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A LABORATORY STUDY OF THE SOIL STABILIZING EFFECTIVENESS OF A COMPLEX SALT OF ABIETIC ACID

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Technical Development Note No 35

July 1944

U S. DEPARTMENT OF COMMERCE

CIVIL AERONAUTICS ADMINISTRATION

WASHINGTON, D. C.

UNITED STATES DEPARTMENT OF COMMERCE

JESSE H JONES, *Secretary*

CIVIL AERONAUTICS ADMINISTRATION

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CA INFORMATION AND STATISTICS

FOREWORD

In a letter to the Administrator of Civil Aeronautics, dated April 3, 1942, the Director of Base Services, Army Air Forces, approved the inauguration by the Technical Development Division, Civil Aeronautics Administration, of an investigation for the purpose of developing natural or synthetic chemical substances, either organic or inorganic, that would be effective as soil stabilizing agents Endorsement of this project and certification of its military importance were given by the Secretary of War to the Secretary of Commerce in a letter dated April 21, 1942

Since this investigation was classified as being of an emergency nature, special attention has been given to the following factors in the selection of materials to be studied

1 Effectiveness and ease of application of the material under adverse construction conditions
2 Proximity of sources of the material to areas in which it may be used
3 Ease of transportation to sites where the material may not be locally available
4 Quantity of the material available for use

To date the work on this project has progressed in a satisfactory manner A report on this study entitled "Soil Stabilization by the Use of Rosin", Technical Development Note No 34, contains data showing that resinous materials can be effectively used as soil stabilizing agents The present report, "A Laboratory Study of the Soil Stabilizing Effectiveness of a Complex Salt of Abietic Acid", Technical Development Note No 35, is the second of this series As conclusive data concerning other materials under investigation become available, additional reports will be released

A LABORATORY STUDY OF THE SOIL STABILIZING EFFECTIVENESS OF A COMPLEX SALT OF ABIETIC ACID

SUMMARY

This report presents the results obtained from a laboratory investigation of the soil stabilizing properties of a complex salt of abietic acid, known commercially under the trade name "Resin Stabilizer 321." This material, a finely powdered white resinous substance, is exceptionally light, weighing only 16 pounds per cubic foot, and, not being hygroscopic, can be packaged and stored without deterioration or loss of effectiveness

In order to fully evaluate the effectiveness of this agent, eight different soil types, ranging in texture from silty fine sand to clay, were employed The response of each soil to treatment with 0 2 and 0 5 percent of stabilizer was measured by three procedures, namely, California Bearing Ratio Tests (modified), Water Absorption Tests, and Unconfined Compression Tests

While the effectiveness of the stabilizer varied with the different soils, all were greatly benefited by treatment For instance, the addition of Resin 321 more than doubled the bearing ratio value of soaked specimens of every soil type and materially reduced the amount of expansion In all cases, the rate of water absorption was greatly reduced Untreated specimens of all soils failed by slaking in less than 1 day of soaking while treated specimens remained in excellent condition even after being subjected to the same conditions for a period of 7 days The unconfined compressive strength tests showed that Resin 321 does not add to the cohesion of the soil system

It is believed that the laboratory data obtained to date are sufficiently extensive to be conclusive and that the next phase in the evaluation of this material should be the correlation of data obtained from the laboratory with observations on actual field installations. Consequently, it is recommended that field test sections be installed at an early date. If the behavior of these sections substantiates the findings of this laboratory study, then the stabilizing value of Resin 321 will have been definitely proven and use of this material for the construction of roads, runways and other pavement surfaces not subject to high wheel loadings should be of considerable value.

Since the amount of this material required for successful treatment is extremely small, its use should be especially advantageous for the construction of military installations in forward combat areas where the only feasible means of transporting materials may be by unimproved roads or by air.

INTRODUCTION

In a previous report,[1] it was shown that various types of resinous materials are effective as soil stabilizing agents. Some of these materials proved to be of especial value, being effective in quantities as small as 0.2 percent, based on the dry weight of the soil. Attention was directed to the possible military value of such agents.

Of the materials synthesized in the laboratory in our earlier studies, one, a complex salt of abietic acid, is produced on a small-scale basis by the Hercules Powder Company, Wilmington, Delaware. This compound, referred to as "Resin Stabilizer 321," is the only highly effective material so far investigated that can be made available in the quantities required for use in the present war. Therefore, it was decided to evaluate this material further before continuing with studies on the other equally, or possibly more, effective materials which are at present available only in laboratory quantities.

This decision was supported by a letter dated August 3, 1943, from the Chief of Engineers, United States Army, in which he expressed the interest of his office in the possible military use of this material. The plan of study formulated for this investigation was discussed with representatives of the office of the Chief of Enginners, and their suggestions have been incorporated in the program.

The laboratory testing was conducted at the University of Missouri and at Princeton University under contract with the Civil Aeronautics Administration.

DESCRIPTION OF MATERIALS

Resin Stabilizer 321

Resin Stabilizer 321 is the complex salt corresponding to one molecule of sodium abietate and three molecules of abietic acid. It is compounded by reacting sodium hydroxide with abietic acid in such proportions that one-fourth of the acid is neutralized. The results of an investigation of the chemical properties of this material are discussed in the Appendix.

The resin is a very finely powdered white substance having a melting point of 155° to 160° C. It is not hygroscopic and may be conveniently packaged and stored without deterioration or loss of effectiveness. As produced, the material

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[1] Hans F. Winterkorn and George W. McAlpin, "Soil Stabilization by the Use of Resin," Technical Development Note No. 34.

is exceptionally light, having a weight of only 16 pounds per cubic foot

At the present time, the available quantity of this material is rather limited, however, the amount is adequate for extensive laboratory and field investigations. It is understood that the manufacturer has perfected a large-scale production process and that a plant capable of producing sufficient quantities to meet any demands can be constructed in a comparatively short time

Soils

Eight different soils, varying in texture from silty fine sand to clay, were used in this study The plasticity index of these soils ranged from 2 to 31

In all soil stabilization by the use of chemicals, especially where the quantity of admixture employed is very small, the chemical properties of the soils are of considerable importance For this reason, the base exchange capacity, the base saturation, the percent of carbon, the percent of organic matter, and the pH values have been carefully determined for each of the soils These data, together with the physical properties of the soils, are shown in table I The grain size-distribution curves are shown in figure 1 and the moisture-density relationships in figure 2.

TESTING PROCEDURES

Unfortunately, there exists no generally accepted laboratory method of evaluating the soil stabilizing effectiveness of chemical admixtures The test procedure employed for soil-cement is not applicable and most of the sixteen or more methods used for soil-bitumen do not appear to be sufficiently consistent to be adopted for the evaluation of a new type of stabilizing material

Since the California Bearing Ratio Test[2] is now extensively used for the design of base courses for flexible pavements, it was employed as the basic test for this study, with such slight modification as appeared necessary for the proper evaluation of a chemically treated soil Inasmuch as the chief factor in the action of Resin 321 as a soil stabilizer is its ability to reduce the moisture absorption of a soil, tests were performed to obtain additional information on this factor At the completion of the absorption cycle, supplemental data were obtained on the comparative strength of treated and untreated specimens by running unconfined compression tests

California Bearing Ratio Tests

The California Bearing Ratio tests were made on representative soil samples containing 0 0, 0 2, and 0 5 percent, respectively, of Resin Stabilizer 321 In preparing the treated specimens the chemical was added to the dry soil and thoroughly dispersed before the addition of the water

Before proceeding with the evaluation of the expansion and bearing ratio values, it was necessary to determine the moisture-density relationship for each soil sample to be tested This was done by the static-load method In this procedure samples of each soil (approximately 14 pounds) were mixed with increments of water to obtain a range of moisture contents well on both sides of the optimum Each sample was then placed in a 6-inch diamter mold, lightly tamped, and compressed

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[2] O. J Porter, "The Preparation of Subgrades," Proc., Highway Research Board, Vol 18, Part II (1938); also, O J. Porter, "Foundations for Flexible Pavements," Proc , Highway Research Board, Vol. 22 (1942)

TABLE I

IDENTIFICATION OF THE SOILS EMPLOYED

Physical Characteristics								
Lab. Symbol	Series and Texture	Specific Gravity	Liquid Limit(1)	Plastic Limit(1)	Plasticity Index	Shrinkage Limit(1)	Optimum Moisture(1)	Maximum Density (2)(3)
P	Stephenville Loam sand	2.65	19.0	17.0	2.0	-	11.3 (4)	110 2 (4)
B	Zaneis Sandy Clay	2.66	22.1	18.0	4.1	14.4	10 7 (4)	124.0 (4)
E	Durant Sandy Loam	2.63	22 5	18 3	4 2	15 3	10 4	125 2
L	Foard Loam	2 64	23 4	17 8	5 6	16 3	10.8	122 3
U	River Wash Silty Clay Loam	2.68	31 8	20.1	11 7	14 9	11.5	125.7
M	Zaneis Clay Loam	2.65	32.1	18 4	13 7	15.6	12.3	126.0
N	Miller Silty Clay	2.68	44.9	18 8	26 1	12 6	13 5	124.0
V	Vernon Clay	2 72	53 5	22.4	31 1	12.7	15 0	119 0

Chemical Characteristics										
Lab Symbol	Base Exchange Capacity(5)	Base Saturation(5)(6)						pH Value	Carbon(1)	Organic Matter(1)
		Ca	Mg	Sr	Mn	K	Na			
P	5.62	3.59	1 91	0 004	0 026	0.490	2 95	6.9	0.56	1 00
B	9 28	4.77	3.81	0.016	0.032	0.492	2 89	6 5	0 76	1 36
E	8 84	6.15	2 16	0.013	0 190	0 358	2 73	6 4	1 38	2 47
L	8.71	6.20	3.12	0 026	0 286	0.435	2.88	7.0	0 82	1 47
U	10.15	19 86 (7)	3 88	0.046	0 053	0.691	3.62	7.7	0 74	1.32
M	16.24	8.46	8 92	0.022	0 024	0 569	3.06	6 5	1 00	1.79
N	13 59	8.45	6.56	0.042	0.082	0 883	3 65	6.6	1.10	1 95
V	18 48	11 46	8.20	0.022	0.043	0 944	2.95	6.7	1 70	3 04

(1) Expressed in percent by weight of dry soil (2) Static-load method - 2000 pounds per square inch
(3) Dry weight in pounds per cubic foot. (4) The moisture - density relationship for these soils was difficult to determine by the static-load method The values given are those used in molding the specimens. (5) Expressed in milli-equivalents per 100 grams of soil (6) Calcium was determined by titration - others by use of spectroscope (7) Due to Calcium Carbonate ($CaCO_3$).

under a static load of 2,000 pounds per square inch In applying the load between 1,000 and 2,000 pounds per square inch, the head of the hydraulic testing machine was lowered at a rate of approximately 0 05 inches per minute The maximum load was maintained on the sample for 1 minute before being gradually released during a period of about 20 seconds

The dry densities[3] for the various moisture conditions of each sample were obtained, the values plotted against their corresponding moisture contents, and a smooth curve drawn through the resulting points The weight per cubic foot and the corresponding percentage of moisture at the peak point of this curve were taken as the maximum dry density and the optimum moisture content, respectively, of the particular soil

In preparing the specimens for the California tests the soil was mixed with an amount of water corresponding to the optimum moisture content, placed in a 6-inch diameter mold, lightly tamped, and compacted by the application of a static load, as previously described

The compacted specimens, still in the mold, were oven-dried for about 2 days at a temperature of 65° C[4] They were then weighed, covered with a 7-inch filter paper, and a perforated base plate clamped over the top The mold was then inverted and a filter paper, a perforated base plate with an adjustable stem, and a 10-pound surcharge were placed on top of the specimen A gage and tripod assembly, used for measuring the amount of swell of the specimens, was fastened over the mold and the stem of the perforated plate was adjusted to give a zero gage reading The mold was then placed in a tank, surrounded with water to a level below the top of the mold, and the specimen allowed to absorb moisture from the bottom by capillarity for a period of 24 hours At the end of this time the gage reading measuring the amount of expansion was noted, and the specimen was removed from the tank and weighed to determine the amount of water absorbed

The mold was again placed in the tank of water, this time being completely immersed, and allowed to soak for 4 days During this time the expansion was measured twice a day and the percentage thereof calculated in terms of the height of the specimen before soaking

At the end of the soaking period, the 10-pound surcharge, the perforated plates, and the filter paper were carefully removed The specimen was allowed to drain for 1 minute, after which its weight was determined

The same specimen, still remaining in the mold, was used for the penetration test A 10-pound surcharge was placed on top of the specimen before it was centered under the loading head of the testing machine. The penetration piston, having an end area of 3 square inches, was firmly seated on the specimen and the dial adjusted to a zero reading before the start of the test. In applying the load, the head of the machine was lowered at a rate of approximately 0.05 inches per minute The load in pounds per square inch was recorded at points of 0 05, 0 1, 0.15, 0 2, 0 3, 0.4,

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[3] Dry density $= \frac{W}{V(1+w)}$, where W = total weight of the specimen as molded; V = total volume of the specimen, w = the moisture content of the specimen $= \frac{\text{weight of water}}{\text{dry weight of soil}}$. Knowing the diameter of the mold, the volume of the specimen was computed by measuring its height The moisture content was determined from small representative samples of the soil

[4] This departure from the standard California procedure was found to be advisable as a result of earlier experiments in which the triaxial compression test was used These tests showed that in order to develop its greatest stabilizing powers, Resin 321, the same as other chemical and bituminous stabilizing agents, requires a certain amount of curing or drying back

and 0 5 inches of penetration From these results the bearing ratio (relative bearing value) of the treated and untreated specimens was computed as a percentage of the following standard loads for each increment of penetration

Penetration in Inches	Standard Load in Pounds per Square Inch[5]
0 1	1000
0 2	1500
0 3	1900
0 4	2300
0 5	2600

Water Absorption and Unconfined Compression Tests

For these tests, specimens 2 inches in diameter and 2 inches in height were prepared with 0 0, 0 2, and 0 5 percent of Resin Stabilizer 321 All specimens were compacted to the maximum density at optimum moisture content as previously determined by the static-load method

Forty-two specimens were molded for each soil - 14 for each percentage of admixture Duplicate specimens were exposed to the following conditions of treatment

a No drying back, no soaking
b Drying back to 75, 50, and 25 percent, respectively, of the optimum moisture content
c Drying back to 75, 50, and 25 percent, respectively, of the optimum moisture content, and subsequent soaking

At the completion of each of these conditions of treatment, the unconfined compressive strength of the specimens was determined For the soaked specimens, the rate of moisture absorption was measured

Drying was accomplished in an oven, the temperature of which ranged from 50° to 70° C After the specimens were removed from the oven, they were placed in an airtight container for 48 hours to allow for a uniform distribution of the moisture content

The procedure employed for soaking the specimens consisted of placing them in 1-7/8 inches of water for 7 days During this period, the specimens were periodically removed from the water, weighed, and the increase in moisture content computed

The unconfined compressive strength tests were run on a Carver hydraulic press at a constant rate of load increase Only the load at failure was recorded

TEST RESULTS

The data obtained from the California Bearing Ratio tests, the moisture absorption and the unconfined compression tests, follow this text On the basis of these data, the following statements may be made

California Bearing Ratio Tests

(See figures 3 through 11)

1 Treatment with Resin 321 greatly increased the bearing ratio value of all soil employed in this investigation

[5] Values for crushed stone

2 In all cases but one (soil P), treatment with 0.5 percent of Resin 321 proved more effective in increasing the bearing ratio value than treatment with 0.2 percent

3 The increase in effectiveness of 0.5 percent of Resin 321 over 0.2 percent, as measured by their bearing ratios, was not proportional to the amount of admixture used except with soil N.

4 In all cases but one (soil E), treatment with Resin 321 reduced by more than 50 percent the expansion upon exposure to water

5 In four cases (soils L, U, N, and V), 0.5 percent of Resin 321 was more effective than 0.2 percent in reducing the expansion; in one case (soil M), 0.2 percent was more effective than 0.5 percent, in three cases (soils P, B, and E), only slight differences were observed between the effectiveness of treatment with 0.2 percent and 0.5 percent

6 In the case of the untreated soils, those that showed the greatest expansion upon exposure to water also showed the lowest bearing ratio values

7 Treatment with Resin 321 decreased the water absorption in all cases

8 In all cases, treatment with 0.5 percent resulted in less absorption than treatment with 0.2 percent

9 The decrease in the percent of absorption was most pronounced in the less plastic soils (P, B E, and L).

Water Absorption Tests

(See figures 12 through 16)

10 Treatment with Resin 321 greatly reduced the moisture absorption of all soils tested

11 All untreated specimens failed by slaking in less that 1 day of immersion in water

12 For all soils except U, treatment with Resin 321 prevented failure upon immersion in water

13. For similar moisture contents at the beginning of soaking, the percent of optimum moisture obtained by the treated specimens after 7 days of soaking was less than that obtained by the untreated specimens in 1 hour of soaking, for all soils except U

14 In most cases, 0.5 percent of Resin 321 was more effective in reducing the water intake than 0.2 percent.

15 The increase in effectiveness of 0.5 percent over 0.2 percent was not proportional to the amount of admixture used.

16 The water content of treated specimens of soils E, B, L, and M, which had been dried back to moisture contents of approximately 60 percent of optimum, was, after one day of soaking, below the optimum moisture for compaction The water content of the treated specimens of soils P, N, V, and U exceeded the optimum moisture content under the same conditions.

17 In all cases of treated soils, drying of the specimens previous to soaking decreased their final water content. No critical moisture content was found below which drying would be undesirable.

Unconfined Compression Tests

(See figures 17 and 18)

18 All untreated specimens failed upon immersion in water and consequently no compressive strength data could be obtained

19 After 7 days of soaking, the treated specimens of each soil, which had moisture contents at the beginning of soaking of approximately

70 percent, had compressive strengths (expressed in pounds per square inch) as follows E – 86, M – 80, B – 68, P – 36, L – 36, N and V – less than 32, and U – failed during immersion.

20 For similar moisture contents at the time of the test, the treated specimens that were soaked had considerably less compressive strength than those that were not soaked

21 For the specimens that were tested at moisture contents attained by drying-back alone (no soaking), the strength-moisture content relationship of the treated and untreated specimens, was very similar

22 In the unsoaked condition, both the treated and untreated specimens of soils N, M, V, and U showed considerably greater strengths at the lower moisture contents than did the specimens of soils E, B, L, and P

DISCUSSION

Test Methods Employed

In order to understand the true meaning of the test data presented, it is necessary to study the relationship between the test method employed and the properties of the soil systems evaluated by each of these methods

The California Bearing Ratio Test was developed primarily for use in the design of flexible pavement base courses and is of value because it has been correlated with field performance Being of an empirical nature, however, the test possesses meaning only for those materials for which it was designed, namely, natural soils The standard test procedure prescribes a soaking period of 4 days which for natural soils is usually sufficient to permit saturation of that portion of the specimen within the action zone of the penetration plunger However, for waterproofed soil specimens in which the rate of water absorption is retarded, this saturated condition may not occur within the specified time Consequently, the bearing ratio data from such soil systems cannot be used in conjunction with the standard design curves which were developed for use with natural soils In the present study the bearing ratio data are used only as a means of indicating the relative effect of treatment on the stability of the soil

Another factor to be considered in reviewing the data from the California test is the relationship between the rate of penetration and the viscous or plastic resistance of the tested specimens It is a well-known fact that the reaction of a plastic material, such as asphaltic cement, to an imposed load depends on the rate at which the load is applied, while appearing rigid under a sudden application, such materials tend to flow when the same or even lesser loads are applied more slowly It is possible, therefore, that the rate of penetration specified for these tests is too high for waterproofed cohesive soil systems and that some of the high-bearing ratios obtained in these tests are more indicative of the compressibility of the soil sample than of its stability. It is not known to what extent each of these contribute to satisfactory behavior in the field where fleeting rather than stationary loads are the rule Such questions can only be answered by actual experimental field installation

As described under "Testing Procedures," all specimens used in the California Bearing Ratio tests were partially dried before being immersed The shrinkage resulting from this drying was sufficient, in the cases of the more plastic soils, to cause a void between the specimens and the sides of the mold Consequently, at the start of the soaking period, water was accessible to the specimen from the sides as well as from the top and the bottom A review of the test data shows that this shrinkage caused no significant discrepancies in the test results, due, most likely, to the fact that the specimens swelled quickly when wetted, thereby completely refilling the mold

Water Absorption Tests in which unconfined 2-inch specimens were immersed for a period of 7 days, give more representative data on the water absorption properties of the soil than do corresponding results obtained from the California Bearing Ratio Tests where larger specimens were soaked for only a 4-day period

These tests, however, are not suitable for use with soils, or soil systems, possessing low cohesive properties, since in these cases the specimens often fail by slaking due to a lack of lateral confinement This condition also holds true for calcareous materials such as caliche and for soils containing large amounts of calcium carbonate Such materials, although making excellent base courses when laterally confined, may disintegrate rapidly when subjected to moisture while in an unconfined condition It is, therefore, apparent that although the unconfined moisture absorption test does give an indication of the effect of treatment with most soils, for the special materials mentioned above, it possesses neither quantitative nor qualitative value for determining their suitability for field construction

Unconfined Compressive Strength Tests on specimens that have been previously subjected to soaking provide a means of evaluating the stabilizing effectiveness of Resin 321 However, the severity of the immersion test employed in this study caused many of the specimens to fail before a measure of their strength could be made By confining the specimens during the soaking and compression tests, more quantitative data could be obtained

The strength of specimens that have not been soaked previous to testing is not indicative of the degree of stabilization These data were of value in this study, however, for determining whether or not Resin 321 added to the cohesion of the soil system

In summarizing, it may be said that in order to evaluate properly the test data and to fully understand the discussions which follow, it is necessary to keep in mind the foregoing ideas concerning the test methods Although it may seem that the tests employed show little correlation between laboratory and field, it must be remembered that no laboratory tests now in use offer a direct indication of what happens in an actual field placement of chemically stabilized soil The results obtained indicate only the relative value of treatment by Resin 321 as measured by the best laboratory tests now available for approximating the various factors affecting field installations

Effect of Resin 321

All test data obtained in this investigation show that treatment with Resin 321 reduces the moisture absorption of soils This reduction pertains not only to the total amount of water absorbed but also to the rate at which this absorption occurs While both effects are important, it appears that the latter is the more significant. It is known that a certain amount of water, if rapidly absorbed, may destroy the coherence of a soil specimen, while if slowly absorbed may leave the specimen intact, resulting only in a lowering of its compressive strength[6] This phenomenon was best illustrated by a number of tests made during this study in which untreated specimens failed on reaching moisture contents at which the treated samples stood up quite well That this is due to different rates of water intake seems certain since the stabilizer does not add to the cohesive properties of the soil This latter fact is confirmed by a study of figures 17 and 18 From these curves it can be seen that, for unsoaked specimens, the moisture content-compressive strength relationship is practically independent of the percentage of treatment.

The compressive strength of the treated specimens was found to depend not only on their water content but also upon the manner in which this value was reached. For equal water contents, a specimen which had been dried back from a higher to a lower value showed greater compressive strength than one which had reached the same water content from the dry side by absorption This phenomenon, which is of both practical and theoretical significance, has been observed to occur also in other types of stabilized soil

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[6] Hans F Winterkorn, "The Mechanism of Water Attack on Dry Cohesive Soil Systems," - Soil Science, Vol 54, No 4, (1942)

The data obtained in this investigation do not allow the drawing of definite conclusions concerning the optimum amount of stabilizer to be used with the different soils, as only two different percentages of the stabilizer were employed. However, the bar graph shown in figure 11, which summarizes the effect of Resin 321 on moisture intake, shows little difference between the influence of 0.2 and 0.5 percent of the stabilizer. While this observation is substantiated by the moisture absorption data from the California tests, the bearing ratio values for the more plastic soils, especially soil N, are considerably higher with 0.5 percent of the stabilizer than they are with 0.2 percent. On the basis of the data obtained in this and previous work, it may be stated that the optimum amount of stabilizer probably lies between 0.2 and 1 percent, the optimum increasing with the amount and activity of the clay contained in the soil system. Experiments made previously with Resin 321 and similar resin complexes of higher alkali content indicate a shifting of the optimum amount required toward smaller values with an increasing alkali content of the stabilizer. Consequently, an increase in the amount of Resin 321 above its optimum range does not result in an improved stability and in some cases may even be detrimental. The fact that there is an optimum amount of alkali that may be added to a soil to obtain best results is corroborated by experiments in which soap was used in combination with road oil for soil treatment.[7] Although substances with higher alkali content represent a more active stabilizer than Resin 321, they are more hygroscopic and necessitate greater care in shipping and application.

Relative Susceptibility of the Soils to Stabilization

One of the primary purposes of this investigation was to determine the effectiveness of Resin 321 in treating different types of soils. The soils used were selected on the basis of their physical characteristics and vary from silty fine sand (P) to clay (N and V). In order to judge the soils on the basis of their suitability as base courses or temporary wearing surfaces after treatment with Resin 321, they have been arranged in accordance with the data obtained from the different tests. Inasmuch as no single test employed tells the entire story about a soil, a composite rating has been made that gives appropriate weight to the rating obtained from each test. All ratings are based on the performance of the specimens treated with 0.5 percent of Resin 321 and are arranged in order of descending acceptability.

The data from the different tests indicate the following ratings of the soils:

California Bearing Ratio Tests	
a. Bearing ratio value	E, B, N, L, U, V, M, P
b. Expansion during soaking	B, P, E, L, U, M, N, V
Water Absorption Tests[8]	E = B, M = L, P, N, V, U
Unconfined Compression Tests on Soaked Specimens	E, M, B, P = L, N = V, U

Since the bearing ratio and expansion data were obtained on the same specimens, these results can be correlated to obtain a composite rating of the soils. The same procedure can be followed for the absorption and compression test data, since they, too, were obtained on similar specimens. These composite ratings follow:

California Bearing Ratio Tests	E = B, L, U, M, V, (N and P, indefinite)

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7 "Oiling of Earth Roads, Application of Surface Chemistry," Industrial and Engineering Chemistry, (1933).

Water Absorption Tests and Unconfined Compression Tests on Soaked Specimen	E = B, M = L, P, N, V, and U

It will be noted that the ratings are quite similar The best graded soils, E and B, rank highest while the most plastic soil, V, is shown to be the lease desirable It is believed that the merits of soils N and P relative to the other soils, although indefinite in the California tests, are fairly well shown by the absorption and compression test data The variation in the rating of soil U is probably due to difference in the types of tests, in the California method the specimens are confined while in the other tests they are unconfined

Further understanding of the effectiveness of Resin 321 with the different soils can perhaps be obtained by discussing the specific characteristics of each soil that may influence its susceptibility to stabilization

Soil P has a mechanical composition of 77 percent sand, 12 percent silt, and 11 percent clay, and a plasticity index of two The absorption data indicate that Resin 321 is effective in reducing the water intake of this soil The bearing ratio value of the treated specimens, while the lowest of all the soils tested, was more than twice that of the untreated specimens It appears that this soil does not possess sufficient cohesion to be rendered suitable for use as a wearing surface by a purely waterproofing agent However, if it is to be confined, as in a base course, it should perform satisfactorily, and such treatment would be beneficial

Soil U has a mechanical composition of 39 percent sand, 41 percent silt, and 20 percent clay Its liquid limit is 31.8 percent and its plasticity index 11 7 On the basis of these physical characteristics, this soil would normally be expected to make a good showing in all the tests However, as indicated by the different order of rankings, its performance was somewhat irregular In the moisture absorption tests the treated specimens showed distress after only 3 days of soaking, and their moisture content at the end of this time had reached 200 percent of the optimum for compaction In the California tests, however, where the specimen was confined during the soaking period, treatment greatly increased the bearing ratio value and decreased the amount of expansion

An explanation of this divergence of action may be found in the chemical properties of soil U This soil is the only one employed in the investigation that gives an alkaline reaction It has a pH value of 7 7 and contains 1 28 percent of calcium carbonate, which is a relatively high amount for such materials It is known from past experience that the presence of free carbonate in such proportions makes a soil susceptible to slaking when immersed in water, if unconfined However, when confined, such soils have been found to perform satisfactorily. This same trend has been noted in granular stabilization when the action of limestone aggregate and screenings has been compared with that of silicious gravel Unconfined water absorption tests on specimens containing these materials usually indicate that the gravel is superior, while the results from actual field installations show the limestone to be the more desirable For this reason, it appears that the ef-

[8] This rating is based on the absolute increase in moisture content of those specimens, which, before soaking, had been dried back to a moisture content of 70 percent of optimum It is difficult to decide whether it is more appropriate to express the amount of water intake by this method or as a percentage of the respective optimums of each soil The latter basis is theoretically attractive and may also be of practical importance when the percentage of air voids remains constant However, from an engineering point of view, a water intake of, for example, 150 percent of the optimum may affect two soils in an entirely different manner For instance, an intake of such an amount of water would cause a highly cohesive soil to expand much more than it would a soil low in cohesion The effect of such volume change is not considered when the water intake is expressed as a percentage of the optimum This fact should be kept in mind when evaluating water absorption data For the tests in this study, however, the same rating of the soils was obtained by each method

fectiveness of Resin 321 with soils containing calcium carbonate cannot be properly evaluated by unconfined water absorption tests

Soil B has a mechanical composition of 67 percent sand, 11 percent silt, and 22 percent clay Its plasticity index is 4 1 Experience in bituminous soil stabilization has demonstrated that soils containing 65 percent or more of coarse-grained components usually respond well to treatment The main reason for the good showing of soil B is probably its gradation Of importance also is the low coefficient of permeability This value, for a dry density of 110 pounds per cubic foot, was 5 x 10^{-8} centimeters per second The pH value of 6 5 shows that the soil reacts slightly acid, a fact that is favorable to the action of Resin 321

Soil E has a mechanical composition of 50 percent sand, 32 percent silt, and 18 percent clay While the consistency indices for this soil are the same as those for soil B, it does not have as good a sand-silt ratio However, its silt-clay ratio is somewhat better than that for soil B Noteworthy in comparing the properties of these two soils is their content of organic matte , which is 2 47 percent for soil E and 1 36 percent for soil B Past experience has demonstrated that dry-land organic matter may be very helpful in the stabilization of soil, in contrast to wet-land organic matter which is usually detrimental Inasmuch as the organic matter contained by these soils is of the dry-land type, the good showing of soil E may be partly due to its higher organic matter content

Soil L has a mechanical composition approximating that of soil E, namely, 55 percent sand, 28 percent silt, and 17 percent clay However, the performance of soil L is considerably inferior to that of soil E Major differences in character of these two soils are. Soil L has a permeability of the order of magnitude of 10^{-7} centimeters per second which is about 10 times more pervious, at comparable densities, than soil E, soil L contains only 1 47 percent organic matter, as compared to 2 47 percent contained by soil E, soil L is neutral, possessing a pH value of 7 as compared with one of 6 4 for soil E

Soil M has a mechanical composition of 45 percent sand, 30 percent silt, and 25 percent clay The clay portion of this soil is very active, as shown by the shrinkage of the California specimens from the molds during drying and by the high base exchange capacity

This latter property also indicates a high water affinity, a fact indicating that water may be attracted to the soil with sufficiently great energy to offset the advantage of its low permeability, which is of the order of magnitude of 10^{-9} centimeters per second In comparing the action of soils M and L, it should be noted that the water affinity of soil M is much higher than that of soil L This fact is illustrated by the differences in their base exchange capacities,, 16 24 milli-equivalents per 100 grams of soil against 8 71, and also by the difference in their liquid limits which for soil M is 32 1 percent and for soil L 23 4 percent

Soils N and V have mechanical composition, respectively, of 33 and 34 percent sand, 27 and 21 percent silt, and 40 and 45 percent clay They are the most plastic of the soils employed, the plasticity index of N being 26 1 and that of V being 31 1 Both soils exhibit a great affinity for water and, during moisture absorption and drying, both undergo considerable volume change While both the water affinity and the volume change are reduced by the addition of Resin 321 the properties of the treated systems are still far from those of a desirable base course material.

The data and discussions presented so far on the relative merits of the different soils after treatment with Resin 321 makes it apparent that the gradation of a soil is an important factor with regard to its susceptability to stabilization It is true, of course, that in all types of stabilization work, the more nearly the graduation of a soil approximates that of a mechanically stabilized system or of an E-39 soil, the less the stabilizing effort required.

While gradation is thus very important, the preceding discussion of the individual soils shows definitely that it is not the whole story It may be stated that any and every physical and chemical property possessed by a soil influences its susceptibility to chemical stabilization This situation presents an open invitation for attempts to find a single correlation between the susceptibility of the soil to stabilization and one or more of the better known soil properties, such as the plasticity index, content of organic matter, pH value heat of wetting, etc Although these attempts may produce important information, they are liable to lead to over-emphasis on some one factor The only way to avoid succumbing to some of the attractive but dangerous half-truths is to survey the problem from the focal point of a single theoretical concept of the action mechanism of the Resin 321

A Theoretical Concept of the Stabilizing Action of Resin 321[10]

Resin Stabilizer 321 possesses a balanced inorganic and organic character, which may also be called a hydrophilic and a hydrophobic character The hydrophilic character is mainly due to its alkali content which also makes it a good dispersing agent for most soils The hydrophobic character is due to the bulk of the abietic acid molecule These characters are localized on specific parts of the complex molecule of the stabilizer and induce the molecule to orient and arrange itself in accordance with the inorganic or organic nature of the material with which it comes in contact The balanced character of this agent is furthermore evidenced by the fact that it is neither soluble in water nor, so to speak, insoluble, but disperses easily into particles of ultra-micron size On the other hand, the water affinity of the material is small enough not to attract water from a moist atmosphere

Because of its alkalinity and spontaneous dispersion into ultra-microns in contact with water, the stabilizer may exert a dispersing effect on the treated soil Such an effect often results in a greater final density than that obtainable without treatment This greater density results also in a decreased permeability However, whether this dispersing effect is evident or not, a decrease of the permeability of the soil can be expected by transfer of sodium ions from the stabilizer to the soil, making the latter, at least in part, a sodium soil It is well known that the sodium modifications of most soils possess the lowest permeabilities for a given pore space and pore size

After or while fulfilling the function of making a soil less pervious, the stabilizer becomes irreversibly changed in such a way that it loses its dispersing power There is no reason to believe that there exists only one specific mechanism for the latter process, rather, a great number of reactions may and probably do occur either singly or in unison The irreversibility may be caused by exchange reaction between the sodium and the hydrogen ions on the stabilizer and the hydrogen and other adsorbed ions on the soil particles The type and amount of humus in the soil undoubtedly play a role in this connection The irreversibility may also be caused by purely physical adsorption phenomena, or by any and all physical or chemical surface phenomena, which are known to play a roll in the soils In this connection the importance of microbiological phenomena must not be overlooked

This fixing of the stabilizer by the soil occurs already in the moist medium, however, drying accentuates this fixing by inducing the complex molecules of the stabilizer to orient their inorganic hydrophilic faces towards the inorganic soil particles and their hydrophobic resinous ends toward the atmosphere

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[9] Civil Aeronautics Administration's classification (corresponds to an A-1 soil as classified by the Public Roads Administration)

[10] This concept, while a product of intuition rather than of detailed analysis, appears to be contradicted by none of the known facts, indeed, it appears to be the only concept which harmonizes some apparently contradictory data The respective ideas were conceived by Dr Hans F Winterkorn during the winter of 1942-43 and were recorded in affidavit sworn to on May 22, 1943

Becoming fixed in this position, the stabilizer shields the water attraction centers on the soil particles and does not permit easy wetting of the system The stabilizer decreases the water affinity as well as the accessibility of the internal surface of cohesive soils while interfering little or not at all with their cohesion In this connection it should be stated that the resin stabilizer is usable only for soils of sufficient clay content to possess inherent cohesion under dry and moist conditions The stabilizer does not add cohesion to a system; rather it tends to maintain the natural cohesion of the soil by preventing the entrance of excessive amounts of water

It should be kept in mind that Resin 321 is not an unique material but only one member of a large family of actual or possible resinous stabilizing agents Other members of this family have already been investigated or are being investigated in the laboratory at the present time

CONCLUSIONS

From the results of the investigation described in this report, the following conclusions are drawn with respect to the soil stabilizing effectiveness of Resin 321

1. Treatment with Resin 321 reduces the total amount and the rate of water absorption and, through this action, protects cohesive soil systems against the detrimental effect of moisture fluctuations
2. The quantity of stabilizer required for effective treatment is very small; 0.2 percent, on the basis of the dry weight of the soil (approximately 1 pound per square yard for a 6-inch depth of treatment), greatly improved all soils tested in this study
3. Resin 321 is mainly a waterproofing agent and does not add to the natural cohesion of a soil, therefore it is not effective with soils possessing low cohesive properties
4. The action mechanism of Resin 321 is very complex; for this reason, experiments and observations designed to further its evaluation must be based on as broad a factual foundation as possible

Since these data show that, from a laboratory point of view, Resin 321 is an effective stabilizing agent, it is recommended that its evaluation be furthered by the construction of field test sections

APPENDIX

CHEMICAL TESTS MADE FOR THE CHARACTERIZATION OF RESIN STABILIZER 321

Tests Performed

1. Determination of the acid number of Resin 321 by means of the A.S.T M method D464-42 and by a modified method permitting longer time of reaction between the alkali and the stabilizer
2. Gravimetric determination of the sodium content of Resin 321
3. Determination of the melting point of Resin 321 on the plate of a Fisher-Johns melting point apparatus
4. Determination of the melting point of pure abietic acid prepared from Resin 321
5. Potentiometric titration of pure abietic acid with alkali in an aqueous medium
6. Potentiometric titration of the Resin 321 with alkali and acid, respectively, in an aqueous medium.

7. Determination of moisture absorption of completely and partially neutralized rosin in an atmosphere over a 30 percent aqueous solution of sulfuric acid at room temperature.

Discussion of Results

The data obtained in tests 1 through 4 are given in table II. They show that Resin 321 is a derivative of abietic acid with a composition corresponding very closely to the theoretical composition of the complex salt consisting of 1 molecule of sodium abietate and 3 molecules of abietic acid. The fact that the acid number of the stabilizer is somewhat lower than the theoretical, and that the melting point is also lower than that found by other investigators for the above named complex salt, indicates the presence of some impurities. However, the melting points for this type of materials are rather erratic and consequently are not always reliable criteria.

The data obtained in tests 5 and 6 are given graphically in figure 19. This figure shows that the alkali contained in the commercial stabilizer is considerably less active than the alkali in a freshly prepared material of the same composition. This behavior is due to the fact that aqueous dispersions of alkali-abietic acid complexes represent colloidal systems in which aging plays a considerable role. This is an important characteristic with respect to the use of these materials in soil stabilization, a logical consequence of this characteristic is the improvement of the water resistance of soils treated with a compound such as Resin 321 by dry-curing previous to exposure to water.

The data obtained in test 7 are given in table III. They indicate that abietic acid which has one-fourth of its acid number satisfied by sodium ions (this corresponds to the composition of Resin 321) possesses a low water affinity. This is an advantage in the case of shipping under conditions of high atmospheric moisture content.

TABLE II

A COMPARISON OF THE PROPERTIES OF RESIN STABILIZER 321, ABIETIC ACID, AND A COMPOUND CONSISTING OF 1 MOLECULE OF SODIUM ABIETATE AND 3 MOLECULES OF ABIETIC ACID

Compound	Acid Number	Percent of Sodium	Melting Point
1 sodium abietate - 3 abietic acids	136.4 (1)	1.86 (2)	170-175 (2) 205-208 (3)
Resin Stabilizer 321	126.0 (4) 133.5 (5)	1.64 (6)	155-161
Pure abietic acid prepared from Resin Stabilizer 321	184.8 (7) 185.8 (1)		164 (8)(7)

(1) From theoretical computations
(2) Dupont and Desalbres
(3) Palkins and Harris, J. A. C. S., Vol. 56, (1934)
(4) A. S. T. M. method
(5) Modified method permitting longer time of contact.
(6) Possibility of small loss in gravimetric analysis due to non-availability of platinum ware
(7) As found in laboratory

(8) The following data are given in the literature for the melting point of abietic acid obtained by
  a Vacuum distillation of rosin - 158° C
  b Extraction with boiling acedic acid - 161°-165° C
  c Crystallization from colophony - 137° -166° C

TABLE III

MOISTURE ABSORPTION OF COMPLETELY AND PARTIALLY NEUTRALIZED ROSIN IN AN ATMOSPHERE OVER A 30 PERCENT AQUEOUS SOLUTION OF SULFURIC ACID AT ROOM TEMPERATURE

	Percent of water intake on basis of dry weight specimen			
Percent Neutralization	1 day	3 days	1 week	2 weeks
100	11 05	13 4	15 5	16.7
75	7 72	8 56	9.15	10 4
50	4 26	4 52	4 55	6.55
25 (Resin 321)	1 75	1 86	1 91	3 11
0	0 18	0 18	0 2	0 3

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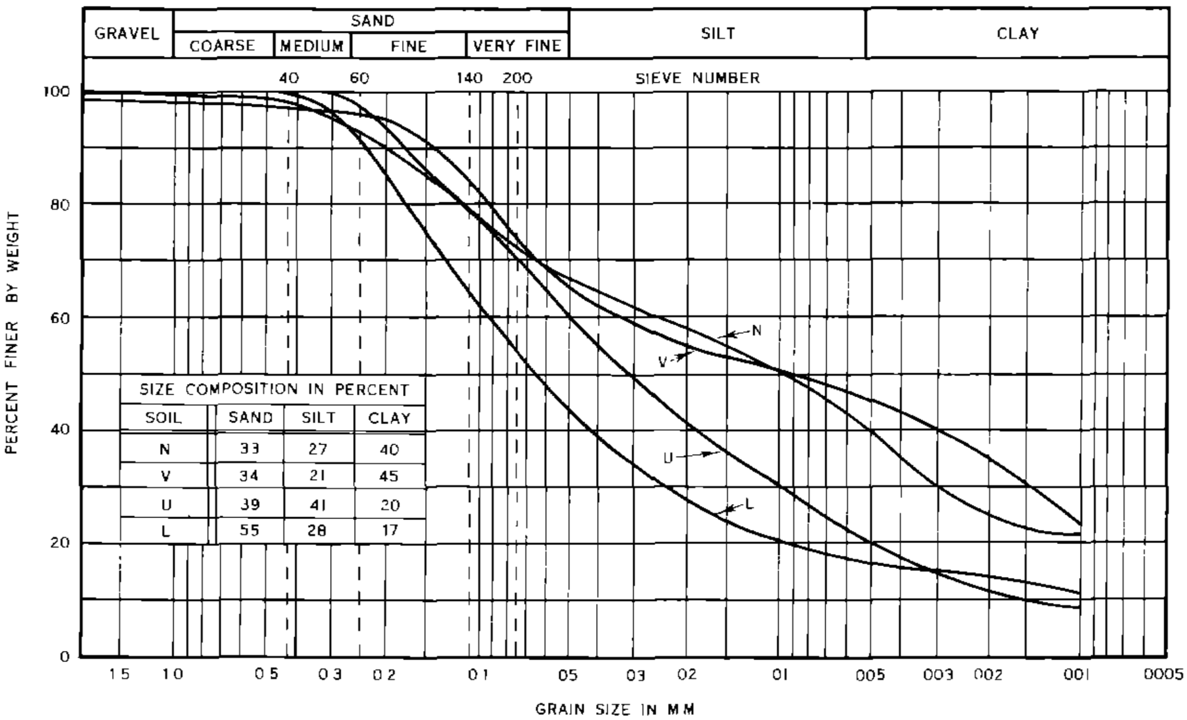


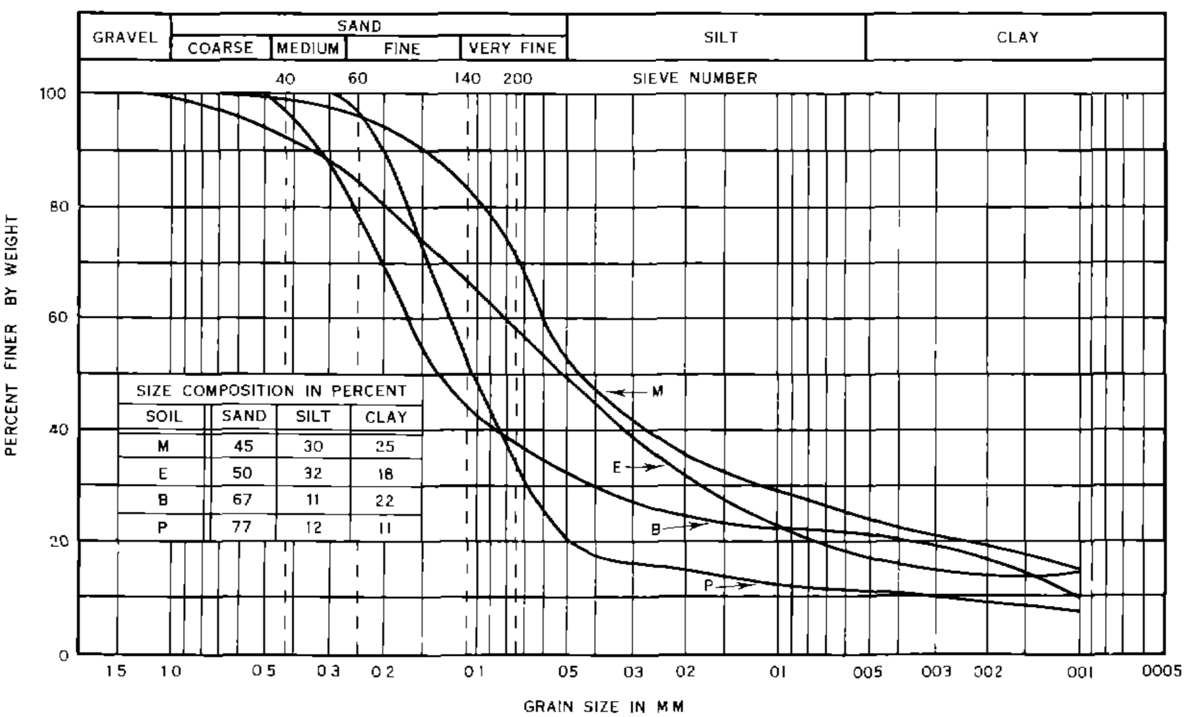


Figure 1 Grain Size - Distribution Curves of the Different Soils

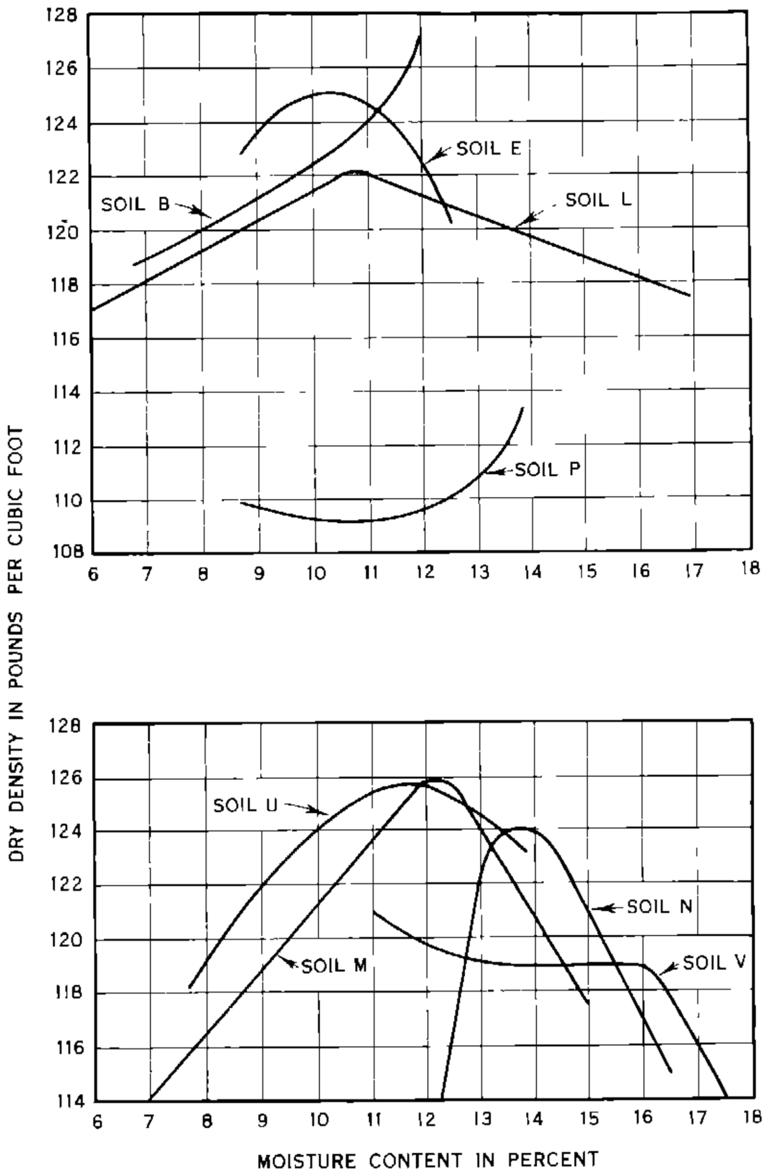


Figure 2 Moisture - Density Relationship of the Different Soils

PERCENT RESIN 321	DRY DENSITY OPTIMUM	DRY DENSITY MOLDED	MOISTURE CONTENT OPTIMUM	MOISTURE CONTENT MOLDED	MOISTURE CONTENT FINAL	PERCENT EXPANSION	CBR PERCENT
0 0	124 0	124 3	10 7	10 6	9 1	0 84	41
0 2	124 0	124 0	10 7	10 1	6 3	0 12	154
0 5	124 0	124 2	10 7	9 9	6 2	0 10	157

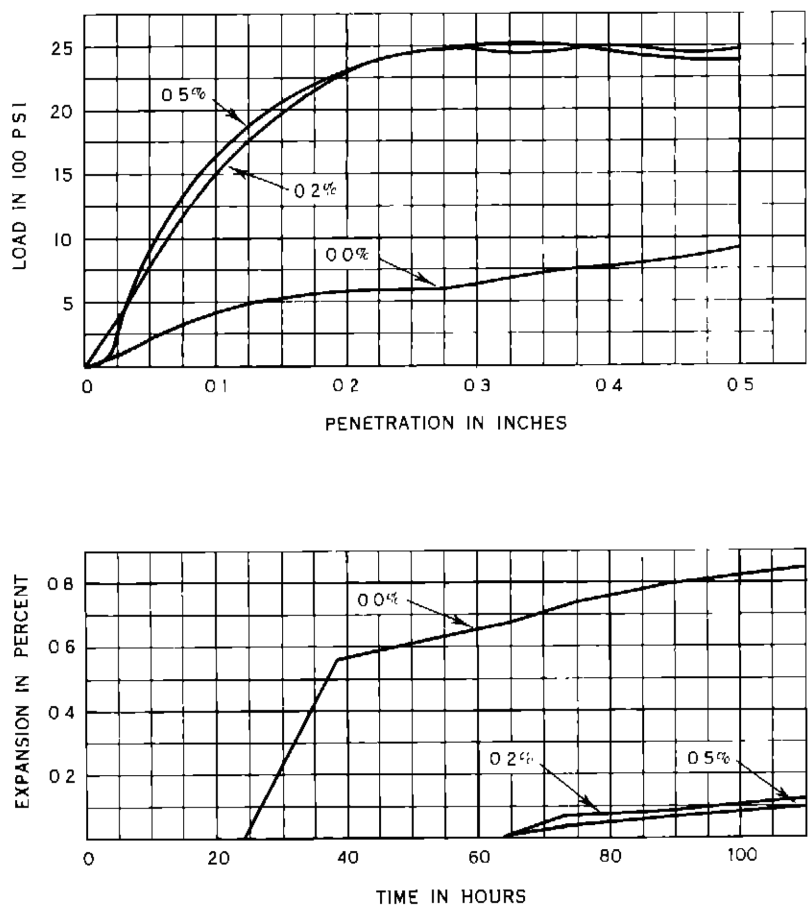


Figure 3 California Bearing Ratio Test Data - Soil B

PERCENT RESIN 321	DRY DENSITY OPTIMUM	DRY DENSITY MOLDED	MOISTURE CONTENT OPTIMUM	MOISTURE CONTENT MOLDED	MOISTURE CONTENT FINAL	PERCENT EXPANSION	C B R PERCENT
0 0	125 2	124 8	10 4	10 2	9 2	0 43	70
0 2	125 2	125 2	10 4	10 4	6 0	0 24	230
0 5	125 2	124 6	10 4	10 3	5 6	0 27	246

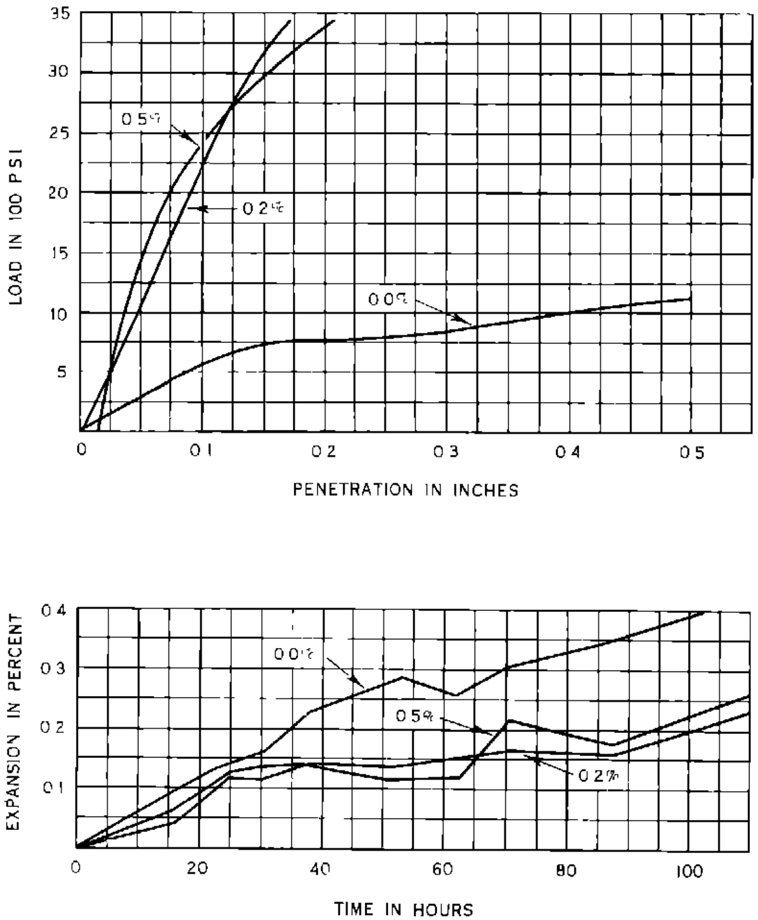


Figure 4 California Bearing Ratio Test Data - Soil E

PERCENT RESIN 321	DRY DENSITY OPTIMUM	DRY DENSITY MOLDED	MOISTURE CONTENT OPTIMUM	MOISTURE CONTENT MOLDED	MOISTURE CONTENT FINAL	PERCENT EXPANSION	C B R PERCENT
0 0	122 3	121 0	10 8	11 3	11 8	1 03	27
0 2	122 3	122 2	10 8	10 2	6 0	0 57	68
0 5	122 3	121 8	10 8	10 9	5 8	0 41	106

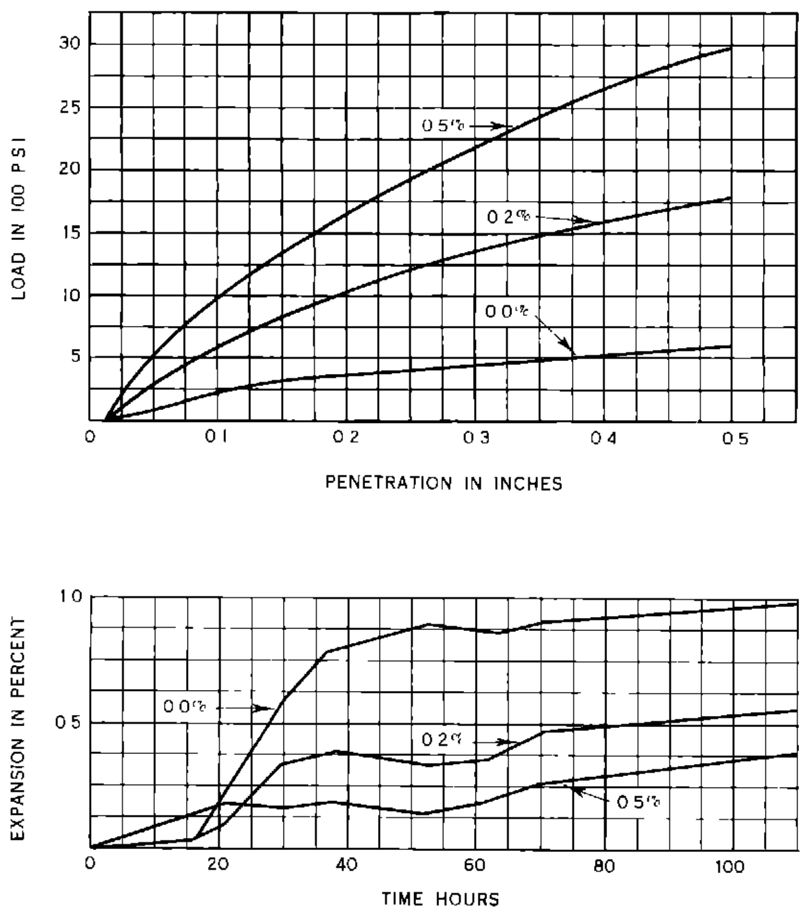
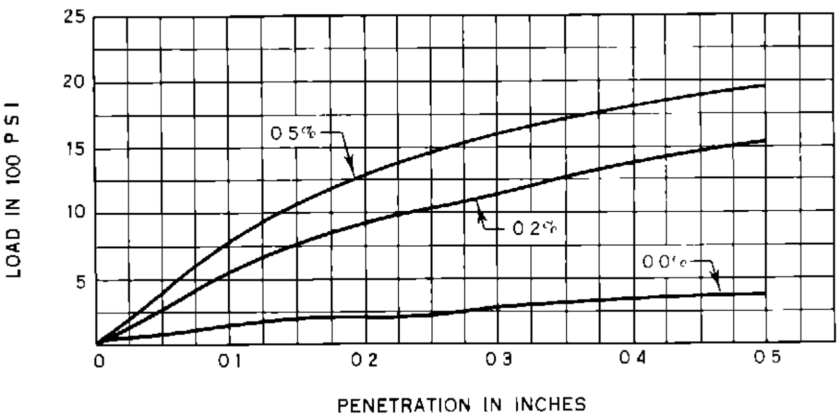


Figure 5 California Bearing Ratio Test Data - Soil L

PERCENT RESIN 321	DRY DENSITY OPTIMUM	DRY DENSITY MOLDED	MOISTURE CONTENT OPTIMUM	MOISTURE CONTENT MOLDED	MOISTURE CONTENT FINAL	PERCENT EXPANSION	C B R PERCENT
0 0	126 0	124 7	12 3	11 4	11 8	2 30	15
0 2	126 0	122 0	12 3	13 4	10 5	0 56	61
0 5	126 0	124 2	12 3	12 6	10 9	0 80	82



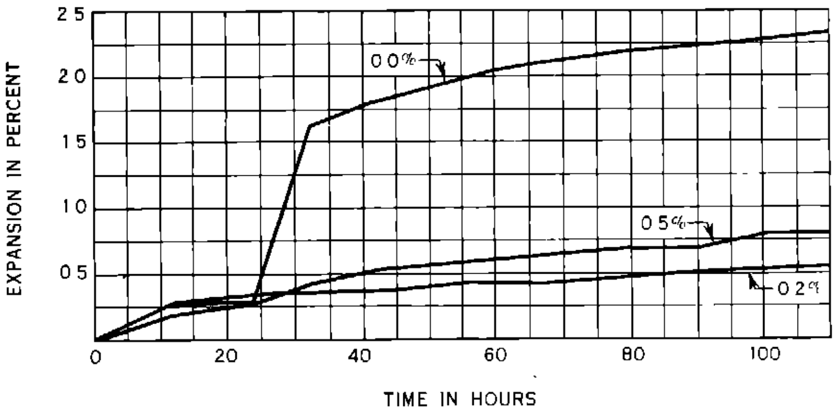
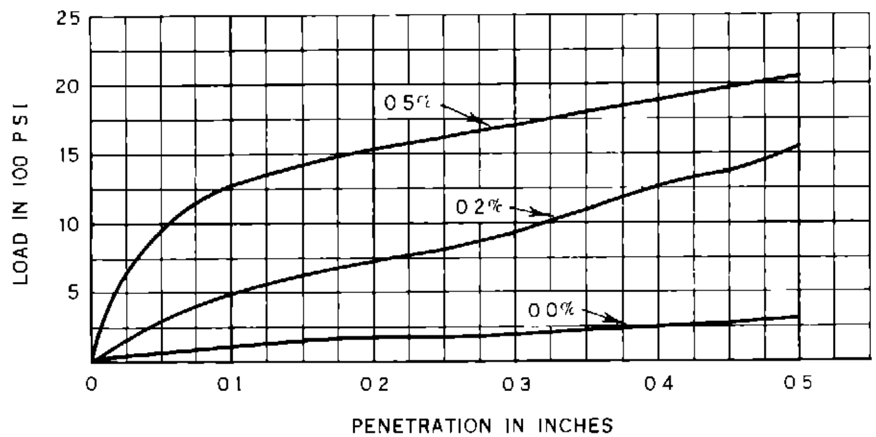


Figure 6 California Bearing Ratio Test Data - Soil M

PERCENT RESIN 321	DRY DENSITY OPTIMUM	DRY DENSITY MOLDED	MOISTURE CONTENT OPTIMUM	MOISTURE CONTENT MOLDED	MOISTURE CONTENT FINAL	PERCENT EXPANSION	C B R PERCENT
0 0	124 0	123 0	13 5	13 2	13 3	3 20	11
0 2	124 0	123 5	13 5	12 9	11 7	1 63	50
0 5	124 0	122 5	13 5	13 1	11 3	0 96	128



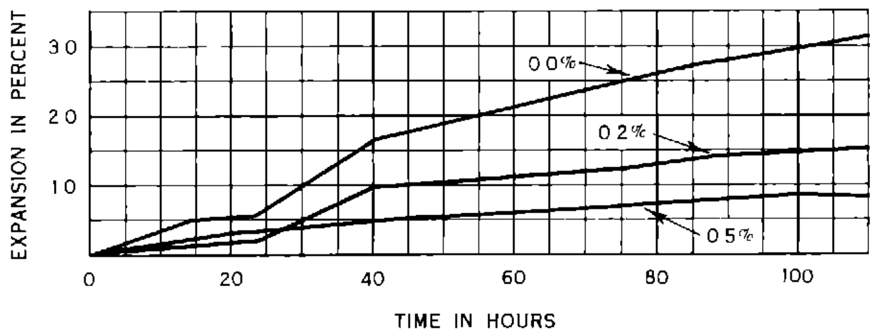


Figure 7 California Bearing Ratio Test Data - Soil N

PERCENT RESIN 321	DRY DENSITY		MOISTURE CONTENT			PERCENT EXPANSION	C B R PERCENT
	OPTIMUM	MOLDED	OPTIMUM	MOLDED	FINAL		
0 0	110 2	109 9	11 3	11 4	17 2	0 33	21
0 2	110 2	110 9	11 3	11 8	6 8	0 07	71
0 5	110 2	110 8	11 3	10 6	5 5	0 12	56

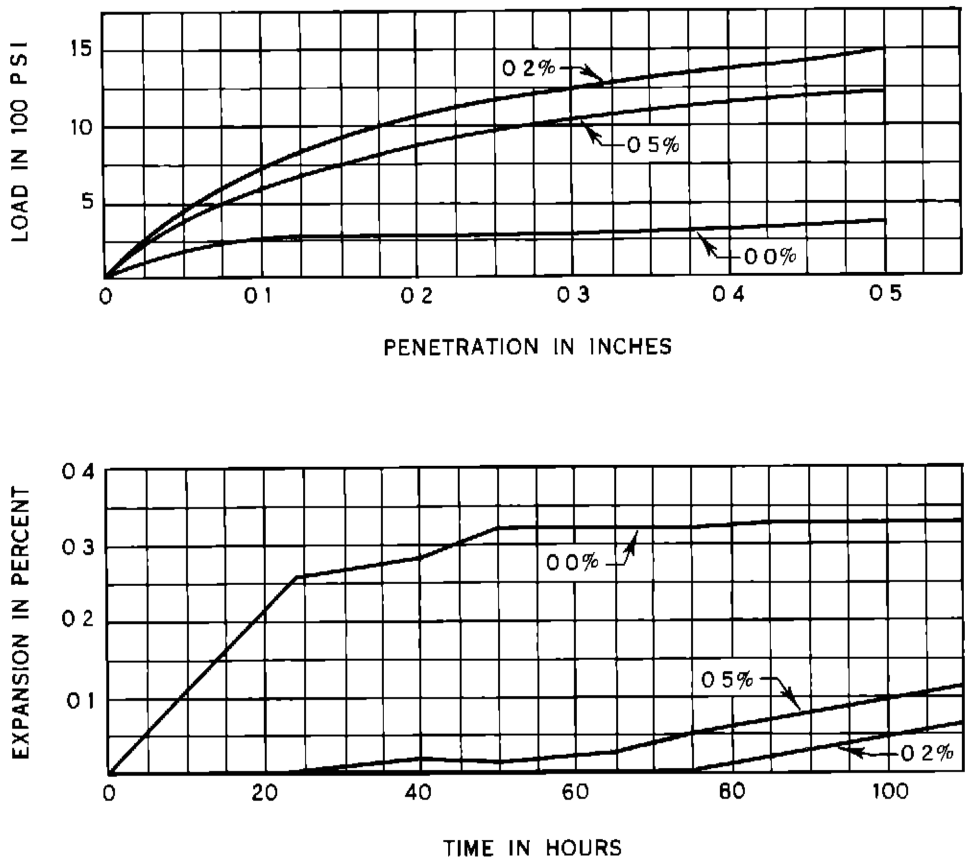


Figure 8 California Bearing Ratio Test Data - Soil P

PERCENT RESIN 321	DRY DENSITY		MOISTURE CONTENT			PERCENT EXPANSION	C B R PERCENT
	OPTIMUM	MOLDED	OPTIMUM	MOLDED	FINAL		
0 0	125 7	121 2	11 5	11 8	12 8	2 44	10
0 2	125 7	121 2	11 5	11 9	11 0	1 27	55
0 5	125 7	121 7	11 5	11 1	10 0	0 67	92

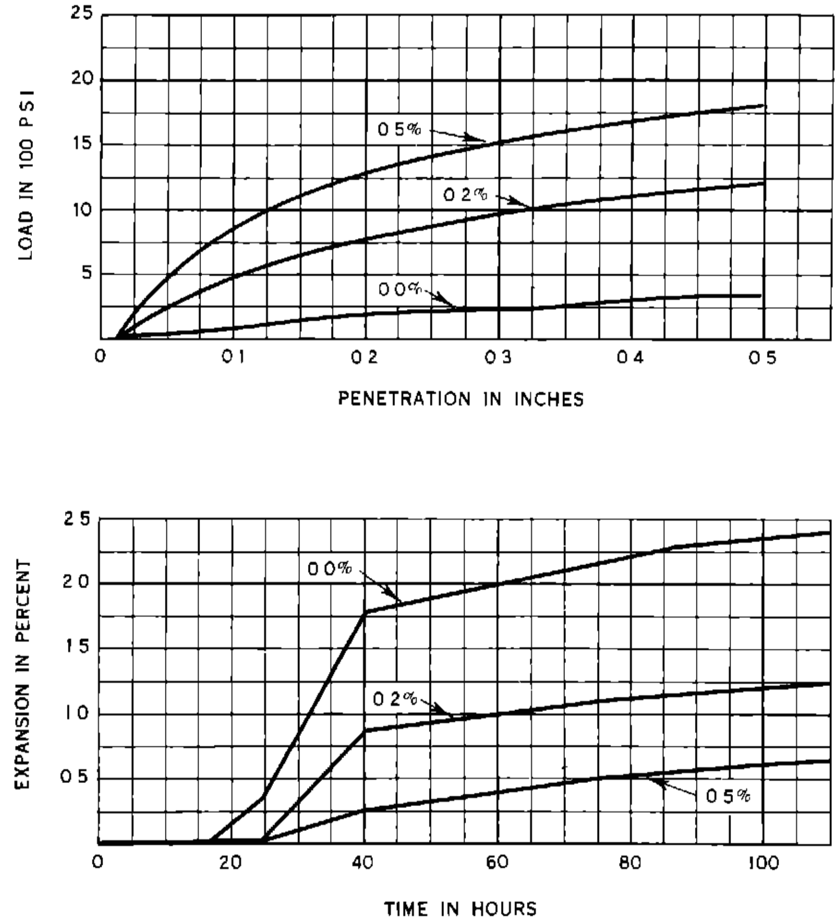


Figure 9 California Bearing Ratio Test Data - Soil U

PERCENT RESIN 321	DRY DENSITY		MOISTURE CONTENT			PERCENT EXPANSION	CBR PERCENT
	OPTIMUM	MOLDED	OPTIMUM	MOLDED	FINAL		
0 0	119 0	121 5	15 0	14 1	15 0	3 75	14
0 2	119 0	120 0	15 0	14 6	13 2	1 67	73
0 5	119 0	121 3	15 0	13 9	12 5	1 43	87

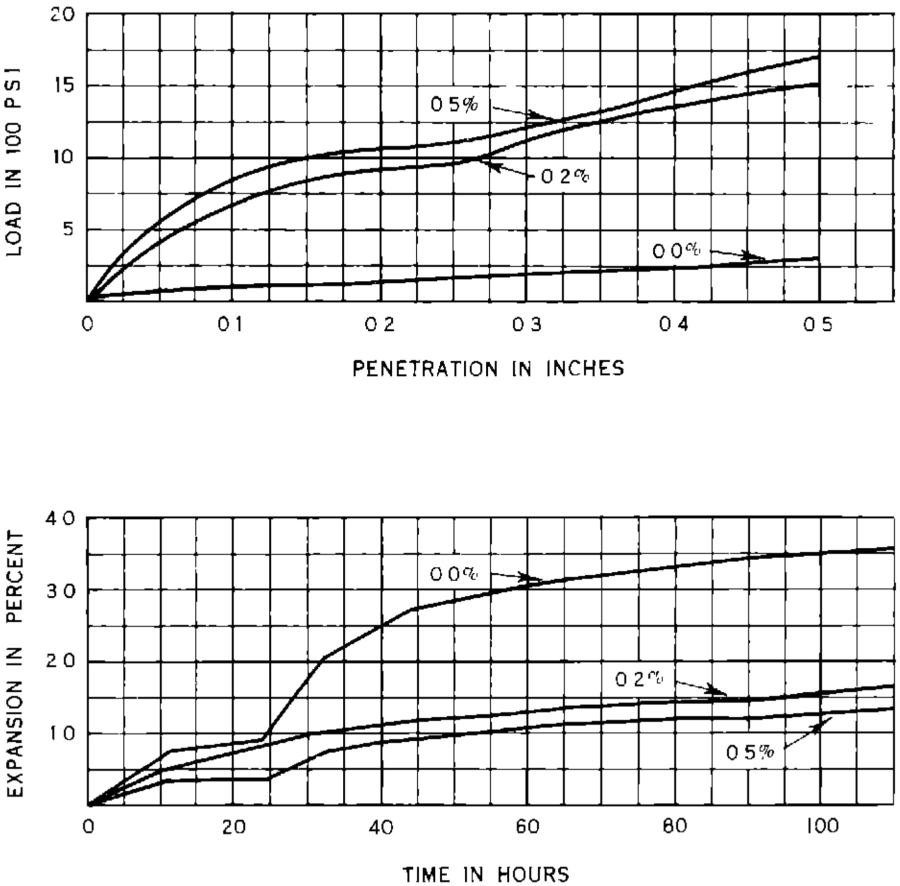


Figure 10 California Bearing Ratio Test Data - Soil V

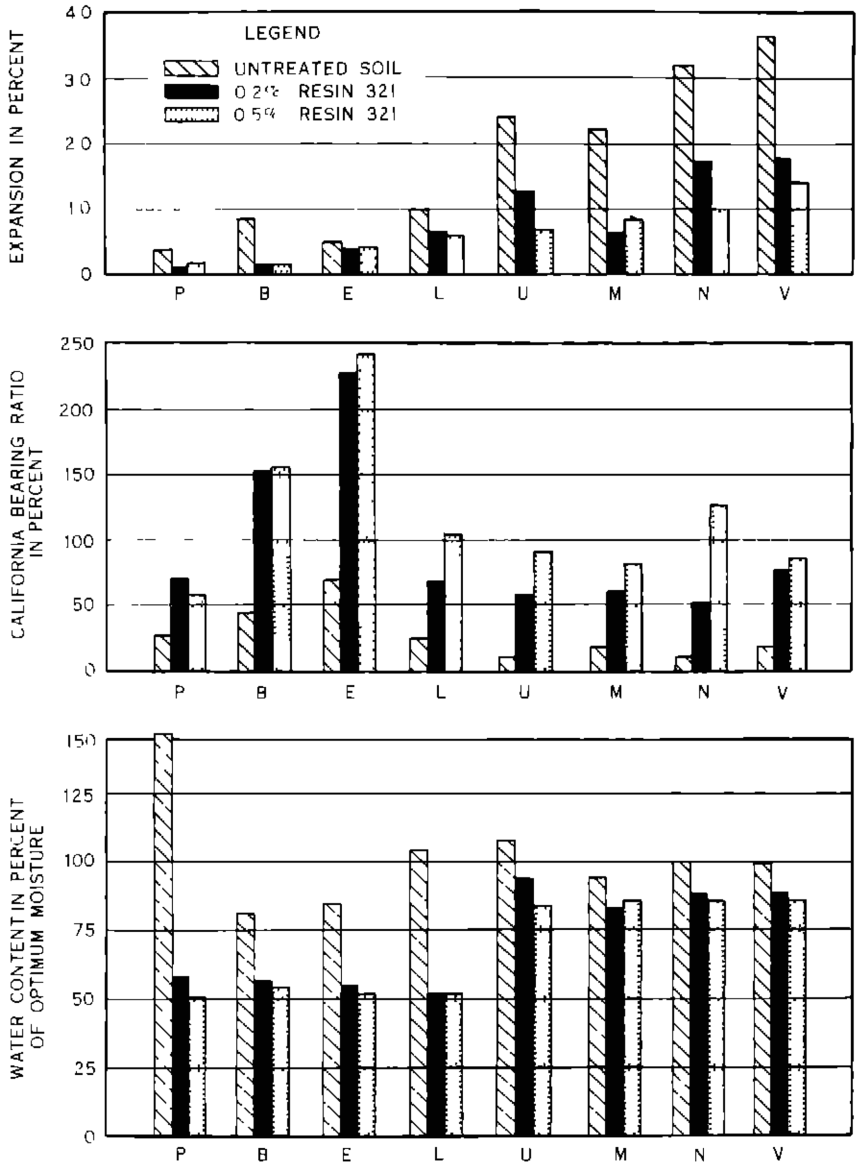


Figure 11 Stabilizing Effect of Resin 321 on the Different Soils as Indicated by the California Bearing Ratio Tests

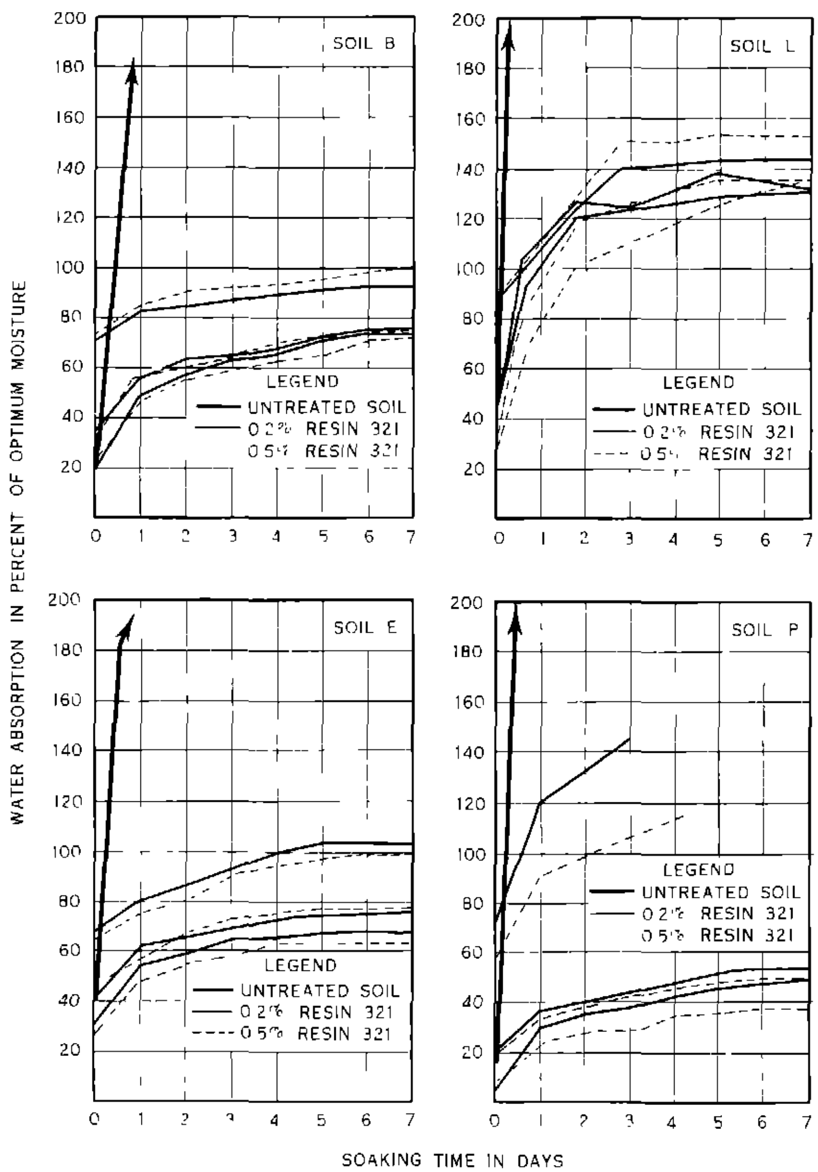


Figure 12 Water Absorption Test Data - Soils B, L, E, and P

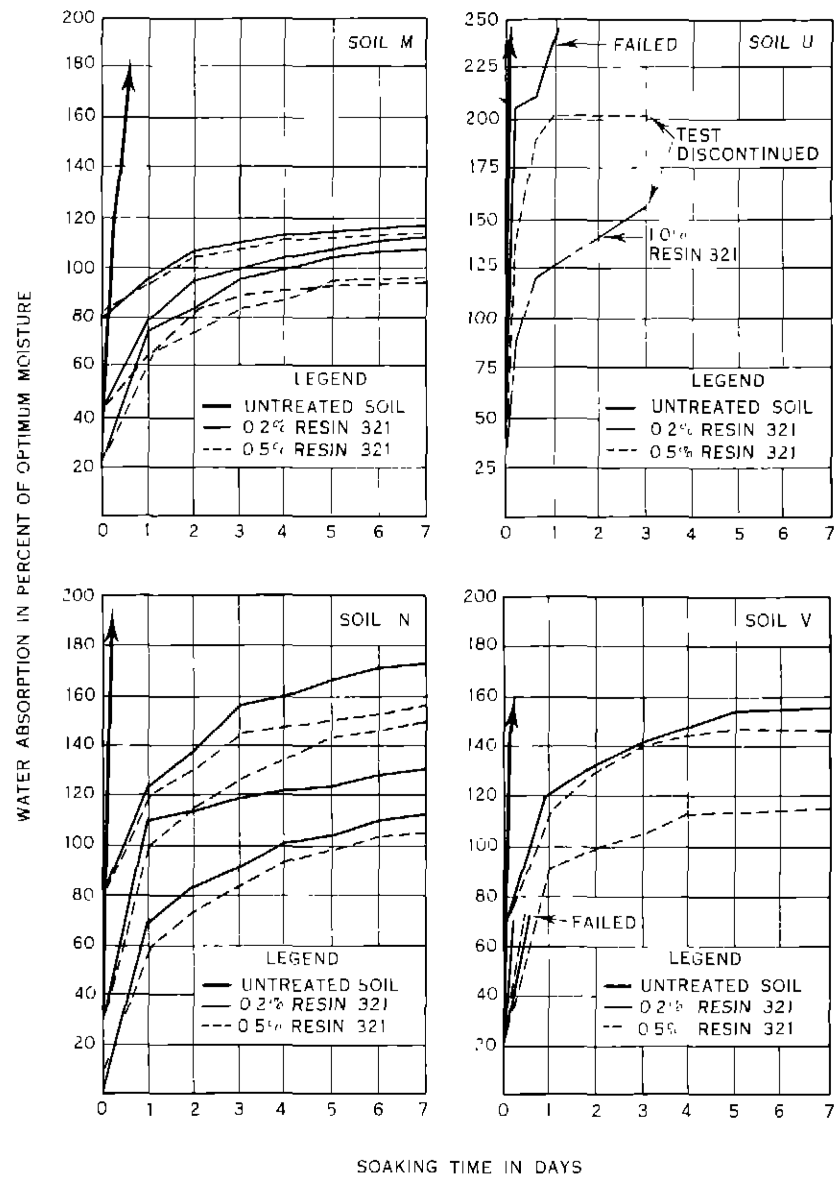


Figure 13 Water Absorption Test Data - Soils M, U, N, and V

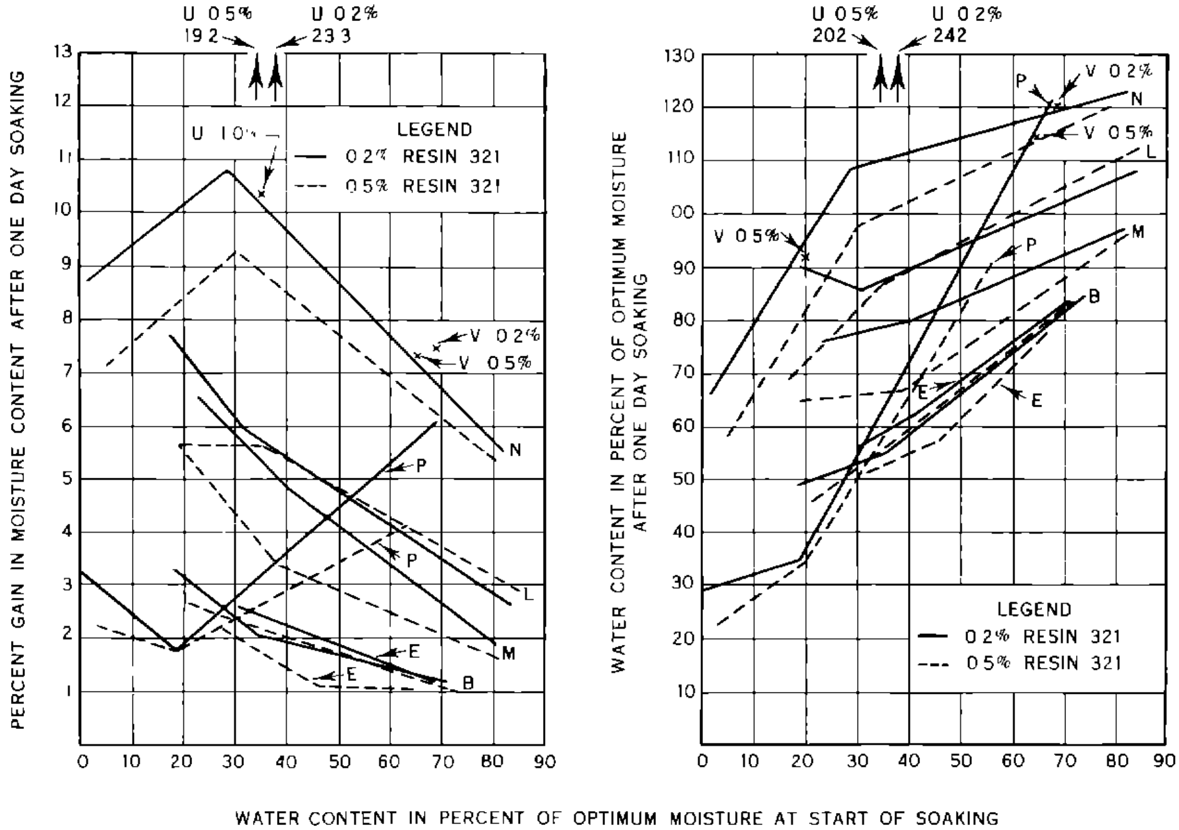


Figure 14 Influence of the Moisture Content at the Start of Soaking on the Water Absorption of the Different Soils

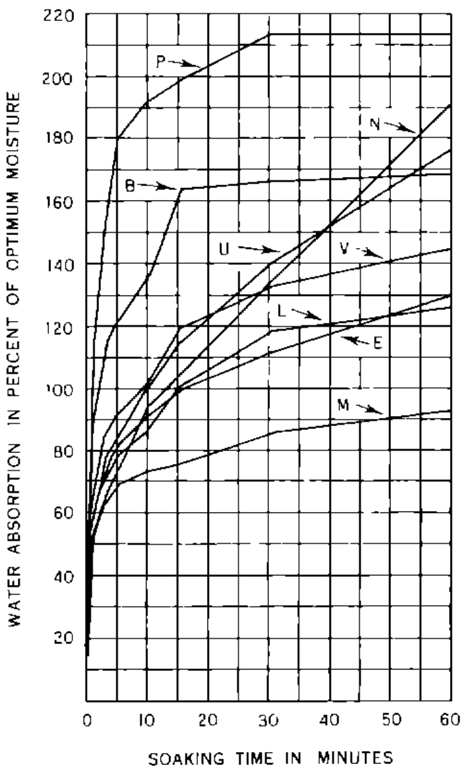


Figure 15 Water Absorption of Untreated Soil Specimens - One Hour of Soaking

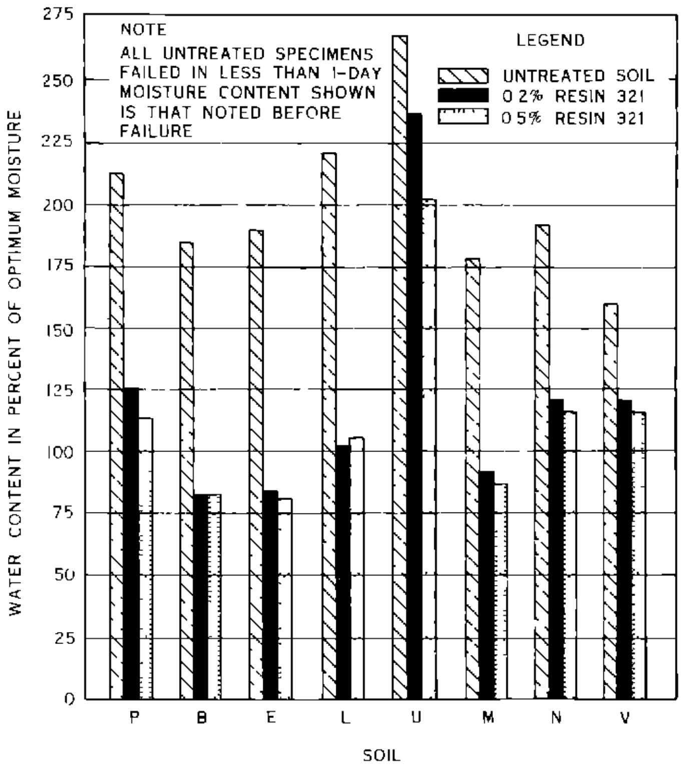


Figure 16 Effect of Resin 321 in Reducing the Water Absorption of the Different Soils - One Day of Soaking

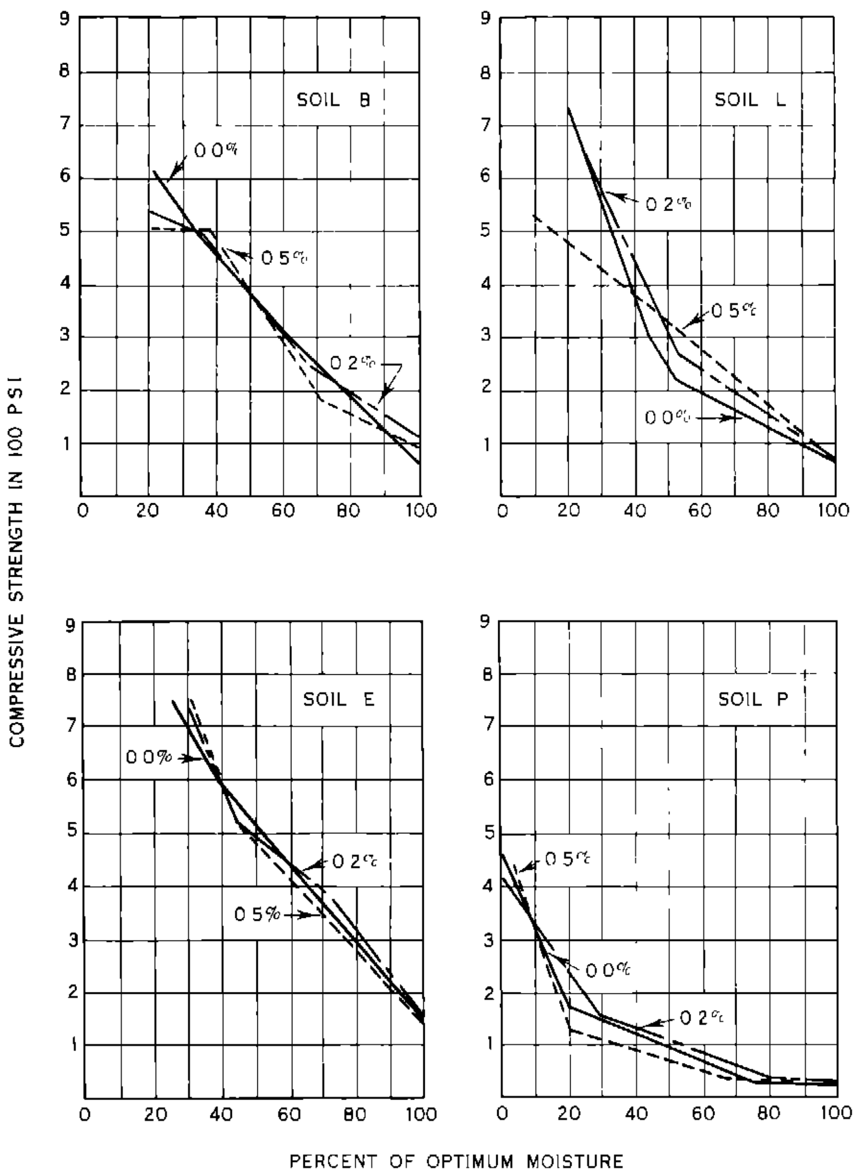


Figure 17 Compressive Strength Test Data - Unsoaked Specimens of Soils B, L, E and P

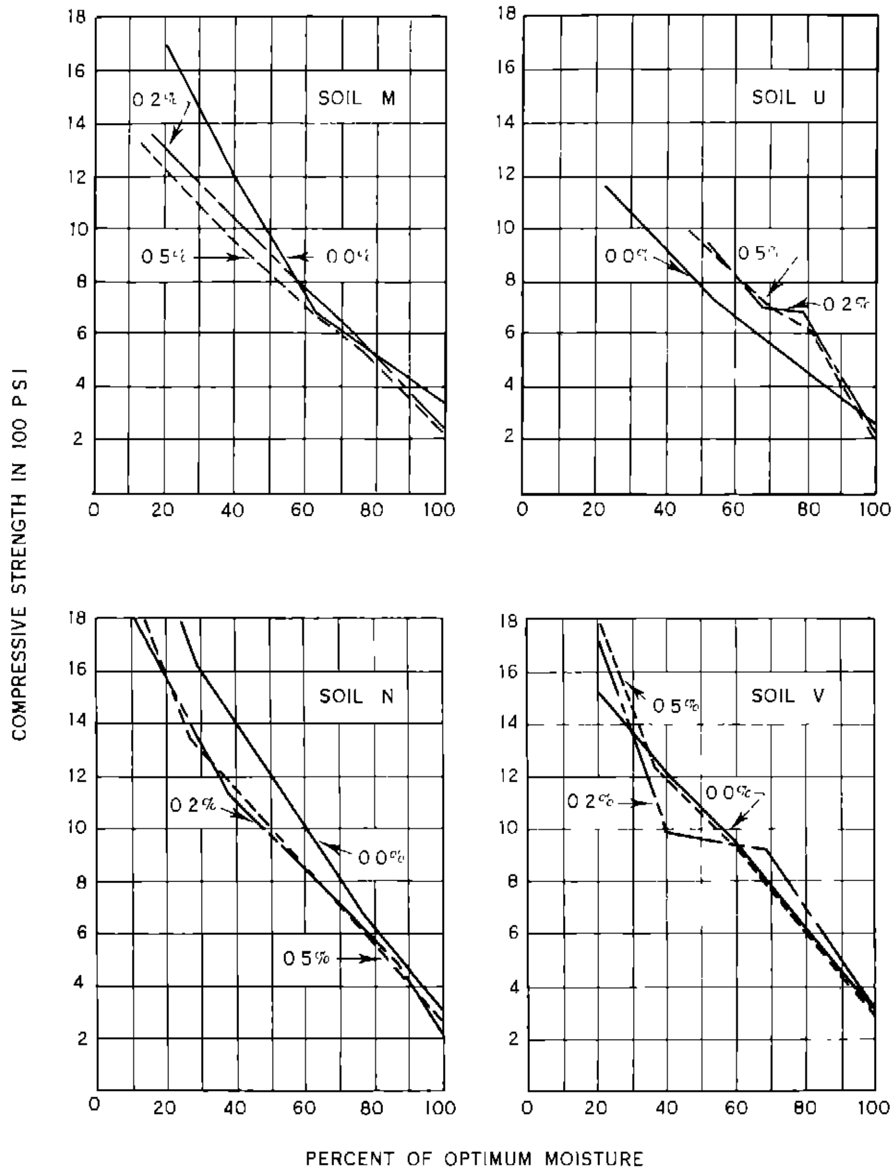


Figure 18 Compressive Strength Test Data - Unsoaked Specimens of Soils M, U, N, and V

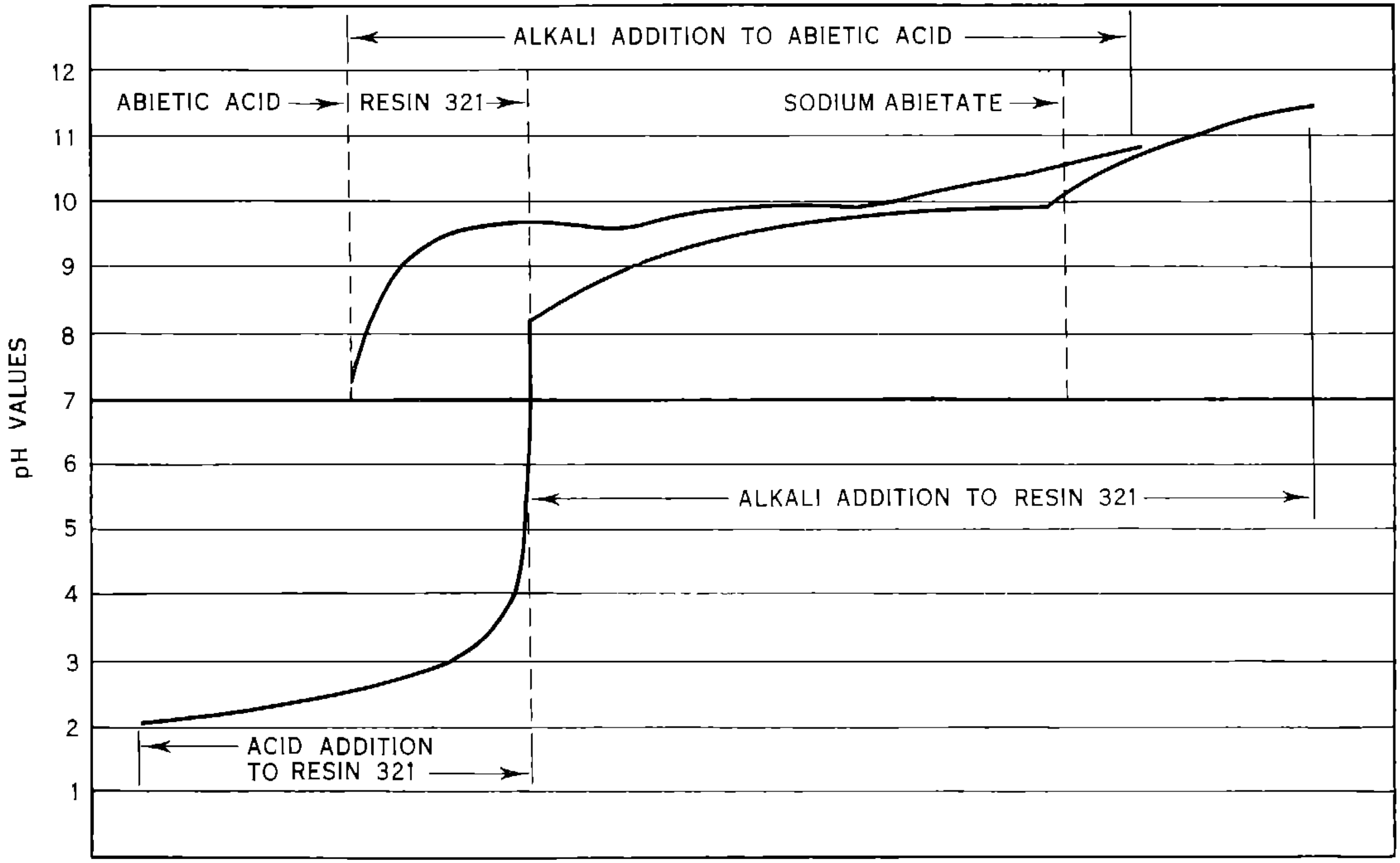


Figure 19 Results of Potentiometric Titration of Abietic Acid and of Resin 321