

INFLUENCE OF THE MINUS 200 FRACTION ON  
ENGINEERING PROPERTIES OF SOIL AND GRAVEL

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Michigan State Highway Department  
John C. Mackie, Commissioner  
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## SYNOPSIS

This report describes a laboratory study made to determine the effect that changes in the minus 200 portion of soil have on the soil or gravel samples as a whole, how such variations are reflected by Atterberg limits and other soil classification procedures, and how certain soil characteristics may be affected by the testing procedures used. The effects produced by the presence of organic materials have been emphasized.

A fine grained soil in its natural state and as modified by four individual ionic substitutions, which in effect represented five soils, were used in the basic study. Two gravels (meeting MSHD specifications for 22A and 23A materials) were used to determine the effect of different soil fines on whole gravels. Powdered lignin and humic acid, prepared in the laboratory, were used to represent extremes of organic variations in the soil. Pure clays and selected soil fines were also included in certain tests.

All of the modified samples used were classified by standard soil testing procedures and their properties determined by such laboratory weathering tests as moisture absorption, swelling, freeze-thaw, and by compression strength measurements.

Although the methods used are subject to certain limitations, it was found that:

1. Characteristics and properties of fine grained soils can be altered by chemically modifying the minus 200 portion of the sample but such modifications have no significant effect on the properties of normally graded aggregates containing a limited amount of this fraction.
2. Atterberg limit tests generally reflect the performance of altered cohesive soils. Certain specific exceptions, however, indicate such tests should be supplemented by additional study.
3. Plasticity characteristics of the fine portion of normally graded gravel are not a factor in general performance of the sample as a whole.
4. A detailed series of tests, arranged for proper statistical analysis, are necessary if quantitative results are desired concerning the effects of soil modifications on performance of the soil mass as a whole.

## PREFACE

Research Project 54 E-14, "Investigation of the Influence of Soil Particles Passing the No. 200 Sieve on the Stabilization of Gravel," was initiated by the Research Laboratory Division in 1954, at the suggestion of O. L. Stokstad, Design Development Engineer. The scope of this project as outlined in the proposed program (2-9-55) required an investigation of the effect of organic material on a soil sample as a whole, having as its principal objectives:

1. Determine the effect that natural organic material has upon the strength, compaction, and swell characteristics of a soil, and its Atterberg limits and indices.
2. Establish a criterion for allowable amounts of organic material in soil binders.

This project was originally assigned to Roy J. Leonard who worked on it until his resignation in the summer of 1955, when only a portion of the work planned had been completed. Before leaving, he prepared a progress report which was published as Research Report No. 229 (6-7-55).

After reviewing this report, O. L. Stokstad wrote E. A. Finney (7-29-55), recommending continuation of the project, and suggesting no major changes for the program. He felt that better understanding of the influence of natural variations in gravel should be obtained and suggested the following areas where additional information was needed:

1. Specifications regarding organic matter in the minus 200 fraction.
2. Influence of other properties and characteristics of the minus 200 fraction.
3. Testing procedures and their effects on soil properties.
4. Specifications for general control of the minus 200 fraction.

At a meeting held on August 8, 1955, attended by O. L. Stokstad and E. A. Finney for the Department and Profs. A. E. Erickson and E. H. Kidder of Michigan State University, it was decided to continue this pro-

ject under the direction of a steering committee consisting of those present at the meeting and a member to be appointed from the MSU Department of Civil Engineering (1).

In the summer of 1957 this project was assigned to Mrs. Josette Portigo, a graduate student and full-time Laboratory employee. A program was prepared in conjunction with the Department of Civil Engineering of a scope suitable for graduate work for Mrs. Portigo leading to the degree of Doctor of Philosophy in Civil Engineering. Prof. G. C. Blomquist was appointed as Mrs. Portigo's program adviser. The project, as outlined by the steering committee, consisted of a physical, chemical, and mineralogical investigation of soil binder particles passing the 200 sieve and a physical effects study of the influence of these particles on the stabilization of gravel. The principal objectives were:

1. Improve criteria for the selection of type and amount of fine grained soil particles as used for the stabilization of gravel.
2. Investigate the effects of natural organic material on the stabilization and physical properties of fine soil particles.
3. Investigate the properties of several fine-grained soils for possible future experiments with additives for stabilization.

Supervision of this program for the MSHD was assigned to the Research Laboratory Division. Mrs. Portigo completed the work required for her thesis and received her degree in June 1960. The following fall, she resigned from the MSHD to return to the Republic of the Philippines.

This report was prepared by R. C. Mainfort from the more important and significant data contained in the PhD. thesis, and other phases of the work not included in the thesis that were added to this program after its transfer to the Soils and Pavement Evaluation Unit. In general, the report is divided into two parts: 1) the effect on the soil itself of modifying the minus 200 portion of fine grained soils by physical and chemical means, and 2) the effect that such changes could have when the modified soil formed the fines fraction of a gravel graded to be suitable for base course construction.

## INFLUENCE OF THE MINUS 200 FRACTION ON ENGINEERING PROPERTIES OF SOIL AND GRAVEL

The usefulness of a soil for highway engineering purposes depends largely on proper blending of the different sizes of particles found in any normal soil-aggregate mixture. Particles having diameters of 2 mm or more, as retained on the U. S. Standard No. 10 sieve, are classified as gravel. Those passing the No. 10 sieve but retained on the No. 40 are considered coarse sand. Fine sands lie between the No. 40 and No. 200 sieves. Included in materials passing the No. 200 sieve are the chemically active soil fines which, among other characteristics, provide plasticity to the total soil mass.

In order that a soil mixture may provide adequate support for loads, it should be so graded that there are sufficient points of contact between coarse particles to create satisfactory internal friction, and it should contain sufficient fine materials to provide adequate cohesion between the coarse particles. By laboratory testing and field observations, the proper proportions of fine and coarse materials have been developed for optimum performance. Such values are now controlled by rigid specifications and inspection. Gradation of coarse materials can be controlled by sieve analysis in a very satisfactory manner. The detrimental effects of the highly active fine material are controlled by limiting both the quantity of minus 200 material allowed in the sample, and the plasticity of the minus 40 fraction. Although largely empirical, these controls have proved satisfactory for practically all highway construction. However, in some cases, properly designed mixtures have not performed as well as expected and the cause has not been apparent. Such conditions have focused increasing attention on the properties of clay and colloidal fractions of soil, the effect this chemically active portion can have on the soil sample as a whole, how variations in such material can affect laboratory control tests, and how manipulation required by certain test procedures may affect soil properties and the test itself.

Among the more important constituents of the minus 200 fraction are the organic materials found in varying quantities in most soils. Such materials are readily compressible, easily decomposed, and generally have a high capacity for absorbing water. Because of these properties,

the presence of organic matter in soil complicates the problems of highway construction. If organic material is present in small quantities (2 percent or less), it is usually considered to have no appreciable effect on the soil mixture. Highly organic soils are normally wasted during construction.

Relatively little is known concerning the influence of various quantities of organic materials on the performance of base course mixtures, or upon present methods of evaluating soil properties. One reason for this is the absence of a rapid method for measuring the nature and degree of decomposition of organic matter in soil systems.

The interrelationships of causes and effects, as related to the minus 200 portion of soils, require a study of broad scope and can be approached only by systematic examination of different phases of the problem. This report describes only a portion of such an overall study. It is concerned primarily with the effects that different types and quantities of organic matter have on various soils, and an evaluation of the susceptibility of these soil treatments to classification by normal soil testing procedures. In addition, the effect of variations in finer particles on gravel mixtures as a whole was also studied.

## PHYSICO-CHEMICAL PROPERTIES OF SOILS

For better understanding of the problems pertaining to the minus 200 fraction of soils, and to develop testing methods for studying such problems, it was necessary to review certain fundamental aspects of the physico-chemical properties of soils.

Included in the minus 200 fraction of soils are very fine sands, silts, clay minerals, and organic and inorganic colloids. All these have often been combined under the designation "clay." Clays, however, are not merely a category of soil particle size but represent a distinct group of chemical compounds capable of entering into chemical reactions. Because of their small size, clay minerals provide the lattice structure and the tremendous surface area required for absorption of ions, water, and organic molecules, and for exchange of anions and cations. Clay minerals are built up from two basic structural units: the silica tetrahedron (a silicon atom surrounded by four closely packed oxygen atoms) and the aluminum octahedron (an aluminum atom surrounded by six closely packed oxygen atoms). In both cases the oxygens or hydroxyls are equidistant from the silicon or aluminum atoms.

The known clay minerals may be grouped and described as follows:

1. The Kaolin Group consists of kaolinite, dickite, nacrite, and halloysite. This group is characterized by a 1:1 lattice (one silicon tetrahedral layer to one aluminum octahedral layer). Differences within the group are due to stacking of units. The sheets are compact so that there is very little substitution within the lattice. The external surfaces are relatively inert but show absorption characteristics. Ionic exchange properties are found on the unsatisfied valences at the edges of the particles. Kaolin clays have slight hydration and absorptive properties, low base exchange capacity, and low cation absorption.

2. The Montmorillonite Group consists of montmorillonite, beidellite, and nontronite. These clay minerals have a 2:1 lattice (two silicon tetrahedra with one aluminum octahedron between) which expands and contracts with the amount of water present. There is considerable lattice substitution so that the lattice charge is always unbalanced. Water and other polar molecules can enter between the layers, resulting in lattice expansion.

3. The Illite Group includes chlorites and vermiculites. The minerals in this group are characterized by a 2:1 lattice with the units relatively fixed in position, and thus non-expanding.

4. The Impure Mixed Layer Clay Group is widespread and does not have constant properties. Mixed layers of montmorillonite and illite are quite common. The mixed layer clays offer an explanation of the numerous clay minerals which do not appear to belong to any of the major groups.

Organic colloids as found in soil are usually defined as a mixture of dark colored amorphous organic compounds formed in the soil as the result of decomposition by micro-organisms of organic matter of plant and animal origin. They consist primarily of substances which are resistant to further decomposition (largely lignins and modified lignin complexes), of substances in the process of decomposition (hemicelluloses and proteins), of substances resulting from decomposition (organic acids, bases, etc.), and of microbial-synthesized substances (largely organic nitrogenous complexes and hemicelluloses).

The decomposition products of organic matter are usually leached away by ground water so that eventually only the most resistant remain in the soil. These comprise the lignins, the lignin complexes, and some proteins. Some soil scientists believe that such residues can be beneficial to the soil if certain amounts of clay are present.

Winterkorn (2), in his study of Loess Pompeano from Argentina, found that its organic content of about 6.5 percent furnished a degree of waterproofing as long as bacteriological action was prevented. High percentages of both lignins and proteins were found in this soil.

In its pure state lignin is completely resistant to attack by any micro-organism. Protein, on the other hand, is readily decomposed by many micro-organisms under practically all conditions. It is believed, however, that protein can be protected from decomposition by both the lignin and the clay portion of soils. The clay-protein relationship appears to benefit both the protein and clay, primarily by reducing the absorptive capacity of clay for water or easily hydrated cations. The swelling of certain montmorillonite clays, for example, can be reduced by the addition of organic ions. It has been shown (3) that highly stable (insoluble in water) aggregate compounds can be formed from parts, each of which might be readily soluble in water. Physico-chemical actions such as this could be very significant in natural soil combinations and offer an explanation of the effects that certain chemical additives have with some soils.



Soil organic materials are generally mixtures of several components which may be in different states of decomposition. However, regardless of its state of decomposition, each component is a definite chemical compound in itself, and as such could be expected to act as would any pure compound of the same composition, when applied to soil. For this reason it was felt that laboratory-prepared organic materials could be used in place of natural organic substances. Thus, closer control could be exercised over the form and quantity of organic additives used than could be obtained with naturally occurring organic matter.

In developing a testing program for this study the following theoretical concepts pertaining to cohesive soils were considered:

1. Clay and colloid fractions of soils are capable of base exchange and adsorption activities, both of which are surface phenomena influencing cohesion, plasticity, volume change, and water-holding properties of soils.

2. Cohesive soils contain clay and colloidal materials in sufficient amounts to allow surface phenomena to influence the properties of soil.

3. The amount of water absorbed by colloids during swelling varies with the kind of adsorbed ions which saturate the exchange positions.

4. The principles of base exchange and adsorption permit the alteration of the surface character of soil colloids by chemical means, so that the water-attracting properties of the mineral surfaces can be changed.

5. Organic material in soils in excess of exchange capacity of the clay and colloids can in itself become an agent for adsorbing water molecules and thus increase the possibility of swelling.

From these factors it can be seen that the properties of the cohesive portion of a soil depend on the exchangeable base present and on the organic content. Certain combinations of organic materials and bases could be expected to give optimum properties to the soil. Other combinations could be detrimental. The magnitude and significance of such variations and their effects on different soils are not known, but they could have considerable effect on the performance of highway base course and subgrade materials.

AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS CLASSIFICATION

CLAY	SILT	FINE SAND	COARSE SAND	GRAVEL		
SIEVE SIZES		200	40	10	4	3/8" 3/4"
DIAMETER IN MILLIMETERS						

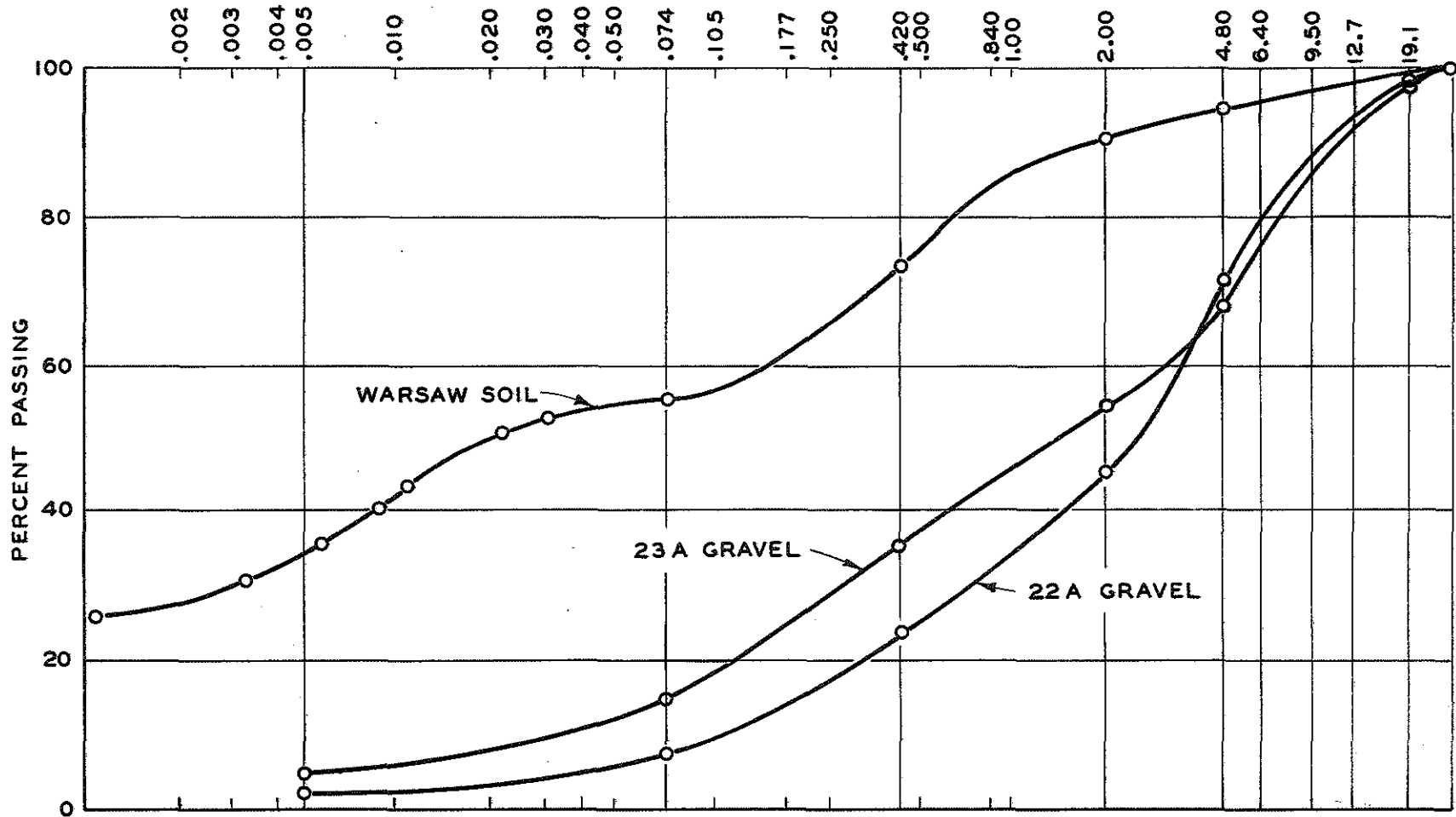


Figure 1. Particle size distribution of the test mixtures.

## TEST MATERIALS

The primary materials used in this study were a) a natural soil, b) different ionic modifications of this soil, and c) organic additives used for the soil treatments. In addition, samples of two gravels meeting MSHD specifications for base course construction were used to test certain variations.

The basic soil sample was obtained from borings along the right of way of M 43 between Richland and Kalamazoo. This soil is classified pedologically as Warsaw by the MSHD and the sample is representative of the C-horizon of this soil, although containing some B-horizon material.

TABLE 1  
CHARACTERISTICS OF THE WARSAW TEST SOIL

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Liquid Limit	28.0
Plastic Limit	15.1
Plasticity Index	12.9
Shrinkage Limit	11.7
Shrinkage Ratio	1.87
Maximum Density	119.1 pcf
Optimum Moisture	13.5 percent
Specific Gravity (minus 10 portion)	2.64
Passing No. 40 Sieve	74 percent
Passing No. 200 Sieve	55 percent

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The soil samples were air dried, thoroughly pulverized in the laboratory, and combined into one batch sample for use in the testing program. The grain size distribution of this mixture is shown in Fig. 1. Texturally, the soil is classified as clay. Other physical constants, obtained by standard soil testing methods, are listed in Table 1. By the Highway Research Board classification system this soil is an A-6(5), and rated as a poor subgrade material.

The base exchange capacity of the soil is shown in Table 2. There are several accepted methods for obtaining base exchange values of clay minerals, the general basis of which is washing the sample with an ammonium salt (a salt not naturally occurring in soils), and determining the amount of absorbed  $\text{NH}_4$  ions by measuring the difference between the original and final concentrations of the washing solution. In this study the method described by Olsen and Bray (4) was used. The loss in base exchange capacity of the samples, after treatment with hydrogen peroxide, indicates the presence of some organic material in the original sample.

TABLE 2  
BASE EXCHANGE CAPACITY OF THE WARSAW TEST SOIL

Form of Treatment	Base Exchange Capacity, milliequivalents per 100 g of sample
A. Treated with hydrogen peroxide	
1. Passing No. 20 sieve	4.35
2. Passing No. 40 sieve	6.25
3. Passing No. 140 sieve	8.60
B. Not treated with hydrogen peroxide	
1. Passing No. 20 sieve	4.90
2. Passing No. 40 sieve	7.35
3. Passing No. 140 sieve	10.80

X-ray diffraction analysis of the soil sample showed the clay minerals to consist primarily of illite, kaolinite, interstratified vermiculites and chlorite, and quartz. Infra-red absorption spectra indicated the presence of illite, kaolinite, and quartz. The x-ray diffraction tests were made with equipment of the MSU Soil Science Department. Infra-red absorption tests were made at the MSHD Research Laboratory Division.

The organic additives to the soil were laboratory samples of lignin and humic acid. The lignin was a commercially available pine wood product in the form of a brown powder. The humic acid was extracted from a sample of muck in the laboratory by a method suggested by Bremner (5).

The precipitated humic acid was washed with slightly acidified distilled water and stored to remain in a moist condition.

The use of synthetic organic matter, rather than that naturally occurring in soils, was considered necessary to obtain controlled amounts of the additive. It would be almost impossible to obtain soil samples containing given quantities of organic matter. Lignin was selected to represent organic matter in equilibrium with soil micro-biological activity and is assumed to undergo no further decomposition in the soil. Humic acid represents organic matter at a different stage of decomposition.

Homo-ionic soils (those containing only one adsorbed cation) were prepared using a method similar to that described by Winterkorn (6). Essentially, this method consists of leaching the soil with an electrolyte containing the desired cation (usually in a chloride solution), in sufficient concentration to saturate base exchange capacity. Excess chemicals were washed from the sample by leaching with distilled water. By chemical analysis, this method has been found to be about 90 percent efficient.

"Hydrogen" soil was prepared by soaking a quantity of raw soil for several days in a solution of 0.2 normal hydrochloric acid, and washing the treated soil on a Büchner funnel until the wash water tested entirely free of chlorides.

Calcium, ferric, and aluminum soils were prepared by soaking raw soil in the corresponding chloride and leaching the free chloride ions with distilled water.

After treatment, the chloride-free homo-ionic samples were air dried, pulverized with a rubber tipped pestle, and quantities portioned and prepared for the required tests.

During this study all of the prepared soil types (natural, hydrogen, ferric, aluminum, and calcium) were tested with 0 to 4 percent lignin, and 0 to 3 percent humic acid, all quantities being based on the dry weight of the untreated soil.

## TEST PROCEDURES

Numerous testing procedures were used to determine the effects of ion exchange on soil properties and how such properties could be altered further by the addition of organic materials. The tests were also intended to show the effects that variations in minus 200 material may have on the reliability of normal testing procedures.

Standard soil testing procedures were used to determine how the treatments affected Atterberg limits and other soil constants. Oven-dried samples were not used in these tests because of the possible effect of higher temperatures on soil properties. It is generally accepted that oven drying reduces the liquid limit of organic soils, and in certain cases alters properties of the clay fraction (7). These conclusions were verified for the soils used in this study. Atterberg limit tests were made with both air dried and oven dried soils containing different amounts of organic materials (lignin). The liquid limits were lowered in all cases when oven drying was used. These changes, however, were not in proportion to the organic content of the sample, indicating that organic content is not the only property affected by oven drying. In addition to testing for the effect of treatments on the soil properties, certain tests were also devised to simulate field weathering conditions.

Optimum moisture and maximum density tests were determined with the Harvard compaction device. Results obtained with this equipment closely duplicated those determined by the standard Proctor test and this method had the decided advantage of requiring much less of the specially prepared soil for each test. All samples used in the testing program were made by the Harvard compaction equipment.

Samples to be tested were compacted by static loading to pre-determined optimum conditions in a cylindrical steel mold 2.69 in. high by 1.34 in. in diameter. These dimensions gave a height-to-diameter ratio of 2:1 and a volume of 1/453.6 cu ft. Twenty-four samples were prepared for each condition of test. Half were air dried in the laboratory for a 7-day period, the other half were stored in a moist cabinet for 7 days at constant moisture content. After curing, three samples of each group (dry and moist) were broken by unconfined compression. The

remaining nine samples of each group were subjected to the following laboratory exposure:

1. 14-day capillary absorption in which the samples were placed on a saturated pad in a closed moist cabinet (at approximately 100-percent relative humidity) and allowed to absorb water. Samples were weighed periodically. In some cases when either saturation or failure of the sample was reached within 7 days, the test was terminated at this point.

2. Capillary absorption plus four cycles of alternate freezing and thawing. Each cycle of freezing and thawing consisted of 16 hr of freezing at a temperature of 0 to -10 F followed by 8 hr thawing on a capillary absorption pad in the moist cabinet.

3. Capillary absorption plus four cycles of freezing and thawing plus four cycles of alternate wetting and drying. A wetting and drying cycle consisted of 16 hr drying in an oven at 140 F followed by 8 hr immersion in water.

Weights were obtained periodically during all of the tests and unconfined compressive strengths obtained after each phase.

Information concerning volume change of the samples during moisture absorption was obtained by a modification of the method described in AASHTO Designation T 116-54. The apparatus used was a modified consolidometer device to which was added a perforated piston. The upward movement of the soil samples during capillary moisture absorption was measured by a micrometer gage. The samples used were 2.5 in. in diameter by 1 in. high, smaller than those specified in the AASHTO Designation.

## TEST RESULTS

The test results are discussed here in two general categories: 1) the effects of ionic and organic modifications on the soil properties as indicated by Atterberg limits, volume change, and optimum moisture and density, and 2) the effects of these modifications on performance of the soil as a whole and their effect on stability of the mass. From these results it could be determined whether normal classification tests accurately predict soil performance under a wide variety of conditions.

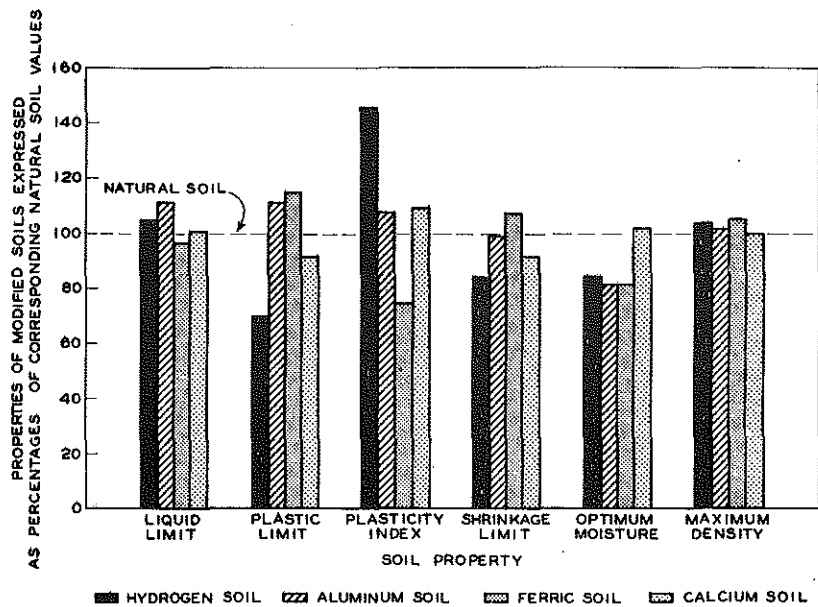


Figure 2. Effect of ion modifications on properties of the test soils.

Fig. 2 shows the effects of ionic modification on the basic soil expressed as a percentage of the corresponding natural soil property. The more significant effects are shown by the plasticity index, and to a lesser degree by the shrinkage limit. According to these results hydrogen modification is detrimental and the ferric beneficial. Generally, however, the physical characteristics of the soil were not too greatly affected by ionic modifications. Hydrogen, aluminum, and ferric treatments slightly increased maximum density values.



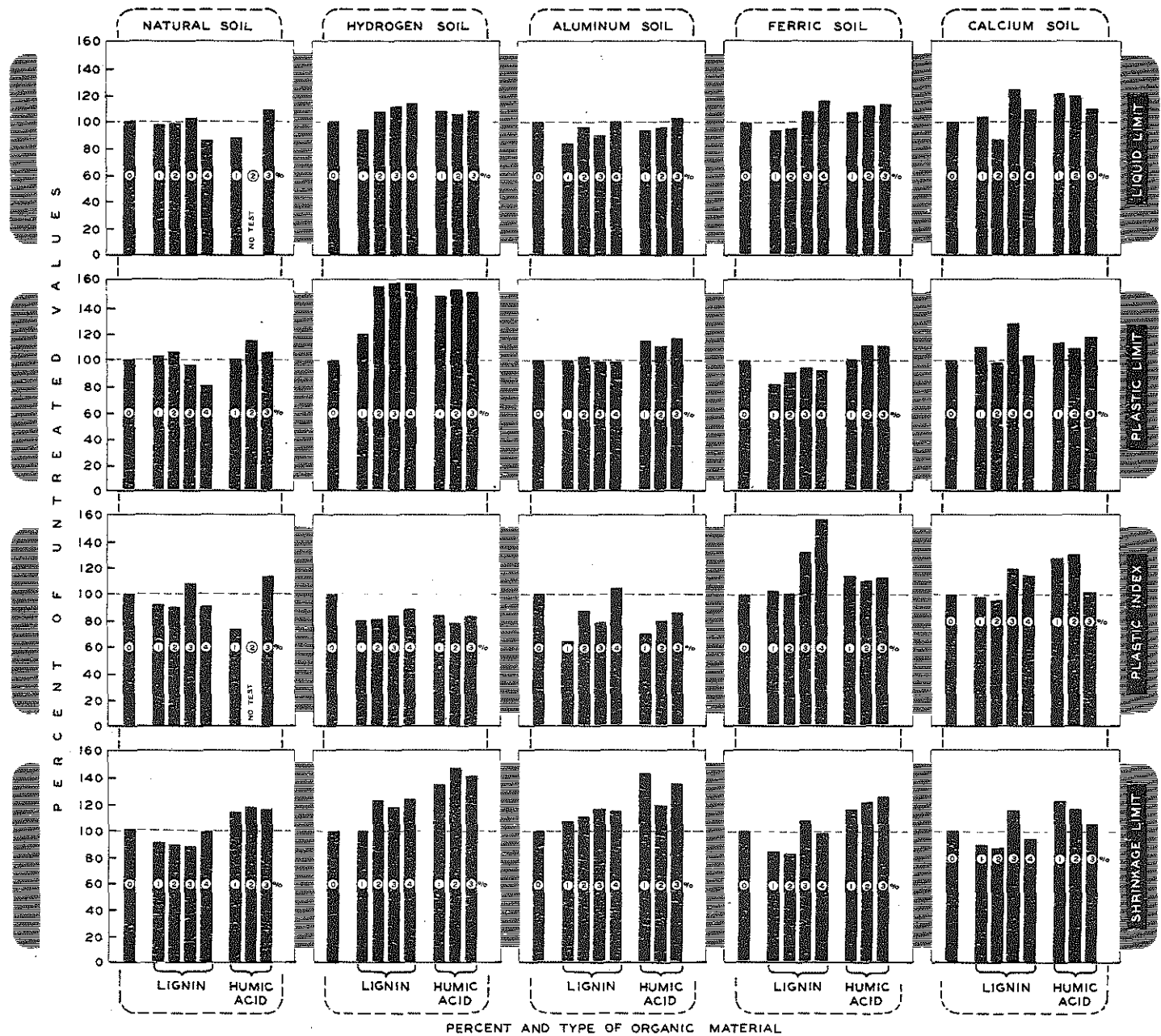


Figure 3. Effect of organic material on Atterberg limits for the five soil types.

Fig. 3 indicates the effect that different quantities of organic materials (lignin and humic acid) have on Atterberg limits of each soil type. From the standpoint of highway construction control, the most important of these properties is the plasticity index. The presence of organic material in quantities as low as 1 percent caused certain variations in plasticity index values, particularly those obtained when humic acid was added to calcium soil. In general, organic material acted to reduce the plasticity index when present in quantities under 2 percent. Humic acid and higher percentages of lignin increased the plasticity index of ferric and calcium soils.

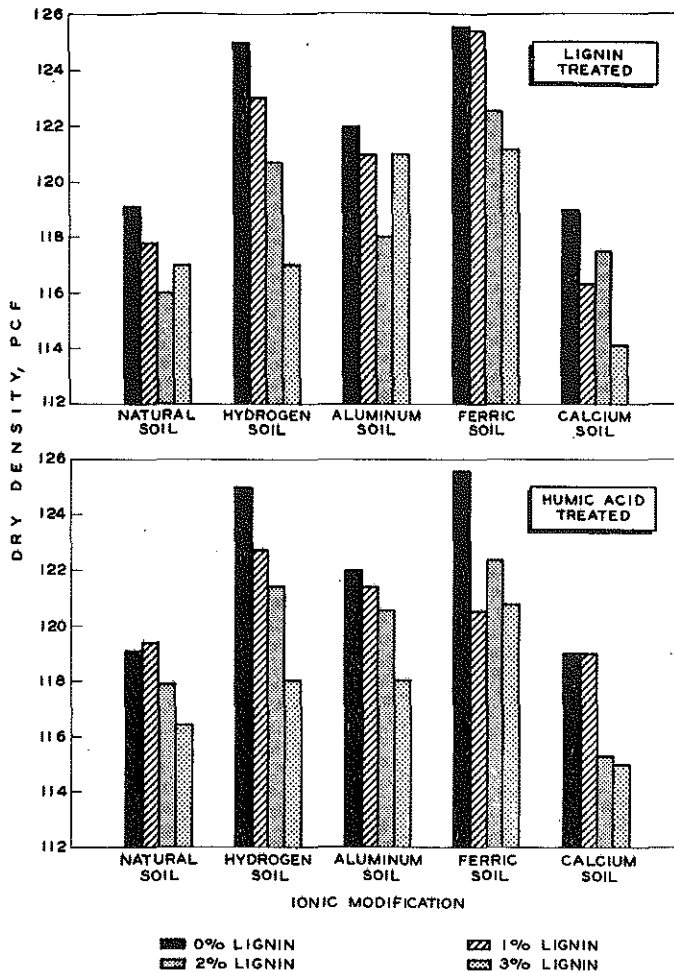


Figure 4. Effect of organic materials (lignin and humic acid) on the compaction of natural and modified soils.

The effect of organic treatment on maximum density of each ionic soil modification is shown in Fig. 4. In nearly all cases organic materials reduced maximum density. These data show a maximum dry density differential of as much as 10 pcf, due to a combination of ionic and organic modifications.

Fig. 5 shows that for all practical purposes, ionic modification alone has no appreciable effect on capillary moisture absorption. Figs. 6 through 10, however, indicate that moisture absorption characteristics can be altered, at least temporarily, by organic materials. These tests were made during the absorption and freeze-thaw portions of the laboratory weathering tests. With the air dried samples lignin particularly reduced water intake. This should be expected from a material which

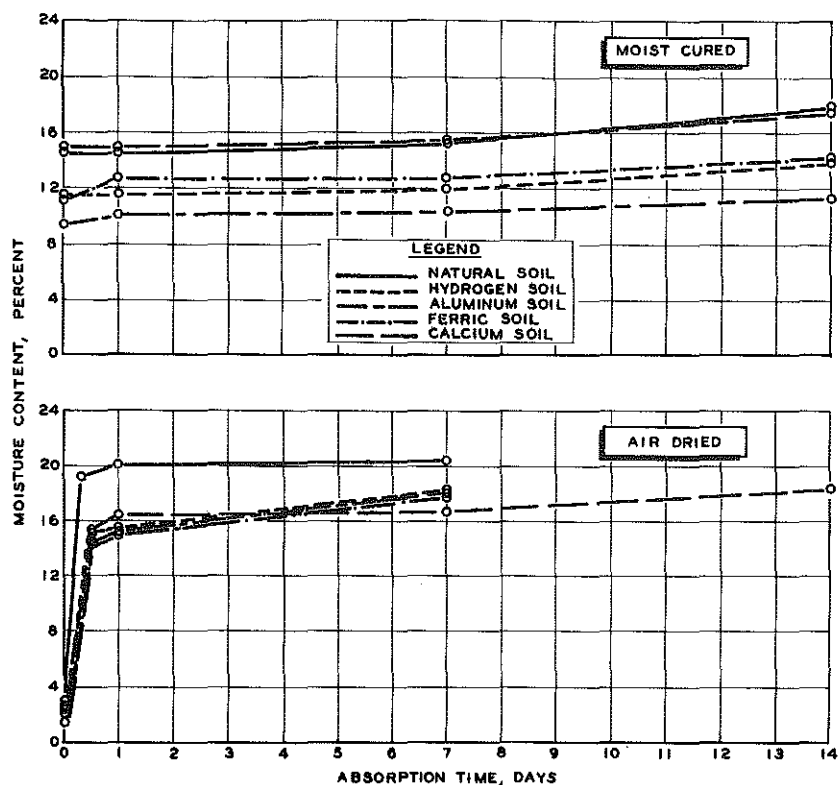


Figure 5. Effect of ionic modification on capillary moisture absorption.

has long been considered a waterproofing agent for soils. It should be noted, however, that the water repellency of lignin diminishes during freeze-thaw cycles, thus following a pattern found in all resinous soil waterproofing agents. Absorption characteristics of moist-cured samples were relatively unaffected by the organic additives, but in some cases the treatments were detrimental--allowing slightly higher moisture intake. Generally, it would not be expected that natural soil organic matter would greatly reduce water absorption characteristics under field conditions.

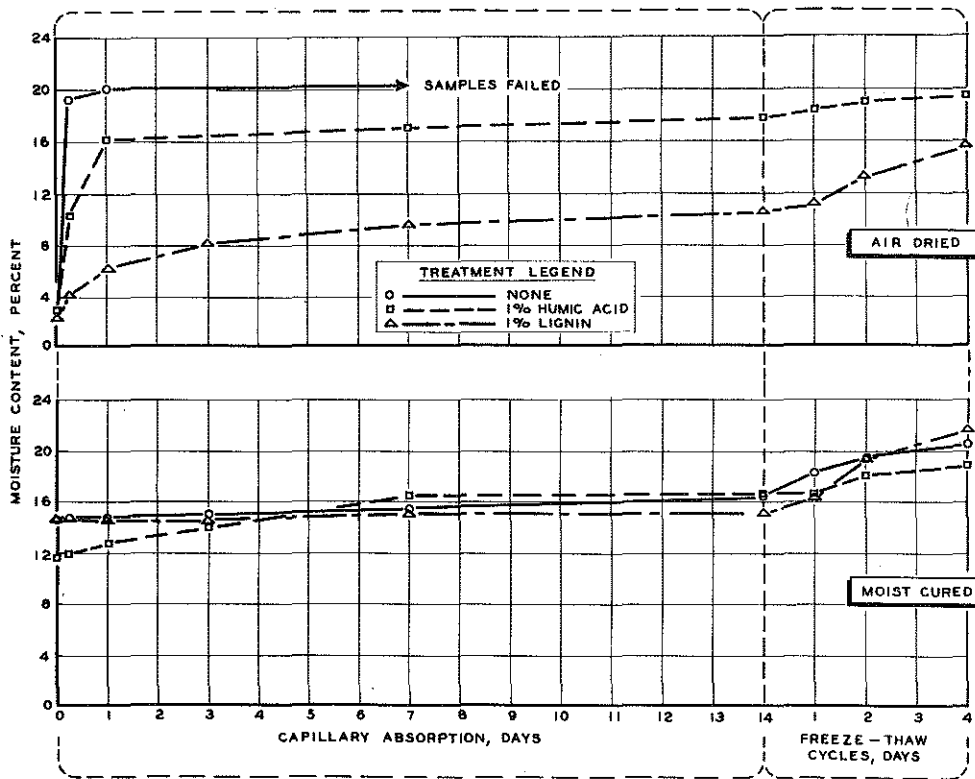


Figure 6. Effect of organic materials on moisture absorption of samples during laboratory weathering tests (Natural soil).

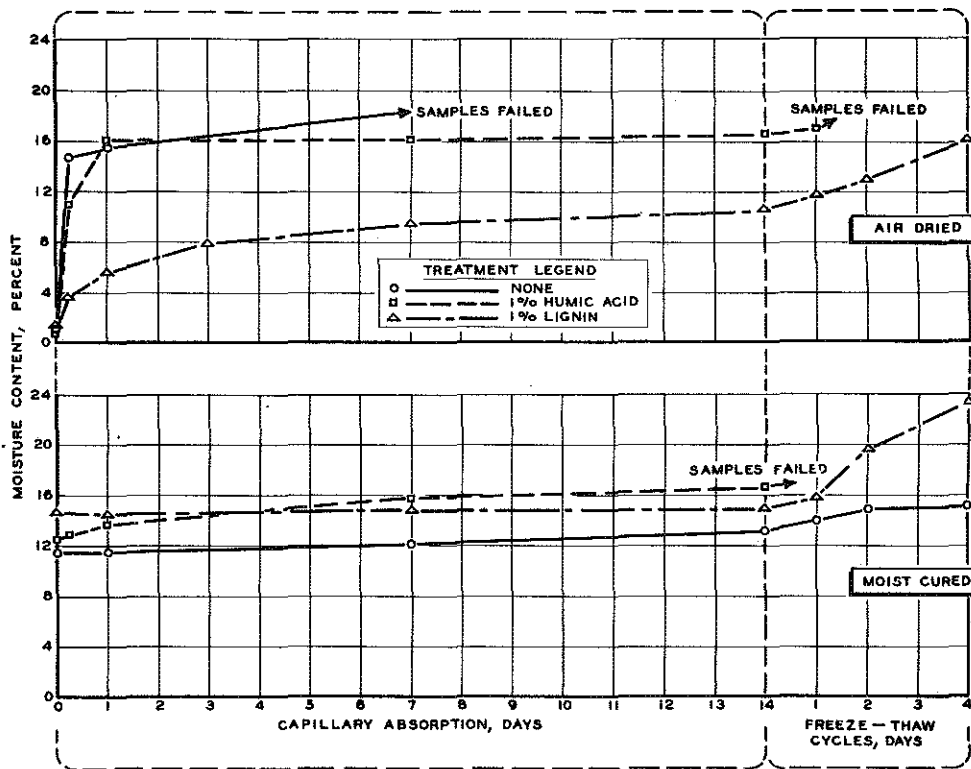


Figure 7. Effect of organic materials on moisture absorption of samples during laboratory weathering tests (Hydrogen soil).

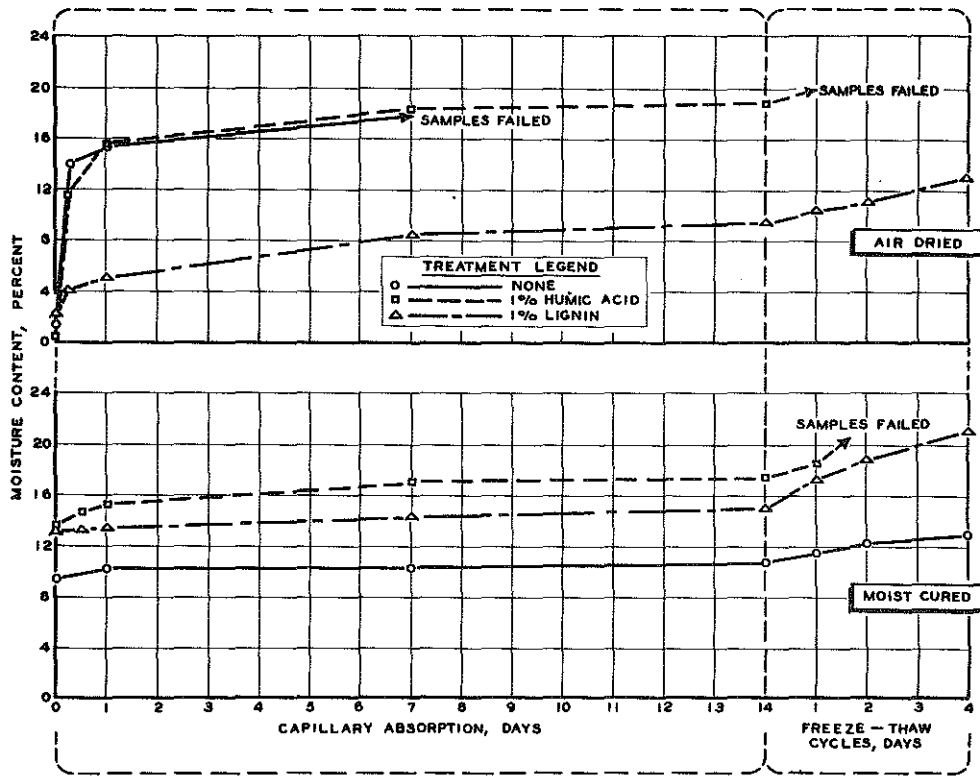


Figure 8. Effect of organic materials on moisture absorption of samples during laboratory weathering tests (Aluminum soil).

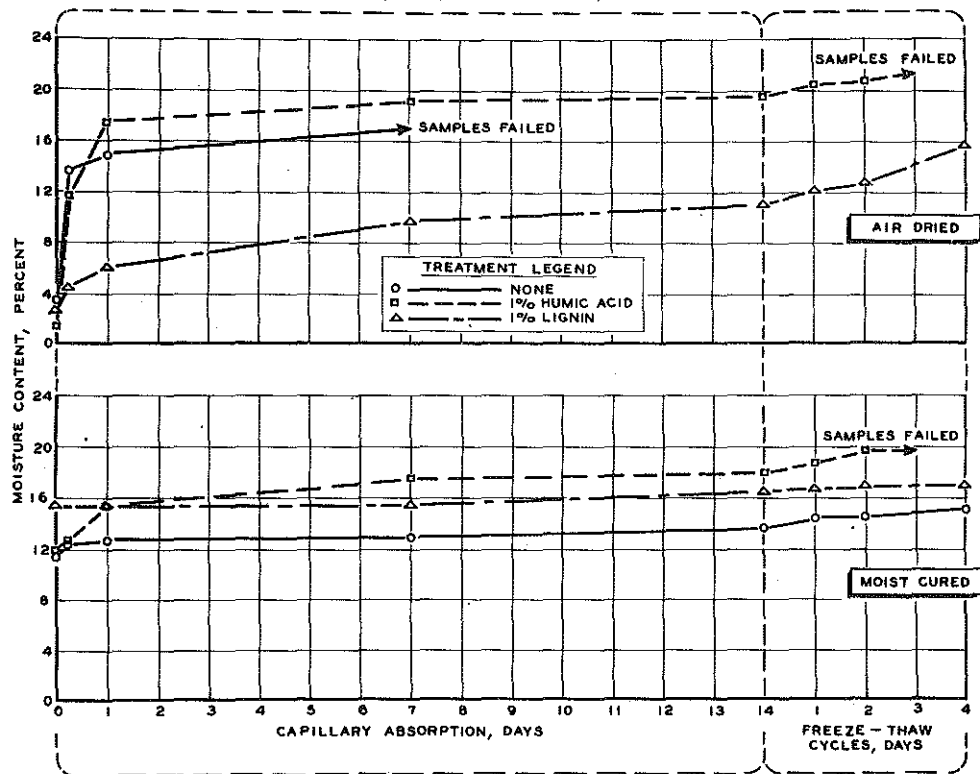


Figure 9. Effect of organic materials on moisture absorption of samples during laboratory weathering tests (Ferric soil).

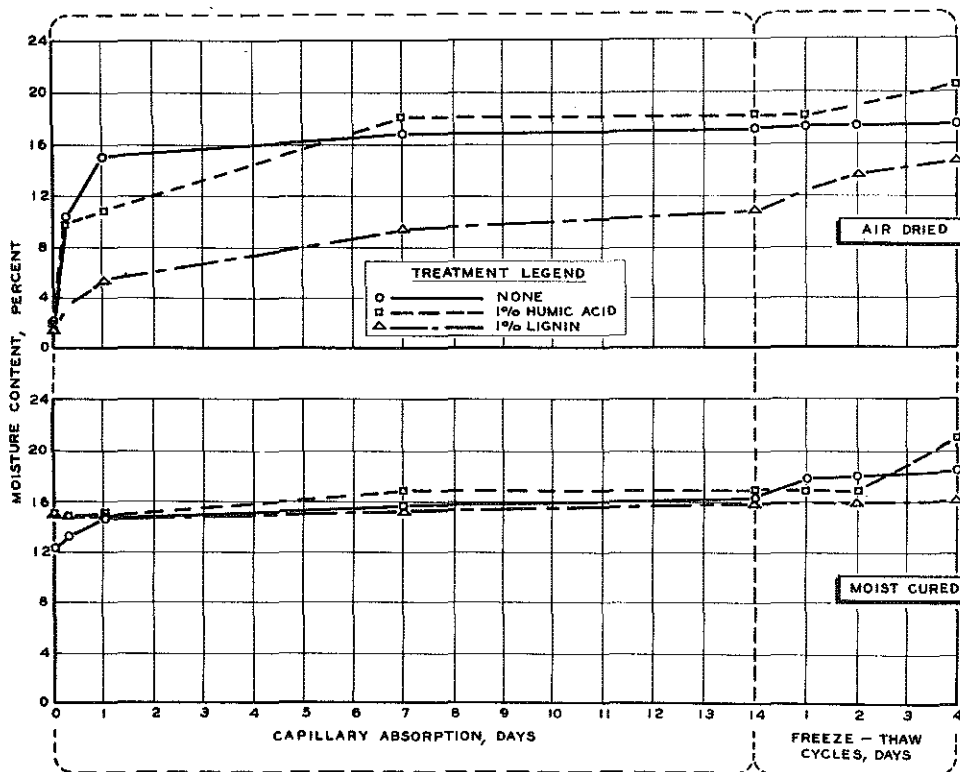


Figure 10. Effect of organic materials on moisture absorption of samples during laboratory weathering tests (Calcium soil).

Fig. 11 shows the effects of different quantities of lignin on the compressive strength of each homo-ionic soil modification. Strengths of natural and calcium soils were slightly decreased by adding lignin. Its addition, however, significantly increased the strength of hydrogen, aluminum, and ferric soils in both air dried and moist cured conditions. Except for the ferric soil, these results are reflected by the Atterberg limit tests. These data also indicate that bonding effects of the lignin are independent of the methods used to cure the samples. This is also reflected by the capillary absorption test results (Fig. 11), in which the compressive strengths generally average as high for the moist cured samples as for the air dried. In most tests, at least 2-percent lignin was required to cause a significant change in the sample's resistance to moisture attack. Hydrogen soils were the least responsive to lignin treatment in this test.

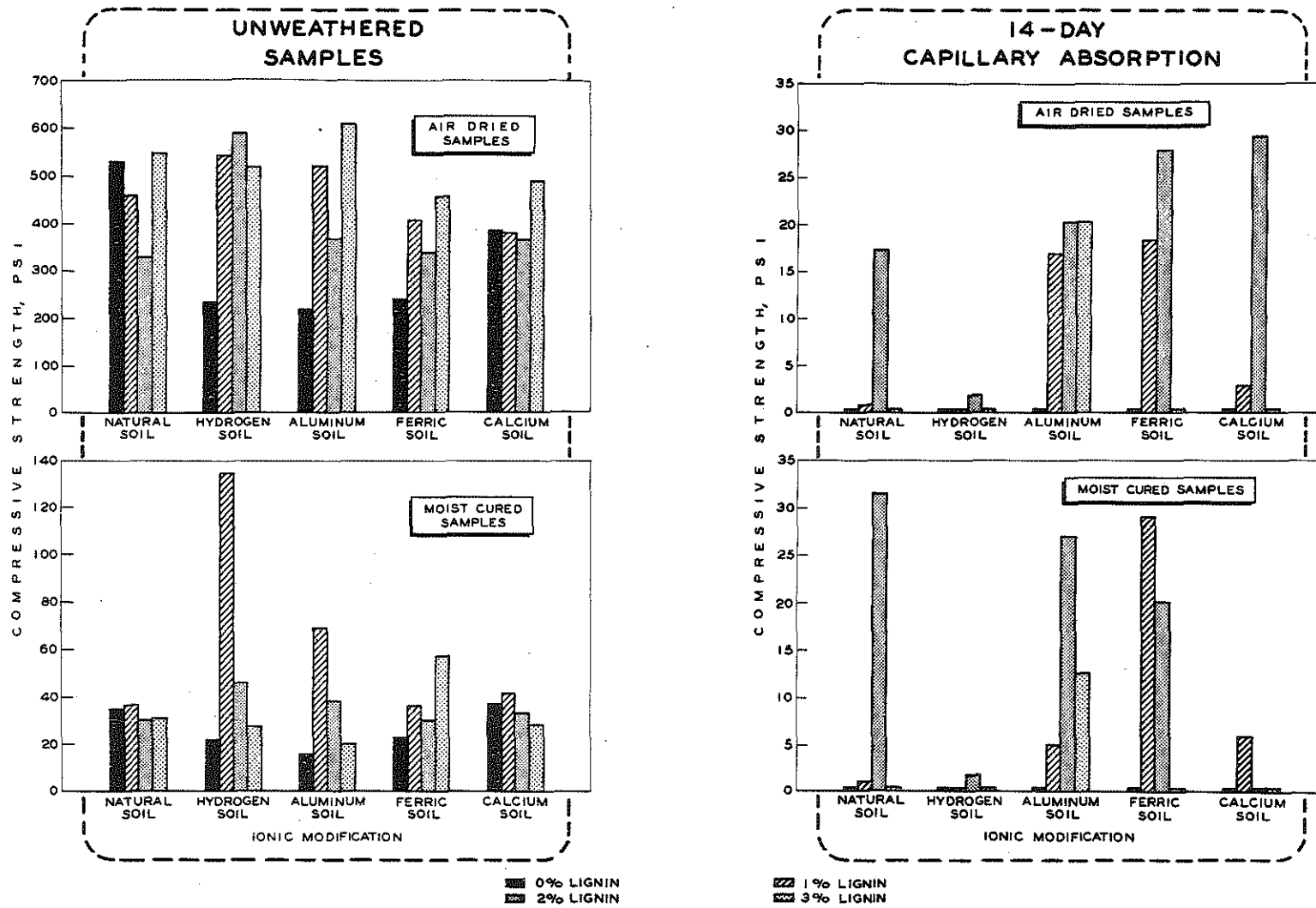


Figure 11. Effect of organic material (lignin) on the strength of modified soils.

Fig. 12 shows the effect of homo-ionic modification on the swell characteristics of the test soil. In this test each soil was compacted to its own optimum conditions so that densities and moisture contents varied. Significantly, the low density soils, natural and calcium, showed the least swell. Fig. 13 shows the effects of different quantities of lignin on the swelling of various homo-ionic soils. In all but one case, the swelling characteristics were improved by the addition of 1-percent of lignin. More than this amount was detrimental. The sole exception was the aluminum soil which benefitted by all lignin treatments, with 2 percent being the optimum value. The beneficial effects of 1-percent lignin and the good response of aluminum soils were indicated by the Atterberg limit tests.

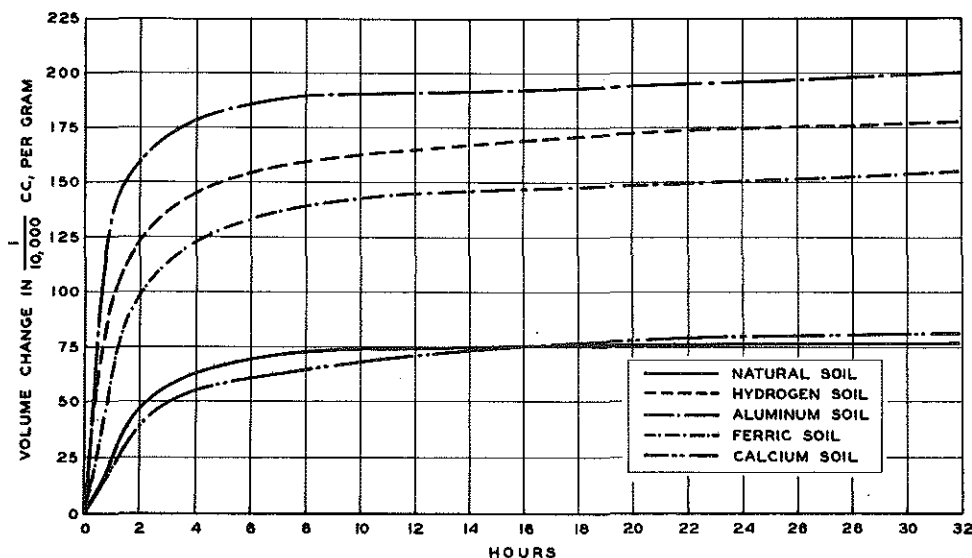


Figure 12. Effect of ion modification on swelling characteristics of soils.

Fig. 13 also shows the results of a similar test in which humic acid was used as the organic additive. Results were erratic. All quantities of humic acid increased the swelling of hydrogen and calcium soils. Humic acid reduced the swelling of ferric soils at all levels of treatment and, with the exception of 1-percent treatment, improved the aluminum soils. Natural soil was improved only by adding 3-percent humic acid. Swelling characteristics of the soils could not be predicted too well by the Atterberg limit tests.



With the exception of a few individual samples all treatments failed when subjected to the freeze-thaw test. The samples, already softened by capillary absorption, yielded readily to the forces of the freeze-thaw test. Aluminum and calcium soils treated with 1-percent lignin barely

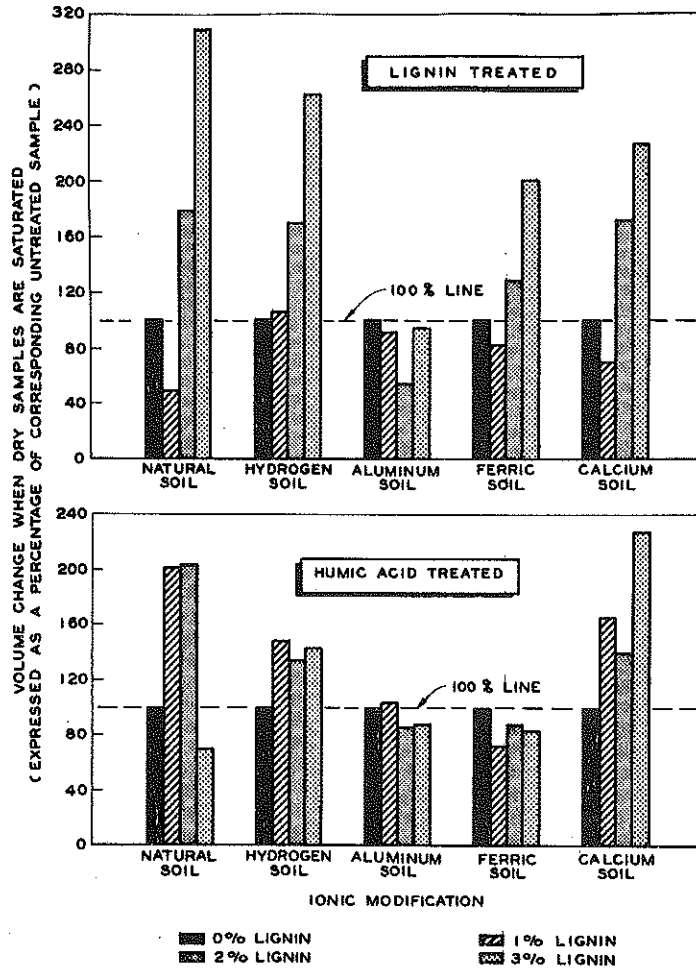


Figure 13. Effect of organic materials (lignin and humic acid) on the swelling characteristics of different soils.

survived the tests, and withstood only a very low compressive load (about 6 psi). These exposure tests indicate that soil modifications, due to alterations of surface characteristics, may be of insufficient magnitude to affect field performance significantly. They also show that the bonding and waterproofing value of lignin is only temporary.

## EFFECT ON GRAVEL SAMPLES OF VARIATION IN MINUS 200 FRACTION

The tests described in the first part of this report show the changes that can be made in the properties of a fine grained soil when the minus 200 portion is modified. This is of particular interest when evaluating the properties of subgrade soils. For base construction, however, much coarser materials are used, and the minus 200 portion represents but a small fraction of the whole. For example, MSHD specifications for aggregate base and surface courses require that the fines content not exceed 7 percent by weight of the aggregate sample.

Detailed tests were performed to determine the effect that altering the properties of the minus 200 portion would have on typical gravel samples. For this purpose, however, tests were limited to plasticity determination because this property is considered to exert considerable influence on the performance of the sample. Other tests might also be useful but were not made during this study.

Two gravels, meeting MSHD specifications 22A and 23A, respectively, were obtained from different locations and used as the basic materials. Their gradation curves are included in Fig. 1. Modifications were made by removing the native minus 200 fraction and substituting the desired type and amount of minus 200 fines. The different modifications were added, individually, to the plus-200 portion in 1-percent increments from 0 to 10 percent, based on the weight of the whole sample. As required by the Atterberg limit test, only that portion of the sample passing the No. 40 sieve was used in this determination. However, all proportions and quantities used were based on the weight of the entire (3/4-in. top size) sample. Following the addition of each percentage of minus 200 material, plastic limit tests were made and the quantity causing the first indication of plasticity was recorded. The type of minus 200 material used and the quantity required to reach the threshold of plasticity in the sample are shown in Table 3. The values are expressed as percentages of the entire gravel sample.

From these data it can be seen that quality of the minus 200 fraction exerts very little influence on the sample when present in the quantity usually allowed in base course materials. In most cases tested, the

quantity of minus 200 material required to reach even the threshold of plasticity is greater than the upper limit of 10 percent used in the tests. Only when using pure clay could significant plasticity be obtained within the limits of minus 200 material allowed by MSHD specifications. Of these, only the highly plastic montmorillonite retained significant plasticity within MSHD specification limits when mixed with 33-percent silt. The chances of finding minus 200 material containing such a high percentage of pure montmorillonite clay are very slight.

TABLE 3  
EFFECT OF MODIFYING MINUS 200 MATERIAL  
ON PLASTICITY PROPERTIES OF TWO GRAVELS

Type of Minus 200	Amount Required For Threshold Plasticity, percent of whole sample	
	22A Gravel	23A Gravel
Native to sample	10+	10+
Native material, clay size only	10+	10+
Pure kaolinite clay	5	6
Pure illite clay	7	10+
Pure montmorillonite clay	2	2
Silt + kaolinite (1:2)	10+	10+
Silt + kaolinite (1:1)	10+	10+
Silt + illite (1:2)	10+	10+
Silt + montmorillonite (1:2)	6	6
Warsaw soil fines (from Part I)	8	10+
Ionic modified Warsaw soil	8	--
Warsaw soil, clay size only	8	10+
Native to sample + lignin (3:1)	8	10
Native to sample + lignin (1:1)	--	7

The homo-ionic modifications and addition of a reasonable amount of organic material in the Warsaw soil--as used in the first part of this study--had no significant effect on plasticity of the whole sample, as compared with using natural Warsaw soil as the fines portion. However, as organic material was increased from a 1:3 to a 1:1 ratio of the total minus 200 fraction its effect on plasticity was noticeable. This represents an organic content of at least 5 percent.

From these results it would appear that with the exception of extreme cases, the plasticity characteristics of a stabilized gravel would hardly be affected by altering the quality of the minus 200 fraction. Even though plasticity tests are made only on the minus 40 portion of the gravel, restricting the minus 200 portion to 7 percent or less creates a ratio of plus 200 to minus 200 material unfavorable to plasticity. Alteration in the quality of minus 200 material could affect characteristics other than plasticity. However, it is hardly conceivable that such changes would be of a magnitude sufficient to affect the predominately plus 200 mixture. Generally, any physico-chemical changes in the finer portion of the soil are reflected to some degree by plasticity. If plasticity cannot be altered to a significant degree it is unlikely that other changes, under the same conditions, will significantly affect test results. Possible exceptions might be the effects that certain chemical treatments could have on the frost susceptibility of certain soils. Such possible effects were not included in this study.

## DISCUSSION AND CONCLUSIONS

Although a large amount of test data has been obtained during this study the scope of the project was so broad that in many cases only qualitative results can logically be derived from the information. Furthermore, the use of synthetic organic materials, although well intended and logically conceived, is subject to considerable question. This is particularly true of the powdered lignin which, although definitely an organic material, has in its manufactured form the ability temporarily to waterproof the soil with which it is in contact. This affects the rate of moisture absorption and related soil properties in a manner unlikely to be found under natural field conditions. It could also affect the comparison between soil classification tests and performance under laboratory test conditions. Another possible variable lies in the questionable stability of the ionically modified soils. There are indications that even under normal storage conditions certain of these altered soils tend to revert to their original condition or to some other ionic condition.

In spite of these limitations, however, certain trends and conclusions were obtained. The more important are:

1. Soil characteristics and properties can be altered by modifying the minus 200 portion of the sample. Such variations, however, are significant only with such fine grained soils as might be used in subgrade construction. Changes in the quality of the minus 200 portion of a normally graded stabilized gravel have no significant effect on the gravel as a whole.

2. Ionic modification alone alters certain soil properties as reflected by Atterberg limits, maximum density, and the reaction of the soil to moisture absorption and load application. By chemical substitution of certain ions, plasticity index values were changed from 12.9 to values ranging from 9.4 to 18.7. Compressive strengths of dry samples were reduced by all of the ionic treatments. These changes in soil properties could be due to the ionic treatment itself, or to effects produced by the leaching and manipulation required to alter the sample. The use of homo-ionic soils represents extreme conditions unlikely to be found in the field.

3. Addition of synthetic organic materials considerably altered the properties of both natural and homo-ionic soils. Plasticity index values varied with the amount and type of organic additive as well as with the

form of soil used. Generally, these organic materials when present in amounts not over 2 percent, lowered the plasticity index. The only significant exception was humic acid with the calcium soil. Maximum densities were reduced, generally in proportion to the amount of organic material added. Compressive strengths were increased by organic additives, but much of this increase was lost when the samples were subjected to moisture absorption and other destructive laboratory weathering tests. The temporary water repellency of the lignin had some effect on these tests.

4. In general, the performance of all the different modified samples used in the study (as indicated by compressive strength, moisture absorption, and volume change) was reflected by the Atterberg limit tests. There were several specific exceptions, however, which indicate that under certain conditions these tests should be supplemented by additional test methods before a true index of soil quality can be determined. The work indicates that extensive testing will be necessary to isolate such cases, and to determine how much of this variation is due to experimental error and how much to actual change in the material.

5. The use of synthetic materials as organic additives, although valuable and necessary for obtaining control of organic content, may not be representative of normal conditions found in soils. For this reason supplementary tests should be made, using natural soil organic materials.

6. Characteristics of normally graded gravels, as reflected by plasticity tests, could not be significantly changed by altering the physical and chemical properties of the minus 200 portion. For most of these alterations, not even the threshold of plasticity could be reached by adding up to 10 percent of the altered minus 200 material. Only when highly plastic, pure montmorillonite clay was substituted as the total minus 200 portion could plasticity be approached. From these tests it appears that the quality of the fines portion of a normally graded stabilized gravel (as reflected by Atterberg limit tests) is not a factor in the characteristics of the gravel as a whole. To be a factor, such material would have to be present in much higher quantities than allowed by MSHD specifications for base course materials. The effects of altering the minus 200 fraction on frost susceptibility of soil were not investigated in this study.

7. Oven dried samples should not be used in studying the properties of minus 200 materials. Atterberg limit test results for the soil both with and without added organic material were affected by oven drying at 105 C. It is recommended that air drying be used when preparing soils for laboratory testing.

8. The commercial grade of powdered lignin used in these studies acted as both a bonding and a waterproofing agent for the soils. Based on the dry weight of the soil, 2-percent lignin was optimum. The benefits obtained by adding lignin to fine-grained soils were severely reduced under laboratory weathering conditions, indicating that its benefits under these conditions are only temporary. A form of lignin (wood liquor from the residues of paper mills) is sometimes used for treating graded aggregate road surfaces and bases. Such treatments become quite hard when dry, but soften readily upon contact with moisture.

9. Changes in soil due to ionic modification (and to a certain extent, to the addition of organic materials) are largely surface phenomena which exert very little influence on structural properties. Tests made during this study indicate that such modifications may be of insufficient magnitude and permanence to exert a significant influence on the engineering properties of soils under field construction conditions.

10. Specialized soil testing equipment and techniques such as those involving the electron microscope, differential thermal analysis, and flame photometry are excellent methods for use in research and laboratory studies. However, at present such methods are not feasible for routine soil testing purposes. They should be used to supplement rather than to replace normal soil testing methods.

11. The effects produced by modifying the minus 200 portion of a fine grained soil can be determined quantitatively only by an extensive series of tests in sufficient quantity and of such arrangement as to permit a statistical analysis of the results. The field covered in this work was so broad that in most cases insufficient specific data were obtained to permit other than a qualitative evaluation.

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