A STUDY OF MICHIGAN SOILS AND CLAYS AND THEIR AFFINITY FOR BITUMINOUS MATERIALS

Thesis for the Degree of B. S.

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THESIS

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A Study of Michigan Soils and Clays and Their Affinity for Bituminous Materials

A Thesis Submitted to

The Faculty of

Michigan State College

of

Agriculture and Applied Science

by

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Candidates for the Degree of

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Preface

In the field of the Civil Engineer, there is a great need for practical research, especially in that portion of the field dealing with low cost road building. We have chosen for our thesis "A STUDY OF MICHIGAN SOILS AND CLAYS AND THEIR AFFINITY FOR BITUMINOUS MATERIALS" because we feel that we can add to the work already done in this field, by studying the stability of twelve typical soils, treated with different percentages of emulsion, cut-back and road-oil.

Because of the shortness of time and the quantity of material to be covered, we six have joined together for the purpose of making a more rounded study of twelve typical Michigan soils.

We take this opportunity to thank Professor Kinney for his aid, criticism, and patience in working with us as an adviser; also the Civil Engineering Department for the use of their equipment and library. We are also indebted to the Standard Oil Company of Indiana as well as the American Bitumuls Company for supplying us with road-oils, cut-backs, and emulsions.

Introduction

The development of universally applicable means of stabilizing soils is undoubtedly the most important thing we now have to consider in the low cost construction field.

In the United States alone there are over three million miles of roads, of which the majority are of earth construction. Beside the use of the theory of soil stabilization for the finished roads, engineers are now considering the reasons why concrete pavements fail. The main reason is the lack of a suitable subgrade and applying the principles of stabilization to the subgrade before the concrete slab is laid.

Since we are located in the State of Michigan we will limit this study to the soils of Michigan. There are over sixty thousand miles of dirt roads in this State; some of them are trunkline roads, but the majority are roads used to connect farms with the market centers, and it is to these roads that we will devote our time.

To make our test real and to have some meaning, we have collected a total of twelve soils from scattered locations in the lower peninsula and each will be tested individually.

We must keep in mind the fact that having developed a method which is applicable to one class of soil,

we cannot take this data to a new location and apply it without understanding the new conditions and still expect to have the same satisfactory results.

The matter of soil stabilization may be divided into two parts, one where the character of the soil is changed by methods such as varying the clay content, the sand content, etc., and the other that of substituting in the particular soil some material that will preserve the characteristics of the soil when it is at its best moisture content. It is a well known fact, although not widely appreciated, that almost any soil when at the right water content will support very heavy loads with but little deformation. If this condition could be maintained the year around- having the well packed smooth surfaces as in the early summer instead of the mud holes and dusty surfaces- or, putting it another way, if the soil could be so treated that it would not be changed in volume throughout the year, there would be little need for pavement other than a thin wearing course to take care of the abrasion.

Asphaltic products, (we have taken emulsions, cutbacks, and road oil), are used in this connection with the view either of surrounding a layer of earth when at its best water content so that the water can get neither in nor out, employing a heavy asphalt coating, or of replacing the moisture throughout by a suitable low

viscosity asphalt product. We have undertaken to try both of these methods in this survey.

Sand and clay are two very common soils and are widely distributed. Sand-clay mixes have been made that have proven satisfactory and further study on the subject will undoubtedly bring better results in the future.

Let us first study the ingredients we will use in our mix. Sand consists of minute particles of rock; when dry it is very unstable because it has little if any power of cementation because it undergoes no further decomposition; when wet to the right degree it is very stable as noted by the sands of Daytona Beach, beacuse the sand particle becomes surrounded with a film of moisture which tends to hold the particles together. Thus we can see that a pure sand road, while it might be all right in wet weather, becomes of no value as a load-bearing surface during dry weather.

On the other hand, if the natural soil is clay we have a hard compact road during the dry season, because clay possesses a cementing quality, but in the wet season the clay becomes plastic and sticky, depending on the water content, and is incapable of supporting weight.

A mixture of the two in the right proportions, however, gives what is known as a "sand-clay" road and is fairly stable the year around. We intend in this study to take the natural soil, which may or may not

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be of the right proportion of sand and clay, and by surrounding the particles with asphaltive material retain the proper binder and produce a stable surface.

The theory of stabilization, then, "is the adding of an adhesive that will furnish films more substantial than moisture alone by permanently destroying the clay and colloidal properties responsible for detrimental volume change in the soil mixture."

Previous investigations have taken samples secured from short stretches of existing roads whose firmness and water-resisting qualities were noted in contrast to the prevailing earth roads. In these tests top soil (soil skimmed from the surface of the field to shallow depths) was used. It was thought that from long cultivation such deposits had undergone weathering, water separation and the probable influence of organic acid which gave to them their superior consistency and binding stability. We in our experiments will try to find what is in the soil and what has to be added to make a good stable road.

In a good stabilized road the essential constituents are coarse aggregate and soil mortar. The mortar includes coarse sand, which supplies hardness and internal friction, fine sand and silt (passing a 40 sieve and retained on a 270) which are interspersed with the sand to provide interlock, and clay which on the surface of the sand and silt acts as a cement providing cohesion. The action of this mix when moist is to have

the clay expand enough to fill the voids and leave the sand undisturbed. Likewise too much water would cause the clay to expand to the extent of dislodging the sand particles, causing the entrance of more water and causing loss of stability.

Almost all the research that has been done has been with the use of asphalt emulsion, which has proved fairly satisfactory in the applications that have been tried in road construction so far. We will go further in this study with emulsion and will also try several mixes using cutbacks and road oils.

A definition of a few of the terms that we will use in our study might be helpful to the report at this time.

Emulsion: A combination of water and an oily substance made miscible with water through the action of a saponifying or other agent.

Cutback: Petroleum or tar residue which have been fluxed back with its own or similar distillates.

Road oil: A bituminous material with an asphaltic base fluxed with soft lubricating oil.

We have gone still further into this subject by testing for the chemical content of the soil by a special analysis worked out by the soils department of Michigan State College. This procedure has never been tried before to our knowledge and we will endeavor to see if there is any connection between the chemical content of a soil and the success or failure of the

road stability.

Because of these reasons, we believe that there is much need for experimentation on this type of road construction.

Soil stabilization is very economical, first, because we use the natural soil without the addition of further ingredients and we will also limit ourselves to a total of five per cent of asphaltic material.

Application of the asphaltic material can be made cold, doing away with the necessity of heating the asphalt and the aggregate. The heating of the asphaltic material is a dangerous practice in the hands of inexperienced operators because of the volatile nature of the material and the fact that further distillation and chemical action might take place with more heat than necessary.

Application of the emulsion especially and of the oils and cutback to some extent may be made during rainy or damp weather because of the necessity of having a certain amount of water film around the particles so as to carry the bituminous material for complete coverage.

There is much less chance for "bleeding" of the asphaltic material during hot weather because of the minimum amount used and the method of complete coverage.

The expense and necessary engineering is kept at a minimum due to the simplicity of the structure.

It is with these thoughts in mind that we have made the following study.

PROCEDURE

The procedure of investigation followed was two-fold in nature, having standard recognized tests as one part and experiments of various natures as the other part. The standard tests, consisting of several divisions, were handled in such a manner that the method could be easily and quickly applied to any road to give the physical, chemical, water-resisting and otner characteristics of the soil. Now having the properties of the soil, the experiments that were carried out attempted to establish definite relationships between the soil properties and stabilized soils using road oil, cutback, and emulsion to provide an economical method.

No strict rules can be devised for sampling soils because the manner of taking the sample will always depend on the nature of the problem involved and application of test results. The twelve soil samples used in this testing operation, however, represent the lower peninsula of Michigan. As the amount of soil used in this system of analysis is very small when compared to a field or portion of a field problem, the field soil samples should be selected with care from representative locations.

Composite samples are preferable to single soil samples because experience has shown that soil constituents vary considerably with soil locations. Usually marked

differences in this respect will be found between soil samples taken from slopes, knolls, and low lands. Also due to soil weathering processes, a soil naturally forms layers called horizons, having marked differences in physical and chemical properties. The twelve soils handled in this project are of the above mentioned nature.

As a general rule, six sampling spots, spaced about equal distances apart along the section and staggered three on each side of the road bed, give fair representative samples. Mix the soil obtained from the six sampling spots to form one composite sample of the road. Having the twelve composite samples, the soil samples were thoroughly dried in air and any lumps or clods were broken with a rubber covered pestle. A representative test sample of the quantity required to perform the desired tests was selected by the method of quartering.

From the quarter sample, the following tests were run: water-asphalt preferential test, chemical analysis, physical analysis, sieve analysis, and soil fines. For brevity, the soils are designated by numbers.

The water-alphalt preferential test is usually intended to determine the water-resisting properties of a soil to be stabilized and is made on a sample of dust passing a two hundred mesh sieve. Fifty(50) mls. of heavy fuel oil, sixty to seventy percent asphalt, heated to 140°F. is placed in the sample bottle. To this is added ten grams of dust passing two hundred mesh sieve.

The bottle is then placed in the hot water bath and the mixture stirred for five minutes with a mechanical mixer, (Fig. 1.) revolving at a speed of 1500 r.p.m. After five minutes, one hundred (100) mls. of distilled water of 140°F. is added and the mixture again stirred for another five minute period.

After the sample has had time to settle and the water become clear, the amount of clean dust in the bottom of the jar (Fig. 2.) is estimated and recorded as the percent of total dust separated. If the dust is of satisfactory quality it will remain in the oil and no free particles will be observed in the water at the bottom of the jar. The dust retained in the oil may cause all or a portion of the oil to settle to the bottom, after a certain length of time. If dust is of a poor quality, showing a strong affinity for water, the dust will be concentrated in the bottom of the jar, having separated from the oil. The test is reported by estimation the percentage of dust which separates. Using these terms, 0 Percent separation would be entirely satisfactory; 100 percent would be entirely unsatisfactory. At the present it is considered that a separation up to 25 percent may be tolerated.

The chemical analysis was carried out according to methods described in "Technical Bulletin No. 132; Soil Testing; October 1935" by C.H.Spurway. As many of these tests are very sensitive, they are easily contaminated;

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hence, pure chemicals and clean glassware apparatus are necessary for good test results. The test results were read by comparing the color of precipitate with the color charts of the bulletin, and for comparing the test results with the color charts, except where otherwise noted, face the light, place the tube on the paper adjacent to the color, and view the solution in the tube lengthwise. For practical interpretation of the test results see the section in the bulletin on interpretation of test results.

The physical analysis of the soils was handled according to specifications given in "Standard Specifications for Highway Materials and Method of Sampling and Testing" adopted by the American Association of State Highway Officials. Also, the sieve analysis and soil-fines were tested by methods devised in the above specifications. The tests carried out are listed below according to specification or test number to simplify the work and to save time.

Plastic Limit.....T. 90
Liquid Limit.....T. 89
Mechanical Analysis.....T. 88
Plastic Index.....T. 91
Shrinkage.....T. 92
Sieve Analysis.....T. 27

Of all the various experiments tried in the second part of the investigation only those that contributed materially to the work will be discussed because several ideas and methods that were attempted failed absolutely in their aim or proved of no value whatsoever to the subject. To include in the procedure the large number that failed would merely cause confusion; consequently

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only the methods giving results of worthwhile nature will be explained. Capillary attraction, water absorption, and stability were the projects that showed feasible results.

Capillary attraction between the twelve soils and the road materials was investigated in view of the fact that such attraction would be evident on a stabilized soil. Road oil was poured in five test tubes until a half inch was contained in each tube, care being taken to pour the oil in such a manner that none touched the sides of the container. To tube number one, a small portion, equivalent to one half inch in the test tube, of dry soil was placed directly on top of the road oil and tamped firmly but not too firmly to cause the soil to be forced by pressure into the oil. Half-inch tamped layers were added until a total height of four inches was reached. The capillary rise of the oil was measured every twenty four hours until the maximum height of rise was reached, which on the average required three weeks. The four remaining tubes were handled in the same manner except that the soil samples contained four, eight, twelve, and sixteen percent of water by weight. All twelve soils were tested by the above procedure using road oil, cutback, and emulsion, giving one hundred and eighty samples for comparison.

In order to run absorption and stability tests, soil briquettes had to be prepared and weathered. Five hundred grams of dry soil, selected by quartering, was mixed with

the necessary percent of water to bring the soil between the range of its liquid limit and plastic limit; the addition of water greatly aided in coating the soil particles with road material and brought moisture content of the soil nearly to normal conditions. Two percent of road soil and material by weight was added to the slightly wet soil, thoroughly mixed by hand until all the soil particles were coated with road material. After mixing, the mixture was allowed to stand until all excess water had dried out or evaporated. Three, four, and five percent of road material batches were made using again road oil, emulsion, and cutback as the road material and all twelve soils. Five percent being the highest percent up to which it would be economical to use.

Having lost all the water that would evaporate or dry out, the batches were compressed into briquettes by the compression apparatus shown in Figure 3. Dividing each batch into three parts, three briquettes were made to be tested later. Each one third of the batch was pressed and rodded into a two inch diameter by four inch high cylindrical mold and then compressed at a total load of one hundred and forty pounds for two minutes without extruding around the compression cylinder. The rodding consisted of tamping the soil ten times with a one half inch circular tamping rod while soil was being placed into the molds.

After compressing the samples were forced from the molds and dried to constant weight in an oven maintained at 140°F. for twenty four hours. From the oven, the samples were allowed to weather in the air until all cracking and shrinkage had ceased.

The equipment for the absorption test consisted of a common ordinary flat bottomed container filled partly full of water with a stiff wire screen of large mesh supported by bricks at the elevation of the water surface on top of the screen, a heavy white blotter was placed thereby forming a water mat similar to earth. The container was also equipped with a water-feeding device which maintained the water in the container at constant level at the surface of the diatomecous blotter surface.

The previously dried samples were placed on end on the wet surface of the blotter and the container covered and sealed against loss of moisture. The sample briquettes were weighed when placed in the water container and at each twenty four hour interval until the briquettes reached a constant weight which required from twenty four hours to five days according to the different combinations of soils and road material. By comparing the original weight of the sample with water absorbed sample, the waterproofing qualities of the combinations could be ascertained.

At the end of 168 hours, the samples which had been subject to absorption tank were tested for stability, care being taken to prevent any loss of moisture until tests were run.

The testing device consisted of the following: A heavy cylindrical mold two and one-sixteenth inches inside diameter by five inches in height was fitted with a tool steel disc in one end which shall perfectly fit the inside diameter of the mold. In center of disc, a circular aperture having an area of exactly one square inch with the edge of this aperture tapering outward to leave a cutting edge of the face toward the inside of the mold was fitted. A plug, equal in thickness to the aperture and entirely closing the aperture was provided. The plug was placed in the aperture and the sample to be tested firmly pressed into the mold until in perfect contact with the disc and plug at the bottom end. A cylindrical steel plunger two inches in diameter and six inches long was then placed on top and a pressure of a few pounds applied, the load released and the plug removed.

The entire ensemble was then placed in a vertical position under the traveling head of a hydraulic compression machine (Fig. 4) equipped to measure the load, which is applied. The bottom of the disc and mold was placed on a device which allowed extrusion of the sample extruded. The load was applied on the plunger at such a uniform rate to press the plunger into the mold at about one inch per minute. As the plunger goes down, the maximum total load exerted by the compression machine was observed and recorded. This total load was reported as stability of soil mixtures in pounds per square inch.

From the above investigations, the following data and graphs were compiled.



Fig. 1



Fig. 2



Fig. 3

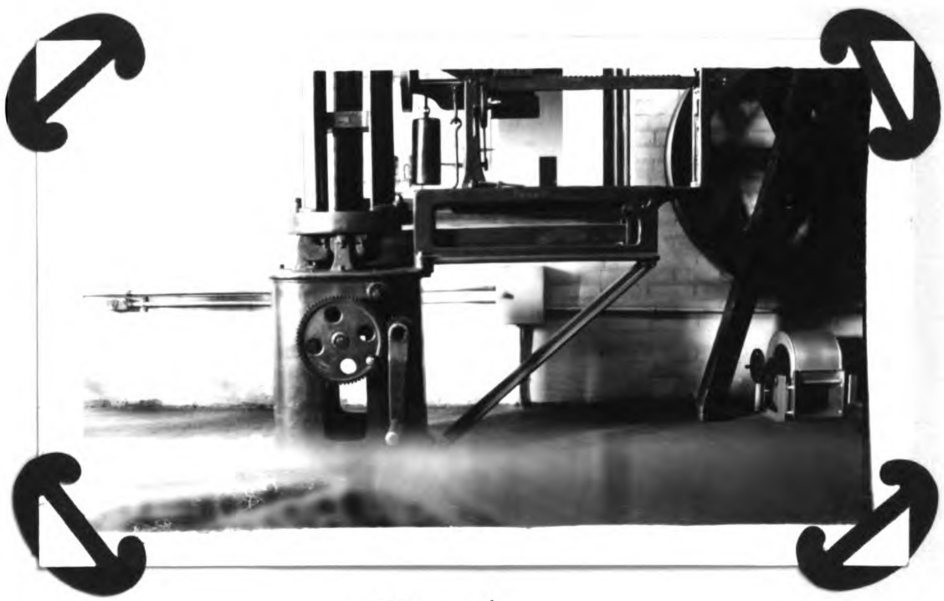


Fig. 4

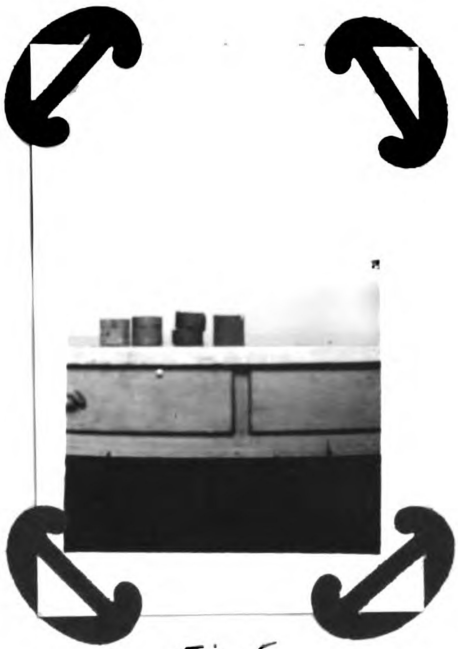


Fig 5



Fig. 6

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Soil Table

Name	Number Soil	Name of Soil
Wagner	1	Hillsdale A2 Jonesville
Alvord	2	Naponee Silty Clay Loam- C. F. Kellog
Hall	3	Van Buren- C-Horizon Saugatuck
Baugh	4	Fox Sturgis- B24"-48"
Wagner	5	Longree Type Mackinac Co. Jo. Veach Strong, Mich.
Hall	6	Roselawn Sandy Loam- Brown Horizon 12"-30"
Alvord	7	Fox Gray Sandy Loam A2, C.F.Kellogg
Bissell	8	Hillsdale Miami
Bissell	9	Ontonagon Clay C. Horizon- Parant Materal at 8 ft.
Marlatt	10	Hillsdale Jonesville B24"-48"
Marlatt	11	Hillsdale E. Miami
Baugh	12	X

Bitumen

Emulsion- Bit-U-Mals Soil Stabilizer AE-D

Road Oil- Standard Asphalt Road Oil #4

Cut Back- Standard Cutback Asphalt Surface Treatment

DISCUSSION

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SOILS

Soil #1 Hillsdale #2 Jonesville

Soil #3 Longeree Type O Veatch

Investigation

by

Sidney Wagner

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| 4 |
| 8 |
| 12 |
| 16 |

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| 2 |
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| 2 |
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Soil #1 Hillsdale A_2 Jonesville

This soil was a reddish brown in color having a specific gravity of 1.02 and particles uniform in size. The following data is the results of the tests that were made on the soil.

Liquid limit 14.0%
Plastic limit 12.8%
Shrinkage 6.2%
Percentage of sand 27.6
Percentage of clay 10.0
Percentage of silt 62.4
Percentage of total which passed 200 mesh sieve 29.3
Plastic index 1.2%
Field moisture 13.5

Capillary Action

Road Oil		Emulsion		Cutback	
% Water	Rise	% Water	Rise	% Water	Rise
0	2⅝"	0	0"	0	⅞"
4	3"	4	1/8"	4	1¼"
8	2 7/8"	8	1/8"	8	1¼"
12	2¼"	12	¼"	12	1¼"
16	2¼"	16	¼"	16	1¼"

Water Absorption by Briquettes

% Road Material	Dry Wt.	Wt. 24 Hrs.	Wt. 48 Hrs.	Wt. 72 Hrs.	% Absorption
			Road Oil		
2	177.7	---	---	---	0.0
3	200.3	---	---	---	0.0
4	167.9	---	---	---	0.0
5	181.3	---	---	---	0.0
			Emulsion		
2	205.3	205.9	206.1	206.1	0.39
3	141.7	141.8	142.3	142.3	0.42
4	170.9	170.9	171.3	171.3	0.235
5	212.6	212.6	212.8	212.8	0.094
			Cutback		
2	---	---	---	---	---
3	194.1	194.4	195.1	195.1	0.515
4	242.8	243.6	245.7	245.7	1.15
5	183.1	183.4	183.5	183.5	0.218

Road Oil

% Material
2
3
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5

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Road

% Water
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8
12

Stability of Briquettes

Road Oil		Emulsion		Cutback	
% Material	Lb/Sq.In.	% Material	Lb/Sp.In.	% Material	Lb/Sq.In.
2	1550	2	1920	2	---
3	1610	3	2300	3	2100
4	1700	4	3500	4	2710
5	1730	5	7330	5	2830

Chemical Analysis

Nitrate	2 P.P.M.
Phosphorous	½ "
Calcium	0 "
Magnesium	5 "
Iron	35 "
Chloride	0 "
Potassium	10 "
Intensely Acid	Ph. 3

Soil # 5 Longrie Type Mackinac O.Veatch

This soil was a dark gray having a specific gravity of 0.98 and fine uniform particles although the soil contained a great deal of material similar to that found in peat swamps. The following data is the result of the tests that were made on this soil.

Liquid limit	35.0%
Plastic limit	0.0%
Shrinkage	4.8%
Percentage of sand	22.8
Percentage of clay	7.6
Percentage of silt	69.6
Percentage passing 200 mesh sieve	26.6
Plastic index	35.0%
Field Moisture	36.7%

Capillary Action

Road Oil		Emulsion		Cutback	
% Water	Rise	% Water	Rise	% Water	Rise
0	2¼"	0	0"	0	1"
4	2¼"	4	1/16"	4	1"
8	2 3/8"	8	3/16"	8	1"
12	3"	12	¼"	12	1 1/8"
16	2½"	16	¼"	16	1"

Water Absorption by Briquettes

ROAD OIL

% Road Material	Dry Wt.	Wt. at 24 Hrs.	Wt. at 48 Hrs.	Wt. at 72 Hrs.	Percent Absorption
2	143.9	144.1	144.2	144.2	0.708
3	155.1	155.2	155.6	155.6	0.323
4	144.8	145.0	145.3	145.3	0.345
5	179.8	180.1	180.0	180.0	0.111
		EMULSION			
2	160.8	164.3	165.7	165.7	3.05
3	135.4	137.8	139.7	139.7	3.18
4	180.0	181.6	181.9	181.9	1.06
5	138.9	139.3	140.1	140.1	0.79
		CUTBACK			
3	139.5	140.0	140.4	140.4	0.641
4	174.9	175.3	175.8	175.8	0.515
5	174.4	175.0	175.8	175.8	0.805

Stability of Briquettes

Road Oil		Emulsion		Cutback	
% Material	Lb/Sq.In	% Material	Lb/Sq.In.	% Material	Lb/Sq.In.
2	900	2	2290	X	---
3	1290	3	5010	3	1540
4	1380	4	6960	4	3100
5	1450	5	9560	5	3260

Chemical Analysis

Nitrate	10 P.P.M.
Phosphorous	½ "
Calcium	0 "
Magnesium	2 "
Iron	40 "
Chloride	0 "
Potassium	0 "
Strongly Acid	Ph. 5

The water perferential test made on both soils indicated a very strong affinity for the oil with very little soil settling to the bottom of the glass jar. According to a careful estimate, the percent separation of both soils was around ten which is entirely satisfactory.

Figures 1b and 5b show the trend of the capillary action of the road materials as they pertain to the two soils. It is noted that the road oil showed the highest capillary action in each sample with a maximum rise of four percent water for soil one and of twelve percent water for soil five. Following the road oil, the cutback and emulsion are in the order named and again the highest capillary rise takes place at the same water percentage for cutback as for the road oil. It is thought that the water percentage for greatest capillary rise should be near the liquid limit as happened to be true in the above cases. The emulsion shows very little tendency to rise which probably is due to the fact that the emulsion contains water thereby the evaporated water out of the soil is partly replaced by water from the emulsion. Neither of the soils show a more effective capillary action over the other.

The results of the absorption tests prove that in both soils the waterproofing qualities of road oil stand alone when compared to the emulsion and cutback. Although the road oil mixture had the greatest capillary action and the best waterproofing qualities, it had the poorest resistance to shear with the emulsion mixture

acting in the reverse order of poor capillary rise and waterproofing but showing the greatest stability. All the mixtures increase in stability as the percentage of road material is increased.

Observations concerning the physical and chemical tests show the following: Both soils contained sufficient sand, approximately one-fourth, which appears of necessity to provide stability along with enough clay, seven to ten percent, to give the sand a binding material. Also each soil contained over twenty five percent passing the 200 mesh screen which gave sufficient filler along with sand and binder. Each soil was strongly acid in nature and high in iron content, indicating soils of that nature can be stabilized economically with a bituminous road material.

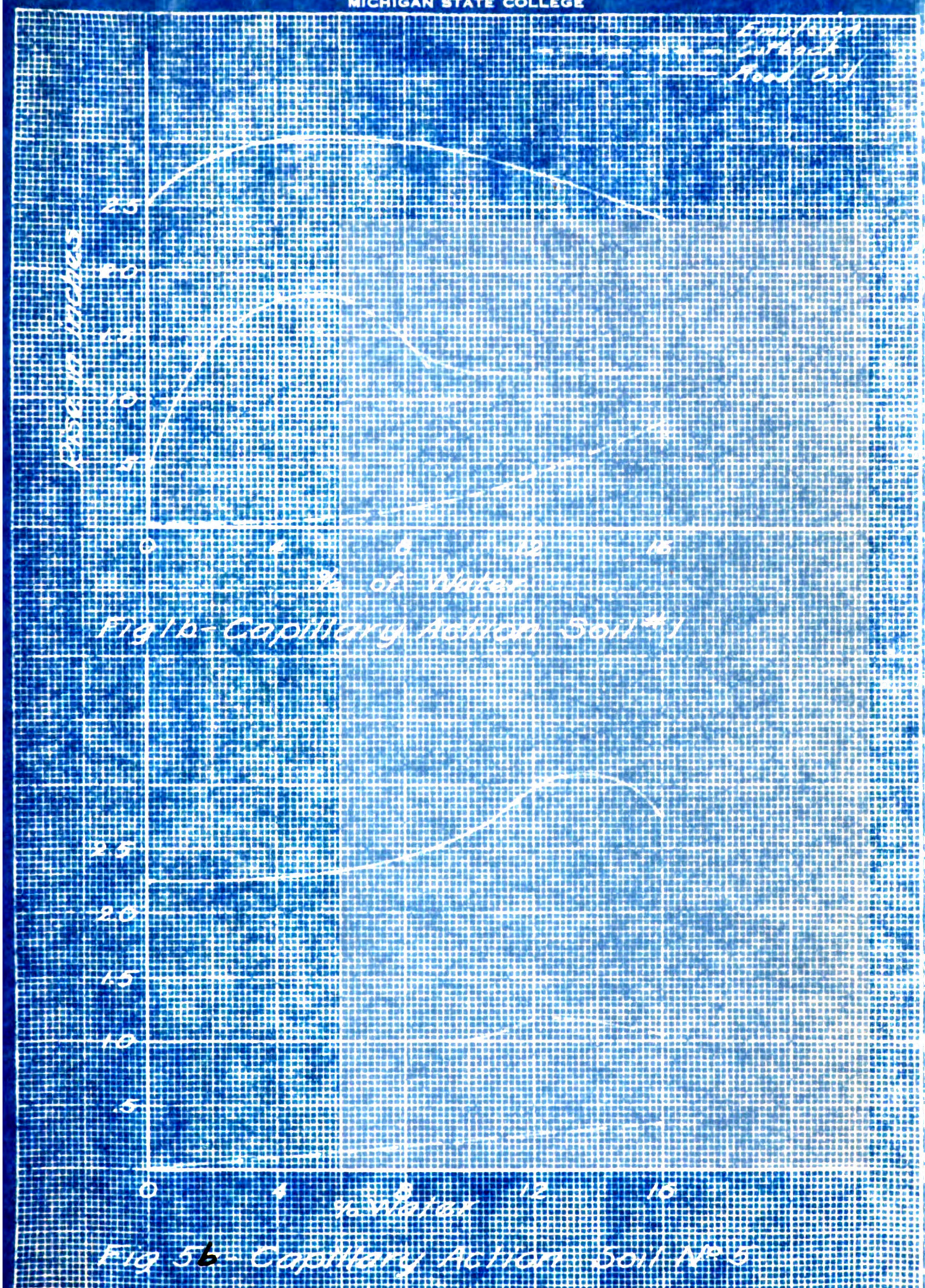
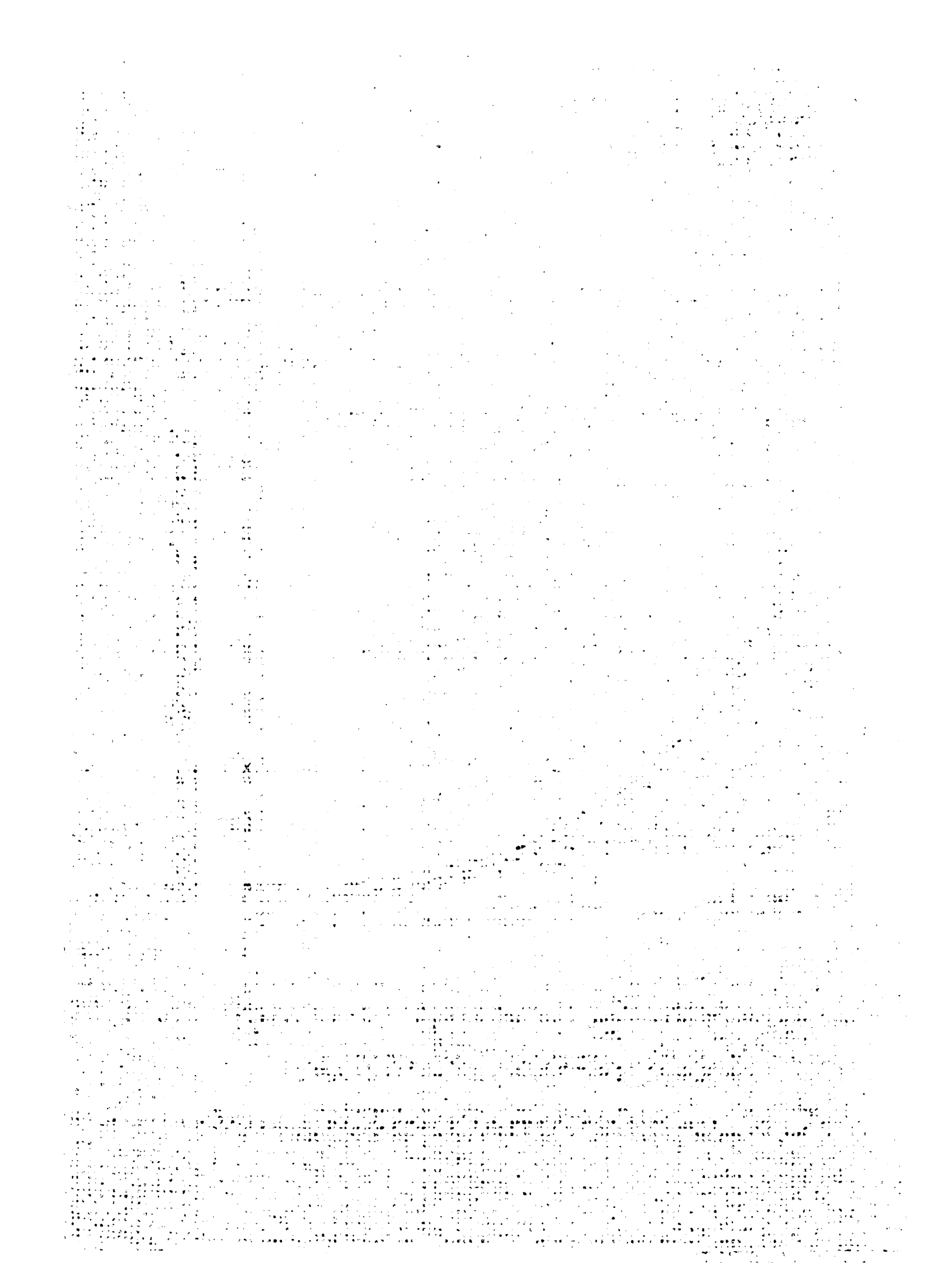
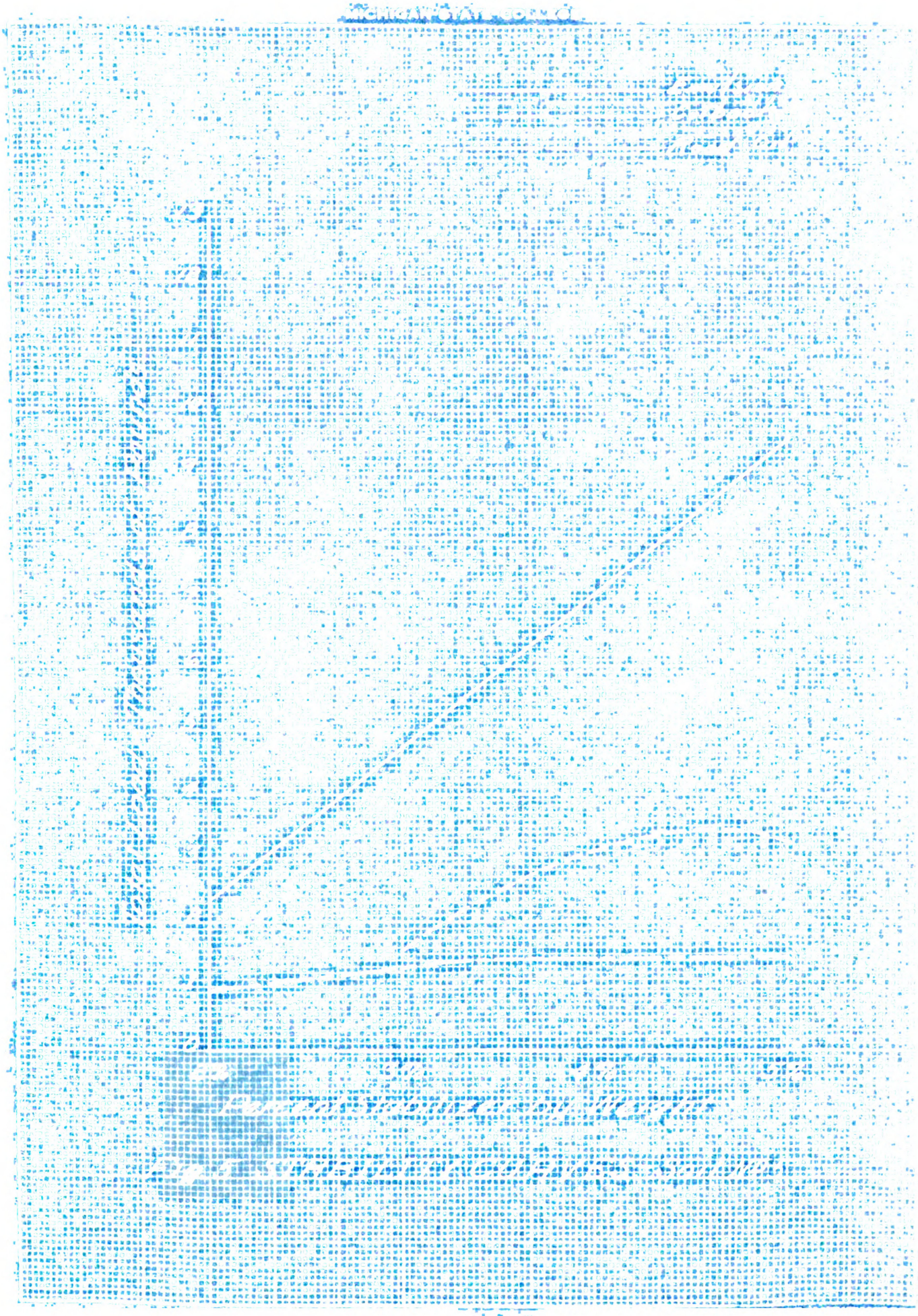
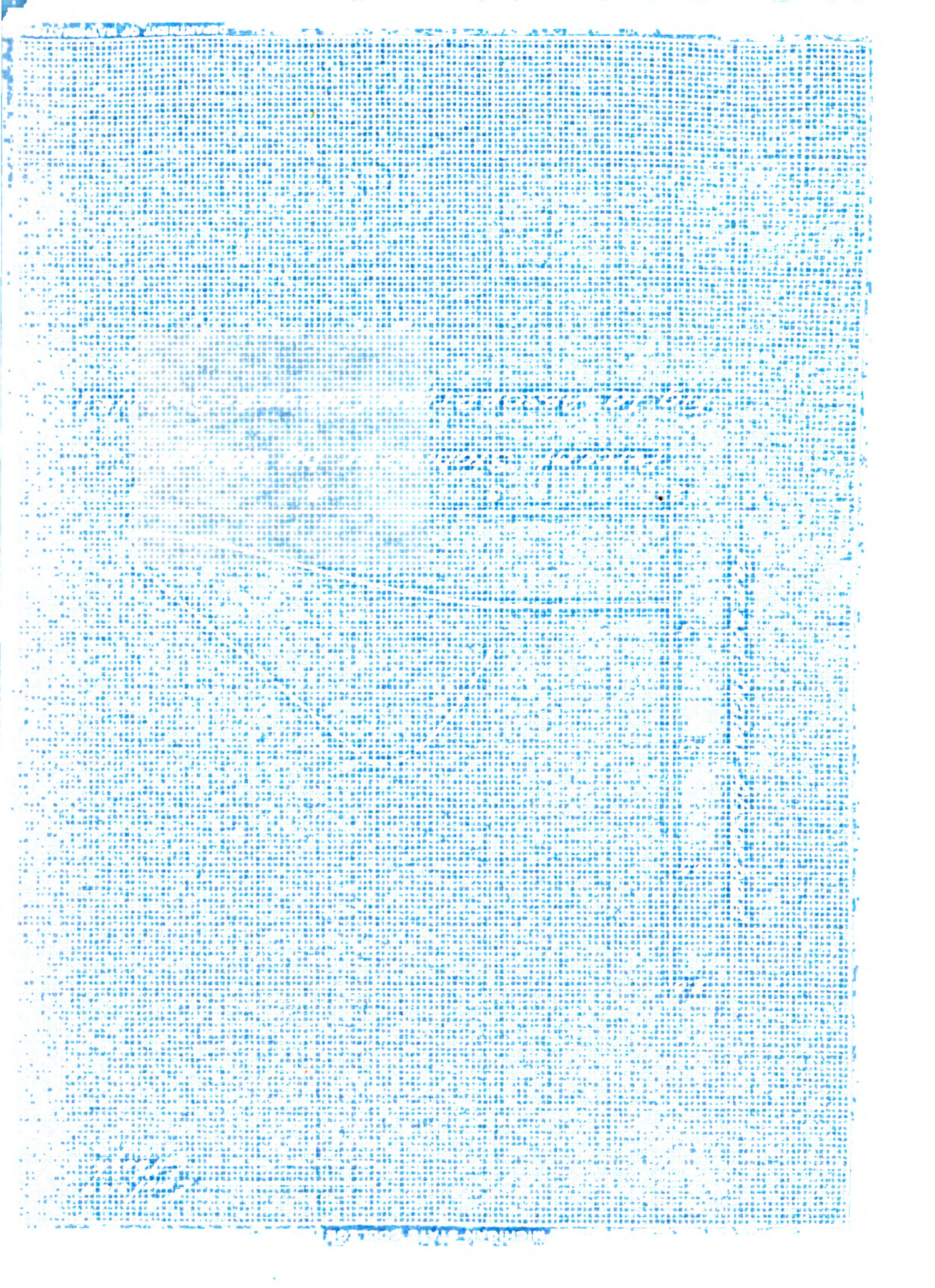


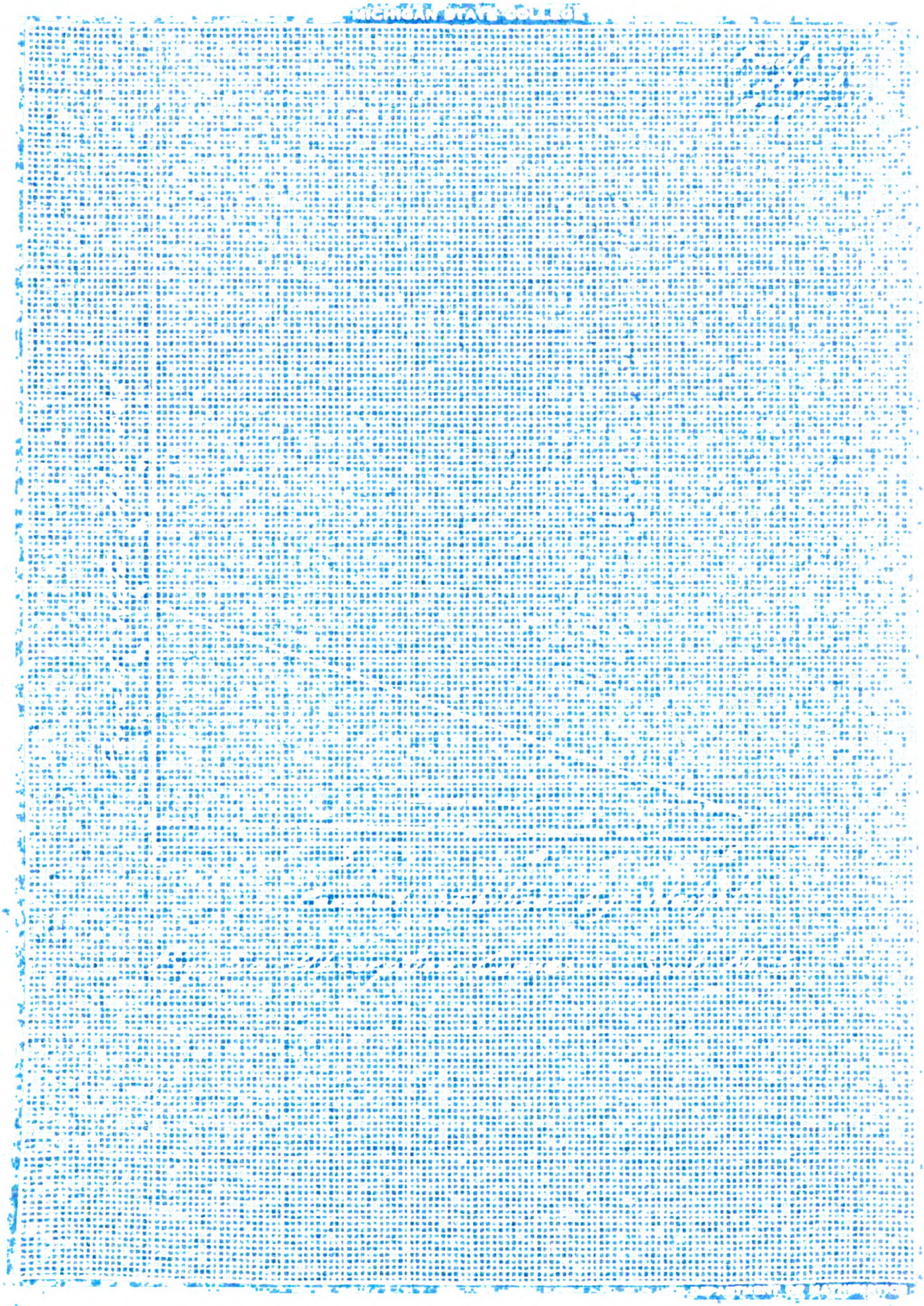
Fig 10-Capillary Action Soil #1

Fig 5b Capillary Action Soil No 5









Soil #2 Naponee Silty Clay Loam

Soil #7 Fox Gray Sandy Loam

Investigation

by

James L. Alvord

Soil #2 Naponee Silty Clay Loam

The results of the preliminary tests on Soil #2 are as follows:

Physical		Chemical	
Liquid Limit	48.6%	Calcium	200 p.p.m.
Plastic Limit	26.5%	Chlorides	20 p.p.m.
Plastic Index	22.1%	Nitrates	25 p.p.m.
Field Moisture	39.6%	Manganese	C
Shrinkage Limit	17.1%	Ammonia	C
Clay	65.4%	Magnesium	7 p.p.m.
Sand	17.6%	Carbonates	High
Silt	17.0%	Potassium	C
Passing #200	89.48%	Aluminum	1 p.p.m.
		Iron	10 p.p.m.
		Nitrites	C
		Phosphorus	C
		Sulfates	C
		Acid Reaction	Strongly alkaline pH = 9

This soil has a high clay content and in its natural state was in a hard lumpy form. It contained practically no stones nor organic matter and was very stable when dry, but absorbed water quite rapidly and soon became very unstable.

Soil #7 Fox Gray Sandy Loam A2

The results of the preliminary tests on Soil #7 are as follows:

Physical		Chemical	
Liquid Limit	22.2%	Calcium	40 p.p.m.
Plastic Limit	16.5%	Chlorides	20 p.p.m.
Plastic Index	5.7%	Nitrates	5 p.p.m.
Field Moisture	18.2%	Manganese	C
Shrinkage Limit	15.82%	Ammonia	2 p.p.m.
Clay	17.25%	Carbonates	C
Sand	76.7%	Potassium	5 p.p.m.
Silt	6.05%	Aluminum	C
Passing #200	9.8%	Iron	10 p.p.m.

Chemical (cont.)

Nitrites----------0
Phosphorus----------1/2 (low)
Magnesium----------15 p.p.m.
Sulfates----------150 p.p.m.
Acid Reaction------Strongly acid
pH = 5

This was a red loam which contained some pieces of coarse aggregate with a maximum size of about 2". It also contained some pieces of organic matter composed largely of small hair-like roots. It was quite dusty when dry, but compacted well when wet.

The data for the final tests are as follows:

Capillary Action

Soil #2--- Road Oil		Soil #2--- Cutback	
Percent water	Rise in inches	Percent water	Rise in in.
0%	1.8	0%	.4
4%	1.85	4%	.9
8%	1.7	8%	.7
12%	1.7	12%	.75
16%	1.9	16%	1.50

Soil #7--- Road Oil		Soil #7--- Cutback	
% water	Rise in inches	% water	Rise in in.
0%	1.9	0%	.6
4%	2.7	4%	1.3
8%	2.6	8%	1.3
12%	2.2	12%	1.2
16%	2.2	16%	1.4

Absorption and Stability data

Soil	Bitumen	% Bitumen	Absorption	Stability (lbs.)
2	Emulsion	2	23.9%	150
2	"	3	15.8%	750
2	"	4	11.3%	440
2	"	5	7.1%	150
7	"	2	0.89%	7,500
7	"	3	0.45%	10,600
7	"	4	0.53%	11,400
7	"	5	0.80%	22,400
2	Road Oil	2	29.0%	125
2	"	3	22.2%	775
2	"	4	20.2%	
2	"	5	3.8%	3,000
7	"	2	0.59%	7,100
7	"	3	0.32%	7,500
7	"	4	0.65%	
7	"	5	0.00%	9,500
2	Cutback	2	Failed	Failed
2	"	3	15.3%	650
2	"	4	12.8%	525
2	"	5	19.4%	450
7	"	2	1.2%	7,800
7	"	3	0.76%	10,600
7	"	4	0.78%	16,500

The <u>water preferential test</u> is not an accurate quantitative test, but merely shows the relative and approximate affinity of the dust for oil or water. The results of this test showed that soil #2 had a greater affinity for water than for oil, as about 60%-70% of the dust settled out of the oil to the bottom of the container. Soil #7 showed a greater for oil and did not settle out any appreciable amount. The results of these tests are also borne out by the results of the absorption tests, as soil #2 absorbed water quite freely and soil #7 absorbed very little water.

For the absorption test the samples were left in the water bath until they maintained a constant weight. The Naponee Silty Clay Loam absorbed water rapidly and had reached its maximum weight at the end of the first day. The Fox Gray Sandy Loam absorbed very little water and at the end of four days in the water bath in most cases had absorbed less than 1%. Some of the clay samples fell apart when taken out of the water bath and consequently it was impossible to make stability tests on those samples. Other clay samples cracked badly and when put in the water bath absorbed water until the water reached the cracks and then the absorption stopped. These samples gave inconsistent readings for both the absorption and stability tests.

The results of the capillary tests indicate that the wetter the soil, the greater the degree of capillarity. This would seem to show that if the stabilizing agent is to be applied to the road in a manner that depends upon capillary action, it would be preferable to apply the stabilizer in damp weather or else wet the soil above the level of the stabilizing agent. The emulsion used in these tests failed to rise any appreciable amount, but the cutback and road oil rose quite evenly. The degree of capillarity was slightly greater in soil #7, which was the soil with the least amount of clay.

The stability test showed that the stability is

dependent upon the amount of water absorbed. Soil #2, which was the clay and absorbed the most water, in practically all cases was very soft when taken from the water bath and tested for stability. This soil gave inconsistent results and was too wet to be stable. Soil #7, which seemed to contain an ideal mixture for stabilization, was very hard and resisted high loads before failing. For the Fox Gray Sandy Loam the emulsion seemed to be more efficient than the others, while the cutback was better than the road oil. Soil #2 had too great a proportion of clay to be stabilized by so small a percentage of stabilizing agent.

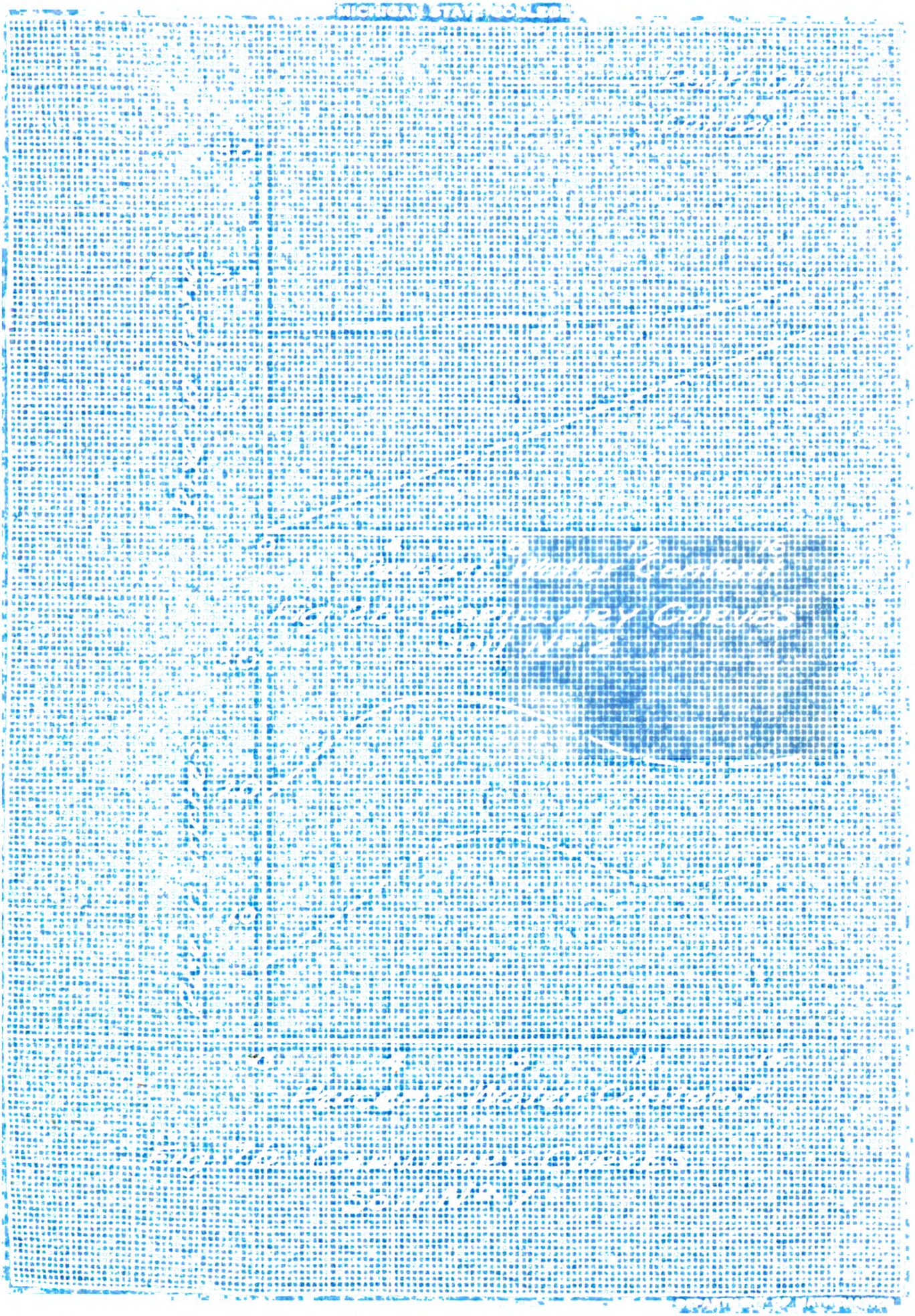
The mechanical tests, which were made according to specifications, show that #2 is a typical clay soil while #7 is more of a sandy soil. The results of these standard tests are given in the preceding table.

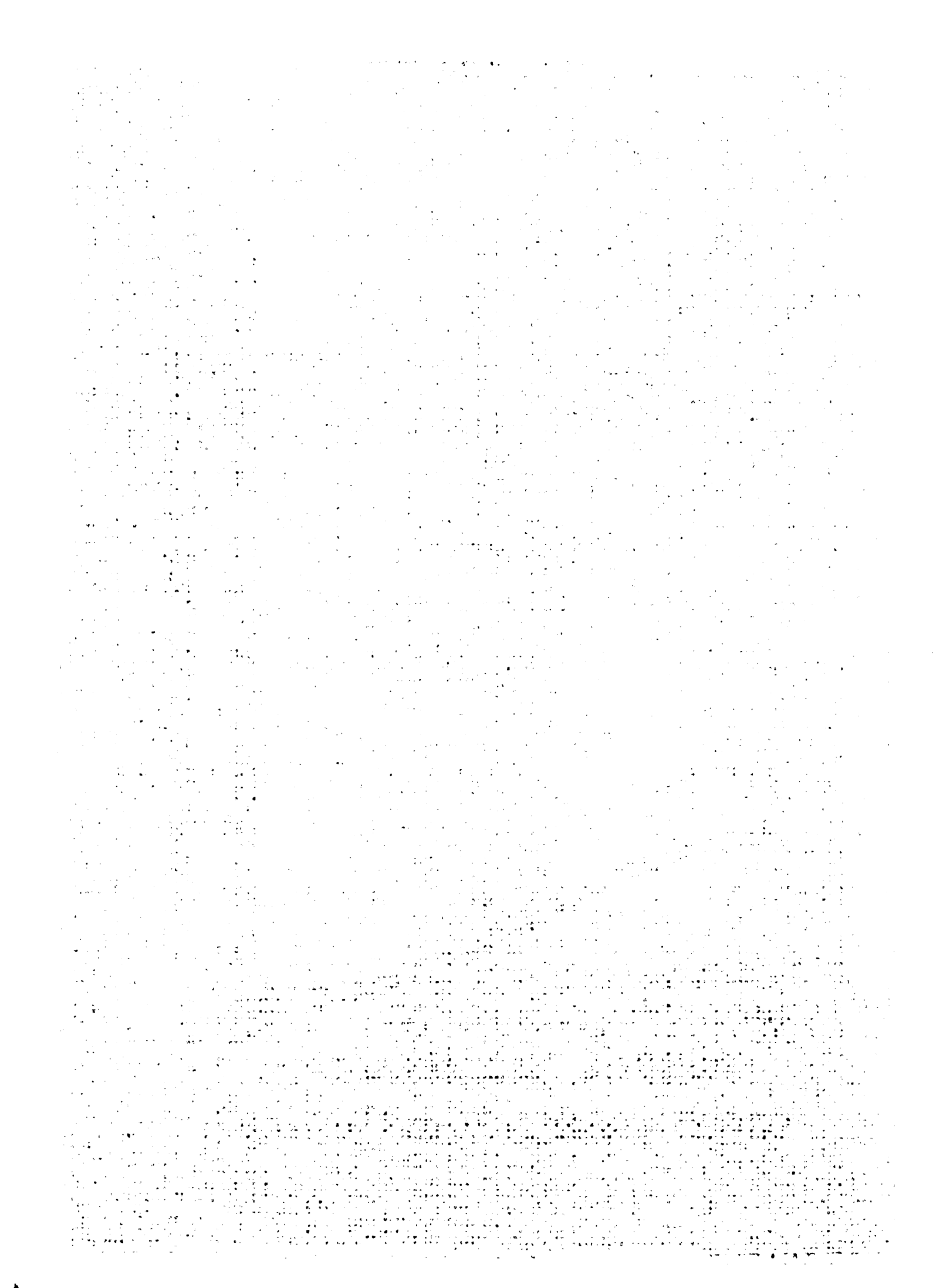
All the chemical tests were made according to instructions in the booklet by C. H. Spurway of the Agricultural Experiment Station of Michigan State College. These tests showed that the Napanee Silty Clay Loam was strongly alkaline and the Fox Gray Sandy Loam was strongly acid. The various chemical constituents of the soils may be found in the preceding tables.

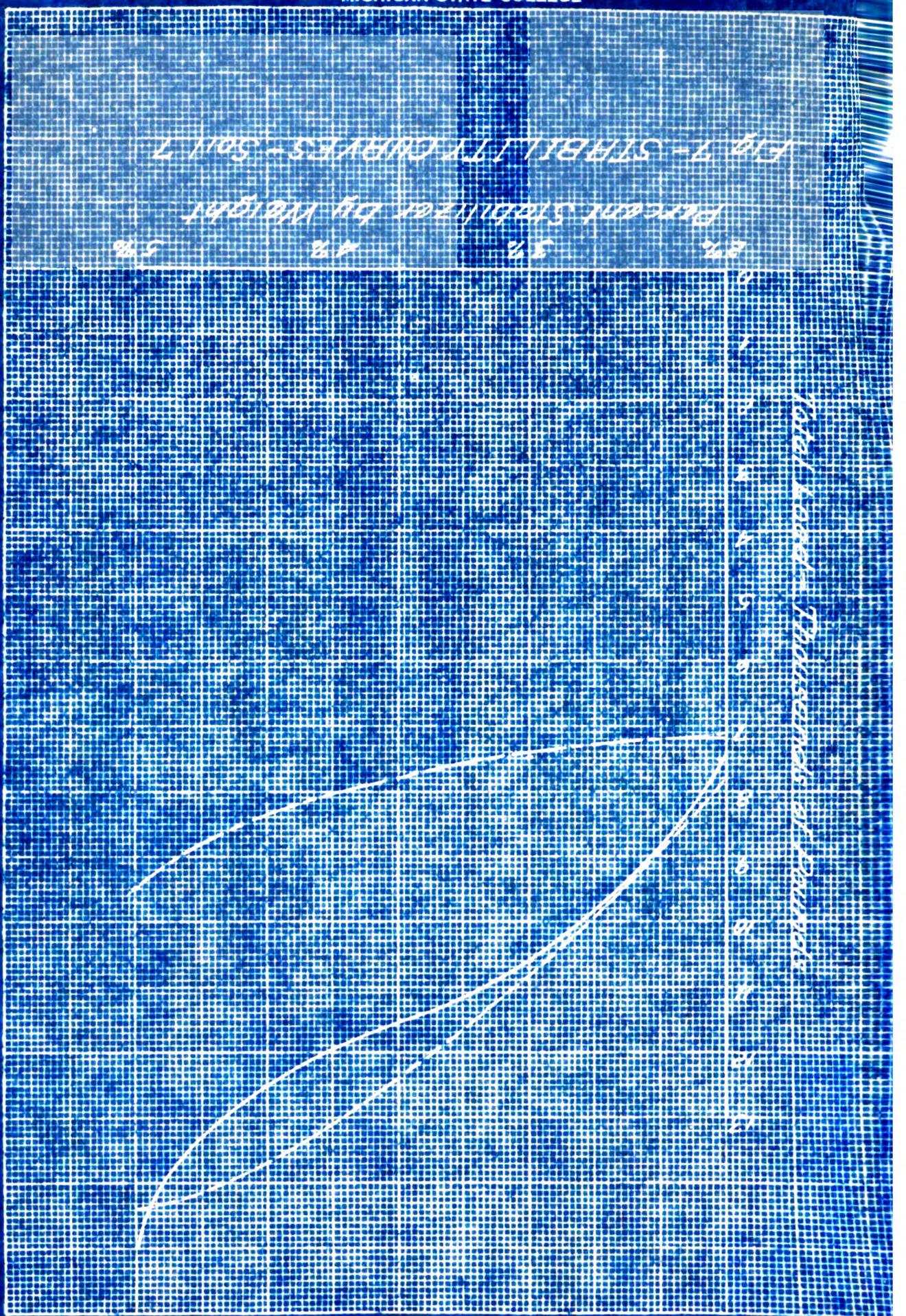
It is rather futile to attempt to make any definite conclusions about all soils on the basis of these two

alone, so many more soils will have to be investigated before accurate statements may be made. Nevertheless it would be interesting to see if the stability and the absorption of a soil to be stabilized are interdependent in any degree as those two soils happen to indicate. Other possibilities include the investigation of similar soil with just a variation of the chemical constituents; unfortunately neither the time nor the large variety of soils were available for use in this investigation.

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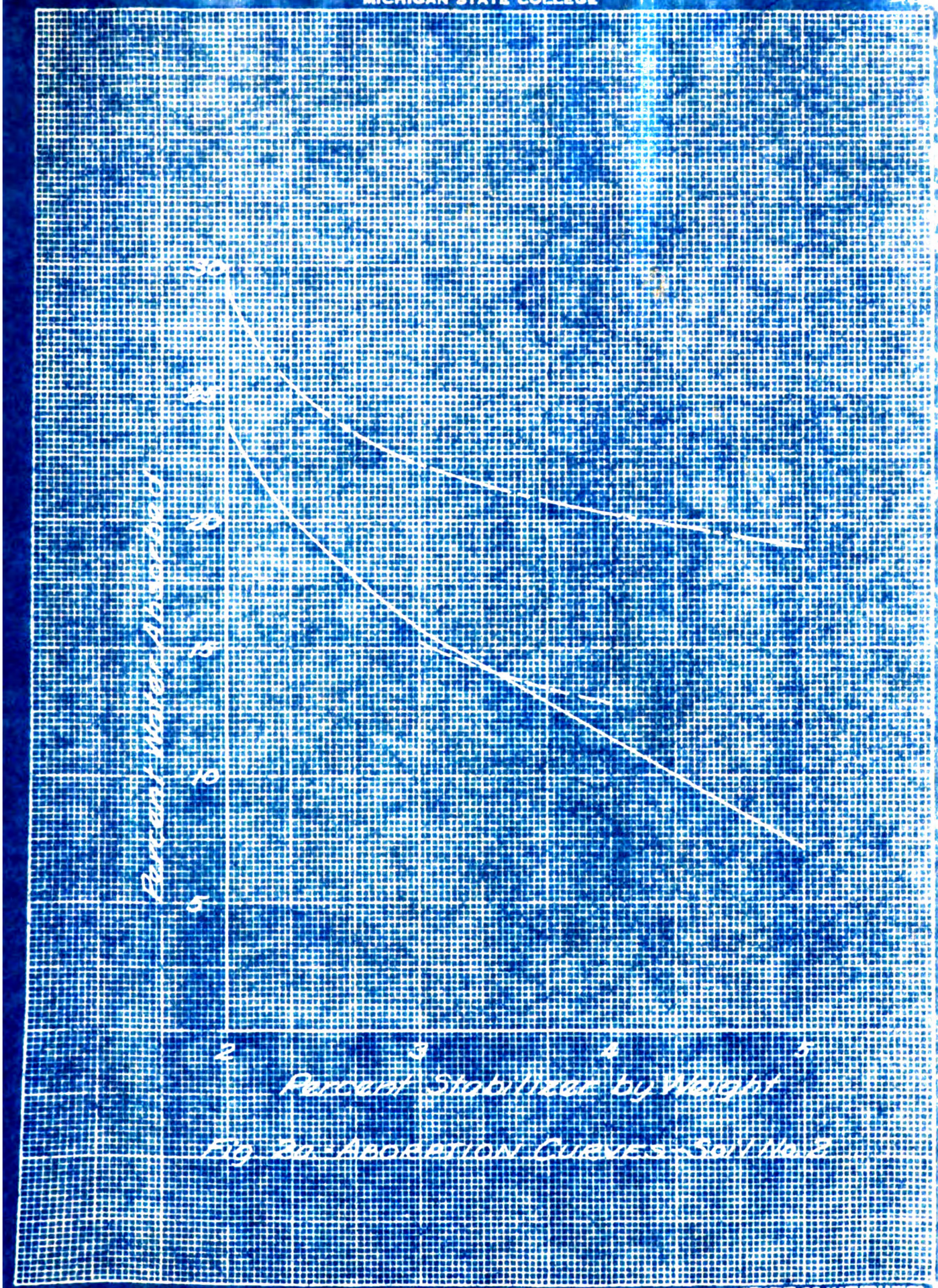
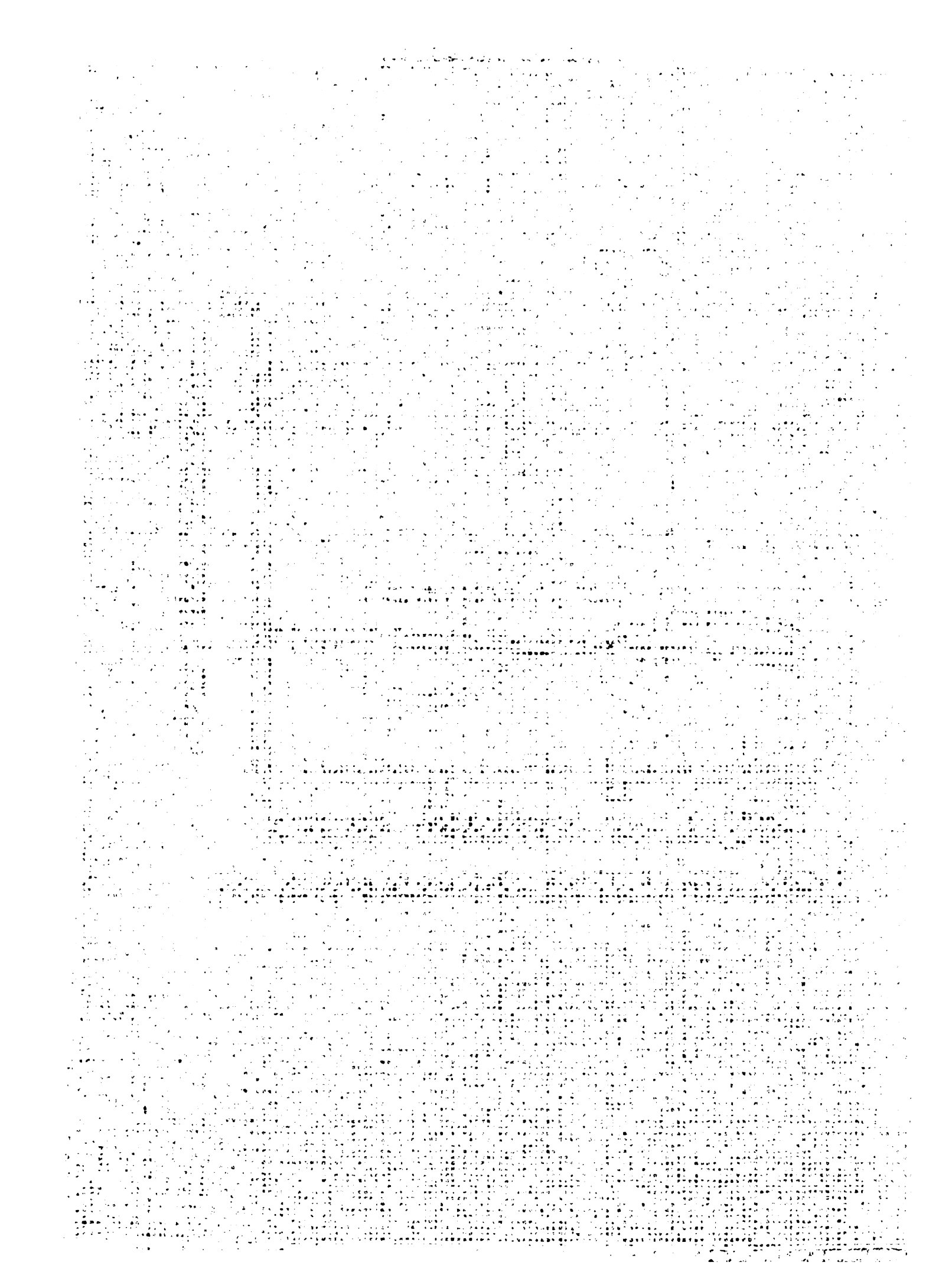


Fig. 2a. Absorption Curves - Soil No. 2



Soil #4 Fox Sturgis B 24"-48"

Soil #12 Composition X

Investigation

by

D. Duane Baugh

Soil #4 Pit Strata "B" 24"-48"

The results of physical and chemical tests on Soil #4 are as follows:

Physical		Chemical	
Liquid Limit	27.2%	Nitrate	C
Plastic Limit	17.8%	Phosphorus	1 p.p.m.
Plastic Index	9.4%	Potassium	C
Shrinkage Limit	20.0%	Calcium	present
Sand	80.2%	Carbonate	absent
Silt	5.8%	Ammonia	2 p.p.m.
Clay	14.0%	Nitrite	C
Passing 200	24.9%	Magnesium	1 p.p.m.
Field moisture	14.8%	Iron	40 p.p.m.
Soiltex pH strongly acid	5	Aluminum	C
		Manganese	C
		Sulfate	C
		Chloride	C

This sample consisted of a soil somewhat resembling an ordinary type of road gravel as it might come from the pit, being of a reddish brown color and containing a large amount of stone, varying in size up to about 3" maximum. The sample had a considerable amount of stability in the dry condition and a considerable portion of the sample was in large lumps, held together by the presence of clay.

Soil #12 X Brand

The results of the tests of the Soil #12 are as follows:

Physical		Chemical	
Liquid limit	24.4%	Nitrate	2 p.p.m.
Plastic limit	C	Ammonia	C
Plastic index	24,4%	Nitrite	C
Shrinkage limit	23.0%	Phosphorus	C
Sand	46.0%	Potassium	10 p.p.m.
Silt	37%	Calcium	present
Clay	17%	Magnesium	C

Physical (cont.)		Chemical (cont.)	
Passing 200	56.8%	Iron	30 p.p.m.
Field moisture	23.4%	Aluminum	0
Soiltex	medium acid	Carbonate	0
		Manganese	0
		Sulfate	0
		Chloride	0
		Sodium	0

Soil #12 was a fine, sandy loam, light greyish in color, with a large percentage of silt as was determined by mechanical analysis. This sample contained no lumps, or stone, but did contain a considerable amount of organic matter such as fine threadlike roots. As this sample was limited in quantity it was impossible to mix samples for cut back and road oil in more than one percentage and therefore there is insufficient data to plot all stability and absorption curves for this soil.

Soil	Bitumen	% of Bitumen	% Absorption	Total Load
#4	Emulsion	2	1.3	3,400
"	"	3	1.9	5,500
"	"	4	1.0	7,700
"	"	5	1.6	6,100
"	Cut back	2	2.2	6,350
"	"	3	1.4	7,650
"	"	4	1.1	10,100
"	"	5	1.5	6,100
"	Road oil	2	.7	4,400
"	"	3	.5	5,100
"	"	4	.0	0
"	"	5	.1	6,400
#12	Emulsion	2	10.8	0
"	"	3	1.3	10,400
"	"	4	2.3	11,500
"	"	5	1.4	7,900
"	Cut back	3	1.2	9,350
"	Road oil	3	18.3	0

CAPILLARITY

Soil	Bitumen	% water	Height (inches)
#1	Cutback	0	1.25
"	"	4	1.25
"	"	8	1.75
"	"	12	2.25
"	"	16	1.5
"	Road oil	0	2.1
"	"	4	1.5
"	"	8	1.5
"	"	12	2.25
"	"	16	2.4
"	Emulsion	0	.5
"	"	4	.5
"	"	8	.75
"	"	12	1.0
"	"	16	2.25
#12	Cutback	0	1.0
"	"	4	1.25
"	"	8	1.4
"	"	12	1.5
"	"	16	1.1
"	Road oil	0	2.25
"	"	4	1.75
"	"	8	2.0
"	"	12	1.25
"	"	16	2.5
"	Emulsion	0	.25
"	"	4	.5
"	"	8	.5
"	"	12	.75
"	"	16	.75

The water-asphalt preferential test made on both soils indicated a strong preference for the oil. The results of both were similar in that in each test the oil separated from the mixture and sank to the bottom of the bottle, leaving water on top. This was due, perhaps, to the fact that the soil particles had a high affinity for the oil and became thoroughly mixed with it. This mixture of oil particles and heavier

soil grains formed a mat of material which had a specific gravity greater than that of water and thus sank to the bottom of the bottle. As this test is not accurate in a quantitative sense, it should be sufficient to observe that neither of these soil samples exhibited an appreciable affinity for water.

The results of the capillarity test are brought out in the preceding figures. It is noted that in each sample the road oil showed the highest capillary action, with cutback and emulsion next in order. It was observed that the cutback and road oils showed evidences of capillarity before the emulsion, which did not tend to rise in the tube until the soil had begun to dry out. It is thought that the oil replaced the water particles as evaporation took place. More effective capillarity took place in the case of Soil #4 than #12, which was a finer textured soil. This is explained by the fact that smaller particles require a larger quantity of asphalt to cover the surfaces of a certain weight of soil.

It is significant to note the upward trend of all curves, and this trend is verified by the observations made in mixing samples of soil for briquettes. It was impossible to mix asphalt with perfectly dry samples, as the small amount of oil caused the soil to ball up. As the amount of water was increased, ease and completeness of the mixing was noted, until the moisture content somewhere approaching liquid limit

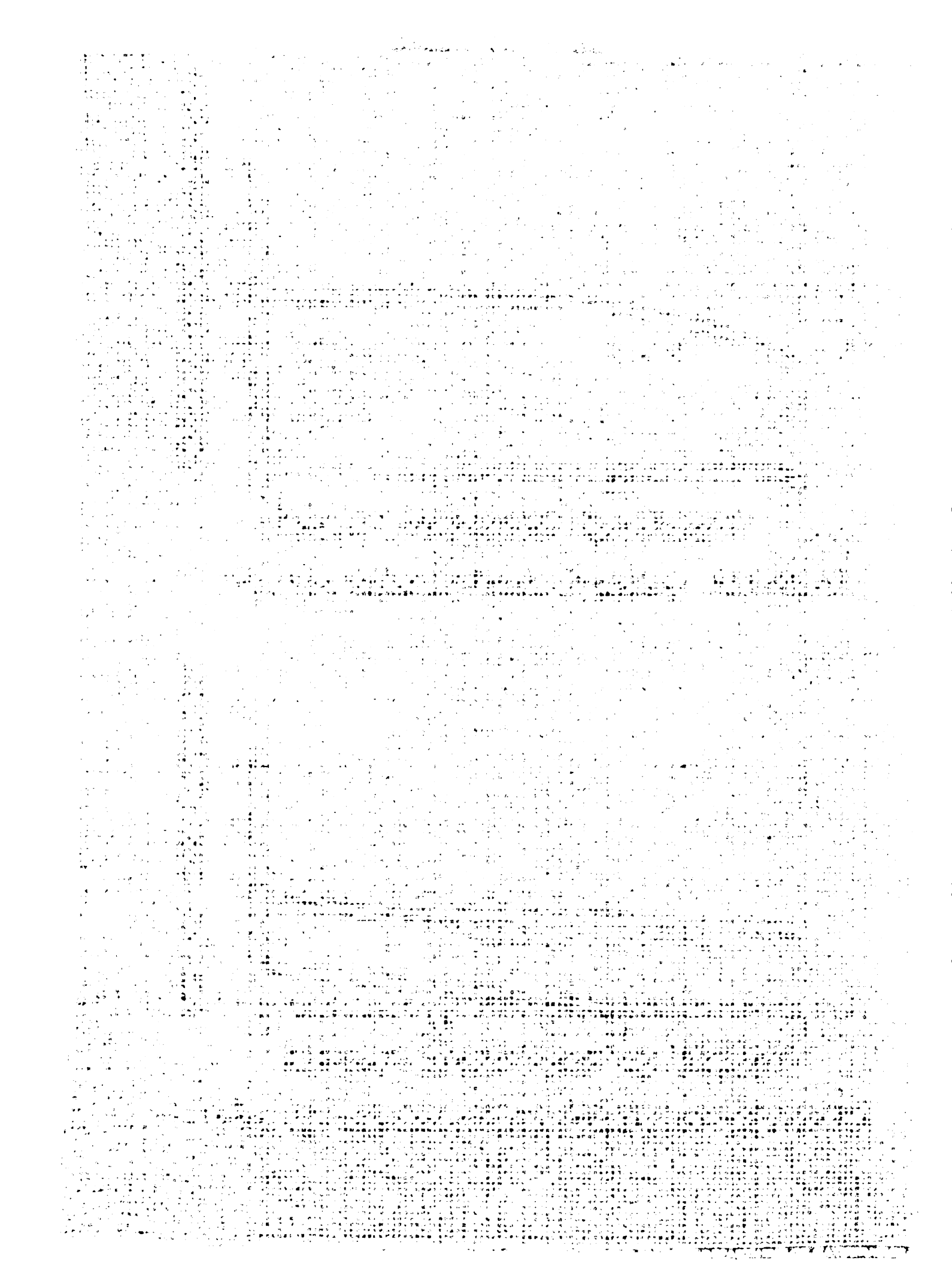
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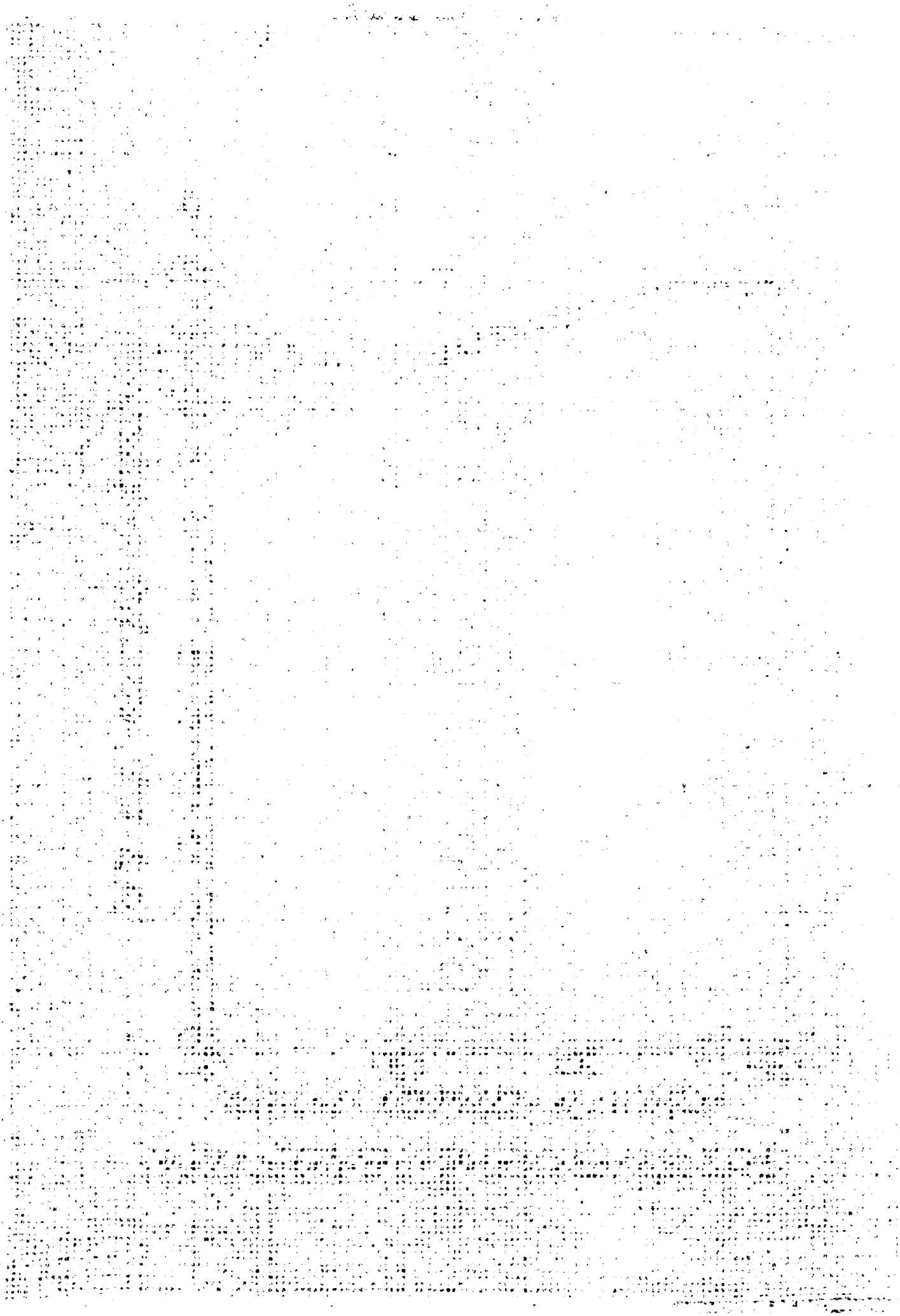
The results of the absorption tests, with the exception of two samples, show absorption of less than 3%, and the percentage seems to be independent of the quantity of stabilizer after an amount sufficient to coat soil particles is provided. For example, Soil #12 with 8% emulsion absorbed 10.8% moisture and was incapable of withstanding any load. The mixture consisting of 3% emulsion, however, absorbed but 1.3% and was highly satisfactory as to stability, and addition of more asphalt did not appreciably improve resistance to shear. The other sample having a high amount of absorption was Soil #12 with 3% road oil, which absorbed 18.3% moisture. This was close to the liquid limit for this soil and disintegrated under slight load. It is regrettable that insufficient samples of soil made it necessary to limit the number of samples to one percentage of road oil and cutback.

It should be well to make a few general observations about these two soils as shown by physical and chemical tests. First of all, it should be noted that each soil contained a fairly high percentage of sand, which seems essential to obtain satisfactory stability. It is also important to remember that Soil #4 was of a fairly stable nature without addition of any stabilizer. Also each soil contained

over 25% passing through the 200 mesh screen, as well as a considerable quantity of clay.

In regard to chemical tests, perhaps the outstanding observation is that both soils are acid in nature, which may or may not be an indication of the success of stabilization. It is significant, also, that each soil was very high in iron content. As a general observation it should be tentatively concluded that both soils may be economically stabilized with a bituminous material.





Soil #10 Hillsdale Jonesville

B 24"- 48"

Soil #11 Hillsdale Miami

Investigation

by

Donald Marlatt

The results of physical and chemical tests on Soil # 10 are as follows:

Physical		Chemical	
Liquid limit	27.6%	Nitrates	5 P.P.M.
Plastic limit	16.2%	Ammonia	2 "
Plastic index	11.4%	Nitrites	1 "
Field Moisture	24.9%	Phosphorus	0 "
Shrinkage limit	8.3%	Potassium	0 "
Sand	54.0%	Calcium	100 "
Clay	30.0%	Chlorides	150 "
Silt	16.0%	Magnesium	0 "
Pass 200 sieve	43.0%	Iron	25 "
		Aluminum	0 "
		Carbonates	0 "
		Manganese	0 "
		Sulfates	150 "
		Soiltex Test	PH-5 Strongly Acid.

Soil # 10 was a subsoil taken from 24" to 48" below the survace. It was a light brown color and approximately sand. The soil in the sample was mostly in large lumps, but was easily broken up. There was a small amount of small stones, but the percentage of stone was very small.

Results of Physical and Chemical Tests on soil # 11.

Physical		Chemical	
Liquid limit	45.3%	Nitrates	2 p.p.m.
Plastic limit	22.3%	Ammonia	0 "
Plastic index	23.0%	Nitrites	1 "
Field Moisture	23.8%	Phosphorus	0 "
Shrinkage limit	25.5%	Potassium	0 "
Sand	22.0%	Calcium	100 "
Clay	64.0%	Chlorides	50 "
Silt	14.0%	Magnesium	1 "
Pass 200 sieve	71.4%	Iron	10 "
Soiltex Test PH-9 Very strongly Alkaline		Aluminum	0 "
		Carbonates	2 "
		Manganese	0 "
		Sulfates	150 "

Soil # 11 was a gray color and mostly clay. It was evidently a subsoil. The sample was in the form of

small hard lumps and had to be pulverized before it could be tested. The sample contained no particles larger than a number ten screen.

Capillary Action Test Soil #10

Road Oil		Cut Back	
% water	Rise--inches.	% water	Rise--inches
0	1½	0	½
4	2 3/8	4	1
8	2¼	8	1¼
12	2½	12	1½
16	2¼	16	1¾

Capillary Action Test Soil #11

Road Oil		Cut Back	
% water	Rise--inches	% water	Rise--inches
0	½	0	1
4	¾	4	1¼
8	1	8	1½
12	1½	12	1 7/8
16	2	16	2

The Emulsion would not rise with either soil.

Absorption Table for Soil # 10

% Stabilizer	% Absorption (% of dry weight of briquette)
Emulsion:	
2%	3.8
3%	1.5
4%	1.7
5%	1.6
Road Oil:	
2%	8.8
3%	1.2
4%	1.1
5%	0.9
Cutback:	
2%	3.1
3%	2.0
4%	1.6
5%	1.4

Absorption Table for Soil # 11

% Stabilizer	% Absorbed (% of dry weight of briquette)
Emulsion:	
2%	11.6
3%	failed
4%	11.5
5%	4.7
Road Oil, 2%	failed
3%	"
4%	10.0
5%	8.5

Note: failed means that the briquette completely disintegrated and could not be weighted. The shortage of material in sample # 11 prevented making the briquette with the cutback as a stabilizer.

Stability Tests on Soil # 10

% Stabilizer	Total Load in Pounds		
	Emulsion	Road Oil	Cutback
2	9,800	4,300	9,800
3	12,500	9,500	---
4	14,600	9,800	12,200
5	16,500	9,000	13,000

Note: In tables of stability and on the stability graphs the total load is used instead of shear. The briquettes being of the same size, the total load gives the same comparative results as the shear would.

Stability Tests on Soil # 11

% Stabilizer	Total Load in Pounds	
	Emulsion	Road oil
2	7,800	failed
3	9,000	"
4	13,000	5,500
5	8,600	6,000

No samples were made for the cutback.

The Water Preferential Test on soils # 10 and 11 showed that they both had a greater affinity for asphalt than for water. Soil # 11 showed less than 10% of the soil settling out, while with soil # 10 none settled out. The soil raised

the specific gravity of the oil so that it settled to the bottom of the bottle and the water went to the top.

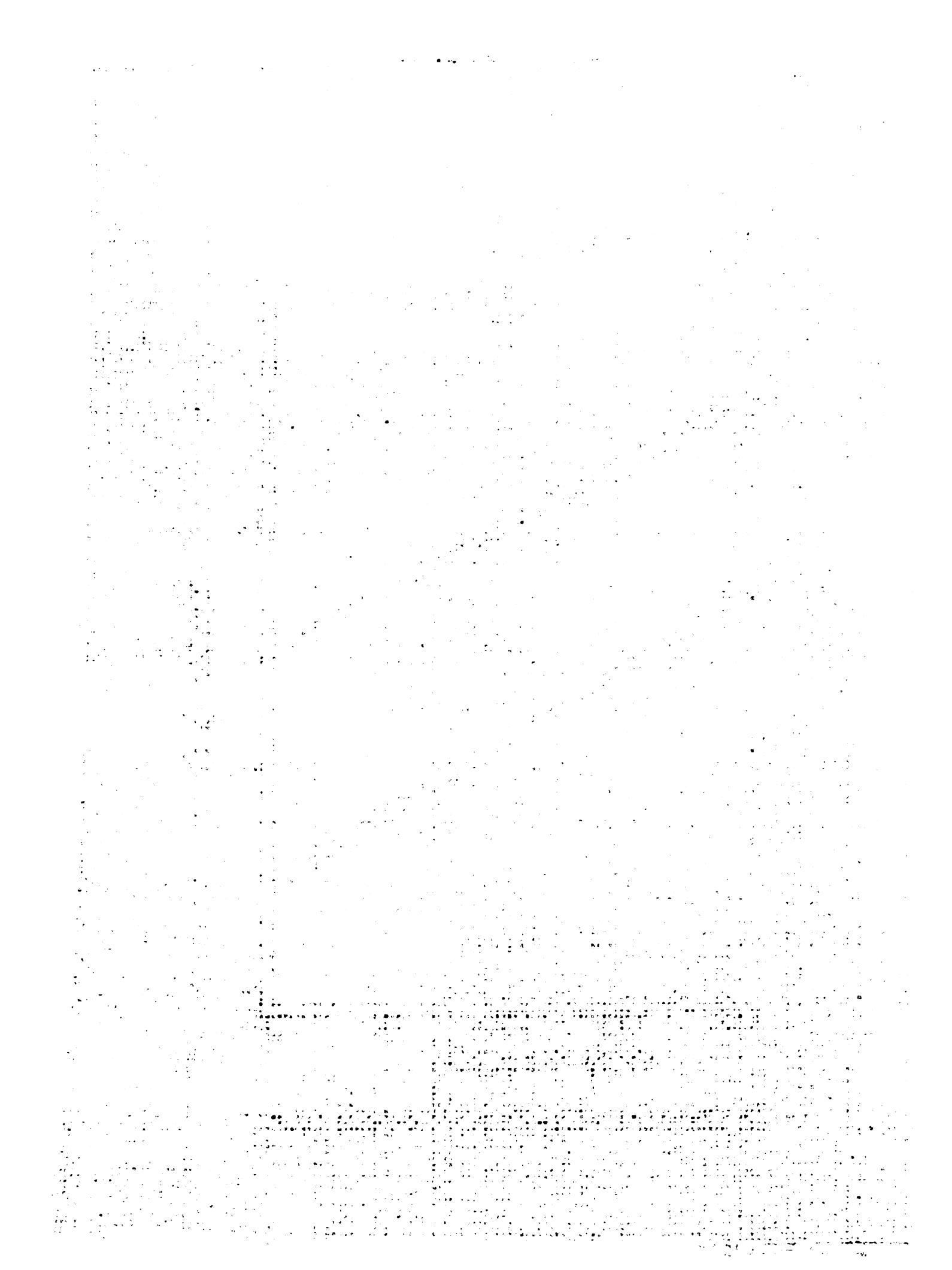
The absorption test showed that the amount of water absorbed depended on the amount of stabilizer used, and also on the type of soil. On soil # 10, the absorption on the 2% samples were much higher than the other percents. The 2% Road oil samples absorbed more than the cutback or the Emulsion. Soil # 11 did not stand up very well under the absorption test. Both the Emulsion and the Road oil absorbed more water than soil # 10. Probably the reason for this was that soil # 11 had a larger percent of clay content than # 10. Soil # 11 was a very strongly alkaline soil, while # 10 was strongly acid. This may have had some bearing on the absorption, but it is believed that the clay content had more to do with the results.

The capillary action test on these soils proved very interesting. The rise seemed to vary directly with the percent of water in the soil, for the cutback and the Road oil. The emulsion would not rise at all. This shows that stabilization with emulsion would require a more thorough mixing than the cutback or the road oil. The oil and cutback in the samples containing the water rose much faster at first than the dry samples. But at the end of the period of three weeks, the difference was not so noticeable.

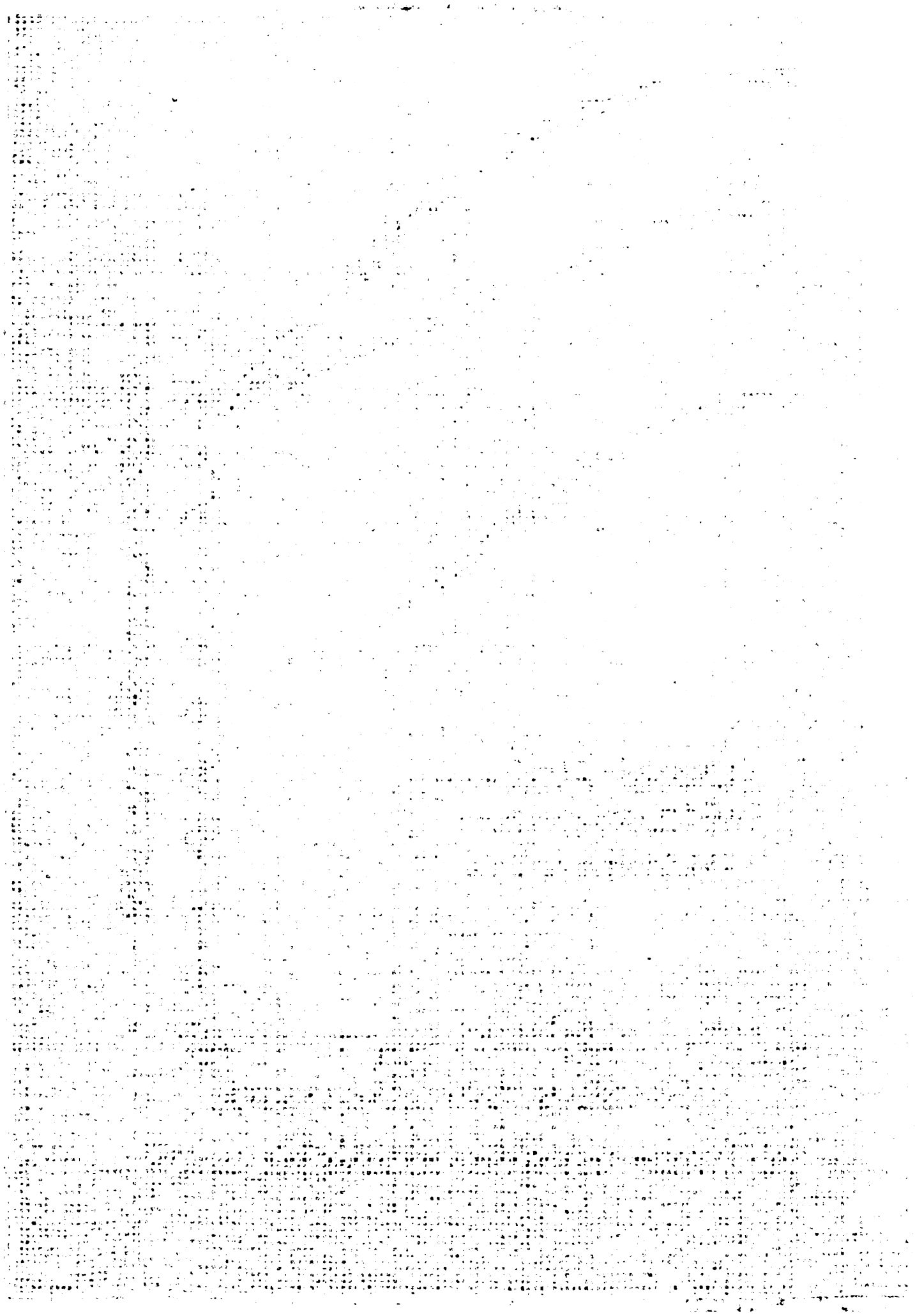
The stability tests showed the strength to vary directly with the percent of stabilizer with the emulsion having the greatest strength and the cutback next and then the Road oil. This does not necessarily mean that the road oil is not as good as the emulsion because the road oil is a slow setting

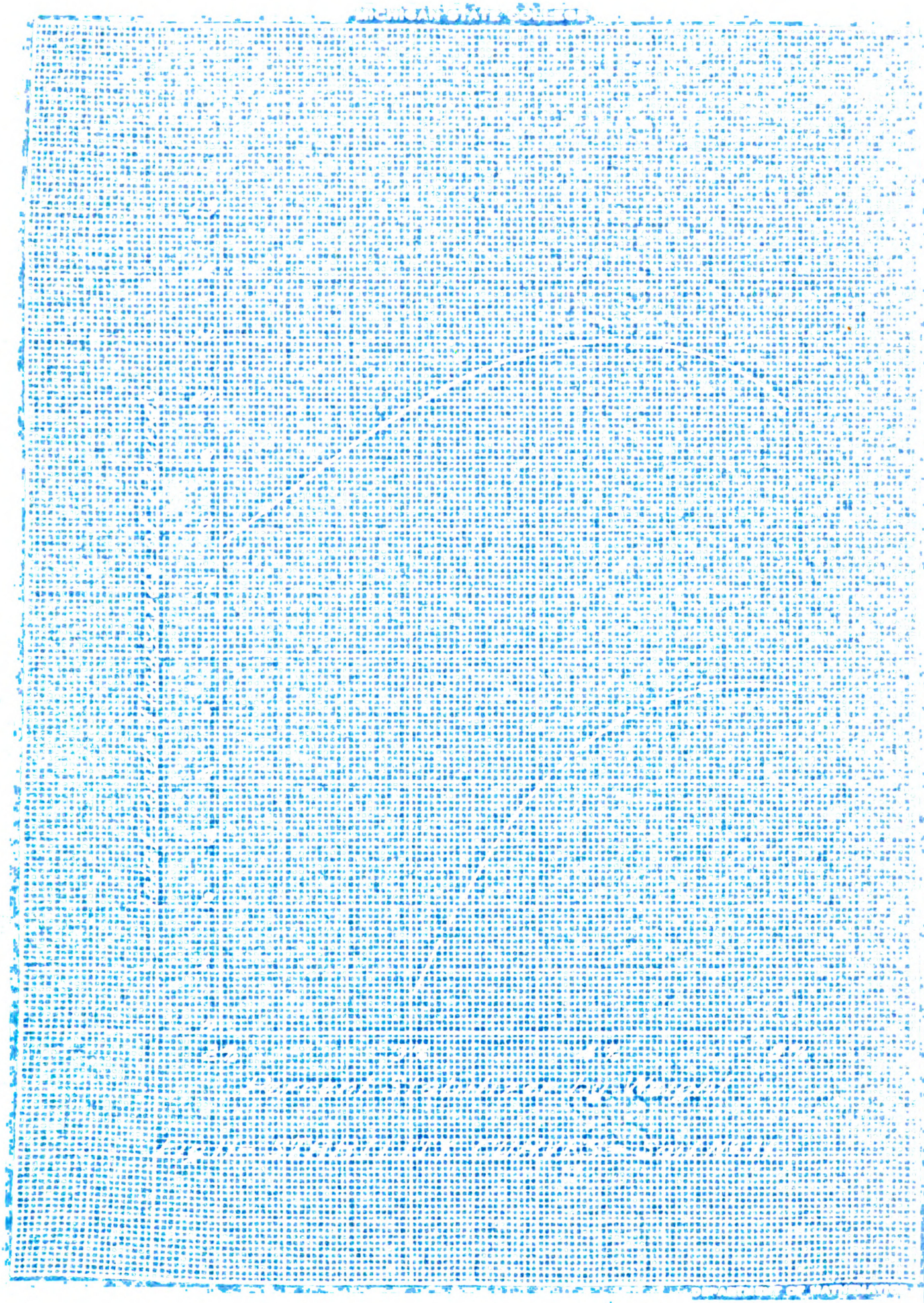
asphalt and did not hve time to reach its greatest strength before tne briquettes were tested. Soil # 10 was more stable than # 11, probably due to tne larger percent of sand and tne smaller percentage of clay.

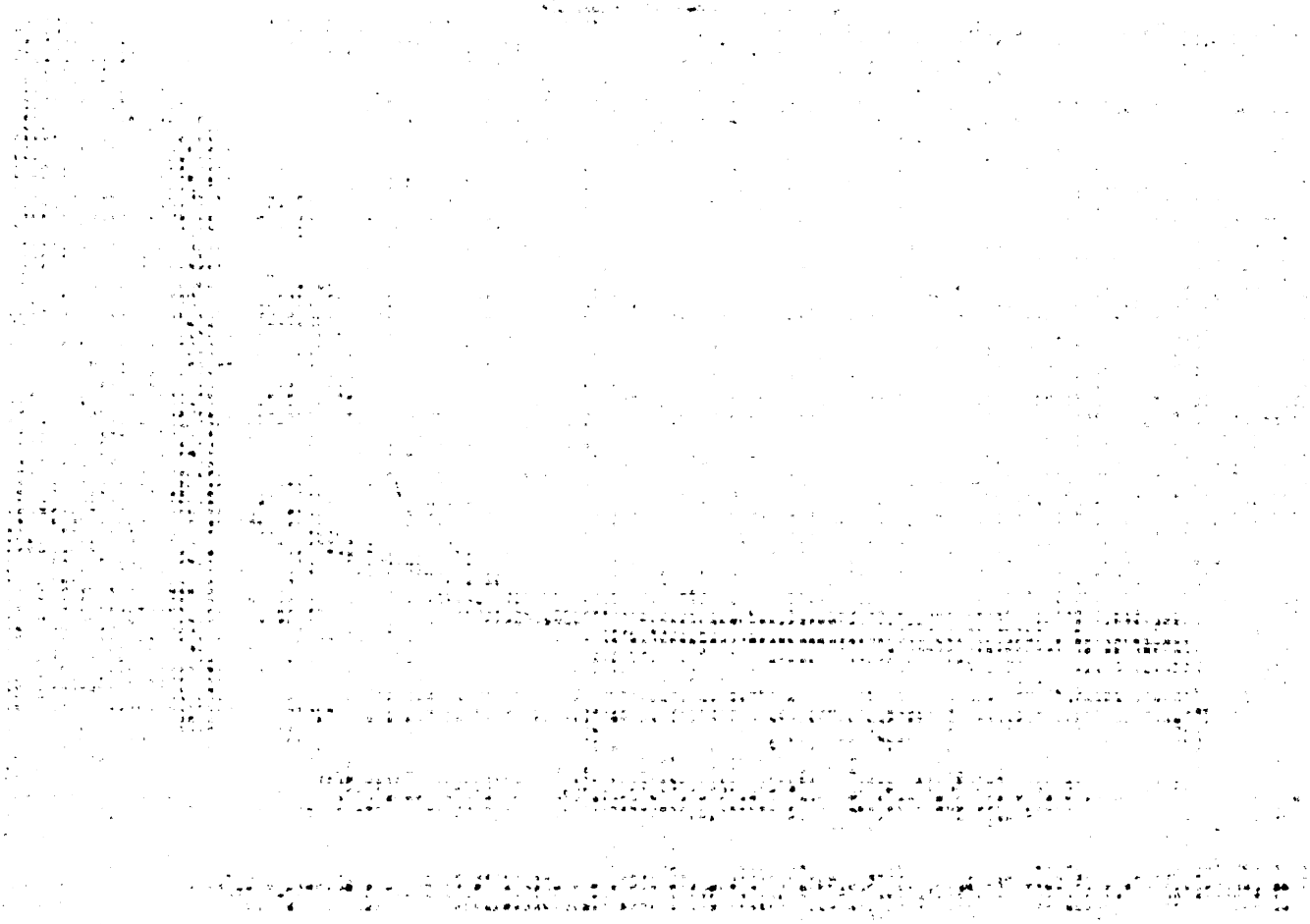
Tne chemical tests did not snow any thing very conclusive. The stability of soil # 11 was lower and the absorption higher than # 10. Soil # 10 was acid and soil # 11 alkaline, but this is not very reliable because of tne entirely different physical composition of tne soil.

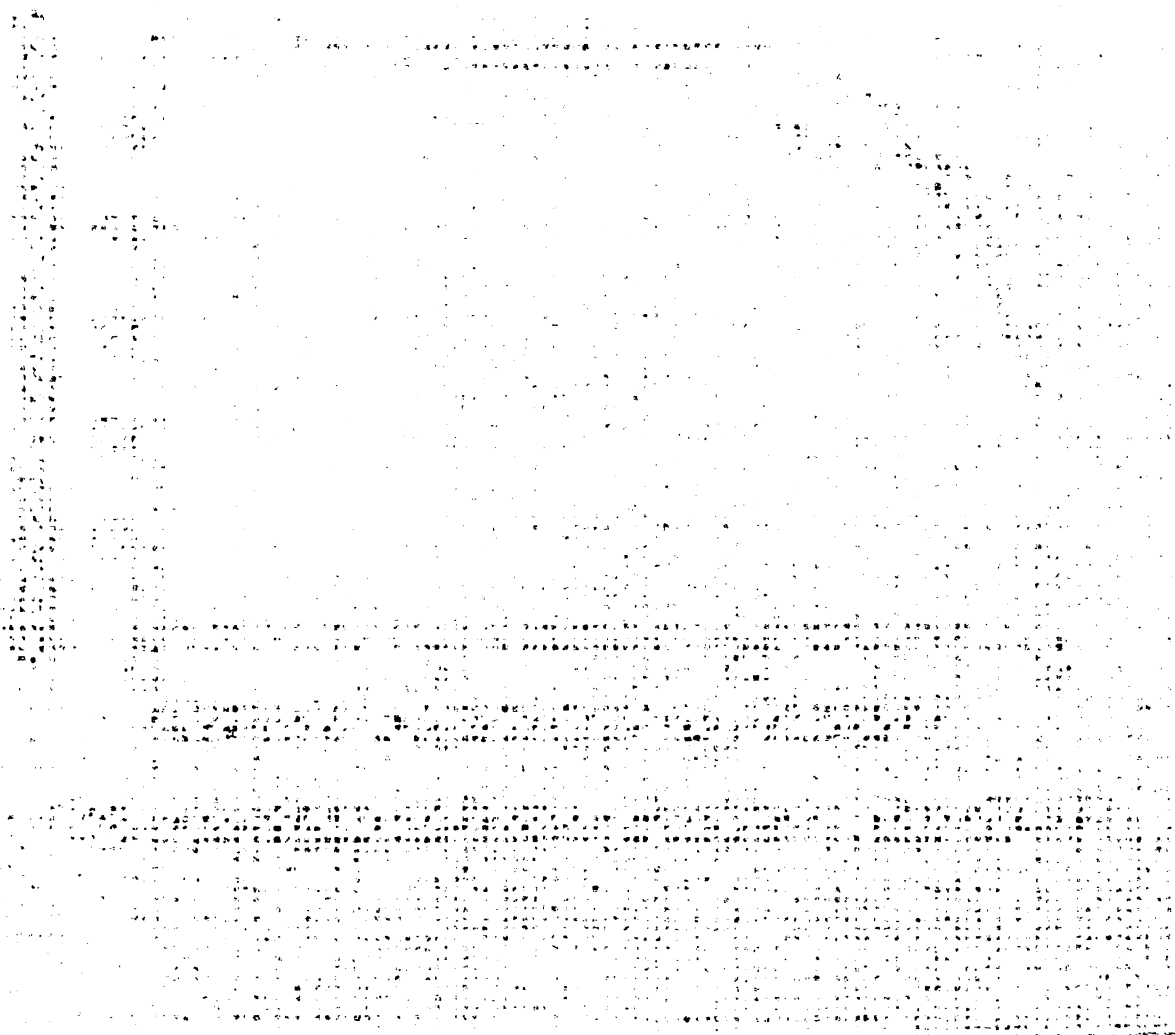












Soil #3 Van Buren C-Horizon Saugatuck

Soil #6 Roselawn Sandy Loam

Investigation

by

David John Hall

Soil #5 Van Buren C Horizon Saugatuck

The results of the physical and chemical tests on soil #5 were as follows:

Physical		Chemical	
Liquid Limit	22%	Nitrate	2 p.p.m.
Plastic limit	0%	Phosphorus	1/2 p.p.m.
Plasticity index	22%	Ammonia	2 p.p.m.
Field moisture	25%	Nitrites	1 p.p.m.
Shrinkage limit	15%	Potassium	10 p.p.m.
Sand	96%	Calcium	40 p.p.m.
Silt	0%	Magnesium	0
Clay	4%	Aluminum	3 p.p.m.
Passing #200	1.17%	Carbonates	0
Soiltex pH	5.5	Manganese	0
acid		Iron	10 p.p.m.
		Sulfates	600 p.p.m.
		Chlorides	20 p.p.m.
		Sodium	0

This soil consists of a light tan mixture and is of a very uniform grain size. It was loose and there seemed to be no tendency to lump even when wet.

Sieve analysis

On #10	.03%
Pass #10 on #20	.09%
Pass #20 on #40	3.22%
Pass #40 on #65	65.60%
Pass #65 on #100	25.10%
Pass #100 on #200	4.78%
Pass #200	1.17%

Soil #6 Roselawn Sandy Loam- Brown Horizon

The results of the physical and chemical tests on this soil were as follows:

Physical		Chemical	
Liquid limit	26.8%	Nitrate	2 p.p.m.
Plastic limit	0	Ammonia	0
Plasticity Index	26.8%	Nitrites	0
Field Moisture	28.9%	Phosphorus	1/2 p.p.m.

Physical (cont.)		Chemical (cont.)	
Shrinkage Limit	0	Potassium	0
Sand	96%	Calcium	100 p.p.m.
Silt	0	Magnesium	0
Clay	4%	Iron	50 p.p.m.
Passed #200	1.31%	Aluminum	0
Soiltex pH	4.3	Carbonates	0
strongly acid		Sulfates	0
		Chlorides	50 p.p.m.

Sieve Analysis

On #10	.03%
Pass #10 on #20	.09%
Pass #20 on #40	11.49%
Pass #40 on #65	72.70%
Pass #65 on #100	10.50%
Pass #100 on #200	3.68%
Pass #200	1.52%

This soil was a dark brown in color, probably coming from under the top soil. It contained no lumps and the grain size seemed to be uniform.

Soil	Bitumen	% Bitumen	% absorption	Total load lbs. per sq.in.
#3	Emulsion	2	failed	failed
"	"	3	2.9	800
"	"	4	2.7	1,750
"	"	5	1.8	5,850
"	Cut back	2	1.2	500
"	"	3	1.0	1,000
"	"	4	.55	1,950
"	"	5	.35	1,800
"	Road Oil	2	failed	failed
"	"	3	"	"
"	"	4	"	"
"	"	5	"	"
#8	Emulsion	2	1.1	2,000
"	"	3	1.0	2,000
"	"	4	1.0	2,300
"	"	5	1.0	2,800
"	Cutback	2	1.6	2,100
"	"	3	.8	2,100
"	"	4	.6	2,200
"	"	5	0.0	2,600

Soil	Bitumen	% Bitumen	% absorption	Total load
#6	Road oil	2	failed	failed
"	"	3	"	"
"	"	4	"	"
"	"	5	0	3,200

Soil	Bitumen	% water in soil	Rise in inches
#6	Emulsion	0	0
"	"	4	0
"	"	8	0
"	"	12	0
"	"	16	0
"	Cutback	0	3/4
"	"	4	1/2
"	"	8	1/4
"	"	12	1/8
"	"	16	3/4
"	Road oil	0	7/8
"	"	4	1/2
"	"	8	3/8
"	"	12	0
"	"	16	1/8
#6	Emulsion	0	0
"	"	4	0
"	"	8	0
"	"	12	0
"	"	16	0
"	Cutback	0	1
"	"	4	3/8
"	"	8	1/2
"	"	12	1/4
"	"	16	1/8
"	Road oil	0	7/8
"	"	4	3/4
"	"	8	1/4
"	"	12	1/4
"	"	16	0

The water preferential test could not be performed on both soils because of the lack of fine material necessary for the test. In one of the soils a test was run with what little fine material

was available and this showed a strong affinity for the oil. (Roselawn Sandy Loam.) In executing a test for the affinity of both the soils for water, the soils were placed in a container and water poured over them and the container shaken vigorously. Because of the lack of fine material in the soil the material immediately settled to the bottom, leaving the water in a clear state.

For some reason, probably due to the lack of fineness in the material, the capillary action test brought negative results. In both soils it seemed that the bitumen rose to about the same height no matter what per cent of water was used. In some cases, road oil in particular, capillary action seemed to decrease with a higher per cent of water, but this may be attributed to the lack of proper tamping of the test sample. A conclusion as to the capillary action when the grain size was almost uniform would be that there was less surface in contact to transport the bitumen carrying water.

Because of the fact that it was impossible to mix the oil, cutback and emulsion in a dry state with the soil and have an even distribution of the material, an amount of water, about ten per cent in the oils and cutbacks and up to the liquid limit in the emulsion, was added to the soil when mixing. In the case of both #3 and #6 soil the briquettes

were very unstable when coming from the molding machine, but on drying them for twenty-four hours in the constant temperature thermometer, they became stable, with the exception of the road oil mixes.

In the absorption tests performed on the finished briquettes, it was found in every case that the soil absorbed water varying directly with the percentage of bitumen in the sample. In every case this absorption was very low, and this is also attributed to the same reason as the low capillary action tests, that being the uniform grain size and the large voids size in the briquette.

In the stability tests, using the compression machine with a speed of drop of one half inch per minute, none of the samples seemed to stand up under any real load at all. In the case of Soil #5 there was a complete failure in the mixes using road oil, a total load of but 1550 pounds in the case of a four per cent cut-back, and a 5850 pound load in a five per cent emulsion. Emulsions proved to give the strongest mix in both cases, probably due to the better distribution of the bitumen.

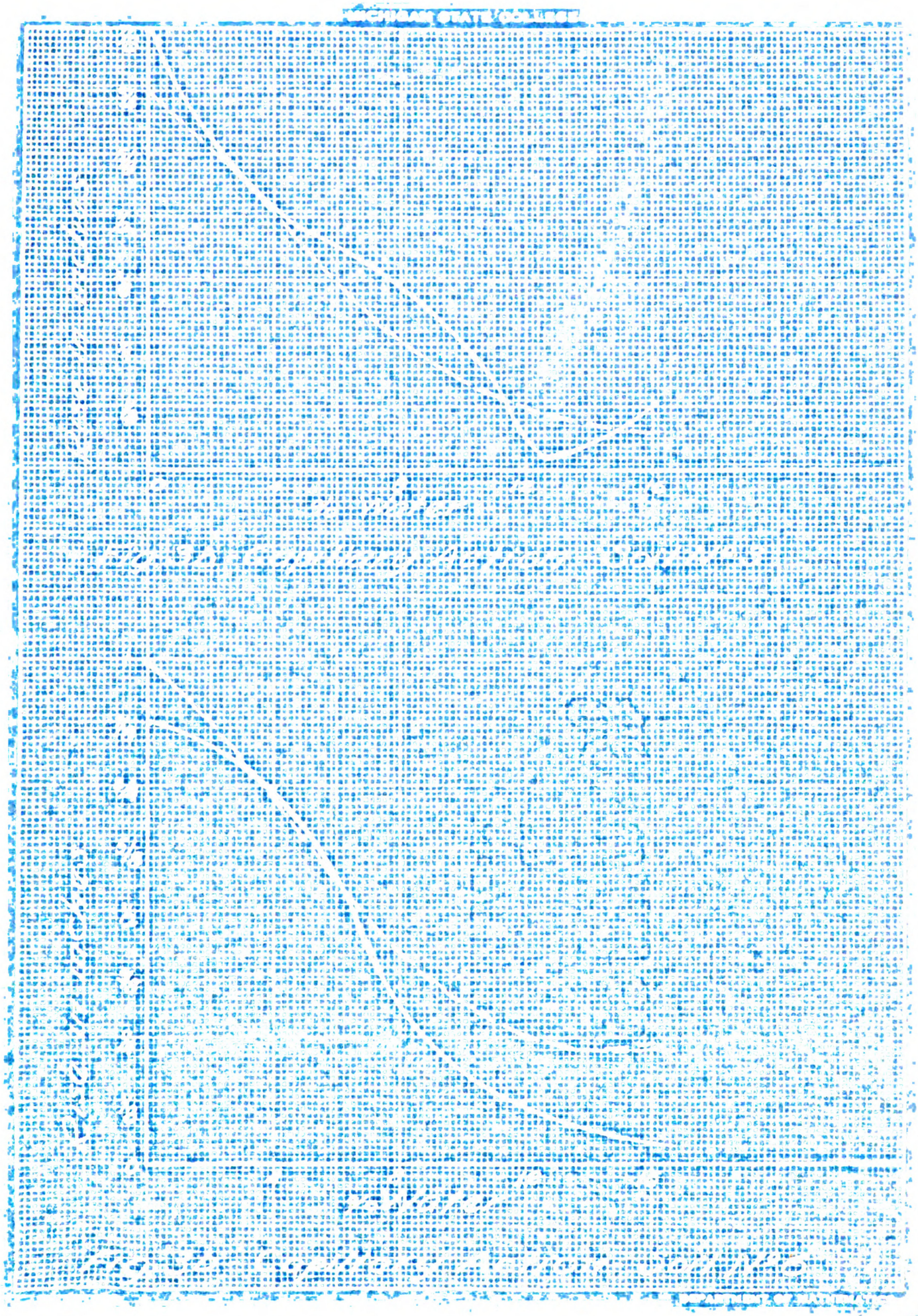
In Soil #6 there was little apparent connection between the amount of bitumen added and the breaking strength. The total breaking load was low in all cases, and in the oil there was failure in every

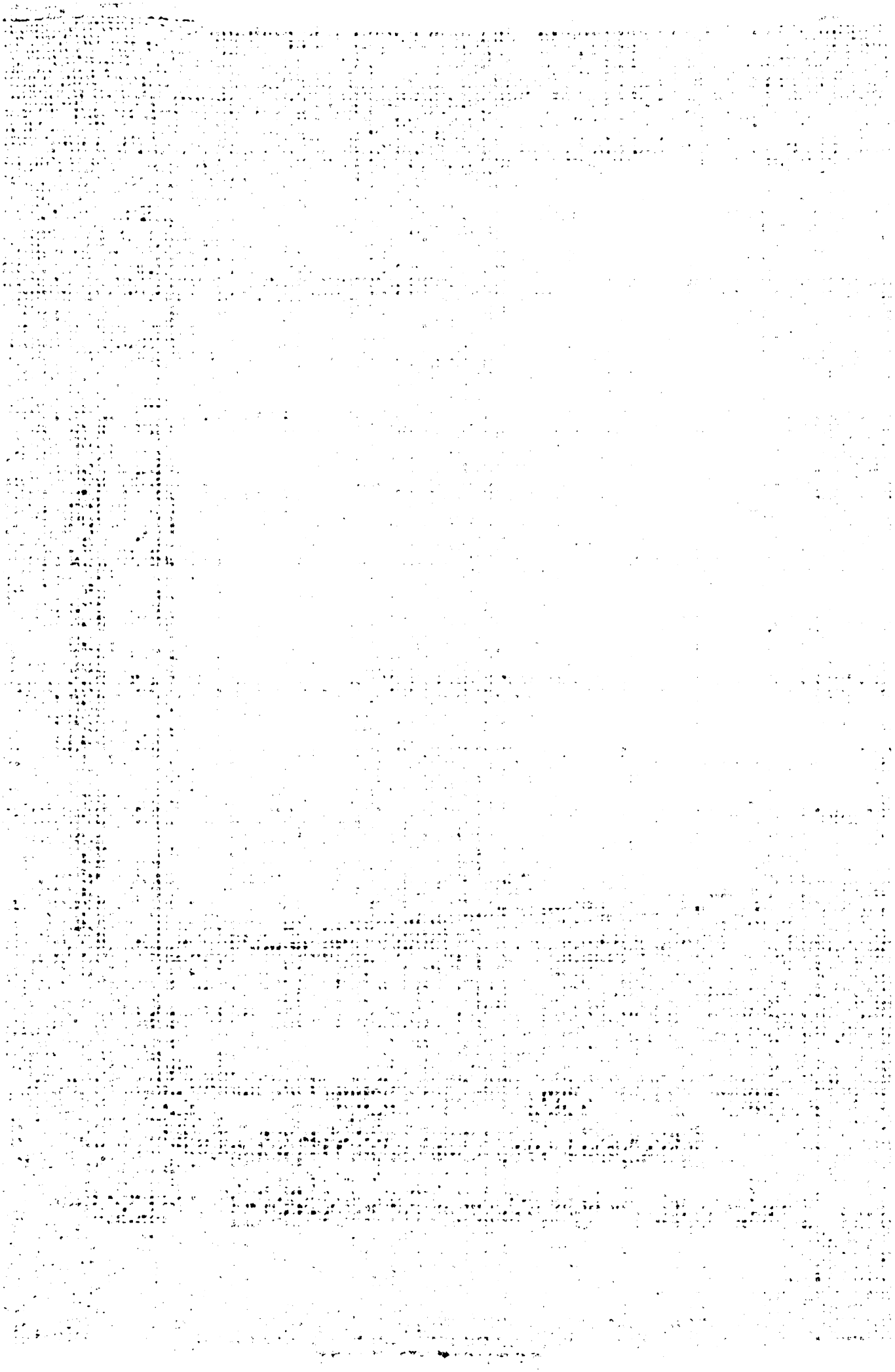
instance except the five per cent mix.

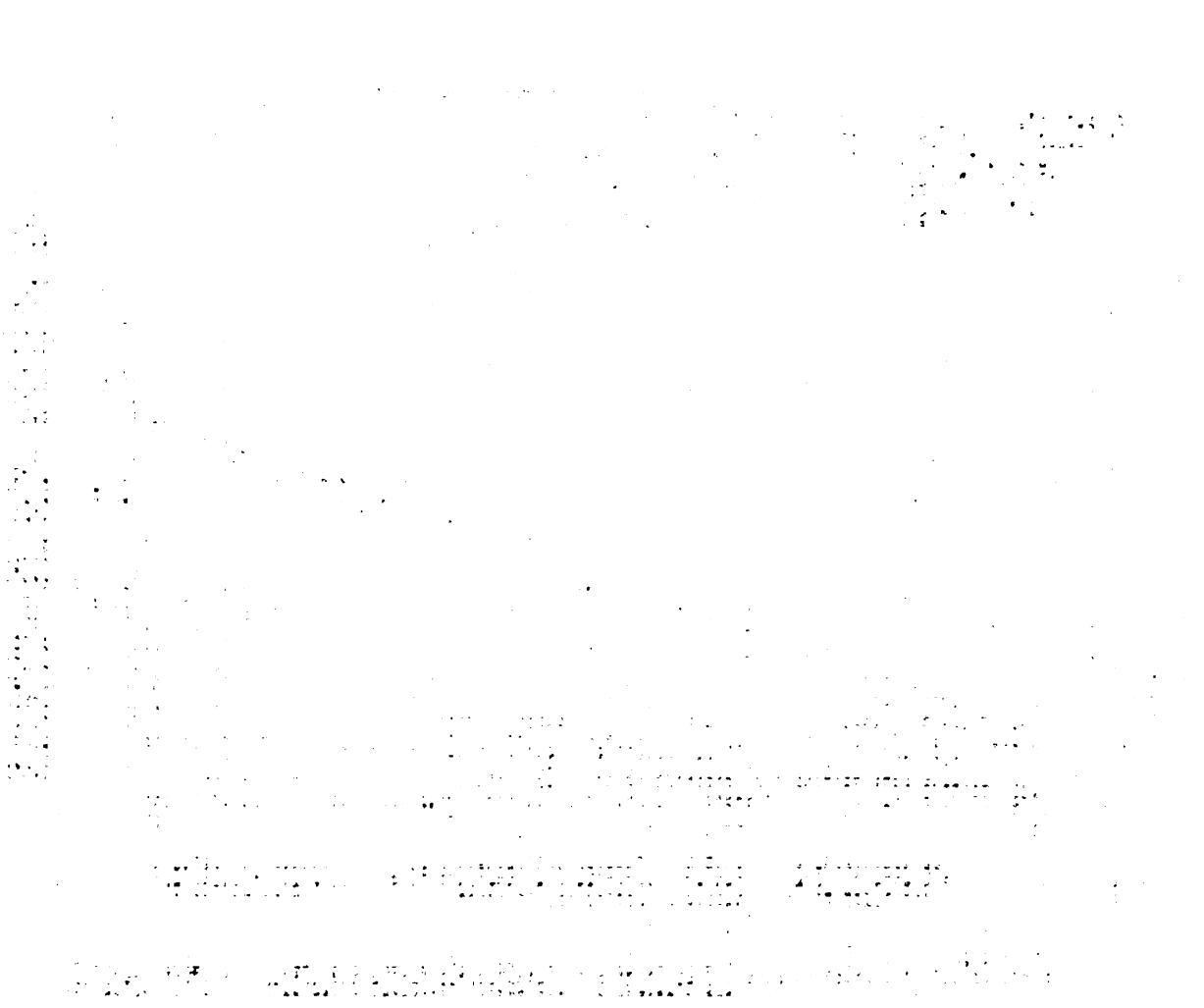
Both soils were nearly all sand, which is too much to make a real stabilized mix. While a greater percentage of the soil should be sand, there should be a certain amount of clay and silt to help fill the voids and make a dense mass when mixed with bitumen. Since this study took only the natural soil with nothing added, it would be helpful to go still further and by adding finer materials see when the most stabilized soil could be obtained.

In the chemical test, both of the soils showed acidity, and this might have some connection with the stability obtained, but since the biggest factor in stability is the fineness in the material, not much can be obtained from the chemical tests, as they are covered up by the poorness of the soil. Soil #3 contained a fairly large amount of sulfate and calcium, while #6 contained a high amount of calcium. As to these chemical tests, it might be wise to go at the testing in another way, and by the addition of these chemicals to a known stabilized soil, see what their reaction would be.

As a general conclusion, it is shown that both these soils are uneconomical to be stabilized with a bituminous material.









Soil #8 Hillsdale Miami

Soil #9 Ontonagon Clay

Investigation

by

Warren C. Bissell

Soil #6, named by the soils department Hillsdale Miami, is a light grey soil which is hard and lumpy when dry. After water has been added to it and it has been screened through a 200 mesh sieve, it is found that 88.6% passes the sieve.

In this sample there were only a few particles of coarse sand present. The clay content was found to be rather high (43.8%), thus accounting for its pasty characteristics when placed in water.

As is shown in the accompanying table, the capillary action increased with the water content. Using emulsion in the capillarity test, it was noted that no capillary action took place despite the varying water content, but using the cutback and road oil, an increased water content increased the capillary action. It can be easily seen that the more water present to evaporate, the more space there is for the cutback and road oil to fill. The evaporating water creates a vacuum and pulls the oil up to fill the voids. This is not true of the emulsion, because the water in the soil tends to dilute it.

The soil was found to be strongly alkaline. It was high in calcium and sulfates but low in nitrites, aluminum, nitrates, manganese and sodium.

In mixing up a batch of stabilized soil, it was found that by adding enough water to exceed the liquid limit, the emulsion, cutback, and road oil would mix very well, but if the soil was mixed dry, the bituminous material would collect in bunches throughout the sample. It is a regrettable fact that there was very little of Soil #8 and #9 to be obtained, and thus there could be no absorption and stability test run on the soils using cutback and road oil.

Soil #8 Data

Physical Characteristics

Liquid Limit	38.4%
Plastic Limit	15.6%
Plastic Index	22.8%
Field Moisture	19.2%
Shrinkage Limit	14.0%
Sand	32.6%
Conv. Clay	43.5%
Conv. Silt	23.9%
Passing #200 sieve	88.5%
Acidity pH	8.0

Capillary Reading (Rise in inches)

Water Content	Emulsion	Cut back	Road Oil
0%	0	2/8"	1 6/8"
4%	0	7/8"	15/8"
8%	0	1"	2"
12%	0	1 2/8"	2 4/8"
16%	0	1 4/8"	2 7/8"

Water Preferential Test- 100% in oil.

Stabilized Soil #8 Data

Emulsion	Water absorbed	Stability
2%	11.9	1,800
3%	7.2	3,350
4%		4,430
5%		900
Cut back		
2%	18.7	3,050
Road oil		
2%	21.4	0

Chemical tests

Nitrates	1	p.p.m.	Iron	10	p.p.m.
Phosphorus	5	"	Aluminum	0	
Potassium	20	"	Manganese	0	
Calcium	200	"	Sulfates	600	"
Magnesium	4	"	Chlorides	20	"
Amonia	10	"	Sodium	0	
Nitrites	0		Carbonates	present	
	Acidity		Strongly alkaline		

An analysis of Soil #9, named Ontonagon clay, revealed that only one tenth of one per cent was retained on a 200-mesh sieve. From this low percentage of material retained it would seem that the soil would be very hard to stabilize because of a lack of coarse material which is necessary in an ideal mix. Tests confirm this suspicion.

The soil came in large red lumps and became very red when wet. It required a great amount of work to get this material in shape for testing as it was very hard to pulverize with a rubber mallet.

The high clay content and low sand content of these soils produced a very stable material when it was dry, but as soon as the samples of stabilized material were placed in water they became practically useless for supporting weight, by absorbing large quantities of water.

On testing the soil for its chemical content, it was found to be strongly alkaline. Calcium and sulfate were present in large quantities while very little sodium, manganese, aluminum, nitrites, ammonia, and phosphorus were found.

Stabilized Soil #9

Emulsion	% water absorbed	Stability
2%	23	600
3%	19.3	1,400
4%	13.7	0
5%	14.9	550

Chemical tests

Nitrates	2 p.p.m.	Iron	15 p.p.m.
Phosphorus	1 "	Aluminum	0
Potassium	5 "	Manganese	0
Calcium	200 "	Sulfates	300 "
Magnesium	7 "	Chlorides	35 "
Ammonia	.5 "	Sodium	0
Nitrites	1 "	Carbonates	present

Strongly alkaline

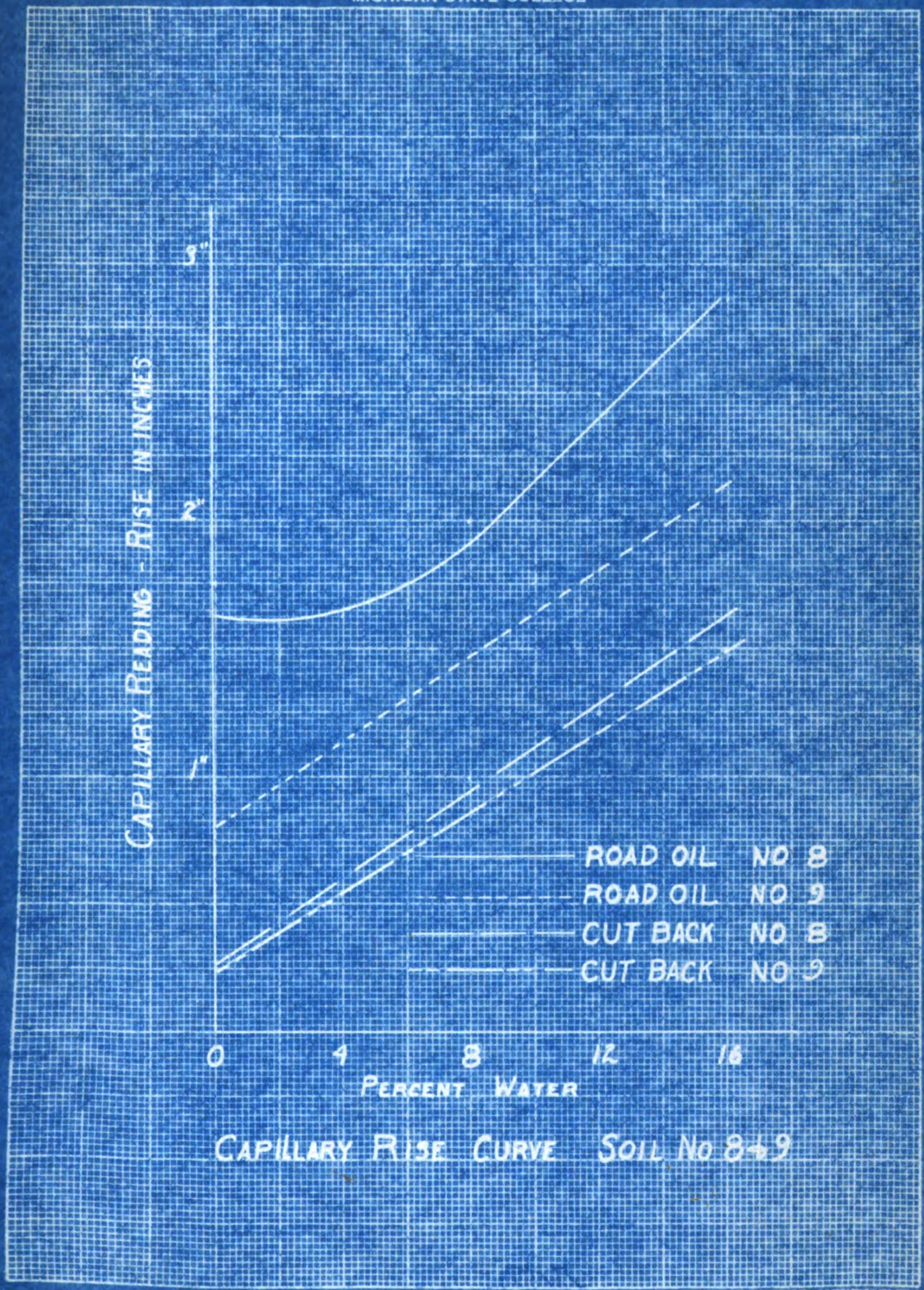
Physical tests

Liquid limit	45.4%
Plastic limit	24.1%
Plastic index	21.3%
Field moisture	29.2%
Shrinkage limit	9.3%
Sand	11.3%
Conv. Clay	63.3%
Conv. Silt	25.4%
Passing #200 sieve	89.9%
Acidity	pH=8

Capillary readings (rise in inches)

Water Content	Emulsion	Cutback	Road Oil
0%	0	2 2/8	6 6/8
4%	0	5 5/8	1 2 2/8
6%	0	2 2/8	1 3 3/8
12%	0	1 1 1/8	1 7 7/8
18%	0	1 4 4/8	2 1 1/8

Water preferential test: 100% in oil



CAPILLARY RISE CURVE SOIL NO 8&9

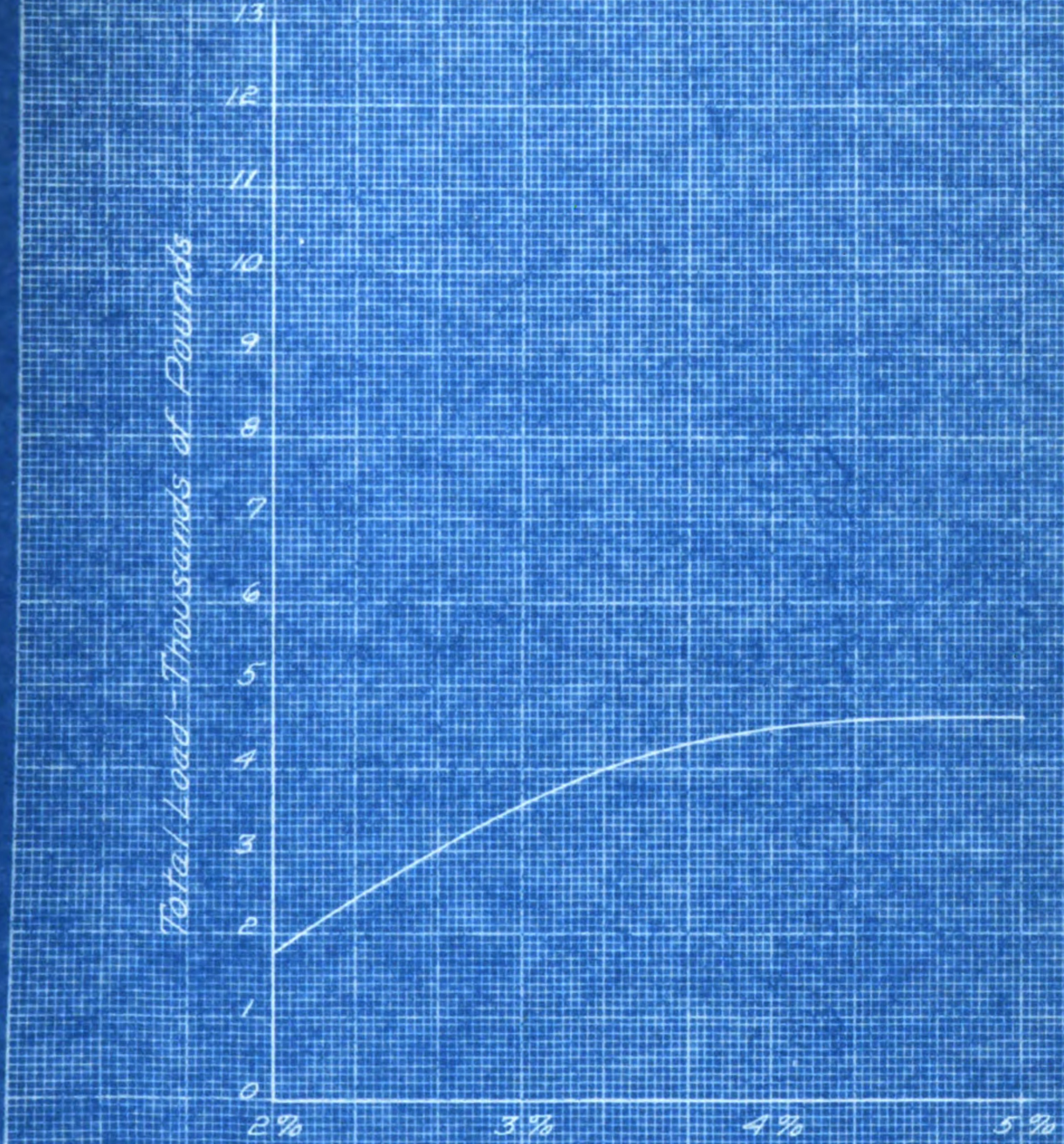
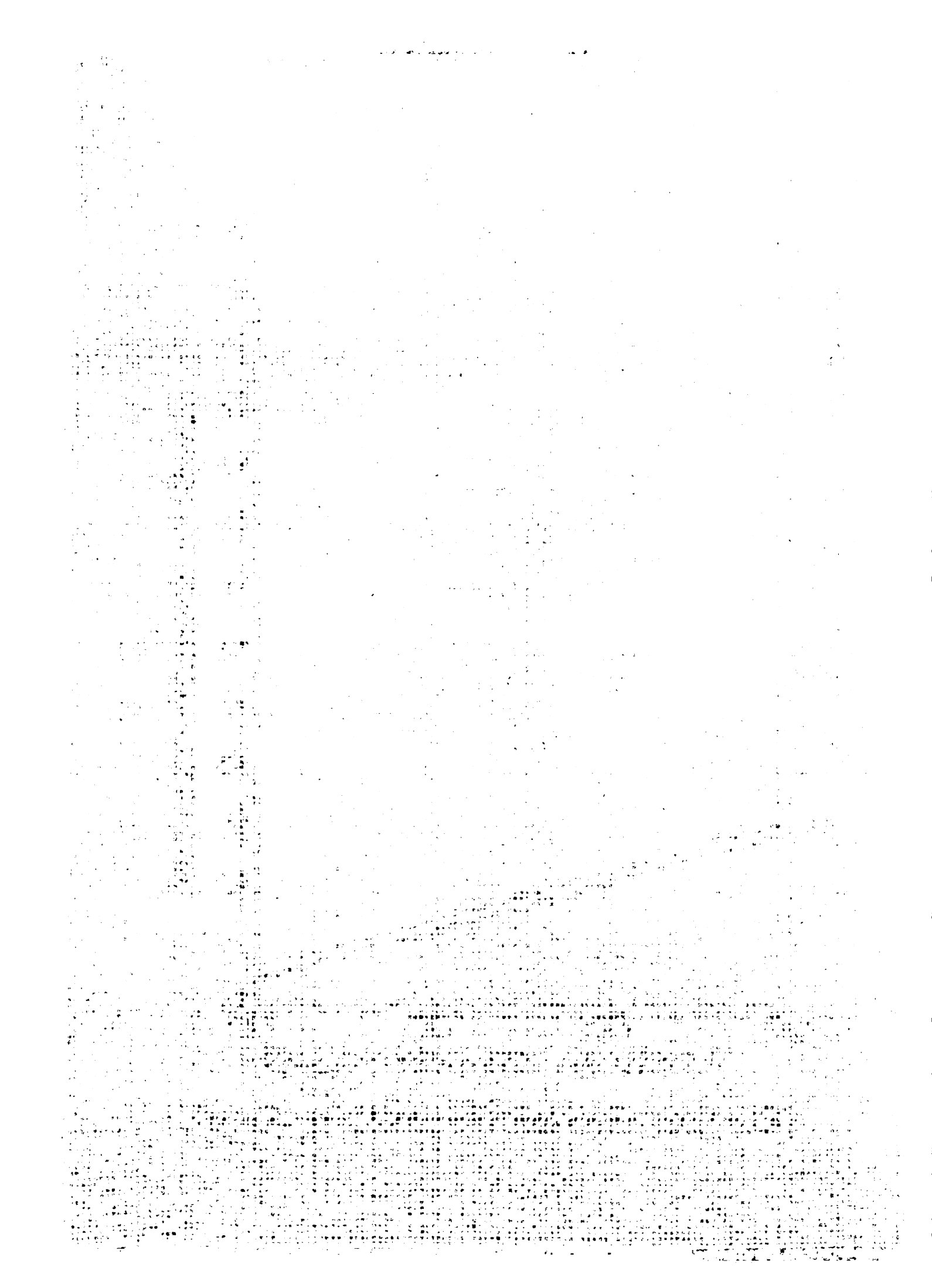
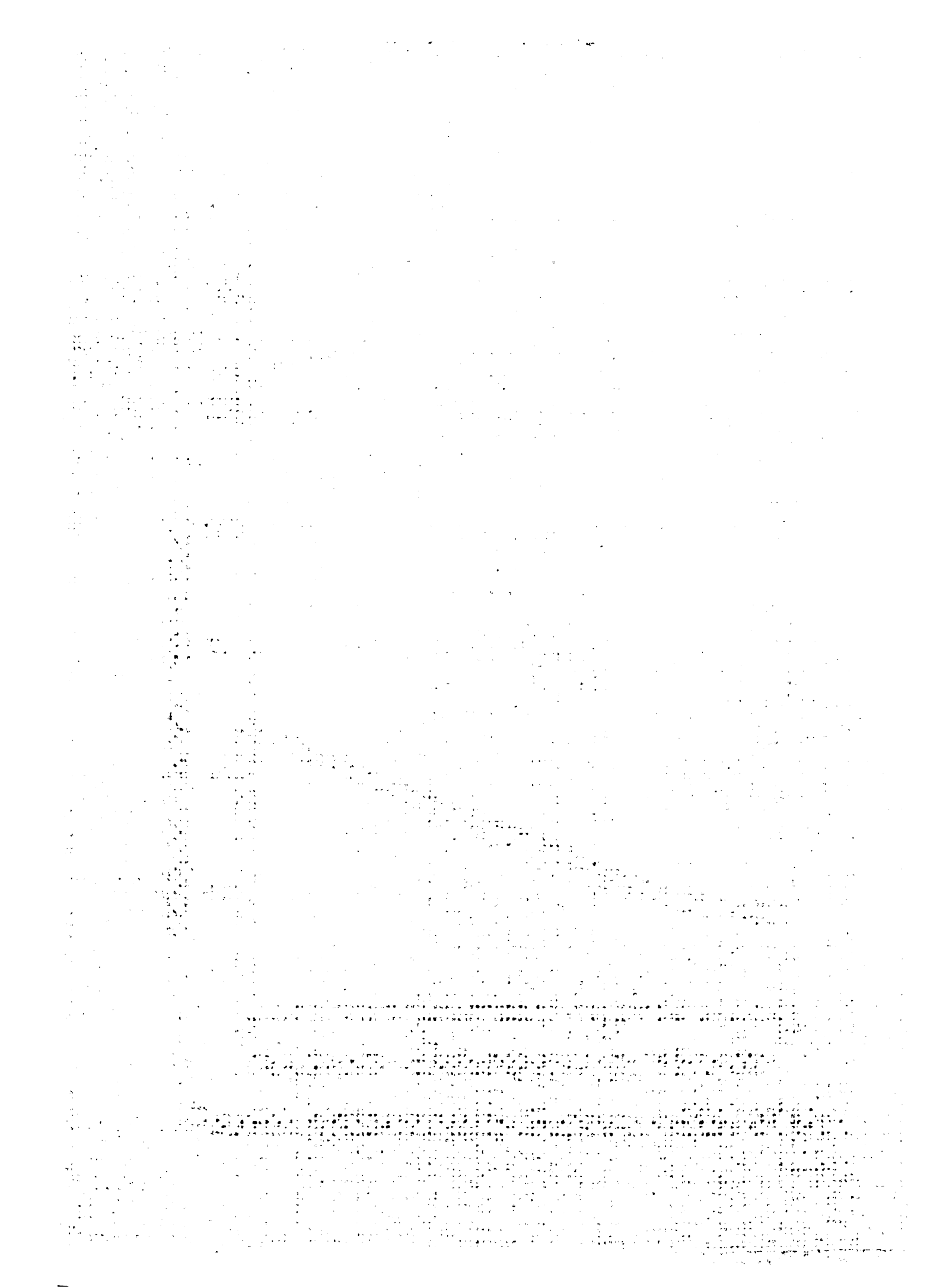


Fig 8 STABILITY CURVES - Soil N°8





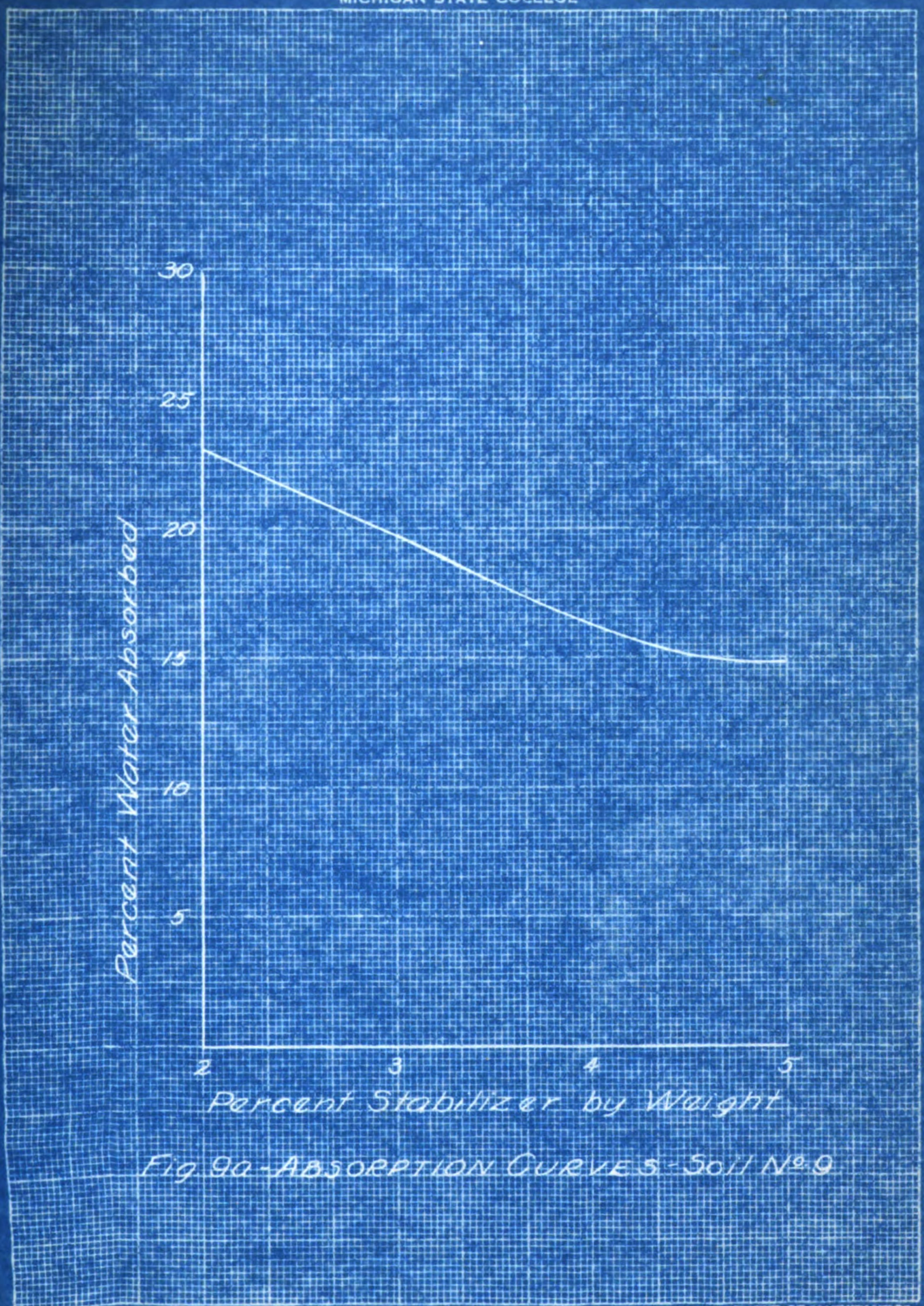


Fig. 9a - Absorption Curve 5 - Soil No. 9

SUMMARY

The capillarity test in a general way illustrated the importance of water in the mixing process of stabilization. Unlike other types of bituminous road surfaces, which may be mixed hot and dry, this type of treatment, in order to be done economically, must be mixed cold, either by the mixed-in-place process or by a surface penetration treatment. A cold mixing process seems to require a certain percentage of moisture approaching the liquid limit of the soil in order to provide a homogeneous mixture and uniform coating of soil particles. It was observed that after the mixing process was completed the samples required from twenty-four to seventy-two hours to dry, depending upon the texture of the soil and the amount of water present, in order to be of the ideal state to compress into briquettes. The average percentage of moisture was estimated at about 5%. Too little moisture caused the soil to crumble when compressed; too much moisture caused excess plasticity.

It may be noted that of the three asphaltic materials studied, the emulsion showed the least tendency to mix due to capillarity, especially during the first few hours of the test. However, as the soil dried out through evaporation the

emulsion tended to rise, replacing the water particles as evaporation took place. It was observed that capillarity was practically negligible in the case of fine textured soils containing no water whatever, but showed up very satisfactorily as the moisture content was increased. This is illustrated in the composite graphs showing capillarity in the case of soils #2, #8, and #9, each of which contain a high percentage of fine material. On the other hand, it is significant that soil #12, which was high in sand and contained a considerable amount of gravel, showed the greatest height of rise. In practically all tests, however, the trend of the curve was upward as the percentage of water was increased. This verifies the observation that water is a necessary medium for dispersion of the asphalt.

The Water-Asphalt preferential test seemed to furnish a fairly conclusive means of determining the affinity of a soil for an asphalt and provided a fairly dependable criterion for predicting the success of stabilization. It is noted that this test, as it was performed, was not strictly a quantitative one, it being impossible to measure accurately the amount of soil settling out. In cases where the soil showed high affinity for asphalt, the heavier soil grains combined with oil particles and caused this heavier material to sink to the

bottom of the bottle. Soils exhibiting this tendency in the water-asphalt preferential test were successfully stabilized, while those showing little or no affinity were, in general, unsuccessful.

There is a very definite and close relation between stability and absorption tests. For example, a sample absorbing more than two or three percent moisture during absorption test ordinarily will absorb water throughout the whole briquette and in this plastic state will have practically no stability. On the other hand, a sample having a small percentage of absorption is practically as stable as the original dry sample before absorption. It should be noted that from the combined stability curves, those samples which were strongest were those which had a large percentage of sand and a fairly low quantity of clay. It appears desirable that a soil should contain at least 50% sand and from 10% to 35% clay for maximum stability. Soils having a high percentage of silt, or having a percentage of clay of less than 5% or more than 50%, cannot be stabilized economically, and furthermore from the trend of the stability curves it is quite safe to say that stability of these types of soils is not appreciably increased by the addition of bitumen.

Stability and absorption tests also indicated that after an amount of bitumen sufficient to obtain a low absorption factor was added, there was not additional benefit derived from addin more asphalt.

In comparing the three bitumens tested it was noted that stability of all samples made with cutbacks and emulsions were very comparable, neither showing definite superiority. However, samples stabilized with road oil were somewhat inferior in strength as compared to those stabilized with the other two materials. This condition may be expected, since the base of both emulsion and cutback is a hard asphalt, and in the one case the water evaporates, causing the asphalt to cement the soil particles together, while in the other, the same result is obtained through the evaporation of the light volatile fluid. Road oil, on the other hand, consists of a soft asphalt as a base and does not set up when exposed to the air. This should explain why road oil is not so good a stabilizer as emulsion or cutback. It is very probable that soils stabilized with a road oil would, after considerable weathering, increase in strength as the lighter constituents of the road oil evaporate out. It is felt, however, that the results of these tests on stability are not too conclusive. It has been definitely proved that stabilized soil

samples are improved by weathering and aging.

Perhaps the outstanding feature of the results of the chemical tests was that those soils which were highly acid were those which could be easily stabilized, and those soils which could not be stabilized were alkaline in nature. It is doubtful if the acidity of a soil has any effect on the stability, but it does seem to furnish an indication at least of the success to be expected of stabilizing. It would be interesting to continue the investigation of the effect of acidity on stabilization, as this acidity test can be very easily made in a few minutes anywhere in the field and, if it proved dependable, would be very valuable as well as simple. In regard to other chemical tests, the results of this investigation show no outstanding connection between chemical analyses and stability of the soil sample.

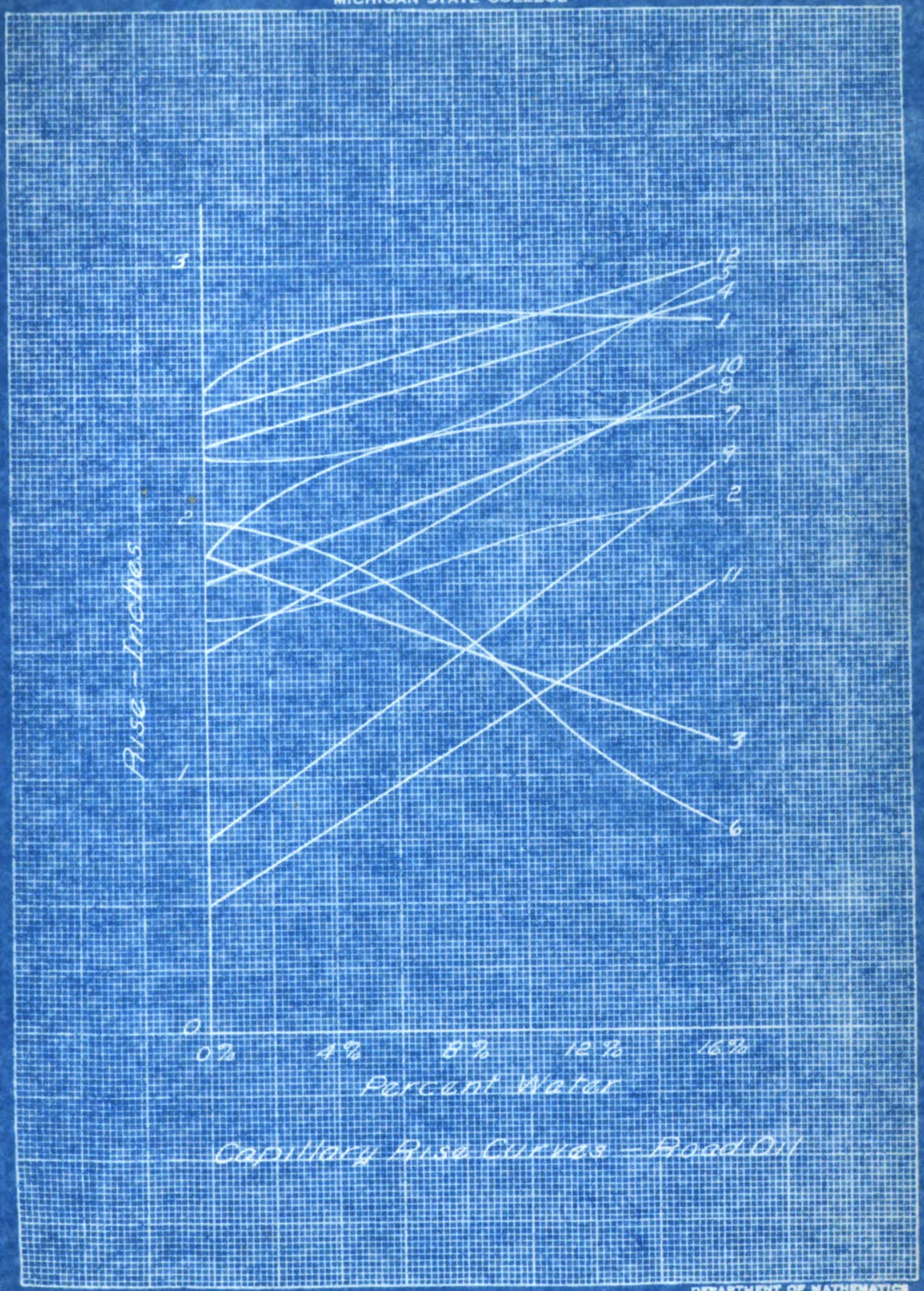
As a result of the observations made of that data studied in this investigation, it is felt that the following conclusions and comments are justified:

1. Soils containing less than 5% or more than 50% clay cannot economically be stabilized.
2. Presence of water is necessary in order to mix bitumen into the soil.
3. Optimum moisture content for mixing is somewhat less than liquid limit for the soil.

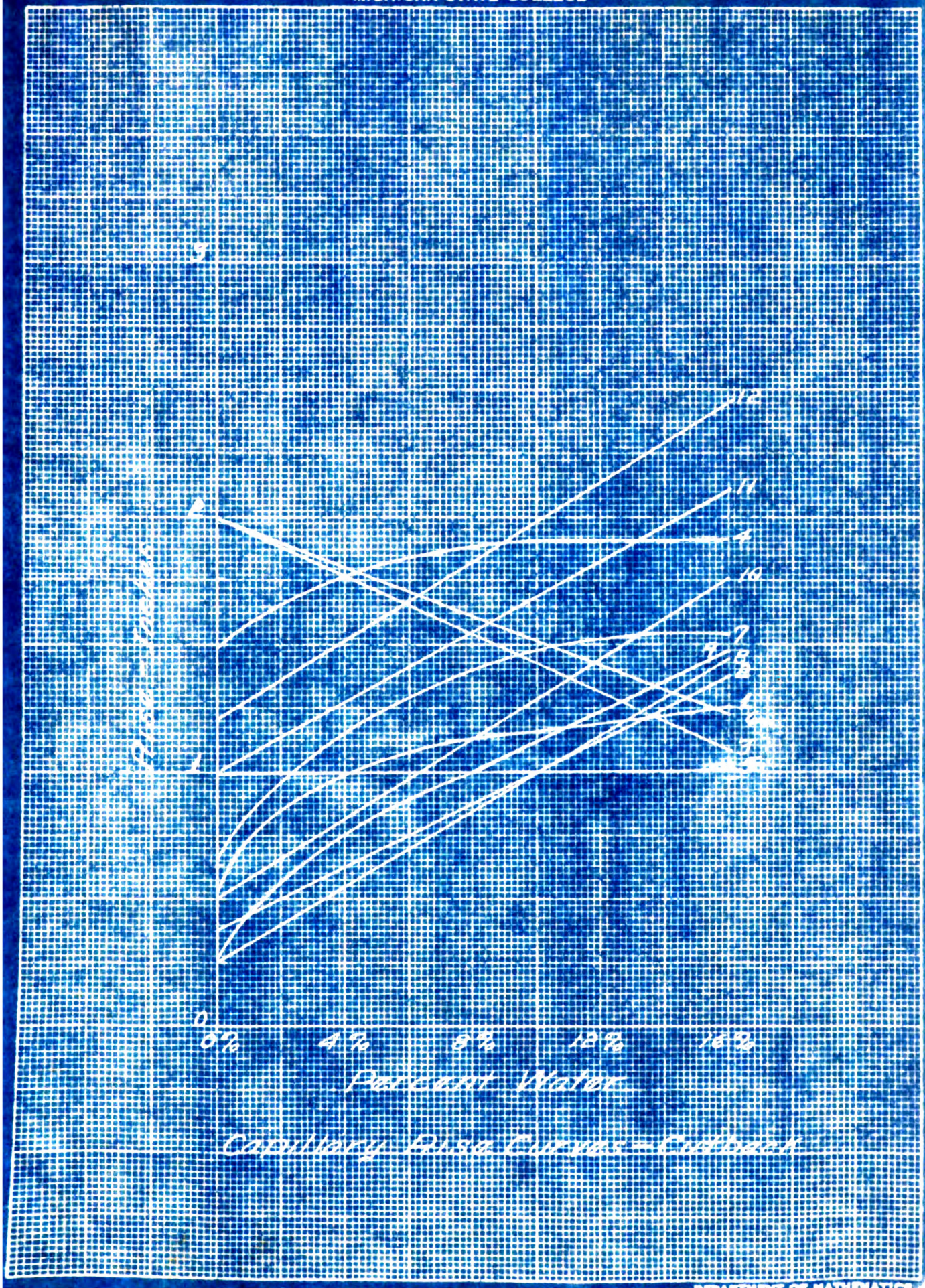
4. After mixing, soils must be dried from 24 to 72 hours before compressing or rolling the surface.
5. Absorption of more than 5% moisture is an indication that the soil will fail.
6. Each soil has a definite percentage of bitumen required to obtain stability, and an increase in this percentage will not appreciably strengthen the mixture.
7. Presence of bitumen in a soil having a clay content of over 75% does not increase resistance to absorption.
8. Capillary action is higher with cutbacks and road oils than with emulsions.
9. Cutbacks and emulsions provide higher stability than road oils.
10. The water preferential test does not seem to indicate the amount of absorption to be expected. The only soil to settle out did not absorb any more water than some of the others.
11. The Soiltex test for acidity is an indication of the success to be expected of stabilization.
12. In a soil with uniform grain size, capillary action is negative because of the full void space retarding capillary action.

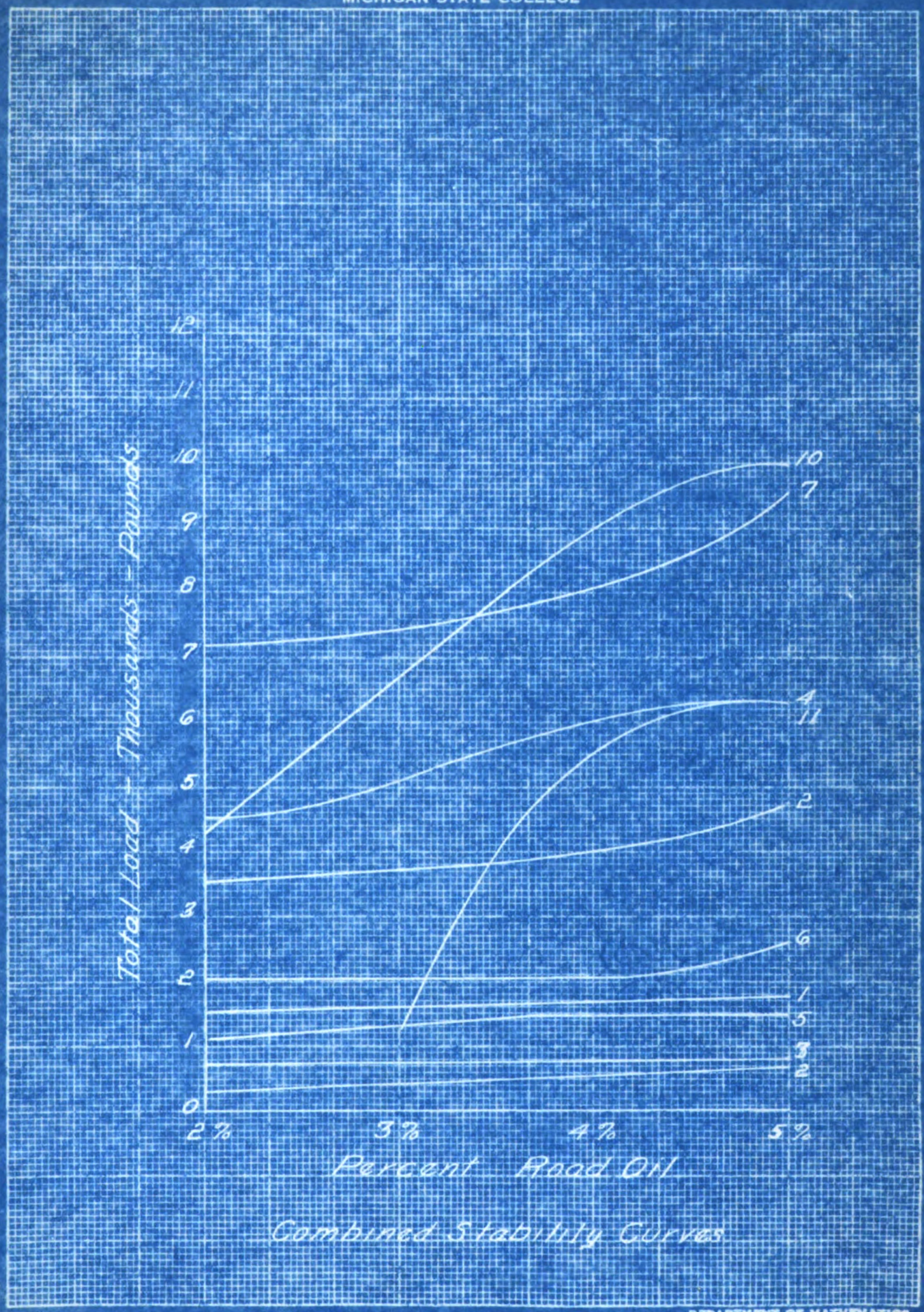
Soil	Liquid Limit in %	Plastic Limit in %	Plastic Index in %	Field Moisture in %	Shrinkage Limit in %
1	14.0	12.8	1.2	13.5	6.2
2	48.6	26.5	22.1	39.3	17.1
3	23.0	0	22.0	23.0	0
4	27.2	17.8	9.4	24.3	20.0
5	35.0	0	35.0	36.7	4.8
6	26.8	0	26.8	28.9	0
7	22.2	16.5	5.7	16.2	15.3
8	38.4	15.8	22.8	19.2	14.0
9	45.4	24.1	21.3	29.2	9.3
10	27.8	16.2	11.4	24.9	8.3
11	45.3	22.3	23.0	23.8	25.5
12	24.4	0	24.4	23.4	23.0

Soil	Sand %	Conv.Clay %	Conv.Silt %	% Passing #200	Acidity pH
1	27.3	10.0	62.4	29.3	3
2	17.3	65.4	17.3	69.5	9
3	96.0	4.0	0	1.2	5.5
4	80.2	14.0	5.8	29.4	5
5	22.3	7.3	69.6	26.6	5
6	96.0	4.0	0	1.5	4.5
7	76.7	17.3	6.9	9.6	5
8	32.6	43.5	23.9	66.3	6
9	11.3	63.3	25.6	89.9	6
10	54.0	30.0	16.0	43.3	5
11	22.0	64.0	14.0	71.4	9
12	46.0	17.0	37.0	56.8	5.5

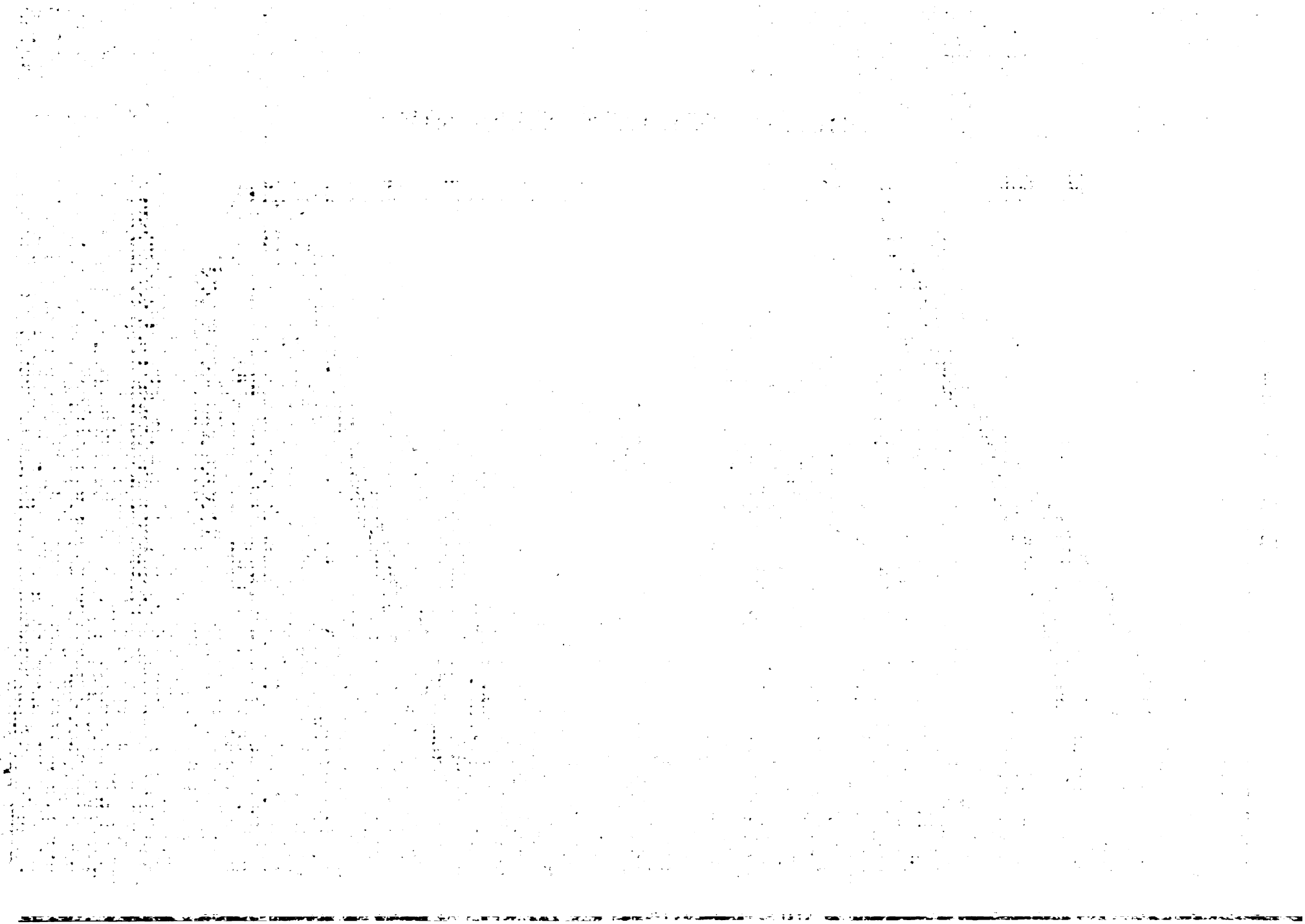


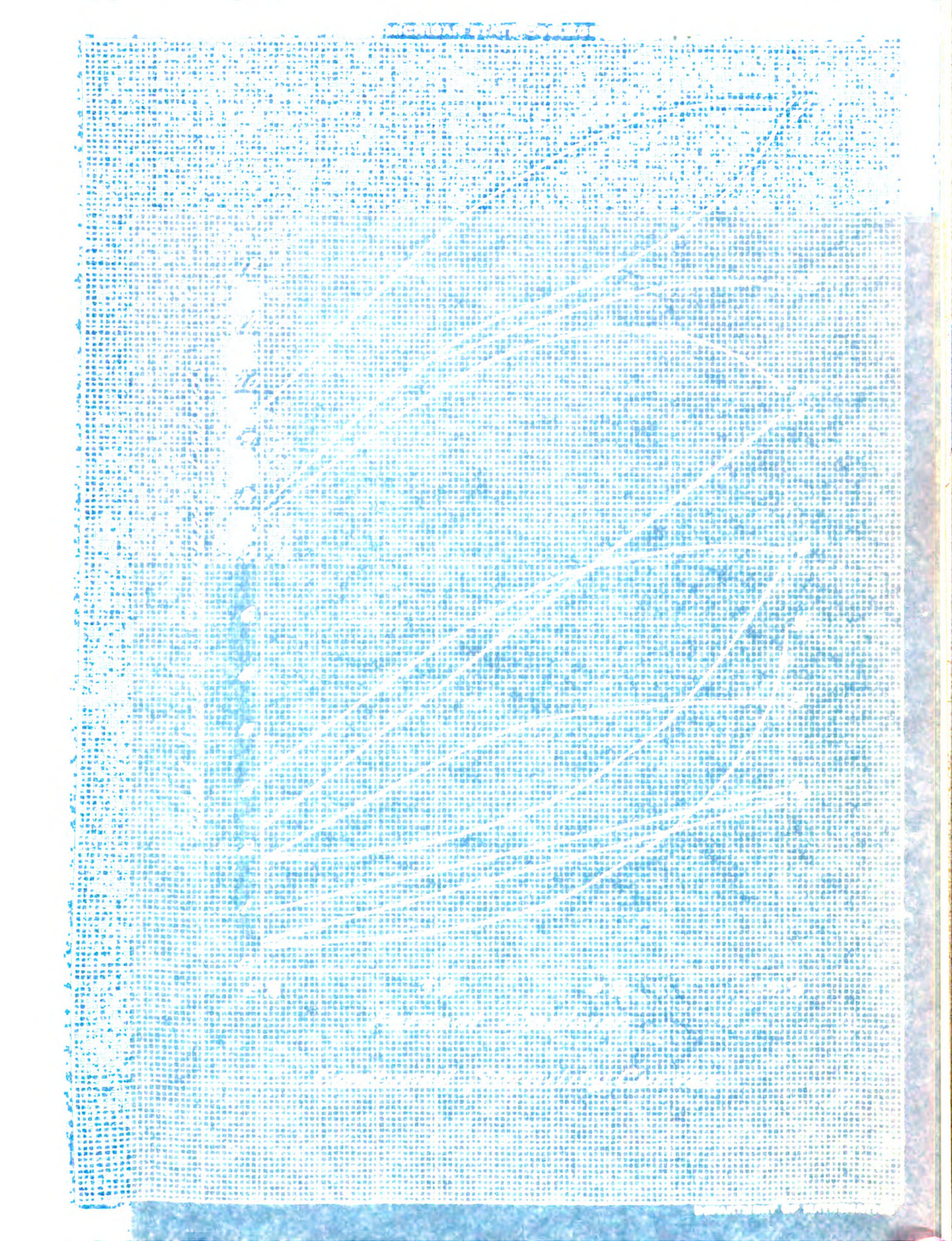
Capillary Rise Curves — Road Oil

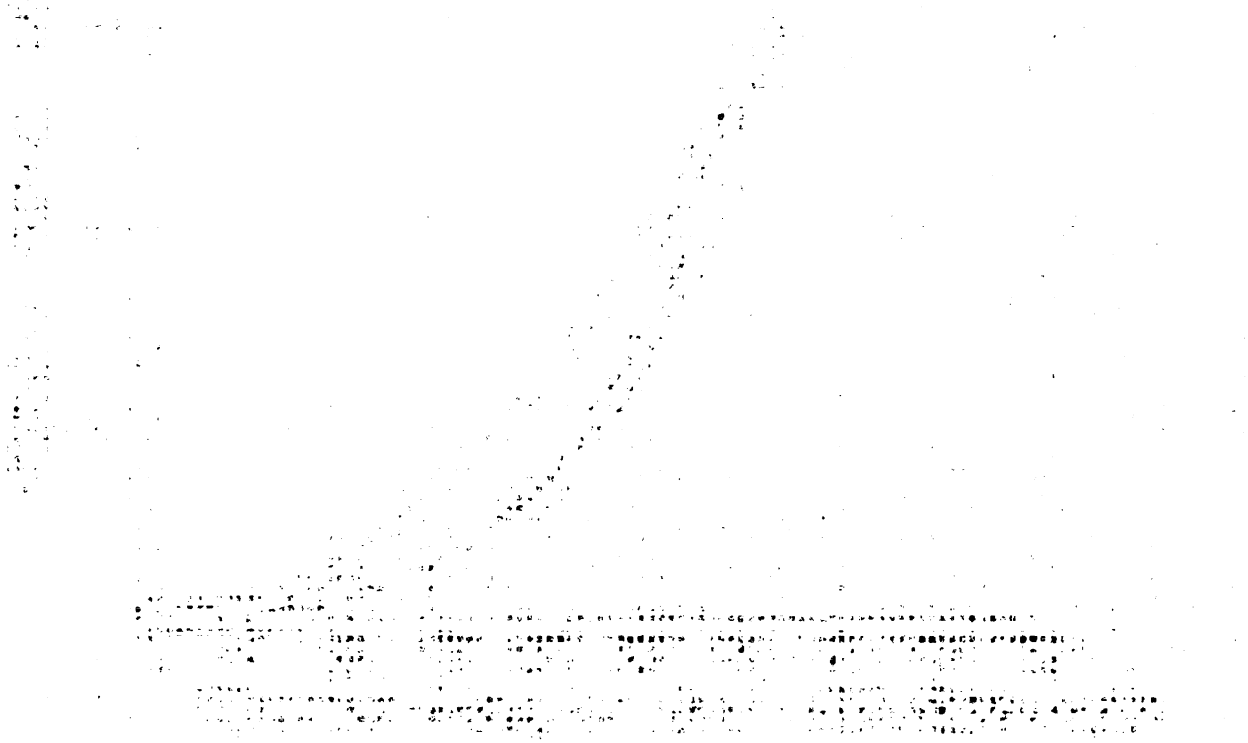

0%
4%
8%
12%
14%
Percent Water
Capillary Rise Curves - Subsoil



Combined Stability Curves







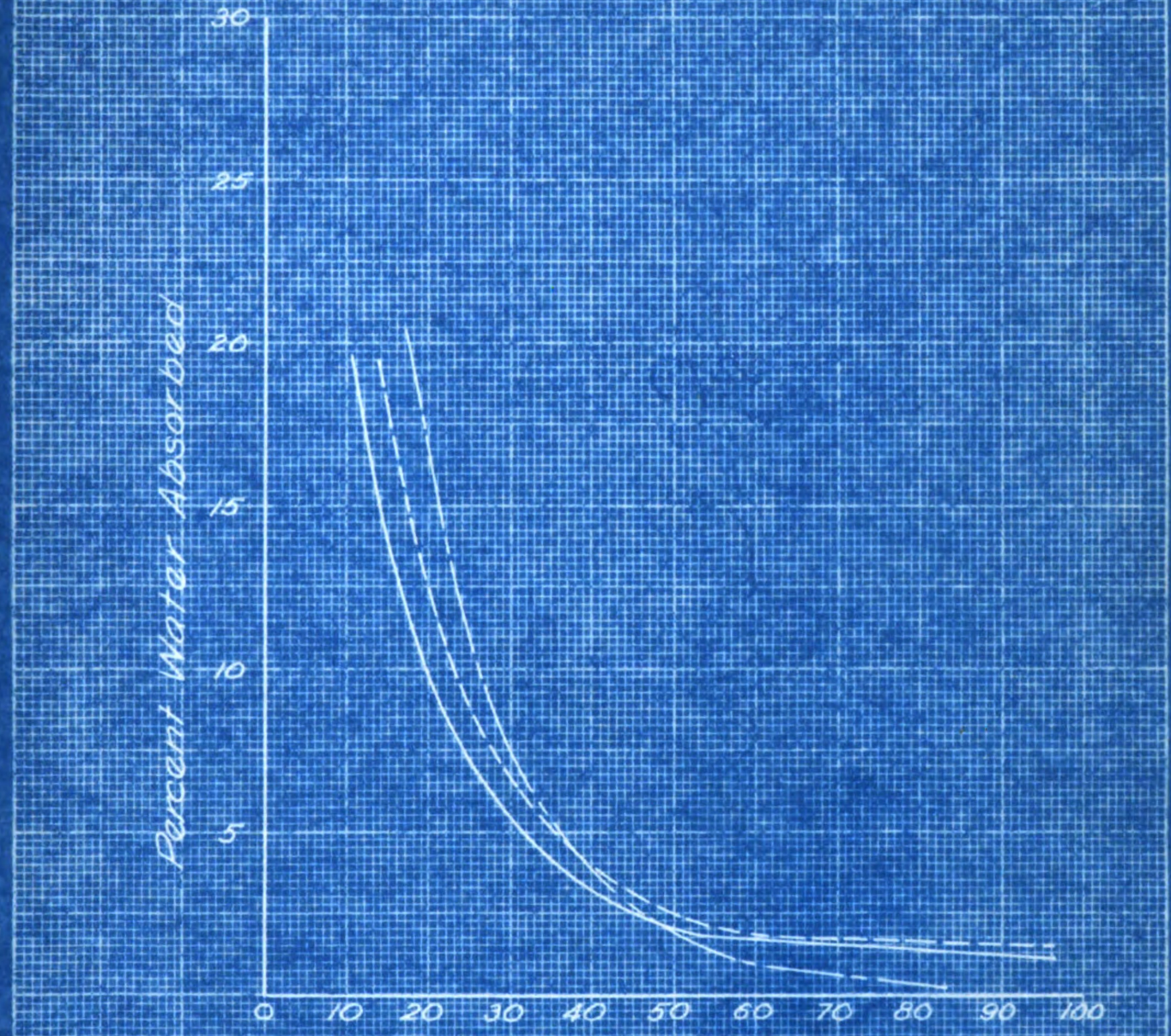


Fig. 14a - ABSORPTION CURVES.

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