SOIL-CEMENT BASE COURSE

By

MILAGROS C. HERNANDEZ

Bachelor of Science in Civil Engineering
Mapua Institute of Technology
Manila, Philippines
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Report Adviser

Faculty Representative

Dean of the Graduate School

PREFACE

The purpose of this report is to present a guide in the design and execution of actual projects in soil-cement road work. Good engineering control on the job and the evaluation of laboratory findings for the design of the mixtures are essential to produce a good soil-cement base course.

Grateful acknowledgment is made to the Highway Research Board, American Association of State Highway Officials, American Road Builders' Association, and Portland Cement Association for their research publications which have been the source of valuable information for this study and to Dr. Moreland Herrin, Research Professor in Civil Engineering, Oklahoma A & M College for his helpful advice in the preparation of this report.

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CHAPTER I

INTRODUCTION

This report is written primarily with a view to write a standard specification on soil-cement base course for adoption by the Bureau of Public Highways of the Philippine Islands and for incorporation in its Standard Specifications for Highways and Bridges.

Although the Philippineshas numerous gravel deposits, there are sections where there is practically none. This is especially true in the flat wide valleys which are remote from the mountains. The rocks and boulders carried by the rivers from the mountains are deposited along its way and in the further end of the rivers, where the flow is slower, the fine sands are the ones deposited. This being the case, attributes to the absence of gravel in certain sections of the country. Due to this, materials for base course had to be hauled great distances which results in high costs. In order to avoid such unnecessary high costs, some substitute material must be resorted to. In this connection, it is deemed satisfactory to make use of the local soil by stabilizing it with cement since cement is manufactured locally in the Islands.

By means of soil-cement stabilization the existing natural soil can be made into a better material with a supporting or carrying power better than or equivalent to that of gravel, stone, or other base course material, depending on the physical and chemical properties of the soil concerned. Because of this, it is necessary to conduct tests on the existing soil before any construction operation is started in order to determine the type and characteristic of the soil. In this report, these have all been discussed prior to the preparation of the specifications.

It is hoped that this will help to relieve if not entirely solve the problem with respect to the availability of base course materials in certain portions of the Islands. This will help in the reduction of the construction cost since it does away with the heavy cost of hauling base course materials from great distances.

CHAPTER II

SOIL-CEMENT AS A BASE COURSE

Soil-cement as a base course is equally adaptable to small town streets, provincial roads, super-highways or airports. Its rigidity renders it capable of distributing the pressure of traffic over an increased area of subgrade thereby greatly lessening the unit pressure per square inch. Construction of soil-cement roads can be carried out all year round except during heavy rainstorms.

Use of Soil-Cement

Soil-cement is used as a low-cost base for light-traffic paving on township, county, and state roads and residential city streets in the U.S.A.[2]. It is commonly used instead of six to eight inches of granular type bases because it has equal or greater load-carrying capacity and an equal or lower construction cost. It is also being used as base course for concrete pavements to eliminate distortion on heavy clay soils due to moisture and volume changes and to increase the bearing value of subgrades. Soil-cement is not capable of withstanding continued heavy loads nor the abrasive action of traffic which causes potholing and raveling, particularly during periods of rainy weather;

therefore, it is not suitable for use as a surface course[1]. This type of construction forms an excellent base for a wearing course or a surface treatment and is recommended only as such.

Structure of Soil-Cement

Soil-cement is a mixture of pulverized soil, portland cement and water. By the addition of portland cement, many soils which in their natural condition would be unstable for use as base courses can be made to serve satisfactorily for such purposes. Through the process of combining the cement, soil and water, and thoroughly mixing and compacting the resulting product, a new structural material is formed when the cement hydrates and crystallizes[1]. Study of soil-cement mixtures in the laboratory and field indicates that each cement grain picks up a varying number of soil grains (depending on the grain size of the soil) and as the cement hydrates and crystallizes, a new and larger soil grain or agglomeration is produced. The more cement is added, the larger the soil grains or agglomerations become. The agglomeration of cement and soil grains is shown by the tests of soil-cement mixtures of low cement content. These agglomerations of cement grains and soil grains can also be thought of as links in a chain and when enough cement has been added to link all agglomerations together, with pockets of trapped soil, the mixture becomes a structural material rather than a soil.

In comparison with concrete it appears that in the case of concrete, the cement mortar coats the aggregate, while in soil-cement the cement is coated by the soil; for this reason a somewhat different result can be expected and is obtained. Soil-cement should, therefore, be considered as distinct from concrete and as having different applications.

Factors Influencing Physical Properties of Soil-Cement Mixtures

The properties of compacted and hydrated soil-cement mixtures are dependent to a great extent upon the types of soil involved. Certain differences in properties and in cement reaction are due to variations in the chemical composition of the soils[(3)]. For instance, lateritic clays with a relatively low silica-sesquioxide ratio (colloids low in silica and high in the sesquioxides of iron and aluminum) pulverize more readily and react more favorably with cement than do northern podzolic or chernozem clay soils which have relatively high silica-sesquioxide ratios. Laboratory studies and field experience have shown the differences that may occur in the properties of soil-cement mixtures made with different clay soils.

Sandy soils too may react differently with cement depending upon their chemical makeup and surface chemical properties. For instance, a great variance exists betwen the relatively poor effectiveness of cement with the A horizon (topsoil) of many podzolic soils and the much greater effectiveness of cement with the C horizon (parent material) from the same soil profile. In these soils the organic matter in the A horizon is considered to be the chief offender, as it may retard or almost completely arrest the cement reaction.

Because of the tremendous effect organic matter may have on some soil-cement mixtures, special laboratory studies and field experiments have been conducted to ascertain what soils can be satisfactorily stabilized with cement. Sandy soils of this type may be satisfactorily treated. Soil identification and careful sampling are, of course, prerequisites to effective soil-cement testing and construction. In this connection, the Pedological system of soil identification which includes information on both the physical and chemical properties of soils is recommended for soil-cement work.

Other factors which have pronounced influence on the physical properties of soil-cement mixtures include the quantity of cement and water added; the density to which the mixture is compacted; the length of time the soil, cement, and water are mixed prior to compaction; and the degree of pulverization of the soil if it is a clay[3]. To evaluate these effects a series of tests have been made to determine the influence of various factors upon the compressive strength and resistance to wetting and drying and to freezing and thawing of compacted hydrated soil-cement mixtures. For convenience these test series were identified as follows:

Series 1 - Effect of density

Series 2 - Effect of molding moisture content

Series 3 - Effect of length of mixing time

Series 4 - Effect of degree of pulverization

Series 5 - Effect of air-entraining cement

Series 6 - Effect of the quantity of cement

Series 7 - Effect of high early strength cement

The physical properties of the soils used in these test series are listed in Table I. The first group in Table I is composed of five sandy soils all identified as soil 2a. (The numbers after the 2a, i.e. 2a-2, 2a-3, etc., indicate different samples from approximately the same area). The second is a group of five silty soils; third, of four clayey soils; and fourth, of a single clay soil, very heavy textured and extremely plastic.

TABLE I

GRADATION AND PHYSICAL TEST CONSTANTS* OF RESEARCH SOILS

Soil No.	Used in Test Series No.	Gradation-% of Total: Sand 2.0 to 0.25 mm.	Sand 0.25 to 0.05 mm.	Silt 0.05 to .005 mm.	Clay .005 to .000 mm.	Physical Test Constants: Liquid Limit	Plasticity Index	Shrinkage Limit	Textural Class	AASHO Soil Group
2a	1, 2	39	49	3	9	12	NP		Fine Sand	A-2
2a-2	3	24	49	8	19	26	11	18	Sandy Loam	A-2
2a-3	1, 2	35	46	8	11	13	NP	21	Loamy Sand	A-2
2a-4	1, 2, 3, 5	27	47	7	19	17	1	17	Sandy Loam	A-2
2a-6	6, 7	26	57	6	11	14	NP	20	Loamy Sand	A-2
4b-3	1, 2, 3	2	17	57	24	38	13	25	Silty Clay Loam	A-4
4b-4	3	3	12	59	26	35	12	26	"	A-4
4b-5	1, 2, 3, 5	2	9	64	25	34	10	24	"	A-4
4b-6	4	2	7	67	24	37	12	20	"	A-4
4d	1, 2, 6, 7	1	8	67	24	34	14	16	"	A-4
6e	1, 2	2	10	35	53	49	26	17	Clay	A-6-7
6e-2	3	2	9	40	49	47	26	18	"	A-6-7
6e-4	1, 2, 3, 5	1	11	51	37	51	28	17	Silty Clay	A-6-7
7h	4, 6	8	9	36	47	37	18	16	Clay	A-7
7d	1, 2	0	14	18	68	118	83	14	Clay	A-7

* Obtained using Standard AASHO and ASTM Procedures

TABLE II

COMPRESSIVE STRENGTHS AND WET-DRY AND FREEZE-THAW LOSSES OF SOIL-CEMENT COMPACTED TO AASHO STANDARD AND AASHO MODIFIED MAXIMUM DENSITIES AND OPTIMUM MOISTURE CONTENTS

Compaction* System	Density pcf	Moisture Content %	Compressive Strength psi			Wet-Dry Loss %		Freeze-Thaw Loss %	
			Age in Days			No. of Test Cycles			
			2	7	28	12	24	12	24
Soil 2a-4, 8% Cement by Volume									
A	121.0	10.8	265	665	800	3	5	5	7
B	128.5	9.0	435	732	1303	3	4	5	5
C	121.0	9.0	263	632	769				
Soil 4d, 12% Cement by Volume									
A	108.0	17.0	352	596	668	3	7	3	6
B	121.5	12.5	787	933	1202	3	27	3	6
C	108.0	12.5	229	277	293				
Soil 6e-4, 12% Cement by Volume									
A	102.5	18.5	203	417	486	31	86	9	35
B	115.5	13.8	326	427	709	28	97	5	6
C	102.5	13.8	70	138	149				

* A - AASHO Standard Maximum Density, AASHO Standard Optimum Moisture Content
B - AASHO Modified Maximum Density, AASHO Modified Optimum Moisture Content
C - AASHO Standard Maximum Density, AASHO Modified Optimum Moisture Content

The relative quality of mixture produced using basic molding data obtained with the two compaction methods, namely, the AASHO Standard Method and the Modified AASHO Method at different water contents is indicated in Table II. Compressive strengths obtained using System B (AASHO Modified Maximum Density, AASHO Modified Optimum Moisture Content) were considerably greater than those obtained using System A (AASHO Standard Maximum Density, AASHO Standard Optimum Moisture Content) as indicated in Table II. This we might expect, as according to Series 1 (effect of density) the high densities are beneficial. Apparently at these higher densities less water is required in the mixture to effectively utilize the cement, and the acceptable moisture content is thus lower for the densities achieved by System B than for the lower densities of Series 2 (effect of molding moisture content). As there is little difference between the wet-dry and freeze-thaw data for specimens compacted by Systems A or B and as the compressive strengths are much higher using System B, it appears that the soil-cement mixture compacted by System B is of the higher quality.

It is important to note that the density indicated by the AASHO Modified Method as maximum for the silty and the clayey material is so great that it is difficult to obtain in construction practice. Methods of compaction which will produce this density are not generally available, and the density most likely to be obtained in construction is about that indicated as maximum by the ASTM method.

It is apparent that if only this latter density were obtained with a mixture compacted at the relatively low AASHO Modified optimum moisture content, the resulting quality of the mixture would be impaired. This is indicated in Table II by the compressive strength data for the mixtures compacted using System C (AASHO Standard Maximum Density, AASHO Modified Optimum Moisture Content).

It appears, therefore, that if densities as great as those obtained by the AASHO Modified compaction procedure could be assured, in combination with their respective optimum moisture contents, soil-cement mixtures of superior quality would be produced. However, as these densities are not readily attained in practice, it usually is desirable to construct a soil-cement mixture near the AASHO Standard optimum moisture content and to obtain as high a density as possible, preferably equal to AASHO Standard density or greater. This procedure will provide sufficient water in the mixture to effectively utilize the cement at the particular density obtained.

The inclusion of damp clay lumps is not particularly harmful as indicated by the data in Table III and may be permitted in soil-cement construction in accordance with properly written specifications. The inclusion of dry clay lumps, however, is harmful and should not be permitted. To eliminate the possibility of dry clay lumps, clayey soils, when necessary, can be pre-wetted a short time prior to construction.

TABLE III

MOLDING DATA FOR SOIL 7h, PLUS 12% CEMENT BY VOLUME, AASHO OPTIMUM MOISTURE CONTENT 16.8%, MAXIMUM DENSITY 108.4 PCF. (SPECIMENS MOLDED ONLY FOR WET-DRY AND FREEZE-THAW TESTS)

Set No.	Data on Clay Lumps: % Included	Data on Clay Lumps: Moisture Content %: When Added To Mix	Data on Clay Lumps: Moisture Content %: After Mixing	Moisture Content of Specimen %: Minus No. 4	Moisture Content of Specimen %: Total Mixture	Density of Specimen pcf.	Loss Due to 12 Cycles %: W-D	Loss Due to 12 Cycles %: F-T
	0	----	--	17.2	17.2	109.0	3	3
A	20	2	2	17.0	14.2	111.0	33	32
	40	2	2	17.0	11.0	109.0	100	100
B	20	2	9 to 13*	--	17.5	109.5	5	4
	40	2	11 to 16+	--	18.0	109.5	10	6

* 20% clay lumps (unpulverized soils retained on No. 4 sieve) after damp mix completed

\+ 30% clay lumps (unpulverized soils retained on No. 4 sieve) after damp mix completed.

Effect of Moisture and Density (Series 1 & 2)

The moisture content of a soil-cement mixture and the density to which the material is compacted have a great influence upon the quality of the product after hydration.

For general soil-cement construction, the most effective moisture content is approximately equal to or slightly above the optimum moisture content indicated by AASHO method T 134; moisture contents below the optimum may produce silty and clayey mixtures of inferior quality. The quality improves as the density increases; thus, mixtures at proper moisture content should be compacted to the highest practical density, at least equal to that obtained by AASHO method T 134.

For special soil-cement construction where very heavy compactive effort is available, the quality of the mixture may be improved by lowering the moisture content and greatly increasing the density. However, to take advantage of this, special laboratory tests are necessary to establish moisture and density control limits, and careful checks must be made in the field to insure that these control limits are closely maintained.

Effect of Prolonged Mixing Periods (Series 3)

Prolonged periods of damp mixing impaired somewhat the quality of the mixture. However, with most soils, mixing periods as long as four (4) hours were not seriously harmful provided the mixture was intermittently mixed several times an hour and provided the moisture content at time of compaction was at or slightly above the optimum prevailing at that time. The optimum moisture content generally increases as the length of mixing time increases; therefore, moisture-density tests are necessary toward the end of the damp-mixing period to determine the new optimum prevailing at that time.

Effect of Clay Balls in the Mix (Series 4)

The quality of silty and clayey soil-cement mixtures was highest when 100 per cent of the soil (exclusive of gravel, stones, etc.) was pulverized to pass a No. 4 sieve. However, the quality was not seriously affected by the presence of as much as 30 per cent of unpulverized soil, provided the lumps of soil were damp at the time the soil-cement mixture (at optimum moisture content or slightly above) was compacted. If the soil lumps were dry at the time they were compacted in the soil-cement, the quality of the material was seriously impaired.

Effect of Air-Entraining Cement (Series 5)

Soil-cement mixtures containing air-entraining (Type IA) cement behaved approximately the same as those containing Type I cement. Moisture density relations, compressive strengths, and wet-dry and freeze-thaw test results were sufficiently similar to show that the cements may be used interchangeably in soil-cement construction.

Effect of High Cement Contents (Series 6)

The compressive strength and resistance to wetting and drying and freezing and thawing increased as the cement content was increased. Good quality mix was obtained with cement contents generally in the range of 8 per cent to 14 per cent (depending upon the soil). However, mixtures having unusually high compressive strength (2000 to 4000 psi) and excellent resistance to alternate freezing and thawing and wetting and drying were obtained with relatively high cement contents of, say, 22 per cent to 30 per cent, by volume.

Effect of High-Early-Strength Cement (Series 7)

High-early-strength (Type III) cement hardened soil-cement mix at a faster rate than Type I cement. Prolonged mixing periods of several hours did not seriously impair the quality of mix containing Type III cement. Thus, for special construction where high early strength is required, Type III cement may be used.

Test data show that water-holding capacity, as reflected in the physical test constants, gives a general indication of cement requirements, with needs increasing with water-holding capacity[4]. Likewise, grain size and surface area are a similar general indication, with cement requirements increasing with decrease in grain size and increase in surface area. These same factors also influence maximum density, with a trend for cement requirements to decrease with increases in density. However, since grain size indicates the AASHO soil group, the grain size of a soil has some added significance.

All tests of strengths and durability indicate the influence of cement with each soil. That is, each soil-cement mixture will attain a certain strength or soil loss with a certain satisfactory cement content, and increasing cement contents by the next few increments above this amount does not produce the same significant increases in strength or large decreases in soil loss as did the lower increments of cement.

The study of test results and the action of soil-cement mixtures during test and in the field also throw some light on the probable functioning of cement in producing a hard, durable structural material. Lower cement contents may change the soil characteristics but as cement contents are increased, a condition is reached where the addition of more cement changes the material from a different soil to a structural material.

All the test data also indicate that some undetermined factor is present in soil which does have a prevailing influence on the ability of cement to harden the compacted soil-cement. The fact that compressive strengths vary for soils of similar grain size and water-holding capacity, that cement requirements vary for soils having similar AASHO soil grouping, similar density, similar strengths, similar water-holding capacity, and other similarities gives substantial support to the hypothesis that there is some such factor, other than physical relations, which plays an important role in determining the influence of soil in compacted soil-cement relations.

Effect of Type of Soil

The particle-size distribution, chemical composition of the soil and, possibly, the nature of adsorbed ions are factors which must be tested, studied and evaluated.

The Portland Cement Association states that almost any soil which can be pulverized can be stabilized with cement, but it may be uneconomical at the present time to pulverize some soils such as heavy clays[8]. The following limits are based on those suggested by the Highway Research Board for soils that can be economically stabilized:

Particle-size distribution limits:

Maximum size	3 inches
Passing 1/4 inch sieve	> 50 per cent
Passing No. 40 sieve	> 15 per cent
Passing No. 200 sieve	< 50 per cent

Plasticity test limits:

Liquid limit	< 40 per cent
Plasticity index	< 18 per cent

The soil should be low in organic matter for successful stabilization since this constituent tends to reduce the strength of soil-cement. Although in some cases soils with 3 to 4 per cent of organic matter have been successfully stabilized, about 2 per cent is considered to be the safe upper limit and with some otherwise suitable soils, as little as 0.5 per cent of organic matter has rendered the soil unsuitable for stabilization.

Aside from organic matter, the chemical composition of the soil is believed to be of importance only if appreciable quantities of deleterious salts are present. The harmful effect is due not to a reaction affecting the setting of the cement, but to a subsequent disruption of the soil-cement structure caused by crystallization of highly hydrated salts in the pores. Such effects have been observed in the laboratory, but it is not known to what extent they may occur in the field.

The laboratory work on a wide range of soils indicates that the red and yellow soils, high in irons and aluminum content and relatively low in silica content, usually respond readily to hardening with cement. In the absence of chemical composition, ionic or other chemical tests, these soils responding readily to hardening are thought and spoken of as soils which "like" cement or have a strong affinity for cement. In other words, some soils of relatively low density, high water-holding capacity, and even high colorimetric organic value may harden satisfactorily with as little as 8 per cent cement. These soils, obviously, have some predominate "liking" or affinity for cement which overcomes what are otherwise unfavorable physical factors. Furthermore, a soil not "liking" cement can be made to "like" cement by the simple use of a moderate amount of another soil.

CHAPTER III

SOIL-CEMENT DESIGN

Soil-cement design consists of three important steps: first, sampling; second, testing; and third, interpretation of the test results[5].

Since soils differ, it is reasonable to conclude that different soils will require different amounts of cement, so it is necessary that the tests be performed on representative samples of the soils to be encountered. The destructive forces acting upon the base are chiefly climatic and their intensities will vary with localities, so proper interpretation of the test results are essential.

Sampling

The soil samples to be tested must represent the soils that are to be encountered. Taking samples at definite intervals may involve the testing of a large number of samples, many of which may be duplicates. Also, such a procedure can not be followed with any degree of certainty until grading operations have been completed. Soils of a common origin which have undergone the same degree of development are found to be very similar in physical and chemical characteristics. They may be identified visually by their color, structure, texture, and relief, assisted by a knowledge of the geology of the locality. Soil maps are also of great assistance.

When a soil-cement project is proposed, a soil survey is made, identifying and locating the series of soils within the construction limits of the road. A key sample, weighing about 200 lbs., is taken from the two lower horizons of each soil series. Usually the average project will contain only 3 to 5 different soil series, necessitating only 6 to 10 key samples. It has been found that samples from the same horizon in the same soil series are quite similar and will require approximately the same amount of cement stabilization. After the grading has been completed, small samples, taken for the depth to be stabilized and at intervals of 500 ft., are carried to the laboratory for moisture-density relation tests. At the time the samples are taken, a note is also made as to the soil series and horizon to which they belong. The results of tests on these samples establish the optimum moisture for maximum density of the soil at intervals of 500 ft. and the soil series and horizon designates the key sample to use in selecting the required amount of cement. The results of tests on these samples give the field control data for the construction of the base on the entire project.

Testing

The following tests are performed on the key samples:

1. Mechanical analysis
2. Physical test constants (L.L., P.L., etc.)
3. Organic content
4. Specific gravity
5. Moisture-density relations of raw soil and with cement admixtures
6. Compression tests of soil-cement mixtures
7. Freeze-thaw durability
8. Wet-dry durability

The procedures for performing these tests are well known and can be found in the AASHO Standard Specifications for Highway Materials and Methods of Sampling and Testing - Part II and ASTM Book of Standards - Part 3.

Field Control

The above tests are performed in the central laboratory while certain tests such as moisture determinations and relative density tests must be made in the field during the construction of the base. Sufficient moisture determinations are made before and after the addition of water and cement to maintain strict control before compaction is completed. Also, points are selected at approximate intervals of 250 feet for relative density tests. A specimen is made of the soil-cement mixture at each point at the time compaction operation begins by compacting the mixture in the mold.

For uniform and accurate results, the mold is placed on a concrete block during the process. The dry density of the specimen is the standard density of the mixture at the point. After the base has been compacted, a field density determination of the base is made in the same spot as was the standard density and the result used in determining the relative density obtained. The relative density is the ratio of the field and standard densities. For good work, this value should not be below 0.95.

Interpretation of Test Results

In general, the optimum moisture for maximum density of the raw soil is equal to that of the admixture. Examination of test results on the key sample will give the relationship. The most important thing is that sufficient moisture is present in the mixture at the time it is compacted.

The importance of having sufficient moisture in the soil-cement mixture was discovered by accident in the North Carolina laboratory while making some check tests on a soil where cement requirements had been previously established. Through a slight error the specimens were made at the proper density, but at a moisture content a little below optimum. When submitted to the durability tests, their loss was excessive, indicating a higher cement requirement. The compression test also gave lower results. An investigation followed which revealed that the moisture content of soil-cement specimens at the time they were made had a decided influence on their strength and durability. Further investigation also showed that the optimum moisture percentage of maximum density was higher by about two for a mixture that had set for a few hours, allowing the cement to hydrate than that determined from a fresh mixture. These findings justified the "working optimum" referred to above which is the laboratory optimum plus two.

Determination of Cement Requirement

The determination of the amount of cement necessary to satisfactorily stabilize a soil is a matter of prime importance. The use of more than is necessary needlessly increases the cost of the work and the use of too little may result in base failures[5]. The durability requirement will therefore determine the minimum cement content while economy will determine the maximum cement content because of cement being the more costly ingredient in soil-cement mixtures. However, the results of the durability tests are generally used to establish the cement requirement. Originally it was the practice to permit a maximum loss of 10 per cent of the specimen after exposure to 12 cycles of freezing and thawing or wetting and drying, whichever showed the greatest loss. The maximum volume change should also not be greater than 5 per cent. Recently, however, the type of soil stabilized has been taken into consideration. Table IV gives the permissible losses for various types of soil.

TABLE IV

PERMISSIBLE SOIL-CEMENT LOSSES FOR VARIOUS TYPES OF SOIL

*PRA Soil Group	Revised USBPR Soil Group	**Allowable Soil-Cement Loss
A-2, A-3	A-1-a, A-1-b, A-2-4 A-2-5, A-3	14%
A-4, A-5	A-2-6, A-2-7, A-4 A-5	10%
A-6, A-7	A-6, A-7-5, A-7-6	7%

* Public Roads Administration

** Resulting from 12 cycles of either the ASTM Wet-Dry or Freeze-Thaw Test

The time necessary to determine the amount of cement necessary for satisfactory stabilization is about five to six weeks. The use of the series classification of soils permits the accumulation of data that may be utilized for future work, thereby overcoming the time element necessary for the determination of the cement requirement.

The amount of cement and water required for satisfactory results varies considerably according to the clay content, silt content, maximum density, voids, water-holding capacity and other physical characteristics of the soil. In general, the finer the texture of the soil the more cement is required to harden it to a satisfactory degree. Another important controlling factor is the affinity of the soil for cement, in fact this may be the predominating factor[1]. In many cases the addition of a small amount of another soil to a soil which has little affinity will very greatly increase this attraction of the resultant mixture for cement. A soil can be acid, alkaline, or neutral, and still react equally well to cement but soils having high organic content are the least satisfactory.

Because of these numerous variable factors, the best proportioning of ingredients can be determined through laboratory tests and trial mixes only. It has been found, however, that the cement requirement for each horizon of a particular soils series under the pedological classification will be approximately the same wherever the soil series may occur. The cement requirement may vary widely between groups and within any one group of the Public Roads Administration system of classification; nevertheless, the requirement for each soil group will be nearly constant and fall within a narrow range for soils located in a particular small area.

Experience indicates that the desirable cement content is usually within the range of 7 per cent to 14 per cent by volume of the compacted soil-cement mixture. The exact percentage which is best for use in a particular case should be determined by laboratory tests and experimenting. Higher cement contents have been used in special cases. Theoretically cement contents lower than 7 per cent would produce satisfactory results with some soils, but for practical reasons lower contents are not recommended. Variations in proportioning should be by 2 per cent increments or decrements as more precise measurement is impracticable.

For many soils the quantity of cement required is about 2.7 bags per cubic yard of the compacted mixture or 0.45 bags per square yard of six inches compacted depth[2]. Since one bag of cement is considered as one cubic foot, such a mixture is commonly considered to contain ten per cent cement by volume. On this basis, sandy soils are likely to require seven to twelve per cent cement by volume and silty and clayey soils twelve to sixteen per cent by volume. Some very fine textured soils require higher percentages of cement.

Water Content

There are two requirements which control the amount of water needed in a soil-cement mixture: one is that there be the right amount of water present for hydration of the cement and to produce the necessary durability and strength; the other is that the moisture content be the optimum required for satisfactory compaction of the mixture[1]. Experience indicates that the two requirements are satisfied at approximately the same moisture content. The optimum moisture content for compaction may be determined by the latest AASHO standard test T-99 which is used to determine the optimum moisture content and maximum density for soils used in embankment construction. Cement can be successfully spread and mixed whenever the moisture content of the raw soils does not exceed the optimum by more than two per cent. Higher moisture contents should be avoided.

The quantity of water required will vary with the texture of the soil and increase as the quantity of fine grain soils in the mixture increases. Water to be added to pulverized and mixed soil and cement for a square yard of six inch compacted soil-cement varies from about five gallons for granular, sandy soils to about eight gallons for silty and clayey soils[2]. Dry, windy weather may cause evaporation of water from the mixture before compaction and amount to two or more gallons per square yard.

A soil-cement mixture at optimum moisture content, when squeezed firmly will form a cast that will cling together and will moisten the hand but water cannot be squeezed out of the mixture.

For sandy soil-cement mixtures, moisture contents at the optimum for maximum density are ideal for durability and strength; but for silty soils and clay soils slightly more than the optimum quantity is needed.

The maximum density as indicated by the standard test produces a soil-cement having satisfactory durability and compressive strength. An increase or slight decrease in density above or below standard maximum density for sandy soil-cement mixtures is not particularly beneficial or detrimental. An increase in density is definitely beneficial and a decrease is detrimental for silty or clayey soil-cement mixtures.

The terms "optimum moisture content" and "maximum density" as used above in connection with compaction of the soil-cement mixture, are applicable to the conditions of the standard test only. Any variation in the compactive effort would cause a variation in the corresponding optimum moisture content and maximum density.

CHAPTER IV

EQUIPMENT REQUIREMENTS

The type and size of required equipment will depend on the construction method to be used and on the size of the job. Bigger jobs will need more equipment. In this chapter, is listed the minimum construction equipment necessary to achieve average daily production. The list of field testing equipment is adequate to furnish a field laboratory to conduct the field control tests.

Construction Equipment

The following list covers minimum construction equipment requirements to achieve an average from 1,000 to 1,500 linear feet or 22-feet roadway, 2,400 to 3,700 square yards, 6 inches thick per 10-hour day. Experienced crews can exceed these averages. Additional equipment will permit increased daily production and small projects may be built with less equipment[6].

1 - subgrade rooter (adjustable scarifier on power grader will reduce equipment needs)

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

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

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

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

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

1 - 1,000-gal. pressure distributor for water. (Minimum water-spreading requirements 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 appropriate valves 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).

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

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

2 - double-drum sheepsfoot roller, types to be dictated by soil conditions. Range of foot pressures to be approximately:

Sandy soils, specify unit pressures of 50 to 100 lb. 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 lb. per sq. in. with tamping feet of approximately 7-sq. in. area.

Heavy clays and soils containing considerable aggregate, specify unit pressures of 200 to 400 lb. per sq. in. with tamping feet of 5 to 6-sq. in. area.

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

1 - Broom drag, optional. Helpful on finishing surface on some soils.

1 - Roadmixer which can be used instead of disc harrow, spring-tooth cultivators, heavy duty gang plow, pressure distributor, and spike tooth harrow.

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

Field Testing Equipment for Soils Engineer

The soils engineer must be well equipped to perform properly the field tests required to control moisture and density. These field control tests are fundamentally important and should not be neglected[6]. The following items will equip a field laboratory adequately. Each item is important and fills a definite need on the job.

1. Portable shed, 5 x 7 ft. (converted trailer makes an excellent field laboratory)
2. Plumber's furnace or equivalent
3. Split Proctor mold and rammer
4. Harvard balance with weights or equivalent
5. Torsion balance with weights, 15-lb. capacity or equivalent
6. Set sieves, 1-in., 1/2-in., Nos. 4, 5, 10, 60, 100, 200
7. Field density determination apparatus
8. 3-in. dia. soil auger
9. Quantity of sand of known dry weight per cu. ft.
10. 2-in. paint brush
11. Hammer and 1-in. carpenter's chisel
12. Dozen tin pie plates or 1/2-gal. syrup pails and 2-fry pans, 12" dia.
13. 100-cc. glass graduate
14. 10-in. butcher knife, 12-in. steel straightedge and 10-in. trowel

15. 12-qt. pail and two large spoons

16. Maximum and minimum thermometer

17. Wet and dry bulb thermometer with relative humidity chart

18. Slide rule

19. Ruler

20. 50-ft. metallic tape and 100-ft. chalk line

21. Job notebook, graph paper, scratch pad, pencils, etc.

Check of Construction Equipment

As the equipment arrives on the job, it is checked in detail to be sure it is in good operating condition and conforms to construction requirements for the job. Careful attention to all details before the job starts will prevent costly delays during construction.

All the tractors should be in A-1 condition and one should be equipped with street plates. The tractor equipped with street plates is used in final finishing operations where it is necessary to operate over the compacted roadway and the street plates protect the surface from the tearing action of the tractor cleats.

A careful check of the pressure distributor and feeder tanks should cover not only their operating condition, but also the ability of the equipment to deliver water to the project at an average rate of not less than 100 gallons per minute during water-spreading operations[6]. Check the motors, pumps and driving mechanism. In case a bituminous pressure distributor is used, it should be flushed with cold water and valves and spray bars cleaned as needed for full operation.

The water supply will need critical checking for purity and to insure an adequate supply, and the water pumps will likewise need a preliminary run to insure satisfactory operation.

The size of feet on the sheepsfoot rollers and the unit pressures on the feet with the rollers empty and filled should be checked to determine if the job requirements are met. Most projects require tamping rollers equipped with a sheepsfoot having an area of about 7 square inches which can be loaded to give unit pressures varying from 100 to 200 or 250 lb. per sq. in. The water-tightness of the rollers should be checked by filling with water.

Under normal operating conditions, one double-drum sheepsfoot roller can compact about 300 linear feet of 20-ft. roadway for a 6-in. depth in about one hour. Sufficient rollers should be brought to the job to compact the maximum day's run in about two hours. With an average production of about one-quarter mile per day, two double-drum sheepsfoot rollers should be provided on the job.

Storage of at least one day's cement requirements should be provided and cement shipments planned. Plans should also be made for hauling the cement to the job to reduce time losses to a minimum. In many cases, the cement will be hauled to the job early the day of processing. Cement can sometimes be stored in piles along the road to good advantage. In any case, a definite routine should be decided upon and the crew advised of this routine.

Offset disc harrows leave the roadway in a level, uniform condition. They are generally designed with the rear row of discs moving material to the left of the direction of travel. Each left rear cutting disc should be removed and a steel baffle or guard plate mounted on the outside of the frame to hold material in the roadway. A harrow so equipped can be pulled near the edge of treatment repeatedly without throwing substantial amounts of material onto the shoulder which later must be returned to the roadway by hand or with a motor patrol.

The field cultivators should have their power lift and depth-control mechanisms in smooth working order, and be of the type having rows of teeth extending wider than the wheels. This places teeth back of the cultivator and tractor wheels so they always loosen the material packed by the equipment. They should be equipped with 4 or 5-in. shovels on all but each outside tooth. Each outside tooth should be equipped with 2-in. double-pointed shovels and a steel baffle or guard plate mounted on the frame outside the 2-in. shovels to prevent these shovels throwing excessive quantities of material on the shoulder. These guards serve the same purpose as they do on the discs. Two complete sets of shovels should always be available for replacing worn shovels.

The most important items to check on the motor grader are the power unit, the blade-operating mechanism, the play in the blade-operating mechanism and the condition of the cutting blade. Since close blade control is required in final finishing operations, there should be a minimum of play in the blade-operating mechanism and a new, straight, cutting blade should be installed on the mold board before operations start.

A tandem self-propelled smooth roller should be provided. Such a unit exerts about the same unit pressures on both wheels and will leave a minimum of wheel marks. It permits laps of full roller width and can iron out a section more rapidly than a three-wheel roller which can lap only the width of the narrowest wheel. The wheels must be clean, wheel cleaners attached and in working order, and the power and clutch mechanism in smooth working order. A misfiring motor or grabbing clutch will cause shoving and rutting of the surface. A dirty wheel will pick up soil-cement and ruin the surface on succeeding revolutions. Faulty cleaners will permit material picked up occasionally to pack on the wheel and be a constant source of trouble. Unusual care should be exercised in checking the smooth roller, as it is a final finishing tool and many will judge the entire job by the surface it produces. Further, it is not generally realized that the final finishing requires skill and experience and there may not be a full appreciation of the technique of the operation. Soil-cement does iron out readily but it cannot be treated as a simple operation to be performed by the casual worker on the job.

A spike-tooth harrow works efficiently in cutting out compaction planes but should be provided with an adjustable frame to govern the angle to which the teeth incline to the roadbed. It will cause some ridging in the mulch which will be present after smooth rolling unless prevented. A uniform mulch is easily produced by a broom drag or by attaching the ends of a long chain to opposite front corners of the harrow and allowing the chain to drag on the surface behind the harrow.

It is often advantageous to fasten various pieces of equipment together in a train. Couplings on the equipment may be lacking or inadequate and several spare chains and hooks should be provided for various uses.

CHAPTER V

CONSTRUCTION METHODS

There are various methods which may be used to accomplish the work involved in soil-cement construction, any of which may produce approximately equivalent results. The operations involved and their sequence are about the same, the difference being chiefly in the amount and kinds of equipment used. One machine developed specially for the purpose will perform the scarifying, pulverizing, adding of cement and water, and mixing in a single pass, leaving only the final shaping, compacting and finishing to be done as separate operations. Other machines will pick up the pulverized soil with the cement spread over it, perform the mixing and deposit the mixed material behind it ready for shaping, compacting and finishing. Although the use of such machines is increasing, the methods described below probably represent the most prevalent practice and are indicative of the several separate processes involved in performing the work[1].

Initial Preparation

Prior to the initiation of actual construction operations on a soil-cement stabilization project the subgrade should be carefully constructed to exact crown, grade, profile and superelevation. Any deviations should be corrected with particular care, as the final contour of the finished roadway will conform very closely to the crown, grade and cross-section of the subgrade.

After the subgrade has been brought to the required section it is important that rigid control be maintained of grade, crown and depth of treatment, and to insure that the scarifying operations are carried to the full width.

Pulverization

In general, this operation should start by scarifying a sufficient length for two days of processing. No more work should be opened up at a time than can be handled with the available organization. The scarifier teeth should be adjusted to scarify within one-half inch of the depth to be treated. The remaining one-half inch of depth will be obtained during pulverizing and mixing operations. The depth of adjustment is extremely important and should be made with care and precision. In order to control better the depth, the wheels of scarifying equipment should be kept on the undisturbed roadway to the extent that it is practicable to do so.

Pulverization of the soil is very essential in order that there may be an intimate mixture of the soil, cement and water. This may well be done by the use of offset disc harrows, rotary tillers, spring tooth cultivators, or other similar equipment. Care should be exercised to prevent longitudinal shifting of material.

In general, the pulverizing process should continue until at least 80 per cent of the soil, exclusive of stone and gravel, will pass a standard No. 4 sieve. Many soils which are difficult to pulverize in their natural state may be made mellow and capable of ready pulverization by pre-wetting to permit absorption of water. The amount of water needed to accomplish best results in the pulverizing process will vary according to the type of soil but should not be more than necessary to make the moisture content approximately equal to the optimum needed for mixing and compacting. As the clay content of the soil increases, closer control of the moisture content at the time of pulverizing is necessary. When the heavier soils have moisture contents near shrinkage limit they may shrink together so tightly and hard that pulverizing is slow and difficult. When the moisture content is near or above the plastic limit they cut readily but pack together again.

Water should be added consistently in advance of the pulverizing operations, preferably at least twenty-four hours, so that it will have ample time to soak into the lumps and soften them. It is desirable to apply most of the necessary water well in advance to reduce the work involved and time required for processing the soil and water to uniformity just before the cement is spread.

When pulverizing is about one-half completed good results may be obtained by the use of a three or four-bottom gang plow, adjusted for proper depth control which, starting near the center, throws the material toward the center, covering and turning the entire section. This brings up the bottom lumps for pulverization and establishes clean-cut edges to the full depth. These operations should be continued until all material has been pulverized to the required depth. Excess depth must be avoided.

During the rainy season, the builder may find it economical to have a supply of canvas or waterproof paper on hand to cover the pulverized soil and protect it from rains[6]. This cover should extend onto the shoulder for two feet on each side to help prevent water running from the shoulder onto the pulverized roadway.

During the summer construction months, there is no great danger of the pulverized material or the subgrade getting too wet. It is common practice to add the equivalent of an inch to an inch and a half or more of rain during processing. Obviously, a fast heavy rain must fall to equal this amount. However, a construction routine should be established which will safeguard the pulverized soil from the occasional heavy rain. Sandy soils should be left spread out uniformly. They will then absorb any rain and protect the subgrade from becoming wet. If the subgrade becomes wet, it is too soft to pack on and is difficult to dry out. On the other hand, the pulverized sandy soil dries readily. On clay loam and clayey projects, the pulverized soil should be windrowed in the center to produce a trench about a foot wide and six inches deep on each side. All low places in the grade, where water would accumulate, should be located and a trench dug through the shoulder to drain out any water collecting in the low place. Daily attention to this routine will safeguard pulverized soil from storms effectively during the normal construction season.

In general, pulverizing operations should be planned so that no more roadway is pulverized ahead of construction than can be processed in two days.

Spreading Cement

Prior to the spreading of cement, samples of raw materials should be tested for moisture content to indicate the minimum quantities of water to be added[1]. These moisture tests enable fairly close estimates to be made of total quantities of water required for optimum moisture content.

Before spreading begins the area to be treated should be bladed to a smooth surface. The cement may then be spread over it by mechanical spreading machines or by spotting the sacks of cement at the desired spacing on the pulverized soil and then dumping and spreading the cement by hand labor. Care should be exercised to see that the bags of cement are spotted accurately at the proper intervals both transversely and longitudinally. When the bags are opened the cement should be dumped so that it forms a uniform transverse windrow across the area being processed. It is desirable that a spike-tooth harrow or nail drag make at least two round trips to spread the cement uniformly.

Mixing Soil and Cement-Road-Mix Method

As soon as cement spreading is completed the mixing of the soil and cement should be started using field cultivators and rotary tillers. Tentative depth adjustments should be made and watched closely during mixing[1]. As mixing progresses the mixture becomes lighter, permitting cultivator wheels and rotary tillers to work deeper into the roadway, and depth adjustment must be made to compensate for this difference. Men should be stationed at the turn-around areas to level the ends and shovel out any raw soil dragged in by equipment. All equipment which has a tendency to displace the material either laterally or longitudinally should make a return trip in the opposite direction over the same ground to replace the material in approximately its original position. When the entire roadway has been covered by cultivators and tillers and when cement has been incorporated with the soil, a gang plow should be used to turn up the bottom material and speed the mixing. The plow should be started in the center, casting the mixture toward the center and working out to the edges. The second plowing should be reversed, starting near edges and casting the mixture away from center. The depth of plowing should be very carefully controlled.

Mixing should be continued until a uniform color is obtained from top to bottom of the mix. When dry mixing is nearly completed, samples should be taken for moisture content determination and estimate of total water required to be added to the mixture.

Water Application and Damp Mix-Road-Mix Method

The same equipment, such as cultivators, harrows, plows and rotary tillers, may be used in wet mixing as in dry mixing with the exception of pressure distributors for water. Water spreading should extend to and include about 5 feet of turn-around cover on one end, and 5 feet beyond the end of the cement spread on the other end[1].

Each application of water should be followed immediately by mixing operations with the field cultivators and rotary tillers. On steep grades, the loss of water may be minimized by running a spike-tooth harrow immediately behind the water distributor in the train with the tillers and cultivators.

Water should be added in as large increments as the equipment and soil will permit. One gallon of water per square yard per application can be handled with most soils. As the moisture content approaches the optimum, the application should be reduced to one-half gallon, or slightly less, per square yard. Representative samples of the full depth of mixed material should be taken and moisture-density tests made to determine the field optimum moisture content of the mixture during the application of water and in time to determine the total amount of water required to be added. It is usually better to get a little too much water in the mix rather than not enough.

Soil-cement, when at optimum moisture content, is not mushy, muddy or wet like freshly mixed concrete, but generally is just moist enough to moisten the hands and pack in the hands to form a reasonably light cast.

Care must be exercised to avoid getting the section so wet that the rollers will not pack out. Since a uniform moisture content is required for the full roadway width, and water is applied at a uniform rate for the full width, it is essential that the depth of soil-cement be uniform; otherwise a nonuniform moisture content will result and show up as "dry streaks". Dry streaks are generally produced by lack of uniformity in depth of treated material, or by plugged holes in the spray bars.

The gang plows should be used to turn mixture as in dry mixing, trenches should be cut to check distribution, and edges should be given close attention. The water added should be sufficient to bring the mixture to or slightly above the optimum moisture content, as this will permit some evaporation loss during packing.

Mixing Soil and Cement-Traveler Mixer Method

Several kinds of traveling mixing plants are adaptable to the processing of soil-cement. Some types make it necessary for the pulverization of soil to be performed in an operation ahead of the mixing, in which case the methods and procedures previously outlined apply. Satisfactory results have been obtained through the use of traveling plants where the pulverizing, blending and mixing operations are done in a single pass of the machine(1). This machine consists essentially of a specially designed high-speed cutting rotor which is regulated to cut to a predetermined depth, and which pulverizes the soil and disperses the cement and moisture in a single operation.

The most important and fundamental requirements for satisfactory results in this type of construction are accurate control of processed depth, uniform blending of materials, proper dispersement of liquid through entire quantity, and uniform coating of mixed materials.

When operations are begun they proceed slowly and frequent depth measurements should be made to check the accuracy of the depth-ratchet settings of the machine. If the depth is in error the cement content and the water content will also be in error.

Water Application-Traveler Mixer Method

In soil stabilization work, moisture control is the key to density and the moisture should be evenly distributed in the mix from top to bottom and should be closely controlled as to quantity until the base is tamped and finished. The water supply in the traveler mixer method usually comes from a water truck that keeps pace with the machine, feeding the liquid through a hose into the water-gauge mechanism where it is dispersed through pugmill agitation. Further checks of moisture in clay balls should be made at time of compaction to be sure they are damp and near optimum, since dry clay balls packed into the mass will absorb moisture later and rupture the completed work.

Since about two per cent of the moisture of raw material is lost through the action of wind, temperature conditions, and mixing with cement, the ultimate moisture should be optimum plus two per cent. This is usually acquired by proceeding with less and adding the deficiency through the water-feeding mechanism of the machine. Care must be exercised to avoid getting the section so wet that the rollers will not pack out.

Shaping and Compacting

When the water application has been completed, compaction should be started with sheepsfoot rollers beginning at the edges and working toward the center. It is beneficial for the sheepsfoot rollers to be hooked off center to the tractors so that the tractor tread will pack the very edge of the soil-cement mixture. This also aids in obtaining uniform compaction because as the direction of rolling is reversed, the tractor travels in a different track each time. It is essential that sufficient water be added during mixing operations to keep the moisture content at optimum or slightly above during the entire compaction operation.

When the rollers have compacted about two-thirds of the depth of the layer, the preliminary shaping should be completed with motor graders. The rollers should operate with the motor grader and if areas of deep mulch develops, the rollers should concentrate on these areas until a mulch of uniform depth is obtained. A uniform mulch at proper grade at this stage of operation will be a major factor in reducing final shaping and finishing.

After preliminary shaping, the sheepsfoot rollers should continue packing operations until about one inch of loose mulch remains. They should then be removed from the section and the motor grader used to give the section its final shape. During this interval, it may be necessary to add a small amount of water to replenish evaporation losses. Very sandy soils which offer little resistance to compaction cannot be compacted satisfactorily with sheepsfoot rollers but can generally be satisfactorily compacted by using pneumatic-tired equipment instead.

The sheepsfoot rollers and the wheels of the motor patrol leave smooth, damp compaction planes on their last trips over the section. It is difficult to knit a thin layer of soil-cement onto these areas firmly enough to prevent later raveling, therefore, these compaction planes must be removed after final shaping and before final smooth rolling begins. This is achieved quickly and easily by pulling the spike-tooth harrow, nail drag or weeder over the section. It should be pulled by a tractor equipped with street plates or by a pneumatic-tired farm tractor. The teeth of the harrow should be set to penetrate just below the compaction planes. Small ridges and furrows left by the harrow or nail drag may be removed by a drag broom or a heavy chain looped behind the harrow from each forward outside corner. Broom drags are especially useful on stony soils.

At this stage it is generally desirable to use pneumatic-tired rollers on the section to give the loose mulch initial compaction. This operation is absolutely necessary if the soil is quite sandy and the sheepsfoot roller has left a deep mulch. After this initial pneumatic-tire rolling, the section should be bladed again to final grade and section. During this final blading sticks or small stones may catch under the blade and cause ruts in the top. These should be removed and ruts filled immediately with processed material. The smooth rolling should then be started at one edge rolling to the center, then begin on the opposite edge and again roll to the center. Usually two or three times over with the smooth roller will be sufficient. It is imperative that the surface mulch be maintained in a moist condition during the final finishing operation; therefore, a very light application of water and a light rolling with pneumatic-tired roller may be used to give the surface a light texture.

Construction Joints and Turn-Arounds

Considerable care should be exercised in construction of joints and turn-arounds to prevent damaging the previously completed section and to assure continuity of properly prepared soil-cement mixture of uniform depth. Regardless of what processing method is used, the section mixed, shaped and compacted in a single working period should end in a completed section extending the full width of the proposed course with a section ahead scarified and pulverized ready for mixing during the next working period. At the end of each completed section a trench approximately 12 inches wide should be cut across the processed soil-cement for the full depth of the treatment and perpendicular to the centerline of the road. The side adjacent to the completed work should be cut vertical and straight. The subsequent steps vary according to the processing method used.

When the traveling mixing plant method is used the plant begins its operations in this trench as the mixed material is deposited behind the machine. Some supplemental hand work may be necessary to properly distribute and shape the material at the joint.

When the road-mix method is used a rather involved series of operations is required at the construction joints. Several methods have been used successfully, one of which is described below:

As soon as the trench has been excavated at the end of the completed section, two square timbers, each equal in length to half the width of the treatment and in the thickness to the depth of the treatment, should be laid against the vertical face of the trench to serve as headers to protect the square edge of the joint. The remainder of the trench should then be backfilled with loose material temporarily.

After the cement has been spread and processing begun on the next section the following working period, the material next to the headers should be pushed ahead about 10 or 15 feet over the top of the adjacent material where it will be mixed as the processing equipment turns in it. The 10 to 15-foot length of subgrade thus exposed should then be trimmed to true section. A layer of heavy building paper should next be laid over approximately 3 feet of the exposed subgrade, up over the headers and extending back over the previously completed section about 25 to 30 feet. The paper on top of the completed section should then be covered with earth for a sufficient depth to prevent damage to the soil-cement underneath when equipment turns on the earth cover.

As soon as the turn-around has been completed the soil and cement previously pushed ahead should be pushed back over the exposed subgrade to the headers and the processing continued with the equipment using the prepared turn-around. After the dry mixing of the soil and cement has been done and the damp mixing has been partially completed, the headers should be cleaned off and the adjacent material again pushed ahead temporarily. The paper should then be cut off just below the forward edge of the headers and the 3-foot strip on the subgrade should be entirely removed.

The exposed subgrade should then be trimmed to true section again and the material which was pushed ahead be replaced on the subgrade. The flap of paper over the headers should then be folded back over the turn-around cover, the headers should be removed and the space they occupied filled with soil-cement mixture by hand shoveling. At the joint the mixture should be built up about two inches higher on the new section than it is on the completed section in order to provide ample material for cutting a smooth joint after the earth cover has been removed.

The mixing and compacting of the new section should then be completed after which the earth cover should be removed from the previously completed section and the joint trimmed and compacted. Most of the earth cover may be removed with a motor grader but care should be taken not to tear the paper and to leave a thin layer of earth on the paper. To avoid damage by equipment to the soil-cement underneath the earth cover, the paper and the small amount of earth cover remaining should then be peeled off by hand.

The paper laid on the subgrade prior to replacing the dry mix acts as a parting plane between the subgrade and the dry mix and enables the same true bottom to be obtained after the water spread as before. If it were not for this procedure the subgrade might be somewhat irregular and the thickness of soil-cement mixture variable next to the joint because of the movements of the processing equipment in turning and in pulling up onto the earth turn-around cover. The paper also serves as a parting plane between the earth turn-around cover and the completed soil-cement underneath. The flap which is folded back over the turn-around cover when the headers are removed prevents any intermixing of raw soil and the soil-cement being processed.

Control of Operations

For best results from the standpoints of economy and quality of work produced, the various mixing, watering, compacting and finishing operations should be well organized so that all are in progress simultaneously and the various equipment units follow one another in a train-like formation[1]. To complete each operation separately over the entire area before the next is started would cause unnecessary and costly delays and might consume so much time that the cement would begin to set up before the manipulation is completed.

As the equipment units move over the roadbed in the mixing process there will be a tendency to drag some of the cement and soil forward. This migration can be overcome by making each alternate pass over the same strip in the opposite direction.

It is essential that the various phases of the construction operations follow one another in quick succession. If the soil is pulverized and water added very far in advance of the mixing operations, the soil may re-compact or the particles re-combine into hard lumps and the moisture content may change considerably so that the work will have to be repeated. If cement is spread over a greater length of roadbed than can be processed within a few hours, the water reaching it from the soil or as rain may cause it to set before being properly mixed. For this reason no part of the work should proceed faster than the subsequent operations can be completed and the spreading of cement should be limited to the length of roadbed that can be completed, preferably including placing of a curing cover, within the same working period.

Density and Depth Checks

It is important that field density checks be made the next day after construction in order that any necessary corrections may be made in compaction equipment and procedure without undue delay. In addition to the depth or thickness information obtained through holes dug in the completed base for density tests, the edges of the completed pavement should be exposed at frequent intervals to obtain additional information on thickness.

Surface Protection

As soon as the final rolling is completed, and in no case later than the morning following the final finishing, a protective cover should be placed over the entire section to prevent surface evaporation and moisture losses in the soil-cement mixture during the hydration and curing period. The protective cover may be of wet canvas, burlap, straw, hay or other satisfactory material. Wetted earth should not be used for this purpose as it may form a bond with the base course.

As the completed section is to serve only as a base course, bituminous surface treatment or some other type of wearing course is necessary to withstand the abrasive action of traffic. When some type of bituminous treatment is to follow immediately after completion of the base course, satisfactory results have been obtained by covering the base with a prime coat of about 0.2 gal. per sq. yd. on the day following the final finishing and rolling. The type of asphalt or tar used in the prime coat and the rate of application will vary according to the particular job conditions but special consideration should be given to the harmful effect if the priming material penetrates to any considerable depth into the stabilized base. This penetration can be prevented by first applying water to the completed section in sufficient quantity to fill surface voids and to allow for some surface run-off. The bituminous material should then be applied immediately after free water disappears from the surface. This is followed by a seal coat of about 0.3 gal. of bituminous material and 25 lb. of chips per sq. yd.

CHAPTER VI

MAINTENANCE

In those areas where the soil-cement roadway fails, due to poor subgrade or excessive local loadings, the broken material should be removed from the roadway. The space thus made available should be cleaned out to a depth of 6 to 8 inches and filled with a soil-cement mixture of the same cement content, moisture content and density as originally used on the roadway(6). In many cases it will be practical to use a small concrete mixer, soil from the shoulder, with appropriate quantities of cement, and the material can be compacted from the bottom up to the required density with a hand-made rammer.

When a bituminous surface wears down to the soil-cement under normal usage, it should be replaced with a similar seal coat. In case the seal coat shoves and ruts and peels loose from the soil-cement, due to no failure of the grade or inadequacy of bituminous material used, it should be removed from the soil-cement, the soil-cement carefully cleaned down to hardened material, and the seal replaced in the usual manner.

In case the bituminous surface shoves, ruts or peels due to improper quantity of aggregate or bituminous material, it will be repaired in the same manner as such defects are repaired on bituminous roads.

CHAPTER VII

Specification

The following specifications for soil-cement roadways cover a construction procedure which has given excellent field results. Each project should be supervised by an engineer who has familiarized himself with available construction and laboratory data[6].

Item 206 - Soil-Cement Base Course

206 - 1.1 This item shall consist of a foundation or base course of soil and portland cement uniformly mixed, moistened and compacted in accordance with this specification, and shaped to conform to the lines, grades, thicknesses and typical cross-section shown on the plans. Construction shall proceed as follows:

a) The soil in the roadway shall be pulverized for the necessary depth and the full width to be treated with cement.

b) Portland cement shall be uniformly spread and mixed with the pulverized soil.

c) Water shall be added as needed with a pressure distributor and shall be uniformly incorporated in the mixture in the amounts required to attain the optimum moisture content specified by the Engineer for the soil-cement mixture.

d) The mixture shall be compacted uniformly with sheepsfoot rollers in one continuous operation from the bottom of treatment to the surface. The mixture shall be compacted at the optimum moisture content and to the density specified by the Engineer.

e) After compaction is completed with the sheepsfoot rollers, the surface shall be shaped, and then finished with a smooth-wheeled roller.

The equipment used shall be in suitable operating condition and approved by the Engineer. Equipment not satisfactory to the Engineer shall be removed and satisfactory equipment supplied.

Materials

206 - 2.1 CEMENT: Cement shall conform to all requirements of ASTM Standard Specifications for Portland Cement C-150 or AASHO Specification M-85[7]. Only Type I cement shall be used unless otherwise designated on the plans or provided by Special Provisions. Different brands of cement, or the same brand of cement from different mills shall not be mixed during use, nor shall they be used alternately unless the mix has been approved. The contractor shall provide suitable means for storing and protecting the cement from dampness. Bags of cement, which for any reason have become partially set or which contain lumps of caked cement, shall be rejected. The use of cement salvaged from discarded or

used bags will not be permitted. One (1) cubic foot of portland cement shall be considered as weighing ninety-four (94) pounds.

Contractors, at their option, may use bulk cement, provided the apparatus for handling, weighing and spreading the cement is approved by the Engineer in writing.

206 - 2.2 WATER SUPPLY: Before construction is started, the Contractor shall develop a good and sufficient supply of water and have it available throughout the work[7]. The supply shall be adequate to furnish water for all purposes for which water is needed as hereinafter specified.

The water used in the construction of this base course shall be free from salt, oil, acid, organic matter or other deleterious substances and shall be subject to the approval of the Engineer.

Full compensation for furnishing all material, labor, and supplies and all incidental work necessary to deliver an adequate supply of water in compliance with the intent of these Specifications shall be paid for at the contract unit price per M. L. (1000 liters).

206 - 2.3 SOIL: The soil for this roadway shall consist of the natural material in the roadway or selected soil which shall be approved by the Engineer. It shall have a liquid limit not exceeding 40 per cent and a plasticity index not exceeding 18 per cent. More than 50 per cent of the soil material shall pass the 1/4-in. sieve and more than 15 per cent the No. 40 sieve; but not more than 50 per cent shall pass the No. 200 sieve.

Construction Methods

206 - 3.1 PREPARATION OF THE EXISTING ROADWAY: Before undertaking other construction operations, the existing roadway, including shoulders and ditches so directed by the Engineer, shall be scarified, bladed, or otherwise shaped to conform with the lines, grades, and cross-section shown on the plans or staked by the Engineer. Any high places in the roadbed shall be cut to grade and the resulting material hauled and deposited on low areas or on fill slopes as directed by the Engineer. Should there remain any depressions or narrow embankments, sufficient approved material shall be obtained and placed to bring the surface of the roadway to the exact lines, grades, and cross-section established.

206 - 3.2 PULVERIZING: Prior to the application of cement, the soil to be treated shall be scarified and pulverized for sufficient width and depth to give the compacted cross-section shown on the plans.[6]. Pulverizing shall continue until eighty per cent (80%) of the soil, by dry weight, exclusive of gravel or stone, shall pass a No. 4 sieve, and the soil shall be manipulated until the percentage of moisture in the soil does not exceed by more than two (2) the percentage of moisture specified by the Engineer for the soil-cement mixture before compaction. The length of roadway scarified and pulverized at any time shall not exceed the length which can be completed in accordance with this specification in two (2) working days except by special permission of the Engineer.

206 - 3.3 APPLICATION OF CEMENT: The pulverized soil shall be shaped to the approximate cross-section on the plans and the specified quantity of portland cement required for the full depth of treatment shall be uniformly spread over the surface in one operation in a manner satisfactory to the Engineer. No equipment, except that used in spreading and mixing, will be allowed to pass over the freshly spread cement until it is mixed with the soil.

206 - 3.4 MIXING: Immediately after the cement has been distributed it shall be mixed with the loose soil for the full depth of treatment as shown on the plans. Care must be exercised that no cement is mixed below the desired depth. Mixing may be accomplished with field cultivators, gang plows, disc harrows or other implements approved by the Engineer and shall be continued for as long a period of time and repeated as often as may be necessary to insure a thorough, uniform and intimate mix of the soil and cement and until the resulting mixture is homogeneous and uniform in appearance. The mixture shall then be shaped to the approximate lines and grades shown on the plans.

206 - 3.5 APPLICATION OF WATER: Immediately after mixing of soil and cement is complete, the moisture content of the soil-cement mixture shall be determined by the Engineer and, if required, water shall be uniformly applied in such quantities and at such a rate as directed by the Engineer. A water supply and pressure-distributing equipment shall be provided which will permit the continuous

application of all water required on the section of roadway being processed within three (3) hours. Each application or increment of water shall be partially incorporated by field cultivators, gang plows, disc harrows or other implements approved by the Engineer. This equipment shall be of sufficient size and capacity to distribute the moisture uniformly throughout the full depth of the mixture in one (1) operation. Particular care shall be exercised to insure satisfactory moisture distribution along the edges of the section. When water spreading and mixing is completed, the percentage of moisture in the mixture, on a basis of dry weight, shall not vary from the specified optimum percentage of moisture of the mixture by more than ten per cent (10%). This specified optimum moisture shall be determined in the field by a moisture-density test on representative samples of soil-cement mixture obtained from the roadway.

206 - 3.6 COMPACTION: Prior to the beginning of compaction, and as continuation of mixing operations, the mixture shall be thoroughly loosened for its full depth and then shall be uniformly compacted with a sheepsfoot roller. Compaction shall begin at the bottom and shall continue until the entire depth of soil-cement mixture is uniformly compacted to the density specified by the Engineer. This specified density shall be determined in the field by a moisture-density test on representative

samples of soil-cement obtained from the roadway. The sheepsfoot roller shall be of the size, shape, and weight specified by the Engineer as best suited to give the required densities in the soil-cement mixture being compacted. The rate of operation and number of rollers shall be sufficient to compact uniformly the section of roadway being processed for the specified width and depth within two (2) hours.

After the mixture is compacted, the surface of the treated roadway shall be reshaped to the required lines, grades and cross-sections and then shall be lightly scarified to loosen any imprints left by the compacting or shaping equipment, until a surface mulch of not more than one inch in thickness is obtained. The resulting surface then shall be thoroughly rolled with a smooth-wheel tandem roller of the size specified by the Engineer. Preliminary pneumatic-tire rolling will be permitted. The rolling shall be done in such a manner as to produce a smooth, closely-knit surface, free of cracks, ridges or loose material, conforming to the crown, grade and line shown on the plans.

206 - 3.7 CURING AND PROTECTION OF SOIL-CEMENT: After the roadway has been finished as specified herein, it shall be protected against rapid drying for a period of seven (7) days by applying a two (2) inch covering of earth, not less than two (2) kilos of straw or hay per square meter or other materials approved by the Engineer, which will be moistened initially and subsequently as may be necessary. This protection shall be omitted only upon written approval of the Engineer.

Any finished portion of the roadway adjacent to construction which is traveled by equipment used in constructing an adjoining section shall be continuously covered with at least six (6) inches of earth to prevent equipment from marring the surface of the completed work.

The Contractor shall erect and maintain suitable barricades and (when so indicated in the special provisions) shall employ watchmen to exclude traffic from the newly constructed roadway for the period herein prescribed, and these barriers shall be so arranged as not, in any way, to interfere with or impede public traffic on any lane intended to be kept open, and necessary signs and lights shall be maintained by the Contractor, clearly indicating any lanes open to the public[7]. Where, as shown on the plans or indicated in the special provisions, it is necessary to provide traffic across the roadway, the Contractor shall at his expense, construct suitable and substantial crossings to bridge over the soil-cement. Such crossings, as constructed, shall be adequate for the traffic and satisfactory to the Engineer.

Any part of the soil-cement base course damaged by traffic or other causes prior to its final acceptance shall be repaired or replaced by and at the expense of the Contractor in a manner satisfactory to the Engineer. The Contractor shall protect the soil-cement base course against both public traffic and the traffic caused by his own employees and agents.

206 - 3.8 ALTERNATE METHOD OF CONSTRUCTION: If approved by the Engineer in writing, a machine or combination of machines which will do the work of pulverizing the soil, spreading cement or water, mixing the materials, or compacting and finishing the mixture may be used in lieu of the method specified herein(6). Machines for mixing soil, cement and water should preferably be of a type which will mix the material progressively for the entire width of roadway. When a machine is used, precaution must be exercised to obtain the specified depth and straight longitudinal edges conforming to the crown and grade specified on the plans with all materials adjacent to the edges compacted to the same density as the remainder of the roadway. When the machine will handle only part of the roadway width, it shall work forward with successive increments so the roadway may be compacted and finished for full width in one operation. In any event, when machine mixing is used, the resulting soil-cement mixture shall be compacted at the optimum moisture content specified by the Engineer before there is any appreciable moisture loss and the compaction operation shall be a continuation of the mixing operation in such a manner that the moistened soil-cement mixture does not remain undisturbed after mixing and before compacting for more than thirty (30) minutes.

206 - 3.9 CONSTRUCTION LIMITATIONS: Cement shall be applied only to such an area that all the operations specified in Paragraphs 3.3 to 3.6, inclusive, can be

continuous, and all but final surface finish completed within six (6) hours after the beginning of water application to the thoroughly mixed soil-cement. No cement shall be applied when the percentage of moisture in the soil in the subgrade immediately beneath the pulverized material exceeds the optimum moisture content specified by the Engineer for that particular soil or when the percentage of moisture in the pulverized soil exceeds the optimum moisture of the soil-cement mixture by more than two (2). When any of the operations after the application of cement are interrupted for more than two (2) hours for any reason, or when the uncompacted soil-cement mixture is wetted by rain so that the average moisture content exceeds the tolerance given in Paragraph 3.5, the entire section shall be reconstructed in accordance with this specification.

206 - 3.10 DENSITY AND THICKNESS DETERMINATION: The density of the soil-cement base course shall be determined by the Engineer after each day's construction. Any portion which has a density of two (2) kilos or more below that specified by the Engineer shall be removed and replaced to meet this specification.

The thickness of the soil-cement base course shall be determined from measurements of cores drilled from the finished base course or from thickness measurements at holes drilled in the finished base course at intervals not to exceed one-hundred fifty (150) meters. The average thickness of base course constructed during one (1) day shall be within one-half (1/2) inch of the thickness shown on the plans, except that the thickness at any one place may be within three-quarters (3/4) of an inch of that shown on the plans. Where the average thickness shown by the measurements made in one (1) day's construction is not within the tolerances given above, the Contractor will be required to reconstruct this day's work at his own expense.

206 - 3.11 PROTECTION FROM RAIN: No cement shall be applied during rainy weather.

206 - 3.12 OPENING TO TRAFFIC: The Contractor will not be permitted to drive heavy equipment over completed portions, but pneumatic-tired equipment required for hauling cement and water and for shaping the section may be permitted after the surface has hardened sufficiently to prevent the equipment marring the surface, provided protection and cover specified in Paragraph 3.7 are not impaired[6]. Completed portions may be opened to traffic after the seven (7) day's protection specified in Paragraph 3.7, provided the surface has hardened sufficiently to prevent marring of the surface by traffic.

Method of Measurements

206 - 4.1 The area to be paid for under this item shall be the number of square meters of soil-cement base course completed and accepted as measured complete in place. The width for measurement will be the width from outside edge to outside edge of completed base course, as placed

in accordance with the plans or as otherwise required by the Engineer in writing. The length will be the actual length measured along the center line of the surface. No allowance will be made for any work done outside the lines established by the Engineer.

206 - 4.2 Water applied shall be measured by the 1,000 liter units in tanks or tank trucks of known capacity, or by means of meters of an approved type, furnished and installed by the Contractor at his own expense.

206 - 4.3 Cement to be paid for shall be the number of barrels specified by the Engineer for incorporation in the roadway.

206 - 4.4. The volume of earth to be paid for moved in accordance with Paragraph 3.1 shall be the number of cubic meters measured in original position and computed by average end area method.

The measurement shall not include the volume of any subgrade material or road metalling found in the roadbed and merely scarified in site and later replaced in the improvement entirely by road mixing or similar in site methods or operations.

Basis of Payment

206 - 5.1 The quantity, measured as provided above in 4.1, shall be paid for at the contract unit price per square meter bid for soil-cement base course, which price and payment shall be full compensation for scarifying and pulverizing the roadway, for handling, hauling and

spreading cement, mixing the cement with the pulverized soil, mixing the water with the soil-cement mixture, compacting the mixture, surface finishing, placing protective cover on the roadway, including all costs of labor, equipment, supplies and all other items covered by this specification except for those items on which separate contract unit prices are required.

206 - 5.2 The accepted quantity of water, measured as provided above in 4.2 shall be paid for at the contract unit price per M. L. (1000 liters), which price and payment shall be full compensation for providing and spreading on the roadway the water required to produce the moisture content specified for the soil-cement mixture and for wetting the protective cover on the completed base course. This price shall not include any costs incurred in mixing the water with the soil and cement.

206 - 5.3 The accepted quantity of cement, measured as provided above in 4.3, shall be paid for at the contract unit price per barrel of cement, which price shall include the price of cement delivered. Payment shall be made only for cement actually incorporated in the completed work.

206 - 5.4 The volume of earth, measured as provided above in 4.4, shall be paid for at the contract unit price per cubic meter, which price and payment shall constitute full compensation for the removal of any undesirable material from the roadway or the addition of earth required in the roadway in accordance with Paragraph 3.1.

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Name: Milagros C. Hernandez Date of Degree: May 26, 1957

Institution: Oklahoma A & M College Location: Stillwater, Okla.

Title of Study: SOIL-CEMENT BASE COURSE

Pages in Study: 69 Candidate for Degree of Master of Science

Major Field: Civil Engineering

Scope of Study: Soil-cement was first used in road construction in the U.S.A. in 1935 and since then has been used on an increasing scale. The ways in which soil-cement may be used successfully is treated in this study. The structure and factors influencing the physical properties of soil-cement mixtures are discussed as well as sampling and testing of the raw or natural soil and the interpretation of the test results in connection with the design of the mixtures. Construction methods and necessary equipment to accomplish the job are also discussed. Included in this study is a specification to help project engineers in the construction procedure. Materials used are mainly the results of research studies conducted by the Highway Research Board, Portland Cement Association, American Association of State Highway Officials, and Amerian Road Builders' Association.

Findings and Conclusions: Soil type, cement content, compaction and method of mixing are the chief factors which affect the quality of soil-cement. Most soils with clay contents not exceeding about 30 per cent can be successfully processed while soils containing organic matter or deleterious chemicals are generally unsuitable. The moisture content of the processed soil affects both the uniformity of mixing and the compaction obtained. Good compaction is essential to obtain high quality soil-cement mixtures. Moisture content necessary for cement hydration and satisfactory compaction of the mixture are approximately the same and should not exceed the optimum of more than 2 per cent.

ADVISER'S APPROVAL ______________________

VITA

Milagros C. Hernandez

Candidate for the Degree of

Master of Science

Report: SOIL-CEMENT BASE COURSE

Major Field: Civil Engineering

Biographical:

Personal data: Born in Catmon, Malabon, Rizal, Philippines, January 12, 1928, the daughter of Marcelina de la Cruz and David D. Hernandez

Education: Attended elementary school in Caloocan, Rizal, and Manila, Philippines; graduated from Mapua Institute of Technology (high school department) in 1947; received the degree of Bachelor of Science in Civil Engineering from the Mapua Institute of Technology in July 1951; completed requirements for Master of Science degree in Civil Engineering in May 1957.

Professional experience: Entered the Philippine government service with the Bureau of Public Works in 1951, and is now an Assistant Civil Engineer in the Philippine Bureau of Pulic Highways.