changes. The moisture contents indicative of some specific state of soil stability similarly varies when the viscosity of the free water changes.

Due to the change of the kind of adsorbed ions on the particles of one type of soil, the liquid limit varied between 39 and 57, the plasticity index between 16 and 40, and the percentage of colloids between 11 and 28. The moisture content increase, indicating the swell of the samples in the Terzaghi compression device when the pressure was reduced from 3.2 kgr. per sq. cm. to 0, varied between 1 and 5 percent.[2]

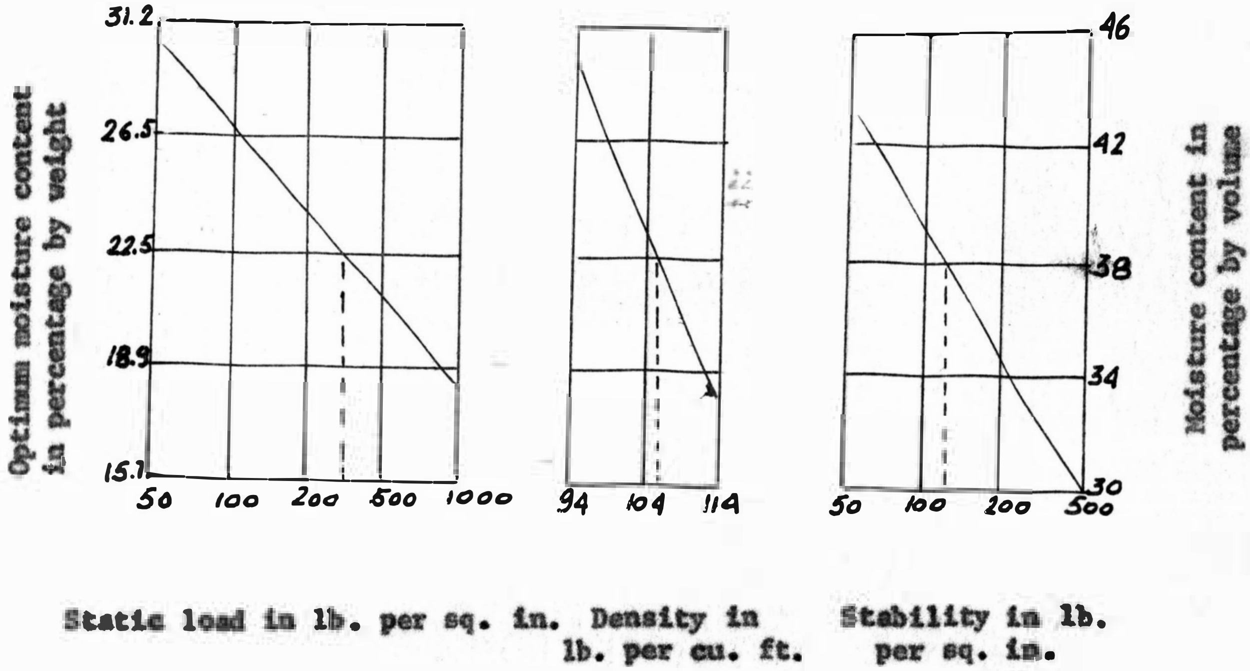


Figure 2. Relation of Optimum Moisture Content to Compacting Pressure, Attained Densities, and Stabilities.

Source: C. A. Hogentogler and E. A. Willies, Transactions of the American Society of Civil Engineering, vol. 103, 1938.

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[2] Ibid., p. 1167.

The optimum moisture content at which maximum density is reached is not a constant for a particular soil, but varies as the compacting pressure is changed. The relation of optimum moisture content to compacting pressure, attained densities, and stabilities, are shown in Figure 2.

Types of Soil Stabilization

The availability of required materials largely determines the methods to be used in soil stabilization. In some locations, such as the southeastern part of the United States, nature provided deposits of sand, clay and top soil having the grading and character required in the best of road soils.

In some locations, binder soils and aggregates are available for producing mixtures having the properties of the best of the naturally good soils. In other locations, materials are available for the graduations required in roads, but the binder soil may be of inferior quality. Finally, there are locations where there is deficiency of the aggregate required for properly graded mixtures.

> Studies of the best of natural road soils indicate that the design requirement of the stable soil mixtures should indicate the following:
>
> (1) The aggregate should be hard and durable enough to resist weathering, traffic abrasion, and crushing. Sound, tough particles or fragments of gravel, stone, slag, or combinations of them, crushed to the proper size, should prove suitable. Certain types of shales and similar materials that break and weather rapidly when alternately frozen and thawed, or wetted and dried, should not be used.
>
> (2) The soil fines should be of a character such as to provide graded mixtures with the proper balance of capillarity and adhesion without risk of detrimental volume change.

It is particularly essential that the fines do not swell enough in the presence of moisture to cause the clay particles to become a lubricant instead of a binder.

(3) When local materials are available for the proper proportioning of aggregate and binder soil, but the natural clay does not have the binder value required in highly stable road surfaces, a number of admixtures may be used singly or in some combination. There are, first, the chemical salts; calcium chloride, sodium chloride and magnesium chloride; and, second, the waste products of industry, such as sulfite liquor from the manufacture of wood pulp, "blackstrap" from the molasses industry, and huge accumulations of waste sizes of the mineral aggregate industry.

(4) When only fine or poorly graded materials are available, the asphaltic, tar, and Portland cement binders may be utilized to provide stable base courses to be covered with bituminous surfacing.[3]

Admixtures Affect Soils in a Number of Ways

Among the ways that admixtures may assist in stabilizing soils are the following:

(1) By adsorbing moistures from the air and reducing evaporation from the road surface, some chemicals may serve to keep the roads in a damp condition.

(2) By electro-chemical action, chemicals and the waste products may serve to increase the density and stability of road mixtures.

(3) By chemical action, the same materials may combine with each other, or with certain of the natural clay constituents, and thus form water insoluble cements of high binding value.

(4) The Portland cement and bituminous materials serve the double purpose of binders and of eliminating the destructive water-absorbent properties of the clay binders.[4]

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[3] *Ibid.*, p. 1169.

[4] *Ibid.*, p. 1170.

It is hard to distinguish between the electro-chemical and the purely chemical actions of admixtures for increasing the stability of soil. However, alone or in some combination, they seem to explain both the performances of soil roads in service and also to suggest relatively simple procedures for future construction.

Admixtures of hydrated lime, and certain types of stone dust seem very well suited for increasing the adhesion of bituminous binders for certain soils. Chloride salts, by electrolytic action in addition to their deliquescent and water retentive actions, may cause the compacted mixture to attain densities greater than untreated soils. The salts also minimize the volume change of the binder which is productive of disintegration of the untreated surfaces with changing moisture conditions.

Mixtures of acidic and neutral materials seem to attain greater stability than that of either one separately. Limestone dust as well as certain slags seem well suited for use as pre-treatments, or with other mixtures to neutralize acid soils. This may be especially good in the case of siliceous clays. In some base courses now being constructed, an acid clay is mixed with non-acid aggregate.

In the formation of material colloided cements one has to consider two types of either rock powder or clays. The first type consists of those which on soaking in water or watery solutions, soften to the extent that they become slightly glue-like. The other type would be those materials which do not possess this quality. To a small extent, many of the sandstone, trap and limestone powders are in this way made glue-like and more so by water soluble inorganic salts.

As a result, it is possible to construct low type surfaces of only waste limestone or slag screening treated with the chloride salt solutions.

Admixtures of Portland Cement and Bituminous Materials

Attempts to stabilize the fine grained soils by admixtures of lime and cement materials were made in Iowa and South Dakota as early as 1924, and in Ohio several years later. The results were not very promising, but it should be remembered that at this time, the requirements of the thorough distribution of the admixture, the high degree of compaction and the protective surface treatment now used, were not recognized.

As recently as 26 years ago, research on the use of Portland cement for stabilizing soil bases had been conducted in South Carolina. The purpose of this work has been to develop a base material that could be constructed at less cost than that required to provide one of properly graded sand, clay or topsoil.

The results of these experiments looked so favorable, that a number of similar roads are being constructed in other states. Experimental base courses constructed with available soil materials and the various tars, asphaltic emulsions and cut backs, and oils show similar promise.

Summary

A review of the development of soil stabilization points out the fact that the main means followed in practice until several years ago, involved the use of granular materials. With the rising demand for farm-to-market roads, the use of water retentive chemicals was found to be a valuable aid in the construction and stabilization road mixtures. Attention was next directed toward the use of water-insoluble binders, including bituminous materials and Portland cement for stabilizing poorly graded and fine-grained soils.

> (1) Soil stabilization involves film phenomena in one or more of the following steps: (a) Removal of the air film by wetting the soil particles; (b) making the liquid films stronger and more lasting by use of deliquescent and water-retentive electrolytes; (c) use of waste aggregate materials to provide the proper neutrality of the mixtures; and (d) replacement of the liquid or air films with bituminous materials, Portland cement, and other insoluble binders in the stabilization of fine or poorly graded soils.
>
> (2) Admixtures which have been found unsatisfactory for treating road surfaces subjected to abrasion by traffic and action of the climatic elements may provide benefit when used in base courses protected from these influences by impervious bituminous surfacings. The use of adhesives is not expected or intended to render the soil sufficiently hard or tough to resist the abrasive action of traffic, but simply to render it resistant to water from capillary and thus to retain the same stability that the soil had at the density obtained during construction.
>
> (3) Use of natural soil with the thinner films, or chemical solutions to reduce the thickness of the films and thus provide greater density, furnishes three distinct benefits to soil structures in service. The thinner the films the smaller is the quantity of free water that can be released as the soil becomes warmer. Consequently, soil with chemically thinned films retain greater uniformity of stability under changing temperatures.[5]

Reduced film thickness helps soil to reach high density with less compactive effort. This would lower the cost of compacting fills, and earth dams, and less time would be required under equal traffic condi-

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[5] Ibid., p. 1179.

tions for road mixtures to become stable. The last aid of reduced film thickness is especially important in base-course construction. This is because base-course construction requires highest density possible in the shortest time, in order to prevent additional and, perhaps non-uniform compaction of the base-course, after the wearing surface is applied.

The freezing point lowers as the thickness of the film diminishes. Because of this quality, the denser the soil at relatively low moisture content, the less likelihood of the film freezing, even if the soil consists of water alone. A double protection against damage to stabilized soil, due to frost, is obtained when the chemicals used also depress the freezing point.

From a practical stand-point, soils that are particularly sensitive to small changes in moisture content are undesirable for embankment construction. Such soils when used as binders in stabilized road mixtures, will react quickly to variations in moisture content with consequent changes in stability and cementing properties. The basic relationship between soil particles and surrounding moisture films are applicable to both embankments and stabilized soil roads. Any tests revealing these relationships are valuable aids in the design and construction of either embankments or stabilized soil roads.

CHAPTER II

SOIL SURVEYS AND SOIL SAMPLING FOR SOIL-CEMENT

The field engineer, who actually selects soil samples on which soil-cement testing will be conducted, will find this chapter to be of particular interest.

Soil surveys can be thought of in terms of aggregate surveys, the reason being that soils are the aggregates for soil-cement construction. Thus, the need for care and accuracy in conducting these surveys is apparent

Soil Surveys

Included in a soil survey is an examination of soils existing over a definite area, a description of these soils and a location of the limits of extent of the various soils. There are two general types of soil surveys. One of these types is a survey of existing roadway subgrades that are at present at proper grades. The other is a survey of new locations where the grade line has been set down on paper, but not yet graded in the field.

In either case, the first thing to do is to obtain a general layout map of the project, and the grading and ground profile plans.

Two things should be kept in mind when making a soil survey for soil-cement construction. The first of these is to obtain information so that samples of each soil type and horizon can be tested for cement requirements in a laboratory. The second is to obtain enough information concerning the location of the various soil types and horizons so that the laboratory findings can be properly used during construction. This may include the use of selective grading so that the best soils can be placed in the upper position of the subgrade.

The various layers of the soil profile are studied through the A, B and C horizons. The C horizon is studied deep enough to include all materials that have been or will be excavated for the project. Ordinarily, these are marked physical characteristics accompanying the soil forming processes. These characteristics are expressed by differences in color, texture, structure and consistency in the profile.

Also noted are the character of the topography, drainage conditions, vegetation, depth of roots, and the grain size of the soil.

An inspection of the upper 10 in. of the subgrade will usually follow the profile study. This inspection will be made at sufficiently close intervals so as to locate each change in soil type. It may, however, be necessary to investigate the soil condition to a much greater depth if the survey is to determine the suitability of the soils to serve as subgrades.

Soil Sampling

In soil sampling, it is not always necessary to take a large number of samples, although a minimum number will naturally be needed for a comprehensive study of the project area.

In testing the soil sample, there are a few tests which seem to be compulsory. The most important is the moisture density test of the soil mixed with about 10% cement to see how the material will react. Other tests include: grain size, liquid limit, plastic limit, organic matter and compressive strength.

The number of small samples taken for exploratory tests will vary with the soil surveyor, his familiarity with the soils and his confidence in identifying the soils. In many instances, it will be possible to take only one sample of each of the different soil horizons of each soil type as they occur in the field. When exploratory test data are complete, this data can be analyzed and locations chosen for taking large soil samples for soil-cement tests. Soil samples for exploratory tests should weigh about 25 lbs. Soil samples for complete soil-cement testing should weigh about 125 lbs.[6]

Large soil samples taken from a graded roadway are usually taken by digging a trench from center line to the edge of the proposed soil-cement roadway. Exploratory tests are made on these samples to determine their reaction with cement. Plans are then made so that the soil requiring high cement content will be in the lower levels of the grade while only soils that require a low cement factor are placed in the upper 10 or 12 in. of grade.

When sampling soils the condition of the soil profile must be considered, that in the natural profile there is a great change in soil character at a single location with increase in depth, than there is at locations which are considerably longitudinal distances apart. For instance, the A horizon soil usually is similar over considerable area, whereas the B horizon soil a short distance below can be entirely different from the A horizon at that point. Also, of course, the B horizon soil is usually similar over considerable area, and different from the underlying C horizon material at any single location.[7]

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[6]"Soil-Cement Mixtures Laboratory Handbook," Third Edition, Portland Cement Association, p. 21.

[7]Ibid.

CHAPTER III

SOIL-CEMENT TESTS

This chapter on soil-cement tests is a detailed discussion and will probably be of interest to the field engineer and designer.

Moisture-Density Test

The A.S.T.M. and A.A.S.H.O. moisture-density tests are used to determine the relationship between the moisture content of soil-cement mixtures and the density resulting when it is compacted before cement hydration, using a standard compacting force.

When soil, cement and water are being mixed, a change takes place. The soil seems to become more or less coagulated, because of a base exchange phenomenon, bringing about an increase in internal friction.

As a result of this chemical phenomenon and partial cement hydration, moisture density relations of a soil-cement mixture will vary. These variations show up as an increase in the optimum moisture content and a decrease in the maximum density of the soil-cement mixture as the damp mixing time increases. These changes are shown in Appendix IV. This is the reason that soil-cement construction specifications require that moisture-density relations be established in the field near the end of the damp mixing procedure. And that the relationship be determined using soil-cement taken directly from the construction area.

During construction, to assure maximum density, additional water must be added to the roadway to bring the soil to its optimum moisture. To determine how much water will have to be added, estimates are made on the basis of moisture density tests made either in the field or laboratory. These tests are fine to get the road mix close to its optimum moisture, but in the last few minutes, samples from the roadway determine the last two or three points near the peak of the moisture density curve, to insure bringing the soil to its optimum moisture content.

> The moisture-density relations of soil-cement mixtures are of utmost importance because:
>
> (1) In the laboratory they make it possible to mold duplicate specimens with a fixed degree of compaction at any one moisture content and in each case the density of the specimens will be practically the same;
>
> (2) In the field during construction, the moisture-density relations are used for moisture and density control to insure satisfactory construction. In soil-cement work only the peak of the regular or parabolic type curve is used since this gives the greatest density. It is at this density that wet-dry and freeze-thaw specimens containing different cement contents are molded and tested by alternate wetting and drying, and alternate freezing and thawing, to determine the quantity of cement that is necessary to harden adequately the soil.
>
> Moisture-density tests in the laboratory should be made on the soil-cement mixture as rapidly as possible and before cement hydration had processed to any great extent. This is necessary since test specimens which are designed from these data are molded only after a few minutes mixing of soil, cement and water and before cement hydration.[8]

<u>Description of Moisture-Density Test Method</u>

The moisture-density relations of the soil-cement mixtures are determined in accordance with A.S.T.M. Designation: D560-44. To record the data, form sheets are provided. To separate the gravel, sand, and other

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[8] "Soil-Cement Mixtures Laboratory Handbook," <u>Portland Cement Association</u>, p. 26.

soil particles without reducing the particle size, the air dry mixture is passed through a No. 4 sieve. Next, the required cement is added to the above mixture and it is mixed to a uniform color. The soil-cement mixture is then immediately compacted to prevent any chemical reactions between the cement and water.

After compaction, the mold is trimmed so that the specimen is approximately 4.6 in. in height and is $\frac{1}{30}$ cu. ft. in volume. To get the exact weight of the specimen, we subtract the weight of the mold. From the center plane, we take 100 gr. sample for moisture determination. This sample is placed in an oven at 110 C^{o} to dry to a constant weight. With this information we can calculate the moisture content of the mixture. This procedure establishes the relationship of moisture content to density.

Percent Cement by Volume at Maximum Density

After moisture-density relations have been established, we can determine the amount of cement by volume. Also, the variations in moisture content and density can be determined for different percent of cement volume. To determine these figures, we use the following formula which is illustrated below:

$$\text{Percent cement by volume} = \left(\frac{D - \frac{D}{C}}{94}\right) 100 \text{ where;}$$

D = oven-dry density of soil-cement in lb. per cu. ft.
C = 100 + percent cement by weight of oven-dry soil
divided by 100.
$\frac{D}{C}$ = weight of soil per cu. ft. of compacted soil-cement
$D - \frac{D}{C}$ = lb. cement per cu. ft. compacted soil-cement.

94 = weight in pounds per cu. ft. of loose cement.[9]

In the example the maximum oven-dry density of soil-cement, D, assumed 105 lbs. per cu. ft. and the mixture contained 8.69 percent cement by weight of soil. C therefore equals $\frac{100 + 8.69}{100}$ or 1.0869. The weight of soil per cu. ft. $\frac{D}{C}$, is $\left(\frac{105}{1.0869}\right)$ or 96.40 lbs. Thus, the weight of cement per cu. ft. of soil-cement, $D - \frac{D}{C}$, is 105.00 - 96.40 or 8.60 lbs.; and the cement content by volume is $\left(\frac{8.60}{94}\right) 100 = 9.15$ percent.

Field Moisture-Density Checks

Daily construction operations are controlled by moisture-density relations when no plus No. 4 aggregate is present. In determining the future cement content of the roadway the moisture-density tests are performed with the plus No. 4 aggregate removed.

To have uniform job control, it may be desirable to prepare tables and graphs to show the relationship of the cement content in the minus No. 4 soil and the plus No. 4 aggregate content.

The following example covers one such calculation:

Given:

10 percent cement by volume in total compacted mixtures.
Roadway contains 30 percent plus No. 4 aggregate

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[9] *Ibid.*, pp. 34-35.

Minus No. 4 soil-cement mixture:
Maximum density, 106.9 lbs.
Optimum moisture content, 18.4 percent
Cement content, 12.5 percent by volume

Determine:
Plus No. 4 aggregate present when minus No. 4 soil-cement mixture contains 12 percent cement by volume with cement content by volume in total compacted volume remaining at 10 percent.

Volume occupied by minus No. 4 soil-cement mixture containing 12 percent cement by volume (11.28 lb.) will be attained by reducing 1 cu. ft. of compacted volume containing 10 percent cement by volume, 9.4 lbs., a proportionate amount and will equal 0.833 cu. ft. $\left(\frac{9.4}{11.28}\right)$.

The difference between 1 cu. ft. and 0.833 cu. ft. or 0.167 cu. ft. represents the apparent volume occupied by the plus No. 4 aggregate.

0.167 cu. ft. of plus No. 4 aggregate weighs 27.1 lbs. 0.167 x (bulk specific gravity of 2.60) x 62.4.

The 0.833 cu. ft. of minus No. 4 soil-cement is assumed to weigh 106.9 lbs. per cu. ft., or the 0.833 cu. ft. will weigh 89.1 lbs. It contains 9.4 lbs. of cement or 11.8 percent by weight, $\left(\frac{9.4}{79.7}\right)$, of minus No. 4 soil and therefore 79.7 lb. (89.1 - 9.4) of soil. Soil and plus No. 4 aggregate will weigh 106.9 lbs. (79.7 + 27.1). The 27.1 lbs. of plus No. 4 aggregate represents 25.4 percent of the roadway soil $\left(\frac{27.1}{106.9}\right)$.

Therefore, a table is started showing:
(1) Cement content by volume of minus No. 4 soil-cement, percent;
(2) Cement content by weight of minus No. 4 soil, percent;
(3) Plus No. 4 aggregate content, percent.[10]

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[10]"Soil-Cement Roads - Construction Handbook," Portland Cement Association, p. 86.

Similar computations are made to cover other plus No. 4 aggregate contents to give the following table:

TABLE I. VARIATIONS OF CEMENT CONTENT BY VOLUME OF MINUS AND PLUS NO. 4 SOIL

Cement content by volume of minus No. 4 soil-cement, percent	11.0	11.5	12.0	12.5	13,0	13.5	14.0
Cement content by weight of minus No. 4 soil, percent	10.7	11.2	11.8	12.4	12.9	13.5	14.0
Plus No. 4 aggregate content, percent	14.4	20.2	25.4	30.0	34.0	37.7	40.9

Source: "Soil-Cement Construction Handbook," Portland Cement Association, p. 87.

Determination of Optimum Moisture by Wet-Dry and Freeze-Thaw Tests

Specimens containing equal or uniform amounts of cement by volume are selected from the irregular moisture-density curve. As the densities decrease with increased moisture contents, it will be found that the cement content by weight will vary for each specimen. These tests will usually be conducted with about 14 percent cement by volume. Although the wet-dry test is the most severe test for heavy clay soil-cement specimens, it is a good idea to run both wet-dry and freeze-thaw tests the first few times these soils are investigated. After the optimum moisture content is determined, more specimens with different cement contents are molded using this established optimum to determine cement contents.

Most soil-cement mixtures immediately after being compacted to maximum density at optimum moisture content have enough stability to carry light traffic. The wet-dry tests were first designed to determine whether the hardened soil-cement would stand up under severe moisture variation, while the freeze-thaw test was to determine the stability of the mixture under alternate freezing and thawing.

> Alternative freezing and thawing is particularly severe on soil-cement specimens molded using soils in the sand to silty clay loam textural range. In sandy soil-cement mixtures, the test definitely shows whether the cement is reacting favorably and has sufficient cementing power to overcome the expansion of water in the voids of the soil-cement as it freezes. In the loam, silt loam, and silty clay loam soil-cement mixtures, the test shows:
>
> (1) Whether there is sufficient cement in the specimens to overcome the expansive force of the water freezing in the voids.
>
> (2) Whether there is sufficient cement in the specimens to overcome the formation of ice layers.
>
> Failure of many of the silt soil-cement specimens is caused by sealing of the specimens on all sides. In certain instances, it is necessary to use a sharp-pointed instrument to loosen this scale, inasmuch as the normal brushing after thawing sometimes fails to remove it because of the structure of the scale and the high surface tension of the water film between the scale and the remaining portion of the specimen.[11]

Conducting Wet-Dry Test

After a seven-day storage period in a high humidity atmosphere,

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[11] *Op. cit.*, p. 27.

the specimens are submerged in tap water. The tap water is at room temperature and the specimen remain in the water for a period of five hours. The specimens are then removed and one specimen (volume and moisture change specimen) is weighed and measured.

To get a drying effect, the specimens are put in an oven at about 71° Centigrade for 42 hours. When the specimens are removed, both of them are weighed and one specimen measured. The specimen which is not weighed is given two firm strokes on all sides with a wire scratch brush. To completely cover the total area of the specimen twice, about 18 or 20 vertical strokes will be required on the sides while four strokes will be required for each end. This specimen is then weighed to find the amount of weight lo t.

This process takes about 45 hours. This cycle will have to be completed 12 times and on the data collected, the following calculation can be performed:

Calculations

The volume of specimen at the time of molding, and subsequent volume changes are calculated as a percentage of the original molded volume.

The moisture content of specimen at the time of molding and subsequent moisture contents are calculated as a percentage of the original oven-dry weight of the specimen.

The soil-cement loss of specimen is calculated as a percentage of the original oven-dry weight of the specimen. Therefore, the oven-dry weight of the specimen at 110 degrees Centigrade is corrected for its water of hydration. For instance, if the final oven-dry weight of a specimen containing a sandy loam soil (Appendix I) is 4.10 lbs., divide this weight by 1.025 which gives 4.00 lbs. If the original calculated oven-dry weight of the molded specimen was 4.20 lbs., the soil-cement loss is 0.20 lbs., or (0.20 ÷ 420) 100 = 4.8 percent. Soil-cement losses are usually reported to the nearest whole number so it would be considered 5 percent.[12]

Conducting Freeze-Thaw Test

After a seven-day storage in an atmosphere of high humidity, the specimens are separated from the specimen carrier with water saturated pad or blotters of some type. This assembly is put in a refrigerator which has a constant temperature, not warmer than -23 degrees Centigrade for 22 hours. After 22 hours in the refrigerator, the specimens are removed, one specimen (volume and moisture change specimen), is weighed and measured. Both specimens are then allowed to thaw in a moist room or suitable container. During this thawing period, the adsorbent pads under the specimens should have access to water to allow the specimen, through capillary action, to absorb water.

The volume and moisture change specimen is measured after 22 hours of thawing, and both specimens are weighed. The soil-cement loss specimen is given two firm strokes on all areas with the wire scratch brush. Eighteen or 20 vertical strokes of the brush on the sides and 4 strokes on each end will completely cover the specimen twice. After this brushing process, the specimen is weighed to determine the loss of weight by brushing.

The above process requires 48 hours of alternate freezing and thawing. The 48-hour-long cycle is repeated 12 times which gives enough data to permit calculations of volume and moisture change and the

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[12] *Ibid.*, p. 53.

soil-cement losses.

Determination of Optimum Moisture by Compressive Strength Tests

Specimens are broken by compression at ages of 2, 7 and 28 days; this gives compressive strength data for study and analysis. Specimens after being stored in a room at room temperature and humidity of 100%, are first soaked in water and then broken by compression. Specimens are 2 in. in diameter and 2 in. in height; they are molded using the minus No. 4 portion of the soil and are soaked in water for one hour before breaking. Larger specimens may include plus No. 4 minus 3/4 in. materials but they should be soaked longer before breaking. The standard 4 in. diameter specimens are soaked about 4 hours. To insure fixed cement influence, fixed cement content by volume is used regardless of the type of soil. Usually, cement contents of 6 and 10 percent are used, but sometimes higher cement contents are investigated. To get a bench-mark for comparison, the cement contents by volume are fixed. These fixed cement contents place the same number of grains in every test specimen of a series, regardless of the density of the mass.

The moisture-density data obtained using the standard A.S.T.M. method gives the moisture and density basis for the construction of the compression test specimens. In the method of molding 2 in. specimens of minus No. 4 soil-cement, a designed quantity of soil-cement at optimum moisture is weighed out and compacted in the machine to an exact height of 2 in. Force of compaction is applied using the double piston method, with force applied to the top piston but leaving both top and bottom pistons free to move during the compaction operation. The quantity of soil-cement weighed out and placed in the machine is such that the test specimens have the exact density that large specimens would have at that particular moisture content if compacted by the standard A.S.T.M. method in the standard size mold.

The influence of cement in producing compressive strength in compacted soil-cement mixtures can be analyzed from two viewpoints. The cement influence will be evident by increases in strength with increases in age, and by increases in strength with the increases in cement content. In well reacting soil-cement mixtures containing 6 percent and 10 percent, the increases will be considerable; for instance, 100 or 200 lbs. per sq. in. Thus, for a normally reacting soil-cement mixture the 6 percent cement specimens will show increases in strength with age. The 10 percent specimens will likewise show increased strength with age, and in addition, at any fixed age, they will show greater strength than the 6 percent specimens of the same age.

A study of the strength data is of particular value prior to molding wet-dry and freeze-thaw specimens, as this information will help in selecting cement contents for wet-dry and freeze-thaw testing. The range in compressive strengths for soil-cement mixtures requiring various cement quantities for hardening is shown in Appendix 5. These compressive strength data were obtained from specimens 2 in. in diameter and 2 in. in height, (h/d ratio = 1.0). If equipment is available for molding compressive strength specimens having uniform density, and having an h/d ratio of 2, specimens of such size may have advantages over the 2 x 2 specimens. Of course, if specimens other than 2 x 2's are used, data from such specimens will not be directly comparable with the data in Appendix 5.

Soil-cement mixtures that do not react normally and which will not pass the wet-dry and freeze-thaw tests will give little or no compressive strength with 6 and 10 percent cement. Before molding wet-dry and freeze-thaw specimens of mixtures falling in this category, it is necessary to mold additional compressive strength specimens containing 14 percent cement by volume will prove adequate, although occasionally 18 percent cement content specimens or even 22 percent and 26 percent specimens are molded. With this data it is possible to estimate the cement content required for hardening the soil, and it will be possible, therefore, to design more systematically the cement contents to be investigated in the wet-dry and freeze-thaw specimens.[13]

Compressive strength tests may also be used to check soils previously tested. Compressive strengths should be about the same, when

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[13] *Ibid.*, p. 55.

the field data indicates that a soil is similar, it has the same texture and is from the same soil series and horizon as the previously tested soil. This system can also be used to check cement requirements.

Compressive test specimens can also be molded using the standard 4 in. diameter moisture density mold. The specimens are then molded at the designed moisture and density values, with each specimen having the same cement content by volume. The cement content by weight will vary as the dry density varies. Fourteen percent of volume is a good cement content to use in this test. The specimens are again stored at room temperature with a high humidity. The specimens are broken at ages of 2, 7 and 28 days. Before breaking the specimens, they should be immersed in water, the 2 in. ones for 1 hour and the 4 in. ones for 4 hours. The test results at 2 and 7 days should usually be good enough for determining the moisture content at which maximum compressive strength will be obtained. This moisture is considered to be the tentative optimum moisture content. The usual wet-dry and freeze-thaw soil-cement specimens are then molded at this tentative moisture content. Also an additional set of specimens are molded at a moisture content about two percentage points wetter than this tentative level. The optimum moisture content for maximum resistance to wetting and drying and freezing and thawing should be established by the results of these tests.

Estimation of Cement Requirements

Experiments show that certain soil tests or soil characteristics and certain soil-cement tests or soil-cement characteristics can be used to indicate general cement requirements for producing a structural material of compacted soil-cement. As discussed (in Appendix I) very useful relations are shown by the U. S. Public Roads Administration soil grouping. Thus:

A - 2 soils will probably require 6, 8 and 10 percent cement;

A - 3 soils will probably require 8, 10 or 12 percent cement;

A - 4 and A - 5 soils will probably require 8, 10 or 12 percent cement; and

A - 6 and A - 7 soils will probably require 10, 12 or 14 percent cement.

In addition to these general cement ranges, the following detail information will be useful for determining the cement content to be used when molding wet-dry and freeze-thaw specimens.

A - 2 and A - 3 Soils

In most cases, before cement contents are selected for molding wet-dry and freeze-thaw specimens of the A - 2 and A - 3 soils, time and energy can be saved by first determining the organic content of the raw soil, and by testing compressive strength test specimens with at least 6 percent and 10 percent cement. This procedure is particularly desirable if the soils are from the A or B horizon of the soil profile. If the organic content is over about 2,000 parts per million, compressive strength specimens containing 6, 10 and 14 percent cement by volume should be molded. If possible, the molding of wet-dry and freeze-thaw specimens should be delayed until the seven-day strength results are obtained.

In considering compressive strengths and cement contents, it should be remembered that compressive strength specimens normally contain only the minus No. 4 sieve soil material plus cement; whereas, the wet-dry and freeze-thaw specimens may contain some plus No. 4 soil.

The A - 3 soils usually require 10 or 12 percent cement. Only the best of the A - 3 soils, well graded from gravel to fine sand, will require about 8 percent cement. If compressive strengths are high, it can be assumed that the A - 3 soil is reacting with the cement in an excellent manner and wet-dry and freeze-thaw specimens may be molded at 6, 8 and 10 percent cement. Generally, however, it will be found that 8, 10 or 12 percent cement will best cover the test range for the A - 3 soils, except when they contain high organic contents and have low compressive strength. In this latter case it will be necessary to mold specimens of higher cement contents, or select a possible borrow soil to replace the poor A - 3 soil.

Another possible solution to the economical hardening of poorly reacting A - 2 and A - 3 soils is the use of an admixture with the soil. The admix should preferably be a friable clay loam, or similar textured soil or calcium chloride. Admixes of this type generally make a soil mixture that will react with cement economically.

A - 4 and A - 5 Soils

Cement contents to be used with A - 4 soils will depend to a great extent upon the texture of the soil, and upon the soil horizon from which the soil was selected. The A - 4 soils from the A horizon of the soil profile in normal farm country contain considerable silt and organic matter. These A horizon silts can be divided into two types:

(1) The well-drained type, rather coarse silt soils;

(2) The slowly-drained, finely graded silts, that are soft and mellow to the touch. In these cases, compressive strength data may not be as significant as they are for A - 2 and A - 3 soils; however, they may be of considerable value in segregating soils into Type (A) and (B). In addition, silts in Type A will usually have soil-cement densities of about 110 lbs. per cu. ft., with optimum moisture contents around 15 percent. Silts in Type B will usually have densities of about 100 lbs. per cu. ft., and optimum moisture content about 20 percent. Wet-dry and freeze-thaw specimens of the coarser graded A - 4 soils in Type A may be molded at 8, 10 and 12 percent by volume. The black A horizon A - 4 soils in Type B should be molded containing 12, 14 and 16 percent cement by volume.

Soils in the A - 4 group from the B and C horizons of the soil profile should generally be molded containing 8, 10 and 12 percent cement by volume; however, if time permits, compressive strength tests should be made before setting up cement requirements for the wet-dry and freeze-thaw specimens. The strength results may be used in deciding whether to mold specimens at 8, 10 and 12 percent, or 10, 12 and 14 percent.

Available data on A - 5 soils indicate that the above remarks for A - 4 soils also apply to the A - 5 soils.

A - 6 and A - 7 Soils

When the moisture-density curve is a regular parabolic type curve and the optimum moisture is less than 20 percent and the density of the order of 106 and 107 lbs. per cu. ft., it may be assumed that the soil is going to react rather well with cement, and wet-dry and freeze-thaw specimens can be molded containing 10, 12 and 14 percent cement by volume.

If the moisture-density relation curve is definitely irregular, it may be necessary to determine the optimum moisture content by use of compressive strength tests. When the optimum moisture content has been rather definitely indicated from these tests, wet-dry and freeze-thaw test specimens are molded at this moisture content, and at this moisture content plus about two percentage points of water. Usually, at this stage of the testing, it is well to mold only four specimens, two at each moisture content, one for the wet-dry and one for the freeze-thaw test. These specimens will contain one cement content, usually 14 percent cement by volume.[14]

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[14] *Ibid.*, pp. 60-61.

CHAPTER IV

SOIL CEMENT ROAD CONSTRUCTION

Construction Operation

In general, the project engineer should be responsible for:

1. Crown, grade and line
2. Depth and width of treatment
3. Portland Cement content
4. Satisfactory pulverization of roadway soil
5. Satisfactory mixture of soil and Portland Cement
6. Satisfactory mixture of moisture and soil-cement
7. Satisfactory compaction and surface finish
8. Satisfactory cover to curtail evaporation

The soil engineer makes tests for and is generally responsible with the resident engineer for:

1. Pulverization and moisture control
2. Density and depth control[15]

Outline of Mixed-in-Place Construction Operations

Construction work can be divided into two general operations, preparing for processing and progressive processing.

Preparing for processing consists of:

1. Scarifying roadway for a depth of 5 1/2 in. and for the specified width;

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[15] *Op. cit.*, pp. 26-27.

2. Pulverizing the scarified roadway for a depth of 6 in.; and these operations precede the actual construction or "processing" operations.

Construction or processing operations are continuous from the application of cement on the section to final rolling and covering. The progressive processing operations consist of:

1. Spotting and spreading Portland Cement;

2. Mixing Portland Cement and pulverized roadway soil;

3. Adding required water and mixing with soil-cement;

4. Compacting mixture from the bottom with sheeps foot rollers to uniform density;

5. Shaping section to crown and grade;

6. Scarifying surface compaction planes;

7. Smooth-rolling section to final crown, grade and surface;

8. Placing protective cover to prevent surface evaporation losses from compacted roadway.[16]

Initial Scarifying

Depth of scarifying is controlled mostly by the smoothness of the existing roadway. The teeth are adjusted to scarify a depth of 5 1/2 inches, leaving pulverizing and mixing operations to obtain the last 1/2 in. The scarifier should stop every 5 ft., at the beginning of operations and make needed adjustments, thus insuring definite depth control.

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[16] Ibid., p. 28.

Pulverizing

During pulverizing operations, the disks should be left open to allow for greater depth control. If the disks are not closed at the end of the section, the longitudinal drag will be greater than if they were closed.

Spreading Portland Cement

After pulverizing is completed on the first section, the operations of spreading cement, mixing soil and cement, adding and mixing water, compacting surface finishing and placing protective cover can get underway. These operations, since they are continuous, usually start with the spreading of cement.

> For example, with a cement content of 10 percent by volume specified, the cement requirements per sq. yd. for a 6 in. compacted depth will be $3 \times 3 \times \frac{6}{12} \times \frac{10}{100}$ or 0.45 bags of cement per sq. yd. For a 20-ft. road, 6 in. in depth, the requirements per lin. ft. will be $20 \times \frac{6}{12} \times \frac{10}{100}$ or 1.00 bag of cement per lin. ft. of roadway will require 100 bags of cement. Spreading cement in four longitudinal rows will place 25 bags in each row which, when spaced at four ft. intervals, will extend the 100 ft. Therefore, each bag must cover four ft. longitudinally and five ft. transversely across the road. The first row of bags will be placed 2 1/2 ft. from the edge, the second row 7 1/2 ft. from the edge, and the other two rows will measure equal distances from the opposite edge. The location of these rows are marked with a heel scratch by the straw boss in the loose soil. The cement-spreading market line is placed along the shoulder as a guide and advanced with spreading operations. Widened curves will require more cement and vary the cement spread.[17]

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[17] *Ibid.*, pp. 31-32.

Raw Soil Moisture Samples

> Large composite raw soil samples are obtained at each 100-ft. station ahead of cement-spreading operations. They are quartered down to 100-to 150-grm. samples although the use of 300-to to 400-grm. samples with torsion balance are preferred.[18]

These samples are checked for water content so the amount of water to be added can be determined. Also by knowing the moisture content of the raw soil, it is possible to estimate evaporation losses which took place during the dry mixing period.

Mixing Soil and Portland Cement: Dry Mix

The Dry Mix is accomplished with the use of field cultivators. As the Dry Mix progresses, the mixture becomes lighter permitting the cultivator wheels to work deeper into the roadway. Because of this, depth adjustment must be watched carefully and adjustments made to allow for it.

Soil-Cement Moisture Samples

As the Dry Mix is completed, samples are taken to determine moisture content. This is necessary for determining the amount of water to be added during the moist mix. The details regarding these calculations are given in the chapter on "Soil Cement Tests."

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[18] Ibid., p. 33.

Water Spreading and Mixing: Moist Mix

It is possible to mix cement with soil without forming cement balls when the moisture does not exceed the optimum moisture of the soil-cement mixture by more than two. Preferably, the moisture content of the raw soil should be one or two percentage points below the optimum for efficient mixing. Under some weather conditions, cement will be mixed with the soil near the optimum and little additional water need be added.

> A critical check of water-pumping, hauling and distributing equipment is more important. It is not unusual to add the equivalent of an inch to an inch and one-half of rain, as much as 8 gal. per sq. yd. On a section 1,500 ft. long and 20 ft. wide, water requirements might run as high as 25,000 to 30,000 gal. At an average distribution rate of 1,000 gal. every 10 minutes with one pressure distributor, it would require from 250 minutes (4 hours, 10 minutes) to 300 minutes (5 hours) to spread this water. Obviously, two 1,000 gal. pressure distributors would be required to spread this quantity of water in the time permitted by specifications or at least half of it would need to be spread the previous day before processing starts.[19]

Moisture Density Control

The laboratory tests determine the optimum moisture and density to be used for the general soil types found on the project. These factors must be checked every day to cover variations in cement content and moisture of soil which will be found during construction.

> For example, variations in compacted depth from the specified 6 in. will produce variations in cement content, since the cement is spread at a uniform rate. Further, the

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[19] Ibid., pp. 43-44.

> moisture-density relations may change as the moist mixing period is extended.[20]

Mixing at Junction With Previous Work

Mixing operations at the header during moist mixing were given in detail as these operations were described for the dry mix material. These will have been mixed at the header by the time water spreading has been completed. This brings the operation under control for the entire section.

Preparation for Compaction

To allow compaction from the bottom up, the entire mixture is loosened with field cultivators. This loosening process will leave a loose mass of a uniform mixture of soil, cement and water.

Compacting Mixture

As soon as a section is prepared for compaction, sheep foot rollers go to work compacting the section.

> The section is first rolled transversely against the adjoining work. The transverse or cross-rolling is extended back about fifteen feet and continued until the rollers are about two-thirds packed out. Longitudinal packing then starts at each edge, progresses to the center of the roadway and back to the edges to permit the rollers to pack out uniformly.[21]

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[20] *Ibid.*, p. 45.

[21] *Ibid.*, p. 46.

Removing Top Compaction Planes

The smooth, damp compaction planes left by the last trips of the sheeps foot rollers can be removed with the aid of a spike tooth harrow. The spike tooth harrow is pulled over the section by a tractor with street plates with the teeth set to just penetrate below the compaction planes. Ridges and furrows left by the harrow can be removed by dragging a heavy chain or broom drag behind the harrow.

Supplementary Pneumatic-Tire Rolling

By first rolling a section with pneumatic-tire equipment, final smooth rolling may be more quickly accomplished with less danger of soil-cement to stick to the smooth roller.

Final Smooth Rolling

A smooth roller is used to put the final touch on a section. The final rolling is done in lengths of about 50 ft. adjoining the previous day's work. The smooth roller puts the final crown and grade on the bulk of the section but a motor grader is used in some places.

Placing Protective Cover

A protective cover of straw or shoulder soil is needed as soon as the smooth rolling is completed. In the case where shoulder soil is used, the motor grader can be used to apply it.

<u>Opening to Traffic</u>

Construction equipment, as long as it does not harm the surface, may use the completed roadway. After 7 days of protection, the surface may be cleaned of the protective cover and opened to traffic.

<u>Construction Costs</u>

Many miles of soil-cement roads give reliable construction cost data. A tabulation of projects is given in Appendix III.

CHAPTER V

INVESTIGATION OF SOME PROBLEMS IN SOIL-CEMENT STABILIZATION

This chapter is a detailed discussion of some problems in soil-cement stabilization for the interest of the field engineer.

The Stabilization of Heavy Clay Soils With Cement

Granular soils and the cohesive soils with liquid limits less than 40 percent, are now being successfully stabilized with cement. Construction is normally undertaken by the "mix-in-place" method using a cement content of 10 percent by weight. If the use of the process could be extended to cohesive soils with liquid limits greater than 40 percent, it would be advantageous. This could be accomplished by adding sand as well as cement to the cohesive soil, but such a procedure increases the cost of construction.

> To determine whether a heavy clay soil (liquid Limit 70 percent) could be stabilized with cement, laboratory experiements were made to determine the unconfined compressive strength at an age of seven days of the clay-cement mixtures containing from 10 to 40 percent cement. The test specimens were compacted to maximum density and optimum moisture content. Some specimens were maintained at a constant moisture content in a damp atmosphere during a curing period, while others were immersed in water for five days. The resulte (Figure 3) showed that, while 10 percent of cement was sufficient to produce a material with adequate strength at constant moisture content, 20 percent was required to prevent the material breaking down in the presence of free water. Further tests showed that stability in the presence of free water could be achieved with 15 percent of cement if supplemented by 2 percent of hydrated lime.
>
> Similar experiments made with another type of clay (liquid limit 75 percent) showed that 20 percent of cement with 2 percent

of hydrated lime was required to prevent break-down of the stabilized soil on immersion in water.[22]

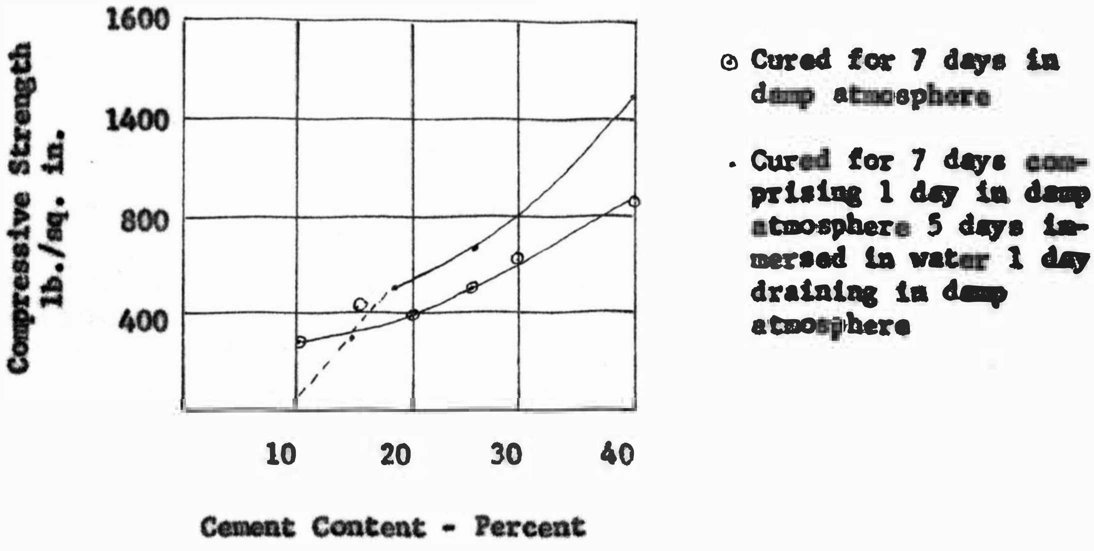

Figure 3. The Effect of Cement Content on the Compressive Strength of Clay Cement Specimens

Source: D. J. MacLean and K. E. Clare, Third International Conference on Soil Mechanics and Foundation Engineering, Volume 1, 264, 1953.

The above experiments will have to be tried with other types of cohesive soils, but they do show that if adequate mixing can be obtained in the field, the soil-cement process can be expanded. The process can be expanded so as to deal with some cohesive soils with higher liquid limits than those that are now being used. The strength of the stabilized soil after immersion in water seems to offer the best means of evaluation when such soil-cement mixtures are to be used under humid climatic conditions.

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[22]D. J. MacLean and K. E. Clare, Third International Conference on Soil Mechanics and Foundation Engineering, Volume 1, 264, 1953.

Full scale experiments have shown that mix-in-place equipment of the rotary tiller type is not capable of mixing cement adequately with heavy clay soils, but satisfactory results have been obtained with twin-shaft pottery pug-mills. In order to study the efficiency of such a mixer the compressive strength of soaked specimens of stabilized soil processed in the mixer and tested at an age of seven days was expressed as a percentage of the corresponding strength of similar specimens made by mixing the soil and cement in a laboratory double-paddle mixer. With a clay (liquid limit 70 percent), an efficiency of 45 percent was obtained with a pottery mixer when the cement and lime were mixed with the clay at a moisture content of 27 percent. The efficiency rose to 67 percent when the moisture content was increased to 37 percent. This mixer was used in the construction of an experimental road of clay stabilized with 15 percent of cement and 2 percent of lime. The material produced had a granular texture, quite unlike the original clay.

The experiments indicated that the stabilization of a fairly wide range of clay soils with cement and lime should be possible in practice.[23]

Effect of Organic Matter in Soil-Cement Stabilization

Cement will hydrate with water present in the soil. Soil that is free from organic materials, forms a hard matrix of set cement around the soil particle.

Calcium, silicate and aluminate ions are believed liberated into the water by grain of hydrating of Portland Cement. These in time combine to form the hydrated calcium silicate and aluminate compounds which make up the matrix of the hardened cement paste. The ability that active organic matter has of combining with calcium ions may account for its retarding effect, therefore, ions would not be available for the reaction in which the matrix compounds are formed.

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[23]*Ibid.*

This view is explained by the results of experiments in which the amounts of calcium absorbed by the soils described above were determined.

> One hundred g. of the air-dried soil were shaken with 250 ml. of a saturated solution of calcium hydroxide, the suspension was filtered and the amounts of calcium remaining in the filtrates were determined. In Figure 4 the absorption of calcium is plotted against the seven-day strengths obtained with 10 percent of normal Portland Cement; this shows that setting was prevented when the amounts of calcium absorbed exceeded 70 mg. per 100 gr. of dry soil.
>
> The retarding effect of organic matter of this type can be reduced or eliminated if a water-soluble calcium salt is added to the soil simultaneously with the cement. The salt is believed to satisfy the absorptive capacity of the organic matter for calcium ions, thus permitting the calcium from the cement to complete its reaction with the other components in a normal manner. The nitrate, chloride, ~~hypochlorite, acetate and hy-~~ droxide of calcium have all been found to be suitable for this purpose. Only the chloride and hydroxide are available economically in the quantities required for road making, and of these the chloride has been found to be the most effective. A convenient method of incorporation is by the use of a form of rapid-hardening Portland Cement to which 2 percent by weight of calcium chloride is added during manufacture.[24]

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[24]*Ibid.*, p. 265.

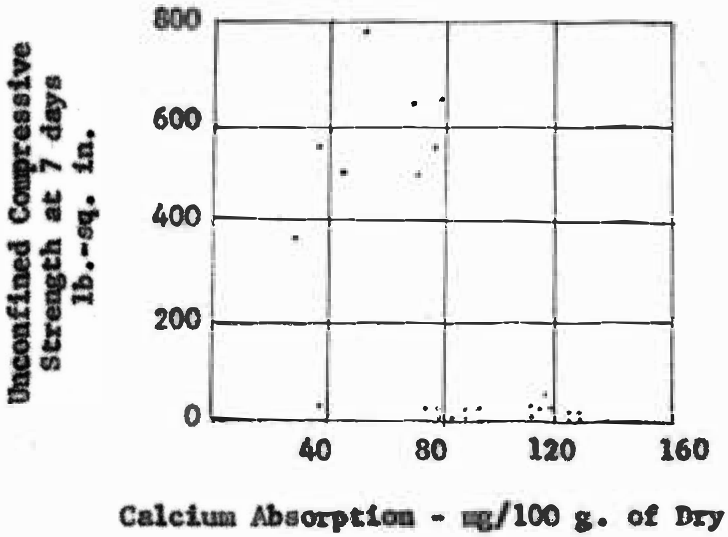

Figure 4. Effect of the Absorption of Calcium by Organic Sandy Soils on the Unconfined Compressive Strengths of Mixtures of the Soils With Ten Percent of Normal Portland Cement

Source: D. J. MacLean and K. E. Clare, Third International Conference on Soil Mechanics and Foundation Engineering, Volume 1, 265, 1953.

TABLE II. UNCONFINED COMPRESSIVE STRENGTHS AFTER 7 DAYS OF SPECIMENS OF ORGANIC SAND, STABILIZED WITH 10 PERCENT OR NORMAL PORTLAND AND 10 PERCENT WITH RAPID HARDENING CEMENT

Sample Number	Unconfined Compressive Strength (lb./sq. in.) Normal Portland Cement	Rapid-Hardening Cement
1	11	30
2	650	915
3	21	415
4	17	327
5	15	181
6	22	379
7	42	80
8	10	747
9	8	167

Source: D. J. MacLean and K. E. Clare, Third International Conference on Soil Mechanics and Foundation Engineering, Volume 1, 265, 1953.

The seven-day unconfined compressive strengths of specimens prepared with a series of samples or organic sand, taken from different points on a proposed road site and stabilized with 10 percent of Normal Portland Cement and 10 percent of rapid-hardening cement. Table II shows that in all but two cases satisfactory hardening was obtained with the rapid-hardening cement.

Tests with other samples have confirmed the above finding that the amount of calcium chloride present in the rapid-hardening cement is sometimes insufficient to provide the necessary concentration of calcium ions. Satisfactory strengths have been obtained in such cases by adding calcium chloride separately in proportions up to 3 percent by weight of the soil, together with 10 percent of normal Portland Cement.[25]

Discussion of Calcium Chloride Tests

Calcium chloride is very effective in improving the cement reaction with poorly reacting sandy soils; but $CaCl_2$ has a minor effect upon the reaction of cement with normally reacting soils.

The extent to which $CaCl_2$ is effective with these poorly reacting soils is shown in Table III.

According to Table III, Soils 1 and 4 are the most responsive to $CaCl_2$ treatment. To explore the reason for this it is first necessary to explore the reasons why the soils are so poorly reacting. Without doubt, the major reason is the presence of organic matter in some form of decomposition and may or may not occur as a coating in the soil grains.

As shown in Table III, Soils 1 and 2 contain 11,000 p.p.m. organic matter compared to 4,000 and 7,000 p.p.m., respectively for

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[25]Ibid.

Soils 3 and 4. Since Soil 2 responds to treatment with 22 percent cement, whereas Soil 1 requires +30 percent, it is apparent that the actual amount of organic matter present is not of prime importance so long as it is high and is of a certain type. This is further shown by the fact that soil 3 (4,000 p.p.m. organic) requires +26 percent cement, whereas Soil 2 (11,000 p.p.m. organic) requires only 22 percent cement.

TABLE III. EFFECT OF $CaCl_2$ IN REDUCING CEMENT CONTENT FOR HARDENING POORLY REACTING SANDY SOILS

Soil Number	Organic Content	Cement Content to Harden, Percent by Volume		
		Without $CaCl_2$	With $CaCl_2$, by wt. 0.6	Percent of soil 1.0
	p.p.m.			
1	11,000	+30	14	12
2	11,000	22		16
3	4,000	+26	16	15
4	7,000	+27	14	

Source: Miles D. Cotton and E. J. Felt, Highway Research Board, Volume 23, 322, 1943.

According to Table IV shown, Soils 1 and 3 are by far the strongest, whereas the best graded and most dense soils are 2 and 3. The soils with the most organic matter (11,000 p.p.m.) are 1 and 2. From these comparisons it is difficult to evolve any relation between gradation, density, organic content, and cement reaction with $CaCl_2$ present.

TABLE IV. COMPARISON OF COMPRESSIVE STRENGTHS

Soil Number	Maximum Density	Compressive Strengths, lb. per sq. in. 18% Cement by Volume 1% $CaCl_2$ by Weight of Soil	
		Seven Days	Twenty-eight Days
	lbs. per cu. ft.		
1	115 ±	975	1,500
2	118 ±	710	980
3	118 ±	1,260	1,560
4	114 ±	675	810

Source: Miles D. Cotton and E. J. Felt, Highway Research Board, Volume 23, 523, 1943.

The question as to why $CaCl_2$ improves these poorly reacting soils is, of course, of interest. If it is assumed that the poor reaction is due to the presence of organic matter in the soil, then it is logical to assume that the soil could be improved by either removing the organic matter or rendering it inactive to cement by some chemical action. Obviously the $CaCl_2$ does not remove the organic, so therefore, it must inactivate it.

In concrete work under ordinary temperatures, the use of $CaCl_2$ is limited to 2 percent by weight of cement. This small quantity increases the rate of hydration so that high strength is obtained at early ages.

From this discussion it appears that the action of the $CaCl_2$ is at least two-fold.

(1) It hastens the hydration of the cement.

(2) It reacts chemically with the organic matter in the soil rendering it partially inactive.

Mixing Period

As with straight soil-cement (with poorly reacting sand soils), at least a four hour damp mixing period is helpful in soil-cement $CaCl_2$ mixtures. The reason for this may be the scouring action during the mixing period, which helps to dislodge the organic film on the sand grain. This results in a better soil-cement mixture because the cement has a better foundation on which to stick.

Method of Adding $CaCl_2$

Tests. Under normal conditions the $CaCl_2$ may be added to the test specimen in solution as part of the mixing water.

Under emergency construction the $CaCl_2$ can be added to the soil in the form of dry flakes. Part of the mixing water should then be added, followed by the rest of the mixing water. Excess rubbing of the mixture should be avoided.

> Construction. In many instances, it is believed that simplest construction will involve the addition of $CaCl_2$ in the form of dry flakes. Least interference with normal construction operations will be obtained by adding the chemical the day before soil-cement construction. After adding the $CaCl_2$ some water may be required to dissolve it. The soil-$CaCl_2$ mixture should then be mixed to obtain uniform distribution.

If equipment is available, uniform application of $CaCl_2$ will be obtained by adding it in solution, either as part of the mixing water during soil-cement processing, or as part of the water used to pre-wet the soil the day before soil-cement construction.[26]

The most efficient and economical procedures to follow during construction will have to come from experience. Experience with concrete and soil-cement paving construction indicates that adding calcium chloride in the field presents no difficulty or costly procedures.

Gumbotil Soil By Lime and Portland Cement Admixtures

Gumbotil or "Gumbo" is a peculiar gray to nearly black, waxy, sticky soil which is encountered frequently in southwest Iowa and in other glaciated regions of the South Dakotan, Illinoisan, Kansan and Nebraskan stages of the Pleistocene epoch.[27]

Developing in the zone of accumulation under poor drainage conditions, Gumbo is a heavy, impervious, clayey material which contains relatively high percentages of fine clay and colloidal material. Gumbo is very plastic at normal moisture contents and presents very serious problems to any construction, design or maintenance of highways. Any practical means of modifying this soil to improve its engineering property would be a boom to engineers responsible for the highways in Gumbo regions and would greatly benefit the highway user.

The sample of gumbo used was taken from a pit dug in the back slope of a cut section on the north side of Iowa Primary Road 92 at Station 740 + 60 approximately 4 mi. east of U. S.

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[26] Miles D. Cotton and E. J. Felt, Highway Research Board, 1943, p. 525.

[27] M. G. Spangler, Highway Research Board, Vol. 29, pp. 561-566, 1949.

Highway 71, near Cumberland, in Cass County, Iowa. The sample pit was 2 to 3 ft. below the slope surface and 10 or 12 ft. below the natural ground surface before the highway cut was made. The location of the sample is such that the soil is presumed to be of Nebraskan age, though some authorities believe it is Kansan. In any event, it is a very old and highly weathered material.

The comparisons between the properties of this gumbotil soil and its natural state and those of the soil plus admixtures indicate that, in general, the engineering properties of the soil were improved by the addition of lime and of Portland Cement. There was a marked decrease in liquid limit produced by the addition of both these materials. Also, the plastic limit was increased and consequently the plasticity index was decreased. The decrease in PI was from 41.7 for the natural soil to 2.0 for 8 percent lime admixture, and 3.5 for 8 percent cement. As the percent added increased, the lime produced a much more rapid decrease in PI than the cement. For example, 2 percent of lime reduced the PI to 8.0 whereas 2 percent of cement only reduced it to 27.5.

Similar favorable modification of the soil was noted with respect to the shrinkage factors and the strength of the soil as revealed by the CBR tests. Both the lime and cement improved these properties of the soil, and again the lime was the more effective of the two for equal amounts of admixture. It will be noted in Table V shown that soaking the samples containing the lime and cement admixtures increased the CBR values as compared to the values "as molded." This, of course, is contrary to the usual effect of soaking natural soils and is probably due to the cementing action of the admixtures.

The addition of either lime or cement did not improve the density characteristics of the soil. In fact they appear to be affected somewhat adversely. The addition of 4 percent of lime to the soil decreased the standard A. A. S. H. O. density from 97.5 for the natural soil to 92.8 pcf. Two percent lime and 4 percent cement reduced the density to 96.3 and 96.5 pcf. respectively. These changes are not considered to be significant in view of the very favorable modification of the soil with respect to plasticity, shrinkage and swell, and strength properties.

This is only an indication of its possibility to modify favorably the gumbotil soils of southwest Iowa by the addition of lime or Portland cement. Also the indications are that lime is more effective than Portland cement and produces more extensive modification for the same amount of added material.[28]

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[28] Ibid.

TABLE V. CALIFORNIA BEARING RATIO TEST ON GUMBO SOIL AND VARIOUS MIXTURES OF SOIL - LIME AND SOIL - CEMENT

(specimens molded to standard AASHO density)

Mixture	Penetration	As Molded		Soaked 4 days		
		Load	CBR	Load	CBR	Swell
	in.	psi.	%	psi.	%	%
Natural Soil	0.1	42		22		1.0
	0.5	59	2.5	30	1.2	
Soil + 2% lime	0.1	170		450		0
	0.5	190	7.3	600	23.0	
Soil + 4% lime	0.1	83		200		0
	0.5	170	6.6	240	9.3	
Soil + 4% lime	0.1	93		150		0.08
	0.5	120	4.6	170	6.7	

Source: M. G. Spangler, Highway Research Board, Volume 29, 561-566, 1949.

Curing of Soil-Cement Bases

Result of moisture tests on 1,092 samples of soil-cement, covered with six different materials, are summarized below:

1 - All control (uncovered) panels lost moisture during the 7-day curing period. Panels that were wetted just prior to applying materials remained higher in moisture content throughout the 7-day period than the non-wetted panels.

2 - Moisture loss and fluctuations in moisture were greater in the top 3/4 in. than in the 3/4 to 1 1/2 in. level.

3 - The control panels dropped more percentage points in moisture content than did any of the other panels.

4 - All earth-covered panels efficiently retained moisture in the soil-cement throughout the curing period. The efficiency of this type of curing is dependent upon constant attention to keeping the earth wet.

5- Waterproof paper efficiently retained moisture in all panels covered with this material. The paper was destroyed by the power broom on the fifth day of curing, resulting in a sharp decrease in moisture content.

6 - In the amount used, calcium chloride as a cover material, was not very effective in retaining moisture in soil-cement during the curing period. Loss in moisture on these sections was exceeded only by the uncovered panels.

7 - All cover materials except calcium chloride were effective in preventing the entrance of rain water into the soil-cement base.

8 - Humidity affected moisture content in the soil-cement; high humidity resulted in higher moisture contents. Changes in humidity seemed to have greater influence on moisture contents.

9 - In practically all cases, panels on which the surface was wetted immediately prior to covering maintained higher moisture contents throughout the curing period than did those panels on which the surface was not wetted.[29]

Chemical Determination of Cement Content of Soil - Cement Mixtures From Cement Hardened Bases

The method for determining the cement content of a soil-cement mixture was found to give accurate and informative results. Since the calcium content varies with the different soil types and also varies somewhat with different shipments of cement, for extreme accuracy it is essential that a test be made first to determine the calcium content of each. This is best accomplished by mixing the soil and cement and determining the calcium content of the mixture. This is advisable with each soil type encountered and with each shipment of cement. It is natural to find some variation in the calcium content of the soil. Also

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[29]A. W. Maner, "Curing of Soil Cement Bases," Highway Research Board, Volume 31, p. 557, 1952.

it is practical to estimate the uniform calcium content of the cement.

General Summation

At the present time, no effort has been made to draw sharp lines between soil characteristics and treatment requirements. General conclusions are justified regarding characteristics of soils.

1. The liquid limit must be below 50.
2. The plasticity index must be below 25.
3. The clay content must be below 35.
4. The percentage of solids at maximum density must be 60 or greater.
5. The soil must possess a "regular" moisture density curve.

If a soil meets the above specifications, it is evident that it can be effectively hardened by the addition of a reasonable amount of cement. The cement required to harden the soil effectively will be approximately the same as that producing effective hardening in a similar soil in the same treatment group.

CHAPTER VI

THE LONG TIME PERFORMANCE OF SOIL-CEMENT ROADS

This chapter is the result of a questionnaire which was sent to 12 different states for investigation of the long time performance of 20 different constructions that have been constructed more than 20 years ago. The information for this investigation is collected from Appendix III. The extra information about these constructions have been collected from "Soil-Cement Mixtures for Roads", proceedings of the seventeenth annual meeting of the Highway Research Board.

Only nine replies were received among these 12 states. The following discussion is the summation of the collected information and the reply. The received questionnaires are in Appendix VI.

South Carolina

During the winter of 1936 and 1937, 11.36 miles of Route 63 in Hampton County were constructed by contract. The specification required a compacted base 22 ft. wide and 6 in. thick. This base was covered with a mixed-in-place bituminous wearing surface 1/2 in. thick and 20 ft. wide.

The soil in this project varied from almost pure fine sand to soil containing as much as 25 percent clay. Six percent cement by weight was used with sandy soil and 10 percent with soil containing considerable clay. No curing was provided but in most instances weather conditions were favorable to retard evaporation of moisture.

A failure due to improper construction occurred in a section of road one half mile long after the base had been surfaced and under traffic for a short time. The surfacing had been shown and it was discovered that the top of the cement stabilized base was soft for a depth of 1 in. No serious trouble has developed from this failure and it has been necessary to patch only a few square yards.

Since then no complete failure has been noticed and no reconstruction except resurfacing has been done. The average daily traffic is 800 vehicles.

Illinois

During September, 1939, a soil-cement road, the first to be constructed in Illinois, was built near Rockford in Winnebago County. The preliminary tests were made jointly by the Division of Highways, Springfield, and the Portland Cement Association, Chicago. Construction work was done by the Winnebago County Highway Department. The section was 1.12 miles long and the soil-cement surface was 18 ft. wide and 6 in. thick. The section was entirely experimental and was constructed at approximately the same time that several other experimental sections were under way in the Middle West.

The soil was classified after soil tests as a sandy loam, and as an A-2 subgrade material grading to either A-3 or A-4 groups.

The only failure occurred soon after construction and the apparent cause was listed as underground seepage of water under the base.

The daily traffic is estimated at 350 vehicles per day.

Kansas

State Highway Department of Kansas with the help of Portland Cement Association constructed the soil-cement road in Stafford County. The road was constructed in 1938--1.42 miles. The base was 28 ft. wide and 6 in. thick.

Success of the construction could be attributed to the character of the terrain and subgrade soils. The project traverses an old river bed filled with sand across the valley.

No failure or any type of cracking has been observed since construction. The present average daily traffic is 1800 vehicles per day and 500 commercial.

Pennsylvania

During the year 1937 another soil cement project was built in Lebanon County, Pennsylvania. The length of construction was 1.97 miles, the base was 14 ft. wide and 6 in. thick. Ten per cent cement used by volume.

Shortly after completion it was recommended the project be given a prime coat and surface treatment due to raveling. The following fall another surface treatment was applied. In 1942 a report of the project showed sinking at the quarter points, the edges raveling and some transverse and longitudinal cracks. Additional surface treatment was applied in 1945 and 1949. In 1957 a one inch surface course was applied by a portable mixer. The roadway at present is in good condition with no apparent soft spots or cracks. The average daily traffic is 300 vehicles per day.

Virginia

This project in New Kent County was constructed in 1938. The length of this experimental road was 2.00 miles and the base was 20.5 ft. wide and 6 in. thick.

The soil on this project was classified as an A-7-5 soil by the H.R.B classification and 8 + 10 cement percent by volume used.

Surface was treated 1938, plant mix 1.5 in. in 1944 and sealed in 1949. This project has given very good service considering that 540 cars, two axle trucks and 20 tractor trailer trucks are the average daily traffic.

Washington

The road was constructed in Whitman County during 1938 one mile long and the base was 20 ft. wide and 6 in. thick. The average daily traffic is listed as 790 vehicles per day.

The construction cost and the project was supported by Portland Cement. So far no cracking and failure has been noticed. The road is in perfect condition.

Missouri

Five different constructions were questioned in Missouri.

One of them was constructed in Moniteau County during 1936. The length of this experimental road was 1.56 miles and base was 22 and 30 ft. wide and 6 in. thick. The purpose of this construction was to investigate the performance of soil-cement in typical Missouri clay soil. The Portland Cement Association financed the construction.

Test sections consisted of worn out gravel roads which were programmed for improvement consisting of base construction to support thin bituminous surface treatment.

The cement used for percent by volume varied between 10 and 13; average assumed 12 for the complete project. Optimum moisture content on the average was 15.5 and the maximum density was 111 pounds per cu. ft.

Today after 23 years this road has a 1094 vehicle per day traffic and is in very good condition except in some isolated edge failures. The roadway should be resurfaced to improve riding qualities.

In connection with an extensive field study of variations in materials and methods in base construction and soil stabilization on Route 100 TR, Franklin County, two miles of soil-cement stabilization were built. These sections were constructed to obtain definite cost and manipulation data as well as to determine the service values of the various suggested types of stabilization under uniform field conditions. The subgrade consisted almost entirely of the Union Silt Loam, a loessial type soil of the A - 4 group. The original wearing surface consisted of approximately one inch of mixed stone and gravel rather poorly bonded.

Today the capacity of these projects are 1500 vehicles per day and the road conditions were studied for different thicknesses and different cement percent by volume. Six percent cement, 5 in. thickness, the portion contains a few scattered longitudinal cracks and scattered small areas map cracking. Patches are fairly numerous. Eight percent cement, 6 in. thick and 6 percent cement, 6 in. thick. The riding surface is from very good to excellent condition. Only indication of distress is shallow rutting in outside wheel track.

The other project was constructed in St. Clair County. The length of the road was 4.96 miles; base was 22 ft. wide and 6 in. thick; cement used percent by volume 8 + 10.

Today this road has 1926 vehicle per day traffic and there is only some map cracking seen on the roadway. Road now has average of 4.6 in. of bituminous mat mixture on 5.8 in. of S. C. Base.

The last project was in Nodaway County constructed in 1938 4.44 miles long and the base was 22 ft. wide, 6 in. thick. Cement used percent by volume 10.

The road has a 820 vehicle per day traffic and is in very good condition except some isolated cracking and edge failures.

Maryland

The project in Worcester County was constructed in 1938. The length of this experimental road was 2.61 miles and the base was 16 ft. wide and 6 in. thick.

The surface treatment was bituminous cut-back and chips. The average daily traffic is listed as between 100 and 200 A.D.T. During the life of this road so far, it has received applications of Surface Treatment.

So far, no serious cracking has been noticed. However, at intervals of approximately several hundred feet, there are ridges across the road about 1 or 2 inches high. They may have been caused by expansion during extremely hot weather.

California

The project in Siskiyou County was constructed in 1938. The length of this experimental road was 3.00 miles and the base was 22 ft. wide and 6 in. thick.

This project was one of the first of its type to be constructed in California. A considerable amount of experimenting took place in its construction. Mixing was accomplished by the use of farm equipment and apparently was not consistent. The daily traffic is 1420 A.D.T.

Also, tests have been made as to strength of the soil-cement. The lowest and highest strengths found were 130 psi and 1233 psi respectively. The average of all 10 days tests recorded was 934 psi.

Three resurfacing have taken place during the life of the road and they are as follows:

1943 0.10 feet of PMS (Plant Mix Surfacing)

1954 0.17 feet of PMS

1958 0.33 feet of PMS

Before each surfacing the existing surface was badly cracked and broken in the wheel tracks. The base apparently cracked early and has not appreciably deteriorated further.

The second project in Kern-139-A was also constructed during

1938. The length of this road was 1.00 mile and the base was 22 ft. wide and 6 in. thick.

Two blankets of Plant Mix Surfacing have been placed over the original construction. One in 1945 and the thickness was 1 1/2 in. and the second one in 1956 was 1 in. thick.

The daily traffic for this road is 1520. There is no distortion of the pavement but transverse cracks across pavement 3 to 10 feet apart.

No data has been received on the Redwood City project.

Summary and Conclusions

I - The moisture-density test is an essential test to determine the cement percent and the amount of water. It is also important for moisture density curves. If there is an irregularity in these curves, compressive, freeze-thaw, and wet-dry tests should be run for the compressive strength and durability of the mixture. Portland cement Association made extensive investigation to determine the importance of the above mentioned tests for soil cement stabilization. (Soil-Cement Mixtures - Laboratory Handbook.)

II - Soil-cement stabilization is especially good for granular soils with low liquid limit values. (The reasons have been discussed in the fifth chapter and the conclusions summarized.)

III - Soil with high clay contents needs a long time mixing for an adequate soil-cement mixing.

IV - Calcium chloride admixture partially inactivates the chemical reaction of the organic matter in the soil and hastens the hydration of the cement. This property has been established by the Illinois State Highway Department.

V - The engineering properties of gumbotil soil improves by the addition of lime and Portland cement. These materials increase the plastic limit, decrease liquid limit and plastic index of the soil. Iowa State College investigated this problem for Iowa highways.

VI - In construction operations satisfactory pulverization of roadway soil, satisfactory mixture of soil and Portland cement, satisfactory mixture of moisture and soil-cement, satisfactory compaction and surface finish, and satisfactory cover to curtail evapporation should be done. One failure in any of these items has a big influence on the entire construction.

VII - The soil cement road construction has a long-time performance almost as good as concrete pavement.

Bearing in mind the fact that the primary objective of the above research was to produce a subgrade which would not undergo such volume changes that pavement distortion produced, satisfactory results will be accomplished by the cement modified soil without having to produce a hardened subgrade. Furthermore, the hardened soil can prove its beneficial influence even after 25 years.

VIII - Soil-cement stabilized roads under heavy traffic did not need extra maintenance comparing with flexible and concrete pavements.

APPENDICES

APPENDIX I

DESCRIPTION OF CLASSIFICATION GROUPS

Granular Materials - Containing 35 percent or less passing the No. 200 sieve.

Group A - 1 - The typical material of this group is a well-graded mixture of stone fragments or gravel, coarse sand, fine sand and a non-plastic or feebly plastic soil binder. However, this group includes also stone fragments, gravel, coarse sand, volcanic cinders without soil binder.

Subgroup A - 1 - a includes those materials consisting predominantly of stone fragments or gravel, either with or without a well-graded binder of fine material.

Subgroup A - 1 - b includes those materials consisting predominantly of coarse sand either with or without well-graded soil binder.

Group A - 3 - The typical material of this group is fine beach sand or fine desert below sand without silty or clay fines or with a very small amount of nonplastic silt. The group includes also stream-deposited mixtures of poorly-graded fine sand and limited amounts of coarse sand and gravel.

Group A - 2 - This group includes a wide variety of gravel materials which are border-line between the materials falling in groups A - 1 and A - 3 and the silt-clay materials of groups A - 4, A - 5, A - 6, A - 7. It includes all materials containing 35 percent or less passing the No. 200 sieve which cannot be classified as A - 1 or A - 3, due to fines content or plasticity or both, in excess of the limitations for those groups.

Subgroups A - 2 - 4 and A - 2 - 5 include various granular materials containing 35 percent or less passing to No. 200 sieve and with a minus No. 40 portion having the characteristics of the A - 4 and A - 5 groups. These groups include such materials as gravel and coarse sand with silt contents or plasticity indexes in excess of the limitations of Group A - 1, and fine sand with nonplastic silt content in excess of the limitations of Group A - 3.

Subgroups A - 2 - 6 and A - 2 - 7 include materials similar to those described under Subgroups A - 2 - 4 and A - 2 - 5 except that the fine portion contains plastic clay having the characteristics of the A - 6 or A - 7 group. The approximate combined effects of plasticity indexes in excess of 10 and percentages passing the No. 200 sieve in excess of 15 is reflected by group index values of 0 to 4.

Silt-Clay Materials containing more than 35 percent passing the No. 200 sieve.

Group A - 4 - The typical material of this group is a nonplastic or moderately plastic silty soil usually having 75 percent or more passing the No. 200 sieve. The group includes also mixtures of fine silty soil and up to 64 percent of sand and gravel retained on No. 200 sieve. The group index values range from 1 to 8, with increasing percentages of coarse material being reflected by decreasing index values.

Group A - 5 - The typical material of this group is similar to that described under Group A - 4, except that it is usually of diatomaceous or micaceous character and may be highly elastic as indicated by the high liquid limit. The group index values range from 1 to 12, with increasing liquid limits and decreasing percentages of coarse material.

Group A - 6 - The typical material of this group is a plastic clay soil usually having 75 percent or more passing the No. 200 sieve. The group includes also mixtures of fine clayey soil and up to 64 percent of sand and gravel retaining on the 200 sieve. Materials of this group usually have high volume change between wet and dry states. The group index values range from 1 to 16, with increasing values indicating the combined effect of increasing plasticity indexes and decreasing percentages of coarse material.

Group A - 7 - The typical material of this group is similar to that described under Group A - 6, except that it has the high liquid limits characteristic of the A - 5 group and may be elastic as well as subject to high volume change. The range of group index values is 1 to 20, with increasing values indicating the combined effect of increasing liquid limits and plasticity indexes and decreasing percentages of coarse material.

Subgroup A - 7 - 5 includes those materials with moderate plasticity indexes in relation to liquid limit and which may be highly elastic as well as subject to considerable volume change

Subgroup A - 7 - 6 includes those materials with high plasticity indexes in relation to liquid limit and which are subject to extremely high volume changes.[30]

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[30] "Soil Cement Mixtures," Laboratory Handbook, Third Edition, p. 18, Portland Cement Association.

TABLE VI. CLASSIFICATION OF HIGHWAY SUBGRADE (WITH SUGGESTED SUBGROUPS)

General Classification	Granular Materials (35% or less of total sample passing No. 200)							Silt – Clay Materials (More than 35% of total sample passing No. 200)			
Group Classification	A – 1			A – 2							A-7
	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7-5 A-7-6
Sieve Analysis,											
Per Cent Passing:											
No. 10	50 Max.										
No. 40	30 Max.	50 Max.	51 Min.								
No. 200	15 Max.	25 Max.	10 Max.	35 Max.	35 Max.	35 Max.	35 Max.	36 Min.	36 Min.	36 Min.	36 Min.
Characteristics of fraction passing No. 40											
Liquid Limit				40 Max.	41 Min.	40 Max.	41 Min.	40 Max.	41 Min.	40 Max.	41 Min.
Plasticity Index	6 Max.		N. P.	10 Max.	10 Max.	11 Min.	11 Min.	10 Max.	10 Max.	11 Min.	11 Min.
Group Index	0		0	0		4 Max.	8 Max.		12 Max.	16 Max.	20 Max.

Source: Merlin Grant Spangler, Soil Engineering, p. 167, International Textbook Company, 1951.

APPENDIX II

SOIL CEMENT ROAD CONSTRUCTION EQUIPMENT REQUIREMENTS

I - 1 - Subgrade rooter (adjustable scarifier on power grader will reduce equipment needs.)

II - 2 - 9 ft. offset disc harrow, minimum diameter of discs 24 in.

III - 6 - 1 1/2 ton truck or equivalent.

IV - 4 - 35-40 h.p. truck type tractor. (One tractor equipped with street plates.)

V - 2 - 8 ft. heavy duty spring tooth field cultivators with teeth back of wheels, power lift, depth control mechanism, 1 3/4 to 2 in. double-pointed shovels on each outside tooth and 4 to 5 in. shovels on remaining teeth.

VI - 1 - 3 or 4-bottom heavy duty gang plow, 14 to 18 in. mold board with power lift and adjustable depth levers.

VII - 1 - 1,000 gal. pressure distributor for water. (Minimum water-spreading requirement should be considered as averaging 100 gal. per minute during water spreading. This will require that the 1,000 gal. pressure distributor be filled and then emptied on the roadway at a rate of 200 gal. per minute, once every 10 minutes. A feeder tank can be equipped with a 300-gal. per minute pump and approximate values and spreading bar to provide a satisfactory, inexpensive pressure distributor. Water spreading will become slow and expensive unless critical attention is given to water supply and spreading.

VIII - 2 - 1,000 gal. feeder tank on truck or equivalent.

IX - 1 - 10 ft. spike-tooth harrow. Teeth not more than 1 1/2 in. apart.

X - 1 - Power-controlled auto patrol, 12 ft. blade (tandem drive preferred.)

XI - 2 - Double-drum sheeps foot roller, types to be dictated by soil conditions. Range of foot pressure to be approximately:

Sand soils, specify unit pressures of 50 to 100 lbs. per sq. in. with tamping feet of 8 to 12 sq. in. area.

Sandy loams and light clay loams, specify unit pressures of 100 to 200 lbs. per sq. in. with tamping feet of approximately 7 sq. in. area. Heavy clay and soils containing considerable aggregate, specify unit pressures of 200 to 400 lbs. per sq. in. with tamping feet of 5 to 6 sq. in. area.

XII - 1 - Tandem self-propelled smooth-wheel roller, sizes to be dictated by soil conditions.

Sandy soils, specify 3 to 5 tons.

Sandy loams and light clay loams, specify 5 to 8 tons.

Heavy clays and soils containing considerable aggregate, specify, 8 to 12 tons.

XIII - 1 - Broom drag, optional. Helpful on finishing surface on some soils.[31]

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[31] W. H. Mills, Jr., L. D. Hicks, F. W. Vanghan, R. R. Litchiser, J. E. Wood, "Progress in Soil Cement Construction", Highway Research Board, Volume 19, 524-536, 1939.

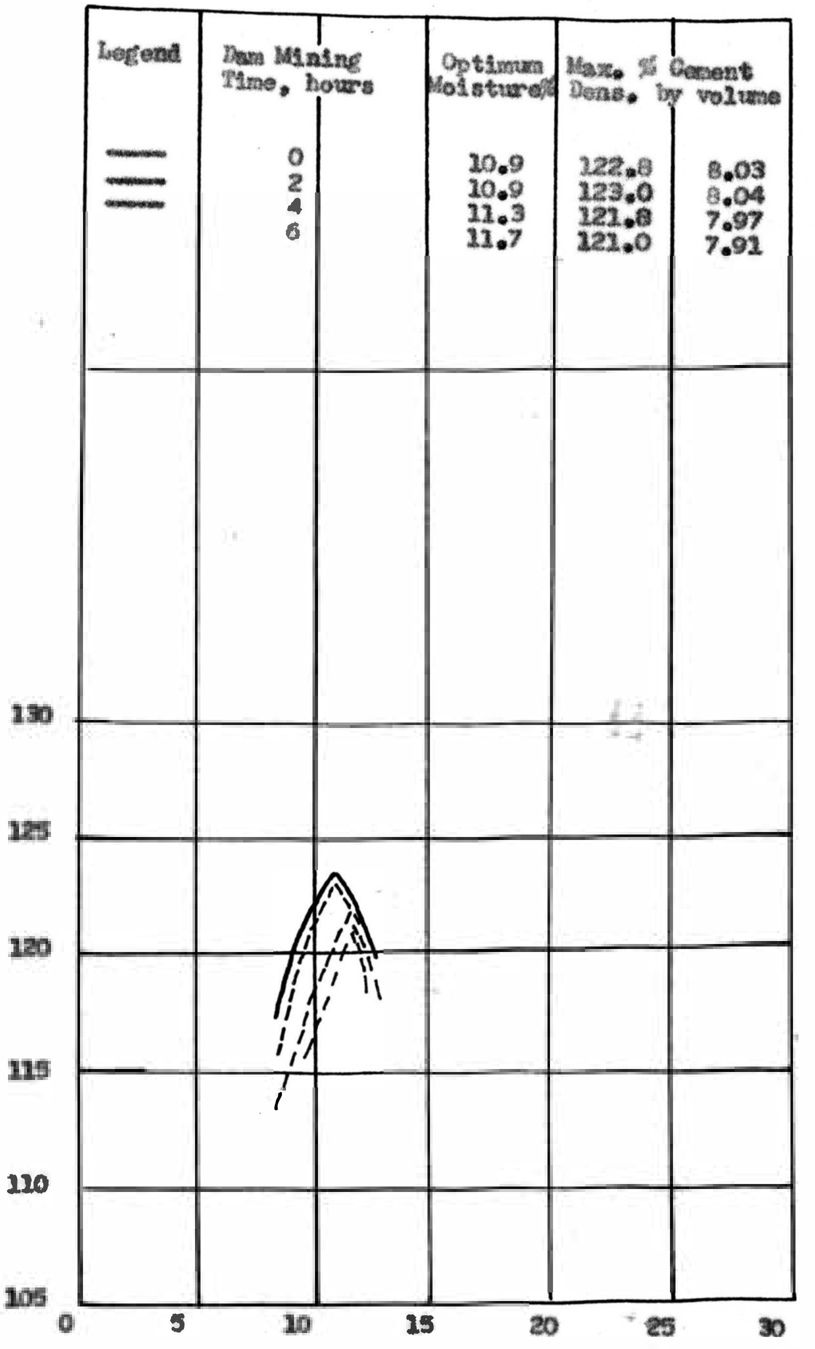
APPENDIX III

SUMMARY OF COST DATA FOR SOIL - CEMENT ROADS

State	County	Year built or awarded	Length Miles	Width, ft.	Area sq. yd.	Cement Used Percent by Volume	Unit Prices expressed in cost per sq. yd. Cement	Processing	Water	Total	Total Cost Per Mile	Remarks
Ill.	Winnebago	1936	1.12	18	11,827	10	$0.226	$0.222	$0.059	$0.507	$5,354	Force Account
Mo.	Moniteau	1936	1.56	22 + 30	20,143	12	0.300	0.339	---	0.639	8,248	Force Account
Calif.	Redwood City	1937	0.34	20	3,955	8	0.212	0.140	0.015	0.367	4,312	Force Account
Mass.	Haverhill Winona Ave.	1937	0.28	22 - 34	4,600	10	0.210	0.162	0.009	0.381	---	City Forces (Low rental costs)
Mass.	Haverhill Smiley Ave.	1937	0.14	36	2,920	10	0.239	0.128	0.006	0.373	----	City Forces (Low rental costs)
Mo.	Franklin	1937	1.00	22	12,858	6 + 8	0.161	0.270	---	0.431	5,545	Force account - machine
Mo.	Franlin	1937	0.99	22	12,723	6 + 8	0.182	0.150	---	0.332	4,230	Force account - road mix
Mo.	St. Clair	1937	4.98	22	64,440	8 + 10	0.287	0.116	0.013	0.416	5,396	Contract
Pa.	Lebanon	1937	1.97	14	16,184	10	0.247	0.165	—	0.412	3,380	Force Account
S.C.	Hampton	1937	11.36	22	146,317	10	---	—	—	0.495	6,389	Contract - machine
Calif.	Kern 139-A	1938	1.00	22	12,900	9	0.203	0.152	0.015	0.370	4,778	Force Account
Calif.	Siskiyou	1938	3.00	22	33,720	9	0.353	0.101	0.018	0.472	6,093	Contract
Ga.	Calhoun	1938	5.38	21	72,645	8, 10 + 12	0.270	0.130	—	0.400	4,940	Contract - Machine
Ga.	Calhoun	1938	5.34	21	70,869	8, 10 + 12	0.281	0.120	—	0.401	4,955	Contract - Machine
Kan.	Stafford	1938	1.42	28	24,276	8 + 10	0.264	0.181	0.014	0.459	7,818	Contract
Ky.	Daviess	1938	6.54	20	80,960	8 + 10	0.225	0.22	0.042	0.487	5,708	Contract
Md.	Worcester	1938	2.61	16	24,405	10	0.265	0.132	---	0.397	3,700	Force Account
Mo.	Nodaway	1938	4.44	22	57,243	10	0.254	0.139	0.012	0.405	5,177	Contract
Va.	New Kent	1938	2.00	20 1/2	23,487	8 + 10	0.227	0.194	—	0.421	4,939	Force Account
Wash.	Whitman	1938	1.00	20	11,730	6 + 7	0.255	0.249	0.017	0.521	6,117	Force Account
						Averages	$0.245	—	—	$0.434	5,092	20 ft. wide

APPENDIX IV

MOISTURE - DENSITY RELATIONS OF SOIL CEMENT MIXTURES AFTER PROLONGED DAMP MIXING PERIODS



Legend	Dam Mining Time, hours	Optimum Moisture%	Max. Dens.	% Cement by volume
———	0	10.9	122.8	8.03
— — —	2	10.9	123.0	8.04
- - - -	4	11.3	121.8	7.97
	6	11.7	121.0	7.91

Moisture Content - Per Cent of Oven Dry Weight

Source: Soil Cement Mixtures Laboratory Handbook, p. 75, Portland Cement Association.

APPENDIX V

CHARACTERISTICS OF SOIL AND SOIL - CEMENT
AND THEIR RELATION TO CEMENT CONTENT REQUIRED FOR ADEQUATE HARDNESS AND SERVICEABILITY

	Treatment Group									
	I				II			III		
Cement Content by volume, per cent	4 and 6	8			10 and 12					
U. S. P. R. A. Soil Group	A-2	A-2 and 3	A-4 and 5	A-6 and 7	A-2 and 3	A-4 and 5	A-6 and 7	A-2 and 3	A-4 and 5	A-6 and 7
	Range in Test Values									
Soil or Soil-Cement characteristics:			(1)	(2)	(3)					
Liquid Limit of the raw soils	10-32	11-40	19-39	35-52	14-30	25-50	34-72	9-33	25-40	41-66
Plasticity index of the raw soil	0-19	0-22	3-20	17-37	0-26	1-23	14-43	0-11	7-17	18-40
Silt content of the raw soil, per cent	6-39	3-36	29-66	12-45	0-26	16-72	7-66	0-16	51-79	15-64
Clay content of the raw soil, per cent	4-31	3-30	5-42	13-49	0-25	5-28	15-60	0-15	12-26	23-61
Organic content of the raw soil, parts per million	tr-4,000	tr-30,000	tr-3,500 (4)	tr-620	tr-20,000	tr-7,600 (5)	tr-6,000	2,500 - 36,000	tr-6,000 (6)	tr-32,000
Solids of soil - cement, per cent	62-76	60-75	59-70 (7)	52-69	61-75	58-72 (8)	49-67	61-73	58-62 (9)	52-63 (10)
Density of soil - cement, lb. per cu. ft. oven-dry wt.	99-129	110-127	103-122 (11)	88-117	104-125	96-113	86-112	102-121	98-103	84-103
Optimum moisture of soil-cement, per cent	7-19	8-16	12-17	13-30	7-19 (12)	12-23	15-30	8-20 (13)	17-21	18-31
Compressive strength 10 per cent cement Specimens, lb. per sq. in. Age, 7 days	443-1,002 (15)	247-894	326-668	382-800 (16)	144-613 (17)	150-621	202-655	35-148 (18)	304-489 (19)	166-388
Age, 28 days	726-1,078	373-1,261	464-920	460-710	326-920	207-890	248-939	212-515	327-570	223-600
Number of soils included in group	(20) 27	66	(21) 25	7	61	38	36	6	10	20

APPENDIX III

Source: Soil Cement Construction Handbook, Portland Cement Association.

APPENDIX V

Source: Soil Cement Mixtures Laboratory Handbook, Portland Cement Association, p. 59.

APPENDIX VI

QUESTIONNAIRE

STATE South Carolina COUNTY Hampton LENGTH IN MILES 11.36

QUESTIONS:

Thickness 6 in. base - 3/4 in. bituminous surfacing

Type of Surfacing Bituminous

Is road now in use? Yes

Present average daily traffic 800

Present Conditions:

a) Intact (No failure): Yes

b) Isolated cracking Yes

c) Map cracking and breakage Yes

d) Complete Failure None

Has there been any reconstruction of this road? No, only resurfacing.

If so, what was the condition when it was broken up? ______

Have any tests been made as to strength of the soil cement? No

One 60 pound retreatment 1950

Comments: One 80 pound retreatment 1958

STATE Illinois COUNTY Winnebago LENGTH IN MILES 1.12

QUESTIONS:

Thickness 6 inches

Type of Surfacing Seal Coat

Is road now in use? Yes

Present average daily traffic 350 (Estimated)

Present Conditions:

a) Intact (No failure): See (b) and (c)

b) Isolated cracking Yes

c) Map cracking and breakage Yes

d) Complete Failure No

Has there been any reconstruction of this road? Yes, 207 Lin. Ft.

If so, what was the condition when it was broken up? Complete base failure. The failure occurred soon after construction and was apparantly caused by underground seepage of water under the base. Base course was removed, drains instilled, and a crushed stone base replaced. Road surface has remained satisfactory after reconstruction.

Have any tests been made as to strength of the soil cement? No

Comments: The map cracking has affected approximately 3.2 per cent of the surface area. Base course was completed in July, 1936, but was not sealed until August 1937. Soil in subgrade and incorporated in soil-cement base course was naturally sandy. This road is in reasonably good condition objectional only in that it is rough riding.

STATE Kansas COUNTY Stafford LENGTH IN MILES 1.42

QUESTIONS:

Thickness 6 inch Soil Cement

Type of Surfacing 2 inch Bituminous Material

Is road now in use? Yes

Present average daily traffic 1800 V. P. D., 500 Commercial

Present Conditions:

a) Intact (No failure): Yes

b) Isolated cracking

c) Map cracking and breakage

d) Complete Failure

Has there been any reconstruction of this road? New surface course 1958.

If so, what was the condition when it was broken up? Isolated cracking typical of Soil-Cement Base courses.

Have any tests been made as to strength of the soil cement? No

Comments: This road has been satisfactory since construction. No serious defects or heavy maintenance required. New surface applied due to increased traffic volumes. Success of this construction probably due to character of terrain and subgrade soils. The project traverses an old river bed filled with sand clear across the valley.

STATE Pennsylvania COUNTY Lebanon LENGTH IN MILES 1.97

QUESTIONS:

Thickness About 8 inches including 6 inches S/C and 2 inches of bituminous surfacing.

Type of Surfacing Latest, 1957, AT-1, 1 inch Bituminous with Pa. No. 1B aggregate.

Is road now in use? Yes

Present average daily traffic 300 vehicles per day

Present Conditions:

a) Intact (No failure): Good condition

b) Isolated cracking None visible

c) Map cracking and breakage None visible

d) Complete Failure No

Has there been any reconstruction of this road? No reconstruction of S/C base. Bituminous surface has been given several treatments.

If so, what was the condition when it was broken up? ---

Have any tests been made as to strength of the soil cement? Numerous cores were taken but there is no record of any tests run on them other than measuring for depth of S/C Stabilization.

Comments: Shortly after completion it was recommended the project be given a prime coat and surface treatment due to raveling. The following fall another surface treatment was applied. In 1942 a report of the project showed sinking at the quarter points, the edges raveling, and some transverse and longitudinal cracks. Additional surface treatments were applied in 1945 and 1949. In 1957 a one-inch surface course was applied by a portable mixer. The roadway at present is in good condition with no apparent soft spots or cracks.

STATE Virginia COUNTY New Kent LENGTH IN MILES 2.00

QUESTIONS:

Thickness 6 inches Soil-cement base

Type of Surfacing Surface treated 1938, Plant mix 1 1/2 inches 1944, Sealed 1949.

Is road now in use? Yes

Present average daily traffic 540 Cars and two axle trucks and 20 tractor trailers trucks

Present Conditions:

a) Intact (No failure): 85 per cent

b) Isolated cracking 6 per cent

c) Map cracking and breakage 5 per cent

d) Complete Failure 4 per cent

Has there been any reconstruction of this road? Edge patching of base.

If so, what was the condition when it was broken up? The clay soil in low places with poor drainage was wet, and has pushed causing edge failures in the soil-cement base.

Have any tests been made as to strength of the soil cement? None

The soil on this project was classified as an A-7-5 soil

Comments: by the H. R. B. classification. This project has given very good service considering that many two axle trucks use this road hauling logs and pulpwood during the winter and early spring.

STATE Washington COUNTY Whitman LENGTH IN MILES 1.00

QUESTIONS:

Thickness 6 inch road mix type cement treated base

Type of Surfacing 2 inch road mix with N. S. Seal

Is road now in use? Yes

Present average daily traffic 790

Present Conditions:

a) Intact (No failure): Yes, few edge breaks have been patched

b) Isolated cracking No

c) Map cracking and breakage No

d) Complete Failure No

Has there been any reconstruction of this road? No

If so, what was the condition when it was broken up?

Have any tests been made as to strength of the soil cement? No

Comments: This one mile section was first experimental use of Portland cement. mixed with existing base material in attempt to stabilize the material for foundation. This section has been in use since its treatment in 1938 and has been given three seal coats over the road mix treatment that was placed on cement treated base. The limits of this section are marked by posts.

STATE Missouri COUNTY Moniteau LENGTH IN MILES 1.56

QUESTIONS:

Thickness 6 inches

Type of Surfacing 27 pound surface treatment

Is road now in use? Yes

Present average daily traffic 1094 V. P. D.

Present Conditions:

a) Intact (No failure): Small isolated edge failures

b) Isolated cracking None

c) Map cracking and breakage None

d) Complete Failure None

Has there been any reconstruction of this road? No

If so, what was the condition when it was broken up?

Have any tests been made as to strength of the soil cement? No

Comments: Received maintenance Bituminous Mat in 1946. Maintenance Seal Coat applied in 1958 to correct map cracking and raveling. Roadway should be resurfaced to improve riding qualities.

STATE Missouri COUNTY Franklin LENGTH IN MILES 1.00

QUESTIONS:

Thickness 5 inches and 6 inches

Type of Surfacing 85 pound drag treatment

Is road now in use? Yes

Present average daily traffic 1500

Present Conditions:

a) Intact (No failure): See Comments

b) Isolated cracking " "

c) Map cracking and breakage " "

d) Complete Failure " "

Has there been any reconstruction of this road? Added 12 yd./sta. deck and a seal coat in 1947 by contract.

If so, what was the condition when it was broken up?

Have any tests been made as to strength of the soil cement? No

Comments: Station 927+ 45 - 940+00—0.238 mile 6% Cement-5" thick

940+00 - 953+50—0.256 mile 8% Cement-6" thick

953+50 - 980+20—0.505 mile 6% Cement-6" thick

927+45 to 950+00+-. This portion contains a few scattered longitudinal cracks and scattered small areas of map cracking (30-40 sq. ft.) Patches are fairly numerous. There is occasional shallow rutting in the right wheel track in both the East bound and West bound lanes. Distress in this portion is very probably due to the fact that ledge rock is very close to the surface. Generally, the riding surface is very good to excellent. 950+00 to 980+20. Riding surface is very good to excellent. Only indication of distress is shallow rutting in outside wheel track of both lanes. Rutting seems to be more predominant in West bound lane.

STATE Missouri COUNTY Franklin LENGTH IN MILES 0.99

QUESTIONS:

Thickness 6 inches

Type of Surfacing 30 pound Seal Coat (?)

Is road now in use? Yes

Present average daily traffic 1500

Present Conditions:

a) Intact (No failure): See Comments

b) Isolated cracking " "

c) Map cracking and breakage " "

d) Complete Failure " "

Has there been any reconstruction of this road? 12 yd./ sta. deck and seal coat in 1947 by contract

If so, what was the condition when it was broken up?

Have any tests been made as to strength of the soil cement? No

Comments: Road mix Station 980+20 - 1006+56 — 0.499 mile 6% Cement 1006+56 - 1032+05.5 — 0.483 mile 8% Cement 980+20 to 1029+00. Riding surface within these station limits is very good to excellent . Only indication of distress is shallow rutting in the outside wheel tracks of both lanes. Seems to be more predominant in the West bound lane.

1029+00 to 1032+05.5. This portion has numerous scattered areas of map cracking and longitudinal cracking. There are numerous scattered patches. This portion did not receive the last seal coat treatment.

STATE Missouri COUNTY St. Clair LENGTH IN MILES 4.98

QUESTIONS:

Thickness 6 inches

Type of Surfacing 1 inch Bituminous Mat

Is road now in use? Yes

Present average daily traffic 1926

Present Conditions:

a) Intact (No failure): ____

b) Isolated cracking ____

c) Map cracking and breakage Some

d) Complete Failure ____

Has there been any reconstruction of this road? No

If so, what was the condition when it was broken up? ____

Have any tests been made as to strength of the soil cement? No

Comments: Received light maintenance mats in 1945 and 1952 and maintenance seal coats in 1953 and 1959. Road now has average of 4.6 inch of Bituminous Mat Mixture on 5.8 inch of SC base.

STATE Missouri COUNTY Nodaway LENGTH IN MILES 4.44

QUESTIONS:

Thickness 6 inches

Type of Surfacing 40 pound surface treatment

Is road now in use? Yes

Present average daily traffic 320

Present Conditions:

a) Intact (No failure): ____

b) Isolated cracking Isolated cracking and edge failures

c) Map cracking and breakage ____

d) Complete Failure ____

Has there been any reconstruction of this road? No

If so, what was the condition when it was broken up? ____

Have any tests been made as to strength of the soil cement? No

Comments: Received maintenance mat in 1945. Cored by PCA, July 1958. Approximate mat thickness 3 inches. Old mat dead and gravel apparently chewed core sample into small fragments. Sides of hole showed hard, dense soil-cement base. Samples could not be tested.

STATE Maryland COUNTY Worcester LENGTH IN MILES 2.61

QUESTIONS:

Thickness 6 inches

Type of Surfacing Surface Treatment - i.e. Bituminous Cut-back and chips

Is road now in use? Yes

Present average daily traffic low - perhaps between 100 and 200 ADT

Present Conditions:

a) Intact (No failure):

b) Isolated cracking Yes

c) Map cracking and breakage

d) Complete Failure

Has there been any reconstruction of this road? No

If so, what was the condition when it was broken up? ——

Have any tests been made as to strength of the soil cement? Materials Division is investigating records; will advise you later.

Comments: A small amount of cracking along the edges of the road is apparent. It does not appear to be serious. At intervals of perhaps several hundred feet there are ridges across the road about 1 or 2 inches high. They may have been caused by a transverse crack in the base and a slight rise or "blowup" caused by expansion during extremely hot weather. They are not of a serious matter. I am advised that during the life of this road so far, it has received three (3) applications of Surface Treatment.

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