SOIL-CEMENT DESIGN IN NORTH CAROLINA

By L. D. Hicks

Asst Engineer of Materials and Tests
North Carolina State Highway and Public Works Commission

SYNOPSIS

The determination of the amount of portland cement necessary for satisfactory stabilization of various soils is generally accomplished by submitting specimens containing mixtures of known quantities of cement and the soils to freezing and thawing and wetting and drying durability tests. Arbitrary values of maximum loss establish the quantity required.

Since the necessary amount of cement for satisfactory stabilization varies with the type of soil, it is absolutely necessary that the durability tests be made on samples that truly represent each kind of soil on a project The method of soil classification developed by the Bureau of Chemistry and Soils, which groups soils according to their origin and development, has been found to be an excellent means of identification of soils, and its use in making soil surveys and taking samples not only prevents duplication of samples, but allows the accumulation of data that can be used with confidence on future work, thereby eliminating the necessity for repeated durability tests

Soil-cement mixtures must contain sufficient moisture to hydrate the cement or their strength and durability are impaired The use of low optimum moisture values even if high densities are secured by greater compactive effort might prove detrimental. A "working optimum" which is equal to the optimum moisture of the raw soil plus two is suggested for use in the field

The use of arbitrary values of maximum loss by durability tests for the determination of the cement requirement for the stabilization of soils in all sections of the country does not seem logical In localities not subject to extremely low temperatures it would seem that only sufficient cement is needed to render plastic soils non plastic and to harden cohesionless soils Arbitrary values of maximum loss by durability tests should be determined for each section of the country by correlation of the results of durability tests with field behavior

Soil-cement design as discussed in this paper is the method used in determining the amount of portland cement necessary to stabilize satisfactorily a given soil in order that the stabilized soil may function as a base on which a relatively thin surface or armor-coat may be placed This determination must be based on the results of tests that may indicate the ability of the soil-cement mixture to withstand the destructive forces to which it is exposed. 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 is essential Soil-cement design consists of three important steps: first, sampling; second, testing; and third, interpretation of the test results.

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 In North Carolina the soils within the area of the proposed project are identified as to series and samples taken of the "B" and "C" horizons

The classification of soils into series

groups is used by the Bureau of Chemistry and Soils and takes into consideration the origin and development of the soil. 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 and are available for 87 of the 100 counties in the State.

A normal soil profile consists of three main horizons or layers The top layer, called the "A" horizon, is the lightest in both texture and color, due to the leaching action of water. It is known as the horizon of impoverishment. The second layer, called the "B" horizon, is the heaviest, darker in color and more plastic, due to its greater clay content This condition is due to the accumulation of fine material, silt and clay, carried by the water that passed through the "A" horizon The "B" horizon is known as the horizon of accumulation and its color, structure and texture usually are the distinguishing characteristics of the series to which the soil belongs The third layer, or "C" horizon, is the parent material and is somewhat variable in color and is more or less non-uniform. This condition of non-uniformity is due to lack of soil development In residual soils, the original rock structure is plainly visible and in sedimentary soils the layers of the original deposits are discernible

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 lb, is taken from the two lower horizons of each soil series. The "A" horizon is usually only a few inches thick and generally will constitute only a small portion of the subgrade, so material from this horizon may be ignored with safety Usually the average project will contain only three to five different soil series, necessitating only six to ten 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 for stabilization, irrespective of the county in which it occurs When once the cement requirement for a particular horizon in a particular soil series has been established, it has been found unnecessary to test a key sample of the soil for the determination of the cement requirement

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 or more or less standardized

Samples of the subgrade taken at intervals of 500 ft are submitted to the following tests

1. Mechanical analysis
2. Physical test constants (L. L., P L, etc)
3. Specific gravity.
4. Moisture-density relations of raw soil.

Moisture-density relations of the soil mixed with cement are not determined by test 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 It is standard practice in North Carolina to increase the optimum moisture percentage of the raw soil by two to obtain the "working optimum" This is in addition to the moisture allowed for evaporation

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 for 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

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 ft 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 this 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.

DETERMINATION OF CEMENT REQUIREMENT

The determination of the amount of cement necessary satisfactorily to 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. 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. The following tabulation gives the permissible losses for various types of soil

Type of soil	Max loss permitted, Percentage
A-1, A-2, A-3	14
A-4, A-5	10
A-6, A-7	8

The cement requirement for satisfactory stabilization of soils belonging to the most common series in North Carolina has been established and work continues, as war conditions permit, on other series. The time necessary to determine the amount of cement necessary for satisfactory stabilization is about five to six weeks and it is impossible, in most cases, to be able to give the necessary information to the road planning department in time for the preparation of the proposal and contract 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.

FUTURE CONSIDERATIONS

There are several factors that now enter soil-cement design methods that warrant serious consideration. Many questions have been raised as to the adequacy of the test methods, the maximum loss permissible after the durability test for determination of the cement requirement, the necessity for the wetting and drying durability test, and others Most of us realize the need for fewer and quicker tests

In North Carolina we have followed the methods outlined in this paper, but have experimented some with cement contents less than the requirements So far the results of these experiments are satisfactory. It is reasonable to conclude that more cement is needed in localities subject to extreme cold than in those where the climate is more temperate We have also found that in every case but one that the freezing and thawing test is the most severe test. In the future it is planned to use other sections with reduced cement contents and try to establish a fewer number of cycles in the freezing and thawing test as a criterion for work in our State. The wetting and drying durability test may be eliminated entirely. Another plan is to determine the cement necessary to reduce the plasticity index of the more plastic soils of the A-6 and A-7 groups to zero and consider this quantity as that necessary for their stabilization.

There are several approaches to the problem of expediting the design of soil-cement bases and it is believed that local conditions should be given every consideration. Sufficient cement to eliminate the harmful effects of water on clay may be all that is required in temperate localities, while in localities of extreme cold the forces introduced by freezing will have to be overcome. Uniform durability requirements for all localities are not logical.

DISCUSSION ON SOIL-CEMENT DESIGN

MR C. A HOGENTOGLER, *Public Roads Administration:* Some people have been worried about heavy soils and low density after compaction. Perhaps Mr. Hicks will tell about a job he had in North Carolina in heavy clay of relatively low density.

MR. HICKS. We have one or two series of soils in N. C. that produce very heavy clays, among them a well known soil called the "Iredell" It is derived from a basic crystalline rock, either gabbro or diorite, and the B horizon of this soil is extremely plastic. It has a local name, "Bull Tallow." It is a bad actor, and gives us a lot of trouble in subgrades, under pavements, or any other type of road work.

We were called upon to stabilize a

project in Alamance County, which contained this series of soil Incidentally, the gabbro and diorite are intrusive rocks and you are liable to find a section of Iredell soil in a cut the width of your hand, or it may be a mile long This particular project was three and a quarter miles long, and most of the soil was Iredell. The remainder was related to the Iredell soil, and had a B 2 horizon that was just as bad an actor.

The plasticity of the soil in the B horizon ran up to 32 We were able to stabilize this soil, the worst part of it, that with the 30 P. I, with 14 per cent cement It was deemed economical at that time, because the bulk of the project did pass through the C horizon which could be stabilized with 10 per cent. The average on the project was 11½ per cent, I believe We were able to mix the cement with the soil and compact it at optimum moisture and get good density The density of the soil was about 95 lb. per cu ft

This project has gone through three winters. Incidentally, it went through 11 months of traffic without a surface and part of those 11 months was winter time but it held up fairly well. There were some signs of scaling and cracking. So far, it has gone through three winters and there is no sign of failure. It carries a large volume of traffic between two small cotton mill towns; and while there are no huge trucks going over it, there are a lot of cars, and, maybe, two or three-ton trucks It is holding up nicely, and we do not mind stabilizing Iredell soil if we have to

MR. R. C. SCHAPPLER, *Missouri State Highway Department*: We have had difficulty with clay soils. I am curious to know if you maintained the pulverization requirement on the 32 P. I. soil the same as you would for the other, more easily treated soils.

MR HICKS: We were afraid of the same thing before we started the project, but in working with the soil in the laboratory, we found that slaking would facilitate pulverization After the soil had been broken up initially it would be in lumps which we were afraid would act as stone in sand, and tumble around, without breaking up but we discovered that a slight addition of water would cause slacking of those lumps. We added water to about half of the optimum. If the cement is added at that time the cement seems to have some effect on the entire mass. When the mixture is approximately at optimum, maybe, a little below, the heavy clay will feel like garden loam The slacking effect of water is the secret of pulverizing that clay, but one must be careful not to get in too much It has to be put in carefully

MR. SCHAPPLER: I would like to put in a word of caution for other parts of the country, the probability is, as I see it, that the Southern clays (lateritic type) will react in that manner However the Northern clays (podsolic type) will not behave as well for stabilization

MR. HICKS. Would not any clay that is plastic slake in the presence of water? If water is put to it and it is damp, you won't get the slaking effect, but if it is fairly dry it will start to disintegrate when the water hits it

MR SCHAPPLER: We have had plenty of serious trouble in trying to get down to the grading of the pulverization requirement. There are certain types of our clays that will not slake after they reach a certain size, about the size of their structure. Even in the presence of water they will take a considerable period of immersion to break up or disperse

MR M. D CATTON, *Portland Cement Association* Mr Schappler's discussion of pulverization of the heavier textured clays also touches on a point being covered by some research now under way in the Portland Cement Association soil-cement laboratory A brief discussion of the available data may be helpful

As Mr Schappler mentions, some of the Northern clays are not so easily pulverized as the Southern clays. That raises the point that on some projects, there may be some clay balls in the mix at time of compaction

The research project under way in the P C A soil-cement laboratory was designed to evaluate more accurately than has been done in the past two factors:

(1) The amount of clay balls that might be permitted in a compacted soil-cement mixture and,

(2) The influence of the moisture content of these clay balls at the time of construction on the subsequent hardness and durability of the completed work

Initial data are just now becoming available The most outstanding fact shown so far is that the moisture content of the clay balls at the time of compaction is of great importance

One series of the tests under way is divided into two parts to conform to our conception of some of the forces of soils and soil mechanics which will be effective in completed soil-cement construction In one series the clay balls were added at an air-dry condition near the shrinkage limit of the soil and in the other series the clay balls were added in a moist condition. Various quantities of clay balls, ranging from 20 to 40 per cent, are included in the test specimens.

About all that we have of enough significance to comment on this morning is that the specimens molded with air-dry clay balls disintegrated and went to pieces rapidly with very little exposure to wetting and drying and freezing and thawing.

On the other hand, the specimens containing the clay balls near the optimum moisture resisted or stood up in the A.S T M. soil-cement tests not only better than we were willing to speculate on but also with greater quantities of contained clay balls So that at the moment the preliminary tests show clearly that aside from the question of pulverization is the practical consideration that when the mixture is compacted, the contained clay balls very obviously should be up toward the optimum moisture. The tests show that when they are in that condition, they are not exerting the detrimental forces that dry clay balls exert.

A moment will be taken to speculate on the detrimental forces produced by the dry clay balls in the compacted and hydrated mixture As we see it, after compacting the dry clay balls into the mixture, they absorb moisture in the presence of water and induce expansion forces in the clay that we know can be very substantial The specimens contained 20 per cent clay balls, which is in conformance with specifications in common use, at or near optimum moisture The only evidence of the harmfulness of 20 per cent moist clay balls was that, where they were exposed on the surface of the specimen, they washed or brushed out but there was no internal rupture of the specimen

An interesting case in point comes to mind at the moment from the paper on soil-cement road construction presented before the Highway Research Board by Mr Guy Larson of Wisconsin some five years ago [1] He gave the details of a soil-cement road project built in Wisconsin in the fall of 1936 and noted that clay had been added to the mixture, some 25 per cent, as I recall it. He reported the results of tests on a very large number of cores, taken from the completed work. All cores showed clay balls about the size of the end of the little finger well dispersed throughout the mass. A number of the cores were subjected to a hundred cycles of freezing

[1] Guy H Larson, "Experimental Soil-Cement Road in Wisconsin," *Proceedings*, Highway Research, Vol 17, Part II, Soil-Cement Mixtures for Roads (1917)

and thawing and yet they did not rupture or disintegrate. The speaker knows from personal experience and observation on the job while it was being built that the clay balls were damp at the time the soil-cement mixture was compacted. The job has been in service for six winters with those clay balls present and is still in good, serviceable conditions.

So we can go back to that Wisconsin experience to get verification of the laboratory findings that the presence of a quantity of balls in the mixture, at a moisture content near the optimum moisture, are not unduly destructive

The research data now available do not indicate the need of changing pulverization specifications now in general use permitting as much as 20 per cent clay balls in the mixture. On the other hand, the data emphasizes that it is very important that the clay balls be near optimum at the time the soil-cement mixture is compacted

MR. W. H. CAMPEN, *Omaha Testing Laboratories*. We had occasion on one job to use a certain amount of a clay which had a P. I. of about 60 The way we pulverized that or reduced its size was by alternations of wetting and drying. By a combination of wetting and drying, it was reduced to the really fine sizes. This particular thing was discovered on this soil in the course of a soil survey, from the observation that as the samples of clay were taken out of the deposits and stood by the sides of the test hole, they were slacking and breaking up very rapidly as they dried. We therefore took advantage of that phenomenon to later pulverize it